2018 San Diego Regional Harbor Monitoring Program
FINAL REPORT

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FINAL
2018 REGIONAL HARBOR MONITORING PROGRAM REPORT

December 2020

Prepared for:
Port of San Diego
City of San Diego
City of Oceanside
County of Orange

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RHMP Cover Photo Captions: Top from left to right: Jeremy Burns of Wood piloting the Early Bird III (EB3) custom pontoon boat in south San Diego Bay; bat stars from north San Diego Bay; the Early Bird II at dock in Mission Bay; sunset over America's Cup Harbor in San Diego Bay. Center: The coastal shrimp *Hepatacarpus* sp. from the mouth of Oceanside Harbor. Bottom from left to right: Sampling of sediments with the tandem Van Veen in Dana Point Harbor; sampling of sediments in Oceanside Harbor; and a Pacific seahorse captured in Mission Bay.

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EXECUTIVE SUMMARY

The Regional Harbor Monitoring Program (RHMP) provides a comprehensive survey of the quality of water, sediments, and aquatic life on a 5-year cycle in four southern California embayments in the San Diego region: Dana Point Harbor, Oceanside Harbor, Mission Bay, and San Diego Bay. These water bodies are collectively referred to as the San Diego Regional Harbors. The RHMP was developed by the Port of San Diego, the City of San Diego, the City of Oceanside, and the County of Orange to evaluate status and trends related to a variety of environmental condition indicators and to determine whether beneficial uses are being attained and protected in the four harbors. The RHMP is coordinated with the larger-scale regional Southern California Bight Regional Monitoring Program (Bight Program) managed by the Southern California Coastal Water Research Project (SCCWRP).

The RHMP sampling areas were partitioned into five strata classified as either freshwater-influenced, marina, industrial/port, deep, or shallow regions for comparative assessments. Sampling was performed at a total of 75 water and sediment quality stations, and benthic trawls were performed at 15 locations, with stations positioned according to a stratified random sampling design. Surface water and sediment chemistry, sediment toxicity, and biological community conditions were quantified to determine the overall environmental conditions of the harbors. To evaluate the contributions and spatial distribution of pollutants, concentrations of chemical indicators were compared among strata and harbors. To determine whether the waters and sediments sustain healthy biota, a weight-of-evidence approach was used that combined the indirect lines of evidence (LOEs) (chemistry and toxicity) with the direct LOEs (benthic infauna and demersal communities). Determinations of long-term trends were based on comparisons of the 2018 RHMP findings with historical conditions to evaluate whether conditions are improving or deteriorating over time.

In addition, an analysis of fecal indicator bacteria data collected over the past ten years within the San Diego Regional Harbors was conducted to assess whether waters are safe for body contact activities. An effort to address the risk of eating fish in the harbors was also performed by collecting target fish species during benthic trawls for tissue analysis. Results of the historical fecal indicator bacteria (FIB) analysis are summarized in this core monitoring report and presented in full in Appendix P, and results of the 2018 RHMP Fish Bioaccumulation Study will be included in a stand-alone report.

The results and conclusions are discussed in relation to the following core monitoring questions:

1) *What are the contributions and spatial distributions of inputs of pollutants to the harbors?*

Consistent with prior RHMP monitoring efforts, areas of the harbors most closely associated with human uses (i.e., the marina and industrial/port strata) tended to have elevated chemical concentrations and greater exceedances of chemical thresholds in surface waters and sediments, as compared with areas that were not closely associated with anthropogenic influences (i.e., deep and shallow strata). It should be noted that freshwater-influenced areas had mixed results. The likely impacts for the marina stratum are primarily driven by elevated 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/port stratum, which is located solely along the eastern shore of San Diego Bay, also had elevated concentrations of metals and organics in sediments.

Contrary to most other chemical concentrations that have remained consistent or decreased over time, the concentrations of pyrethroid pesticides and PBDEs increased in 2018 relative to that observed in 2008 and 2013, with a majority of detections located at sites in the freshwater-influenced strata. Active constituents in flame retardants (PBDEs) also increased from when they were first measured in 2013 to 2018, primarily in freshwater-influenced locations with some detections in the marina and industrial/port strata. The increases for these chemicals may be related to increased runoff from upland sources as a result of above normal precipitation observed in 2017 compared to drought conditions that were experienced prior to the 2008 and 2013 sampling periods. DDTs and PBDEs are both banned chemical classes, but pyrethroid pesticides continue to be used as authorized by the Department of Pesticide Regulation so their rate of application in local watersheds may also have had some influence on the increased concentrations observed in the sediments in 2018.

2) Do the waters and sediments in the harbors sustain healthy biota?

A majority of the area within the San Diego Regional Harbors was found to support healthy biota, based upon a weight-of-evidence approach that combines physical, chemical, and toxicological LOEs with biotic LOEs. Consistent with historical surveys, areas directly associated with anthropogenic disturbance and inputs of pollutants (marinas, industrial/port, and some of the freshwater-influenced areas) tended to have elevated chemistry.

Surface water chemistry and physical water quality parameters were largely supportive of healthy biota based on water quality benchmarks. All chemical and physical indicators measured met available water quality objectives, with the exception of copper, primarily in the marina stratum where 80% (12 of 15) of stations exceeded the criterion continuous concentration water quality objective of 3.1 µg/L, and dissolved oxygen, which fell below the Basin Plan water quality objective of 5.0 mg/L near the sediment surface at one location in the deep stratum, and two locations in freshwater-influenced stratum.

Using the State of California sediment quality objective (SQO) approach, sediment quality region-wide was also considered to be largely protective of healthy biota with 72% of stations classified as either unimpacted or likely unimpacted based on a combined metric that includes sediment chemistry, toxicity, and benthic community lines of evidence (Figure ES-1). Particularly noteworthy, 89% of the 2018 RHMP sampling stations were classified as non-toxic, with 11% considered to have low toxicity according to the SQO methodology; no sites were considered to be moderately or highly toxic. The SQO chemistry LOE rated 57% of stations with minimal or low exposure and 37% with moderate exposure. There were very few stations with high exposure (5%; 4 stations). Benthic infauna at 55% of sites, had an abundance and diversity indicative of healthy communities with reference or low disturbance conditions according to the SQO benthic LOE. However, 32% of sites had moderately disturbed benthic communities and 13% of sites had highly disturbed benthic communities according to the SQO benthic LOE. A majority of the moderately and highly disturbed benthic communities were located in marina and freshwater-influenced strata, with 74% and 65% of sites in these strata in the combined moderate and high disturbance categories, respectively. The variation in disturbance scores observed among benthic communities was a significant driver for final integrated SQO scores. Benthic infaunal communities are complex and are susceptible to multiple stressors such as elevated chemistry, physical disturbance, temperature changes, freshwater exposure, and substrate type.

The demersal fish and invertebrate communities were also composed of healthy individuals; both species diversity and abundance were consistent with those of prior regional monitoring assessments, and minimal abnormalities were observed. Overall, the diversity, abundance, and biomass recorded in 2018 support the premise that the San Diego Regional Harbors are supportive of healthy fish and epibenthic macroinvertebrate assemblages.

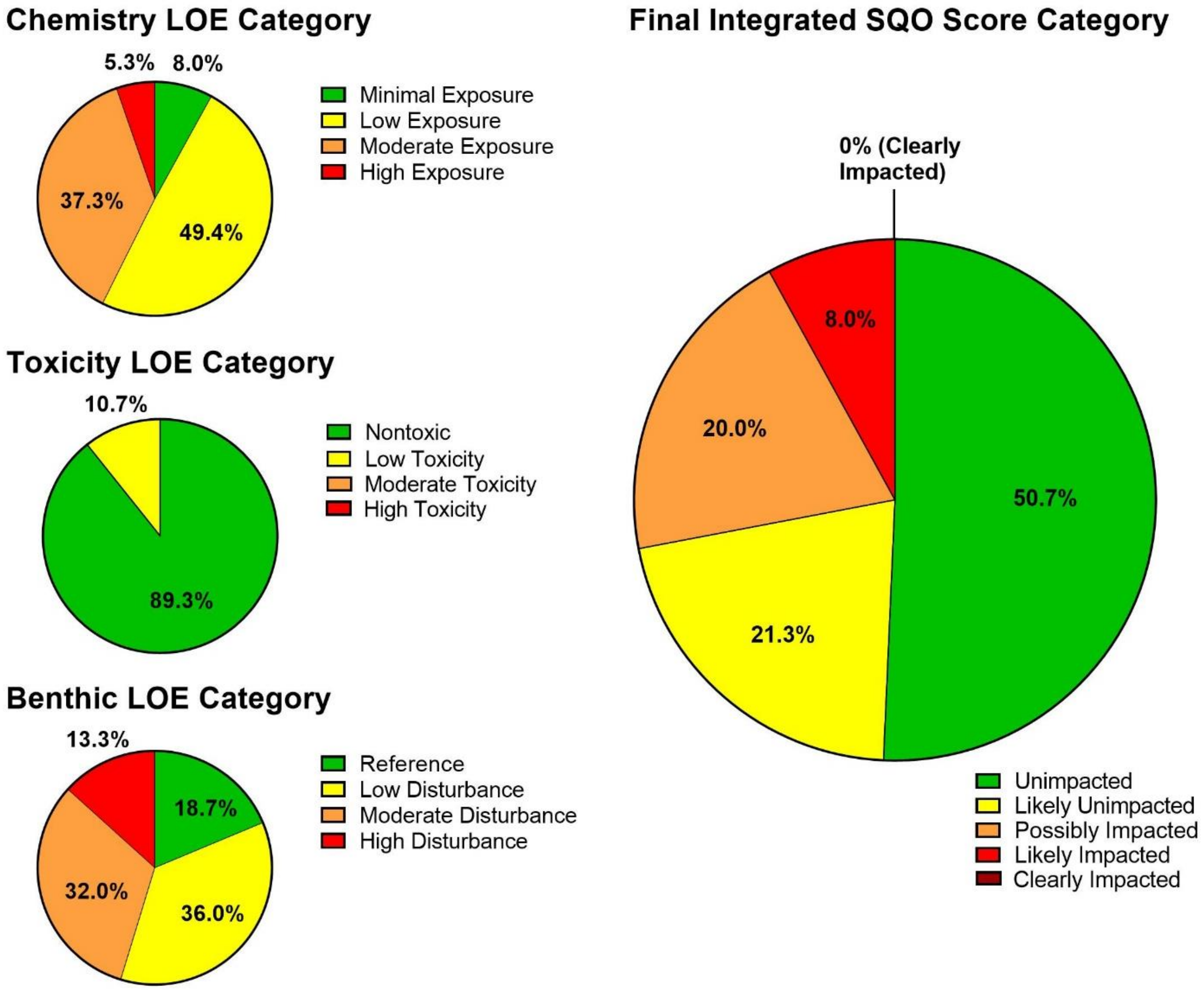

Figure ES-1. Percentage of RHMP Stations in each Sediment Quality Objective LOE and Overall Assessment Categories in 2018

3) What are the long-term trends in water and sediment quality in the harbors?

Historical conditions for the 2018 RHMP were determined based on a review of multiple studies completed from 1994 to 2013. Regional conditions were found to be improving over time or remaining steady based on the integration of multiple lines of evidence, including surface water chemistry, sediment chemistry, sediment toxicity, and epibenthic invertebrate and fish communities. Regulations, a variety of source controls, dredging, and other cleanup activities have led to significant improvements in toxicity and concentrations of a number of chemicals of potential concern in the sediments over the past few decades. However, the condition of benthic infaunal communities appears to have declined since 2008, with a greater proportion of sites in the moderate and high disturbance categories (27% in 2008, 40% in 2013, and 45% in 2018). The areas of particular concern remain primarily within marinas and around industrial/port regions and certain freshwater-influenced locations.

Overall, the rate of improvement in both sediment and water quality appears to have slowed over time when compared to conditions documented over the course of the past two decades. Toxicity in 2018 was similar to that in 2013 showing considerable improvement over historical conditions. Similarly, concentrations of dissolved trace metals and PAHs in the water column and several classes of sediment contaminants (mercury, PAHs, PCBs, and chlordanes) show decreases relative to that reported historically (i.e., pre-2008) and more stable concentrations over the past 10 years. However, concentrations of pyrethroid pesticides and PBDEs increased in 2018 relative to that observed in both 2013 and 2008, particularly in the freshwater-influenced stratum (note that PBDEs were not measured in the 2008 RHMP). This observation again is possibly related to a wetter than normal year prior to the sampling efforts in 2018. For a number of other chemicals, long-term trends were less obvious.

Of all sediment quality metrics, the benthic community shows the greatest variation over time, with many individual revisited sites having scores spanning multiple categories between reference and disturbed over time without a clear consistent pattern. Several factors that could be potential causes of increased direct or indirect benthic community disturbance recently include: 1) Climate change with record warm temperatures recorded in the San Diego region in 2018; 2) above average rainfall in the wet season prior to the monitoring efforts in 2018 potentially resulting in scouring and deposition of sediments, decreased salinity, increased chemicals associated with local runoff, and increased organic matter with the potential to decrease dissolved oxygen concentrations at the sediment surface; and 3) Invasive species including a notable increase in the population the pollution-tolerant polychaete *Pseudopolydora paucibranchiata* and Asian mussel *Musculista senhousia* in 2018 compared to 2013. In 2018 this invasive polychaete was the dominant species in two of the six locations total that were considered to have likely impacted conditions based on the final integrated SQO approach, both of which had benthic communities classified as moderately disturbed.

Consistent with prior surveys the demersal fish and invertebrate community is diverse, appears healthy, and continues to show a reduced incidence of physical anomalies such as tumors or fin rot with only 1 fish found to have a small tumor in 2018 (0.1%) compared to 0.6% in 2008 and up to 5% reported in the 1970s.

Overall, historical results based on water and sediment chemistry and toxicity tests indicate that widespread efforts to improve regional harbor health have been successful, with various regulatory actions and controls directed toward minimizing levels of contaminants that have the potential to cause toxicity.

4) *Are the waters in the harbors safe for body contact activities?*

An effort to address this RHMP question was conducted in 2018 by compiling historical data sets and evaluating concentrations and trends in FIB monitored at numerous locations within the San Diego Regional Harbors over a 10-year period extending from 2008 through 2018. A summary of this historical bacteria analysis is provided herein to address this question. A full supplemental report for this historical bacteria analysis is included as Appendix P.

Data were compiled for enterococcus, fecal coliform, and total coliform, but *post hoc* analysis focused on enterococcus as the primary indicator to reflect the latest water quality objectives (WQOs) provided in the 2018 adoption of the Bacteria Provisions for the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California (ISWEBE Plan; State Water Resources Control Board [SWRCB], 2019) and amendment to the Water Quality Control Plan for Ocean Waters of California (Ocean Plan; SWRCB, 2018), which identify enterococcus as the most appropriate FIB for the enclosed bays that characterize the San Diego Regional Harbors.

Results of this analysis indicate that potential impacts on human health from contact exposure are limited overall, particularly during the dry season, and general recommendations to avoid water contact during or immediately following wet weather events near storm drain or watershed inputs should be followed. Concentrations of enterococcus in all harbors were generally greatest during wet season sampling. During the dry season, less than 10% of the samples collected from 2008 through 2018 across all harbors exceeded historical WQOs for enterococcus. During the wet season, exceedances of the historical WQOs were also less than 10% over the same 10-year period among all samples from Dana Point Harbor and Oceanside Harbor. However, wet season exceedances for historical WQOs for enterococcus in Mission Bay and San Diego Bay were greater, ranging from 23 to 63% of total samples over the same 10-year period.

Based on a combined assessment of all stations across all harbors and within the individual harbors, no obvious temporal trends between years were apparent for enterococcus concentrations over the 10-year period evaluated. However, when evaluating data for individual sites on the Clean Water Act Section 303(d) list of water quality impaired segments, decreases in enterococcus are apparent for several locations, including Baby Beach in Dana Point Harbor, and Shelter Island Shoreline Park and Tidelands Park in San Diego Bay.

5) *Are fish in the harbors safe to eat?*

In 2018, the RHMP also continued to support larger-scale regional efforts to assess concentrations of select bioaccumulative chemicals of potential concern in tissue from select target fish species. Target fish for tissue analysis were opportunistically collected during the benthic trawls to assess demersal fish and macroinvertebrate communities during the RHMP monitoring efforts. This effort is being conducted in association with the Bight Program and the Surface Water Ambient Monitoring Program (SWAMP) Bioaccumulation Oversight Group (BOG) in support of a decadal Coastal Fish Survey at 27 fishing zones within the southern California Bight. Data analyses and reporting for this effort are in progress at the time of this publication, and a stand-alone supplemental report will be finalized in 2021 for the RHMP that will include methods and a summary of results for the San Diego Regional Harbors.

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LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
>	greater than
≥	greater than or equal to
<	less than
µg/g	microgram(s) per gram
µg/kg	microgram(s) per kilogram
µg/L	microgram(s) per liter
µS/cm	microSiemens per centimeter
µm	micron
µmol/g	micromole(s) per gram
µmol/gOC	micromole(s) per gram of organic carbon
%	percent
∑SEM:AVS	ratio of the sum of SEM to AVS
§	Section
AB 411	California Assembly Bill 411
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
ASTM	ASTM International
AVS	acid volatile sulfide
Bight	Southern California Bight
Bight ’98	Southern California Bight 1998 Regional Monitoring Program
Bight ’03	Southern California Bight 2003 Regional Monitoring Program
Bight ’08	Southern California Bight 2008 Regional Monitoring Program
Bight ’13	Southern California Bight 2013 Regional Monitoring Program
Bight ’18	Southern California Bight 2018 Regional Monitoring Program
Bight Program	Southern California Bight Regional Monitoring Program
BOG	Bioaccumulation Oversight Group
BPTCP	Bay Protection and Toxic Cleanup Program
BRI	Benthic Response Index
CA LRM	California Logistic Regression Model
Cal/EPA	California Environmental Protection Agency
CCC	criterion continuous concentration
CDFW	California Department of Fish and Wildlife
CEDEN	California Environmental Data Exchange Network
CLP	Contract Laboratory Program
cm	centimeter(s)

ACRONYMS AND ABBREVIATIONS (Continued)

CMC	criterion maximum concentration
COC	chain-of-custody
CSI	Chemical Score Index
CTD	conductivity-temperature-depth
CTR	California Toxics Rule
DCE	Dancing Coyote Environmental
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
dGPS	differential Global Positioning System
DNA	deoxyribonucleic acid
DO	dissolved oxygen
DOC	dissolved organic carbon
DQO	data quality objective
EC_{50}	median effective concentration
EI	ecological index
ER-L	effects range–low
ER-M	effects range–median
ESB	equilibrium partitioning sediment benchmark
FeS	iron sulfide
FIB	fecal indicator bacteria
FID	further identification
fOC	fraction of organic carbon
GC	gas chromatograph
H_2SO_4	sulfuric acid
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
IBI	Index of Biotic Integrity
ISWEBE	Inland Surface Waters, Enclosed Bays, and Estuaries of California
km	kilometer(s)
kg	kilogram(s)
km^2	square kilometer(s)
LC_{50}	median lethal concentration
LCS	laboratory control sample
LCSD	laboratory control sample duplicate
LDC	Laboratory Data Consultants, Inc.
LOE	line of evidence

ACRONYMS AND ABBREVIATIONS (Continued)

LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
MBAS	methylene blue-activated substances
MCB	Marine Corps Base
MDL	method detection limit
Merkel	Merkel and Associates, Inc.
mg	milligram(s)
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
mL	milliliter(s)
MLLW	mean lower low water
MLOE	multiple lines of evidence
mm	millimeter(s)
MS	matrix spike
MSD	matrix spike duplicate
N	nitrogen
NA	not applicable
NCI	negative chemical ionization
ng/L	nanogram(s) per liter
NH_4	ammonia
NH_4Cl	ammonium chloride
NIST	National Institute for Standards and Technology
nMDS	Non-metric multidimensional scaling
NOAA	National Oceanic and Atmospheric Administration
O/E ratio	ratio of observed to expected taxa
OCHCA	County of Orange Health Care Agency
OEHHA	Office of Environmental Health Hazard Assessment
OWPP	Ocean Water Protection Program
PAH	polycyclic/polynuclear aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PBMS	performance-based measurement system
PCA	principal components analysis
PCB	polychlorinated biphenyl
Physis	Physis Environmental Laboratories, Inc.
P_{MAX}	maximum probability model
POTW	publicly owned treatment work
psu	practical salinity unit(s)

ACRONYMS AND ABBREVIATIONS (Continued)

PVC	polyvinyl chloride
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RBI	Relative Benthic Index
REC-1	water contact recreation beneficial use
RHMP	Regional Harbor Monitoring Program
RHMP Agencies	Port of San Diego, City of San Diego, City of Oceanside, County of Orange
RIVPACS	River Invertebrate Prediction and Classification System
RL	reporting limit
San Diego Regional Harbors	Dana Point Harbor, Oceanside Harbor, Mission Bay, and San Diego Bay
SCAITE	Southern California Association of Ichthyological Taxonomists and Ecologists
SCAMIT	Southern California Association of Marine Invertebrate Taxonomists
SCCWRP	Southern California Coastal Water Research Project
SDDEH	County of San Diego Department of Environmental Health
SDG	sample delivery group
SDRWQCB	San Diego Regional Water Quality Control Board
SEM	simultaneously extracted metals
SIMPROF	similarity profile
SIYB	Shelter Island Yacht Basin
SM	Standard Method
SP	solid-phase (toxicity test)
SQO	sediment quality objective
SWAMP	California Surface Water Ambient Monitoring Program
SWI	sediment-water interface test
SWRCB	California State Water Resource Control Board
TMDL	Total Maximum Daily Load
TOC	total organic carbon
TSS	total suspended solids
TVV	tandem Van Veen
UCR	University of California Riverside
USEPA	United States Environmental Protection Agency
VRG	Vantuna Research Group
Weston	Weston Solutions, Inc.
Wood	Wood Environment & Infrastructure Solutions, Inc.
WQO	water quality objective

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 (collectively referred to as the “RHMP Agencies”) in response to a July 24, 2003 request by the San Diego Regional Water Quality Control Board (SDRWQCB) under Section (§) 13225 of the California Water Code. The RHMP is a comprehensive survey of the quality of water, sediments, and aquatic life to determine whether beneficial uses are being attained and protected in Dana Point Harbor, Oceanside Harbor, Mission Bay, and San Diego Bay. These water bodies are collectively called the San Diego Regional Harbors. The RHMP is composed of a core monitoring program and supplemental focused special studies. The initial program was designed to address five major questions posed in the SDRWQCB’s request:

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

To answer the core questions, the RHMP study uses an iterative approach that has included extensive research of historical information for the four harbors, mapping of the harbors into strata, identification of indicators to be monitored to assess trends, comparison to reference values (i.e., threshold levels), and use of statistical methodologies to evaluate findings in a scientifically rigorous manner that also complements the larger Southern California Bight (Bight) Regional Monitoring Program (Bight Program). The RHMP uses a weight-of-evidence approach to assess the health and overall status of the harbors and compare findings to recent historical conditions to determine whether conditions are improving or deteriorating over time. Key indicators of ecological health measured in this program and reported herein to address Questions 1–3 include (1) quantification of contaminants within surface waters and sediments, (2) laboratory toxicity tests of whole sediments, (3) characterization of benthic infaunal communities, and (4) characterization of demersal fish and epibenthic macroinvertebrate communities. To assess whether the waters are safe for human body contact (Question 4), an analysis of fecal indicator bacteria data collected over the past ten years within the San Diego Regional Harbors was conducted and reported separately in Appendix P. An effort to address the risk of eating fish in the harbors (Question 5) was performed by collecting target fish species during benthic trawls for tissue analysis and will be reported in a separate stand-alone report in 2021.

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[1] A supplemental report including a historical analysis of bacteria in the San Diego Regional Harbors was prepared to address this question and is included as Appendix P.

[2] A supplemental report including methods and a summary of fish bioaccumulation results will be prepared to address this question.

1.1 Recent History of the RHMP

1.1.1 RHMP Pilot Project

A three-year RHMP Pilot Project began in 2005 to validate the efficacy of the proposed RHMP study design and appropriate level of sampling effort to address the program's goals. The Pilot Project illustrated that a stratified random study design with approximately 15 stations in each of five strata (industrial/port, marina, freshwater-influenced, deep, and shallow) should be adequate to statistically assess differences among strata and trends over time. The stratified random study design approach is also consistent with the Bight Program methodology, although different strata are used for the two programs. Recent historical conditions of the harbors for comparison purposes were determined based on a review of various targeted and randomized studies completed during a 10-year period from 1994 through 2004.

Primary contaminants of concern identified and analyzed for the RHMP Pilot project included copper, zinc, and nickel in the water column, and a suite of trace metals (copper, cadmium, chromium, copper, lead, nickel, and zinc), and polycyclic aromatic hydrocarbons (PAHs) in the sediments. Since the RHMP Pilot Project, a suite of organochlorine pesticides and polychlorinated biphenyl (PCB) congeners have been added in accordance with the Sediment Quality Objective (SQO) method requirements. Pyrethroid pesticides were also added to the list of contaminants of potential concern in 2008 in both the Bight Program and RHMP, recognizing growing concern due to their ubiquitous presence in watersheds and documented toxicity in southern California. Polybrominated diphenyl ethers (PBDEs), often used in products for fire suppression, were added to the 2013 and 2018 Bight Program and RHMP due to their history of use, frequent detection, and documented toxicity and bioaccumulation potential. PBDEs were banned in California in 2008, but pyrethroid pesticides continue to be used for pest control throughout southern California and elsewhere.

1.1.2 Relationship to the Bight Program Regional Monitoring Studies

The Bight Program began in 1994. Its goal was to complete a comprehensive regional monitoring survey every five years to provide a “snapshot” of conditions in the Southern California Bight and to ultimately describe trends and changes that occur on a region-wide scale (Southern California Coastal Water Research Project [SCCWRP], 1998). Like the RHMP, the core monitoring efforts for the Bight Program center on status and trends related to sediment quality and associated biological communities. The RHMP was developed to complement and support the Bight Program while addressing the five core questions specific to the San Diego Regional Harbors. The RHMP has also included special studies to address specific questions determined to be locally important to the region by the RHMP Agencies. Methodologies for the RHMP are consistent with those required by the Bight Program, and data derived by the RHMP are submitted to SCCWRP for inclusion in the Bight Program database. Representatives of the RHMP participated on most of the Bight 2018 Regional Monitoring Program (Bight ’18) workgroup committees throughout the development of the key goals, questions, and planning documents, and continue to participate through ongoing Bight-wide quality assurance (QA) and quality control (QC), data analysis, and reporting efforts.

In addition to the core sediment quality monitoring, the RHMP in 2018 continued to support several additional components of the Bight '18 Program, including the following: (1) an assessment of benthic debris; (2) a new project to evaluate the composition of meiofaunal assemblages in coastal California sediments; (3) a new effort to assess potential ocean acidification impacts on epibenthic invertebrates and demersal fish; and 4) an assessment of bioactive chemical contaminants in sediments and fish tissue using bioanalytical screening assays. Methods implemented under the RHMP to support these special studies are described in Section 2 of this report, and results, including data collected by RHMP, will be reported later under separate cover by the lead researchers and SCCWRP.

The 2018 RHMP also supplemented concurrent state-wide efforts by the California State Water Resources Control Board (SWRCB) to evaluate the extent and magnitude of bioaccumulative compounds in fish species that people eat: https://mywaterquality.ca.gov/monitoring_council/bioaccumulation_oversight_group/index.html. For this last effort, target fish species collected in demersal trawls for RHMP were submitted to the California Department of Fish and Wildlife (CDFW) in support of the Office of Environmental Health Hazard Assessment (OEHHA) implementation of fish consumption guidelines for coastal areas. The results will also help the SWRCB further calibrate scientific models developed for SQOs.

1.1.3 The 2008 and 2013 RHMP Summary of Findings

The RHMP completed its first two core monitoring programs during the summers of 2008 and 2013 in coordination with the 2008 and 2013 Bight Regional Monitoring Programs (Bight '08 and Bight '13) to address the five core questions presented in Section 1.0. A high-level summary of results of the 2008 and 2013 RHMP efforts suggested the following:

1. What are the contributions and spatial distributions of inputs of pollutants to the harbors? A majority of sites in the San Diego Regional Harbors had minimal to low chemical concentrations in both the overlying waters and sediments. Areas of the harbors most closely associated with anthropogenic (human-related) uses (i.e., marina, industrial/port, and freshwater-influenced strata) tended to have elevated chemical concentrations in the surface waters and sediments, as compared with areas that were not closely associated with anthropogenic influences (i.e., deep and shallow strata).
2. Do the waters and sediments in the harbors sustain healthy biota? A majority of areas within the harbors had water and sediment quality conditions that were found to be supportive of healthy biological resources. Areas associated with localized anthropogenic inputs of pollutants, most notably the marina and industrial/port strata and a limited set of freshwater-influenced stations, had conditions that were less suitable for supporting healthy benthic infauna. Demersal fish and invertebrate communities appeared healthy throughout the harbors with a diversity and abundance of species that were consistent with prior Bight Program studies.
3. What are the long-term trends in water and sediment quality in the harbors? Overall, RHMP-wide conditions were found to be improving over time based on multiple lines of evidence (MLOE), including surface water chemistry, sediment chemistry, sediment toxicity, and benthic infaunal community health. While this trend was apparent for RHMP-wide conditions, not all areas of the harbors showed improvement over time (e.g., the

marina stratum), nor were improvements with time as evident when assessing the subset of stations revisited from prior Bight studies.

4. Are the waters in the harbors safe for body contact activities? In 2008, indicator bacteria levels were well below California Assembly Bill 411 (AB 411) standards for total and fecal coliforms and enterococci, with most of the stations having bacterial levels that were below detection limits. Indicator bacteria analyses were excluded from the 2013 monitoring program based on both the lack of detections from samples in the 2008 program and the limited information provided by the program's low sample resolution.

5. Are fish in the harbors safe to eat? Assessment of fish tissue concentrations in 2013 was the first coordinated effort inclusive of all San Diego Regional Harbors and will serve as a baseline dataset for future study efforts. Results of the study found concentrations of PCBs and mercury to exceed current available human health fish thresholds published by OEHHA. Mean concentrations of PCBs in both predator and forage fish species exceeded the OEHHA no consumption guideline of 120 ppb in San Diego Bay but were well below this value in the other three embayments. Similarly, the mean tissue concentration of mercury in predatory fish from San Diego Bay exceeded the 70-ng/g OEHHA criterion for women aged 18–45 years and children 1–17 years to consume no more than three servings per week; however, mean tissue concentrations of mercury in the other three harbors were below this criterion. The mean concentration of mercury in forage fish was less than all human health criteria. Based on prior published studies in San Diego Bay, concentrations of chemicals in fish tissue appear to be decreasing over time for this particular embayment.

1.2 Components of RHMP in 2018

In 2018, the RHMP focused on answering the five core questions from the SDRWQCB §13225 letter discussed in Section 1.0. Efforts to answer four of these five questions are reported herein. An assessment of the degree of bioaccumulation of selected contaminants in fish tissue (addressing the fifth question posed in SDRWQCB's initial request related to the human health risk from consumption) was initiated during this program, but analyses are still in progress at the time of this publication, and the results of this effort will be provided at a later date under separate cover. At the time of this publication, a draft report entitled "*Contaminant Bioaccumulation in Edible Sport Fish Tissue*" has been distributed by SCCWRP and the State of California Surface Water Ambient Monitoring Program (SWAMP) for peer review (McLaughlin et al., 2020, draft). This report includes data collected by the RHMP in 2018.

The 2018 RHMP builds on the findings from the 2008 and 2013 RHMPs and was again closely associated with the Bight Program. The 2018 RHMP study design was tailored to answer the core study questions discussed above. One primary adjustment from 2013 is the re-inclusion of an analysis of indicator bacteria. These analyses were excluded from the 2013 monitoring program based on both the lack of detections from samples in the 2008 program and the limited information provided by sampling only once every five years during an ambient monitoring program. Therefore, the effort related to indicator bacteria analyses included data extraction and *post hoc* analysis of data from focused monitoring efforts in the San Diego Regional Harbors to assess the protection of beneficial uses at beaches and bays in southern California. These data were compiled directly from RHMP Agencies' beach water quality monitoring programs, which more appropriately address bacteria monitoring. Methods and results from this effort are briefly summarized in the body of this report (Sections 2.3 and 6.0, respectively), with additional details provided in a stand-alone report located in Appendix P.

Analysis of trends for an integrated evaluation of sediment quality using the SQO approach focuses on the past ten years of data, which have been collected and analyzed in a consistent manner during the past three RHMP efforts. Available data collected more than ten years ago (back to 1994) is included for a historical evaluation of individual lines of evidence, including several chemicals of concern in the sediments, amphipod survival, and demersal fish and invertebrate assemblages. Results from several studies prior to 1994 are cited in the discussion for context, but this data has not been incorporated for analysis purposes due to inconsistencies in experimental design and measurement methods.

1.3 2018 RHMP Report Structure

This report presents the results of the 2018 RHMP, which assessed the overall health of the harbors based on MLOE: water quality (Section 3.1), sediment quality, including chemistry, toxicity, and benthic infaunal communities (Section 3.2), and demersal fish and macroinvertebrate communities (Section 3.4). The conclusions of the 2018 RHMP are discussed in the context of four[3] of the five core questions related to the status and trends of environmental conditions in the harbors.

Each main section of the report (Methods, Results, Discussion, and Conclusion) is organized in a consistent order starting with water quality (physical and chemical characteristics); sediment quality (chemistry, toxicity, benthic community individual lines of evidence followed by an integrated assessment of all three lines of evidence using the SQO approach), then demersal fish and macroinvertebrates. The Results section focuses only on the most recent data collected in 2018 (addressing Questions 1 and 2 related to current status). Comparison to historical results is presented in the Discussion to assess Question 3 related to long-term trends. Short sections related to Question 4 (Are the waters in the harbors safe for body contact activities?) the Methods and Conclusion with a complete report for this evaluation included as Appendix P.

1.4 A Brief Introduction to the History and Physical Characteristics the Four San Diego Regional Harbors

The four harbors monitored under the RHMP are all semi-enclosed embayments located in southern California, but each has its own unique set of characteristics that are important to consider when interpreting data and making comparisons among them. Their geography and current and historical uses have considerable influence on current water and sediment quality conditions and biological communities.

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[3] The core question pertaining to bioaccumulation of contaminants in fish tissue will be addressed in a supplemental report specific to those fish captured in the San Diego Regional Harbors for the RHMP, and an additional report by the SWRCB for an overall assessment of fish tissue chemical concentrations throughout southern California.

Dana Point Harbor

Dana Point Harbor is a small, man-made recreational harbor constructed in the late 1960s. Of the four harbors included in the RHMP, Dana Point Harbor has the highest overall density of resident commercial and recreational vessels. The harbor is divided into two main northern and southern regions with approximately 2,500 boat slips in an area encompassing approximately 0.35 square mile (0.9 square kilometer [km^2]). Sampling stations in this harbor represent four RHMP strata: marina, freshwater-influenced, shallow, and deep. The entire perimeter of the harbor is surrounded by a rip-rap boundary, except for a sandy beach near the northern end of the embayment referred to as Baby Beach. There are multiple municipal storm drain inputs into Dana Point Harbor; however, none are directly from major watershed sources.

Oceanside Harbor

Oceanside Harbor is another small, man-made recreational harbor, created around the same time (1963) as Dana Point Harbor. This harbor is divided into two main northern and southern sections but is also connected to a third basin farther to the north that is operated by the Marine Corps Base (MCB) at Camp Pendleton. This basin on MCB Camp Pendleton was not assessed under the RHMP. Sampling stations in Oceanside Harbor included those in marina, freshwater-influenced, and deep RHMP strata. The harbor, excluding the northern MCB basin, has approximately 800 boat slips in an area encompassing 0.11 square mile (0.28 km^2). The entire perimeter of Oceanside Harbor is surrounded by a rip-rap boundary. There are multiple municipal storm drain inputs into Oceanside Harbor; however, none are directly from major watershed sources.

Mission Bay

Larger in size (approximately 3.9 square miles [10 km^2]) and more diverse in characteristics, Mission Bay is a natural shallow embayment that has been substantially modified by dredging and filling operations that occurred in the late 1940s. Mission Bay is a popular recreational area, with six marinas, several resorts, a golf course, and the Sea World Marine Park, all within its immediate boundaries. Mission Bay has 27 miles (43 kilometers [km]) of shoreline, 19 of which are sandy beaches, with eight locations designated as official swimming areas.

Physical characteristics vary greatly throughout Mission Bay. The entrance and western portions of the bay receive substantial open ocean influence through tidal flushing and are predominantly lined with rip-rap. Conversely, the eastern portion of the bay is predominantly lined with sandy beaches but is constrained geographically, reducing water movement and exchange, particularly in the far inner reaches (Kinnetic Laboratories, 1994). Apart from the channel entrance and the semi-enclosed marina in Quivira Basin, the depth of the bay is relatively constant, between 1 and 3 meters below mean lower low water (MLLW) throughout. Mission Bay's extensive sloping sandy shorelines and shallow bottom in many areas provide extensive eelgrass bed habitats throughout much of the bay.

Mission Bay is used primarily for recreation and is composed of RHMP strata representative of marinas, shallow-water habitat, freshwater-influenced areas, and deep-water habitat. There are approximately 1,800 permanent boat slips in nine marinas and several offshore mooring locations throughout Mission Bay. Mission Bay has approximately 100 storm drain inputs, all with dry weather flow interceptors, and three watershed inputs from Rose Creek, Cudahy Creek, and Tecolote Creek, which are all located in the eastern portion of the bay and drain a collective watershed area of 80 square miles (207 km^2).

San Diego Bay

The largest and most diverse of the four harbors, San Diego Bay is a natural embayment that has been modified significantly over time by dredging and filling operations beginning in the early 1900s. It is unique among the harbors monitored for the RHMP because it is used for both recreation and industry and is the only harbor in this study with industrial/port activity. San Diego Bay is 15 miles (24 km) long and varies from 0.2 to 3.6 miles (0.3 to 5.8 km) in width. It is 17 square miles (44 km^2) in area at MLLW (Wang et al., 1998). San Diego Bay has sampling stations encompassing all five RHMP strata types. The larger size and multiple uses of San Diego Bay create smaller micro-environments that may vary greatly from the mouth to the southern portion of the bay.

San Diego Bay is unique among the harbors monitored for the RHMP because of its historical usage and the extent of previous impacts to the marine environment within the bay. San Diego grew rapidly in the 1880s, with the establishment of several military installations, and over the next few decades, the population and industry grew rapidly (Canada, 2006). Today, San Diego Bay has a large working waterfront, as well as several military facilities. The San Diego International Airport is also adjacent to the bay. Recreational boating is a large component of the activity on the bay, with numerous marinas throughout, as well as several offshore anchorages. As the largest estuary in southern California, San Diego Bay provides critical habitat for both marine and estuarine fish species. The bay also provides extensive shallow water eelgrass habitat that supports unique assemblages of fishes, as well as important nursery habitat for juvenile fishes (Pondella et al., 2009a; Williams et al., 2015).

There are approximately 200 municipal storm drains as well as six urban rivers/creeks (Sweetwater River, Otay River, Switzer Creek, Chollas Creek, Paleta Creek, and Paradise Creek) that contribute watershed inputs into San Diego Bay (City of San Diego, 2013).

2.0 METHODS

2.1 Field Sampling

Field sampling was conducted by Wood Environment & Infrastructure Solutions, Inc. (Wood), formerly Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler), from July 10 through September 12, 2018. Core monitoring activities consisted of the following:

- Water quality sampling
- Sediment sampling for chemistry and toxicity
- Benthic infaunal assessments
- Trawl net sampling to quantify the demersal fish and epibenthic macroinvertebrate communities

Additional samples of biota, trash, and sediments were collected to support a variety of special studies for the Bight Program in 2018, as described below.

2.1.1 Station Selection

A total of 75 stations were sampled during the 2018 RHMP for water and sediment quality, the same number as in 2008 and 2013. At 15 of these sites, trawls were conducted for analysis of demersal fish and epibenthic macroinvertebrates; 18 sites were trawled in 2008, and 15 in 2013. Out of the 75 stations in 2018, 54 were new sites that had not been sampled and analyzed before during the RHMP or prior Bight monitoring efforts. The remaining 21 stations were locations that have been evaluated during prior RHMP/Bight Monitoring programs (revisited sites). Of the total revisited sites, 17 were located in San Diego Bay and four were located in Mission Bay (Table 2-1). Seven of the revisited sites in 2018 were also the same locations where trawls had been conducted before. Among the 21 revisited sites, 12 were sampled during the Bight 1998 Regional Monitoring Program (Bight ’98), and nine were sampled during Bight 2003 Regional Monitoring Program (Bight ’03). All sites (new and revisited) were selected using a probability-based, stratified random sampling approach during the first year of monitoring. The selection of the 21 revisited sites was accomplished in 2013 by random selection of all sites previously monitored.

During the 2008 and 2013 RHMPs, the harbors were classified into five distinct strata: marina, industrial/port, freshwater-influenced, deep (greater than 12 feet MLLW), and shallow (less than 12 feet MLLW) areas. The strata were developed to help associate the status and trends in specific geographic regions with various activities and influences from the overall RHMP-wide data set. Strata were segregated into the marina, industrial/port, and freshwater-influenced strata based on potential activities or inputs from these locations that may have a direct influence on the benthic marine environment based on proximity. There is a crossover at some sites that, for example, may be in a marina but also influenced by stormwater. In these cases, the predominant strata based on proximity was used as the single classification for these sites. Freshwater-influenced areas were considered to be those areas that had either large nearby storm drains (greater than 36 inches in diameter) or nearby creek or river inputs. The shallow and deep strata included locations that were outside of areas clearly within or directly influenced by the other three strata. Although sites within the marina, industrial/port, and freshwater-influenced strata can be further divided into deep and shallow locations, depth was not used as a comparative designation for these sites, and these sites were also not included in the pool of locations in the separate shallow and deep strata. All five strata are present in San Diego Bay; Mission Bay and Dana Point Harbor have four strata (deep, freshwater-influenced, marina, and shallow); and Oceanside Harbor has three strata (deep, freshwater-influenced, and marina) (Table 2-1).

To assign strata designations to individual sites, uniformly sized hexagons depicting the strata were first overlaid on maps of each of the harbors. Hexagons were set at 30.5 meters per side. A total of 15 stations were randomly selected within each of the five RHMP strata, with the stipulation of at least one station location within each available stratum per harbor. Sampling was conducted within a 100-meter radius of the nominal station coordinates in accordance with Bight ’18 protocols, as determined by a differential Global Positioning System (dGPS). Coordinates of sampling stations were recorded. There were four sediment and water grab stations in Dana Point Harbor, four in Oceanside Harbor, nine in Mission Bay, and 58 in San Diego Bay.

Otter trawl sampling stations were selected at 15 RHMP stations using the probability-based, random-sampling approach. One trawl station each was located in Dana Point Harbor and Oceanside Harbor, three trawl stations were in Mission Bay, and ten trawl stations were in San Diego Bay. The trawls in Dana Point and Oceanside Harbor were conducted at similar locations as in 2008 and 2013. Two of the trawl sites in Mission Bay and five in San Diego Bay were also revisited locations sampled previously in 2008 and 2013. Epibenthic communities were evaluated using net tows conducted in accordance with standard Bight Program protocol at each of the 15 RHMP trawl stations.

Final GPS coordinates for each sampling location were derived by SCCWRP following agreement on the strata maps and experimental design specific to RHMP. The statistical methodology to select the sites was conducted in accordance with the *Bight ’18 Sediment Quality Assessment Work Plan* (SCCWRP, 2018d). All of the sites analyzed for the RHMP were fully integrated into the Bight ’18 Program.

Table 2-1 presents the coordinates and strata designations for each RHMP sampling location and indicates trawl locations and revisited sites.

Table 2-1. Actual RHMP Sampling Locations

Region	Station ID	Actual Latitude (dd.ddddd°)	Actual Longitude (-ddd.ddddd°)	2018 RHMP Stratum	Water and Sediment Grabs	Trawl	Previous Bight Site?
Dana Point Harbor	B18-10065	33.46066	-117.70090	Shallow	X		New Site
	B18-10066	33.46009	-117.69398	FWI	X		New Site
	B18-10067	33.45884	-117.69925	Marina	X		New Site
	B18-10068	33.45762	-117.69139	Deep	X	X	New Site
Oceanside Harbor	B18-10069	33.21276	-117.39514	Marina	X		New Site
	B18-10070	33.20929	-117.39532	FWI	X		New Site
	B18-10071	33.20798	-117.39754	Deep	X	X	New Site
	B18-10072	33.20428	-117.39137	Marina	X		New Site
Mission Bay	B18-10015	32.78731	-117.20999	FWI	X		New Site
	B18-10016	32.78454	-117.24059	Shallow	X	X	New Site
	B18-10017	32.78439	-117.21531	Shallow	X	X	Revisit
	B18-10019	32.76814	-117.24172	Deep	X	X	Revisit
	B18-10020	32.75827	-117.24439	Deep	X		New Site
	B18-10073	32.78060	-117.24926	Shallow	X		Revisit
	B18-10074	32.77707	-117.24997	Marina	X		New Site
	B18-10075	32.76728	-117.23576	Marina	X		Revisit
	B18-10438 (overdraw)	32.76652	-117.21854	Shallow	X		New Site (Overdraw)
North San Diego Bay	B18-10022	32.72408	-117.18307	Deep	X	X	Revisit
	B18-10023	32.71750	-117.21556	Deep	X	X	New Site
	B18-10024	32.71480	-117.18302	Deep	X	X	Revisit
	B18-10029	32.70189	-117.15893	FWI	X		New Site
	B18-10030	32.68784	-117.23027	Deep	X	X	New Site
	B18-10076	32.72654	-117.17654	FWI	X		New Site
	B18-10077	32.72496	-117.18335	Shallow	X		Revisit
	B18-10078	32.72304	-117.22373	Marina	X		New Site
	B18-10079	32.72046	-117.22078	Marina	X		New Site
	B18-10080	32.71882	-117.22629	Marina	X		Revisit
	B18-10081	32.71823	-117.23040	Marina	X		Revisit
	B18-10082	32.71643	-117.22662	Marina	X		New Site
	B18-10083	32.71256	-117.23131	Marina	X		New Site
	B18-10084	32.71208	-117.23282	Marina	X		Revisit
	B18-10112	32.71627	-117.17632	Deep	X		Revisit
	B18-10113	32.71614	-117.17398	Deep	X		New Site
	B18-10114	32.70260	-117.16180	Industrial/Port	X		Revisit
	B18-10115	32.69442	-117.15254	Industrial/Port	X		New Site
	B18-10116	32.69140	-117.15337	Deep	X		Revisit
	B18-10117	32.69188	-117.23837	Deep	X		Revisit

Table 2-1. Actual RHMP Sampling Locations

Region	Station ID	Actual Latitude (dd.ddddd°)	Actual Longitude (-ddd.ddddd°)	2018 RHMP Stratum	Water and Sediment Grabs	Trawl	Previous Bight Site?
Central San Diego Bay	B18-10031	32.68665	-117.13354	FWI	X		New Site
	B18-10032	32.67526	-117.14397	Shallow	X		Revisit
	B18-10034	32.66526	-117.14985	Shallow	X	X	Revisit
	B18-10035	32.66075	-117.14543	Shallow	X		New Site
	B18-10036	32.65816	-117.14437	Shallow	X	X	Revisit
	B18-10119	32.69004	-117.14320	Industrial/Port	X		New Site
	B18-10121	32.68780	-117.14076	Industrial/Port	X		New Site
	B18-10123	32.68549	-117.13635	Industrial/Port	X		New Site
	B18-10124	32.68433	-117.13126	Industrial/Port	X		New Site
	B18-10126	32.68173	-117.13109	Industrial/Port	X		New Site
	B18-10127	32.67920	-117.12836	Industrial/Port	X		New Site
	B18-10132	32.67427	-117.12466	Industrial/Port	X		New Site
	B18-10133	32.67313	-117.12943	Deep	X		New Site
	B18-10136	32.67028	-117.12350	Industrial/Port	X		New Site
	B18-10137	32.66776	-117.12199	Industrial/Port	X		New Site
	B18-10139	32.66359	-117.12270	Industrial/Port	X		New Site
	B18-10140	32.66056	-117.12296	Industrial/Port	X		Revisit
	B18-10141	32.66045	-117.12539	Deep	X		New Site
	B18-10142	32.66009	-117.11918	Industrial/Port	X		New Site
	B18-10143	32.65763	-117.12312	Industrial/Port	X		New Site
	B18-10144	32.65118	-117.12296	Deep	X		Revisit
	B18-10178	32.68753	-117.13087	FWI	X		New Site
South San Diego Bay	B18-10037	32.64698	-117.11822	FWI	X	X	Revisit
	B18-10038	32.64268	-117.12624	Shallow	X	X	New Site
	B18-10039	32.64158	-117.13904	Shallow	X	X	New Site
	B18-10040	32.64175	-117.11708	FWI	X		New Site
	B18-10041	32.62848	-117.12540	Shallow	X		New Site
	B18-10042	32.62559	-117.11127	Shallow	X	X	New Site
	B18-10043	32.61635	-117.10320	Shallow	X		New Site
	B18-10044	32.61409	-117.09877	FWI	X		New Site
	B18-10085	32.62588	-117.13571	Marina	X		New Site
	B18-10086	32.62355	-117.13363	Marina	X		Revisit
	B18-10087	32.62166	-117.10217	Marina	X		New Site
	B18-10088	32.62153	-117.13015	Shallow	X		New Site
	B18-10179	32.64968	-117.10863	FWI	X		New Site
	B18-10180	32.64777	-117.11644	FWI	X		New Site
	B18-10181	32.64819	-117.11340	FWI	X		New Site
	B18-10200	32.61784	-117.09824	FWI	X		New Site

Notes: Mission Bay site B18-10018 (freshwater-influenced) was abandoned due to depth and safety reasons. Overdraw site B18-10438 was sampled instead. FWI = freshwater-influenced

2.1.2 Distribution of Sites by Harbor

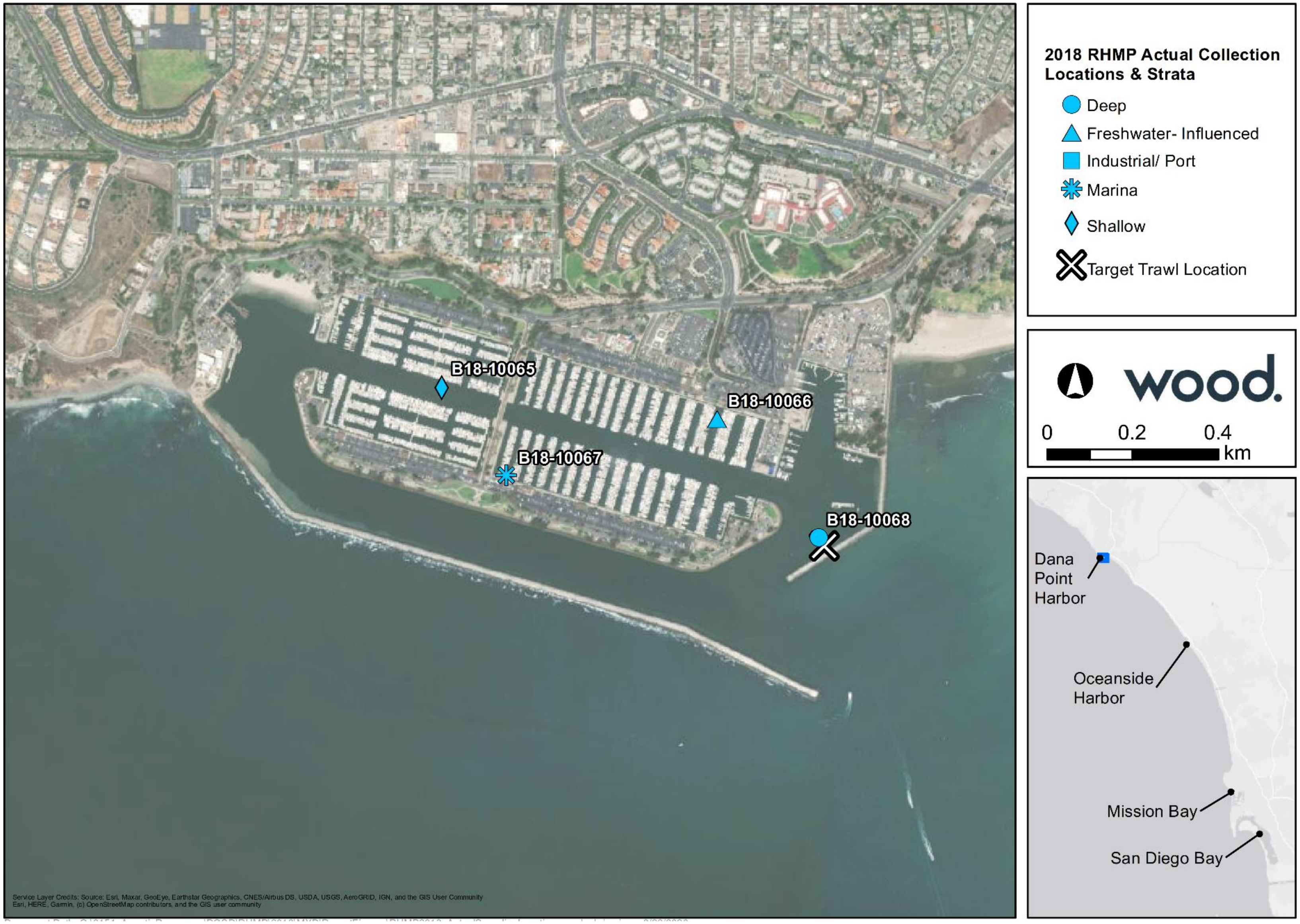
Because of physical geography (i.e., impermeable, or sloped sediment surfaces) or access and safety restrictions, final sampling locations differed from the originally proposed sites in a few instances. At Station B18-10179 (Sweetwater Channel), the GPS coordinates placed the sample location upstream beyond a security buoy channel barrier. The site was sampled as close as possible to the proposed station, approximately 180 meters away. In east Mission Bay, Station B18-10015 ended up on land. The vessel approached as close as possible to the target site, with sampling conducted approximately 165 meters away. Lastly, at Station B18-10043 in south San Diego Bay, samples were collected approximately 130 meters away from the target location due to unsafe shallow conditions. One other station in the freshwater-influenced stratum in Mission Bay (Station B18-10018) was abandoned due to shallow depths and the inability to safely sample nearby. This site was replaced with overdraw Station B18-10438 (shallow stratum) in accordance with the Bight Program protocol. Differing depths at some locations compared with conditions during prior surveys and the requirement to move sampling locations slightly from proposed sites resulted in the redesignation of strata types in a few cases. In such cases, the stratum originally assigned was adjusted to the most appropriate stratum based on the actual sampling location. In the end, there was a relatively even distribution of stations across strata; 15 stations each were sampled in the marina, deep, and industrial/port strata as originally proposed, 14 stations were sampled in the freshwater-influenced stratum, and 16 stations were sampled in the shallow stratum. A total of four sediment and water quality stations were sampled in Dana Point Harbor, four were sampled in Oceanside Harbor, nine were sampled in Mission Bay, and 58 were sampled in San Diego Bay. The number of stations among harbors was scaled based on the overall size of each harbor. A brief description of sample locations in each harbor for the 2018 RHMP is summarized below and included in Table 2-2. Specific locations of the sediment, water quality, and trawl sampling stations in each harbor are shown in Figures 2-1a through 2-f (from north to south).

- In Dana Point Harbor, there was one sampling station in each of the marina, freshwater-influenced, deep, and shallow strata (Figure 2-1a).
- In Oceanside Harbor, two stations were located within the marina stratum, and one station was in each of the freshwater-influenced and deep strata (near the mouth of the harbor) (Figure 2-1b).
- In Mission Bay, four stations were located in the shallow stratum, two were in the deep stratum, one was in the freshwater-influenced stratum (near the Cudahy Creek outflow in eastern Mission Bay), and two were in the marina stratum within the Mission Bay Yacht Club in Santa Barbara Cove and the Dana Landing embayment (Figure 2-1c).
- In San Diego Bay, of the 58 sediment and water quality stations, 15 were located in the industrial/port stratum, ten were in the marina stratum, 11 were in the freshwater-influenced stratum, 11 were in the shallow stratum, and 11 were in the deep stratum (see Figures 2-1d, 2-1e, and 2-1f). The marina stations were in Shelter Island Yacht Basin (SIYB), America’s Cup Harbor, the Coronado Cays, and Chula Vista Yacht Marina. A total of five of the 11 freshwater-influenced stations were located within or near the Sweetwater Channel in south San Diego Bay, and two were outside the mouth of Chollas Creek. The remaining stations were located near a storm drain in the Laurel Hawthorn embayment,

near the mouth of Switzer Creek, and two were located along the southeastern shore of San Diego Bay between the Chula Vista Marina and Telegraph Canyon. Industrial/port stations were located exclusively along the eastern shoreline of San Diego Bay, extending north from Sweetwater Channel to the Embarcadero Marina Park.

Table 2-2.
RHMP Sampling Strata Summary

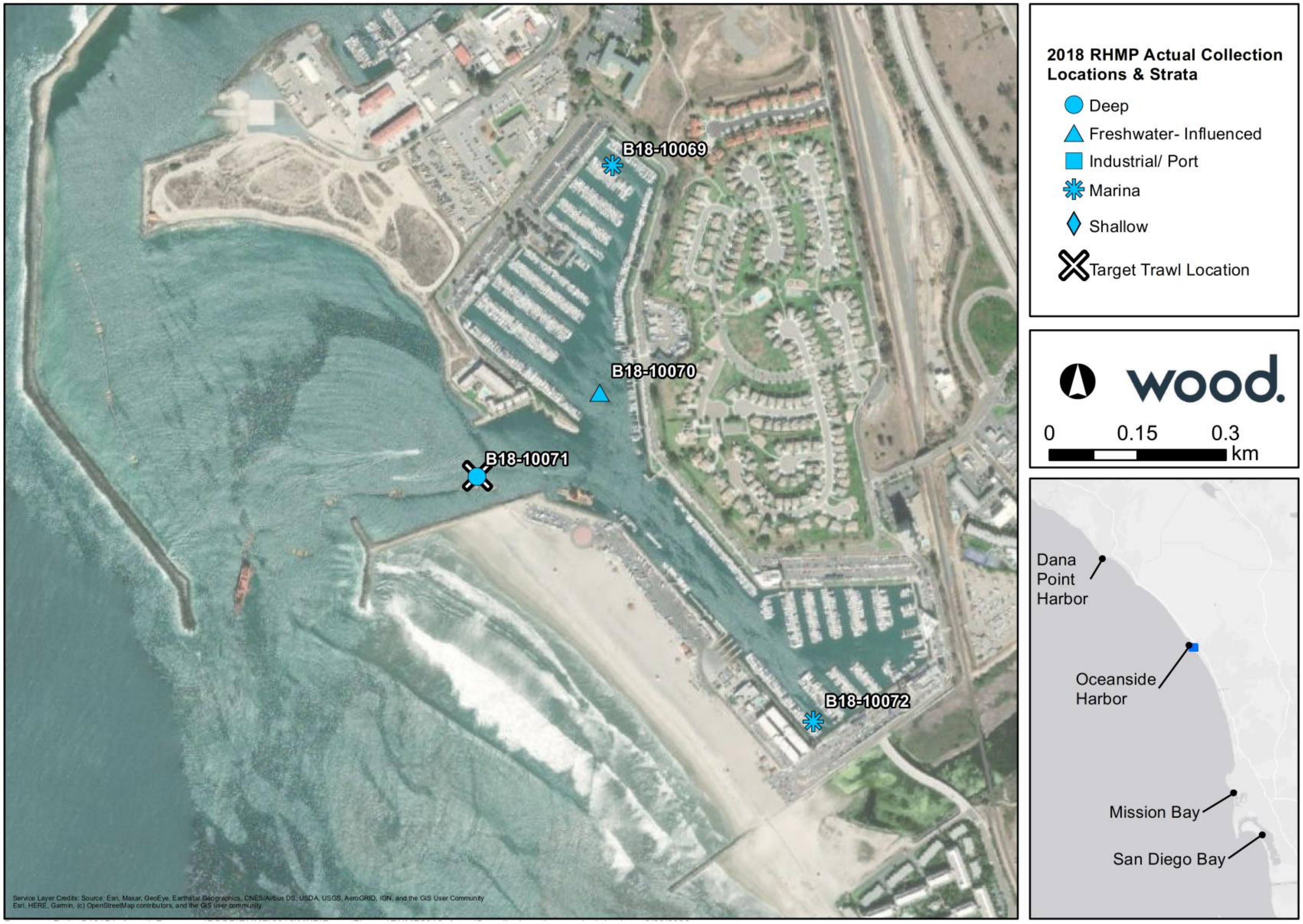
Harbor	Number of Samples in Each Stratum					Total
	Deep	Freshwater-Influenced	Marina	Industrial/ Port	Shallow	
Dana Point Harbor	1	1	1	0	1	4
Oceanside Harbor	1	1	2	0	0	4
Mission Bay	2	1	2	0	4	9
San Diego Bay	11	11	10	15	11	58
Total	15	14	15	15	16	75



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

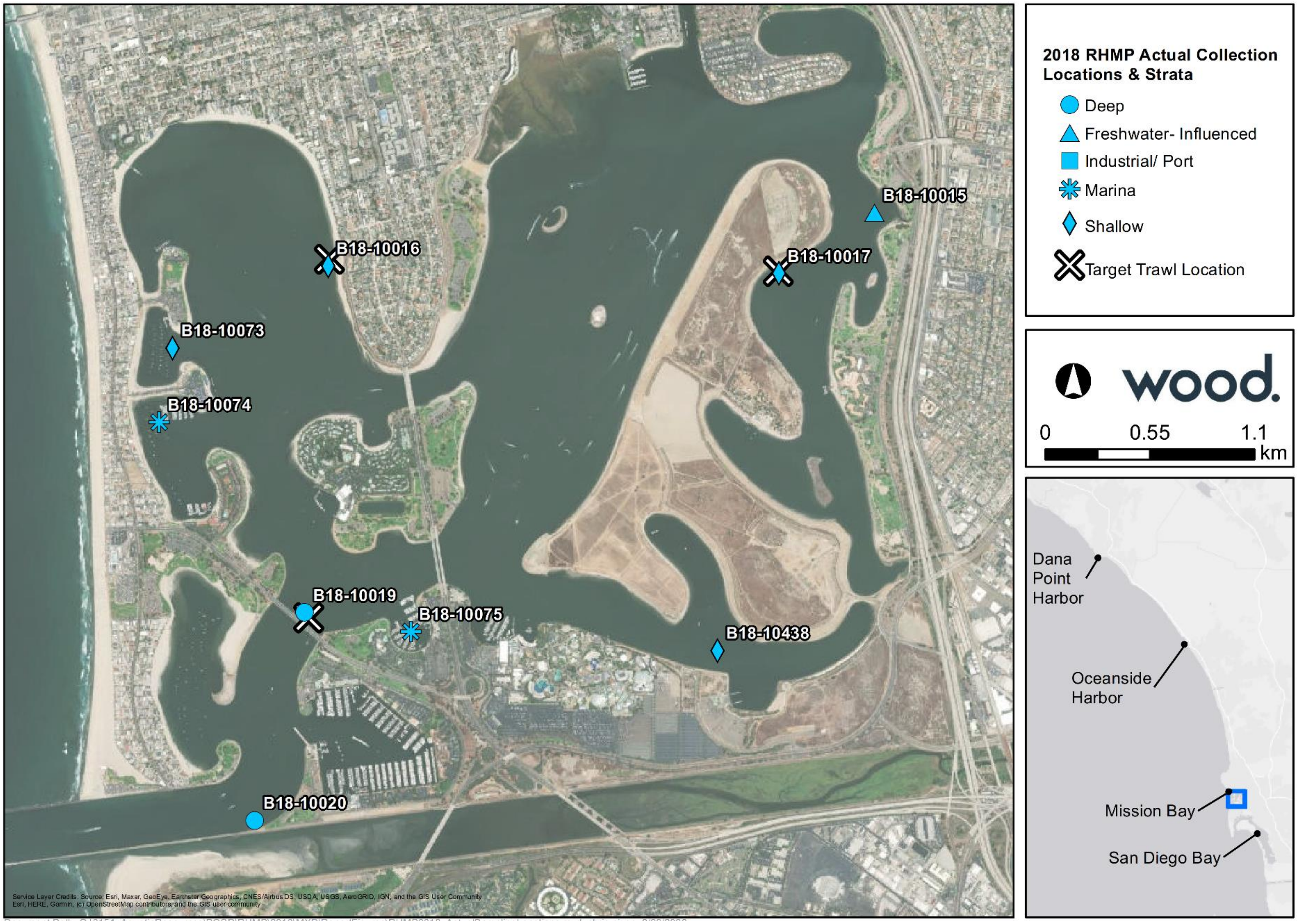
Figure 2-1a. Sampling Stations and Strata in Dana Point Harbor

Note: The targeted trawl station in Dana Point Harbor (B18-10068) was moved to the sample location monitored in 2013 located within the entrance channel, as shown in Figure 2-2a, due to a torn net on the first attempt from hard substrate interference (likely misplaced rip rap) at the original targeted location.



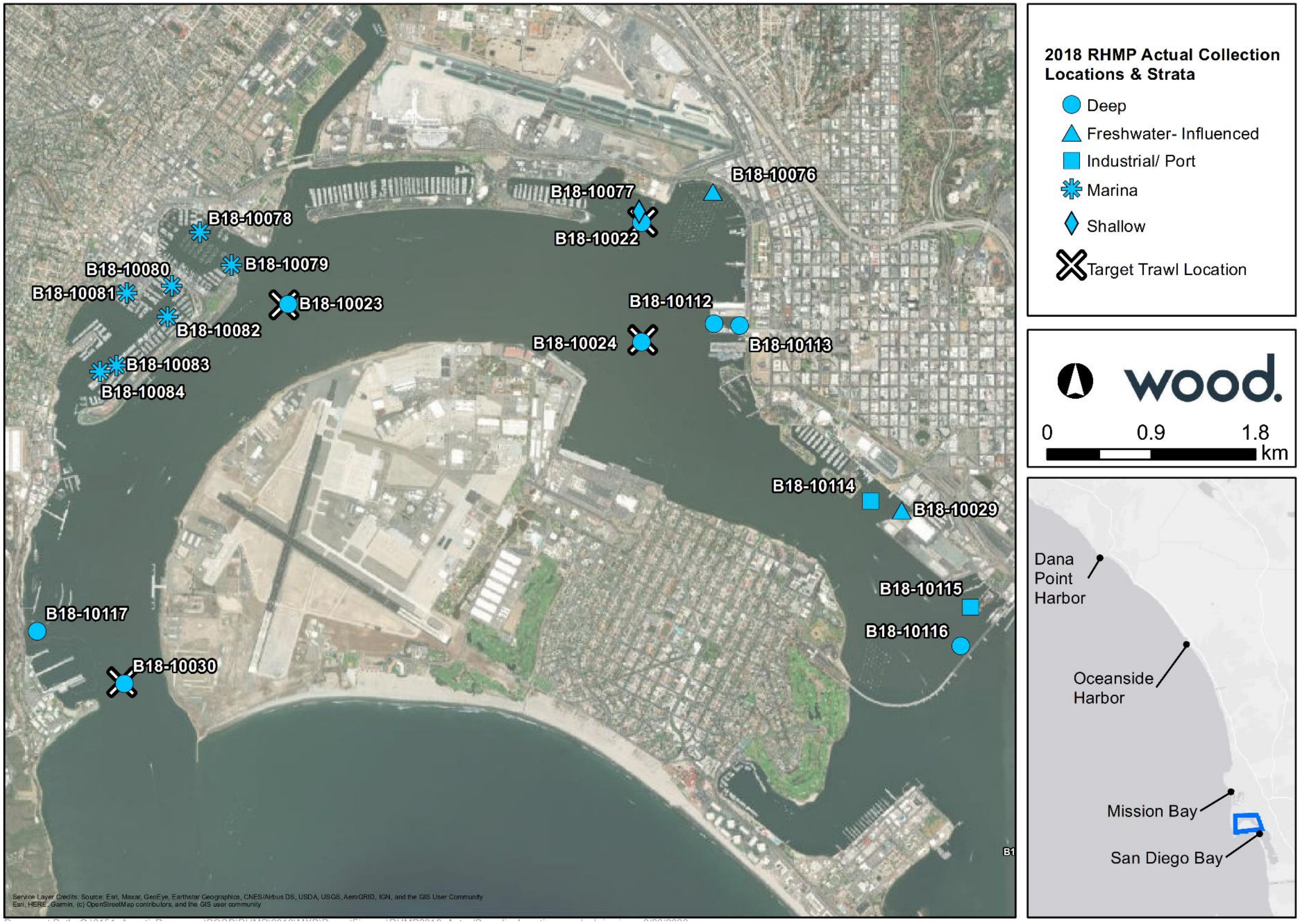
Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 2-1b. Sampling Stations and Strata in Oceanside Harbor



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 2-1c. Sampling Stations and Strata in Mission Bay



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 2-1d. Sampling Stations and Strata in North San Diego Bay

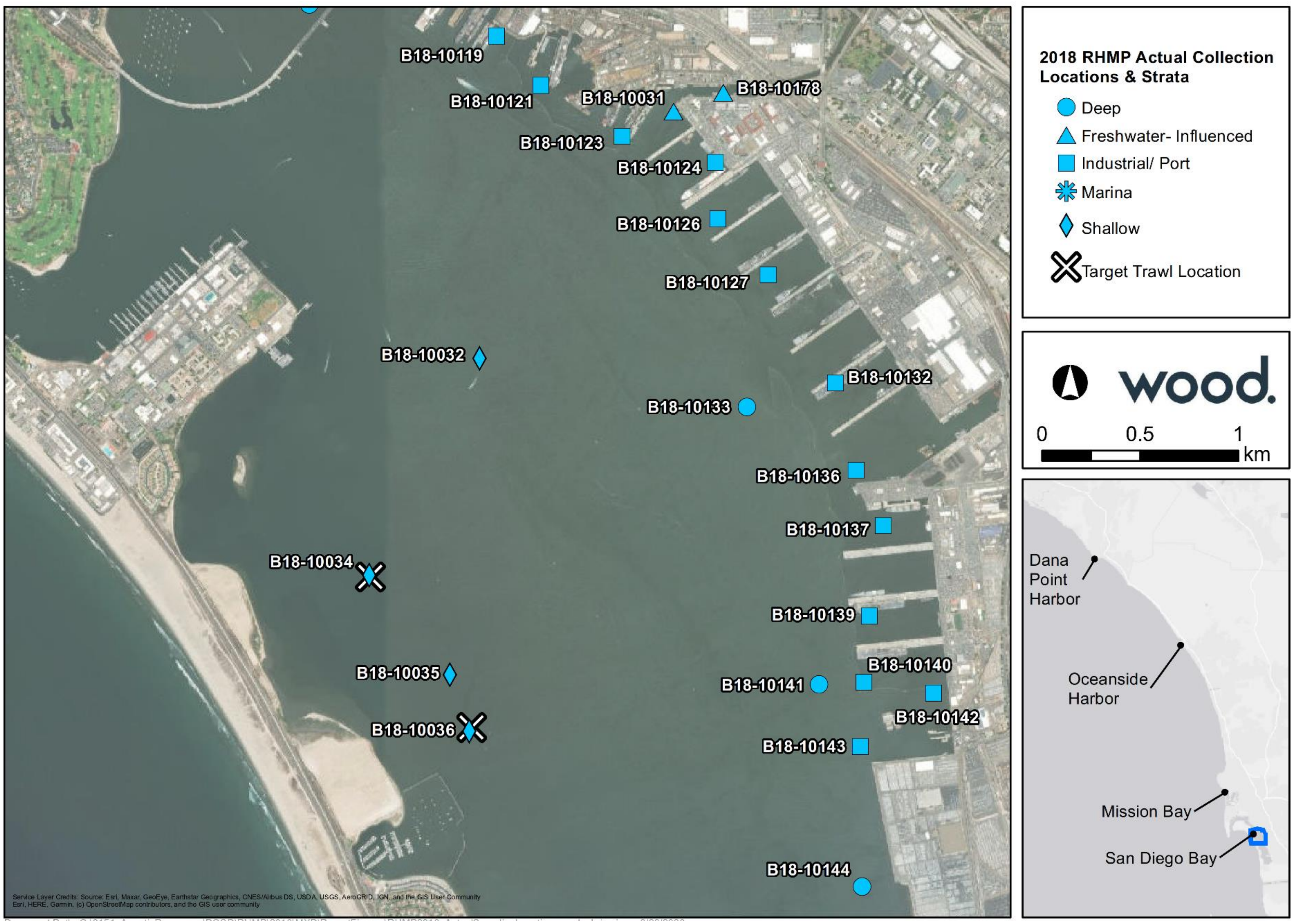


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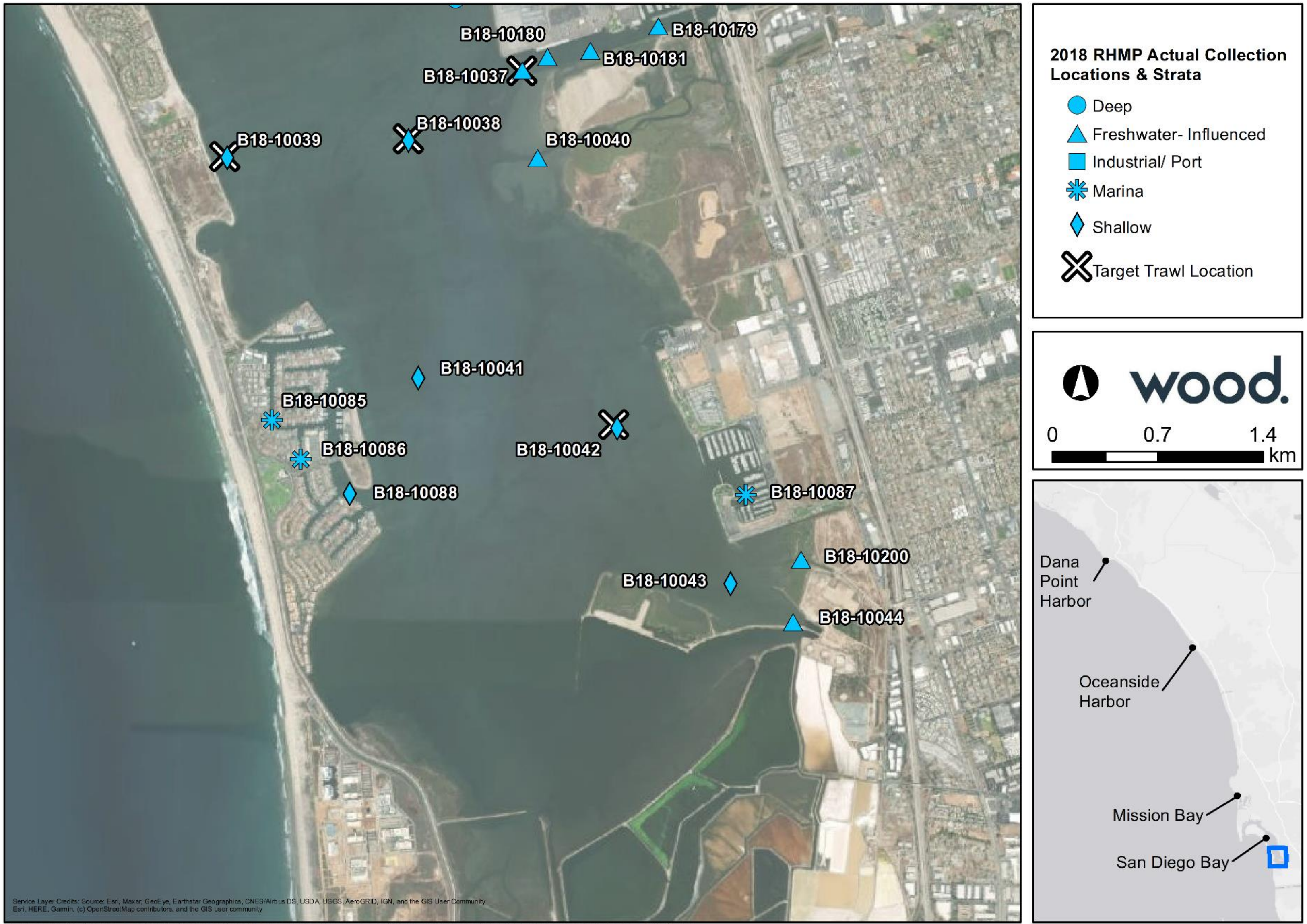
Figure 2-1e. Sampling Stations and Strata in Central San Diego Bay



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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Figure 2-1f. Sampling Stations and Strata in South San Diego Bay

2.1.3 Water Quality Sampling

Water quality was sampled at 75 stations. Methodologies and associated QA/QC procedures are detailed in the project-specific Work Plan and Quality Assurance Project Plan (QAPP), prepared by Wood, and approved by the RHMP Agencies (Wood, 2018a and 2018b). Field observations and coordinates of sampling stations during collection were recorded on sampling data forms and electronically on a field tablet. Station locations are shown in Figures 2-1a through 2-1f and are listed with coordinates in Table 2-1, as well as Appendix A, Table A-1.

Upon arriving at a sampling station, the vessel was anchored with the engine off for at least five minutes prior to initiating water sampling. Discrete water samples were collected at each station 1 meter below the surface using a 2.2-liter acrylic Niskin™ bottle (Photograph 1). For dissolved trace metals, a subsample of water from the Niskin bottle was immediately filtered in the field through a 0.45-micron (µm) filter into a disposable sterile, self-contained Nalgene vessel (Thermo Scientific brand) using a hand pump (Photograph 3). The filter apparatus was pre-cleaned in the field with three aliquots of deionized water and rinsed three times with site water prior to collection for analysis of dissolved metals.

Subsamples of water for analysis of total metals, ammonia, nitrate, orthophosphate, methylene blue-activated substances (MBAS; surfactants), oil and grease, dissolved organic carbon (DOC), total organic carbon (TOC), total suspended solids (TSS), and PAHs were carefully poured directly from the Niskin bottle into pre-labeled sample bottles with proper preservative where appropriate (Photograph 2). Subsamples for analysis of dissolved metals remained in the sealed filter vessel. All samples were logged on a chain-of-custody (COC) form (Appendix O), and then transferred immediately to an ice chest and kept at approximately 4 degrees Celsius (°C) on wet ice during holding and transport[4]. Additional data, including weather, wind speed and direction, and water color and odor, were recorded on field data sheets (Appendix E). A complete list of analytes and associated target reporting limits (RLs) are provided in Table 2-3, and Appendix B, Table B-1. Samples were submitted to Physis Environmental Laboratories, Inc. (Physis) located in Anaheim, California, for chemical analyses. All samples were transported on ice via courier to Physis and were analyzed within the required holding times for most analyses. See Section 5.2.5 for a discussion on those samples and associated analytes with holding time exceedances.

After collection of water samples for chemical analysis, physical parameters of the water column were assessed using a Sea-Bird Electronics SBE-19 Plus™ conductivity-temperature-depth (CTD) profiler instrument equipped with sensors that measure specific conductance, temperature, dissolved oxygen (DO), pH, and light transmission (transmittance). The DO and pH sensors were calibrated prior to the week of monitoring; the transmittance, conductivity, and temperature sensors were calibrated annually by Sea-Bird Electronics, Inc. To initiate a cast, a 3-minute acclimation period was used to bring the CTD sensors into thermal equilibrium with the ambient seawater and to ensure that all sensors were reading accurately. A second calibration check of the CTD measurements of pH, temperature, DO, and salinity was performed at each location by measuring these parameters independently at a depth of approximately 1-m below the surface using hand-held YSI brand meters that were calibrated daily prior to field sampling. The CTD profiler was then lowered at a speed of 0.25–0.50 meter per second, while scanning and logging

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[4] Subsamples for nitrate and orthophosphate analyses were immediately frozen following collection.

measurements at eight scans per second until the instrument was within 1 meter of the bottom (Photograph 4). After casts at each station, data were downloaded and saved onto a field computer and then checked to ensure that the CTD profiler had been turned on properly, the depth was accurate, and all water quality measurements had been recorded throughout the cast. The CTD profiler was calibrated post-cruise after each week of sampling. Data from the CTD was processed using Sea-Bird Electronics software. Scans were binned by 1-meter depth intervals to produce a manageable data set for analysis. Vertical profile plots prepared for each measured parameter at each sampling station are provided for reference in Appendix E.

Leveraged Special Study Related to Water Quality – Ocean Acidification

Water quality parameters collected in the harbors for the RHMP, particularly pH, will also be used to support a new leveraged study during Bight ’18 to assess potential ocean acidification impacts on epibenthic invertebrates and demersal fish.

Photographs 1 and 2. Collection of water samples using a Niskin bottle and subsequent processing aboard the R/V Early Bird II

Photograph 3. Field filtration for analysis of dissolved trace metals

Photograph 4. Water column profile sampling using a CTD profiler.

Table 2-3.
Chemical Analyses of Water Samples

Analyte	Analysis Method	Water Target RLs [a]	Units
pH	Field Measurement	--	--
Specific Conductance	Field Measurement	--	µS/cm
Dissolved Oxygen	Field Measurement	--	mg/L
Temperature	Field Measurement	--	°C
Salinity	Field Measurement	--	psu
Transmittance	Field Measurement	--	%
Total Suspended Solids	SM 2540 D		mg/L
Ammonia-N	SM 4500-NH_3 D	0.05	mg/L
Methylene Blue-Activated Substances (MBAS)	SM 5540 C	0.025	mg/L
Nitrate-N	USEPA 300.0/SM 4500-NO_3 E	0.05	mg/L
Oil and Grease	USEPA 1664B	1.0	mg/L
Dissolved Organic Carbon (DOC)	SM 5310 B	0.5	mg/L
Total Organic Carbon (TOC)	SM 5310 B	0.5	mg/L
Total Orthophosphates P	SM 4500-P E	0.05	mg/L
Aluminum (Al)	USEPA 1640	1.0	µg/L
Antimony (Sb)	USEPA 1640	0.015	µg/L
Arsenic (As)	USEPA 1640	0.015	µg/L
Barium (Ba)	USEPA 200.8	0.5	µg/L
Beryllium (Be)	USEPA 1640	0.01	µg/L
Cadmium (Cd)	USEPA 1640	0.005	µg/L
Chromium (Cr)	USEPA 1640	0.025	µg/L
Cobalt (Co)	USEPA 1640	0.01	µg/L
Copper (Cu)	USEPA 1640	0.01	µg/L
Iron (Fe)	USEPA 1640	1.0	µg/L
Lead (Pb)	USEPA 1640	0.005	µg/L
Manganese (Mn)	USEPA 1640	0.02	µg/L
Mercury (Hg)	USEPA 245.7	0.02	µg/L
Molybdenum (Mo)	USEPA 1640	0.01	µg/L
Nickel (Ni)	USEPA 1640	0.005	µg/L
Selenium (Se)	USEPA 1640	0.015	µg/L
Silver (Ag)	USEPA 1640	0.02	µg/L
Thallium (Tl)	USEPA 1640	0.01	µg/L
Tin (Sn)	USEPA 1640	0.01	µg/L
Titanium (Ti)	USEPA 1640	0.07	µg/L
Vanadium (V)	USEPA 1640	0.04	µg/L
Zinc (Zn)	USEPA 1640	0.005	µg/L
Polycyclic Aromatic Hydrocarbons (PAHs) [b]	USEPA 625	5.0	ng/L

Notes: Metals analysis consists of both total and dissolved fractions. Filtering for the dissolved fraction occurred in the field immediately after collection.

a. Reporting limits provided by Physis Environmental Laboratories.

b. Includes acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[e]pyrene, benzo[g,h,i]perylene, benzo[k]fluoranthene, biphenyl, chrysene, dibenz[a,h]anthracene, dibenzothiophene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, perylene, phenanthrene, pyrene, 2,6-dimethylnaphthalene, 1-methylnapthalene, 2-methylnapthalene, 1-methylphenanthrene, and 2,3,5-trimethylnaphthalene.

% = percent; °C = degrees Celsius; µg/L = microgram(s) per liter (parts per billion); µS/cm = microSiemen(s) per centimeter; mg/L = milligram(s) per liter; ng/L = nanogram(s) per liter; psu = practical salinity unit(s); RL = reporting limit; SM = Standard Method; USEPA = United States Environmental Protection Agency

2.1.4 Sediment Sampling

Sediment sampling was performed at the same 75 stations as the water quality sampling and on the same day, following the Bight ’18 protocols outlined in the *Bight ’18 Sediment Quality Assessment Field Operations Manual* (SCCWRP, 2018c), the *Bight ’18 Quality Assurance Manual* (SCCWRP, 2018b), and the project-specific Work Plan and QAPP for the RHMP (Wood, 2018a and 2018b). Detailed field notes regarding the sampling station, visual sediment characteristics, and other observations of potential value at the site were recorded during sample collection. Field observations and the sampling station coordinates were recorded on field data sheets and on a field tablet provided by SCCWRP that was integrated with the dGPS unit. Station locations are shown in Figures 2-1a through 2-1f and are listed with coordinates in Table 2-1, as well as Appendix A, Table A-1. Raw field data sheet scans are provided in Appendix E. All samples were logged on a COC form (Appendix O) and then placed in a cooler on ice. Samples were stored at 4°C in the dark until delivered to the appropriate laboratory for analysis following collection.

Benthic sediments were collected using a stainless-steel, 0.1-square-meter tandem Van Veen (TVV) grab sampler (Photograph 5). A minimum of two 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, the surface disturbance was minimal, and the penetration depth was at least 5 centimeters (cm) for sediment chemistry or toxicity and 7 cm for benthic infaunal analyses. Rejected grab samples were discarded and resampled. Prior to subsampling for analyses, the physical characteristics of each grab sample were recorded (color, odor, grain size, any macrofauna or algae observed, shell debris, etc.). Each sample processed was photographed (including sampling station identification, date, and time recorded on a whiteboard, as shown in Photograph 6). A photograph log of all sediments collected is provided for reference in Appendix M.

One of the two grab samples from the first deployment of the TVV was used for benthic infaunal samples. For infaunal analysis, the depth of an intact grab sample was recorded, and the entire sample was sieved onboard the vessel immediately after collection (Photographs 7 and 8). The sieve consisted of a 1.0-millimeter (mm) stainless-steel mesh screen mounted at the bottom of an aluminum sieve box. Site water was pre-filtered through an in-line 20-µm fiber filter and used to wash the sediment through the screen. After sieving, the remaining debris and infauna were carefully transferred to one or more pre-labeled 1-liter polycarbonate containers and treated with a relaxant solution of Epsom salts for approximately 30 minutes. After the relaxant exposure, the infaunal samples were preserved in the field with a 10% formalin solution.

The remaining grab sample from the first deployment and subsequent grab samples were used for sediment chemistry, grain size, and toxicology analyses. Sediments were collected from the top 5 cm of each grab, avoiding sediment within 1 cm of the sides of the TVV (Photographs 9 and 10). After a sufficient volume of sediment was collected, sediments were homogenized. Previous Bight Program sampling methodology required the collection and transfer of intact sediments directly from the TVV sampler into sample containers for analysis. However, due to the heterogeneity often observed in shallow bay sediments over small spatial scales, even within a single grab sample, this methodology may result in inconsistent results for paired sediment physical, chemical, and toxicological analyses. To enhance consistency and comparability among sediment samples collected during the 2018 RHMP, sediments were thoroughly homogenized in the field in a 5-gallon bucket with a clean Teflon liner using a stainless-steel spoon prior to transfer to analytical containers.

Two pre-labeled 4-ounce jars were filled with homogenized sediment for chemical analyses; a third jar was filled and saved as an archive sample. Approximately 150–200 grams of sediment were also collected for grain-size analysis at each sampling station and placed in a pre-labeled 1-quart Ziploc™ bag. Sediment for physical and chemical analyses was stored during collection efforts at 4°C on ice and frozen at -20°C within 48 hours. All samples were transported on ice via courier to Physis and were analyzed within the required holding times for most analyses. Additional subsamples of homogenized sediment from each station were also collected and transferred to Wood in San Diego to be archived frozen as a contingency if needed at a later date. Sediment samples were analyzed for the analytes listed in Table 2-4 and Appendix B, Table B-2.

Following the collection of benthic infaunal and sediment chemistry samples, subsamples were then collected for toxicity testing. For toxicity, 5 liters of the homogenized sediment also sampled for chemistry was placed in a Teflon bag with headspace removed and stored on ice. Samples for toxicity testing were transported on ice to Wood Aquatic Toxicology Laboratory located in San Diego, California, for laboratory testing of whole sediments using embryos of the Mediterranean mussel (*Mytilus galloprovincialis*) and a marine amphipod (*Eohaustorius estuarius*).

Table 2-4.
Chemical Analyses of Sediment Samples

Analyte	Analysis Method	Sediment Target RLs [a, b]	Units
Total Solids	USEPA 160.3/SM 2540 B [c]	0.1	%
Total Organic Carbon	USEPA 9060	0.01	%
Grain Size	SM 2560 D	0.1	%
Aluminum	USEPA 6020/6010B [d]	NA	mg/kg
Antimony	USEPA 6020/6010B [d]	0.05	mg/kg
Arsenic	USEPA 6020/6010B [d]	0.05	mg/kg
Barium	USEPA 6020/6010B [d]	NA	mg/kg
Beryllium	USEPA 6020/6010B [d]	0.05	mg/kg
Cadmium	USEPA 6020/6010B [d]	0.01	mg/kg
Chromium	USEPA 6020/6010B [d]	0.05	mg/kg
Copper	USEPA 6020/6010B [d]	0.01	mg/kg
Iron	USEPA 6020/6010B [d]	5.0	mg/kg
Lead	USEPA 6020/6010B [d]	0.01	mg/kg
Mercury	USEPA 245.7 [d]	0.02	mg/kg
Nickel	USEPA 6020/6010B [d]	0.02	mg/kg
Selenium	USEPA 6020/6010B [d]	0.05	mg/kg
Silver	USEPA 6020/6010B [d]	0.02	mg/kg
Zinc	USEPA 6020/6010B [d]	0.05	mg/kg
Total Nitrogen	USEPA 9060	4.0	mg/kg
Total Phosphorus	USEPA 6020	4.0	mg/kg
Ammonia	SM 4500-NH_3 D	0.2	mg/kg
Acid Volatile Sulfides	Plumb 1981 and TERL	0.1	mg/kg
Simultaneous Extracted Metals	USEPA 200.8	0.0004-0.0124	µmol/g
PAHs [e]	USEPA 8270D	5.0	µg/kg
Chlorinated Pesticides [f]	USEPA 8270D	0.5-50	µg/kg
Fipronil & Degradates [g]	USEPA 8270D-NCI	0.5	µg/kg
Pyrethroid Pesticides [h]	USEPA 8270D-MRM	0.5-10	µg/kg
PCB Congeners [i]	USEPA 8270D PCB [d]	0.2-10	µg/kg
PBDEs [j]	USEPA 8270D-NCI	0.1	µg/kg

Notes:

a. Sediment reporting limits are on a dry-weight basis.

b. Reporting limits provided by Physis Environmental Laboratories.

c. Standard Methods for the Examination of Water and Wastewater, 19th Ed. American Public Health Association, 1995.

d. USEPA. 1986–2004. SW-846. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, 3rd Ed.

e. Includes acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[e]pyrene, benzo[g,h,i]perylene, benzo[k]fluoranthene, biphenyl, chrysene, dibenz[a,h]anthracene, dibenzothiophene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, perylene, phenanthrene, pyrene, 2,6-dimethylnaphthalene, 1-methylnapthalene, 2-methylnapthalene, 1-methylphenanthrene, and 2,3,5-trimethylnaphthalene.

f. Includes cis-chlordane, trans-chlordane, o.p'-DDT, p,p'-DDT, o.p'-DDD, p,p'-DDD, o.p'-DDE, p.p'-DDE, p,p'-DDMU, aldrin, BHC-alpha, BHC-beta, BHC-gamma, BHC-delta, cis-nonachlor, trans-nonachlor, oxychlordane, DCPA (Dacthal), dicofol, dieldrin, toxaphene, endosulfan sulfate, endosulfan-I, endosulfan-II, endrin, endrin aldehyde, endrin ketone, heptachlor, heptachlor epoxide, hexachlorobenzene, methoxychlor, mirex, and perthane.

g. Includes fipronil, fipronil desulfinyl, fipronil sulfide, and fipronil sulfone.

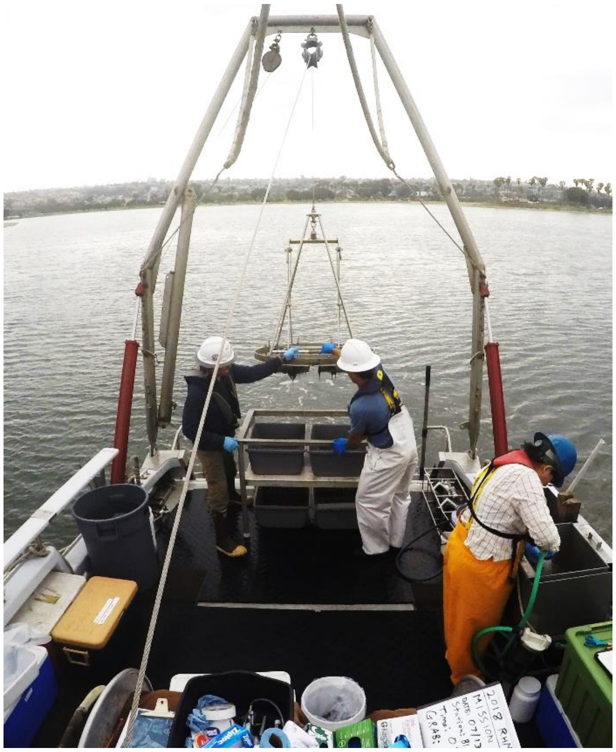
h. Includes allethrin, bifenthrin, total cyfluthrin, total cypermethrin, Danitol (fenpropathrin), deltamethrin/tralomethrin, esfenvalerate, fenvalerate, fluvalinate, lambda-cyhalothrin, *cis*-permethrin, *trans*-permethrin, and prallethrin.

i. Includes congeners: PCB-3, 5, 8, 15, 18, 27, 28, 29, 31, 33, 37, 44, 49, 52, 56(60), 66, 70, 74, 77, 81, 87, 95, 97, 99, 101, 105, 110, 114, 118, 119, 123, 126, 128, 137, 138, 141, 149, 151, 153, 156, 157, 158, 167, 168+132, 169, 170, 174, 177, 180, 183, 187, 189, 194, 195, 199(200), 201, 203, 206, and 209.

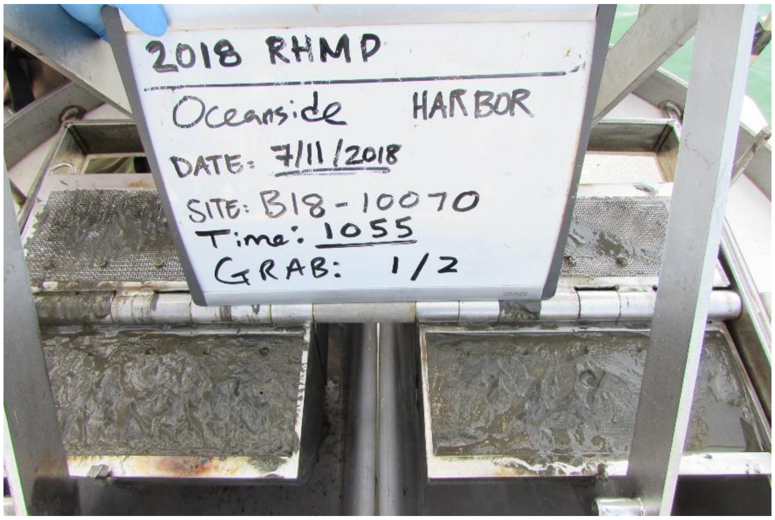
j. Includes PBDE-17, 28, 47, 49, 66, 85, 99, 100, 138, 153, 154, 183, 190, and 209.

% = percent; µg/kg = microgram(s) per kilogram (parts per billion); µmol/g = micromole(s) per gram; mg/kg = milligram(s) per kilogram (parts per million); NA = not applicable SM = Standard Method; RL = reporting limit; USEPA = United States Environmental Protection Agency

Photographs 5 through 10 below show the sampling process using the Van Veen grab sampler.



Photograph 5. Retrieval of the TVV grab sampler in Mission Bay



Photograph 6. TVV grab showing an acceptable intact sediment sample for processing

Photographs 7 and 8. Processing a sediment grab through the 1-mm sieve for benthic infauna analyses

Photographs 9 and 10. Subsampling sediments from the top 5 cm of the TVV grab sampler for chemistry and toxicity analyses

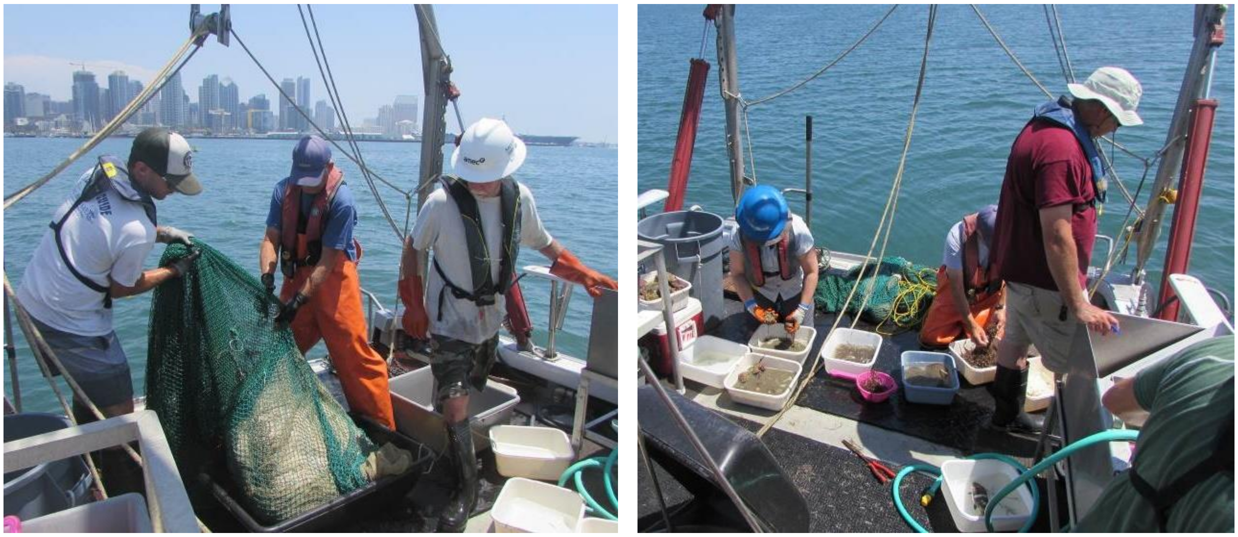
Leveraged Special Studies Related to Sediment Quality

Sampling efforts conducted during the RHMP also provided a valuable leveraging opportunity to support several special studies conducted during Bight ’18. One study led by Dr. Holly Bik of the University of California at Riverside (UCR) was focused on an evaluation of meiofaunal communities throughout the Southern California Bight. To support this effort, a subsample of sediment was collected at all 75 RHMP stations after homogenization. Approximately 100 grams of sediment was placed in a single pre-labeled Ziploc™ bag for each location and saved on ice prior to shipment to SCCWRP for subsequent distribution to UCR for analysis. The meiofaunal analysis is ongoing now at the University of Georgia. A second special study led by Dr. Alvina Mehinto of SCCWRP included a screening assessment of sediment and sportfish tissue samples collected from across the Southern California Bight for bioactive chemical contaminants using bioanalytical screening assays. More than 100 samples, including 12 from the RHMP, were screened using an androgen receptor assay, estrogen receptor assay, and aryl hydrocarbon receptor assay. A subset of the samples subsequently will be screened using non-targeted chemical analysis, with a goal to establish habitat-specific chemical fingerprints and identify bioactive chemicals.

2.1.5 Trawls for Assessment of Demersal Fish and Macroinvertebrate Communities

Demersal fish and epibenthic macroinvertebrate samples were collected with a standard 25-foot semi-balloon otter trawl with a 29-foot footrope, 1.5-inch mesh, and 0.5-inch cod-end mesh, following Bight ’18 protocols (SCCWRP, 2018c) and the project-specific Work Plan and QAPP (Wood, 2018a and 2018b). Trawls were performed along isobaths for a minimum of 5 minutes (bottom time) at an approximate speed of 2.0 knots at each station. Station information was recorded directly onto electronic field data sheets created specifically for Bight ’18 as well as hard-copy field datasheets. Trawl sampling start and end coordinates were automatically recorded on the field computer, as were 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 sampling information is provided in the field data sheets in Appendix E. Trawl locations and tracks are displayed in Figures 2-2a through 2-2f, as well as Appendix A.

Upon retrieval of the trawl net after a successful deployment, the catch was placed in shallow tubs for sorting and processing (Photographs 11 and 12). All specimens were sorted into broad taxonomic categories, and then counted and identified to the lowest possible taxon. Unidentified organisms were fixed using 10% buffered formalin, preserved using 70% ethanol, and returned to the laboratory for further identification (FID). A single representative of each species encountered was retained and preserved (in the same manner as FID species) to be added to the project voucher collection of the entire Bight ’18 trawl catch. When applicable, a second specimen of the same species was retained for an additional verification step, deoxyribonucleic acid (DNA) bar-coding. DNA vouchers were preserved in 95% ethanol. If only one individual for a given species was caught, or if organisms were too large for preservation, a fin clip, or an appendage (from invertebrates, when applicable) was used for the DNA voucher. If organisms were too large to be easily preserved (e.g., large bat rays), or their identification was obvious from a photograph (e.g., California spiny lobster), photographic vouchers were created, and the specimens were released.



Photographs 11 and 12. Otter trawl retrieval and subsequent species sorting and documentation aboard the R/V Early Bird II.

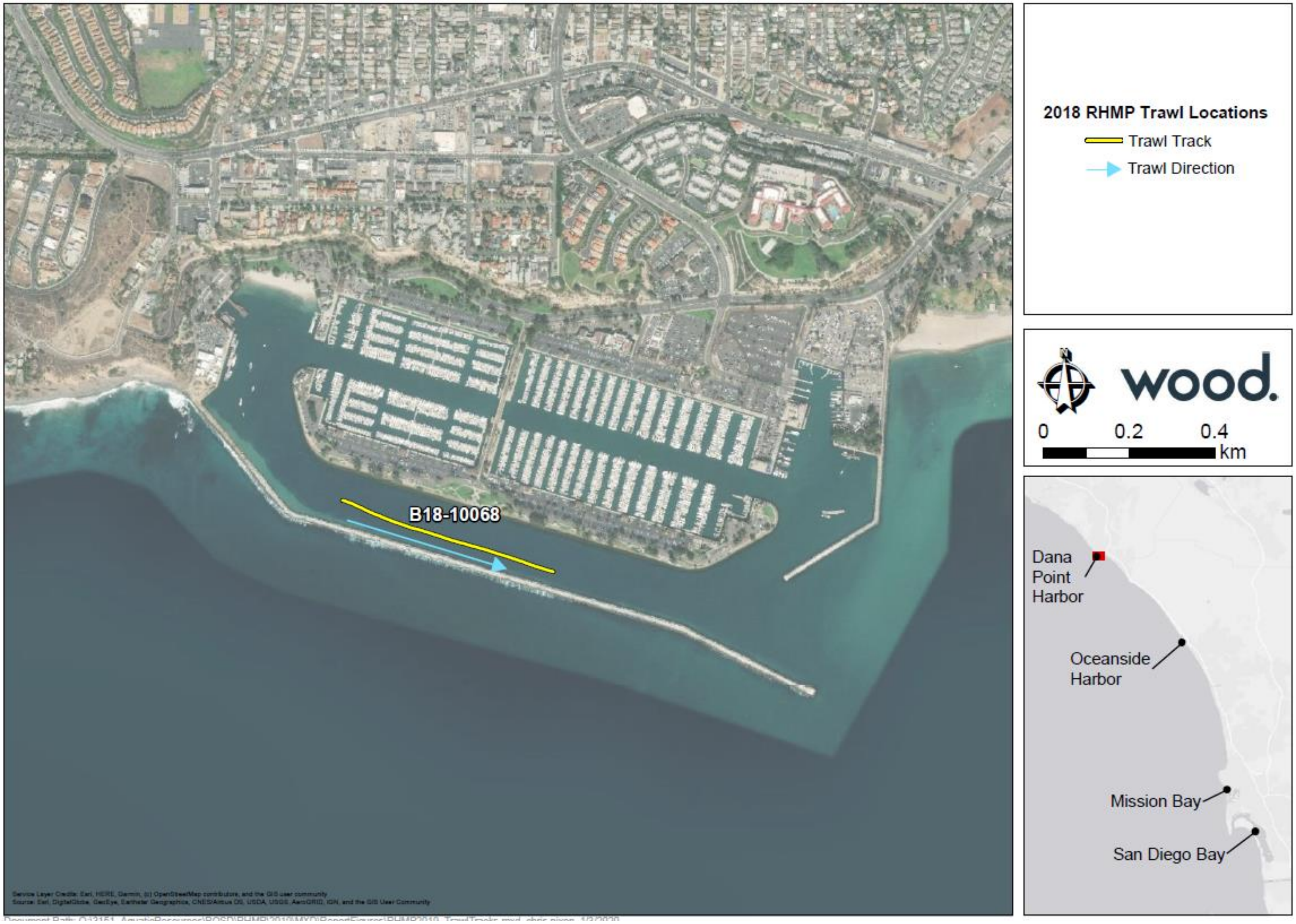


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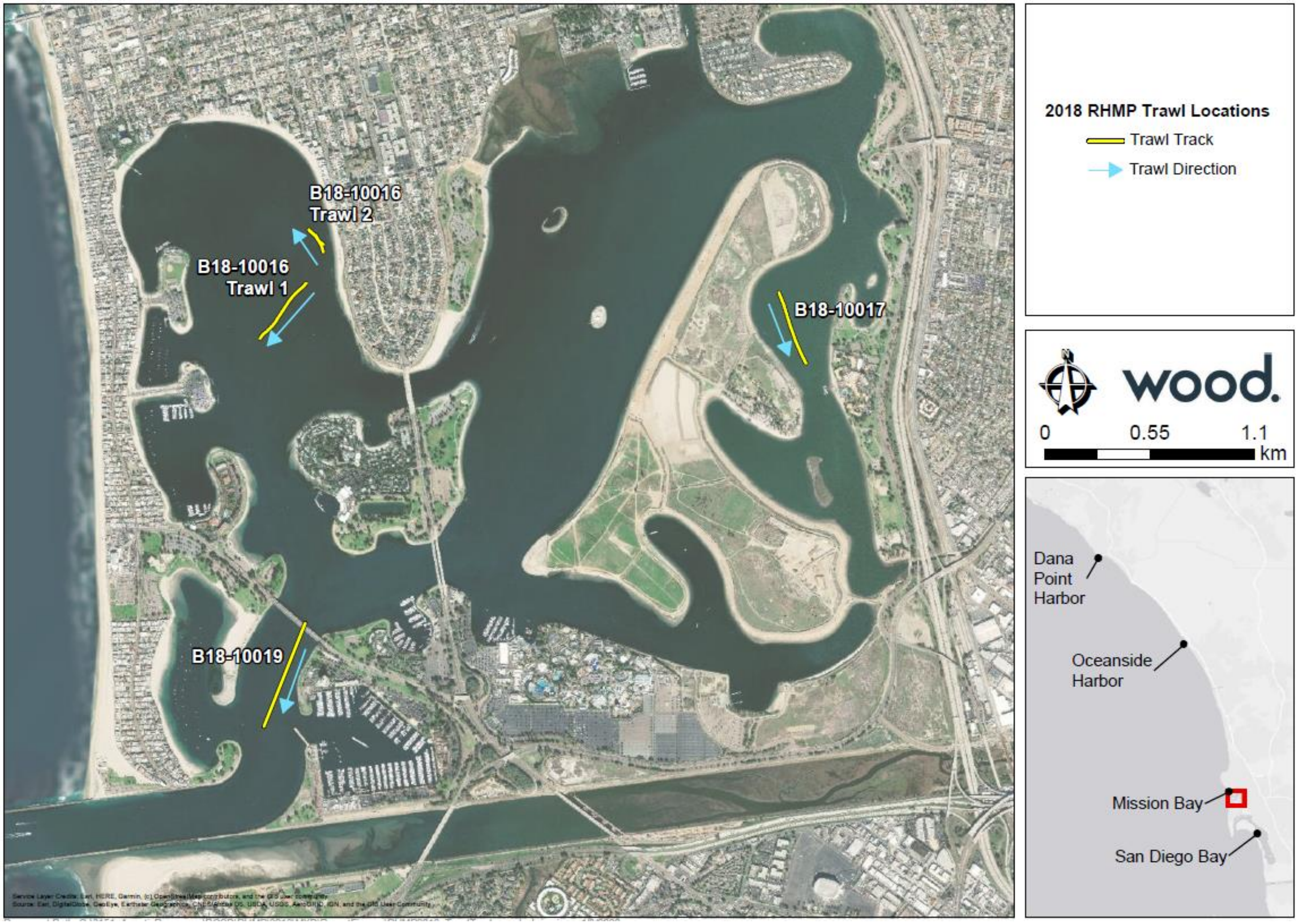
Figure 2-2a. Trawl Location in Dana Point Harbor

Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2-2b. Trawl Location in Oceanside Harbor



Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2-2c. Trawl Locations in Mission Bay

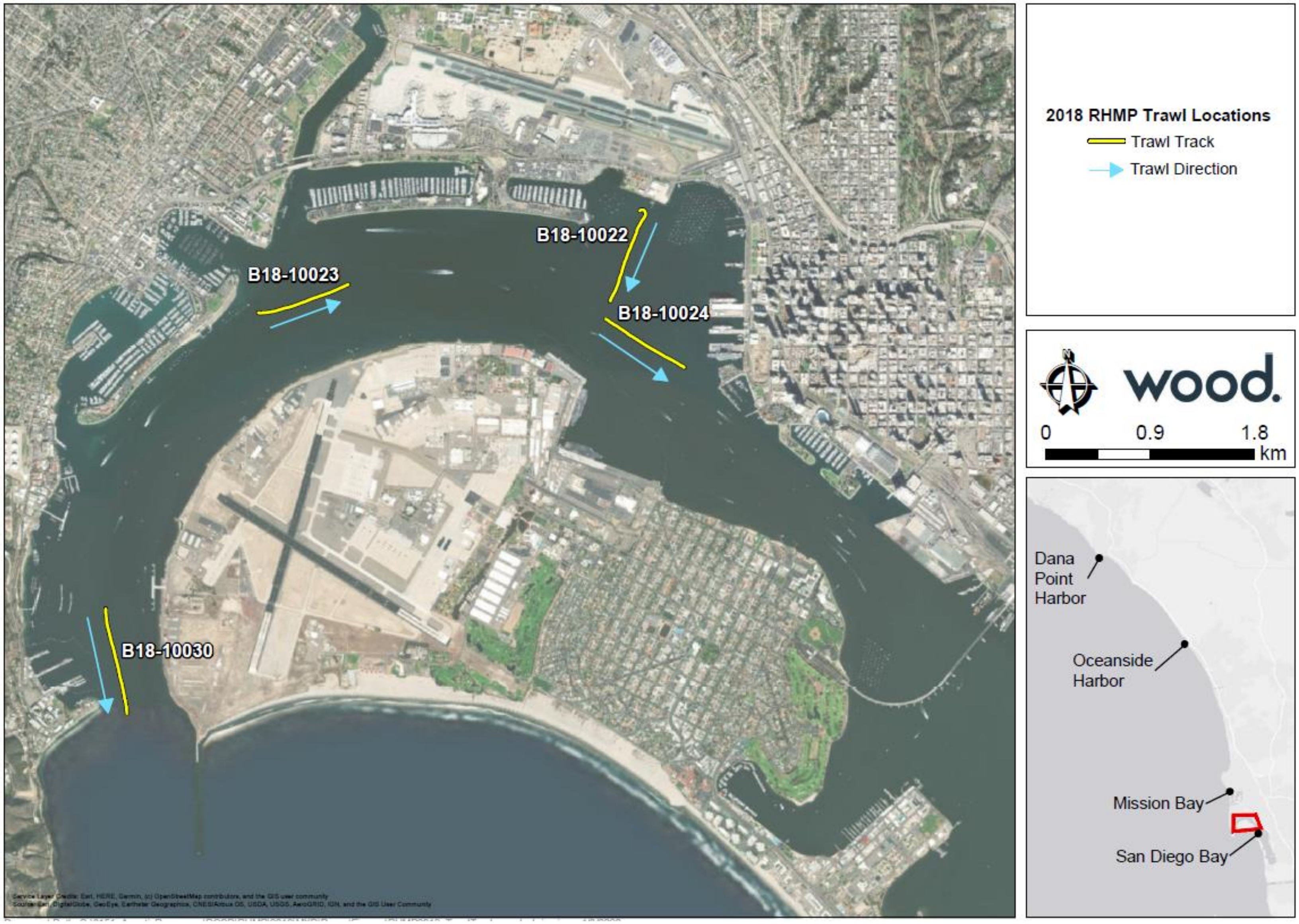


Figure 2-2d. Trawl Locations in North San Diego Bay

Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

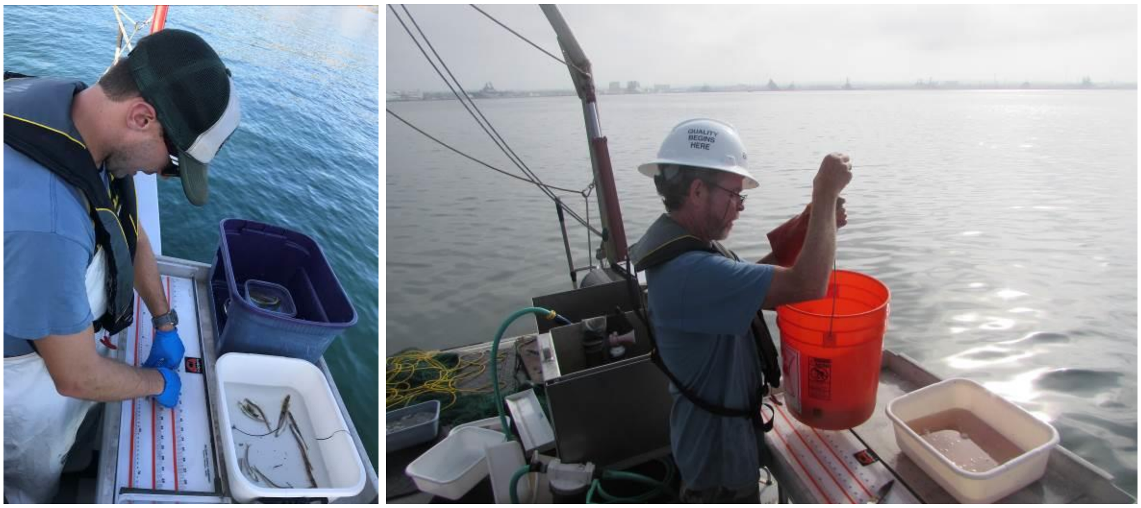
Figure 2-2e. Trawl Locations in Central San Diego Bay

Figure 2-2f. Trawl Locations in South San Diego Bay

For both fish and invertebrates, each individual specimen was visually examined for abnormalities and disease symptoms (e.g., tumors, parasites, fin erosion, and internal and external lesions), which, if found, were noted on the field datasheets. (For a full list of potential abnormalities, see the field data sheets in Appendix E). When fish and invertebrates exhibited a new instance of disease or parasite, pathology vouchers were also created and cataloged.

Photographs were taken of each individual with species identification, date, and sampling station identifier information. (See Appendix N for a field photograph log with representative photographs of each species collected). A complete library with photographs of all specimens collected during the RHMP trawls is available in electronic format. Individual specimens saved for vouchering were retained by being fixed in 10% buffered formalin and later preserved with 70% ethanol (or, for DNA vouchers, 95% ethanol), and the rest of the catch was released immediately after sorting.

After taxonomic identification, fish specimens caught were enumerated and measured for standard length (i.e., to the end of the vertebrae) and grouped into 1-cm interval size classes (Photographs 13 and 14). All individuals 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. Larger organisms were weighed individually, and their biomass added to the total weight for that particular species. At stations where more than 250 individuals of one species were caught, the aliquot method (as detailed in SCCWRP, 2018c) was used to determine the number of individuals and catch weight. Macroinvertebrates were enumerated and weighed using the same procedure as for fish, where smaller species were grouped into a batch weight, and larger individuals were weighted separately and then totaled per species. *In situ* species identification and weight QA/QC procedures were employed on a subsample of both fish and macroinvertebrates caught at each station. A more complete description of QA/QC procedures related to the benthic trawls is provided in the *Bight '18 QA Manual* (SCCWRP, 2018b) and the project-specific Work Plan and QAPP (Wood, 2018a and 2018b).



Photographs 13 and 14. Fish identification and measurement following a trawl

Leveraged Special Studies Associated with Benthic Trawls

Two leveraged studies to assess concentrations of bioaccumulative contaminants in fish tissue and assessment of marine debris were conducted concurrently with RHMP trawl sampling. The bioaccumulation study supported a key RHMP-specific question (Are fish in the harbors safe to eat?) but was also conducted in close coordination with SWRCB as part of a larger-scale assessment to answer the same question in coastal regions statewide (see additional details in Section 2.2 below). Likewise, assessment of any debris collected during the trawls continues to be of interest and is reported for the RHMP, as well as a larger-scale assessment throughout southern California coastal waters as part of the Bight Program. At the end of each trawl, any captured debris (e.g., plant material, plastic, and cans) was quantified, weighed, and recorded on a specific Trawl Debris Form created for the Bight program (see Appendix E).

2.2 Assessment of Bioaccumulation – Are Fish in the Harbors Safe to Eat?

An assessment of bioaccumulation of select contaminants of concern in fish was conducted to address one of the five key RHMP questions related to whether common sportfish captured are safe to eat. This effort was coordinated with larger-scale assessments conducted by the State of California in coastal areas throughout the entire state in 2008 and 2018 as described below, and in southern California separately as part of the Bight Program in 2013. The efforts in 2008 and 2018 supported the State of California OEHHA evaluation of contaminant levels in sport fish and issuance of Fish Consumption Advisories for water bodies in California. The CDFW, under the auspices of the SWRCB SWAMP Bioaccumulation Oversight Group (BOG) program, conducted their most recent decadal Coastal Fish Survey within the Southern California Bight from June 1 through September 30, 2018, during the same period of time as monitoring for the RHMP. These efforts were closely coordinated by the RHMP, CDFW, and the BOG program to maximize the capture of target species and also provide leverage to increase efficiency and minimize duplication of efforts. While only benthic trawls were used to collect fish for RHMP, the BOG program collected targeted fish species using a variety of gear, including seines, trawls, hook and line, traps, and spears. Fish tissues were analyzed for a suite of organochlorine pesticides, PAHs, PBDEs, PCBs, arsenic, mercury, selenium, and percentage of lipids.

To support this effort, select fish specimens from target species captured during RHMP trawls were characterized (length and weight measured), photographed, individually wrapped in acetone-cleaned aluminum foil, placed in a labeled plastic bag, and frozen. An example of photo documentation and processing of a fish sample for tissue analysis is shown in Photograph 15. Target species for tissue analysis (statewide) included white croaker, kelp bass, and Pacific chub mackerel (primary target species) and shiner surfperch, California halibut, yellowfin croaker, barred sand bass, spotted sand bass, olive rockfish, and California scorpionfish (secondary target species). After summarizing those fish retained and agreeing on those to be analyzed, frozen fish were shipped overnight to the State of California BOG Program located at the CalState Moss Landing Marine Laboratory in Moss Landing, California. Fish were organized into composite groups of similar size along with various individual fish to process for analysis. A total of 75 samples associated with the RHMP (collectively captured by the RHMP and the BOG Program) were submitted to Physis for processing and chemical analysis. These data will support several data gaps identified during the 2013 RHMP (Amec Foster Wheeler, 2017b) and follow-up efforts in 2014 that focused on shallow-water habitats in San Diego Bay (Amec Foster Wheeler, 2017a).

These data will also be used to assess tissue contaminant trends over time and may be used to help fulfill data gaps identified in the State of California SQO Decision Support Tool to evaluate the relationship between contaminants in fish tissue and sediments and associated human health risk. Additional detail regarding the methods and a complete summary of results will be reported later under separate cover by the SWRCB (for the statewide effort), and a stand-alone supplemental report will be completed in 2021 for the RHMP that will include methods and a summary of fish bioaccumulation results for the San Diego Regional Harbors.

Agency Code: Wood
Program: 2018 RHMP/Bight '18
Station Name: B18-10071
Sample Type/Use: Otter Trawl
Date /Time Collected: 7/11/18 0643
Circle One: 95% ethanol 10% formalin [✓ None]
Taxon Name: Yellow Fin Crocker
ID by: BT Fish: #1 of 1 Tot Lngth:

Photograph 15. Processing and photo documentation of fish for tissue analyses

2.3 Indicator Bacteria Analysis – Are Waters Safe for Body Contact Activities?

In 2018, the SDRWQCB requested that an assessment of human health risk related to the water contact recreation (REC-1) beneficial use be reincorporated into the RHMP. However, the RHMP Agencies determined fecal indicator bacteria (FIB) testing performed on a regularly scheduled basis would provide a more informative and accurate assessment of the extent, magnitude, and trends as compared to a single set of samples collected every five years during an ambient monitoring program, which may capture anomalous results. Therefore, the historical FIB analysis presented in this report consists of extraction and *post hoc* analysis of data from focused long-term monitoring efforts to assess REC-1 at beaches and bays throughout southern California. Dry and wet season data were collected and reported over the past ten years from the RHMP Agencies' water quality monitoring programs for this assessment.

Data for Dana Point Harbor were obtained from the County of Orange Health Care Agency (OCHCA) Ocean Water Protection Program website (OCHCA, 2020); data for the City of Oceanside were obtained directly from the City of Oceanside via a data request from the

Watershed Protection Program; and Mission Bay and San Diego Bay data were obtained from the California SWRCB Beach Monitoring Database (SWRCB, 2020). The SWRCB Beach Monitoring Database is the data repository for the County of San Diego Department of Environmental Health (SDDEH) Beach and Bay Water Quality Program (SDDEH, 2020). The Port of San Diego also provided data directly for San Diego Bay, which were also included in the SDDEH database. These databases included information collected from routine beach water quality programs required under AB 411, as well as a Total Maximum Daily Load (TMDL) program for Indicator Bacteria at Baby Beach in Dana Point Harbor and Shelter Island Shoreline Park in San Diego Bay (SDRWQCB, 2008; Resolution No. R9-2008-0027).

The results of the effort are summarized in Section 6.0 and included as a full stand-alone report for reference in Appendix P.

2.4 Laboratory Analyses

Methods for laboratory analyses, including chemical analysis of water and sediment samples, grain-size analysis, sediment toxicity testing, benthic infaunal species identification, and fish tissue chemical analyses are presented in the following sections.

2.4.1 Chemistry

A complete list of chemical constituents and the associated analytical methods and reporting limits for both water and sediment chemistry is provided in Appendix B, Tables B-1 and B-2. A summary of analyses and reporting limits are shown in Tables 2-3 and 2-4 for waters and sediments, respectively. All chemical analyses were conducted according to the specifications of the SWRCB SWAMP (https://www.waterboards.ca.gov/water_issues/programs/swamp/). Chemical analyses were performed by Physis using the United States Environmental Protection Agency (USEPA) Methods or Standard Methods (SM). Sediment samples were also analyzed for grain size (partitioned into gravel, sand, silt, and clay) by Physis using SM 2560 D.

2.4.2 Toxicity

Sediment bioassay tests were used to quantify species-specific responses following exposure to surficial sediments under controlled laboratory conditions by Wood Aquatic Toxicology Laboratory. In accordance with SQOs and Bight ’18 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.

Standard QA/QC measures for toxicity testing included an assessment of concurrent laboratory control performance, replicate variability, and statistical power, as described in the *Bight ’18 Toxicology Laboratory Manual* (SCCWRP, 2018e). As an added QA measure for the amphipod test, a fine-grained sediment control was included with each batch of tests to assess whether fine material, common in bays and harbors, might have a negative impact on amphipod survival. Fine-grained material has been documented as an occasional confounding factor for *Eohaustorius*, which naturally occurs in medium- to coarse-grain-sized sediments. Reference toxicant tests were also performed with each test batch for both species to assess the relative sensitivity of the test organisms to a single known chemical (ammonia [NH_4]) over time and between laboratories.

Detailed project-specific methods for these tests are provided in the *Bight '18 Toxicology Laboratory Manual (*SCCWRP, 2018e) and the project-specific Work Plan and QAPP (Wood, 2018a and 2018b). A summary of methods is also provided in a stand-alone report prepared by Wood Aquatic Toxicology Laboratory and is included in Appendix G.

Solid-Phase Testing

Ten-day SP acute survival tests using the marine amphipod *Eohaustorius estuarius* (*E. estuarius*) were conducted in accordance with procedures outlined in the USEPA amphipod testing manual (USEPA, 1994) and ASTM International (ASTM) Method E1367-03 (ASTM, 2006a). On the day before test initiation, 2-cm aliquots of sediment from each site were placed in each of five replicate glass jars, followed by approximately 800 milliliters (mL) of filtered clean seawater. Five replicate controls were used to determine the health of the amphipods and application of proper test procedures by exposing the amphipods to clean sediment following the same protocols used for the test sediments. The test chambers were acclimated overnight, and, on Day 0 of the test, 20 amphipods were placed in each of the test chambers. Amphipods that did not bury in the sediment within 1 hour were removed and replaced. Samples were monitored daily for obvious mortality, sublethal effects, and/or abnormal behavior, as described in the amphipod testing manual. Water quality parameters, including DO, temperature, salinity, and pH, were monitored daily. Overlying and interstitial ammonia was 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 survival percentage in each chamber was recorded. The survival percentage was calculated for control and test sediments, and tests were considered to be acceptable if there was greater than 90% mean survival in the control.

A 96-hour reference toxicant test was conducted concurrently with the sediment test to assess the sensitivity of the test organisms relative to historical control chart measurements and to evaluate the potential influence of ammonia toxicity on the test organisms. The reference toxicant test was performed using ammonium chloride (NH_4Cl) with target concentrations of 15.6, 31.2, 62.5, 125, and 250 milligrams (mg) of NH_4 per liter. Ten test organisms were added to each of the four replicates of each concentration. Subsamples of water were obtained at test initiation and were analyzed for total ammonia. The more toxic un-ionized fraction of ammonia was then calculated using total ammonia along with pH, salinity, and temperature. The estimated concentrations of total ammonia and un-ionized ammonia that resulted in 50% mortality of the organisms (LC_{50}, the median lethal concentration) were calculated from the data. The LC_{50} values were then compared with historical laboratory data for the test species following exposure to ammonia to assess relative sensitivity over time, as a basis for comparison with ammonia measurements in sediment pore water. The results of this test were used in combination with the control performance to assess the health of the test organisms and the application of proper test procedures. Finally, as with sediment chemistry, a single-blind duplicate sample was tested in each laboratory to assess comparability region-wide among laboratories.

An example whole sediment test setup and close up photograph of the amphipod *Eohaustorius estuarius* are shown in Photographs 16 and 17.

Photographs 16 and 17. Solid-phase toxicity testing using the amphipod Eohaustorius estuarius. Note the burrows in the jars at the sediment surface.

Sediment-Water Interface Testing

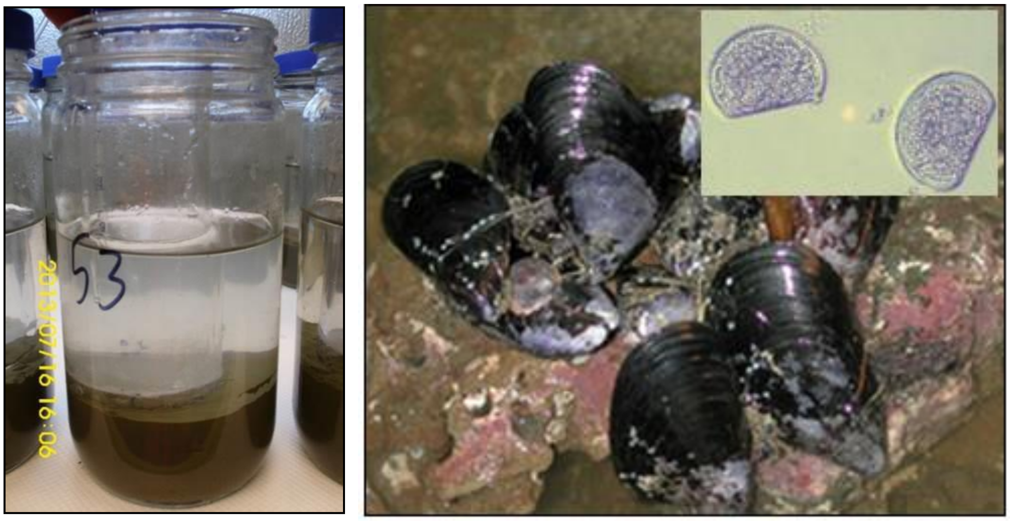
SWI bioassays were performed to estimate the potential chronic toxicity of contaminants fluxed from sediments to the overlying water. Forty-eight-hour SWI bioassays using the Mediterranean mussel *M. galloprovincialis* were conducted in accordance with procedures outlined in USEPA, 1995, and Anderson et al., 1996. On the day before test initiation, 5-cm aliquots of sample sediment were placed in each of five replicate glass chambers, followed by approximately 300 mL of clean filtered seawater. Five replicate method controls were used to verify that the test system was not causing toxicity by exposing the bivalve larvae to test chambers with screen tubes but no sediment. Following the addition of sediment and water, test chambers were left overnight to acclimate prior to the addition of the mussel embryos. Polycarbonate tubes with a 20-µm Nitex™ mesh screen mounted inside (approximately 1 cm above a bottom lip) were lowered into each glass chamber so that the sediment surface was located just below the mesh screen. Approximately 250 bivalve embryos were placed inside the screen tube in each of the test chambers. During the first 24 hours of development, embryos remain on the screen near the sediment surface, before becoming water-borne veliger larvae. Water quality parameters, including DO, temperature, salinity, and pH, were measured daily; overlying and interstitial ammonia was 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 embryos into glass shell vials with clean filtered seawater. The vials were preserved with formalin and scored by technicians at Wood Aquatic Toxicology Laboratory. The percentage of normal-alive embryo development was calculated for the control and test sediments. Tests were considered to be acceptable if there was greater than 70% mean control normal-alive embryo development.

A 48-hour reference toxicant test was also conducted concurrently with the SWI test to assess the sensitivity of the test organisms relative to historical control chart measurements and to evaluate the potential influence of NH_4 toxicity on the test organisms. The reference toxicant test was performed using NH_4Cl, with target concentrations of 1.0, 2.0, 4.0, 6.0, 8.0, 10, and 20 mg of

NH_4 per liter[5]. Approximately 250 embryos were added to each of the five replicates of each concentration. Subsamples of water were obtained at test initiation and were analyzed for total ammonia. The more toxic un-ionized fraction of ammonia was then calculated using total ammonia along with pH, salinity, and temperature.

The concentrations of total ammonia and un-ionized ammonia that caused 50% mortality (LC^{50}) and 50% reduction in 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 with historical laboratory data for the test species with NH_4Cl. The results of this test were used in combination with the control performance to assess the health of the test organisms and the application of proper test procedures.

An example test setup and image of the adult Mediterranean mussel (*M. galloprovincialis*) are shown in Photographs 18 and 19.



Photographs 18 and 19. SWI toxicity testing using embryos of the bivalve Mytilus galloprovincialis – embryos added to the inner screened chamber. Adult Mytilus species shown on the right with normal embryos after 48 hours of development (inset).

2.4.3 Benthic Infauna Sample Processing and Taxonomic Identification

Benthic infaunal samples were transported from the field to the laboratory and stored in a 10% formalin solution for at least six days for proper fixation of specimen tissue. The samples were then transferred from formalin to 70% ethanol for laboratory processing. In accordance with the *Bight ’18 Macrobenthic (Infaunal) Sample Analysis Laboratory Manual* (SCCWRP, 2018a), the organisms were initially sorted (using a dissecting microscope) into nine categories: annelids,

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[5] These toxicant test concentrations represent a range that it likely to encompass a typical dose response for each test species.

annelid fragments, arthropods, echinoderms (non-ophiuroid), ophiuroids, ophiuroid arms, molluscs, miscellaneous phyla, and debris and plastics.

The samples were initially sorted to remove debris and group organisms into taxonomic classes by Merkel and Associates, Inc., (Merkel) located in San Diego, California. Species identification to the lowest possible taxon and enumeration of species in the sorted samples were performed by specialized taxonomists of Dancing Coyote Environmental (DCE), based in Pauma, California. For nomenclature and orthography, taxonomists primarily used the publication titled *A Taxonomic Listing of Benthic Macro- and Megainvertebrates from Infaunal and Epifaunal Monitoring and Research Programs in the Southern California Bight*, edition 12, developed by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT, 2018). A QA/QC procedure was performed on each of the sorted samples to ensure 95% organism removal efficiency.

2.5 Data Analysis - Assessment Indices, Benchmarks, and Integrated Lines of Evidence

To help characterize water quality, sediment quality, and biological community conditions currently and over time, a suite of primary and secondary benchmark indicators has been incorporated into the RHMP. The background and summary of initial metrics developed for the program are provided in a 2005 planning document prepared for the RHMP (Weston, 2005a). Since the development of the program in 2005, additional indicators have become available and vetted, particularly the use of the integrated SQO lines of evidence. Additional chemicals of potential concern such as pyrethroid pesticides and PBDEs have also been identified as important measures to add to both the Bight Program and RHMP since their initial development. In 2013 and in this report, assessment of sediments has shifted towards the use of integrated measures of sediment quality, with less weight and reliance on outdated measures such as effects range-low (ER-L) and effects range-median (ER-M) screening level values (described further below). However, the ability to calculate SQO scores for older data consistent with the latest guidance is limited because not all of the SQO-required components were measured; therefore, this report has continued to preserve the use of the ER-M quotient as a sediment chemistry metric for comparison. Metrics used for assessment and comparisons are described below in order of waters, sediments, and demersal fish and macroinvertebrates.

2.5.1 Water Quality - Trace Metals

Benchmark chemistry values for an evaluation of water quality, including three select trace metals measured during the RHMP (copper, nickel, and zinc), were derived from the California Environmental Protection Agency (Cal/EPA) Region 9 California Toxics Rule (CTR). The CTR values are also consistent with the latest USEPA Ambient Water Quality Criteria (USEPA, 2017). These benchmarks, expressed as dissolved concentrations, include both short-term acute values, which are referred to as criterion maximum concentrations (CMCs), and long-term chronic values, which are referred to as criterion continuous concentrations (CCCs), as shown in Table 2-5 and presented on figures in the Results section. Original RHMP benchmarks using total metals are not included in this report, given that the CTR and USEPA water quality objectives (WQOs) are based on the dissolved fraction. The dissolved fraction is considered to be the more bioavailable and, therefore, the more biologically meaningful concentration.

Table 2-5.
RHMP Benchmark Thresholds for Water Chemistry

Measure	Water Quality Objectives (µg/L)	
	Acute (CMC)	Chronic (CCC)
Dissolved Copper (water)	4.8	3.1
Dissolved Zinc (water)	90	81
Dissolved Nickel (water)	74	8.2

Notes:
µg/L = microgram(s) per liter; CCC = criterion continuous concentration; CMC = criterion maximum concentration

2.5.2 Sediment Quality

Overview of the Sediment Quality Objective Approach Using Integrated Multiple Lines of Evidence

The sediment quality of the San Diego Regional Harbors was assessed using the State of California SQO approach, as described in the *Water Quality Control Plan for Enclosed Bays and Estuaries–Part 1, Sediment Quality* (SWRCB and Cal/EPA, 2009) and updated methodology to derive SQO calculations in Bay et al. (2014). SQOs are used to evaluate existing biological community conditions and the potential for chemically-mediated effects on benthic organisms. The SQOs use three primary lines of evidence (LOEs): sediment chemistry, sediment toxicity, and condition of the benthic infaunal community. Combined, these three LOEs form a multiple-line-of evidence (MLOE) approach to provide a final integrated station-level assessment (Figure 2-3 provides a general overview of the process). The integration uses the decision matrices presented in Appendix C (Tables C-5 and C-6). The station-level assessment results in one of six possible station-level assessments: unimpacted, likely unimpacted, possibly impacted, likely impacted, clearly impacted, and inconclusive (Appendix C, Tables C-7 and C-8) to determine whether SQOs are met at each sampling station. Both individual LOEs and the integrated SQO scores are used as metrics for comparison purposes

The specific methods used for each SQO LOE and the integration of the MLOE approach are described briefly in this section, based on the *Sediment Quality Assessment Technical Support Manual* (Bay et al., 2014) with the latest updates provided on the SWRCB website at https://www.waterboards.ca.gov/water_issues/programs/bptcp/sediment.html.

SQO metric scoring criteria for each LOE are provided in Appendix C for reference. Methods using the three lines of evidence to assess sediment quality (chemistry, toxicity, and benthic community) using both SQO and other traditional methods are described separately within this section below.

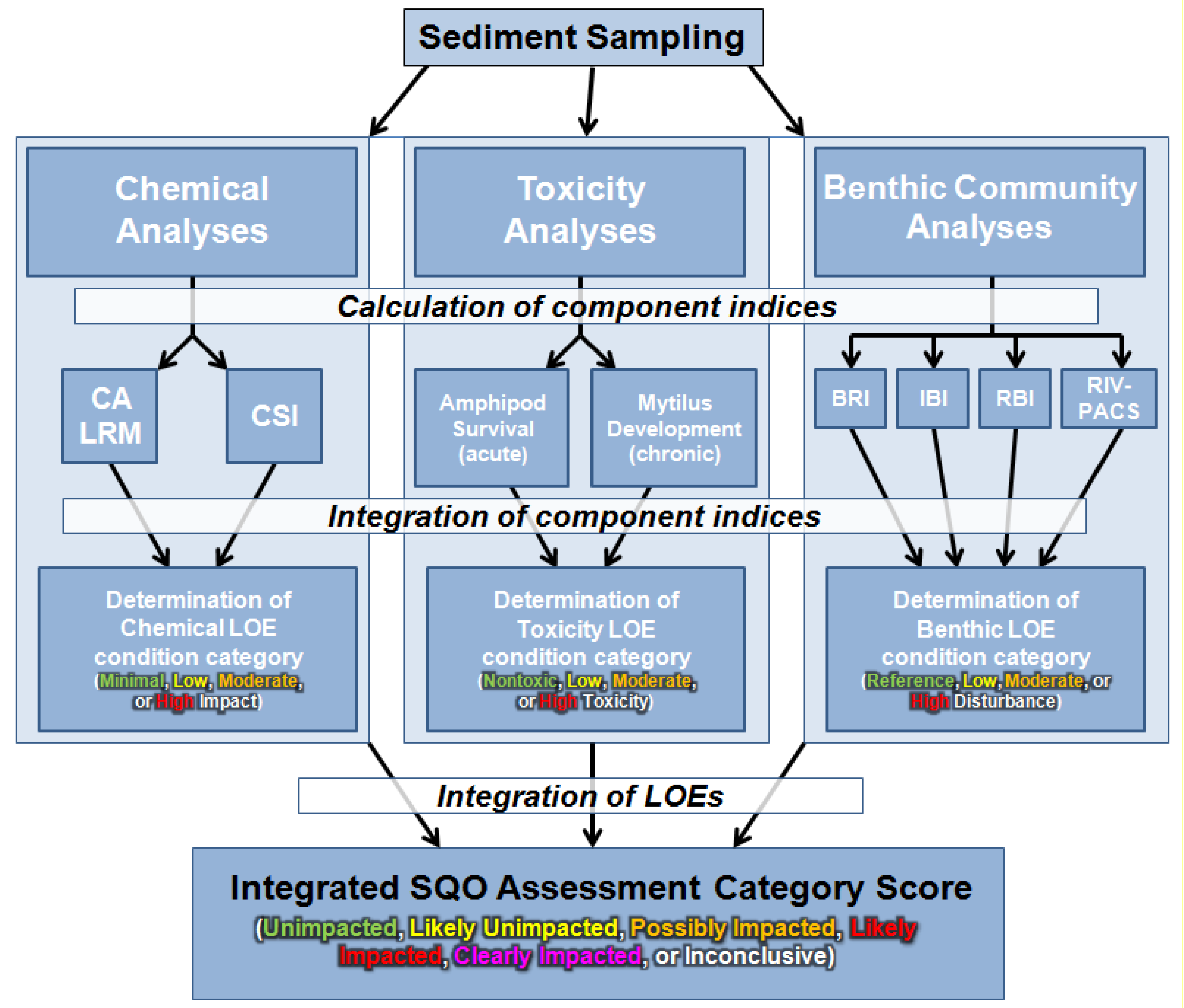


Figure 2-3. **Overview of the SQO Station Assessment Process**

Sediment Chemistry

An evaluation of current conditions for individual chemicals of potential concern in the sediments for the RHMP (see Table 2-6) was conducted in two primary ways: 1) Data for each chemical are presented in box plots that show median values and ranges for each stratum and harbor (see Section 2.5.1); and 2) Data for individual chemicals are shown on maps that show the relative concentrations of each chemical spatially among all sites by creating breakpoints based on percentile distributions of all values for each chemical recorded in the RHMP (e.g., 10th, 25th, 50th, 75th, and 95th percentiles). The first approach provides a simple comparison of concentrations among the different strata and harbors, while the second approach provides a way to visually see patterns among the sites. *Note that neither of these approaches provide an evaluation of whether or not the concentrations presented are of toxicological significance*, although the second approach, in particular, may be used to focus in on specific areas of greater or lesser concern with regard to contaminant inputs.

The SQO approach was the primary integrated method used to assess potential impacts on benthic communities based on sediment chemistry for the RHMP. Concentrations of chemicals detected in sediments were evaluated using two independent metrics: 1) the California Logistic Regression Model (CA LRM) and 2) the Chemical Score Index (CSI). These SQO methodologies were developed for the State of California using local data sets and two independent approaches. The CA LRM method, similar in many ways to the ER-L and ER-M approach, uses logistic regression to estimate the probability of sediment toxicity based on the chemical concentration, using data collected only in the State of California. The CSI, on the other hand, uses chemistry data to predict the occurrence and severity of benthic community disturbance. Selected chemical constituents are compared with a series of concentration ranges that correspond to predicted benthic disturbance levels in southern California (Ritter et al., 2012).

The CA LRM results in a single integrated metric value representing multiple chemicals in the sediments, whereas the CSI results in individual scores for a suite of key “indicator” chemicals, as well as a combined integrated score. Individual chemical concentration ranges for each exposure category are pre-determined for the CSI. For this reason, a CSI score can be attributed to individual chemicals and can also be presented on plots of data for comparison purposes. One important caveat is that the CSI represents only one of the two metrics used for the combined sediment chemistry SQO LOE score. The range of chemical concentrations used to calculate CSI scores for select chemical constituents used for the SQO method is provided in Table 2-6.

The CSI and CA LRM tools categorize sediments into four categories based on exposure potential to cause biological effects. The four categories are minimal exposure, low exposure, moderate exposure, or high exposure potential, with each category assigned a score of 1 to 4 with a score of 1 indicating minimal exposure, and so on (Appendix C, Table C-1). Each final sediment chemistry LOE category was determined by averaging the CA LRM and the CSI. If the average fell midway between two categories, it was rounded up to the greater exposure level category.

For comparison purposes, CSI concentrations for each exposure potential category are shown on plots in the Results section of this report against the median and range of measured values among harbors and strata. Although the CA LRM method does not provide concentration values that can be plotted on a figure, this method does rank the chemicals based on their potential to cause toxicity. This provides a valuable assessment of the primary chemicals most likely estimated to cause toxicity for moderate and high exposure categories.

The SQO chemistry LOE provides a regionally relevant set of sediment chemistry metrics that can be used as an effective trend analysis tool as the specific information required for these analyses continues to be collected over time. A comparison of SQO metrics is now possible between 2008, 2013, and 2018 surveys and is presented in the Discussion section of this report. However, the integrated ER-M quotient metric described below continued to be used for the assessment in this report because the CSI and CA LRM were only introduced into the Bight Program in 2008

The SQO indices will now serve as a primary integrated metric approach to assess sediment chemical exposure risk. A specific threshold used for historical comparison purposes for sediment chemistry is the breakpoint between Low Exposure and Moderate Exposure potential (% of stations above or below this breakpoint).

Table 2-6.
Chemical Concentration Ranges for Chemical Exposure Categories used in the CSI Calculation

Chemical		CSI Exposure Category			
		Minimal (1)	Low (2)	Moderate (3)	High (4)
Metals (mg/kg)	Copper	≤52.8	>52.8 - ≤**96.5**	>**96.5** - ≤406	>406
	Lead	≤26.4	>26.4 - ≤**60.8**	>**60.8** - ≤154	>154
	Mercury	≤0.09	>0.09 - ≤**0.45**	>**0.45** - ≤2.18	>2.18
	Zinc	≤113	>113 - ≤**201**	>**201** - ≤629	>629
Organics (µg/kg)	HPAH[1]	≤313	>313 - ≤**1325**	>**1325** - ≤9320	>9320
	LPAH[2]	≤85.4	>85.4 - ≤**312**	>**312** - ≤2471	>2471
	alpha-Chlordane	≤0.50	>0.50 - ≤**1.23**	>**1.23** - ≤11.1	>11.1
	gamma-Chlordane	≤0.54	>0.54 - ≤**1.45**	>**1.45** - ≤14.5	>14.5
	Total DDDs	≤0.77	>0.77 - ≤**3.56**	>**3.56** - ≤26.37	>26.37
	Total DDEs	≤1.19	>1.19 - ≤**6.01**	>**6.01** - ≤45.84	>45.84
	Total DDTs	≤0.61	>0.61 - ≤**2.79**	>**2.79** - ≤34.27	>34.27
	Total PCBs[3]	≤11.9	>11.9 - ≤**24.7**	>**24.7** - ≤288	>288

Notes:
This table reflects the changes to the CSI category ranges implemented in March 2019 by the USEPA Region 9. Final CSI scores in this report were calculated using the March 2019 thresholds.

Bold values represent threshold values.

1. Total HPAHs is the benzo(a)anthracene, benzo(a)pyrene, benzo(e)pyrene, chrysene, dibenz(a,h)anthracene, fluoranthene, perylene, and pyrene.
2. Total LPAHs is the sum of sum acenaphthene, anthracene, phenanthrene, biphenyl, naphthalene, 2,6-dimethylnapthalene, fluorene, 1-methylnapthalene, 2-methylnapthalene, and 1-methylphenanthrene.
3. Total PCBs for CSI comparison used the sum of 16 select PCB congeners (PCB-8, 18, 28, 44, 52, 66, 101, 105, 110, 118, 128, 138, 153, 180, 187, and 195) multiplied by a correction factor of 1.72. See SQO Technical Manual for more detail (Bay et al., 2014). Note that this list is a subset of the total 209 PCB congeners.

µg/kg = microgram(s) per kilogram; CSI = Chemical Score Index; DDD = dichlorodiphenyldichloroethane; DDE = dichlorodiphenyldichloroethylene; DDT = dichlorodiphenyltrichloroethane; HPAH = high-molecular-weight polycyclic aromatic hydrocarbon; LPAH = low-molecular-weight polycyclic aromatic hydrocarbon; mg/kg = milligram(s) per kilogram; PCB = polychlorinated biphenyl

The ER-M Quotient

Historically, sediment chemistry in California and elsewhere has been evaluated using a variety of different screening-level approaches to assess whether contaminants in sediments are at a level of potential ecological concern and are able to cause adverse biological effects. One approach that has had widespread use for marine sediments is a screening-level effects-based method published by Long et al. (1995) that derived screening-level threshold concentration values based on a comparison of toxicity results with associated chemical concentrations in an extensive nationwide data set comprised of results from both laboratory and field studies. The outcome of this assessment was the derivation and publication of an ER-L concentration calculated as the lower tenth percentile of the observed effects concentrations and the ER-M concentration calculated as the 50th percentile of observed effects concentrations. Concentrations below the ER-L are less likely to result in adverse biological effects, while concentrations above the ER-M are considered more likely to result in adverse biological effects (Long et al., 1995). ER-L and ER-M values for individual chemicals, although useful assessment metrics when used appropriately, have significant limitations as predictive measures of effects, as has been documented in the literature (Wenning et al., 2005). For reference, individual ER-L and ER-M concentrations for available constituents are provided in Appendix D (Table D-3), but these are no longer used for single chemical comparisons in the RHMP due to their documented shortcomings and the newer more regionally applicable approach using the SQO methodology described above for the chemistry LOE. Although assessment using individual ER-M values is no longer conducted, the use of an integrated metric derived using all individual ER-M values for each chemical has still been retained in this report for comparison to past results and results using the newer SQO methodology.

A mean ER-M quotient for a given chemical is defined as the ratio of the sample concentration to its respective ER-M value (measured concentration/ER-M). The ER-M quotient is a unitless value that can then be averaged among all chemicals that have an ER-M value. A mean of the ER-M quotient thus provides a method that integrates the effects of multiple contaminants for a more robust assessment of exposure and the potential for adverse effects (Wenning et al., 2005). For the RHMP, the mean ER-M quotient was calculated using concentrations of the chemicals listed in Appendix D (Table D-4). Based on various projects with the SDRWQCB, a mean ER-M quotient value of less than 0.2 has been considered to be conservatively protective of potential toxic effects (Weston, 2005b).

Simultaneously Extracted Metals – Acid Volatile Sulfide (SEM-AVS)

Bioavailability and potential toxicity of metals in sediments are affected by the physical properties of sediments (e.g., grain size), as well as the presence of other chemicals that interact with the metals (e.g., oxygen and sulfides). The relationship between the concentration of simultaneously extracted metals (SEM) and acid volatile sulfide (AVS) can be used to help predict the bioavailability of metals and toxicity of sediments by estimating the capacity of sulfides to bind to metals, as described in the methodology developed by the USEPA (2005) .

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. Laboratory and field experiments have shown that, if the ratio of the sum of SEM to AVS (∑SEM:AVS) is greater than 1, there are not likely to be any biologically available metals in solution, and metal toxicity is not anticipated (Burgess at al., 2013). A ratio of less than 1 may indicate the potential for toxicity due to enhanced bioavailability of trace metals. A further review of historical regional chemistry and toxicity data from southern California by Weston indicated that a ∑SEM:AVS ratio of greater than 40 provided a more reasonable estimate of a toxic threshold for the RHMP (Weston, 2005b). SEM-AVS model predictions of metal toxicity were compared with actual results of sediment bioassay tests.

A review of more recent literature indicates that the fraction of organic carbon (fOC) also has a strong effect on trace metal toxicity and should be taken into consideration when evaluating SEM-AVS ratios for predictive purposes. The USEPA normalized SEM-AVS to organic carbon content using the following formula, where fOC is the fraction of organic carbon:

$$\frac{\sum(\mathrm{SEM} - \mathrm{AVS})}{\mathrm{fOC}}$$

In 2005, the USEPA released a document titled *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Metals Mixtures (Cadmium, Copper, Lead, Nickel, Silver, and Zinc)* (USEPA, 2005). Based on numerous evaluations, the USEPA found that ESB metric values less than 130 micromoles per gram of organic carbon (µmol/gOC) are unlikely to have adverse toxicological effects; values between 130 and 3,000 µmol/gOC result in uncertain toxicological effects; and ESB values greater than 3,000 µmol/gOC are likely to cause toxicological effects. In general, the ESBs apply only to sediments that have at least 0.2% total organic carbon by dry weight (USEPA, 2012). The ESB was also calculated for both the 2013 and 2018 RHMP data sets for comparisons.

Toxicity

During the development of the RHMP, historical toxicity test results in the San Diego Regional Harbors were reviewed to help establish threshold levels for sediment toxicity. The marine amphipod *E. estuarius* is considered an ideal test species because of its relatively high sensitivity to toxic substances and the availability of historical data for this species within the study area. Mean survival, normalized to performance in the control, was used for historical comparisons. The threshold effect level was set at a 20% decrease in survival relative to the control; a value below 20% has often been used historically as an indicator of nontoxic sediments (Thursby et al., 1997). The bivalve SWI test using embryos of the Mediterranean mussel *M. galloprovincialis* was used as a secondary indicator of sediment toxicity. The endpoint used to measure toxicity for this test was the control-adjusted percent normal-alive embryo development. The benchmark threshold level for normal development was set at 60% (i.e., a threshold value of 10% below the control acceptability criterion). Although both thresholds have merit and can be used to assess changes over time, they have little relation to current SQO methods with which to assess the degree of toxicity.

The primary metric to assess toxicity herein is the integrated toxicity LOE of the SQO analysis described below, which uses both the whole sediment amphipod survival test and the bivalve SWI embryo development test. A specific benchmark threshold for comparison purposes is the breakpoint between Low Toxicity and Moderate Toxicity.

Sediment toxicity was assessed using the methodology described in Chapter 4 of the *Sediment Quality Assessment Technical Support Manual* (Bay et al., 2014) summarized in Appendix C (Tables C-2 and C-3). One-tailed t-test results assuming unequal variance were conducted between each sampling station and the control test results to determine whether they were significantly different. Raw data (% survival or % normal-alive) remained untransformed prior to statistical analysis. Each station was then categorized as being nontoxic, or having low toxicity, moderate toxicity, or high toxicity, based on both statistical significance and percent effect relative to the control, as shown in Table 2-7. The final toxicity LOE category was then calculated using the average of the test responses. When the average fell midway between two categories, the value was rounded up to the higher toxicity category per the SQO guidance. However, it should also be noted that results for each species are closely evaluated independently as each species will have unique sensitivity profiles to different chemicals of concern.

Table 2-7.
Thresholds for Calculating Toxicity Categories

Test Species/Endpoint	Nontoxic (%)	Low Toxicity (% of Control)	Moderate Toxicity (% of Control)	High Toxicity (% of Control)
Amphipod - % Survival	90 to 100	82 to 89[a]	59 to 81[b]	<59
Bivalve - % Normal-alive	80 to 100	77 to 79[a]	42 to 76[b]	<42

Notes:
a. If the response is not significantly different from the negative control, then the category becomes nontoxic. However, additional details in the toxicity flow-chart in the SQO manual should be consulted to assess actual final toxicity category designation.
b. If the response is not significantly different from the negative control, then the category becomes low toxicity. However, additional details in the toxicity flow-chart in the SQO manual should be consulted to assess actual final toxicity category designation.
% = percent

The SQO toxicity LOE provides a regionally relevant set of toxicity metrics that can be used as an effective trend analysis tool as the specific information required for these analyses continues to be collected over time. A valid comparison of SQO metrics is possible between 2008, 2013, and 2018 surveys and was performed for this report. However, comparisons with older data will continue to use the 20% effect approach for amphipods described above because the bivalve SWI test, a component of the SQO metrics, was only introduced into the Bight Program in 2008. Results from the two test species will also continue to be evaluated and compared separately in addition to the combined metric over time to ensure any current observations and trends related to either of these distinct, unrelated species are properly captured.

Benthic Infauna

Benthic infauna indices used to make historical comparisons during prior RHMP efforts have included the Benthic Response Index (BRI), the Shannon-Wiener Diversity Index, organism abundance, and taxa richness. During the development of the RHMP, the BRI was identified as a primary indicator for evaluating infaunal assemblages in the harbors, while the other three indices were considered secondary indicators. The BRI threshold level for unimpaired communities in embayments was set at 39.96, which is the value separating the reference and low disturbance categories (Ranasinghe et al., 2003). Note that lower BRI scores indicate healthier communities.

Research in California embayments has since shown that the use of a combination of benthic indices provides a more accurate description of benthic infaunal community condition than does the use of a single index (Ranasinghe et al., 2009). Benthic infaunal community condition was assessed using benthic indices specifically tailored to southern California marine bays and estuaries as described in Chapter 5 of Bay et al., (2014). An integrated benthic community assessment score is derived from four different benthic indices: (1) the Index of Biotic Integrity (IBI); (2) the Relative Benthic Index (RBI); (3) the BRI; and (4) the River Invertebrate Prediction and Classification System (RIVPACS).

Each index categorizes benthic condition into one of four disturbance categories:

- **Reference**: A community that would occur at an undisturbed reference site for that habitat
- **Low Disturbance**: A community that may exhibit some indication of stress, but is within measurement variability of, or statistically similar to, reference condition
- **Moderate Disturbance**: A community that exhibits clear evidence of physical, chemical, natural, or anthropogenic stress
- **High Disturbance**: A community exhibiting a high magnitude of stress

Details about the history, background, and development of the indices and literature citations are provided in Ranasinghe at al. (2012). The four indices are summarized as follows:

- **IBI**: The IBI compares the values of four different metrics with the ranges expected under reference conditions. The metrics used to calculate the IBI are the total number of taxa, the number of mollusc taxa, abundance of *Notomastus sp.* (a polychaete), and percentage of sensitive taxa.
- **RBI**: The RBI is the weighted sum of (1) four community metrics related to biodiversity (total number of taxa, number of crustacean taxa, abundance of crustacean individuals, and number of mollusc taxa); (2) abundance of three positive indicator taxa; and (3) presence of two negative indicator taxa. The data needed to calculate the RBI are total number of taxa, number of mollusc taxa, number of crustacean taxa, number of crustacean individuals, number of individuals of *Monocorophium insidiosum*, *Asthenothaerus diegensis*, and *Goniada littorea* (positive indicators), and presence of *Capitella capitata* complex and Oligochaeta (negative indicators).
- **BRI**: The BRI is the abundance-weighted pollution tolerance score of the organisms present in a benthic sample. The higher the BRI score, the more degraded the benthic community represented by the sample. Two types of data are needed to calculate the BRI: the abundance of each species and their pollution tolerance score, P.
- **RIVPACS**: The RIVPACS index is based on a predictive model and is a ratio of the number of reference taxa present in a test sample (observed or “O”) to the number of taxa expected to be present (“E”) in a reference sample from a similar habitat (the O/E ratio). Calculation of the RIVPACS score is a three-step process. The first step places the test sample habitat into one of 12 southern California marine bay reference sample groups. This habitat determination is based on the test station’s bottom depth, salinity, latitude, and longitude, using a linear discriminant function. The second step is to determine, for each test sample, the identity and number of taxa expected to occur, based on the probability of group membership per habitat (i.e., taxa with a ≥50% capture rate in the reference pool). In the final step, the reference taxa observed in the sample are counted, the O/E ratio is calculated, and this value is compared to published response ranges to determine the RIVPACS condition category.

Benthic community condition disturbance categories were assigned for each index (Appendix C, Table C-4), and benthic condition was then determined by integrating the four benthic indices into a single category. The two median scores of the four benthic indices were used to determine the benthic condition at each sampling station. If the median score fell between two categories, the value was rounded up to the higher disturbance category to provide the most conservative estimate of benthic community condition. As with both toxicity and chemistry, evaluation of patterns and trends related to each of the four benthic community indices are conducted in addition to the integrated SQO score, as each index provides a unique assessment of the community characteristics.

A comparison of SQO benthic infauna results is possible between the 1998 and 2003 Bight surveys and 2008, 2013, and 2018 RHMP surveys. Note that an independent review of historic data identified a few mostly minor discrepancies in the calculations of these metrics in 2008. There have also been minor updates in the SQO calculation tool since 2008. These factors may have some small unknown impact on the historical comparisons made in this report and it is recommended that the full 2008 data set (as well as data from earlier surveys) be reanalyzed at some point for more accurate trend analyses.

The SQO indices will now serve as a primary integrated metric approach to assess benthic community health. A specific threshold used for historical comparison purposes is the breakpoint between Low Disturbance and Moderate Disturbance (% of stations above or below this breakpoint).

Secondary benchmark threshold values have also been developed for indicators of benthic infaunal diversity using the Shannon-Wiener Index with a benchmark value of 2.0 and taxa richness with a benchmark threshold of 24 taxa. Note that higher values indicate healthier communities. Both benchmark values were determined to represent reference ambient values in the San Diego Regional Harbors based on an evaluation of historical data conducted during development efforts for the RHMP (Weston, 2005b). The Shannon-Wiener Index increases as both the richness and the evenness of the community increase, and typical Shannon-Wiener Index values are generally between 1.5 and 3.5 in most ecological studies, with values rarely greater than 4 (http://biology.kenyon.edu/courses/biol229/diversity.pdf).

A complete summary of threshold benchmarks for assessment of benthic communities is shown in Table 2-8.

Table 2-8.
SQO Thresholds for Benthic Infauna Community Condition

Index	Reference	Low Disturbance	Moderate Disturbance	High Disturbance
BRI	<39.96	≥39.96 – <49.15	≥49.15 – ≤73.26	>73.26
IBI	0	1	2	3 or 4
RBI	>0.27	>0.16 to ≤0.27	>0.08 – ≤0.16	≤0.08
RIVPACS	>0.90 – <1.10	>0.74 – ≤0.90 or ≥1.10 – <1.26	>0.32 to ≤0.74 or ≥1.26	≤0.32

Notes: BRI = Benthic Response Index; IBI = Index of Biotic Integrity; RBI = Relative Benthic Index; RIVPACS = River Invertebrate Prediction and Classification System

2.5.3 Fish and Macroinvertebrates

Total abundance, biomass, and community indices were calculated for both demersal fish and epibenthic macroinvertebrates captured during the otter trawl sampling.

Community indices calculated included the following:

- **Taxa Richness:** Defined as the total number of unique taxa identified at a station.
- **Shannon-Wiener Diversity Index:** Calculated by summing ($-p_i * \ln(p_i)$) for each species, where p_i is the count for species "i" divided by the total count of the sample.
- **Percent Dominance of Top Species**: Defined as the number of different species comprising 75% of the total count of the sample.
- **Pielou's Evenness Index:** Calculated using the Shannon-Wiener Diversity Index ÷ ln(species count).
- **Ecological Index (EI) for Individual Species:** Calculated by (number of individuals as a % of catch + weight of the individuals as a % of catch) × (% frequency of catch).
- **Predator Abundance:** Defined as the number and percentage of top predators in the population (fish only).

These indices have all remained consistent over time with the recent addition of predator abundance in 2013.

2.6 Data Presentation and Analysis

Results for all 75 water and sediment sampling locations were included for all analyses. This includes the 54 newly selected sites and the 21 revisited sites. All new and revisited sites were combined, as they were all originally selected using the same stratified random approach. This is the same analysis approach used by the overall Bight Program. Results from the 21 revisited sites were also separated out for a more targeted analysis of trends using only this subset of data.

Simple tabular and graphical summaries were prepared for all measurements made under this program. Many of the key measures were also plotted on maps for easy spatial reference and comparison. Median values and ranges of water and sediment chemistry, toxicity, and benthic community metrics were calculated separately for each of the five strata and each of the four harbors. Note that more robust comparisons of water and sediment quality between strata are possible due to the balanced experimental design with 14–16 sites in each stratum across all harbors. The unbalanced design among the harbors (four samples each in Dana Point and Oceanside Harbor, nine in Mission Bay, and 58 in San Diego Bay) limits the ability to make statistically powerful conclusions between the harbors. Although data are presented for individual harbors, less focus and weight are placed on interpreting differences among harbors compared to the strata.

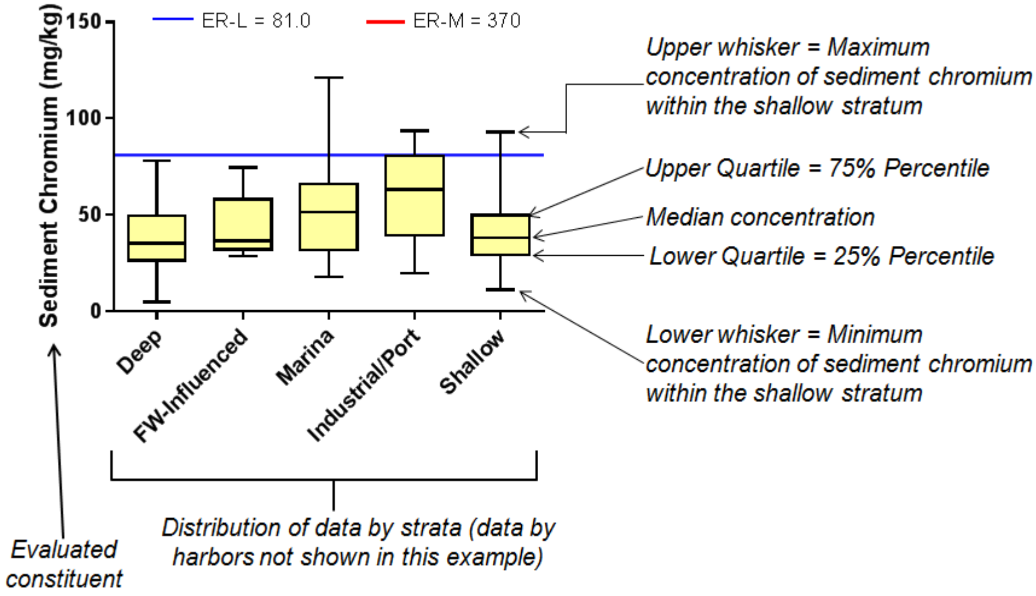
Benthic trawl data and associated species metrics were summarized similarly among harbors, but not between strata due to the fewer sites evaluated using trawls, and their locations in open areas of the harbors outside of the marina, port/industrial, and freshwater-influenced strata. Because of its size and variation in habitat and oceanic influence, San Diego Bay was divided into three ecological regions (northern, central, and southern) for comparisons among demersal fish and macroinvertebrate populations recognizing the limitations with the relatively few sites and unbalanced design. This division of San Diego Bay is consistent or similar to that used for a variety of other fish and macroinvertebrate community studies in San Diego Bay, including the prior RHMP efforts (2008 and 2013 RHMP, Williams et al., 2015, Pondella et al., 2009).

A summary of current conditions presented for individual chemical, toxicological, and biological measurements is followed in the Results section of this report by an analysis of integrated metrics using the SQO approach and other biological community metrics. A comparison of current results to past data for analysis of trends is included in the Discussion section. A more in-depth analysis of select locations considered to be likely impacted, where the lines of evidence were not all in agreement based on the three SQO lines of evidence, as well as sites with impaired benthic communities, is also included in Discussion Sections 4.7 and 4.8.

2.6.1 Statistical Analyses

Descriptive Analyses and Univariate Comparisons

The median value, quartiles, and range of results were used as descriptive statistics for the five strata and four harbors individually, as well as combined sites overall. Box plots were used to graphically show this information. An example is provided in Figure 2-5 for reference. For each of the key metrics or indices, percentages of stations with a particular score (i.e., reference, low, moderate, high) below specific threshold benchmark values are summarized by stratum, followed by statistical comparisons. General characteristics between harbors were also assessed, but statistical comparisons were limited for this evaluation due to the uneven distribution of samples among the harbors.



Upper whisker = Maximum concentration of sediment chromium within the shallow stratum

Upper Quartile = 75% Percentile

Median concentration

Lower Quartile = 25% Percentile

Lower whisker = Minimum concentration of sediment chromium within the shallow stratum

Distribution of data by strata (data by harbors not shown in this example)

Evaluated constituent

Figure 2-4. Box Plot Example Showing the Median, 25th and 75th Percentiles, and Data Range Values

Differences in surface water, sediment, and benthic infaunal parameters were compared statistically among strata using analysis of variance (ANOVA) or the nonparametric alternative, the Kruskal-Wallis test. The use of ANOVA requires that data meet assumptions, including normal distribution of the data and equal variances. Normality was tested using the D'Agostino normality test, and variances were tested using Bartlett's test and a newer recommended Brown-Forsythe test. When assumptions were not met, data were transformed using the arcsine square-root for proportion data (i.e., percent amphipod survival), and square-root or log transformations for the other indicators, following the methods of Zar (1999), and assumptions were retested. Most of the chemistry data were log transformed prior to analysis, given the skewed distribution of much of these data. If either untransformed or transformed data met the assumptions required for the use of parametric tests, ANOVAs were performed. Otherwise, nonparametric tests (Kruskal-Wallis tests) were performed. Differences were considered to be statistically significant at a p-value of <0.05, which indicates a 95% certainty that the differences were not due simply to chance. ANOVA and Kruskal-Wallis tests can test for overall significant difference, but to discern significant differences between any two given strata, *post hoc* multiple comparisons were performed using Tukey's multiple comparisons test (parametric) or Dunn's multiple comparisons test (non-parametric) with results provided for reference in Appendix K.

Spearman rank correlation and regression analyses were also performed to evaluate the relationships among individual chemicals, grain size, TOC, integrated chemistry metrics (mean ER-M quotient and the SQO CSI Index), and various benthic community metrics. Significance levels were established at p<0.05. Graphical figures of regression analyses are presented herein.

All general statistics and univariate comparisons were performed using GraphPad Prism® Version 8.0 statistical software.

Assessment of Patterns Among Multiple Measures and Indices using Multivariate Comparisons

A suite of multivariate analyses was also employed to help visualize and define complicated relationships between benthic community populations among the harbors and strata, as well as benthic community measures and various associated key chemical and physical parameters:

1. Multivariate cluster analysis was performed separately for demersal fish abundance and benthic infauna abundance to identify similar station habitats and species communities grouped by station and by species. Fish abundance was log transformed and benthic infauna fourth-root transformed prior to analysis. The clusters were based on a Bray-Curtis similarity distance matrix using an agglomerative, hierarchical clustering algorithm in which samples are fused at progressively decreasing similarity until a dendrogram is produced. Clustering can be tested using the similarity profile (SIMPROF) routine in Primer which examines whether the similarities observed in the data are smaller and/or larger than those expected by chance, or in other words that there are meaningful groups produced by the clustering analysis. A useful tool for the RHMP dataset is to use paired station and species clusters to create a "heatmap", in which darker squares represent higher abundances than lighter squares. Additionally, the relationship of stations and species from the cluster analysis is preserved, whereby stations (or species) placement on their respective axis reflects how similar those stations are.

2. Principal components analysis (PCA) was performed as an exploratory multivariate tool to assess relationships between sediment chemistry and physical characteristics. This descriptive ordination analysis is a valuable and relatively easy-to-use tool to help visualize relationships and partition variance. Samples in an ordination are represented by their location in space and their relationship to other samples and are visualized by their distance, where samples closer in space are more similar to one another. These results are graphically reduced from high-dimensional relationships and shown as a 2-dimensional plots showing the strength of relationships between different measured parameters. The two axes, PC1 and PC2, represent the direction in which the variance of sample points projected perpendicularly onto the axis is maximized (Clarke et al., 2014). While this does not preserve the high-dimensional relationship of all points as not all axes are selected, the more variance that is captured by the two axes is representative for how well the analysis describes the structure of the samples. PCA analysis requires data to be normally distributed to meet all assumptions and is not well adapted to abundance and biomass data which can be highly skewed and will overweight high values. While transformations can reduce skewedness, they cannot remedy the dominance of zeros in community data (absence of most species in most samples), which will result in poor relationships between samples (Clarke et al., 2014). Therefore, PCA is best applied to abiotic data such as sediment chemistry and physical characteristics. Data analyzed in this report were log transformed for sediment data and arcsine square-root transformed for percent TOC and percent fines.
3. Non-metric multidimensional scaling (nMDS) is an ordination routine conceptually similar to PCA but can fit a model in fewer dimensions than PCA and does not assume linear relationships. Relationships using nMDS are reduced to a 2-dimensional representation of their similarity shown as relative distances between samples. nMDS plots presented in this report used log-transformed demersal fish abundance and fourth-root-transformed benthic infauna abundance. Sample variables (such as harbor, strata, LOE group, etc.) in an ordination can be analyzed for statistical significance by conducting an analysis of similarity (ANOSIM) routine, which is a permutational test using the group-average of a group of samples to test the null hypothesis that the ordination could have occurred by chance (Clarke et al., 2014).

All multivariate analyses were performed using PRIMER-e version 7 statistical software and graphing program.

2.6.2 Historical Comparisons

Monitoring data collected by the RHMP in 2018 were compared with historical data to assess changes over time in water and sediment chemistry, sediment toxicity, benthic infauna, and demersal fish and macroinvertebrate populations. Temporal and spatial trends were analyzed to determine how concentrations have changed over time, how strata differ from each other within and among harbors, and how differences in both strata and harbors have changed over time. Historical data were compiled to derive measurements for comparison to assess changes in the harbors over time (Appendix D, Table D-2). Historical analyses were conducted using all available data collected during the 2008, 2013, and 2018 RHMP field efforts. Relevant historical data from Bight ’98, and Bight ’03, and the Bay Protection and Toxic Cleanup Program (BPTCP), as well as

San Diego Bay-specific studies that quantified demersal fishes (Pondella et al., 2006; Allen, 1999) were also included for comparison where appropriate.

An evaluation of changes in metrics over time was conducted using three distinct methods: 1) Data that has been collected in a consistent manner over the past ten years by RHMP was compared by calculating the percentage of stations below respective threshold values between the three monitoring periods in 2008, 2013 and 2018; 2) Box plots with median concentrations and the range of data for select indicators were created using all available datasets from pre-1998 on, and 3) A focused trend analysis was completed for 21 of the individual 2018 RHMP stations that have been revisited in the past. These comparisons are provided in the Discussion of the report at the end of each respective section related to water quality and sediment quality.

Despite generally consistent methods and sampling equipment, some of the sampling designs and goals of the various studies used to develop historical values varied from the randomized approach used for the RHMP and Bight Program. In particular, some of these studies included targeted designs focused on identifying conditions at potentially impaired locations (i.e., the BPTCP) or site-specific characterization programs. Areas identified as potentially impaired in studies pre-RHMP were evaluated and are discussed where applicable under the historic evaluation sections within the Discussion of this report. Differences in experimental designs, along with a few discrepancies related to the calculation of benthic indices in 2008, must be considered when drawing conclusions based on historical trend analyses. Given these differences and discrepancies, the use of statistical analyses for trend comparisons was limited, with a focus on less rigorous quantitative and univariate statistical comparisons at this time. Differences in strata over time (2008–2018) were assessed using a two-way ANOVA, and differences between 2008 and 2018 were assessed using Welch’s t-test for select metrics. Results of historical statistical comparisons are provided for reference in Appendix K.

2.7 Quality Assurance and Quality Control

Specific QA/QC methods for all field activities, laboratory analyses, data analysis and usability, and reporting activities are provided in detail in the project-specific RHMP QAPP and also summarized in the project-specific Work Plan (Wood, 2018a and 2018b). QA/QC methodologies were conducted in accordance with the *Bight ’18 Sediment Quality Assessment Field Operations Manual* (SCCWRP, 2018c) and the *Bight ’18 Quality Assurance Manual,* prepared by the Bight ’18 Sediment Quality Planning Committee (SCCWRP, 2018b). The format for the RHMP QAPP followed the SWAMP 25-element structure and associated goals and objectives (http://www.waterboards.ca.gov/water_issues/programs/swamp/tools.shtml#qa). Specific information related to data analysis and reporting QA/QC is re-summarized below for reference.

2.7.1 Data Analysis and Reporting QA/QC

QA/QC extends throughout each stage of the program. Following the initial collection of the data, a third party reviewed the raw data and laboratory reports, as described in the following section. Raw validated data were then entered into the SCCWRP Bight ’18 database and RHMP-specific database for analyses not required in the Bight program (e.g., water column chemistry). A 100% QA check of these data against the laboratory reports and associated raw data was performed before proceeding with subsequent data analysis. Subsequent steps included the creation of spreadsheets for statistical analysis and graphing and summary tables for the report. Each of these steps required a 100% QA check to ensure proper transcription, reporting units, analysis parameters and methods, and use of significant figures. Any data and associated conclusions included in the report have also undergone a 100% QA check against the raw data and summary tables. A more detailed summary of the complete data QA/QC process (encompassing a review of raw data, data processing and analysis, and reporting activities) is provided in the accompanying QAPP for the RHMP (Wood, 2018b).

2.7.2 Third-Party QA/QC Review

It is critical that all data used for subsequent analyses and interpretation for the RHMP be verified, not only internally by those producing the data, but also by an independent third-party reviewer. Raw chemistry data and associated laboratory reports were submitted to Laboratory Data Consultants, Inc. (LDC) for third-party review. At the time of this report, all toxicity and chemistry data for Bight ’18 have undergone a third-party QA/QC review at SCCWRP, and the Bight ’18 toxicology committee has finalized a technical report for both of these components of the Bight Program (Parks et al., 2020, Du et al., 2020). The Bight ’18 trawl committee has completed QA/QC and a draft report at the time of this publication, with a final deliverable expected in early 2021. A separate draft report summarizing contaminant bioaccumulation in edible sport fish in the southern California Bight has also been distributed for review at the time of this publication with a final report expected before the end of December 2020. Finally, a draft Bight ’18 report for the benthic infauna is still being prepared at the time of this publication with an expected final report delivery in 2021 along with an integrated report including all SQO lines of evidence. All analysis and QA/QC efforts associated with these activities through the Bight Program are being compared to independent assessments and findings for all data related to or specific to the RHMP.

An independent third-party peer review of the draft RHMP report was also performed by Dr. Howard Bailey of Nautilus Environmental Company in British Columbia, Canada. This review largely focused on the main conclusions and general consistency with the results presented in a draft version of the report.

3.0 RESULTS

The Results section of this report highlights observations for all measurements made during the 2018 RHMP monitoring period. A more integrated analysis of the results and assessment of trends over time is provided in the Discussion (Section 4).

3.1 Water Quality

Water quality indicators for the RHMP include vertical profiles of temperature, salinity, pH, DO, and light transmittance measured in the field, and analysis of a suite of physical and chemical parameters (TOC, DOC, nutrients, TSS, MBAS, oil and grease, trace metals, and PAHs).

3.1.1 Physical Water Quality Parameters and Depth Profiles

Physical water quality data provide information that can be used to help interpret chemical and biological results and identify potential factors related to changes observed over time. Physical parameters measured during the RHMP included temperature, salinity, pH, DO, and light transmittance. Continuous measurements were recorded from the surface to the bottom at each station, and data were bin-averaged from 1 meter below the surface to 1 meter above the seafloor.

Data summaries and graphical depth profiles of physical water quality parameters at all 2018 RHMP stations are presented in Appendix E. A summary of measurements by strata and harbor are provided in Table 3-1 and Table 3-2, respectively. In addition, box plots are presented for each physical parameter to compare distributions among strata and harbors. Each box plot shows the 25th percentile, median, 75th percentile, and range of average values throughout the water column. A single depth-averaged value was calculated for each station prior to inclusion in all field water quality plots; the number of stations (n) included in each plot is shown in parentheses.

Table 3-1.
Ranges of Water Quality Parameters by Stratum

Parameter	Stratum				
	Deep	**Freshwater-Influenced**	**Marina**	**Industrial/Port**	**Shallow**
Number of Stations	*15*	*14*	*15*	*15*	*16*
Temperature (°C)	17.4 – 26.0	23.0 – 29.0	20.7 – 28.5	22.1 – 26.1	21.3 – 28.2
Salinity (psu)	33.6 – 34.9	33.3 - 36.3	33.6 – 35.8	32.3 – 34.9	32.7 – 36.2
pH	7.84 – 8.28	7.85 – 8.15	7.74 – 8.19	7.71 – 8.03	7.65 – 8.25
Dissolved Oxygen (mg/L)	4.9 – 11.0	4.7 – 8.6	5.1 – 8.3	5.4 – 6.8	5.2 – 9.2
Light Transmittance (%)	25.8 – 78.7	23.5 – 70.0	13.9 – 79.1	46.1 – 74.5	35.5 – 74.6

Notes:
%= percent; °C = degrees Celsius; mg/L = milligram(s) per liter; pH = hydrogen ion concentration; psu = practical salinity unit(s)
Ranges in this table are based on binned depths (1-meter increments) at all stations. The number of values available at each station varied from 1 to 20, depending on depth.

**Table 3-2.
Ranges of Water Quality Parameters by Harbor**

Parameter	Harbor			
	Dana Point Harbor	**Oceanside Harbor**	**Mission Bay**	**San Diego Bay**
Number of Stations	*4*	*4*	*9*	*58*
Temperature (°C)	23.0 – 23.7	23.2 – 24.5	20.8 – 27.3	17.4 – 29.0
Salinity (psu)	33.3 – 33.9	33.6 – 33.8	32.7 – 35.3	32.3 – 36.3
pH	7.97 – 8.04	8.08 – 8.15	7.95 – 8.25	7.65 – 8.28
Dissolved Oxygen (mg/L)	4.9 – 8.3	5.7 – 7.6	6.2 – 11.0	4.7 – 10.2
Light Transmittance (%)	23.5 – 74.6	13.9 – 69.1	50.0 – 78.7	28.4 – 79.1

Notes:
%= percent; °C = degrees Celsius; mg/L = milligram(s) per liter; pH = hydrogen ion concentration; psu = practical salinity unit(s)
Ranges in this table are based on binned depths (1-meter increments) at all stations. The number of values available at each station varied from 1 to 20, depending on depth.

Temperature

Although thermoclines are typical of this geographic region during the late summer months, temperatures did not vary substantially with depth. Differences between the surface and bottom temperatures for most stations were generally less than 1–2°C, with the greatest difference of 4.6°C at the deepest station (20-m depth at B18-10030 in north San Diego Bay). Stations in the deep and industrial/port strata in Mission Bay and San Diego Bay tended to exhibit more stratified temperature profiles. In addition, average surface temperatures (i.e., within 1 meter of the surface) did not vary substantially among harbors. To best display this data given the variability, the distribution of temperature among strata and harbors is shown in two graphical illustrations: Figure 3-1a shows the range of water column averages, while Figure 3-1b shows the range of values from the top meter and bottom meter of the water column.

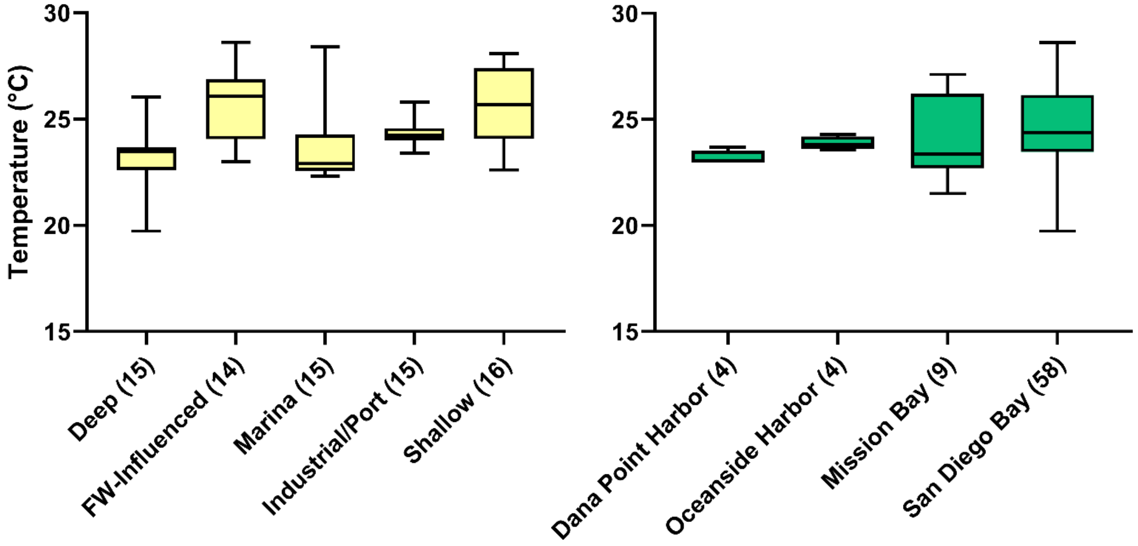


Figure 3-1a. Field Measurements of Temperature Showing the Distribution of Results from Averaged CTD Vertical Profiles Within Each Strata and Harbor

Box plots show the median, 25th percent quartiles, and range of average values throughout the water column. The number of stations (n) is shown in parentheses.

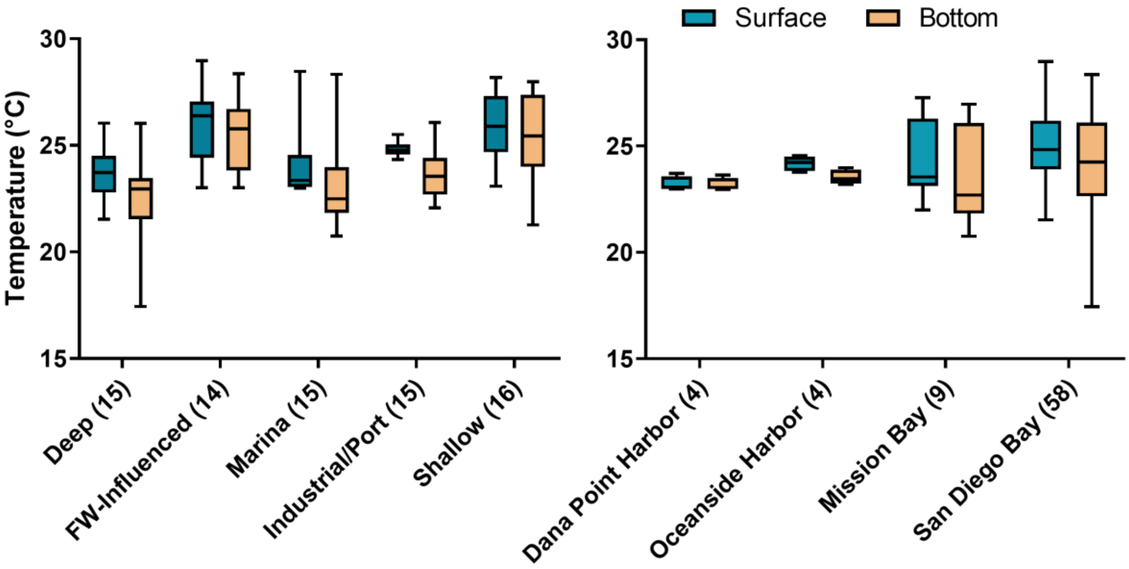


Figure 3-1b. Field Measurements of Surface and Bottom Temperature Showing the Distribution of Results Within Each Strata and Harbor

Box plots show the median, 25th percent quartiles, and range of values from the top meter and bottom meter of the water column. The number of stations (n) is shown in parentheses.

Salinity

Salinity varied little with depth, generally less than 1 practical salinity unit (psu) from top to bottom. On average, salinity values were also very similar among all strata and harbors, with surface salinities ranging from 33.3 psu (B18-10066, Dana Point Harbor, freshwater-influenced stratum) to 36.3 psu (B18-10044, south San Diego Bay, freshwater-influenced stratum). The distribution of salinity among strata and harbors is shown in Figure 3-2.

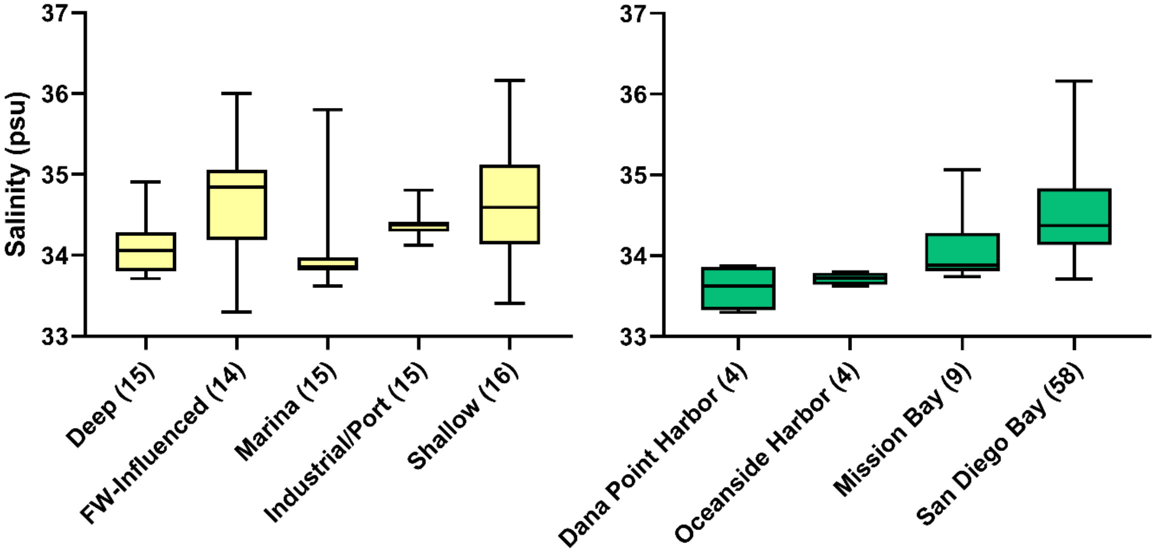


Figure 3-2. Field Measurements of Salinity Showing the Distribution of Results from Averaged CTD Vertical Profiles Within Each Stratum and Harbor

Box plots show the median, 25th percent quartiles, and range of average values throughout the water column. The number of stations (n) is shown in parentheses.

pH

Measures of pH were largely consistent with depth at all stations, generally differing by no more than 0.1 unit from top to bottom. Across all stations, pH within surface waters ranged from 7.65 (Station B18-10043, south San Diego Bay, shallow stratum) to 8.24 (Station B18-10023, north San Diego Bay, deep stratum), and average values were slightly basic in all harbors and strata. The distribution of pH among strata and harbors is shown in Figure 3-3.

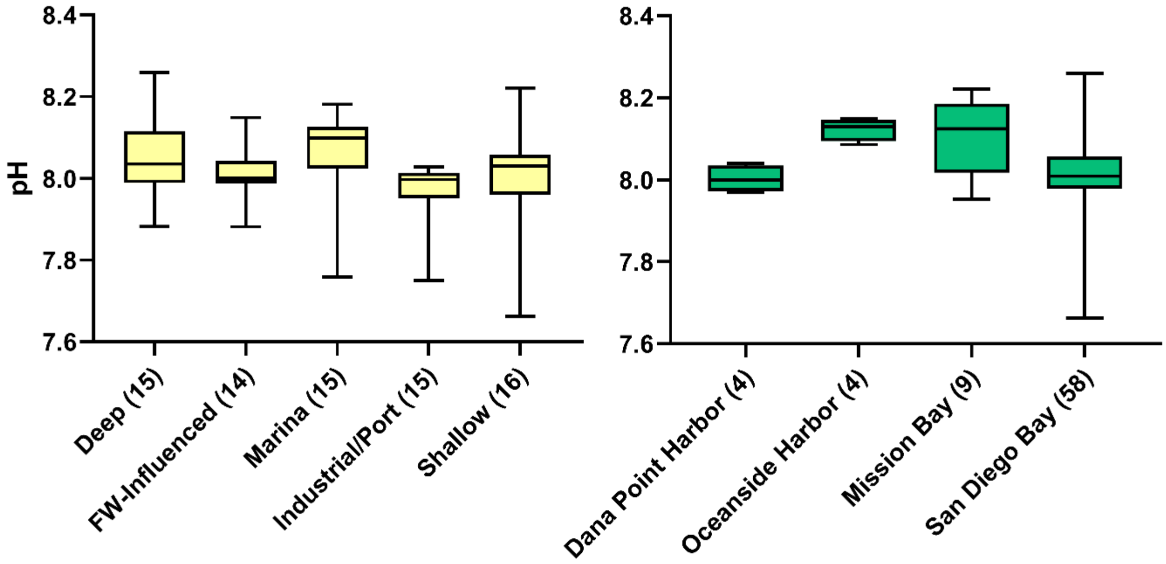


Figure 3-3. Field Measurements of pH Showing the Distribution of Results from Averaged CTD Vertical Profiles Within Each Stratum and Harbor

Box plots show the median, 25th percent quartiles, and range of average values throughout the water column. The number of stations (n) is shown in parentheses.

Dissolved Oxygen

The level of dissolved oxygen generally decreased with depth at most stations. At 1 meter below the surface, the concentration of DO at all sampling stations was greater than the minimum 5.0 mg/L WQO in the San Diego Basin Plan. However, at deeper points in the profile, concentrations of DO at three stations fell below 5.0 mg/L, including two in the freshwater-influenced stratum in San Diego Bay (B18-10044 and B18-10178) and one in the deep stratum in Dana Point Harbor (B18-10068), as depicted in Figure 3-4b. To best display this data given the variability, especially within deeper water profiles, the distribution of DO among strata and harbors is shown in two graphical illustrations: Figure 3-4a shows the range of water column averages, while Figure 3-4b shows the range of values from the top meter and bottom meter of the water column.

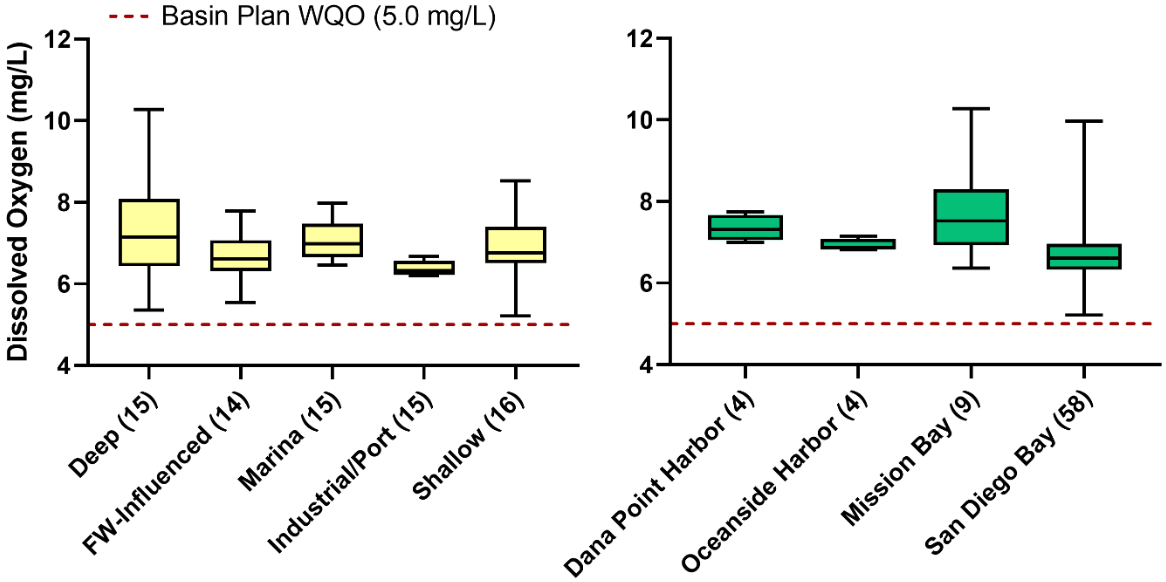


Figure 3-4a. Field Measurements of Dissolved Oxygen Showing the Distribution of Results from Averaged CTD Vertical Profiles Within Each Stratum and Harbor

Box plots show the median, 25th percent quartiles, and range of average values throughout the water column. The number of stations (n) is shown in parentheses.

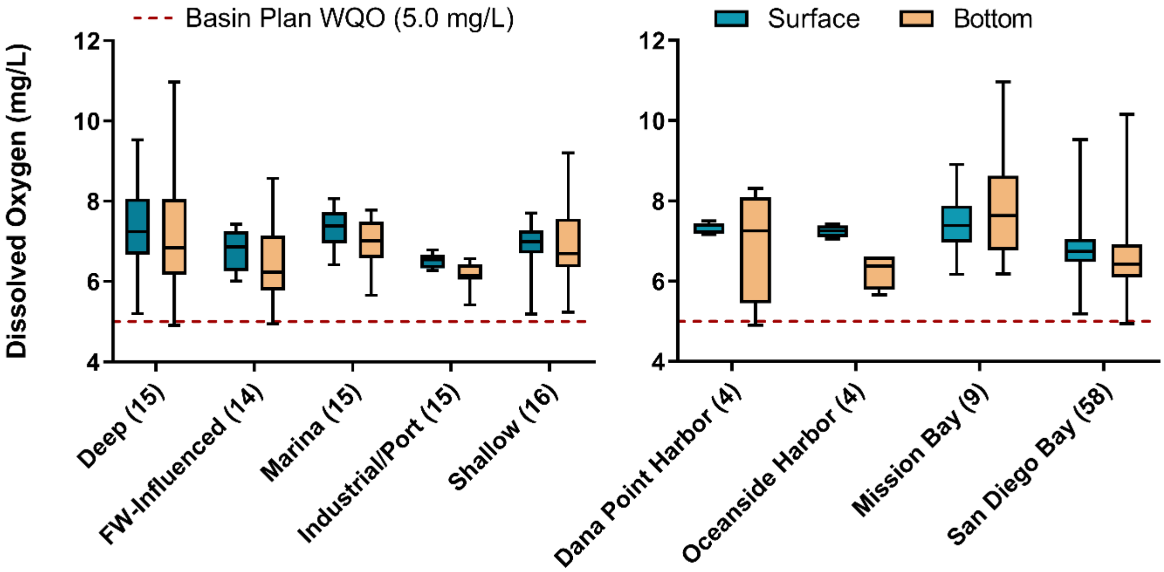


Figure 3-4b. Field Measurements of Surface and Bottom Dissolved Oxygen Showing the Distribution of Results Within Each Stratum and Harbor

Box plots show the median, 25th percent quartiles, and range of values from the top meter and bottom meter of the water column. The number of stations (n) is shown in parentheses.

Light Transmittance

Light transmittance (i.e., water clarity) remained relatively consistent across strata and harbors and tended to decrease with depth; however, a subset of 27% of stations experienced increased transmittance between the surface and bottom waters. Declines in light transmittance from the surface to the bottom were most pronounced in the industrial/port strata, with an average decrease of 10%, and the marina stratum, with an average decrease of 8%. The distribution of light transmittance values among strata and harbors is shown in two ways: Figure 3-5a shows the range of water column averages, while Figure 3-5b shows the range of values from the top meter and bottom meter of the water column.

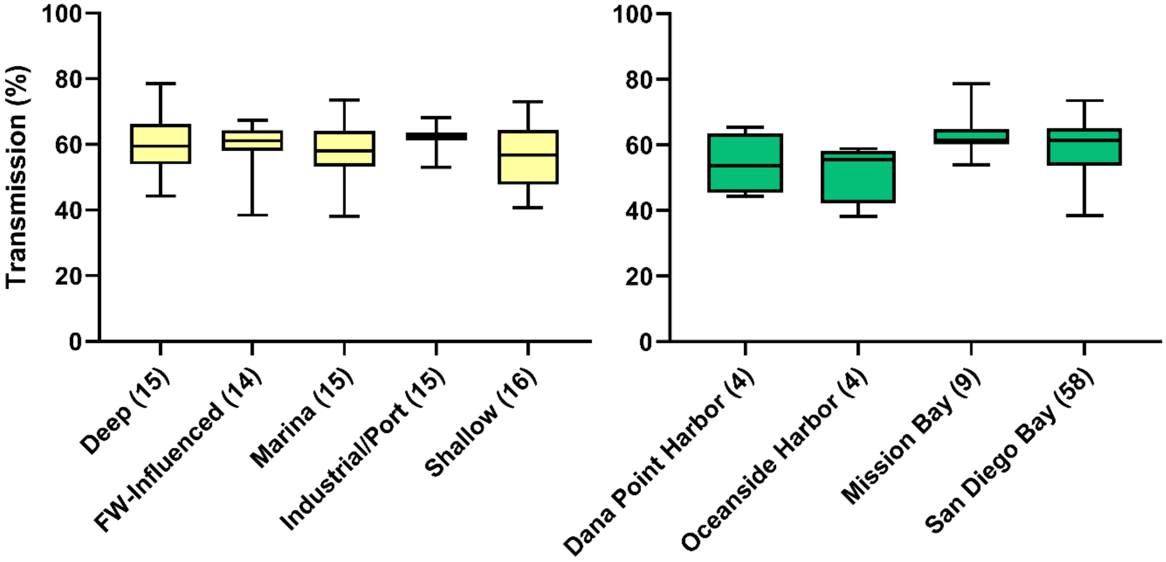


Figure 3-5a. Field Measurements of Light Transmittance Showing the Distribution of Results from Averaged CTD Vertical Profiles Within Each Stratum and Harbor

Box plots show the median, 25th percent quartiles, and range of average values throughout the water column. The number of stations (n) is shown in parentheses.

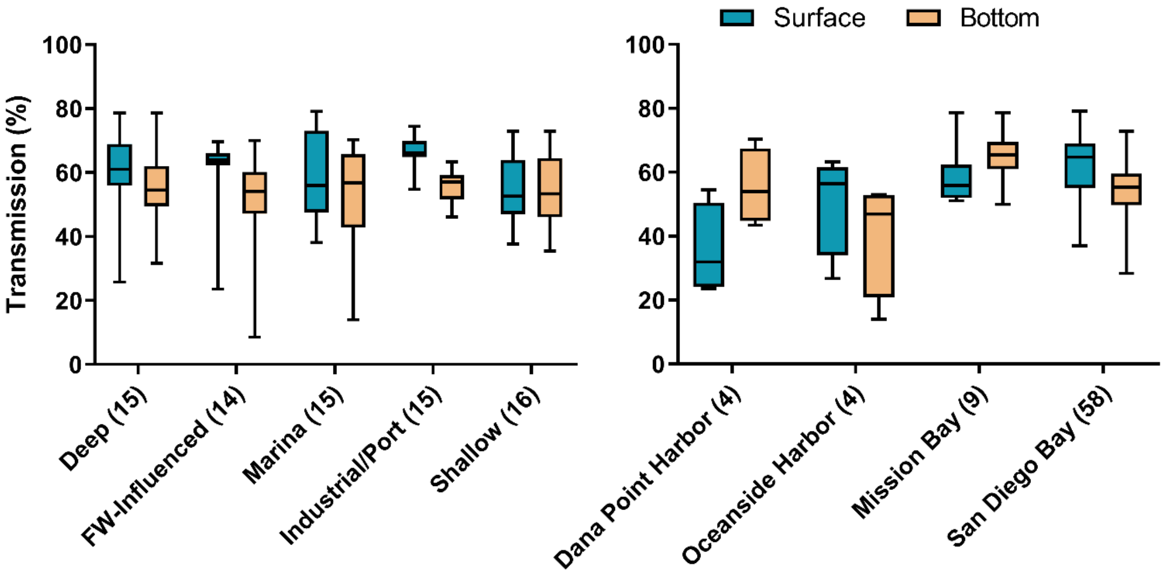


Figure 3-5b. Field Measurements of Surface and Bottom Light Transmittance Showing the Distribution of Results Within Each Stratum and Harbor

Box plots show the median, 25th percent quartiles, and range of values from the top meter and bottom meter of the water column. The number of stations (n) is shown in parentheses.

3.1.2 Analytical Chemistry for Surface Water

Surface water samples collected from the 75 RHMP sampling stations were analyzed for the analytes listed in Table 2-3. Surface water chemistry results for all stations are summarized in Table 3-3 and are reported in full in Appendix F.

Table 3-3.
2018 RHMP Water Chemistry Results Summary

Harbor	Strata	Sample ID	Conventionals (mg/L)								Total PAHs (ng/L)	Dissolved Trace Metals (µg/L)																					
			Dissolved Organic Carbon	Total Organic Carbon	Total Suspended Solids	Ammonia-N	Nitrate-N[1]	Total Orthophosphate as P[1]	Oil & Grease	Methylene Blue Active Substance		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Iron (Fe)	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Thallium	Tin	Titanium	Vanadium	Zinc
Dana Point Harbor	Deep	B18-10068	1.22	1.33	13.1	0.024 J	0.0266	0.0236	< 1.00	0.0255	1.07 J	7.83	0.115	1.33	5.46	0.006 J	0.047	0.190	0.018	2.50	< 0.500	0.020	2.47	< 0.01	9.21	0.239	< 0.005	< 0.01	0.009 J	< 0.005	18.1	1.95	8.46
	Freshwater-Influenced	B18-10066	1.03	1.35	8.05	0.014 J	0.0183 J	0.0207	< 1.00	0.0145 J	< 1.00	6.19	0.124	1.37	5.80	0.015	0.079	0.157	0.054	11.3	0.538 J	0.060	5.26	< 0.01	8.98	0.604	< 0.005	< 0.01	0.008 J	< 0.005	17.7	1.85	25.5
	Marina	B18-10067	1.30	1.32	9.25	< 0.007	0.0105 J	0.0214	< 1.00	0.0145 J	< 1.00	4.98 J	0.112	1.35	5.32	0.006 J	0.044	0.162	0.012	7.47	0.533 J	0.039	2.16	< 0.01	8.96	0.252	< 0.005	< 0.01	0.007 J	0.008 J	22.7	1.89	15.0
	Shallow	B18-10065	1.34	1.05	4.35	0.015 J	0.0325	0.0201	< 1.00	0.0182 J	< 1.00	4.48 J	0.107	1.35	5.81	0.012	0.042	0.181	0.010 J	4.58	< 0.500	0.029	1.72	< 0.01	9.08	0.222	< 0.005	< 0.01	0.010 J	0.018	19.7	1.90	10.6
Oceanside Harbor	Deep	B18-10071	1.32	1.28	11.9	< 0.007	< 0.01	0.0209	< 1.00	0.052	3.57	3.54 J	0.124	1.59	3.73	< 0.005	0.033	0.149	< 0.005	1.48	< 0.500	< 0.003	2.52	< 0.01	9.64	0.194	0.021	< 0.01	0.007 J	0.019	12.1	2.01	6.13
	Freshwater-Influenced	B18-10070	1.29	1.23	6.20	< 0.007	< 0.01	0.0209	< 1.00	0.0469	< 1.00	16.1	0.132	1.67	4.77	< 0.005	0.042	0.332	< 0.005	5.68	< 0.500	0.006	3.83	< 0.01	9.59	0.206	0.021	< 0.01	0.006 J	0.160	14.1	2.17	16.9
	Marina	B18-10069	1.31	1.47	7.55	< 0.007	0.014 J	0.0284	< 1.00	0.031	< 1.00	3.47 J	0.111	1.56	6.88	< 0.005	0.032	0.112	0.017	7.46	< 0.500	0.023	4.53	< 0.01	9.24	0.202	0.015 J	< 0.01	< 0.005	< 0.005	16.1	2.15	18.6
		B18-10072	1.16	1.22	8.80	0.019 J	0.0253	0.0272	< 1.00	0.011 J	< 1.00	3.18 J	0.114	1.62	6.94	< 0.005	0.041	0.137	< 0.005	6.13	0.785 J	< 0.003	13.8	< 0.01	9.16	0.201	0.011 J	< 0.01	< 0.005	0.008 J	15.1	2.08	33.7
Mission Bay	Deep	B18-10019	1.30	1.56	12.2	< 0.007	< 0.01	0.0227	< 1.00	0.0255	4.05	< 3.00	0.116	1.39	5.55	< 0.005	0.025	0.099	0.008 J	1.34	< 0.500	0.026	2.89	< 0.01	9.45	0.203	0.009 J	< 0.01	< 0.005	< 0.005	17.2	2.09	0.629
		B18-10020	1.40	1.65	3.45	0.018 J	0.0267	0.0222	< 1.00	0.0192 J	< 1.00	< 3.00	0.111	1.37	4.20	< 0.005	0.027	0.136	< 0.005	0.86	0.849 J	0.030	1.27	< 0.01	8.79	0.221	0.025	< 0.01	< 0.005	0.034	10.5	1.95	2.58
	Freshwater-Influenced	B18-10015	1.98	1.77	8.90	< 0.007	< 0.01	0.0410	< 1.00	0.0296	< 1.00	14	0.143	1.84	18.6	< 0.005	0.068	0.270	0.120	1.24	1.23	0.059	20.5	< 0.01	9.59	0.403	0.045	< 0.01	< 0.005	0.017	10.3	2.59	1.92
	Marina	B18-10074	1.95	2.19	7.60	< 0.007	< 0.01	0.0246	< 1.00	0.0278	< 1.00	< 3.00	0.113	1.35	4.37	< 0.005	0.021	0.104	< 0.005	1.10	0.854 J	0.022	2.11	< 0.01	8.75	0.189	< 0.005	< 0.01	< 0.005	< 0.005	10.4	2.09	3.57
		B18-10075	1.28	1.44	4.20	0.026 J	< 0.01	0.0310	< 1.00	0.0242 J	< 1.00	< 3.00	0.114	1.38	5.88	< 0.005	0.031	0.095	0.011	1.37	0.785 J	0.038	2.94	< 0.01	8.83	0.202	0.007 J	< 0.01	< 0.005	< 0.005	11.2	2.07	3.22
	Shallow	B18-10016	1.69	1.99	4.15	< 0.007	< 0.01	0.0196 J	< 1.00	0.0233 J	< 1.00	< 3.00	0.115	1.39	5.69	< 0.005	0.043	0.113	0.033	0.87	0.891 J	0.042	3.14	< 0.01	9.06	0.217	0.039	< 0.01	< 0.005	0.010	10.1	2.27	0.495
		B18-10017	1.60	2.09	3.90	0.016 J	< 0.01	0.0513	< 1.00	0.0274	< 1.00	4.51 J	0.139	2.02	10.7	< 0.005	0.042	0.044	0.491	1.17	1.05	0.043	21.7	< 0.01	9.04	0.302	0.048	< 0.01	0.007 J	0.054	10.3	2.68	0.707
		B18-10073	1.71	1.81	4.60	< 0.007	< 0.01	0.0219	< 1.00	0.0237 J	< 1.00	< 3.00	0.118	1.39	3.81	< 0.005	0.025	0.127	0.020	1.02	0.725 J	0.032	2.10	< 0.01	8.86	0.190	0.012 J	< 0.01	< 0.005	< 0.005	12.5	2.20	2.84
		B18-10438 (overdraw)	1.75	1.92	4.50	< 0.007	< 0.01	0.0332	< 1.00	0.0201 J	1.10 J	< 3.00	0.143	1.44	7.78	< 0.005	0.031	0.059	0.037	1.22	1.73	0.012	5.51	< 0.01	9.03	0.202	0.019	< 0.01	< 0.005	< 0.005	11.0	1.84	1.28
San Diego Bay - North	Deep	B18-10022	1.82	2.13	4.25	0.078	< 0.01	0.0219	< 1.00	0.0182 J	8.76	< 3.00	0.130	1.35	6.29	0.007 J	0.022	< 0.013	0.033	1.77	< 0.500	< 0.003	2.32	< 0.01	9.40	0.300	0.016	< 0.01	0.008 J	< 0.005	21.5	2.26	5.69
		B18-10023	1.48	1.09	7.90	0.015 J	< 0.01	0.018 J	< 1.00	0.0064 J	2.27	< 3.00	0.123	1.30	5.60	0.009 J	0.024	0.193	< 0.005	0.18	< 0.500	< 0.003	0.894	< 0.01	8.90	0.198	0.022	0.100	< 0.005	< 0.005	18.0	2.22	3.14
		B18-10024	1.55	1.61	3.65	0.017 J	0.0119 J	0.0282	< 1.00	0.0191 J	5.91	< 3.00	0.128	1.24	8.09	< 0.005	0.031	< 0.013	0.915	0.90	< 0.500	< 0.003	2.40	< 0.01	8.89	0.299	0.017	< 0.01	0.006 J	< 0.005	15.5	2.20	3.46
		B18-10030	1.38	1.64	8.45	0.007 J	< 0.01	0.0181 J	< 1.00	0.0092 J	15.7	< 3.00	0.159	1.40	5.69	0.011	0.028	0.199	< 0.005	0.76	< 0.500	< 0.003	1.54	< 0.01	8.83	0.252	0.014 J	0.046	< 0.005	< 0.005	28.8	2.40	2.19
		B18-10112	1.58	1.76	2.70	0.039	0.0227	0.0271	< 1.00	0.0314	25.2	< 3.00	0.143	1.34	6.87	< 0.005	0.075	< 0.013	0.031	0.85	< 0.500	0.102	2.99	< 0.01	9.26	0.299	0.020	< 0.01	< 0.005	0.008 J	16.0	2.13	3.80
		B18-10113	1.58	1.87	2.65	0.062	0.0242	0.0253	< 1.00	0.0068 J	24.7	3.47 J	0.127	1.50	9.79	0.007 J	0.023	< 0.013	0.039	0.81	< 0.500	< 0.003	3.50	< 0.01	9.41	0.325	0.024	< 0.01	< 0.005	< 0.005	32.8	2.37	3.49
		B18-10116	1.65	1.62	5.45	0.025 J	< 0.01	0.0378	< 1.00	0.0155 J	6.90	< 3.00	0.140	1.33	9.14	0.005 J	0.028	0.053	0.045	1.56	< 0.500	< 0.003	3.47	< 0.01	9.60	0.375	0.023	< 0.01	0.007 J	< 0.005	22.0	2.30	4.28
		B18-10117	1.50	1.75	12.4	0.009 J	< 0.01	0.0301	< 1.00	0.0101 J	5.71	< 3.00	0.133	1.45	5.68	0.011	0.071	0.128	< 0.005	0.70	< 0.500	< 0.003	1.37	< 0.01	8.79	0.314	0.016	< 0.01	< 0.005	< 0.005	13.7	2.41	8.40
	Freshwater-Influenced	B18-10029	1.65	1.55	3.55	0.020 J	0.021	0.0303	< 1.00	0.0159 J	10.7	< 3.00	0.143	1.27	7.12	< 0.005	0.023	< 0.013	0.043	1.32	< 0.500	< 0.003	4.71	< 0.01	9.18	0.338	0.022	< 0.01	0.006 J	0.006 J	11.3	2.16	4.50
		B18-10076	1.66	1.68	3.90	0.009 J	< 0.01	0.0321	< 1.00	0.0127 J	9.99	< 3.00	0.127	1.28	7.33	< 0.005	0.066	< 0.013	0.039	1.24	< 0.500	0.089	3.59	< 0.01	9.29	0.322	0.017	< 0.01	0.006 J	0.006 J	16.4	2.20	5.85
	Industrial/Port	B18-10114	1.75	1.69	3.65	0.019 J	0.0168 J	0.0210	< 1.00	0.0191 J	6.79	< 3.00	0.144	1.42	7.41	0.006 J	0.021	< 0.013	0.050	1.44	< 0.500	< 0.003	4.50	< 0.01	9.13	0.361	0.018	< 0.01	0.008 J	< 0.005	33.8	2.44	5.65
		B18-10115	1.70	1.75	3.35	0.030 J	0.0185 J	0.0344	< 1.00	0.0173 J	16.5	< 3.00	0.147	1.34	7.53	< 0.005	0.027	< 0.013	0.054	1.55	< 0.500	< 0.003	5.69	< 0.01	9.18	0.372	0.026	< 0.01	< 0.005	0.019	26.2	2.37	5.88
	Marina	B18-10078	1.43	1.64	12.4	0.021 J	< 0.01	0.0326	< 1.00	< 0.005	12.2	< 3.00	0.149	1.47	6.38	< 0.005	0.036	0.141	< 0.005	3.59	0.684 J	< 0.003	2.42	< 0.01	8.39	0.302	0.016	< 0.01	< 0.005	0.103	12.5	2.38	10.4
		B18-10079	1.55	1.62	9.90	0.016 J	< 0.01	0.0324	< 1.00	0.0215 J	19.2	< 3.00	0.142	1.39	7.49	< 0.005	0.035	0.125	< 0.005	1.79	< 0.500	< 0.003	1.94	< 0.01	9.04	0.299	0.015	< 0.01	< 0.005	< 0.005	12.1	2.35	6.36
		B18-10080	1.80	1.78	5.40	0.025 J	< 0.01	0.0275	< 1.00	0.0101 J	5.87	< 3.00	0.151	1.49	5.77	0.021	0.046	0.151	< 0.005	9.61	< 0.500	< 0.003	2.33	< 0.01	9.01	0.281	0.016	< 0.01	< 0.005	0.012	18.0	2.30	27.0
		B18-10081	1.68	1.61	11.2	0.017 J	< 0.01	0.0254	< 1.00	0.0087 J	3.98	3.33 J	0.144	1.34	5.58	< 0.005	0.066	0.117	< 0.005	8.80	< 0.500	< 0.003	2.28	< 0.01	9.71	0.303	0.023	< 0.01	< 0.005	< 0.005	9.39	2.19	23.2
		B18-10082	1.53	1.60	5.90	0.015 J	< 0.01	0.0262	< 1.00	0.0069 J	2.73	3.35 J	0.126	1.49	6.12	< 0.005	0.042	0.137	< 0.005	9.16	< 0.500	< 0.003	2.23	< 0.01	8.66	0.249	0.007 J	< 0.01	< 0.005	< 0.005	17.8	2.49	26.3
		B18-10083	1.28	1.36	11.3	0.016 J	< 0.01	0.0258	< 1.00	< 0.005	13.8	3.02 J	0.132	1.33	4.66	< 0.005	0.038	0.161	< 0.005	5.71	< 0.500	< 0.003	2.10	< 0.01	8.83	0.287	0.013 J	< 0.01	< 0.005	< 0.005	13.2	2.44	18.2
		B18-10084	1.50	1.58	5.85	0.014 J	< 0.01	0.0243	< 1.00	0.0178 J	10.2	3.18 J	0.132	1.26	5.63	0.017	0.036	0.138	< 0.005	3.39	< 0.500	< 0.003	1.80	< 0.01	8.85	0.277	< 0.005	< 0.01	< 0.005	< 0.005	14.1	2.25	18.4
	Shallow	B18-10077	1.91	2.09	5.85	0.033	< 0.01	0.0326	< 1.00	0.0191 J	11.8	< 3.00	0.133	1.29	8.83	< 0.005	0.032	< 0.013	0.044	1.08	< 0.500	< 0.003	3.38	< 0.01	9.39	0.353	0.023	< 0.01	0.007 J	< 0.005	18.0	2.22	5.66
San Diego Bay - Central	Deep	B18-10133	1.73	1.75	2.89	0.018 J	< 0.01	0.0383	< 1.00	0.0109 J	10.1	< 3.00	0.149	1.36	8.21	< 0.005	0.065	0.115	< 0.005	3.40	1.09	0.073	8.19	< 0.01	9.42	0.597	0.016	0.015 J	< 0.005	< 0.005	17.5	2.40	4.95
		B18-10141	1.76	1.83	4.70	0.018 J	< 0.01	0.0461	< 1.00	< 0.005	11.8	< 3.00	0.135	1.45	9.54	0.010	0.042	0.038	0.061	3.30	< 0.500	< 0.003	7.93	< 0.01	9.08	0.454	0.009 J	< 0.01	0.013	0.008 J	9.17	2.33	4.69
		B18-10144	1.44	2.04	5.40	0.049	< 0.01	0.0441	< 1.00	0.0424	13.6	< 3.00	0.171	1.40	10.5	< 0.005	0.059	< 0.013	0.073	2.81	0.764 J	< 0.003	9.71	< 0.01	9.07	0.588	0.016	< 0.01	0.005 J	0.011	8.23	2.62	3.94
	Freshwater-Influenced	B18-10031	1.67	2.10	4.50	0.021 J	0.011 J	0.0404	< 1.00	0.0055 J	12.6	< 3.00	0.134	1.52	8.18	< 0.005	0.057	0.108	0.055	3.20	< 0.500	0.033	6.92	< 0.01	8.10	0.489	0.013 J	< 0.01	< 0.005	0.006 J	20.3	2.43	7.40
		B18-10178	1.99	1.71	3.60	0.030 J	0.011 J	0.0412	< 1.00	0.0146 J	32.1	3.04 J	0.133	1.50	8.85	0.012	0.055	0.096	0.074	2.64	0.694 J	0.038	9.25	< 0.01	8.58	0.536	0.019	< 0.01	< 0.005	< 0.005	26.2	2.52	7.81
	Industrial/Port	B18-10119	1.56	1.97	3.75	0.016 J	0.0168 J	0.0344	< 1.00	0.005 J	22.1	3.51 J	0.121	1.50	9.30	< 0.005	0.048	0.111	0.049	2.64	< 0.500	0.028	6.46	< 0.01	8.07	0.437	0.021	< 0.01	< 0.005	< 0.005	30.0	2.56	7.52
		B18-10121	1.75	1.62	5.25	0.014 J	0.0114 J	0.0331	< 1.00	0.0073 J	10.8	< 3.00	0.134	1.53	8.26	0.005 J	0.053	0.101	0.052	2.94	< 0.500	0.029	6.22	< 0.01	8.54	0.560	0.023	< 0.01	< 0.005	< 0.005	23.1	2.43	7.52
		B18-10123	1.83	1.89	3.80	0.011 J	0.0134 J	0.0326	< 1.00	0.0077 J	12.1	< 3.00	0.128	1.52	9.29	0.018	0.054	0.125	0.052	3.36	< 0.500	0.022	6.67	< 0.01	8.41	0.547	0.014 J	< 0.01	< 0.005	< 0.005	24.2	2.47	5.57
		B18-10124	1.92	2.01	3.54	0.0353	< 0.01	0.0402	< 1.00	0.005 J	9.80	< 3.00	0.119	1.51	10.3	< 0.005	0.057	0.122	0.016	3.34	< 0.500	0.036	8.33	< 0.01	9.10	0.513	0.016	0.030	< 0.005	< 0.005	18.6	2.48	4.84
		B18-10126	1.78	1.94	2.65	0.0324	< 0.01	0.0407	< 1.00	0.0173 J	17.8	< 3.00	0.116	1.56	9.81	< 0.005	0.051	0.123	< 0.005	3.28	< 0.500	0.037	8.19	< 0.01	9.10	0.477	0.011 J	0.026	< 0.005	< 0.005	20.8	2.47	5.21
		B18-10127	1.64	1.82	2.10	0.0148 J	< 0.01	0.0379	< 1.00	0.0055 J	11.3	< 3.00	0.122	1.52	10.1	< 0.005	0.054	0.115	< 0.005	3.19	< 0.500	0.032	8.69	< 0.01	9.26	0.484	0.008 J	0.015 J	< 0.005	< 0.005	21.5	2.51	4.68
		B18-10132	1.99	1.76	3.06	0.0186 J	< 0.01	0.0397	< 1.00	0.0560	11.4	< 3.00	0.138	1.39	8.03	< 0.005	0.628	0.114	< 0.005	3.58	< 0.500	1.85	8.64	< 0.01	9.39	0.476	0.015 J	0.017 J	< 0.005	0.110	15.6	2.38	4.68
		B18-10136	1.69	1.93	3.59	0.0269 J	< 0.01	0.0457	< 1.00	0.0055 J	12.0	< 3.00	0.108	1.50	8.68	< 0.005	0.057	0.114	< 0.005	3.19	< 0.500	0.028	7.54	< 0.01	9.54	0.480	0.020	0.016 J	< 0.005	< 0.005	21.7	2.45	4.78
		B18-10137	1.84	1.72	2.45	0.0212 J	< 0.01	0.0467	< 1.00	< 0.005	12.5	3.17 J	0.116	1.63	10.0	< 0.005	0.058	0.103	< 0.005	2.73	0.984 J	0.046	8.56	< 0.01	8.91	0.420	0.013 J	0.010 J	< 0.005	< 0.005	19.9	2.43	5.04
		B18-10139	1.56	1.93	3.79	0.0311	< 0.01	0.0475	< 1.00	0.0132 J	14.5	< 3.00	0.113	1.53	8.61	< 0.005	0.062	0.215	< 0.005	4.13	< 0.500	0.046	8.44	< 0.01	9.05	0.482	0.018	< 0.01	< 0.005	< 0.005	17.9	2.35	4.85
		B18-10140	1.66	1.65	3.50	0.0293 J	< 0.01	0.0472	< 1.00	0.0091 J	12.3	< 3.00	0.119	1.33	7.68	< 0.005	0.046	0.104	< 0.005	2.90	< 0.500	0.023	8.74	< 0.01	8.96	0.452	0.009 J	0.012 J	< 0.005	< 0.005	18.1	2.25	4.59
		B18-10142	1.68	1.93	4.40	0.0485	< 0.01	0.0386	< 1.00	< 0.005	19.5	< 3.00	0.107	1.40	8.67	< 0.005	0.049	0.050	0.061	3.00	< 0.500	< 0.003	9.99	< 0.01	9.23	0.485	0.016	< 0.01	0.005 J	0.005 J	11.5	2.39	4.83
		B18-10143	1.50	1.94	6.90	0.0578	< 0.01	0.0417	< 1.00	0.0392	8.60	< 3.00	0.109	1.50	10.1	< 0.005	0.046	0.032	0.064	2.86	< 0.500	< 0.003	9.17	< 0.01	9.30	0.474	0.015 J	< 0.01	0.007 J	0.008 J	6.75	2.52	4.25
	Shallow	B18-10032	1.89	2.03	7.55	0.014 J	< 0.01	0.0436	< 1.00	< 0.005	6.69	4.08 J	0.132	1.55	8.31	0.011	0.052	0.101	0.053	2.35	< 0.500	0.036	4.90	< 0.01	8.29	0.403	0.012 J	< 0.01	0.007 J	< 0.005	24.3	2.58	3.68
		B18-10034	1.92	2.29	8.20	0.0392	< 0.01	0.0414	< 1.00	0.015 J	6.41	< 3.00	0.123	1.41	8.51	< 0.005	0.039	< 0.013	0.067	2.47	< 0.500	0.004 J	9.38	< 0.01	9.13	0.429	0.015	< 0.01	0.009 J	0.006 J	8.39	2.60	3.37
		B18-10035	1.54	2.07	8.80	0.0678	< 0.01	0.0399	< 1.00	0.021 J	6.98	6.75	0.121	1.42	7.83	< 0.005	0.042	< 0.013	0.060	2.43	< 0.500	0.004 J	8.51	< 0.01	9.18	0.439	0.008 J	0.014 J	0.009 J	0.006 J	7.32	2.58	4.25
		B18-10036	1.91	2.27	7.70	0.0242 J	< 0.01	0.0440	< 1.00	0.0415	9.30	< 3.00	0.122	1.54	9.05	< 0.005	0.050	< 0.013	0.068	2.28	< 0.500	< 0.003	9.66	< 0.01	9.00	0.450	0.017	< 0.01	0.007 J	< 0.005	7.21	2.64	3.24
San Diego Bay - South	Freshwater-Influenced	B18-10037	2.51	2.24	11.3	0.013 J	< 0.01	0.0409	< 1.00	0.0189 J	4.09	< 3.00	0.149	1.50	12.9	< 0.005	0.039	< 0.013	0.072	3.37	< 0.500	< 0.003	13.2	< 0.01	9.66	0.463	0.015 J	0.083	0.006 J	< 0.005	5.38	2.68	4.76
		B18-10040	2.01	1.85	3.44	0.0165 J	< 0.01	0.0427	< 1.00	0.0196 J	6.60	3.54 J	0.133	1.57	11.5	0.041	0.064	0.150	0.030	3.05	1.21	0.059	11.9	< 0.01	8.99	0.542	0.013 J	0.053	< 0.005	0.019	21.2	2.82	3.15
		B18-10044	2.39	2.67	6.26	< 0.007	< 0.01	0.0466	< 1.00	0.0246 J	2.26	3.53 J	0.139	2.04	15.6	0.034	0.044	< 0.013	0.061	4.48	0.975 J	0.014	15.7	< 0.01	8.62	0.491	0.009 J	0.015 J	< 0.005	0.006 J	9.35	3.70	1.67
		B18-10179	1.86	2.05	18.4	0.0139 J	< 0.01	0.0409	< 1.00	0.0156 J	5.53	< 3.00	0.107	1.81	24.0	0.022	0.057	0.040	0.094	2.93	0.528 J	< 0.003	22.1	< 0.01	9.38	0.400	0.010 J	0.112	0.012	< 0.005	9.74	3.42	6.64
		B18-10180	2.08	2.19	13.7	0.0204 J	< 0.01	0.0401	< 1.00	0.024 J	3.56	< 3.00	0.102	1.53	16.8	< 0.005	0.047	0.0137 J	0.080	2.63	< 0.500	< 0.003	15.7	< 0.01	9.45	0.445	< 0.005	0.076	0.013	< 0.005	7.31	2.61	4.93
		B18-10181	1.95	2.26	15.4	0.0275 J	< 0.01	0.0409	< 1.00	0.0201 J	3.17	< 3.00	0.132	1.58	20.0	0.010 J	0.053	< 0.013	0.080	2.92	0.587 J	< 0.003	18.1	< 0.01	9.55	0.400	0.010 J	0.065	0.011	< 0.005	9.75	2.72	5.19
		B18-10200	1.99	2.16	6.24	0.0194 J	0.026 J	0.0402	< 1.00	0.0335	3.80	< 3.00	0.138	2.04	14.1	< 0.005	0.045	0.068	0.044	5.59	0.968 J	0.016	21.4	< 0.01	8.82	0.475	< 0.005	< 0.01	< 0.005	0.016	8.01	4.29	3.99
	Marina	B18-10085	2.07	2.20	22.1	0.018 J	0.0255	0.0483	< 1.00	0.0228 J	5.64	< 3.00	0.123	1.49	14.1	0.009 J	0.054	< 0.013	0.113	4.54	< 0.500	< 0.003	19.1	< 0.01	9.54	0.438	0.008 J	0.079	0.010 J	0.010 J	7.33	2.77	11.2
		B18-10086	1.63	1.76	15.9	0.016 J	0.0122 J	0.0474	< 1.00	0.0189 J	4.24	< 3.00	0.137	1.47	13.6	0.025	0.045	< 0.013	0.096	5.11	< 0.500	< 0.003	24.1	< 0.01	9.44	0.409	< 0.005	0.071	0.006 J	< 0.005	6.16	3.07	12.8
		B18-10087	2.24	2.64	14.5	0.019 J	< 0.01	0.0360	< 1.00	0.0401	7.28	< 3.00	0.112	1.59	13.3	0.017	0.075	< 0.013	0.060	5.16	0.719 J	< 0.003	14.6	< 0.01	9.42	0.463	0.015 J	0.070	0.010 J	0.010	7.12	2.82	10.7
	Shallow	B18-10038	2.04	1.88	23.6	0.018 J	< 0.01	0.0319	< 1.00	0.0212 J	5.92	< 3.00	0.149	1.52	9.07	0.011	0.054	0.026	0.079	2.38	< 0.500	< 0.003	8.94	< 0.01	9.41	0.473	0.007 J	0.052	0.013	0.009 J	7.13	2.49	3.48
		B18-10039	1.53	1.83	5.60	0.0452	< 0.01	0.0514	< 1.00	0.0342	12.5	< 3.00	0.136	1.47	8.22	< 0.005	0.046	< 0.013	0.070	2.58	< 0.500	< 0.003	12.6	< 0.01	8.94	0.466	0.020	< 0.01	0.005 J	0.006 J	7.39	2.52	3.98
		B18-10041	2.25	2.27	12.0	< 0.007	< 0.01	0.0327	< 1.00	0.0195 J	1.26 J	< 3.00	0.125	1.61	10.4	0.110	0.047	< 0.013	0.048	2.45	0.563 J	< 0.003	12.1	< 0.01	9.43	0.406	0.008 J	0.048	0.010	0.005 J	6.52	2.55	3.21
		B18-10042	2.28	1.89	11.4	0.0253 J	< 0.01	0.0357	< 1.00	0.0217 J	8.94	< 3.00	0.105	1.60	12.1	< 0.005	0.057	< 0.013	0.090	2.37	0.761 J	< 0.003	13.8	< 0.01	9.41	0.438	0.007 J	0.066	0.012	0.007 J	7.12	2.52	3.58
		B18-10043	2.26	2.78	3.04	0.0165 J	< 0.01	0.0518	< 1.00	0.0287	3.73	< 3.00	0.158	1.86	15.2	< 0.005	0.068	0.037	0.089	2.59	0.978 J	0.019	19.4	< 0.01	8.98	0.490	< 0.005	0.031	< 0.005	< 0.005	10.3	3.46	2.30
		B18-10088	1.99	1.98	13.6	0.0123 J	< 0.01	0.0422	< 1.00	0.0418	1.21 J	< 3.00	0.125	1.65	11.5	0.026	0.056	< 0.013	0.058	3.07	< 0.500	< 0.003	15.4	< 0.01	9.66	0.441	0.015	0.089	0.009 J	0.013	8.01	2.68	4.88

Notes:
mg/L = milligrams per liter
µg/L = micrograms per liter
ng/L = nanograms per liter
Data reported to the method detection limit
< = not detected at or above the stated level
J = estimated result, below the reporting limit

PAH = Polycyclic Aromatic Hydrocarbons
[1] Nitrate and Orthophosphate as P samples were immediately frozen following collection to minimize microbial activity and extend the 2-day method holding time. These samples were kept frozen until processing and analysis.
Total PAHs were calculated by the sum of all tested PAHs. Non-detects were treated as 0 and estimated results were treated as the reported value for summing purposes.

Table 3-3.
2018 RHMP Water Chemistry Results Summary

Harbor	Strata	Sample ID	Total Trace Metals (µg/L)																				
			Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Iron (Fe)	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Thallium	Tin	Titanium	Vanadium	Zinc
Dana Point Harbor	Deep	B18-10068	127	0.096	1.34	6.55	< 0.005	0.042	0.337	0.047	3.43	73.5	0.109	3.56	< 0.01	7.87	0.359	< 0.005	< 0.01	0.009 J	< 0.005	17.6	2.14	8.29
	Freshwater-Influenced	B18-10066	57.8	0.119	1.38	5.24	0.007 J	0.082	0.246	0.055	10.2	25.5	0.084	6.04	< 0.01	8.71	0.608	< 0.005	< 0.01	0.008 J	< 0.005	22.9	1.97	25.0
	Marina	B18-10067	68.5	0.102	1.33	5.44	< 0.005	0.047	0.283	0.029	8.87	39.1	0.115	2.54	< 0.01	8.63	0.283	< 0.005	< 0.01	0.011	0.007 J	16.2	1.93	18.2
	Shallow	B18-10065	65.4	0.095	1.41	5.30	0.015	0.043	0.356	0.025	6.05	22.1	0.086	2.26	< 0.01	8.62	0.282	< 0.005	< 0.01	0.009 J	< 0.005	27.4	2.07	13.3
Oceanside Harbor	Deep	B18-10071	75.7	0.099	1.41	4.57	< 0.005	0.026	0.241	< 0.005	2.13	43.7	0.043	3.41	< 0.01	9.04	0.222	0.007 J	< 0.01	< 0.005	< 0.005	17.9	2.22	7.87
	Freshwater-Influenced	B18-10070	65.8	0.117	1.67	5.53	< 0.005	0.030	0.220	0.011	5.82	35.6	0.052	4.08	< 0.01	8.56	0.272	0.025	< 0.01	0.008 J	0.025	18.1	2.31	17.5
	Marina	B18-10069	123	0.086	1.52	5.67	< 0.005	0.033	0.284	0.385	8.71	85.8	0.157	5.58	< 0.01	8.58	0.288	0.016	< 0.01	0.010 J	< 0.005	18.2	2.32	19.9
		B18-10072	41.1	0.112	1.55	8.38	< 0.005	0.040	0.181	< 0.005	6.70	30.3	0.024	13.2	< 0.01	9.38	0.212	0.011 J	< 0.01	< 0.005	0.006 J	13.5	2.10	32.5
Mission Bay	Deep	B18-10019	95.0	0.089	1.33	4.70	< 0.005	0.026	0.251	0.237	1.40	71.1	0.132	4.40	< 0.01	8.06	0.225	0.005 J	< 0.01	0.007 J	< 0.005	18.3	2.29	1.11
		B18-10020	43.7	0.088	1.44	4.47	< 0.005	0.033	0.201	< 0.005	0.791	27.7	0.121	2.44	< 0.01	8.67	0.186	< 0.005	< 0.01	< 0.005	< 0.005	16.7	2.14	0.960
	Freshwater-Influenced	B18-10015	61.5	0.124	1.95	18.8	< 0.005	0.033	0.284	0.125	1.07	46.5	0.134	20.1	< 0.01	8.87	0.303	0.012 J	0.011 J	< 0.005	< 0.005	13.2	2.73	2.20
	Marina	B18-10074	68.7	0.098	1.40	5.34	< 0.005	0.028	0.208	0.012	1.15	54.6	0.123	2.96	< 0.01	8.85	0.231	0.040	< 0.01	< 0.005	0.033	15.1	2.30	1.32
		B18-10075	97.2	0.096	1.50	5.19	0.011	0.027	0.260	0.057	1.92	67.3	0.155	4.06	< 0.01	8.26	0.223	0.010 J	< 0.01	< 0.005	< 0.005	18.0	2.36	3.80
	Shallow	B18-10016	55.4	0.088	1.58	4.83	< 0.005	0.026	0.172	0.056	0.873	43.2	0.103	5.01	< 0.01	8.68	0.227	0.016	< 0.01	< 0.005	< 0.005	15.4	2.54	0.568
		B18-10017	97.1	0.127	2.09	12.2	< 0.005	0.044	0.134	0.122	1.39	61.0	0.183	23.1	< 0.01	8.66	0.338	0.043	< 0.01	0.005 J	0.017	15.0	2.84	1.61
		B18-10073	95.9	0.092	1.40	4.47	< 0.005	0.022	0.251	0.029	1.36	71.5	0.135	3.33	< 0.01	8.24	0.245	0.015 J	< 0.01	< 0.005	< 0.005	18.5	2.46	1.40
		B18-10438 (overdraw)	31.7	0.109	1.43	8.16	< 0.005	0.032	0.098	0.049	1.38	45.3	0.065	7.50	< 0.01	8.69	0.227	0.016	< 0.01	< 0.005	< 0.005	13.4	2.00	1.57
San Diego Bay - North	Deep	B18-10022	158	0.108	1.34	7.59	0.005 J	0.030	0.206	0.083	1.44	72.9	0.203	6.77	< 0.01	9.38	0.368	0.030	< 0.01	0.009 J	0.008 J	27.1	2.54	4.89
		B18-10023	54.3	0.125	1.39	4.50	< 0.005	0.029	0.269	< 0.005	1.79	33.0	< 0.003	1.28	< 0.01	8.54	0.282	0.023	0.059	< 0.005	0.012	31.2	2.30	3.03
		B18-10024	97.8	0.115	1.25	7.15	< 0.005	0.060	0.101	0.062	1.32	58.8	0.288	5.96	< 0.01	8.39	0.353	4.18	< 0.01	0.007 J	0.007 J	22.4	2.39	4.14
		B18-10030	62.6	0.114	1.31	4.76	< 0.005	0.046	0.249	< 0.005	1.23	55.9	0.023	3.09	< 0.01	8.48	0.335	0.024	0.019 J	< 0.005	< 0.005	20.3	2.44	6.82
		B18-10112	90.1	0.119	1.34	7.15	< 0.005	0.024	0.090	0.057	1.10	40.8	0.092	5.53	< 0.01	9.13	0.327	0.021	< 0.01	0.006 J	0.007 J	23.9	2.37	5.14
		B18-10113	83.8	0.114	1.33	6.73	< 0.005	0.098	0.077	0.063	1.19	40.3	0.319	6.38	< 0.01	9.14	0.369	0.033	< 0.01	0.007 J	0.009 J	26.0	2.40	3.92
		B18-10116	216	0.115	1.27	8.10	< 0.005	0.027	0.261	0.097	1.96	128	0.285	8.27	< 0.01	8.84	0.432	0.020	< 0.01	0.009 J	0.007 J	22.0	2.63	6.22
		B18-10117	102	0.114	1.41	5.63	0.013	0.076	0.297	< 0.005	1.28	65.3	0.204	4.97	< 0.01	8.42	0.351	0.014 J	0.010 J	< 0.005	< 0.005	25.6	2.61	4.03
	Freshwater-Influenced	B18-10029	128	0.120	1.49	8.24	0.006 J	0.027	0.153	0.081	1.91	56.9	0.174	7.70	< 0.01	9.49	0.397	0.011 J	< 0.01	0.005 J	< 0.005	47.9	2.64	5.80
		B18-10076	127	0.147	1.41	8.16	< 0.005	0.037	0.207	0.079	2.07	71.9	0.254	7.34	< 0.01	8.78	0.417	0.016	< 0.01	0.008 J	0.013	29.7	2.55	6.73
	Industrial/Port	B18-10114	189	0.113	1.39	7.08	< 0.005	0.030	0.212	0.085	1.87	78.2	0.220	8.47	< 0.01	8.82	0.402	0.021	< 0.01	0.008 J	0.008 J	36.4	2.60	5.68
		B18-10115	143	0.120	1.43	8.17	< 0.005	0.030	0.180	0.084	2.24	84.6	0.207	8.62	< 0.01	9.15	0.416	0.030	< 0.01	0.008 J	0.019	31.5	2.56	7.39
	Marina	B18-10078	148	0.115	1.49	6.80	0.005 J	0.042	0.403	0.023	3.44	109	0.195	5.17	< 0.01	8.09	0.346	0.016	< 0.01	< 0.005	< 0.005	22.1	2.70	15.1
		B18-10079	92.8	0.115	1.51	6.74	0.005 J	0.041	0.298	0.020	2.21	87.9	0.134	5.09	< 0.01	8.31	0.373	0.020	< 0.01	< 0.005	< 0.005	17.3	2.52	6.57
		B18-10080	31.1	0.118	1.53	5.80	0.007 J	0.037	0.188	< 0.005	9.73	17.4	< 0.003	3.14	< 0.01	8.87	0.286	< 0.005	< 0.01	< 0.005	< 0.005	21.0	2.45	27.3
		B18-10081	26.4	0.118	1.53	7.03	0.010 J	0.068	0.175	< 0.005	10.6	16.0	0.117	3.16	< 0.01	8.68	0.362	0.027	0.011 J	< 0.005	0.012	15.8	2.34	24.0
		B18-10082	18.2	0.122	1.44	5.22	0.010	0.039	0.299	< 0.005	9.74	12.9	< 0.003	2.83	< 0.01	8.80	0.284	0.010 J	< 0.01	< 0.005	< 0.005	20.7	2.36	27.9
		B18-10083	32.6	0.123	1.47	5.69	< 0.005	0.033	0.190	< 0.005	6.6	17.1	< 0.003	2.80	< 0.01	8.80	0.278	0.008 J	< 0.01	< 0.005	< 0.005	20.4	2.48	18.1
		B18-10084	67.5	0.116	1.77	6.54	0.025	0.042	0.410	0.050	3.86	35.9	< 0.003	3.65	< 0.01	8.54	0.305	0.012 J	< 0.01	< 0.005	< 0.005	111	3.76	11.2
	Shallow	B18-10077	219	0.111	1.33	9.02	< 0.005	0.064	0.378	0.105	1.92	111	0.430	7.84	< 0.01	8.99	0.389	0.021	< 0.01	0.008 J	0.014	27.8	2.65	6.89
San Diego Bay - Central	Deep	B18-10133	115	0.142	1.46	8.44	< 0.005	0.116	0.297	0.029	3.81	77.4	0.380	10.4	< 0.01	9.25	0.624	0.020	0.016 J	< 0.005	0.027	23.3	2.49	7.32
		B18-10141	184	0.092	1.42	8.57	< 0.005	0.040	0.311	0.099	3.18	89.3	0.158	11.1	< 0.01	8.25	0.472	0.012 J	< 0.01	0.009 J	0.012	18.5	2.62	5.34
		B18-10144	265	0.133	1.51	11.0	< 0.005	0.047	0.364	0.146	3.81	187	0.230	14.5	< 0.01	9.04	0.814	0.018	0.018 J	0.012	0.017	17.7	3.16	5.72
	Freshwater-Influenced	B18-10031	161	0.125	1.39	9.38	0.020	0.054	0.312	0.094	3.95	68.2	0.300	9.94	< 0.01	7.38	0.494	0.013 J	< 0.01	0.008 J	0.020	25.4	2.67	7.09
		B18-10178	91.8	0.124	1.48	8.78	< 0.005	0.052	0.230	0.096	3.34	43.7	0.259	11.1	< 0.01	7.78	0.573	0.014 J	< 0.01	0.006 J	0.007 J	33.8	2.76	7.39
	Industrial/Port	B18-10119	138	0.109	1.49	7.65	0.017	0.053	0.339	0.090	3.48	70.9	0.299	10.0	< 0.01	7.46	0.485	0.012 J	< 0.01	< 0.005	< 0.005	30.8	2.77	9.21
		B18-10121	122	0.104	1.51	8.62	0.008 J	0.050	0.285	0.079	3.57	52.7	0.219	9.44	< 0.01	7.58	0.551	< 0.005	< 0.01	0.006 J	< 0.005	34.5	2.75	13.1
		B18-10123	88.9	0.127	1.33	7.16	< 0.005	0.057	0.222	0.076	3.89	36.0	0.173	9.06	< 0.01	8.03	0.572	0.018	< 0.01	0.006 J	< 0.005	20.9	2.54	9.79
		B18-10124	85.6	0.112	1.67	9.86	< 0.005	0.053	0.269	0.036	3.83	42.9	0.157	9.87	< 0.01	9.03	0.530	0.013 J	0.035	< 0.005	0.009 J	25.0	2.54	5.91
		B18-10126	93.1	0.106	1.65	8.90	0.006 J	0.053	0.293	0.031	4.05	50.2	0.180	9.82	< 0.01	9.25	0.534	0.012 J	0.023	< 0.005	< 0.005	22.0	2.52	5.63
		B18-10127	98.9	0.102	1.43	8.26	< 0.005	0.055	0.256	0.021	3.39	50.9	0.167	10.1	< 0.01	8.94	0.513	0.012 J	0.017 J	< 0.005	0.006 J	21.6	2.50	5.28
		B18-10132	88.6	0.099	1.54	10.0	< 0.005	0.055	0.250	0.019	3.21	45.1	0.147	10.2	< 0.01	8.96	0.489	0.020	0.019 J	< 0.005	0.006 J	24.5	2.55	4.55
		B18-10136	93.1	0.103	1.47	10.4	< 0.005	0.073	0.261	0.029	3.47	48.2	0.230	9.26	< 0.01	8.91	0.514	0.017	< 0.01	< 0.005	0.006 J	22.9	2.47	5.16
		B18-10137	135	0.102	1.42	9.16	< 0.005	0.057	0.284	0.032	3.25	73.7	0.188	10.9	< 0.01	8.82	0.482	0.019	0.011 J	< 0.005	< 0.005	24.1	2.52	5.18
		B18-10139	137	0.103	1.45	9.70	< 0.005	0.059	0.302	0.034	4.74	79.5	0.187	11.0	< 0.01	9.16	0.543	0.018	0.015 J	< 0.005	< 0.005	24.5	2.54	4.85
		B18-10140	145	0.106	1.41	9.12	< 0.005	0.111	0.318	0.033	3.73	83.2	0.372	11.1	< 0.01	8.56	0.471	0.018	0.012 J	< 0.005	0.028	25.6	2.52	5.33
		B18-10142	181	0.094	1.35	10.9	< 0.005	0.038	0.289	0.112	3.58	81.0	0.150	12.7	< 0.01	8.47	0.505	0.009 J	0.014 J	0.009 J	0.010 J	17.1	2.74	5.32
		B18-10143	208	0.098	1.46	9.32	< 0.005	0.052	0.306	0.126	3.69	134	0.194	12.7	< 0.01	8.72	0.541	0.012 J	< 0.01	0.008 J	0.014	15.3	2.78	5.97
	Shallow	B18-10032	297	0.105	1.42	8.58	0.008 J	0.058	0.548	0.114	2.99	131	0.418	9.16	< 0.01	7.82	0.510	0.017	< 0.01	0.008 J	0.011	35.6	3.00	4.78
		B18-10034	375	0.096	1.41	8.38	< 0.005	0.052	0.672	0.145	3.64	226	0.441	12.9	< 0.01	8.43	0.542	0.014 J	0.011 J	0.010 J	0.027	23.4	3.24	6.26
		B18-10035	392	0.100	1.64	7.92	< 0.005	0.046	0.629	0.150	3.44	208	0.448	12.2	< 0.01	8.40	0.571	0.017	0.010 J	0.012	0.019	23.8	3.15	6.44
		B18-10036	414	0.085	1.48	10.5	0.006 J	0.046	0.714	0.163	3.42	260	0.490	13.4	< 0.01	7.63	0.559	0.007 J	0.025	0.013	0.019	24.3	3.39	7.53
San Diego Bay - South	Freshwater-Influenced	B18-10037	116	0.112	1.55	13.3	< 0.005	0.052	0.14	0.100	3.55	71.9	0.148	15.5	< 0.01	8.93	0.510	0.007 J	0.063	0.007 J	0.009 J	13.0	2.93	7.44
		B18-10040	93.5	0.129	1.51	11.1	0.025	0.039	0.208	0.089	7.25	42.7	0.148	13.7	< 0.01	8.14	0.526	< 0.005	0.038	0.005 J	< 0.005	14.8	2.79	3.85
		B18-10044	145	0.126	1.67	16.7	< 0.005	0.067	0.257	0.114	5.63	128	0.209	20.7	< 0.01	8.18	0.552	0.017	0.017 J	< 0.005	< 0.005	15.4	4.06	2.98
		B18-10179	105	0.102	1.57	26.8	0.011	0.049	0.155	0.099	3.15	53.6	0.081	22.8	< 0.01	9.27	0.455	0.008 J	0.101	0.012	< 0.005	12.4	3.16	7.45
		B18-10180	114	0.102	1.48	16.4	0.034	0.047	0.170	0.092	2.75	59.3	0.096	17.7	< 0.01	8.89	0.434	0.008 J	0.079	0.011	< 0.005	11.7	2.74	5.64
		B18-10181	93.3	0.109	1.57	16.9	0.010 J	0.055	0.114	0.098	2.79	52.4	0.087	19.9	< 0.01	9.35	0.441	0.011 J	0.086	0.010 J	0.006 J	10.9	2.76	5.63
		B18-10200	186	0.120	2.23	15.8	< 0.005	0.047	0.242	0.078	5.10	96.2	0.208	25.9	< 0.01	8.03	0.542	0.009 J	0.021	< 0.005	0.010	16.9	4.66	5.16
	Marina	B18-10085	288	0.086	1.68	11.5	0.017	0.055	0.412	0.156	8.84	152	0.313	23.0	< 0.01	8.36	0.509	0.011 J	0.082	0.011	0.024	20.9	3.32	12.5
		B18-10086	169	0.137	1.53	10.8	0.025	0.052	0.232	0.135	6.55	95.6	0.079	25.7	< 0.01	9.12	0.489	0.013 J	0.091	0.012	0.011	14.1	3.26	13.4
		B18-10087	81.6	0.110	1.53	10.7	< 0.005	0.064	0.094	0.092	5.83	40.0	0.014	14.8	< 0.01	9.28	0.418	0.009 J	0.092	0.009 J	0.006 J	10.8	2.90	11.9
	Shallow	B18-10038	207	0.134	1.44	10.2	0.020	0.053	0.396	0.127	3.26	145	0.238	11.6	< 0.01	8.92	0.557	< 0.005	0.096	0.013	0.034	16.7	2.74	5.04
		B18-10039	220	0.093	1.52	9.79	< 0.005	0.042	0.418	0.138	3.00	140	0.219	15.3	< 0.01	8.48	0.514	0.014 J	0.017 J	0.009 J	0.016	15.6	2.96	6.14
		B18-10041	67.9	0.104	1.58	12.8	0.062	0.040	0.123	0.064	2.56	37.3	0.022	13.0	< 0.01	9.07	0.383	< 0.005	0.084	0.014	0.006 J	12.2	2.60	3.90
		B18-10042	111	0.107	1.45	12.3	0.009 J	0.048	0.155	0.090	2.97	59.7	0.054	15.1	< 0.01	9.11	0.441	0.012 J	0.076	0.013	0.007 J	11.7	2.69	4.05
		B18-10043	90.9	0.128	1.61	15.0	< 0.005	0.067	0.152	0.073	2.81	59.9	0.115	21.4	< 0.01	8.43	0.519	0.015 J	0.018 J	< 0.005	< 0.005	18.7	3.77	2.92
		B18-10088	103	0.100	1.47	11.7	< 0.005	0.050	0.131	0.080	3.47	56.6	0.042	17.0	< 0.01	9.13	0.444	0.016	0.073	0.010	0.007 J	11.5	2.72	5.64

Notes:
mg/L = milligrams per liter
µg/L = micrograms per liter
ng/L = nanograms per liter
Data reported to the method detection limit
< = not detected at or above the stated level
J = estimated result, below the reporting limit

Contaminants of Concern in Surface Waters

Based on a review of historical data, concentrations of copper were considered to be a primary indicator of water quality, followed by zinc and nickel (Weston, 2005b). The results and patterns for these three trace metals are highlighted below in addition to another commonly detected water quality constituent of concern, PAHs. A summary of other chemical and physical measures is provided herein with raw values for all measurements provided in Appendix F.

For dissolved trace metals, the acute (CMC) and chronic (CCC) values provided by USEPA for ambient saltwater water quality criteria were used for comparison purposes (CTR, 40 Code of Federal Regulations 131.38 and USEPA, 2017; https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#a). All values, with the exception of cadmium and lead, have criteria that are the same between USEPA and the CTR. For these two metals, the lower USEPA values were used. Available water quality criteria for dissolved trace metals are summarized in Table 3-4.

Box plots are presented for select water quality indicators to compare distributions among strata and harbors to water quality criteria (if available). Each box plot shows the 25th percentile, median, 75th percentile, and range of concentrations, with dashed horizontal lines indicating respective water quality criteria. Statistical comparisons between strata were performed for primary and secondary indicators (copper, nickel, and zinc) as well as total PAHs using Kruskal-Wallis tests on log-transformed data. All tests showed a significant difference in chemical concentrations between strata. Detailed results of statistical analyses, including multiple comparisons tests, are presented in Appendix K.

Table 3-4.
Ambient USEPA and CTR Saltwater Water Quality Criteria for Dissolved Trace Metals

Trace Metal	Dissolved Concentration (µg/L)	
	Acute CMC	Chronic CCC
Arsenic	69	36
Cadmium[a]	33.7	7.9
Chromium (VI)[b]	1100	50
Copper	4.8	3.1
Lead[a]	210	8.1
Mercury[c]	1.8	0.94
Nickel	74	8.2
Selenium	290	71
Silver	1.9	NA
Zinc	90	81

Notes:

a. Values for cadmium and lead reflect USEPA criteria only, which are more stringent than the CTR.

b. Reported chromium values for RHMP included the sum of its two natural forms; chromium III and chromium IV.

c. CMC and CCC values for mercury are provided by USEPA and not listed in the CTR; however, a separate water quality objective 0.05 µg/L is provided in the CTR for human health consumption of water and organisms

µg/L = microgram(s) per liter; CCC = criterion continuous concentration; CMC = criterion maximum concentration

Copper

A comparison of copper concentrations in surface waters among strata and harbors is shown with box plots in Figure 3-6. The USEPA acute CMC and the chronic CCC values are shown on the figure for comparison. In addition, the percentage of stations with copper concentrations meeting the CTR criteria is summarized in Table 3-5 among strata. Dissolved copper concentrations met (i.e., were below) the CMC and CCC at 84% and 63% of all of the RHMP stations, respectively. Concentrations of dissolved copper were highest in the marina stratum, followed by the industrial/port and freshwater-influenced strata; concentrations in these strata only met (i.e., were below) the CCC at 20%, 53%, and 57% of stations, respectively (Table 3-5). The remaining two strata (deep and shallow) had dissolved copper concentrations that were entirely below the CMC, and mostly below the CCC (87% and 94%, respectively) (Figure 3-6, Table 3-5).

Among harbors, Dana Point and Oceanside Harbor had the highest median concentrations of dissolved copper, while Mission Bay had the lowest (all below the CCC and CMC). San Diego Bay had the widest range of dissolved copper concentrations, with the highest concentrations observed in the marina stratum, followed by freshwater-influenced and industrial/port strata.

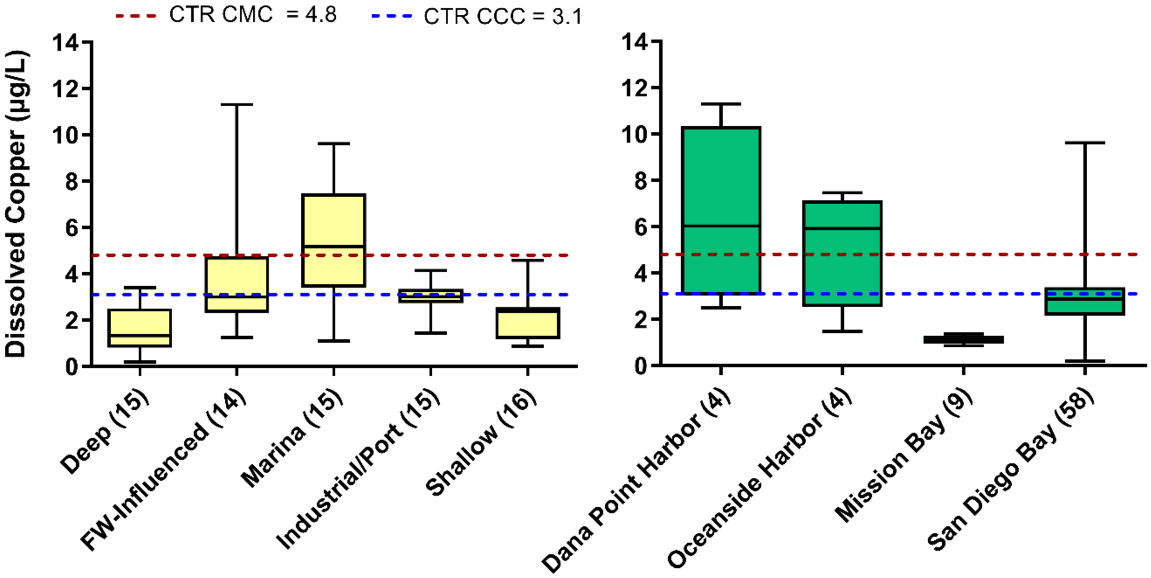


Figure 3-6. Comparison of Surface Water Dissolved Copper Concentrations Among Strata and Harbors

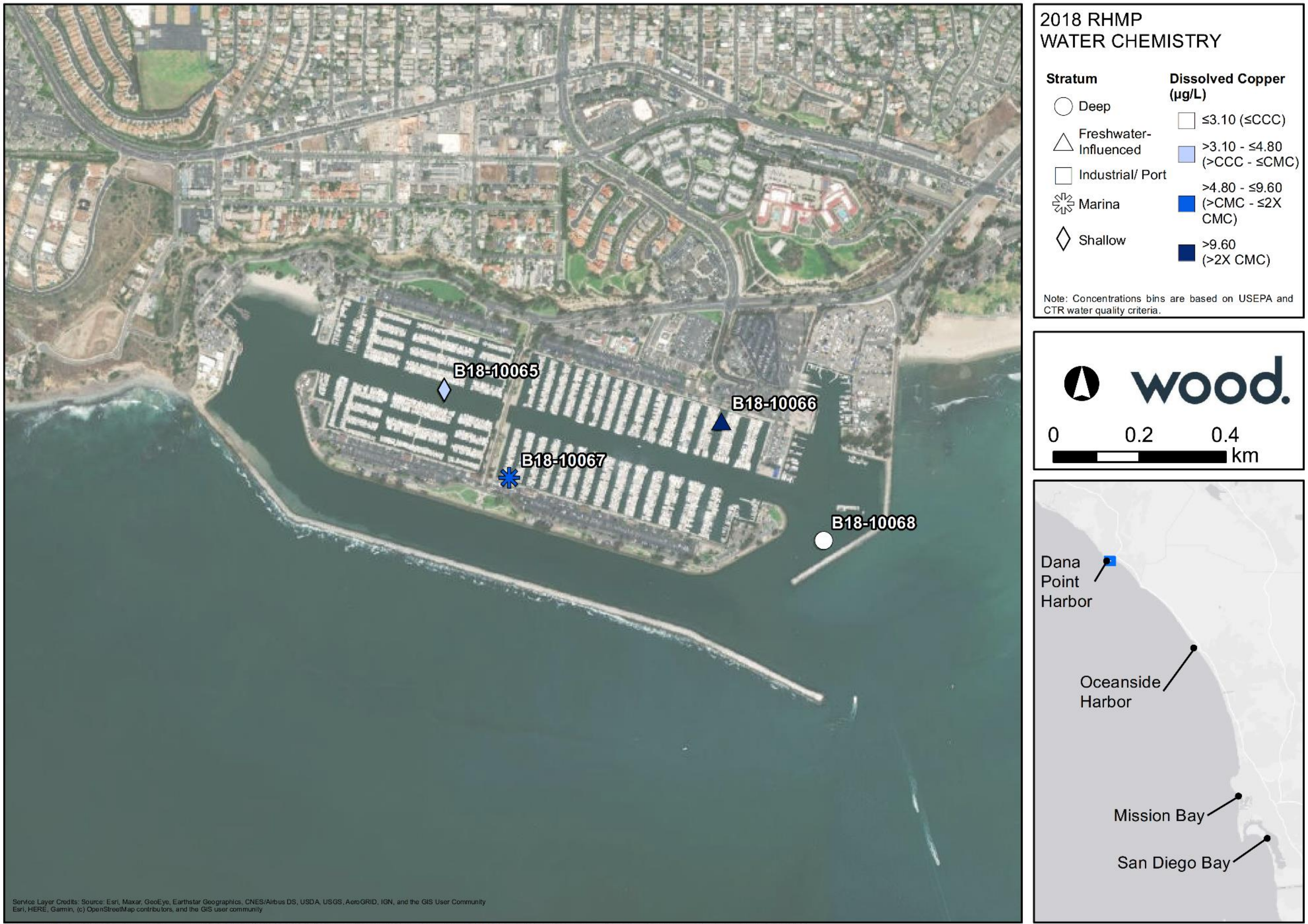
Box plots show the median, 25th percent quartiles, and range concentrations. The number of stations (n) is shown in parentheses.

Table 3-5.
Percentage of Stations with Results Meeting CTR Criteria for Dissolved Copper by Stratum

Indicator		Threshold Value	Percentage of 2018 RHMP Stations Meeting CTR Criteria					
			Deep (%)	Freshwater-Influenced (%)	Marina (%)	Industrial/ Port (%)	Shallow (%)	All Stations (%)
# of stations			*15*	*14*	*15*	*15*	*16*	*75*
Dissolved Copper	CMC	4.8 µg/L	100	79	40	100	100	84
	CCC	3.1 µg/L	87	57	20	53	94	63

Notes:
% = percent; µg/L = microgram(s) per liter; CCC = continuous chronic criterion; CMC = continuous maximum criterion

The spatial distributions of dissolved copper concentrations for each harbor are shown in Figures 3-7a through 3-7f. Sample concentrations were divided into four different bins to differentiate measured values. Bins were based on the USEPA and CTR chronic CCC (3.1 µg/L) and acute CMC (4.8 µg/L) criteria, as follows: below the CCC, between the CCC and CMC, between the CMC and twice the CMC, and greater than twice the CMC.



Note: Concentrations bins are based on USEPA and CTR water quality criteria.

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Figure 3-7a. Distribution of Dissolved Copper Concentrations in Surface Waters of Dana Point Harbor

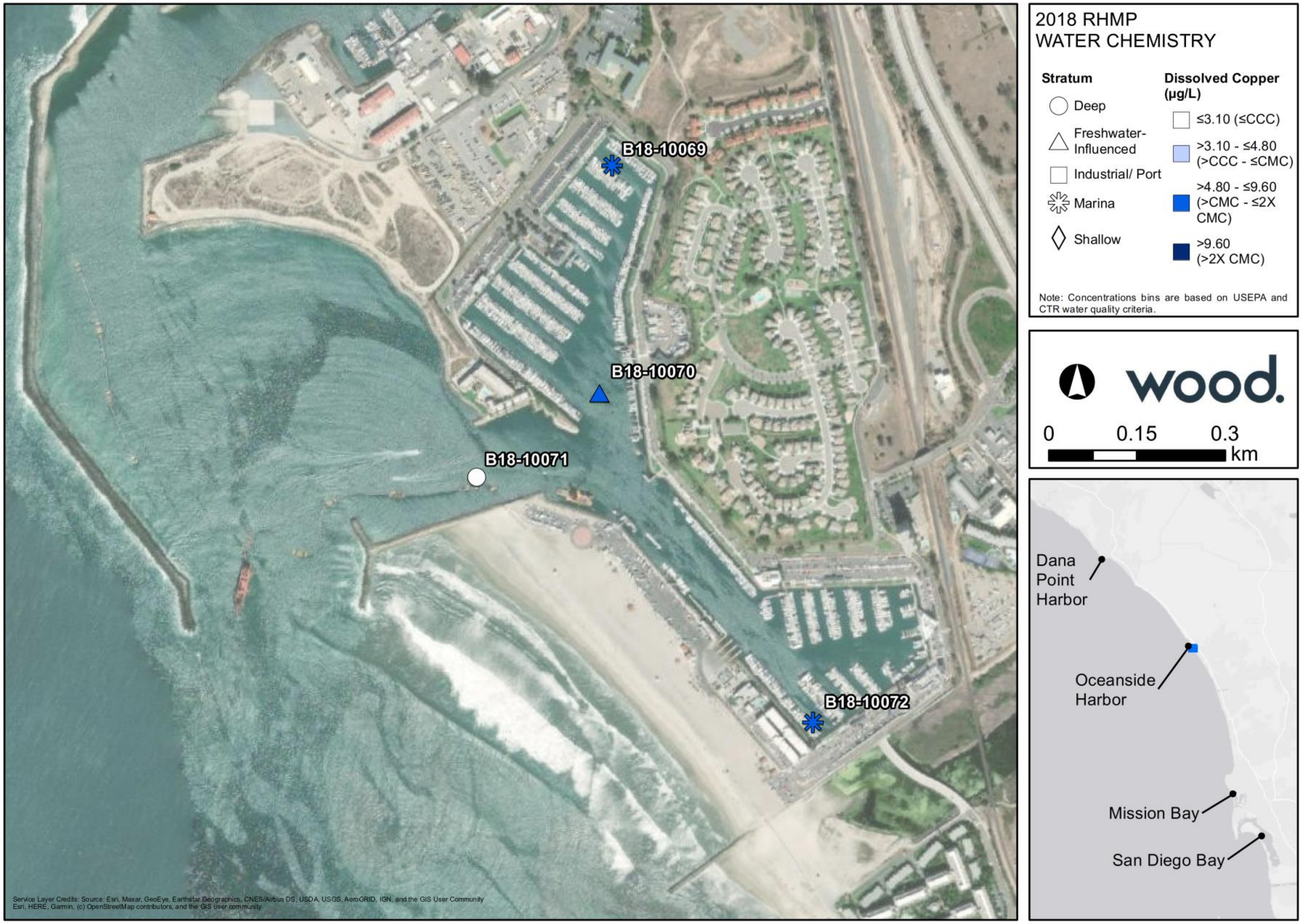

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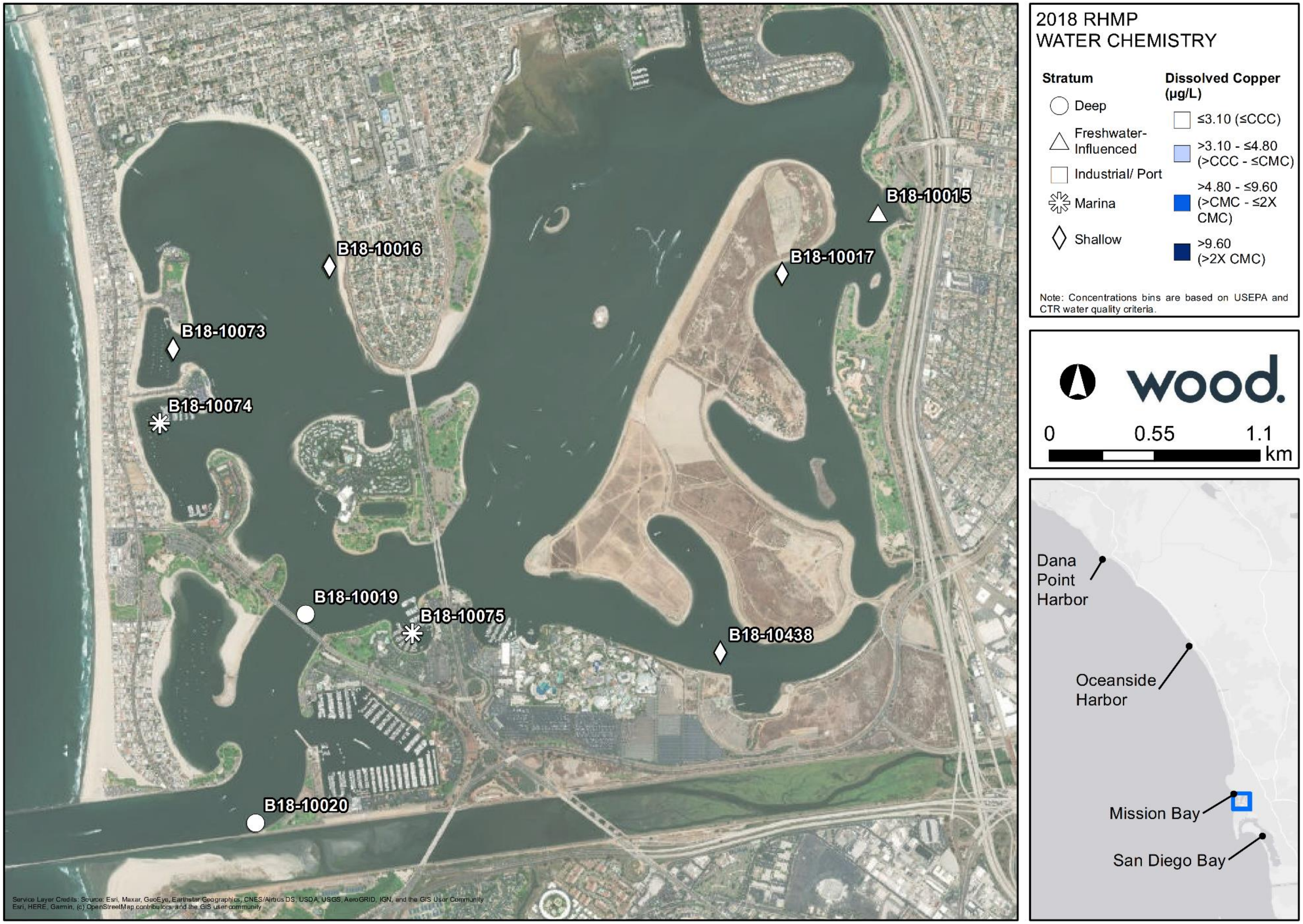
Figure 3-7b. Distribution of Dissolved Copper Concentrations in Surface Waters of Oceanside Harbor



Note: Concentrations bins are based on USEPA and CTR water quality criteria.

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Figure 3-7c Distribution of Dissolved Copper Concentrations in Surface Waters of Mission Bay

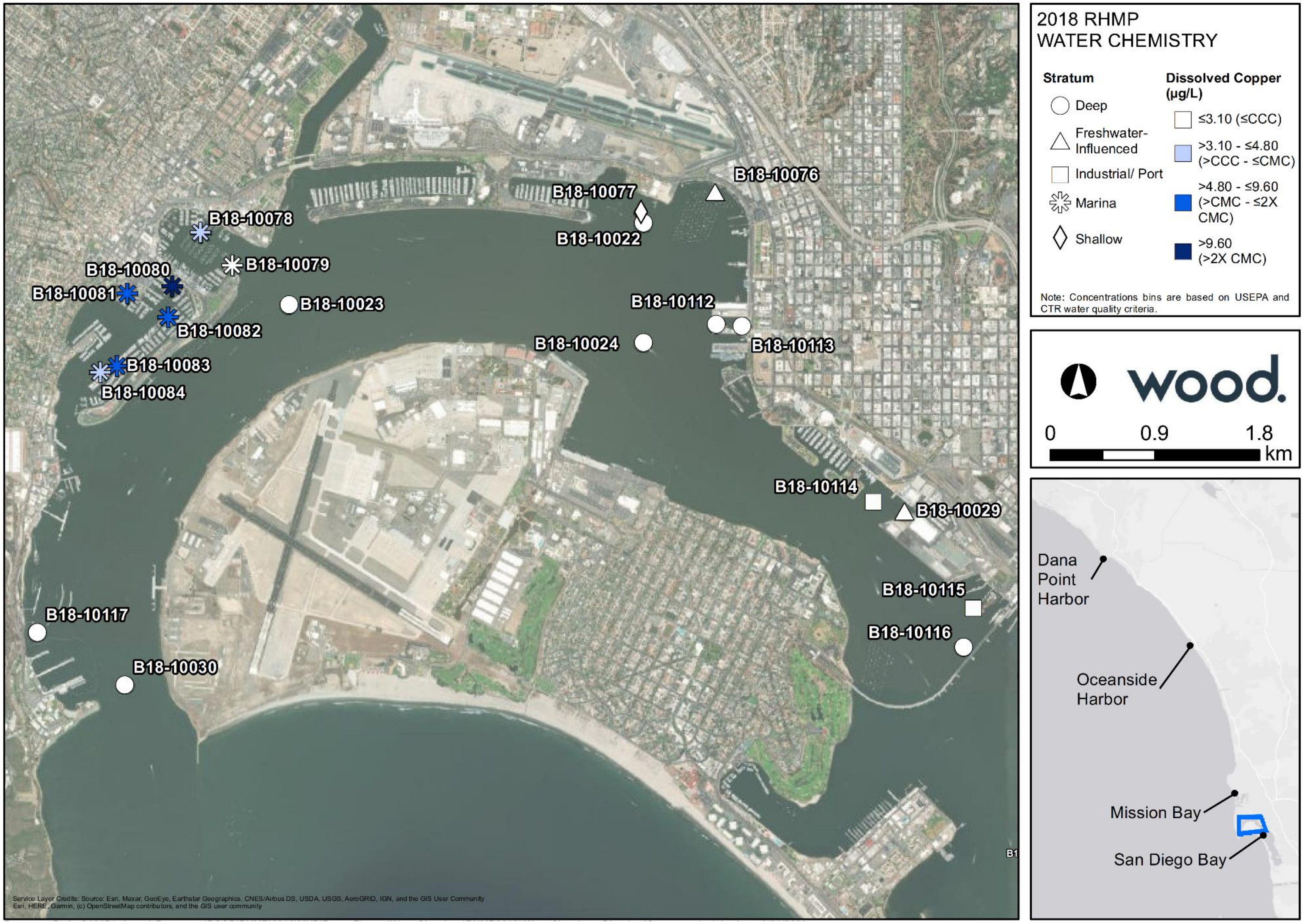

Figure 3-7d. Distribution of Dissolved Copper Concentrations in Surface Waters of North San Diego Bay

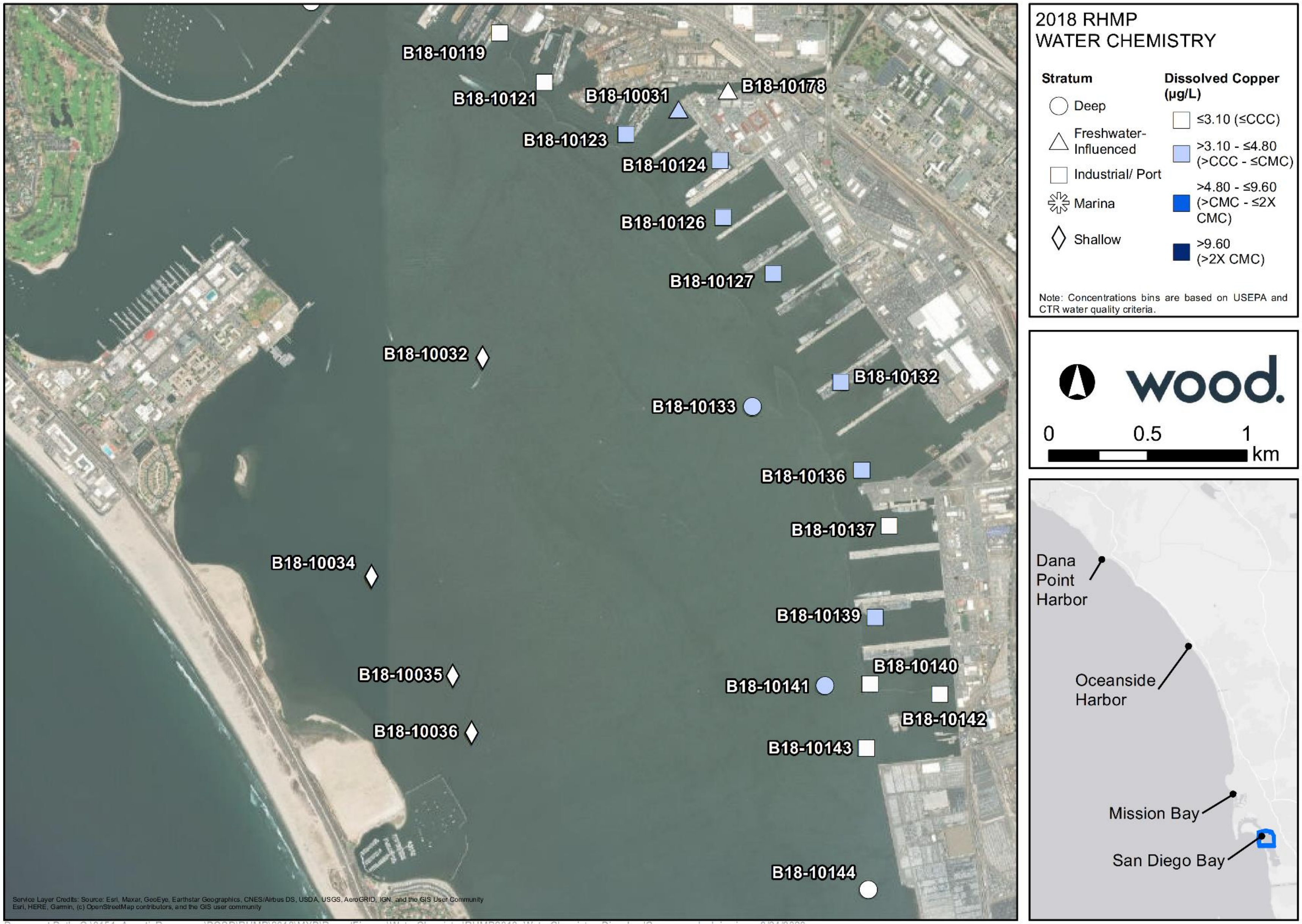

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Figure 3-7e. Distribution of Dissolved Copper Concentrations in Surface Waters of Central San Diego Bay

Note: Concentrations bins are based on USEPA and CTR water quality criteria.

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Figure 3-7f. Distribution of Dissolved Copper Concentrations in Surface Waters of South San Diego Bay

Zinc

At all sampling stations, concentrations of dissolved zinc were well below the CTR and USEPA CMC and CCC of 90 and 81 µg/L, respectively (Figure 3-8). The highest median concentrations of zinc were recorded in the marina stratum and within Oceanside Harbor.

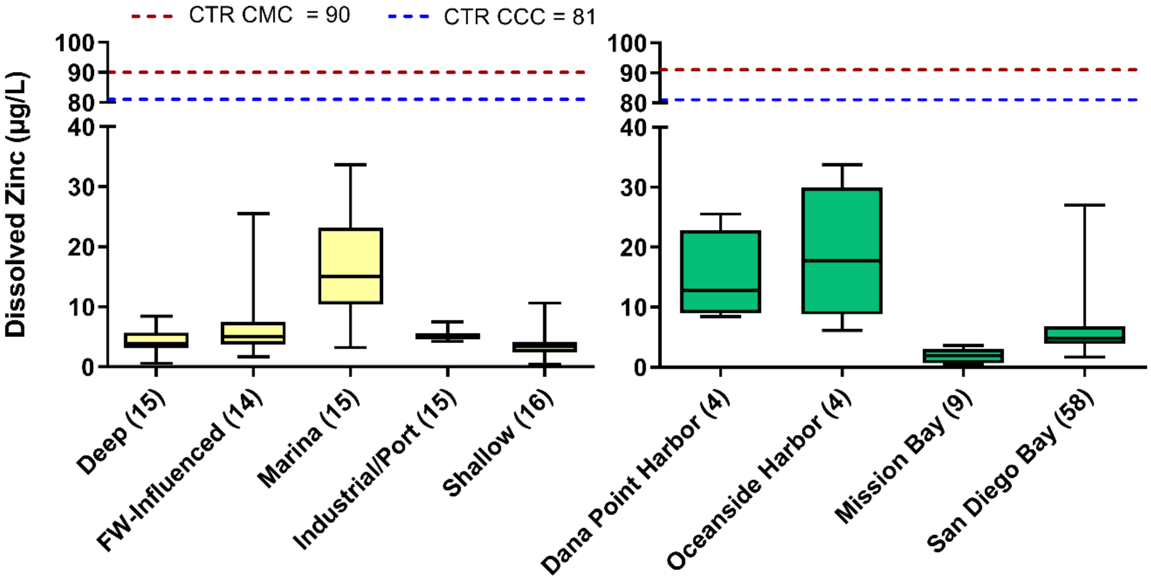

Figure 3-8. Comparisons of Dissolved Zinc Concentrations Among Strata and Harbors in Surface Waters

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Nickel

All stations had concentrations of dissolved nickel well below CTR and USEPA CMC and CCC values of 74 µg/L and 8.2 µg/L, respectively. There were no appreciable differences in nickel concentrations among the different strata or harbors (Figure 3-9).

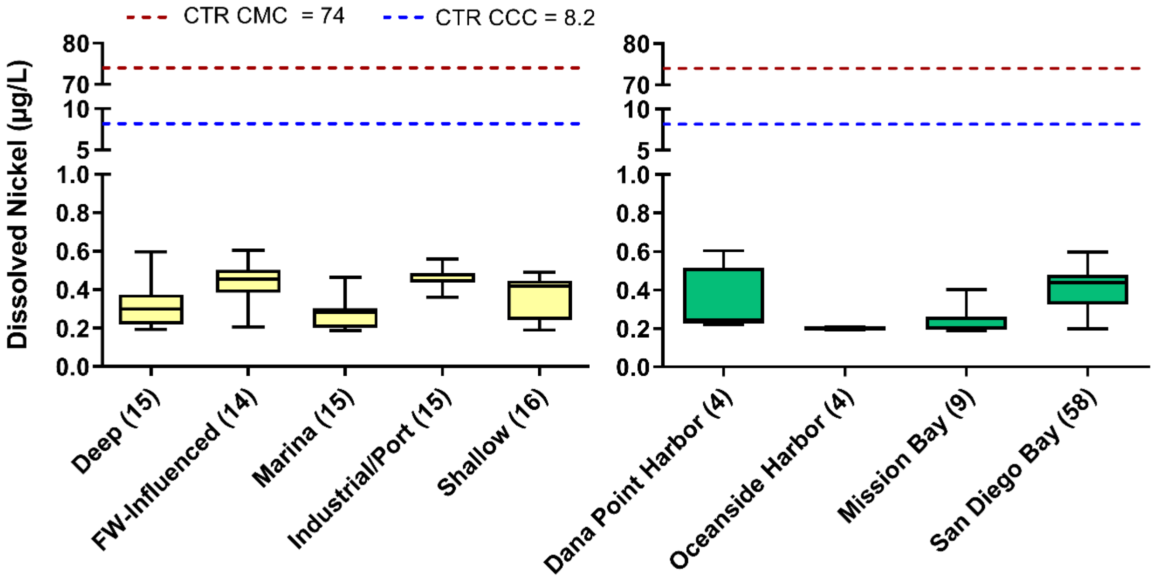

Figure 3-9. Comparisons of Dissolved Nickel Concentrations Among Strata and Harbors in Surface Waters

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Other Dissolved Metals

All other trace metals measured in surface waters during the RHMP had dissolved concentrations below their respective CTR and USEPA acute and chronic water quality criteria among all harbors and strata (see Appendix F).

Total PAHs

While PAHs were detected in surface waters at most stations, the greatest median concentrations of PAHs were observed in the industrial/port stratum and in San Diego Bay (Figure 3-10). Widely accepted aquatic wildlife criteria for total PAHs are not currently available for USEPA Region 9. However, individual PAH concentrations were below the currently available threshold values for the protection of aquatic life referenced in the British Columbia Environmental Protection and Sustainability Division guidelines (1993), https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-wqgs/pahs/pahs-or.pdf.

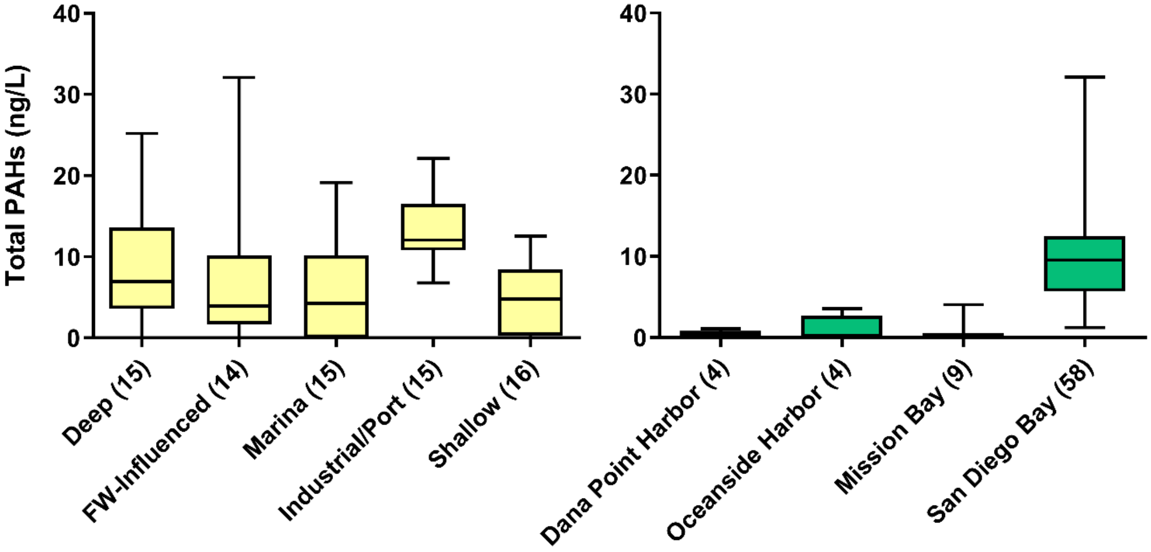

Figure 3-10. Comparison of Total PAHs Among Strata and Harbors in Surface Waters

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

General Chemistry

A summary of general water chemistry measurements by strata and harbor is provided in Tables 3-6 and Table 3-7, respectively. Levels of nutrients and MBAS (surfactants) were relatively consistent, with limited variability overall across all strata and harbors. DOC and TOC also had limited variability with the exception of a slight elevation in concentrations in the southern portion of San Diego Bay. Oil and grease were not detected at any stations in the San Diego Regional Harbors. TSS concentrations were variable among strata and harbors with the greatest concentrations observed in the marina, freshwater-influenced, and shallow strata in San Diego Bay (Tables 3-6 and 3-7).

Table 3-6.
Ranges of General Water Chemistry Parameters by Stratum

Parameter	Units	MDL	Stratum				
			Deep	Freshwater-Influenced	Marina	Industrial/ Port	Shallow
Number of stations	*NA*	*NA*	*15*	*14*	*15*	*15*	*16*
DOC	mg/L	0.14	1.22 – 1.82	1.03 – 2.51	1.16 – 2.24	1.5 – 1.99	1.34 – 2.28
TOC	mg/L	0.14	1.09 – 2.13	1.23 – 2.67	1.22 – 2.64	1.62 – 2.01	1.05 – 2.78
TSS	mg/L	0.5	2.65 – 13.1	3.44 – 18.4	4.2 – 22.1	2.1 – 6.9	3.04 – 23.6
Ammonia-N	mg/L	0.007	ND – 0.078	ND – 0.030	ND – 0.026	0.011 – 0.058	ND – 0.068
Nitrate-N	mg/L	0.01	ND – 0.027	ND – 0.026	ND – 0.026	ND – 0.019	ND – 0.033
Total Orthophosphate as P	mg/L	0.01	0.018 – 0.046	0.021 – 0.047	0.021 – 0.048	0.021 – 0.048	0.020 – 0.052
Oil & Grease	mg/L	1	ND	ND	ND	ND	ND
MBAS	mg/L	0.005	ND – 0.052	0.006 – 0.047	ND – 0.040	ND – 0.056	ND – 0.042

Notes:
DOC = dissolved organic carbon; MDL = method detection limit; MBAS = methylene blue activated substances; mg/L = milligram(s) per liter; NA = not applicable; ND = not detected above method detection limit; TOC = total organic carbon; TSS = total suspended solids

Table 3-7.
Ranges of General Water Chemistry Parameters by Harbor

Parameter	Units	MDL	Harbor			
			Dana Point Harbor	Oceanside Harbor	Mission Bay	San Diego Bay
Number of stations	*NA*	*NA*	*4*	*4*	*9*	*58*
DOC	mg/L	0.14	1.03 – 1.34	1.16 – 1.32	1.28 – 1.98	1.28 – 2.51
TOC	mg/L	0.14	1.05 – 1.35	1.22 – 1.47	1.44 – 2.19	1.09 – 2.78
TSS	mg/L	0.5	4.35 – 13.1	6.20 – 11.9	3.45 – 12.2	2.10 – 23.6
Ammonia-N	mg/L	0.007	ND – 0.024	ND – 0.019	ND – 0.026	ND – 0.078
Nitrate-N	mg/L	0.01	0.011 – 0.033	ND – 0.025	ND – 0.027	ND – 0.026
Total Orthophosphate as P	mg/L	0.01	0.020 – 0.024	0.021 – 0.028	0.020 – 0.051	0.018 – 0.052
Oil & Grease	mg/L	1	ND	ND	ND	ND
MBAS	mg/L	0.005	0.015 – 0.026	0.011 – 0.052	0.019 – 0.030	ND – 0.056

Notes:
DOC = dissolved organic carbon; MDL = method detection limit; MBAS = methylene blue activated substances; mg/L = milligram(s) per liter; NA = not applicable; ND = not detected above method detection limit; TOC = total organic carbon; TSS = total suspended solids

3.2 Sediment Quality

The overall quality of surface sediment was evaluated, as detailed in Section 2, using a MLOE approach, as provided by the *Water Quality Control Plan for Enclosed Bays and Estuaries - Part 1, Sediment Quality* (SWRCB and Cal/EPA, 2009) and updated SQO guidance provided in Bay et al. (2014). Sediment samples were tested for three indicators, known as individual LOEs. LOEs included chemistry, toxicity, and benthic community condition to measure contaminant exposure and the potential effects on organisms.

The combination of these three LOEs constitutes the sediment quality triad (Long and Chapman, 1985), which provides an integrated understanding of surface sediment conditions and ecological health. Section 2.5.2 provides more details on the calculation and use of the integrated SQO LOEs.

3.2.1 Sediment Chemistry

Sediment samples from each station were analyzed for trace metals, SEM and AVS, organic compounds (including PAHs, organochlorine pesticides, PCB congeners, pyrethroid pesticides, fipronils, and polybrominated diphenyl ethers [PBDEs]), grain size, TOC, total ammonia, total phosphorus, and total nitrogen. A comprehensive list of analytes submitted for analysis and associated target RLs is provided in Table 2-4 and Appendix B, Table B-2.

Sediment chemistry results are provided in Table 3-8. Further detail for individual chemical constituents and integrated metrics follows.

Table 3-4.
2018 RHMP Sediment Chemistry Results Summary

Harbor	Strata	Station ID	General Chemistry					AVS-SEM Values and Calculations					CSI Score	CSI Category	Mean ER-M Quotient	Metals (mg/kg)													
			Ammonia-N (mg/kg)	Percent Solids (%)	Total Nitrogen (%)	Total Phosphorus (mg/kg)	Total Organic Carbon (%)	Acid Volatile Sulfides (mg/kg)	Acid Volatile Sulfides (µmol/g)	Sum of SEM (µmol/g)	SEM:AVS Ratio	SEM:AVS Ratio norm. to fOC				Antimony (Sb)	Arsenic (As)	Barium (Ba)	Beryllium (Be)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Mercury (Hg)	Nickel (Ni)	Selenium (Se)	Silver (Ag)	Zinc (Zn)
Dana Point Harbor	Deep	B18-10068	12.8	57.7	0.09	815	1.07	36.9	1.15	1.75	1.52	55.8	1.38	Minimal Exposure	0.11	0.259	7.86	119	0.535	0.520	38.6	93.6	20500	10.2	0.027	15.1	0.710	0.144	162
	Freshwater-Influenced	B18-10066	13.5	43.0	0.16	871	2.18	110	3.43	5.18	1.51	80.1	2.00	Low Exposure	0.32	0.416	11.2	181	1.04	0.788	70.6	461	32700	22.7	0.087	25.6	0.973	0.319	386
	Marina	B18-10067	16.3	37.0	0.20	958	2.26	234	7.30	8.54	1.17	54.8	2.02	Low Exposure	0.42	0.397	15.9	173	1.07	0.452	85.3	664	38100	30	0.084	28.2	0.996	0.339	616
	Shallow	B18-10065	10.4	65.3	0.05	626	0.81	50.7	1.58	1.89	1.20	38.6	1.39	Minimal Exposure	0.13	0.168	6.16	117	0.327	0.158	54.6	142	13900	9.28	0.021	12.9	0.513	0.095	112
Oceanside Harbor	Deep	B18-10071	25.6	49.6	0.13	645	1.55	128	3.99	0.454	0.114	-228	1.38	Minimal Exposure	0.11	0.148	8.45	149	0.484	0.380	53.7	55.9	33200	8.80	0.025	21.6	0.551	0.096	127
	Freshwater-Influenced	B18-10070	4.13	44.9	0.14	727	1.75	42.3	1.32	1.65	1.25	19.2	1.71	Low Exposure	0.17	0.209	10.1	165	0.765	0.323	68.6	156	41500	14.2	0.073	26.8	0.697	0.145	202
	Marina	B18-10069	3.10	44.1	0.12	724	1.42	20.6	0.642	4.90	7.63	300	2.20	Low Exposure	2.61	0.224	11.6	185	0.851	0.225	72.7	489	47600	24.4	0.373	26.3	0.612	0.203	331
		B18-10072	14.3	58.2	0.08	589	1.13	13.0	0.405	3.70	9.13	292	1.76	Low Exposure	0.21	0.185	8.22	137	0.567	0.213	51.5	282	33400	16.5	0.162	18.6	0.438	0.158	260
Mission Bay	Deep	B18-10019	8.88	77.9	0.01 J	208	0.19	0.906	0.028	0.084	2.97	29.3	1.00	Minimal Exposure	0.01	0.066	1.68	15.0	0.062	0.043	6.09	2.08	3940	1.75	0.005	1.47	0.116	0.035	12.1
		B18-10020	19.9	74.4	0.01 J	252	0.21	1.42	0.044	0.134	3.03	42.8	1.00	Minimal Exposure	0.02	0.078	1.87	26.5	0.084	0.093	8.99	4.08	6100	2.41	0.010	2.32	0.118	0.039	21.4
	Freshwater-Influenced	B18-10015	13.6	59.0	0.10	599	1.62	39.1	1.22	0.811	0.665	-25.2	1.58	Minimal Exposure	0.14	0.291	12.1	94.7	0.856	0.272	44.6	35.7	34100	31.4	0.054	15.5	0.611	0.153	135
	Marina	B18-10074	23.5	43.3	0.17	563	1.97	291	9.08	0.616	0.068	-429	1.17	Minimal Exposure	0.10	0.187	7.35	92.1	0.464	0.234	43.2	71.2	27300	15.5	0.062	12.7	0.607	0.189	111
		B18-10075	4.13	40.5	0.22	701	2.43	112	3.49	1.61	0.460	-77.6	1.69	Low Exposure	0.25	0.278	10.4	128	0.623	0.245	54.9	108	34500	26.9	0.143	16.5	0.799	0.227	170
	Shallow	B18-10016	43.2	45.4	0.15	553	1.96	106	3.31	0.534	0.161	-141	1.00	Minimal Exposure	0.08	0.189	6.92	61.1	0.472	0.276	33.5	25.3	22700	15.3	0.040	10.6	0.599	0.179	85.2
		B18-10017	9.75	38.4	0.17	798	2.04	118	3.68	1.03	0.279	-130	1.31	Minimal Exposure	0.15	0.352	16.4	117	1.38	0.274	59.7	50.6	46700	43.7	0.071	21.1	0.839	0.236	166
		B18-10073	51.6	42.2	0.18	649	2.03	222	6.92	0.504	0.073	-316	1.00	Minimal Exposure	0.09	0.188	8.00	102	0.585	0.272	47.3	38.0	30300	15.9	0.061	14.1	0.713	0.226	107
		B18-10438 (overdraw)	11.9	39.5	0.19	779	2.35	19.9	0.621	1.41	2.27	33.5	1.33	Minimal Exposure	0.14	0.295	14.2	184	1.08	0.295	70.8	80.2	49600	24.6	0.062	22.1	0.855	0.245	174
North San Diego Bay	Deep	B18-10022	9.85	70.5	0.01 J	292	0.25	7.85	0.245	0.985	4.02	296	1.05	Minimal Exposure	0.07	0.107	4.00	67.7	0.217	0.165	28.6	33.2	15800	12.5	0.154	6.27	0.173	0.229	85.6
		B18-10023	9.24	71.2	0.02	272	0.32	23.9	0.745	0.439	0.589	-95.8	1.00	Minimal Exposure	0.04	0.152	2.95	33.1	0.133	0.071	16.6	19.4	10900	7.82	0.063	4.19	0.143	0.112	46.9
		B18-10024	15.5	56.9	0.07	481	0.83	13.3	0.415	1.83	4.41	170	1.43	Minimal Exposure	0.31	0.218	6.97	83.4	0.454	0.169	42.0	77.9	24500	24.3	0.289	11.5	0.340	0.438	134
		B18-10030	16.0	79.7	0.01 J	187	0.17	2.04	0.064	0.068	1.07	2.69	1.00	Minimal Exposure	0.10	0.088	2.46	8.67	0.042 J	0.025	5.36	3.17	4060	2.65	0.009	1.20	0.097	0.041	10.8
		B18-10112	9.41	64.5	0.06	404	0.79	6.65	0.207	1.75	8.45	195	1.74	Low Exposure	0.15	0.277	6.67	65.1	0.402	0.352	36.1	66.1	20700	26.5	0.330	12.9	0.301	0.483	117
		B18-10113	22.0	51.7	0.10	618	1.15	50.0	1.56	2.45	1.57	77.9	1.86	Low Exposure	0.22	0.284	9.52	91.0	0.525	0.248	53.0	109	29500	35.7	0.369	14.9	0.507	0.602	175
		B18-10116	3.65	79.1	< 0.01	176	0.12	0.965	0.030	0.352	11.7	269	1.00	Minimal Exposure	0.03	0.132	4.16	9.67	0.093	0.030	8.67	10.2	8500	6.82	0.024	1.94	0.097	0.094	33.9
		B18-10117	32.1	47.7	0.22	847	1.89	266	8.30	1.24	0.149	-373	1.41	Minimal Exposure	0.14	0.263	9.45	111	0.657	0.512	48.0	79.3	31100	20.4	0.174	16.6	0.695	0.341	159
	Freshwater-Influenced	B18-10029	11.7	52.7	0.13	588	2.50	265	8.26	2.70	0.327	-223	2.73	Moderate Exposure	0.41	0.618	7.74	89.5	0.514	0.479	46.8	111	26300	54.3	0.333	15.2	0.482	0.484	271
		B18-10076	12.0	61.2	0.07	602	1.24	7.95	0.248	2.27	9.15	163	2.25	Low Exposure	0.37	0.239	7.75	74.6	0.410	0.377	56.7	87.7	23700	46.5	0.358	14.7	0.343	0.636	173
	Industrial/Port	B18-10114	14.3	50.9	0.13	567	1.75	46.5	1.45	3.19	2.20	99.2	2.48	Moderate Exposure	0.27	0.391	8.84	101	0.624	0.243	59.9	133	31500	48.8	0.472	15.6	0.460	0.649	218
		B18-10115	22.1	55.2	0.09	584	1.01	11.8	0.368	2.52	6.85	213	1.93	Low Exposure	0.21	0.290	8.61	88.4	0.544	0.216	50.9	122	28700	37.7	0.399	13.9	0.403	0.643	183
	Marina	B18-10078	12.7	55.2	0.07	570	0.92	12.2	0.380	2.60	6.83	241	2.11	Low Exposure	0.36	1.64	8.47	75.2	0.503	0.170	47.2	158	24700	34.1	1.07	11.8	0.386	0.479	170
		B18-10079	9.84	64.8	0.06	511	0.71	5.74	0.179	1.67	9.33	210	1.65	Low Exposure	0.17	0.241	7.18	63.1	0.333	0.147	34.9	92.8	20100	22.7	0.516	9.01	0.278	0.352	119
		B18-10080	7.85	47.9	0.12	784	1.32	2.41	0.075	5.10	67.9	381	2.13	Low Exposure	0.45	0.245	14.6	97.4	0.807	0.258	66.0	242	40600	51.7	1.84	18.0	0.507	0.420	268
		B18-10081	8.29	53.6	0.09	596	1.16	5.04	0.157	4.08	26.0	338	2.52	Moderate Exposure	0.37	0.335	9.91	90.4	0.651	0.150	49.8	219	29500	41.3	1.43	13.0	0.397	0.324	203
		B18-10082	9.88	54.0	0.09	600	0.98	3.37	0.105	3.31	31.5	327	1.83	Low Exposure	0.24	0.215	10.3	81.5	0.568	0.127	47.8	164	28700	32.2	0.887	12.2	0.355	0.270	178
		B18-10083	17.4	54.5	0.12	569	1.22	14.8	0.462	3.00	6.51	208	1.86	Low Exposure	0.21	0.208	7.81	72.4	0.529	0.157	44.8	173	25600	27.0	0.616	12.2	0.415	0.337	169
		B18-10084	10.4	48.2	0.14	719	1.43	3.19	0.099	3.35	33.6	227	1.77	Low Exposure	0.22	0.240	10.1	94.2	0.547	0.184	53.6	149	31300	29.6	0.641	15.2	0.478	0.478	178
	Shallow	B18-10077	8.74	72.1	0.02	324	0.33	15.5	0.483	1.01	2.09	159	1.05	Minimal Exposure	0.08	0.103	4.21	59.0	0.237	0.157	29.5	37.3	15300	15.3	0.169	6.17	0.178	0.327	88.7
Central San Diego Bay	Deep	B18-10133	2.17	67.3	0.02	422	0.33	2.82	0.088	0.889	10.1	243	1.00	Minimal Exposure	0.10	0.081	11.6	227	0.791	0.076	38.7	49.1	39500	15.2	0.080	15.6	0.243	0.119	112
		B18-10141	3.29	71.3	0.03	242	0.48	11.8	0.368	0.975	2.65	126	1.36	Minimal Exposure	0.10	0.140	5.02	60.4	0.340	0.159	27.9	53.5	18200	14.0	0.150	7.78	0.211	0.354	81.6
		B18-10144	5.03	71.6	0.04	274	0.46	26.4	0.823	0.785	0.954	-8.29	1.17	Minimal Exposure	0.46	0.129	4.32	47.0	0.319	0.074	22.5	54.0	17000	10.2	0.083	7.06	0.169	0.216	76.9
	Freshwater-Influenced	B18-10031	8.90	58.1	0.09	438	1.60	122	3.80	2.40	0.630	-87.9	2.41	Moderate Exposure	0.28	0.415	7.22	77.0	0.554	0.302	44.6	120	27200	41.8	0.268	13.5	0.424	0.472	198
		B18-10178	15.4	51.2	0.16	446	3.50	1060	33.1	2.99	0.090	-859	2.92	Moderate Exposure	0.64	0.867	8.32	94.5	0.575	0.763	41.3	108	29900	54.6	0.137	14.7	0.620	0.401	294
	Industrial/Port	B18-10119	8.70	58.3	0.08	450	1.12	180	5.61	1.66	0.295	-353	1.93	Low Exposure	0.18	0.258	6.92	85.7	0.554	0.179	44.4	110	27200	30.7	0.304	12.2	0.374	0.474	160
		B18-10121	8.42	53.7	0.09	611	1.18	19.4	0.605	2.51	4.14	161	2.25	Low Exposure	0.28	0.387	10.7	106	0.642	0.251	60.3	149	33500	48.5	0.502	15.8	0.405	0.715	210
		B18-10123	9.72	55.6	0.10	524	1.54	33.4	1.04	2.67	2.56	106	2.55	Moderate Exposure	0.31	0.469	9.65	87.0	0.659	0.240	53.0	174	31200	47.1	0.346	14.4	0.462	0.616	224
		B18-10124	14.6	45.4	0.16	757	2.05	111	3.46	2.95	0.852	-24.9	2.50	Moderate Exposure	0.36	0.496	12.8	112	0.920	0.422	79.7	228	44000	62.3	0.711	21.7	0.629	1.07	313
		B18-10126	4.56	55.2	0.09	490	1.34	71.2	2.22	2.22	0.998	-0.320	2.17	Low Exposure	0.25	0.230	8.72	82.6	0.686	0.234	59.9	162	32400	41.9	0.506	16.2	0.459	0.800	206
		B18-10127	5.05	53.9	0.11	587	1.45	70.2	2.19	2.24	1.02	3.41	2.46	Moderate Exposure	0.45	0.693	9.90	94.0	0.624	0.520	69.0	196	33000	367	0.661	28.5	0.501	1.56	255
		B18-10132	6.63	72.9	0.01 J	218	0.25	5.97	0.186	0.699	3.75	205	1.17	Minimal Exposure	0.06	0.120	2.77	74.3	0.243	0.078	18.0	57.4	15400	7.72	0.065	7.14	0.130	0.100	69.9
		B18-10136	7.13	53.7	0.10	540	1.27	10.3	0.321	3.11	9.68	220	1.97	Low Exposure	0.22	0.292	9.02	96.7	0.685	0.230	62.1	154	34500	41.9	0.429	17.1	0.382	0.677	210
		B18-10137	10.7	49.6	0.12	609	1.45	33.1	1.03	3.22	3.12	151	1.97	Low Exposure	0.24	0.297	9.62	120	0.835	0.241	69.1	191	42600	40.5	0.447	19.8	0.508	0.748	233
		B18-10139	11.5	53.3	0.09	505	1.04	22.7	0.708	2.28	3.21	151	1.57	Minimal Exposure	0.16	0.187	8.07	106	0.610	0.139	50.7	132	34200	25.1	0.249	16.0	0.346	0.448	168
		B18-10140	9.11	50.4	0.12	561	1.40	25.3	0.789	2.55	3.23	126	1.88	Low Exposure	0.21	0.193	10.1	100	0.803	0.208	61.2	157	38200	33.9	0.360	17.5	0.485	0.674	209
		B18-10142	16.7	49.4	0.12	554	1.40	51.2	1.60	3.10	1.94	107	2.33	Low Exposure	0.60	0.359	9.21	101	0.690	0.235	62.7	193	38300	37.8	0.418	17.5	0.505	0.782	226
		B18-10143	5.78	66.8	0.05	272	0.55	29.5	0.920	1.15	1.25	41.4	1.22	Minimal Exposure	0.09	0.144	4.78	47.3	0.347	0.091	26.9	69.0	18100	15.1	0.134	7.59	0.204	0.314	98.2
	Shallow	B18-10032	12.5	72.8	0.01 J	263	0.26	8.53	0.266	1.09	4.10	318	1.05	Minimal Exposure	0.08	0.138	4.26	32.1	0.281	0.136	21.0	44.3	11700	13.9	0.193	5.20	0.201	0.386	87.8
		B18-10034	14.2	57.6	0.07	403	0.88	28.5	0.889	2.10	2.36	137	1.52	Minimal Exposure	0.15	0.156	6.72	57.3	0.462	0.142	45.2	79.7	24100	27.9	0.347	11.4	0.283	0.614	153
		B18-10035	11.1	57.3	0.06	458	0.83	24.7	0.770	2.08	2.70	158	1.38	Minimal Exposure	0.15	0.252	7.02	56.8	0.443	0.141	45.0	77.8	24800	26.0	0.330	10.9	0.254	0.881	156
		B18-10036	19.9	52.6	0.08	497	0.97	96.7	3.02	2.02	0.671	-102	1.52	Minimal Exposure	0.16	0.183	7.60	61.8	0.649	0.162	52.6	88.0	28800	29.6	0.355	12.5	0.307	0.673	184
South San Diego Bay	Freshwater-Influenced	B18-10037	18.0	54.7	0.11	484	1.14	166	5.18	1.53	0.295	-320	1.38	Minimal Exposure	0.13	0.159	6.88	95.6	0.538	0.184	43.0	91.6	31600	18.9	0.145	13.1	0.346	0.419	160
		B18-10040	5.41	73.9	0.01 J	176	0.15	9.01	0.281	0.341	1.21	40.1	1.00	Minimal Exposure	0.03	0.082	1.30	33.4	0.111	0.092	17.3	10.4	11000	2.82	0.014	4.20	0.090	0.120	36.5
		B18-10044	12.4	46.7	0.16	565	1.73	284	8.86	1.13	0.128	-447	1.60	Minimal Exposure	0.16	0.227	9.97	111	0.943	0.692	57.2	85.2	44100	24.4	0.131	19.7	0.630	0.491	220
		B18-10179	10.6	56.6	0.10	450	1.25	37.2	1.16	2.19	1.89	82.2	1.38	Minimal Exposure	0.15	0.201	6.73	113	0.566	0.377	40.7	86.6	32800	24.2	0.094	13.8	0.316	0.369	200
		B18-10180	10.1	63.9	0.07	409	0.76	19.9	0.621	1.33	2.14	92.8	1.41	Minimal Exposure	0.10	0.129	5.93	86.6	0.430	0.143	34.7	70.3	26500	14.8	0.106	10.8	0.265	0.304	125
		B18-10181	10.9	58.9	0.08	464	0.93	32.0	1.00	1.56	1.56	60.5	1.36	Minimal Exposure	0.13	0.135	6.37	100	0.476	0.151	36.8	72.1	29700	15.7	0.094	12.1	0.292	0.285	134
		B18-10200	27.3	57.9	0.13	301	1.66	494	15.4	0.953	0.062	-871	1.48	Minimal Exposure	0.11	0.356	6.13	64.9	0.382	0.651	21.7	36.8	17700	13.8	0.048	8.39	0.501	0.194	127
	Marina	B18-10085	6.08	62.2	0.05	311	0.53	95.8	2.99	1.85	0.620	-214	1.49	Minimal Exposure	0.10	0.127	3.69	49.8	0.335	0.101	26.7	105	17200	10.8	0.093	7.83	0.201	0.343	149
		B18-10086	6.93	63.2	0.04	328	0.51	9.32	0.291	2.06	7.07	346	1.49	Minimal Exposure	0.11	0.165	3.48	58.0	0.375	0.127	28.3	113	18100	12.0	0.094	8.58	0.192	0.344	144
		B18-10087	4.05	54.4	0.09	434	0.98	68.5	2.14	2.81	1.31	68.2	1.71	Low Exposure	0.16	0.173	7.50	94.5	0.746	0.253	53.1	141	34200	18.6	0.105	15.2	0.377	0.619	227
	Shallow	B18-10038	6.04	72.5	0.01 J	226	0.21	7.38	0.230	0.875	3.80	307	1.00	Minimal Exposure	0.05	0.099	3.83	31.1	0.181	0.094	13.8	25.4	9860	7.27	0.094	3.77	0.107	0.215	68.7
		B18-10039	8.11	44.2	0.16	739	1.51	53.2	1.66	3.17	1.91	100	1.90	Low Exposure	0.25	0.242	11.9	92.4	0.971	0.218	83.2	138	47100	40.3	0.473	20.6	0.429	0.946	299
		B18-10041	9.45	60.3	0.06	426	0.65	74.4	2.32	1.71	0.737	-93.8	1.21	Minimal Exposure	0.09	0.130	6.63	45.9	0.361	0.167	28.8	44.7	21400	13.1	0.132	8.14	0.261	0.323	153
		B18-10042	13.0	46.0	0.15	595	1.42	39.2	1.22	2.56	2.09	94.0	1.54	Minimal Exposure	0.16	0.176	9.73	87.1	0.719	0.185	55.4	93.6	39600	25.0	0.190	16.9	0.370	0.448	219
		B18-10043	11.7	49.6	0.12	400	1.45	324	10.1	0.928	0.092	-633	1.42	Minimal Exposure	0.11	0.214	6.23	67.4	0.538	0.483	32.2	54.3	26400	17.0	0.075	11.1	0.361	0.298	156
		B18-10088	10.8	46.0	0.17	730	1.63	70.6	2.20	3.63	1.65	87.6	1.85	Low Exposure	0.22	0.341	11.9	98.6	0.881	0.311	69.7	144	46100	34.5	0.282	20.4	0.520	0.869	328

Notes:
All values reported in dry weight
ug/kg = micrograms per dry kilogram
mg/kg = milligrams per dry kilogram
umol/g = micromoles per gram
< Data reported to the method detection limit
J = estimated result, below the reporting limit, but above the MDL
% = percent
CSI = Chemical Score Index

Table 3-4.
2018 RHMP Sediment Chemistry Results Summary

Harbor	Strata	Station ID	Total PAHs[1] (µg/kg)	Total PCBs[1] (µg/kg)	Pesticides (µg/kg)							Total PBDEs[1] (µg/kg)	% Fines (Silt + Clay)
					2,4'-DDD & 4,4'-DDD	2,4'-DDE & 4,4'-DDE	2,4'-DDT & 4,4'-DDT	Total Detectable DDTs[2]	Total Chlordanes[3] (µg/kg)	Total Pyrethroids[1] (µg/kg)	Total Fipronils[4] (µg/kg)		
Dana Point Harbor	Deep	B18-10068	266	1.15	< 0.267	1.95	< 0.194	1.95	< 0.25	2.90	< 0.25	2.74	52.6
	Freshwater-Influenced	B18-10066	681	5.52	< 0.267	4.05	< 0.194	4.05	2.21	32.0	0.55	56.3	67.1
	Marina	B18-10067	381	4.57	< 0.267	1.88	< 0.194	1.88	< 0.25	7.28	< 0.25	14.5	67.3
	Shallow	B18-10065	211	5.31	0.321 J	2.10	< 0.194	2.42	0.195 J	0.819	< 0.25	8.43	45.8
Oceanside Harbor	Deep	B18-10071	196	0.410	0.561	2.58	< 0.194	3.14	< 0.25	1.65	< 0.25	5.28	50.0
	Freshwater-Influenced	B18-10070	132	1.51	< 0.267	1.89	< 0.194	1.89	< 0.25	0.383 J	< 0.25	4.99	62.3
	Marina	B18-10069	182	5348	0.554	2.60	< 0.194	3.15	< 0.25	0.410 J	< 0.25	20.4	52.9
		B18-10072	543	6.21	< 0.267	2.86	< 0.194	2.86	< 0.25	1.14	< 0.25	24.7	43.6
Mission Bay	Deep	B18-10019	45.6	< 0.168	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	6.4
		B18-10020	31.7	< 0.168	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	0.746	8.9
	Freshwater-Influenced	B18-10015	807	2.71	< 0.267	1.27	< 0.194	1.27	4.14	13.9	< 0.25	9.11	51.9
	Marina	B18-10074	170	1.05	< 0.267	0.387 J	< 0.194	0.387 J	< 0.25	0.254 J	< 0.25	2.27	47.8
		B18-10075	405	8.26	< 0.267	0.890	< 0.194	0.890	< 0.25	0.297 J	< 0.25	14.4	44.4
	Shallow	B18-10016	118	0.165 J	< 0.267	0.217 J	< 0.194	0.217 J	< 0.25	0.437 J	< 0.25	1.68	39.3
		B18-10017	287	1.97	< 0.267	0.649	< 0.194	0.649	0.670	2.66	< 0.25	7.89	56.2
		B18-10073	258	1.00	< 0.267	0.399 J	< 0.194	0.399 J	< 0.25	< 0.28	< 0.25	2.11	39.1
		B18-10438 (overdraw)	388	2.73	< 0.267	0.302 J	< 0.194	0.302 J	< 0.25	< 0.28	< 0.25	7.05	56.7
North San Diego Bay	Deep	B18-10022	208	4.17	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	19.2
		B18-10023	120	1.28	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	0.423 J	0.896	17.2
		B18-10024	2292	6.11	< 0.267	0.463 J	< 0.194	0.463 J	< 0.25	0.253 J	< 0.25	0.768	50.3
		B18-10030	30.4	< 0.168	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	0.201	2.4
		B18-10112	2386	29.5	< 0.267	1.06	< 0.194	1.06	< 0.25	1.20	< 0.25	1.05	50.4
		B18-10113	5126	12.2	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	1.29	< 0.25	5.56	63.9
		B18-10116	130	0.261	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	6.2
		B18-10117	1635	4.71	< 0.267	0.671	< 0.194	0.671	< 0.25	0.972	< 0.25	0.944	56.6
	Freshwater-Influenced	B18-10029	3289	43.9	3.76	6.86	< 0.194	10.6	22.7	57.4	1.97	13.3	54.2
		B18-10076	2221	189	1.73	3.58	< 0.194	5.31	13.0	23.1	< 0.25	5.13	56.5
	Industrial/Port	B18-10114	4101	40.3	< 0.267	2.18	< 0.194	2.18	4.54	16.1	< 0.25	7.46	68.5
		B18-10115	3325	35.1	0.759	0.915	< 0.194	1.67	0.198 J	0.450 J	< 0.25	1.40	56.6
	Marina	B18-10078	2527	241	0.975	1.69	< 0.194	2.67	< 0.25	0.325 J	< 0.25	6.00	44.4
		B18-10079	2181	41.7	< 0.267	0.614	< 0.194	0.614	< 0.25	< 0.28	< 0.25	1.92	48.4
		B18-10080	1080	20.2	< 0.267	0.736	< 0.194	0.736	< 0.25	0.944	< 0.25	< 0.05	62.6
		B18-10081	1235	34.0	0.972	2.23	< 0.194	3.20	4.27	3.07	< 0.25	2.11	57.7
		B18-10082	421	12.6	< 0.267	0.517	< 0.194	0.517	< 0.25	< 0.28	< 0.25	1.21	54.6
		B18-10083	736	11.9	< 0.267	0.689	< 0.194	0.689	< 0.25	0.232 J	< 0.25	0.904	53.4
		B18-10084	896	8.19	< 0.267	0.779	< 0.194	0.779	< 0.25	< 0.28	< 0.25	1.36	65.0
	Shallow	B18-10077	486	5.46	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	0.472	25.2
Central San Diego Bay	Deep	B18-10133	178	2.34	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	83.1
		B18-10141	437	6.95	0.978	< 0.2	9.35	10.3	< 0.25	< 0.28	< 0.25	0.186	60.2
		B18-10144	161	4.57	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	23.4
	Freshwater-Influenced	B18-10031	2278	42.7	1.26	4.16	< 0.194	5.42	10.7	24.2	0.29	9.00	66.9
		B18-10178	3891	47.8	12.8	13.8	< 0.194	26.7	46.8	127	3.85	58.6	67.0
	Industrial/Port	B18-10119	2615	35.7	< 0.267	0.979	< 0.194	0.979	0.219 J	1.57	< 0.25	2.52	74.5
		B18-10121	2254	32.2	1.58	1.49	< 0.194	3.07	0.782	1.67	< 0.25	5.00	68.2
		B18-10123	1796	99.4	3.71	2.51	< 0.194	6.22	4.44	15.0	< 0.25	6.62	73.4
		B18-10124	2386	57.4	< 0.267	2.05	< 0.194	2.05	2.01	3.43	< 0.25	7.80	87.5
		B18-10126	1386	44.5	< 0.267	1.24	< 0.194	1.24	< 0.25	1.70	< 0.25	3.62	68.3
		B18-10127	2573	76.1	< 0.267	2.17	< 0.194	2.17	0.377 J	< 0.28	< 0.25	5.11	74.7
		B18-10132	639	4.81	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	3.06	19.2
		B18-10136	1024	17.6	< 0.267	0.896	< 0.194	0.896	< 0.25	0.525	< 0.25	4.14	75.9
		B18-10137	1678	17.2	< 0.267	1.15	< 0.194	1.15	< 0.25	1.15	< 0.25	20.1	82.7
		B18-10139	1041	7.57	< 0.267	0.434 J	< 0.194	0.434 J	< 0.25	< 0.28	< 0.25	< 0.05	64.6
		B18-10140	1325	10.5	< 0.267	0.645	< 0.194	0.645	< 0.25	< 0.28	< 0.25	2.41	76.7
		B18-10142	2139	14.5	22.8	0.851	198	221	< 0.25	0.253 J	< 0.25	1.85	75.5
		B18-10143	348	6.81	< 0.267	0.238 J	< 0.194	0.238 J	< 0.25	< 0.28	< 0.25	4.89	22.6
	Shallow	B18-10032	282	4.26	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	0.691	22.7
		B18-10034	307	4.34	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	44.9
		B18-10035	328	5.68	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	41.4
		B18-10036	238	3.04	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	50.1
South San Diego Bay	Freshwater-Influenced	B18-10037	303	9.28	< 0.267	0.579	< 0.194	0.579	< 0.25	0.669	< 0.25	2.44	52.1
		B18-10040	23.8	< 0.168	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	10.6
		B18-10044	300	5.63	< 0.267	1.56	< 0.194	1.56	< 0.25	5.91	< 0.25	19.5	60.6
		B18-10179	389	10.4	< 0.267	3.60	< 0.194	3.60	1.18	4.99	< 0.25	8.11	32.4
		B18-10180	253	5.88	< 0.267	0.557	1.61	2.17	< 0.25	2.34	< 0.25	8.71	34.0
		B18-10181	296	4.85	< 0.267	0.697	1.48	2.18	< 0.25	3.10	< 0.25	3.57	47.4
		B18-10200	421	5.68	2.76	5.167	< 0.194	7.93	3.02	36.4	< 0.25	8.81	63.0
	Marina	B18-10085	135	1.09	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	0.225 J	< 0.25	1.46	26.7
		B18-10086	285	2.49	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	0.376 J	< 0.25	13.6	30.0
		B18-10087	133	3.77	< 0.267	0.348 J	< 0.194	0.348 J	< 0.25	0.224 J	< 0.25	1.74	64.8
	Shallow	B18-10038	85.9	1.64	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	14.6
		B18-10039	219	4.64	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	69.1
		B18-10041	104	1.59	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	21.7
		B18-10042	227	1.60	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	75.4
		B18-10043	297	5.23	< 0.267	1.56	2.25	3.81	< 0.25	3.81	< 0.25	1.89	31.9
		B18-10088	236	1.42	< 0.267	< 0.2	< 0.194	< 0.267	< 0.25	< 0.28	< 0.25	< 0.05	86.6

Notes:

All values reported in dry weight
ug/kg = micrograms per dry kilogram
mg/kg = milligrams per dry kilogram
umol/g = micromoles per gram
< Data reported to the method detection limit
J = estimated result, below the reporting limit, but above the MDL
% = percent
CSI = Chemical Score Index

PAH = Polycyclic Aromatic Hydrocarbons
PCB = Polychlorinated Biphenyl
PBDE = Polybrominated diphenyl ethers
1 = The specific compounds comprising the sums of the PAH, PCB, PBDE, and pyrethroid groups are listed in Table 2-4.
2 = Total detectable DDTs includes the sum of 2,4'-DDD, 4,4'-DDD, 2,4'-DDE, 4,4'-DDE, 2,4'-DDT, and 4,4'-DDT
3 = Total Chlordanes incldues the sum of alpha-chlordane, gamma-chlordane, cis-nonachlor, trans-nonachlor and oxychlordane.
4 = Total Fipronils include the sum of fipronil, fipronil desulfinyl, fironil sulfide, and fipronil sulfone.
Non-detects were treated as 0 and estimated results were treated as the reported value for summing purposes.

Mean ER-M Quotient

Mean ER-M quotients across strata and harbors are graphically depicted in Figure 3-11, and the percentage of stations with ER-M quotients below the threshold by strata is presented in Table 3-9. In the 2018 RHMP, results for 59% of stations met (i.e., were below) the conservative threshold value of 0.2 indicative of potential biological effects. All strata and harbors had at least one station with results that did not meet the mean ER-M quotient threshold of 0.2, with the highest value of 2.61 from a station in the marina stratum in Oceanside Harbor (B18-10069), driven primarily by an exceptionally elevated concentration of total PCBs at this location. Stations in the industrial/port strata, followed by stations in the marina stratum, had the highest median ER-M quotient values (Figure 3-11), with only 27 and 33% of stations, respectively, meeting the ER-M quotient threshold (Table 3-9). A majority of stations in the deep and shallow strata had values below the ER-M quotient threshold (80% and 88%, respectively; Table 3-9).

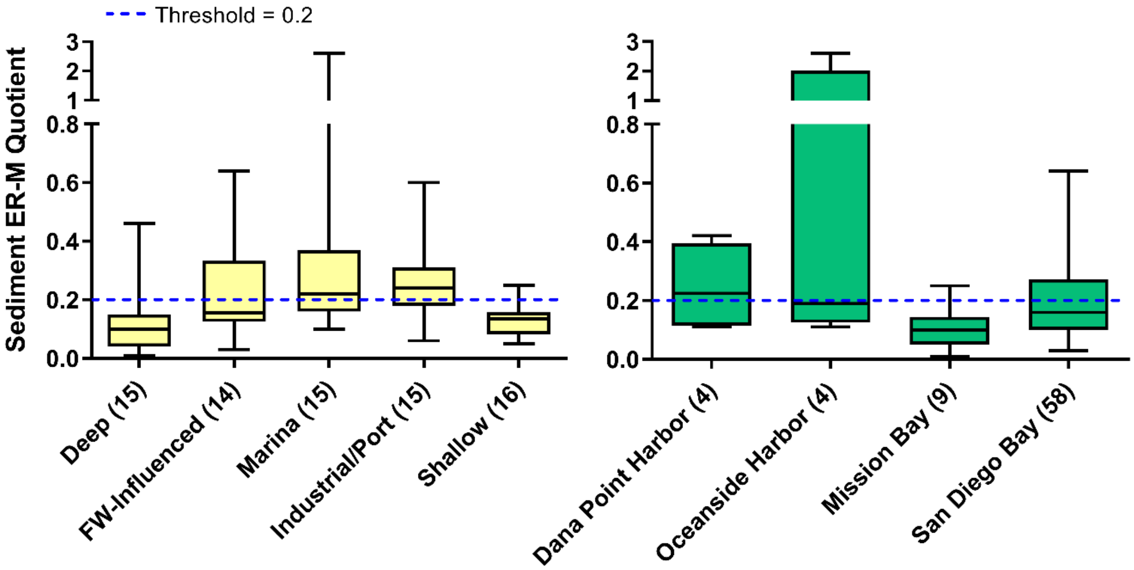

Figure 3-11. Comparisons of ER-M Quotients Among Strata and Harbors
Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Table 3-9.
Percentage of Stations Meeting Mean ER-M Quotient Threshold by Stratum

Indicator	Threshold Value	Percentage of 2018 RHMP Stations Meeting Mean ER-M Quotient Threshold					
		Deep (%)	Freshwater-Influenced (%)	Marina (%)	Industrial/ Port (%)	Shallow (%)	All Stations (%)
# of stations		*15*	*14*	*15*	*15*	*16*	*75*
Mean ER-M Quotient	0.2	80	64	33	27	88	59

Notes:
% = percent; ER-M = Effects Range-Median

Individual Chemicals in the Sediment

Further analyses comparing the differences among strata and harbors for select individual chemicals measured for the RHMP are provided below. The chemicals highlighted in the body of the report include those identified as priority pollutants based on historical data analysis and are also known contaminants of potential concern based on other studies in the region. These contaminants include a suite of trace metals, PAHs, pesticides, PCBs, and PBDEs.

Box plots are presented for each priority pollutant to compare sediment quality among strata and harbors. Each box plot shows the 25th percentile, median, 75th percentile, and range of values compared to appropriate thresholds, if applicable. The regionally relevant SQO CSI was used as a single LOE screening-level metric for several individual chemical constituents listed in Table 2-6. The CSI uses chemistry data to predict the occurrence and severity of benthic community disturbance. Using this metric, index-specific response ranges were developed for individual chemicals resulting in four chemical exposure categories: minimal (category 1), low (category 2), moderate (category 3), and high (category 4). For chemicals with CSI threshold values, box plots include lines delineating each exposure category for comparison purposes. If no CSI thresholds were available for a given chemical, no comparison lines were included in the box plots. Note importantly that the CSI metric is only one of two metrics used to assess sediment chemistry exposure potential using the integrated SQO approach, *thus comparisons using the CSI values alone should be made carefully with this caveat noted*. The second sediment chemistry index, the LRM, is based on a modelling approach that does not pre-assign chemical concentration ranges for each SQO category and therefore cannot be plotted as a numeric value for comparison purposes. Please refer to the following Results Section 3.3 and associated figures and maps showing an integrated SQO analysis of sediment chemistry exposure potential using both the CSI and LRM metrics combined. Further discussion on the derivation and application of the SQO sediment chemistry metrics is provided in the Methods Section 2.5.2.

Statistical comparisons between strata were performed for each of the chemicals discussed in this section using ANOVAs (or Kruskal-Wallis tests if assumptions for parametric tests were not met) on log-transformed concentration data. All tests showed a significant difference in chemical concentrations between strata. Detailed results of statistical analyses, including multiple comparisons tests, are presented in Appendix K.

Maps are also presented for select contaminants of concern to show the spatial distribution of sediment chemical concentrations throughout the harbors. Concentration bins were based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution of each chemical measured during the 2018 RHMP. The display of sediment concentrations in this manner for each chemical allows comparisons to be made among individual sites relative to the entire RHMP dataset. This method is useful to help identify potential sources of contaminants and areas that may require further assessment; however, *it should also be noted that elevated concentrations for each individual chemical on its own does not provide a good measure of the likelihood of causing ecological impairment in sediments*. As noted previously, the integrated SQO analysis and associated maps in the following Section 3.3 should be referred to for assessment of the potential for chemical exposure to cause biological effects based on combined chemical concentrations, in addition to the toxicity and benthic community LOEs. A follow-up review of the concentrations of individual chemicals of concern driving the SQO chemical LOE score, integrated scores including toxicity and benthic community, along with other available data and literature outside of the SQO framework (e.g., physical characteristics, physical disturbance, and other contaminants of potential concern) can then be used more appropriately to help identify the primary chemical(s) of concern at any given site. See the Discussion section of this report for a more in-depth causal assessment analysis of those sites considered to be impacted using the integrated SQO approach.

Sediment Metals

Arsenic

Industrial/port and marina strata had the highest median concentrations of arsenic, while the deep stratum had the lowest. Arsenic concentrations ranged from 1.3 mg/kg in south San Diego Bay to 16.4 mg/kg in Mission Bay, with an average across all stations of 7.9 mg/kg. Dana Point and Oceanside Harbors had the highest median concentrations of arsenic, followed by Mission Bay and San Diego Bay (Figure 3-12). The distribution of arsenic among strata and harbors in 2018 is displayed in Figure 3-12.

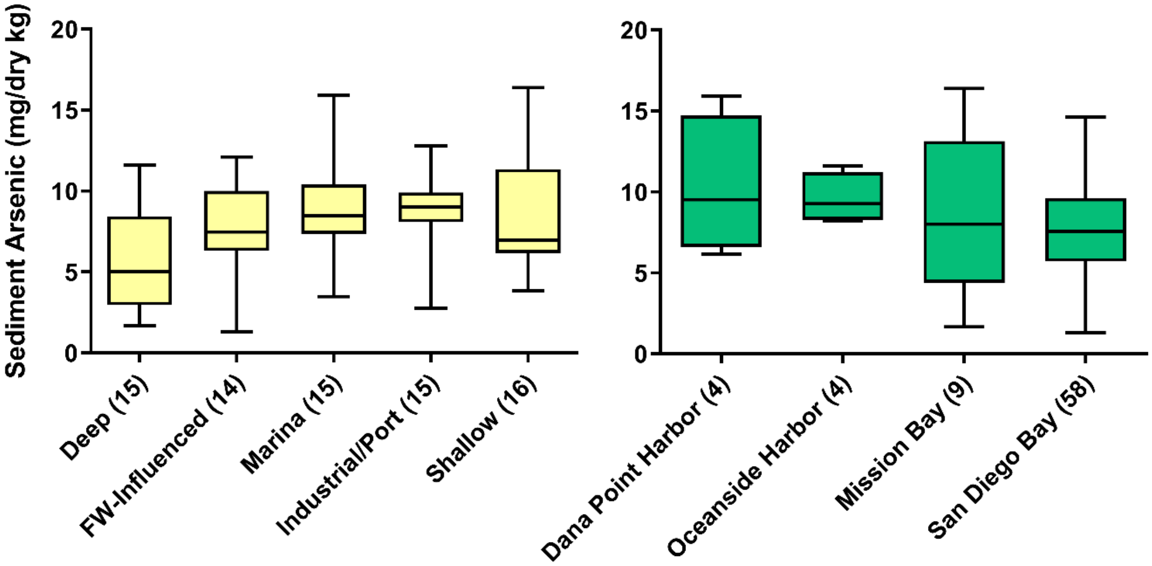

Figure 3-12. Comparisons of Sediment Arsenic Concentrations Among Strata and Harbors

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses. Arsenic is not included in the CSI calculation hence the exclusion of exposure category lines on this figure.

Cadmium

Freshwater-influenced stations had the highest median concentration of cadmium among all strata, while the deep stations had the lowest median concentration overall. Cadmium concentrations ranged from 0.025 mg/kg in north San Diego Bay to 0.788 mg/kg in Dana Point Harbor, with an average concentration of 0.247 mg/kg across all stations. Dana Point Harbor had the highest median concentration of cadmium, while Mission Bay and San Diego Bay had the lowest. The distribution of cadmium concentrations among strata and harbors in 2018 is shown in Figure 3-13.

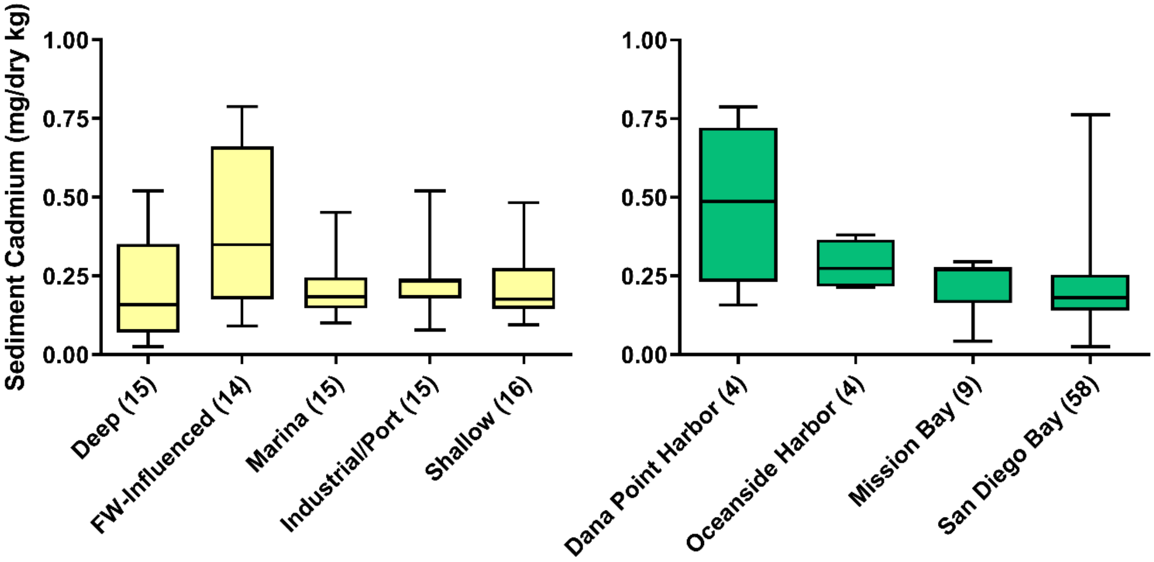

Figure 3-13. Comparisons of Sediment Cadmium Concentrations Among Strata and Harbors

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses. Cadmium is not included in the CSI calculation hence the exclusion of exposure category lines on this figure.

Chromium

Stations in the industrial/port stratum had the highest median chromium concentration, while stations in the deep stratum had the lowest. Chromium concentrations ranged from 5.36 mg/kg in north San Diego Bay to 85.3 mg/kg in Dana Point Harbor, with an average of 45.2 mg/kg among all samples. While Dana Point Harbor had the highest median chromium concentration, Oceanside Harbor had similarly elevated concentrations compared to San Diego Bay and Mission Bay. The distribution of chromium among strata and harbors in 2018 is displayed in Figure 3-14.

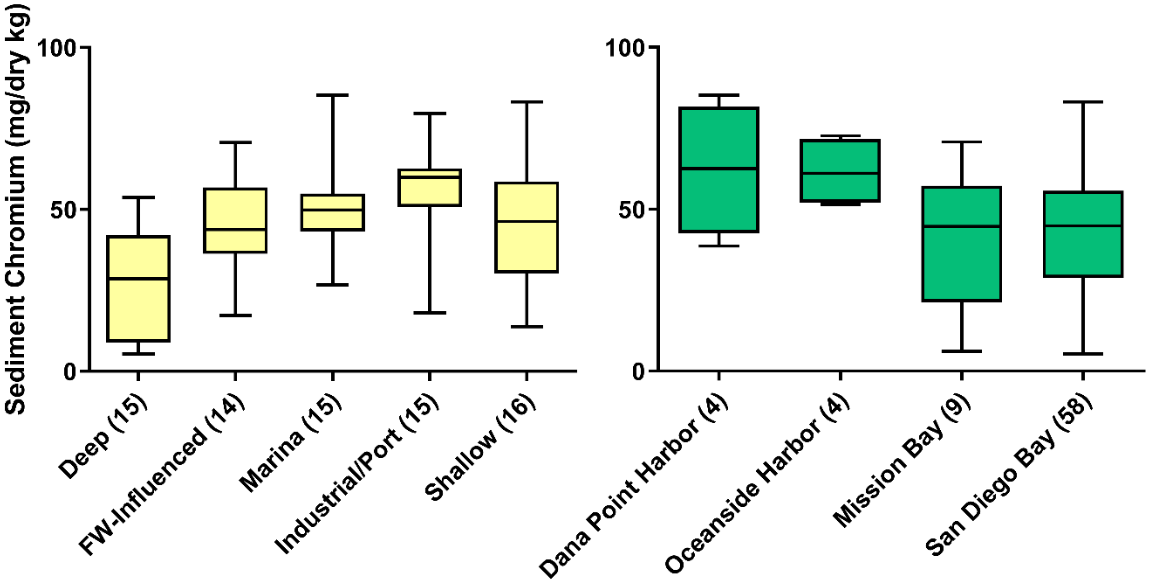

Figure 3-14. Comparisons of Sediment Chromium Concentrations Among Strata and Harbors

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses. Chromium is not included in the CSI calculation hence the exclusion of exposure category lines on this figure.

Copper

Concentrations of copper in the sediments ranged from 2.08 mg/kg in the deep stratum in Mission Bay to 664 mg/kg in the marina stratum in Dana Point Harbor, with an average of 117 mg/kg among all RHMP samples collected. Stations in the marina and industrial/port stratum had the highest median copper concentrations among strata, and Dana Point Harbor and Oceanside Harbor had the highest median copper concentrations among the harbors.

Sediment copper concentrations in all strata and harbors were compared to CSI thresholds, as shown in Figure 3-15. A total of 17 stations (23%) were considered to pose minimal exposure potential related to copper (CSI Category 1). Most of the stations (43%) were classified as having moderate exposure potential related to copper, a majority of which were among the marina and industrial/port strata. Three stations (two in Dana Point Harbor and one in Oceanside Harbor; 4%) were considered to have high exposure potential related to copper (CSI Category 4).

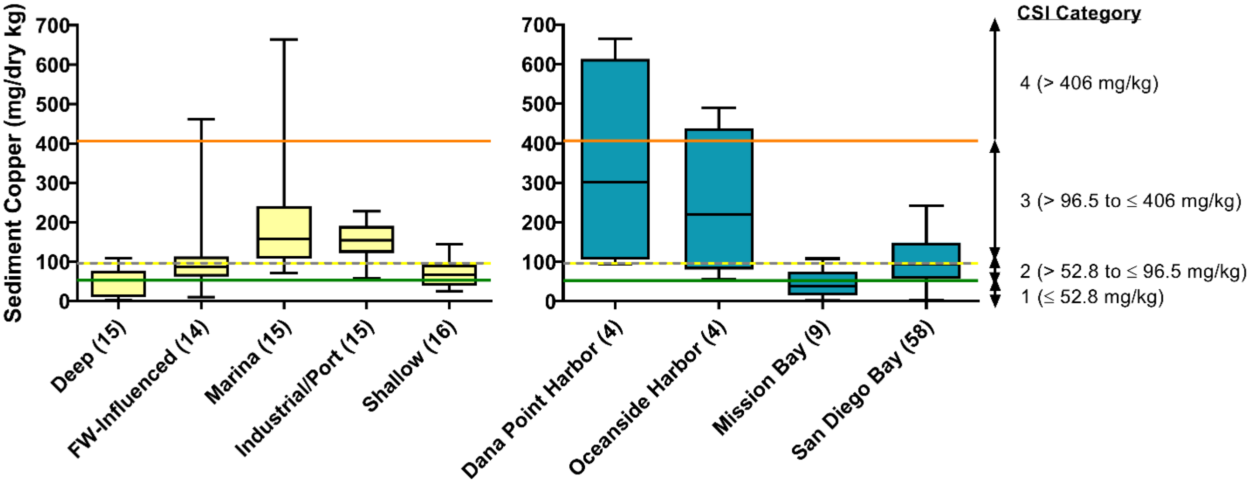

Figure 3-15. Comparisons of Sediment Copper Concentrations Among Strata and Harbors to SQO CSI Category Thresholds

1 = Minimal Chemical Exposure; 2 = Low Exposure; 3 = Moderate Exposure; 4 =High Chemical Exposure

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

The spatial distribution of sediment copper throughout the harbors is shown in Figures 3-16a through 3-16f. Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution of sediment copper concentrations measured in the 2018 RHMP.

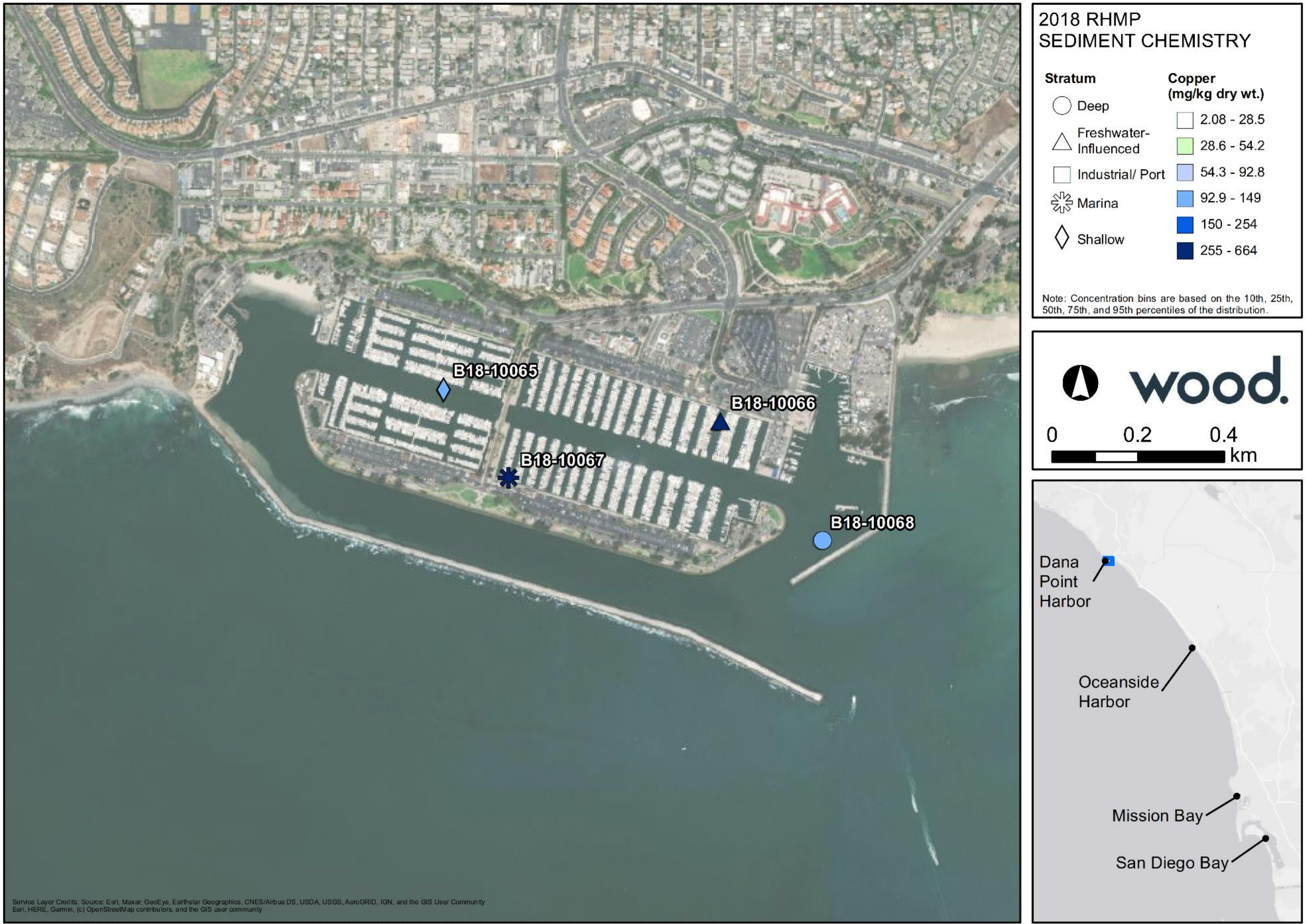

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Figure 3-16a. Spatial Distribution of Sediment Copper Concentrations in Dana Point Harbor

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Figure 3-16b. Spatial Distribution of Sediment Copper Concentrations in Oceanside Harbor

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Figure 3-16c. Spatial Distribution of Sediment Copper Concentrations in Mission Bay

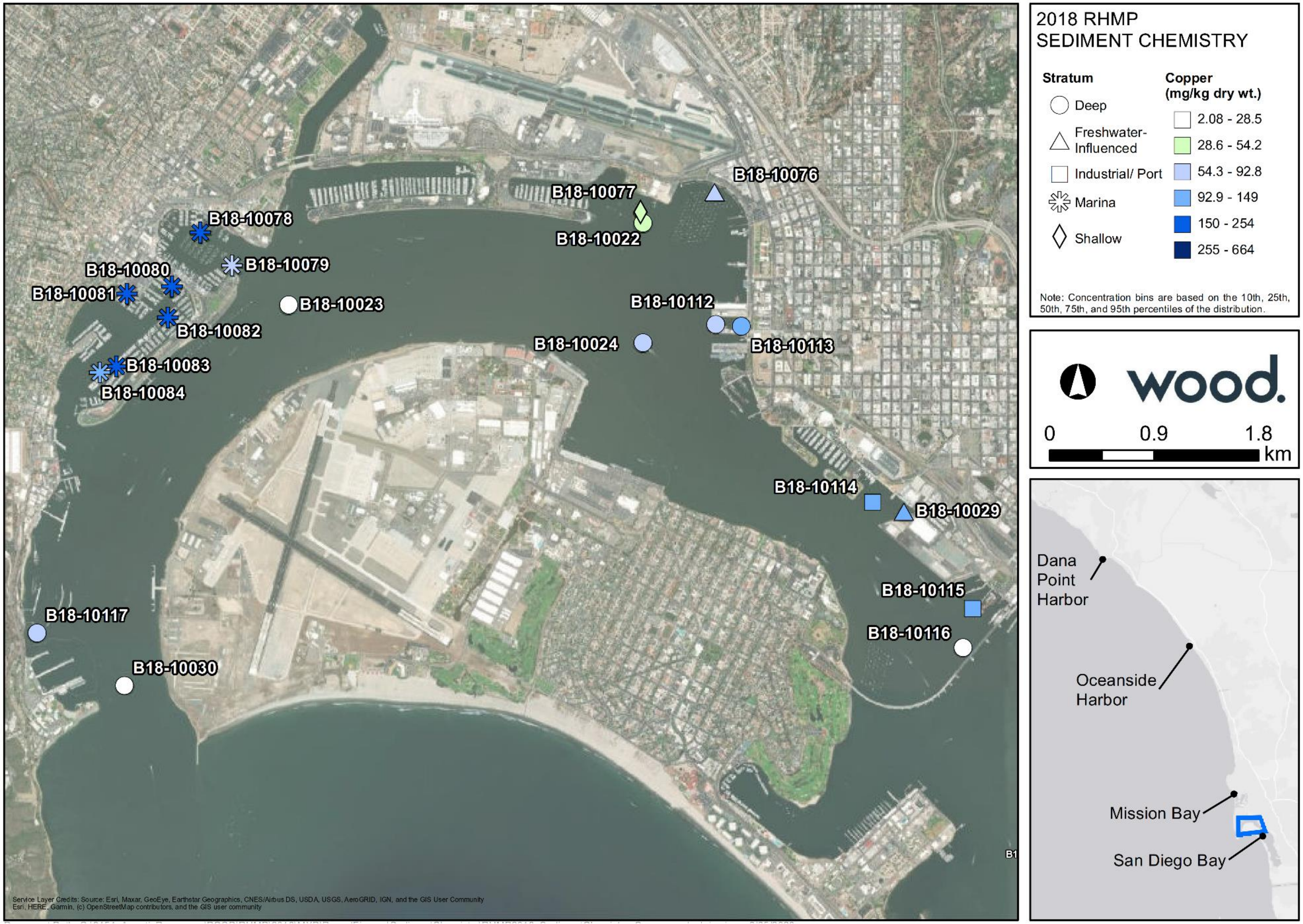

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Figure 3-16d. Spatial Distribution of Sediment Copper Concentrations in North San Diego Bay

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Figure 3-16e. Spatial Distribution of Sediment Copper Concentrations in Central San Diego Bay

Note: Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution.

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Figure 3-16f. Spatial Distribution of Sediment Copper Concentrations in South San Diego Bay

Lead

Concentrations of lead ranged from 1.75 mg/kg in the deep stratum in Mission Bay to 367 mg/kg in the industrial/port stratum in central San Diego Bay, with an average of 29.6 mg/kg among all RHMP samples collected. Stations in the industrial/port stratum had the highest median concentration of lead among strata, while stations in the deep stratum had the lowest. Concentrations of lead were similar among harbors, except for San Diego Bay, which had elevated concentrations particularly in the industrial/port stratum.

Figure 3-17 compares the concentrations of lead among strata and harbors to the CSI exposure category thresholds. Based on CSI categories for lead, the majority of stations (57%; n=43) were considered to pose minimal exposure potential, with only one station (1%) in the moderate exposure category (3), and one station (1%) in the high exposure category (4). Both stations classified as having moderate to high exposure potential for lead were located within central San Diego Bay in the industrial/port stratum.

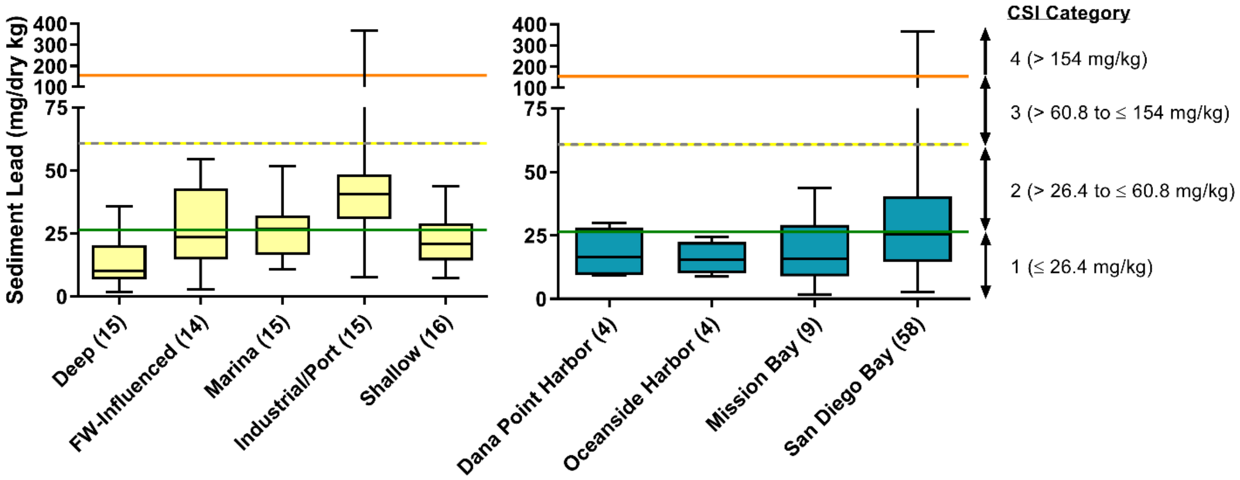

Figure 3-17. Comparisons of Sediment Lead Concentrations Among Strata and Harbors to SQO CSI Category Thresholds

1 = Minimal Chemical Exposure; 2 = Low Exposure; 3 = Moderate Exposure; 4 =High Chemical Exposure

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

The spatial distribution of sediment lead throughout the harbors is shown in Figures 3-18a through 3-18f. Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution of sediment lead concentrations measured in the 2018 RHMP.

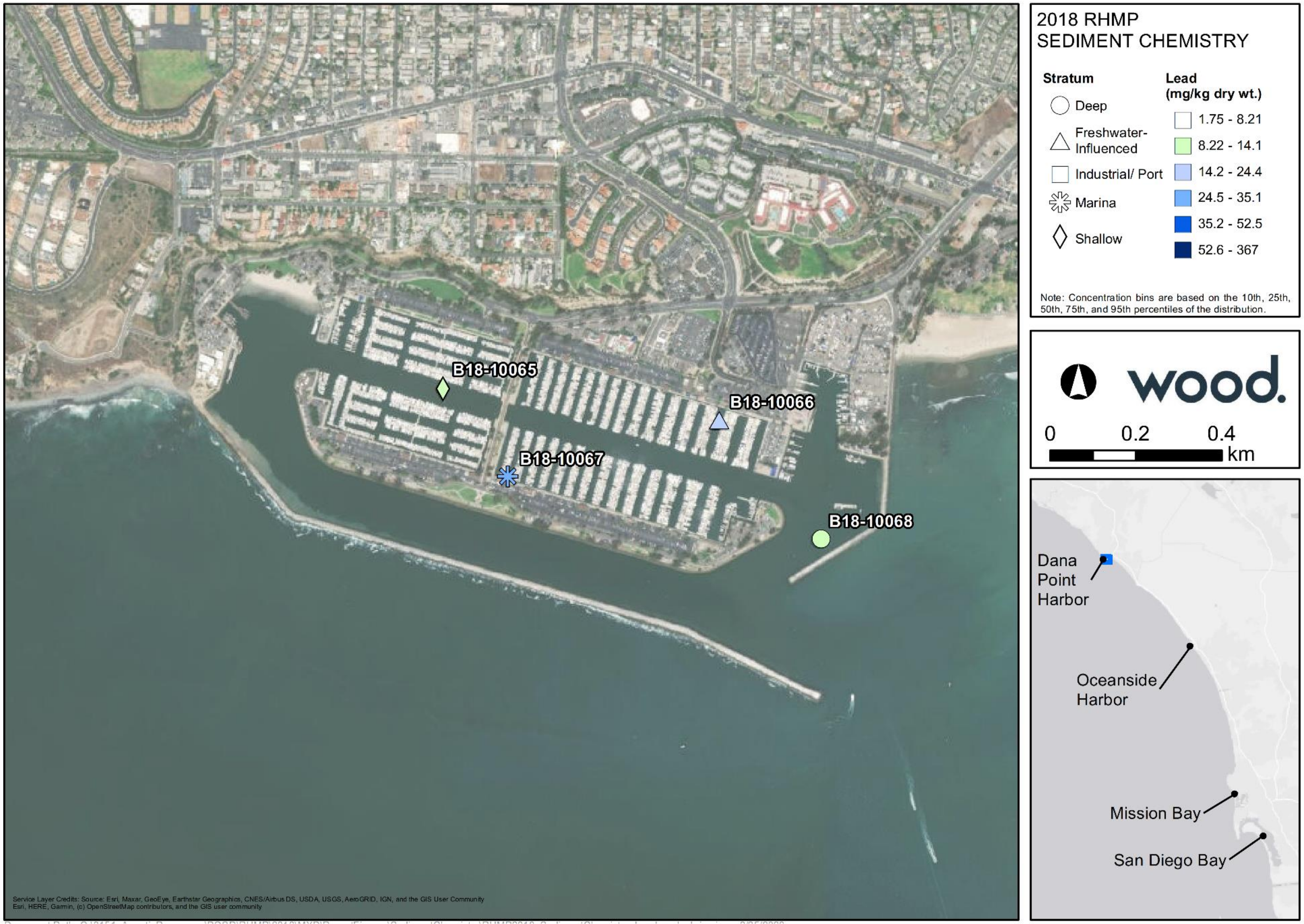

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Figure 3-18a. Spatial Distribution of Sediment Lead Concentrations in Dana Point Harbor

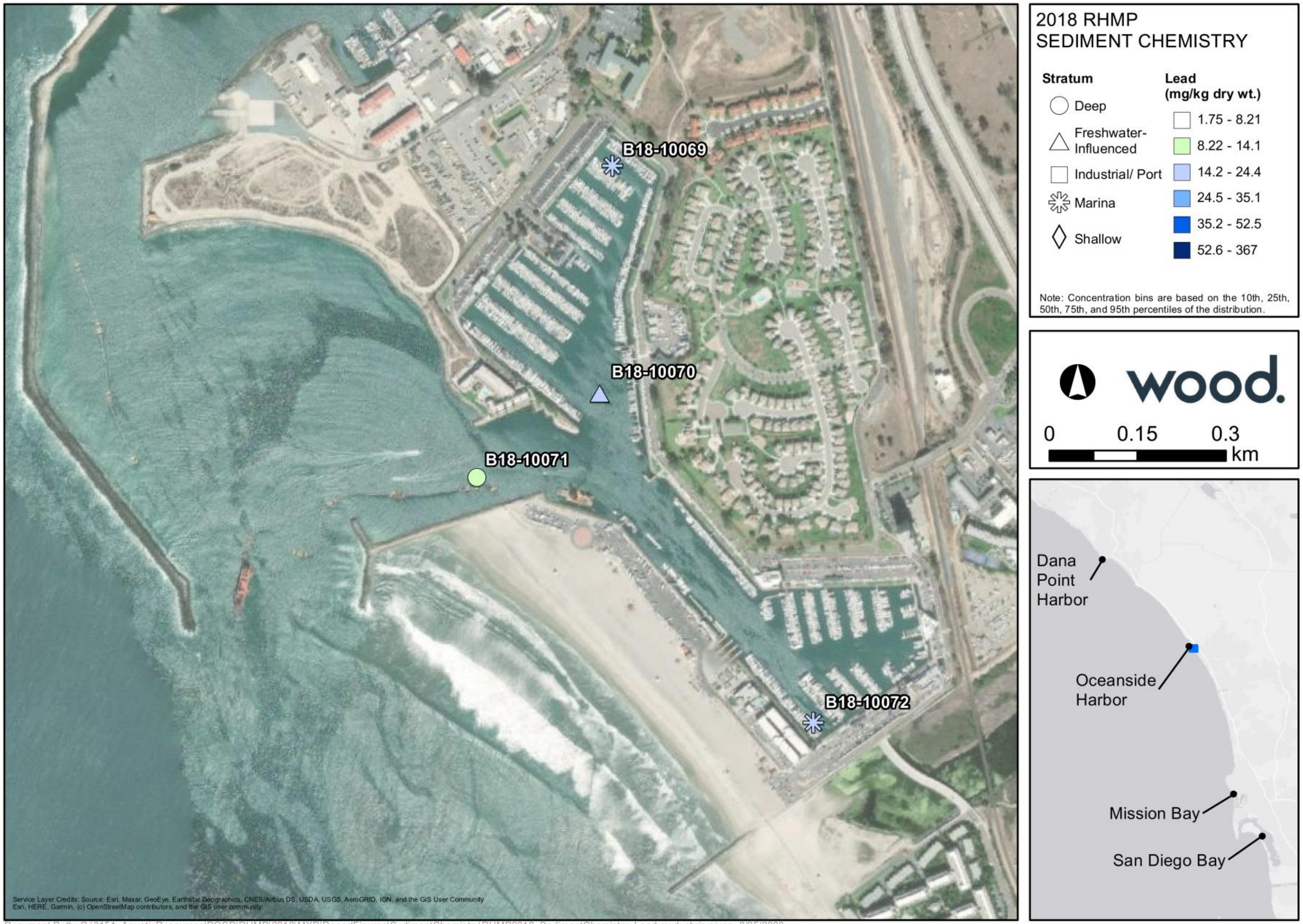

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Figure 3-18b. Spatial Distribution of Sediment Lead Concentrations in Oceanside Harbor

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Figure 3-18c. Spatial Distribution of Sediment Lead Concentrations in Mission Bay

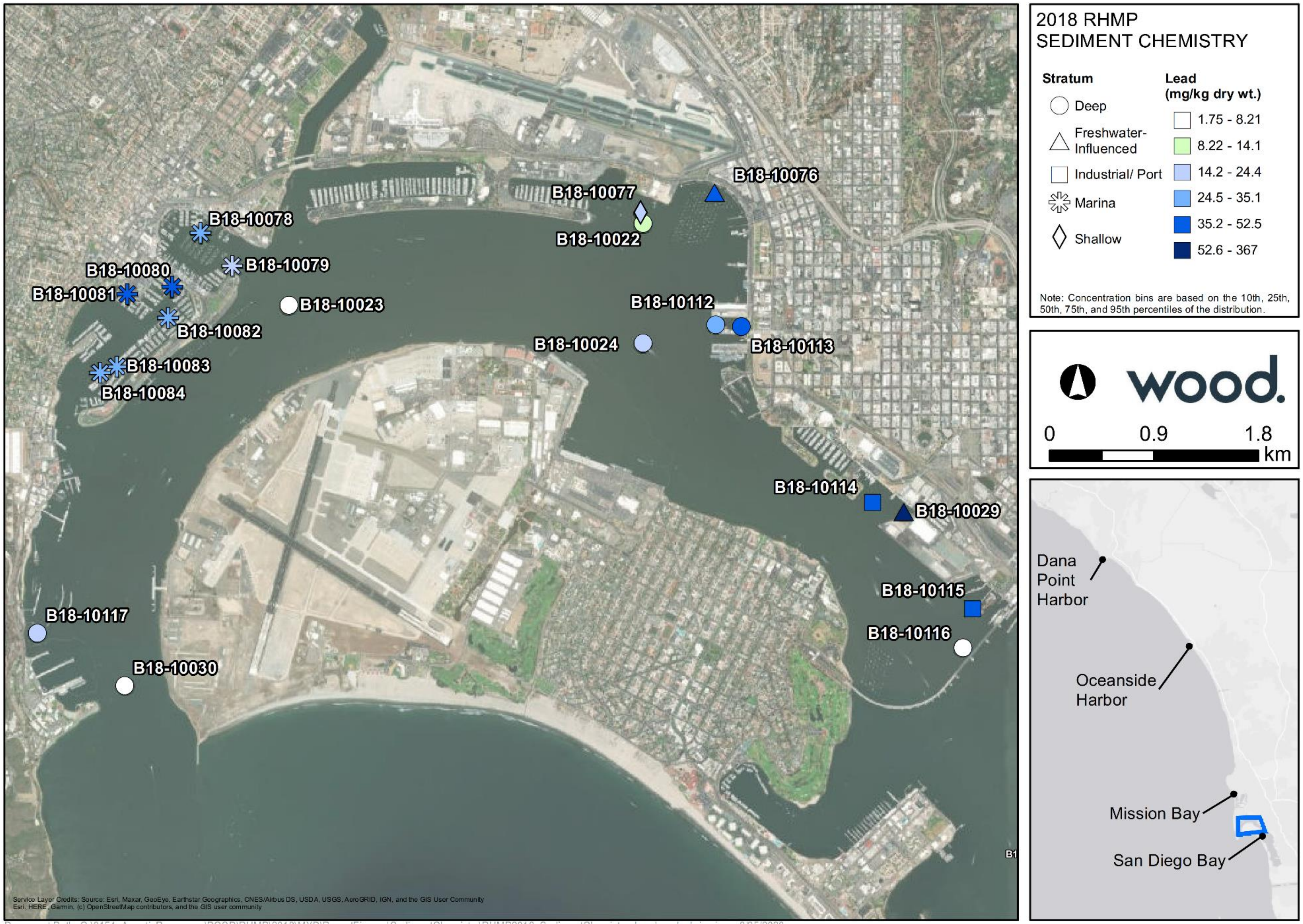

Figure 3-18d. Spatial Distribution of Sediment Lead Concentrations in North San Diego Bay

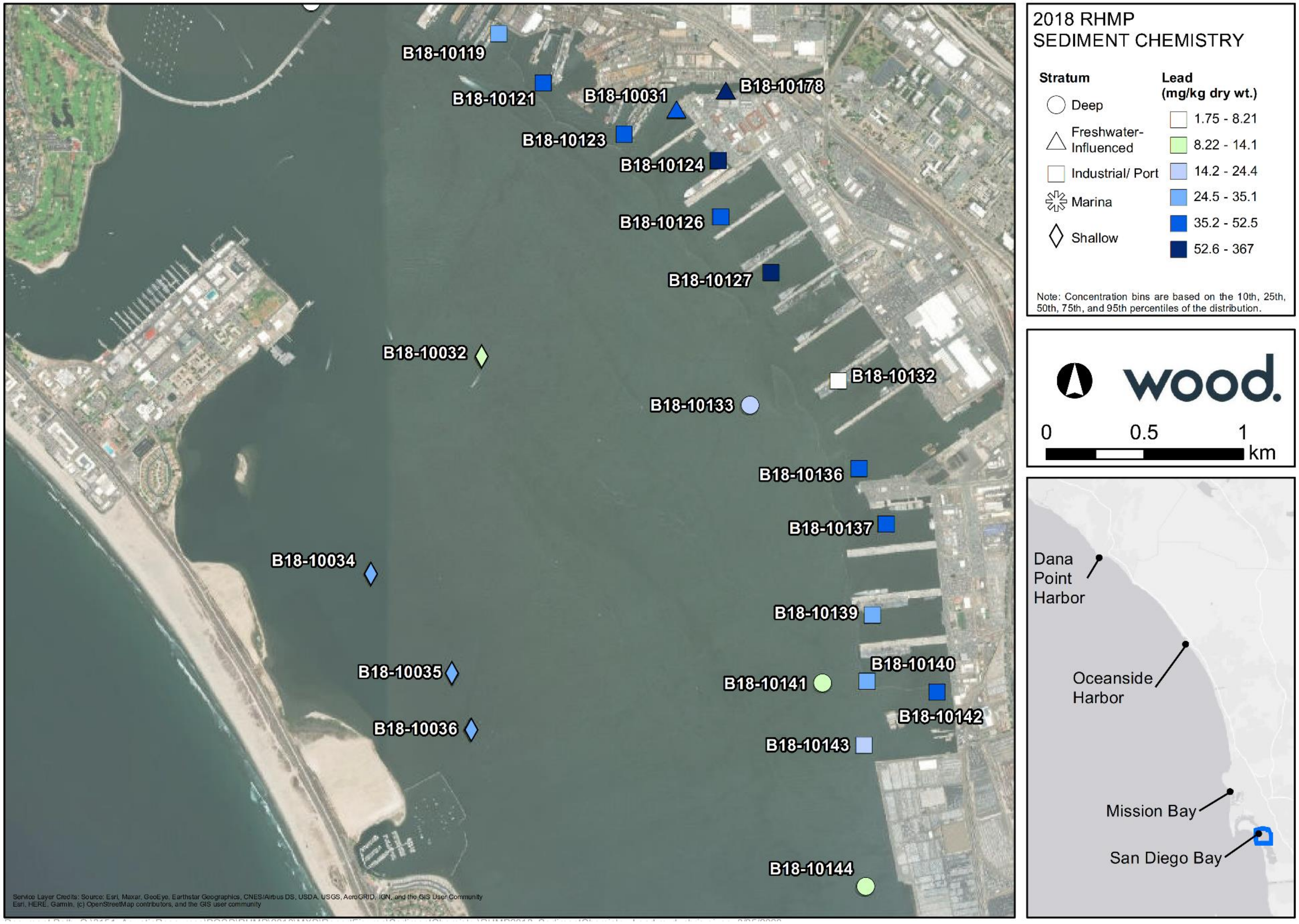

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Figure 3-18e. Spatial Distribution of Sediment Lead Concentrations in Central San Diego Bay

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Figure 3-18f. Spatial Distribution of Sediment Lead Concentrations in South San Diego Bay

Mercury

Concentrations of mercury ranged from 0.0053 mg/kg in the deep stratum in Mission Bay to 1.84 mg/kg in the marina stratum in north San Diego Bay, with an average of 0.28 mg/kg among all RHMP samples collected. Stations in the marina and industrial/port strata had the highest median concentration of mercury among strata. Median concentrations of mercury were similar among harbors, except for San Diego Bay, which had higher concentrations.

Figure 3-19 compares the concentrations of mercury among strata and harbors to the CSI exposure category thresholds. Based on CSI categories for mercury, most stations (52%) were considered to have low exposure potential (CSI Category 2), followed by 31% of stations with minimal exposure potential (CSI Category 1), as displayed in Figure 3-19. Thirteen stations (17%) in San Diego Bay, primarily in the marina and industrial/port strata, were considered to pose moderate exposure potential for mercury (CSI Category 3), and none were in the high exposure category.

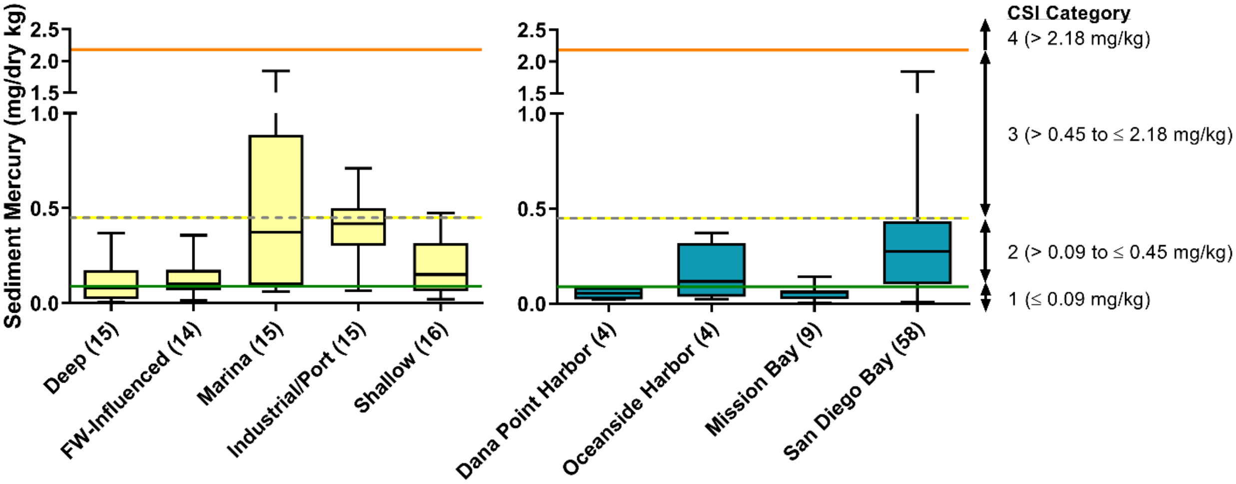
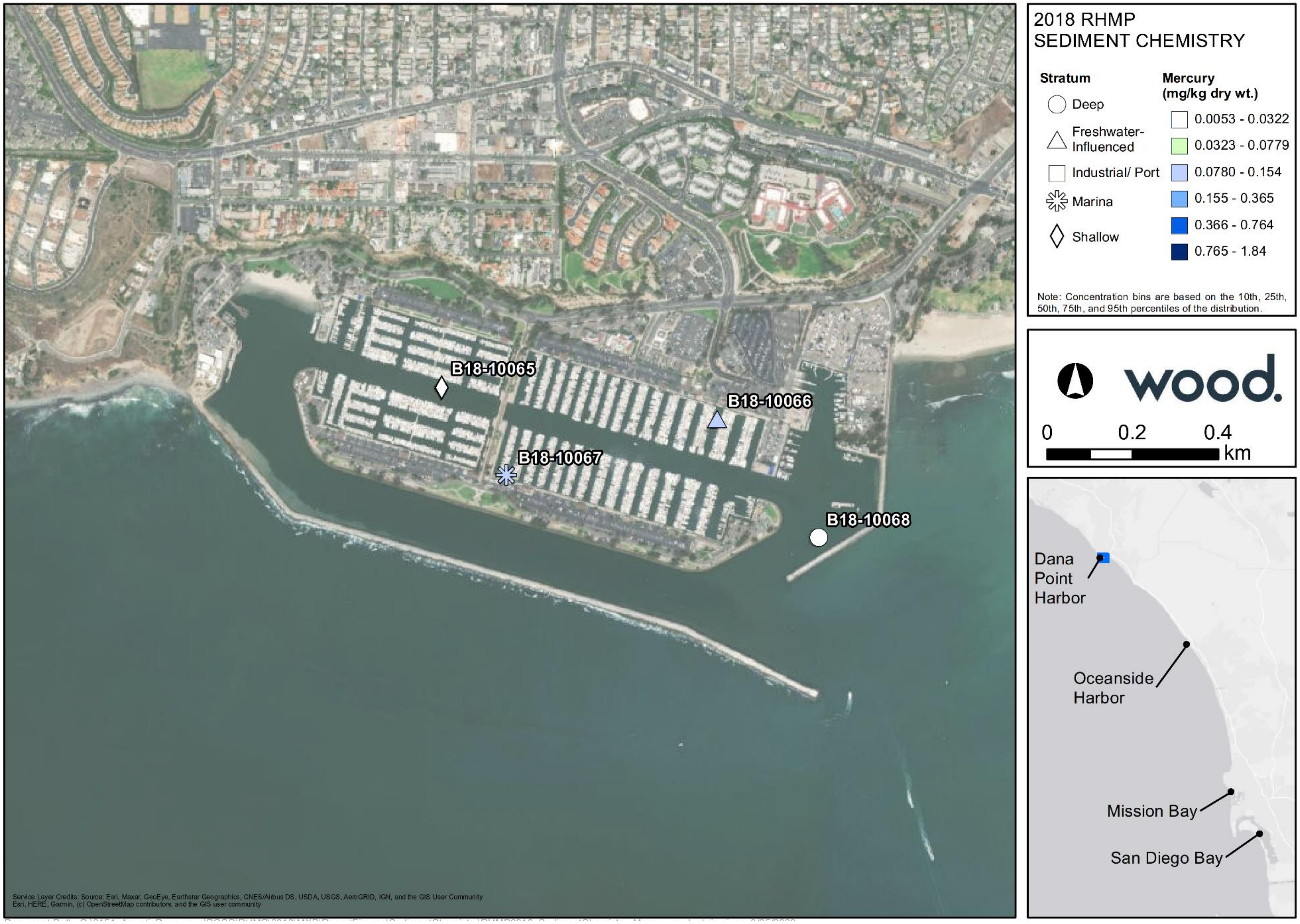


Figure 3-19. Comparisons of Sediment Mercury Concentrations Among Strata and Harbors to SQO CSI Category Thresholds

1 = Minimal Chemical Exposure; 2 = Low Exposure; 3 = Moderate Exposure; 4 =High Chemical Exposure

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

The spatial distribution of sediment mercury concentrations throughout the harbors is shown in Figures 3-20a through 3-20f. Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution of sediment mercury concentrations measured in the 2018 RHMP.



Note: Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution.

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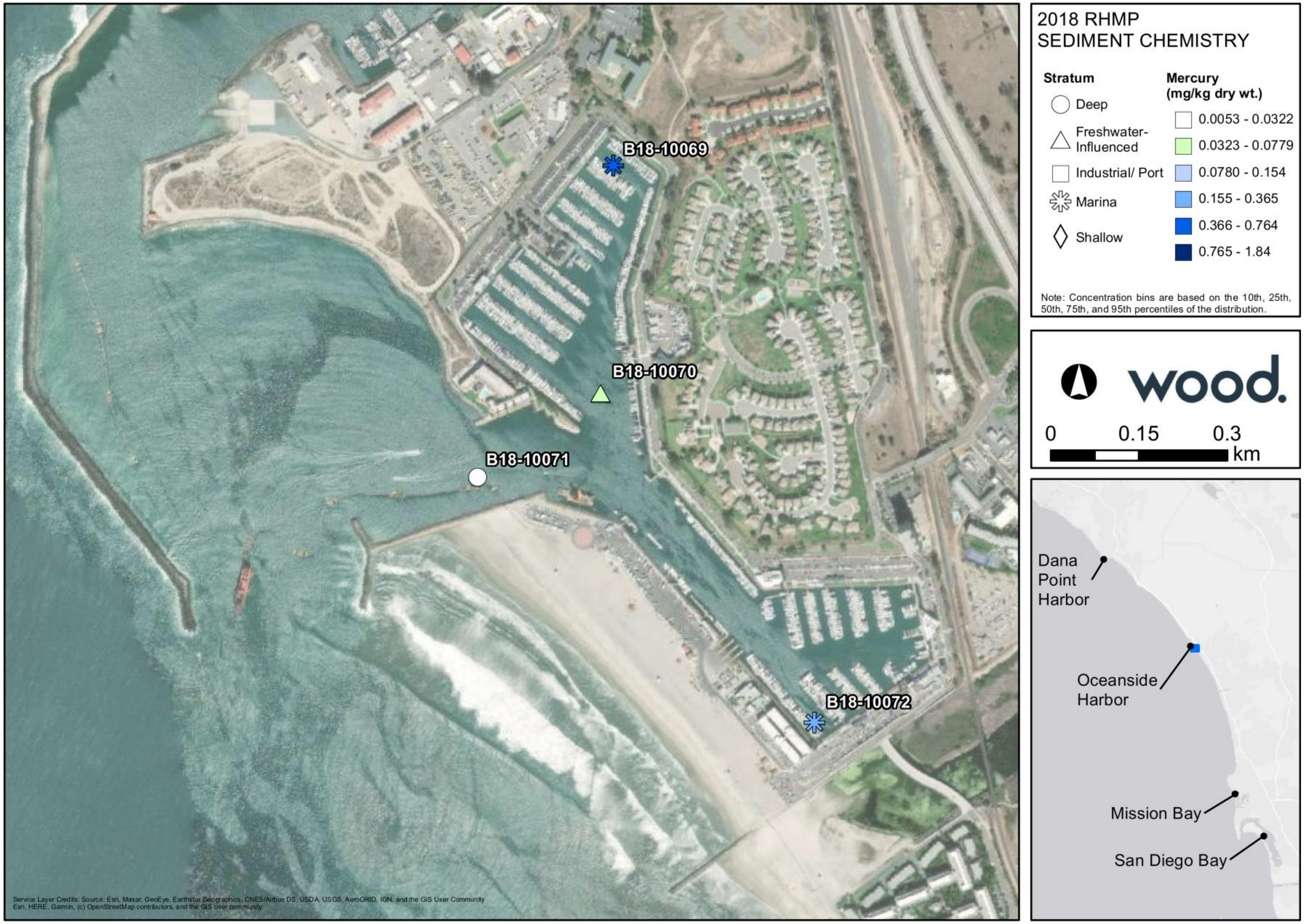
Figure 3-20a. Spatial Distribution of Sediment Mercury Concentrations in Dana Point Harbor



Note: Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution.

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Figure 3-20b. Spatial Distribution of Sediment Mercury Concentrations in Oceanside Harbor

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Figure 3-20c. Spatial Distribution of Sediment Mercury Concentrations in Mission Bay

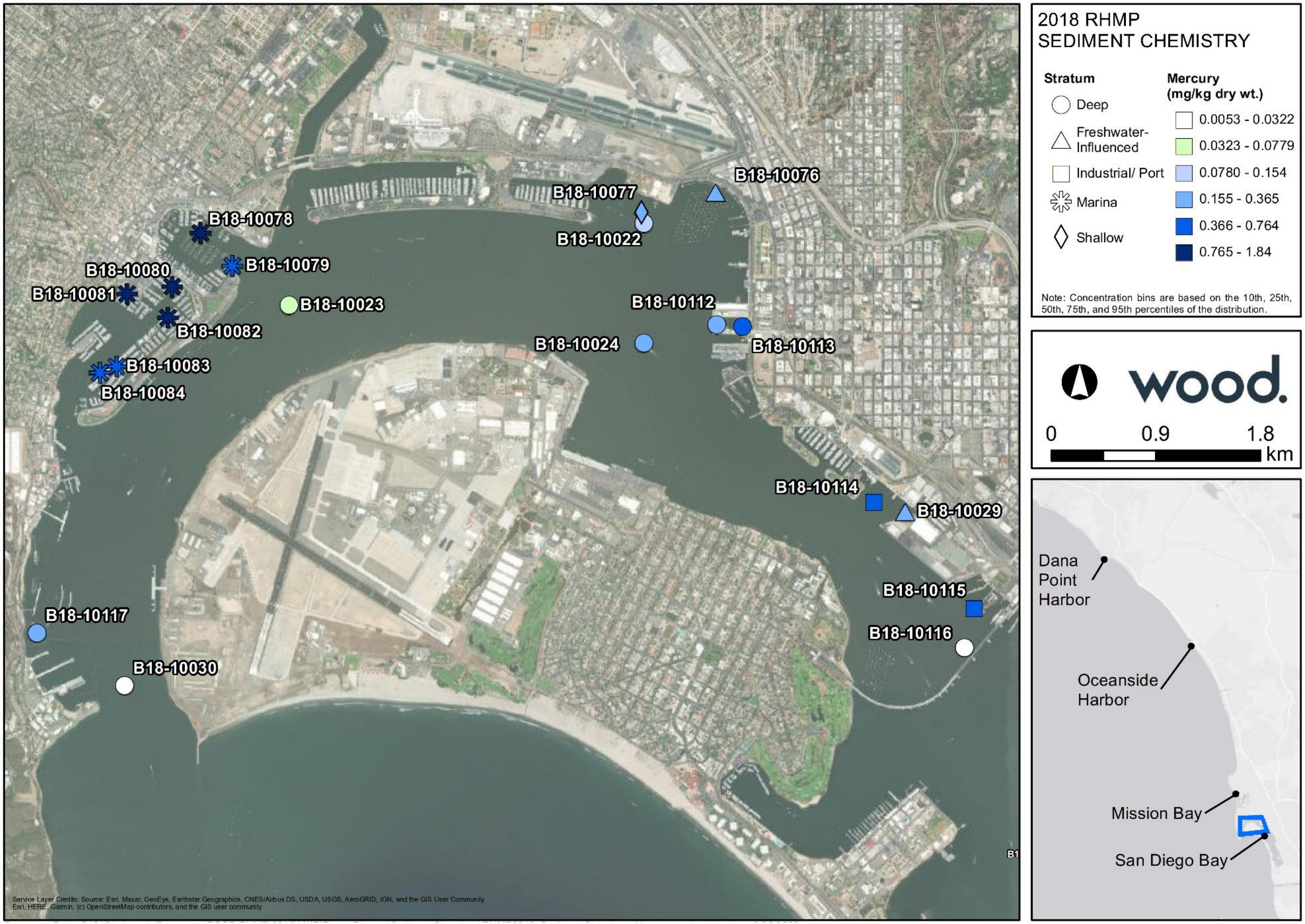
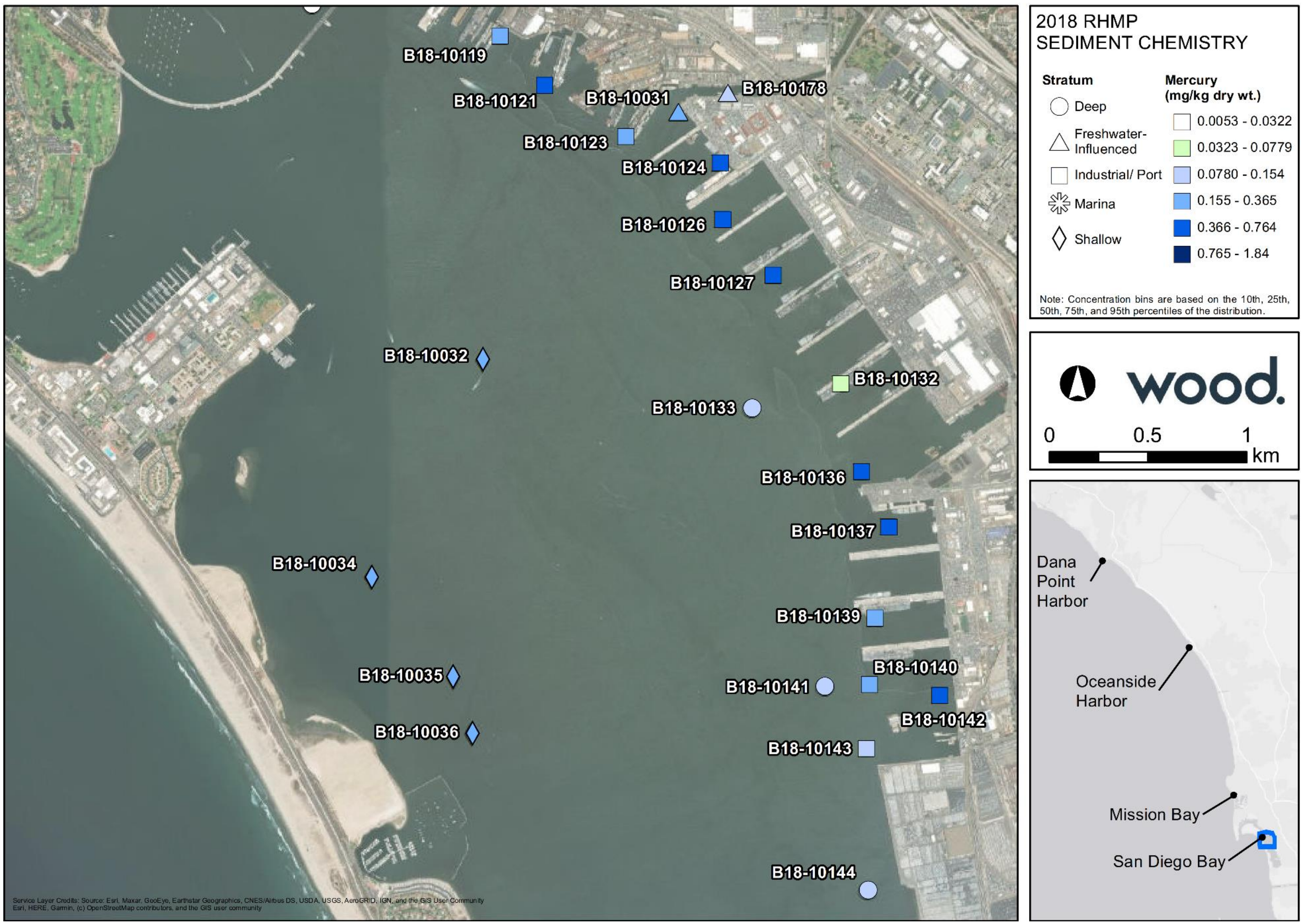


Figure 3-20d. Spatial Distribution of Sediment Mercury Concentrations in North San Diego Bay



Note: Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution.

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Figure 3-20e. Spatial Distribution of Sediment Mercury Concentrations in Central San Diego Bay

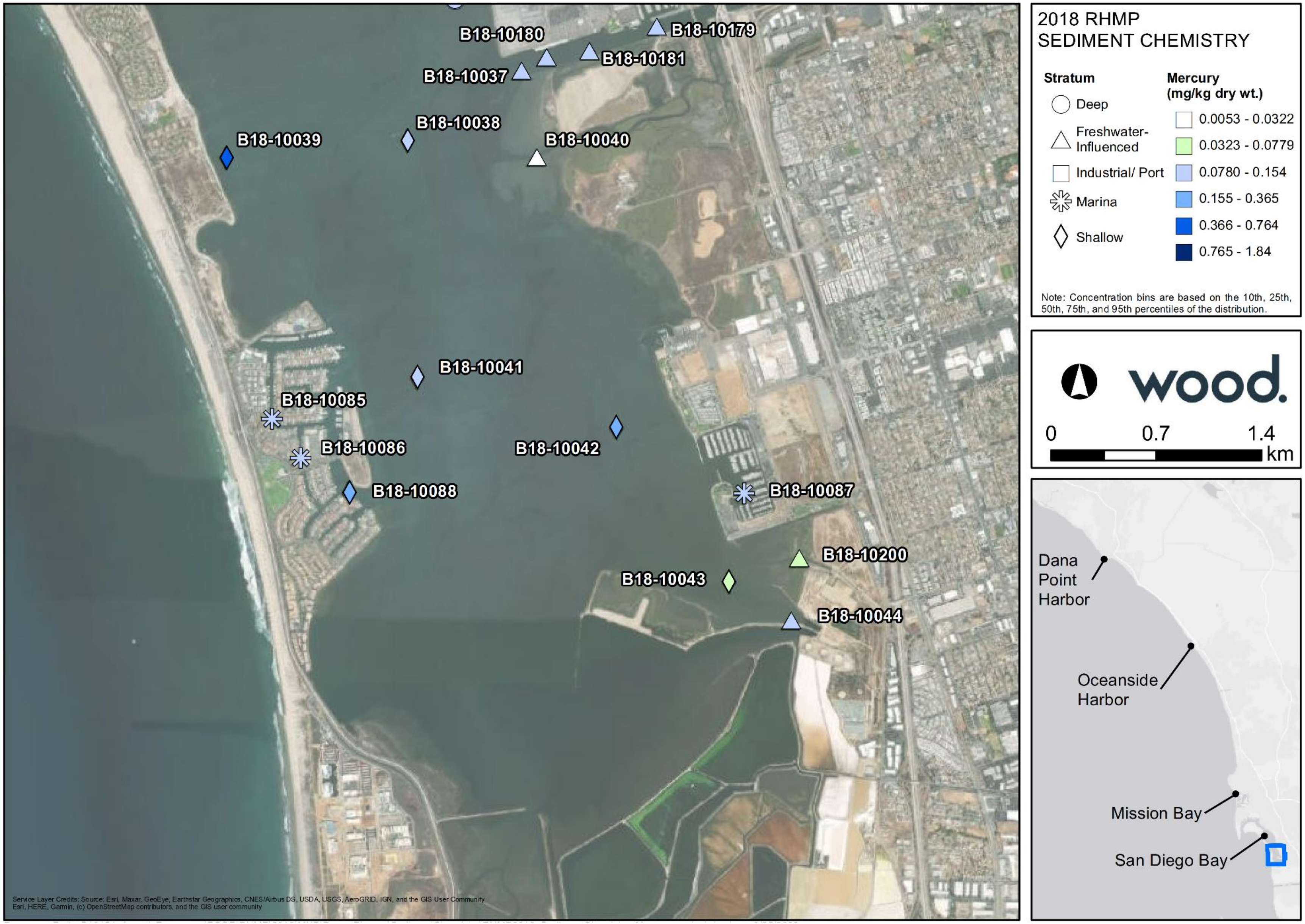

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Figure 3-20f. Spatial Distribution of Sediment Mercury Concentrations in South San Diego Bay

Nickel

Nickel concentrations ranged from 1.2 mg/kg in the deep stratum in north San Diego Bay to 28.5 mg/kg in the industrial/port stratum in central San Diego Bay, with an average of 13.6 mg/kg among all stations. Industrial/port stations had the highest median concentration of nickel, while deep stations had the lowest. Oceanside Harbor had the highest median concentration of nickel, followed by Dana Point Harbor, San Diego Bay, and Mission Bay.

The distribution of nickel among strata and harbors in 2018 is shown in Figure 3-21. Given the relatively low variability in concentrations of nickel measured throughout the Regional Harbors, maps showing nickel concentrations are not provided in the text herein, but are included for reference in Appendix F.

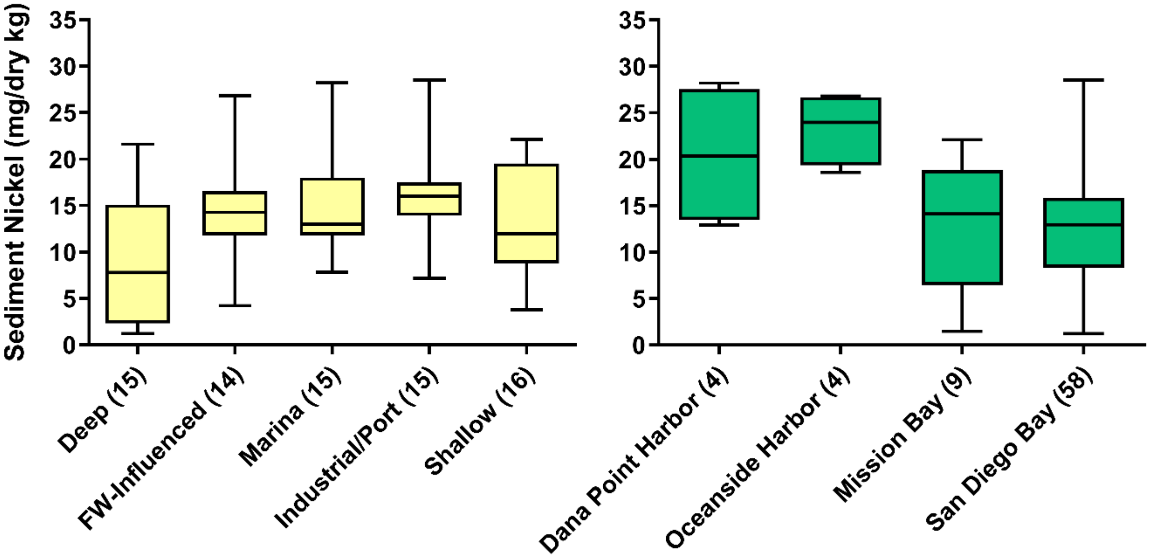

Figure 3-21. Comparisons of Sediment Nickel Concentrations Among Strata and Harbors

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses. Nickel is not included in the CSI calculation hence the exclusion of exposure category lines on this figure.

Zinc

Concentrations of zinc ranged from 10.8 mg/kg in the deep stratum in north San Diego Bay to 616 mg/kg in the marina stratum in Dana Point Harbor, with an average of 171 mg/kg among all RHMP samples collected. Stations in the marina, industrial/port, and freshwater-influenced strata had similarly elevated concentrations of zinc. Among harbors, median concentrations of zinc were highest in Dana Point Harbor and Oceanside Harbor.

Figure 3-22 compares the concentrations of zinc among strata and harbors to the CSI exposure category thresholds. Based on CSI categories for zinc, most stations were considered to have minimal to low exposure potential (68%) and moderate exposure potential (32%), as shown in Figure 3-22. Most of the stations scored as having moderate exposure potential were located within the marina and industrial/port strata. The only harbor without a station in the moderate exposure category was Mission Bay, while Dana Point Harbor had the highest measured concentration of zinc (616 mg/kg at Station B18-10067). No stations fell within the high exposure potential category.

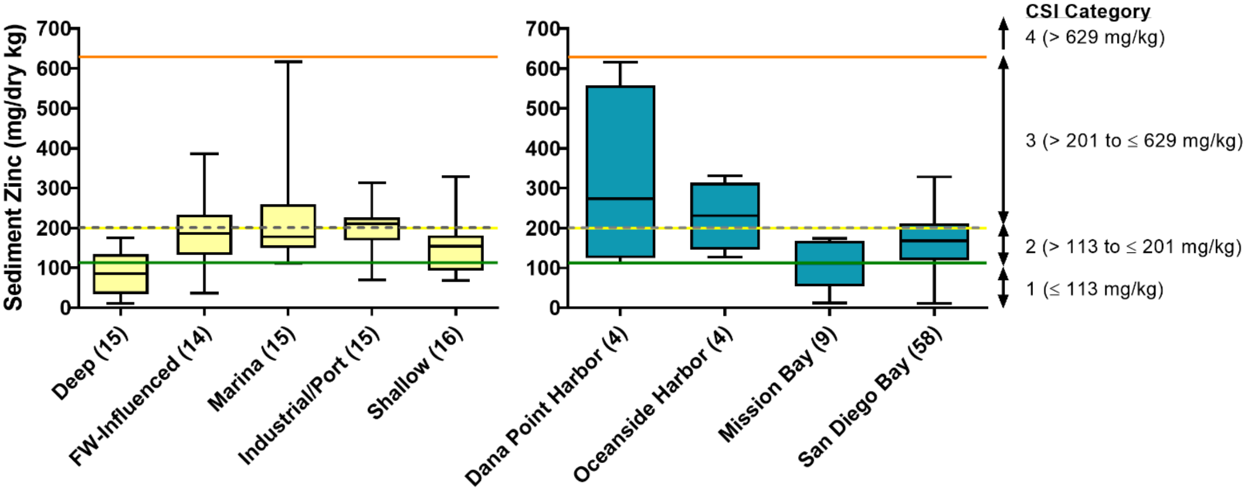

Figure 3-22. Comparisons of Sediment Zinc Concentrations Among Strata and Harbors to SQO CSI Category Thresholds

1 = Minimal Chemical Exposure; 2 = Low Exposure; 3 = Moderate Exposure; 4 =High Chemical Exposure

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

The spatial distribution of zinc among harbors is detailed in Figures 3-23a through 3-23f. Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution of sediment zinc concentrations measured in the 2018 RHMP.

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Figure 3-23a. Spatial Distribution of Sediment Zinc Concentrations in Dana Point Harbor

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Figure 3-23b. Spatial Distribution of Sediment Zinc Concentrations in Oceanside Harbor

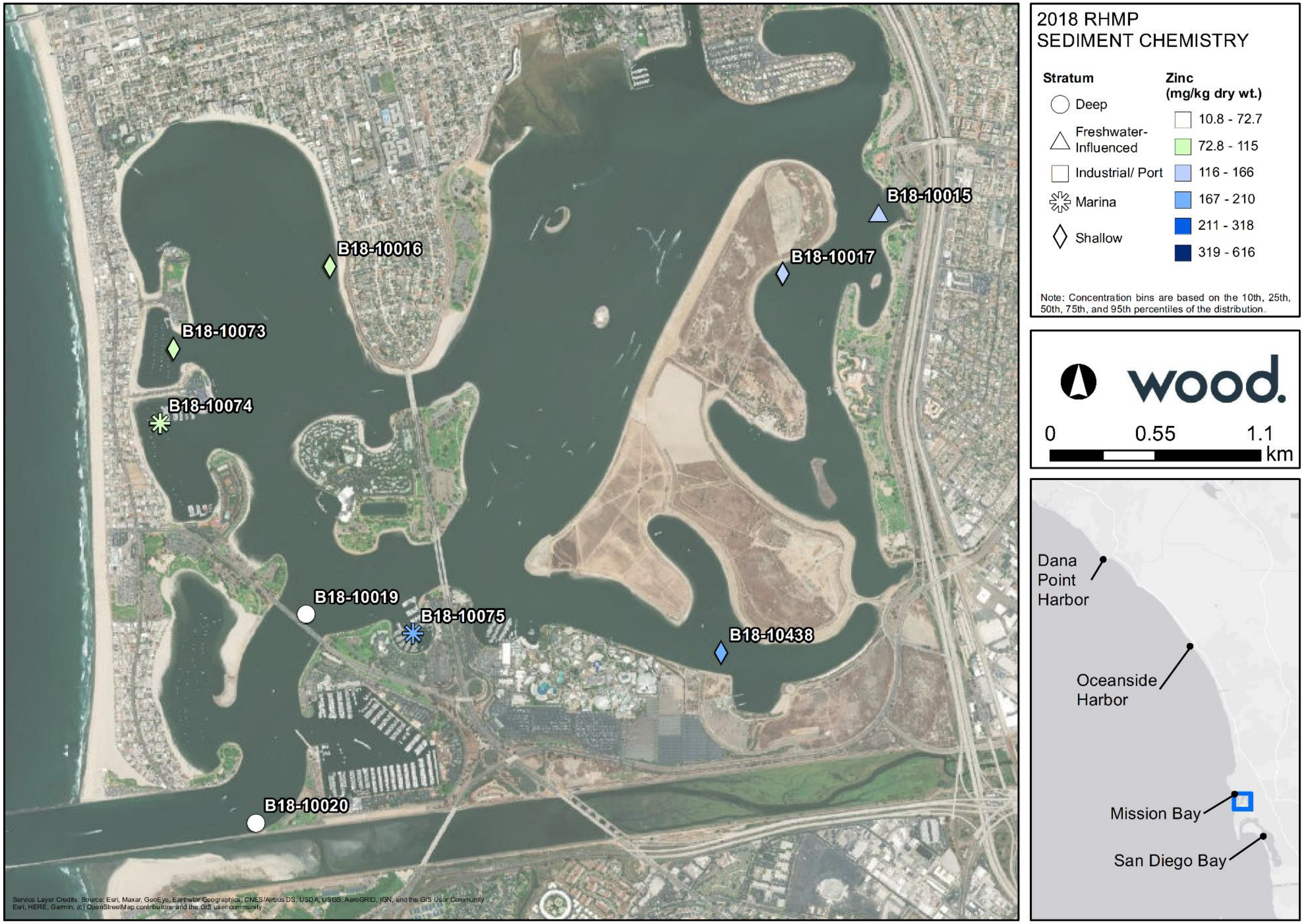

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Figure 3-23c. Spatial Distribution of Sediment Zinc Concentrations in Mission Bay

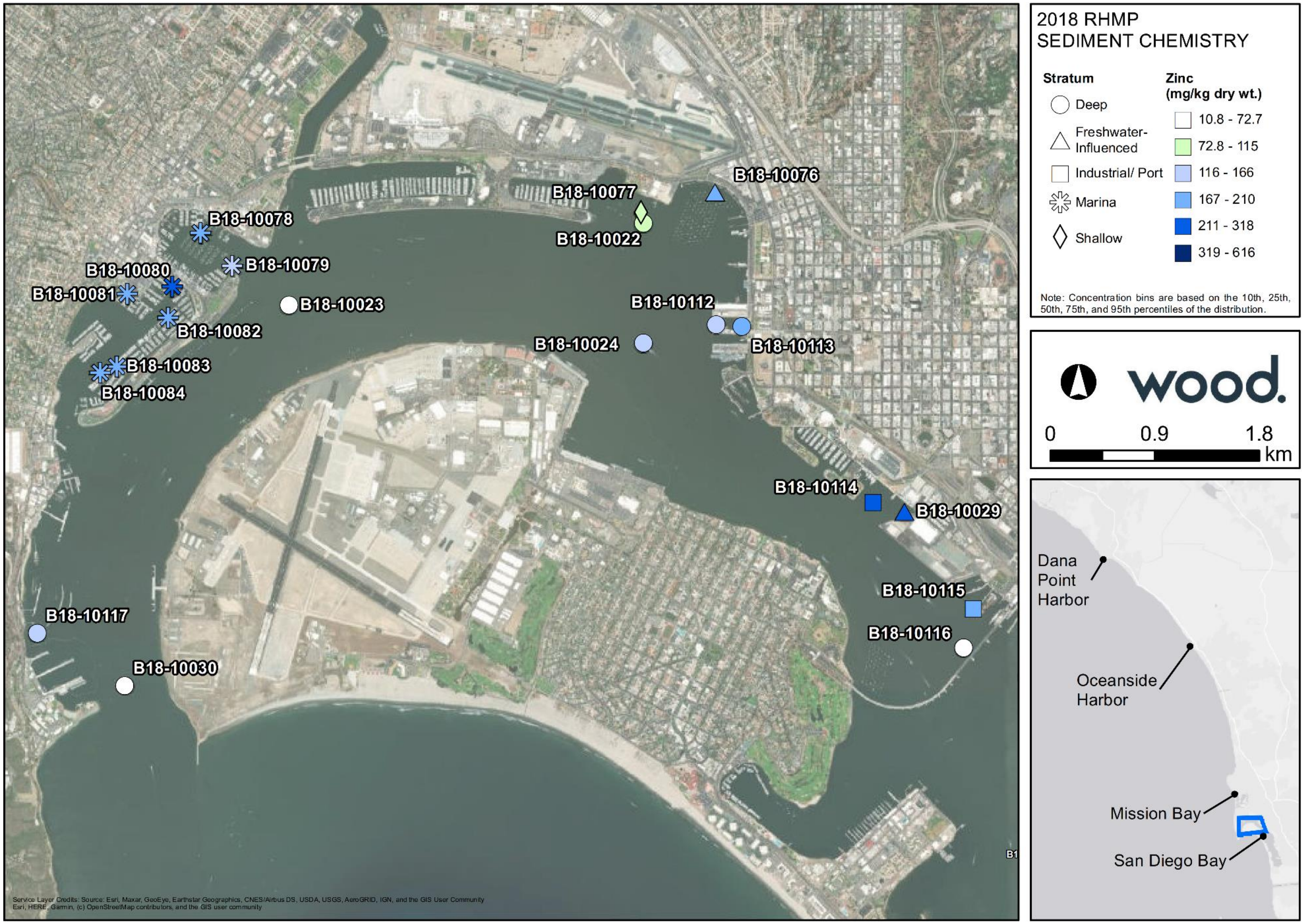

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Figure 3-23d. Spatial Distribution of Sediment Zinc Concentrations in North San Diego Bay

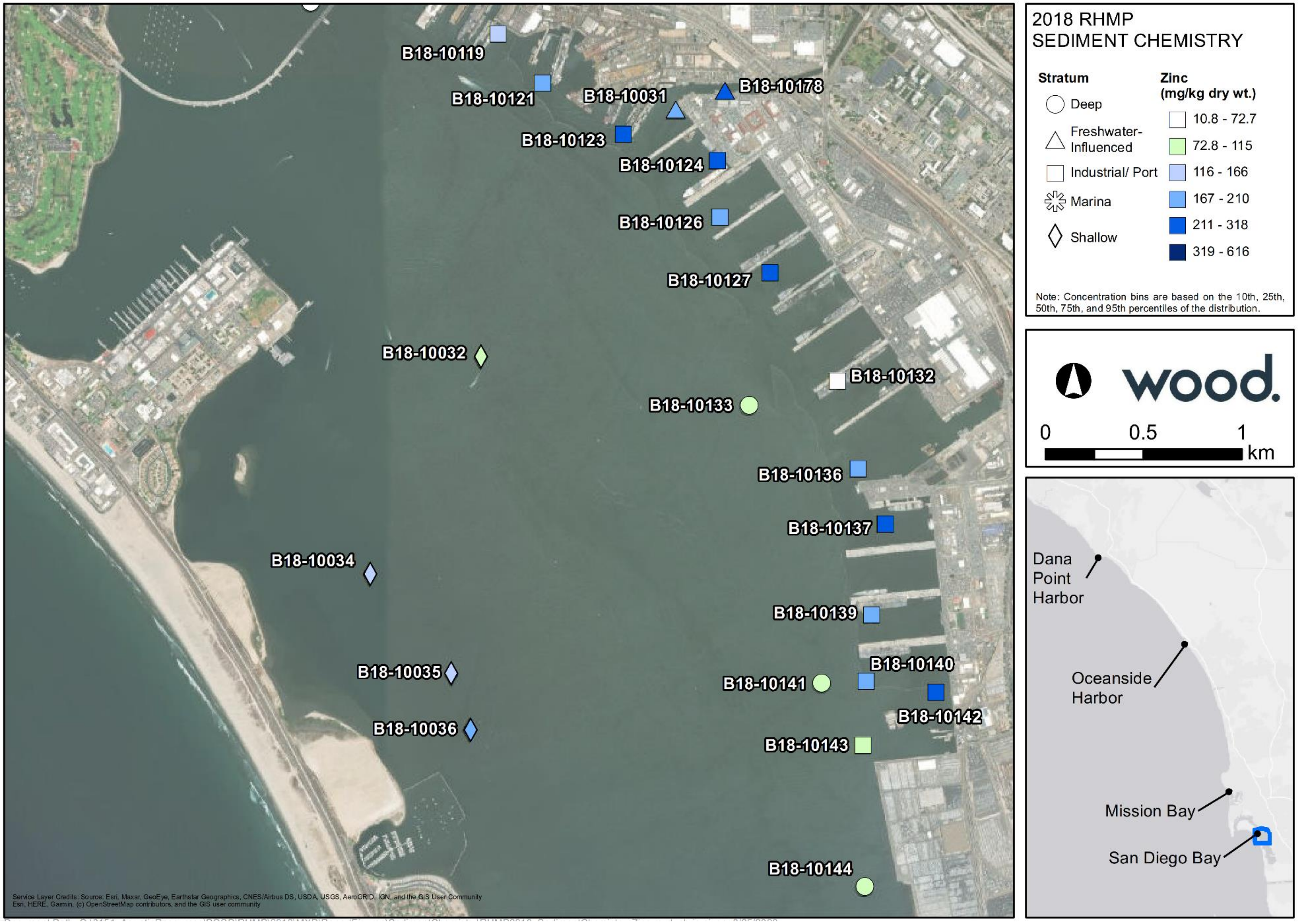

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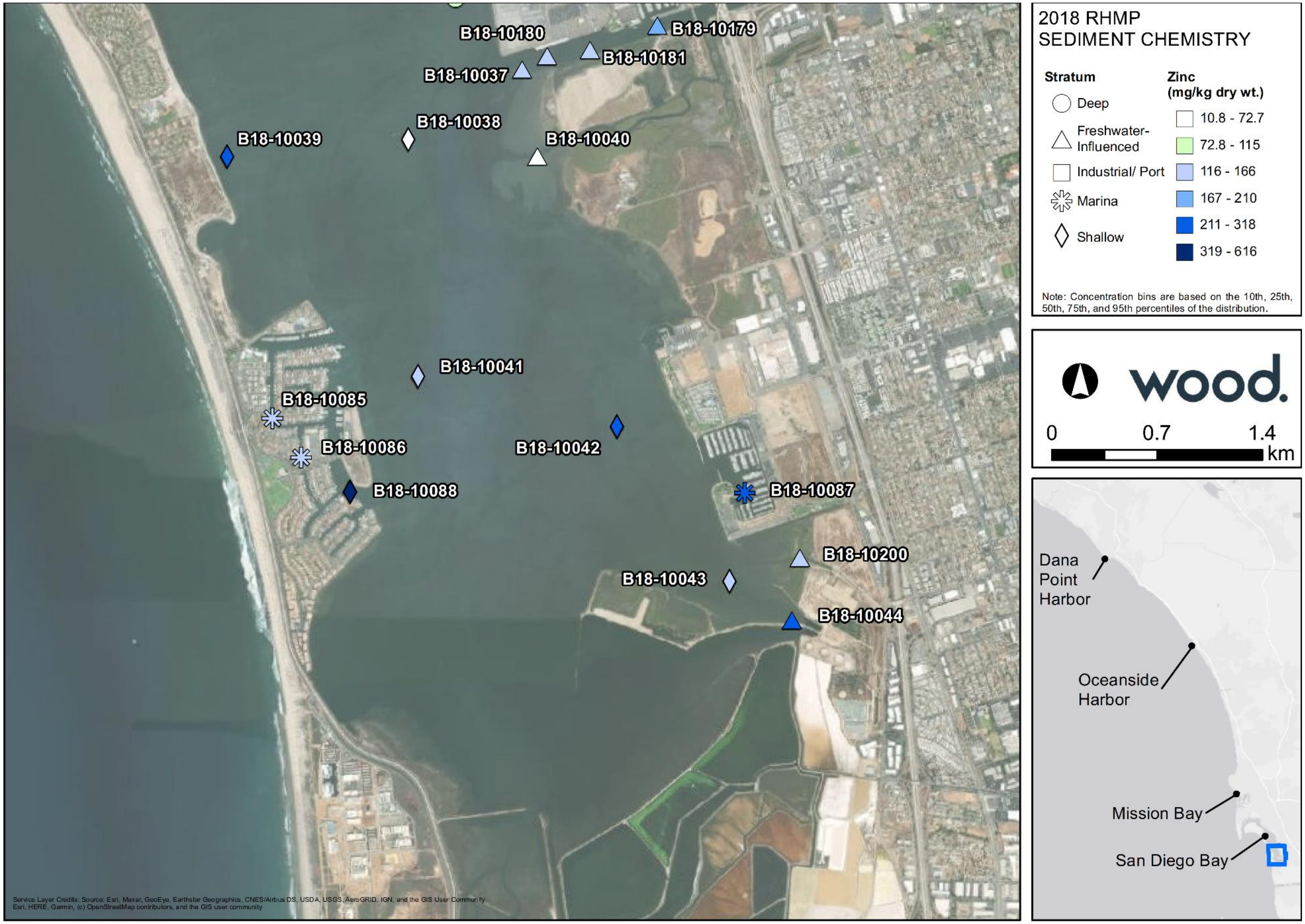
Figure 3-23e. Spatial Distribution of Sediment Zinc Concentrations in Central San Diego Bay



Note: Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution.

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Figure 3-23f. Spatial Distribution of Sediment Zinc Concentrations in South San Diego Bay

Sediment Organics

Total PAHs

Concentrations of total PAHs (the sum of 25 individual PAHs) ranged from 23.8 micrograms per kilogram (µg/kg) in the freshwater-influenced stratum in south San Diego Bay to 5,126 µg/kg in the deep stratum in north San Diego Bay, with an average of 967 µg/kg among all RHMP samples collected. Stations in the industrial/port stratum had the highest median total PAH concentration among strata, and stations in the shallow stratum had the lowest. San Diego Bay had the highest median total PAH concentrations in the sediment, followed by Dana Point Harbor, Oceanside Harbor, and Mission Bay.

The distribution of total PAHs among harbors and strata is detailed in Figure 3-24, and maps showing the spatial distribution of total PAHs among harbors are included in Figures 3-25a through 3-25f. Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution of sediment total PAH concentrations measured in the 2018 RHMP.

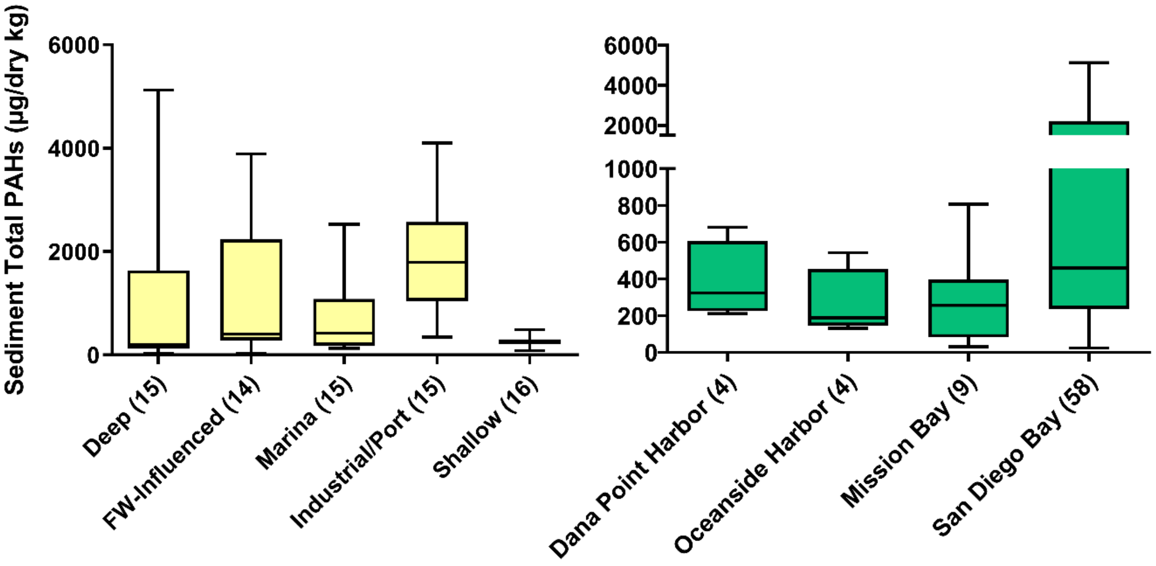

Figure 3-24. Comparisons of Sediment Total PAH Concentrations Among Strata and Harbors

Total PAHs are not included in the CSI calculation hence the exclusion of exposure category lines on this figure. The number of stations (n) is shown in parentheses. PAHs are broken in to low- and high-molecular-weight fractions for the CSI – see Figures 3-26 and 3-27.

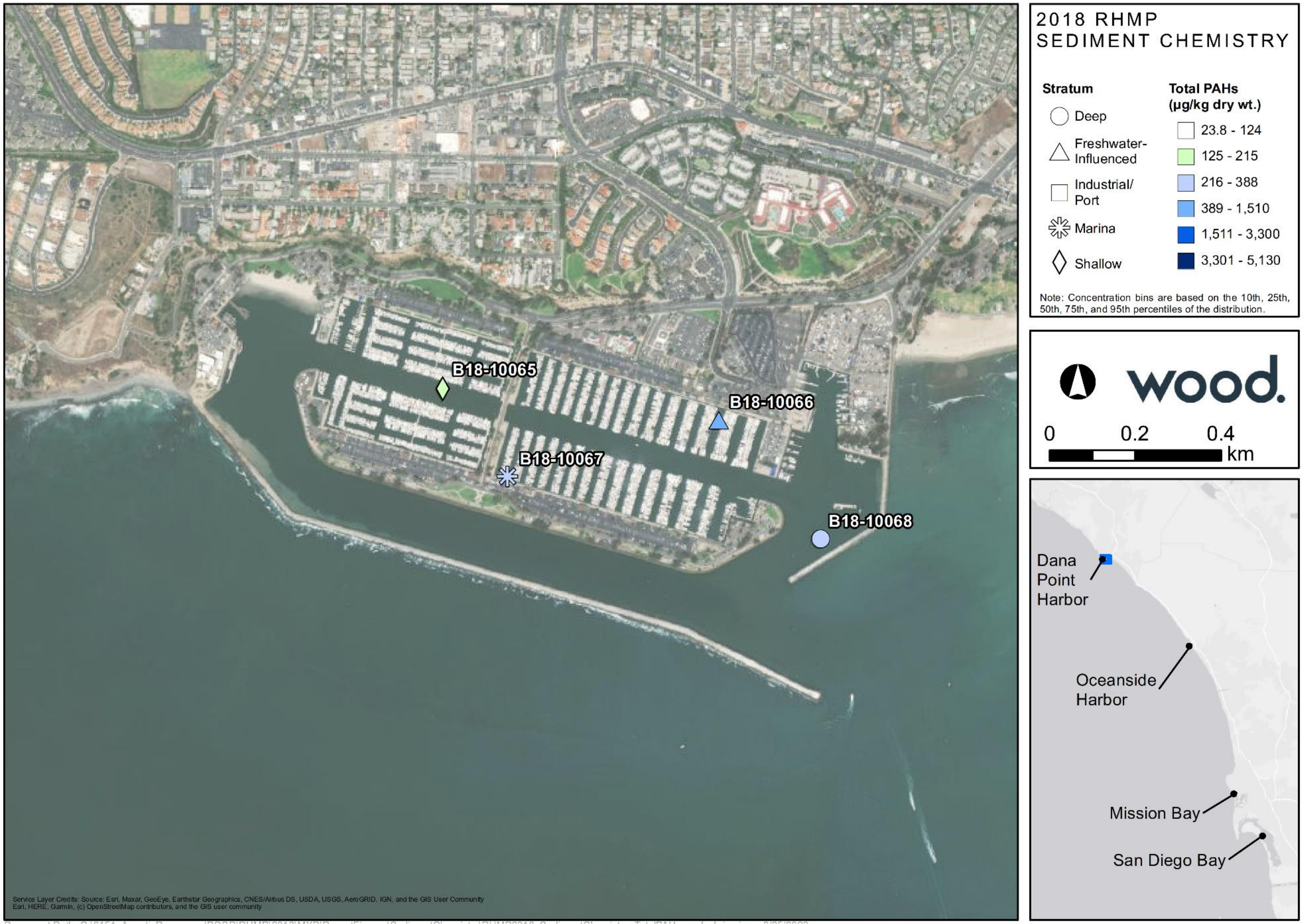

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Figure 3-25a. Spatial Distribution of Sediment Total PAH Concentrations in Dana Point Harbor

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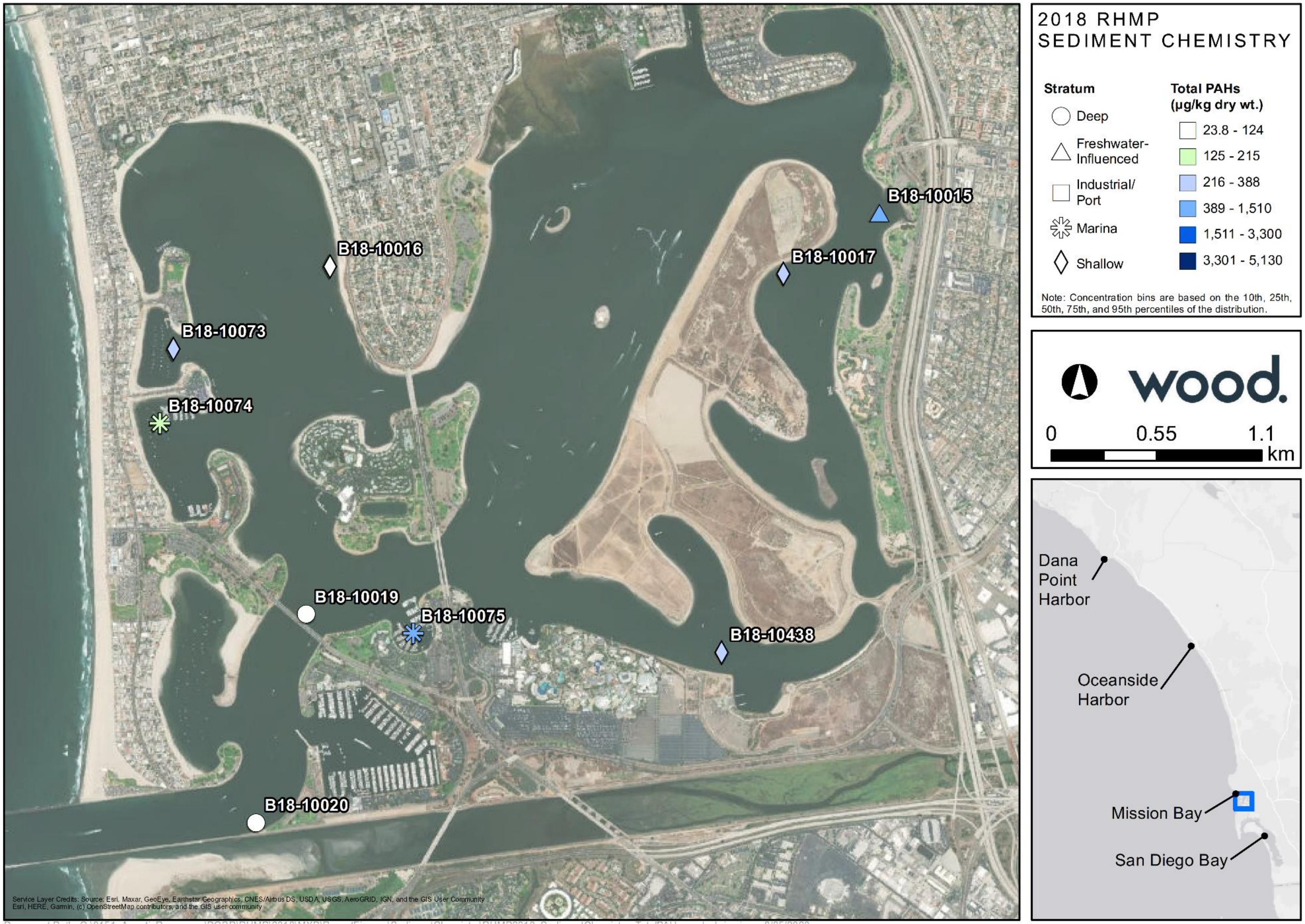
Document Path: O:\3151 AquaticResources\POSD\RHMP\2018\MXD\ReportFigures\SedimentChemistry\RHMP2018 SedimentChemistry TotalPAHs.mxd chris nixon 8/25/2020

Figure 3-25b. Spatial Distribution of Sediment Total PAH Concentrations in Oceanside Harbor



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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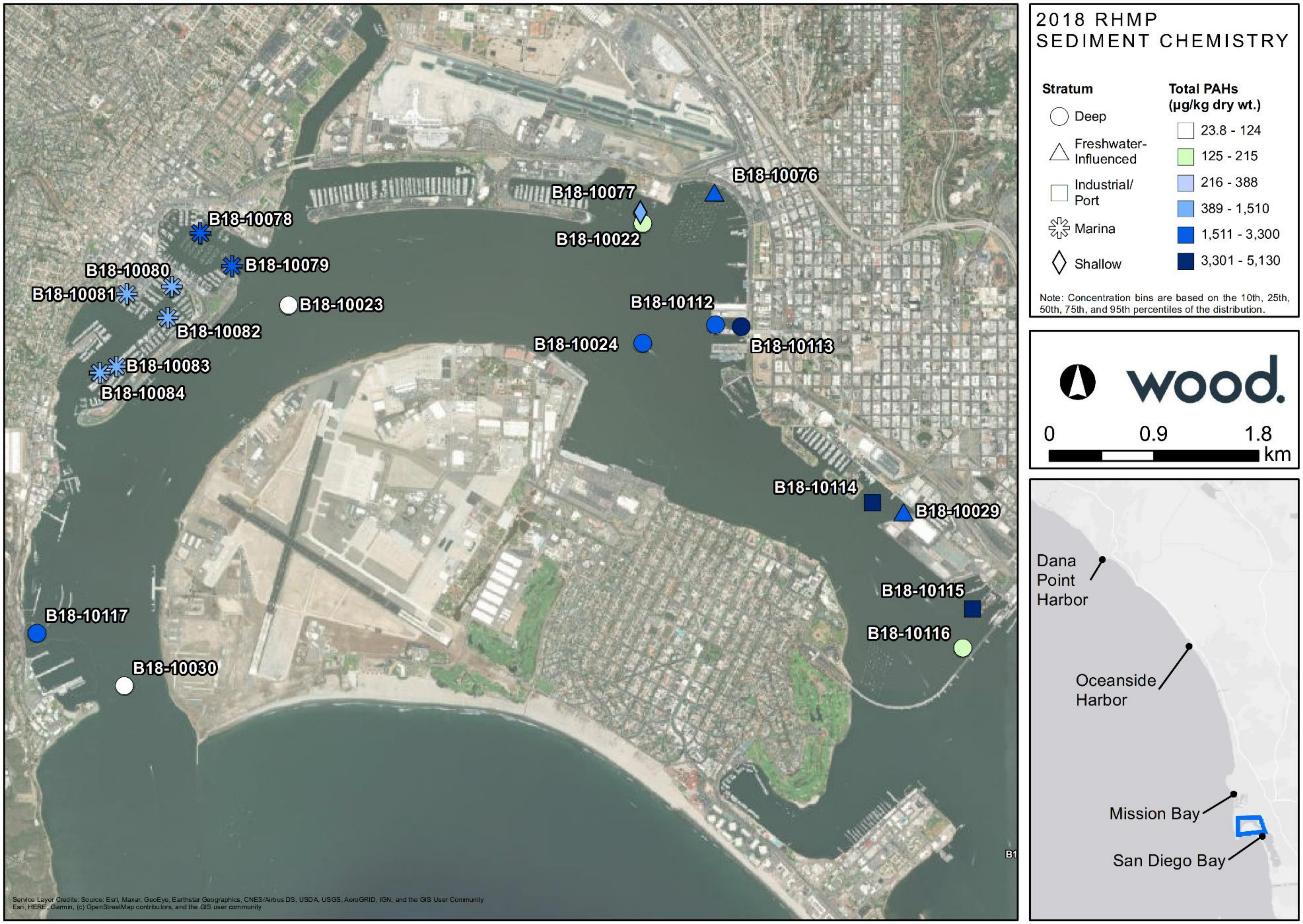
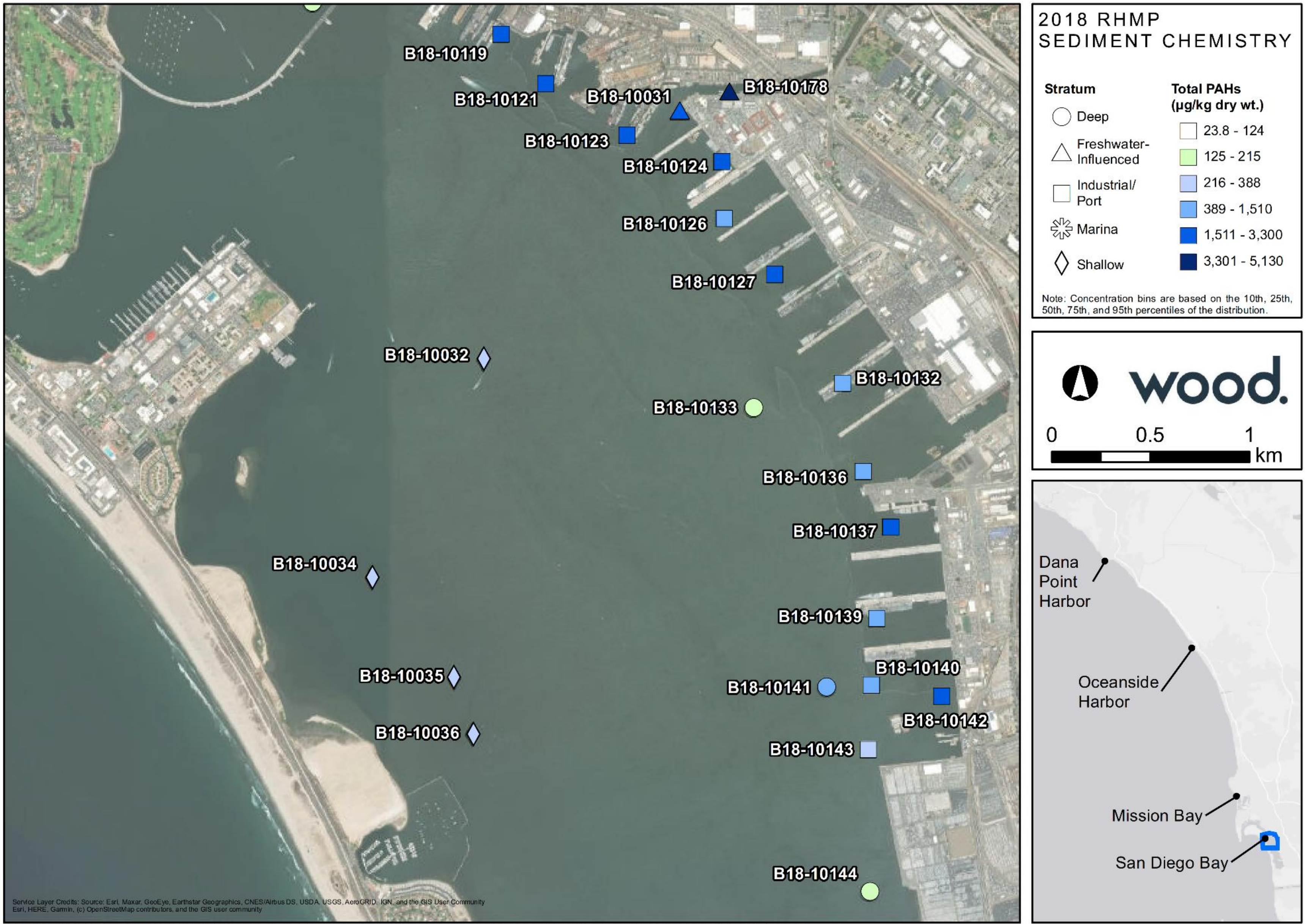
Figure 3-25c. Spatial Distribution of Sediment Total PAH Concentrations in Mission Bay



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 3-25d. Spatial Distribution of Sediment Total PAH Concentrations in North San Diego Bay



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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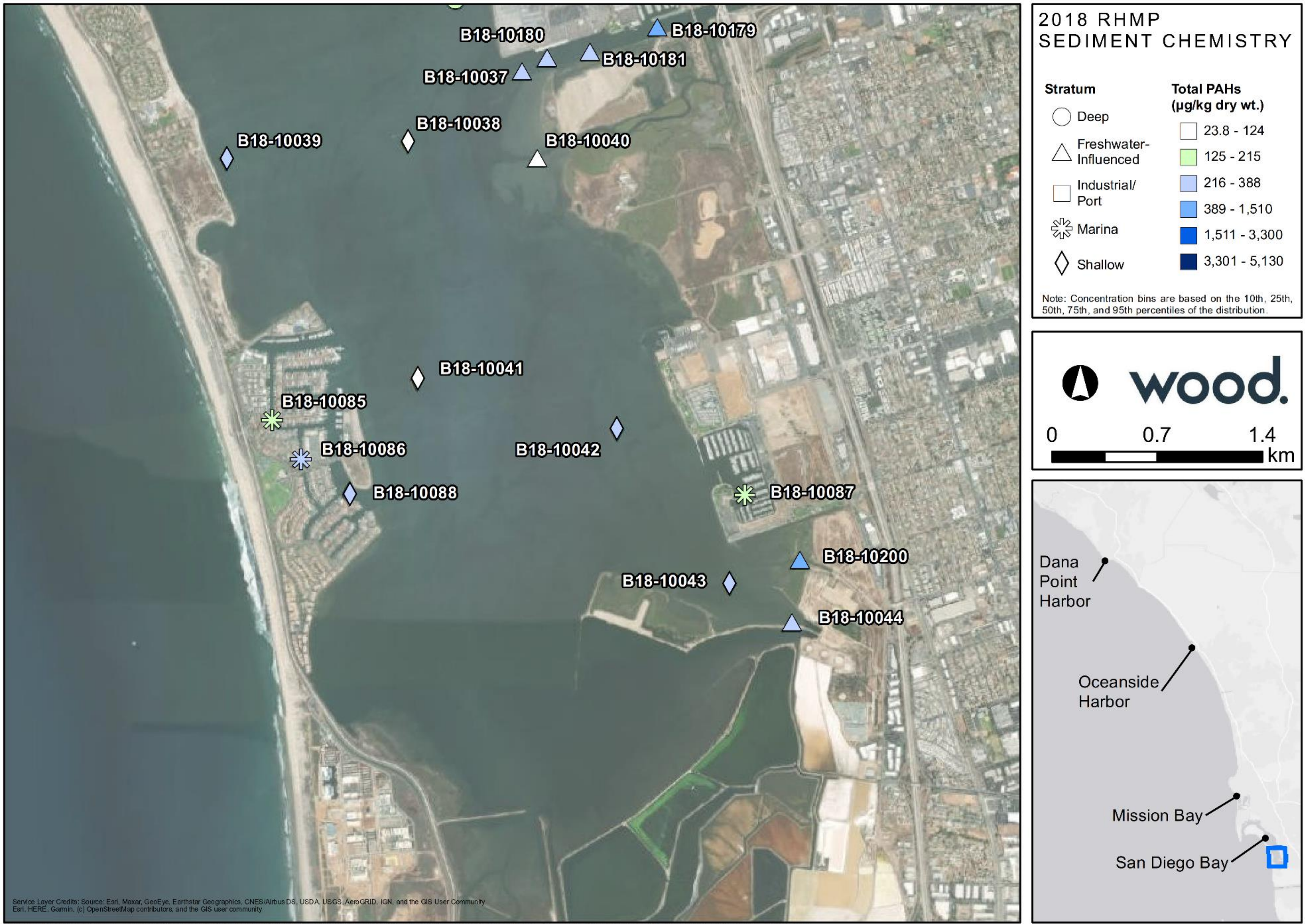
Figure 3-25e. Spatial Distribution of Sediment Total PAH Concentrations in Central San Diego Bay



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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Figure 3-25f. Spatial Distribution of Sediment Total PAH Concentrations in South San Diego Bay

Sediment concentrations of low-molecular-weight PAHs (LPAHs) and high-molecular-weight PAHs (HPAHs) were incorporated separately into the calculation of the integrated SQO CSI score. A total of 10 individual PAHs comprise the LPAH sum, and 8 individual PAHs comprise the HPAH sum as shown in Table 2-6. LPAH and HPAH concentrations are compared to CSI category thresholds in Figures 3-26 and 3-27, respectively. The majority of stations (83%) fell within the minimal exposure potential category for LPAHs. Stations within Dana Point Harbor, Oceanside Harbor, and Mission Bay were all in the minimal exposure category, as shown in Figure 3-26. A single station (B18-10113), located in the deep stratum in north San Diego Bay, was considered to have high exposure potential. See laboratory reports in Appendix F for individual LPAH concentrations.

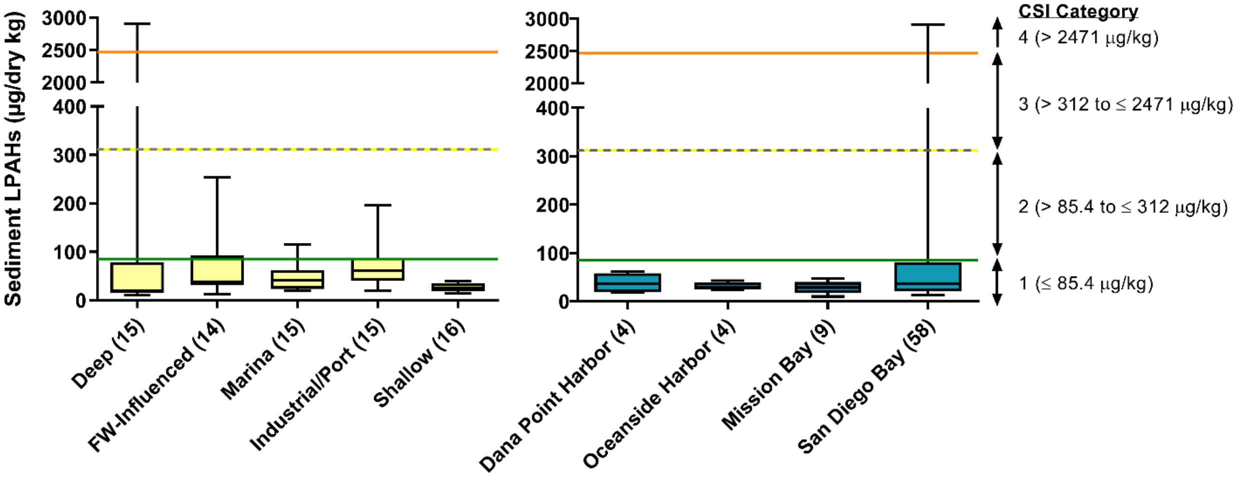

Figure 3-26. Comparisons of Sediment Total LPAHs Among Strata and Harbors to SQO CSI Category Thresholds

1 = Minimal Chemical Exposure; 2 = Low Exposure; 3 = Moderate Exposure; 4 =High Chemical Exposure

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Similarly, most stations (61%) fell within the minimal exposure category for HPAHs. All harbors had at least one station within the low exposure category, while San Diego Bay was the only harbor with stations in the moderate exposure category (eight stations; 11%), as displayed in Figure 3-27. Of the moderate exposure stations, at least one was located in each stratum, except for the shallow stratum, and were predominately found in the north and central San Diego Bay. No stations fell within the high exposure category for HPAHs. See laboratory reports in Appendix F for individual HPAH concentrations.

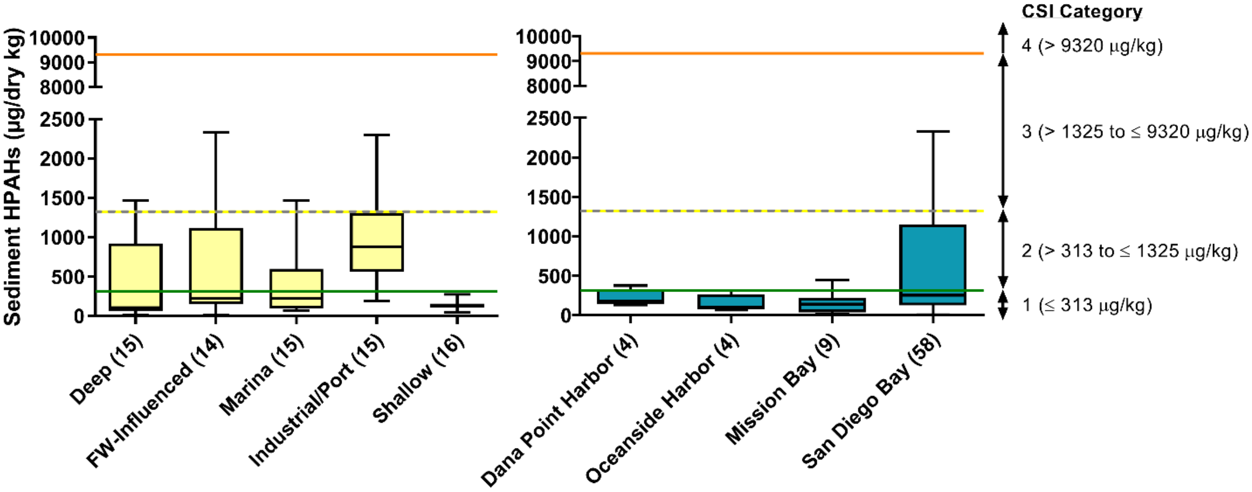

Figure 3-27. Comparisons of Sediment Total HPAHs Among Strata and Harbors to SQO CSI Category Thresholds

1 = Minimal Chemical Exposure; 2 = Low Exposure; 3 = Moderate Exposure; 4 =High Chemical Exposure

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Chlorinated Pesticides – Chlordanes and DDT

Total chlordanes represented the sum of alpha-chlordane, gamma-chlordane, *cis*- and *trans*-nonachlors, and oxychlordane. Chlordanes were only detected at 18 of 75 stations (24%), with the two highest detections located in the freshwater-influenced strata: 46.8 µg/kg central San Diego Bay (B18-10178) and 22.7 µg/kg in north San Diego Bay (B18-10029). The freshwater-influenced and industrial/port strata had the most frequent detections of total chlordane. Chlordanes were not detected at any of the stations in the deep strata, while the other strata had between one and two stations with detections of total chlordane, although none had concentrations exceeding 4.27 µg/kg.

The highest detected concentrations in Dana Point Harbor and Mission Bay were 2.21 µg/kg and 4.14 µg/kg, respectively. No total chlordane was detected in Oceanside Harbor.

Only alpha- and gamma-chlordane are included in the calculation of the integrated SQO CSI score. Figure 3-28 compares the concentrations of alpha- and gamma-chlordane among strata and harbors to the CSI exposure category thresholds. The majority of stations (87% and 85%) fell within the minimal exposure potential category for alpha-chlordane and gamma-chlordane, respectively. All stations in the moderate to high exposure categories for alpha- and gamma-chlordane were located in San Diego Bay, predominantly in the freshwater influenced and industrial/port strata. The distribution of alpha- and gamma- chlordanes among strata and harbors is shown in Figure 3-28. Given the limited frequency of detection and overall low concentrations of chlordanes, maps are not included in the text herein, but are provided for reference in Appendix F.

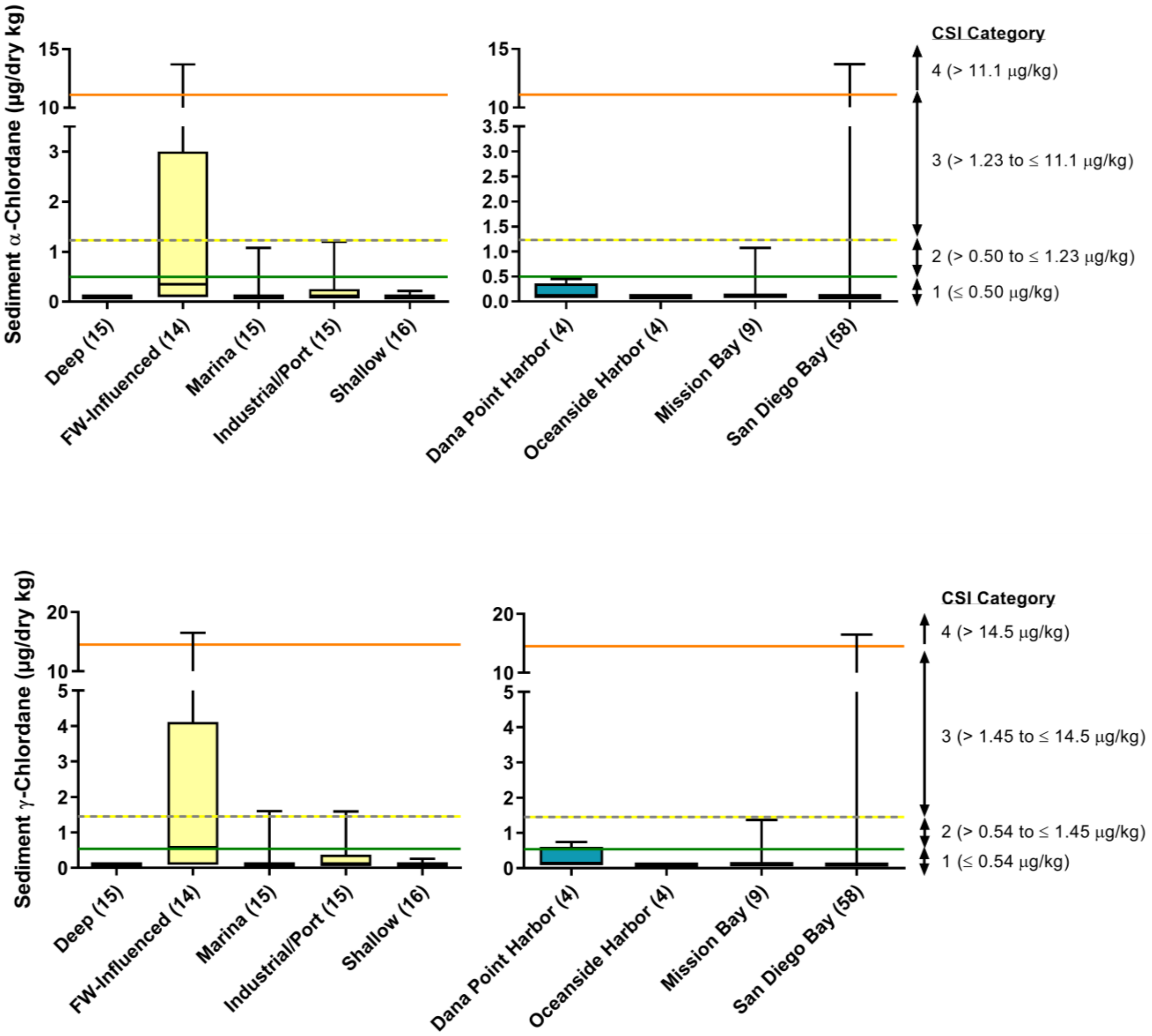

Figure 3-28. Comparisons of Sediment Alpha (α) and Gamma (γ) Chlordane Concentrations Among Strata and Harbors to SQO CSI Category Thresholds

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Total detectable DDTs (sum of DDDs, DDEs, and DDTs) were detected at 51 of 75 stations (68%), with the highest detected concentration of 221 µg/kg in the industrial/port stratum of central San Diego Bay (Site B18-10142). Stations in the industrial/port and freshwater-influenced strata had the highest median concentrations of total detectable DDTs, while stations in the shallow stratum had the lowest. San Diego Bay had the eight highest detected concentrations, while the highest concentrations in Dana Point Harbor, Oceanside Harbor, and Mission Bay were 4.05 µg/kg, 3.15 µg/kg, and 1.27 µg/kg, respectively.

Sediment concentrations of total DDDs (2,4'- and 4,4'-DDD), total DDEs (2,4'- and 4,4'-DDE), and total DDTs (2,4'- and 4,4'-DDT) were incorporated separately into the calculation of the integrated SQO CSI score. Most stations fell into the minimal to low exposure categories for total DDDs and total DDEs (95% and 97%, respectively). The few remaining stations, located in the freshwater-influenced and industrial/port strata, were considered to have moderate exposure potential. Total DDTs (the parent compound) were only detected at five stations (7%), all located in San Diego Bay; two of these stations were considered to have moderate to high exposure potential, with concentrations of 9.35 µg/kg (Station B18-10141) and 197.6 µg/kg (Station B18-10142). The distribution of total DDDs, total DDEs, and total DDTs among harbors and strata is shown in Figure 3-29. Given the limited variability and overall low concentrations of DDTs at a majority of locations, maps are not included in the text herein for this class of chemicals, but are provided for reference in Appendix F.

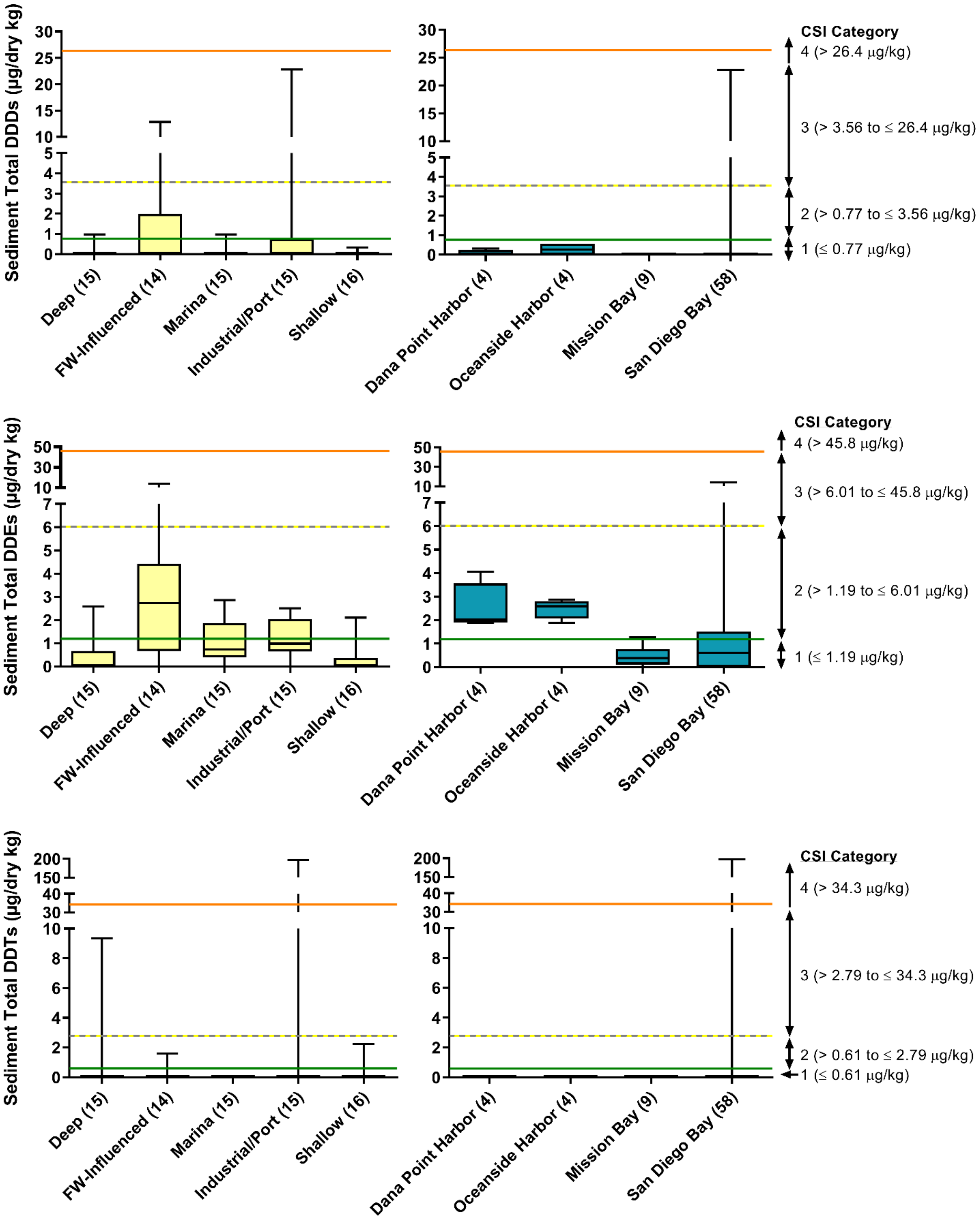

Figure 3-29. Comparisons of Sediment Total DDD, Total DDE, and Total DDT Concentrations Among Strata and Harbors to SQO CSI Category Thresholds

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Total PCBs

Concentrations of total PCBs (the sum of all 62 reported PCB congeners; see Table 2-4) ranged from non-detect (at four stations) to 5,348 µg/kg at one location in the northern portion of Oceanside Harbor (Station B18-10069). For comparison to CSI thresholds, the sum of total PCBs only includes 16 select congeners[6] multiplied by a correction factor of 1.72 to estimate a total PCB concentration in accordance with guidance in the *SQO Technical Support Manua*l (Bay et al., 2014). A reduced list of congeners was selected for the California SQO program in order to provide greater compatibility with historical data sets in California which often have a reduced congener list. The 1.72 factor is used to approximate the total concentration of PCBs based on the expanded list of 43 congeners measured in the Bight ‘18 Program[7] which is also consistent with an expanded list used historically by the National Oceanic and Atmospheric Administration (NOAA) Status and Trends Program. The list of 62 congeners (listed in Table 2-4) analyzed for RHMP includes all 43 measured by the Bight Program and is also inclusive of the 16 used for the SQOs. The list used for the SQO approach and NOAA comprises those congeners that are some of the most common ones found in commercial Aroclor mixtures, are most frequently detected in environmental samples, and also includes those identified as being predicted to be the most toxic (NOAA, 1993; Sericano, 1993).

The distribution of total PCBs (including only the 16 SQO congeners) among harbors and strata is provided in Figure 3-30 for comparison to CSI thresholds. When applying the 1.72 correction factor to the sum of the 16 congeners used for the SQO calculation, the median total PCB concentration comprised an average 94% of the total PCBs based on the sum of all 62 congeners measured by the RHMP.

Using the CSI thresholds, 77% of stations were categorized as having either minimal or low exposure potential. All sixteen stations (21%) in the moderate exposure category were located in San Diego Bay, while the only station in the high exposure category was in Oceanside Harbor (Station B18-10069). The concentration of total PCBs at Station B18-10069 was more than 22 times greater than the next highest concentration measured in the RHMP suggesting a localized area of concern at this location.

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[6] Including PCB-8, 18, 28, 44, 52, 66, 101, 105, 110, 118, 128, 138, 153, 180, 187, and 195 (Bay et al., 2014)

[7] Including PCB-8, 18, 28, 37, 44, 49, 52, 66, 70, 74, 77, 81, 87, 99, 101, 105, 110, 114, 118, 119, 123, 126, 128, 138, 149, 151, 153, 156, 157, 158, 167, 168, 169, 170, 177, 180, 183, 187, 189, 194, 195, 201, and 206 (SCCWRP 2018 Quality Assurance Manual).

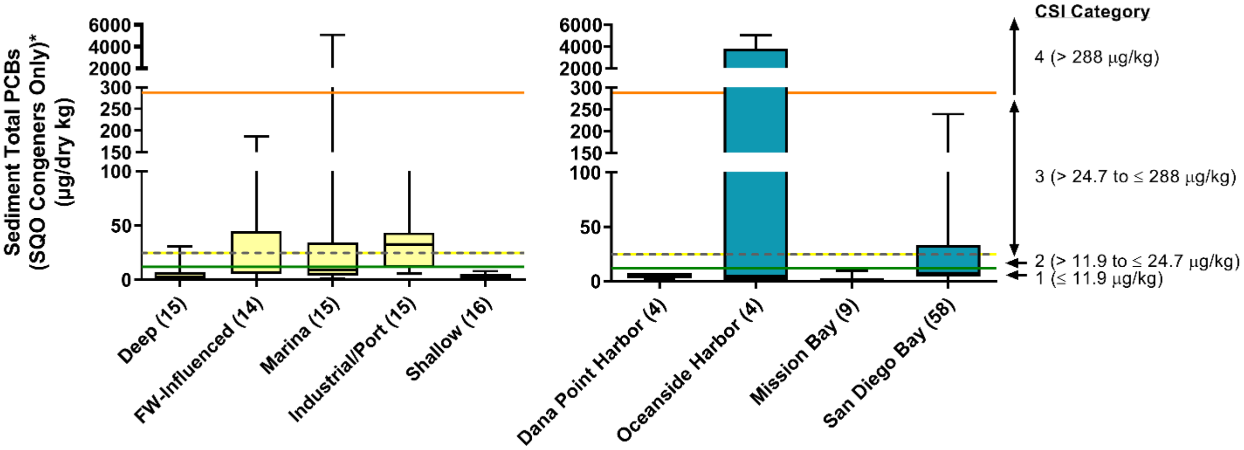
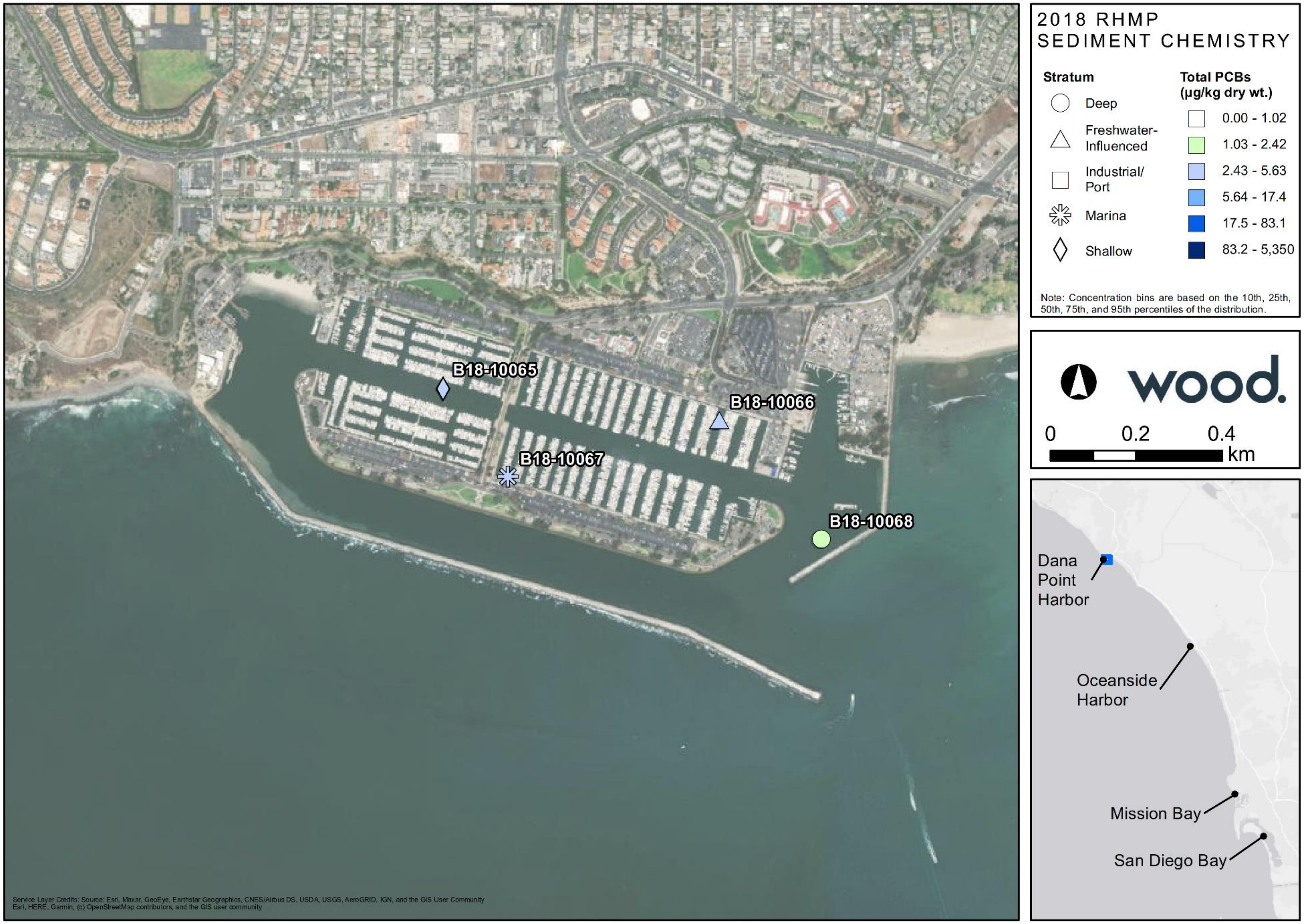


Figure 3-30. Comparisons of Sediment Total PCB Concentrations (SQO Congeners Only)* Among Strata and Harbors to SQO CSI Category Thresholds

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

** Total PCBs for CSI comparison used the sum of 16 select PCB congeners (PCB-8, 18, 28, 44, 52, 66, 101, 105, 110, 118, 128, 138, 153, 180, 187, and 195) multiplied by a correction factor of 1.72 to estimate a total concentration according to the SQO Technical Manual (Bay et al., 2014). Box plots showing total PCBs, including all 62 reported congeners, are included in Appendix F for comparison. Note that this list is a subset of the total 209 PCB congeners.*

The spatial distribution of total PCBs (sum of all 62 measured congeners) among harbors is shown in Figures 3-31a through 3-31f. Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution of sediment PCB concentrations measured in the 2018 RHMP.



Note: Concentration bins are based on the 10th, 25th, 50th, 75th, and 95th percentiles of the distribution.

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Figure 3-31a. Spatial Distribution of Sediment Total PCB Concentrations in Dana Point Harbor

Note: Concentrations of total PCBs presented in maps is equal to the sum of all 62 reported congeners (Table 2-4).

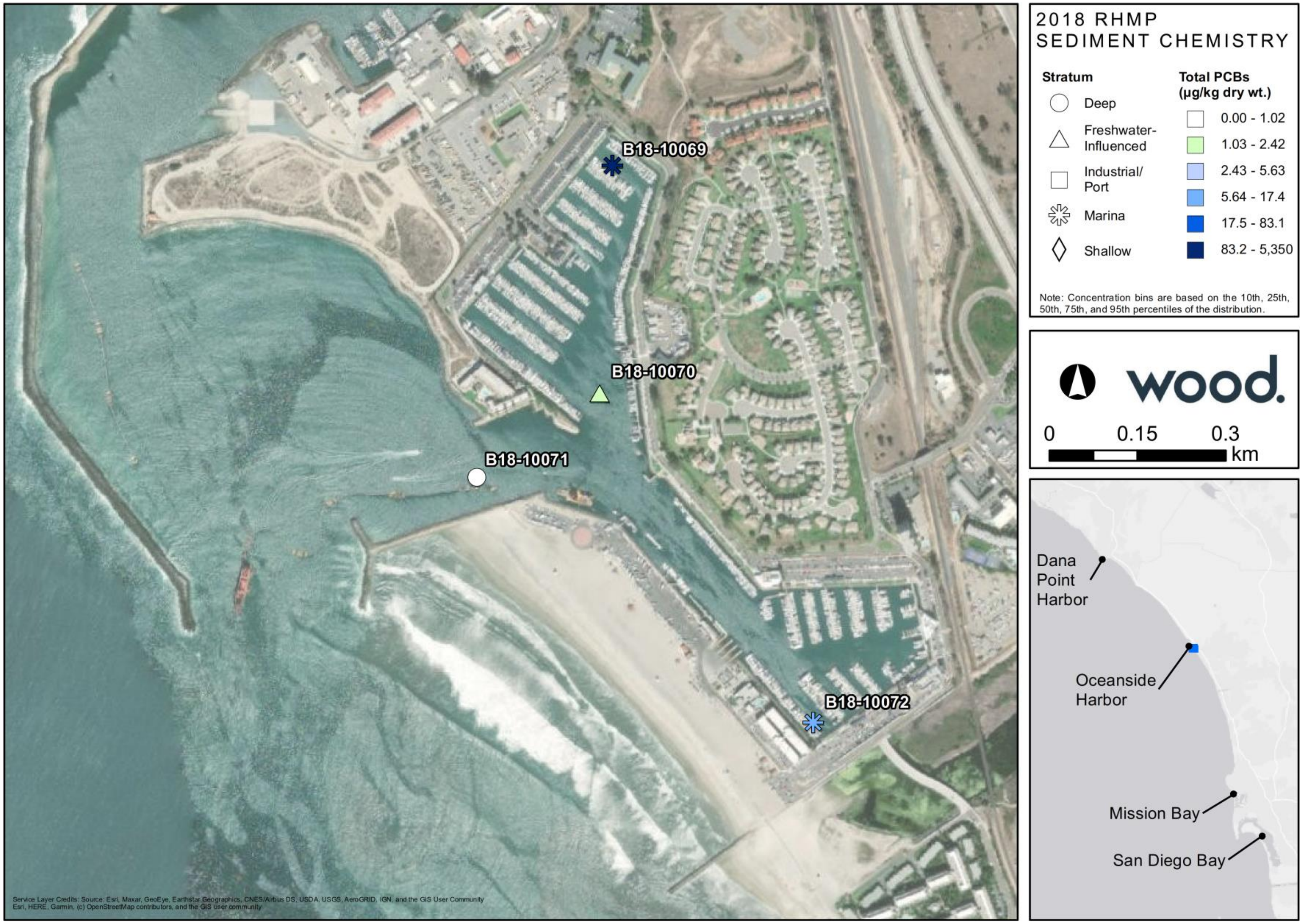

Figure 3-31b. Spatial Distribution of Sediment Total PCB Concentrations in Oceanside Harbor

Note: Concentrations of total PCBs presented in maps is equal to the sum of all 62 reported congeners (Table 2-4).

Figure 3-31c. Spatial Distribution of Sediment Total PCB Concentrations in Mission Bay

Note: Concentrations of total PCBs presented in maps is equal to the sum of all 62 reported congeners (Table 2-4).

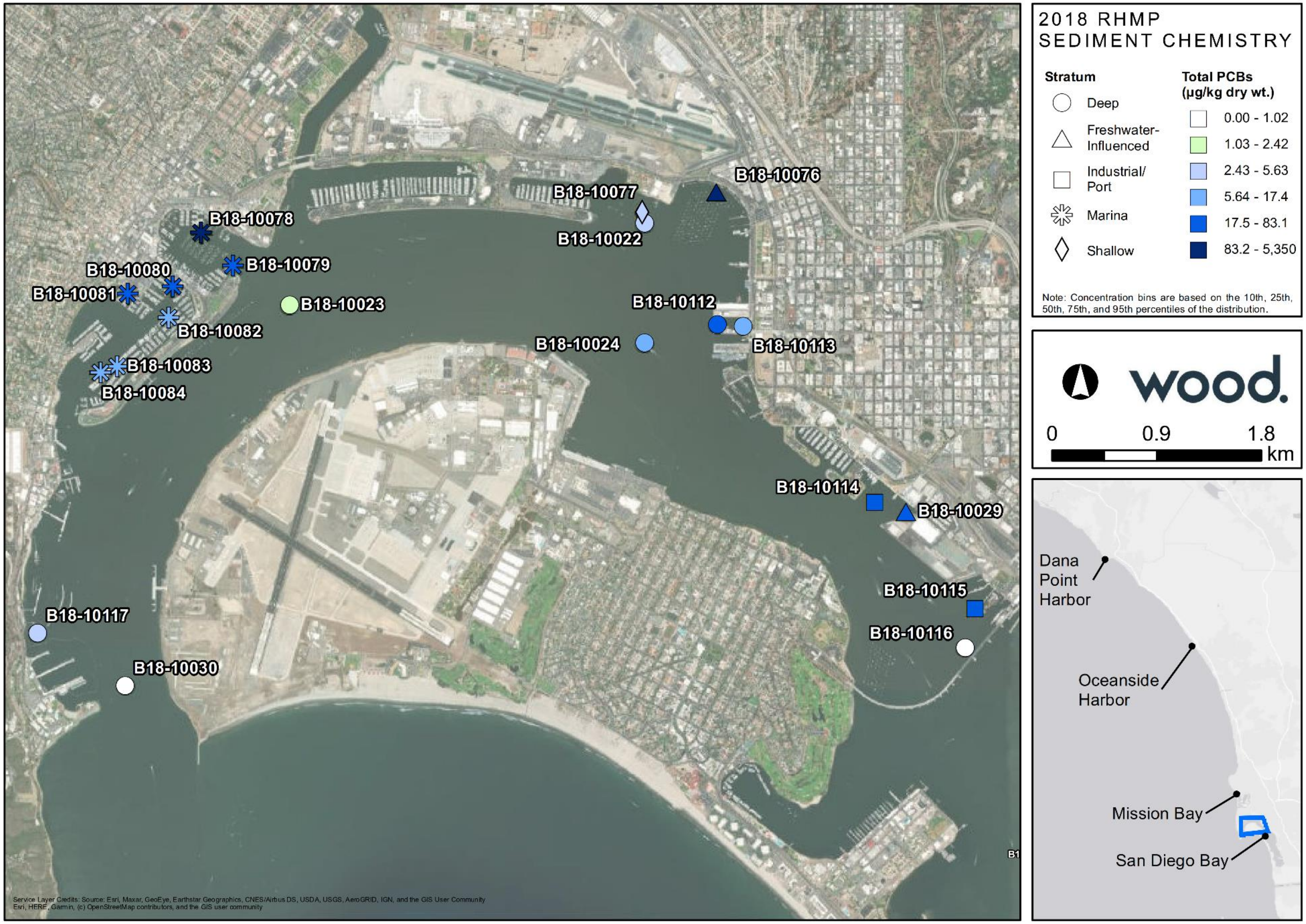

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Figure 3-31d. Spatial Distribution of Sediment Total PCB Concentrations in North San Diego Bay

Note: Concentrations of total PCBs presented in maps is equal to the sum of all 62 reported congeners (Table 2-4).

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Figure 3-31e. Spatial Distribution of Sediment Total PCB Concentrations in Central San Diego Bay

Note: Concentrations of total PCBs presented in maps is equal to the sum of all 62 reported congeners (Table 2-4).

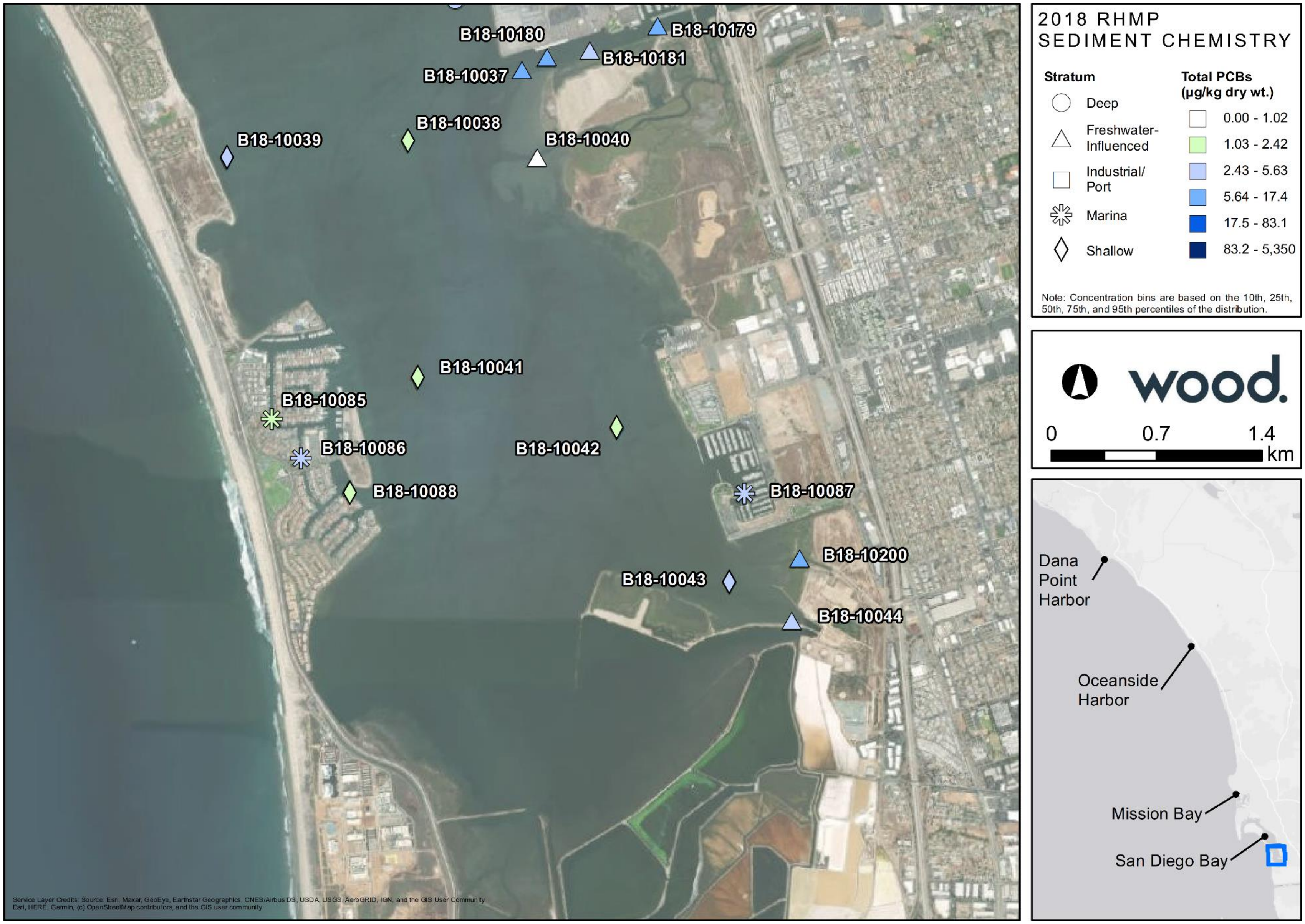


Figure 3-31f. Spatial Distribution of Sediment Total PCB Concentrations in South San Diego Bay

Note: Concentrations of total PCBs presented in maps is equal to the sum of all 62 reported congeners (Table 2-4).

Other Sediment Contaminants of Potential Concern

A summary of results for two additional broad classes of compounds of potential concern identified by both the Bight Program and RHMP (current use pesticides and PBDEs) that are not included in the SQO calculations are summarized below. Of the pesticides, pyrethroids have been identified as a class of greatest concern due to their current widespread use and documented toxicity to sediment dwelling organisms at very low concentrations, hence a greater focus on this class compared to other current use pesticides which were all detected infrequently in 2018. Further discussion on their history of use and potential for toxicity and bioaccumulation based on measurements made in 2018 are provided in the Discussion Section 4.2.3.

Total Pyrethroids

During the 2018 RHMP, 39% of stations (n = 29) had non-detectable concentrations of pyrethroids in the sediment (<0.28 µg/kg). Total pyrethroid concentrations were dominated by detections of bifenthrin and permethrin, accounting for 80 to 100% of the total concentrations measured. Concentrations of pyrethroids were highest in the freshwater-influenced stratum, where pyrethroids were detected at 13 of 14 stations (93%). The highest pyrethroid concentrations were measured in San Diego Bay, focused around freshwater-influenced stations near the mouths of Chollas Creek (127 µg/kg), Switzer Creek (57.4 µg/kg), and the storm drain in the Laurel Hawthorn embayment (23.1 µg/kg). Dana Point Harbor (highest detected concentration of 32.0 µg/kg), Oceanside Harbor (3.15 µg/kg), and Mission Bay (13.9 µg/kg) also had numerous stations with detected pyrethroids (Figure 3-32, Appendix F). Given the relatively low frequency of detection of pyrethroid pesticides at elevated concentrations across all RHMP sites, maps are not included in the text herein for this class of chemicals, but are provided for reference in Appendix F.

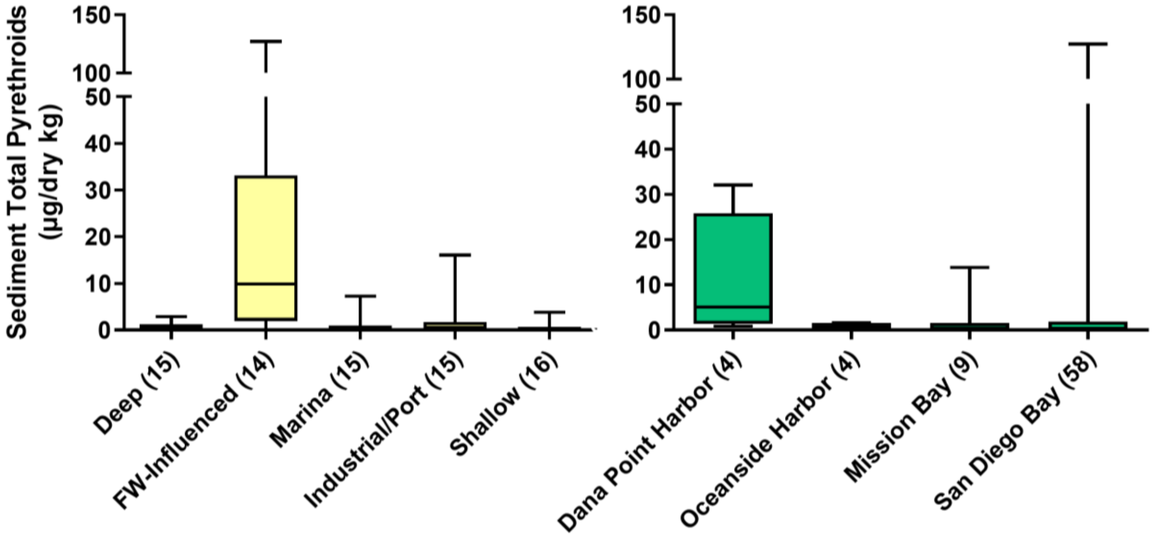


Figure 3-32. Comparisons of Sediment Total Pyrethroid Concentrations Among Strata and Harbors

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses. Pyrethroid pesticides are not included in the CSI calculation hence the exclusion of exposure category lines on this figure.

Other Pesticides

A suite of additional pesticides (including toxaphene, fipronil, and others) was analyzed and reported for the RHMP with complete results provided in the laboratory reports in Appendix F. A vast majority of these compounds, with a few exceptions, were not detected.

Fipronil was detected in sediments at only five RHMP locations (7%), four of which were in the freshwater-influenced stratum. Detected concentrations of fipronil ranged from 0.29 to 3.85 µg/kg in the freshwater-influenced stratum in central San Diego Bay. Detections of less than 2 µg/kg were also detected in north San Diego Bay (freshwater-influenced and deep strata) and in the freshwater-influenced stratum in Dana Point Harbor.

Total PBDEs

During the 2018 RHMP, concentrations of total PBDEs were detectable at 79% of stations (n=59), ranging from non-detect (less than 0.05 µg/kg) to 58.6 µg/kg, with the highest concentrations observed in the freshwater-influenced stratum and in Dana Point Harbor and Oceanside Harbor (Figure 3-33). Maps comparing the distributions of total PBDEs among strata and harbors are included in Appendix F.

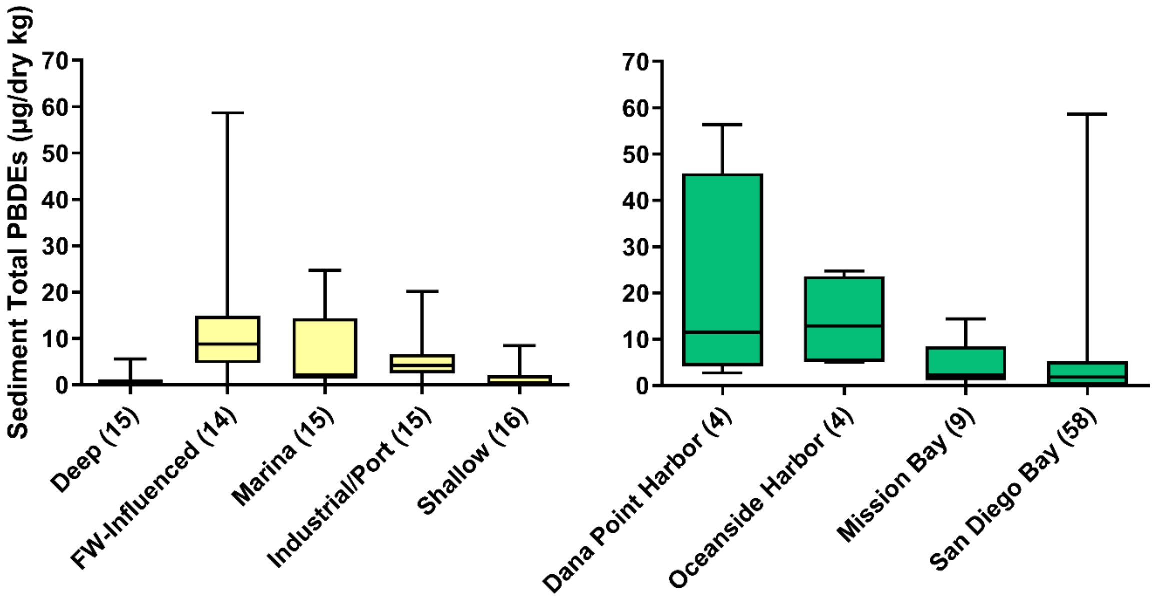


Figure 3-33. Comparisons of Sediment Total PBDE Concentrations Among Strata and Harbors

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses. PBDEs are not included in the CSI calculation hence the exclusion of exposure category lines on this figure.

Sediment Chemical/Physical Properties that may Influence Toxicity and Distribution of Contaminants of Potential Concern

Several chemical/physical properties of the sediments were analyzed that can provide important information on the distribution and potential toxicity of associated contaminants of concern. Three key physical properties measured for RHMP included SEM, AVS, TOC, and grain size. The ∑SEM:AVS ratio provides a measure of expected bioavailability of trace metals, and both TOC and grain size can have a strong influence on the binding of contaminants of concern, altering their distribution and bioavailability. A summary of results for these physical parameters and relationships to both sediment chemistry and toxicity is provided below.

Simultaneously Extracted Metals-Acid Volatile Sulfide (SEM-AVS)

An evaluation of the relationship between SEM and AVS was performed to assess the potential for heavy metals (cadmium, copper, lead, nickel, silver, and zinc) found in the sediment to cause toxic effects on benthic infauna. A summed SEM to AVS (∑SEM:AVS) ratio value of 40 or higher was considered to be a threshold above which trace metals are likely to become bioavailable at toxic concentrations to sediment dwelling organisms, as determined by Weston following a review of published literature and historical data for the RHMP (Weston, 2005b).

Only one site, Station B18-10080 located in the marina stratum within the inner portion of SIYB in San Diego Bay had an ∑SEM:AVS ratio that was greater than the threshold value of 40 (as shown in Table 3-10 and Figure 3-34); however, this site was also found to be non-toxic to both amphipods and bivalve embryos, though neighboring Site B18-10082 showed moderate toxicity to the bivalve.

Table 3-10.
SEM-AVS Threshold Comparison by Stratum

Indicator	**Threshold Value**[a]	**Percentage of 2018 RHMP Stations Meeting the Threshold Value**					
		Deep (%)	**Freshwater-Influenced (%)**	**Marina (%)**	**Industrial/ Port (%)**	**Shallow (%)**	**All Stations (%)**
# of stations		*15*	*14*	*15*	*15*	*16*	*75*
∑SEM:AVS Ratio	40	100	100	93	100	100	99

Notes:
a. The target value of 40 is a ratio of the sum of SEM to AVS. Values below the threshold of 40 are predicted to have limited trace metal bioavailability due to the presence of sulfide.
% = percent; ∑SEM:AVS = ratio of the sum of simultaneously extracted metals (SEM) to acid volatile sulfide (AVS)

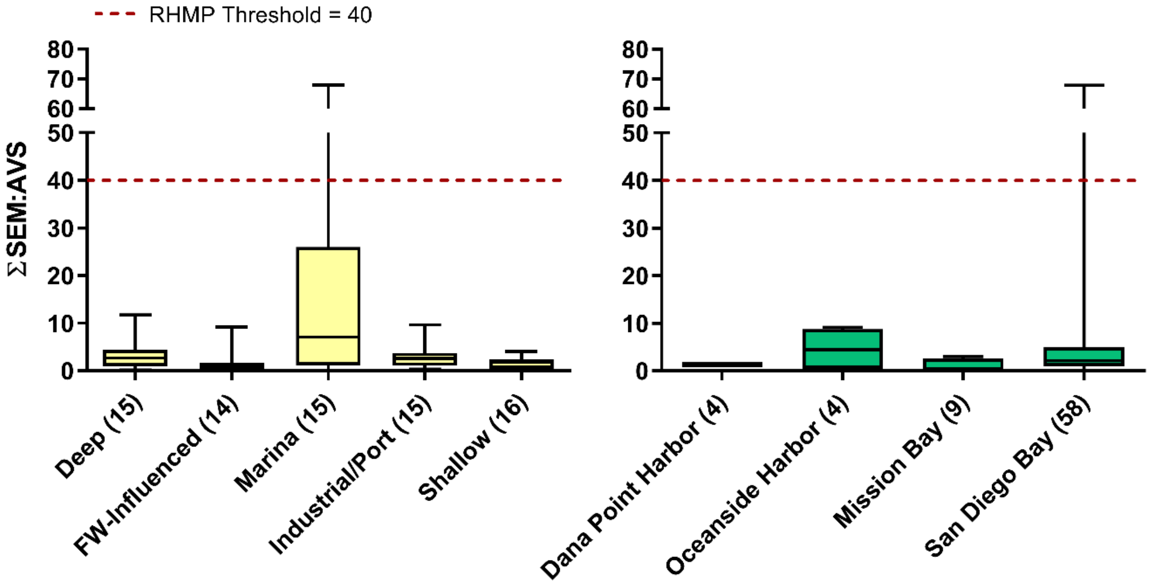


Figure 3-34. Comparisons of Sediment ∑SEM:AVS Ratios in Sediments Among Strata and Harbors

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Relationship Between ∑SEM:AVS and Amphipod Toxicity

The bioavailability of metals, as indicated by ∑SEM:AVS, was statistically correlated with amphipod survival, but the relationship was very weak and driven primarily by the single data point in SIYB with elevated ∑SEM:AVS. The ∑SEM:AVS was not correlated with a measure of the benthic community condition based on BRI scores (Figure 3-35).

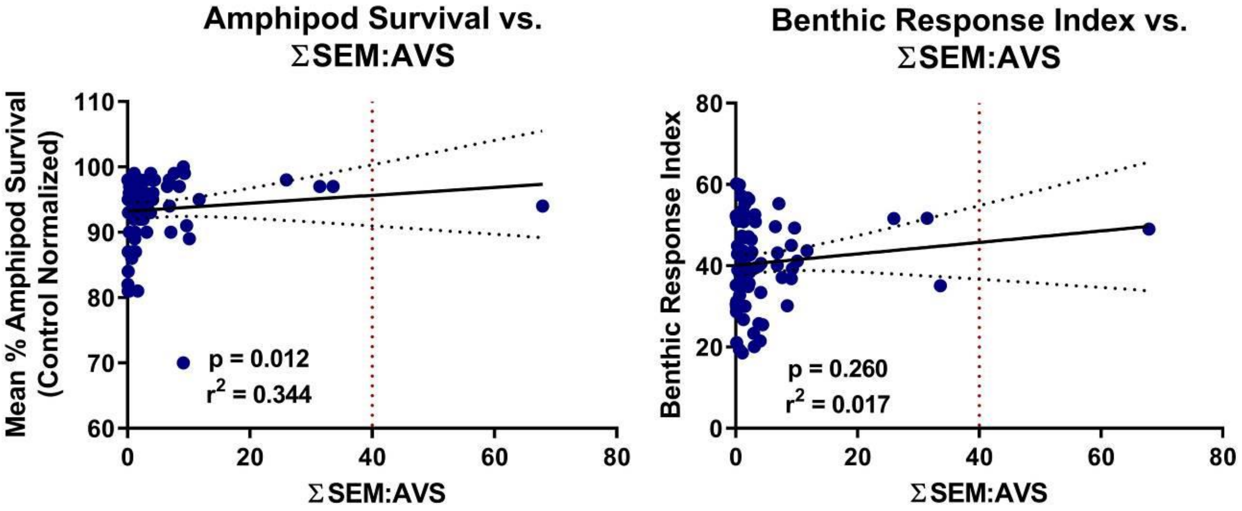


Figure 3-35. Relationship of ∑SEM:AVS to Amphipod Survival and the Benthic Response Index

Calculation of the ESB metric (USEPA, 2005) for the 2018 RHMP data found several stations among all strata with values between 130 and 3,000 µmol/gOC, which is considered to potentially result in toxic effects due to trace metals, but none with a value greater than 3,000 µmol/gOC, where toxicity is more certain, as shown in Figure 3-36 among all strata and harbors.

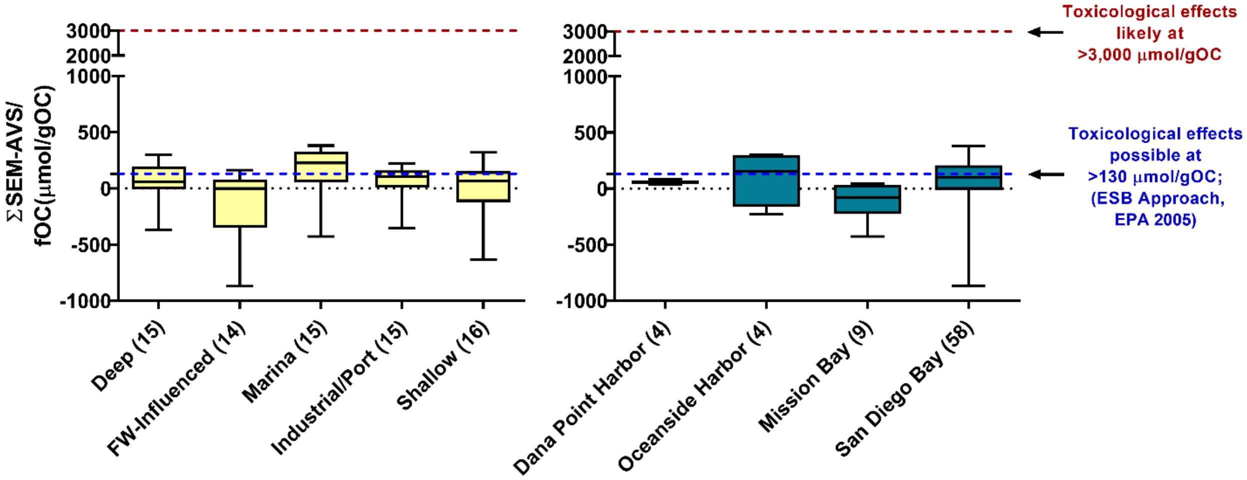


Figure 3-36. Concentrations of SEM-AVS Normalized to Organic Carbon Among Strata and Harbors to Assess the Bioavailability of Trace Metals Using the USEPA Equilibrium Partitioning Sediment Benchmark Approach

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Grain Size and TOC

Physical characteristics, including sediment TOC and grain size, are summarized in Table 3-8 with the complete dataset provided in Appendix F. Grain size and TOC data are used to help interpret biological responses and to help understand the distribution of contaminants within sediments, as elevated TOC and fine grained size particles tend to be associated with elevated chemistry where anthropogenic influences are likely. Elevated TOC and fine grain size can also reduce the bioavailability of contaminants of concern through physical binding processes.

The grain size characteristics of sediments varied considerably among sites both within individual strata and between the harbors (Figure 3-37). Several locations in the deep and freshwater strata in Mission Bay and San Diego Bay had uniform sandy sediments with less than 10% fines (silt + clay) while multiple locations in all of the different strata had sediments that were >60% fines. Among the strata, the finest sediments on average were noted in the industrial/port stratum, but also varied substantially ranging from 19 to 88% fines. Sediments in Dana Point Harbor and Oceanside Harbor were the most consistent regionally ranging from 44 to 67% fines among these sites collectively. The variability in grain size characteristics throughout Mission Bay and San Diego Bay in particular, highlights the physical complexity of these environments.

TOC also varied considerably from a low of 0.1% at Site B18-10116 in the deep strata in north San Diego Bay to 3.5% at freshwater-influenced Site B18-10178 within the mouth of Chollas Creek in central San Diego Bay. The distribution of TOC by strata and harbor are depicted in Figure 3-38.

Maps showing the distribution of TOC are provided for reference in Appendix F.

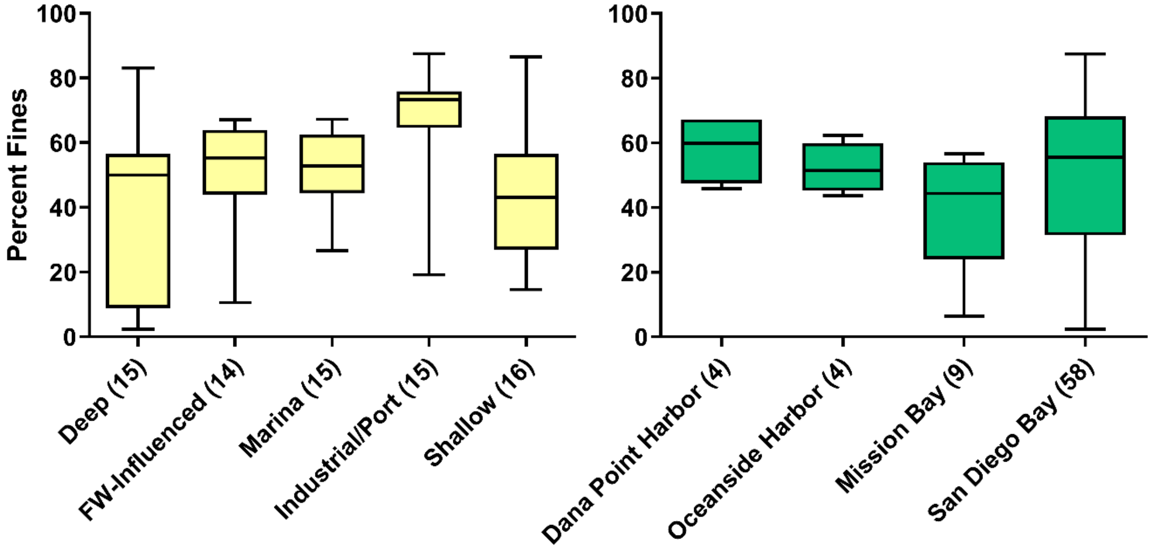


Figure 3-37. Comparisons of Percent Fine Grain Size Fractions Among Strata and Harbors

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

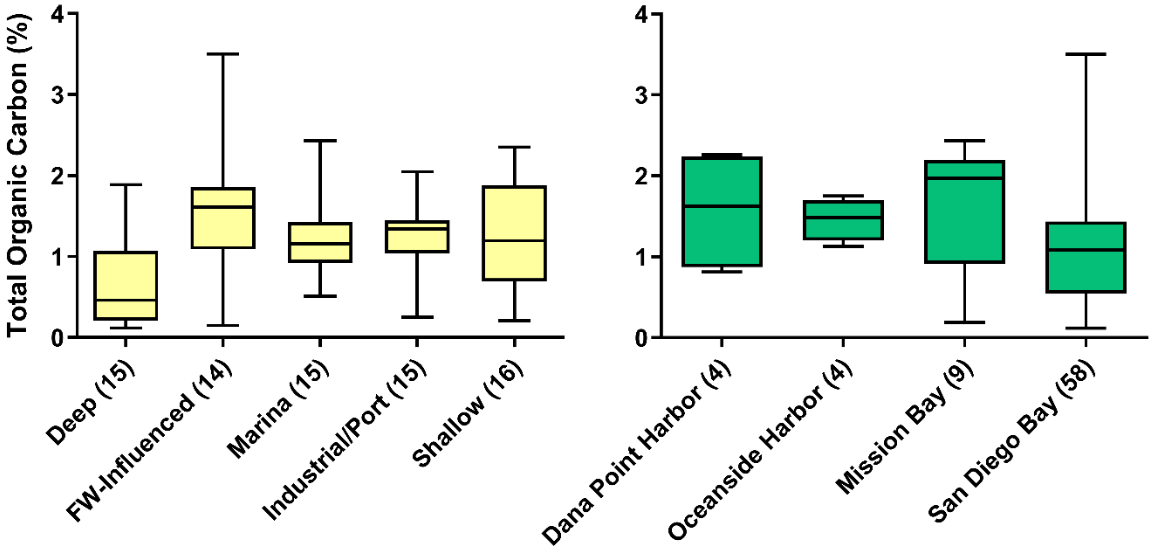


Figure 3-38. Comparisons of Total Organic Carbon Fractions Among Strata and Harbors

Box plots showing median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

SQO Chemistry Lines of Evidence

Chemical SQO analysis included the integration of two sediment chemistry quality guidelines: the CA LRM and the CSI (discussed in the Methods Section 2.5.2). The integration of these two indices yields the final chemistry LOE, which provides a measure of the estimated magnitude of chemical exposure at each station, based on a scale of four exposure categories (minimal, low, moderate, and high).

Overall, 57% percent of the RHMP stations in 2018 were categorized as having minimal or low chemical exposure (Table 3-11). The majority of stations within the deep (93%) and shallow (87%) strata were categorized as having either minimal or low exposure potential. The only strata classified as having stations with minimal exposure were deep (33%) and freshwater-influenced (7%). The majority of stations within marina (73%) and industrial/port (80%) strata were categorized as having either moderate or high exposure potential.

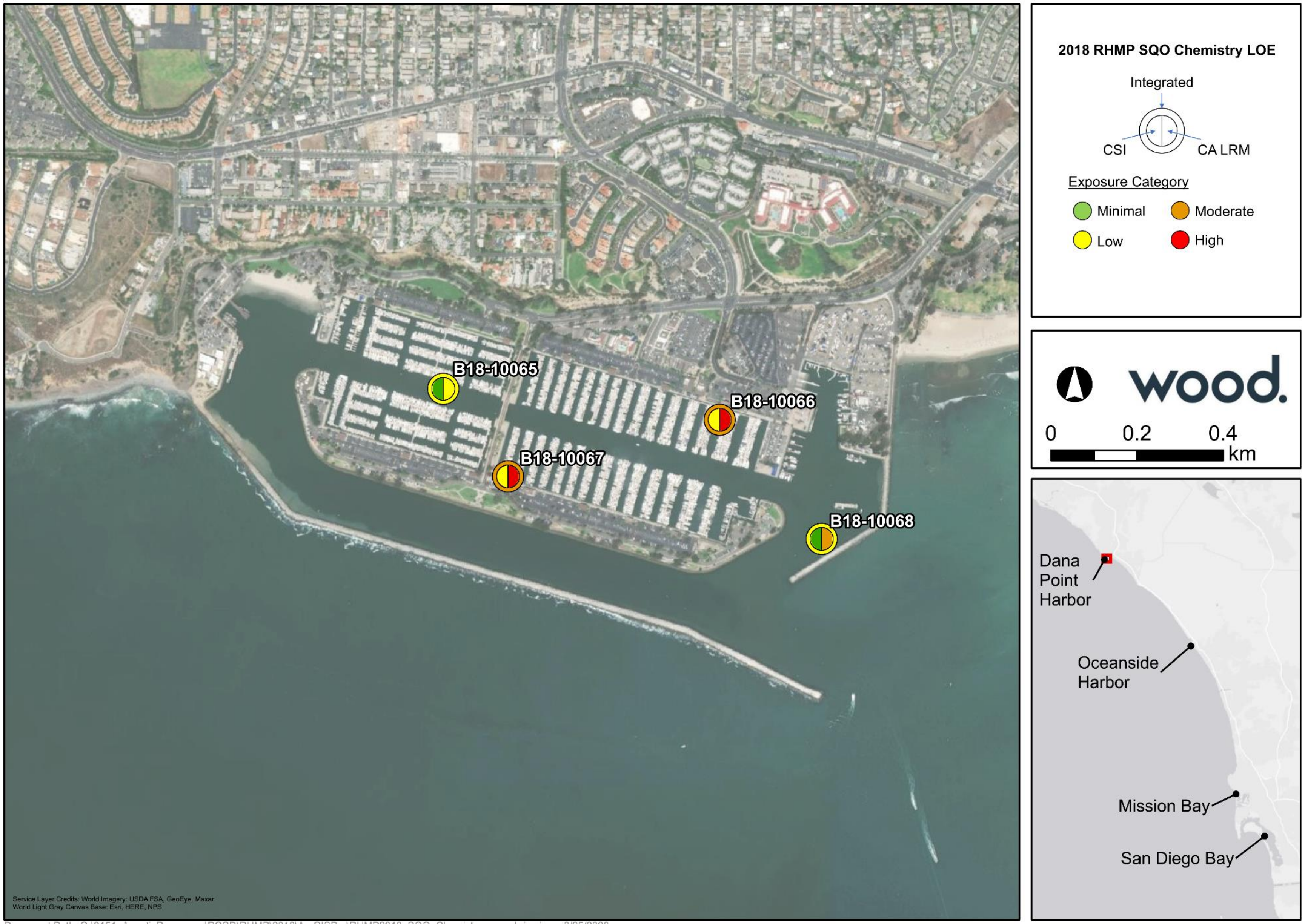
Table 3-11.
Percentage of RHMP Stations in each Sediment Quality Objective Chemistry LOE Category

Chemistry LOE Category	Percentage of 2018 RHMP Stations Per Chemistry LOE Category					
	Deep (%)	Freshwater-Influenced (%)	Marina (%)	Industrial/ Port (%)	Shallow (%)	All Stations (%)
# of stations	*15*	*14*	*15*	*15*	*16*	*75*
Minimal Exposure	33	7	0	0	0	8
Low Exposure	60	50	27	20	87	49
Moderate Exposure	7	29	73	67	13	38
High Exposure	0	14	0	13	0	5

Notes:
% = percent; LOE = line of evidence

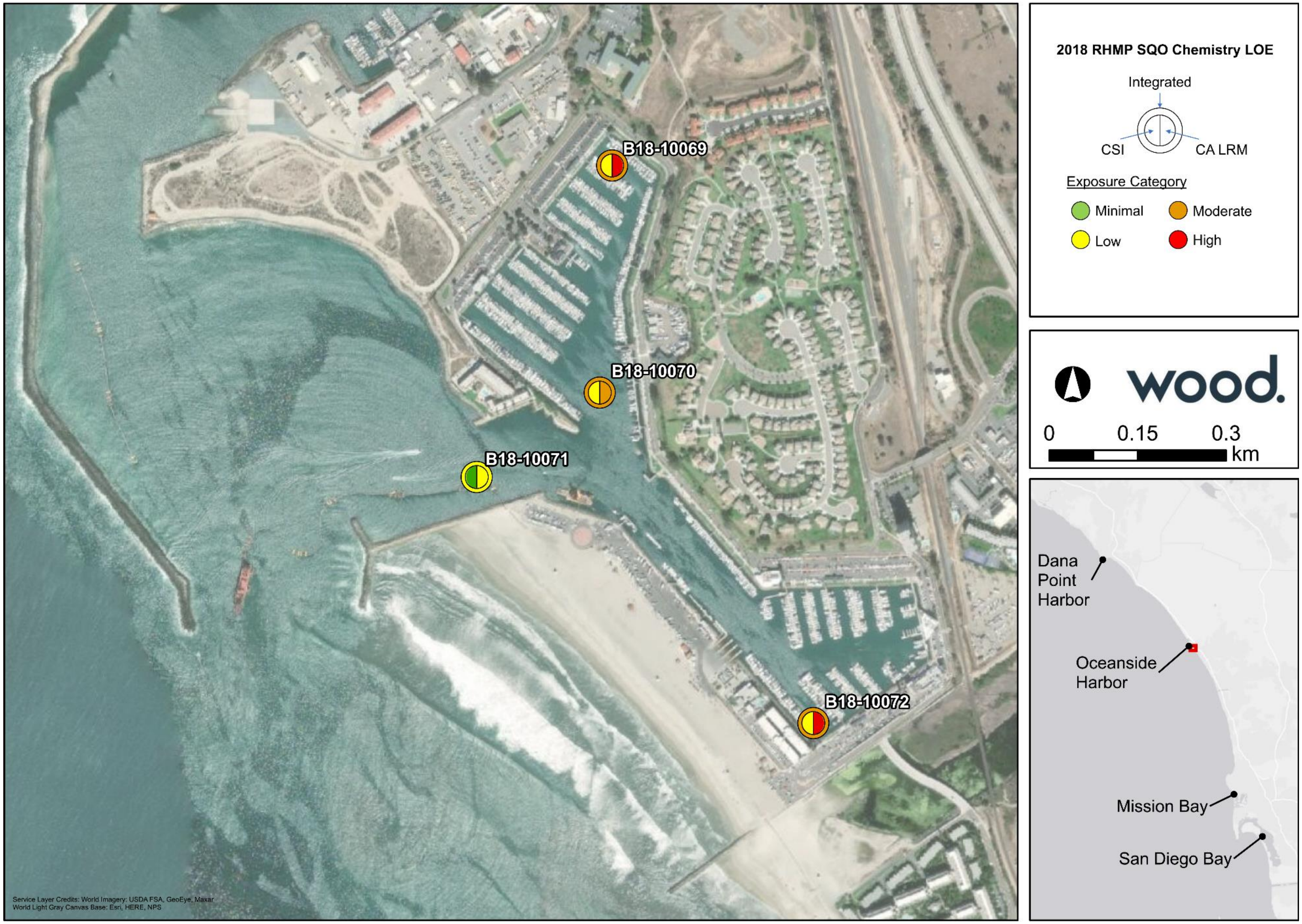
Analysis of each harbor found only San Diego Bay to have stations with high exposure potential following the SQO approach, with 7% (4 of 58) of the San Diego Bay stations falling in this category (see Figures 3-39d and 3-39f). In 2018, the fraction of stations with minimal to low exposure categories for the SQO chemistry LOE was 50% in Dana Point Harbor, 25% in Oceanside Harbor, 89% in Mission Bay, and 55% in San Diego Bay.

A summary of integrated SQO scores showing results for both the CA LRM and CSI (half circles), and an integrated score derived from these two metrics (shown by the outer ring), are displayed on maps for all harbors in Figures 3-39a through 3-39f. Note that in many cases there is disagreement of 1 to 2 categories between the two sediment chemistry SQO indices with the LRM more conservative throughout.



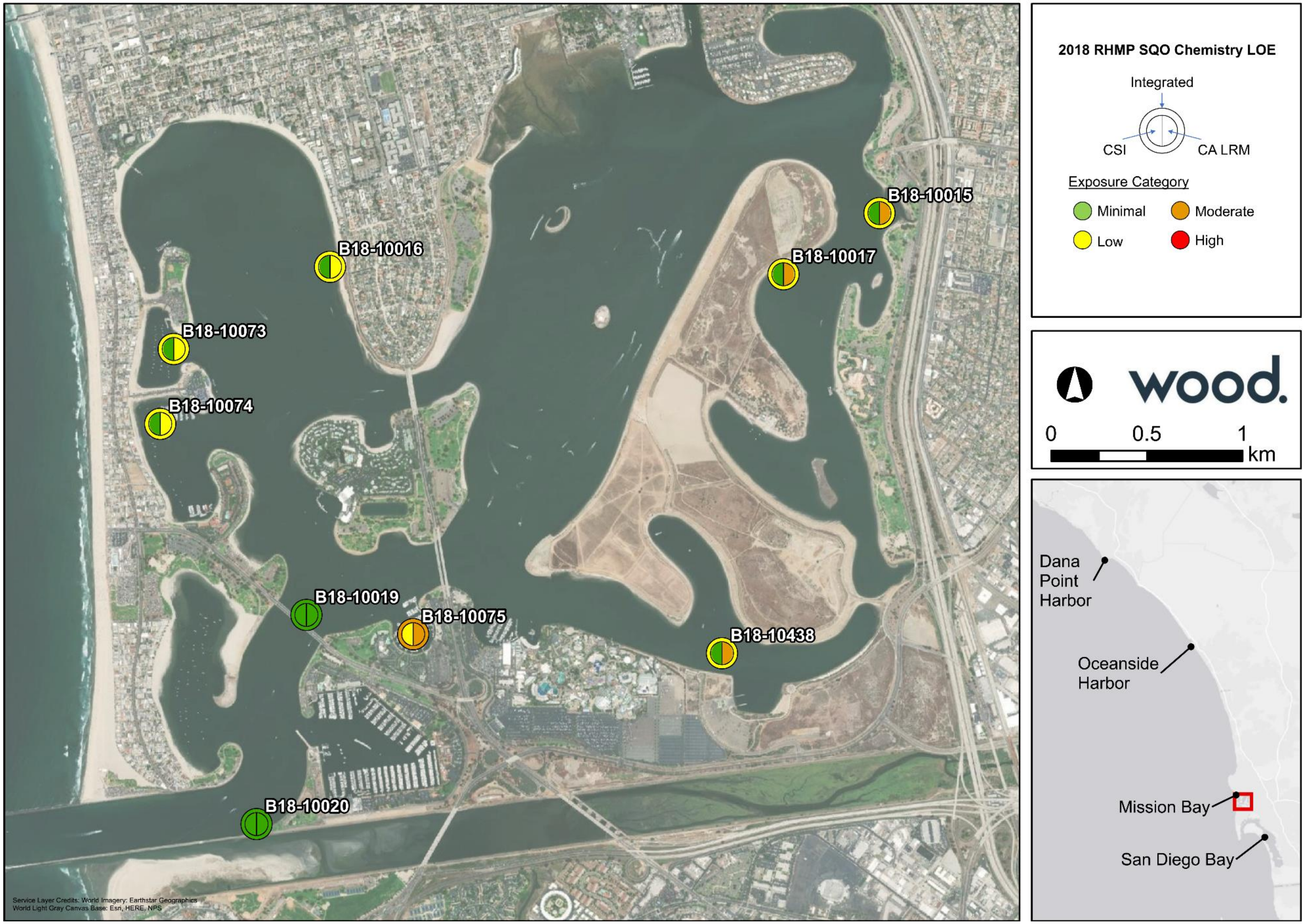
Service Layer Credits: World Imagery: USDA FSA, GeoEye, Maxar
World Light Gray Canvas Base: Esri, HERE, NPS

Figure 3-39a. Integrated Chemistry LOE Results using the SQO Approach for Dana Point Harbor



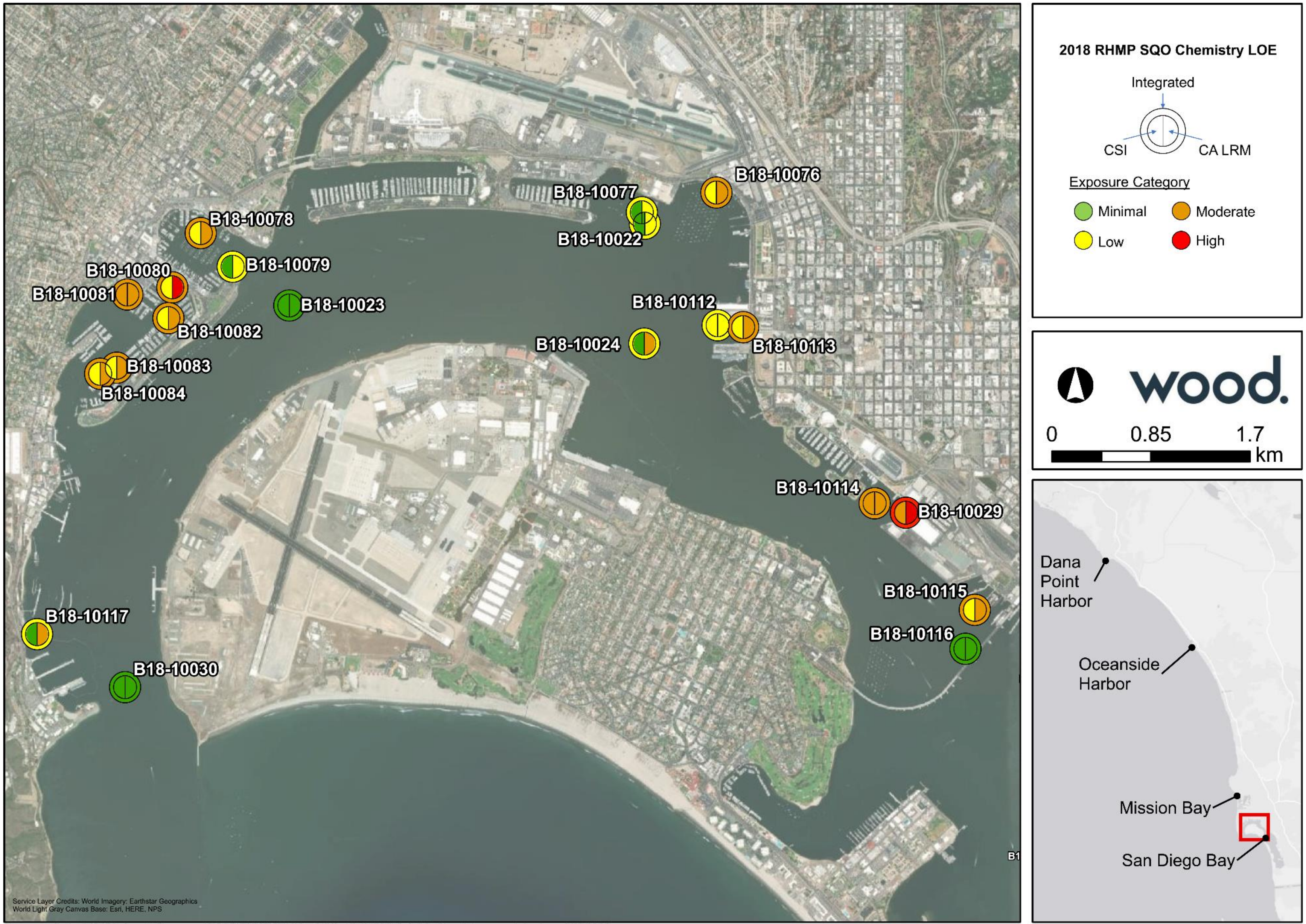
Service Layer Credits: World Imagery: USDA FSA, GeoEye, Maxar
World Light Gray Canvas Base: Esri, HERE, NPS

Figure 3-39b. Integrated Chemistry LOE Results using the SQO Approach for Oceanside Harbor



Service Layer Credits: World Imagery: Earthstar Geographics
World Light Gray Canvas Base: Esri, HERE, NPS

Figure 3-39c. Integrated Chemistry LOE Results using the SQO Approach for Mission Bay



Service Layer Credits: World Imagery: Earthstar Geographics
World Light Gray Canvas Base: Esri, HERE, NPS

Figure 3-39d. Integrated Chemistry LOE Results using the SQO Approach for North San Diego Bay

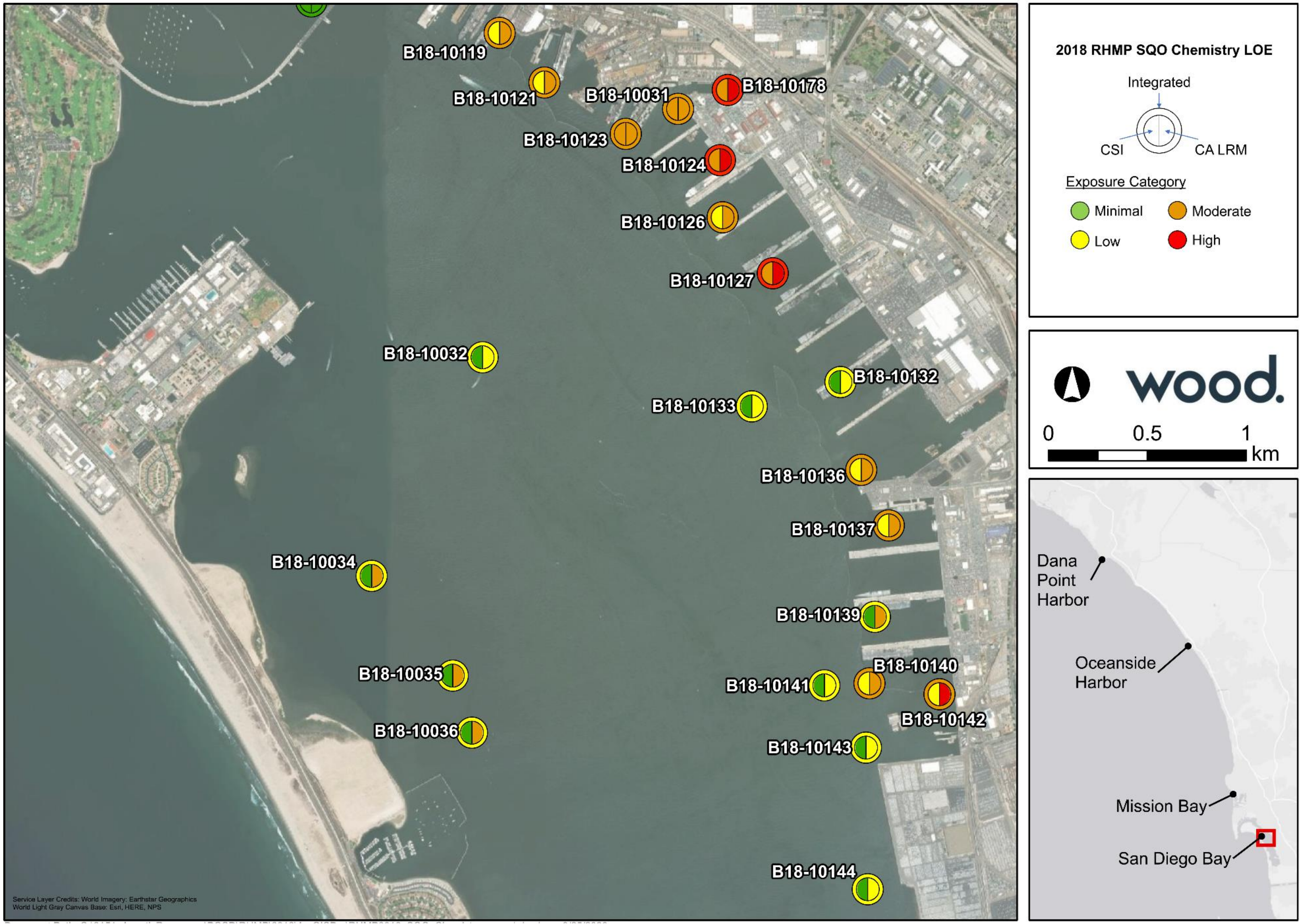


Figure 3-39e. Integrated Chemistry LOE Results using the SQO Approach for Central San Diego Bay

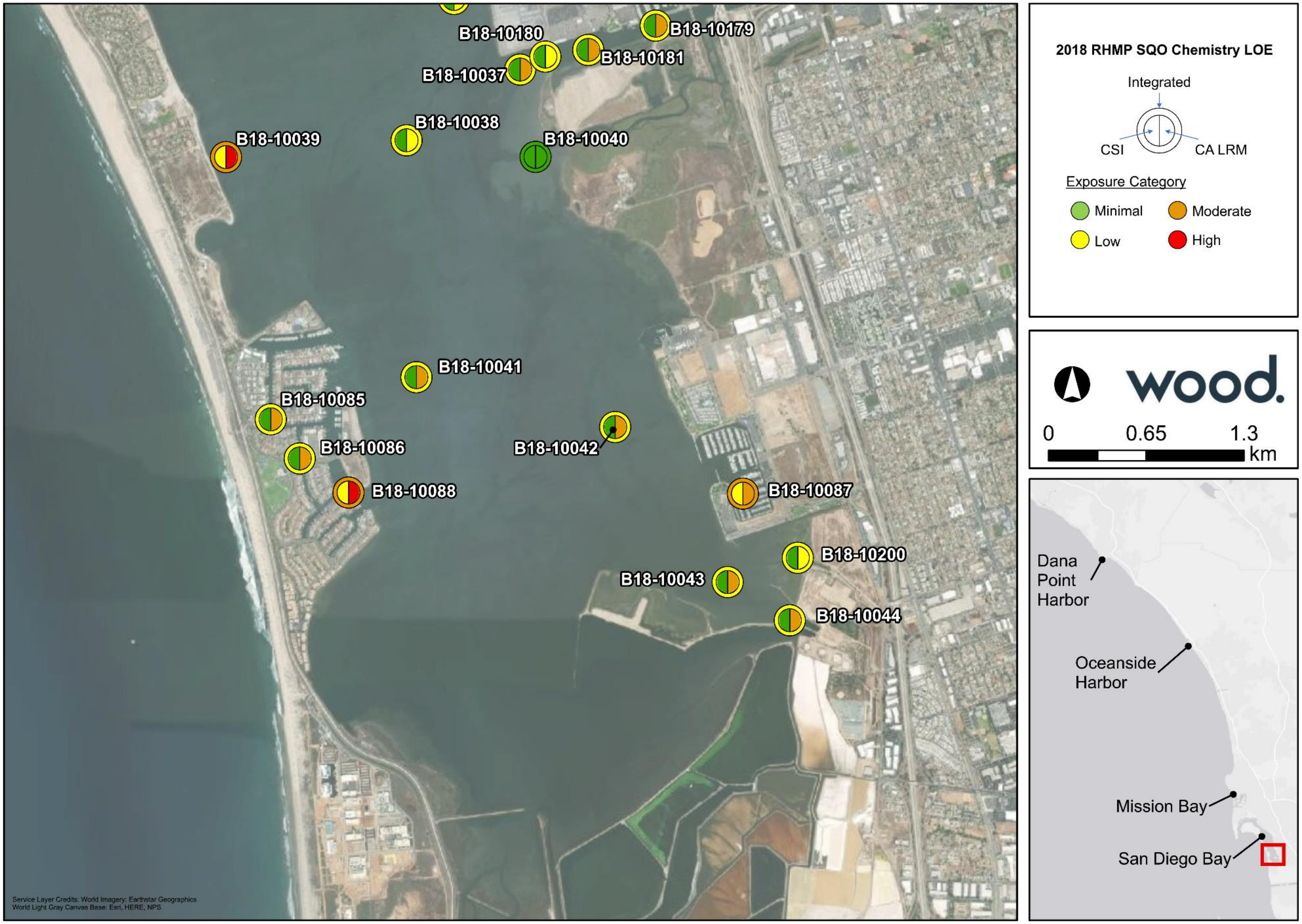


Figure 3-39f. Integrated Chemistry LOE Results using the SQO Approach for South San Diego Bay

3.2.2 Sediment Toxicity

Two independent toxicity tests using the amphipod *Eohaustorius estuarius* exposed to whole sediment, and bivalve embryos exposed to the sediment-water interface were used to evaluate this second LOE using the SQO framework. Results for each species individually are presented first in box plots (Figures 3-40 and 3-41) comparing results in 2018 among strata and harbors. Individual and integrated SQO scores for toxicity are then shown on maps in Figures 3-42a through 3-42e.

Results of the sediment toxicity tests for all stations are provided in Appendix G (Table G-1 and G-2 for the amphipod and bivalve tests, respectively). A summary of SQO scores for both species individually and combined is provided in Appendix Table G-3, and a complete report by the Wood Aquatic Toxicology Laboratory follows in Appendix G with detailed methods, all data, and statistical analyses. The results of statistical comparisons are presented in Appendix K.

As part of the final *Bight '13 Toxicity Report*, a scalable interactive map containing mean station results for both the amphipod test and bivalve test results conducted in support of the entire Bight Program (including Bight '98, Bight '03, Bight '08, and Bight '13) was developed and is available via the following link: https://sccwrp.maps.arcgis.com/apps/webappviewer/index.html?id=bb8abeffdce94ef9945d2a8c044c6858. Data for 2018 will be included in 2021.

In summary, toxicity was limited throughout all harbors and strata. All 75 stations were nontoxic or had low toxicity, according to the integrated SQO scores using both test species.

Amphipod Survival

Toxicity to amphipods was minimal in every stratum and harbor, with mean control-normalized survival greater than 71% across all samples tested (Figure 3-40). Only one of the 75 stations (1%) sampled was classified as having moderate toxicity using the amphipod test (Station B18-10072 located in the inner southwestern corner of Oceanside Harbor; Figure 3-42b). Mean percent survival (normalized to controls) showed no statistically significant difference among strata, with results ranging from 96% to 98% (Figure 3-40).

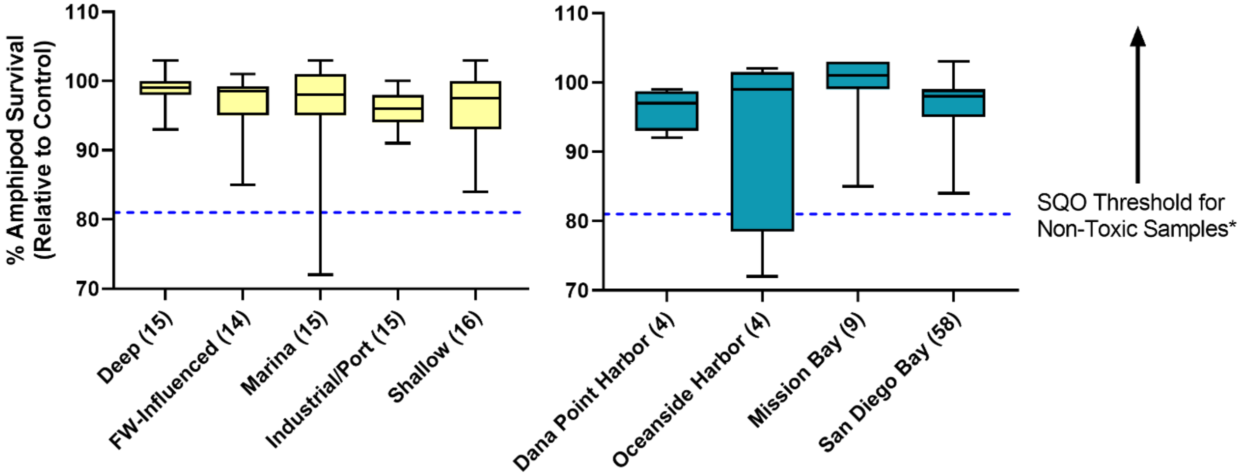


Figure 3-40. Comparisons of Amphipod Survival Among Strata and Harbors

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

**Nontoxic samples include sites identified as having no toxicity or low toxicity. The threshold shown is the highest response between low toxicity and moderate toxicity categories (81% relative to the control), assuming a statistically significant difference is observed using a one-tailed t-test assuming unequal variance.*

Some values exceed 100% if mean survival in the sample is greater than that in the associated control.

Table 3-12.
Percentage of Stations Considered Nontoxic Using Amphipod Survival and the SQO Approach (No Toxicity or Low Toxicity Categories)

Indicator	**Threshold Value**	**Percentage of 2018 RHMP Stations Considered Non-toxic (Non-Toxic + Low Toxicity Categories Combined)**					
		Deep (%)	**Freshwater-Influenced (%)**	**Marina (%)**	**Industrial/ Port (%)**	**Shallow (%)**	**All Stations (%)**
# of stations		*15*	*14*	*15*	*15*	*16*	*75*
Amphipod Survival	Moderate Toxicity (SQO)	100	100	93	100	100	99

Notes:
SQO = Sediment Quality Objective; % = percent

Mediterranean Mussel (*Mytilus galloprovincialis*) Development

In 2018, all stations (with the exception of Station B18-10082) were considered non-toxic using the chronic bivalve embryo development SWI test following the SQO guidance criteria, defined as those sites classified as non-toxic or having low toxicity (Table 3-13). Station B18-10082, located within the inner portion of SIYB in north San Diego Bay, was classified as having moderate toxicity. Mean normal-alive embryo development (normalized to the control) ranged from 77% to 111% across all RHMP sampling stations in 2018. Mean percent normal-alive embryo development (normalized to controls) exceeded 90% and showed no significant differences among strata, ranging from 96% in the marina stratum to 101% in the industrial/port stratum (Figure 3-41).

**Table 3-13.
Percentage of Considered Non-toxic Using the Bivalve Embryo Development SWI Test and the SQO Approach (No Toxicity or Low Toxicity Categories)**

Indicator	Threshold Value	Percentage of 2018 RHMP Stations Considered Non-toxic (Nontoxic + Low Toxicity Categories Combined)					
		Deep (%)	Freshwater-Influenced (%)	Marina (%)	Industrial/ Port (%)	Shallow (%)	All Stations (%)
# of stations		*15*	*14*	*15*	*15*	*16*	*75*
Bivalve Embryo Development % Normal/Alive	Moderate Toxicity (SQO)	100	100	93	100	100	99

Notes:
SQO = Sediment Quality Objective; % = percent

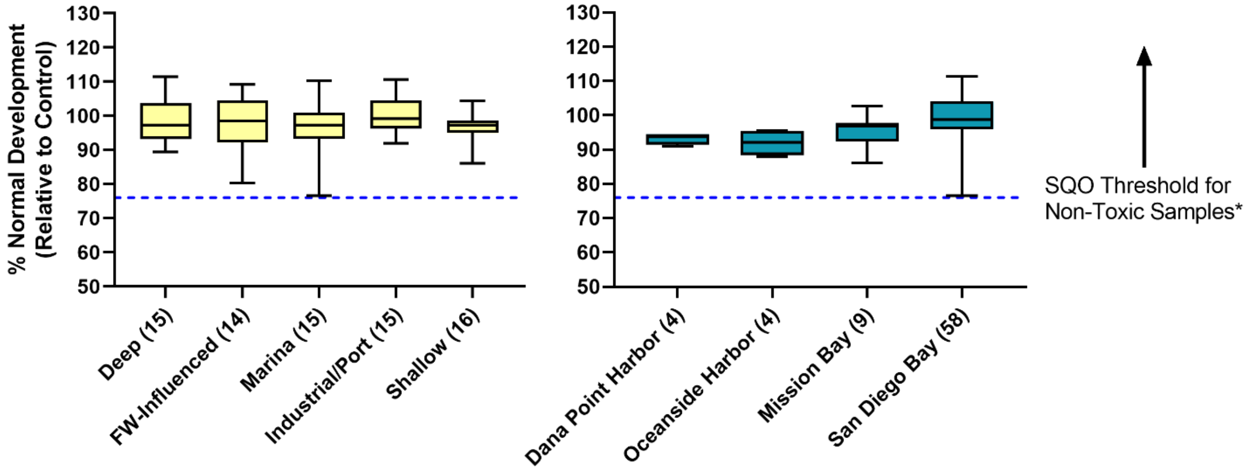


Figure 3-41. Comparisons of Mussel Embryo Development Among Strata and Harbors

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

**Nontoxic samples include sites identified as having no toxicity or low toxicity. The threshold shown is the highest response between low toxicity and moderate toxicity categories (78% relative to the control), assuming a statistically significant difference is observed using a one-tailed t-test assuming unequal variance. Some values exceed 100% if mean survival in the sample is greater than that in the associated control.*

Integrated Toxicity LOE SQO Scores

A summary of integrated SQO scores showing results for both toxicity test species, and an integrated score derived from these two metrics (shown by the outer ring), are displayed on maps for all harbors in Figures 3-42a through 3-42f. Note the limited frequency of toxicity and the consistent concurrence between the two species with the exception of Station B18-10072 located in Oceanside Harbor where the amphipod showed moderate toxicity and the bivalve showed none, and Station B18-10082 in north San Diego Bay (Shelter Island Yacht Basin) that showed moderate toxicity to the bivalve embryos but no toxicity to the amphipods. These results suggest that different chemicals or chemical classes are likely responsible for the different effects observed at these two locations given the varying sensitivity of these two species to different compounds.

Figure 3-42a. Integrated Toxicity LOE Results Using the SQO Approach for Dana Point Harbor

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 3-42b. Integrated Toxicity LOE Results Using the SQO Approach for Oceanside Harbor

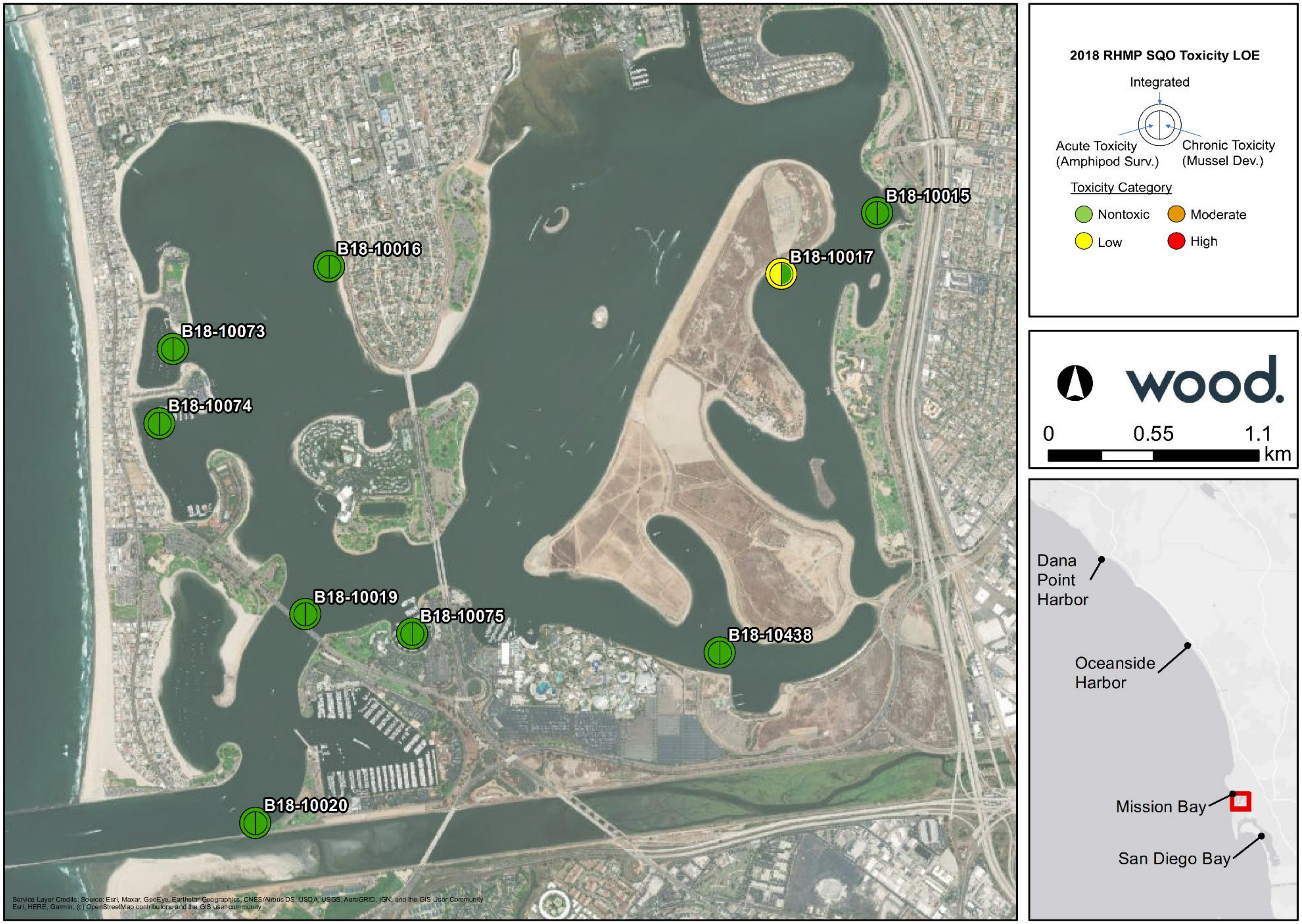
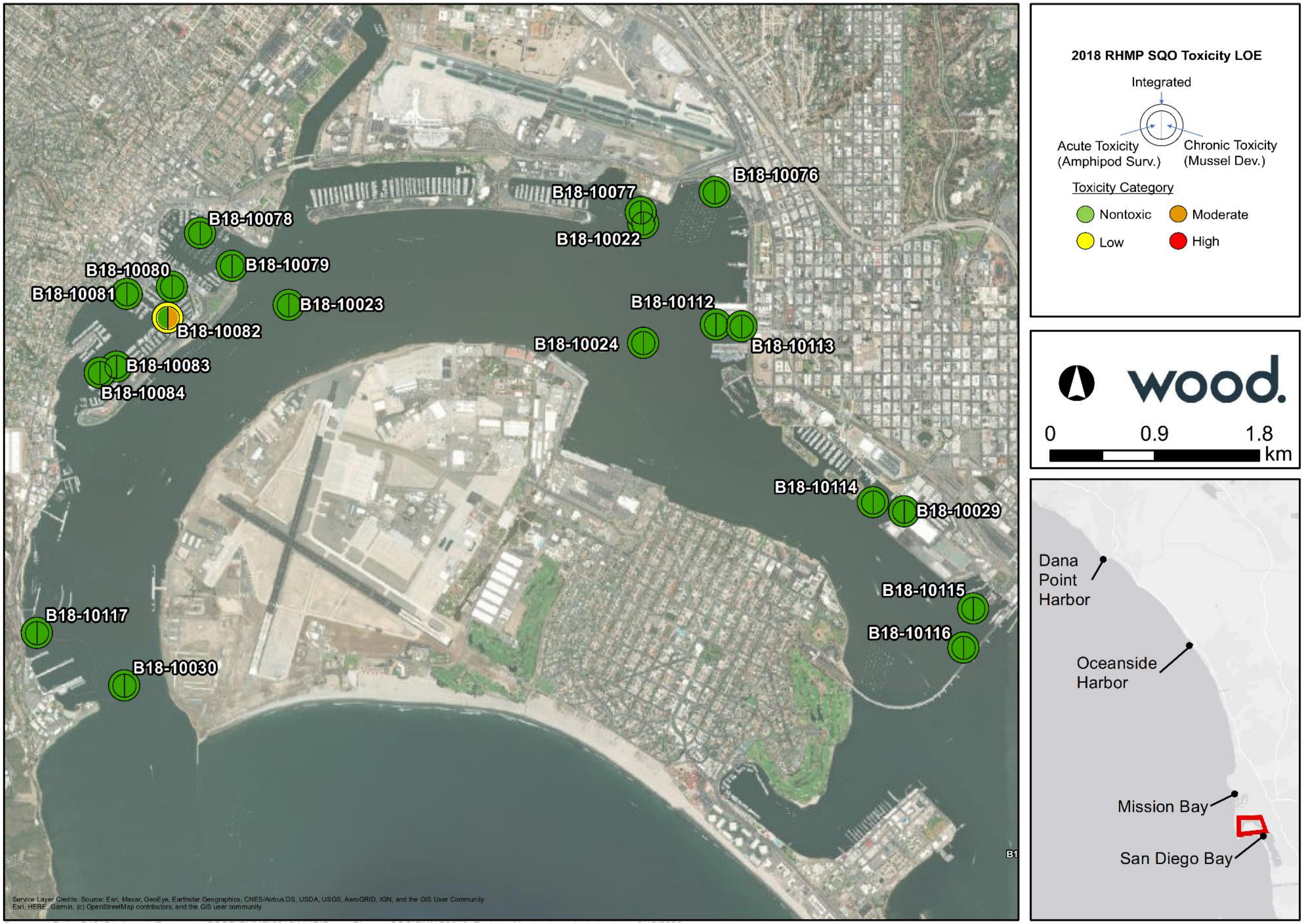


Figure 3-42c. Integrated Toxicity LOE Results Using the SQO Approach for Mission Bay



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 3-42d. Integrated Toxicity LOE Results Using the SQO Approach for North San Diego Bay

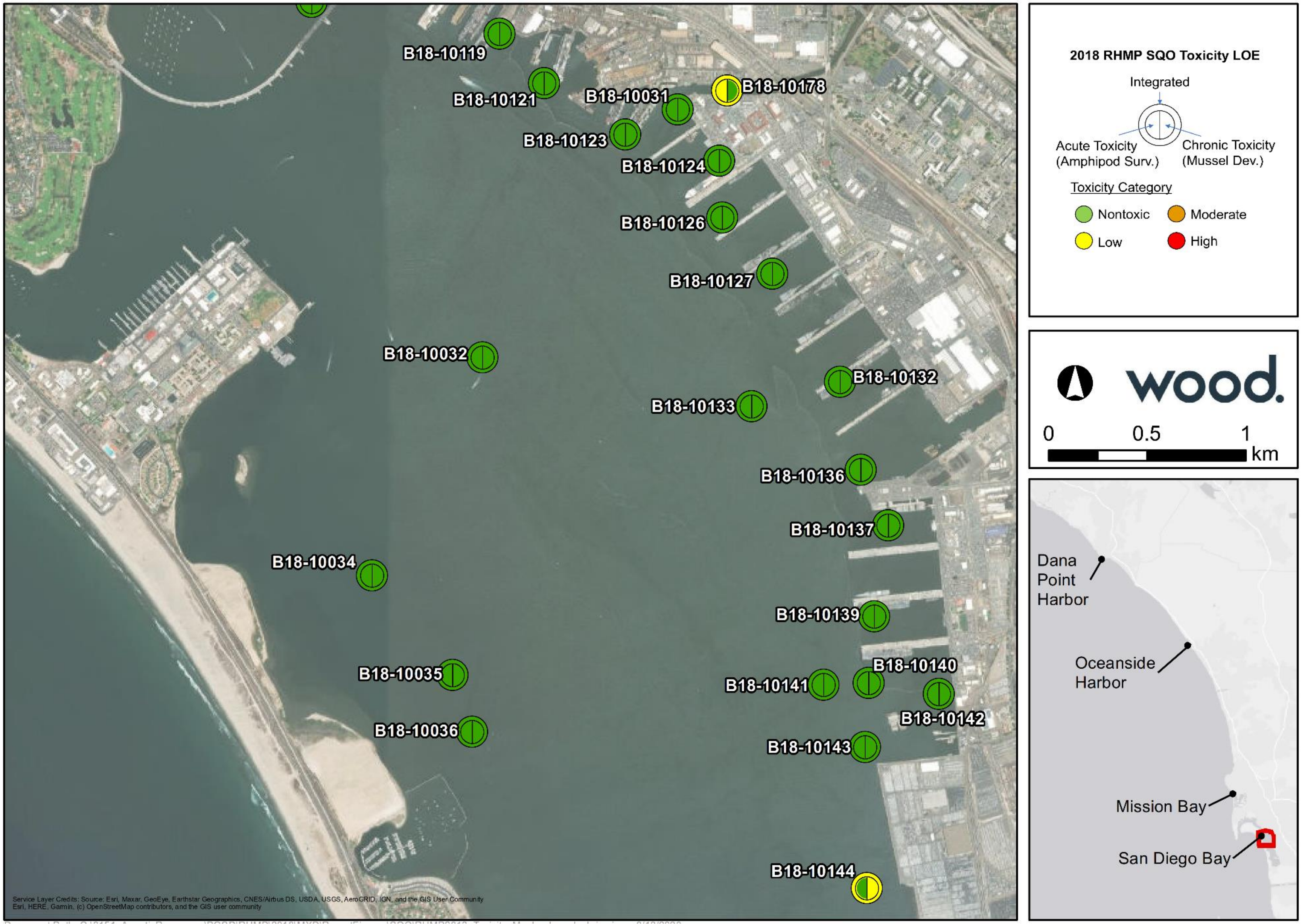
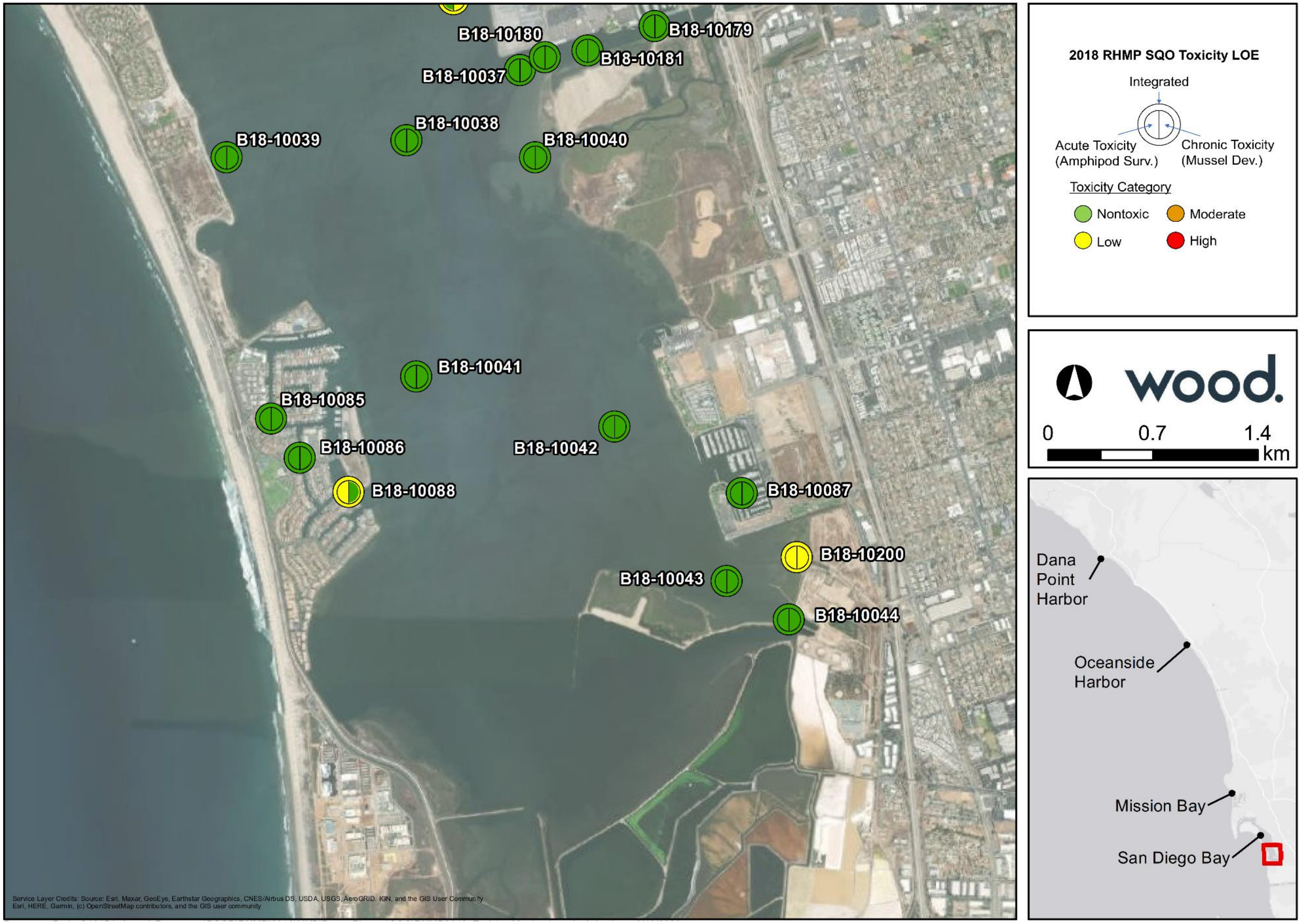


Figure 3-42e. Integrated Toxicity LOE Results Using the SQO Approach for Central San Diego Bay



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 3-42f. Integrated Toxicity LOE Results Using the SQO Approach for South San Diego Bay

3.2.3 Benthic Infauna

An evaluation of benthic infaunal communities is arguably the most direct line of evidence as an indicator of the quality of the sediments within which they live. It is these communities and the higher order species in the food chain that depend on them that warrant utmost protection. Benthic infaunal communities are directly affected by chemical constituents, but also influenced by other non-chemical physical characteristics and physical disturbance. These complexities make the benthic community the most challenging to evaluate and ultimately understand. Recognizing these complexities, a variety of different metrics have been developed from simple number and diversity indices to the more sophisticated multi-metric indices that incorporate various characteristics of the benthic infauna.

Sediment samples collected by TVV grab were sieved for benthic invertebrates to determine the relative health of the benthic infaunal communities throughout the harbors. The original primary indicator of benthic community condition for the RHMP was the BRI, while secondary indicators included the Shannon-Wiener Index and taxa richness (i.e., the number of taxa present). The SQO scores are now used as another primary indicator of benthic community health, which includes the BRI as one of the four integrated metrics. Results from each index are presented individually and are then followed with an integrated analysis following the SQO approach based on all four indices, the BRI, RBI, IBI, and RIVPACs.

Taxonomic identification and abundance for each taxon encountered in all samples are provided in Appendix H (Table H-1). Primary and secondary indicator values for all stations are provided in Table H-2, and a summary of SQO benthic community indices is provided in Table H-3. Statistical relationships between benthic infaunal community metrics and measures relative to sediment chemistry are shown graphically in Appendix K.

Individual Benthic Community Metrics

Two of the most common individual benthic community indices, the Shannon-Wiener Diversity Index and taxa richness, are described below. Both of these numeric indices are a measure of taxonomic diversity, but the Shannon-Wiener index weights for evenness of the abundance distribution of each taxon in a community, while taxa richness is a simple tally of the number of unique taxa encountered at a station. Higher values are indicative of healthier benthic infaunal communities and, for this analysis, stations with Shannon-Wiener index values greater than 2.0 and taxa richness values greater than 24 were considered to be equivalent to a reference condition (Weston, 2005b).

Shannon-Wiener Diversity Index

Assessment of all 2018 RHMP stations combined showed a wide range of Shannon-Wiener index values from 0.80 to 3.35. 67% of the stations had SWI values considered to represent a historical reference condition (i.e., SWI greater than 2.0) for the San Diego Regional Harbors (Figure 3-43 and Appendix H). Differences in the SWI were statistically significant across strata using ANOVA with deep stations having the greatest median SWI value, followed closely by industrial/port and shallow stations. These three strata had median values above the reference threshold. In contrast, the freshwater-influenced and marina strata had the lowest diversity using the SWI, with median SWI values below the reference threshold. By individual harbor, the percentage of stations with SWI values representative of a reference condition was 50% in Dana Point Harbor, 75% in Oceanside Harbor, 89% in Mission Bay, and 64% in San Diego Bay.

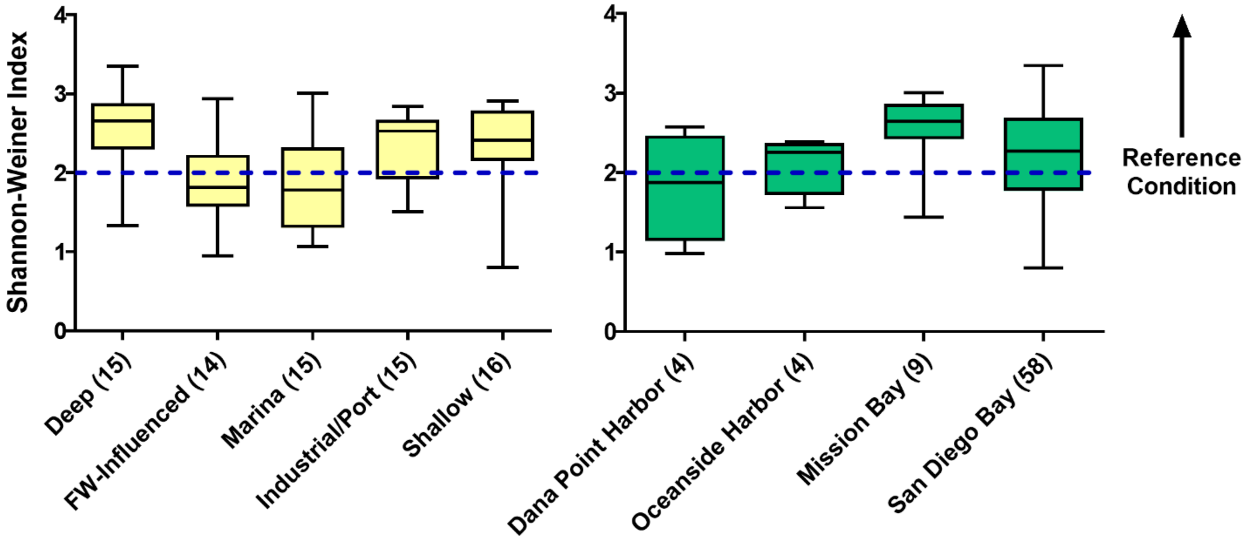


Figure 3-43. Shannon-Weiner Index for Benthic Infauna Among Strata and Harbors in 2018

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Taxa Richness

Assessment of all 2018 RHMP stations combined showed a wide range of taxa richness values from 6 to 60 infaunal taxa per station. Variability in taxa richness was high within all of the five strata and in Mission and San Diego Bay. Taxa richness values indicated slightly poorer benthic community conditions than was determined by the Shannon-Wiener Index. In 2018, 57% of all RHMP stations combined had taxa richness values that were considered to represent a historic reference condition (i.e., greater than 24 taxa) for the San Diego Regional Harbors. Differences in taxa richness were statistically significant across strata using ANOVA with deep and shallow stations having the highest mean taxa richness, although the greatest richness was observed at one of the marina locations located in Mission Bay (Station B18-10075) . By individual harbor, the percentage of stations with taxa richness representative of a reference condition was 0% in Dana Point and Oceanside Harbors, 78% in Mission Bay, and 62% in San Diego Bay (Figure 3-44).

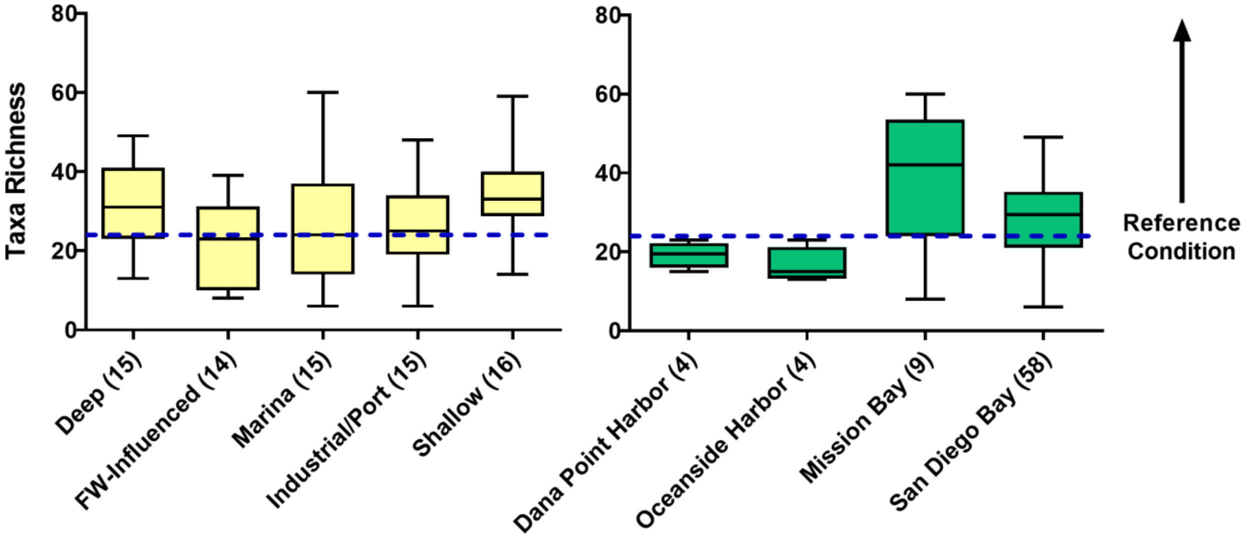


Figure 3-44. Benthic Infauna Taxa Richness Among Strata and Harbors

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Multi-metric and Predictive Benthic Community SQO Indices

Results from a suite of three multi-metric benthic indices (the BRI, IBI, and RBI), along with the RIVPACS observed/expected taxa predictive model, are presented below. RIVPACS is the only index based on a predictive model of expected taxa; the other three are multi-metric indices that incorporate organism sensitivity and abundance. Each index is calculated and categorized into four disturbance categories (reference, low, moderate, and high disturbance). All four of these indices are evaluated independently but are also ultimately used to provide a single integrated benthic community score using the SQO approach.

Benthic Response Index (BRI)

The BRI is an abundance-weighted pollution tolerance score of the organisms present in a benthic sample. For the BRI, lower values indicate a less disturbed benthic community (i.e., better conditions), while for Shannon-Wiener diversity and taxa richness, lower values indicate a more disturbed benthic community. The BRI is also one of the four LOEs that constitute the benthic biology portion of the SQO analysis. Comparison with historical data used information provided in the previous RHMP reports (Weston, 2010a; Amec Foster Wheeler, 2016) and data gathered during prior Bight-related efforts and other monitoring programs as discussed in Section 4.4.2. Because the BRI provides a continuous numeric value and is catered specifically to pollution tolerance, an expanded analysis that includes an evaluation of the relationship between the BRI and integrated sediment quality metrics (the CSI and the ER-M quotient) is possible and is included for this one metric.

A plot showing BRI scores relative to the SQO thresholds for this individual metric among strata and harbors is presented in Figure 3-45. Differences in the BRI were statistically significant across strata using ANOVA (Appendix K). Results of the BRI analysis for all RHMP stations in 2018 showed a range of values from 18.5 to 60.1, with higher values representative of more disturbed conditions (Figure 3-45). Across all RHMP stations, 50% were defined as being representative of a reference condition (i.e., a BRI score <39.96), 25% were in the low disturbance category, 25% were in the moderate disturbance category, and none were in the high disturbance category (i.e., a BRI score of >73.27) (Table 3-14).

Consistent with taxa richness and the SWI, results of the BRI indicated that the deep and shallow strata had the least disturbed infaunal communities, with combined reference and low disturbance percentages of 100% and 94%, respectively (Table 3-14). Eight of the ten lowest BRI scores were in the deep stratum. All other strata had multiple stations in the reference and low categories, and the percentage of moderately disturbed stations ranged from 33% to 47% for the freshwater-influenced, marina, and industrial/port strata.

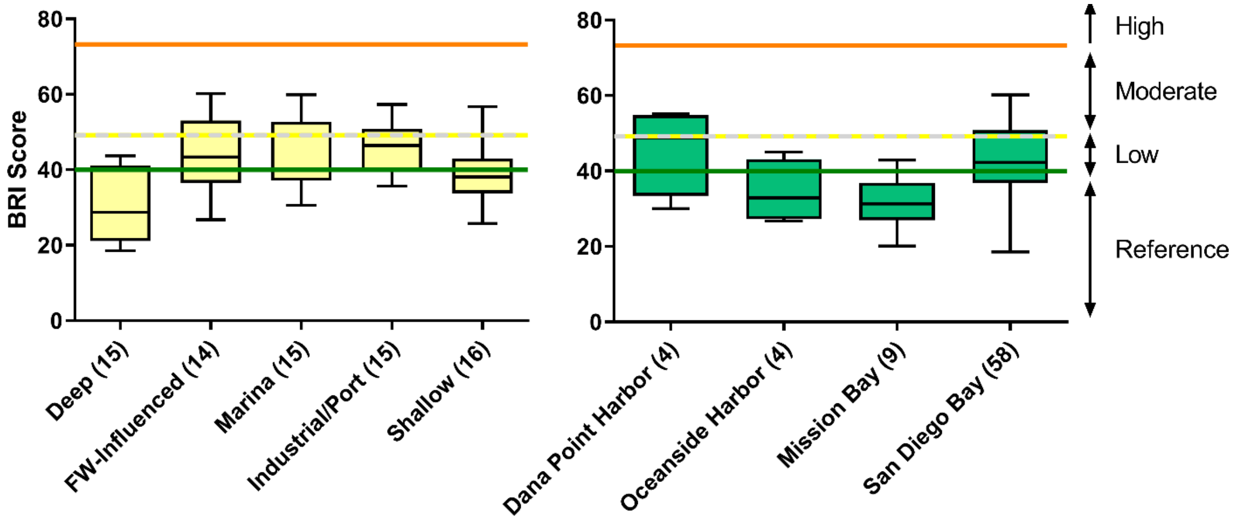


Figure 3-45. Comparisons Benthic Response Index (BRI) Values Among Strata and Harbors in 2018

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

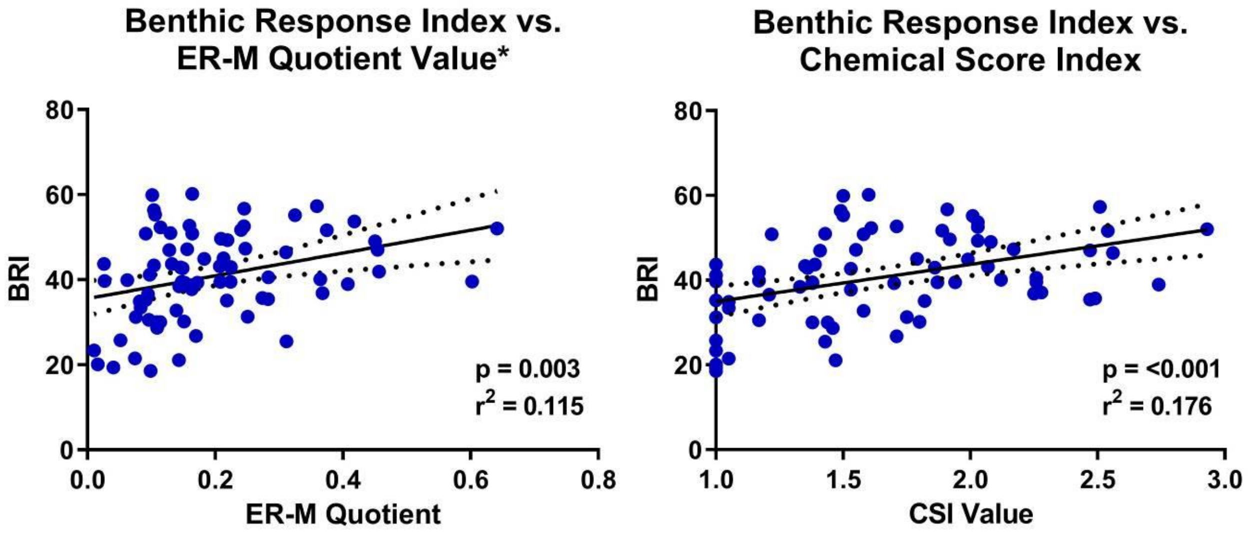
Table 3-14.
Percentage of RHMP Stations Among Strata in Each Benthic SQO Category for the BRI in 2018

BRI Category	Percentage of 2018 RHMP Stations Per BRI Category					
	Deep (%)	Freshwater-Influenced (%)	Marina (%)	Industrial/ Port (%)	Shallow (%)	All Stations (%)
# of stations	*15*	*14*	*15*	*15*	*16*	*75*
Reference	73	50	33	27	63	50
Low Disturbance	27	7	20	40	31	25
Moderate Disturbance	0	43	47	33	6	25
High Disturbance	0	0	0	0	0	0

Notes:
% = percent; BRI = Benthic Response Index; RHMP = Regional Harbor Monitoring Program

Assessments of each harbor separately indicated that Mission Bay and Oceanside Harbor had the least disturbed benthic community conditions based on the BRI, both with median scores in the reference category for this metric (Figure 3-45). The median community conditions in Dana Point Harbor and San Diego Bay, according to the BRI, were determined to have low disturbance.

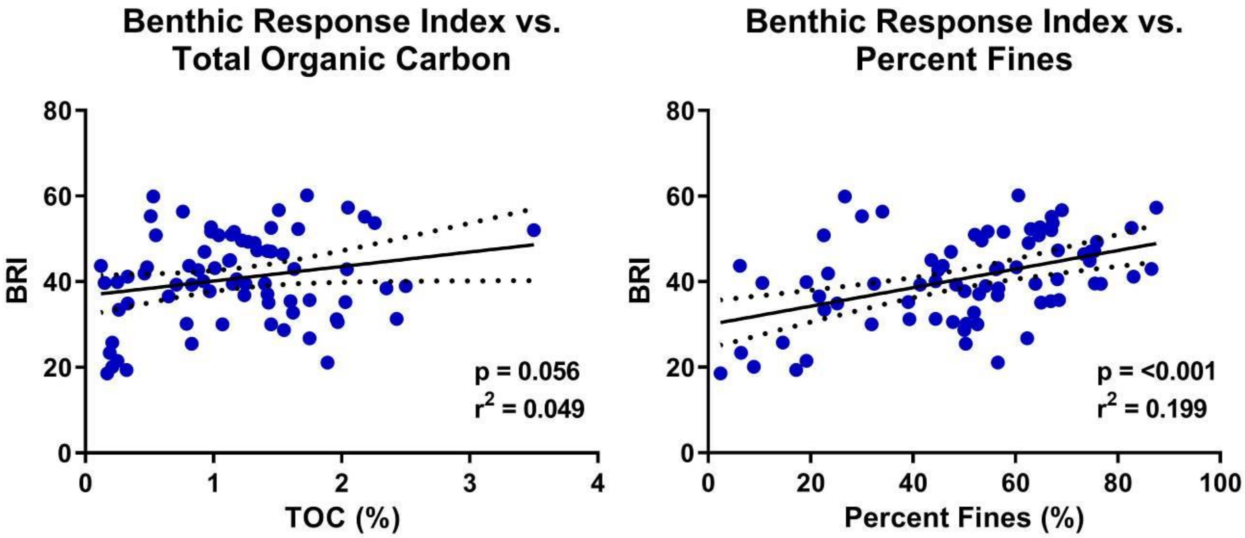
The relationships between the BRI and enhanced sediment chemistry using the integrated chemical measures of the ER-M quotient and the SQO CSI are shown in Figures 3-46a and 3-46b. For the ER-M quotient analysis, a single station (B18-10069) with high PCB concentrations skewed the analysis to a substantial degree. The ER-M quotient at this site was 4 to 261 times greater than other sites throughout the San Diego Regional Harbors, suggesting that site B18-10069 is not representative of regional conditions and should be evaluated on an individual basis. Therefore, statistical analyses were also performed without Site B18-10069 to better evaluate the relationship between the ER-M quotient and the BRI on a regional scale. When the outlier was excluded (confirmed statistically using the Grubb's test), the r^2 value increased from 0.011 to 0.115). Figure 3-46a, below, excludes this station; however, the initial analysis that includes the station is presented in Appendix K for comparison. The CSI score was developed by assessing the relationship between sediment chemistry and benthic community conditions in southern California bays and estuaries (hence the applicability of evaluating this relationship). Statistically significant relationships are shown for both comparisons; however, the degree of predictability represented by r^2 was very low in both cases due to substantial scatter among the data points. Note that the BRI is just one LOE used to assess benthic community conditions. This metric has been used as a primary indicator based on widely available historical data that were used to calculate this pre-set target for comparative purposes. The more robust SQO methodology incorporates the BRI with three other measures of benthic community quality, as described later in this section.



(a) (b)

Figure 3-46. Relationship Between the BRI and (a) the Mean ER-M Quotient *(Outlier Station B18-10069 Excluded) and (b) the CSI in 2018.

The relationship between the BRI and TOC and percent fines was also evaluated, as these physical parameters alone may affect infaunal community structure, both when they are on the low end and high end of the spectrum. With all data combined, there was no significant relationship between the BRI and TOC, likely due to the relatively limited range of TOC (which had a maximum concentration of 3.5%) within and among the harbors and strata (Figure 3-47a). There was, however, a significant relationship between the BRI scores and percent fines (Figure 3-47b). A more in-depth analysis of benthic community relationships to chemical constituents and physical parameters is provided in Section 4.4.



(a) (b)

Figure 3-47. Relationship Between the BRI and (a) TOC and (b) Percent Fine Sediment in 2018

The Index of Biological Integrity (IBI)

The IBI compares the values of four different metrics with the ranges expected under reference conditions. The metrics used to calculate the IBI are the total number of taxa, number of mollusc taxa, abundance of *Notomastus* sp. (a polychaete), and percentage of sensitive taxa.

In 2018, 62% of all RHMP stations combined had IBI values that were considered to represent a reference condition based on the SQO approach (Table 3-15). Combining sites classified as having either a reference or low disturbance based on the IBI results in a high proportion of sites in these two categories ranging from 74 to 94% among all strata. Results of the IBI by stratum indicated that the deep and shallow stations had the least disturbed infaunal communities, with combined reference and low disturbance percentages of 93% and 94%, respectively. The marina and freshwater-influenced strata had the lowest fraction of sites in these two categories (74 and 79%, respectively). A plot showing IBI scores relative to the SQO thresholds for this individual metric among strata and harbors is presented in Figure 3-48. Differences in the IBI were not found to be statistically significant across strata using ANOVA (Appendix K).

By individual harbor, the percentage of stations with IBI values representative of reference and low disturbance conditions combined was 75% in Dana Point Harbor (n=3), 50% in Oceanside Harbor (n=2), 89% in Mission Bay (n=8), and 88% (n=51) in San Diego Bay (Figure 3-48).

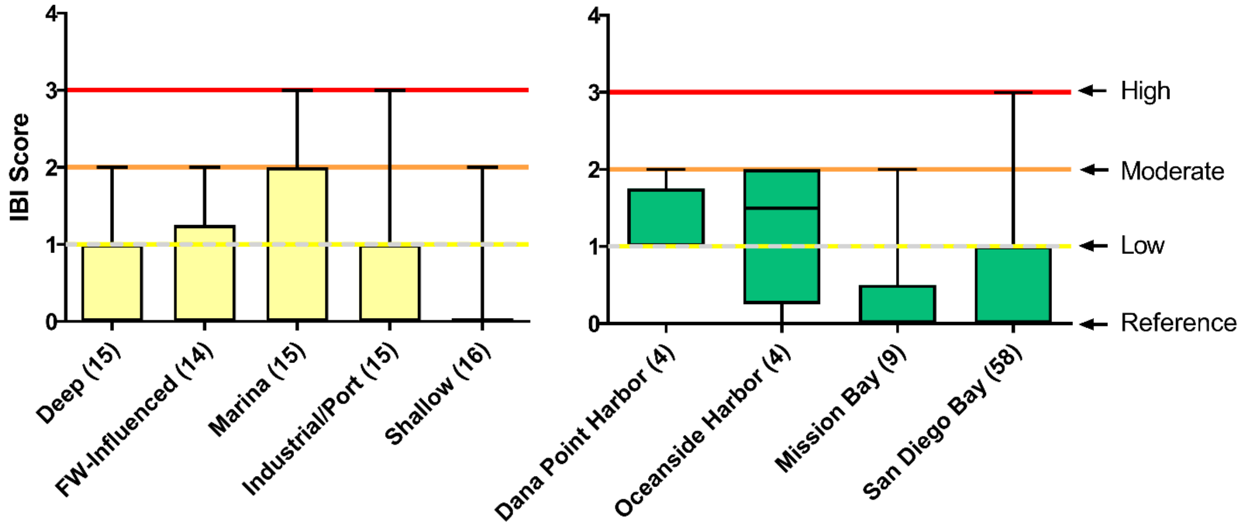


Figure 3-48. Comparison of Index of Biological Integrity (IBI) Values Among Strata and Harbors in 2018

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Table 3-15.
Percentage of RHMP Stations Among Strata in Each Benthic SQO Category for the IBI in 2018

IBI Category	Percentage of 2018 RHMP Stations Per IBI Category					
	Deep (%)	Freshwater-Influenced (%)	Marina (%)	Industrial/ Port (%)	Shallow (%)	All Stations (%)
# of stations	*15*	*14*	*15*	*15*	*16*	*75*
Reference	60	36	61	73	81	62
Low Disturbance	33	43	13	13	13	23
Moderate Disturbance	7	21	13	7	6	11
High Disturbance	0	0	13	7	0	4

Notes:
% = percent; IBI = Index of Biological Integrity; RHMP = Regional Harbor Monitoring Program

The Relative Benthic Index (RBI)

The RBI is the weighted sum of (1) four community metrics related to biodiversity (total number of taxa, number of crustacean taxa, abundance of crustacean individuals, and number of mollusc taxa); (2) abundance of three positive indicator taxa; and (3) presence of two negative indicator taxa. The data needed to calculate the RBI are total number of taxa, number of mollusc taxa, number of crustacean taxa, number of crustacean individuals, number of individuals of *Monocorophium insidiosum, Asthenothaerus diegensis*, and Goniada littorea (positive indicators), and presence of *Capitella capitata* complex and Oligochaeta (negative indicators).

In 2018, 29% of all RHMP stations combined had RBI values that were considered to represent a reference condition based on the SQO approach (Table 3-16). Combining sites classified as having either a reference or low disturbance based on the RBI results in a wide range in the proportion of sites in these two categories from 21% for the freshwater-influenced strata to 81% for the shallow strata in 2018. The marina, deep, and industrial strata had a relatively similar proportion of sites in these two disturbance categories (40 to 54%). A plot showing RBI scores relative to the SQO thresholds for this individual metric among strata and harbors presented in Figure 3-49. Differences in the RBI were not found to be statistically significant across strata using ANOVA (Appendix K).

By individual harbor, the percentage of stations with RBI values representative of reference and low disturbance conditions combined was 25% in Dana Point (n=1), 25% in Oceanside Harbor (n=1), 67% in Mission Bay (n=6), and 50% (n=29) in San Diego Bay (Figure 3-49).

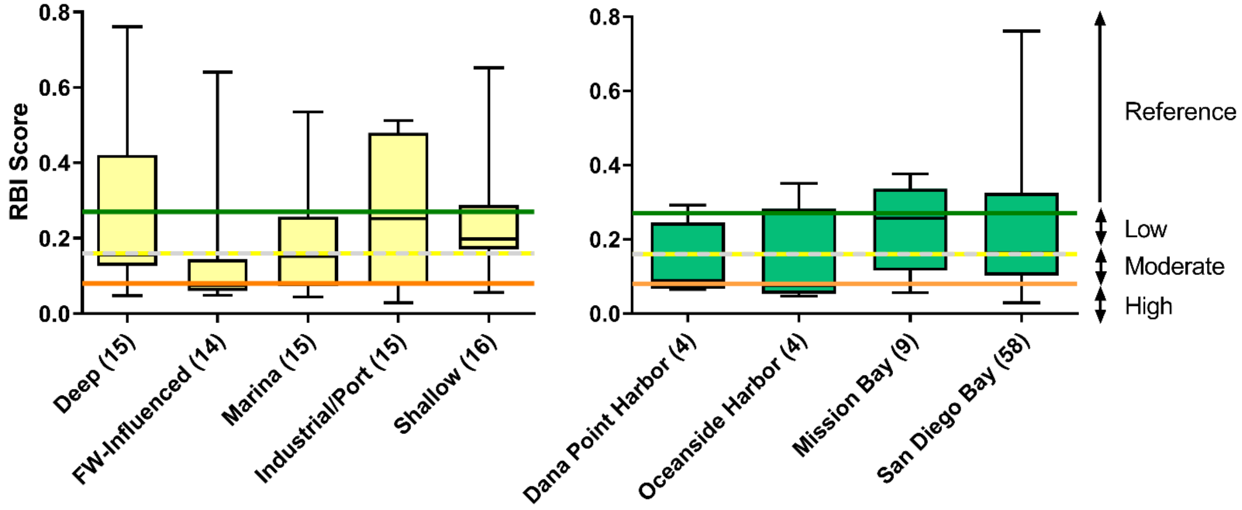


Figure 3-49. Comparisons of Relative Benthic Index (RBI) Among Strata and Harbors in 2018

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Table 3-16.
Percentage of RHMP Stations Among Strata in Each Benthic SQO Category for the RBI in 2018

RBI Category	Percentage of 2018 RHMP Stations Per RBI Category					
	Deep (%)	Freshwater-Influenced (%)	Marina (%)	Industrial/ Port (%)	Shallow (%)	All Stations (%)
# of stations	*15*	*14*	*15*	*15*	*16*	*75*
Reference	40	14	20	46	25	29
Low Disturbance	7	7	20	7	56	20
Moderate Disturbance	40	22	20	20	13	23
High Disturbance	13	57	40	27	6	28

Notes:
% = percent; RBI = Relative Benthic Index; RHMP = Regional Harbor Monitoring Program

The River Invertebrate Prediction and Classification System (RIVPACS)

The RIVPACS index is based on a predictive model and is a ratio of the number of reference taxa observed in a test sample to the number of taxa expected to be present in a reference sample from a similar habitat (the O/E ratio). The O/E ratio is calculated, and this value is compared to published response ranges to determine the RIVPACS condition category. This index retains the word “River” in the name as it was originally developed for freshwater riverine environments using the same O/E approach, despite being modified for use with marine estuarine species as well.

With all RHMP stations combined, the presence of benthic communities considered to represent a reference condition in 2018 as measured by the RIVPACS benthic community index was just 1% in 2018 (Table 3-17). This metric using an observed/expected modelled approach frequently gave the benthic communities the highest disturbance score of the four individual indices. Combining sites classified as having either a reference or low disturbance based on the RIVPACS approach in 2018 only slightly improved the results with only one station in each of freshwater-influenced, industrial/port, and shallow strata (all in San Diego Bay) resulting in a score within the reference/low categories (Table 3-17, Figure 3-50). Differences in the RIVPACS index were not statistically significant across strata using ANOVA, however, similar to the BRI, stations in the industrial/port strata had the least disturbed community conditions using this metric, but differed from the other individual metrics which classified the shallow and deep strata as having the least disturbed communities.

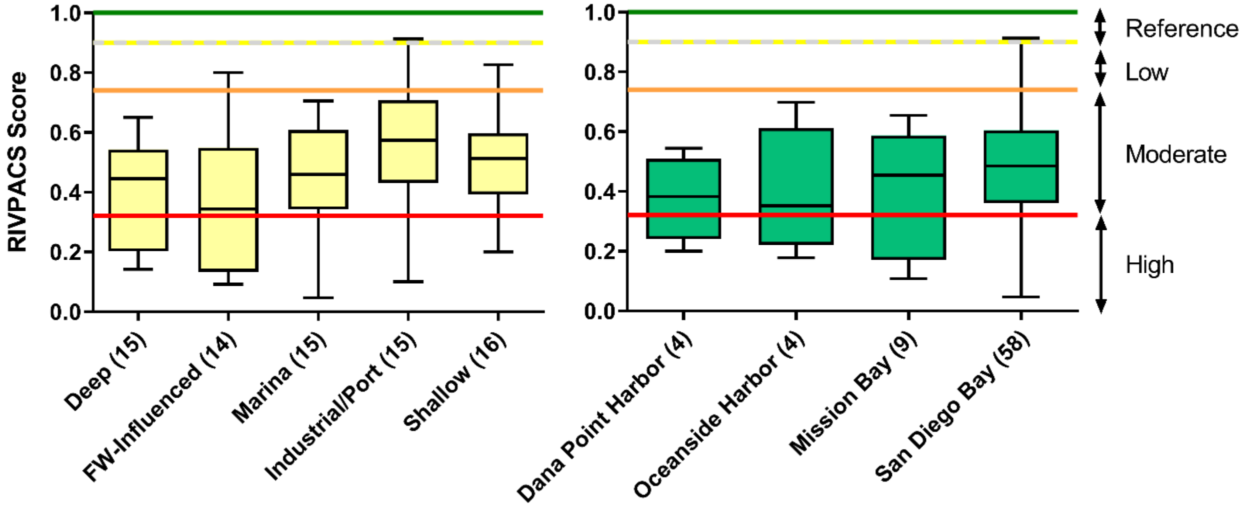


Figure 3-50. Comparisons of River Invertebrate Prediction and Classification System (RIVPACS) Values Among Strata and Harbors in 2018

Box plots show the median, 25th percent quartiles, and range of values. The number of stations (n) is shown in parentheses.

Table 3-17.
Percentage of RHMP Stations Among Strata in Each Benthic SQO Category for RIVPACS in 2018

RIVPACS Category	Percentage of 2018 RHMP Stations Per RIVPACS Category					
	Deep (%)	Freshwater-Influenced (%)	Marina (%)	Industrial/ Port (%)	Shallow (%)	All Stations (%)
# of stations	*15*	*14*	*15*	*15*	*16*	*75*
Reference	0	0	0	7	0	1
Low Disturbance	0	7	0	0	6	3
Moderate Disturbance	73	50	87	80	88	76
High Disturbance	27	43	13	13	6	20

Notes:
% = percent; RIVPACS = River Invertebrate Prediction and Classification System; RHMP = Regional Harbor Monitoring Program

Integrated Assessment of the Benthic Community Condition Based on the SQO Approach Incorporating all Four Benthic Indices

An integrated assessment of benthic community condition using the SQO approach incorporates results from all indices described above: the BRI IBI, RBI, and RIVPACS. To integrate these four indices, the highest and lowest index scores are discarded, and the final assessment of benthic community disturbance is determined by the two median index scores, as prescribed in the SQO technical guidance document (Bay et al., 2014).

Integrated benthic community LOE results are summarized by stratum in Table 3-18 and are graphically shown by both strata and harbor in Figure 3-51 using stacked bar charts. Given its size and associated variability in habitat and physical water quality characteristics (e.g., eelgrass beds, temperature, and currents), results for San Diego Bay are also shown separately in Figure 3-52 with results divided among the north, central, and south regions.

According to the SQO integrated benthic LOE, benthic infaunal communities were categorized as having reference conditions at 19% of all RHMP stations combined and low disturbance conditions at 36% of the stations (Table 3-18). Communities representative of moderate and high disturbance conditions were observed at 32% and 13% of the stations, respectively. By individual index type, the BRI and IBI rated many more stations in the reference and low disturbance categories (75% and 85% of stations, respectively) than did the RBI and RIVPACS (49% and 4% of stations, respectively) (Appendix H). Additionally, the BRI was the only index that did not rate any sites with high disturbance. As a result, the SQO benthic LOE generally indicated lower benthic community quality than did single indicator analyses using the BRI, Shannon-Wiener index, or taxa richness indicators.

Table 3-18.
Percentage of RHMP Stations in Each Sediment Quality Objective Benthic Community LOE Category

Benthic LOE Category	**Percentage of 2018 RHMP Stations Per Benthic LOE Category**					
	Deep (%)	**Freshwater-Influenced (%)**	**Marina (%)**	**Industrial/ Port (%)**	**Shallow (%)**	**All Stations (%)**
# of stations	*15*	*14*	*15*	*15*	*16*	*75*
Reference	20	14	13	20	25	19
Low Disturbance	46	21	13	40	56	36
Moderate Disturbance	27	29	61	27	19	32
High Disturbance	7	36	13	13	0	13

Notes:
% = percent; LOE = line of evidence; RHMP = Regional Harbor Monitoring Program

Differences in the integrated SQO benthic community index were statistically significant across strata using ANOVA (Appendix K). By strata, the shallow stations were identified as having the least impacted communities, with 81% in the reference and low disturbance categories combined. There were no shallow stations categorized as high disturbance. Deep and industrial/port strata had a majority of stations in the reference and low disturbance categories combined, 66% and 60%, respectively. The marina and freshwater-influenced stations showed the greatest impact on benthic infauna, with 74% and 65% in the combined moderate and high disturbance categories, respectively.

Among harbors, benthic communities in Mission Bay exhibited the least disturbed conditions, with 78% of stations (7 of 9) in the reference and low disturbance categories combined, and one station (11%) each in the moderate disturbance and high disturbance categories. In San Diego Bay, 55% of stations (n=32) were classified with benthic communities representative of reference and low disturbance conditions combined, while 31% (n=18) were in the moderate disturbance category. Eight stations in San Diego Bay (14%) were considered to have high disturbance conditions for the benthic community, located in the marina, industrial/port, and freshwater-influenced strata. A notable observation in San Diego Bay was the decrease in reference and low disturbance communities noted from north to south across the three ecoregions as shown in Figure 3-52. This trend does not follow overall patterns of sediment contamination based on chemical concentrations in the sediment, but rather may relate more to changes in temperature and flushing as explored further in Section 4.4.1. Dana Point Harbor had one station (25%) in the low disturbance category and three (75%) in the moderate disturbance category. Oceanside Harbor had one station (25%) in the reference category, two (50%) in the moderate disturbance category, and one (25%) in the high disturbance category located in the channel near the mouth of the harbor. This specific location is dredged annually, likely having an influence on the biological community at this location which was highly disturbed; the site was non-toxic and had low chemical concentrations, as discussed further in Section 4.4.1.

A spatial representation of benthic community SQO scores are presented in Figures 3-53a through 3-53f for all harbors. Results for the four individual benthic indices are represented with color-coded quarter circles, and the final integrated SQO score is shown by the color of the outer ring.

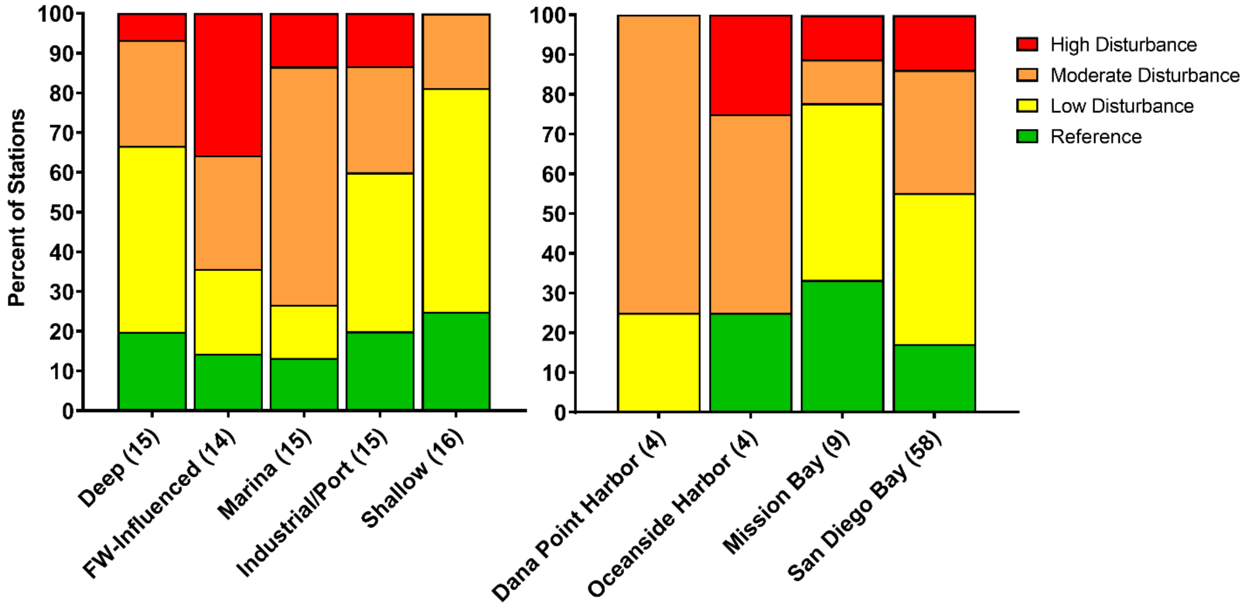


Figure 3-51. Comparisons of the SQO Benthic Infaunal LOE Among Strata and Harbors in 2018

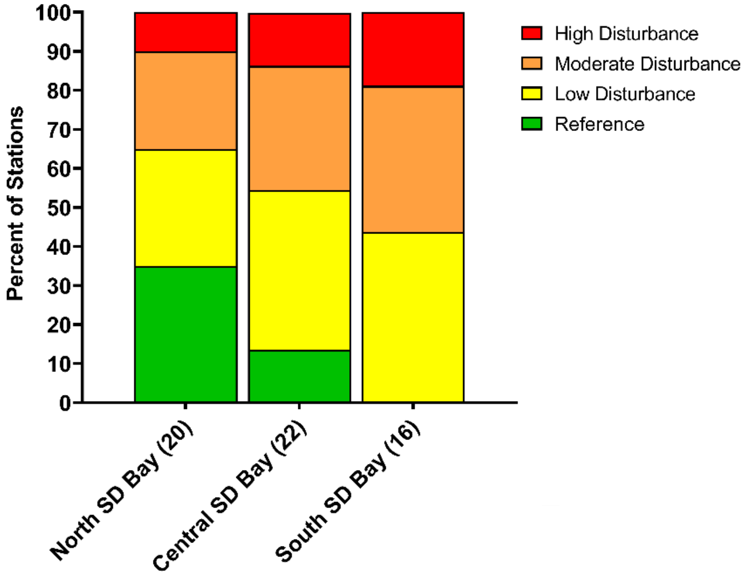


Figure 3-52. Comparisons of the SQO Benthic Infaunal LOE Among Ecoregions in San Diego Bay in 2018

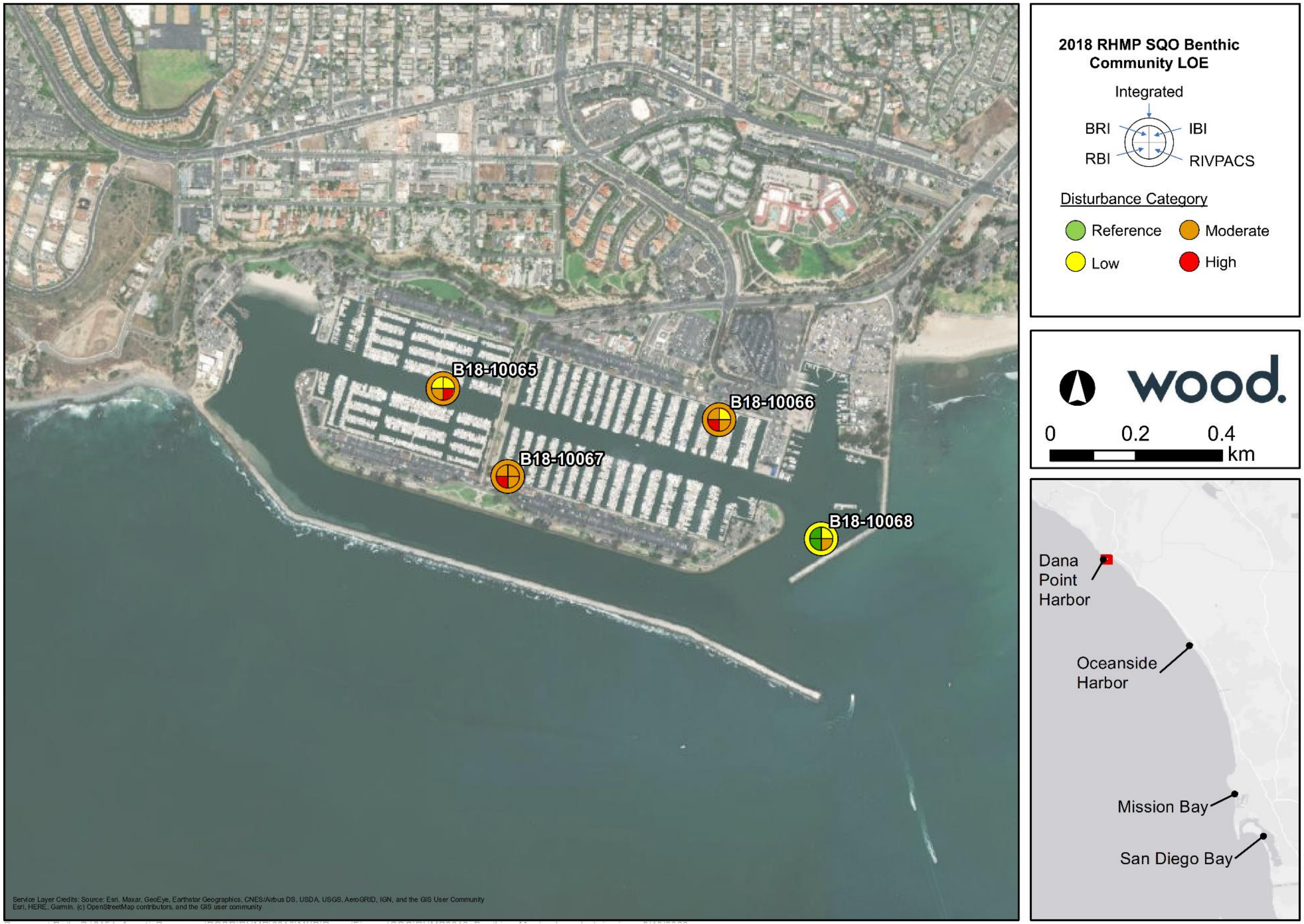
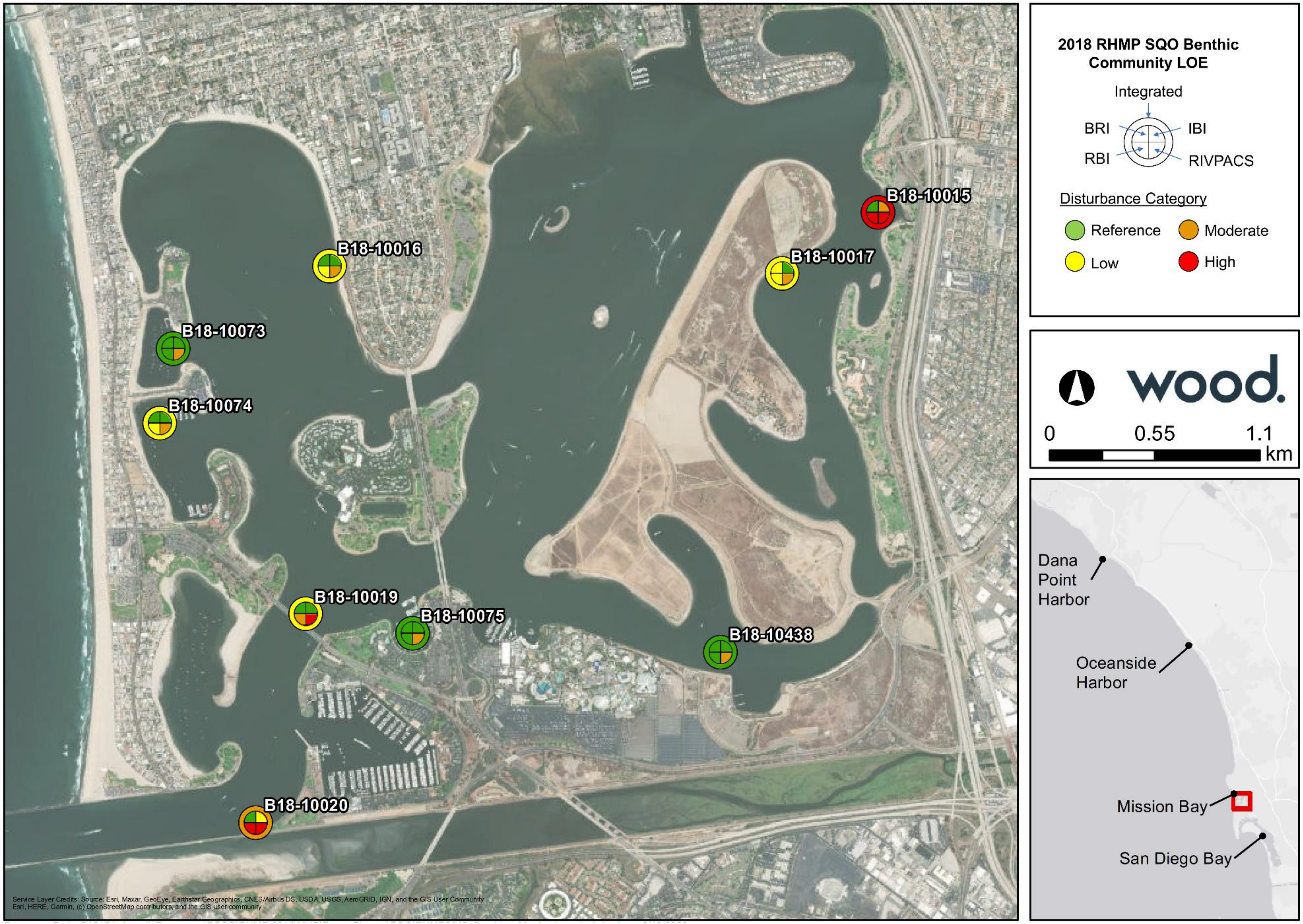


Figure 3-53a. Integrated Benthic Community LOE Results Using the SQO Approach for Dana Point Harbor

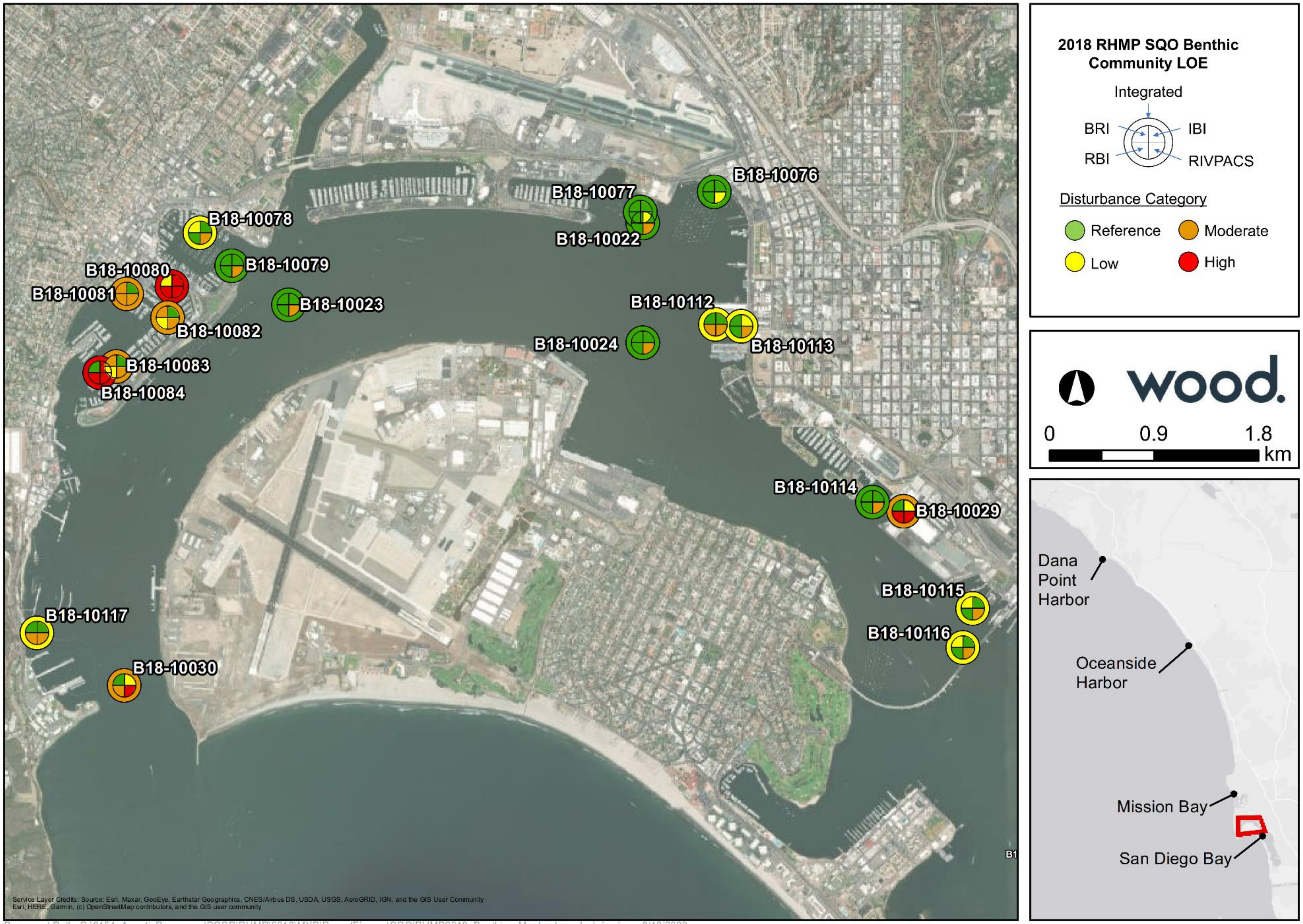
Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 3-53b. Integrated Benthic Community LOE Results Using the SQO Approach for Oceanside Harbor



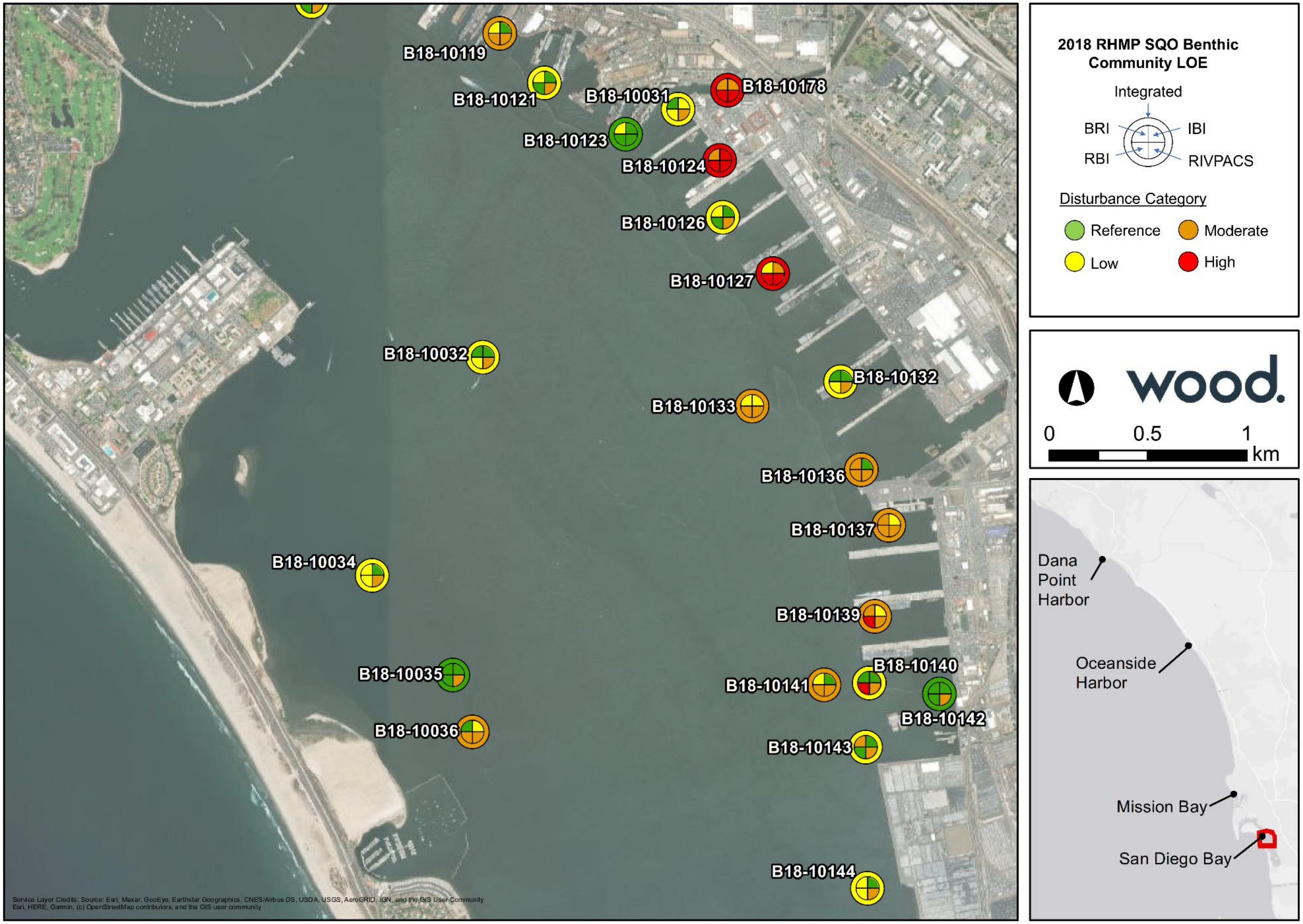
Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 3-53c. Integrated Benthic Community LOE Results Using the SQO Approach for Mission Bay



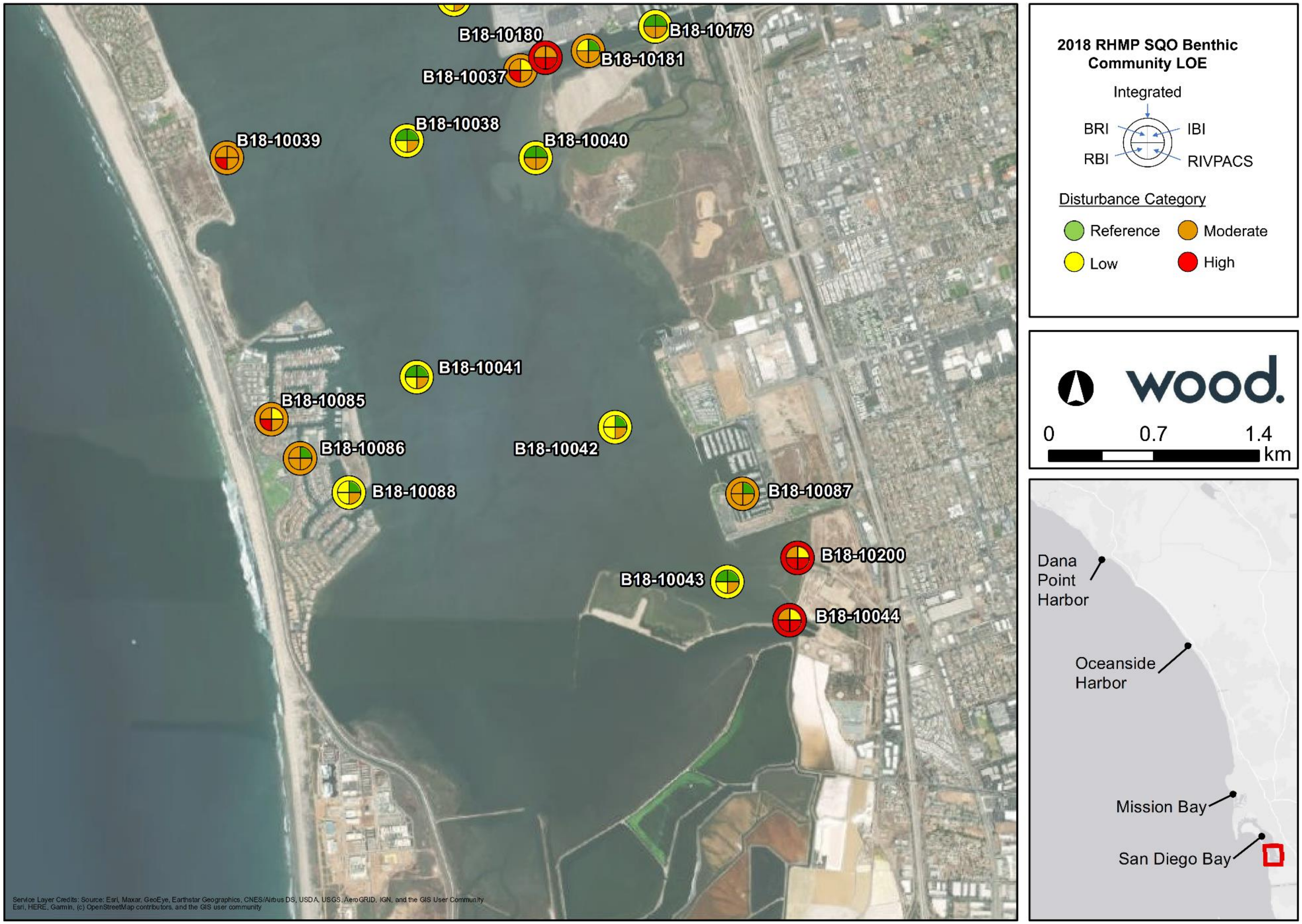
Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 3-53d. Integrated Benthic Community LOE Results Using the SQO Approach for North San Diego Bay



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 3-53e. Integrated Benthic Community LOE Results Using the SQO Approach for Central San Diego Bay



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 3-53f. Integrated Benthic Community LOE Results Using the SQO Approach for South San Diego Bay

Benthic Community Assessment Among Strata and Harbors using Additional Statistical and Graphical Tools

To help visually and statistically compare the similarity or differences in benthic communities among different strata and harbors, a suite of additional statistical and associated graphical analyses were performed as follows.

ANOSIM was performed separately for RHMP stratum and location using pairwise tests for each combination of station type based on the community composition (abundance). San Diego Bay was broken up into the three north to south ecoregions for this evaluation. The results are presented in Figures 3-54 and 3-55 using nMDS plots as a way to condense information from multidimensional data into a 2-D representation or ordination. In these plots, those stations with similar benthic communities will be closer to one another. These analyses were conducted using PRIMER statistical software with detailed statistical outputs provided for reference in Appendix K.

Analysis of station location pairwise comparisons showed that the infaunal community structures were statistically different among all five different sampling strata (Figure 3-54). Most of the stations within each stratum were similar to each other; however, the stations in the deep and freshwater-influenced strata had a greater variety of benthic community structure within those strata than was observed for the other strata.

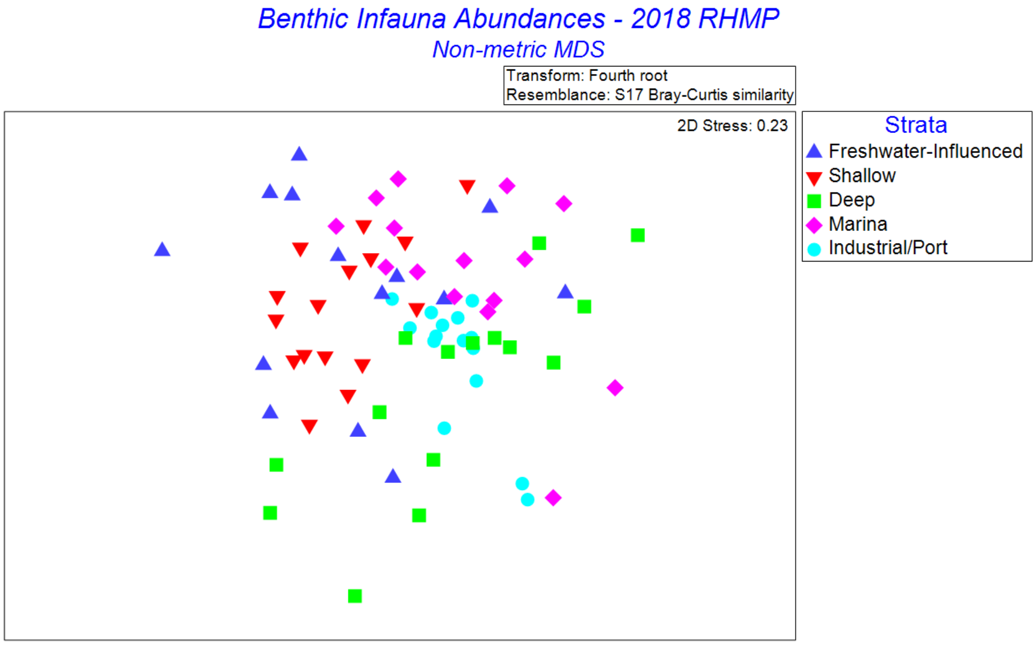


Figure 3-54. Benthic Infauna Community Relationships Among Strata in 2018

When the analysis was performed by harbor and region, Mission Bay and south San Diego Bay had relatively similar and unique benthic communities as well as Dana Point Harbor and Oceanside Harbor as shown in Figure 3-55. Substantial overlap is also noted for sites in north and central San Diego Bay. These results support the overall experimental design of the RHMP with the breakout of different strata as they appear to have unique assemblages though with varying degrees of overlap.

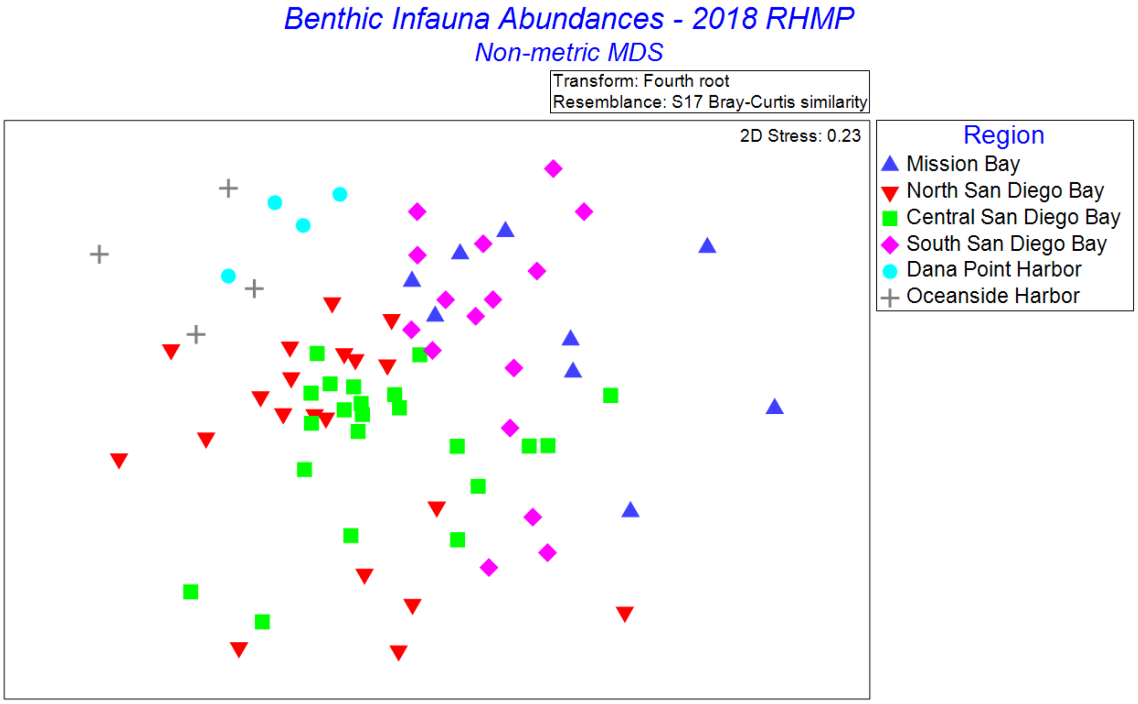


Figure 3-55. Benthic Infauna Community Relationships Among Harbors in 2018

3.3 Integrated SQO Station Assessment Using Chemistry, Toxicity, and Benthic Multiple Lines of Evidence

As described previously, an integrated measure of the quality of sediments for the RHMP is assessed using the SQO guidelines based on the three LOEs, including sediment chemistry, toxicity, and benthic infaunal community condition. This MLOE approach evaluates both the severity of measured biological effects and the potential for chemically mediated effects and integrates the three LOEs to provide an overall station-level assessment of sediment quality. The assessment places a station into one of five qualitative condition categories, ranging from unimpacted to clearly impacted. Individual LOE assessments and the complete SQO station assessments are provided in Appendix J. Consistent with measures of the benthic community based on ecoregions in San Diego Bay, this assessment also shows integrated results broken out by these same three regions for comparison purposes given the differences in benthic community noted from north to south.

Combining all the 2018 RHMP stations, the SQO assessment identified 51% of stations as unimpacted (n=68), 21% as likely unimpacted (n=16), 20% as possibly impacted (n=15), and 8% (n=6) as likely impacted (Table 3-19a and 3-19b). No stations were considered to be clearly impacted. Of the six stations in the study area that were likely impacted, two were in the freshwater-influenced stratum, two were in the marina stratum, and two were in the industrial/port stratum. One station was located in Oceanside Harbor, and the other five were in north and central San Diego Bay. Likely impacted stations with mixed signals of impairment are discussed individually in Section 4.7.

Assessment of the results by stratum indicated that all strata except the marina stratum had most sites in the combined unimpacted or likely unimpacted SQO categories (Table 3-19a).

Table 3-19a.
Percentage of RHMP Stations in Each Integrated Sediment Quality Objective Category, Assessment by Strata

Integrated SQO Category	Percentage of 2018 RHMP Stations Per Integrated SQO Category					
	Deep (%)	Freshwater-Influenced (%)	Marina (%)	Industrial/ Port (%)	Shallow (%)	All Stations (%)
# of stations	*15*	*14*	*15*	*15*	*16*	*75*
Unimpacted	60	36	27	60	69	51
Likely Unimpacted	40	36	13	7	12	21
Possibly Impacted	0	14	47	20	19	20
Likely Impacted	0	14	13	13	0	8
Clearly Impacted	0	0	0	0	0	0

Notes:
% = percent; RHMP = Regional Harbor Monitoring Program; SQO = sediment quality objective

Table 3-19b.
Percentage of RHMP Stations in Each Integrated Sediment Quality Objective Category, Assessment by Harbor and Ecoregion in San Diego Bay

Integrated SQO Category	Percentage of 2018 RHMP Stations Per Integrated SQO Category						
	Dana Point Harbor (%)	Oceanside Harbor (%)	Mission Bay (%)	North San Diego Bay (%)	Central San Diego Bay (%)	South San Diego Bay (%)	All Stations (%)
# of stations	*4*	*4*	*9*	*20*	*22*	*16*	*75*
Unimpacted	25	25	67	65	50	38	51
Likely Unimpacted	0	25	33	5	22	38	21
Possibly Impacted	75	25	0	20	14	24	20
Likely Impacted	0	25	0	10	14	0	8
Clearly Impacted	0	0	0	0	0	0	0

Notes:
% = percent; RHMP = Regional Harbor Monitoring Program; SQO = sediment quality objective

Sediment quality based on all three LOE differed somewhat among harbors. Overall, Mission Bay had sediment quality conditions that were scored as the least impacted, with six of the nine stations (67%) classified as unimpacted and the other three (33%) as likely unimpacted (Figures 3-56 and 3-58c). Dana Point Harbor and Oceanside Harbor had variable results. One of the stations (25%) in Dana Point Harbor was classified as unimpacted, and three (75%) were classified as possibly impacted (Figures 3-56 and 3-58a). In Oceanside Harbor, one station (25%) was classified unimpacted, one (25%) was classified as likely unimpacted, one (25%) was classified as possibly impacted, and one (25%) was classified as likely impacted (Figures 3-56 and 3-58b). In San Diego Bay, 42 of the 58 stations (72%) were classified as unimpacted or likely unimpacted, combined (Figures 3-56, 3-57, and 3-58d through 3-58f).

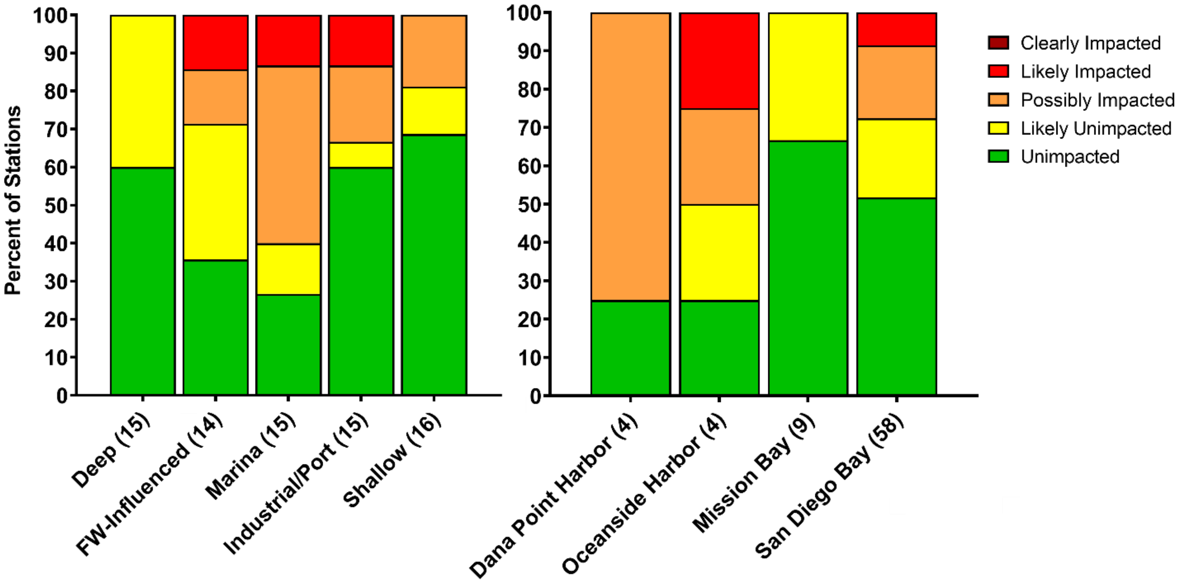


Figure 3-56. Comparisons of the Integrated SQO Results Among Strata and Harbors in 2018

Note: No final station SQO scores were considered "Clearly Impacted."

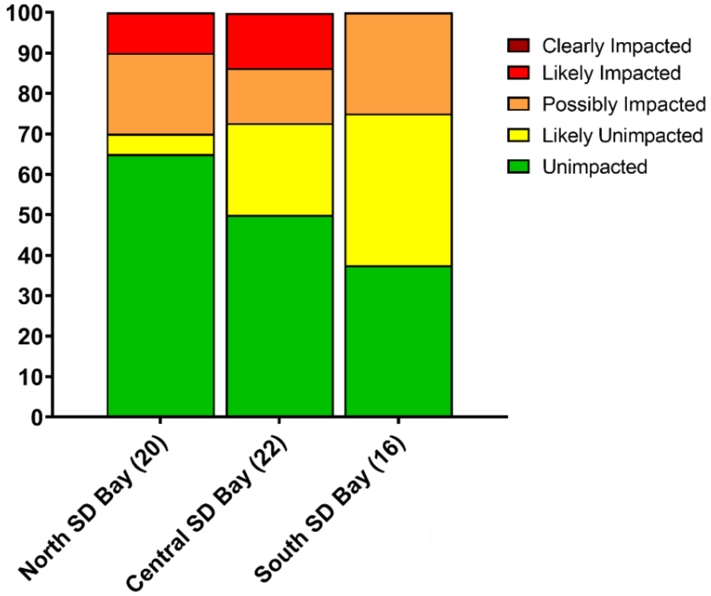
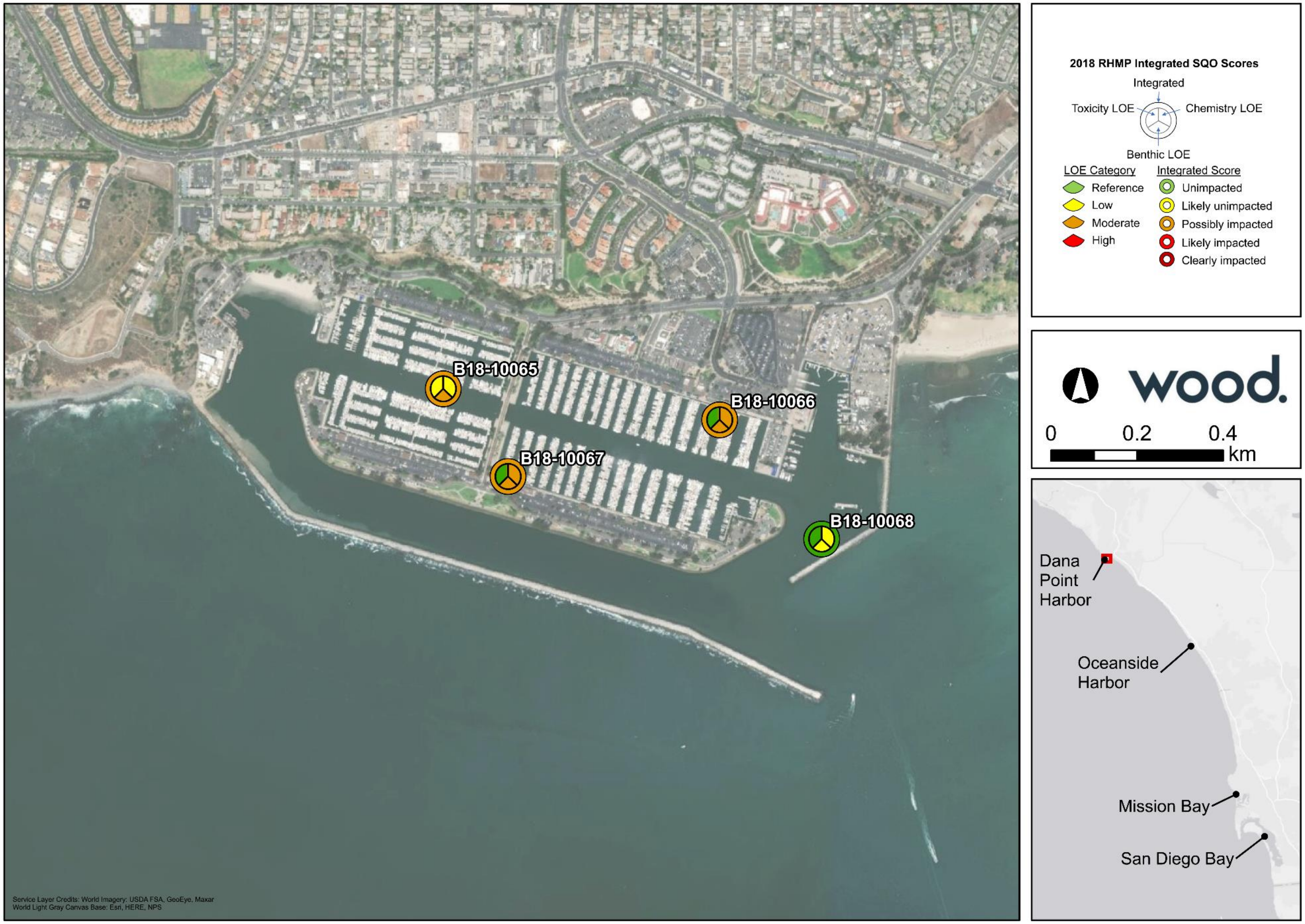


Figure 3-57. Comparisons of the Integrated SQO Results Among Strata and Regions in San Diego Bay in 2018

Note: No final station SQO scores were considered "Clearly Impacted."



Service Layer Credits: World Imagery: USDA FSA, GeoEye, Maxar
World Light Gray Canvas Base: Esri, HERE, NPS

Figure 3-58a. Final Integrated Sediment Quality Objective Scores for Dana Point Harbor

Service Layer Credits: World Imagery: USDA FSA, GeoEye, Maxar
World Light Gray Canvas Base: Esri, HERE, NPS

Figure 3-58b. Final Integrated Sediment Quality Objective Scores for Oceanside Harbor

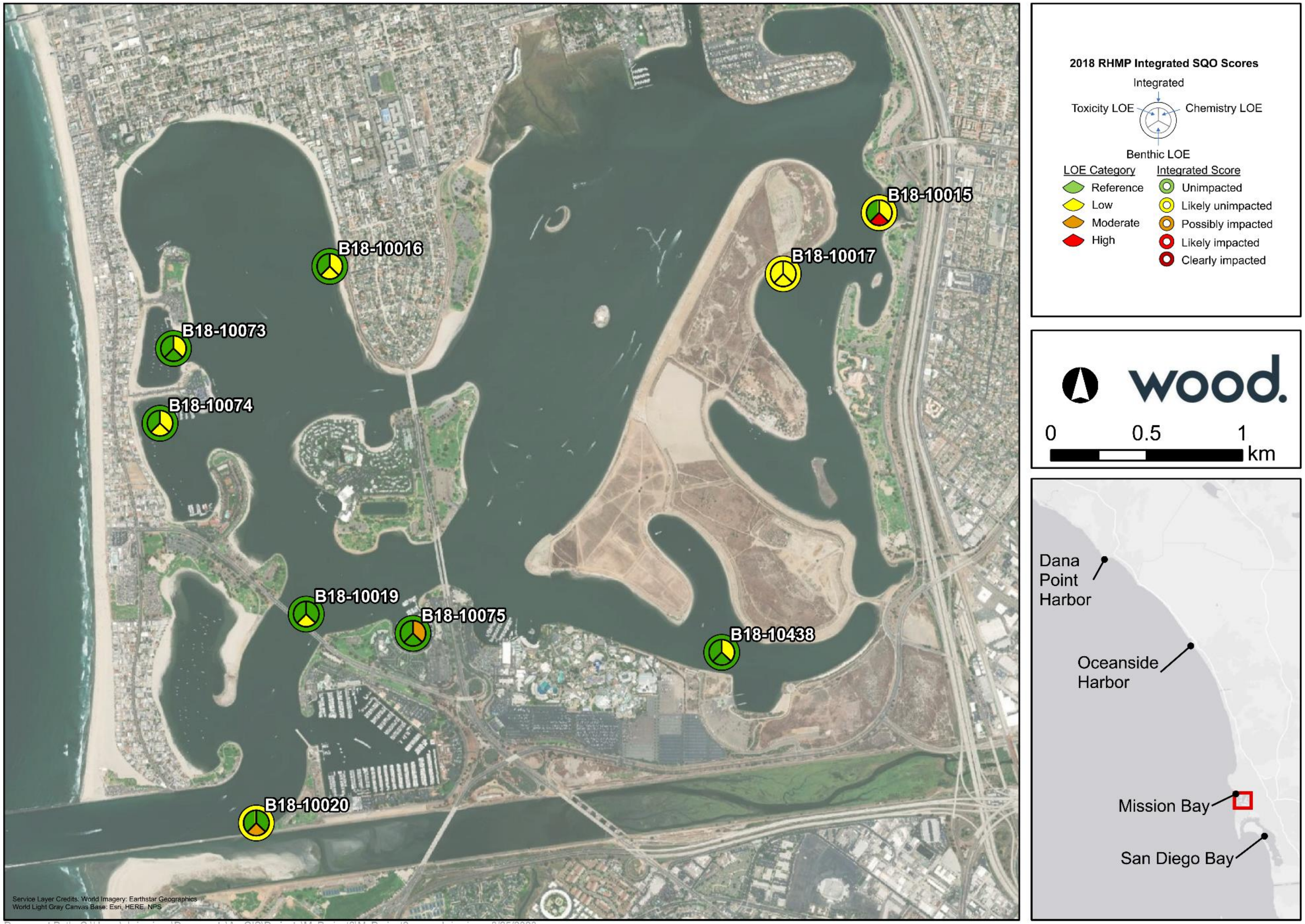
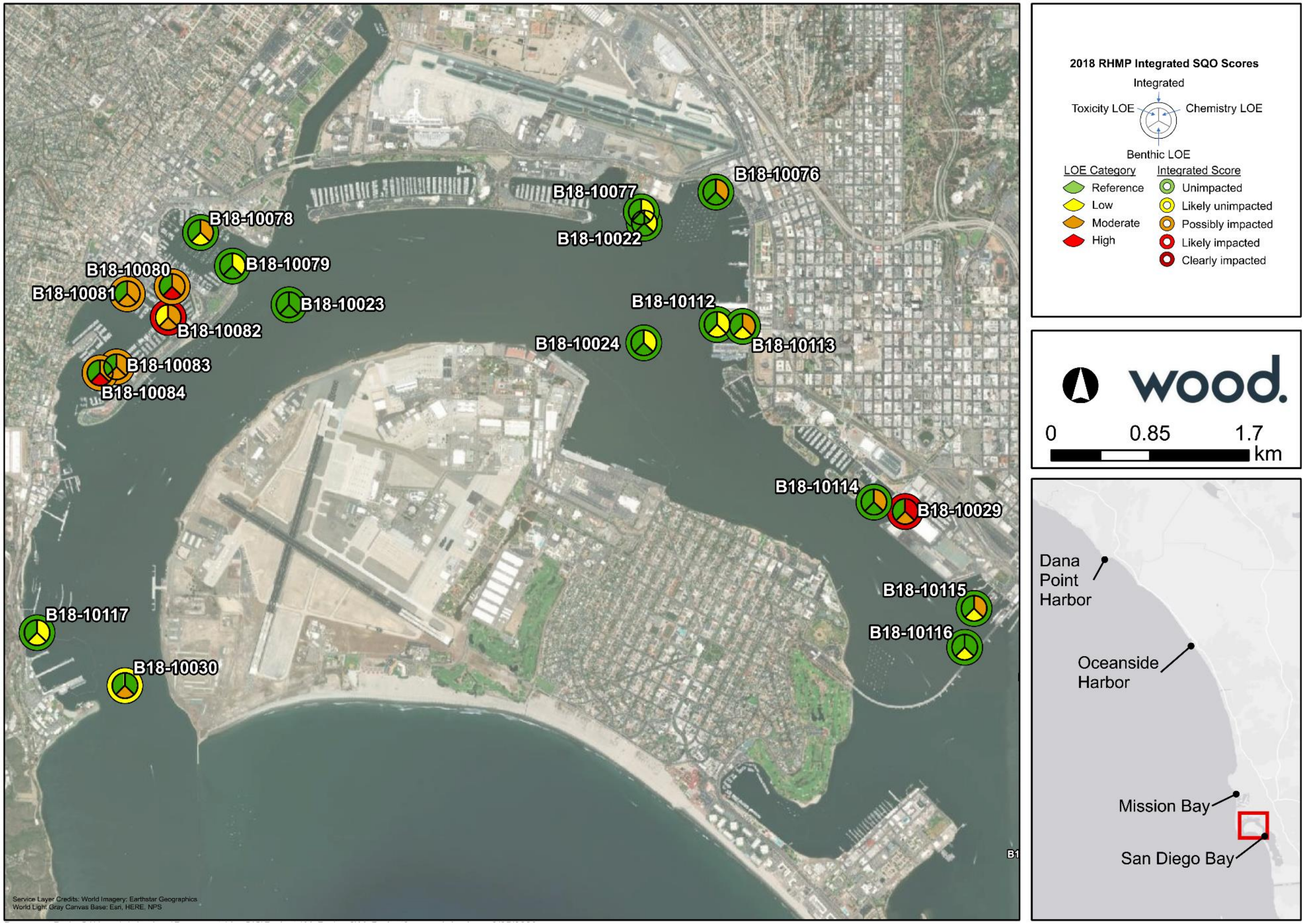


Figure 3-58c. Final Integrated Sediment Quality Objective Scores for Mission Bay



Service Layer Credits: World Imagery: Earthstar Geographics
World Light Gray Canvas Base: Esri, HERE, NPS

Figure 3-58d. Final Integrated Sediment Quality Objective Scores for North San Diego Bay

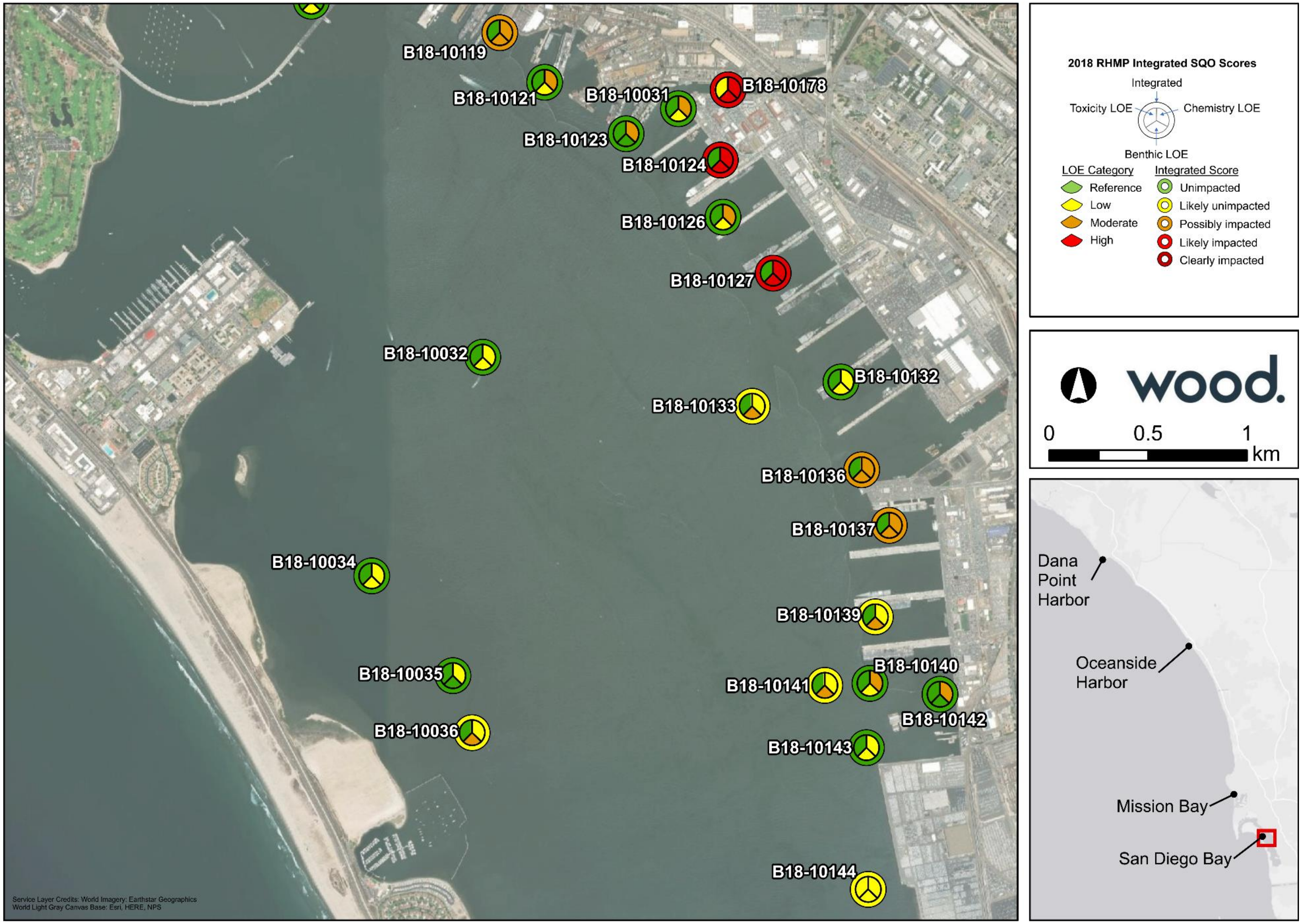


Figure 3-58e. Final Integrated Sediment Quality Objective Scores for Central San Diego Bay

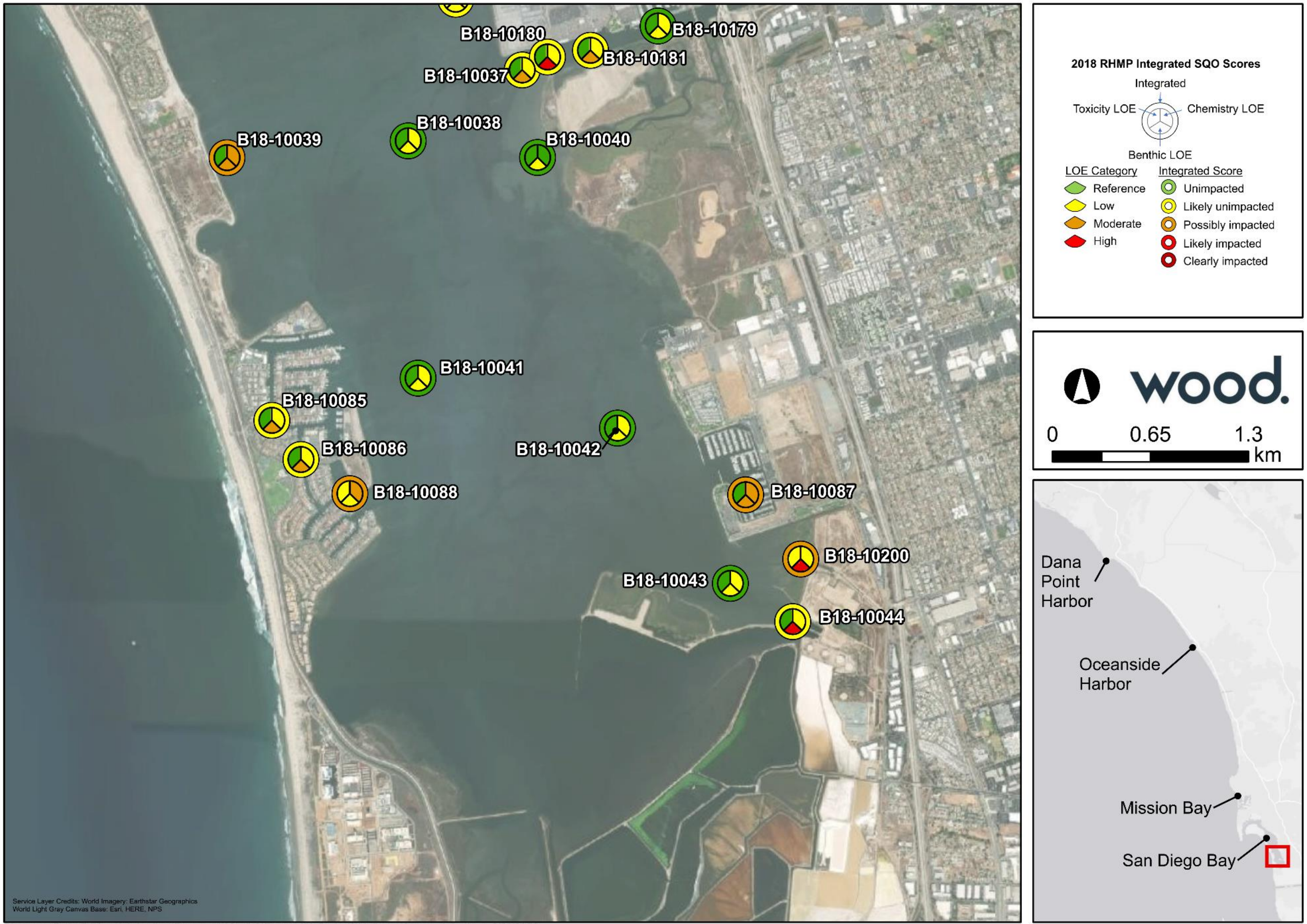


Figure 3-58f. Final Integrated Sediment Quality Objective Scores for South San Diego Bay

3.4 Demersal Fish and Macroinvertebrate Communities

Otter trawls were conducted for a period of approximately 10 minutes at 15 stations to sample the demersal fish and epibenthic macroinvertebrate communities in the harbors. The complete results of the trawl surveys are presented in Appendix I, with fish data summaries and metrics provided in Tables I-1 through Table I-5 and macroinvertebrate data summaries and metrics in Table I-6 through Table I-10.

3.4.1 Fish Community

Fish abundance for all 15 stations in the four harbors totaled 10,231 individuals, representing 32 different species (Appendix I, Table I-1). For all taxa across harbors, the slough anchovy (*Anchoa delicatissima*), northern anchovy (*Engraulis mordax*), spotted sand bass (*Paralabrax maculatofasciatus*), shiner surfperch (*Cymatogaster aggregata*), and round stingrays (*Urobatis halleri*) had the greatest number of individuals. Fish abundance per trawl was greatest at north San Diego Bay Station B18-10022, with 4,563 individuals captured (driven by a large school of northern anchovies) and was lowest at south San Diego Bay Station B18-10042, with 21 individuals captured. A summary of the total abundance of fish caught and average abundance per trawl among all harbors, including the top 10 species across the RHMP by abundance, is provided in Figure 3-59. Photographs of the top 10 species by abundance are presented in Figure 3-60.

The most frequently encountered fish species (i.e., the species collected at the most stations) was determined by calculating the percent frequency of trawl capture (i.e., the number of stations with species present divided by the total number of stations across harbors). Spotted sand bass had the highest capture frequency at 80%, captured at 12 of 15 stations, and in three of the four harbors (absent in Oceanside Harbor). Slough anchovy and round rays were captured at 10 of 15 stations (67%), followed by California halibut at 9 of 15 stations (60%).

Mean abundance per trawl by harbor was greatest in San Diego Bay, with an average of 935 fish per haul (n=10), driven in particular by large schools of anchovies. Broken into the three ecoregions, north San Diego Bay had an average of 1,174 fish per haul (n=4) dominated by a large catch of northern anchovy; south San Diego Bay had an average of 1,019 fish per haul (n=4) dominated by slough anchovy; and central San Diego Bay had an average of 287 fish per haul (n=2), also dominated by slough anchovy. Dana Point Harbor had 409 fish captured in one haul, comprised primarily of northern anchovy followed by shiner surfperch. Oceanside Harbor had 153 fish captured in one haul, comprised mostly of spotfin croaker (*Roncador stearnsii*) and deep body anchovy (*Anchoa compressa*). Mission Bay had an average of 108 fish per haul (n=3), dominated by slough anchovy.

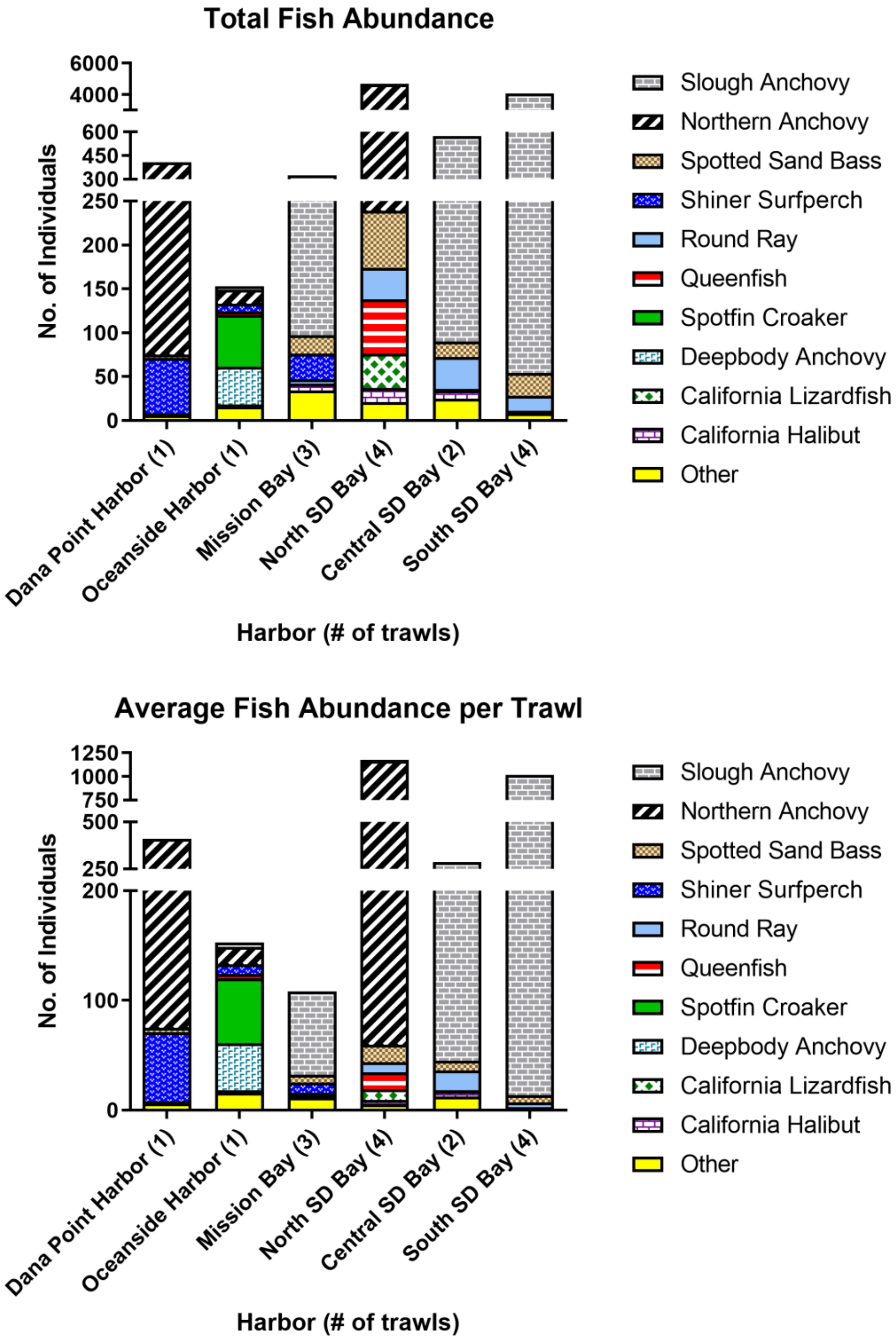
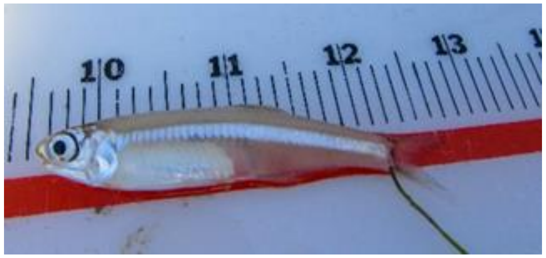


Figure 3-59. Total Abundance (Top) and Average Abundance per Trawl (Bottom) of All Fish Species Captured During Trawls Among Harbors

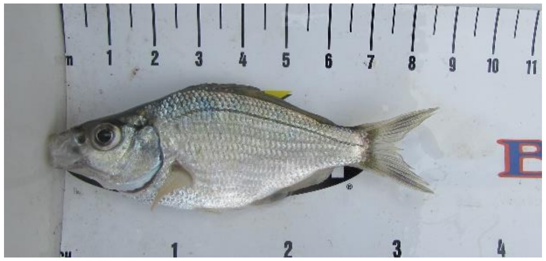
The value in parentheses in the x-axis labels represents the number of trawls performed for each location. The total numbers on the y-axis of the bottom graph represent an average for each trawl when more than one was performed for a given region. The top 10 species (broken out individually) were determined based on the total abundance for all 2018 RHMP trawls combined, while the remainder of species caught were pooled in the "Other" category.



Slough Anchovy

Northern Anchovy

Spotted Sand Bass



Shiner Surfperch

Round Ray

Queenfish

Spotfin Croaker

Deep Body Anchovy

California Lizardfish

California Halibut

Figure 3-60. Top 10 Fish Species Captured During Trawls

Note: Top 10 species were determined based on total abundance for all 2018 RHMP trawls combined.

Fish biomass for all 15 stations totaled 93.4 kg (Appendix I, Table I-2). A summary of the total biomass of fish captured and average biomass per trawl in each of the harbors, including the top 10 species across the RHMP by biomass, is shown in Figure 3-61. Across harbors, species with the highest percentages of total catch biomass regionally were round stingray (23.3 kg), comprising 25% of the total biomass; spotted sand bass (21.2 kg) with 23% of the biomass, and bat ray (*Myliobatis californica*) with 12% of the biomass (11.2 kg). Fish biomass per trawl was greatest at central San Diego Bay Station B18-10034, with 24.3 kg of fish; the lowest total fish biomass was at Mission Bay Station B18-10017, with 0.35 kg of fish.

By harbor, average biomass was greatest in Oceanside Harbor, with 7.55 kg of fish captured at the single station. San Diego Bay had a mean of 7.40 kg of fish captured per station; Mission Bay had a mean of 3.22 kg of fish captured per station; and Dana Point Harbor had 2.40 kg fish at the single station.

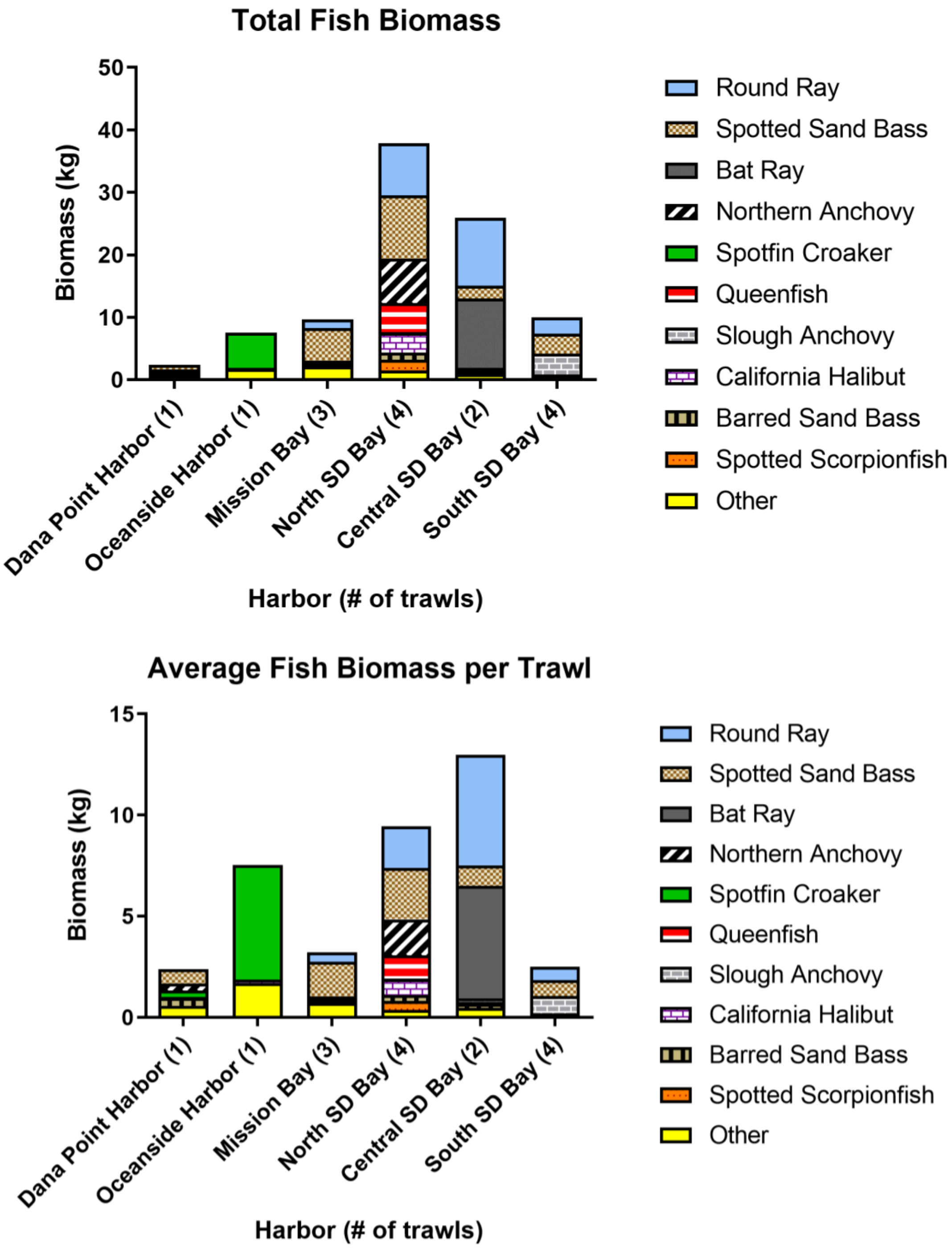


Figure 3-61. Total Biomass (Top) and Average Biomass per Trawl (Bottom) of All Fish Species Captured During Trawls among Harbors

The value in parentheses in the x-axis labels represents the number of trawls performed for each location. The total numbers on the y-axis of the bottom graph represent an average for each trawl when more than one was performed for a given region. The top 10 species (broken out individually) were determined based on the total biomass for all 2018 RHMP trawls combined, while the remainder of species caught were pooled in the "Other" category.

Fish Community Metrics

The Ecological Index (EI) is a metric based on the percentage of individual fish collected, the percentage of biomass, and the percentage of frequency of occurrence (Pondella et al., 2009). This weighted approach emphasizes species that were abundant and caught at many stations, but also gives weight to species that were caught at only a few stations. The “rank” by the EI indicates the relative importance of each species to how energy flows within the food web in each harbor ecosystem (Allen et al., 2002). Because the EI incorporates frequency of catch, this index provides a good measure of what the overall community looks like over time, as discussed further in Discussion Section 4.9.1.

The EI values were calculated for each individual species for all harbors combined (Appendix I, Table I-4 for each individual harbor (Appendix I, Table I-5). Appendix Table I-5 and Figure 3-62 present the ranked EI values of the top three fish species collected from the four harbors separately. The five species with the highest EI value across all harbors were slough anchovy, spotted sand bass, round stingray, northern anchovy, and California halibut (Figure 3-63). In Dana Point Harbor, the three species with the highest EI value were northern anchovy, shiner surfperch, and spotted sand bass. In Oceanside Harbor, the three species with the highest EI value were spotfin croaker, deepbody anchovy, and white surfperch (*Phanerodon furcatus*). In Mission Bay, the three species with the highest EI value were the slough anchovy, spotted sand bass, and round stingray. In San Diego Bay, the fish species with the highest EI value were slough anchovy, northern anchovy, spotted sand bass, round stingray, and bat ray.

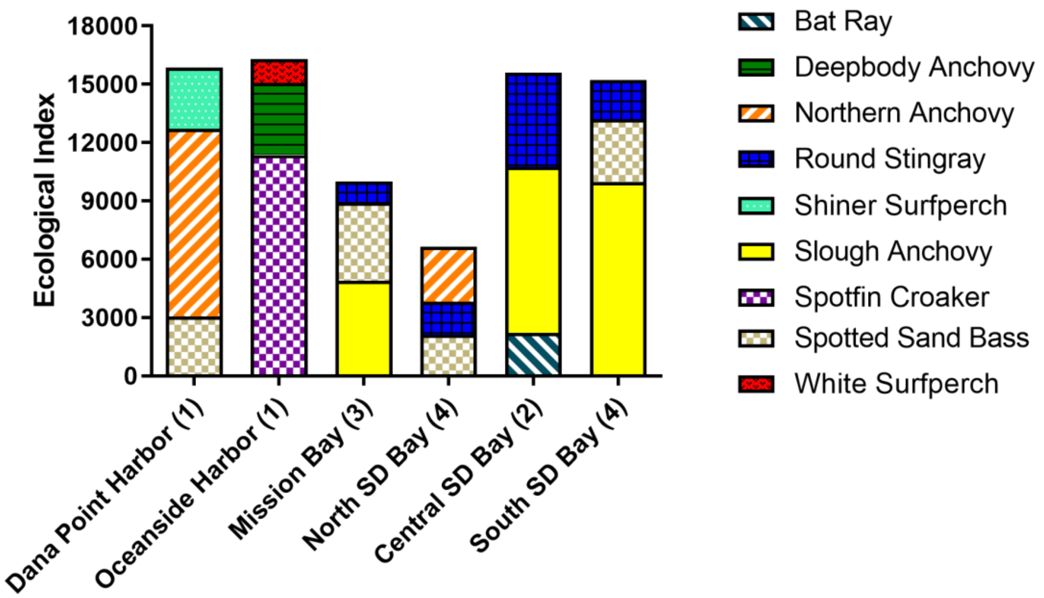


Figure 3-62. Ecological Index for the Top Scoring Fish Species Captured During Trawls in Each Harbor

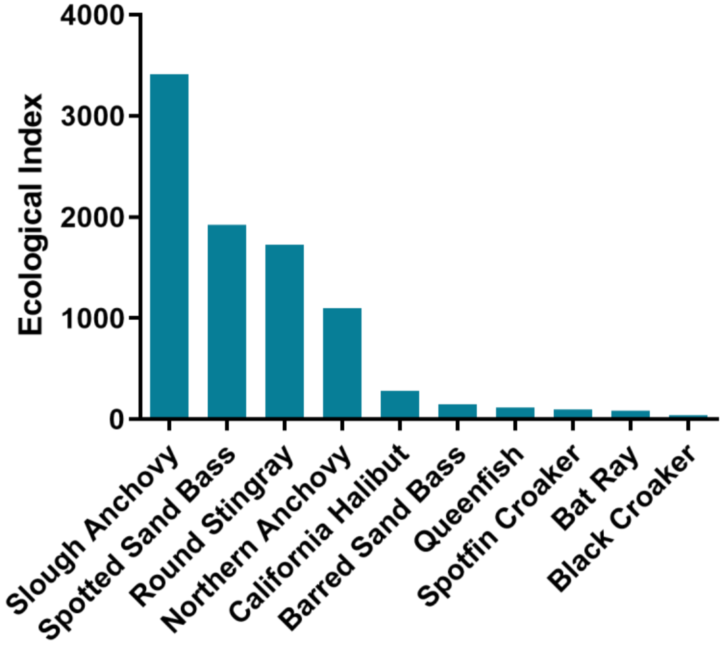


Figure 3-63. Ecological Index for the Top Scoring Fish Species Captured During Trawls Across All Harbors

Mean species richness for all stations was 7.2 species per station (Appendix I, Table I-3). The regional mean Shannon-Wiener Diversity index was 0.80; the regional mean Pielou’s evenness value was 0.42 for all stations; and the regional mean dominance index was 2.9. The regional mean for dominance (i.e., percent composition of the most abundant taxon) was 73.1%. Species richness was highest (14 species) at Oceanside Harbor Station B18-10071 and was lowest (2 species) at south San Diego Bay Station B18-10042. Shannon-Wiener diversity was highest in Mission Bay at Station B18-10016 (H’=1.77), followed closely by Oceanside Harbor at Station B18-10071 (H’=1.76). The lowest Shannon-Weiner diversity was at south San Diego Bay Station B18-10037 (0.02), which also had the lowest evenness index value (0.01). Despite south San Diego Bay Station B18-10042 having the lowest taxa richness and abundance, it exhibited the highest evenness index value (0.99) due to the two species being captured in nearly even numbers. Percent dominance of the most abundant taxon was greatest at south San Diego Bay Station B18-10037, where slough anchovy comprised 99.7% of the catch by number of individuals. One notable observation for all harbors was the proportion of top predator species observed (i.e., sharks, bat rays, California halibut, bass, and rockfish) among all fish captured at each location, ranging from 14% in Oceanside Harbor to an average of 41% in San Diego Bay (see Appendix Table I-3). The bay-wide average proportion of predators per trawl in Dana Point Harbor was 22% and in Mission Bay was 23%. Various studies have suggested that top predators promote species richness and may be good indicators of overall ecological health (Sergio et al., 2008).

Cluster Analysis for Fish Populations

To assess regional fish assemblage structure, abundance data were log transformed to normalize the distribution of the data, and a Bray-Curtis similarity matrix was created from all co-occurring fish species using Primer-e version 7. Station similarity was visualized using an nMDS plot and a heatmap showing the clustering of stations and species (Figures 3-64a and 3-64b). Dana Point and Oceanside Harbors had unique species assemblages and were, therefore, the most separated from other stations, due in part to the large proportion of spotfin croaker, white surfperch, and shiner surfperch. Mission Bay and San Diego Bay were more similar to each other, and both of their fish communities had large proportions of slough anchovy, spotted sand bass, and round stingrays. North San Diego Bay had a slightly different composition compared to the central and southern regions, driven in part by the presence of species such as northern anchovy (*Engraulis mordax*), California lizardfish (*Synodus lucioceps*), California tonguefish (*Symphurus atricauda*), and queenfish (Seriphus politus), which were not observed in other areas of the bay.

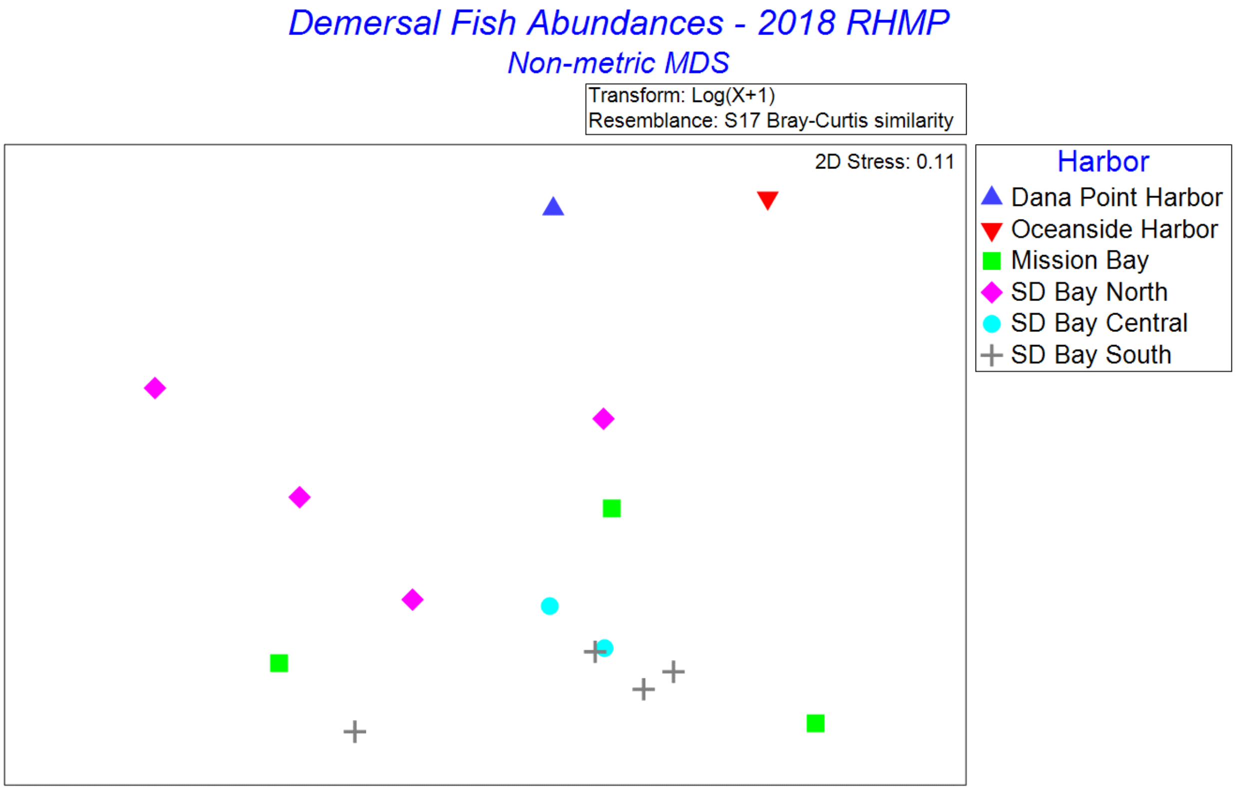


Figure 3-64a. nMDS of Fish Community by Harbor

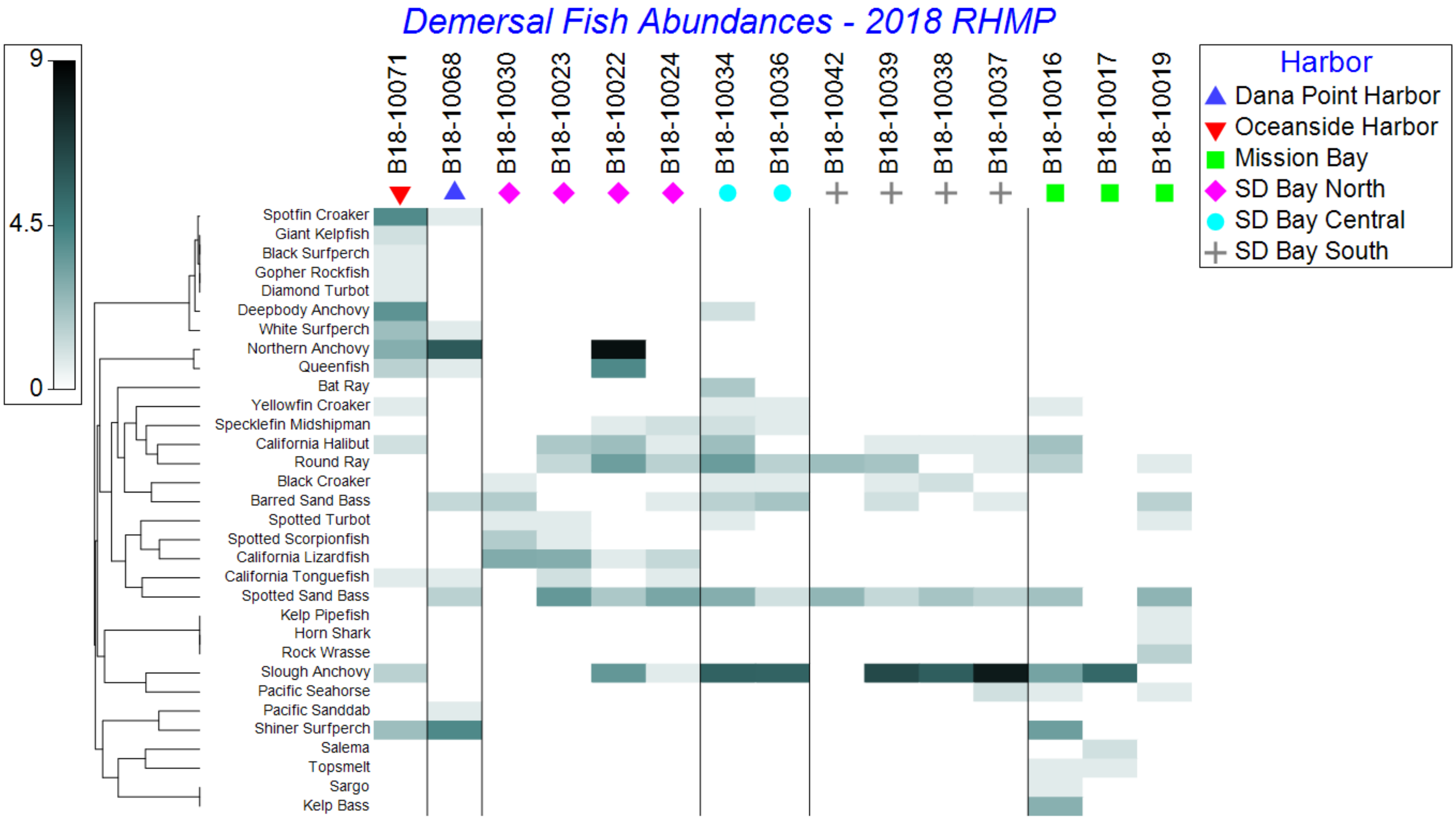


Figure 3-64b. Heatmap Analysis of Captured Fish Species and Station Locations

Note: Scale is log-transformed abundance data that has been normalized for each species. Darker bars represent higher abundances for that species at that station.

Fish Health

Overall, the fish captured appeared healthy. External anomalies such as lesions, tumors, gill parasites, and fin erosion were very rare, observed for only one spotted sand bass caught at Station B18-10034 in central San Diego Bay; this individual had a tumor present at the base of the caudal fin (Table 3-20 and Figure 3-65).

Table 3-20.
Fish Anomalies and Parasites Identified from Benthic Trawls

Station	Harbor	Sampling Date	Species	Common Name	Size Class (cm)	Anomaly
B18-10034	Central San Diego Bay	7/24/2018	*Paralabrax maculatofasciatus*	Spotted Sand Bass	20	Tumor

Notes:
cm = centimeter

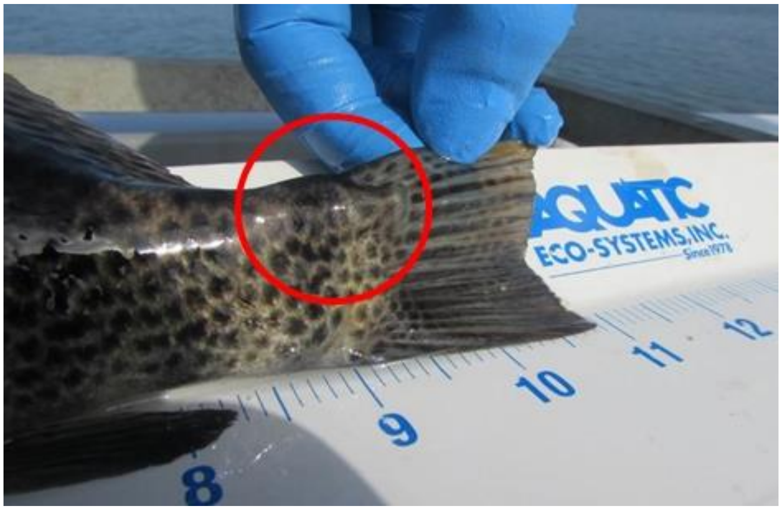


Figure 3-65. Tumor at base of caudal fin on spotted sand bass from Station B18-10034

3.4.2 Epibenthic Macroinvertebrate Communities

Trawl-collected macroinvertebrate abundance for all stations totaled 897 individuals, representing 47 different species (Appendix I, Table I-6, as well as Figure 3-66). The most abundant macroinvertebrates based on total numbers caught across all harbors are the Pacific sand dollar (*Dendraster excentricus*), tunicates (*Pyuridae*), sea pens (*Acanthoptilum* sp), Asian mussel (*Musculista senhousia*), and the navanax sea slug (*Navanax inermis*). Photographs of the top eight most abundant epibenthic macroinvertebrate species are included in Figure 3-67. Note that for some species such as bryozoans and sponges, it was impossible to quantify the number of individuals captured in the trawls because some species broke apart during trawling, and others are colonial and cannot be quantified. These species were marked as “present” for the sake of abundance, and the biomass was measured, but they were not included in abundance calculations.

In general, macroinvertebrate distributions were highly variable and often patchy. While the Pacific sand dollar was the most abundant species (618 individuals), it was only captured at one station in Mission Bay (B18-10019) and led to that station having the highest total invertebrates (642) among all stations. Similarly, the second most abundant taxon, tunicates, were only captured at one station in south San Diego Bay (B18-10039). Sea pens (40% frequency of occurrence), Asian mussels (40%), and Navanax (40%) were more commonly encountered in the trawls across Mission Bay and San Diego Bay, although they were notably absent from Dana Point Harbor and Oceanside Harbor. Five stations had five invertebrate individuals or fewer caught per trawl, with Station B18-10068 in Dana Point Harbor having the lowest richness (two individuals representing two species).

By harbor, mean macroinvertebrate abundance per trawl was greatest in Mission Bay, with 221 individuals per haul (Appendix I, Table I-6). However, this mean abundance was driven by a large group of sand dollars (618 individuals) captured at one station in Mission Bay. Excluding sand dollars, Mission Bay had a mean macroinvertebrate abundance of 15 individuals per trawl, which is comparable to that observed in the other harbors. San Diego Bay had a mean of 21 individuals per haul; Oceanside Harbor had 18 individuals per haul; and Dana Point Harbor had two individuals per haul.

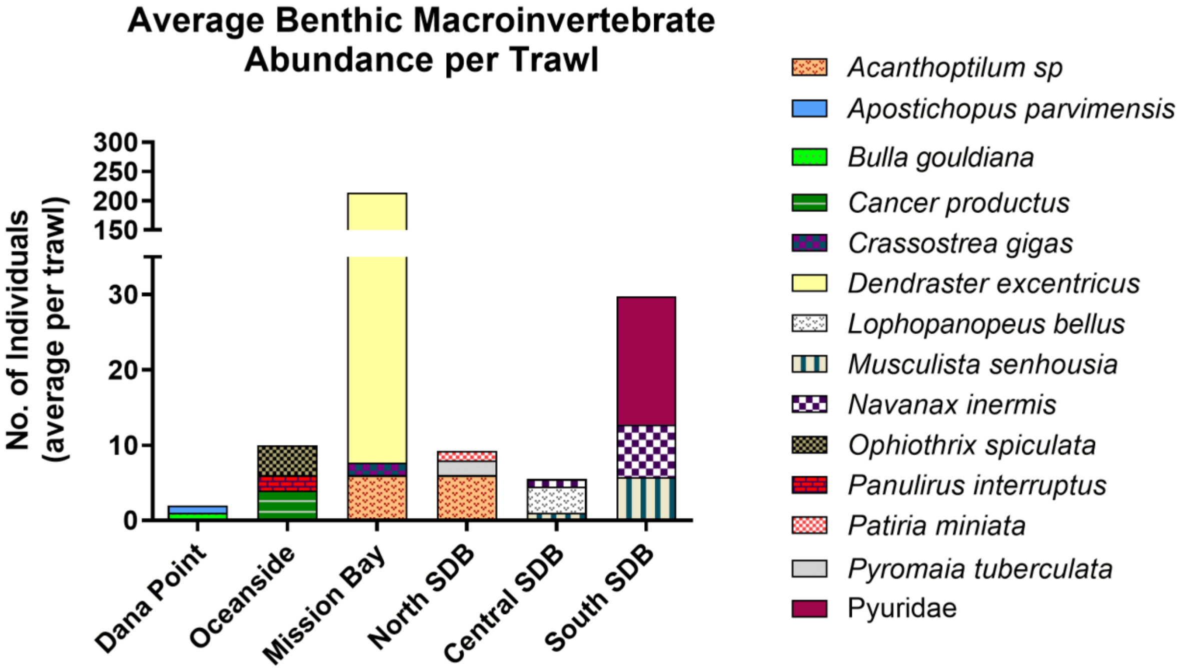


Figure 3-66. Abundance of the Top Epibenthic Macroinvertebrate Species Captured During Trawls among Harbors

 ***Dendraster excentricus*** **(Pacific Sand Dollar)**	 **Pyuridae** **(Tunicate)**
 ***Acanthoptilum* sp** **(Sea Pen)**	 ***Navanax inermis*** **(California Aglaja)**
 ***Musculista senhousia*** **(Asian Date Mussel)**	 ***Lophopanopeus bellus*** **(Black-Clawed Crab)**
 ***Pyromaia tuberculata*** **(Tuberculate Pear Crab)**	 ***Palaemon macrodactylus*** **(Oriental Shrimp)**

Figure 3-67. Top 8 Epibenthic Macroinvertebrate Species Captured During Trawls Based on Total Abundance

Note: Top 8 species were determined based on total abundance for all 2018 RHMP trawls combined. Species that could not be quantified (e.g., bryozoans and sponges) were excluded from total abundance calculations.

Across all harbors and trawls, macroinvertebrate species that composed the highest percentages of total biomass were the bay sponge *Tetilla sp* (10.2 kg, 30.8%), Pacific sand dollar *Dendraster excentricus* (7.0 kg, 21.1%), bay sponge *Suberites sp* (2.8 kg, 8.5%), and California spiny lobster (*Panulirus interruptus*; 2.1 kg, 6.3%). Macroinvertebrate biomass was highest at Mission Bay Station B18-10019 (8.4 kg) due to the large catch of Pacific sand dollars, and at south San Diego Bay Station B18-10039 (7.0 kg) due to a large catch of *Tetilla sp*. Dana Point Harbor Station B18-10068 had the lowest macroinvertebrate biomass with 0.2 kg. A complete summary of biomass data for epibenthic macroinvertebrates is provided in Appendix I, Table I-7.

By harbor, mean biomass per trawl was greatest in Mission Bay, with a mean of 3.93 kg of macroinvertebrates per trawl (Appendix I, Table I-7), followed by San Diego Bay, with a mean of 2.0 kg of macroinvertebrates per trawl. Note that mean biomasses per trawl for these harbors were driven by a large catch of Pacific sand dollars at one station in Mission Bay (B18-10019) and tunicates at one station in south San Diego Bay (B18-10039), as previously noted. Dana Point Harbor had 0.2 kg macroinvertebrates per trawl, and Oceanside Harbor had 0.9 kg macroinvertebrates per trawl.

Macrobenthic Invertebrate Community Metrics

As previously mentioned, for some species such as bryozoans and sponges, it was impossible to quantify the number of individuals captured in the trawls because some species broke apart during trawling, and others are colonial and cannot be quantified. These species were marked as "present" for the sake of abundance, and the biomass was measured, but they were excluded from the diversity metrics discussed below.

The EI value was calculated for each macroinvertebrate species in the same manner used for fish. The "rank" by the EI indicates the relative importance of each species to how energy flows within the food web in each harbor ecosystem (Allen et al., 2002). Table I-8 in Appendix I and Figure 3-68 present the ranked EI values for all harbors combined, and Table I-9 in Appendix I and Figure 3-69 presents the ranked EI value of invertebrate species collected from the four harbors separately. Regionally, the top five species with the greatest EI value were Pacific sand dollar, sea pen *Acanthoptilum sp.*, *Navanax inermis*, Asian mussel, and the California spiny lobster (Appendix I, Table I-8). Distribution of these species was somewhat localized; they occurred only in Mission Bay and San Diego Bay, and sponges were limited to San Diego Bay.

In Dana Point Harbor, the invertebrate species with the greatest EI value were California bubble snail (*Bulla gouldiana*) and warty sea cucumber (*Apostichopus parvimensis*); in Oceanside Harbor, the species with the greatest EI values were rock crab (*Cancer productus*) and brittle star (*Ophiothrix spiculata*); in Mission Bay, the species with the greatest EI values were Pacific sand dollar and bubble snail; and in San Diego Bay, the species with the greatest EI value were Navanax and sea pens (Figure 3-69).

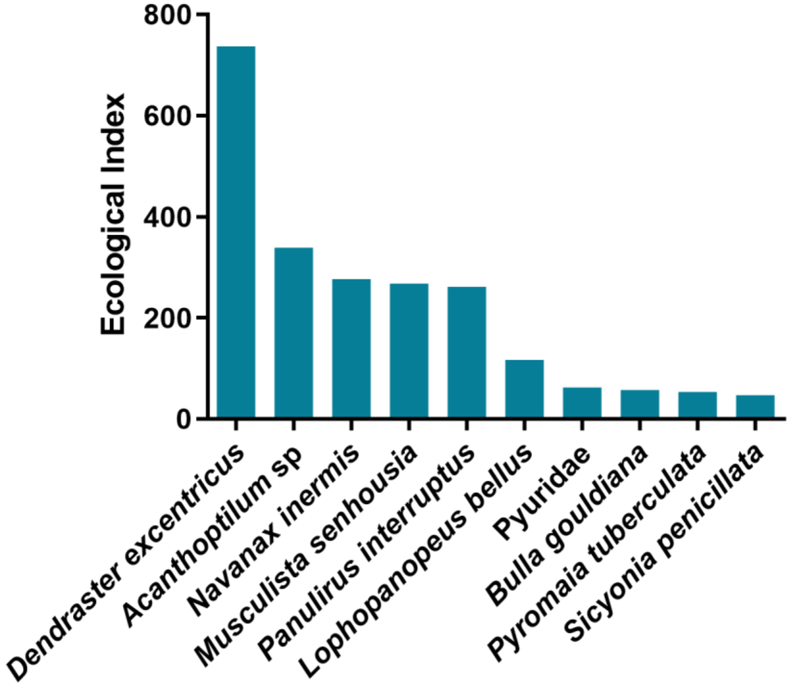


Figure 3-68. Ecological Index for the Top Scoring Epibenthic Macroinvertebrate Species Captured During Trawls Across All Harbors

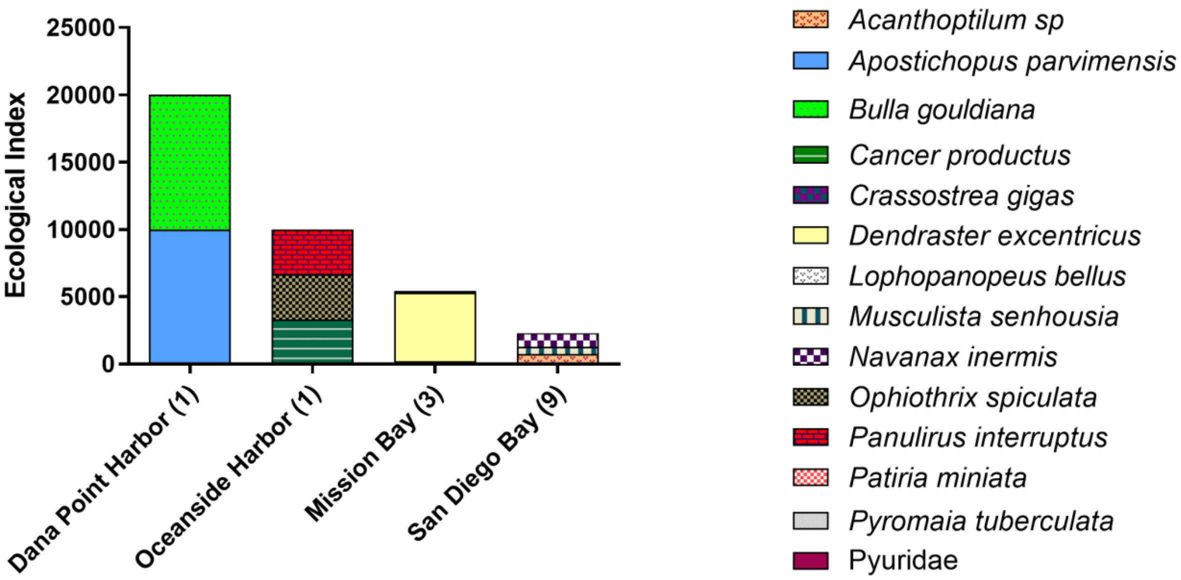


Figure 3-69. Ecological Index for the Top Scoring Epibenthic Macroinvertebrate Species Captured During Trawls in Each Harbor

Mean epibenthic macroinvertebrate species richness for all stations was 6.3 species per station (Appendix I, Table I-10). The regional mean Shannon-Wiener diversity index was 1.1, and the evenness value was 0.8 for all stations; the percentage of dominance of the top taxon was 57%. Species richness was greatest at Mission Bay Station B18-10016, with 13 species collected, and was lowest at Dana Point Harbor Station B18-10068. Shannon-Wiener diversity averaged across harbors was highest in Oceanside Harbor (1.97), although Mission Bay station B18-10016 had the highest single station value (2.21). Dana Point Harbor averaged 0.69, and since only two individuals comprising two species were caught, it had the highest evenness score. Mission Bay and San Diego Bay had an average Shannon-Weiner index score of 1.01, and evenness index scores of 0.65 and 0.77, respectively.

Macroinvertebrate Health

There were no recorded incidents of health anomalies on the macroinvertebrates collected in the 2018 RHMP.

4.0 DISCUSSION

Under the RHMP, a substantial dataset of water and sediment quality exists from which to draw meaningful conclusions for the four designated harbors. This discussion summarizes and highlights key spatial and temporal trends discerned from the results. Each of the following sections discusses the current conditions of the harbors (including spatial trends and potential sources), followed by historical comparisons, in the context of the following core questions[8]:

1. What are the contributions and spatial distributions of inputs of pollutants to the harbors?
2. Do the waters and sediments in the harbors sustain healthy biota?
3. What are the long-term trends in water and sediment quality in the harbors?

The complex relationships among the various parameters measured were examined to assess the potential influence of primary anthropogenic indicators on water and sediment quality conditions in the harbors. The data collected in 2018 continued to provide insight and an enhanced understanding of existing conditions, as well as identified areas where more or less effort may be warranted for future assessments.

The layout of the Discussion mirrors that in the Methods and Results sections, starting with water and sediment quality, followed by the demersal fish and macroinvertebrates. Each section includes a discussion of current conditions, including spatial trends and potential sources of chemicals of concern, followed by an analysis of historical trends. The Discussion section concludes with a more in-depth analysis of select sites that were identified as Likely Impacted by the integrated SQO methodology, and also for the single benthic community LOE where communities were considered to be highly disturbed.

Although several inferences can be made and have been explored and discussed herein, the RHMP was not designed to specifically address cause-and-effect relationships at any particular area of interest. The evaluations conducted herein provided a cursory approach towards identifying factors most likely influencing benthic communities. A more concrete assessment of causal relationships that may affect biological communities will require further focused studies. The ability to make stronger inferences and conclusions will also continue to increase as more data continues to be collected and analyzed in a similar manner over time.

4.1 Water Quality

Physical and chemical characteristics were evaluated throughout the San Diego Regional Harbors to assess spatial and temporal trends in water quality. The following subsections discuss 1) the current physical and chemical conditions observed in the water column during the 2018

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[8] A summary of the results of the historical bacteria analysis is included in the Conclusions section to address Question 5 (*Are the waters in the harbors safe for body contact activities?*). A full supplemental report is included as Appendix P.
A supplemental report will be prepared to address Question 5 (*Are fish in the harbors safe to eat?*) and provided under separate cover.

RHMP, including spatial trends and potential sources of chemicals of concern, and 2) historical comparisons for select physical and chemical characteristics.

4.1.1 Current Water Quality Conditions – Spatial Trends and Potential Sources of Chemicals of Concern

Water Column Physical Parameters

Physical parameters such as temperature, salinity, and pH were relatively uniform across harbors. This is particularly true for smaller harbors such as Dana Point Harbor and Oceanside Harbor, which lack the variability in depths and habitats that are present in Mission Bay and San Diego Bay.

While the concentrations of DO in the water column within 1 meter of the surface at all of the RHMP sampling stations met the Basin Plan WQO of 5.0 mg/L, the DO concentration at depth (1 meter above the seafloor) fell below 5.0 mg/L at two stations in the freshwater-influenced stratum (B18-10178 at the mouth of Chollas Creek in central San Diego Bay, and Site B18-10044 in south San Diego Bay near the mouth of Telegraph Canyon south of the Chula Vista marina), and one in the deep stratum (Site B18-10068 near the mouth of Dana Point Harbor at a moderate depth of only 5 meters). DO concentrations below the 5.0-mg/L Basin Plan threshold have the potential to adversely affect less-mobile demersal species. Both freshwater-influenced locations with low dissolved oxygen at depth had high levels of total organic carbon in the sediment relative to other locations. The breakdown of organics consumes oxygen and can deplete oxygen levels in both the sediments and overlying waters near the substrate (Milliken and Lee, 1990). Other factors that may contribute to the decrease in DO with depth include local geography resulting in areas with limited flushing, particularly if combined with potential illicit discharges of organic waste (such as sewage) from vessels in low-flow areas (such as in marinas and industrial areas).

At the deep location in Dana Point Harbor where low DO was observed near the bottom, the benthic community was considered to have low disturbance based on the integrated SQO benthic community LOE; however, both sites in San Diego Bay with low DO at the bottom were considered to have highly disturbed benthic communities. While physical parameters measured during the RHMP represent a single moment in time, persistent low DO near the sediment surface could play a role in benthic community disturbance. It is important to note, however that DO can vary substantially over short periods of time in these environments due to tides, currents, and diurnal rates of algal photosynthesis and respiration. Therefore, it is difficult to draw conclusions related to direct effects on benthic communities from a single measurement in time.

The average water clarity measured using light transmittance across strata did not show much variability spatially, although some of the deeper stations showed substantial decreases in transmittance from the surface to the bottom. While these measurements capture a moment in time, it is important to consider factors that can produce temporary reductions in transmittance versus persistent reduction in light reaching the bottom. Within marinas (and, likely, the industrial/port stratum and elsewhere), causes of intermittent increases in turbidity may include the resuspension of sediments due to propeller-induced disturbances (Paulson and Da Costa, 1991), discharges from vessels, wind and tidal actions, and planktonic algal blooms. Tidal currents can also have a significant effect on turbidity, particularly near the bottom at the sediment-water interface. Persistent reductions in light have the potential to limit the abundance of primary producers, such as eelgrass and algae, and thus reduce the biodiversity and species abundances (Wong et al., 2020).

Water Column Chemistry

In the water column, all metals besides copper were detected at concentrations below acute and chronic CTR criteria. In general, the spatial distributions of chemical constituents in the water column varied throughout the San Diego Regional Harbors. Those areas immediately associated with anthropogenic disturbance and inputs of pollutants tended to show a greater presence of chemical constituents. This was most notably the case for the marina stratum, but elevated chemical concentrations were also observed in the industrial/port stratum and select stations in the freshwater-influenced stratum, particularly near the mouth of Chollas Creek in San Diego Bay. An assessment of RHMP primary constituents of concern in the water column (dissolved copper, dissolved zinc, dissolved nickel, and total PAHs) follows.

Dissolved Copper

Median dissolved copper concentrations in the marina stratum (5.2 µg/L) were 72 to 285 percent higher than those in other strata, which ranged from 1.3 µg/L in the deep stratum to 3.0 µg/L in the freshwater-influenced and industrial/port stratum. Dissolved copper concentrations in surface waters frequently exceeded acute CTR and ambient EPA criteria (CMC = 4.8 µg/L) for inland surface waters and enclosed bays in the marina stratum (n=9 of 15 sites) and occasionally exceeded criteria in the freshwater-influenced stratum (n=3 of 15 sites) (see Table 3-5 in the Results section). Concentrations of dissolved copper above chronic CTR and EPA ambient water quality criteria (CCC = 3.1 µg/L) were most prominent in the marina stratum (n=12 of 15 sites), industrial/port (n=7 of 15 sites), and freshwater-influenced strata (n=6 of 14 sites) (see Table 3-5 in the Results section). Dissolved copper levels in the surface water were generally lower in the deep and shallow strata (see Figure 3-6 and Table 3-5 in the Results section). Those few sites that exceeded CTR criteria for copper in the deep and shallow strata (n=2 of 15 deep sites and n=1 of 16 shallow sites) were located in close proximity to the other strata where copper may be a source.

Results of the 2018 RHMP are consistent with findings of previous studies that have documented dissolved copper as a contaminant of concern in numerous harbors and marinas in southern California (McPherson and Peters, 1995; SDRWQB, 2005 Copper TMDL for Shelter Island, San Diego Bay; Weston, 2010a; and Amec Foster Wheeler, 2016; Schiff et al., 2003; Schiff et al., 2006, Schiff et al., 2007; LARWQCB Marina del Rey Harbor Toxics TMDL, 2019). The close association between elevated surface water dissolved copper concentrations and marinas documented in the RHMP suggests that copper-based antifouling paints and in-water hull cleaning activities are likely to have a more persistent effect on dissolved copper concentrations in the harbors than do other sources of pollutants such as storm water runoff and industrial inputs both within and outside the marinas.

Dissolved Zinc

Similar to copper, the greatest concentrations of dissolved zinc were observed in the marina stratum. These results appear to indicate localized sources that may be related to boating activity, such as zinc-containing antifoulant paints and sacrificial anodes. However, measured concentrations of dissolved zinc were well below both ambient acute and chronic water quality criteria at all 75 RHMP locations. These results indicate limited toxicological concern related to this trace metal despite patterns of occurrence associated with anthropogenic activity.

Dissolved Nickel

Unlike both dissolved copper and dissolved zinc, concentrations of dissolved nickel were within a tight range (within < 1 µg/L of each other) and showed no pattern among strata or harbors. Measured concentrations of dissolved nickel were well below both ambient acute and chronic water quality criteria at all 75 RHMP locations indicating limited toxicological concern related to this trace metal.

Total PAHs

Total PAHs were present region-wide, but concentrations were below currently available threshold values for individual PAHs for the protection of aquatic life referenced in the British Columbia Environmental Protection and Sustainability Division guidelines (1993) and concentrations expected to be of toxicological concern. There are no standard water quality objectives for PAHs in the U.S. hence the reference to the Canadian guidelines for this class of compounds. The greatest concentrations of these compounds were generally observed in 2018 in the industrial/port stratum located in the north and central portions of San Diego Bay.

Potential sources of PAHs to the industrial/port, marina, and freshwater-influenced strata include petroleum products and byproducts from both boating activities and urban storm water discharges, groundwater flow from historical waste oil and drum disposal sites, shipping activities, spills at fuel docks during fueling, incomplete combustion of fossil fuels, and leaching from creosote pilings (Fairey et al., 1998; Katz, 1998).

4.1.2 Water Quality Historic Comparisons

Water quality in our local bays and harbors is inextricably linked to not only anthropogenic influences and geography, but also regional climatic conditions. In particular, temperature and rainfall can both alter the bioavailability and mobility of contaminants and may physiologically impact benthic communities based on temperature and salinity tolerance ranges (Pollack et al., 2011, Ranasinghe et al., 2010, Coyle et al, 2007). Storm water can also transport additional contaminants into the harbors which will vary depending on the number, size, and intensity of storms in any given year. This section presents a summary of the potential linkage between historical regional climatic conditions and measured physical water quality conditions over time.

Water Column Physical Parameters – Regional Climatic Conditions

Temperature

Long term mean sea surface temperatures recorded off of the pier at the University of California, San Diego Scripps Institution of Oceanography (SIO) are summarized in Figure 4-1, showing an increase over time since records began in 1916. Notably, the latest years plotted between 2014 and 2018 have been the warmest by far. During 2018, the southern California coast experienced record warm ocean water temperatures reaching 26.4°C (79.5°F) in August 2018 which was tied more recently on August 25, 2020 (SIO Shore Stations Program, 2020; https://sccoos.org/data/autoss/timeline/?main=single&station=scripps_pier).

A second plot of surface water temperatures over a shorter period of time from 2010 through 2020 is shown in Figure 4-2 for a monitoring station located in the southern portion of San Diego Bay. Plotted on this figure are periods when the last two Bight surveys occurred during 2013 and 2018. Notably, in 2018, surface water temperatures in south San Diego Bay were approximately 3 to 5°C warmer than in 2013 during the summer sampling periods for the Bight programs. A maximum temperature of 31.6°C (89°F) was recorded during the RHMP sampling period on August 10, 2018. Similar trends were observed at RHMP stations in south San Diego Bay, where surface water temperatures measured ranged from 23.6 to 26.1°C (average = 24.8°C) in 2013 and from 25.8 to 29.0°C (average = 27.4°C) in 2018. In addition, average surface water temperatures across all RHMP stations increased 2.4°C, from 22.5°C in 2013 to 24.9°C in 2018.

It is well known that all species have specific tolerance ranges for temperature; however, the tolerance for individual benthic infaunal species in southern California is unknown. Given that temperatures are increasing, this factor will continue to be an important variable to take into consideration when evaluating and connecting the physical parameters of the water column to the health of benthic infaunal communities for the RHMP. In the southeastern Bering Sea, for example, long term trends in benthic community composition identified significant differences over time for specific functional infaunal groups, namely carnivores, omnivores and surface detritivores that appear to be related to different temperature regimes that occurred over a 17-year period (Coyle et al., 2007). Assessment of the potential effects from elevated temperature on benthic infauna and epibenthic fish and macroinvertebrate communities is explored further in Discussion Sections 4.4 and 4.9, respectively.

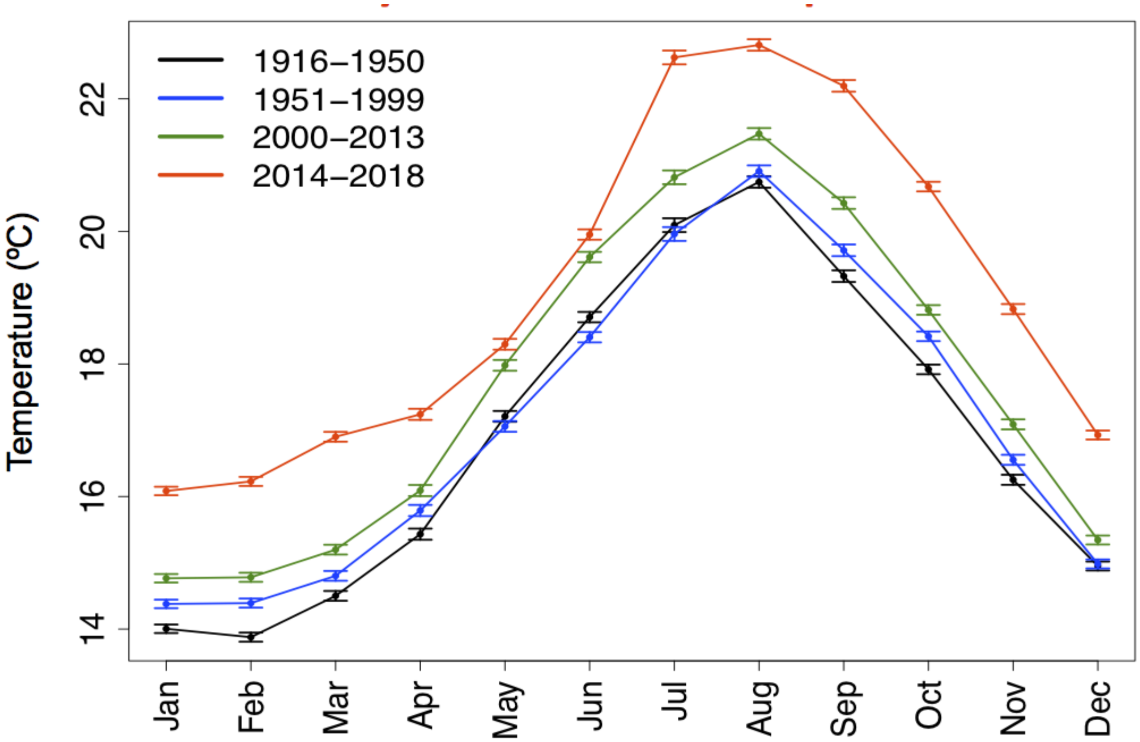

Figure 4-1. **Historical Sea Surface Temperature at Scripps Pier (1916 – 2018)**

Source: Rasmussen et al.

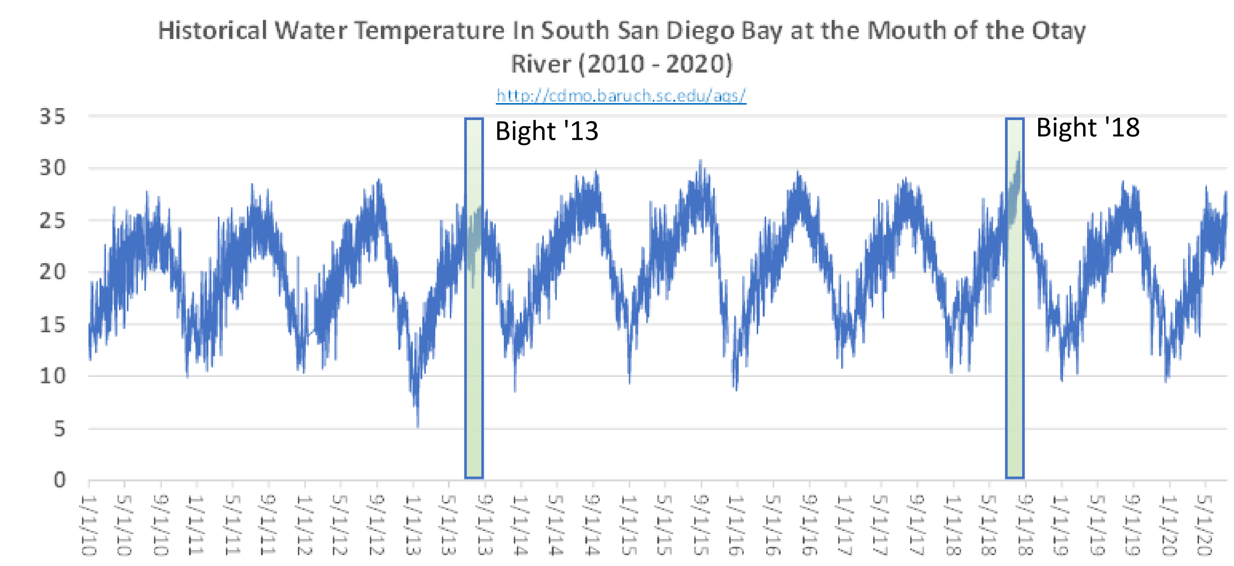

Figure 4-2. **Historical Sea Surface Temperature in South San Diego Bay (2010 – 2020)**

Source: National Estuarine Research Reserve System Centralized Data Management Office
http://cdmo.baruch.sc.edu/aqs/

Rainfall

Rainfall is another environmental factor that can have a substantial influence on both transport of contaminants to the bays and direct effects to benthic communities from physical disturbance and reduced salinity. Rainfall patterns in San Diego can vary substantially from year to year, and the intensity and duration of rainfall can also vary dramatically among storms. A summary of annual rainfall recorded at the San Diego International Airport is provided in Figure 4-3.

In addition to increased temperature, increased runoff relative to that encountered prior to the last two Bight and RHMP monitoring periods may have had some influence on benthic infauna and other RHMP LOE. From October 1, 2017 through September 30, 2018 (i.e., 2017 water year[9]), 12.73 inches of rain was recorded in San Diego at Lindbergh Field (123% of normal), while 2012, 2013, and 2007 were all drought years in San Diego with only 7.90, 6.56, and 3.85 inches of rain recorded during each water year, respectively; (Figure 4-3; https://www.sdcwa.org/annual-rainfall-lindbergh-field. Notably, the 2017 water year included several inches of rain recorded in the San Diego region between January and April 2018, just a few months prior to the RHMP sampling efforts. The increased runoff and associated physical disturbance/sedimentation, chemical inputs associated with settling particles, and reduced salinity all have the potential to cause impacts to the biological communities, particularly in shallow areas directly influenced by a large watershed source or directly in front of large storm drains (i.e., freshwater-influenced stratum). Assessment of the potential effects from rainfall on benthic communities is explored further in Discussion Section 4.4.

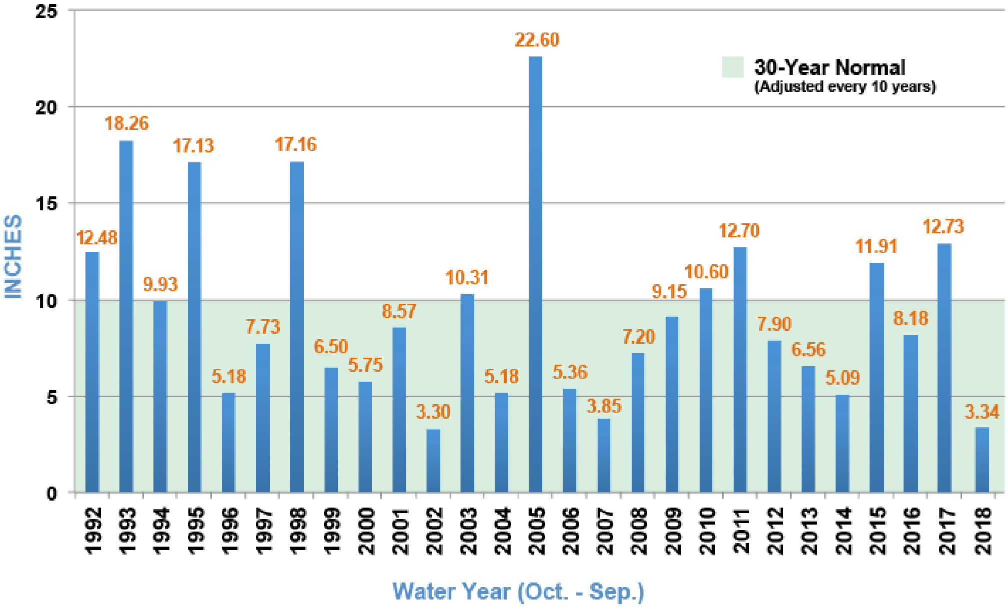

Figure 4-3. Historical Rainfall at Lindbergh Field

Source: https://www.sdcwa.org/rainfall

Note that annual rainfall totals are based on the water year, which is defined as the calendar year that begins October 1 and ends September 30.

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[9] A water year is defined as the calendar year that begins October 1 and ends September 30.

Water Column Chemistry

Overview

Overall, 2018 RHMP surface water quality data suggest conditions appear suitable to support healthy biota. Of the analytical and physical parameters assessed, dissolved copper (primarily in the marina stratum) and DO (primarily in the freshwater-influenced stratum) were the only two parameters observed that did not meet water quality thresholds. Concentrations of all other analytes met water quality criteria, falling beneath threshold values for adverse effects, and generally were similar in concentration to historical conditions (i.e., did not exhibit increasing or decreasing concentrations). Discussion including historical comparisons for individual chemicals, including dissolved copper, dissolved zinc, dissolved nickel, and PAHs, follows.

Dissolved Copper

Historical results for dissolved copper are presented in Figures 4-4a and 4-4b and Table 4-1. For RHMP harbors collectively, dissolved copper concentrations in the surface water have decreased compared with historical conditions (pre-2008). However, dissolved copper concentrations over the past 10 years have been relatively consistent overall (Figure 4-4a), with overall harbor median concentrations of 3.0, 2.9 and 2.7 µg/L in 2008, 2013, and 2018, respectively. The difference in concentration between 2008 and 2018 was statistically significant based on a two-tailed t-test ($p < 0.05$; see Appendix K). For both current (2018) and historic conditions, the overall harbor concentrations observed for copper are primarily influenced by the marina stratum, as shown in Figure 4-4b. In the marina stratum across all harbors, the 2018 median concentration was determined to be 5.2 µg/L, as compared with 6.2 µg/L during the 2013 RHMP and 5.7 µg/L during the 2008 RHMP.

While dissolved copper concentrations exceeded CTR criteria in portions of all four harbors, especially within the marina stratum, the fraction of stations with dissolved copper concentrations below acute and chronic CTR criteria (4.8 and 3.1 µg/L, respectively) has improved slightly since 2008 in the shallow, deep, and marina strata (Figure 4-4a, Table 4-1). However, dissolved copper concentrations in the freshwater-influenced and industrial/port strata were slightly higher in 2018, relative to the previous 2008 and 2013 RHMP sampling efforts.

Overall, the frequency of dissolved copper WQO exceedances observed in 2018 is consistent with historic patterns, particularly in the marina stratum, and indicates that dissolved copper remains a primary contaminant of concern in surface waters. As mentioned previously, the close association between elevated surface water dissolved copper concentrations and marinas documented in the RHMP is consistent with other studies and suggests that copper-based antifouling paints and in-water hull cleaning activities are likely to be a more significant source of dissolved copper concentrations in the harbors than other sources of copper. Other documented sources of copper to the Regional Harbors may include storm water runoff, aerial deposition, historical contamination, various industrial activities and associated discharges (e.g., steam condensate), and motor exhaust (Schiff et al., 2006).

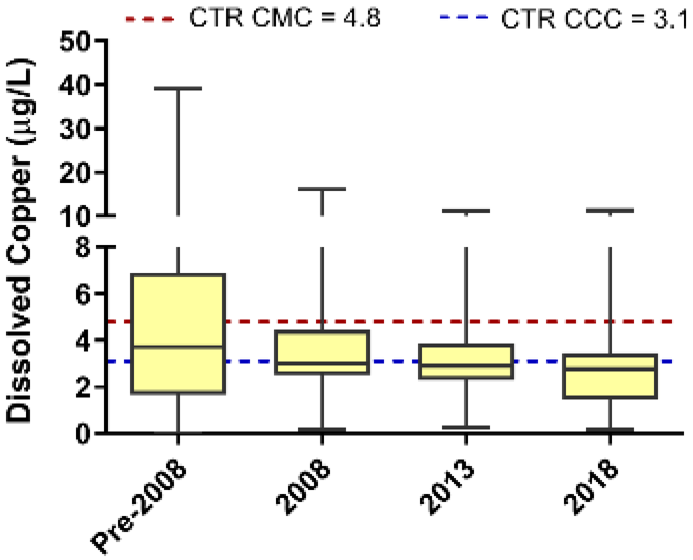


Figure 4-4a. Historical Comparisons for Dissolved Copper Measured in the San Diego Regional Harbors

Box plots show the median, 25th percent quartiles, and range of values

Studies for pre-2008 include all monitoring programs and studies used to develop the historical baselines used in 2013 RHMP reporting.

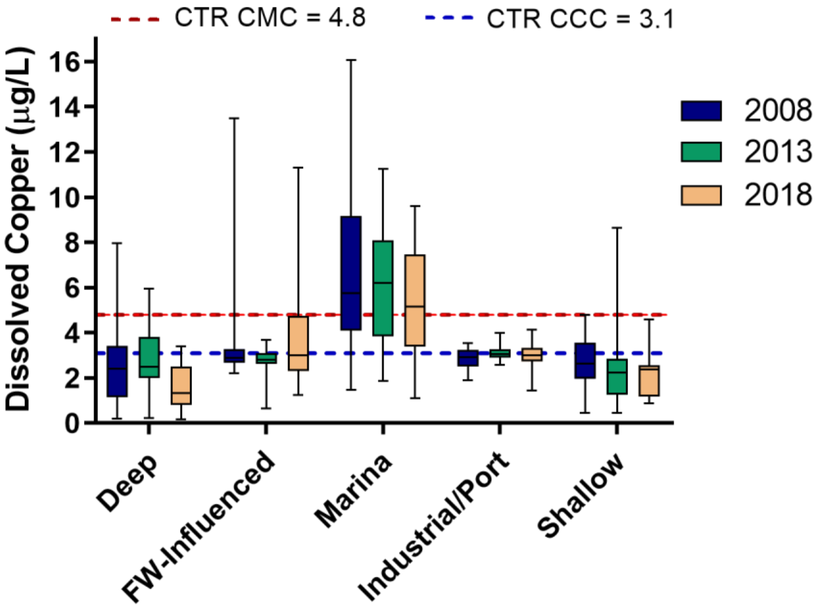


Figure 4-4b. Historical Comparisons for Dissolved Copper Measured in the San Diego Regional Harbors by Strata

Box plots show the median, 25th percent quartiles, and range of values

Table 4-1.
Percentage of Stations with Results Below the CTR Criteria for Dissolved Copper

Assessment Metric	CTR Criteria	Units	Percentage of Stations in Each RHMP Strata Meeting CTR Criteria																	
			Deep (%)			Freshwater-Influenced (%)			Marina (%)			Industrial/Port (%)			Shallow (%)			All Stations (%)		
			2008	2013	2018	2008	2013	2018	2008	2013	2018	2008	2013	2018	2008	2013	2018	2008	2013	2018
Number of Stations:			***15***	***16***	***15***	***15***	***15***	***14***	***16***	***15***	***15***	***15***	***14***	***15***	***14***	***15***	***16***	***75***	***75***	***75***
Dissolved Copper CMC	4.8	µg/L	80	88	100	87	100	79	31	33	40	100	100	100	100	93	100	79	83	84
Dissolved Copper CCC	3.1	µg/L	67	69	87	73	80	57	6	7	20	60	57	53	64	87	94	53	60	63

Notes:
µg/L = microgram(s) per liter; CCC = continuous chronic criterion; CMC = continuous maximum criterion; CTR = California Toxics Rule

Dissolved Zinc

Historical results for dissolved zinc measured in the San Diego Regional Harbors are presented in Figure 4-5. Concentrations of dissolved zinc have decreased since pre-2008 and have remained relatively consistent over the past 10 years. The difference in concentration between 2008 and 2018 was not statistically significant based on a two-tailed t-test (p >0.05; see Appendix K). Dissolved zinc concentrations have been well below both acute and chronic ambient water quality guideline values at all stations during the past three RHMP monitoring periods, indicating limited toxicological concern for this trace metal in the water column.

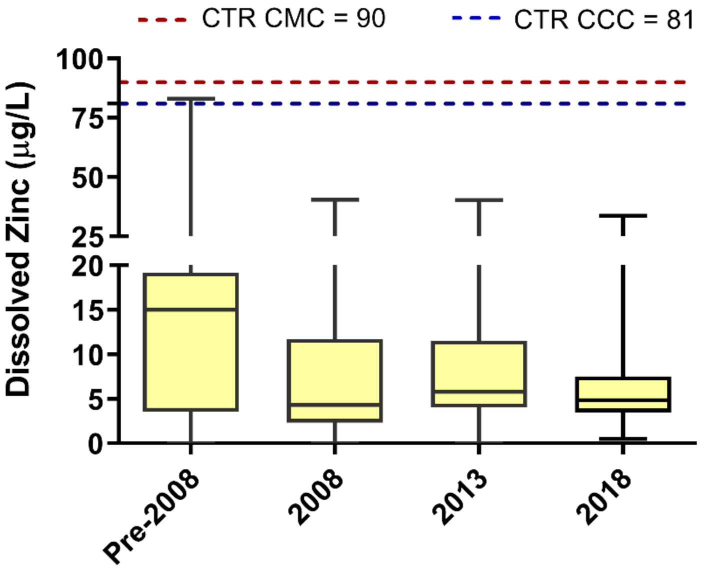


Figure 4-5. Historical Comparisons for Dissolved Zinc Measured in the San Diego Regional Harbors

Box plots show the median, 25th percent quartiles, and range of values

Notes: Studies for pre-2008 include all monitoring programs and studies used to develop the historical baselines used in 2013 RHMP reporting.

Dissolved Nickel

Historical results for dissolved nickel measured in the San Diego Regional Harbors are presented in Figure 4-6. Concentrations of dissolved nickel have decreased substantially since pre-2008. For the past 10 years, concentrations of dissolved nickel have remained consistent (within <1 µg/L) and well below both acute and chronic ambient water quality guideline values (Figure-4-6), indicating limited toxicological concern for this trace metal in the water column. The difference in concentration between 2008 and 2018 was statistically significant based on a two-tailed t-test (p <0.05; see Appendix K).

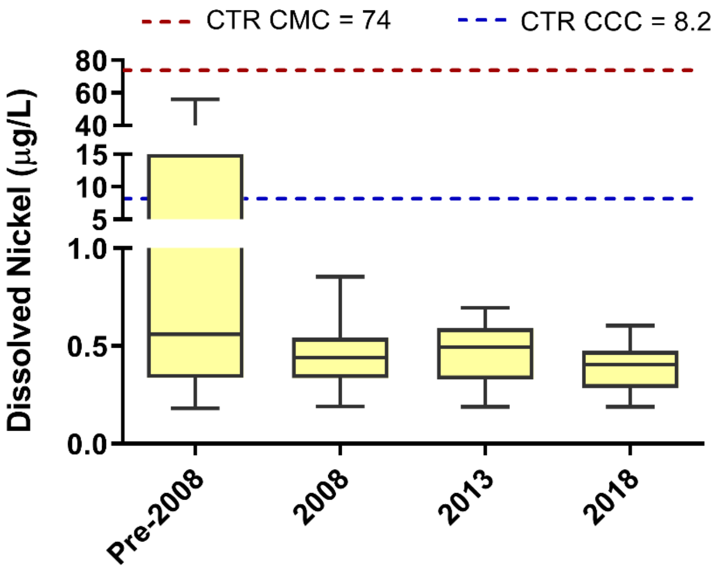


Figure 4-6. Historical Comparisons for Dissolved Nickel Measured in the San Diego Regional Harbors

Box plots show the median, 25th percent quartiles, and range of values

Notes: Studies for pre-2008 include all monitoring programs and studies used to develop the historical baselines used in 2013 RHMP reporting.

Total PAHs

Historical results for total PAHs measured in the San Diego Regional Harbors are presented in Figures 4-7a for all stations combined and Figure 4-7b for each stratum. Results over time indicate a decrease in total PAH concentrations in the water column in 2018 compared to 2008 and 2013 (Figure 4-7a). The difference in concentration between 2008 and 2018 was statistically significant based on a two-tailed t-test ($p < 0.05$; see Appendix K). Decreases in PAHs over time were observed primarily in the deep and freshwater-influenced strata (Figure 4-7b). Concentrations of total PAHs in the water column have also decreased slightly in the industrial/port stratum in San Diego Bay since 2008. This decrease may be related to the replacement of creosote pilings, along with changes in ballast water discharge practices at naval facilities in San Diego Bay since the 1990s. Average surface water concentrations measured in San Diego Bay decreased from 624 ng/L (based on surveys conducted from 1990–1994) to 91.4 ng/L in 1997 (Katz, 1998), then to 32.4 ng/L in the 2008 RHMP, 18.7 ng/L in the 2013 RHMP, and finally to 10.1 ng/L in the 2018 RHMP.

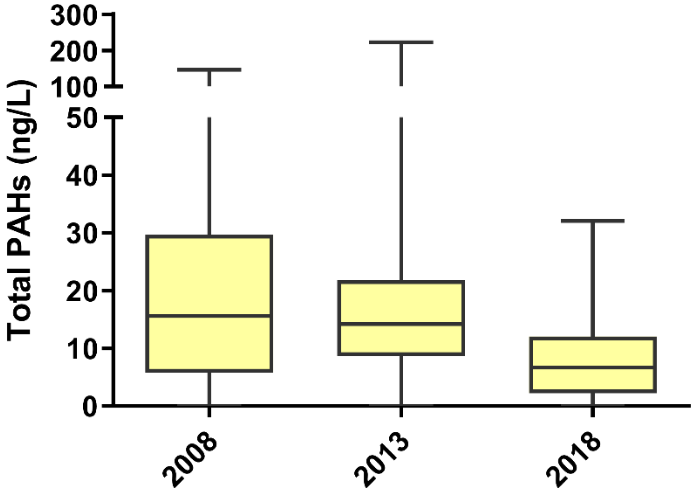


Figure 4-7a. Historical Comparisons of PAHs Measured in the San Diego Regional Harbors

Box plots show the median, 25th percent quartiles, and range of values

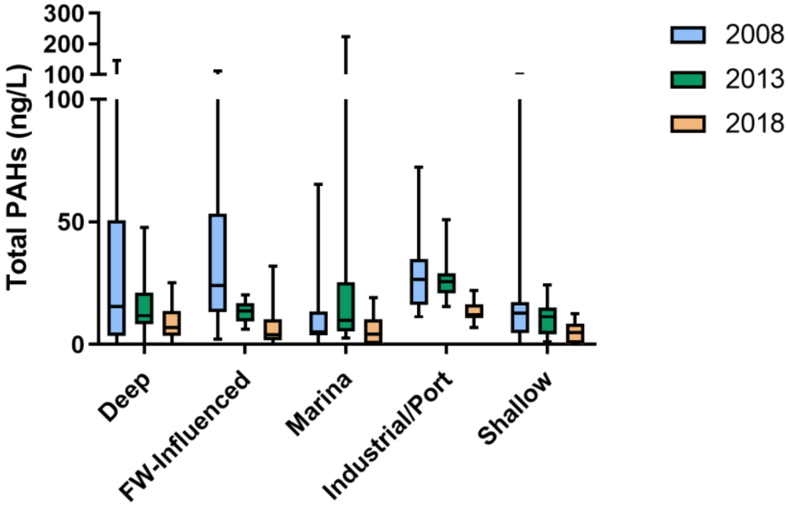


Figure 4-7b. Historical Comparisons of PAHs Measured in the San Diego Regional Harbors by Strata

Box plots show the median, 25th percent quartiles, and range of values

4.2 Sediment Physical Characteristics and Chemistry

Physical characteristics of the sediment were assessed to aid in the interpretation of chemical and biological results. This section first introduces physical characteristics (grain size, TOC, and sulfides (SEM-AVS)) that can have an effect on both the distribution and toxicity of chemicals of concern. A discussion then follows including an evaluation of spatial patterns and sources of primary chemicals of potential concern, a statistical analysis of the relationships between chemical and physical parameters, an integrated analysis of sediment chemistry using the SQO approach, and finally an analysis of historical trends for individual primary chemicals of concern and integrated SQO metrics for sediment chemistry.

4.2.1 Grain Size and TOC

Physical characteristics of the sediments in some cases varied substantially among different stations both within and between strata and harbors, and some cases within a single sampling station. The fraction of fine sediments ranged from 2.4% to 87.5% and the TOC ranged from 0.1% to 3.5% among all stations. Stations with a greater percentage of fine sediments generally had higher fractions of TOC, resulting in a statistically positive relationship (Figure 4-8).

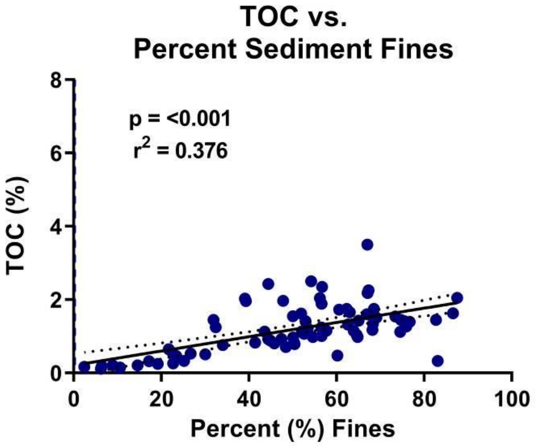


Figure 4-8. Relationship Between TOC and Fine Sediments

Percent fines had a significantly positive relationship with elevated chemistry represented by the ER-M quotient and CSI score, as expected given the greater surface area for chemical binding to occur (Figures 4-9 and 4-10). Note that Site B18-10069 located in Oceanside Harbor was identified as a statistical outlier relative to other sites using Grubb's test due to an elevated concentration of PCBs greatly inflating the ER-M quotient for this location. The ER-M quotient at this site was 4 to 261 times greater than other sites throughout the San Diego Regional Harbors, suggesting that site B18-10069 is not representative of regional conditions and should be evaluated on an individual basis. Therefore, statistical analyses were also performed without Site B18-10069 to better evaluate the relationship between the ER-M quotient and TOC and grain size on a regional scale. Removing this one station improved the statistical relationship between the ER-M quotient and both TOC and grain size, as depicted in Figure 4-9. Relationships between chemical concentrations and natural physical parameters such as TOC and fine sediments can also be used as a tool to identify locations with elevated concentrations beyond what might be expected based on natural or background concentrations in relation to physical properties. Such locations will fall above the regression line as is the case noted for Site B18-10069.

The observed relationship between elevated chemistry and % fines and TOC supports the premise that these two physical parameters both have the ability to increase binding of contaminants through physical processes, ultimately reducing their bioavailability (Baran et al., 2019, ITRC, 2011). However, the statistically significant but weak relationship between the benthic community BRI index and overall chemical concentrations measured using the ER-M quotient and CSI as shown in the Results Figures 3-46a and 3-46b, provides evidence that elevated chemistry associated with fine sediments likely has some influence on benthic community conditions as would be expected, but the degree of variability for these relationships suggest that other physical or chemical factors may be influencing the benthic communities as well.

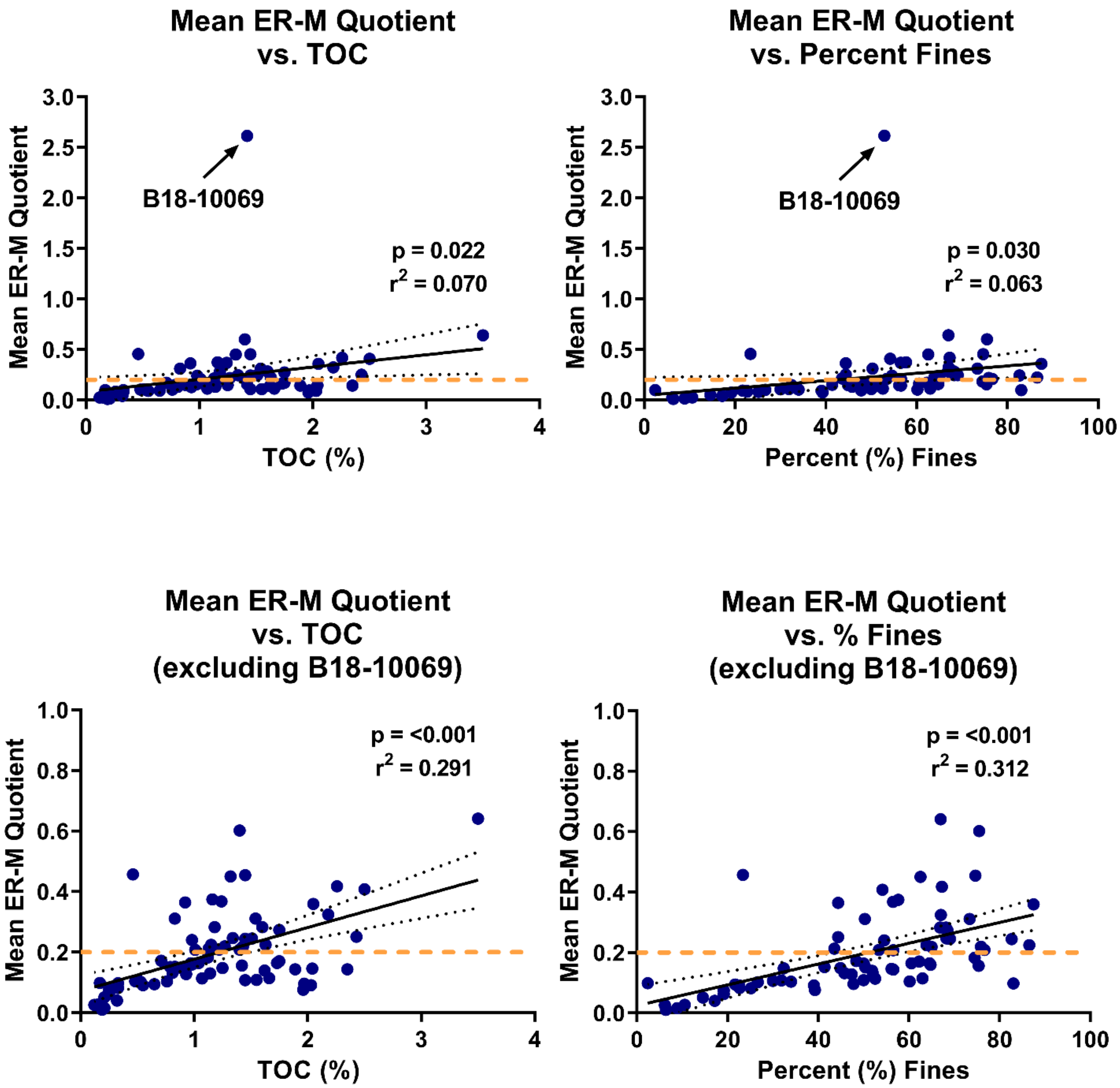


Figure 4-9. Relationship Between TOC and Percent Fine Sediment Relative to Elevated Chemistry Represented by the Mean ER-M Quotient

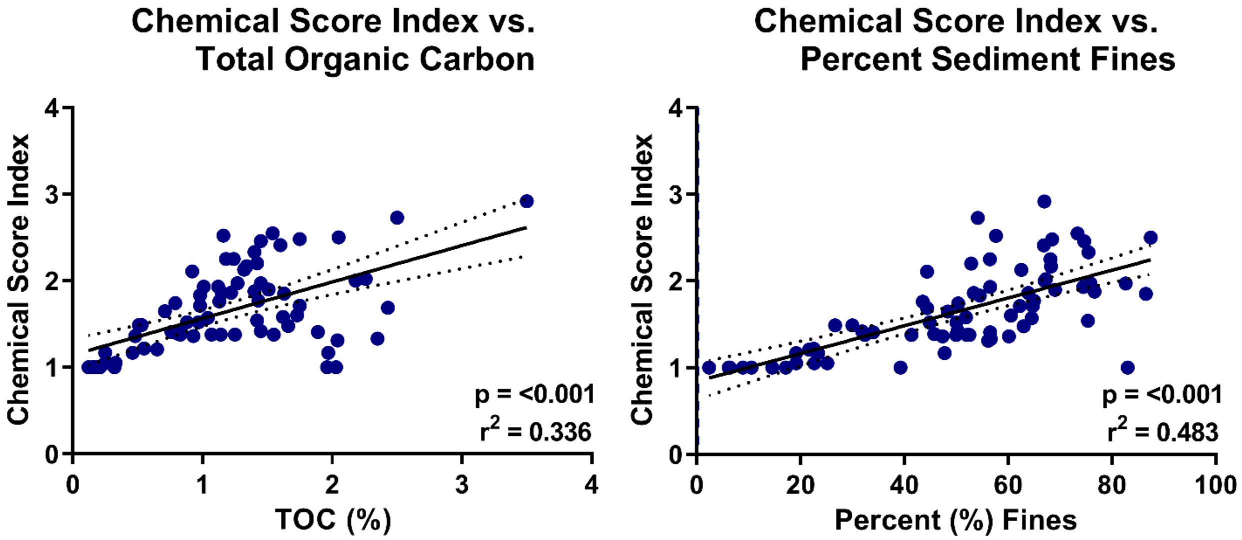


Figure 4-10. Relationship Between TOC and Percent Fine Sediment Relative to Elevated Chemistry Represented by the CSI

To better depict the relationships between % fines, TOC, and sediment chemistry concentrations (represented by the CSI), multivariate analysis using PCA was performed. These results are graphically shown as a 2-D plots showing the strength of relationships between different measured parameters. The two axes, PC1 and PC2, represent different combinations of measured variables that best explain the variability among the sites. The display of the data on the plot represents the direction in which the variance of sample points projected perpendicularly onto the axis is maximized (Clarke et al., 2014). In this case, PC1 captures 53% of the variance while PC2 captures 16% for a total of 69% which suggests that the analysis describes the structure rather well (Clarke et al., 2014). Parameters with tighter correlations cluster closer together in the plot. Note that only the directionality of the vectors is relevant for interpreting the plots, while the origin and size of the vectors on the PCA plot do not have any significance.

In Figure 4-11a, the relationship of measured parameters to different sites and their CSI categorical scores is shown, with the different categories color coded. This plot visually highlights the tight relationship between % fines, TOC, and several chemical constituents, particularly trace metals. There is a weaker relationship between % fines and pesticides (pyrethroids and chlordane) and PBDEs, which are tightly associated with the freshwater-influenced strata where a greater range of grain size was noted. Visual observations also noted substantial variability among samples, as depicted in the photographs of each grab sample provided in Appendix M. Figure 4-11a also shows a fairly distinct grouping of the categorical CSI scores in order from low to high exposure potential along a gradient of grain size from sandy to fine sediments.

Figure 4-11b shows the same relationships between TOC, grain size, and chemical concentrations, but the plot now shows these relationships compared to each location’s strata designation as opposed to the CSI categorical score. This plot shows considerable overlap among physical and chemical properties among the strata, but a few notable observations include: 1) the separation of several freshwater-influenced strata associated with the pesticides and PBDEs with weaker relationships to grain size and TOC; 2) the close grouping of many of the port/industrial sites associated with finer grain size; and 3) limited overlap overall between the deep strata with lower sediment chemical concentrations and a wider range of fine grain size than that observed in the port/industrial strata.

The final PCA plot in this series (Figure 4-11c) shows the % fine grain size fraction for each site as a color-coded bubble with the size of the bubble representing concentration, and the color differentiating the different strata each site belongs to. This “bubble plot” shows the wide range of grain size fractions recorded within all five strata, highlighting the physical complexity of the benthic environments represented by each of the different strata.

The plots demonstrate that physical parameters and chemical concentrations show complex relationships among the RHMP samples, but exploration beyond simple univariate comparisons can highlight relationships that would otherwise be hard to pick out. The plots in Figures 4-11a and 4-11b also provide confidence that the strata selected do indeed have unique characteristics related to likely sources, fate and transport of chemicals, or presence of legacy contaminants, that continues to warrant the same approach for future efforts.

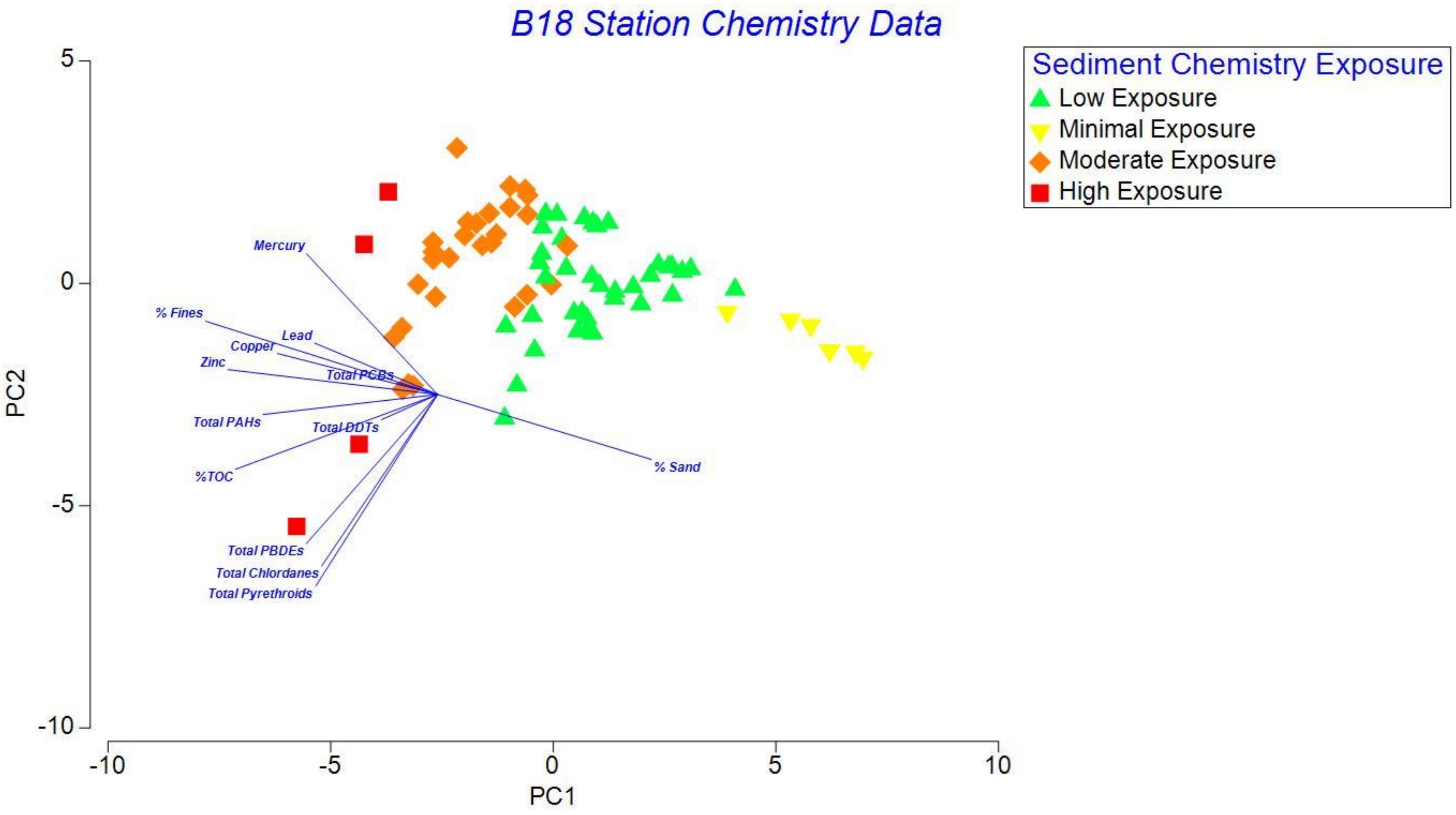


Figure 4-11a. PCA of Sediment Chemistry and Physical Parameters by Sediment Chemistry SQO Category

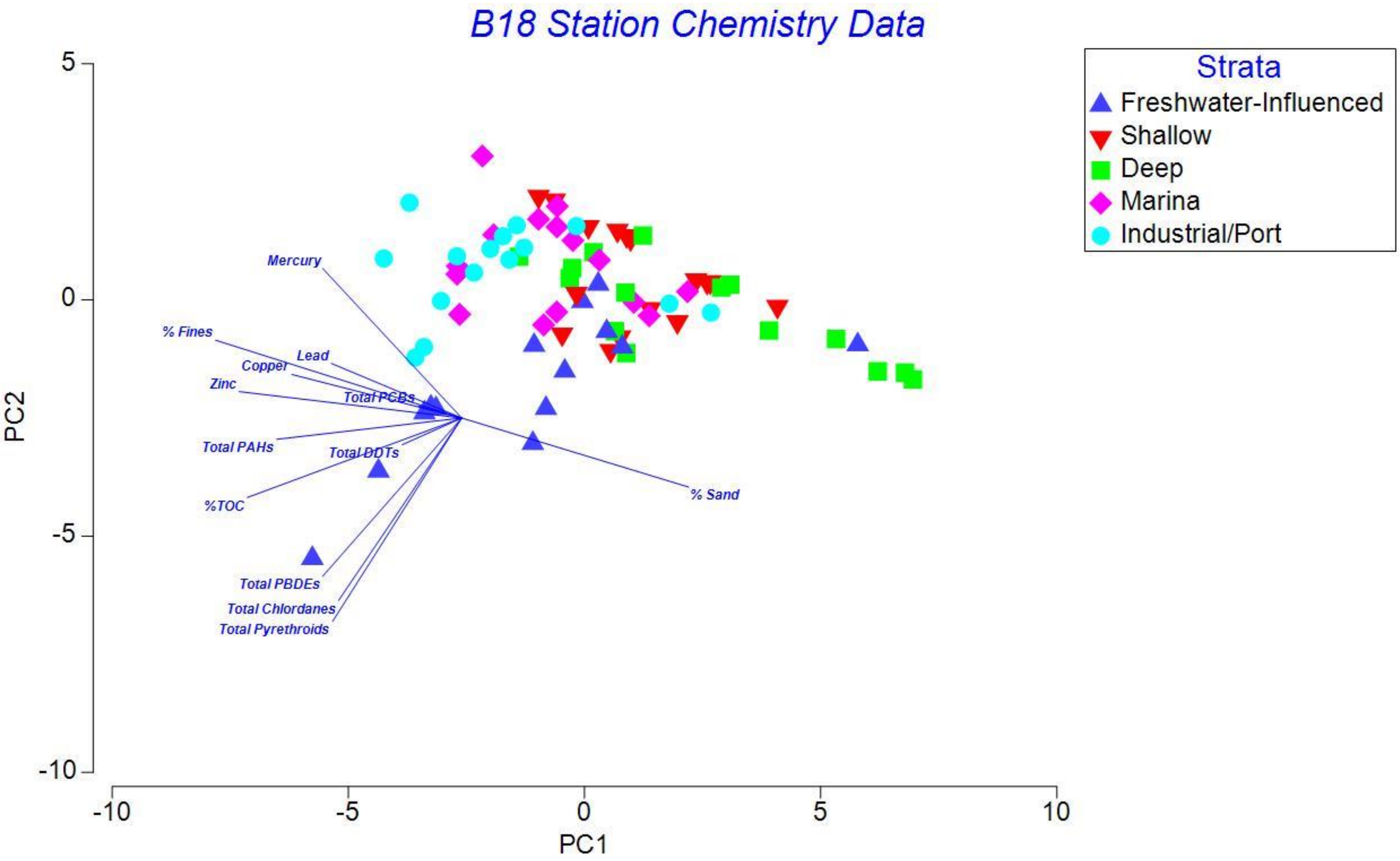


Figure 4-11b. PCA of Sediment Chemistry and Physical Parameters by Strata

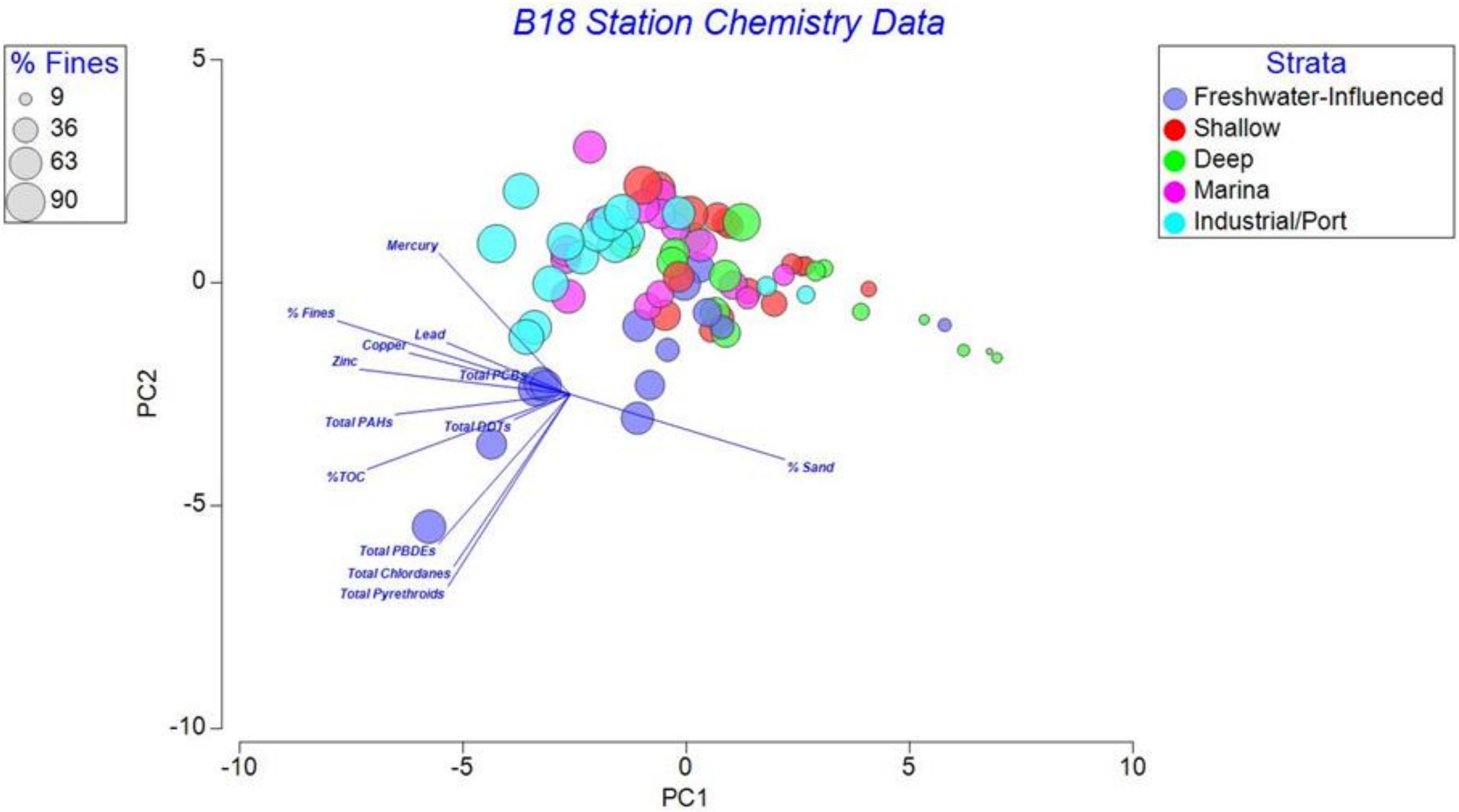


Figure 4-11c. PCA Bubble Plot of Percent Fines by Strata

4.2.2 SEM-AVS

SEM-AVS is an approach often used to assess the potential for trace metals in sediments to cause toxic effects in benthic organisms. Metal contaminants become bioavailable when dissolved in the pore water; sulfide binds metal ions to render them non-bioavailable (Berry et al., 1996). Hence, higher contents of sulfide (and thus lower ∑SEM:AVS ratios) may reduce toxicity in sediments. During the 2018 RHMP, results from all but one station located at the inner portion of Shelter Island Yacht Basin in San Diego Bay (B18-10080) were below an RHMP-specific ∑SEM:AVS threshold of 40, a ratio above which bioavailability of metals might be expected to cause toxicity, based on regional data sets reviewed by Weston (2005b). The sediment from this same site, however, was not toxic in 2018 to either amphipods or bivalve larvae. Following more recent guidance where the SEM-AVS ratio is normalized to organic carbon using the ESB approach (USEPA, 2005), several stations had ESB values between 130 and 3,000 µmol/gOC , indicating potential to result in toxic effects due to trace metals, but no stations had ESB metrics greater than 3,000 µmol/gOC, where toxic effects are considered likely. Overall, both approaches indicated limited bioavailability of trace metals in sediments throughout the harbors at concentrations that might be toxic. This observation is supported by the limited toxicity observed to both amphipods and bivalve embryos during the 2018 RHMP.

4.2.3 Current Sediment Quality Conditions – Spatial Trends and Potential Sources of Chemicals of Concern

The following primary chemicals of concern are those constituents that were considered to have moderate to high exposure potential using the SQO CSI calculation. The other chemicals of concern have been identified as such based on regional use, documented presence in marine embayments, and their potential to cause toxicity and bioaccumulate when present at elevated concentrations. Recall that the CSI is just one of two indices used to assess sediment quality using the SQO approach. Only the CSI, however, is able to assign categorical scores to individual chemicals hence the focus on this one metric for the following chemicals that are included in the SQO calculations. An assessment of integrated sediment chemistry results using the SQO approach are provided in the Results Section 3.3 and are explored further with historical context in Section 4.2.6.

Copper

More than any other constituent measured in the sediments, 43% of stations (n=32) were classified as having moderate exposure potential due to copper, and 4% of stations (n=3) fell into the high exposure category. Within the marina stratum, stations with higher concentrations of copper were generally closer to the inner portions of marinas. Copper in the bay sediments may come from a variety of sources, including urban runoff, industrial activities, atmospheric deposition, and its common use as a biocide in antifouling paints due to its effectiveness in reducing the fouling of boat hulls. Copper is released from hull paints into the water column by passive leaching and as a result of spikes of dissolved copper and particulates from in-water hull cleaning activities, diffusing to the sediments where it can bind to sediment particles (Schiff et al., 2003; Valkirs et al., 2003).

Lead

A majority of RHMP stations (n=73) in 2018 were classified as having low or minimal exposure due to lead. Only one station in 2018 was categorized as having moderate exposure potential and one station categorized as high exposure potential, both in the industrial/port stratum. Overall low exposure due to lead can be attributed to decreased use of leaded gasoline, which was banned in 1996 by the Clean Air Act for use in new vehicles other than aircraft, racing cars, farm equipment, and marine engines. Potential ongoing sources of lead include continued limited use of leaded gasoline, particularly in marine engines, and urban runoff.

A study performed by the City of San Diego (Weston, 2010b) found that sediments entrained by street sweeping machinery had similar copper and lead concentrations to those measured in Chollas Creek (Amec Foster Wheeler, 2018). This suggests that lead continues to enter the marine environment in some areas via urban runoff despite the ban on leaded gasoline for most vehicles.

Mercury

The CSI approach classified 83% of the stations in 2018 (n=62) as having low or minimal exposure potential due to mercury. A total of 17% of the RHMP stations in 2018 (n=13), all in San Diego Bay, were classified has having moderate exposure potential, and no stations were considered to have high exposure potential for this metal. 16 of the 17 sites classified as having moderate exposure potential using the CSI approach were located in the industrial/port and marina strata. Previous studies have associated elevated sediment mercury concentrations with boating activities (including recreational boating, shipping, naval operations, and shipbuilding/repair facilities). Elevated concentrations of mercury observed in the industrial/port and marina strata in San Diego Bay may indicate a legacy contamination issue (Thompson et al., 2009), naturally occurring sources, and/or atmospheric deposition with this contaminant of concern.

Zinc

Using the CSI following the SQO approach, 32% of the stations (n=24) were classified as having moderate exposure potential due to zinc among samples predominantly located in the marina, freshwater-influenced, and industrial/port strata, while the rest fell in the low to minimal exposure potential categories. As with copper, the highest concentrations of zinc in the sediment were associated with areas that have greater boating activities. Potential sources of zinc in marinas include zinc anodes, which are commonly used to prevent electrolytic corrosion of vessel motor and other metal parts, as well as zinc-containing antifoulant paints. Such factors could indicate the reason for the high overall zinc concentrations in the marina stratum. Additionally, zinc deposition also been linked to automobile wear and building materials; hence, zinc concentrations have historically been higher near roadways due to runoff (Golding, 2006). Elevated concentrations of zinc in the sediment in freshwater-influenced locations may be associated with urban runoff.

DDTs

DDT is an insecticide that was widely used in the 1940s and 1950s, and eventually banned in the United States in 1972 (USEPA, 1975). Stations with the highest total DDT concentrations in the 2018 RHMP were in the industrial/port and freshwater-influenced strata, in particular at the south end of Naval Base San Diego (NBSD) and near the mouths of Switzer Creek and Chollas Creek. Because DDTs are no longer in use in the United States, DDTs present in the sediment in the San Diego Regional Harbors are likely to be legacy contaminants. However, increased concentrations in surface sediments near freshwater-influenced locations suggest that urban runoff may be an ongoing source of DDTs in some locations.

A study at the mouth of Chollas Creek found a strong gradient of DDT in sediment from the bay towards the mouth of the creek, indicating that elevated DDT levels in the area may be a consequence of urban runoff and/or legacy contaminants (SCCWRP and SPAWAR, 2005). However, a subsequent study conducted in 2017-2018 that extensively sampled the mouth and tidally influenced area of Chollas Creek found much lower concentrations of total DDTs and a less obvious gradient between the mouth and upper tidally-influenced area (Amec Foster Wheeler, 2018). It is likely that the sample in the bay near Chollas Creek with the elevated DDT concentration collected during RHMP may be a reflection of high spatial variability at this location more so than a temporal trend given the much lower concentrations measured during the follow up study by Amec Foster Wheeler in 2018.

Total Chlordanes

Chlordane is an insecticide that was widely used until it was banned in 1983. Although no longer in use, chlordanes persist as a legacy contaminant (Howard, 1990). As with total DDTs, elevated chlordane levels were closely associated with freshwater-influenced stations, with the greatest concentrations observed near the Laurel Hawthorn embayment storm drain and at the mouth of Chollas Creek. This suggests that elevated chlordane concentrations observed in the freshwater-influenced stratum may be a result of urban runoff and/or legacy contaminants. Similar findings were observed in several past and more recent studies within and near the mouth of Chollas Creek in San Diego Bay, which have identified a gradient of chlordane in sediments toward Chollas Creek (SCCWRP and SPAWAR, 2005; Amec Foster Wheeler, 2018).

PCBs

Elevated levels of PCBs were evident within the industrial/port, marina, and freshwater-influenced strata within San Diego Bay, as well as in Oceanside Harbor. While similar trends in PCB concentrations were observed in San Diego Bay in 2013, no stations in Oceanside had previously been categorized above moderate potential for exposure. The elevated PCBs in north Oceanside Harbor (5,348 µg/kg) was approximately 22 times greater than the next highest concentration measured in the 2018 RHMP. It was the first time this location has been monitored during the Bight/RHMP efforts. Findings of elevated PCBs in San Diego Bay are consistent with previous studies that have detected elevated PCBs both within the waters and sediments of central San Diego Bay (Zeng et al., 2002, McCain et al., 1992, Weston, 2010a, Amec Foster Wheeler, 2016, Bay and Parks, 2020, Windward, 2018a and 2018b, and Douglas, 2019). 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 polyvinyl chloride (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 past industrial activities likely serve as a primary source of PCBs to RHMP sediments.

Other Contaminants of Concern

Arsenic

Arsenic is a naturally occurring trace metal that has been identified as having natural concentrations in the Bay Point Formation, which is the native geological formation in San Diego County (Cathcart and Weis, 2016). Arsenic also may be released from paints, pesticides, wood preservatives, and brass. Concentrations throughout all harbors and all five strata were all within a relatively narrow range of 1.3 to 16 mg/kg. Based on the widespread presence of arsenic at similar and relatively low concentrations across all harbors and strata, there was no evidence that a specific input of arsenic was driving concentrations, and a majority of arsenic observed in sediment is likely naturally occurring. Sediment arsenic concentrations were not included in SQO chemistry LOE calculations.

Total PAHs

PAH compounds are separated out into two fractions representing high (HPAH) and low (LPAH) molecular weight chemicals for the SQO calculations based in their differing physical and toxicological properties (Bay et al 2014; Neff et al, 2005; USEPA, 2003). Primary sources of PAHs include runoff from shipping and industrial activities, fuel spills, industrial and municipal waste discharge, surface runoff, and aerial deposition (Zeng and Vista, 1996).

Although concentrations were elevated in the industrial/port and marina strata, the overall concentrations of sediment PAHs were elevated throughout all strata within San Diego Bay as compared to the other harbors. A recent study at the mouth of Chollas Creek in San Diego Bay found that concentrations of PAHs were elevated in the bay sediments relative to the upper intertidally-influenced areas indicating a primary source of PAHs from in-bay ongoing or historic sources (Amec Foster Wheeler, 2018). In a study completed in 1996, sediment sampled in San Diego Bay had proportions of less than 20% of two-, three-ring PAHs, indicating combustion sources appeared to prevail. Automobile exhausts, probably similar to boat engine exhausts, are known to contain both petroleum residues and incomplete combustion products (Zeng and Vista, 1996).

Creosote treated pier pilings are another major past and ongoing source of PAHs to San Diego Bay. A study by Katz et al. (1995) found a strong relationship between the spatial distribution of seawater PAH concentration and the general location of pilings in San Diego Bay. Compositional analysis of the PAH compounds found in bay seawater with those in creosote and those found in a laboratory flux experiment support the conclusion that creosote pilings are a significant source of PAH loading to San Diego Bay. Over the years however there has been a concerted effort to remove or replace old pier pilings with non-creosote treated alternatives.

LPAHs

One station in the deep stratum in San Diego Bay had an LPAH concentration that was considered to have high exposure potential according to the CSI. All other stations had LPAH concentrations that were considered to have low or minimal exposure potential. LPAHs are considered to be acutely toxic and non-carcinogenic to aquatic organisms (Neff, 1979; Goyette and Boyd, 1989; Honda and Suzuki, 2020). Toxicity potential is enhanced by high water solubility (Duffus, 1980; Uthe, 1991).

HPAHs

Eight stations in four strata (deep, marina, freshwater-influenced, and industrial/port) were identified as having moderate exposure potential due to HPAHs, all within San Diego Bay. HPAHs are not generally acutely toxic; however, they are often carcinogenic (Neff, 1979; Goyette and Boyd, 1989; Honda and Suzuki, 2020).

Total PBDEs

PBDEs, comprised of a class of chemicals used in flame retardants, were identified as an chemical of emerging concern, and have been recommended to be included in ongoing and future studies region-wide (Kimbrough et al., 2009; Dodder et al., 2012). PBDEs are now considered ubiquitous in coastal environments and are particularly associated with areas influenced by urban runoff, as seen by their detection in the 2018 RHMP in multiple harbors with higher concentrations of PBDEs in the industrial/port and freshwater-influenced strata. Little is known about the risk of PBDEs; thus, there are no regulatory criteria for sediment PBDE concentrations at this time. Like PCBs, PBDEs are known to be neurotoxins and endocrine disruptors (Siddiqi et al., 2003). They are also known to be bioaccumulative. Hence, PBDEs have continued to be included in the list of RHMP analytes evaluated in fish tissue to gather data that can support assessment of risk to humans from seafood consumption and to provide a historical context for interpretation once effects and risks are better understood.

During a 2012 study of PBDE concentrations in the southern California Bight, the area-weighted geometric mean total PBDE concentration was found to be 12 µg/kg within embayments (Dodder et al., 2012). Five stations in San Diego Bay, two in Dana Point Harbor, two in Oceanside Harbor, and one in Mission Bay had concentrations above this value, with the two highest values occurring at freshwater-influenced stations in central San Diego Bay (58.6 µg/kg) and Dana Point Harbor (56.3 µg/kg) as shown in Appendix F.

Total Pyrethroids

Over the past 20 years, pyrethroid insecticides have become the dominant pesticide in both agricultural and nonagricultural applications, replacing organophosphate pesticides, which have been phased out (Amweg et al., 2005). Pyrethroid pesticides are relatively well-known urban and agricultural pesticides commonly found in storm water runoff (Weston and Lydy, 2010).

Pyrethroids were detected at 60% of stations in the 2018 RHMP (n=45), and concentrations were greatest near areas with freshwater influence. The association of pyrethroid pesticides with the freshwater-influenced stratum and the higher than average rainfall observed prior to the 2018

RHMP suggest that urban runoff is likely a significant source of pyrethroid pesticides to these locations.

A study that evaluated the toxicity of several pyrethroid pesticides to the amphipod *Eohaustorius estuarius*, the same species used for toxicity testing herein for RHMP, found median lethal effect concentrations (LC_{50}) of 8.0 µg/kg for bifenthrin, 11 µg/kg for cypermethrin, and 140 µg/kg for permethrin (Anderson et al., 2008). By way of comparison another study found concentrations of pyrethroids as low as 2 µg/kg to cause toxicity to freshwater amphipods (Amweg et al., 2005). Toxicity of pyrethroids for other sediment-dwelling marine species are not well studied at this time. Although total pyrethroid concentrations in 2018 exceeded available reported toxic threshold values at a few sites, testing using *Eohaustorius* found these same sites to be either non-toxic or exhibit low toxicity, suggesting limited bioavailability of these compounds for this species at the time when sediments were collected for this study.

Other Pesticides

The interest in the presence, fate, and toxicity of fipronil and related neonicotinoid insecticides has increased in recent years due to their more widespread use over the past two decades in California and elsewhere. Their use has increased as a variety of insects have developed resistance to the organophosphates, carbamates, and pyrethroids, and also as a replacement for banned chemicals such as chlorpyrifos and diazinon (Simon-Delso et al., 2015). Fipronil, specifically, is used as a pesticide to protect crops as well as in veterinary medicine to kill off fleas, lice, ticks, roaches and mites. Despite its increased use, fipronil was detected in sediments at only five RHMP locations, four of which were in the freshwater-influenced stratum. Increased presence of fipronils in the sediment at these locations may be related to runoff as a result of higher than average rainfall observed prior to the 2018 RHMP.

Toxicity data for saltwater benthic (sediment-dwelling) species are limited for fipronil. One laboratory study found reduced reproduction for a saltwater benthic crustacean at a sediment concentration of 30 µg/kg (Chandler et al., 2004) which is more than 7x greater than the highest concentrations recorded during the RHMP in 2018. Total dry weight concentrations of fipronil normalized to organic carbon content (0.02 to 0.13 µg/g TOC) were also less than the interim chronic freshwater sediment quality criteria of 0.3 to 200 µgl/g TOC for individual forms of the chemical developed for the Sacramento River and San Joaquin River watersheds (Bower and Tjeerdema, 2017). These results suggest that the concentrations of fipronil detected at the 5 RHMP locations in 2018 were well below that expected to cause toxicity based on the available literature.

4.2.4 Evaluation of the Relationships between Chemical and Physical Parameters and Strata using PCA and ANOSIM Data Exploration Techniques

An evaluation of the statistical relationships between individual chemical concentrations, other chemical and physical properties, and different strata was performed using PCA and ANOSIM statistical and graphical techniques as described further in the Methods Section 2.6.1. Chemicals and physical parameters for which PCA plots were created include copper, lead, mercury, zinc, total PCBs, total PAHs, total DDTs, total PBDEs, total chlordanes, total pyrethroids, % fines, % sand, and % TOC. The suite of chemicals selected for PCA closely resembles the list used for the SQO calculation with the addition of pyrethroids, PBDEs, and physical parameters. Example plots for lead, PAHs, and pyrethroids are presented below with additional plots for all other aforementioned chemicals and physical parameters located in Appendix K. Additional statistical comparisons including analyses of similarity using ANOSIM and cluster analyses are provided in Appendix K.

The PCA plots shown here are similar to those presented in Figures 4-11a through 4-11c, but in this case the concentration of a single specific chemical is shown for each site as a color-coded bubble with the size of the bubble representing concentration, and the color differentiating the different strata each site belongs to. These “bubble plots” show the same information that has been provided in tables, box plots, and maps in the results section, but make it easier to visualize trends. In the plots below, trends were observed including: 1) lead has a relatively uniform distribution with the exception of one location in the port/industrial stratum with a much higher concentration than the rest (Figure 4-12a); 2) PAHs are elevated in the industrial/port stratum and a subset of the freshwater-influenced sites with relatively similar fine grain size characteristics overall (Figure 4-12b); and 3) pyrethroids are strongly associated with only the freshwater-influenced stratum, but similar to PAHs there is a wide range of concentrations within this single stratum and an association with fine grain size (Figure 4-12c). These plots are useful to help differentiate potential sources, examine variability, and assess co-occurrence patterns among the different chemicals of concern.

As mentioned in Section 4.2.1, assessment using all of the measured parameters listed above was able to account for a sizeable proportion of the variance observed between stations (69.4%). These results, with approximately 30% of the variance unaccounted for, also suggest that chemical and physical parameters besides those included in the analysis must also be contributing to the variable spatial patterns of pollutants (e.g., other biogeochemical parameters, physical disturbance, and oceanographic conditions and transport mechanisms). To statistically evaluate differences in chemical and physical composition among strata and harbors, subsequent pairwise comparisons were conducted using ANOSIM. Results indicated that all RHMP strata designations significantly differed from one another (Appendix K). This finding validates the assignment of stations to the five RHMP strata groupings, as it shows the mixture of chemical and physical parameters differs between strata when all components are factored together (i.e., each of the predesignated strata have unique characteristics and chemical sources). Pairwise comparisons by harbor (included in Appendix K) revealed weak statistical power to resolve groups by sediment chemistry; however, the power to resolve statistical difference by harbor are limited by the unbalanced experimental design with only a few sample locations in Dana Point Harbor, Oceanside Harbor, and Mission Bay compared to San Diego Bay.

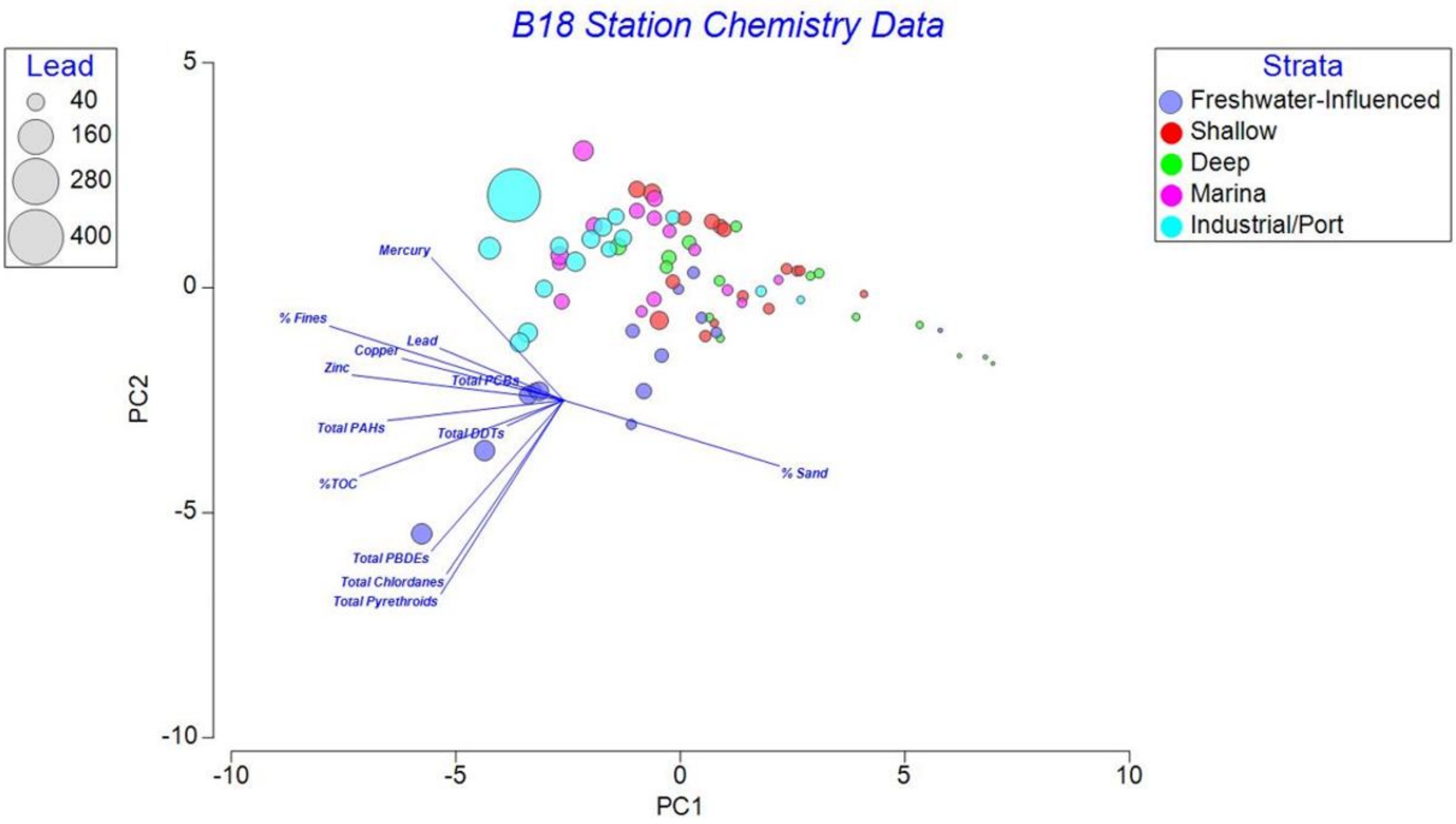


Figure 4-12a. PCA Bubble Plot of Lead Concentrations by Strata

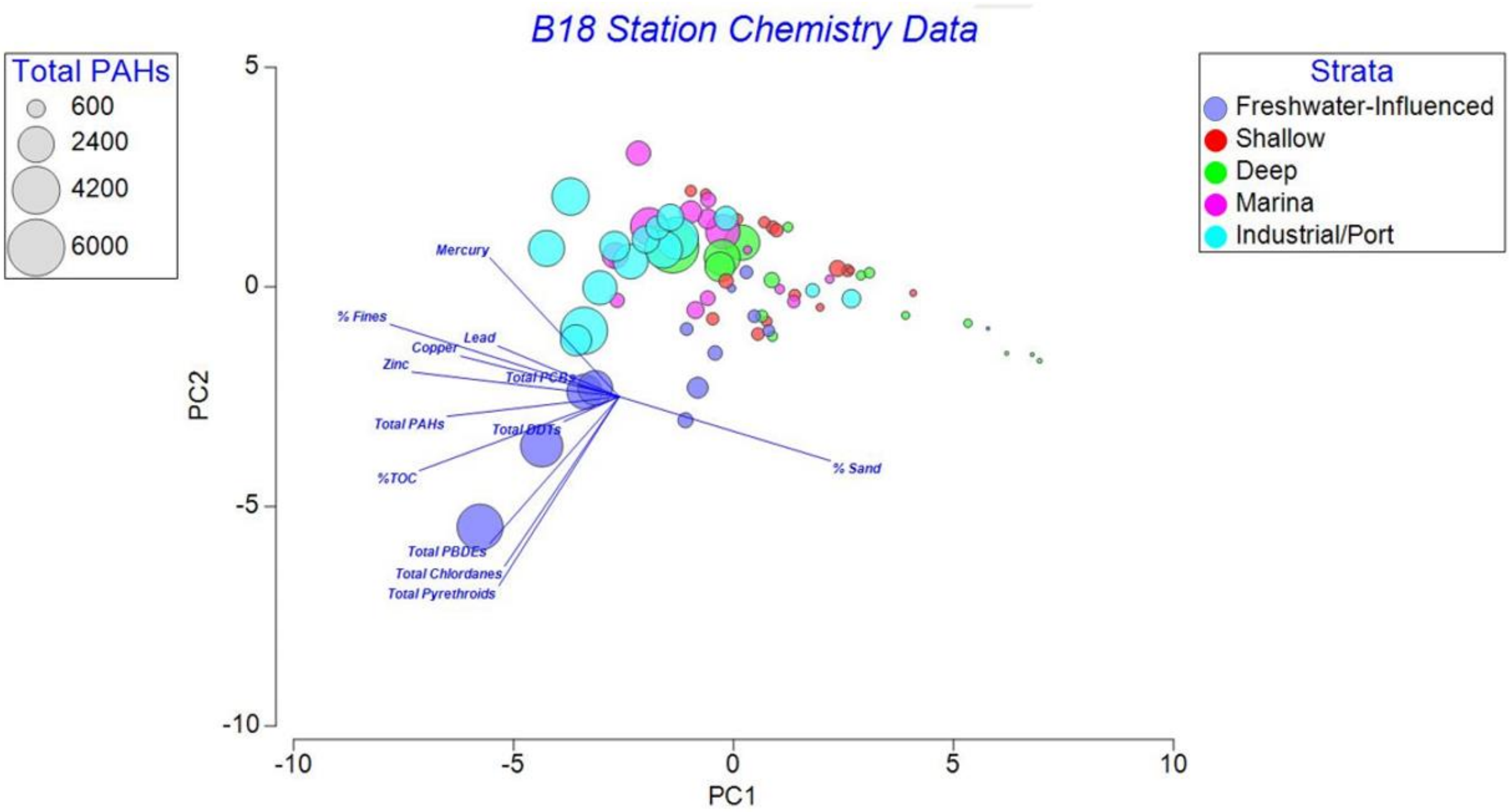


Figure 4-12b. PCA Bubble Plot of Total PAH Concentrations by Strata

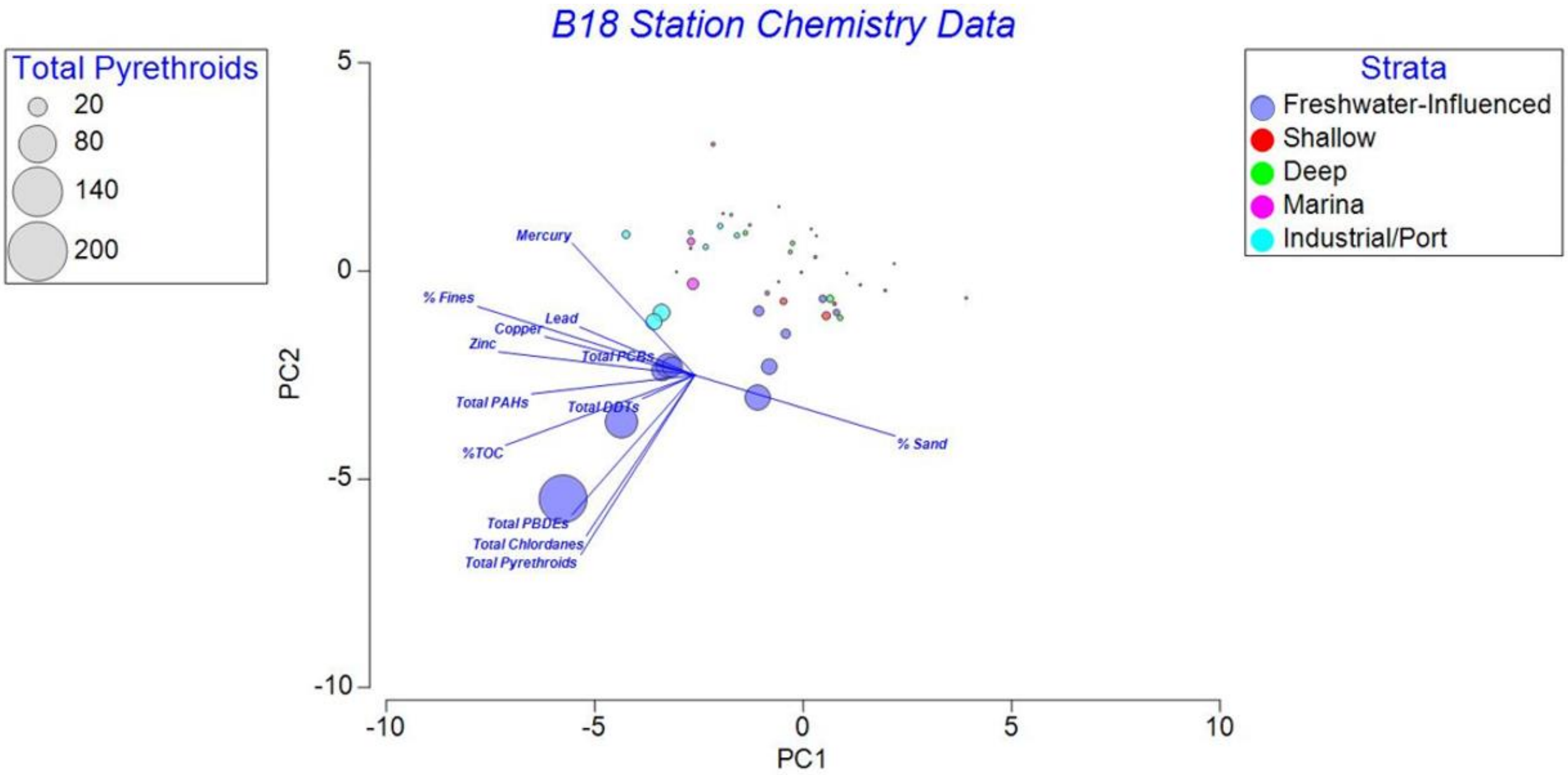


Figure 4-12c. PCA Bubble Plot of Total Pyrethroids Concentrations by Strata

4.2.5 SQO Chemistry Line of Evidence

Based on the long term reduction of chemical concentrations and the presence of healthy benthic communities at a majority of stations, sediment conditions in general appear to be supportive of healthy biota (particularly within the deep and shallow strata, and at most stations in the freshwater-influenced stratum). The greatest sediment chemical exposure potential generally occurred in strata that likely experienced greater anthropogenic influences, most notably the industrial/port and marina strata. Based on the integrated SQO score for the sediment chemistry LOE, more than half (57%) of the RHMP stations (n=43) are considered to have minimal or low exposure potential; 37% (n=28) exhibit moderate exposure potential, and only 5% (n=4) are considered to have high chemical exposure potential, as shown in Figure 4-13. A more detailed discussion related to conditions in the different strata follows.

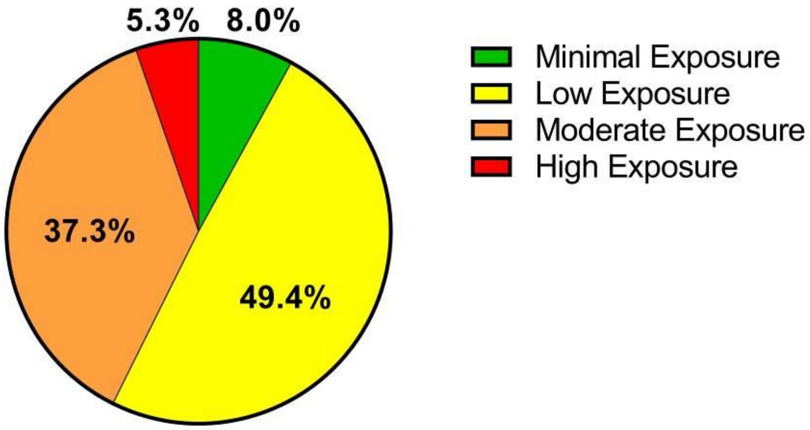


Figure 4-13. Pie Chart Summary of the Fraction of RHMP Stations in Each of the SQO Exposure Potential Categories for the Integrated Sediment Chemistry LOE

Stations in the industrial/port stratum had elevated sediment chemical concentrations relative to many stations in other strata monitored (Figure 4-14). Stations within the industrial/port stratum make up 20% of all sampling stations in San Diego Bay; San Diego Bay is also the only harbor with an industrial/port stratum. These stations are associated with current and past industrial activities, such as ship construction and repair, naval operations, and container shipping. Additionally, the eastern shoreline of San Diego Bay (the primary location of the industrial/port stratum) is adjacent to busy roadways and has inputs from urban watersheds (including Chollas Creek and Paleta Creek). These may be contributing factors to the industrial/port stratum having the greatest percentage of stations (73%; n=11) with results exceeding the mean ER-M quotient threshold of 0.2 among the five strata. Additionally, 80% of stations (n=12) within the industrial/port stratum in San Diego Bay scored in the moderate and high exposure potential categories using the sediment chemistry SQO LOE. These scores were primarily driven by elevated concentrations of sediment copper, mercury, total PCBs, total DDTs, and chlordanes

The marina stratum was classified as having impacted sediment chemistry conditions at many stations (Figure 4-14). Marinas are typically associated with high densities of recreational vessels, high levels of boating activity (including in-water hull cleaning, as well as in-water and topside maintenance), and reduced tidal flushing due to their often semi-enclosed physical configurations. These may be ongoing contributing factors to the marina stratum having 67% (n=10) of the stations exceed the ER-M quotient threshold of 0.2 and 73% (n=11) of stations classified in the moderate exposure potential categories using the SQO sediment chemistry LOE (no marina stations were in the high exposure category). These scores were primarily driven by elevated concentrations of sediment copper, lead, and zinc, and secondarily driven by total PCB and total PAH levels.

The freshwater-influenced stratum overall had lower concentrations of chemicals in the sediments based on both the SQO and ER-M quotient results than the industrial/port and marina strata; however, 43% of these stations (n=6) were still categorized as having moderate and high exposure potential using the SQO sediment chemistry LOEs (Figure 4-14). These scores were primarily driven by zinc concentrations, as well as total PAHs and total chlordane levels. Non-SQO PBDEs and pyrethroids were also strongly associated with this stratum.

The range in chemical exposure categories observed in the freshwater-influenced stratum could be related to the variable physical characteristics observed in these locations. In particular, variability in grain size resulting from the dynamic environments in the freshwater-influenced stratum can affect chemical exposure potential, as chemical concentrations tend to increase with finer sediment which has a greater surface area for chemical binding to occur. For example, three of the four samples located within the Sweetwater Channel in south San Diego Bay were sandy, likely as a result of scouring due to tides, currents, and runoff, and had low chemical exposure. However, the two freshwater-influenced stations near the mouth of Chollas Creek in San Diego Bay with moderate and high chemical exposure were in deeper water, less affected by scouring, and were predominantly composed of silt and clay. These two stations are also surrounded by industrial/port operations and are thus likely to experience disturbances associated with industrial/port activities. The wide variety of potential stressors on freshwater-influenced stations must be considered when making any general conclusions for this stratum.

The deep and shallow strata generally had concentrations that were below established threshold levels for most of the chemical indicators. The deep and shallow strata had 93% (n=14) and 88% (n=14) of stations, respectively, in the minimal and low SQO chemical exposure categories. This indicates that chemical exposure is more closely associated with specific inputs of pollution rather than larger spatial differences in contaminant exposure within the three harbors that included the deep strata (Dana Point, Oceanside, and San Diego Bay). Those locations in the deep and shallow strata that had elevated chemistry were generally located close to or within areas that are likely influenced by activities associated with the other strata, for example Station B18-10113 in northern San Diego Bay, which is located near large piers along the eastern shoreline where cruise ships dock and other maritime activities are common (see Figure 3-39d in the Results section), and Station B18-10088 in southern San Diego Bay, which is located near the Coronado Cays marinas (see Figure 3-39f in the Results section).

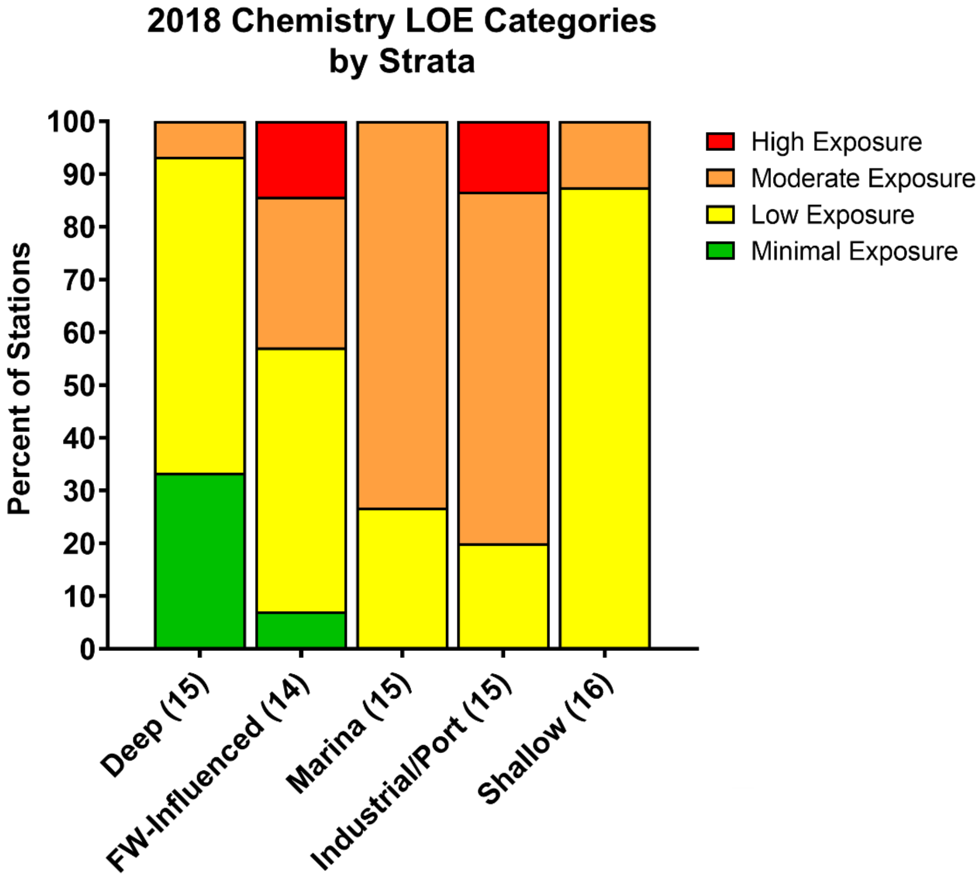


Figure 4-14. Stacked Bar Chart Summary of the Fraction of RHMP Stations by Strata in Each of the SQO Exposure Potential Categories for the Integrated Sediment Chemistry LOE

Despite some of the trends noted above, sediment chemistry concentrations appear to be generally protective of healthy biota in most regions throughout the San Diego Regional Harbors; results from 59% (n=44) of all stations had mean ER-M quotient scores below a 0.2 conservative threshold for toxic effects and 57% (n=43) of all stations considered to have minimal or low exposure potential using the SQO methodology.

4.2.6 Sediment Chemistry Historical Comparisons

A total of 18 indicators were used to assess current status and changes in sediment quality over time based on chemicals of potential concern. These indicators include: 1) the ER-M quotient (% of station above or below a value of 0.2); 2) the 12 individual chemicals/chemical classes comprising the SQO CSI metric; 3) the individual SQO CSI and LRM scores; 4) the combined SQO score using both the CSI and LRM; and 5) pyrethroid pesticide and PBDE concentrations. For all SQO metrics, the % of stations in the combined minimal/low exposure categories and median concentrations were compared over time. For the ER-M quotient, the percent of stations below a threshold of 0.2 was calculated. Exposure categories are not established for pyrethroid pesticides and PBDEs so a specific metric to compare to is not available for these constituents.

For these chemical classes, mean concentrations and the percent increase or decrease in concentration were compared between each year. All of these indicators were evaluated separately for all stations combined and also broken out separately by strata.

Data gathered for an analysis of historical trends included the pre-1998 historical baseline dataset for RHMP, as well as other relevant studies (Bight ’98, Bight ’03, and the 2008 and 2013 RHMPs). An evaluation of changes in chemical concentrations over time was conducted using three distinct methods:

1. Data that has been collected in a consistent manner over the past 10 years by RHMP was compared by calculating the percentage of stations exceeding respective threshold values (Table 4-2) and changes in median concentrations for PBDEs and pyrethroids between the three monitoring periods in 2008, 2013 and 2018 (Figure 4-15);
2. Box plots showing median concentrations and the range of data for select indicators were created using all available datasets from pre-1998 on Figures 4-16 through 4-18; and
3. An analysis of historical trends for 21 of the individual 2018 RHMP stations that have been revisited in the past (Table 4-3).

Finally, at the end of this section a graphical summary of the fraction of RHMP stations in each of the SQO chemical exposure categories for the integrated sediment chemistry LOE by strata over time is shown in Figure 4-19. Indicator metrics and thresholds to assess status and trends, and data sources used for historical comparisons prior to RHMP are provided in Appendix D (Tables D-1 and D-2, respectively).

Sediment Chemistry Threshold Comparisons Between 2008 and 2018 (Historical Evaluation Method 1)

Among the 16 sediment quality indicators based on the SQO chemistry LOEs and ER-M quotient for all RHMP data combined, six showed an improvement of at least 5% in the fraction of stations considered to have minimal or low exposure potential over the past 10 years. The indicators showing improvement include mercury, LPAHs, HPAHs, DDEs, PCBs, and the integrated SQO sediment chemistry score as shown in Table 4-2. These overall improvements were predominantly driven by improvements of mercury in the freshwater-influenced and deep strata, PAHs in the industrial/port stratum, and DDEs and PCBs in the marina stratum. None of the remaining 10 indicators showed a >5% decrease in the proportion of sites in the minimal/low categories between 2008 and 2018.

In addition, five of the indicators (mercury, HPAHs, alpha- and gamma-chlordane, and CSI score) showed a statistically significant decrease in their average concentration between 2008 and 2018 using a two-tailed t-test ($p > 0.05$; see Appendix K).

In contrast to results observed for a number of chemicals, concentrations of PBDEs and pyrethroid pesticides increased in their frequency of detection and median concentrations in 2018 relative to concentrations measured in the previous RHMPs (note that PBDEs were not measured in the 2008 RHMP), particularly in the freshwater-influenced stratum (Figure 4-15 and Appendix F). The increase was statistically significant for pyrethroid pesticides between 2008 and 2018 using a two-tailed t-test ($p > 0.05$; see Appendix K). It is likely that these increases in concentration may be related to increased runoff from upland sources as a result of the above normal precipitation observed in 2017 compared to drought conditions that occurred in 2007 and 2012, the years prior to each regional monitoring effort as shown previously in Figure 4-3. Increased use of pyrethroid pesticides in local watersheds is another possible cause for the trend observed for this particular class of compounds.

Sediment Chemistry Concentration Comparisons over Time (Historical Evaluation Method 2)

A review of data prior to 1998 through 2018 also shows similar trends to that described using only the last 10 years of data for many of the individual chemicals/chemical classes evaluated using the SQO approach. Historical results for copper, zinc, mercury, total PCBs, total PAHs, and the ER-M quotient are provided in Figures 4-16 through 4-18. Based on these plots, an overall decrease in sediment concentrations over time (i.e., since pre-2008) are apparent for mercury, total PCBs, and total PAHs, as well as the integrated ER-M quotient. However, more stable concentrations have been observed over the past 10 years. Concentrations of copper and zinc appear relatively consistent over time; however, the highest concentrations recorded were measured prior to 1998. The reduction in PAH concentrations observed both in the water and sediments over time correspond well with the removal and replacement of creosote treated pier pilings with non-creosote treated alternatives throughout San Diego Bay that continues today and was documented in a study by Katz et al. (1995).

Note that analysis of trends for those datasets including data before 2003 focused on visual plots of the data as opposed to the use of statistical techniques due to inconsistencies in experimental designs and analytical methods and detection limits between the years. As data continues to be collected in future years, data comparability and statistical power will allow for a more robust analysis of trends over time.

Sediment Chemistry Concentration at Revisited Sites (Historical Evaluation Method 3)

A summary of integrated SQO chemistry scores for those 21 RHMP sites that have been visited repeatedly over the years is provided in Table 4-3. Results of this analysis, unlike that observed for several individual chemicals, indicates relatively consistent conditions using the SQO chemistry LOE approach at these particular sites over time. No sites had a score that differed by more than one category over the entire time period evaluated, and the number of sites where the change indicated lower chemistry on average (n=4) was balanced by the same number of sites showing the opposite trend. This approach provides an overall sediment chemistry assessment and thus may not reflect trends for specific individual chemicals within the metric itself due to the influence of the other chemicals used for the integrated calculation.

Table 4-2.
Percentage of Stations in Each RHMP Strata Meeting Sediment Chemistry Metric Thresholds (2008 – 2018)

Assessment Metric	**Threshold Value**	**Units**	**Percentage of Stations in Each RHMP Strata Meeting Sediment Chemistry Metric Thresholds**																	
			Deep (%)			**Freshwater-Influenced (%)**			**Marina (%)**			**Industrial/Port (%)**			**Shallow (%)**			**All Stations (%)**		
			2008	**2013**	**2018**	**2008**	**2013**	**2018**	**2008**	**2013**	**2018**	**2008**	**2013**	**2018**	**2008**	**2013**	**2018**	**2008**	**2013**	**2018**
Number of Stations:			***15***	***16***	***15***	***15***	***15***	***14***	***16***	***15***	***15***	***15***	***14***	***15***	***14***	***15***	***16***	***75***	***75***	***75***
Mean ER-M Quotient[a]	0.2[b]	--	80	87	80	73	67	64	44	40	33	33	36	27	86	87	87	63	64	59
	SQO CSI Value[c]																			
Copper (Cu)	>96.5	mg/kg	73	69	93	53	60	64	19	13	13	20	21	13	93	80	81	51	49	53
Lead (Pb)	>60.8	mg/kg	100	100	100	100	93	100	94	87	100	87	86	87	100	100	100	96	93	97
Mercury (Hg)	>0.45	mg/kg	80	81	100	73	73	100	44	53	53	53	50	67	93	87	94	68	69	83
Zinc (Zn)	>201	mg/kg	93	94	100	73	67	64	38	40	60	47	43	33	93	87	81	68	67	68
Total HPAHs	>1325	µg/kg	87	94	87	67	100	86	88	93	93	40	93	80	100	100	100	76	96	89
Total LPAHs	>312	µg/kg	87	88	93	100	100	100	94	93	100	80	100	100	100	100	100	92	96	99
alpha-Chlordane	>1.23	µg/kg	100	100	100	73	67	71	88	93	100	100	100	100	93	100	100	91	92	95
gamma-Chlordane	>1.45	µg/kg	100	94	100	67	80	71	88	93	93	100	100	87	93	100	100	89	93	91
Total DDDs	>3.56	µg/kg	100	100	100	100	87	86	94	100	100	100	100	87	100	100	100	99	97	95
Total DDEs	>6.01	µg/kg	93	100	100	80	93	86	69	100	100	100	100	100	86	100	100	85	99	97
Total DDTs	>2.79	µg/kg	100	100	93	100	73	100	100	100	100	100	100	93	100	100	100	100	95	97
Total PCBs	>24.7	µg/kg	87	94	93	67	67	71	50	80	73	33	64	47	100	87	100	67	79	77
Integrated SQO Metric	**Exposure Potential**																			
CSI	Between Low and Moderate SQO Categories	--	100	100	100	73	67	79	88	87	93	80	93	73	100	100	100	88	89	89
LRM		--	67	63	73	20	27	21	13	20	13	13	21	13	43	67	38	31	40	32
Integrated Chemistry LOE		--	73	88	93	47	53	57	19	13	27	20	21	20	64	87	88	44	53	57

Notes:

a. The mean ER-M Quotient is a unitless value
b. 0.2 is the mean ER-M quotient threshold for predicted adverse biological effects
c. Threshold values for the CSI represent the category breakpoint between low and moderate potential to cause adverse biological effects (Bay et al 2014).

% = percent; µg/kg = microgram(s) per kilogram; DDD = dichlorodiphenyldichloroethane; DDE = dichlorodiphenyldichloroethylene; DDT = dichlorodiphenyltrichloroethane; ER-M = effects range-median; HPAH = high-molecular weight polycyclic aromatic hydrocarbon; LPAH = low-molecular weight polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; mg/kg = milligram(s) per kilogram.

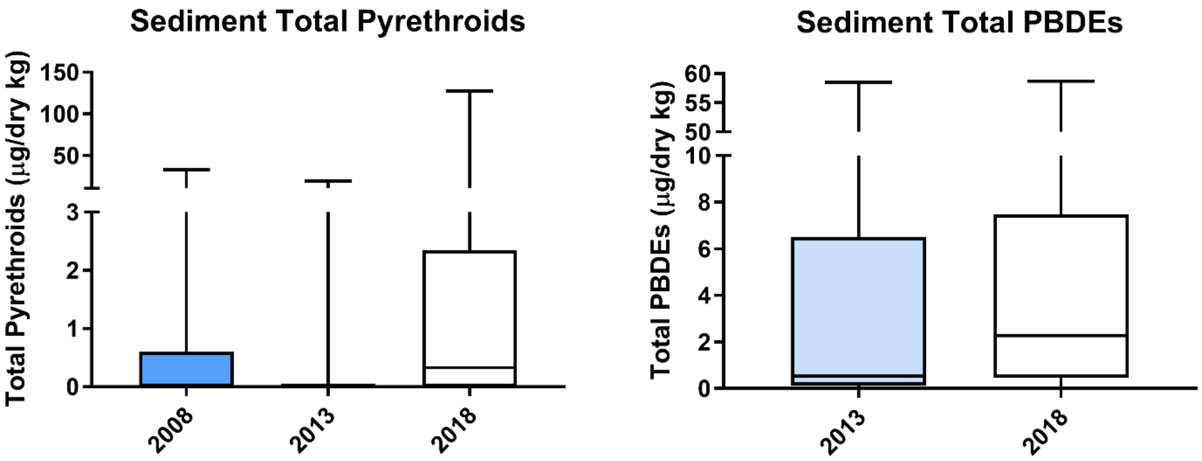


Figure 4-15. Historical Chemical Concentration Comparisons for Pyrethroid Pesticides and PBDEs (2008-2018)

Box plots show the median, 25th percent quartiles, and range of values (all data and strata combined)

Note: PBDEs were not measured in the 2008 RHMP.

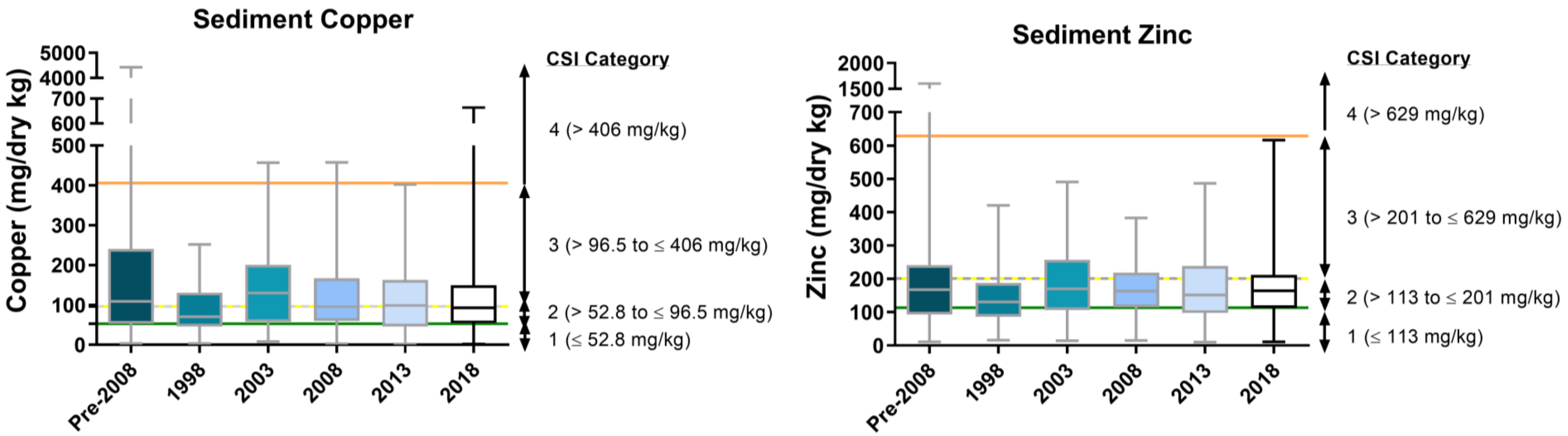


Figure 4-16. Historical Chemical Concentration Comparisons for Copper and Zinc

Box plots show the median, 25th percent quartiles, and range of values (all data and strata combined)

Note: Studies for pre-2008 include all monitoring programs and studies used to develop the historical baselines used in 2013 RHMP reporting

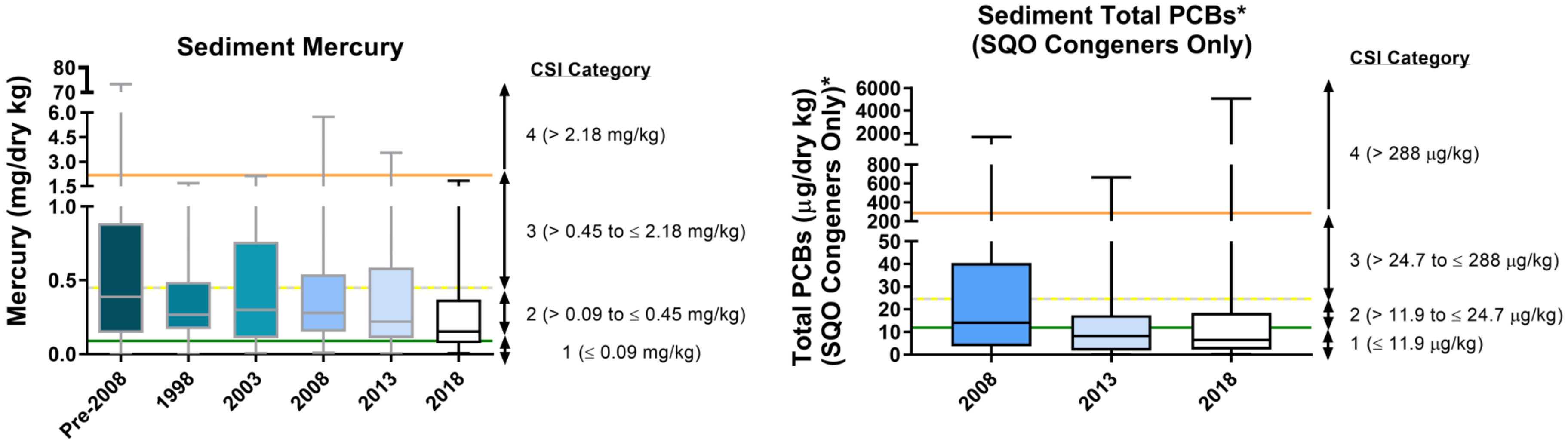
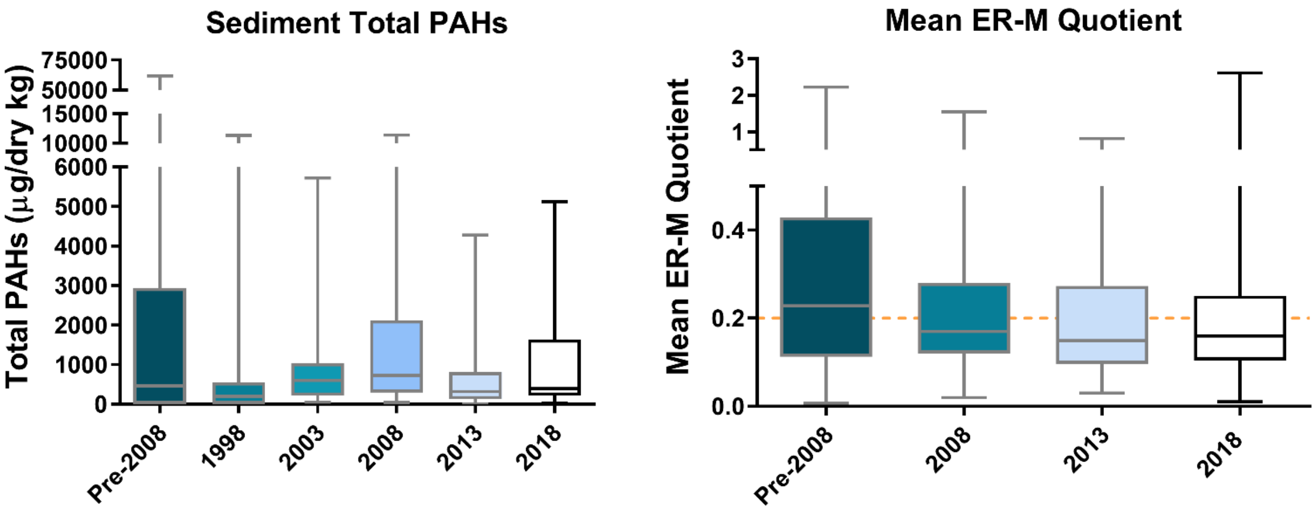


Figure 4-17. Historical Chemical Concentration Comparisons for Mercury and Total PCBs

Box plots show the median, 25th percent quartiles, and range of values (all data and strata combined)

Note: Studies for pre-2008 include all monitoring programs and studies used to develop the historical baselines used in 2013 RHMP reporting

** PCB reporting limits for Bight 1998 and 2003 ranged from 0.03 to 3.0 mg/kg compared to 1.0 mg/kg in 2008 and 0.1 mg/kg in 2013. This discrepancy likely biased pre-2008 concentrations low. Total PCBs for CSI comparison used the sum of 16 select PCB congeners (PCB-8, 18, 28, 44, 52, 66, 101, 105, 110, 118, 128, 138, 153, 180, 187, and 195) multiplied by a correction factor of 1.72 to estimate a total concentration according to the SQO Technical Manual (Bay et al., 2014). Note that this list is a subset of the total 209 PCB congeners.*



*0.2 is the mean ER-M quotient threshold
for predicted adverse biological effects

Figure 4-18. Historical Chemical Concentration Comparisons for Total PAHs and the ERM-Quotient

Box plots show the median, 25th percent quartiles, and range of values (all data and strata combined)

Note: Studies for pre-2008 include all monitoring programs and studies used to develop the historical baselines used in 2013 RHMP reporting.

For the mean ER-M quotient, Site B18-10069 was identified as an outlier relative to other sites using Grubb's test and excluded from regional statistical analyses. This site was included in the plot above to show the range of ER-M quotients observed in 2018.

Table 4-3.
Integrated Sediment Chemistry LOE Scores for Revisited Sites (1998 – 2018)

Harbor	Stratum	1998	2003	2008	2013	2018
Mission Bay	Shallow		4228 Low	6217 Low	8159 Low	10017 Low
	Shallow	2423 Minimal		6216 Minimal	8156 Low	10073 Low
	Deep		4020 Minimal	6212 Minimal	8152 Minimal	10019 Minimal
	Marina	2425 Low		6211 Low	8151 Moderate	10075 Moderate
North San Diego Bay	Shallow	2434 Low		6173 Low	8123 Low	10077 Low
	Marina	2222 Moderate		6161 Moderate	8117 Moderate	10080 Moderate
	Marina		4076 Moderate	6159 Moderate	8116 Moderate	10081 Moderate
	Marina	2226 Moderate		6145 Moderate	8102 Moderate	10084 Moderate
	Industrial/Port	2251 High		6140 Moderate	8100 Moderate	10114 Moderate
	Deep	2263 Moderate		6155 Low	8112 Low	10112 Low
	Deep		4092 Low		8122 Low	10022 Low
	Deep	2436 Moderate		6152 Low	8109 Low	10024 Low
	Deep	2252 Minimal		6129 Minimal	8087 Minimal	10116 Minimal
	Deep	2441 Low		6128 Low	8085 Low	10117 Low
Central San Diego Bay	Shallow		4028 Minimal	6093 Low	8068 Low	10032 Low
	Shallow	2242 Low		6080 Moderate	8060 Low	10034 Low
	Shallow		4116 Low	6071 Moderate	8052 Low	10036 Low
	Industrial/Port		4084 Moderate	6075 Moderate	8056 Moderate	10140 Moderate
	Deep	2262 Moderate		6054 Moderate	8045 Low	10144 Low
South San Diego Bay	Freshwater-Influenced		4148 Low	6040 Low	8029 Low	10037 Low
	Marina		4052 Low	6025 Moderate	8013 Moderate	10086 Low

Integrated SQO Sediment Chemistry LOE Results Over Time (2008-2018)

A summary of final SQO integrated sediment chemistry LOE scores broken out by strata over the past three RHMP monitoring periods between 2008 and 2018 is shown in Figure 4-19. Key observations from these plots include:

1. The deep and shallow strata consistently have the greatest fraction of stations in the low and minimal chemical exposure categories, and both also show an increase in the fraction of sites classified as having minimal/low exposure potential over time;
2. The fraction of stations in the low and moderate exposure categories for the marina stratum have increased over time, with no sites considered to have high exposure potential in 2018;
3. The fraction of stations in each exposure category for the industrial/port strata is consistent over time; and
4. The freshwater-influenced locations appear to show a slight increase in the fraction of stations in the combined minimal/low exposure category over time, however a greater proportion of stations in 2018 were also classified as having high exposure compared to the fraction of sites in 2008.

Collectively these results indicate improving sediment quality conditions over this short 10-year time period based on those constituents included in the SQO calculations. The differences become more apparent when comparing data for certain individual chemicals to older datasets as shown above in Figures 4-16 through 4-18.

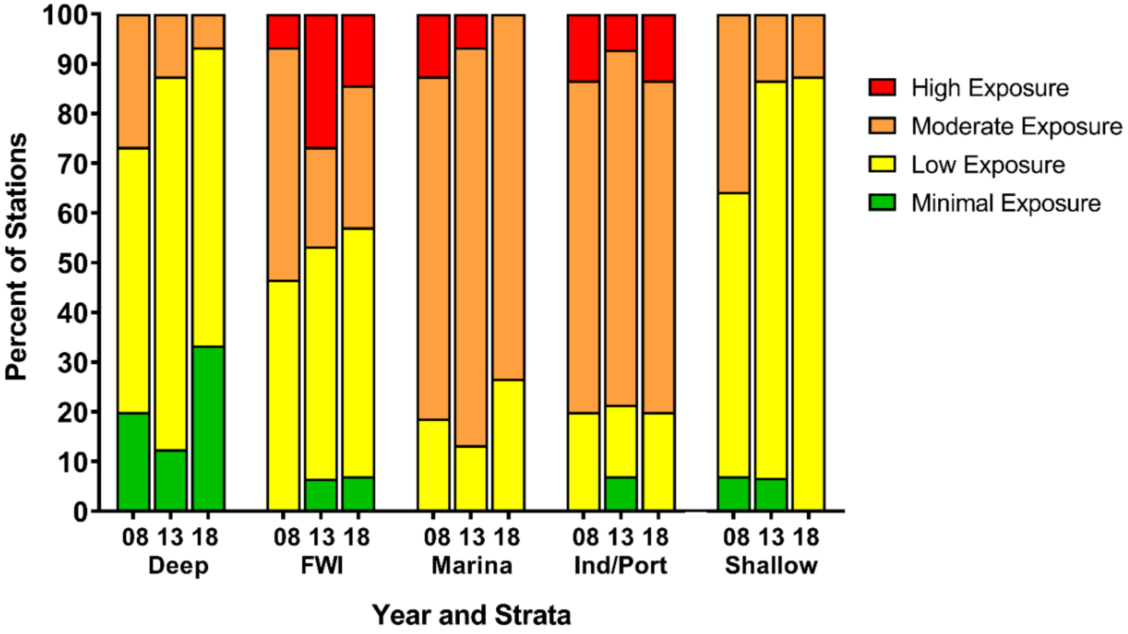


Figure 4-19. Summary of the Fraction of RHMP Stations in Each of the SQO Exposure Potential Categories for the Integrated Sediment Chemistry LOE by Strata Over Time

4.3 Sediment Toxicity

Assessment of toxicity provides another indicator that the San Diego Regional Harbors are supportive of healthy biota; 99% of all RHMP stations (74 of 75) were determined to be nontoxic or to have low toxicity according to both the acute amphipod test and the chronic mussel embryo development test. Furthermore, 100% of the 2018 RHMP stations were classified as either nontoxic or as having low toxicity according to the combined SQO toxicity LOE as shown in Figure 4-20.

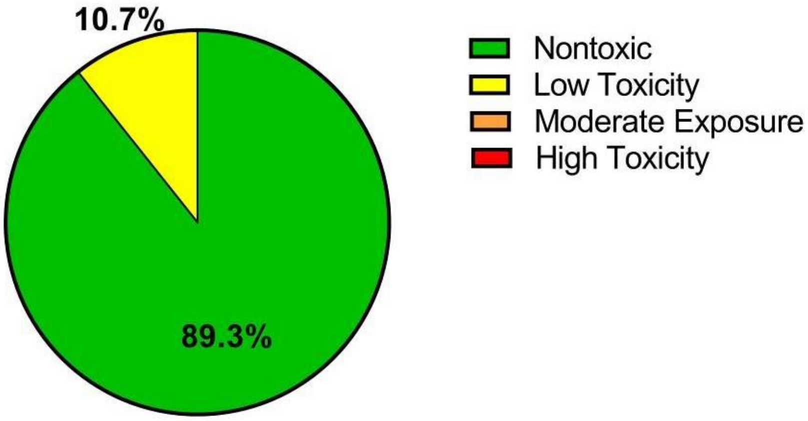


Figure 4-20. Pie Chart Summary of the Fraction of 2018 RHMP Stations in Each of the SQO Categories for the Integrated Toxicity LOE

4.3.1 Sediment Toxicity Historical Comparisons

The discussion below focuses on the historical comparisons of individual species results, followed by integration of results from the two species using the SQO LOE approach.

<u>Amphipod Survival</u>

Bar graphs comparing mean test endpoint results for amphipod survival from 2008, 2013, and 2018 are provided in Figure 4-21. Data are presented as a percent of the control to normalize for differences in organism response to clean material. Mean amphipod survival has been greater than 80% among all harbors and strata during the RHMP between 2008 and 2018 during the RHMP indicating no significant toxicity effect for this species. The incidence of amphipod toxicity during the past 10 years is notably less frequent than that observed during prior Bight Programs and other studies that have tested this same species in the San Diego Regional Harbors as shown in Table 4-4 and Figure 4-22.

Table 4-4.
Historic Percentage of Stations Considered Nontoxic Using Amphipod Survival and the SQO Approach (No Toxicity or Low Toxicity Categories)

Indicator	Percentage of Stations Considered Nontoxic or Low Toxicity		
	2008	2013	2018
Amphipod Survival	96	97	99

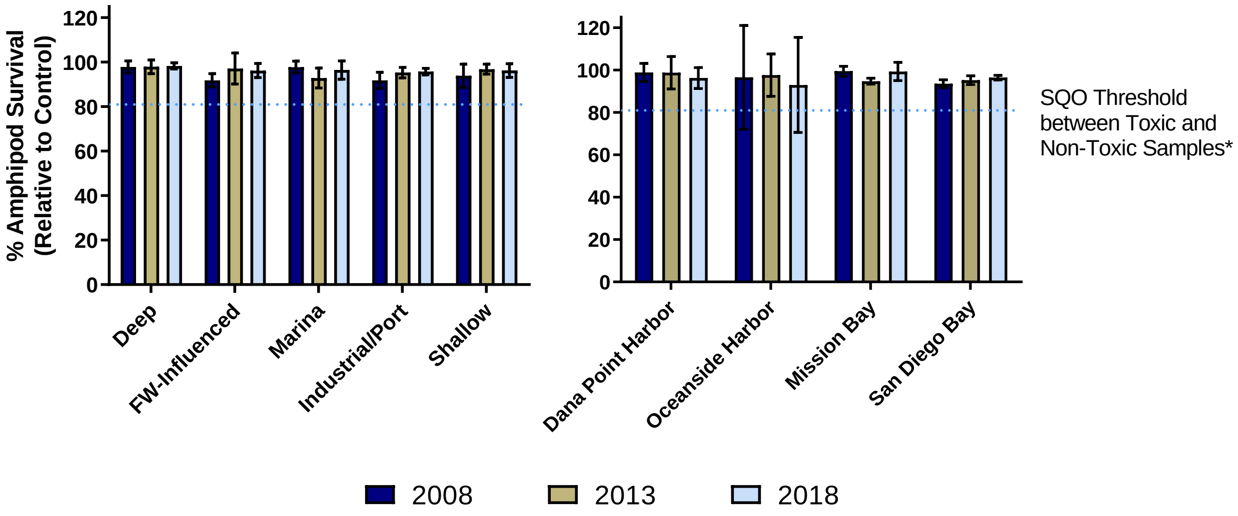


Figure 4-21. Comparisons of Amphipod Survival Among Strata and Harbors (*E. estuarius*) – 2008 and 2018

Mean ± 95% CI

**Nontoxic samples include sites identified as having no toxicity or low toxicity. The threshold shown is the highest response between low toxicity and moderate toxicity categories (81% relative to the control) assuming a statistically significant difference is observed using a standard one-tailed t-test assuming unequal variance.*

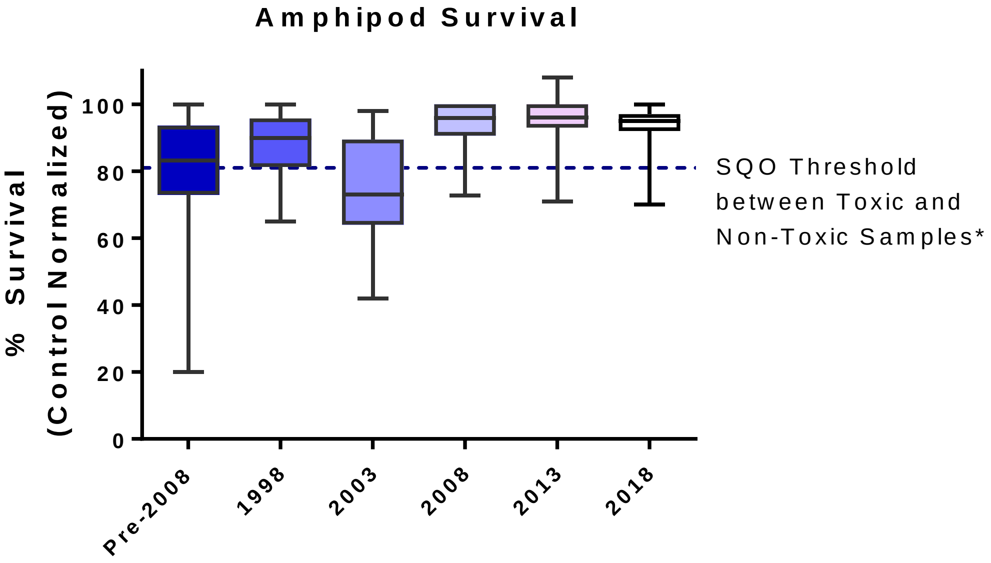


Figure 4-22. Historical Comparisons for Amphipod Survival

Box plots show the median, 25th percent quartiles, and range of values

Notes: Studies for pre-2008 include all monitoring programs and studies used to develop the historical baselines used in 2013 RHMP reporting.

Bivalve Embryo Development

Mean normal-alive embryo development (normalized to the control), ranged from 77% to 111% across all RHMP sampling stations in 2018, which was very consistent with results obtained in 2013 (Figure 4-23). These results correspond to 100% and 99% of samples classified as being nontoxic or having low toxicity in 2013 and 2018, respectively compared to 89% of samples in 2008 (Table 4-5). Greatest improvements for this species were noted in the marina and industrial/port strata as shown in Figure 4-23. Bivalve embryo development has not been tested region-wide prior to 2008 thus limiting the ability to assess the response of this species over a longer time period.

Table 4-5.
Historic Percentage of Stations Considered Non-toxic Using Bivalve Embryos and the SQO Approach (No Toxicity or Low Toxicity Categories)

Indicator	Percentage of Stations Considered Nontoxic or Low Toxicity		
	2008	2013	2018
Bivalve Embryo Development – Normal/Alive	89	100	99

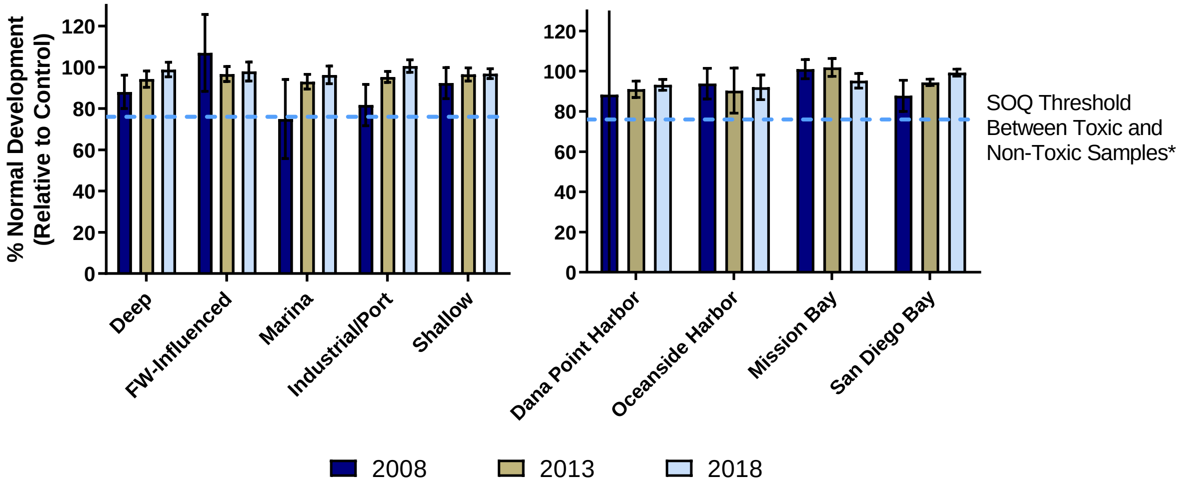


Figure 4-23. Comparisons of Bivalve Embryo Development Among Strata and Harbors (*M. galloprovincialis*) – 2008 and 2018

Mean ± 95% CI

**Non-toxic samples include sites identified as having no toxicity or low toxicity. The threshold shown is the highest response between low toxicity and moderate toxicity categories (78% relative to the control) assuming a statistically significant difference is observed using a one-tailed t-test assuming unequal variance.*

Species Comparisons

Because each species will have unique sensitivity to different chemicals, an evaluation of the response for individual species is important, and an assessment of the comparability between species can also provide additional evidence on potential toxicants of concern. The degree and incidence of toxicity was limited in both 2013 and 2018; however, for those few sites where toxicity has been observed, responses have differed between the two species. In 2018, for example, the one site with moderate toxicity to amphipods (B18-10072 in the southwest corner of Oceanside Harbor) showed no toxicity to bivalve embryos, and conversely, the one site that showed moderate toxicity to bivalve larvae (B18-10082 located in Shelter Island Yacht Basin in San Diego Bay) was nontoxic to amphipods. In 2013, two sites showed moderate toxicity to amphipods (Harbor Island Marina in north San Diego Bay and near the mouth of the Sweetwater Channel in south San Diego Bay), and no sites, including the two with effects to amphipods, were toxic to bivalve embryos. Based on the literature and a variety of tests conducted at Wood Aquatic Toxicology Lab, mussel embryos are much more sensitive to trace metals than amphipods, while conversely, amphipods can be much more sensitive to certain pesticides.

The SQO approach averages results for both species, which in these cases all result in a low toxicity score for the two most recent RHMP efforts (see below), but a closer look at individual sites with moderate or high toxicity for a single species is still important in the overall weight of evidence approach, as effects to any single species may indicate potential effects on many other similar species in the benthic community.

Integrated SQO Sediment Toxicity LOE Results Over Time (2008-2018)

A summary of final SQO integrated sediment toxicity LOE scores broken out by strata over the past three RHMP monitoring periods between 2008 and 2018 is shown in Figure 4-24. A few key observations from the plots are as follows:

1. 100% of stations in the deep, freshwater-influenced, and shallow strata have been classified as being non-toxic, or having low toxicity using the combined toxicity SQO metric during all three RHMP monitoring efforts since 2008.
2. Stations in the marina and industrial/port strata showed a greater incidence of toxicity than the other strata in 2008 (the only strata with sites classified as having moderate toxicity based on both test species results). A reduction in toxicity is most apparent over time in these two strata with notably 100% of stations in the industrial/port stratum classified as non-toxic in 2018.
3. Based on a review of historic data, the moderate integrated toxicity scores in 2008 were driven primarily by toxicity observed in the bivalve embryo development test, thus improvements in integrated toxicity scores over the past 10 years are related primarily to the decrease in toxicity to bivalves.

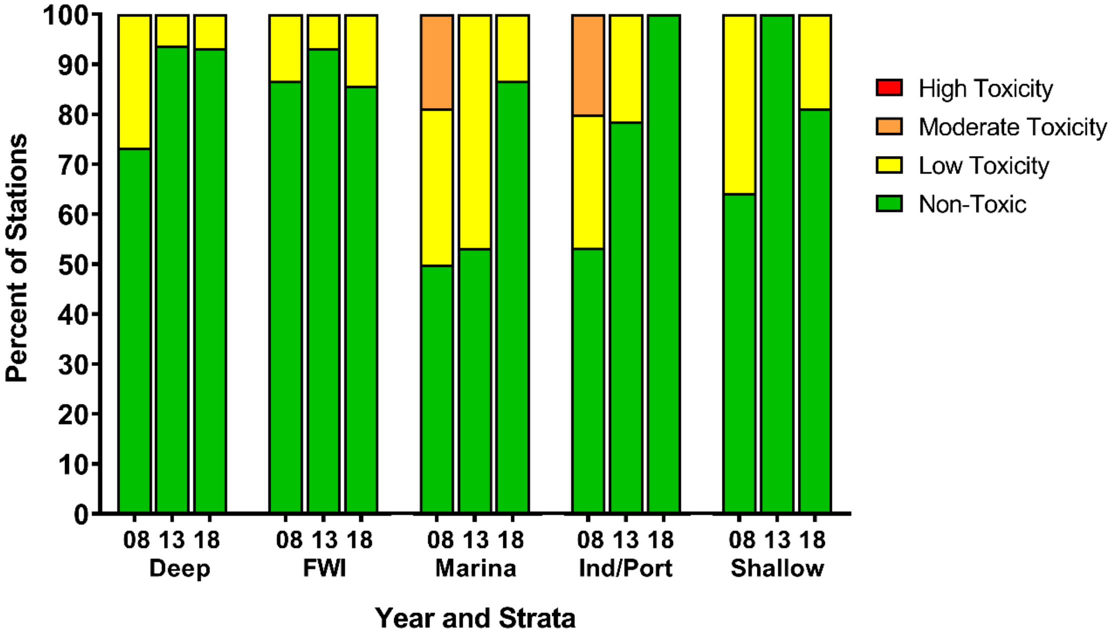


Figure 4-24. Summary of the Fraction of RHMP Stations in Each of the SQO Categories for the Integrated Toxicity LOE by Strata Over Time

Historical Toxicity Results for RHMP Based on Revisited Stations

An evaluation of toxicity based on revisited stations found toxicity using the integrated SQO score to decrease over time at 10 of the 21 stations (48%) across all strata as shown in Table 4-6. Consistent with results based on all of the data, these results show that the greatest decreases in toxicity over the past 10 years have occurred in the marina and industrial/port strata, mostly driven by a decrease in toxicity to bivalves over time.

Table 4-6.
Integrated Sediment Quality Objective Toxicity LOE Results for Revisited Stations (1998–2018)

Harbor	Stratum	1998	2003	2008	2013	2018
Mission Bay	Shallow		4228 High	6217 Nontoxic	8159 Nontoxic	10017 Low
	Shallow	2423 Nontoxic		6216 Nontoxic	8156 Nontoxic	10073 Nontoxic
	Deep		4020 Nontoxic	6212 Nontoxic	8152 Nontoxic	10019 Nontoxic
	Marina	2425 Nontoxic		6211 Nontoxic	8151 Nontoxic	10075 Nontoxic
North San Diego Bay	Shallow	2434 Nontoxic		6173 Low	8123 Nontoxic	10077 Nontoxic
	Marina	2222 Low		6161 Low	8117 Low	10080 Nontoxic
	Marina		4076 Moderate	6159 Low	8116 Nontoxic	10081 Nontoxic
	Marina	2226 Low		6145 Nontoxic	8102 Low	10084 Nontoxic
	Industrial/Port	2251 Moderate		6140 Moderate	8100 Nontoxic	10114 Nontoxic
	Deep	2263 Low		6155 Nontoxic	8112 Nontoxic	10112 Nontoxic
	Deep		4092 Nontoxic		8122 Nontoxic	10022 Nontoxic
	Deep	2436 Nontoxic		6152 Nontoxic	8109 Nontoxic	10024 Nontoxic
	Deep	2252 Nontoxic		6129 Low	8087 Nontoxic	10116 Nontoxic
	Deep	2441 Low		6128 Nontoxic	8085 Nontoxic	10117 Nontoxic
Central San Diego Bay	Shallow		4028 Nontoxic	6093 Nontoxic	8068 Nontoxic	10032 Nontoxic
	Shallow	2242 Nontoxic		6080 Low	8060 Nontoxic	10034 Nontoxic
	Shallow		4116 Low	6071 Low	8052 Nontoxic	10036 Nontoxic
	Industrial/Port		4084 Moderate	6075 Nontoxic	8056 Nontoxic	10140 Nontoxic
	Deep	2262 Moderate		6054 Low	8045 Low	10144 Low
South San Diego Bay	Freshwater-Influenced		4148 Nontoxic	6040 Nontoxic	8029 Nontoxic	10037 Nontoxic
	Marina		4052 Nontoxic	6025 Nontoxic	8013 Nontoxic	10086 Nontoxic

Historical Toxicity Results from the Bay Protection and Toxic Cleanup Program (1992–1994)

Between 1992 and 1994, as part of a statewide monitoring effort referred to as the Bay Protection and Toxic Cleanup Program (BPTCP), a total of 350 sediment samples were collected from San Diego Bay, Mission Bay, and the Tijuana River Estuary and tested for toxicity using the amphipod *Rhepoxynius abronius*. A subset of 164 of these samples were tested using the purple sea urchin *Strongylocentrotus purpuratus* embryo development test on pore-water samples extracted from the whole sediments. Samples for this program were selected using a stratified random sampling design, similar to that used for the Bight Program and RHMP. Toxicity measured during these efforts was demonstrated throughout the three sampled regions, with an increased incidence and concordance occurring in areas of industrial and shipping activity (Fairey et al., 1998). A total of 57% (n=200) of the 350 samples exhibited toxicity to the amphipod *R. abronius* and a total of 74% (n=121) of the 167 undiluted porewater samples were found to cause toxicity to the purple sea urchin embryos.

The two species tested for the BPTCP differ from those used for RHMP over the past 10 years, but they are similar phylogenetically, and the endpoints (10-day survival of amphipods and 48 to 72 hour-embryo development for the mussels and sea urchins) are the same. The greatest difference is related to the exposure type conducted using the embryos; a sediment-water interface test using the mussel embryos for RHMP compared to a porewater test using the purple sea urchin embryos for the BPTCP. Both sea urchins and mussels have similar sensitivity to trace metals which is greater than both amphipod species. Regardless of these differences, the frequency and magnitude of toxicity observed during the BPTCP indicates that conditions have improved considerably from that which existed 25+ years ago.

4.4 Benthic Community Condition

4.4.1 Integrated SQO Benthic Line of Evidence

Benthic community measures are direct indicators of overall community health in response to both natural and anthropogenic disturbances, and so may or may not be closely associated with inputs of pollutants and toxicity (Smith et al., 2003). The impaired benthic community conditions observed within the marina and industrial/port strata are generally associated with elevated chemical exposure, but these stations, as with all other locations, are influenced by a variety of physical factors (propeller wash, tides, and currents), which may also have a substantial influence on the structure and stability of these communities (Katz and Blake, 2005). Other factors explored further in this assessment for RHMP that can affect the benthic communities include physical parameters such as temperature and salinity, dissolved oxygen concentrations, and invasive species.

Using the four benthic LOE indices for an integrated assessment, the RHMP sediments in 2018 were found to support healthy benthic communities (reference plus low disturbance conditions) at 55% of the RHMP stations study-wide (Figure 4-25). The deep and shallow strata were found to have the healthiest benthic communities (67% and 81%, respectively, of stations in reference or low disturbance categories). These locations relative to those in other strata are also generally more exposed to tidal currents and associated flushing. The freshwater-influenced and marina strata had a lower proportion of stations in the reference and low disturbance categories with 35% and 26% of stations, respectively. In the industrial/port stratum, 60% of stations were within the reference and low disturbance categories (see Figure 3-51 in the Results section).

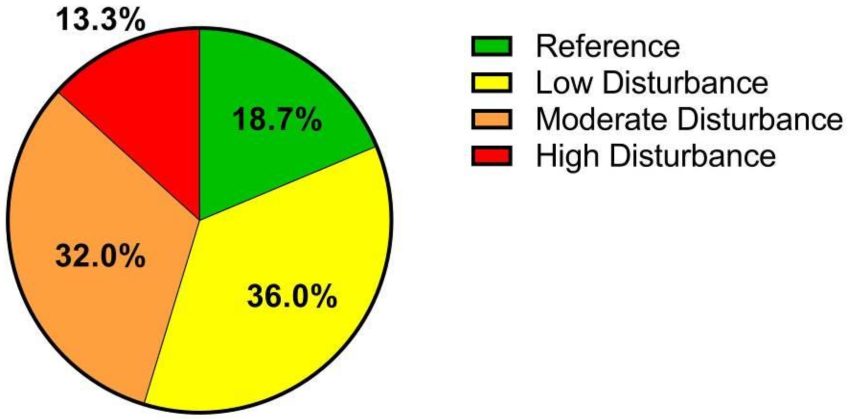


Figure 4-25. Pie Chart Summary of the Fraction of RHMP Stations in Each of the SQO Benthic Community LOE Categories

Freshwater-influenced stations had the most stations (36% [n=5]) with highly disturbed benthic infaunal communities in 2018, which may be related to both physical disturbance (e.g., flushing, scouring, and sediment deposition) and seasonal fluctuations in physical water quality parameters (i.e., low salinity during the wet season), as well as chemical inputs related to watershed runoff-borne contaminants such as pyrethroid pesticides. As described earlier, rainfall during 2017 and early 2018 was above normal and in concordance, concentrations of pyrethroid pesticides and PBDEs noted in 2018 were elevated compared to that observed in 2008 and 2013 which followed drought conditions. Furthermore, in 2008 and 2013, no stations in the freshwater-influenced locations were considered to have highly disturbed communities. However, it should also be noted that a number of freshwater-influenced areas also had communities in 2018 classified as reference or having low disturbance reflecting a lack of consistency across this stratum despite the prior wet year.

Based on ∑SEM:AVS ratios and relatively low sediment chemical concentrations, trace metals were not likely to be bioavailable to the point of causing acute toxic effects at any stations but a single marina location (B18-10080 in SIYB) monitored during the RHMP. The benthic community at this site was classified as highly disturbed, which may be related to the moderate chemical exposure potential and bioavailability of trace metals (in particular, copper, mercury, and zinc) at this location.

At other sites with relatively low chemical concentrations and limited bioavailability based on ∑SEM:AVS ratios, the composition and stability of benthic infaunal communities may have been affected by physical characteristics (e.g., grain size) and physical disturbance. For example, three freshwater-influenced stations near the mouth of Chollas Creek in San Diego Bay (see Figure 3-53e in the Results section) are influenced to varying extents by industrial/port activities and physical disturbance related to propeller wash and scouring or deposition from tides and storm water runoff events (Katz and Blake, 2005). These three sites showed a steady increase in benthic community quality from the inner shallower stations near the mouth, where physical disturbance from both creek inputs and prop wash from heavy vessel traffic is greatest, to outer stations in deeper water; the innermost station in the mouth of Chollas Creek (Station B18-10178), was classified as having a community representative of high disturbance, the next further out (Station B18-10031) had low disturbance, and the furthest out (Station B18-10123) was classified as reference (see Figure 3-53e in the Results section).

Dredging is an activity that can have obvious short-term impacts on benthic communities. An evaluation of areas recently dredged in all San Diego Regional Harbors between approximately 2014 and 2017 was conducted, which identified two RHMP 2018 sampling locations (B18-10071 located at the mouth of Oceanside Harbor) and B18-10178 located in the channel of Chollas Creek to be directly within a recently dredged area. The mouth of Oceanside Harbor is dredged annually, which likely had an impact of the benthic community at this site in 2018, as it was classified as highly disturbed despite no toxicity and low chemistry. The channel of Chollas Creek was dredged in 2016 which also may have impacted benthic communities there depending on how quickly they can recover. Maps showing recently dredged areas in the San Diego Regional Harbors are included in Appendix A for reference.

4.4.2 Benthic Community Historical Comparisons

Historical benthic infauna data used for comparison purposes were summarized in the two prior RHMP reports (Weston, 2010a; Amec Foster Wheeler, 2016), as well as the Bight ’98 and Bight ’03 Monitoring Reports (Ransinghe et al., 2003; Ransinghe et al., 2007). These historical data are presented in several different ways for comparative purposes, including an analysis of historical trends for the 21 revisited sites, followed by comparison of each individual benthic community metric and integrated benthic community SQO scores over time.

Benthic Community Conditions at Revisited Sites

A summary of integrated SQO benthic community scores for those 21 RHMP sites that have been revisited over time is provided in Table 4-7. A majority of the revisited sites had relatively stable benthic community conditions, with scores differing by no more than one category. However, results of this analysis indicated a decline in benthic community condition at 8 of the 21 revisited stations (38%), particularly in the marina stratum. With relatively consistent chemical exposure scores and improving toxicity scores, declines in benthic community conditions at revisited sites may be related to continued site-specific presence of anthropogenic contamination from legacy and ongoing sources, physical site disturbances, warmer temperatures, variable annual rainfall patterns, and/or invasive species

Table 4-7.
Integrated Benthic Community LOE Scores for Revisited Sites (1998 – 2018)

Harbor	Stratum	1998	2003	2008	2013	2018
Mission Bay	Shallow		4228 Moderate	6217 Reference	8159 Moderate	10017 Low
	Shallow	2423 Reference		6216 Reference	8156 Reference	10073 Reference
	Deep		4020 Reference	6212 Low	8152 Low	10019 Low
	Marina	2425 Reference		6211 Low	8151 Reference	10075 Reference
North San Diego Bay	Shallow	2434 Low		6173 Reference	8123 Reference	10077 Reference
	Marina	2222 Low		6161 Moderate	8117 Moderate	10080 High
	Marina		4076 Low	6159 Low	8116 Low	10081 Moderate
	Marina	2226 Low		6145 Low	8102 Reference	10084 High
	Industrial/Port	2251 Low		6140 Low	8100 Low	10114 Reference
	Deep	2263 Reference		6155 Reference	8112 Low	10112 Low
	Deep		4092 Reference		8122 Reference	10022 Reference
	Deep	2436 Reference		6152 Reference	8109 Reference	10024 Reference
	Deep	2252 Reference		6129 Reference	8087 Reference	10116 Low
	Deep	2441 Reference		6128 Reference	8085 Low	10117 Low
Central San Diego Bay	Shallow		4028 Low	6093 Low	8068 Low	10032 Low
	Shallow	2242 Low		6080 Reference	8060 Low	10034 Low
	Shallow		4116 Low	6071 Low	8052 Low	10036 Moderate
	Industrial/Port		4084 Low	6075 Reference	8056 Moderate	10140 Low
	Deep	2262 Low		6054 Moderate	8045 Low	10144 Low
South San Diego Bay	Freshwater-Influenced		4148 Low	6040 Moderate	8029 Low	10037 Moderate
	Marina		4052 Moderate	6025 Moderate	8013 High	10086 Moderate

Shannon Wiener Index and Taxa Richness Over Time

Raw taxa richness values showed a decline from historical surveys, with 61% of stations equivalent to a reference condition in 2018 compared to a range of 83 to 96% among the prior four surveys. The Shannon-Wiener diversity index also indicated less diverse conditions in 2018 compared to that in historical surveys, with 67% of stations equivalent to a reference condition in 2018 compared to a range of 76 to 90% among all prior surveys (Table 4-8). In 2018, both taxa richness and diversity were lowest in the marina and freshwater-influenced strata, with less than 50% of stations in these strata equivalent to reference condition, as shown in the Results Section 3.2.3.

Table 4-8.
Benthic Infaunal Community Index Summary Showing Percentage of Stations Classified as a Reference Condition - All Stations 1998-2018

Metric	Percentage of Stations Equivalent to a Reference Condition				
	1998	2003	2008	2013	2018
n	52	33	75	75	75
Shannon Wiener Index	90	82	76	89	67
Taxa Richness	96	88	85	83	61
BRI	81	42	77*	40	49
IBI	NA	NA	43	44	63
RBI	NA	NA	43	44	29
RIVPACS	NA	NA	17	3	1
Integrated SQO Benthic LOE	NA	NA	31	21	19

Notes:
*2008 results may be erroneously elevated as discussed in Section 4.4.2.
n = total number of sites

SQO Benthic Lines of Evidence Over Time

A historical evaluation of each of the four individual benthic community LOE in addition to the integrated benthic community LOE is presented above in Table 4-8 and discussed in this section.

The Benthic Response Index (BRI)

With all RHMP stations combined, the benthic community condition in 2018 as measured by the BRI varied between years with 49% considered to be representative of a reference community in 2018, which is a slight improvement compared to that observed in 2013 (40%) and 2003 (42%) (Table 4-8). However, a greater number of stations in 2008[10] and 1998 indicated reference conditions using the BRI; 77 and 81%, respectively.

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[10] Some discrepancies were noted in the 2008 RHMP report benthic index calculations (particularly the BRI). An investigation found that the BRI condition scores reported in the 2008 RHMP report were biased low overall, which indicates healthier conditions. Other simple metrics such as the number of taxa present and diversity correlated over time with the BRI so the overall impact with regard to interpretation of trends related to the calculation discrepancies is likely minimal.

Notably, a majority of all RHMP stations combined during the past 10 years are considered to be in either a reference condition or to have low disturbance using the BRI (75 to 89%); however, the fraction of these two categories combined has been decreasing over time. The greatest decreases have occurred in the freshwater-influenced stratum (-36%), the industrial/port stratum (-33%), and the marina stratum (-10%) between 2008 and 2018 (Table 4-8). Very little change was noted for the shallow stratum (93% in 2008 to 94% in 2018), and 100% of the stations in the deep strata were classified as having reference or low disturbance communities among all three RHMP efforts over the past 10 years. The BRI did not classify any stations in the high disturbance categories for any survey. Given the discrepancies identified with the 2008 BRI scores that appear biased low (i.e., higher quality), 2013 and 2018 scores are likely more similar to past results than these data suggest.

The following three benthic community metrics (IBI, BRI, and RIVPACS) discussed below are available for only the past 10 years starting in 2008 when application for the SQO approach was first incorporated into the RHMP.

The Index of Biological Integrity (IBI)

With all RHMP stations combined, the presence of benthic communities considered to represent a reference condition in 2018 as measured by the IBI was greater in 2018 (63%) relative to that in 2008 and 2013 (43 and 44%, respectively; Table 4-8). Interestingly, this trend is the inverse of that observed using the BRI, Shannon Weiner diversity index, and taxa richness metrics.

In 2018, a high proportion of sites (73 to 94% among all strata) were classified as having either reference or low disturbance based on the IBI results (Table 4-9). The marina and freshwater-influenced strata had the lowest fraction of sites in these two categories (73 and 79%, respectively). The proportion of sites in the combined reference/low disturbance categories has decreased somewhat over time in all strata with the exception of the shallow strata which has remained relatively consistent over time. The greatest decrease in the fraction of stations classified as reference or low disturbance over time was in the freshwater-influenced strata which had 100% of stations in these two categories in both 2008 and 2013, compared to 79% in 2018.

The Relative Benthic Index (RBI)

With all RHMP stations combined, the presence of benthic communities considered to represent a reference condition in 2018 as measured by the RBI was less in 2018 (29%) relative to that in 2008 and 2013 (43 and 44%, respectively; Table 4-8). This trend, unlike that for the IBI, is consistent with that observed using the BRI.

Combining sites classified as having either a reference or low disturbance based on the RBI results in a wide range of proportions from 21% for the freshwater-influenced stratum to 81% for the shallow stratum in 2018. The marina, deep, and industrial strata had a relatively similar proportion of sites in the reference and low disturbance categories (40 to 53%; Table 4-9).

The proportion of sites in the combined reference/low disturbance categories based on the RBI have decreased somewhat over time in all strata with the greatest decrease noted in the deep stratum using this metric between 2008 (87%) and 2018 (47%).

The River Invertebrate Prediction and Classification System (RIVPACS)

With all RHMP stations combined, the presence of benthic communities considered to represent a reference condition in 2018, as measured by the RIVPACS benthic community index was just 1% in 2018 compared to 3% in 2013 and 17% in 2008. This metric using an observed/expected modelled approach frequently gave the benthic communities the highest disturbance score of the four individual indices.

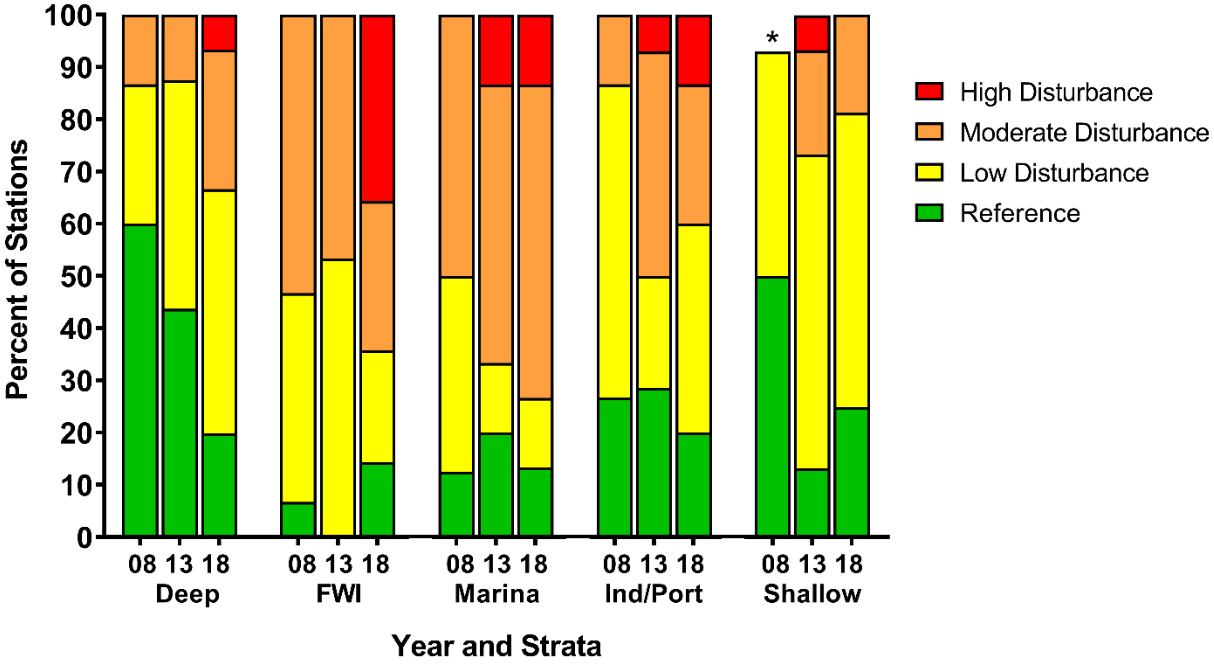
Combining sites classified as having either a reference or low disturbance based on the RIVPACS approach in 2018 only slightly improved the results with only one station in each in the freshwater-influenced, industrial/port, and shallow strata resulting in a score within the reference/low categories. The RIVPACS method also found the proportion of sites in the combined reference/low disturbance categories to have decreased over time in all strata, but to a greater extent overall than the other indices. The proportion of sites in the reference/low disturbance category in 2008 ranged from 27 to 71%, with the lowest disturbance in the shallow stratum, and greatest disturbance in the freshwater-influenced and marina strata, consistent overall with the patterns observed for the other benthic community metrics describe above.

Variability among the Benthic Community Indices Over Time

A total of 6 different metrics summarized in the discussion above and in the Results section were used to describe the health of benthic infaunal communities for the RHMP: number of taxa and diversity (Shannon Wiener Index), and the four indices used for the SQO approach (BRI, IBI, RBI, and RIVPACS). Although variability was noted among the different indices, they all showed a common trend with conditions generally more disturbed in 2018 than during prior years. Decreases in benthic community conditions between 2008 and 2018 were statistically significant for three of the four indices (BRI, RBI, and RIVPACS) based on a two-tailed t-test ($p < 0.05$; see Appendix K). However, with the exception of RIVPACS, the majority of sites using all metrics were considered to have healthy communities, representative of reference or low disturbance conditions. The greatest impairments for each metric were also generally identified at sites in the freshwater-influenced and marina strata. Because each metric has specific defining characteristics, variability among them is expected, and hence it is valuable to use all metrics for an integrated assessment using a multiple line-of-evidence approach. In general, the BRI and IBI considered benthic communities to be in a better (less disturbed) condition than both the RBI and RIVPACs. In some cases for individual sites, all four metrics are similar to one another, such as site B18-10123 outside the mouth of Chollas Creek in San Diego Bay with all four categories indicating reference or low disturbance. In a majority of cases, differences of two or more classification categories were noted among the four indices (e.g., Site B18-10030 near the mouth of San Diego Bay with all four categories of disturbance represented (see Figures 3-53a-f in the Results)). A single integrated categorical score using the SQO approach calculates a median numeric value among the four indices, thus automatically eliminating the lowest and highest score for each final score. This approach provides a simplified method towards an integrated single assessment of benthic community condition, but the variability among the different metrics is also important to consider as each metric provides unique information that may be lost through the calculation of a single integrated score.

Integrated Benthic Community SQO Metric Over Time

As with the multiple individual benthic community indices, the integrated SQO benthic LOE assessment using all four indices also indicated a decrease in benthic community conditions since 2008, as shown by the percentage of RHMP stations in the combined reference and low disturbance categories, with a decrease from 72% in 2008 to 60% in 2013 to 55% in 2018 (Figure 4-26 and Tables 4-9 and 4-10). Decreases in integrated benthic community SQO LOE scores between 2008 and 2018 were statistically significant based on a two-tailed t-test ($p < 0.05$; see Appendix K). The decrease in the reference and low disturbance categories occurred in all strata, with the deep (-20%), marina (-23%), and industrial/port (-27%) showing the greatest change over the past 10 years (Table 4-9, Figure 4-26). The freshwater-influenced and shallow strata showed similar decreases over time; 11 and 12%, respectively. Similarly, an increase was observed in the percentage of stations in the high disturbance category in 2018 (13%) compared to 5% in 2013 and 0% in 2008 as shown in Table 4-10. These increases were predominantly observed in the freshwater-influenced stratum and to a lesser extent in the industrial/port and marina strata (Figure 4-26).



* Note that percent of stations in 2008 Industrial/Port strata do not sum to 100 percent due to an inconclusive sample collected from Station 6291.

Figure 4-26. Summary of the Fraction of RHMP Stations in Each of the SQO Categories for the Integrated Benthic LOE by Strata Over Time Between 2008 and 2018

Table 4-9.
Percentage of Stations in Each RHMP Strata Classified as Reference or Low Disturbance Combined for each SQO Benthic LOE (2008 – 2018)

SQO Benthic Community Assessment Metric	Percentage of Stations in Each RHMP Strata Classified as Reference or Low Disturbance																	
	Deep (%)			Freshwater-Influenced (%)			Marina (%)			Industrial/Port (%)			Shallow (%)			All Stations (%)		
	2008	2013	2018	2008	2013	2018	2008	2013	2018	2008	2013	2018	2008	2013	2018	2008	2013	2018
# of Stations	*15*	*16*	*15*	*15*	*15*	*14*	*16*	*15*	*15*	*15*	*14*	*15*	*14*	*15*	*16*	*75*	*75*	*75*
BRI	100	100	100	93	80	57	63	60	53	100	86	67	93	80	94	89	81	75
IBI	100	94	93	100	100	79	81	80	73	93	93	87	93	100	94	93	93	85
RBI	87	88	47	47	47	21	50	40	40	60	50	53	93	67	81	67	59	49
RIVPACS	60	44	0	27	40	7	38	27	0	60	36	7	71	47	6	51	39	4
Integrated Benthic LOE	87	88	67	47	53	36	50	33	27	87	50	60	93	73	81	72	60	55

Table 4-10.
Integrated SQO Benthic LOE Results Summary - 2008-2018

Stratum	Percentage of Stations Per Benthic LOE Category			
	Reference (%)	Low Disturbance (%)	Moderate Disturbance (%)	High Disturbance (%)
2008 RHMP	31	41	27	0
2013 RHMP	21	39	35	5
2018 RHMP	19	36	32	13

Factors Potentially Influencing the Benthic Communities and Changes Observed over Time

The benthic infaunal communities are integral to the overall ecological structure of the bays and harbors forming a base that supports higher order animals in the food chain, such as associated macroinvertebrates and fish. These communities are also extremely complex and are influenced by a wide variety of factors described in various sections throughout this report. This section brings together and briefly summarizes these factors and provides field observations made during the RHMP sample collection. Key documented factors that can influence benthic communities in addition to anthropogenic chemicals include physical characteristics such as grain size and organic carbon content; physical disturbance (e.g., tides, currents, prop wash, scouring, and deposition); water quality parameters including depressed salinity as a result of watershed runoff or groundwater upwelling, low DO concentrations at the sediment surface, long term changes in pH as a result of ocean acidification, and increased water temperatures; and finally the presence of invasive species.

Although a majority of RHMP locations have communities that are still considered to be healthy, the decrease in overall benthic community scores over recent years warrants enhanced analysis of potential causes. The decrease in community condition is not expected based on the other two primary lines of evidence (toxicity and sediment chemistry), conversely showing an overall positive trend with conditions improving over time. Three key factors have been identified that appear most likely to have had potential direct or indirect impacts on benthic infaunal communities in 2018 as described further below including: 1) increased temperatures related to climate change; 2) magnitude of rainfall during the year prior to sampling; and 3) invasive species.

Temperature

Temperatures world-wide and locally continue to rise due to climate change, as noted previously for Scripps Pier and south San Diego Bay. Record-breaking water temperatures were in fact recorded in 2018 near the time of sampling for the RHMP (see Discussion Section 4.1.2). All species have a preferred and physiological tolerant temperature range. The specific tolerance of individual organisms to temperature for marine benthic infauna in southern California has not been studied based on a review of readily available literature. However, several observations suggest that temperature may be having a noticeable effect on benthic communities at some locations including the following: 1) an overall decrease in the benthic community conditions over the past 20 years despite reduced toxicity and reduced concentrations of a wide range of chemicals of potential concern; 2) a decrease in the presence of reference benthic community conditions from north to south in San Diego Bay despite lower chemical concentrations on average (north San Diego Bay has greater ocean influence and lower water temperatures compared to south San Diego Bay which is semi-enclosed, shallower, and warmer on average); 3) the increase in benthic communities considered highly disturbed among all regions which are most frequently closer to shore or in enclosed regions with limited flushing.

Rainfall

The 2018 RHMP followed a wet year with greater than average rainfall in 2017 and the winter/spring of 2018, compared to drought conditions prior to the 2008 and 2013 regional sampling efforts (see Discussion Section 4.1.2). A few of the storms in 2017 into early 2018 were of high intensity with heavy downpours and greater than 2 inches of rain over a 24-hour period. A range of benthic community conditions was observed for the freshwater-influenced strata from reference to highly disturbed, but of the 10 sites with an integrated SQO score indicating highly disturbed communities, five (50%) were located within the freshwater-influenced strata (see Figures 3-53a through 3-53f in the Results section).

Based on chemicals measured for the SQO approach, overall concentrations in the freshwater-influenced strata were collectively lower on average than that observed in the marina and industrial strata but elevated above that observed in the shallow and deep strata. Four of the five highly disturbed benthic communities in freshwater-influenced locations had low chemical exposure and were nontoxic or had low toxicity. Thus, chemicals related to the SQO list do not clearly stand out as an explanation for the increased benthic community disturbance at the freshwater-influenced sites. An exception to the overall decreasing trend for many of the chemicals in SQO list was the increased concentrations of pyrethroid pesticides and PBDEs that were documented in 2018 compared to prior years, primarily in the freshwater-influenced stratum. Although these sites did not exhibit toxicity from sediments collected in the summer of 2018, the benthic communities in this stratum did show a corresponding increase in the fraction of sites considered to be highly disturbed as shown in Table 4-10 and Figure 4-26.

The combined potential effects from the large storm events in 2017/2018 include physical scouring of the sediments, deposition of sediments, depressed salinity, and transport/deposition of any contaminants associated with the runoff to the marine environment. Another effect related to runoff is the transport of organic matter that settles to the bottom which can then lead to enhanced rates of oxygen depletion at the sediment surface. Two of the three RHMP sites with low DO measured near the sediment surface were freshwater-influenced locations in central San Diego Bay at the mouth of Chollas Creek (B18-10178) and south San Diego Bay near the mouth of Telegraph Canyon (B18-10044). The site by Chollas Creek had the highest TOC content of any sites monitored (3.5%) and the site near Telegraph Canyon also had elevated TOC (1.7%) relative to most other locations. Both of these locations also had highly disturbed benthic communities. Due to variability in DO and other factors described herein over short time periods, a direct cause and effect relationship is not possible at this time, but weight of evidence suggests rainfall is likely a factor having at least some direct and/or indirect influence on benthic communities in the vicinity of runoff inputs.

Invasive Species

Finally, a third documented factor that can largely influence benthic infaunal communities are invasive species. The presence and spread of invasive species may be influenced by all of the same factors described above, in addition to their influx from long distance shipping activities through their attachment and release from bottom surfaces on ships, and transport through any inadvertently discharged ballast water.

One well documented invasive species in the San Diego region is the Asian mussel *Musculista senhousia*. This mussel creates thick mats that can physically alter the bottom structure thus significantly affecting other resident infaunal species. Impacts due to this invasive mussel have been documented in Mission Bay (Crooks, 1998). A review of benthic infaunal data over the past 10 years indicates that *Musculista* are commonly observed throughout the regional harbors although their overall density has varied. The overall population in 2018 was relatively consistent with that observed in 2013 but was much greater than that observed in 2008. A total of 6 of the 24 (25%) stations classified as having moderately disturbed communities using the integrated SQO approach had elevated populations of *Musculista* (>100 individuals). *Musculista* were also observed in 4 of the 10 (40%) stations classified as having highly disturbed benthic communities, although in lower abundances (≤25 individuals).

In addition, a more detailed review of individual sites considered to be likely impacted based on the integrated SQO score using all three LOEs, as well as sites with benthic communities considered to be highly disturbed was conducted as described further in Discussion Sections 4.7 and 4.8. This evaluation found two of the three locations considered to be highly impacted by the integrated SQO assessment method but with mixed signals among the three lines of evidence (B18-10072 in the marina stratum in Oceanside Harbor, and B18-10082 in the marina stratum in north San Diego Bay), were dominated in abundance by the pollution tolerant non-native polychaete *Pseudopolydora paucibranchiata,* a native of Japan*.* A review of benthic community data over the past 10 years shows that *P. paucibranchiata* has been widespread among numerous locations throughout the RHMP; however, a substantial increase (>3x) in the overall population of this species was noted in 2018 compared to that observed in 2008 and 2013. The specific cause for this increase is unknown, but it is likely that the multiple factors described above have had some direct or indirect influence, creating a competitive niche for this invasive species among others.

4.5 Final Integrated SQO Assessment Using all Three Lines of Evidence (Chemistry, Toxicity, and Benthic Community)

Overall integrated SQO assessments used the three LOEs of chemistry, toxicity, and benthic community measures. The SQO classified 72% of all RHMP stations as having unimpacted or likely unimpacted sediment conditions, shown graphically in Figure 4-27 and in Table 4-11. Areas associated with localized anthropogenic inputs of pollutants, most notably the marina and industrial/port strata and, to a limited extent, freshwater-influenced stratum, had conditions that were less suitable for supporting healthy biota.

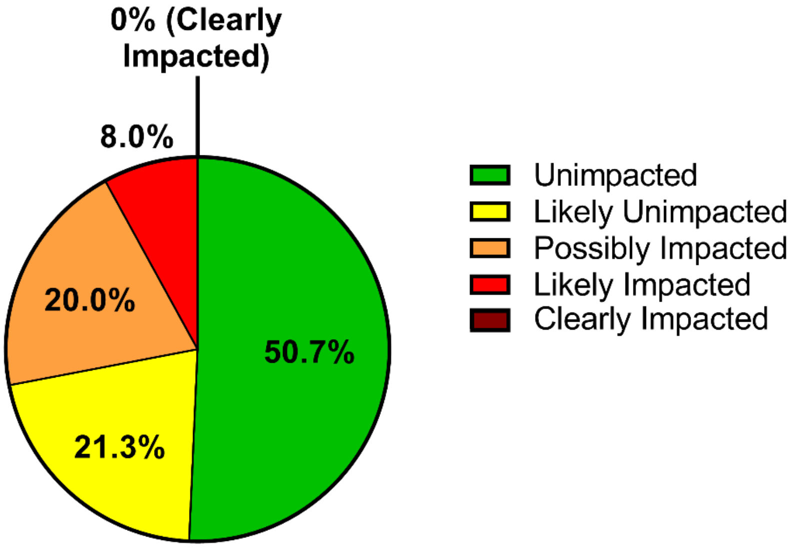


Figure 4-27. Pie Chart Summary of the Fraction of Stations in Each of the Final Integrated SQO Categories

Among strata, the final integrated SQO scores classified 100% of the deep stations, 81% of the shallow stations, and 71% of the freshwater-influenced stations as unimpacted or likely unimpacted. The remaining two strata had 67% (industrial/port) and 40% (marina) stations classified as unimpacted or likely unimpacted (Table 4-12).

While differences among harbors may be attributed to factors such as size, tidal exchange, depth, human uses, and flow rates, and while individual harbors may have some differences in each individual LOE, the overall integrated SQO results appeared to be determined more by stratum type, with more impacted stations in strata associated with anthropogenic influences.

4.5.1 Integrated SQO Station Historical Assessment Using all Three Lines of Evidence (Chemistry, Toxicity, and Benthic Community)

Consistent with the results from RHMP efforts over the past 10 years, the 2018 RHMP continued to find a majority of the sediments to be of good quality (particularly in the deep and shallow strata) with 72% of all locations considered to be unimpacted or likely unimpacted based on the integrated SQO scores (Table 4-11). However, areas associated with localized anthropogenic inputs of pollutants, most notably the marina and industrial/port strata and, to a limited extent, freshwater-influenced stratum, had conditions that were less suitable for supporting healthy biota relative to other strata, as observed in 2008 and 2013 (Table 4-12 and Figure 4-28). No clear trends of improving or declining conditions have been observed in the marina, industrial/port, freshwater-influenced, and shallow strata over the past 10 years based on the final integrated SQO scores (Table 4-12 and Figure 4-28). This is likely a result of differing trends observed in the individual lines of evidence (i.e., overall improvements in chemistry and toxicity LOEs, but overall declines in benthic community conditions). However, there was an improvement in the final integrated SQO scores for the deep stratum, driven primarily by a decrease in chemical concentrations and toxicity (Table 4-12 and Figure 4-28).

Table 4-11.
Percentage of RHMP Stations in Each Integrated Sediment Quality Objective Category, All Stations 2008-2018

Integrated SQO Category	Percentage of Stations Per Integrated Category		
	2008	2013	2018
Unimpacted	55	52	51
Likely Unimpacted	9	20	21
Possibly Impacted	23	13	20
Likely Impacted	11	15	8
Clearly Impacted	1	0	0

Table 4-12.
Percentage of RHMP Stations in the Unimpacted and Likely Unimpacted Integrated Sediment Quality Objective Categories by Strata, 2008-2018

Stratum	Percentage of Stations Unimpacted and Likely Unimpacted		
	2008	2013	2018
Deep	80	94	100
Freshwater-Influenced	73	80	71
Marina	31	40	40
Industrial/Port	60	50	67
Shallow	79	93	81

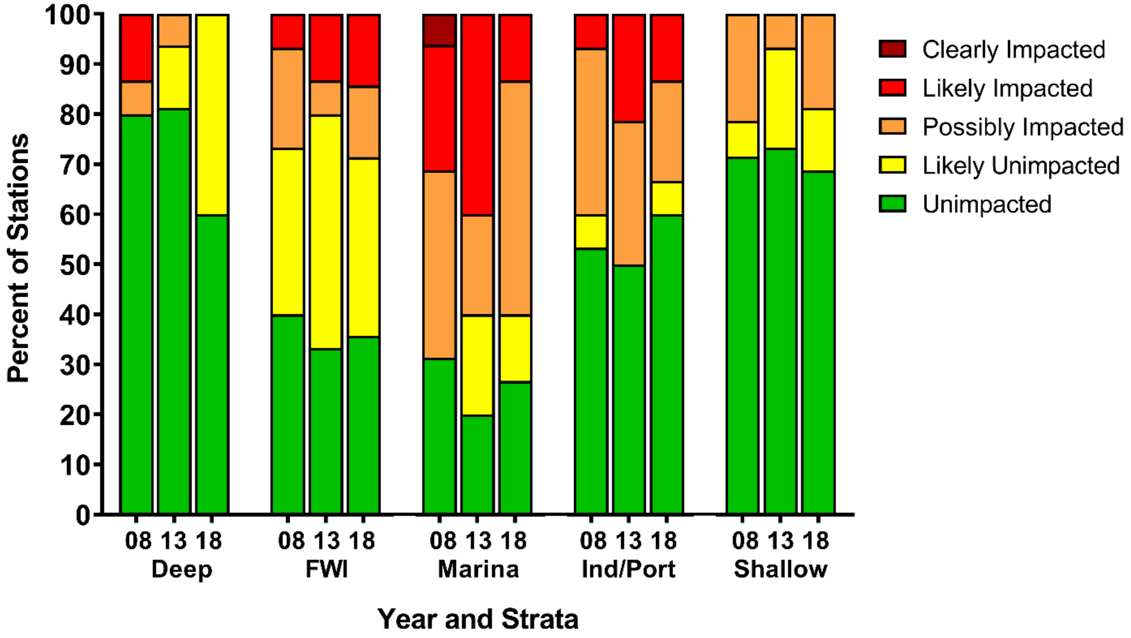


Figure 4-28. Summary of the Fraction of RHMP Stations in Each of the SQO Categories for the Integrated LOE by Strata Over Time

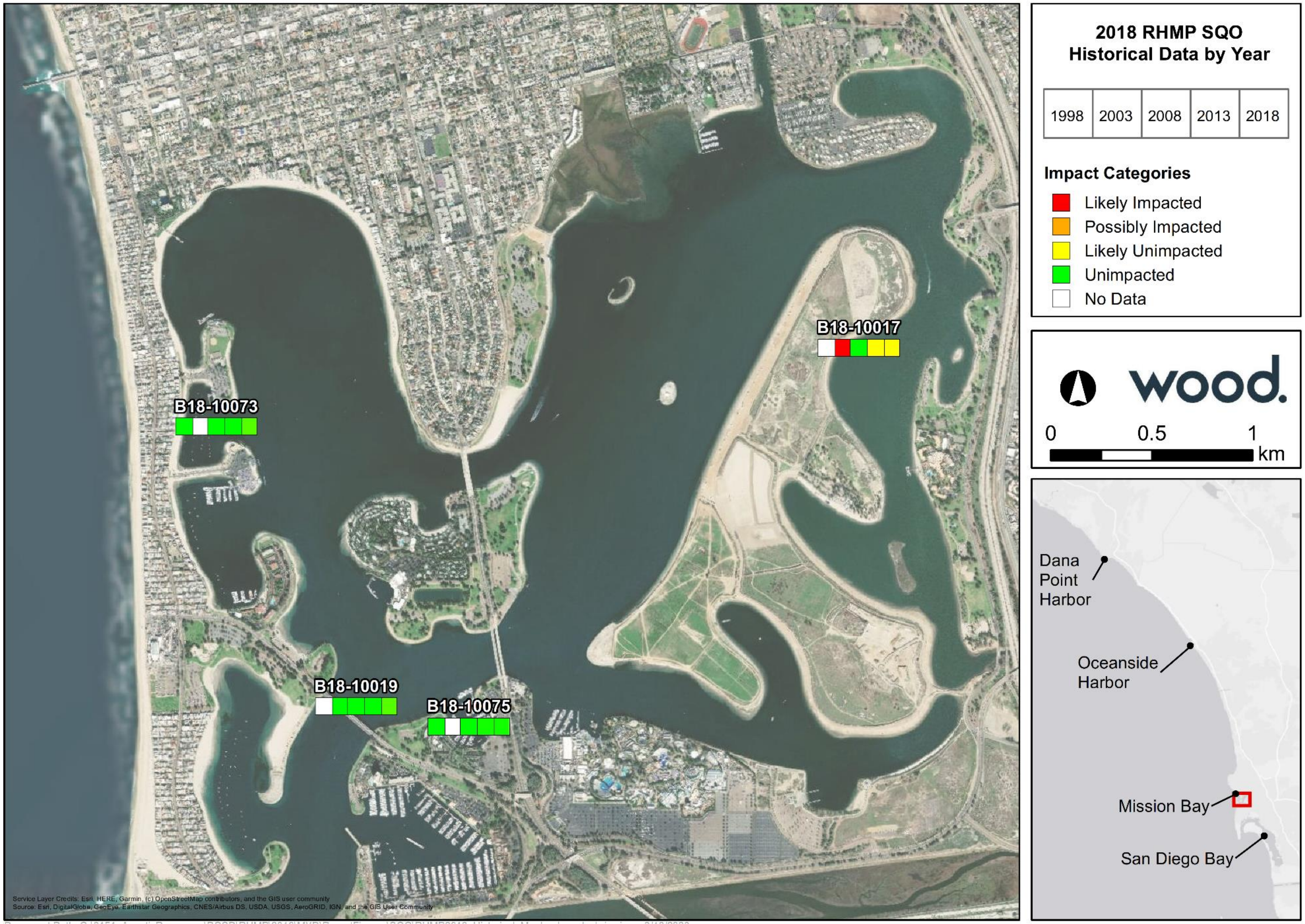
4.5.2 Historical Analysis of Revisited Stations Integrated SQO Scores

A total of 21 stations evaluated in 2018 were the same locations that have been sampled during prior RHMP and Bight surveys with a summary of results presented in Table 4-13 and Figures 4-29a and 4-29b. Of the 21 revisited sites, 4 were located in Mission Bay and 17 were located in San Diego Bay. Note that there were no revisited sites located in Dana Point Harbor and Oceanside Harbor. An assessment of conditions at these specific sites provides a more direct assessment for the evaluation of trends over time by minimizing any potential bias that may arise from randomly selected locations. A review of data from these 21 revisited locations provides evidence that overall sediment quality in 2018 has mostly remained consistent or improved slightly relative to that observed during previous surveys. This conclusion is consistent with that derived by combining all RHMP data together since 2008, including both revisited sites and non-revisited randomly selected sites.

Of 11 revisited stations that were classified as unimpacted in 1998 or 2003, 10 remained unimpacted in 2018 and the remaining station was considered to be likely unimpacted. Many stations increased or decreased by one SQO category, and there were more stations that improved in quality from 1998 or 2003 to 2018 (five stations) than decreased in quality (one station). One station improved across four categories: Station B18-10114 in the industrial/port stratum located in north San Diego Bay, was likely impacted in 1998 and was unimpacted in both 2013 and 2018. Only one station had a consistent negative trend across three categories over the past 10 years: marina Station B18-10084 located in Shelter Island Yacht Basin in north San Diego Bay, which was unimpacted in 2008, likely unimpacted in 2013, and possibly impacted in 2018 driven by changes in the benthic community. However, this same station was also considered to be possibly impacted further back in 1998.

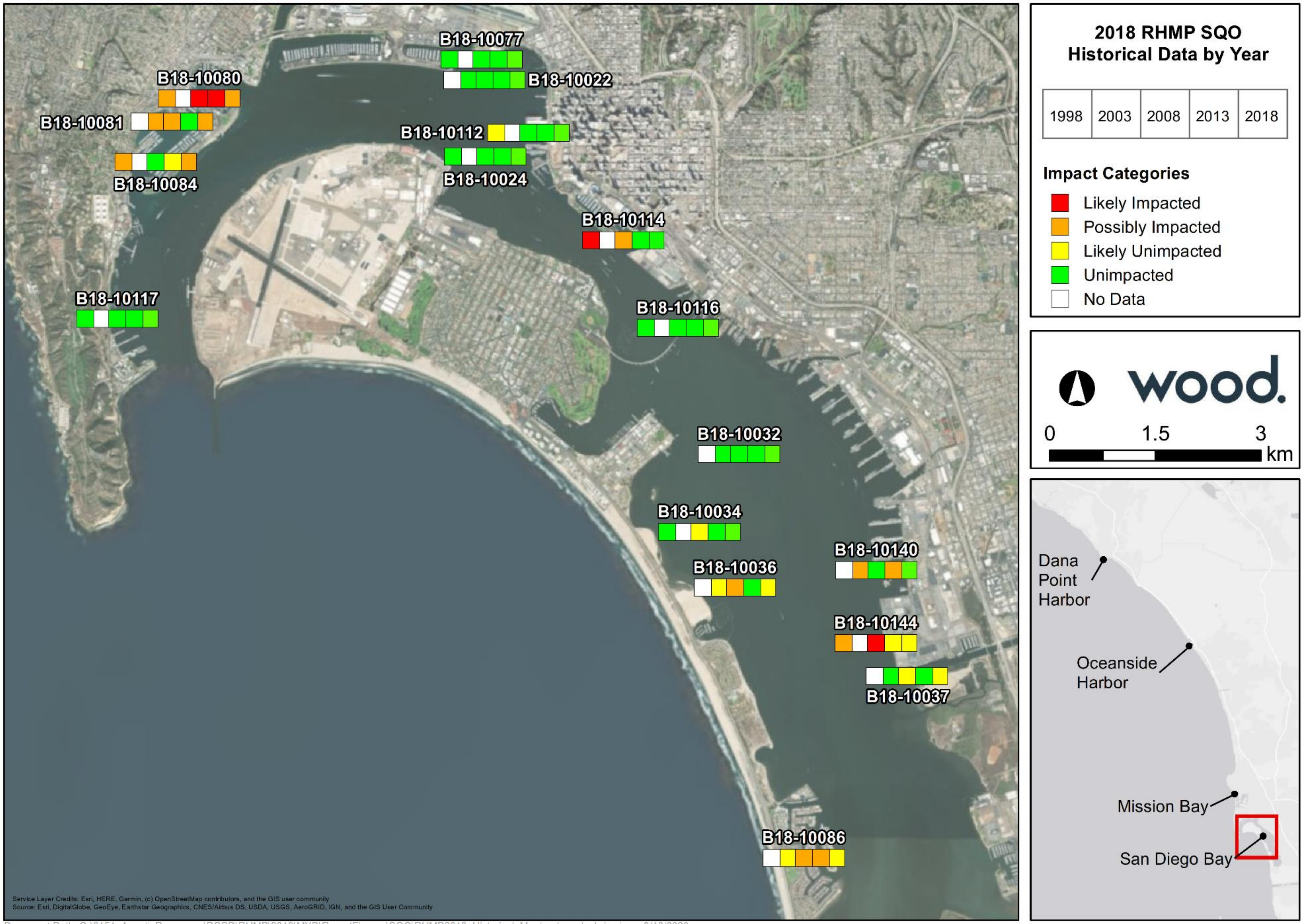
Of note were a few stations with results that spanned three or four SQO categories with no consistent trend over time (e.g., Stations B18-10036 and B18-10017). Station B18-10036 is a shallow location close to the shoreline along the western edge of San Diego Bay. Changes in integrated scores at this location were driven by slight changes (i.e., no more than one category) observed in different lines of evidence during each monitoring year (primarily chemistry in 2008, toxicity in 2013, and benthic community in 2018). This suggests that changes in integrated scores at this location are associated with small-scale variability over time and potential sediment disturbance (e.g., from tides and boating activity) commonly observed at shallow locations.

Shallow Station B18-10017, located in Mission Bay, also had integrated SQO scores that varied over time across all four categories with no clear temporal trend. This station was located close to the shoreline of Fiesta Island in Mission Bay which has considerable recreational activity that could disturb the sediment surface. At this same location, large divots in the shallow sediments from bat rays (bat ray pits) have also been commonly noted, as shown in Photographs in Section 4.11 which also has the potential to physically impact benthic communities in these regions.



Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4-29a. Historical Comparison of Integrated SQO Scores Over Time for Revisited Stations in Mission Bay



Service Layer Credits: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4-29b. Historical Comparison of Integrated SQO Scores Over Time for Revisited Stations in San Diego Bay

Table 4-13.
Integrated Sediment Quality Objective Results for Revisited Stations, 1998–2018

Harbor	Stratum	1998	2003	2008	2013	2018
Mission Bay	Shallow		4228 Likely impacted	6217 Unimpacted	8159 Likely unimpacted	10017 Likely unimpacted
	Shallow	2423 Unimpacted		6216 Unimpacted	8156 Unimpacted	10073 Unimpacted
	Deep		4020 Unimpacted	6212 Unimpacted	8152 Unimpacted	10019 Unimpacted
	Marina	2425 Unimpacted		6211 Unimpacted	8151 Unimpacted	10075 Unimpacted
North San Diego Bay	Shallow	2434 Unimpacted		6173 Unimpacted	8123 Unimpacted	10077 Unimpacted
	Marina	2222 Possibly impacted		6161 Likely impacted	8117 Likely impacted	10080 Possibly impacted
	Marina		4076 Possibly Impacted	6159 Possibly Impacted	8116 Unimpacted	10081 Possibly impacted
	Marina	2226 Possibly impacted		6145 Unimpacted	8102 Likely unimpacted	10084 Possibly impacted
	Industrial/Port	2251 Likely impacted		6140 Possibly Impacted	8100 Unimpacted	10114 Unimpacted
	Deep	2263 Likely unimpacted		6155 Unimpacted	8112 Unimpacted	10112 Unimpacted
	Deep		4092 Unimpacted	6172 Unimpacted	8122 Unimpacted	10022 Unimpacted
	Deep	2436 Unimpacted		6152 Unimpacted	8109 Unimpacted	10024 Unimpacted
	Deep	2252 Unimpacted		6129 Unimpacted	8087 Unimpacted	10116 Unimpacted
	Deep	2441 Unimpacted		6128 Unimpacted	8085 Unimpacted	10117 Unimpacted
Central San Diego Bay	Shallow		4028 Unimpacted	6093 Unimpacted	8068 Unimpacted	10032 Unimpacted
	Shallow	2242 Unimpacted		6080 Likely Unimpacted	8060 Unimpacted	10034 Unimpacted
	Shallow		4116 Likely unimpacted	6071 Possibly Impacted	8052 Unimpacted	10036 Likely unimpacted
	Industrial/Port		4084 Possibly Impacted	6075 Unimpacted	8056 Possibly impacted	10140 Unimpacted
	Deep	2262 Possibly impacted		6054 Likely impacted	8045 Likely unimpacted	10144 Likely unimpacted
South San Diego Bay	Freshwater-Influenced		4148 Unimpacted	6040 Likely Unimpacted	8029 Unimpacted	10037 Likely unimpacted
	Marina		4052 Likely unimpacted	6025 Possibly Impacted	8013 Possibly impacted	10086 Likely unimpacted

The San Diego Regional Harbors appear to have reached a relatively steady state with small improvements relative to conditions observed during surveys conducted since 2008, compared with the much larger improvements noted based on a variety of data collected prior to 2008. Regulations, a variety of significant source controls, dredging, and other cleanup activities have led to improvements over the past few decades in the harbors. The areas of particular concern remain primarily within marinas and around industrial/port regions and certain freshwater-influenced locations although evidence of impacted sediment quality is quite variable within these strata. These areas warrant continued attention. More focused assessments should be able to discern whether the impacts on benthic communities in these areas are related directly to ongoing or legacy chemicals, climate change, more recent watershed pollutant inputs, invasive species, or other chemical or physical factors.

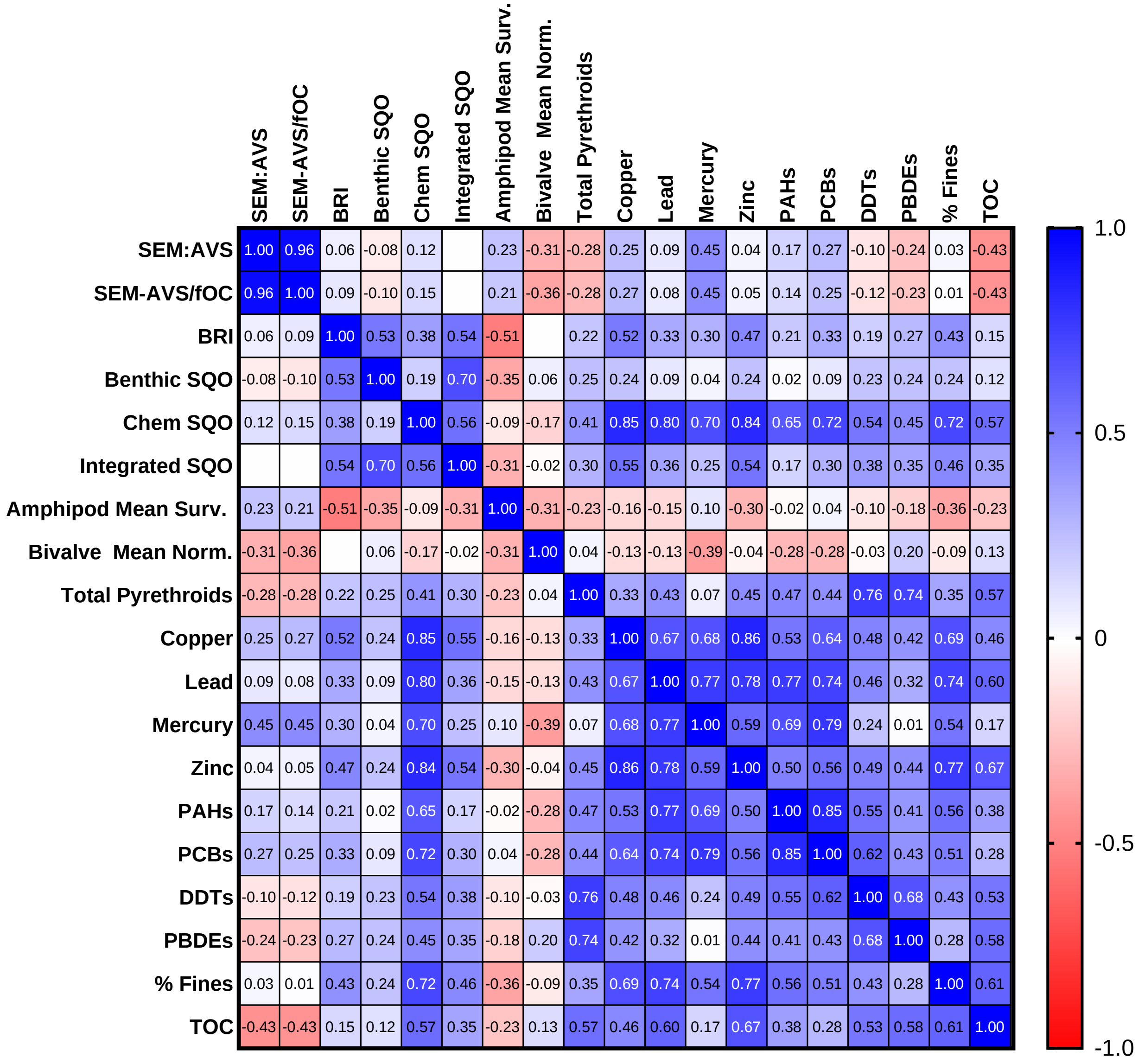
Regarding long-term trend assessments, it should be reiterated that a number of studies used to establish a historical baseline sampled targeted non-randomized station locations, which make direct comparisons with the current randomized approach for RHMP challenging and warrants caution when these results are interpreted as a whole. Comparisons of only those monitoring programs that have used a randomized sampling effort over the past 20 years (i.e., regional Bight Program and RHMP) show fewer noticeable trends than comparisons with targeted studies, except for long-term noted reduction in toxicity. Because a majority of RHMP stations are in good condition, the resolution to determine trends for those fewer impaired locations when all stations are lumped together becomes less powerful; a more accurate assessment of trends has been accomplished herein by comparing patterns over time for the different strata and the historically impacted areas of the harbors with similar sources of stressors.

4.6 Statistical Comparisons Between Chemical and Biological Measurements

This section describes additional statistical analysis procedures to further explore the strength of relationships between measured chemicals of primary concern and biological community measurements for benthic infauna based on the BRI and integrated benthic community SQO scores. This evaluation is useful to help identify any specific individual contaminants of concern that may have a notable influence on the biological community. Comparisons can then be made to the chemicals identified as primary drivers for the two SQO chemistry metrics, the CSI and LRM.

The relationships between the various chemical concentrations, physical characteristics, toxicity, benthic community (BRI), and integrated SQO metric scores for each LOE alone and combined were evaluated using a nonparametric Spearman Rank correlation. Results of this analysis using the entire 2018 RHMP dataset combined are presented in Figure 4-30. In summary, this analysis shows strong correlations among many of the sediment chemical and physical characteristics, but weaker relationships between chemical constituents and benthic community scores. Many of these relationships with a correlation coefficient value (r) greater than approximately 0.23 were statistically significant ($p < 0.05$), despite relatively weak correlations of less than 0.5. This suggests that less than half of the variation can be accounted for by any single benthic community versus chemical concentration comparison. Most notable are relatively strong relationships between copper and zinc concentrations in the sediment correlating with the BRI and the integrated chemistry SQO score. These relationships corroborate results for individual sediment chemistry CSI and LRM scores which are often driven by these two trace metals among others as described further in Discussion Section 4.7 which investigates likely causes for impairment at several individual sites with elevated integrated SQO scores. In support of these observations a local study by Neira et al. (2015) also found a relationship between benthic infauna community characteristics based on recolonization in clean sediment at different locations along a copper gradient in Shelter Island Yacht Basin in San Diego Bay.

A lack of statistical relationship was also noted across all biological and toxicity measures for a few chemicals of concern including pyrethroid pesticides and DDTs.



	SEM:AVS	SEM-AVS/fOC	BRI	Benthic SQO	Chem SQO	Integrated SQO	Amphipod Mean Surv.	Bivalve Mean Norm.	Total Pyrethroids	Copper	Lead	Mercury	Zinc	PAHs	PCBs	DDTs	PBDEs	% Fines	TOC
SEM:AVS	1.00	0.96	0.06	-0.08	0.12		0.23	-0.31	-0.28	0.25	0.09	0.45	0.04	0.17	0.27	-0.10	-0.24	0.03	-0.43
SEM-AVS/fOC	0.96	1.00	0.09	-0.10	0.15		0.21	-0.36	-0.28	0.27	0.08	0.45	0.05	0.14	0.25	-0.12	-0.23	0.01	-0.43
BRI	0.06	0.09	1.00	0.53	0.38	0.54	-0.51		0.22	0.52	0.33	0.30	0.47	0.21	0.33	0.19	0.27	0.43	0.15
Benthic SQO	-0.08	-0.10	0.53	1.00	0.19	0.70	-0.35	0.06	0.25	0.24	0.09	0.04	0.24	0.02	0.09	0.23	0.24	0.24	0.12
Chem SQO	0.12	0.15	0.38	0.19	1.00	0.56	-0.09	-0.17	0.41	0.85	0.80	0.70	0.84	0.65	0.72	0.54	0.45	0.72	0.57
Integrated SQO			0.54	0.70	0.56	1.00	-0.31	-0.02	0.30	0.55	0.36	0.25	0.54	0.17	0.30	0.38	0.35	0.46	0.35
Amphipod Mean Surv.	0.23	0.21	-0.51	-0.35	-0.09	-0.31	1.00	-0.31	-0.23	-0.16	-0.15	0.10	-0.30	-0.02	0.04	-0.10	-0.18	-0.36	-0.23
Bivalve Mean Norm.	-0.31	-0.36		0.06	-0.17	-0.02	-0.31	1.00	0.04	-0.13	-0.13	-0.39	-0.04	-0.28	-0.28	-0.03	0.20	-0.09	0.13
Total Pyrethroids	-0.28	-0.28	0.22	0.25	0.41	0.30	-0.23	0.04	1.00	0.33	0.43	0.07	0.45	0.47	0.44	0.76	0.74	0.35	0.57
Copper	0.25	0.27	0.52	0.24	0.85	0.55	-0.16	-0.13	0.33	1.00	0.67	0.68	0.86	0.53	0.64	0.48	0.42	0.69	0.46
Lead	0.09	0.08	0.33	0.09	0.80	0.36	-0.15	-0.13	0.43	0.67	1.00	0.77	0.78	0.77	0.74	0.46	0.32	0.74	0.60
Mercury	0.45	0.45	0.30	0.04	0.70	0.25	0.10	-0.39	0.07	0.68	0.77	1.00	0.59	0.69	0.79	0.24	0.01	0.54	0.17
Zinc	0.04	0.05	0.47	0.24	0.84	0.54	-0.30	-0.04	0.45	0.86	0.78	0.59	1.00	0.50	0.56	0.49	0.44	0.77	0.67
PAHs	0.17	0.14	0.21	0.02	0.65	0.17	-0.02	-0.28	0.47	0.53	0.77	0.69	0.50	1.00	0.85	0.55	0.41	0.56	0.38
PCBs	0.27	0.25	0.33	0.09	0.72	0.30	0.04	-0.28	0.44	0.64	0.74	0.79	0.56	0.85	1.00	0.62	0.43	0.51	0.28
DDTs	-0.10	-0.12	0.19	0.23	0.54	0.38	-0.10	-0.03	0.76	0.48	0.46	0.24	0.49	0.55	0.62	1.00	0.68	0.43	0.53
PBDEs	-0.24	-0.23	0.27	0.24	0.45	0.35	-0.18	0.20	0.74	0.42	0.32	0.01	0.44	0.41	0.43	0.68	1.00	0.28	0.58
% Fines	0.03	0.01	0.43	0.24	0.72	0.46	-0.36	-0.09	0.35	0.69	0.74	0.54	0.77	0.56	0.51	0.43	0.28	1.00	0.61
TOC	-0.43	-0.43	0.15	0.12	0.57	0.35	-0.23	0.13	0.57	0.46	0.60	0.17	0.67	0.38	0.28	0.53	0.58	0.61	1.00

Figure 4-30. Spearman Rank Correlation Matrix Using Select Indicators of Sediment Quality

Values in each box represent Spearman's Rank Correlation Coefficient (r), a measure of the strength of the relationship with a larger r in the negative or positive direction indicating a stronger relationship with 1.0 equal to a perfect relationship. Positive correlations are shown in blue, negative correlations in red.

To further assess and visualize relationships among stations and strata, multivariate analyses were performed using PCA for sediment chemistry and physical characteristics alone, and relative to the benthic community structure using nMDS. PCA with one-way ANOSIM showed that grouping stations by strata (all strata significantly different from one another) had stronger statistical relationships than grouping by harbor (only North San Diego Bay and South San Diego Bay were statistically different), which validates the approach to target different strata as a key component of the sampling and analysis approach for the RHMP (see Figures 3-54 and 3-55 in the Results section).

Using the RELATE and BEST/BIOENV analysis in PRIMER to correlate the relationship matrices for sediment chemistry and benthic community based on Spearman rank creates a simple mathematical model to gauge how well the chemistry may explain benthic community composition using all input variables combined and individually. Through several iterations, the model returns a statistically significant relationship for the 2018 RHMP dataset, but one that does not account for a high degree of the variation (below 40%), which is similar to what was observed in the 2013 RHMP. BEST/BIOENV analysis showed that the highest correlation of chemistry to the benthic infauna (77.8%) combines percent fines, lead, total DDTs, total pyrethroids and total PBDEs. It should be noted that lead and copper were covariates with very similar vectors (see Figure 4-12a); however, lead was selected by the model as it was able to partition the variance slightly better between stations. Zinc had the highest correlation (59.6%) out of any single constituent (see Appendix K). These results indicate that multiple complex factors must be responsible for observed effects on the benthic infaunal communities in addition to sediment chemistry, likely several measures that were not included in this assessment such as the degree of physical disturbance, frequency, and magnitude of influence from freshwater.

Similar to the 2013 RHMP, Section 4.8 provides a more in-depth assessment of those stations showing the most disturbed benthic communities (based on the SQO assessment of benthic community).

4.7 Assessment of Stations in the Likely Impacted SQO Category

The integrated SQO assessment rated six stations in the 2018 RHMP study area as likely impacted. Of these six stations, two were in the freshwater-influenced stratum, two were in the marina stratum, and two were in the industrial/port stratum. Each of these stations was determined to have moderate or high chemistry exposure and moderate or high benthic community disturbance, while sediment toxicity was either non-toxic or had low toxicity. For three of these six stations, the SQO results were quite conclusive, with high chemical exposure and high benthic community disturbance. These included stations B18-10124, B18-10127 (central San Diego Bay in the industrial/port stratum) and B18-10178 (central San Diego Bay in the freshwater-influenced stratum). Given the concordance among the chemical and benthic community LOEs for these three sites no further discussion is provided. However, the remaining three stations that the SQO classified as likely impacted (stations B18-10072 in Oceanside Harbor in the marina stratum, B18-10029 in north San Diego Bay in the freshwater-influenced stratum, and B18-10082 in north San Diego Day in the marina stratum) had mixed signals of impairment and are discussed further below.

The integrated SQO considers four benthic indices and three chemical components. The four SQO benthic indices can lack applicability when a station has a unique community composition or habitat conditions. This is sometimes evidenced by situations where the four indices disagree with one another, indicating that the benthic community may have been missing key components of one index but not the others. (Note again that this is why the final integrated benthic score discards the high- and low- scoring indices and uses only the median-scoring indices). Chemical indices are based on concentration ranges, and in some cases a constituent or index score may be very close to a category threshold, within the range of analytical error. Therefore, the following is an analysis of stations to determine whether the SQO category of likely impacted appears appropriate, and what primary factors may have been driving the conclusion. Stations identified as being likely impacted based on the final integrated SQO metric are shown in Figure 4-31.

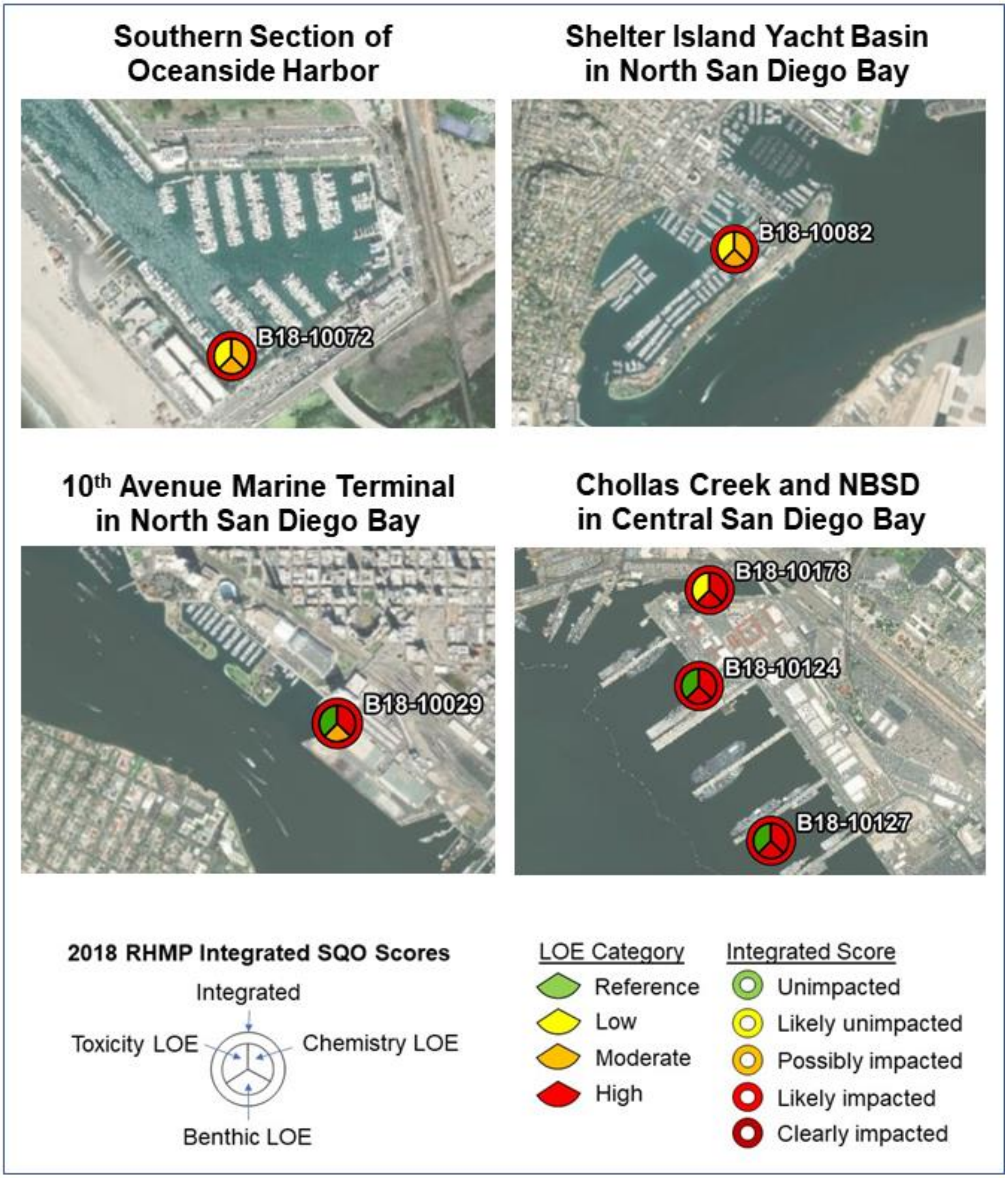


Figure 4-31. Locations of the RHMP Sampling Stations Classified as "Likely Impacted" Using Final Integrated SQO Approach

For reference, a PCA plot that shows comparative relationships between sediment chemistry, physical characteristics, and RHMP strata is provided in Figure 4-32. Sites of interest described above and below in Section 4.8 are identified on the figure.

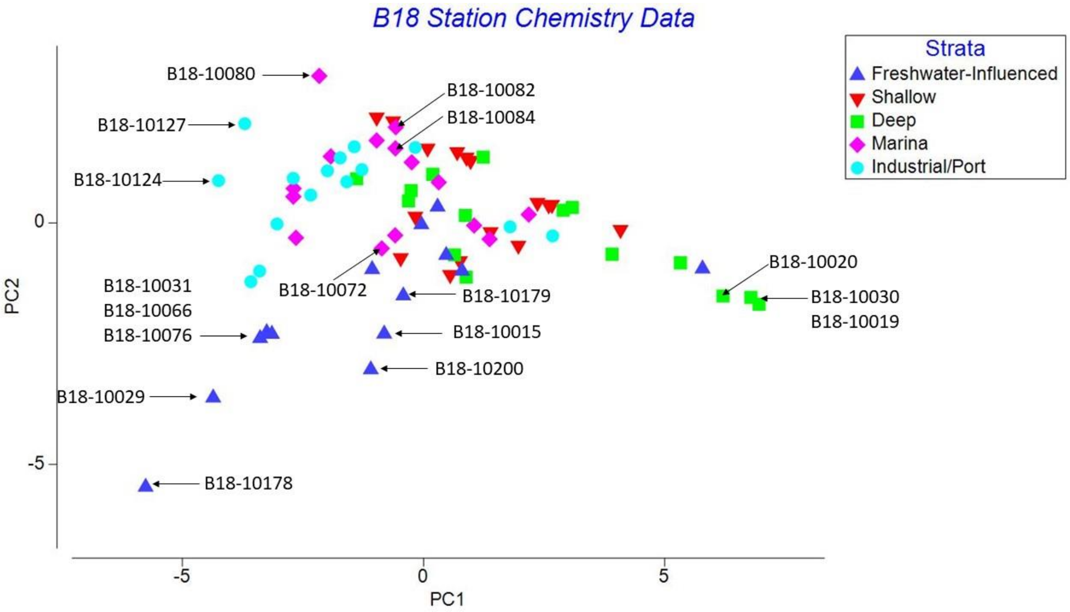


Figure 4-32. PCA of Sediment Chemistry and Physical Parameters by Strata with Stations of Interest Identified

Select Stations IDs are displayed for those locations called out in the text.

4.7.1 B18-10072: Oceanside Harbor in the Marina Stratum

This station was located in the southwestern corner of the Oceanside Harbor in a narrow channel among boat slips. Using the SQO approach the benthic community was classified as having moderate disturbance, there was moderate exposure potential related to chemical concentrations, and the station had low toxicity. Two of the individual benthic LOEs were classified as having low disturbance and the CSI also identified the site as having low exposure potential based on chemical concentrations. The LRM chemistry LOE considered the site to have high exposure potential; however, it was also very close to the threshold of moderate exposure. Copper and zinc were the top two chemicals driving the LRM score at this location. Infaunal taxa richness was relatively low with 16 taxa (two were sensitive) but the RIVPACS expected “reference pool” taxa was also low for the habitat conditions at this location, 5.7, with a total of 4 reference taxa observed (i.e., reference taxa with >50% probability of capture). The benthic community was dominated by the pollution tolerant non-native polychaete *Pseudopolydora paucibranchiata* that has a pollution tolerance value (P-value) of 81.7 (P-value range is -42.0 to 176.7; higher values represent greater pollution tolerance). Based on the enclosed marina location with limited flushing and expected low number of reference taxa, some impact to benthic communities is not unexpected at this location and appears likely to be associated with elevated chemistry concentrations (particularly copper and zinc from ongoing sources such as antifouling paint and in-water hull cleaning), hydrodynamics (limited circulation), and possibly physical disturbance as well due to prop wash. The final integrated SQO category of “likely impacted” appears to be appropriate for this site.

4.7.2 B18-10029: North San Diego Bay in the Freshwater-influenced Stratum

This station was in proximity to a substantial storm water outfall (Switzer Creek) and adjacent to the 10th Avenue Marine Terminal. Following the SQO methodology the benthic community was classified as moderately disturbed and chemical concentrations were elevated resulting in a high exposure category, but the sediment was non-toxic. The benthic community was classified as reference by the BRI and low disturbance by the IBI. Infaunal taxa richness was moderate with 23 taxa (one sensitive taxon) although of the 19.7 reference taxa expected by RIVPACS, only five were observed. There was moderate exposure potential based on chemical concentrations according to the CSI, but concentrations of a number of the chemical constituents were near the threshold limits for low exposure. Other constituents that were elevated included the legacy pesticides chlordane and DDTs (DDDs and DDEs). The LRM value indicated high chemical exposure but was very close to the moderate exposure threshold. The trace metals copper, lead, and zinc were the strongest drivers of the SQO scores for chemical exposure according to the CSI, while zinc and chlordane had the greatest potential impact according to the LRM. The elevated chemistry in the sediment at this location does appear to be a likely factor of potential concern for benthic communities, but the sediments were also notably not toxic. A few known potential confounding factors at this location include physical disturbance from scouring during large runoff events and prop wash related to tugboats docking ships at 10th Avenue Marine Terminal. An aerial photo of tugboats docking a ship at Naval Base San Diego is shown below in Figure 4-33, next to a LIDAR picture of a ship at 10th Ave. Terminal in San Diego showing a divot in the sediments related to prop disturbance. Also notable at this location is the occasional accumulation of trash both in the surface waters and surrounding shoreline, and on the sediment surface noted during diver surveys of the area. The influence of freshwater alone due to close proximity of the station to discharge from Switzer Creek is yet another factor potentially affecting benthic communities at this location. The final integrated SQO category of “likely impacted” appears to be appropriate for this site.

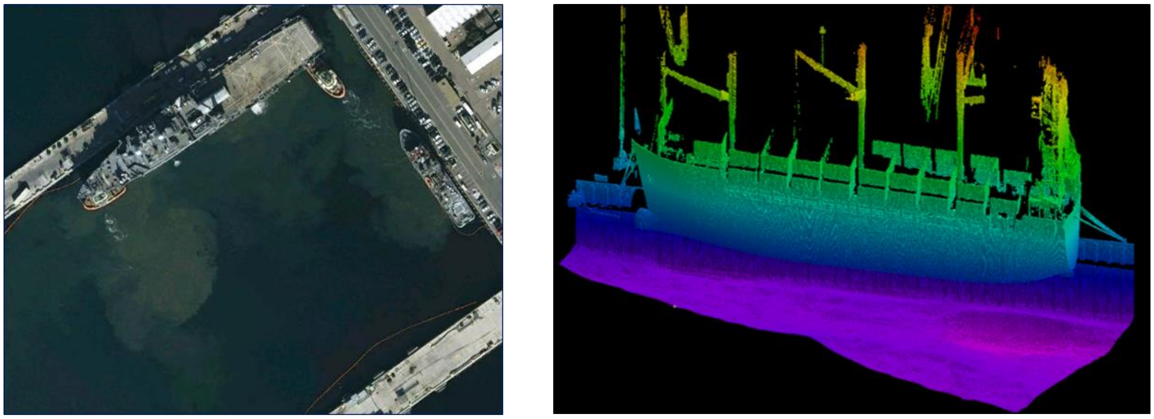


Figure 4-33. Aerial photo of tugboats docking a ship at Naval Base San Diego and a LIDAR picture of a ship at 10th Ave. Terminal in San Diego showing a divot in the sediments related to prop disturbance.

4.7.3 B18-10082: North San Diego Bay in the Marina Stratum

This station was located within the inner portion of Shelter Island Yacht Basin and within a slip channel. Following the SQO approach, the benthic community was considered to have moderate disturbance, chemical concentrations classified the site as having moderate exposure potential, and the sediment showed low toxicity (non-toxic using the amphipod survival test, but moderate toxicity using the bivalve embryo development test). The benthic community was classified as reference by the IBI and low disturbance by the RBI, and none of the benthic LOEs classified it with high disturbance. Infaunal taxa richness was moderate with 25 taxa (five sensitive taxa) and of the 20.9 reference taxa expected by RIVPACS, 11 were observed. The benthic community was dominated by the pollution tolerant *Pseudopolydora paucibranchiata* (71.2% of the community). There was low chemical exposure potential according to the CSI, with copper, lead, and zinc weighted the strongest. Pesticides and PAH concentrations were all within the minimal and low categories of the CSI. Based on the LRM approach, chemicals in the sediment at this location were considered to have moderate exposure potential driven by zinc and copper.

This site has very similar characteristics as Site B18-10072 in Oceanside Harbor, located in the inner portion of an enclosed marina with limited flushing. Impact to benthic communities is not unexpected at this location in the Shelter Island Yacht Basin and appears likely to be associated with elevated chemistry concentrations, particularly copper and zinc from ongoing sources such as antifouling paint and in-water hull cleaning, hydrodynamics (limited circulation), and possibly physical disturbance due to prop wash. Moderate toxicity exhibited by the bivalve embryo test indicates bioavailability of chemical constituents at this site and was a primary factor driving the final category score to be likely impacted. These results indicate that the final integrated SQO category of “likely impacted” appears to be appropriate for this site.

4.8 Evaluation of Additional Sites Classified as Possibly Impacted with High Benthic Disturbance

There were also three stations with final SQO classifications of possibly impacted that had benthic communities that were classified with high disturbance. These included B18-10080 and B18-10084 in north San Diego Bay in the marina stratum and B18-10200 in south San Diego Bay in the freshwater-influenced stratum. A description of these sites and possible stressors for the benthic communities are provided below, and site locations are shown in Figure 4-34.

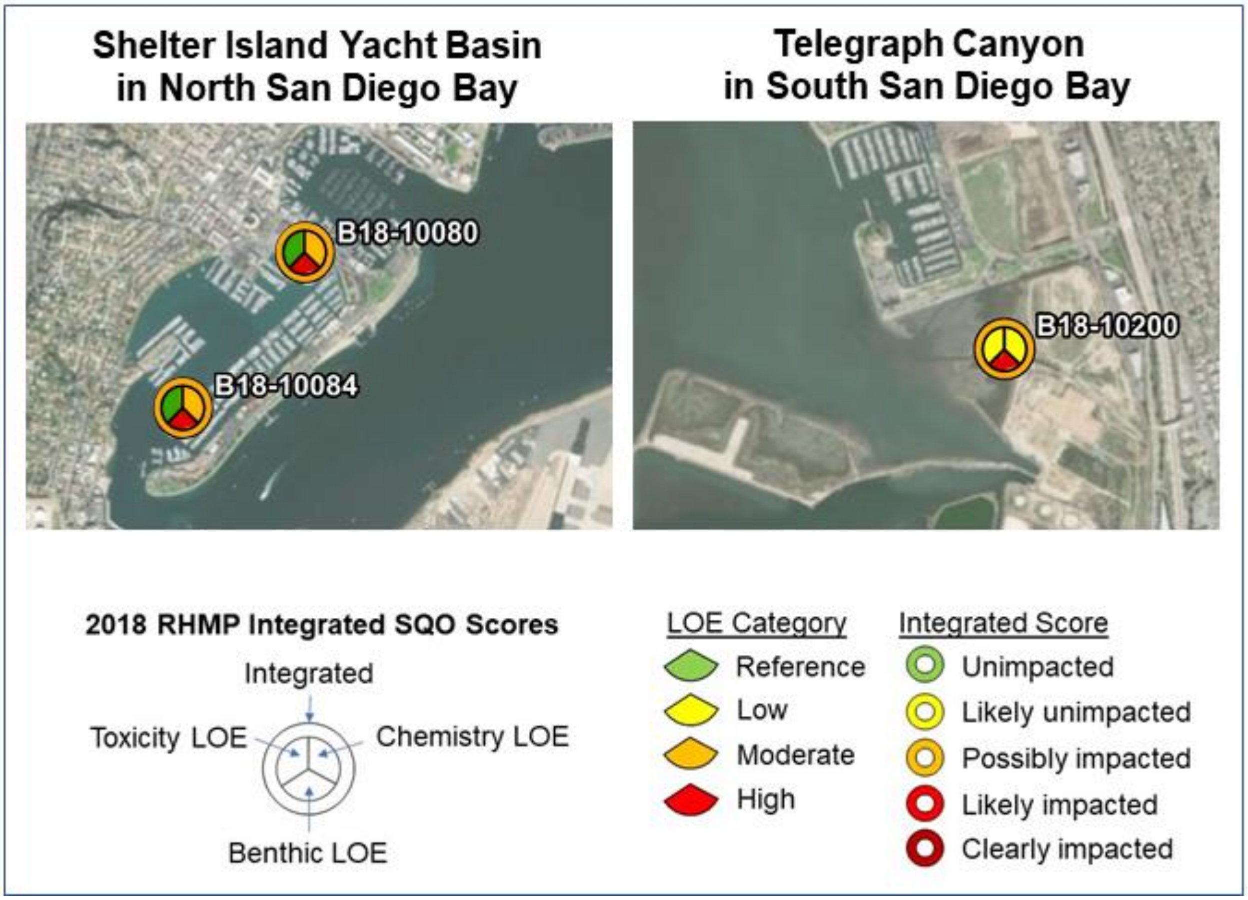


Figure 4-34. Locations of the RHMP Sampling Stations with High Benthic Disturbance and Classified as "Possibly Impacted" Using Final Integrated SQO Approach

4.8.1 B18-10080: North San Diego Bay in the Marina Stratum

This station was located in the inner area of SIYB adjacent to boat slips and likely with habitat conditions very similar to Station B18-10082 in the same basin (63% and 55% fines, respectively). Three of the four benthic LOEs classified the benthic community at this site as having high disturbance except for the BRI, which classified it as having low disturbance. Infaunal taxa richness was relatively low with 13 taxa (one sensitive taxon) and of the 21.3 reference taxa expected by RIVPACS, only 4 were observed. The chemistry LOE indicated high exposure potential using the LRM and low exposure potential using the CSI. Concentrations of metals were all elevated at this station relative to that observed nearby at Station B18-10082, while PAHs and pesticides were similar, and the CSI gave the most weight to copper, zinc, and lead. Based on the LRM approach, chemicals in the sediment at this location were considered to have high exposure potential driven by zinc, mercury, and copper. As with the other two marina sites described above, benthic community impairment at this location appears likely to be associated with elevated chemistry concentrations, particularly copper and zinc from ongoing sources such as antifouling paint and in-water hull cleaning, hydrodynamics (limited circulation), and possibly physical disturbance as well due to prop wash.

4.8.2 B18-10084: North San Diego Bay in the Marina Stratum

This station was located in the outer area of SIYB, adjacent to, but outside of the boat slips. Three of the four benthic LOEs classified the benthic community with high disturbance except for the BRI, which classified it as reference. Infaunal taxa richness was low with 6 taxa (one sensitive taxon) and of the 21.3 reference taxa expected by RIVPACS, only 1 was observed. Total abundance was very low, with 28 individuals, compared to abundance at Stations B18-10080 and B18-10082 in the same basin with 431 and 653 individuals, respectively. The chemistry LOE showed moderate exposure potential using the LRM and low exposure potential using the CSI. Concentrations of metals were somewhat elevated, and the CSI gave the most weight to copper, lead, and zinc while PAHs and pesticides were low. Based on the LRM approach, chemicals in the sediment at this location were considered to have moderate exposure potential driven by zinc, copper, and lead.

Similar to the other marina sites described above, benthic community impairment at this location appears likely to be associated with elevated chemistry concentrations and possibly physical disturbance as well due to prop wash. Unlike the other three marina locations described, this site receives substantial flushing due to the proximity near the mouth of Shelter Island Yacht Basin.

4.8.3 B18-10200: South San Diego Bay in the Freshwater-influenced Stratum

This station was in a confined engineered tidal channel (~8 meters wide) between salt evaporation ponds and Chula Vista Bayfront Park and Harbor. The channel receives direct freshwater input from a concrete-lined open storm water conveyance that daylights near the western end of L Street. Using the SQO methodology, the benthic community was classified as having high disturbance, chemistry indicated low exposure potential (the CSI score was minimal and the LRM score was low), and the sediment had low toxicity. Most metals were in the minimal exposure category (only zinc was in the low exposure category) while pesticide concentrations were somewhat elevated. Two of the four benthic LOEs classified the benthic community as having high disturbance, the BRI classified it as moderate disturbance, and the IBI considered the site to have low disturbance. Infaunal taxa richness was low with 10 taxa (two sensitive taxa) and of the 21.8 reference taxa expected by RIVPACS, only 2 were observed. The infaunal taxa present included a high percentage of non-native species (e.g., the amphipods *Grandidierella japonica* and *Monocorophium uenoi*, and the Asian mussel *Musculista senhousia*) that are known to be disturbance tolerant. The location of this station, within a shallow confined channel that receives urban runoff makes it susceptible to physical stressors and the substrate may become exposed on very low tides; field data indicated a water depth of 6.0 feet on a tide of +5.9 feet. These conditions may not match the typical marine estuary Habitat C conditions defined by the SQO, and the sampling station was fairly unique compared to the other San Diego Bay stations. The influence of freshwater alone due to the close proximity to the discharge channel during periods of runoff, combined with the shallow depth and warm temperatures, may also be physical factors affecting benthic communities at this location.

4.9 Demersal Fish and Macroinvertebrate Community

The demersal fish and epibenthic macroinvertebrates captured during the 2018 RHMP appeared healthy, with minimal abnormalities observed. To provide more context and better evaluate the overall health of the biological communities, the following sections include historical comparisons of demersal fish and epibenthic macroinvertebrate communities in the San Diego Regional Harbors using trawl data from the 2008, 2013, and 2018 RHMPs, as well as Bight ’98 and Bight ’03.

4.9.1 Historical Comparisons for Fish Catch

A summary comparison of fish species diversity, biomass, and abundance during the RHMP in 2008, 2013 and 2018 relative to that during Bight ’98 and Bight ’03 is provided in Table 4-14 (Allen et al., 2002 and 2007; Weston, 2010a). The values for Bight ’98 and Bight ’03 were calculated from the same four harbors that were sampled for the RHMP, but with a different number of stations sampled in each survey. Note that many of the trawls performed in 1998, 2003, and 2008 were 5 minutes in duration, while all trawls performed in 2013 and 2018 had a target time of 10 minutes in duration. Catch and diversity data were normalized to a 10-minute duration, as described in the regional Bight Program monitoring reports (Allen et al., 2002 and 2007).

The demersal community health appears to have remained relatively constant over the past 20 years, based on comparisons with prior Bight ’98 and Bight ’03 survey data, as well as with the 2008 and 2013 RHMP data. The fish communities sampled in the 2018 RHMP were similar to those of prior RHMP and Bight Program surveys in terms of the mean number of taxa caught and mean biomass per trawl, whereas the mean abundance was substantially greater in 2018 (Table 4-14, Figure 4-35). This change is most likely driven by large numbers of slough anchovies captured in Mission Bay and central and south San Diego Bay, as well as large numbers of northern anchovies in Dana Point Harbor and north San Diego Bay. Yearly regional monitoring by California Cooperative Oceanic Fisheries Investigations has found consistently high densities of young of the year anchovy in the Southern California Bight starting in 2015, with a significant increase in the abundance of adult northern anchovy in 2018 and 2019 (Thompson et al., 2018, Thompson et al., 2019), similar to the increase in these species observed in the RHMP and other Regional surveys. Trawling offers a snapshot in time of the species that are present in the trawl track and their abundances, but the same sampling station may have quite varied results due to the mobility of demersal organisms. Overall, the diversity, abundance, and biomass recorded in both the 2018 RHMP and historical data sets, along with minimal abnormalities, support the premise that regional harbors are capable of supporting healthy fish assemblages. However, regarding the demersal fish community, there is further evidence of long-term sustained and possibly improved health of local fish species. The current study is well aligned with the long-term trend of decreasing incidences of fish diseases and anomalies in the Bight since the 1970s, when Mearns and Sherwood (1977) reported an anomaly incidence of 5% (Allen et al., 2007) as compared with an incidence of anomalies of 0.6% in the 2008 RHMP, 0.3% in the 2013 RHMP, and less than 0.1% in the 2018 RHMP.

Table 4-14.
Comparison of Fish Diversity, Abundance, and Biomass During the Last Five Regional Bight Surveys of the San Diego Regional Harbors (1998–2018)

RHMP Historical Fish Comparisons					
Species Diversity (Richness)					
Program	**Number of Stations**	**Total Number of Species**	**Range per Trawl**		**Mean Number of Species per Trawl**
			Minimum Number of Species	**Maximum Number of Species**	
Bight '98	21	26	3	15	8
Bight '03	9	17	3	11	6
2008 RHMP	18	43	2	17	9
2013 RHMP	15	33	4	15	9
2018 RHMP	15	32	2	14	7
Abundance					
Program	**Number of Stations**	**Total Abundance**	**Range per Trawl**		**Mean Abundance per Trawl**
			Minimum Abundance	**Maximum Abundance**	
Bight ’98	21	1,340	6	464	60
Bight ’03	9	593	10	215	66
2008 RHMP	18	866	2	130	48
2013 RHMP	15	2,353	6	568	157
2018 RHMP	15	10,950	20	5019	730
Biomass					
Program	**Number of Stations**	**Total Biomass (kg)**	**Range per Trawl (kg)**		**Mean Biomass (kg) per Trawl**
			Minimum Biomass	**Maximum Biomass**	
Bight ’98	21	174	0.4	27	7.2
Bight ’03	9	55.3	1	17	6.1
2008 RHMP	18	101	0.1	16	5.6
2013 RHMP	15	151	0.4	39	10
2018 RHMP	15	96.3	0.5	23	6.4

Notes:
kg = kilogram(s); RHMP = Regional Harbor Monitoring Program
Data collected during all prior efforts were standardized to 10-minute tow times, as described in the Bight '98 report and subsequent reports. All trawls in 2018 were 10-minutes in duration.

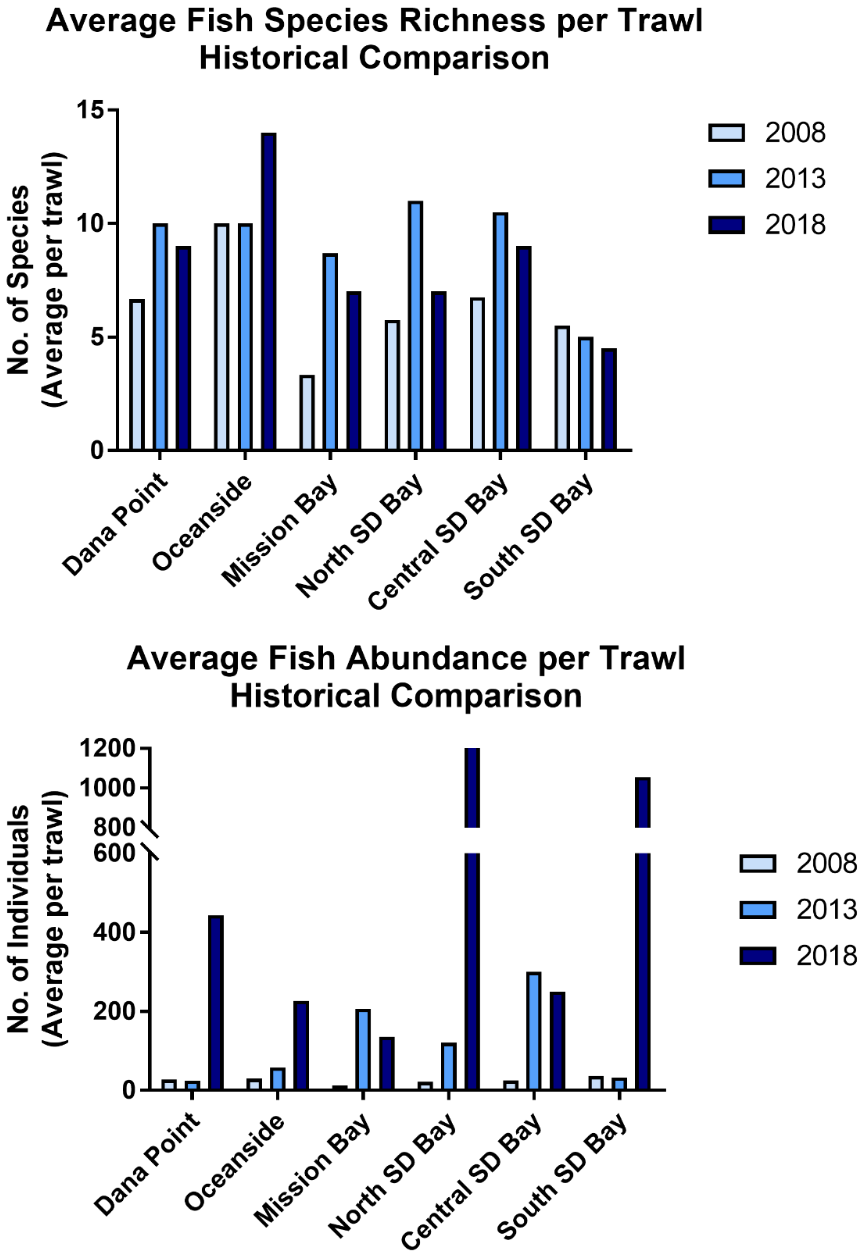


Figure 4-35. Comparison of Fish Taxa Richness and Abundance in the 2008, 2013, and 2018 RHMPs

Data presented for 2008 trawls (which were 5 minutes in duration) were standardized to 10-minute trawl durations. 2013 and 2018 data were standardized to 10-minute trawl durations. Fish species richness data for 2008 were multiplied by 1.4, and fish abundance for 2008 were multiplied by 2.0, following regional Bight Program monitoring guidelines (Allen at al., 2002 and 2007).

Ecological Index for Fish Species in San Diego Bay

Given the number and variety of fish community surveys in San Diego Bay, a more robust historical assessment using the EI is possible for this harbor. Because the EI incorporates frequency of catch, as well as abundance and biomass, this index provides a good measure of what the overall community looks like over time. The EI indicates the relative importance of each species to how energy flows within the food web in each harbor ecosystem (Allen et al., 2002).

A summary of EI results for the last three RHMP efforts (2018, 2013, and 2008) and prior Bight surveys (2003 and 1998) are shown in Table 4-15 for San Diego Bay. While some of the species were only ranked in one survey (e.g., the California scorpionfish in 2018, and California lizardfish in 2013), many of the highly ranked species were common to all five studies. The top six EI scoring fish species in the 2018 RHMP (slough anchovy, spotted sand bass, round stingray, California halibut, bat ray, and barred sand bass) were also in the top 10 in three of the other four surveys (except bat rays and slough anchovy in Bight ’98). This suggests that, overall, species composition in the San Diego Regional Harbors does not appear to be drastically changing at this point in time, despite the warmer temperatures observed in 2018. Continued monitoring of biological communities in the San Diego region will be important to detect any changes in fish communities that may result from larger climatic changes over time (e.g., shifts in species distributions). Recent surveys conducted by the Vantuna Research Group (VRG) in San Diego Bay have noted the increased presence of species that tend to have a more southern distribution, such as the Cortez bonefish (*Albula gilberti*) and longtail goby (*Ctenogobius sagittula*) among 23 others (Williams et al., 2016 and 2019). Such species could be expanding their ranges with the persistence of warmer water.

Table 4-15.
Top 10 Fish Species in San Diego Bay
Based on the Ecological Index and Comparison with Historical Surveys

2018 RHMP **10 Stations** **17 Species**

Species	Percent Total Abundance	Percent Total Biomass	Frequency of Occurance (%)	Ecological Index
Slough Anchovy	94	7.1	40	4052
Spotted Sand Bass	2.2	27	53	1541
Round Stingray	1.3	29	47	1427
California Halibut	0.4	3.8	40	169
Bat Ray	0.1	21	7	142
Barred Sand Bass	0.4	3.1	40	141
Black Croaker	0.1	1.9	33	66
California Scorpionfish	0.1	3.3	13	45
Specklefin Midshipman	0.1	1.6	20	34
California Lizardfish	0.8	0.9	20	33

2013 RHMP **10 Stations** **22 Species**

Species	Percent Total Abundance	Percent Total Biomass	Frequency of Occurance (%)	Ecological Index
Round Stingray	12	57	90	6183
Spotted Sand Bass	3.8	9.2	90	1177
Deepbody Anchovy	21	0.8	50	1092
Slough Anchovy	20	0.2	50	987
California Halibut	2.7	5.0	90	699
Queenfish	21	1.3	30	683
Barred Sand Bass	3.7	2.7	100	639
California Lizardfish	10	3.3	30	408
Bat Ray	0.2	9.9	30	304
Gray Smoothhound	0.6	2.0	50	130

2008 RHMP **10 Stations** **17 Species**

Species	Percent Total Abundance	Percent Total Biomass	Frequency of Occurance (%)	Ecological Index
Spotted Sand Bass	12	23	90	3175.03
Barred Sand Bass	19	8.1	90	2407.19
Round Stingray	13	29	50	2107.99
Yellowfin Croaker	16	15	50	1569.99
Black Croaker	8.1	12	50	1003.08
Slough Anchovy	20	0.1	30	595.64
California Halibut	4.7	1.8	80	518.65
Bat Ray	1.2	5.2	30	191.91
Pacific Seahorse	1.2	0.1	30	37.50
Diamond Turbot	0.8	0.9	20	32.95

2003 Bight **8 Stations** **16 Species**

Species	Percent Total Abundance	Percent Total Biomass	Frequency of Occurance (%)	Ecological Index
Round Stingray	19	46	88	5670
Slough Anchovy	68	1.0	50	3448
Spotted Sand Bass	2.0	9.4	63	711
Bat Ray	0.5	25	25	638
Barred Sand Bass	1.8	6.8	50	426
California Halibut	1.8	3.5	75	392
California Butterfly Ray	0.8	1.7	25	62
Black Croaker	0.8	1.4	25	54
Spotted Turbot	1.3	1.4	13	33
Diamond Turbot	0.5	0.7	25	30

1998 Bight **17 Stations** **16 Species**

Species	Percent Total Abundance	Percent Total Biomass	Frequency of Occurance (%)	Ecological Index
Round Stingray	28	33	71	4292
Spotted Sand Bass	17	22	88	3397
Barred Sand Bass	13	6.0	88	1715
California Halibut	13	6.6	76	1494
Spotted Turbot	5.7	1.5	47	338
Black Croaker	3.6	4.5	41	334
Diamond Turbot	3.4	2.8	47	288
Diamond Stingray	0.5	14	12	169
Specklefin Midshipman	2.6	2.5	18	89
California Tonguefish	4.7	0.1	18	84

Notes:
The four species captured in all 5 surveys are color coded to help visualize changes in patterns among surveys. Total number of stations and total fish species captured during each survey is noted at top-right of each table.

4.9.2 Historical Comparison for Macroinvertebrate Populations

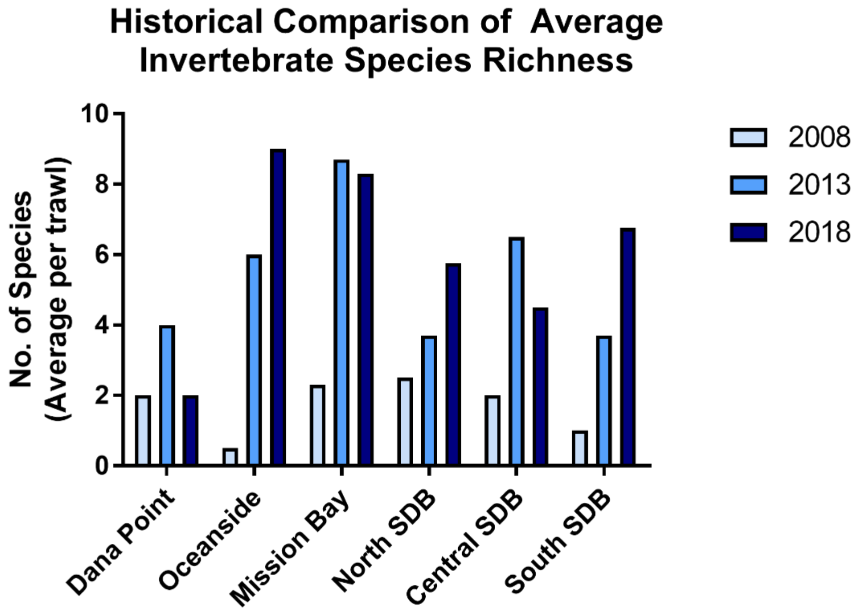
A summary comparison of macroinvertebrate species, diversity, biomass, and abundance during the 2008, 2013, and 2018 RHMPs relative to data from the same four harbors during Bight ’98 and Bight ’03 is provided in Table 4-16. Catch and diversity data were normalized to a 10-minute duration, as described above.

As with fish, the epibenthic macroinvertebrates collected appeared healthy, based on the absence of abnormalities or obvious disease; however, total abundance and biomass of invertebrates, as well as average abundance and biomass per trawl, have varied greatly throughout the historical data collection. Average species diversity, however, has been relatively similar among all surveys between 1998 and 2018. For individual harbors, average species richness per trawl has generally increased since the 2008 RHMP, while average abundance per trawl has been more variable (Figure 4-36). Based on this evidence alone, it is unclear whether there is a trend of decreasing invertebrate abundance and/or biomass, or whether any such differences are due to natural inter-annual variability or directly related to the substrate of the sampling station.

Table 4-16.
Comparison of Macroinvertebrate Diversity, Abundance, and Biomass During the Last Five Regional Bight Surveys of the San Diego Regional Harbors (1998–2018)

RHMP Historical Invertebrate Comparisons					
Species Diversity (Richness)					
Program	**Number of Stations**	**Total Number of Species**	**Range per Trawl**		**Mean Number per Trawl**
			Minimum Number of Species	**Maximum Number of Species**	
Bight '98	21	49	1	18	7
Bight '03	9	29	0	14	6
2008 RHMP	18	44	0	8	5
2013 RHMP	15	40	3	15	6
2018 RHMP	15	47	2	13	6
Abundance					
Program	**Number of Stations**	**Total Abundance**	**Range per Trawl**		**Mean Number per Trawl**
			Minimum Abundance	**Maximum Abundance**	
Bight '98	21	2379	4	772	110
Bight '03	9	2948	0	1950	327
2008 RHMP	18	998	0	468	55
2013 RHMP	15	497	6	95	33
2018 RHMP	15	943	2	674	63
Biomass					
Program	**Number of Stations**	**Total Biomass (kg)**	**Range per Trawl (kg)**		**Mean Biomass (kg) per Trawl**
			Minimum Biomass	**Maximum Biomass**	
Bight '98	21	263	<0.1	125	11.5
Bight '03	9	39	0	20.6	4.3
2008 RHMP	18	148	0	93.6	8.2
2013 RHMP	15	27.4	0.5	4.7	1.8
2018 RHMP	15	35.1	0.2	8.4	2.3

Notes:
Data collected during all prior efforts were standardized to 10-minute tow times, as described in the Bight '98 report and subsequent reports. All trawls in 2018 were 10-minutes in duration.



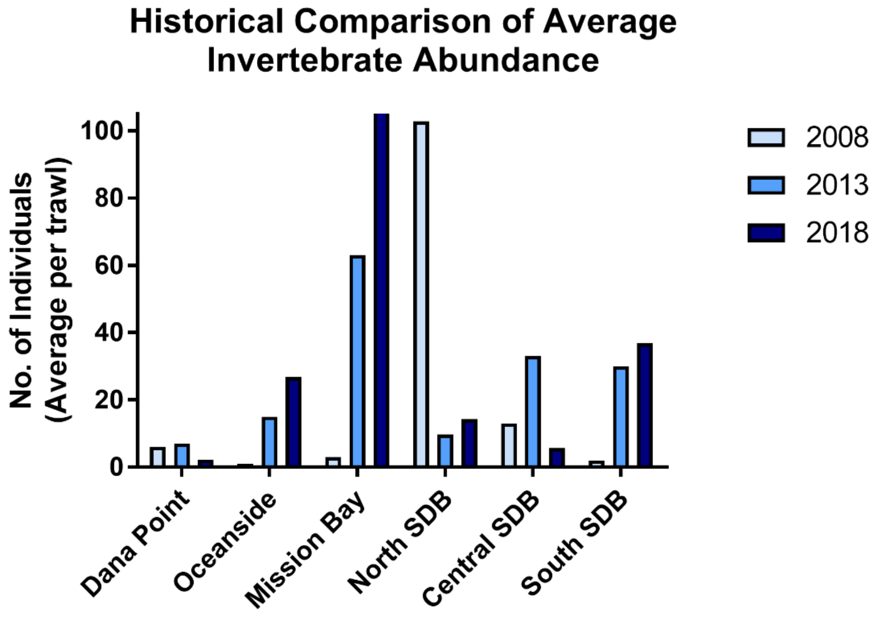


Figure 4-36. Comparison of Epibenthic Invertebrate Species Richness and Abundance During the 2008, 2013, and 2018 RHMP

Note: Data for trawls were standardized to 10-minute trawl durations. Invertebrate species richness data for 2008 were multiplied by 1.4, and invertebrate abundance data for 2008 were multiplied by 2.0, following regional Bight Program monitoring guidelines (Allen at al., 2002).

4.10 Assessment of Spatial and Temporal Variability Regarding Data Interpretation

Many areas within the regional harbors may contain contaminants from past anthropogenic activity or may be subjected to pollution from on-going sources. Although changes in sediment chemistry may be a function of time, they also may reflect spatial changes that may occur at any given site based on transport mechanisms of sediments in the harbors. For example, changes in loading and the binding of contaminants, dredging of bottom sediments, and seasonal changes in physical-chemical properties in the water column that may influence the exchange of metals at the sediment-water interface have all been recognized to be factors affecting temporal and spatial variation in contaminant concentrations and bioavailability (Valdes et al., 2009). Currents, tides, and prop wash are also local factors known to alter the distribution of sediments and associated chemical concentrations (Katz and Blake, 2005). The documented spatial and temporal variability in bays and harbors can result in lower statistical power to detect change when evaluating trends in such habitats.

Small-scale spatial variability was observed visually in the field during sampling efforts, and in the resulting data from the RHMP efforts, where in some cases, stations very close to one another had very different physical, chemical, and/or biological characteristics (e.g., three stations near the mouth of Chollas Creek had highly variable LOE and integrated SQO scores). Visually different substrates, in addition to the variable presence of epibenthic macroalgae, eelgrass, and burrows, were noted at many stations.

Temporal variability that may occur on short time scales is hard to discern without more focused studies. Seasonal or annual changes in climatic conditions such as temperature and precipitation (and associated storm water inputs), and impacts related to physical disturbance such as dredging or propeller wash, are all short-term impacts that cannot be accurately assessed with a sampling program that occurs every five years. Drawing conclusions and ignoring such variability may result in misunderstanding processes occurring within a certain sampling area and must be considered when determining management options for areas deemed impaired. However, as data continues to be collected in a consistent manner, long-term trends in climatic conditions will likely become more obvious.

For example, wetlands have been found to store total mercury from historical anthropogenic influences due to their fine-grained and organic-rich sediments (Ullrich et al., 2001; Spencer et al., 2006). Several physical factors may be occurring in the harbors that also account for spatial variability observed within the data. Tidal inundation as well as cycles of wetting and drying in the shallow stratum, physical sediment reworking by currents, bioturbation, and anoxia in areas of low flow or tidal exchange are all factors that may contribute to variability observed across harbors and strata (Marvin-DiPasquale and Cox, 2007; Laverock et al., 2011). Propeller-induced turbulence from boating activity has also been linked to disturbances such as sediment erosion and the exposure and remobilization of contaminated sediments from the substrate (Lepland et al., 2010). Bioturbation can be carried out by an array of organisms, including polychaete worms, crustaceans, benthic mollusks and echinoderms, fish, rays, and both infaunal and meiofaunal communities (Meysman et al., 2006). Further, bioturbated sediment has been found to increase fluxes of oxygen, total carbon dioxide, and dissolved inorganic nitrogen 2.5 to 3.5 times across the sediment/water interface when compared to non-bioturbated sediment (Laverock et al., 2011). Each harbor in the monitoring program experiences a variety of the aforementioned disturbances on a daily basis. Many cases of spatial variability at the sediment surface were also observed during the 2013 RHMP and again in 2018, as shown in the photographs below. Within a single sampling area, variability in algal or eelgrass cover versus bare substrate, exposed versus inundated substrate, bioturbation via bat ray pits and infaunal activity, as well as spatial variation within a single grab were all observed during both the 2013 RHMP and 2018 sampling efforts.

These inconsistent attributes can have a substantial influence on sediment chemical and physical properties and associated benthic communities.

The likelihood and potential ramifications of spatial and temporal variability must always be considered carefully when assessing conditions at any single location.

Photographs from 2013 and 2018 RHMP showing large-scale and micro-scale spatial variability of sediments in the San Diego Regional Harbors: view of bat ray pit also showing surface macroalgae and the upper edge of an eelgrass bed algal patches intermixed with bare substrate in the shallow stratum near Sites B18-10015 and 10017 (Mission Bay) (top left); aerial view of Mission Bay showing patchy eelgrass beds (top right); noticeable spatial variability in appearance (color, texture, and algae) on the surface of a grab samples (middle); comparison of noticeably different sediment types from a single side-by-side grab sample (south San Diego Bay, Coronado Cays) (bottom left); vertical micro spatial variation in a single grab showing the oxic brown layer over the darker anoxic sediment (bottom right).

4.11 Special Considerations Related to Data Comparison Among Harbors

In addition to physical differences that may result in variation among harbor conditions, it is also important to recognize that smaller sample sizes from smaller harbors, as well as the composition of strata sampled in each harbor, may also skew overall results. Further, in terms of the demersal community, ecosystem health is often measured in terms of biodiversity metrics. Although a more diverse demersal community may indicate a healthy harbor, it does not take into consideration the effect of habitat type on such metrics. For example, at one shallow station in Mission Bay with the presence of eelgrass in the vicinity (B18-10016) a total of 10 different fish species were captured including several known to be strongly associated with eelgrass habitats such as the Pacific seahorse and kelp bass. Likewise, the single trawl with the greatest fish diversity including 14 species (Site B18-10071 in Oceanside Harbor) was located near a rip-rap jetty and included fish species such as the gopher rockfish and black surf perch which are commonly associated with hard structure habitats along with a variety of fish such as diamond turbot and California halibut associated with the soft bottom habitats targeted by the trawl (Kells et al., 2016 and Love, 2011). Therefore, while it might appear that greater diversity of demersal organisms may be a direct result of overall sediment quality, it may actually be more likely a direct result of habitat diversity.

4.12 Data Interpretation Limitations and Considerations

The RHMP provides a complete and detailed assessment of sediment quality and benthic communities in the San Diego region. The information provided by this program may be leveraged with other efforts to further assess conditions at individual sites or across the region, and provides a valuable data resource to further assess changes that may be related to remedial activities, natural attenuation, or effects due to climate change. As indicated throughout this report there are limitations and caveats that are important to consider when drawing conclusions based on the data presented herein, or when combining with other supporting data. Key identified data limitations and considerations are presented below.

- The RHMP sampling methodology offers a “snapshot” in time of conditions of the harbors; it does not assess changes in conditions that may occur on a much shorter time-frame than five years, such as seasonal variability.
- The great diversity of geography and physical habitats, along with physical disturbance, can result in extremely heterogeneous benthic habitats in semi-enclosed bays and harbors, particularly in the shallower regions or areas with significant human activity. This heterogeneity has been clearly observed and noted during sampling efforts for the RHMP. In several cases, samples that were collected relatively close to each other during the RHMP field efforts resulted in substantially different outcomes. Due to the heterogeneity observed in benthic habitats at some locations, trend analyses need to consider the effects of spatial variation. There will be greater confidence for those areas that have a more uniform habitat than those areas with frequent disturbance or varied substrate, as well as those sites that show consistent results over time.
- The integrated SQO approach for assessment of direct effects on biological communities uses three LOEs to provide a robust assessment of surface sediment conditions; however, two limitations of this approach as described by Bay et al. (2014) include the following: (1) the analysis does not identify specific chemicals causing impacts; and (2) This approach assesses only direct impacts on sediment biota and does not address the impacts on human health or wildlife through bioaccumulation and/or biomagnification of contaminants in fish and shellfish.

  - Site-specific studies will be required to tease out specific chemicals or other stressors of concern affecting biological communities, although a preliminary assessment is possible with the current SQO data, as shown in Sections 4.7 and 4.8 of this report for a few RHMP sites.
  - Impacts on human health and wildlife are currently being addressed separately through the coordinated efforts described in Section 1.2 that will be reported under separate cover. Assessment of sediment quality impacts on human health in the future are to be addressed in the State of California using the Phase 2 SQO indirect effects approach as described in the SWRCB Sediment Quality Provisions in the State of California *Water Quality Control Plan for Enclosed Bays and Estuaries–Part 1, Sediment Quality*; State Water Board Resolution No. 2018-0028.These provisions will be incorporated into the new Water Quality Control Plan for Inland Surface Waters and Enclosed Bays and Estuaries Plan (ISWEBE) when it is adopted. The methods to assess tissue contaminants in fish employed for the RHMP in 2018 and previously in 2013 were consistent with these provisions. https://www.waterboards.ca.gov/water_issues/programs/bptcp/sediment.html.

    Development of a revised SQO technical support manual is in progress at this time that will include Phase 2 indirect effects methods for assessment of human health, in addition to the existing Phase 1 direct effects methods for assessment of biological communities (Bay et al., in prep).

- Where impaired benthic communities are observed, careful consideration must be given to physical characteristics and/or non-anthropogenic disturbance that may affect the stability of the communities (e.g., temperature, rainfall, invasive species), as well as a careful look at anthropogenic sources.

- Sediments collected during ambient summer conditions do reflect cumulative impacts over time; however, any small-scale changes that might occur throughout the year that may affect chemical contaminant distributions, potential toxicity, and benthic community structure (e.g., during wet weather conditions or resuspension events) are not explicitly addressed through the current assessment methodology. This tendency is even more pronounced for water quality, which can vary substantially at any given location depending on localized conditions and activities.

- Measures of benthic fish and invertebrate populations represent only a brief snapshot in space and time. These populations, particularly fish, can vary tremendously both spatially and temporally. In addition, the chosen method of capture is designed to target a very specific habitat type where trawls are possible without interference and will typically exclude larger fish that are quicker to move out of the way. Thus, comparisons with other survey methods or inferences on total fish and invertebrate populations must be made with caution. When taken as a whole, region-wide, these data provide a valuable assessment, but conclusions on observations, particularly on a smaller scale, must be clarified with these caveats noted.

- During preparation of the 2013 report, it was noted that the 2008 RHMP report had discrepancies in the benthic index calculations (particularly the BRI) from those reported previously. An investigation found that the BRI condition scores reported in the 2008 RHMP report were biased low overall, which indicates healthier conditions. A re-analysis of a subset of these data confirmed these discrepancies. Despite these discrepancies, other metrics such as the number of taxa present, diversity, and the other SQO metrics generally correlated well over time with the BRI so the overall impact with regard to interpretation of trends related to the calculation discrepancies is likely minimal.

- Method detection limits have varied for some chemicals over time with lower limits currently than that in prior surveys. This difference can influence final reported totals when all analytes for a particular class of chemicals are non-detect, and so must be caveated when making trend comparisons over time for these constituents. This limitation primarily affects those chemical classes with a frequent number of non-detects (e.g., chlordanes).
- As indicated throughout the report, a subset of the total 209 PCB congeners was measured and used for the SQO analysis and additional supporting analyses. For the future, it is recommended that all 209 congeners be measured to capture the full dataset.
- It should also be noted that despite generally consistent methods and sampling equipment, some of the sampling designs and goals of the various studies used to develop historical datasets prior to 1998 varied from the randomized approach used for RHMP and Bight Program. In particular, some of these studies included targeted designs focused on identifying conditions at potential hot spots or site-specific characterization programs.

These limitations in no way reflect deficiencies in the RHMP, but rather are brought forth to help with considerations or caveats that may be required when citing or using the data presented herein for other assessment purposes.

5.0 QA/QC SUMMARY

QA/QC extended throughout each stage of the RHMP-related efforts. The overall QA/QC process employed by the RHMP is summarized in Section 2.6, with a more detailed summary of the complete data QA/QC process (encompassing a review of raw data, data processing and analysis, and reporting activities) provided in the accompanying QAPP for the RHMP (Wood, 2018b).

All data reported herein have undergone the QA/QC process described in the project-specific QAPP for the RHMP and have been considered acceptable for reporting and analysis. In addition, all methodologies and reported data have passed Bight ’18-specific requirements that have been undergoing an independent QA/QC review process through this coordinated program. One extra step required by the RHMP was a Level II internal review of 100% of the analytical chemistry data, as well as a third-party Level IV validation of 10% of the analytical chemistry data associated with the RHMP. Level II and IV validation of chemistry data was performed by LDC. The third-party validation report by LDC and a summary of all qualifiers identified are summarized in tables and are provided in Appendix L. Additional pertinent QA/QC information for all data collection activities is summarized below.

5.1 Field Activities

All field-related activities met QA/QC requirements as set for forth in the project-specific QAPP for RHMP (Wood, 2018b) and the regional Bight monitoring methods outlined in the *Bight ’18 QA Manual* (SCCWRP, 2018b). Requirements included the calibration and collection of data from the CTD and portable field meters used to measure field water quality parameters, field sample documentation, electronic capture of data, vessel positioning, and collection of sediment samples, all within a 100-meter radius of the target locations (with the exception of Stations B18-10179, B18-10015, and B18-10043, as discussed in Section 2.1.2), and all trawl-related activities. Additional details related to QA/QC efforts for the trawling activities are highlighted further below, given the extensive steps and protocols for this effort.

5.1.1 Trawl QA/QC

The quality of fish and invertebrate identification, enumeration, biomass, and length were ensured through pre-survey training, inter-calibration, and in-survey and post-survey audits. Lead Invertebrate and Fish Scientists from Wood reviewed standard sampling procedures prior to field collection. During each survey, the Cruise Leader checked scale calibrations at the start of each day, confirmed that appropriate identification aids and processing equipment were on board, and verified that processing followed the protocol described in the *Bight ’18 Field Operations Manual* (SCCWRP, 2018c). In addition, the Cruise Leader re-weighed and re-measured four species (two fish and two invertebrates, each with at least ten individuals) for 10% of trawls (if ten individuals were not captured, 2 of each were selected). These internal QA/QC checks were detailed in the *Bight ’18 Field Manual*. External Field QA/QC Auditors also conducted one in-survey visit during trawl sampling using the same methods that the Cruise Leader used daily. Completeness objectives for fish and invertebrate counts and weights and fish lengths were 90%, and precision objectives for counts, weights, and lengths were 10%, all of which were met for the RHMP (100% complete).

Accurate taxonomic identification of demersal fish and invertebrate species was ensured by pre-survey training and inter-calibration, in-survey audits, and post-survey voucher checks. Pre-survey QA activities included a taxonomic information transfer meeting, an in-field training/inter-calibration exercise, and an inter-calibration exercise assessing fish and invertebrate identification abilities. To be recognized as Bight ’18 taxonomists, Wood biologists identified specimens of representative fish and invertebrate species in buckets that were given as a test by SCCWRP, where a passing score was required to conduct surveys in the field. A project-assigned taxonomist audited taxonomic identifications in the field during one sampling day of the program. At least one voucher specimen of each species identified in the field was kept and used for taxonomic validation by SCAMIT and Southern California Association of Ichthyological Taxonomists and Ecologists (SCAITE) taxonomists.

The SCAMIT cooperated with Bight ’18 agencies to provide an important element of QA for taxonomic identification. The taxonomic nomenclature used in Bight ’18 followed A Taxonomic Listing of Soft Bottom Macro- and Mega-invertebrates from Infaunal and Epibenthic Monitoring Programs in the Southern California Bight, Edition 18 (SCAMIT, 2018). This list represents a consensus for standard usage of taxa names in publicly owned treatment work (POTW) monitoring programs in the Southern California Bight. In addition, SCAMIT protocols for the use of open nomenclature (SCAMIT, 1986) were followed. Wood taxonomists participated in special SCAMIT/Bight ’18 workshops prior to and after the sampling period that focused on the taxonomy of certain groups to promote uniform identification. The workshops provided training, pooling of regional resources, and local experts to be called upon for assistance during sample analysis. SCAMIT/Bight ’18 continued monthly post-sampling meetings to address taxonomic problems arising during the analysis of the Bight ’18 samples. A synoptic data review of the data set was compiled from all participating Bight ’18 agencies and was conducted to ensure maximum QA/QC efforts for the entire data set.

5.2 Analytical Chemistry

5.2.1 Introduction and Background – Data Review and Validation Summary

As part of the RHMP effort, 75 sediment and 75 surface water samples were collected, in addition to three replicate samples and one equipment blank each for the Niskin bottle and TVV grab sampler. Samples were collected between July 10 and September 12, 2018. Wood submitted the samples for chemical analyses to the primary contract laboratory, Physis, located in Anaheim, California.

Samples were collected in accordance with the approved Work Plan (Wood, 2018a) as submitted to the lead agency, the Port of San Diego. Physis divided and assigned these samples into 19 sample delivery groups (SDGs). Samples were analyzed as described in Section 2.4, and the resultant data were reviewed against data quality objectives (DQOs) as detailed in the project QAPP (dated June 2018, and revised June 2019). Project DQOs were developed using SWAMP criteria where applicable and were consistent with the previous RHMP studies (Weston, 2005a and 2010a, Amec Foster Wheeler, 2016), and related regional monitoring efforts, including Bight ’18, managed by SCCWRP. Access to the results from multiple studies will be leveraged by upload by SCCWRP into a common California Environmental Data Exchange Network (CEDEN) database.

5.2.2 Test Methods

In accordance with the RHMP 2018 Work Plan and QAPP as summarized in Tables 2-3 and 2-4 in the Methods Section, Physis analyzed the surface water samples using the following analytical methods: ammonia by SM 4500-NH3 D, barium by USEPA Method 200.8, trace metals by USEPA Method 1640, mercury by USEPA Method 245.7, MBAS by SM 5540 C, nitrate by SM 4500-NO3 E, oil and grease by USEPA Method 1664B, total and dissolved organic carbon by SM 5310 B, total orthophosphate by SM 4500-P E, PAHs by USEPA Method 625, and TSS by SM 2540 D. Physis analyzed the sediment samples for grain-size distribution by SM 2560 D, percent solids by SM2540 B, AVS by the Plumb 1981 method and SEM by USEPA Method 200.8; ammonia by SM 4500-NH3 D; total nitrogen and TOC by USEPA Method 9060, trace metals and total phosphorus by USEPA Method 6020; mercury by USEPA Method 245.7; and chlorinated pesticides, fipronil and degradates, PBDEs, PCB congeners, PAHs, and pyrethroid pesticides by USEPA Method 8270D.

5.2.3 Data Validation Methodology

Results for all 75 water and sediment samples were subjected to a full Tier II data validation by LDC consistent with USEPA Region 9 protocols to evaluate the usability of the data. The Tier II validation includes a review of the QC results in the laboratory's analytical report and reported on QC summary forms relative to project DQOs. Furthermore, three SDGs, one for water, one for tissues, and one for sediments, were submitted to LDC for a full Level IV validation equating to 10% of the total number of samples analyzed. Level IV review includes all Tier II validation parameters plus validation of initial and continuing calibration verification, tuning and performance checks, surrogate recoveries, and corresponding QA/QC samples. Physis supplied Level IV data deliverables for three SDGs (1807003-008, 1807003-007, and 1807003-021 sediment, waters, and tissues, respectively), which were subjected to full Level IV validation. Note that validation of the tissue data occurred at this time but will be reported under separate cover. This data validation has been performed in general accordance with the following protocols:

- SCCWRP. 2018b. *Quality Assurance (QA) Manual*, Southern California Bight 2018 Regional Marine Monitoring Survey (Bight '18). June 2018.
- USEPA. 2001. Region 9 Superfund Data Evaluation/Validation Guidance, Version 1, R9QA/006.1, December.
- USEPA. 2010. Contract Laboratory Program (CLP) National Functional Guidelines for Inorganic Superfund Data Review, EPA-540-R-013-001. January 2010.
- USEPA. 2008. CLP National Functional Guidelines for Superfund Organic Methods Data Review, EPA-540-R-014-002. June 2008
- USEPA. 1992–2004. SW 846, Third Edition, Test Methods for Evaluating Solid Waste, update 1, July 1992; update IIA, August 1993; update II, September 1994; update IiB, January 1995; update III, December 1996; update IIIA, April 1998; IIIB, November 2004; Update IV, February 20.

The USEPA CLP guidelines listed above were written specifically for the CLP and have been modified for the purposes of these data reviews where they differ from method-specific QC requirements.

5.2.4 Data Quality Objectives

DQOs are defined in the RHMP project-specific QAPP and summarized in Table 7-3 for seawater samples and Table 7-4 for sediments within the QAPP. Accuracy was based on the acceptance of laboratory-derived performance-based control limits (±3 standard deviations). Precision limits for laboratory duplicates and matrix spike (MS)/matrix spike duplicate (MSD) pairs are 25% for both sediments and seawater. A default completeness goal of 90% was used, citing no corresponding SWAMP requirement. Because a full Tier II data validation was performed on all samples and a Level IV data validation on 10% of the data, this summary aims to highlight the overall results of both validations and the data usability and is not a comprehensive review of all data qualifications.

5.2.5 Data Usability

Rejected Data

A rejected ("R-flagged") result is typically due to a significant nonconformance, and the affected data are rendered as unusable. The Tier II validation performed by LDC in addition to the Level IV validation performed by LDC R-qualified and initially rejected 61 (0.5%) individual data points for sediments. The specific constituents included: Endosulfan1 (n=58 for low laboratory control sample (LCS)/laboratory control sample duplicate (LCSD) recoveries, n=1 low MS/MSD recovery) and total nitrogen (n=2 for missed holding times for sediments). However, the data for endosufan1 have been retained in the project database with a flag because this compound, as well as endosulfan2 and its oxidized product endosulfan sulfate, is uncommonly detected in current regional sediment samples. No detections in either of the endosulfan isomers or endosulfan sulfate were detected in the 2013 RHMP. This finding suggests that the lack of endosulfan compounds detected in samples from the 2018 RHMP is not anomalous. In addition, endosulfan1 is not a Bight '18 listed constituent. Two total nitrogen data points with concentrations below detection (samples B18-10116 and its field replicate, B18-20116) were rejected due to out of conformance holding time. All other samples analyzed with this batch had detected concentrations of nitrogen and were flagged as estimated but considered acceptable for reporting.

The Level II validation of seawater identified n=78 (75 field and three field replicates) R-flagged samples for exceeded holding times for nitrate and n=77 samples for orthophosphate for exceeded holding times. For these two general chemistry constituents, the 48-hour holding time was a known time constraint. Therefore, samples were preserved in sulfuric acid (H_2SO_4) and stored at -20°C after sample collection to inhibit the loss of nitrogen and phosphate until preparation for analysis. These Level II rejected compounds were not included in any of the results or analyses highlighted in the RHMP report for 2013 or the prior 2008 RHMP survey.

It is recommended that R-flagged data be excluded from modeling inputs and that data users consider potential bias associated with the use of these results on a constituent-specific basis for each of the root causes identified above. The data are appropriately flagged to indicate potential bias, and a complete description of validation qualifiers, and their application is provided in the level IV validation report.

The remaining results are considered fully usable with the addition of the qualifiers specified in this report. Based on data usability, the calculated completeness is 99.5%, well above the 90% project goal.

Total Versus Dissolved Trace Metals

The total metals concentration should exceed the dissolved concentrations by a relatively consistent percentage in ambient clear marine waters. Copper and zinc were primary trace metals of interest based on past data in addition to observed current and past WQO exceedances for copper, thus results for these two metals are highlighted for this QA/QC assessment.

A comparison of total and dissolved copper across all samples collected is graphically shown for reference in Appendix F. Total copper exceeded the dissolved fraction by 0.3% to 90% across most samples. However, in 13% of samples (n=10), dissolved copper concentrations exceeded the total fraction by a range of 4% to 52%. The greatest discrepancies were generally observed in samples with total copper concentrations below 5 µg/L. A similar consistent trend with total concentrations exceeding or near dissolved concentrations was observed for all other trace metals measured.

As with copper, a consistent pattern was observed among all samples, with total zinc generally exceeding the dissolved fraction, ranging from 0% to 68% across all samples. In sixteen of the samples (approximately 20%), dissolved concentrations exceeded the total fraction by 2 to 170%. The greatest differences were typically associated with concentrations of zinc below 10 µg/L.

These data were all considered acceptable for reporting purposes given the overall consistent relationship between dissolved and total fractions across samples, and differences where the dissolved fraction exceeded total that were predominantly within the range of analytical variability at the low concentrations measured.

Estimated Data

Both the Tier II and Level IV validation identified some method protocol exceptions that warranted an estimated (“J-flagged”) validation qualifier. Based on the validation comments, additional efforts were made to (1) understand the technical rationale for the assigned validation qualifiers, and (2) evaluate the laboratories’ methodologies to ensure that project DQOs were met to confirm data usability. This section describes the performance-based measurement system (PBMS) and the validation rationale for assigning data as estimated.

Performance-based testing is used to quantify actual method performance and any method modifications to “standard” USEPA SW 846 methods to achieve lower detection limits, minimize sample interferences and enhance accuracy and precision by measuring statistically derived control limits applicable to a given matrix. This performance-based approach is USEPA preferred and is particularly appropriate for difficult matrices and low detection limits and is compatible with SWAMP guidelines that provide the basis for this QA/QC program.

To arrive at the PBMS used in this project, the primary laboratory has made several method modifications for low-level testing of sediments, seawater, and tissues. In addition, the laboratory uses instrument-specific software for tuning of gas chromatograph (GC)/mass spectrophotometer (MS) match to a National Institute for Standards and Technology (NIST) target compound library prior to calibration and sample analysis, and calibrations are performed on a mass basis, not using the concentration-based guidelines provided in USEPA SW 846.

5.2.6 Analytical Laboratory Method Modifications

The following summarizes method modifications provided by Physis

- Because of the longer and narrower GC columns used for GC/MS analyses (to maximize compound separation), the analytical run times are significantly extended. The method prescribes a calibration verification “tuning” solution frequency of every 12 hours. However, the laboratory uses a 20-sample batch limit and analyzed the tuning solution at the beginning, middle, and end of each batch.
- Some target analytes for the GC/MS method were analyzed in negative chemical ionization (NCI) mode. These produce nonstandard mass spectra and cannot be verified to the electron ionization spectra in the NIST library. These include pyrethroids and fiporonils, so PCB112 and PCB198 are used as surrogates for these compounds. These two PCB congeners are used as standards because they are not found in the natural environment.
- The RHMP QAPP was revised in June 2019 to indicate that the nutrient subsample for seawater was frozen to -20°C after being logged at the laboratory in order to preserve the nitrate and orthophosphate from degradation due to the method-specified 48-hour holding time constraint.

A review of the above modifications did not identify any appreciable effect on data usability for this validation.

5.3 Toxicity

All toxicity test QA efforts have been successfully completed, and a final database has been submitted to the SCCWRP web portal and incorporated into a final report prepared by the Bight Toxicology Committee (Parks et al., 2020). All standard protocol QA/QC requirements were met for all data reported for RHMP. Details related to all toxicity QA/QC efforts are included in the project-specific Work Plan for RHMP (Wood, 2018a) and *Bight ’18 Toxicology Laboratory Manual* (SCCWRP, 2018e).

5.4 Infauna

All infauna identification and internal sorting QA has been successfully completed for the RHMP samples, and a final database has been submitted to the SCCWRP web portal. A subset of 10% of the identified infauna samples is currently undergoing taxonomic QC coordinated through the Bight Program. There have some discrepancies noted between taxonomists for a small number of species during this external QC effort managed by the Bight Program that are currently being addressed at the time of this report. Details related to all benthic infauna QA/QC efforts are included in the project-specific Work Plan for RHMP (Wood, 2018a) and *Bight ’18 Laboratory Manual for Benthic Infauna Analysis* (SCCWRP, 2018a). A report of the results for the entire Bight ’18 Program is in progress and will include the data collected through the RHMP. A final report by SCCWRP is anticipated to be ready in 2021.

6.0 CONCLUSION AND RECOMMENDATIONS

The 2018 RHMP core monitoring program uses a multiple line of evidence approach that integrates a suite of water and sediment quality measures with biological community monitoring. The program has been designed to effectively answer a suite of core questions regarding inputs, distribution, and magnitude of pollutants of primary concern, the suitability of the harbor environments to support healthy biota, and long-term trends in environmental conditions of the harbors. Core questions also include whether the waters are safe to swim in and whether fish are safe to eat, both of which have been addressed through efforts reported under separate cover. A summary of conclusions regarding the question of whether the harbors are safe to swim is provided as a stand-alone report in Appendix P. A standalone report addressing the question of whether the fish are safe to eat is in progress and will be published under separate cover.

Consistent with the results from RHMP efforts over the past 10 years, the 2018 RHMP continued to find a majority of the sediments to be of good quality with 72% of all locations considered to be unimpacted or likely unimpacted based on the integrated multiple line-of-evidence SQO approach. However, areas associated with localized anthropogenic inputs of pollutants, most notably the marina and industrial/port strata and, to a limited extent, freshwater-influenced stratum, had conditions that were less suitable for supporting healthy biota relative to other strata, as observed in 2008 and 2013. Benthic fish and macroinvertebrate populations continue to appear healthy throughout the four harbors.

Overall, sediment and water quality conditions have generally improved compared to historical conditions. In particular, concentrations of mercury, HPAHs, and alpha- and gamma-chlordanes in sediments and concentrations of dissolved copper, dissolved nickel, and PAHs in the water column have statistically decreased since 2008 based on a two-tailed t-test (Appendix K), and most stations (89%) sampled in 2018 were also non-toxic. While differences between 2018 and pre-2008 conditions indicate notable changes showing lower chemical concentrations and reduced toxicity, more recent conditions over the previous 5 to 10 years are comparatively more stable with subtle gains in quality overall. Despite these positive trends over time for a number of chemicals and toxicity, a decline in benthic community condition has also been observed over the past 10 years with fewer sites considered to have reference conditions, and an increase in the proportion of stations considered to be moderately or highly disturbed based on multiple individual metrics. Possible causes related to these changes (direct and indirect) may include continued site-specific presence of anthropogenic contamination from legacy and ongoing sources, physical site disturbances, impacts including warmer temperatures, variable annual rainfall patterns, and invasive species. Hypotheses of these potential causes are included in the core RHMP monitoring questions provided below:

1) ***What are the contributions and spatial distributions of inputs of pollutants to the harbors?***

Consistent with prior RHMP monitoring efforts, areas of the harbors most closely associated with human uses (i.e., the marina and industrial/port strata) tended to have elevated chemical concentrations and greater exceedances of chemical thresholds in surface waters and sediments, as compared with areas that were not closely associated with anthropogenic influences (i.e., deep and shallow strata; freshwater-influenced areas had mixed results). The likely impacts for the marina stratum are primarily driven by elevated levels of copper both in the surface waters and sediments, as well as other metals (mercury and zinc) and organics in the sediments. The industrial/port stratum, which is located solely along the eastern shore of San Diego Bay, also had elevated concentrations of metals and organics in sediments.

Contrary to most other chemical concentrations which have remained consistent or decreased over time, the concentrations of pyrethroid pesticides increased in 2018 relative to that observed in 2008 and 2013, with a majority of detections located at sites in the freshwater-influenced strata. Active constituents in flame retardants (PBDEs) also increased from when they were first measured in 2013 to 2018, primarily in freshwater-influenced locations with some detections in the marina and industrial/port strata. The increases for these chemicals may be related to increased runoff from upland sources as a result of above normal precipitation observed in 2017 compared to drought conditions that were experienced prior to the 2008 and 2013 sampling periods. DDTs and PBDEs are both banned chemical classes, but pyrethroid pesticides continue to be used as authorized by the Department of Pesticide Regulation so their rate of application in local watersheds may also have had some influence on the increased concentrations observed in the sediments in 2018.

2) Do the waters and sediments in the harbors sustain healthy biota?

A majority of the area within the San Diego Regional Harbors was found to support healthy biota, based upon a weight-of-evidence approach that combines physical, chemical, and toxicological LOEs with biotic LOEs. Consistent with historical surveys, areas directly associated with anthropogenic disturbance and inputs of pollutants (marinas, industrial/port, and some of the freshwater-influenced areas) tended to have elevated chemistry and conditions that were less supportive of healthy benthic infaunal communities.

Surface water chemistry and physical water quality parameters were largely supportive of healthy biota based on water quality benchmarks. All chemical and physical indicators measured met available water quality objectives, with the exception of copper, primarily in marinas where 80% (n=12 of 15) of stations exceeded the CCC of 3.1 µg/L, and dissolved oxygen, which fell below the Basin Plan WQO of 5.0 mg/L near the sediment surface at one location in the deep stratum and two locations in freshwater-influenced stratum.

Using the State of California SQO approach to assess direct effects, sediment quality region-wide was also considered to be largely protective of healthy biota with 72% of stations classified as either unimpacted or likely unimpacted based on a combined metric that includes sediment chemistry, toxicity, and benthic community lines of evidence (Figure 6-1). Particularly noteworthy, 89% of the 2018 RHMP sampling stations were classified as non-toxic, with 11% considered to have low toxicity according to the SQO methodology; no sites were considered to be moderately or highly toxic. The SQO chemistry LOE rated 57% of stations with minimal or low exposure and, although there were very few stations with high exposure (5%), 37% had moderate exposure. Consistent with the sediment chemistry and toxicity LOEs, the benthic infauna at 55% of the sites had an abundance and diversity indicative of healthy communities with reference or low disturbance conditions according to the SQO benthic LOE (Figure 6-2). However, 32% of sites had moderately disturbed benthic communities and 13% of sites had highly disturbed benthic communities according to the SQO benthic LOE. A majority of the moderately and highly disturbed benthic communities were located in marina and freshwater-influenced strata, with 74% and 65% of sites in these strata in the combined moderate and high disturbance categories, respectively. The variation in disturbance scores observed among benthic communities was a significant driver for final integrated SQO scores. Benthic infaunal communities are complex and are susceptible to multiple factors such as elevated chemistry, physical disturbance, temperature, freshwater exposure, and substrate type. For example, one sampling location at the mouth of Oceanside Harbor is dredged annually by the United States Army Corps of Engineers to maintain the navigation beneficial use. This dredging is likely having an influence on the biological community at this location which was considered to be highly disturbed despite no toxicity and low chemistry.

The demersal fish and invertebrate community was also composed of healthy individuals, with a diversity and abundance of species that were consistent with those of prior regional monitoring assessments. Overall, the diversity, abundance, and biomass recorded in 2018, along with minimal abnormalities, support the premise that the San Diego Regional Harbors are supportive of healthy fish and epibenthic macroinvertebrate assemblages.

3) What are the long-term trends in water and sediment quality in the harbors?

Historical conditions for the 2018 RHMP were determined based on a review of multiple studies completed from 1994 to 2013. Regional conditions were found to be improving over time or remaining steady based on the integration of multiple lines of evidence, including surface water chemistry, sediment chemistry, sediment toxicity, and epibenthic invertebrate and fish communities. However, the condition of benthic infaunal communities appears to have declined since 2008, with a greater proportion of sites in the moderate and high disturbance categories (27% in 2008, 40% in 2013, and 45% in 2018). Results for the integrated SQO approach over the past 10 years for the integrated SQO score using all three lines of evidence, as well as each individual LOE (chemistry, toxicity, and benthic community) are summarized in pie charts in Figures 6-1 and 6-2, respectively. Regulations, a variety of source controls, dredging, and other cleanup activities have led to improvements in sediment chemistry and toxicity over the past few decades in the harbors. The areas of particular concern remain primarily within marinas and around industrial/port regions and certain freshwater-influenced locations.

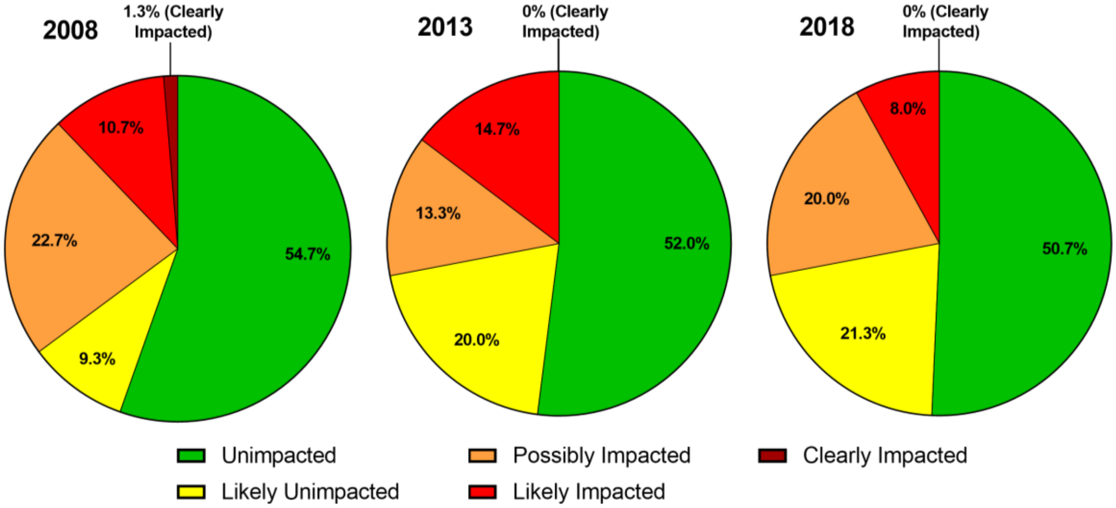


Figure 6-1. Final Integrated SQO Scores for RHMP in 2008, 2013, and 2018

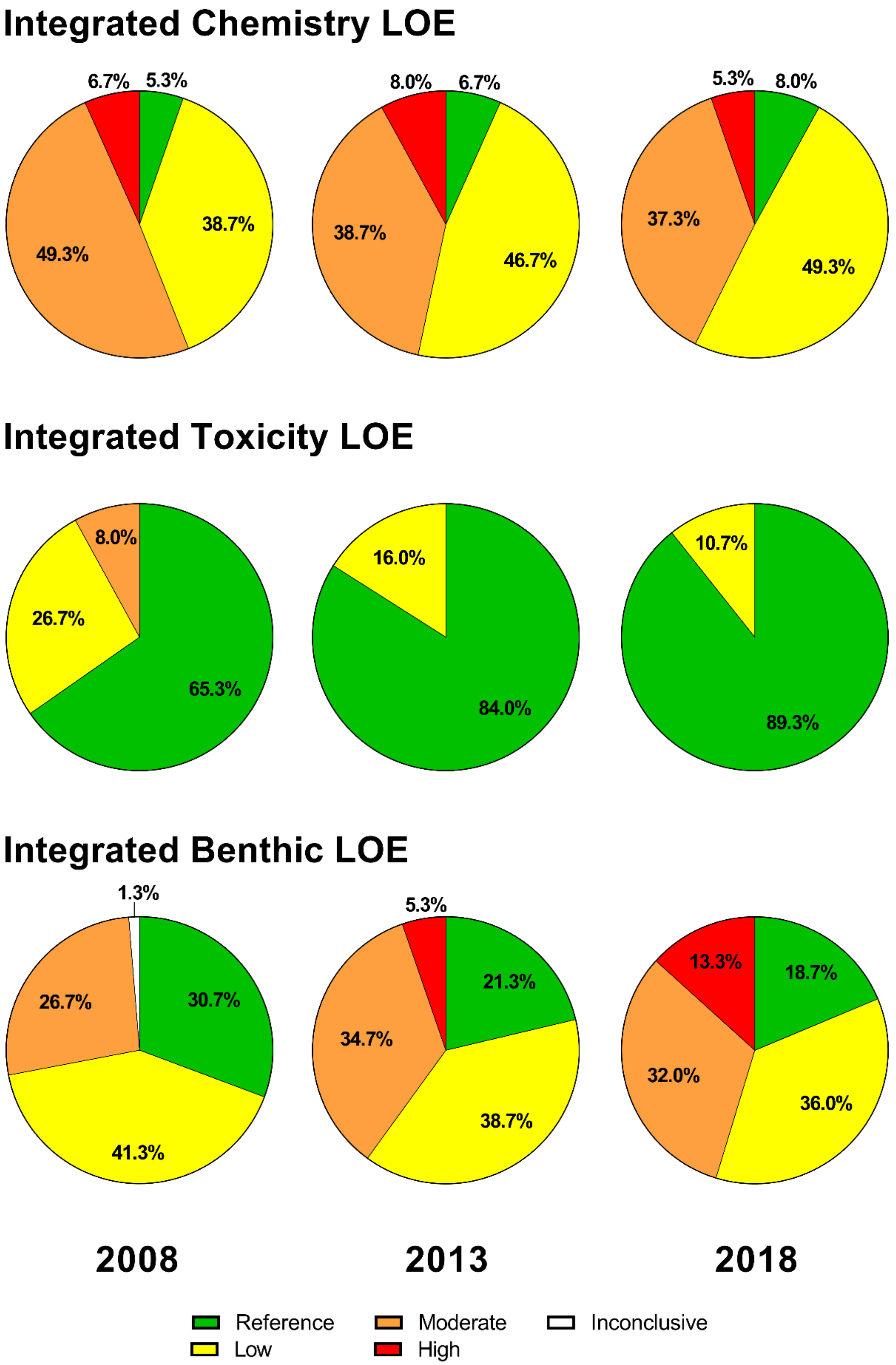


Figure 6-2. Chemical, Toxicity, and Benthic Community SQO Scores for RHMP in 2008, 2013, and 2018

Overall, the rate of improvement in both sediment and water quality appears to have slowed over time when compared to conditions documented over the course of the past two decades. Toxicity in 2018 was similar to that in 2013 showing considerable improvement over historical conditions. Similarly, concentrations of dissolved trace metals and PAHs in the water column and several classes of sediment contaminants (mercury, PAHs, PCBs, and chlordanes) show decreases relative to that reported historically (i.e., pre-2008) and more stable concentrations over the past 10 years. However, concentrations of pyrethroid pesticides and PBDEs increased in 2018 relative to that observed in both 2013 and 2008, particularly in the freshwater-influenced stratum. This observation again is possibly related to a wetter than normal year prior to the sampling efforts in 2018. For a number of other chemicals, long-term trends were less obvious.

The one measure that shows more uncertain results over the past 10 to 20 years is the overall health of the benthic communities based on a number of individual and combined metrics. More than 50% of all RHMP stations combined between 2008 and 2018 are still considered to be in either a reference condition or have low disturbance, although decreases in community conditions were noted over this time-frame among all sites, and more so in the marina, industrial/port, and freshwater-influenced strata. On the other hand, however, a few specific sites in shallow and industrial/port strata showed improvement over the past 10 years highlighting the variability observed for the biological metrics. Of all sediment quality metrics, the benthic community shows the greatest variation over time, with many individual revisited sites having scores spanning multiple categories between reference and disturbed over time without a clear consistent pattern.

Based on the combined evidence available from this study, and other sources cited in the literature, potential causes of increased benthic community disturbance observed in the 2018 RHMP compared to prior years, either directly or indirectly include:

- Potential effects from climate change including record warm water temperatures recorded in San Diego Bay and locally offshore in the summer of 2018.
- Above average rainfall in 2017 and the winter/spring of 2018 just prior to the monitoring efforts in the summer of 2018. Effects from increased rainfall may include physical disturbance through sediment scouring and deposition, decreased salinity, increased chemical concentrations associated with local runoff, and increased organic matter with the potential to enhance oxygen demand at the sediment surface.
- An increase in invasive species, including a notable increase in the population of the pollution-tolerant polychaete *Pseudopolydora paucibranchiata* and Asian mussel *Musculista senhousia* in 2018 compared to 2013. In 2018, *P. paucibranchiata* was the dominant species in two of the six locations total that were considered to have likely impacted conditions and moderately disturbed benthic communities based on the final integrated SQO approach. A total of 6 of the 24 stations classified as having moderately disturbed communities using the integrated SQO approach had elevated populations of *Musculista* (>100 individuals). This species is well known for its ability to significantly alter the benthic substrate and associated benthic community (Crooks, 1998). Although the specific cause(s) resulting in changes in the populations of non-native species is unknown, their presence and spread is likely influenced by all of the same factors described above.

Photographs of the invasive polychaete Pseudopolydora paucibranchiata, and Asian clam Musculista senhousia; pollution tolerant species native to the western Pacific Ocean.

These potential causes are speculative and it should also be noted further that no correlation was found between primary measured chemicals of potential concern in the freshwater-influenced stratum (including pyrethroid pesticides), and benthic community condition based on the BRI.

Fish community health can be used as an indirect measure of sediment and water quality, particularly for those species with a close association with the sediments and high site fidelity (e.g. gobies, spotted sand bass, barred sand bass, among others). The fish communities sampled in the 2018 RHMP were similar to those of prior Bight Program surveys in terms of the mean number of taxa caught per trawl and the mean biomass; however, the mean abundance was greater in 2018, driven in particular by large schools of slough anchovies captured in Mission Bay and central and south San Diego Bay, as well as large schools of northern anchovies captured in Dana Point Harbor and north San Diego Bay. Consistent with prior surveys the demersal fish and invertebrate community is diverse, appears healthy, and continues to show a reduced incidence of physical anomalies such as tumors or fin rot. Only one fish was found to have a small tumor in 2018 (0.1%) compared to 0.6% in 2008 and up to 5% reported in the 1970s.

4) *Are the waters in the harbors safe for body contact activities?*

An effort to address this additional RHMP question was conducted in 2018 by compiling historical data sets and evaluating concentrations and trends in FIB monitored at numerous locations within the San Diego Regional Harbors over a 10-year period extending from 2008 through 2018. A summary of this historical bacteria analysis is provided herein to address this question. A full supplemental report for this historical bacteria analysis is included as Appendix P.

Data were compiled for enterococcus, fecal coliform, and total coliform, but *post hoc* analysis focused on enterococcus as the primary indicator to reflect the latest WQOs provided in the 2018 adoption of the Bacteria Provisions for the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California (ISWEBE Plan; SWRCB, 2019) and amendment to the Water Quality Control Plan for Ocean Waters of California (Ocean Plan; SWRCB, 2018), which identify enterococcus as the most appropriate FIB for the enclosed bays that characterize the San Diego Regional Harbors.

Concentrations of enterococcus in all harbors were generally greatest during wet season sampling. During the dry season, less than 10% of the samples collected from 2008 through 2018 across all harbors exceeded historical WQOs for enterococcus. Of the 10,365 total samples analyzed for the dry season across all harbors, 646 samples exceeded the 30-day geomean WQO and 583 samples exceeded the single sample maximum WQO for enterococcus. During the wet season, exceedances of the historical WQOs for enterococcus were also less than 10%

over the same 10-year period among all samples from Dana Point Harbor and Oceanside Harbor. However, wet season exceedances for historical WQOs for enterococcus in Mission Bay and San Diego Bay were greater, ranging from 23 to 63% of total samples over the same 10-year period. Of the 1,910 total samples analyzed for the wet season across all harbors, 423 samples exceeded the 30-day geomean WQO and 206 samples exceeded the single sample maximum WQO for enterococcus. These results indicate that potential impacts on human health from contact exposure are limited overall, particularly during the dry season, and general recommendations to avoid water contact during or immediately following wet weather events near storm drain or watershed inputs should be followed.

Based on a combined assessment of all stations both across all harbors and within the individual harbors, no obvious temporal trends between years were apparent for enterococcus concentrations over the 10-year period evaluated. However, when evaluating data over the 10-year period for individual sites on the Clean Water Act Section 303(d) list of water quality impaired segments, decreases in enterococcus are apparent for several locations, including Baby Beach in Dana Point Harbor, Shelter Island Shoreline Park, and Tidelands Park in north San Diego Bay.

5) Are fish in the harbors safe to eat?

To address this question, target fish species were collected during benthic trawls for tissue analysis and will be reported in a separate stand-alone report. The report to address this final core monitoring question for 2018 will assess current conditions and will also make comparisons to prior data sets to assess whether any trends may be noted over time. Data analyses and reporting for this effort are in progress at the time of this publication. A stand-alone bioaccumulation report will be finalized in 2021.

Previously, the 2013 RHMP and a follow-up study conducted in 2014 with enhanced sampling in the shallow regions within San Diego Bay found PCBs and mercury to be the primary bioaccumulative chemicals of concern in fish collected from the San Diego Regional Harbors, though risk levels varied depending on location and the species of fish (Amec Foster Wheeler, 2017a and b) No other measured chemicals of concern were identified as a risk to human health based on guidance from the State of California OEHHA.

Concluding Note

The RHMP and the initial regional Bight Monitoring efforts beginning in 1994 represent an integral but relatively recent snapshot of the overall conditions of our bays and harbors. Conditions prior to then, particularly before the implementation of the Clean Water Act in 1972 were quite different based on historical activities, observations, and studies documenting widespread pollution, particularly in San Diego Bay which has a much longer history of human activities than the other three regional harbors. The associated regulatory actions directed towards minimizing levels of contaminants entering our waterways, followed by controls implemented by the RHMP stakeholders and others since then, have made significant strides over the past several decades in improving water quality and associated biological communities in all of the San Diego regional harbors. These strides are more difficult to tease out now that conditions have improved significantly over time, though room for improvement continues as indicated from the results of this latest assessment.

Recommendations

While a majority of the area within the San Diego Regional Harbors was found to support healthy biota based upon integrated SQO scores, declines in benthic community were apparent throughout the harbors, particularly in the marina, industrial/port strata, and freshwater-influenced strata. As noted, it is unclear what specific factors are driving changes in benthic communities over time. However, notable fluctuations in parameters associated with direct and indirect climate change effects on air and water temperatures, rainfall duration and intensity (as well as chemicals associated with runoff), and presence of invasive species were observed in 2018 relative to previous monitoring years. It is becoming critical to understand the impact of climate-related shifts on the benthic indices used for SQO assessments. Continuing to monitor benthic communities through the RHMP while taking these factors into account is highly recommended during future monitoring efforts.

The RHMP has provided an extremely thorough and valuable dataset with which to continue to assess current conditions and trends in the San Diego Regional Harbors. These efforts are among the most comprehensive of any regional monitoring program in the United States. The RHMP also leverages efforts with Bight Program, with added water quality monitoring and special study components. Continuing the RHMP as it is currently designed is a final recommendation to ensure compatibility with prior datasets and to continue to assess status and trends in these water bodies.

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SAMPLING LOCATION TABLES AND MAPS

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APPENDIX P

2018 RHMP HISTORICAL BACTERIA ANALYSIS