SD Public Utilities

South Bay Ocean Outfall Annual Receiving Waters Monitoring & Assessment Report

2015

City of San Diego Ocean Monitoring Program
Environmental Monitoring & Technical Services Division

THE CITY OF SAN DIEGO

June 30, 2015

David Gibson, Executive Officer
California Regional Water Quality Control Board
San Diego Region
2375 Northside Drive, Suite 100
San Diego, CA 92108

Attention: POTW Compliance Unit

Dear Mr. Gibson:

Enclosed is the 2015 Annual Receiving Waters Monitoring and Assessment Report for the South Bay Ocean Outfall, South Bay Water Reclamation Plant as required per Order No. R9-2013-0006 as amended by Order No. R9-2014-0071, NPDES No. CA0109045. This assessment report contains data summaries, analyses and assessments of the various portions of the ocean monitoring program conducted during calendar year 2015, including oceanographic conditions, water quality, sediment conditions, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues. In addition, results of the summer 2015 regional benthic survey of randomly selected sites are also presented. These data are also presented in the similar report required for the South Bay International Wastewater Treatment Plant discharge to the Pacific Ocean (Order No. R9-2014-0009 as amended by Order No. R9-2014-0094, NPDES No. CA0108928), which will be submitted separately by the International Boundary and Water Commission, U.S. Section.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Sincerely,

Peter S. Vroom, Ph.D.
Deputy Public Utilities Director

TDS/akl
cc: U.S. Environmental Protection Agency, Region 9

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South Bay Ocean Outfall

Annual Receiving Waters Monitoring & Assessment Report, 2015

(Order No. R9-2013-0006; NPDES No. CA0109045)

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City of San Diego Ocean Monitoring Program

Environmental Monitoring & Technical Services Division, Public Utilities Department

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June 2016

Table of Contents

Table of Contents

APPENDICES

Table of Contents

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Collage highlighting examples of trawl-caught invertebrates found in the South Bay Ocean Outfall monitoring region (clockwise from top left): the sea slug *Pleurobranchaea californica*; the red crab *Pleuroncodes planipes*; the sea star *Luidia armata*; the crab *Randallia ornata*; the sea star *Pisaster brevispinus.* Photos are from the Bight'13 regional survey voucher collection and were taken by various Marine Biologists.

Acknowledgments:
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Table of Contents

LIST OF TABLES

Chapter 1: General Introduction

No Tables.

Chapter 2: Coastal Oceanographic Conditions

Chapter 3: Water Quality Compliance and Plume Dispersion

Chapter 4: Sediment Conditions

Chapter 5: Macrobenthic Communities

Chapter 6: Demersal Fishes and Megabenthic Invertebrates

Chapter 7: Bioaccumulation of Contaminants in Fish Tissues

Table of Contents

LIST OF TABLES *(continued)*

Chapter 8: San Diego Regional Survey – Sediment Conditions

Chapter 9: San Diego Regional Survey – Macrobenthic Communities

LIST OF FIGURES

Chapter 1: General Introduction

Chapter 2: Coastal Oceanographic Conditions

Chapter 3: Water Quality Compliance and Plume Dispersion

List of Figures *(continued)*

Chapter 4: Sediment Conditions

Chapter 5: Macrobenthic Communities

Chapter 6: Demersal Fishes and Megabenthic Invertebrates

Chapter 7: Bioaccumulation of Contaminants in Fish Tissues

Chapter 8: San Diego Regional Survey – Sediment Conditions

Table of Contents

LIST OF FIGURES *(continued)*

Chapter 9: San Diego Regional Survey – Macrobenthic Communities

LIST OF BOXES

Chapter 3: Water Quality Compliance and Plume Dispersion

LIST OF APPENDICES

Appendix A: Coastal Oceanographic Conditions

Appendix B: Water Quality Compliance and Plume Dispersion

Table of Contents

LIST OF APPENDICES *(continued)*

List of Appendices *(continued)*

Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
ANOSIM	Analysis of Similarity
APHA	American Public Health Association
APT	Advanced Primary Treatment
AUV	Automated Underwater Vehicle
BACIP	Before-After-Control-Impact-Paired
BEST	BIO-ENV + Stepwise Tests
BIO-ENV	Biological/Environmental
BOD	Biochemical Oxygen Demand
BRI	Benthic Response Index
CalCOFI	California Cooperative Fisheries Investigation
CCS	California Current System
CDIP	Coastal Data Information Program
CDOM	Colored Dissolved Organic Matter
CDPH	California Department of Public Health
CFU	Colony Forming Units
cm	centimeter
CSDMML	City of San Diego Marine Microbiology Laboratory
CTD	Conductivity, Temperature, Depth instrument
DDT	Dichlorodiphenyltrichloroethane
df	degrees of freedom
DO	Dissolved Oxygen
ELAP	Environmental Laboratory Accreditation Program
EMAP	Environmental Monitoring and Assessment Program
EMTS	Environmental Monitoring and Technical Services
ENSO	El Niño Southern Oscillation
ERL	Effects Range Low
ERM	Effects Range Median
F:T	Fecal to Total coliform ratio
FET	Fisher’s Exact Test
FIB	Fecal Indicator Bacteria
ft	feet
FTR	Fecal to Total coliform Ratio criterion
g	gram
Global R	ANOSIM test value that examines global differences within a factor
H'	Shannon diversity index
HCB	Hexachlorobenzene
HCH	Hexachlorocylclohexane
IGODS	Interactive Geographical Ocean Data System
in	inches
IR	Infrared
J'	Pielou's evenness index
kg	kilogram
km	kilometer
km^2	square kilometer

Acronyms and Abbreviations

L	Liter
m	meter
m^2	square meter
MDL	Method Detection Limit
mg	milligram
mgd	millions of gallons per day
ml	maximum length
mL	milliliter
mm	millimeter
MODIS	Moderate Resolution Imaging Spectroradiometer
MRP	Monitoring and Reporting Program
mt	metric ton
n	sample size
N	number of observations used in a Chi-square analysis
ng	nanograms
no.	number
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPGO	North Pacific Gyre Oscillation
NWS	National Weather Service
O&G	Oil and Grease
OCSD	Orange County Sanitation District
OEHHA	California Office of Environmental Health Hazard Assessment
OI	Ocean Imaging
OOR	Out-of-range
p	probability
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PDO	Pacific Decadal Oscillation
pH	Acidity/Alkalinity value
PLOO	Point Loma Ocean Outfall
PLWTP	Point Loma Wastewater Treatment Plant
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PRIMER	Plymouth Routines in Multivariate Ecological Research
psu	practical salinity units
r	ANOSIM test value that examines differences among levels within a factor
r_s	Spearman rank correlation coefficient
ROV	Remotely Operated Vehicle
SABWTP	San Antonio de los Buenos Wastewater Treatment Plant
SBIWTP	South Bay International Wastewater Treament Plant
SBOO	South Bay Ocean Outfall
SBWRP	South Bay Water Reclamation Plant
SCB	Southern California Bight

Acronyms and Abbreviations

SCBPP	Southern California Bight Pilot Project
SD	Standard Deviation
SDRWQCB	San Diego Regional Water Quality Control Board
SIMPER	Similarity Percentages Routine
SIMPROF	Similarity Profile Analysis
SIO	Scripps Institution of Oceanography
sp	species (singular)
spp	species (plural)
SSL	Sub-surface Low Salinity Layer
SSM	Single Sample Maximum
SWRCB	Califonia State Water Resources Control Board
tDDT	total DDT
TN	Total Nitrogen
TOC	Total Organic Carbon
tPAH	total PAH
tPCB	total PCB
TSS	Total Suspended Solids
TVS	Total Volatile Solids
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
USGS	United States Geological Survey
USIBWC	International Boundary and Water Commission, U.S. Section
wt	weight
yr	year
ZID	Zone of Initial Dilution
α	alpha, the probability of creating a type I error
µg	micrograms
π	summed absolute distances test statistic
ρ	rho, test statistic for RELATE and BEST tests

Executive Summary

Executive Summary

The City of San Diego (City) conducts an extensive ocean monitoring program to evaluate potential environmental effects from the discharge of treated wastewater to the Pacific Ocean via the South Bay Ocean Outfall (SBOO). The data collected are used to determine compliance with receiving water conditions as specified in National Pollutant Discharge Elimination System (NPDES) regulatory permits for the City's South Bay Water Reclamation Plant (SBWRP) and the South Bay International Wastewater Treatment Plant (SBIWTP) operated by the International Boundary and Water Commission, U.S. Section (USIBWC). Since treated effluent from these two facilities commingle before discharge to the ocean, a single monitoring and reporting program approved by the San Diego Regional Water Quality Control Board and U.S. Environmental Protection Agency (USEPA) is conducted to comply with both permits.

The primary objectives of ocean monitoring for the South Bay outfall region are to:

- measure compliance with NPDES permit requirements and California Ocean Plan (Ocean Plan) water quality objectives,
- monitor changes in ocean conditions over space and time, and
- assess any impacts of wastewater discharge or other man-made or natural influences on the local marine environment, including effects on water quality, sediment conditions, and marine life.

Overall, the state of southern San Diego's coastal waters in 2015 was in good condition based on the comprehensive scientific assessment of the South Bay outfall monitoring region. This report details the methods, scope, results, and evaluation of the ocean monitoring program.

Regular (core) monitoring sites that are sampled on a weekly, monthly or semiannual basis are arranged in a grid surrounding the SBOO, which terminates approximately 5.6 km offshore at a discharge depth of 27 m. Monitoring at shoreline stations extends from Coronado, San Diego (USA) southward to Playa Blanca in northern Baja California (Mexico), while offshore monitoring occurs in waters overlying the continental shelf at depths of about 9 to 55 m. In addition to core monitoring, a broader geographic survey of benthic conditions is conducted each year at randomly selected sites that range from the USA/Mexico border region to northern San Diego County and that extend further offshore to waters as deep as 500 m. These "regional" surveys are useful for evaluating patterns and trends over a larger geographic area, and thus provide important information for distinguishing reference from impact areas. Additional information on background environmental conditions for the region is also available from a baseline study conducted by the City over a 3½ year period prior to wastewater discharge.

Details of the results and conclusions of all receiving waters monitoring activities conducted from January through December 2015 are presented and discussed in the following nine chapters. Chapter 1 represents a general introduction and overview of the City's ocean monitoring program, while chapters 2–7 include results of all monitoring at the regular core stations conducted during the year. In Chapter 2, data characterizing oceanographic conditions and water mass transport for the region are evaluated. Chapter 3 presents the results of shoreline and offshore water quality monitoring, including measurements of fecal indicator bacteria and oceanographic data to evaluate potential movement and dispersal of the plume and assess compliance with water contact standards defined in the Ocean Plan. Assessments of benthic sediment quality and the status of macrobenthic invertebrate communities are presented in Chapters 4 and 5, respectively. Chapter 6 presents the results of trawling activities designed to monitor communities of bottom dwelling (demersal) fishes and megabenthic invertebrates. Bioaccumulation assessments to measure contaminant loads in the tissues of local fishes are presented in Chapter 7. Results of the summer 2015 San Diego regional survey of sediment conditions and benthic macrofaunal communities are presented in Chapters 8 and 9, respectively. In addition to the above activities, the City and USIBWC support other projects relevant to assessing the quality and movement of ocean waters in the region. One such project involves satellite imaging of the San Diego/Tijuana coastal region, of which the 2015 results are incorporated into Chapters 2 and 3. A summary of the main findings for each of the above components is included below.

COASTAL OCEANOGRAPHIC CONDITIONS

Sea surface temperatures were warmer than the long-term average during the winter, summer and fall of 2015, consistent with the El Niño that began in 2013 and persisted and strengthened through the end of the year. Ocean conditions indicative of local coastal upwelling were observed during the spring. As is typical for the South Bay outfall region, maximum stratification (layering) of the water column occurred in mid-summer, while well-mixed waters were present during the winter. Water clarity (% transmissivity) during the year was within historical ranges for the region, with low values predominantly associated with re-suspension of bottom sediments due to waves or storm activity or phytoplankton blooms. The occurrence of plankton blooms corresponded to upwelling as described above. Overall, ocean conditions during the year were consistent with well documented patterns for southern California and northern Baja California. These findings suggest that natural factors such as upwelling of deep ocean waters and changes due to climatic events such as El Niño/La Niña oscillations continue to explain most of the temporal and spatial variability observed in the coastal waters off southern San Diego.

WATER QUALITY COMPLIANCE & PLUME DISPERSION

Compliance with Ocean Plan water contact standards for fecal indicator bacteria (FIB) was evaluated for the eight shore stations located from near the USA/Mexico border to Coronado, as well as the three kelp bed and other offshore stations located west of Imperial Beach and within State jurisdictional waters (i.e., within 3 nautical miles of shore). These standards do not apply to the stations located south of the border, and were not assessed for this area. Overall compliance with the Ocean Plan's single sample maximum (SSM) and geometric mean bacterial standards was 97% for the shore, kelp bed, and other offshore stations combined in 2015. Compliance at the shore stations was ≥57% for the three geometric mean standards and ≥67% for each of the four SSM standards. However, six of these stations (S4, S5, S6, S10, S11, S12) fall within or adjacent to areas already listed by the State and USEPA as impaired waters due to non-outfall related sources; thus, these stations are not expected to be in compliance with Ocean Plan standards. Compliance at the remaining two northernmost shore stations (S8 and S9) was 95% in 2015. Water quality was also high at the kelp bed and offshore stations located within State waters during the year. Compliance at the three kelp bed and four other nearshore stations along the 9-m depth contour was ≥96% for the geometric mean standards and ≥97% for the SSMs, while compliance at the other offshore stations was ≥99% for the SSMs. Compliance was lowest during the wet season (October–April), when about 77% of all elevated FIB counts were detected. A relationship between rainfall and bacterial concentrations in local waters has remained consistent since monitoring began several years prior to wastewater discharge, and is likely associated with outflows of contaminated waters from the Tijuana River (USA) and Los Buenos Creek (Mexico) during and after storm events.

There was no evidence that wastewater discharged to the ocean via the SBOO reached the shoreline in 2015. Although elevated FIB densities were detected along the shore and occasionally at a few nearshore stations located along the 9 and 18-m depth contours, these results did not indicate shoreward transport of the plume, a conclusion consistently supported by remote sensing observations. Instead, other potential sources of bacterial contamination such as coastal runoff from rivers and creeks were more likely to impact nearshore water quality in the South Bay outfall region, especially during the wet season. In addition, bacterial contamination was largely absent along the 28, 38, and 55-m depth contours, including stations I12, I14, and I16 located nearest the SBOO discharge site. During all of 2015, a single sample with elevated FIB densities was collected from station I12 in February. This low rate of FIB contamination near the outfall is expected due to the full secondary treatment at the SBIWTP that began in January 2011.

SEDIMENT CONDITIONS

The composition of benthic sediments at the SBOO stations was similar in 2015 to previous years, varying from fine silts to very coarse sands or other large particles. There were no changes in the amount of fine sediments at the different monitoring sites that could be attributed to wastewater discharge, nor was there any other apparent relationship between sediment grain size distributions and proximity to the outfall. Instead, the range of sediment types present in the region reflects multiple geological origins or complex patterns of transport and deposition from sources such as the Tijuana River and San Diego Bay.

As in previous years, sediment quality was very high in 2015, with overall contaminant loads remaining relatively low compared to available thresholds and other southern California coastal areas. There was no evidence of contaminant accumulation associated with wastewater discharge. Concentrations of the various organic loading indicators, trace metals, pesticides, PCBs, and PAHs varied widely throughout the region, and there were no patterns that could be attributed to the outfall or other point sources. The potential for environmental degradation by various contaminants was evaluated using the effects-range low (ERL) and effects-range median (ERM) sediment quality guidelines when available. The only exceedances of these two thresholds in 2015 were for arsenic, which exceeded its ERL at a single station during both the winter and summer surveys. Neither of these two exceedances occurred at stations near the discharge site and therefore do not appear associated with wastewater discharge.

MACROBENTHIC COMMUNITIES

Benthic macrofaunal communities surrounding the SBOO were similar in 2015 to previous years, with assemblages located near the outfall being similar to those from neighboring farfield sites. These assemblages remained dominated by polychaete worm species that occur in similar habitats throughout the Southern California Bight (SCB). Specifically, the spionid *Spiophanes norrisi* has been the most abundant and most widely distributed species recorded in the region since 2007. Overall, benthic communities in the region appear to be in good condition, remain similar to those observed prior to outfall operations, and are representative of natural indigenous communities. For example, values for several community metrics such as species richness, total abundance, diversity, evenness, and dominance were within historical ranges reported for the San Diego region, and were representative of those that occur in other sandy, shallow to mid-depth habitats throughout the SCB. Benthic response index (BRI) values were also characteristic of undisturbed habitats at 81% of the sites. Only eight stations had BRI values suggestive of a possible minor deviation from reference condition, and these occurred mostly north of the outfall along the 19-m and 28-m depth contours fitting a historical pattern that has existed since monitoring began. Finally, changes in populations of pollution-sensitive or pollution-tolerant species and other indicators of benthic condition continue to provide no evidence of significant environmental degradation in the South Bay outfall region. Thus, no specific effects of wastewater discharge via the SBOO on the local macrobenthic community were identified during the year.

DEMERSAL FISHES AND MEGABENTHIC INVERTEBRATES

Speckled Sanddab dominated fish assemblages surrounding the SBOO in 2015 as they have in previous years, occurring in all trawls and accounting for 67% of the total year’s catch. California Lizardfish were also prevalent as they have been in five of the past six years, occurring in

93% of trawls and accounting for 16% of the total catch. Other species collected in at least half the trawls included California Tonguefish, Hornyhead Turbot, Longfin Sanddab and California Halibut. Although the composition and structure of the SBOO fish assemblages varied among stations and surveys, these differences appear to be due to natural fluctuations of these common species.

Trawl-caught invertebrate assemblages in the region were dominated by the sea star *Astropecten californicus*. This species occurred in 100% of trawls and accounted for 51% of the total invertebrate abundance. An indicator of El Niño conditions off San Diego, the red crab *Pleuroncodes planipes* accounted for 23% of the total year's catch, but only occurred in five trawls during the winter. Other less abundant but common species included the crabs *Portunus xantusii* and *Pyromaia tuberculata*, the gastropod *Philine auriformis*, the shrimps *Sicyonia pencillata* and *Crangon nigromaculata*, and the cymothoid isopod *Elthusa vulgaris*. As with fishes, the composition of the invertebrate assemblages varied among stations and surveys, reflecting mostly large fluctuations in populations of the above species.

Comparisons of the 2015 surveys with results from previous surveys conducted from 1995 through 2014 indicate that trawl-caught fish and invertebrate communities in the region remain unaffected by wastewater discharge. The relatively low species richness and small population sizes of most individual fish and invertebrate species are consistent with the predominantly shallow, sandy habitat of the region. Patterns in the abundance and distribution of specific species were similar at stations located near the SBOO and those farther away, suggesting a lack of significant anthropogenic influence. Finally, external examinations of all fish captured during the year indicated that local fish populations remain healthy, with there being no evidence of physical anomalies or disease.

Contaminants In Fish Tissues

The accumulation of contaminants in marine fishes may be due to direct exposure to contaminated water or sediments or to the ingestion of contaminated prey. Consequently the bioaccumulation of chemical contaminants in local fishes was assessed by analyzing liver tissues from trawl-caught fishes and muscle tissues from fish captured by hook and line. Results from these analyses indicated no evidence to suggest that contaminant loads in fishes captured in the SBOO region were affected by wastewater discharge in 2015. Although a few tissue samples had concentrations of some contaminants that exceeded pre-discharge maximum levels or various standards, concentrations of most contaminants were generally similar to those observed prior to discharge. Additionally, tissue samples that did exceed pre-discharge contaminant levels were found in fishes distributed widely throughout the region. Furthermore, all contaminant concentrations were within ranges reported previously for southern California fishes.

The occurrence of trace metals and chlorinated hydrocarbons in local fishes may be due to many factors, including the ubiquitous distribution of many contaminants in southern California coastal sediments. Other factors that affect bioaccumulation in fishes include differences in physiology and life history traits of various species, while exposure to contaminants can vary greatly between species and even among individuals of the same species depending on their migration habits. For example, an individual fish may be exposed to contaminants at a polluted site and then migrate to an area that is less contaminated. This is of particular concern for fishes collected in the vicinity of the SBOO, as there are many other potential point and non-point sources of contamination.

San Diego Regional Survey

The summer 2015 San Diego regional benthic survey covered an area ranging from offshore of Del Mar south to the USA/Mexico border. A total of 40 new sites selected using a stratified, randomized sampling design were sampled at inner shelf, mid-shelf, outer shelf, and upper slope depths ranging from 9 to 530 m. Included below is a summary of the sediment conditions and soft-bottom macrobenthic assemblages present during the 2015 regional survey.

REGIONAL SEDIMENTS

The composition of sediments at the regional stations sampled in 2015 was typical for continental shelf and upper slope benthic habitats off southern California, and consistent with results from previous surveys off San Diego. Overall, sediments varied by strata and depth as expected. For example, stations sampled within the region bounded by the SBOO core monitoring stations had sediments composed predominantly of fine or coarse sand, whereas stations sampled within the core Point Loma Ocean Outfall (PLOO) monitoring grid were characterized by much finer sediments dominated by clay, silt, and fine sand. Exceptions to this pattern did occur, particularly at outer shelf sites along the Coronado Bank, a southern rocky ridge located southwest of Point Loma. Sediment composition in this area is generally coarser than stations located at similar depths west of Point Loma and further to the north.

As with particle size composition, regional sediment quality in 2015 was similar to previous years, and there was no evidence of habitat degradation. While various indicators of organic loading, trace metals, chlorinated pesticides, PCBs and PAHs were detected, concentrations of these contaminants were relatively low compared to many other coastal areas of the SCB. Almost all contaminants occurred at levels below ERL and ERM thresholds. Further, although contaminant concentrations in San Diego sediments were highly variable, there was no evidence of disturbance that could be attributed to local wastewater discharges from either the SBOO or PLOO. Instead, concentrations of chemical parameters such as total nitrogen, total volatile solids and several trace metals were found to increase with increasing amounts of fine sediments (percent fines). As the percent fines component also increased with depth, many contaminants were detected at higher concentrations in deeper strata compared to shallower inner and mid-shelf regions. For example, the highest levels of most contaminants occurred in sediments along the upper slope where some of the finest sediments were present.

REGIONAL MACROFAUNA

The SCB benthos has long been considered to be composed of heterogeneous or “patchy” habitats, with the distribution of macrobenthic invertebrate species and communities exhibiting considerable spatial variability. Results of the summer 2015 regional survey off San Diego support this characterization, with the major macrofaunal assemblages segregating by habitat characteristics such as depth and sediment type.

The inner to mid-shelf macrofaunal assemblages present off San Diego during 2015 were similar to those found in other shallow, sandy habitats across the SCB, and were characterized by species of polychaete worms such as *Spiophanes norrisi*, *Spiophanes duplex*, and *Mediomastus* sp. Assemblages occurring in somewhat finer, but more mixed sediments along the mid-shelf to outer shelf, were dominated by the brittle star *Amphiodia urtica*, and corresponded to the Amphiodia “mega-community” described previously for the SCB. Similar to patterns described in previous monitoring reports, upper slope habitats off San Diego were characterized by a high percentage of fine sediments with associated species assemblages distinct from those at most shelf stations. These upper slope assemblages typically had relatively high abundances of the polychaetes *Fauveliopsis glabra*, *Eclysippe trilobata*, *Maldane sarsi*, *Notomastus* sp A and *Praxillella pacifica*, the heart urchin *Brissopsis* sp LA1, the ampeliscid amphipod *Ampelisca unsocalae*, and the molluscs *Cadulus californicus*, *Neilonella ritteri* and *Nuculana conceptionis*.

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2015 regional surveys that could be attributed to wastewater discharges, disposal sites, or other point sources. Benthic habitats appear to be in good condition overall, with 88% of the shelf sites being classified in reference condition based on assessments using the benthic response index (BRI). This pattern is consistent with recent findings for the entire SCB mainland shelf.

CONCLUSIONS

The findings and conclusions for the ocean monitoring efforts conducted for the South Bay outfall region during calendar year 2015 were consistent with previous years. Overall, there were limited impacts to local receiving waters, benthic sediments, and marine invertebrate and fish communities. There was no evidence that the wastewater plume from the South Bay outfall reached the shoreline during the year. Although elevated bacterial levels did occur in nearshore areas, such instances were largely associated with rainfall and associated runoff during the wet season and not to shoreward transport of the plume. There were also no outfall related patterns in sediment contaminant distributions, or in differences between the various invertebrate and fish assemblages. The lack of disease symptoms in local fish populations, as well as the low level of contaminants detected in fish tissues, was also indicative of a healthy marine environment.

Chapter 1
General Introduction

Chapter 1. General Introduction

Combined municipal treated effluent originating from two separate sources is discharged to the Pacific Ocean through the South Bay Ocean Outfall. These sources include the South Bay International Wastewater Treatment Plant (SBIWTP) owned and operated by the International Boundary and Water Commission, U.S. Section (USIBWC), and the South Bay Water Reclamation Plant (SBWRP) owned and operated by the City of San Diego (City). Wastewater discharge from the SBIWTP began in January 1999 and is presently subject to the terms and conditions set forth in San Diego Regional Water Quality Control Board (SDRWQCB) Order No. R9-2014-0009 as amended by Order No. R9-2014-0094 (NPDES Permit No. CA0108928), while discharge from the City's SBWRP began in May 2002 and is subject to the provisions set forth in Order No. R9-2013-0006 as amended by Order No. R9-2014-0071 (NPDES Permit No. CA0109045).[1] The Monitoring and Reporting Program (MRP) requirements, as specified in the above and preceding orders, define the receiving waters monitoring requirements for the South Bay coastal region, including sampling design, types of laboratory analyses, compliance criteria, and data analysis and reporting guidelines. The main objectives of the monitoring program are to: 1) provide data that satisfy NPDES permit requirements; 2) demonstrate compliance with California Ocean Plan (Ocean Plan) provisions; 3) detect dispersion and transport of the waste field (plume); 4) identify any environmental changes that may be associated with wastewater discharge via the outfall.

BACKGROUND

The South Bay Ocean Outfall (SBOO) is located just north of the border between the United States and Mexico where it terminates approximately 5.6 km offshore at a depth of about 27 m. Unlike other ocean outfalls in southern California that lie on the surface of the seafloor, the SBOO pipeline begins as a tunnel on land that extends from the two treatment facilities to the coastline, and then continues beneath the seabed to a distance about 4.3 km offshore. From there it connects to a vertical riser assembly that conveys effluent to a pipeline buried just beneath the surface of the seafloor. This subsurface outfall pipe then splits into a Y-shaped (wye) multiport diffuser system with the two diffuser legs each extending an additional 0.6 km to the north and south. The outfall was originally designed to discharge wastewater through 165 diffuser ports and risers, which included one riser at the center of the wye and 82 others spaced along each diffuser leg. Since discharge began, however, consistently low flow rates have led to closure of all ports along the northern diffuser leg and many along the southern diffuser leg in order for the outfall to operate effectively. Consequently, wastewater discharge is restricted primarily to the distal end of the southern diffuser leg, with the exception of a few intermediate points at or near the center of the wye.

RECEIVING WATERS MONITORING

The core sampling area for the SBOO region extends from the tip of Point Loma southward to Playa Blanca in northern Baja California (Mexico), and from the shoreline seaward to a depth of about 61 m. The offshore monitoring sites are arranged in a grid surrounding the outfall, with each station being sampled in accordance with MRP requirements. A summary of the results for quality assurance procedures performed in 2015 in support of these requirements can be found in City of San Diego (2016). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the SDRWQCB and United States Environmental Protection Agency (USEPA) throughout the year are available

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[1] Order No. R9-2014-0009 for the SBIWTP and Order No. R9-2013-0006 for the SBWRP were both amended on November 12, 2014.

online at the City's website (www.sandiego.gov/mwwd/environment/oceanmonitor/index.shtml).

All permit mandated monitoring for the South Bay outfall region has been performed by the City of San Diego since wastewater discharge began in 1999. The City also conducted pre-discharge monitoring for 3½ years in order to provide background information against which post-discharge conditions may be compared (City of San Diego 2000a). Additionally, the City has conducted annual region-wide surveys off the coast of San Diego since 1994 either as part of regular monitoring requirements (i.e., "mini-regional surveys"; see City of San Diego 1998, 1999, 2000b, 2001–2003, 2006–2008, 2010–2015) or as part of larger, multi-agency surveys of the entire Southern California Bight (SCB). The latter include the 1994 Southern California Bight Pilot Project (Allen et al. 1998, Bergen et al. 1998, 2001, Schiff and Gossett 1998) and subsequent Bight'98, Bight'03, Bight'08, Bight'13 programs in 1998, 2003, 2008, and 2013 respectively (Allen et al. 2002, 2007, 2011, Noblet et al. 2002, Ranasinghe et al. 2003, 2007, 2012, Schiff et al. 2006, 2011, Bight'13 CIA 2013, Dodder et al. 2016). These large-scale surveys are useful for characterizing the ecological health of diverse coastal areas and in distinguishing reference sites from those impacted by wastewater or stormwater discharges, urban runoff, or other sources of contamination.

In addition to the above activities, the City and USIBWC jointly fund a remote sensing program for the San Diego coastal region as part of the monitoring efforts for the South Bay and Point Loma outfall areas. This program, conducted by Ocean Imaging, Inc. (Solana Beach, CA), uses satellite and aerial imagery data to produce synoptic pictures of surface water clarity that are not possible using shipboard sampling alone. With public health issues being of paramount concern for ocean monitoring programs in general, any information that helps provide a more complete understanding of ocean conditions is beneficial to the general public as well as to program managers and regulators. Results of the remote sensing program conducted from January through December 2015 are available in Svejkovsky (2016).

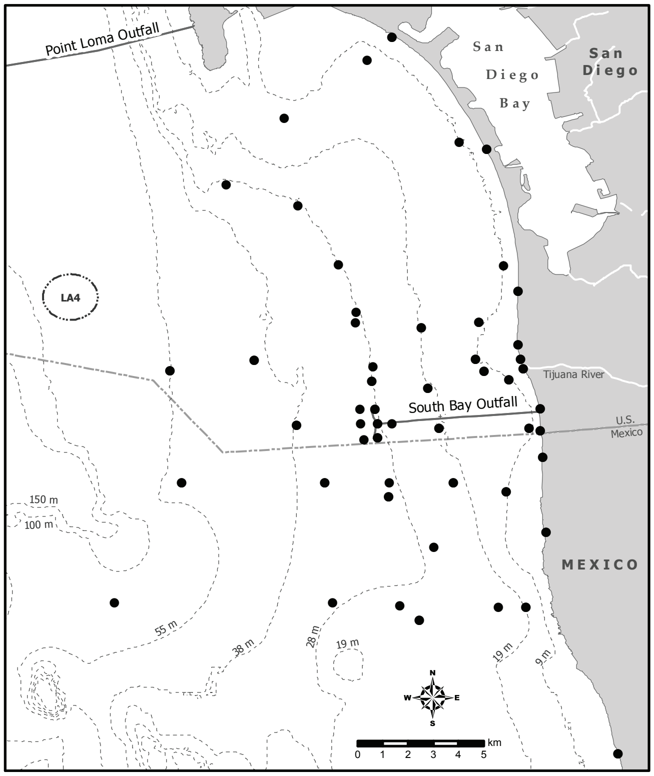

Figure 1.1
Receiving waters monitoring stations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

This annual assessment report presents the results of all receiving waters monitoring activities conducted during calendar year 2015 for the South Bay outfall monitoring region. Included are results from all regular core stations that comprise a fixed-site monitoring grid surrounding the outfall (Figure 1.1), as well as results from the summer 2015 benthic survey of randomly selected sites that ranged from near the USA/Mexico border to northern San Diego County (Figure 1.2). Comparisons are also made to conditions found during previous years (e.g., City of San Diego 2015) in order to evaluate temporal or spatial changes that may be related to wastewater plume dispersion or to other anthropogenic or natural factors. The major components of the monitoring program are covered in the following eight chapters: Coastal Oceanographic Conditions, Plume Dispersion and Water Quality Compliance, Sediment Conditions, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, Bioaccumulation of Contaminants in Fish Tissues, Regional Sediment Conditions, and Regional Macrobenthic Communities.

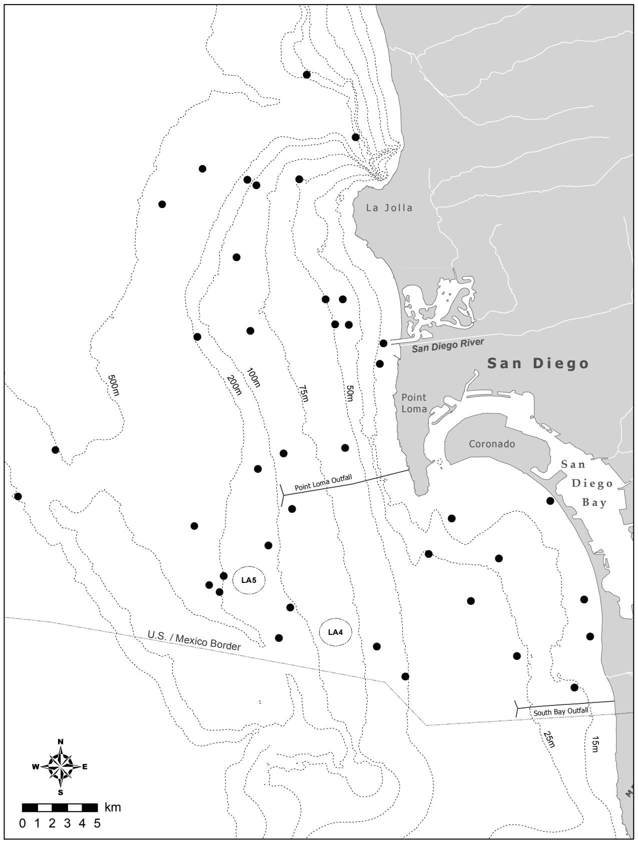

Figure 1.2
Regional random benthic survey stations sampled during July 2015 as part of the City of San Diego's Ocean Monitoring Program.

LITERATURE CITED

Allen, M.J., S.L. Moore, K.C. Schiff, D. Diener, S.B. Weisberg, J.K. Stull, A. Groce, E. Zeng, J. Mubarak, C.L. Tang, R. Gartman, and C.I. Haydock. (1998). Assessment of demersal fish and megabenthic invertebrate assemblages on the mainland shelf of southern California in 1994. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., D. Cadien, E. Miller, D.W. Diehl, K. Ritter, S.L. Moore, C. Cash, D.J. Pondella, V. Raco-Rands, C. Thomas, R. Gartman, W. Power, A.K. Latker, J. Williams, J.L. Armstrong, and K. Schiff. (2011). Southern California Bight 2008 Regional Monitoring Program: IV. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Costa Mesa, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., T. Mikel, D. Cadien, J.E. Kalman, E.T. Jarvis, K.C. Schiff, D.W. Diehl, S.L. Moore, S. Walther, G. Deets, C. Cash, S. Watts, D.J. Pondella II, V. Raco-Rands, C. Thomas, R. Gartman, L. Sabin, W. Power, A.K. Groce, and J.L. Armstrong. (2007). Southern California Bight 2003 Regional Monitoring Program: IV. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Costa Mesa, CA.

Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

[Bight'13 CIA] Bight'13 Contaminant Impact Assessment Committee. (2013). Contaminant Impact Assessment Workplan. Southern California Coastal Water Research Project, Costa Mesa, CA.

City of San Diego. (1998). San Diego Regional Monitoring Report for 1994–1996. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000a). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (1999). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2001). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2000). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2002). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2001). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2002). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2016). Annual Receiving Waters Monitoring & Toxicity Testing Quality Assurance Report, 2015. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Dodder, N., K. Schiff, A. Latker, C-L Tang. (2016). Southern California Bight 2013 Regional Monitoring Program: IV. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2002). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, and S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., K.C. Schiff, C.A. Brantley, L.L. Lovell, D.B. Cadien, T.K. Mikel, R.G. Velarde, S. Holt, and S.C. Johnson. (2012). Southern California Bight 2008 Regional Monitoring Program:VI. Benthic Macrofauna. Technical Report No. 665, Southern California Coastal Water Research Project, Costa Mesa, CA.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., R. Gossett, K. Ritter, L. Tiefenthaler, N. Dodder, W. Lao, and K. Maruya, (2011). Southern California Bight 2008 Regional Monitoring Program: III. Sediment Chemistry. Southern California Coastal Water Research Project, Costa Mesa, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Svejkovsky, J. (2016). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2015 – 31 December, 2015. Ocean Imaging, Solana Beach, CA.

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Chapter 2
Coastal Oceanographic Conditions

Chapter 2. Coastal Oceanographic Conditions

Introduction

The City of San Diego collects a comprehensive suite of oceanographic data from waters surrounding the South Bay Ocean Outfall (SBOO) to characterize conditions in the region and to identify possible impacts of wastewater discharge. These data include measurements of water temperature, salinity, light transmittance (transmissivity), dissolved oxygen, pH, and chlorophyll *a*, all of which are important indicators of physical and biological oceanographic processes that can impact marine life (e.g., Skirrow 1975, Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into marine waters is determined not only by the geometry of an outfall's diffuser structure and rate of effluent discharge, but also by oceanographic factors that govern water mass movement (e.g., water column mixing, ocean currents), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990).

In nearshore coastal waters of the Southern California Bight (SCB) such as the region surrounding the SBOO, ocean conditions are influenced by multiple factors. These include: (1) large scale climate processes such as El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and North Pacific Gyre Oscillation (NPGO) that can affect long-term trends (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, NOAA/NWS 2016); (2) the California Current System coupled with local gyres that transport distinct water masses into and out of the SCB (Lynn and Simpson 1987, Leising et al. 2014); (3) seasonal changes in local weather patterns (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Seasonality is responsible for the main stratification patterns observed in the coastal waters off San Diego and the rest of southern California (Terrill et al. 2009). Relatively warm waters and a more stratified water column are typically present during the dry season from May to September, while cooler waters coupled with greater mixing and weaker stratification characterize ocean conditions during the wet season from October to April (e.g., Sveykovsky 2016). For example, winter storms bring higher winds, rain, and waves that typically result in a well-mixed, non-stratified water column (Jackson 1986). Surface waters begin to warm by late spring and are then subjected to increased surface evaporation. Once the water column becomes stratified, minimal mixing conditions typically remain throughout the summer and into early fall. Toward the end of the year, surface water cooling along with increased storm frequency returns the water column to well-mixed conditions.

Understanding changes in oceanographic conditions due to natural processes such as seasonal patterns is important since they can affect the transport and distribution of wastewater, storm water, and other types of plumes. In the South Bay outfall region these include sediment or turbidity plumes associated with tidal exchange from San Diego Bay, outflows from the Tijuana River off Imperial Beach and Los Buenos Creek in northern Baja California, storm drain discharges, and runoff from local watersheds. For example, outflows from San Diego Bay and the Tijuana River that are fed by 1165 km^2 and 4483 km^2 of watersheds, respectively (Project Clean Water 2012), can contribute significantly to patterns of nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009, Svejkovsky 2010, 2016).

This chapter presents analysis and interpretation of the oceanographic monitoring data collected during calendar year 2015 for the coastal waters surrounding the SBOO. The primary goals are to: (1) summarize oceanographic conditions in the region; (2) identify natural and anthropogenic sources of variability; (3) evaluate local conditions off southern San Diego in context with regional climate processes. Results of remote sensing observations (e.g., satellite imagery) may also provide useful information on the horizontal transport of surface waters and phenomena such as phytoplankton blooms (Pickard and Emery 1990, Svejkovsky 2010, 2016). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of satellite imagery to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site. The results reported herein are also referred to in subsequent chapters to explain patterns of fecal indicator bacteria distributions and plume dispersion (see Chapter 3) or other changes in the local marine environment (see Chapters 4–9).

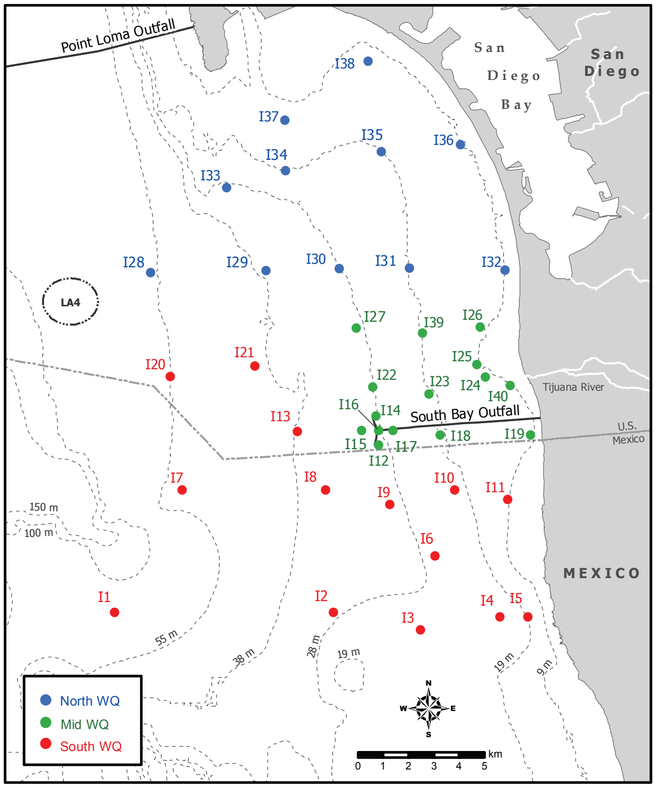

Figure 2.1

Locations of water quality (WQ) monitoring stations where CTD casts are taken around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Materials and Methods

Field Sampling

Oceanographic measurements were collected at 40 water quality monitoring stations arranged in a grid surrounding the SBOO that encompass a total area of ~300 km2 (Figure 2.1). These stations (designated I1–I40) are located between ~0.4 and 14.6 km offshore along or adjacent to the 9, 19, 28, 38, and 55-m depth contours. Each of these offshore stations was sampled quarterly (February, May, August, November), with sampling at all 40 sites completed over 3–5 days (Table 2.1). The stations were grouped together as follows for sampling purposes: (1) "North Water Quality" stations I28–I38 (n = 11); (2) "Mid Water Quality" stations I12, I14–I19, I22–I27, I39, I40 (n = 15); (3) "South Water Quality" stations I1–I11, I13, I20, I21 (n = 14).

Oceanographic data were collected using a SeaBird (SBE 25, Sea-Bird Electronics, Inc., Bellevue WA, USA) conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, conductivity (used to calculate salinity), pressure (used to calculate depth), dissolved oxygen (DO), pH, transmissivity (a proxy for water clarity), and chlorophyll *a* (a proxy for phytoplankton). Vertical profiles of each parameter were constructed for each station by averaging the data values recorded within each 1-m depth bin. This data reduction ensured that physical measurements used in subsequent analyses would correspond to the discrete sampling depths required for fecal indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast. These observations were previously reported in monthly receiving waters monitoring reports submitted to the San Diego Regional Water Quality Control Board (SDRWQCB) (see City of San Diego 2015-2016).

Table 2.1
Sample dates for quarterly oceanographic surveys conducted in the SBOO region during 2015. All stations in each station group were sampled on a single day (see Figure 2.1 for stations and locations).

Station Group	2015 Sampling Dates Feb	May	Aug	Nov
North WQ	5	8	6	12
Mid WQ	4	6	5	13
South WQ	3	7	4	9

Remote Sensing

Coastal monitoring of the San Diego region during 2015 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite imaging data collected during the year were made available for review and download from OI's website (Ocean Imaging 2016), while a separate report summarizing results for the year was also produced (Svejkovsky 2016). Several different types of satellite imagery were analyzed, including Moderate Resolution Imaging Spectroradiometer (MODIS), Thematic Mapper TM7 color/thermal, and high resolution Rapid Eye images. While these technologies differ in terms of capability and resolution, all are generally useful for revealing patterns in surface waters as deep as 12 m.

Data Analysis

Water column parameters measured in 2015 were summarized as quarterly means pooled over all stations by the following depth layers: 1–9 m, 10–19 m, 20–28 m, 29–38 m, 39–55 m. The top layer is herein referred to as surface water while the other subsurface layers account for mid and bottom waters. Unless otherwise noted, analyses were performed using R (R Core Team, 2015) and various functions within the Hmisc, oce, reshape2, Rmisc, and RODBC packages (Wickham 2007, Hope 2013, Harrell et al. 2015, Kelley and Richards 2015, Ripley and Lapsley 2015). For spatial analysis of all parameters, 3-dimensional graphical views were created each quarter for each parameter using Interactive Geographical Ocean Data System (IGODS) software, which interpolates data between stations along each depth contour (Ocean Software 2009).

Vertical density profiles were constructed to depict the pycnocline (i.e., depth layer where the density gradient was greatest) for each survey and to illustrate seasonal changes in water column stratification. Data for these density profiles were limited to the 28-m outfall depth stations (i.e., I2, I3, I6, I9, I12, I14, I15, I16, I17, I22, I27, I30, I33) to prevent masking trends that occur when data from multiple depth contours are combined. Buoyancy frequency (BF), a measure of the water column's static stability, was used to quantify the magnitude of stratification for each survey and was calculated as follows:

$$BF^2 = g/\rho * (d\rho/dz)$$

where g is the acceleration due to gravity, ρ is the density of seawater, and dρ/dz is the density gradient (Mann and Lazier 1991). The depth of maximum BF was used as a proxy for the depth at which stratification was the greatest.

Additionally, time series of anomalies for temperature, salinity, and DO were calculated to evaluate regional oceanographic events in context with larger scale processes (i.e., ENSO events). These analyses were also limited to data from the 28-m outfall depth stations, with all water column depths combined. Anomalies were then calculated by subtracting the average of all 21 years combined (i.e., 1995–2015) from the monthly means for each year.

Results and Discussion

Oceanographic Conditions in 2015

Water Temperature and Density

Surface water temperatures (1–9 m) across the SBOO region ranged from 12.2 to 22.7ºC during 2015 (Appendix A.1). Subsurface water temperatures ranged from 11.1 to 21.7ºC at 10–19 m, 10.7 to 21.7ºC at 20–28 m, 10.6 to 21.7ºC at 29–38 m, and 10.7 to 20.1ºC at 39–55 m. Ocean temperatures varied seasonally as expected throughout the year, with the maximum surface temperature occurring in August. However, warm waters persisted later into 2015, as evidenced by November's mean surface temperature (19.3ºC) which was ~1.6ºC higher than in November 2014 (City of San Diego 2015b). Additionally, all maximum subsurface temperatures occurred in November and were several degrees warmer than during the same time frame in 2014. The warm subsurface layers in November were consistent with El Niño conditions (Leising et al. 2015). Thermal stratification also followed typical seasonal patterns, with the greatest difference between surface and bottom waters (10.8ºC) occurring during August (Figure 2.2, Appendix A.1).

In shallow coastal waters of southern California and elsewhere, density is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, seasonal changes in thermal stratification were mirrored by the density stratification of the water column during each quarter (e.g., Figure 2.3). These vertical density profiles further demonstrated how the water column ranged from well-mixed during February and November with a maximum BF ≤32 cycles^2/min^2, to more stratified in May and August. Stratification values were lower in 2015 than in equivalent months during 2014, mostly due to warmer subsurface waters. As expected, the depth of the pycnocline also varied by season, with the shallowest pycnocline (<5 m) occurring during August when stratification was greatest.

Salinity

Salinities recorded in 2015 were similar to those reported previously for the SBOO region (e.g., City of San Diego 2013b, 2014b, 2015b). Surface salinity ranged from 33.16 to 33.78 psu at 1–9 m (Appendix A.1). Subsurface salinity ranged from 33.01 to 33.78 psu at 10–19 m, 33.07 to 33.77 psu at 20–28 m, 33.20 to 33.77 psu at 29–38 m, and 33.22 to 33.63 psu at 39–55 m. As with ocean temperatures, salinity varied seasonally. The highest values of the year were recorded in offshore surface waters in November (Figure 2.4). This unusual pattern may have been due to different current patterns present during El Niño and the intrusion of a warmer, more saline water mass (Leising et al. 2015, NWS 2016). During May, relatively high salinity >33.36 psu at bottom depths co-occurred with low water temperatures (e.g., Figures 2.2, 2.4). Taken together, low water temperatures and high salinity may indicate upwelling driven either by local winds that typically occur during spring months (Jackson 1986) or by divergent southerly flow in the lee of Point Loma (Roughan et al. 2005).

As in previous years, a layer of relatively low salinity water was evident at subsurface depths throughout the region, especially in May (Figure 2.4, Appendix A.1). It is unlikely that this subsurface salinity minimum layer (SSML) is related to wastewater discharge via the SBOO. First, no evidence has ever been reported of the plume extending simultaneously in multiple directions across such great distances. Instead, remote imaging results (e.g., Svejkovsky 2010), field observations, and other oceanographic studies (e.g., Terrill et al. 2009) have shown the plume to typically disperse in one direction at any given time (e.g., south, southeast, or north) or to occasionally pool above the outfall. Second, similar SSMLs have been reported previously off San Diego and elsewhere in southern California, including Orange and Ventura Counties, which suggests that this phenomenon is related to or driven by larger-scale oceanographic processes (e.g., City of San Diego 2010–2015a, b, OCSD 2015). Finally, other potential indicators of wastewater, such as elevated levels of fecal indicator bacteria or colored dissolved organic matter (CDOM), did not correspond to the SSML (see Chapter 3). Further investigation is required to determine the possible source or sources of this phenomenon. Highly localized areas of low salinity near the outfall that corresponded to higher CDOM values are discussed further in Chapter 3.

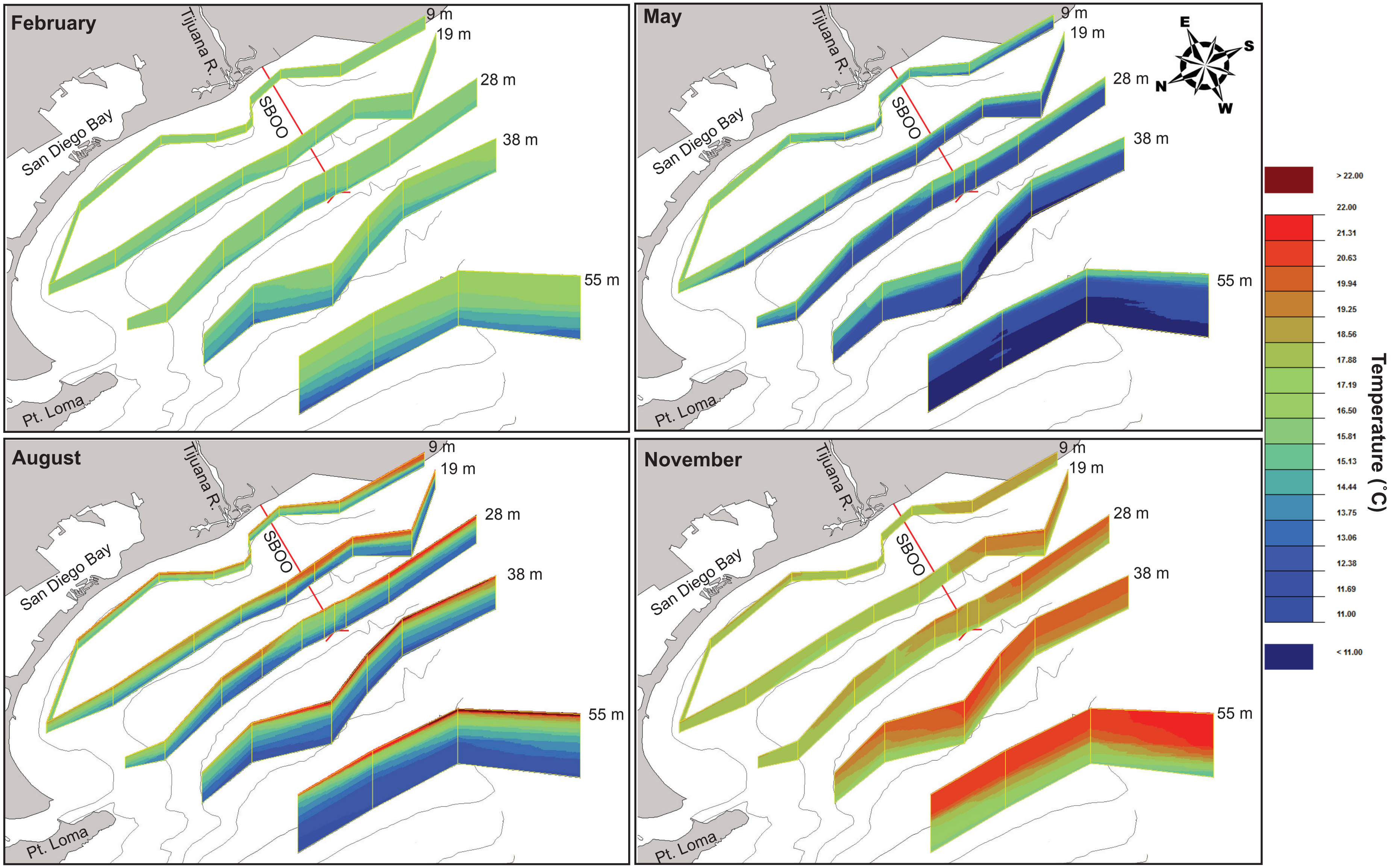

Figure 2.2
Ocean temperatures recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2015. Data were collected over 3–5 days during each of these surveys.

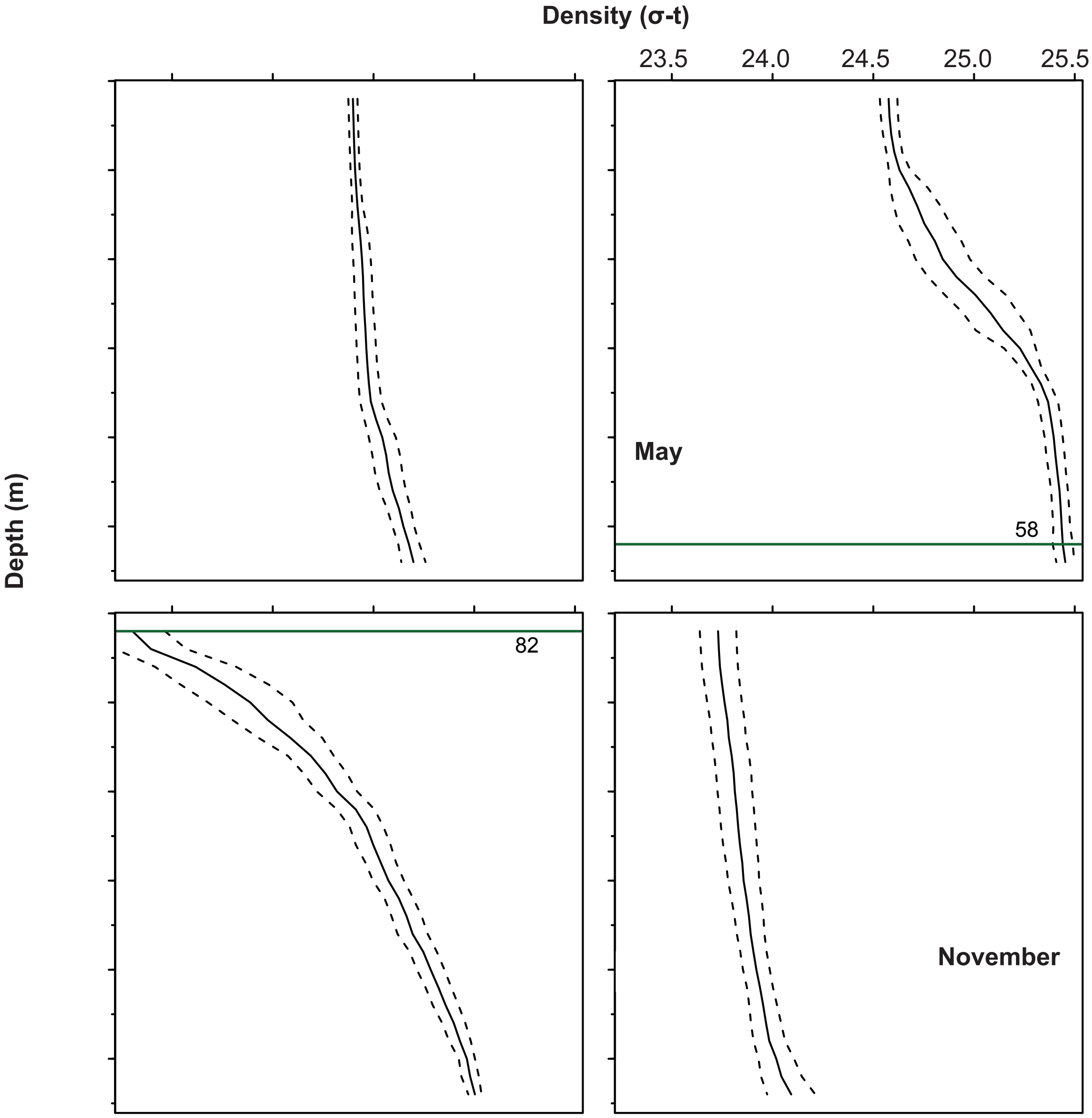

Figure 2.3

Density and maximum buoyancy frequency (BF) for each quarter at outfall depth stations sampled in the SBOO region during 2015. Solid lines are means, dotted lines are 95% confidence intervals (n = 13). Horizontal lines indicate depth of maximum BF with the number indicating the value in cycles^2/min^2. BF values less than 32 cycles^2/min^2 indicate a well-mixed water column and are not shown.

Dissolved oxygen and pH

Overall, DO and pH levels were within historical ranges throughout the year, with ranges of values observed in 2015 narrower than those of 2014 (City of San Diego 2015b). Surface DO ranged from 6.7 to 10.0 mg/L at 1–9 m (Appendix A.1). Subsurface DO ranged from 5.1 to 9.2 mg/L at 10–19 m, 5.3 to 8.7 mg/L at 20–28 m, 5.1 to 8.2 mg/L at 29–38 m, and 4.6 to 7.8 mg/L at 39–55 m. Surface pH ranged from 8.0 to 8.2 at 1–9 m. Subsurface pH ranged from 7.9 to 8.2 at 10–19 m, 20–28 m, and 29–38 m, and from 7.8 to 8.2 at 39–55 m. Changes in pH and DO were closely linked since both parameters reflect fluctuations in dissolved carbon dioxide associated with biological activity in coastal waters (Skirrow 1975).

Changes in DO and pH followed expected patterns that corresponded to seasonal fluctuations in water column stratification and phytoplankton

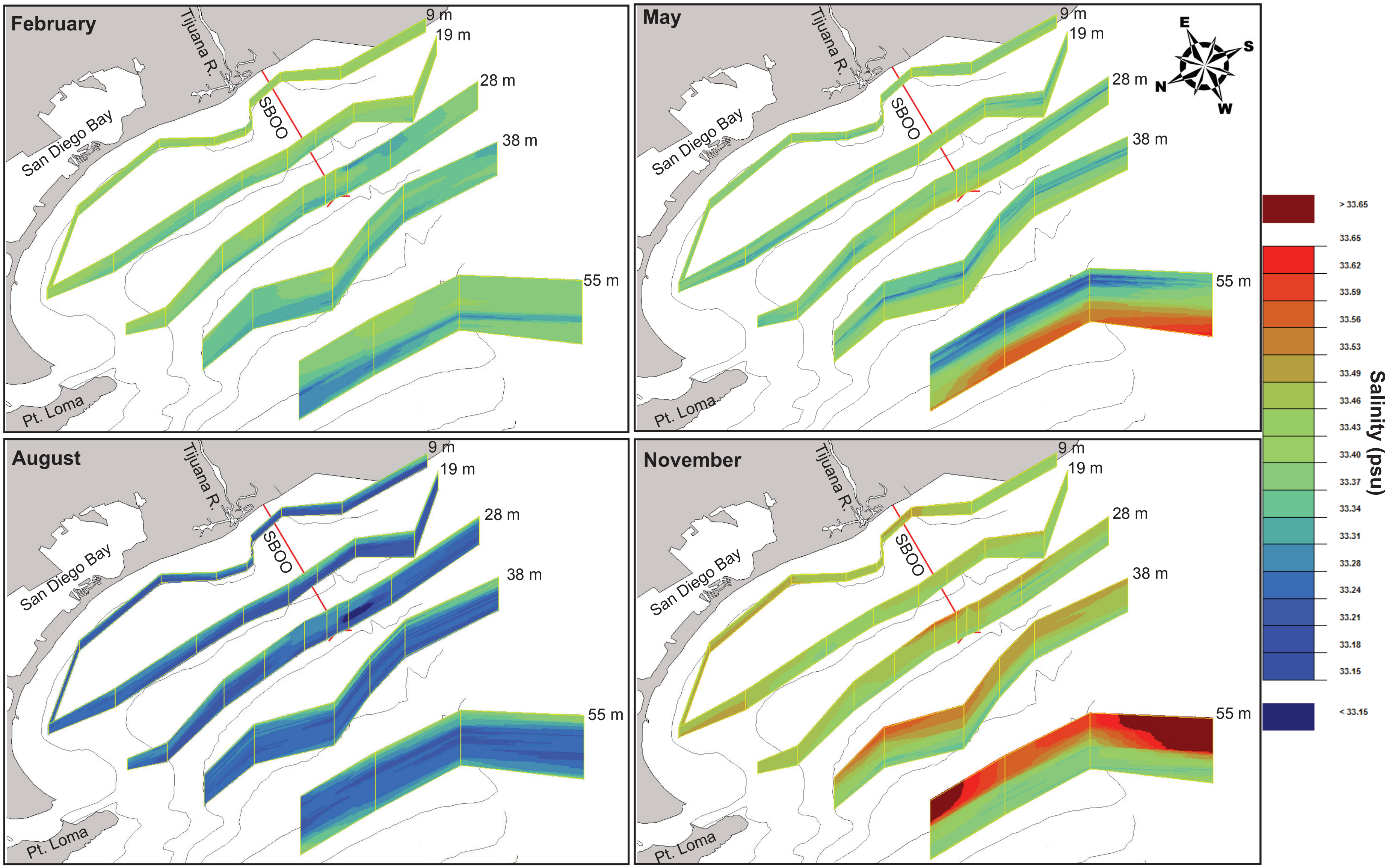

Figure 2.4
Ocean salinity recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2015. Data were collected over 3–5 days during each of these surveys.

productivity. The greatest cross-shelf variation and maximum stratification occurred during the spring (e.g., Appendices A.1, A.2, A.3). Low values for DO and pH that occurred subsurface at many stations in May were likely due to cold, saline, oxygen-poor ocean water moving inshore during periods of local upwelling as described above for temperature and salinity. Conversely, the highest DO concentrations (>9 mg/L) in the SBOO region that occurred during May were associated with a phytoplankton bloom, evident by relatively high chlorophyll *a* concentrations across the region.

Transmissivity

Overall, water clarity during 2015 was within historical ranges for the SBOO region (e.g., City of San Diego 2014b, 2015b). Surface transmissivity ranged from 38 to 90% at 1–9 m (Appendix A.1). Subsurface transmissivity ranged from 27 to 90% at 10–19 m, from 63 to 90% at 20–28 m, from 69 to 90% at 29–38 m, and from 84 to 90% at 39–55 m. In May, reduced transmissivity at mid-water depths tended to co-occur with peaks in chlorophyll *a* concentrations associated with phytoplankton blooms (see following section and Appendices A.1, A.4, A.5). Water clarity at the 9-m depth contour stations tended to be lower than the other stations in the region throughout the year, most likely due to coastal runoff and sediment resuspension due to wave activity (Appendix A.4, CDIP 2016).

Chlorophyll **a**

Concentrations of chlorophyll *a* ranged from 0.2 to 32.2 μg/L during 2015 (Appendix A.1). All relatively high values ≥11 μg/L occurred during May, similar to values reported during 2014 (Appendix A.5, City of San Diego 2015b). As has been reported previously (e.g., Svejkovsky 2011), the highest chlorophyll *a* concentrations coincided with the upwelling events described in previous sections.

Historical Assessment of Oceanographic Conditions

A review of temperature, salinity, and DO data from all outfall depth stations sampled from 1995 through 2015 (Figure 2.5) indicates how the SBOO coastal region has responded to long-term climate-related changes in the SCB, including conditions associated with ENSO, PDO and NPGO events (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, Leising et al. 2014, 2015, NOAA/NWS 2016). For example, seven major events have affected SCB coastal waters during the last two decades: (1) the 1997–98 El Niño; (2) a shift to cold ocean conditions reflected in ENSO and PDO indices from 1999 through 2002; (3) a subtle but persistent return to warm ocean conditions in the California Current System (CCS) that began in October 2002 and lasted through 2006; (4) the intrusion of subarctic waters into the CCS that resulted in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña in 2007 that coincided with a PDO cooling event and a return to positive NPGO values indicating an increased flow of cold, nutrient-rich water from the north; (6) development of another La Niña starting in May 2010; (7) a region-wide warming beginning in the winter of 2013/2014 when the PDO, NPGO and MEI (Multivariate ENSO Index) all changed phase preceding a strong El Niño in 2015. Temperature and salinity data for the SBOO region are consistent with all but the third of these events; while the CCS was experiencing a warming trend that lasted through 2006, the SBOO region experienced cooler than normal conditions during much of 2005 and the first half of 2006. The conditions in southern San Diego waters during 2005–2006 were more consistent with observations from northern Baja California where water temperatures were well below the decadal mean (Peterson et al. 2006). Further, below average salinities that persisted after the subarctic intrusion were likely associated with increased rainfall in the region (Goericke et al. 2007, NWS 2011). During 2015, temperatures were warmer than the long-term average in February, August and November while May was cooler, likely due to upwelling. The increased positive temperature anomalies in the latter half of the year are consistent with the ENSO event that developed to near record levels in 2015 (NOAA/NWS 2016).

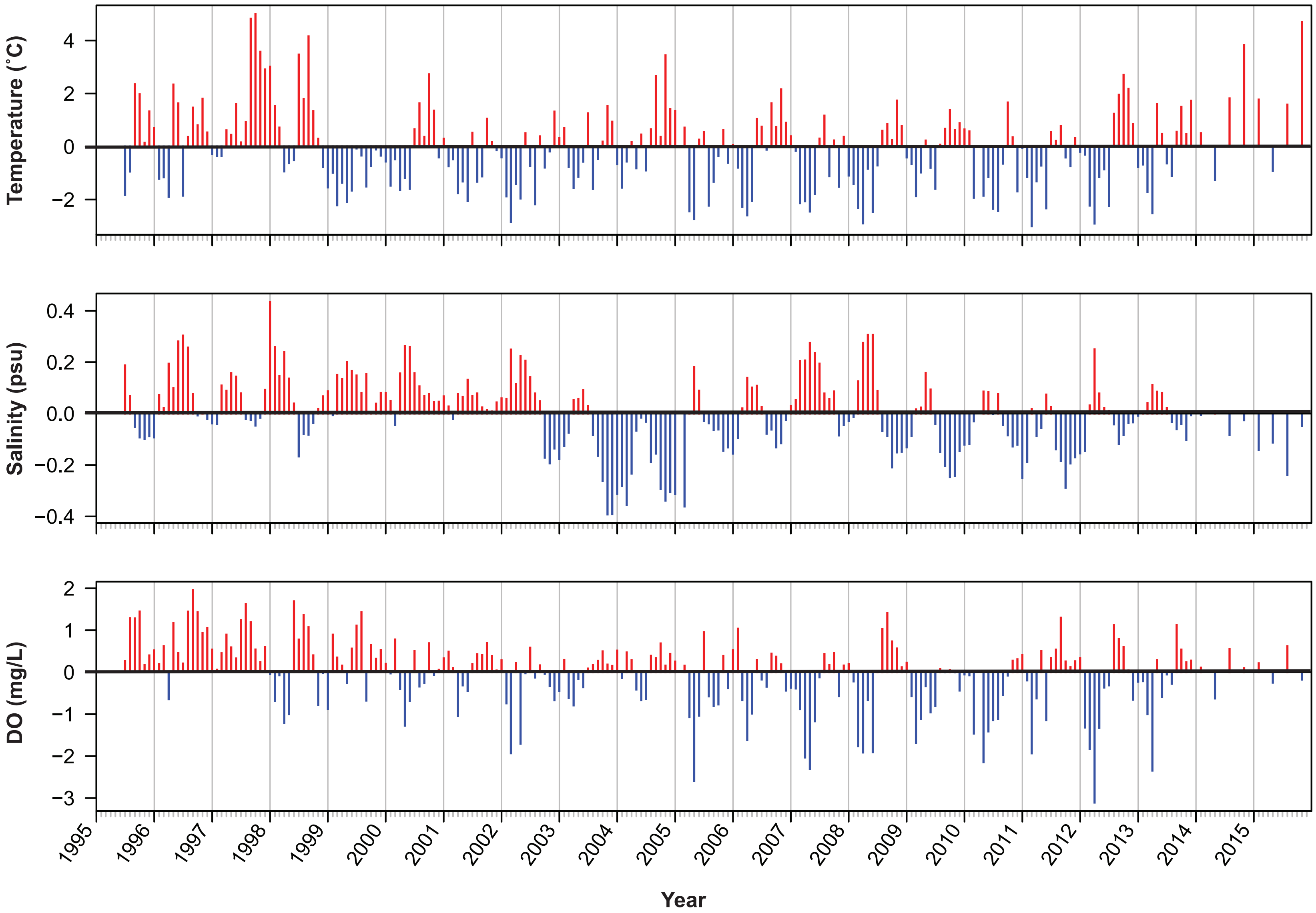

Figure 2.5
Time series of temperature, salinity, and dissolved oxygen (DO) anomalies from 1995 through 2015 at the 13 outfall depth stations sampled in the SBOO region, with all depths combined.

Historical trends in local DO concentrations reflect several periods during which lower than normal DO has aligned with low water temperatures and high salinity. The alignment of these anomalies is consistent with cold, saline and oxygen-poor ocean waters due to strong local coastal upwelling (e.g., 2002, 2005–2012). The overall decrease in DO in the SBOO region over the past decade has been observed throughout the entire CCS and may be linked to changing ocean climate (Bjorkstedt et al. 2012). However, these large negative anomalies have been absent since mid-2013 and were again near neutral conditions during most of 2015.

SUMMARY

Oceanographic data collected in the South Bay outfall region during 2015 were consistent with reports from NOAA that the ENSO-positive conditions that began in 2013 persisted and strengthened through the end of 2015 (Leising et al. 2015, NOAA/NWS 2016). Conditions indicative of local coastal upwelling, such as relatively cold, dense waters with low DO and pH at bottom depths, were observed during May. Phytoplankton blooms, indicated by high chlorophyll *a* concentrations, were only observed during May and were lower in magnitude than recent years.

Overall, water column stratification in 2015 followed seasonal patterns typical for the San Diego region. Maximum stratification occurred in mid-summer, while well-mixed waters were present during the winter. Further, oceanographic conditions were either consistent with long-term trends in the SCB (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, Leising et al. 2014, 2015, NOAA/NWS 2016) or with conditions in northern Baja California (Peterson et al. 2006). These observations suggest that most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego are explained by a combination of local (e.g., coastal upwelling, rain-related runoff) and large-scale oceanographic processes (e.g., ENSO, PDO, NPGO).

LITERATURE CITED

Bjorkstedt, E.P., R. Goericke, S. McClatchie, E. Weber, W. Watson, N. Lo, B. Peterson, B. Emmett, J. Peterson, R. Durazo, G. Gaxiola-Castro, F. Chavez, J.T. Pennington, C.A. Collins, J. Field, S. Ralston, K. Sakuma, S.J. Bograd, F.B. Schwing, Y. Xue, W.J. Sydeman, S.A. Thompson, J.A. Santora, J. Largier, C. Halle, S. Morgan, S.Y. Kim, K.B.P. Merkins, J.A. Hildebrand, and L.M. Munger. (2010). State of the California Current 2009–2010: Regional variation persists through transition from La Niña to El Niño (and back?). California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 51: 39–69.

Bjorkstedt, E.P., R. Goericke, S. McClatchie, E. Weber, W. Watson, N. Lo, B. Peterson, B. Emmett, R. Brodeur, J. Peterson, M. Litz, J. Gómez-Valdés, G. Gaxiola-Castro, B. Lavaniegos, F. Chavez, C.A. Collins, J. Field, K. Sakuma, S.J. Bograd, F.B. Schwing, P. Warzybok, R. Bradley, J. Jahncke, G.S. Campbell, J.A. Hildebrand, W.J. Sydeman, S.A. Thompson, J.L. Largier, C. Halle, S.Y. Kim, and J. Abell. (2011). State of the California Current 2010–2011: Regionally variable responses to a strong (but fleeting?) La Niña. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 52: 36–68.

Bjorkstedt, E.P., R. Goericke, S. McClatchie, E. Weber, W. Watson, N. Lo, W.T. Peterson, R.D. Brodeur, T. Auth, J. Fisher, C. Morgan, J. Peterson, J. Largier, S.J. Bograd, R. Durazo, G. Gaxiola-Castro, B. Lavaniegos, F.P. Chavez, C.A. Collins, B. Hannah, J. Field, K. Sakuma, W. Satterthwaite, M. O’Farrell, S. Hayes, J. Harding, W.J. Sydeman, S.A. Thompson, P. Warzybok, R. Bradley, J. Jahncke, R.T. Golightly, S.R. Schneider, R.M. Suryan, A.J. Gladics, C.A. Horton, S.Y. Kim, S.R. Melin, R.L. DeLong, and J. Abell. (2012). State of the California Current 2011–2012: Ecosystems respond to local forcing as La Niña wavers and wanes. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 53: 41–76.

Bowden, K.F. (1975). Oceanic and Estuarine Mixing Processes. In: J.P. Riley and G. Skirrow (eds.). Chemical Oceanography, 2nd Ed., Vol.1. Academic Press, San Francisco. p 1–41.

[CDIP] Coastal Data Information Program (2016). Archive of offshore wave buoy data. http://cdip.ucsd.edu/themes/cdip?pb=1&d2=p70&u3=s:191:st:1:v:hs_box_plot:dt:2015.

City of San Diego. (2010a). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011a). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012a). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013a). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014a). Point Loma Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014b). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015a). Point Loma Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015b). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015-2016). Monthly Receiving Waters Monitoring Reports for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), January–December 2015. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Goericke, R., E. Venrick, T. Koslow, W.J. Sydeman, F.B. Schwing, S.J. Bograd, W.T. Peterson, R.T. Emmett, J.R. Lara Lara, G. Gaxiola Castro, J.G. Valdez, K.D. Hyrenbach, R.W. Bradley, M.J. Weise, J.T. Harvey, C. Collins, and N.C.H. Lo. (2007). The state of the California Current, 2006–2007: Regional and local processes dominate. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 48: 33–66.

Harrell, F.E.Jr, C. Dupont and many others. (2015). Hmisc: Harrell Miscellaneous. R package version 3.17-0. http://CRAN.R-project.org/package=Hmisc

Hope, R.M. (2013). Rmisc: Ryan Miscellaneous. R package version 1.5. http://CRAN.R-project.org/package=Rmisc.

Jackson, G.A. (1986). Physical Oceanography of the Southern California Bight. In: R. Eppley (ed.). Plankton Dynamics of the Southern California Bight. Springer Verlag, New York. p 13–52.

Kelley, D. and C. Richards. (2015). oce: Analysis of Oceanographic Data. R package version 0.9-17. http://CRAN.R-project.org/package=oce

Largier, J., L. Rasmussen, M. Carter, and C. Scearce. (2004). Consent Decree – Phase One Study Final Report. Evaluation of the South Bay International Wastewater Treatment Plant Receiving Water Quality Monitoring Program to Determine Its Ability to Identify Source(s) of Recorded Bacterial Exceedences. Scripps Institution of Oceanography, University of California, San Diego, CA.

Leising, A.W., I.D. Schroeder, S.J. Bograd, E.P. Bjorkstedt, J. Field, K. Sakuma, J. Abell, R.R. Robertson, J. Tyburczy, W.T. Peterson, R. Brodeur, C. Barcelo, T.D. Auth, E.A. Daly, G.S. Campbell, J.A. Hildebrand, R.M. Suryan, A.J. Gladics, C.A. Horton, M. Kahru, M. Manzano-Sarabia, S. McClatchie, E.D. Weber, W. Watson, J.A. Santora, W.J. Sydeman, S.R. Melin, R.L. DeLong, J. Largier, S.Y. Kim, F.P. Chavez, R.T. Golightly, S.R. Schneider, P. Warzybok, R. Bradley, J. Jahncke, J. Fisher, and J. Peterson (2014). State of the California Current 2013-2014: El Niño Looming. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 55: 51–87.

Leising, A.W., I.D. Schroeder, S.J. Bograd, J. Abell, R. Durazo, G. Gaxiola-Castro, E.P. Bjorkstedt, J. Field, K. Sakuma, R.R. Robertson, R. Goericke, W.T. Peterson, R.D. Brodeur, C. Barceló, T.D. Auth, E.A. Daly, R.M. Suryan, A.J. Gladics, J.M. Porquez, S. McClatchie, E.D. Weber, W. Watson, J.A. Santora, W.J. Sydeman, S.R. Melin, F.P. Chavez, R.T. Golightly, S.R. Schneider, J. Fisher, C. Morgan, R. Bradley, and P. Warybok (2015). State of the California Current 2014-2015: Impacts of the Warm-Water “Blob”. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 56: 31–69.

Lynn, R.J. and J.J. Simpson. (1987). The California Current System: The Seasonal Variability of its Physical Characteristics. Journal of Geophysical Research, 92(C12): 12947–12966.

Mann, K.H. (1982). Ecology of Coastal Waters, A Systems Approach. University of California Press, Berkeley.

Mann. K.H. and J.R.N. Lazier. (1991). Dynamics of Marine Ecosystems, Biological–Physical Interactions in the Oceans. Blackwell Scientific Publications, Boston.

McClatchie, S., R. Goericke, J.A. Koslow, F.B. Schwing, S.J. Bograd, R. Charter, W. Watson, N. Lo, K. Hill, J. Gottschalck, M. l'Heureux, Y. Xue, W.T. Peterson, R. Emmett, C. Collins, G. Gaxiola-Castro, R. Durazo, M. Kahru, B.G. Mitchell, K.D. Hyrenbach, W.J. Sydeman, R.W. Bradley, P. Warzybok, and E. Bjorkstedt. (2008). The state of the California Current, 2007–2008: La Niña conditions and their effects on the ecosystem. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 49: 39–76.

McClatchie, S., R. Goericke, J.A. Koslow, F.B. Schwing, S.J. Bograd, R. Charter, W. Watson, N. Lo, K. Hill, J. Gottschalck, M. l'Heureux, Y. Xue, W.T. Peterson, R. Emmett, C. Collins, J. Gomez-Valdes, B.E. Lavaniegos, G. Gaxiola-Castro, B.G. Mitchell, M. Manzano-Sarabia, E. Bjorkstedt. S. Ralston, J. Field, L. Rogers-Bennet, L. Munger, G. Campbell, K. Merkens, D. Camacho, A. Havron, A. Douglas, and J. Hildebrand. (2009). The state of the California Current, Spring 2008–2009: Cold conditions drive regional differences in coastal production. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 50: 43–68.

[NOAA/NWS] National Oceanic and Atmospheric Administration/National Weather Service. (2016). Climate Prediction Center Website. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory.html.

[NWS] National Weather Service. (2011). Local weather information Website. http://www.nws.noaa.gov/climate/ index.php?wfo=sgx.

[NWS] National Weather Service. (2016). Local weather information Website. http://www.nws.noaa.gov/climate/ index.php?wfo=sgx.

Ocean Imaging. (2016). Ocean Imaging Corporation archive of aerial and satellite-derived images. http://www.oceani.com/SanDiegoWater/index.html.

Ocean Software. (2009). IGODS: Interactive Graphical Ocean Data System Reference Manual and Tutorial; WindowsTM Edition.

[OCSD] Orange County Sanitation District. (2015). Ocean Monitoring Annual Report, Year 2013 – 2014. Marine Monitoring, Fountain Valley, CA.

Peterson, B., R. Emmett, R. Goericke, E. Venrick, A. Mantyla, S.J. Bograd, F.B. Schwing, R. Hewitt, N. Lo, W. Watson, J. Barlow, M. Lowry, S. Ralston, K.A. Forney, B.E. Lavaniegos, W.J. Sydeman, D. Hyrenbach, R.W. Bradley, P. Warzybok, F. Chavez, K. Hunter, S. Benson, M. Weise, J. Harvey, G. Gaxiola-Castro, and R. Durazo. (2006). The state of the California Current, 2005–2006: Warm in the north, cool in the south. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 47: 30–74.

Pickard, D.L. and W.J. Emery. (1990). Descriptive Physical Oceanography. 5th Ed. Pergamon Press, Oxford.

Project Clean Water. (2012). San Diego's Watersheds Website. http://www.projectcleanwater.org/html/watersheds.html

R Core Team. (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ripley, B. and M. Lapsley. (2015). RODBC: ODBC Database Access. R package version 1.3-12. http://CRAN.R-project.org/package=RODBC.

Roughan, M., E.J. Terrill, J.L. Largier, and M.P. Otero. (2005). Observations of divergence and upwelling around Point Loma, California. Journal of Geophysical Research, 110(C04011): 10.1029/2004JC002662.

Skirrow, G. (1975). Chapter 9. The Dissolved Gases–Carbon Dioxide. In: J.P. Riley and G. Skirrow (eds.). Chemical Oceanography. Academic Press, London. Vol. 2. p 1–181.

Svejkovsky J. (2010). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report for: 1 January 2009 – 31 December 2009. Solana Beach, CA.

Svejkovsky J. (2011). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report for: 1 January 2010 – 31 December 2010. Solana Beach, CA.

Svejkovsky J. (2016). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report for: 1 January 2015 – 31 December 2015. Solana Beach, CA.

Terrill, E., K. Sung Yong, L. Hazard, and M. Otero. (2009). IBWC/Surfrider – Consent Decree Final Report. Coastal Observations and Monitoring in South Bay San Diego. Scripps Institution of Oceanography, University of California, San Diego, CA.

Wells, B.K., I.D. Schroeder, J.A. Santora, E.L. Hazen, S.J. Bograd, E.P. Bjorkstedt, V.J. Loeb, S. McClatchie, E.D. Weber, W. Watson, A.R. Thompson, W.T. Peterson, R.D. Brodeur, J. Harding, J. Field, K. Sakuma, S. Hayes, N. Mantua, W.J. Sydeman, M. Losekoot, S.A. Thompson, J. Largier, S.Y. Kim, F.P. Chavez, C. Barcelo, P. Warzybok, R. Bradley, J. Jahncke, R. Goericke, G.S. Campbell, J.A. Hildebrand, S.R. Melin, R.L. DeLong, J. Gomez-Valdes, B. Lavaniegos, G. Gaxiola-Castro, R.T. Golightly, S.R. Schneider, N. Lo, R.M. Suryan, A.J. Gladics, C.A. Horton, J. Fisher, C. Morgan, J. Peterson, E.A. Daly, T.D. Auth, and J. Abell. (2013). State of the California Current 2012-2013: no such thing as an “average” year. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 54: 37–71.

Wickham, H. (2007). Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL http://www.jstatsoft.org/v21/i12/.

Chapter 3
Water Quality Compliance & Plume Dispersion

Chapter 3. Water Quality Compliance and Plume Dispersion

Introduction

The City of San Diego analyzes seawater samples collected along the shoreline and in offshore coastal waters surrounding the South Bay Ocean Outfall (SBOO) to characterize water quality conditions in the region and to identify possible impacts of wastewater discharge on the marine environment. Densities of fecal indicator bacteria, including total coliforms, fecal coliforms, and *Enterococcus* are measured and evaluated in context with oceanographic data (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged into the Pacific Ocean through the outfall. Evaluation of these data may also help to identify other sources of bacterial contamination in the region. In addition, the City's water quality monitoring efforts are designed to assess compliance with the water contact standards specified in the California Ocean Plan (Ocean Plan), which defines bacterial, physical, and chemical water quality objectives and standards with the intent of protecting the beneficial uses of State ocean waters (SWRCB 2012).

Multiple sources of potential bacterial contamination exist in the South Bay outfall monitoring region. Therefore, being able to separate any impacts associated with a wastewater plume from the SBOO or other sources of contamination is often challenging. Examples of other sources of contamination include outflows from San Diego Bay, the Tijuana River, and Los Buenos Creek in northern Baja California (Largier et al. 2004, Nezlin et al. 2007, Gersberg et al. 2008, Terrill et al. 2009). Likewise, storm water discharges and runoff from local watersheds during wet weather can also flush contaminants seaward (Noble et al. 2003, Reeves et al. 2004, Sercu et al. 2009, Griffith et al. 2010). Moreover, beach wrack (e.g., kelp, seagrass), storm drains, and beach sediments can act as reservoirs for bacteria until release into nearshore waters by returning tides, rainfall, or other disturbances (Gruber et al. 2005, Martin and Gruber 2005, Noble et al. 2006, Yamahara et al. 2007, Phillips et al. 2011). Further, the presence of birds and their droppings has been associated with bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2010).

In order to better understand potential impacts of a wastewater plume on water quality conditions, analytical tools based on natural chemical tracers can be leveraged to detect effluent from an outfall and separate it from other non-point sources. For example, colored dissolved organic material (CDOM) has previously been used to identify wastewater plumes in the San Diego region (Terrill et al. 2009, Rogowski et al. 2012a, b, 2013). The reliability of plume detection can be improved by combining measurements of CDOM with additional metrics such as low chlorophyll *a* and salinity, thus facilitating quantification of wastewater plume impacts on the coastal environment.

This chapter presents analysis and interpretation of the microbiological, water chemistry, and oceanographic data collected during calendar year 2015 at water quality monitoring stations surrounding the SBOO. The primary goals are to: (1) document overall water quality conditions in the region; (2) distinguish between the SBOO wastewater plume and other sources of bacterial contamination; (3) evaluate potential movement and dispersal of the plume; (4) assess compliance with water contact standards defined in the Ocean Plan. Results of remote sensing data for the region are also evaluated to provide insight into wastewater transport and the extent of

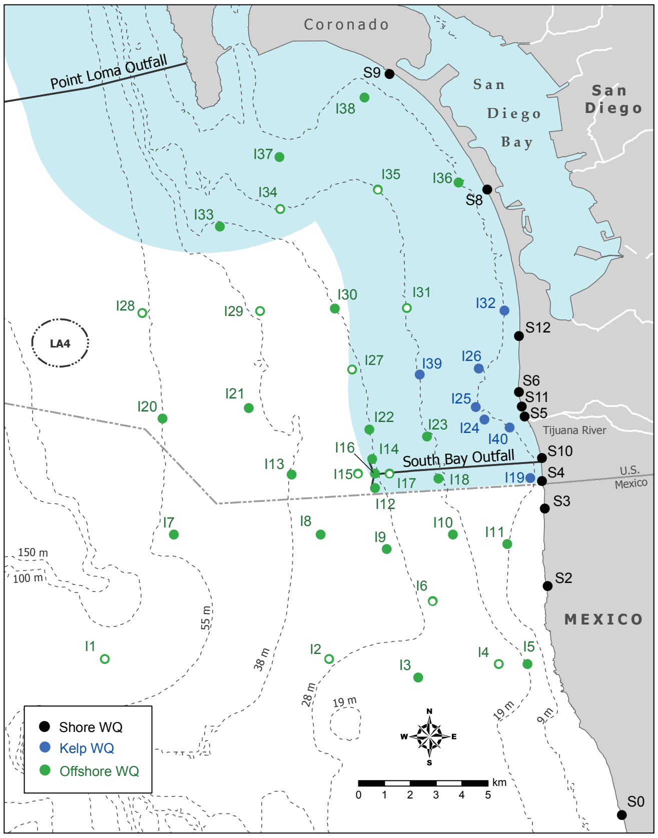

Figure 3.1

Water quality (WQ) monitoring station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program. Open circles are sampled by CTD only. Light blue shading represents State jurisdictional waters.

Table 3.1

Depths from which seawater samples are collected for bacteriological analysis at the SBOO kelp and other offshore stations.

Station Contour	Sample Depth (m) 2	6	9/11	12	18	27	37	55
Kelp								
9-m	x	x	x[a]					
19-m	x			x	x			
Offshore								
9-m	x	x	x[a]					
19-m	x			x	x			
28-m	x				x	x		
38-m	x				x		x	
55-m	x				x			x

[a] Stations I25, I26, I32, and I40 sampled at 9 m; stations I11, I19, I24, I36, I37, and I38 sampled at 11 m

significant events in surface waters during the year (e.g., turbidity plumes).

MATERIALS AND METHODS

Field Sampling

Shore stations

Seawater samples were collected weekly at 11 shore stations to monitor fecal indicator bacteria (FIB) concentrations in waters adjacent to public beaches (Figure 3.1). Of these, stations S4–S6 and S8–S12 are located in California waters between the USA/Mexico border and Coronado and are subject to Ocean Plan water contact standards (see Box 3.1). The other three stations (i.e., S0, S2, S3) are located south of the USA/Mexico border and are not subject to Ocean Plan requirements. Seawater samples were collected from the surf zone at each shore station in sterile 250-mL bottles, transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML), and analyzed to determine concentrations of total coliform, fecal coliform, and *Enterococcus* bacteria. In addition, water temperature and visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. These observations were previously reported in monthly receiving waters monitoring reports submitted to the San Diego Regional Water Quality Control Board (SDRWQCB) (see City of San Diego 2015-2016).

Kelp and other offshore stations

Three kelp bed stations at depths of 9–18 m (I25, I26, I39) and four other nearshore stations along the 9-m depth contour (I19, I24, I32, I40) were monitored five times a month to assess water quality conditions and Ocean Plan compliance in areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking. These seven stations are collectively referred to as "kelp" stations herein. An additional 21 offshore stations were sampled quarterly to monitor FIB levels and to estimate the spatial extent of the wastewater plume. These stations are arranged in a grid surrounding the discharge site along the 9,

Box 3.1

Water quality objectives for water contact areas, California Ocean Plan (SWRCB 2012).

A. Bacterial Characteristics – Water Contact Standards; CFU = colony forming units

(a) *30-day Geometric Mean* – The following standards are based on the geometric mean of the five most recent samples from each site:

1) Total coliform density shall not exceed 1000 CFU/100 mL.
2) Fecal coliform density shall not exceed 200 CFU/100 mL.
3) *Enterococcus* density shall not exceed 35 CFU/100 mL.

(b) *Single Sample Maximum*:

1) Total coliform density shall not exceed 10,000 CFU/100 mL.
2) Fecal coliform density shall not exceed 400 CFU/100 mL.
3) *Enterococcus* density shall not exceed 104 CFU/100 mL.
4) Total coliform density shall not exceed 1000 CFU/100 mL when the fecal coliform:total coliform ratio exceeds 0.1.

B. Physical Characteristics

(a) Floating particulates and oil and grease shall not be visible.
(b) The discharge of waste shall not cause aesthetically undesirable discoloration of the ocean surface.
(c) Natural light shall not be significantly reduced at any point outside of the initial dilution zone as the result of the discharge of waste.

C. Chemical Characteristics

(a) The dissolved oxygen concentration shall not at any time be depressed more than 10 percent from what occurs naturally, as a result of the discharge of oxygen demanding waste materials.
(b) The pH shall not be changed at any time more than 0.2 units from that which occurs naturally.

19, 28, 38, and 55-m depth contours (Figure 3.1). During 2015, quarterly sampling occurred during February, May, August and November over a 3–5 day period (see Table 2.1 in Chapter 2).

Seawater samples for bacterial analyses were collected from three discrete depths at each of the above stations using either an array of Van Dorn bottles or a rosette sampler fitted with Niskin bottles (Table 3.1). During quarterly sampling, aliquots for total suspended solids (TSS) analysis were collected with the FIB samples at all depths, while aliquots for oil and grease (O&G) analysis were collected from surface waters only. Aliquots for each analysis were drawn into appropriate sample containers. FIB samples were refrigerated onboard ship and transported to the CSDMML for processing and analysis. TSS and O&G samples were analyzed at the City's Environmental Chemistry Services Laboratory. Oceanographic data were collected from each station using a CTD to measure temperature, conductivity (salinity), pressure (depth), chlorophyll *a*, CDOM, dissolved oxygen (DO), pH, and transmissivity (see Chapter 2). Visual observations of weather and sea conditions, and human and/or animal activity were recorded at the time of sampling. These observations were also previously reported in monthly receiving waters monitoring reports submitted to the SDRWQCB (see City of San Diego 2015-2016).

Laboratory Analyses

The CSDMML follows guidelines issued by the United States Environmental Protection Agency (USEPA) Water Quality Office and the California Department of Public Health (CDPH) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 2005, CDPH 2000, USEPA 2006). All bacterial analyses were performed within eight hours of sample collection and conformed to standard membrane filtration techniques (APHA 2005).

Enumeration of FIB density was performed and validated in accordance with USEPA (Bordner et al. 1978, USEPA 2006) and APHA (2005) guidelines. Plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values when calculating means and in determining compliance with Ocean Plan standards.

Quality assurance tests were performed routinely on seawater samples to ensure that analyses and sampling variability did not exceed acceptable limits. Bacteriological laboratory and field duplicate samples were processed according to method requirements to measure analyst precision and variability between samples, respectively. Results of these procedures were reported under separate cover (City of San Diego 2016).

Data Analyses

Bacteriology

FIB densities (total coliforms, fecal coliforms, *Enterococcus*) were summarized as monthly means for each shore station and by depth contour and month for the kelp bed stations. Bacterial, TSS, and O&G concentrations were summarized by quarter for the other offshore stations. In order to assess temporal and spatial trends, the data were summarized as the number of samples in which FIB concentrations exceeded benchmark levels. For this report, the single sample maximum standards defined in the Ocean Plan for total coliforms, fecal coliforms, and *Enterococcus* were used as benchmarks to distinguish elevated FIB values. (see Box 3.1 and SWRCB 2012). Bacterial densities were compared to rainfall data from Lindbergh Field, San Diego, CA (see NOAA 2016). Chi-squared Tests (χ^2) were conducted to determine if the frequency of samples with elevated FIB counts differed at the shore and kelp bed stations between wet (October–April) and dry (May–September) seasons, and to determine if elevated FIB counts differed between the three outfall stations (I12, I14, I16) and the other stations located along the 28-m depth contour. Satellite images of the San Diego coastal region were provided by Ocean Imaging of Solana Beach, California (Ocean Imaging 2016) and used to aid in the analysis and interpretation of water quality data (see Chapter 2 for remote sensing details). Finally, compliance with Ocean Plan water contact standards was summarized as the number of times per sampling period that each of the eight shore stations located north of the USA/Mexico border, the seven kelp stations, and the other 10 offshore stations located within State jurisdictional waters exceeded the various standards. These analyses were performed using R (R Core Team, 2015) and various functions within the Hmisc, psych, quantreg, reshape2, R.oo and RODBC packages (Bengtsson 2003, Wickham 2007, Harrell et al. 2015, Revelle 2015, Ripley and Lapsley 2015, Koenker 2016).

Wastewater Plume Detection and Out-of-range Calculations

The potential presence or absence of the wastewater plume was determined at each station using a combination of oceanographic parameters (i.e., detection criteria). All stations along the 9-m depth contour were excluded from analyses due to the potential for coastal runoff or nearshore sediment resuspension to confound a CDOM signal from the outfall (Appendix B.1). Previous monitoring has consistently found that the SBOO plume stays trapped below the pycnocline during seasonal water column stratification, but may rise to the surface when stratification breaks down (City of San Diego 2010–2015, Terrill et al. 2009). Water column stratification and pycnocline depth were quantified using calculations of buoyancy frequency (cycles^2/min^2) for each quarterly survey (see Chapter 2). For the purposes of the plume dispersion analysis, buoyancy frequency calculations included data from those stations that would be most likely to demonstrate the potential plume trapping depth (i.e., all stations located along the 19, 28, 38, and 55-m depth contours). If the water column was stratified (i.e., maximum buoyancy frequency > 32 cycles^2/min^2), subsequent analyses were limited to depths below the pycnocline. Identification of a potential plume signal at a station was based on: (1) high CDOM; (2) low salinity; (3) low chlorophyll *a*; (4) visual interpretation of the overall water column profile. Detection thresholds were adaptively set for each quarterly sampling period according to the following criteria: CDOM exceeding the 95th percentile, chlorophyll *a* below the 90th percentile, and salinity below the 40th percentile. The threshold for chlorophyll *a* was incorporated to exclude CDOM derived from marine phytoplankton (Nelson et al. 1998, Rochelle-Newall and Fisher 2002, Romera-Castillo et al. 2010). These analyses were performed using R (R Core Team, 2015) and various functions within the oce, reshape2, Rmisc, and RODBC packages (Wickham 2007, Hope 2013, Kelley and Richards 2015, Ripley and Lapsley 2015). It should be noted that these thresholds are based on regional observations of ocean properties and are thus constrained to use within the SBOO region only. Finally, water column profiles were visually interpreted to remove stations with spurious signals (e.g., CDOM signals near the sea floor that were likely caused by resuspension of sediments). Exclusion of stations using the chlorophyll *a* and salinity criteria was confirmed as part of the visual interpretation of the profiles.

After identifying the stations and depth-ranges where detection criteria suggested the wastewater plume may be present, potential impact of the plume on water quality was assessed by comparing mean values of DO, pH, and transmissivity within the possible plume to thresholds calculated for similar depths from reference stations. Stations with all CDOM values below the 85th percentile were considered outside the plume and were used as reference stations for that quarterly survey (Appendix B.2). Individual stations were determined to be out-of-range (OOR) compared to the reference stations if values exceeded the narrative water quality standards for these parameters as defined by the Ocean Plan (Box 3.1). The Ocean Plan defines OOR thresholds for DO as a 10% reduction from that which occurs naturally, while the OOR threshold for pH is defined as a 0.2 pH unit change, and the OOR for transmissivity is defined as dropping below the lower 95% confidence interval from the mean. For the purposes of this report, "naturally" was defined for DO as the mean minus one standard deviation (see Nezlin et al., 2016).

RESULTS AND DISCUSSION

Bacteriological Compliance and Distribution

Shore stations

During 2015, compliance with the 30-day geometric mean standards at the eight shore stations located north of the USA/Mexico border ranged from 79 to 100% for total coliforms, 81 to 100% for fecal coliforms, and 57 to 100% for *Enterococcus* (Figure 3.2A). In addition, compliance with the single sample maximum (SSM) standards ranged from 79 to 100% for total coliforms, 75 to 100% for fecal coliforms, 67 to 100% for *Enterococcus*, and 81 to 100% for the fecal:total coliform (FTR) criterion (Figure 3.2B). However, six of these stations (S4, S5, S6, S10, S11, S12) are located within or immediately adjacent to areas listed as impaired waters and are not expected to be in compliance with water contact standards (SOC 2010). Thus, when these stations are excluded, overall compliance at the remaining two shore stations (i.e., S8, S9) was 95% in 2015. In contrast to previous years, reduced compliance occurred during both the wet and dry seasons, with only the months of April and September exhibiting 100% compliance for all standards. This unusual pattern was due to significant rainfall events that occurred during May and July (see Appendix B.3 and NOAA 2016).

Monthly mean FIB densities ranged from 2 to 36,010 CFU/100mL for total coliforms, 2 to 3074 CFU/100mL for fecal coliforms, and 2 to 3681 for *Enterococcus* at the individual stations (Appendix B.3). Of the 572 seawater samples collected along the shore during the year (not including resamples), 11% (n = 61) had elevated FIB (Appendix B.4), which is similar to what was

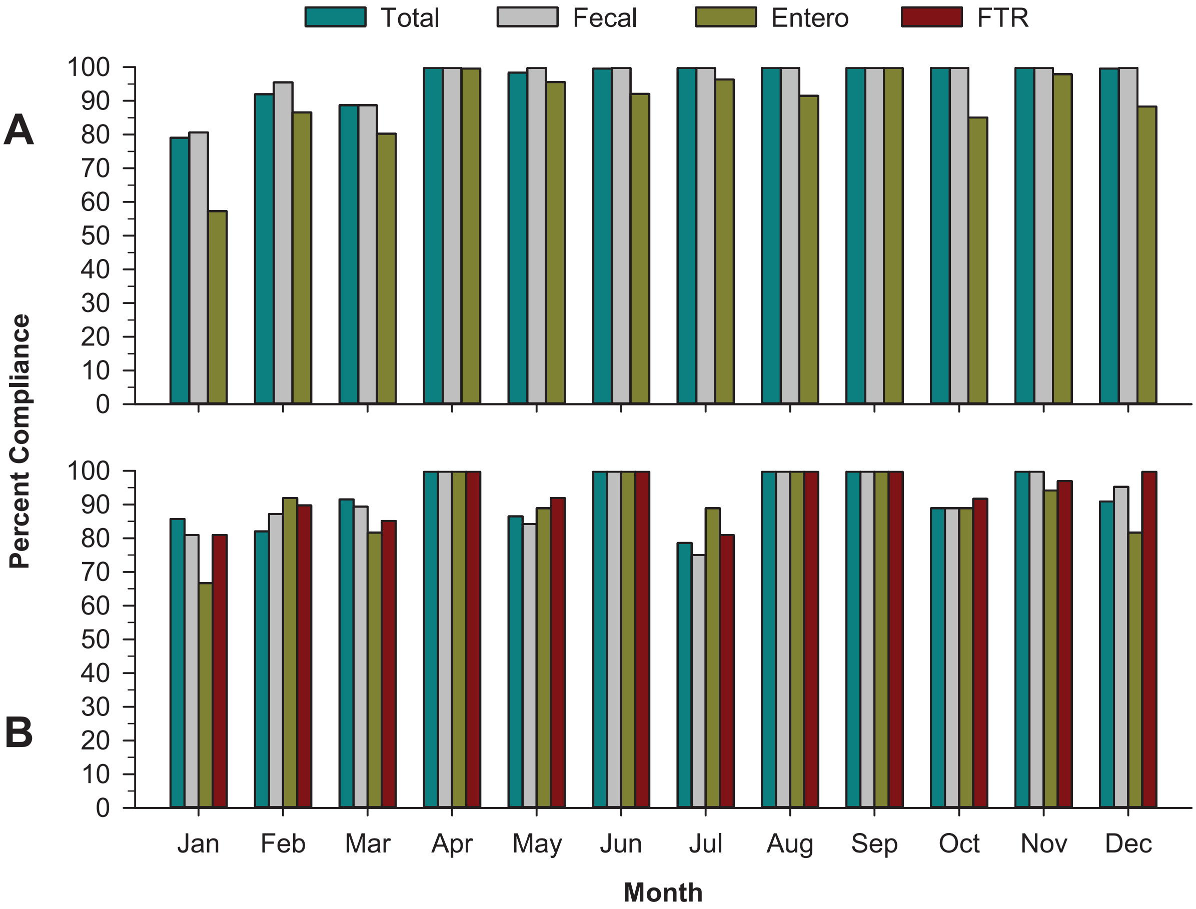

Figure 3.2
Compliance rates for (A) the three geometric mean and (B) the four single sample maximum water contact standards from SBOO shore stations during 2015.

observed during 2014 (City of San Diego 2015). Despite the unusually high amount of rain that fell during the dry season in 2015 (5.40 inches), a majority (74%) of the shore samples with elevated FIB were collected in the wet season when rainfall totaled 4.5 inches (Table 3.2). This general relationship between rainfall and elevated bacterial levels has been evident from water quality monitoring in the region since 1996 (Figure 3.3). For example, historical analyses indicate that a sample with elevated FIB was significantly more likely to occur during the wet than dry season (e.g., 21% versus 7%, respectively; $n = 12{,}270$, $\chi^2 = 461.60$, $p < 0.0001$).

During 2015, elevated FIB were primarily detected at shore stations located close to the mouth of the Tijuana River (S4, S5, S10, S11) as well as in Mexico (S0, S2, S3) (Table 3.2, Appendix B.4). Results from historical analyses also indicated elevated FIB densities occur more frequently at stations near the Tijuana River and south of the international border near Los Buenos Creek than at other shore stations, especially during the wet season (Figure 3.4). Over the past several years, high FIB counts at these stations have consistently corresponded to outflows from the Tijuana River and Los Buenos Creek, typically following rain events (City of San Diego 2008–2015). For example, satellite imagery following a rain event in March shows numerous turbidity plumes, including plumes originating from the Tijuana River and from Los Buenos Creek that overlap with shore stations with elevated FIB (Figure 3.5). Additionally, storm drain runoff was often observed at all three stations located in Mexico.

Kelp stations

During 2015, compliance at the seven SBOO kelp stations was ≥96% for all water contact standards (Figure 3.6). Compliance with the 30-day geometric mean standards ranged from 96%–99% in January, then remained at 100% for the rest of the year. In contrast, compliance with the four SSM standards dropped slightly to as low as 97% during January, February, March, November, and December, corresponding to some of the biggest rainfall events of the year (i.e., 0.28 inches in February to 1.55 inches November).

Monthly mean FIB densities at the kelp stations were lower than those at shore stations, ranging from 2 to 767 CFU/100 mL for total coliforms, 2 to 49 CFU/100 mL for fecal coliforms, and 2 to 20 CFU/100 mL for *Enterococcus* (Appendix B.5). Nothing of sewage origin was observed at these stations. Of the 1239 kelp samples analyzed during the year (not including resamples), only 1% (n = 12) had elevated FIB (Appendix B.6). Of these exceedances, 92% (n = 11) occurred during the wet season (Table 3.3), despite the high levels of rainfall during the dry season months. Historical water quality monitoring data for the region (Figure 3.7) indicate that elevated FIB were significantly more likely to occur during the wet season than during the dry season (8% versus 1%, respectively; $n = 12,836$, $\chi^2 = 336.86$, $p < 0.0001$). As with the

Table 3.2

Number of samples with elevated FIB (eFIB) densities collected from SBOO shore stations during wet and dry seasons in 2015. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

	Seasons		
Station	**Wet**	**Dry**	**% Wet**
North of USA/Mexico Border			
S9	1	1	50
S8	1	1	50
S12	2	1	67
S6	2	1	67
S11	4	2	67
S5	8	3	73
S10	5	1	83
S4	6	0	100
South of USA/Mexico Border			
S3	1	1	50
S2	3	3	50
S0	12	2	86
Rain (in)	4.52	5.40	46
Total eFIB	45	16	74
Total Samples	330	242	58

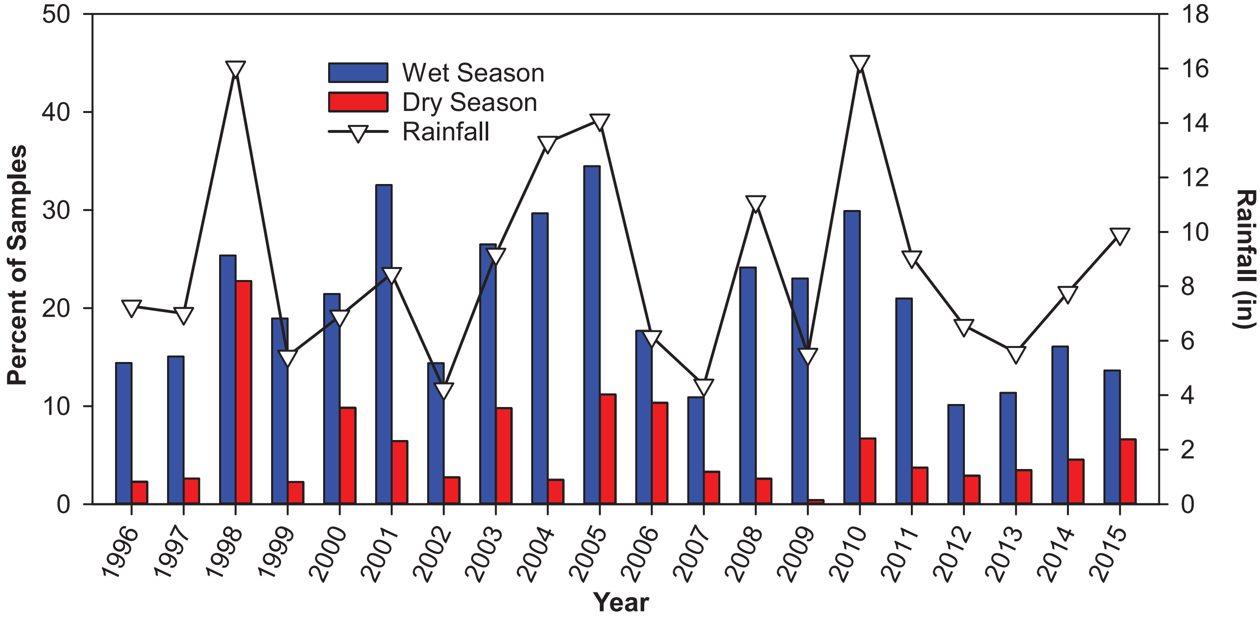

Figure 3.3

Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet versus dry seasons at SBOO shore stations from 1996 through 2015. Rain data are from Lindbergh Field, San Diego, CA. Data from 1995 were excluded as sampling did not occur the entire year.

shore stations, high FIB counts at kelp stations have historically corresponded to outflows from the Tijuana River and Los Buenos Creek, typically following rain events (City of San Diego 2008–2015). This pattern held true in 2015, with all elevated FIB detected at kelp stations located close to the mouth of the Tijuana River (i.e., stations I19, I24, I25, I40) subsequent to significant rainfall (Table 3.3, Figure 3.8, Appendix B.6). Satellite imagery frequently illustrates rain-driven turbidity plumes originating from the Tijuana River overlapping kelp stations with elevated FIB (e.g., Figure 3.5).

Of the 28 samples collected from the kelp stations during 2015, none contained detectable levels of O&G (detection limit = 0.2 mg/L). In contrast, detection rates for TSS ranged from 62% in February and November to 86% in May, with concentrations ≤ 10.6 mg/L (Table 3.4). Seven of the 84 TSS samples collected contained elevated concentrations ≥ 8.0 mg/L. There were no elevated FIB densities associated with these samples.

Other offshore stations

During 2015, water quality was extremely high at all of the non-kelp offshore stations sampled quarterly, including the three stations located closest to the SBOO south diffuser leg (i.e., outfall stations I12, I14, I16). Monthly mean FIB concentrations in seawater samples collected offshore were low, ranging from 2 to 49 CFU/100 mL for total coliforms, 2 to 4 CFU/100 mL for fecal coliforms, and 2 to 8 CFU/100 mL for *Enterococcus* (Appendix B.5). These low FIB densities translated to > 99% overall compliance with the SSM water contact standards for the 10 offshore stations located within State jurisdictional waters (i.e., I12, I14, I16, I18, I22, I23, I33, I36–I38) during the year (Figure 3.9). Only one of the 252 samples collected from the above stations had elevated FIB. This sample was collected in February from station I12 at a depth of 2 m (Table 3.3, Figure 3.8, Appendix B.6).

Historically, samples with elevated bacterial levels have been collected more often at the three

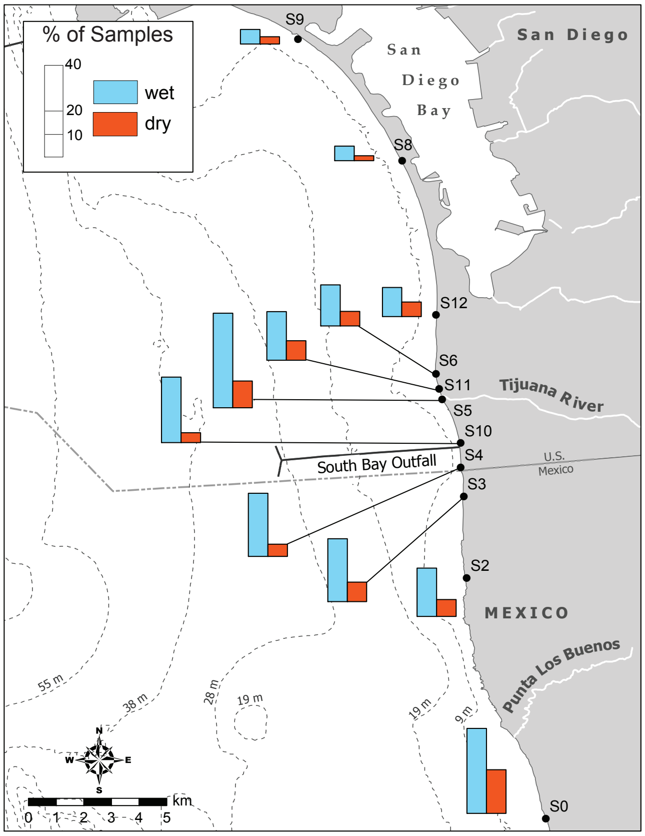

Figure 3.4
Percentage of samples with elevated FIB densities in wet versus dry seasons at SBOO shore stations from 1996 through 2015.

outfall stations when compared to other stations along the 28-m depth contour (11% versus 3%; $n = 5513, \chi^2 = 174.28, p < 0.0001$) (Figure 3.10). In the past, samples with elevated FIB levels were predominately collected at a depth of 18 m. Consequently, it appears likely that these FIB densities were associated with wastewater discharge from the outfall. However, the number of samples with elevated FIB collected from outfall stations has decreased to ≤ 2 samples per year since secondary treatment was initiated at the SBIWTP in January 2011. These results demonstrate improved water quality near the outfall compared to previous years.

Of the 84 samples collected from the offshore stations during 2015, none contained detectable levels of O&G (detection limit = 0.2 mg/L). Total suspended solids were detected in 32 of 252 samples (13%), with concentrations ≤ 10.4 mg/L (Table 3.4). There were three

Figure 3.5
Rapid Eye satellite image showing stations near the SBOO on March 5, 2015 (Ocean Imaging 2016) combined with bacteria levels sampled at shore and kelp stations on March 3 and 7, respectively. Turbid waters from the Tijuana River and Los Buenos Creek, caused by a rain event March 1 and 2, can be seen overlapping stations with elevated FIB (red circles).See Appendices B.4 and B.6 for bacterial sample details.

samples with elevated TSS concentrations of ≥8.0 mg/L, none of which corresponded with elevated FIB densities.

Plume Dispersion and Effects

The dispersion of the wastewater plume from the SBOO and its effects on natural light, DO and pH levels were assessed by evaluating the results of 112 CTD profile casts performed during 2015. Based on the criteria described in the Materials and Methods section, potential evidence of a plume signal was detected a total of 16 times during the year from 13 different stations, while 5–18 stations were identified as reference sites during each quarterly survey (Table 3.5, Figure 3.11, Appendix B.2). Three of the possible detections (~19%) occurred at stations located near the outfall wye (i.e., I12, I15). Of these, only station I12 sampled in February had elevated CDOM detected in surface waters (Appendix B.10) that corresponded with elevated *Enterococcus* in a seawater sample taken at 2 m (Appendix B.6). Additionally, three stations located south of the USA/Mexico border along the 19 and 28-m depth contours showed potential plume characteristics in February (i.e., I6, I10) and in November (i.e., I9) (Figure 3.11). The potential detection of plume at these stations corresponds with near-surface dispersion patterns observed by satellites under typical southward flow conditions (Svejkovsky 2010). However, none of these plume detections were associated with elevated FIB. The remaining potential plume signals may be spurious due to their distance from the outfall and/or proximity to other known sources of organic matter. For example, stations I34 and I35 are located within the possible influence of San Diego Bay tidal pumping, while stations I23, I31, and I39 are located within the possible influence of Tijuana River outflows.

The effects of the SBOO wastewater plume on the three physical water quality indicators mentioned above were calculated for each station and depth where a plume signal was detected. For each of these detections, mean values for natural light (% transmissivity), DO, and pH within the estimated plume were compared to thresholds within similar depths from non-plume reference stations (Appendix B.7–B.11). Of the 16 potential plume signals that occurred during 2015, a total of eight out-of-range (OOR) events were identified for transmissivity (Table 3.5). There were no OOR events for DO or pH. Six of eight OOR events occurred at stations within State jurisdictional waters where Ocean Plan compliance standards apply, and one was associated with elevated FIB (at station I12 in February).

Summary

Water quality conditions in the South Bay outfall region were excellent during 2015. Overall compliance with Ocean Plan water contact standards was ~97%, which was slightly less than the 98% compliance observed during the previous year (City of San Diego 2015). This slight reduction in compliance

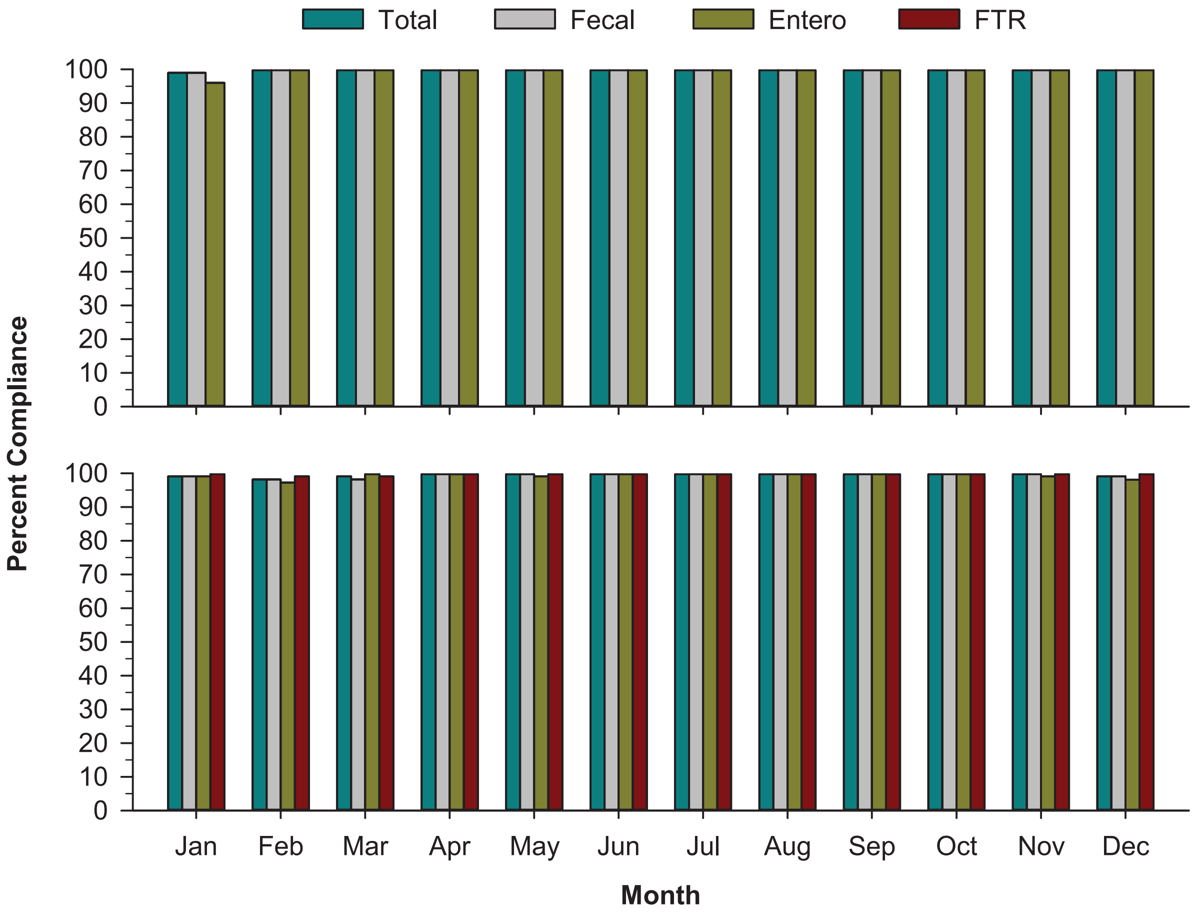

Figure 3.6
Compliance rates for (A) the three geometric mean and (B) the four single sample maximum water contact standards from SBOO kelp stations during 2015.

likely reflects higher rainfall, which totaled 9.92 inches in 2015 in contrast to 7.78 inches in 2014 (City of San Diego 2015). Additionally, only ~5% of all water samples analyzed in 2015 had elevated FIB, of which 77% occurred during the wet season and 87% were from samples collected at the shore stations. This pattern of higher contamination along the shore, especially during rain events, is similar to that observed during previous years and is likely due to runoff from terrestrial point and non-point sources (e.g., City of San Diego 2015). The few samples with high bacteria counts taken north of the USA/Mexico border during the dry weather season were exclusively from the months of May and July which had the two highest monthly rainfall totals of the year.

There was no evidence that wastewater discharged to the ocean via the SBOO reached the shoreline during the year. Although elevated FIB were detected at five different stations in the region, these results did not indicate shoreward transport of the plume, a conclusion consistently supported by remote sensing observations (e.g., Terrill et al. 2009, Svejkovsky 2010-2016). Instead, other sources such as coastal runoff from rivers and creeks were more likely to impact coastal water quality in the South Bay outfall region, especially during rain events. For example, the shore stations located near the mouths of the Tijuana River and Los Buenos Creek have historically had higher numbers of contaminated samples than stations located farther to the north (City of San Diego 2008–2015). It is also well established that sewage-laden discharges from the Tijuana River and Los Buenos Creek are likely sources of bacteria during or after storms or other periods of increased flows (Svejkovsky and Jones 2001, Noble et al. 2003, Gersberg et al. 2004, 2006, 2008, Largier et al.

Table 3.3
Number of samples with elevated FIB (eFIB) densities collected at SBOO kelp and other offshore stations during wet and dry seasons in 2015. Rain data are from Lindbergh Field, San Diego, CA. Stations not listed had no samples with elevated FIB concentrations during 2015.

	Wet	Dry	% Wet
Rain (in)	4.52	5.40	46
Kelp Stations			
9-m Depth Contour			
I19	4	1	80
I24	3	0	100
I25	2	0	100
I40	2	0	100
Total eFIB	11	1	92
Total Samples	735	504	
Other Offshore Stations			
28-m Depth Contour			
I12	1	0	100
Total eFIB	1	0	100
Total Samples	126	126	

2004, Terrill et al. 2009, Svejkovsky 2010). Further, the general relationship between rainfall and elevated bacteria levels in the SBOO region existed before wastewater discharge began in 1999 (see also City of San Diego 2000).

Finally, there was little indication of bacterial contamination in the offshore waters of the SBOO region during 2015. Only a single FIB exceedance occurred within State jurisdictional waters; it occurred in a sample collected from the station closest to the active diffuser at the SBOO. The low number of elevated FIB samples near the outfall is likely related to the initiation of full secondary treatment that began in January 2011.

LITERATURE CITED

[APHA] American Public Health Association. (2005). Standard Methods for the Examination of Water and Wastewater, 21st edition. A.D. Eaton, L.S. Clesceri, E.W. Rice and A.E. Greenberg (eds.). American Public Health Association, American Water Works Association, and Water Pollution Control Federation.

Bengtsson, H. (2003). The R.oo package - Object-Oriented Programming with References Using Standard R Code, Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003), ISSN 1609-395X, Hornik, K., Leisch, F. & Zeileis, A. (eds.).

Bordner, R., J. Winter, and P. Scarpino, eds. (1978). Microbiological Methods for Monitoring the Environment: Water and Wastes, EPA Research and Development. EPA-600/8-78-017.

[CDPH] California State Department of Public Health. (2000). Regulations for Public Beaches and Ocean Water-Contact Sports Areas. Appendix A: Assembly Bill 411, Statutes of 1997, Chapter 765. http://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/Beaches/ APPENDIXA.pdf.

City of San Diego. (2000). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater

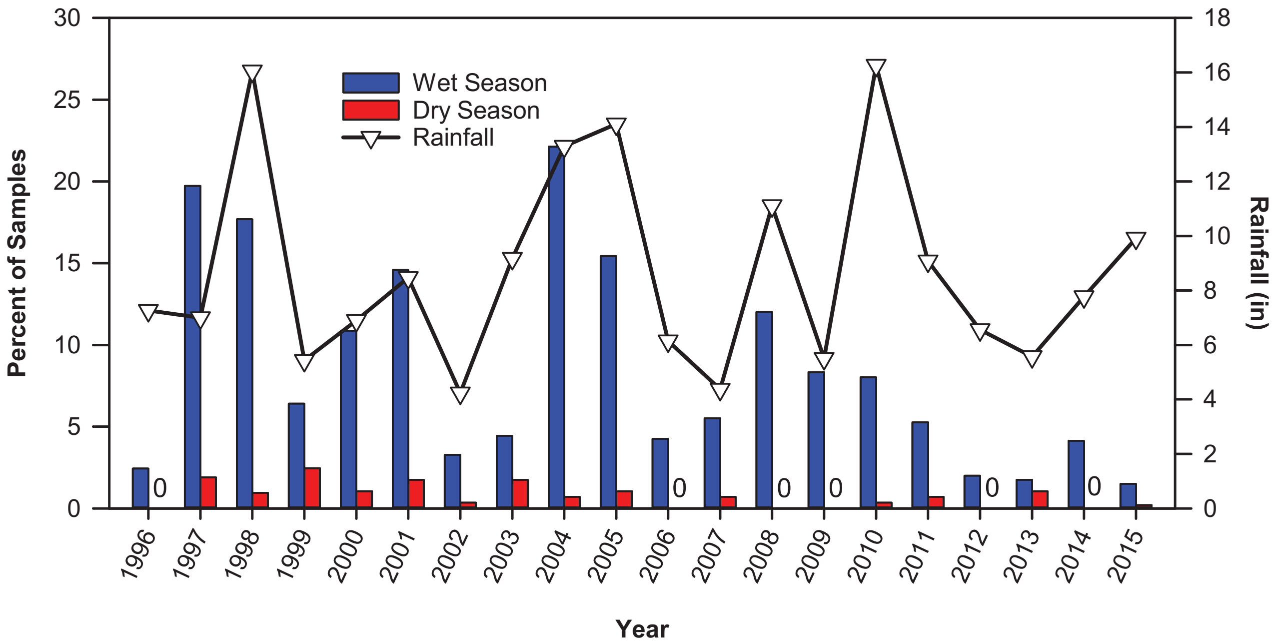

Figure 3.7
Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet versus dry seasons at SBOO kelp stations from 1996 through 2015. Rain data are from Lindbergh Field, San Diego, CA. Data from 1995 were excluded as sampling did not occur the entire year.

Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities

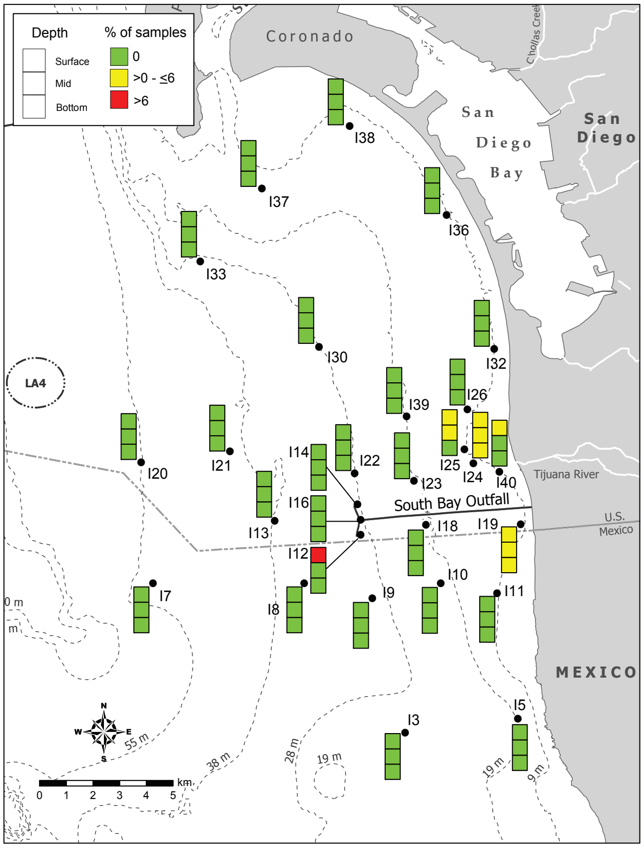

Figure 3.8

Distribution of samples with elevated FIB collected from kelp and other offshore stations during 2015. Data are the percent of samples that contained elevated bacteria densities.

Table 3.4

Summary of total suspended solids (TSS) concentrations in samples collected from the SBOO kelp and other offshore stations during 2015. Data include the number of samples per month (n) and detection rate, as well as the minimum, maximum, and mean[a] of detected concentrations for each month. The method detection limit = 0.2 mg/L for TSS; nd = not detected.

	Feb	May	Aug	Nov
Kelp Stations				
Total Suspended Solids (n = 21)				
Detection Rate (%)	62	86	67	62
Min	nd	nd	nd	nd
Max	9.9	10.6	9.4	9.4
Mean	4.2	4.9	4.8	4.3
Other Offshore Stations				
Total Suspended Solids (n = 63)				
Detection Rate (%)	6	16	2	27
Min	nd	nd	nd	nd
Max	10.4	6.9	7.3	10.0
Mean	4.2	3.9	3.6	4.2

[a] Minimum and maximum values were calculated based on all samples whereas means were calculated on detected values only

Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015-2016). Monthly Receiving Waters Monitoring Reports for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), January–December 2015. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2016). Annual Receiving Waters Monitoring and Toxicity Testing Quality Assurance Report, 2015. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Gersberg, R.M., D. Daft, and D. Yorkey. (2004). Temporal pattern of toxicity in runoff from the Tijuana River Watershed. Water Research, 38: 559–568.

Gersberg, R.M., M.A. Rose, R. Robles-Sikisaka, and A.K. Dhar. (2006). Quantitative detection of hepatitis a virus and enteroviruses near the United States-Mexico Border and correlation with levels of fecal indicator bacteria. Applied and Environmental Microbiology, 72: 7438–7444.

Gersberg, R., J. Tiedge, D. Gottstein, S. Altmann, K. Watanabe, and V. Luderitz. (2008). Effects of the South Bay Ocean Outfall (SBOO) on beach water quality near the USA-Mexico border. International Journal of Environmental Health Research, 18: 149–158.

Grant, S.B., B.F. Sanders, A.B. Boehm, J.A. Redman, J.H. Kim, R.D. Mrse, A.K. Chu,

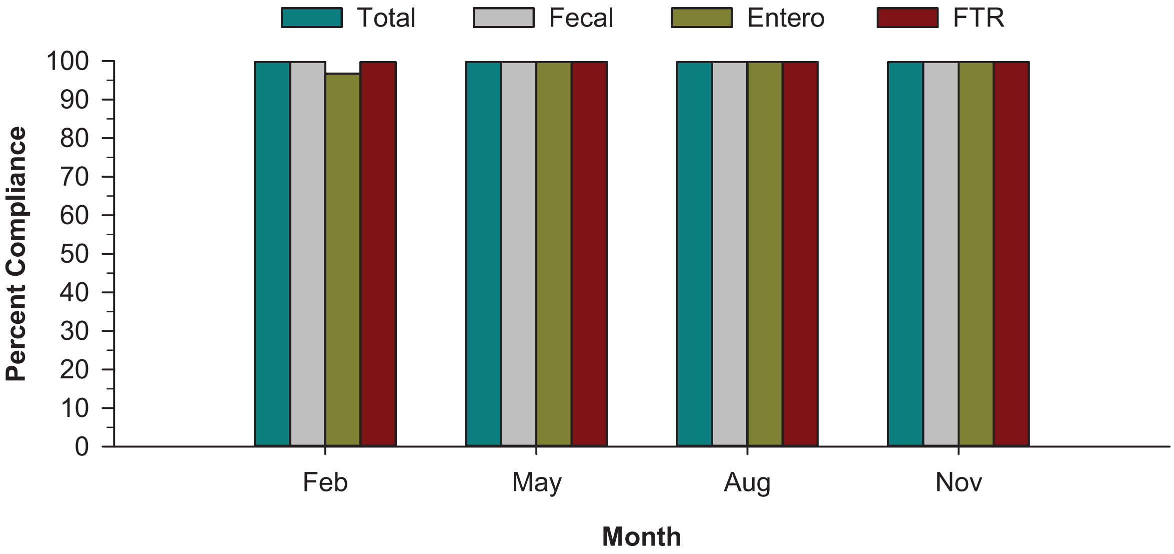

Figure 3.9
Compliance rates for the four single sample maximum water contact standards at SBOO offshore stations during 2015.

M. Gouldin, C.D. McGee, N.A. Gardiner, B.H. Jones, J. Svejkovsky, G.V. Leipzig, and A. Brown. (2001). Generation of enterococci bacteria in a coastal saltwater marsh and its impact on surf zone water quality. Environmental Science Technology, 35: 2407–2416.

Griffith, J.F., K. C. Schiff, G.S. Lyon, and J.A. Fuhrman. (2010). Microbiological water quality at non-human influenced reference beaches in southern California during wet weather. Marine Pollution Bulletin, 60: 500–508.

Gruber, S., L. Aumand, and A. Martin. (2005). Sediments as a reservoir of indicator bacteria in a coastal embayment: Mission Bay, California, Technical paper 0506. Westin Solutions, Inc. Presented at StormCon 2005. Orlando, FL, USA. July 2005.

Harrell, F.E. Jr, C. Dupont and many others. (2015). Hmisc: Harrell Miscellaneous. R package version 3.17-0. http://CRAN.R-project.org/package=Hmisc

Hope, R.M. (2013). Rmisc: Ryan Miscellaneous. R package version 1.5. http://CRAN.R-project.org/package=Rmisc.

Kelley, D. and C. Richards. (2015). oce: Analysis of Oceanographic Data. R package version 0.9-17. http://CRAN.R-project.org/package=oce

Koenker, R. (2016). quantreg: Quantile Regression. R package version 5.21. http://CRAN.R-project.org/package=quantreg

Largier, J., L. Rasmussen, M. Carter, and C. Scearce. (2004). Consent Decree–Phase One Study Final Report. Evaluation of the South Bay International Wastewater Treatment Plant Receiving Water Quality Monitoring Program to determine its ability to identify source(s) of recorded bacterial exceedences. Scripps Institution of Oceanography, University of California, San Diego, CA.

Martin, A. and S. Gruber. (2005). Amplification of indicator bacteria in organic debris on southern California beaches. Technical paper 0507. Weston Solutions, Inc. Presented at StormCon 2005. Orlando, FL, USA. July 2005.

Nelson, N.B., D.A. Siegel, and A.F. Michaels. (1998) Seasonal dynamics of colored dissolved material in the Sargasso Sea. Deep-Sea Research I, 45: 931–957.

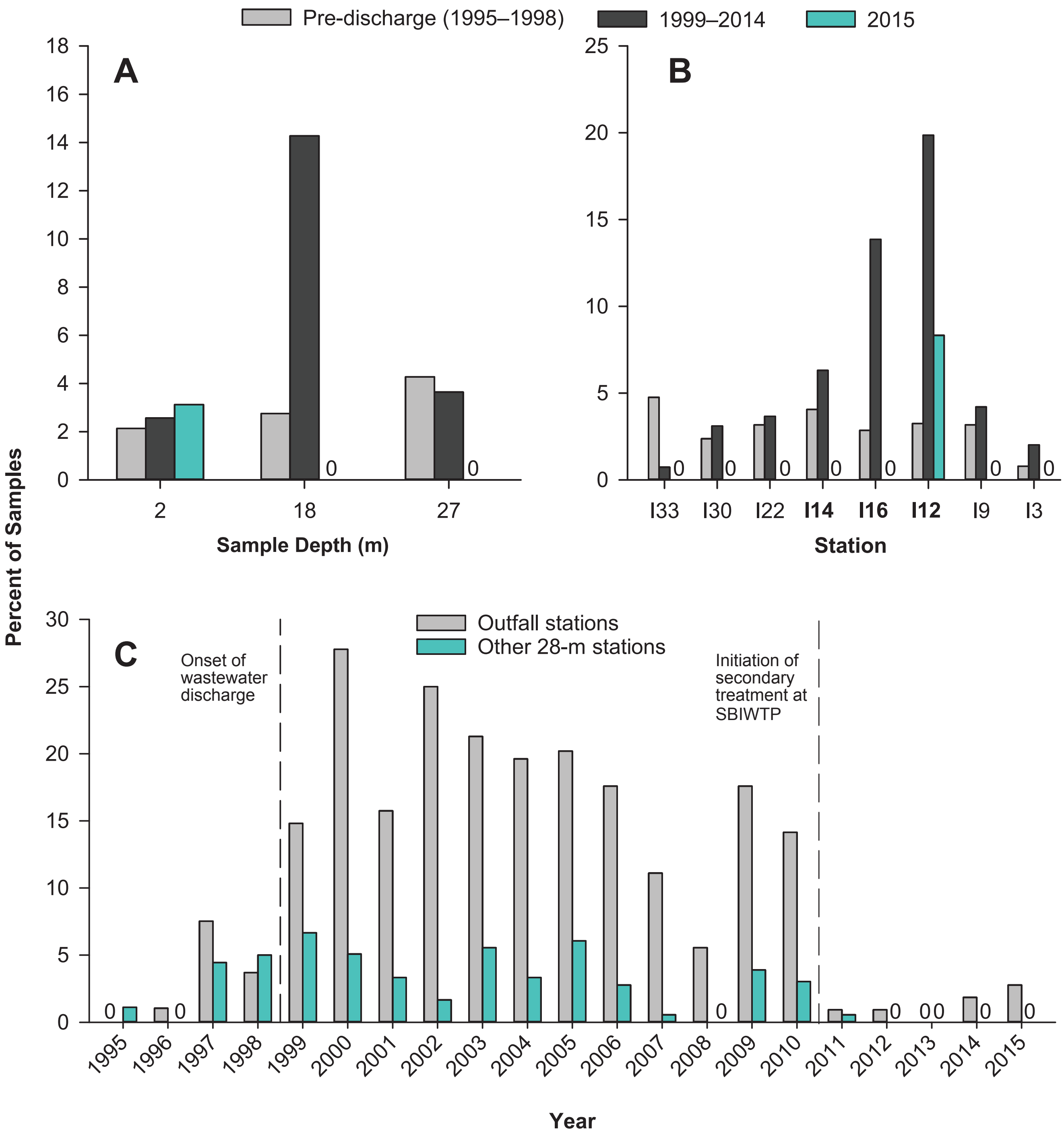

Figure 3.10
Percent of samples collected from SBOO 28-m offshore stations with elevated bacteria densities. Samples from 2015 are compared to those collected from 1995 through 2014 by (A) sampling depth, (B) station listed north to south from left to right, and (C) year. Bold stations = outfall stations (I12, I14, I16).

Nezlin, N.P, J.A.T. Booth, C. Beegan, C.L. Cash, J.R. Gully, A. Latker, M.J. Mengel, G.L. Robertson, A. Steele, and S.B. Weisberg. (2016). Assessment of wastewater impact on dissolved oxygen around southern California's submerged ocean outfalls. Regional Studies in Marine Science. In Press.

Nezlin, N.P., P.M. DiGiacomo, S.B. Weisberg, D.W. Diehl, J.A. Warrick, M.J. Mengel,

Table 3.5

Summary of potential wastewater plume detections and out-of-range values at SBOO non-kelp bed stations during 2015. Stations within State jurisdictional waters are in bold. DO = dissolved oxygen; XMS = transmissivity.

Month	Potential Plume Detections	Out of Range DO	Out of Range pH	Out of Range XMS	Stations
Feb	5	0	0	2	I6, I10[a], **I12**, I20, **I34**[a]
May	5	0	0	4	I15, I30[a], **I31**[a], **I35**[a], **I39**[a]
Aug	4	0	0	1	**I12**, **I23**[a], **I27**, **I35**
Nov	2	0	0	1	I9, **I34**[a]
Detection Rate (%)	14	0	0	7	
Total Count	16	0	0	8	
Total Samples	112	112	112	112	

[a] Out-of-range value for transmissivity

B.H. Jones, K.M. Reifel, S.C. Johnson, J.C. Ohlmann, L. Washburn, and E.J. Terrill. (2007). Southern California Bight 2003 Regional Monitoring Program: V. Water Quality. Southern California Coastal Water Research Project. Costa Mesa, CA.

[NOAA] National Oceanic and Atmospheric Administration. (2016). National Climatic Data Center. http://www7.ncdc.noaa.gov/CDO/cdo.

Noble, R.T., D.F. Moore, M.K. Leecaster, C.D. McGee, and S.B. Weisberg. (2003). Comparison of total coliform, fecal coliform, and enterococcus bacterial indicator response for ocean recreational water quality testing. Water Research, 37: 1637– 1643.

Noble, M.A., J.P. Xu, G.L. Robertson, and K.L. Rosenfeld. (2006). Distribution and sources of surfzone bacteria at Huntington Beach before and after disinfection of an ocean outfall – A frequency-domain analysis. Marine Environmental Research, 61: 494–510.

Ocean Imaging. (2016). Ocean Imaging Corporation archive of aerial and satellite-derived images. http://www.oceani.com/SanDiegoWater/index.html.

Phillips, C.P., H.M. Solo-Gabriele, A.J. Reneiers, J.D. Wang, R.T. Kiger, and N. Abdel-Mottaleb. (2011). Pore water transport of enterococci out of beach sediments. Marine Pollution Bulletin, 62: 2293–2298.

R Core Team. (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Reeves, R.L., S.B. Grant, R.D. Mrse, C.M. Copil Oancea, B.F. Sanders, and A.B. Boehm. (2004). Scaling and management of fecal indicator bacteria in runoff from a coastal urban watershed in southern California. Environmental Science and Technology, 38: 2637–2648.

Revelle, W. (2015). psych: Procedures for Personality and Psychological Research, Northwestern University, Evanston, Illinois, USA, http://CRAN.R-project.org/package=psych Version = 1.5.8.

Ripley, B. and M. Lapsley. (2015). RODBC: ODBC Database Access. R package version 1.3-12. http://CRAN.R-project.org/package=RODBC.

Rochelle-Newall, E.W., and T.R. Fisher. (2002). Production of chromophoric dissolved

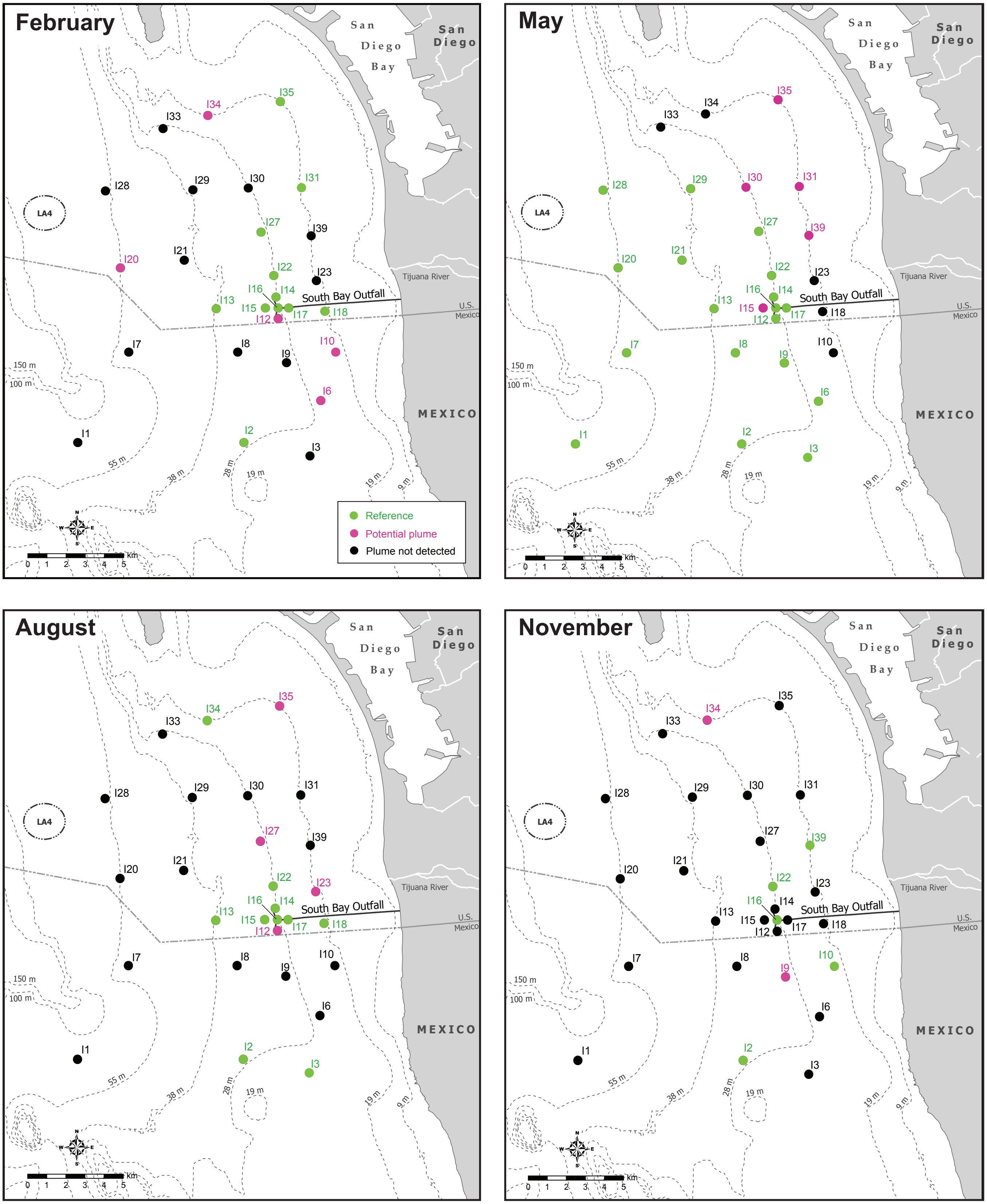

Figure 3.11
Distribution of stations where SBOO plume was potentially detected (pink) and those used as reference stations (green) during quarterly surveys in 2015.

organic matter fluorescence in marine and estuarine environments: an investigation into the role of phytoplankton. Marine Chemistry 77: 7–21.

Rogowski, P., E. Terrill, M. Otero, L. Hazard, S.Y. Kim, P.E. Parnell, and P. Dayton. (2012a). Final Report: Point Loma Ocean Outfall Plume Behavior Study. Prepared for City of San Diego Public Utilities Department by Scripps Institution of Oceanography, University of California, San Diego, CA.

Rogowski, P., E. Terrill, M. Otero, L. Hazard, and W. Middleton. (2012b). Mapping ocean outfall plumes and their mixing using Autonomous Underwater Vehicles. Journal of Geophysical Research, 117: C07016.

Rogowski, P., E. Terrill, M. Otero, L. Hazard, and W. Middleton. (2013). Ocean outfall plume characterization using an Autonomous Underwater Vehicle. Water Science & Technology, 67: 925–933.

Romera-Castillo, C., H. Sarmento, X.A. Alvarez-Salgado, J.M. Gasol, and C. Marrasé. (2010). Production of chromophoric dissolved organic matter by marine phytoplankton. Limnology and Oceanography, 55: 446–454.

Sercu, B., L.C. Van de Werfhorst, J. Murray, and P.A. Holden. (2009). Storm drains are sources of human fecal pollution during dry weather in three urban southern California watersheds. Environmental Science and Technology, 43: 293–298.

[SOC] State of California. (2010). Integrated Report (Clean Water Act Section 303(d) List / 305(b) Report). http://www.waterboards.ca.gov/water_issues/programs/tmdl/integrated2010.shtml.

Svejkovsky, J. (2010). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2009–31 December, 2009. Ocean Imaging, Solana Beach, CA.

Svejkovsky, J. (2011). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2010–31 December, 2010. Ocean Imaging, Solana Beach, CA.

Svejkovsky, J. (2012). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2011–31 December, 2011. Ocean Imaging, Solana Beach, CA.

Svejkovsky, J. (2013). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2012–31 December, 2012. Ocean Imaging, Solana Beach, CA.

Svejkovsky, J. (2014). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2013–31 December, 2013. Ocean Imaging, Solana Beach, CA.

Svejkovsky, J. (2015). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2014–31 December, 2014. Ocean Imaging, Solana Beach, CA.

Svejkovsky, J. (2016). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2015–31 December, 2015. Ocean Imaging, Solana Beach, CA.

Svejkovsky, J. and B. Jones. (2001). Detection of coastal urban storm water and sewage runoff with synthetic aperture radar satellite imagery. Eos, Transactions, American Geophysical Union, 82, 621–630.

[SWRCB] California State Water Resources Control Board. (2012). California

Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency, Sacramento, CA.

Terrill, E., K. Sung Yong, L. Hazard, and M. Otero. (2009). IBWC/Surfrider – Consent Decree Final Report. Coastal Observations and Monitoring in South Bay San Diego. Scripps Institution of Oceanography, University of California, San Diego, CA.

[USEPA] United States Environmental Protection Agency. (2006). Method 1600: Enterococci in Water by Membrane Filtration Using membrane-Enterococcus Indoxyl-β-D-Glucoside Agar (mEI). EPA Document EPA-821-R-06-009. Office of Water (4303T), Washington, DC.

Wickham, H. (2007). Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL http:// www. jstatsoft.org/v21/i12/.

Yamahara, K.M., B.A. Layton, A.E. Santoro, and A.B. Boehm. (2007). Beach sands along the California coast are diffuse sources of fecal bacteria to coastal waters. Environmental Science and Technology, 41: 4515–4521.

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Chapter 4
Sediment Conditions

Chapter 4. Sediment Conditions

INTRODUCTION

Ocean sediment samples are analyzed as part of the City of San Diego's Ocean Monitoring Program to examine the effects of wastewater discharge from the South Bay Ocean Outfall (SBOO) and other anthropogenic inputs on the marine benthic environment. Analyses of various sediment contaminants are conducted because anthropogenic inputs to the marine ecosystem, including municipal wastewater, can lead to increased concentrations of pollutants within the local environment. The relative percentages of sand, silt, clay and other particle size parameters are examined because concentrations of some compounds are known to be directly linked to sediment composition (Emery 1960, Eganhouse and Venkatesan 1993). Physical and chemical sediment characteristics are also analyzed because together they define the primary microhabitats for benthic invertebrates that live within or on the seafloor, and therefore influence the distribution and presence of various species. For example, differences in sediment composition and organic loading impact the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Many demersal fish species are also associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Understanding the differences in sediment conditions and quality over time and space is therefore crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

Both natural and anthropogenic factors affect the composition, distribution, and stability of seafloor sediments on the continental shelf. Natural factors that affect sediment conditions include geologic history, strength and direction of bottom currents, exposure to wave action, seafloor topography, inputs from rivers and bays, beach erosion, runoff, bioturbation by fish and benthic invertebrates, and decomposition of calcareous organisms (Emery 1960). These processes affect the size and distribution of sediment particles, as well as the chemical composition of sediments. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediment and debris from bays, rivers, and streams strongly influence the overall organic content and particle size of coastal sediments. These inputs can also contribute to the deposition and accumulation of trace metals or other contaminants on the sea floor. In addition, primary productivity by phytoplankton and decomposition of marine and terrestrial organisms are major sources of organic loading to coastal shelf sediments (Mann 1982, Parsons et al. 1990).

Municipal wastewater outfalls are one of many anthropogenic factors that can directly influence sediment characteristics through the discharge of treated effluent and the subsequent deposition of a wide variety of organic and inorganic compounds. Some of the most commonly detected contaminants discharged via ocean outfalls are trace metals, pesticides, and various indicators of organic loading such as organic carbon, nitrogen, and sulfides (Anderson et al. 1993). In particular, organic enrichment due to wastewater discharge is of concern because it may impair habitat quality for benthic marine organisms and thus disrupt ecological processes (Gray 1981). Lastly, the physical presence of a large outfall pipe and associated ballast materials (e.g., rock, sand) may alter the hydrodynamic regime in surrounding areas, thus affecting sediment movement and transport and the resident biological communities.

This chapter presents analysis and interpretation of sediment particle size and chemistry data collected at monitoring stations surrounding the SBOO during calendar year 2015. The primary goals are to: (1) document sediment conditions; (2) identify possible effects of wastewater discharge on sediment quality in the region; (3) identify other potential

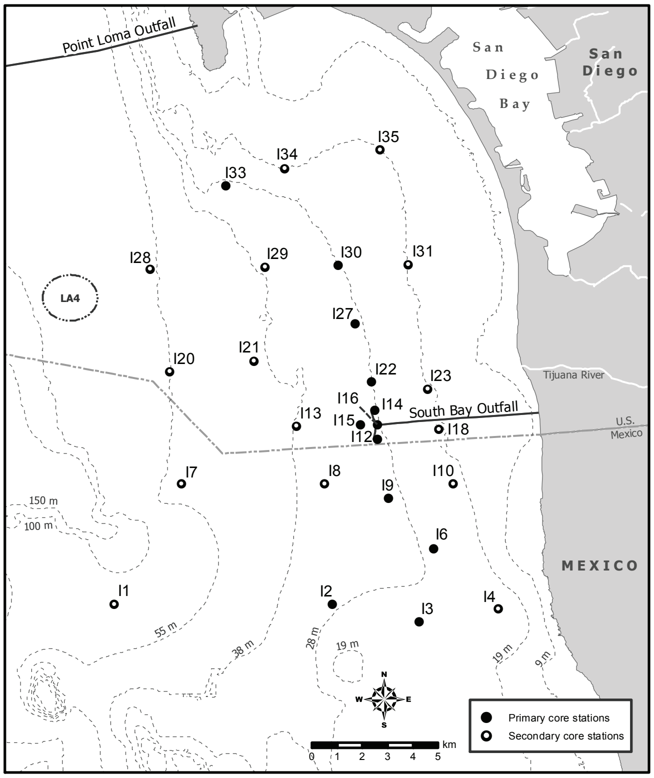


Figure 4.1

Benthic station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

natural and anthropogenic sources of sediment contaminants to the local marine environment.

Materials and Methods

Field Sampling

Sediment samples were collected at 27 monitoring stations in the SBOO region during winter (January) and summer (July) of 2015 (Figure 4.1). These stations range in depth from about 18 to 60 m distributed along or adjacent to four main depth contours. Fifteen stations are located along the 19, 38, or 55-m depth contours, while 12 primary core stations are generally located along the outfall discharge depth contour of 28 m. These latter "outfall depth" stations include four nearfield monitoring sites located within 1000 m of the Y-shaped outfall diffuser structure (i.e., stations I12, I14, I15, I16), four north farfield sites located >1.2 km from the terminus of the northern diffuser leg (i.e., stations I22, I27, I30, I33), and four south farfield sites located >2.3 km from the terminus of the southern diffuser leg (i.e., stations I2, I3, I6, I9).

Each sediment sample was collected from one side of a double 0.1-m^2 Van Veen grab, while the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 5). Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Environmental Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2016). Briefly, sediment sub-samples were analyzed on a dry weight basis to determine concentrations of various indictors of organic loading (i.e., total organic carbon, total nitrogen, total sulfides, total volatile solids), 18 trace metals, 9 chlorinated pesticides (e.g., DDT), 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs). Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix C.1). However, concentrations below MDLs were included as estimated values if the presence of a specific constituent was verified by mass-spectrometry.

Particle size analysis was performed using either a Horiba LA-950V2 laser scattering particle analyzer or a set of nested sieves. The Horiba measures particles ranging in size from 0.5 to 2000 µm. Coarser sediments were removed and quantified prior to laser analysis by screening samples through a 2000 µm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%, and then classified into 11 sub-fractions and 4 main size fractions based on the Wentworth scale (Folk 1980) (see Appendix C.2). When a sample contained substantial amounts of coarse sand, gravel, or shell hash that could damage the Horiba analyzer and/or where the general distribution of sediments would be poorly represented by laser analysis, a set of sieves with mesh sizes of 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, and 63 µm was used to divide the samples into seven sub-fractions.

Data Analyses

Data summaries for the various sediment parameters included detection rate, minimum, maximum, and mean values for all samples combined. All means were calculated using detected values only; no substitutions were made for non-detects in the data (i.e., analyte concentrations <MDL). Total DDT (tDDT), total hexachlorocyclohexane (tHCH), total chlordane, total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix C.3 for individual constituent values). These analyses were performed using R (R Core Team 2015) and various functions within the plyr, reshape2, and zoo packages (Zeileis and Grothendieck 2005, Wickham 2007, Wickham 2011). Contaminant concentrations were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed, while values above the ERL but below the ERM represent levels at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998).

Multivariate analyses were performed using PRIMER v7 software to examine spatio-temporal patterns in the overall particle size composition in the South Bay outfall region (Clarke et al. 2014). These included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). Proportions of silt and clay sub-fractions were combined as percent fines to accommodate sieved samples and Euclidean distance was used as the basis for the cluster analysis. Similarity percentages analysis (SIMPER) was used to determine which sub-fractions were responsible for the greatest contributions to within-group similarity and between group dissimilarity for retained clusters.

Spearman rank correlations were calculated to assess if values for the various parameters co-varied in SBOO sediments. This non-parametric analysis accounts for non-detects in the data without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in rank-based analyses may intensify with increased censoring (Conover 1980). Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis.

RESULTS

Particle Size Distribution

Ocean sediments were diverse across the South Bay outfall region in 2015. The percent fines component (i.e., silt and clay) ranged from 0 to 41% per sample, while fine sands ranged from 1 to 91%, medium-coarse sands ranged from 1 to 91%, and coarse particles ranged from 0 to 23% (Table 4.1). Coarser particles often comprised red relict sands, black sands, and/or shell hash (Appendix C.4). Particle size composition varied within sites between the winter and summer surveys by as much as 78% per size fraction, with the greatest differences occurring at stations I15, I16, I23, and I29 (Figure 4.2). During the past year, sediments from nearfield station I14 were predominantly composed of fine particles and fine sands and were similar to the four north farfield stations. In contrast, sediments from nearfield stations I12, I15, and I16 were predominantly a mixture of fine and medium-coarse sands, more closely resembling sediments from south and west of the outfall (Figure 4.2, Appendix C.4). These results are consistent with historical analysis of particle size data from SBOO sites located throughout the survey area that revealed considerable temporal variability at some stations and relative stability at others, with no clear patterns evident relative to depth, proximity to the outfall, or proximity to

Table 4.1

Summary of particle sizes and chemistry concentrations in sediments from SBOO benthic stations sampled during 2015. Data include the detection rate (DR), mean, minimum and maximum values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1995–1998) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold; na = not available; nd = not detected.

	2015 Summary[a]						
Parameter	**DR (%)**	**Mean**	**Min**	**Max**	**Pre-discharge Max**	**ERL[b]**	**ERM[b]**
Particle Size							
Coarse Particles (%)	44	2.8	0.0	22.6	52.5	na	na
Med-Coarse sands (%)	100	36.5	0.6	90.9	99.8	na	na
Fine Sands (%)	100	50.2	0.9	91.2	97.4	na	na
Fines (%)	98	10.3	0.0	40.7	47.2	na	na
Organic Indicators							
Sulfides (*ppm*)	93	2.03	nd	9.67	222.0	na	na
TN (*% weight*)	94	0.019	nd	0.059	0.077	na	na
TOC (*% weight*)	85	0.21	nd	1.56	0.64	na	na
TVS (*% weight*)	100	0.80	0.30	1.80	9.20	na	na
Trace Metals (ppm)							
Aluminum	100	4508	798	12,700	15,800	na	na
Antimony	37	0.5	nd	1.4	5.6	na	na
Arsenic	100	2.42	0.44	9.17	10.9	8.2	70
Barium	100	20.90	1.42	75.80	54.3	na	na
Beryllium	43	0.07	nd	0.19	2.14	na	na
Cadmium	7	0.08	nd	0.10	0.41	1.2	9.6
Chromium	100	10.0	4.0	21.9	33.8	81	370
Copper	72	2.5	nd	8.0	11.1	34	270
Iron	100	6342	1300	16,600	17,100	na	na
Lead	98	2.2	nd	5.8	6.8	46.7	218
Manganese	100	54.5	6.7	168.0	162.0	na	na
Mercury	39	0.010	nd	0.030	0.078	0.15	0.71
Nickel	100	3.3	0.8	8.0	13.6	20.9	51.6
Selenium	24	0.10	nd	0.18	0.6	na	na
Silver	6	0.05	nd	0.08	nd	1.0	3.7
Thallium	17	2.0	nd	3.2	17.0	na	na
Tin	81	1.0	nd	2.6	nd	na	na
Zinc	100	13.4	1.6	44.6	46.9	150	410
Pesticides (ppt)							
HCB	31	744	160	3800	nd	na	na
Total DDT	35	365	140	860	23,380	1580	46,100
Total Chlordane	2	600	600	600	nd	na	na
Total PCB (ppt)	13	1251	181	3686	na	na	na
Total PAH (ppb)	28	22	3	104	636	4022	44,792

[a] Minimum and maximum values were based on all samples (n = 54), whereas means were calculated on detected values only (n ≤ 54)

[b] From Long et al. 1995

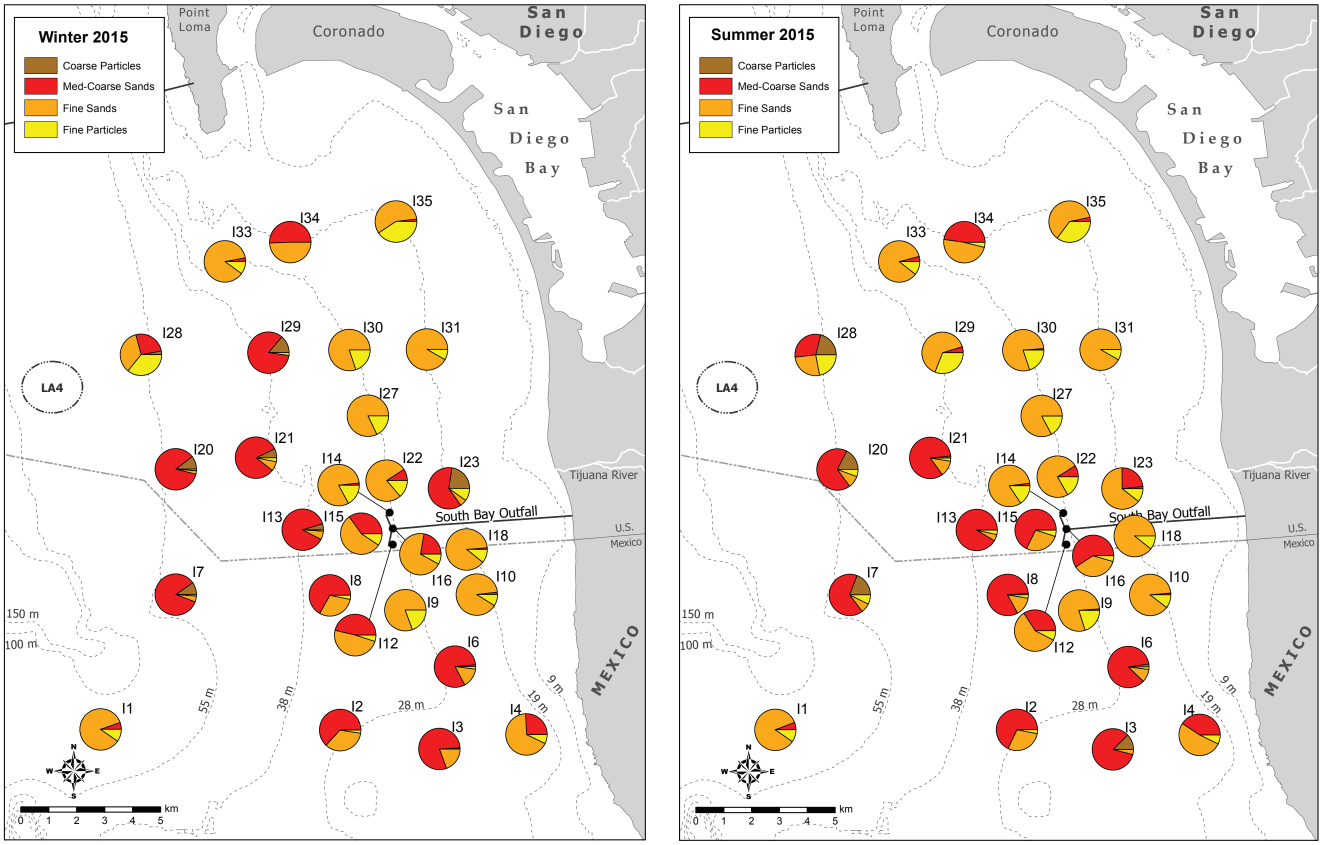
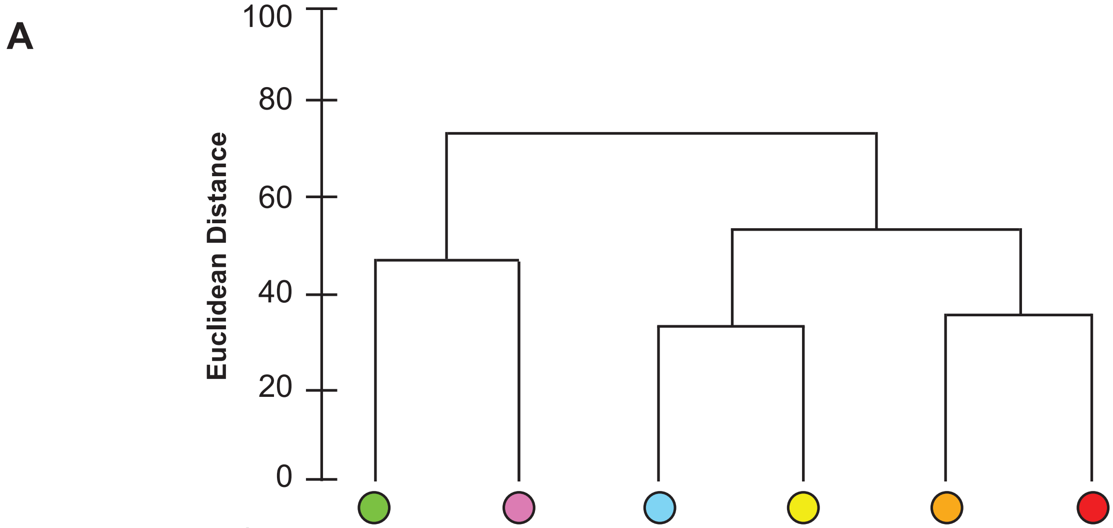


Figure 4.2

Sediment composition at SBOO benthic stations sampled in 2015 during winter and summer surveys.

other sources of sediment plumes (e.g., San Diego Bay, Tijuana River) (City of San Diego 2014, 2015).

Classification (cluster) analysis of the 2015 particle size sub-fraction data discriminated six main cluster groups (cluster groups 1–6) (Figure 4.3). According to SIMPER results, these six groups were primarily distinguished by proportions of very fine sand, medium sand, and coarse sand. Cluster group 1 included winter and summer samples from station I28. Sediments in these two samples had the largest proportion of fine particles (29% fines per sample), the largest proportion of granules (5% per sample) and also averaged 24% very fine sand, 10% medium sand, and 18% coarse sand. Cluster group 2 was the largest group and comprised 24 samples collected primarily at sites located along the 19 and 28-m depth contours, including two of the eight samples from the four nearfield stations. This group also had relatively fine sediments, with the largest proportion of very fine sand (57% per sample), as well as 16% fines, 23% fine sand, and just 3% medium sand per sample. Cluster group 3 included the winter samples from stations I20 and I29. Sediments in these two samples had the largest proportion of coarse sand (71% per sample) and very coarse sand (12% per sample), and the lowest proportion of fine particles, very fine sand, and fine sand (≤2% per sample). Cluster group 4 comprised eight samples, four of which were collected during the winter and summer surveys at stations I7 and I13. This group also included the winter samples from stations I21 and I23 and the summer samples from stations I3 and I20. Sediments represented by group 4 had the second highest proportions of medium, coarse and very coarse sand (33%, 45%, and 10% per sample, respectively). Cluster group 5 comprised six samples, including four from the four nearfield stations and both samples from station I4. These sediments had the highest proportion of fine sand (33% per sample) and also averaged 26% very fine sand and 29% medium sand per sample. Cluster group 6 comprised 12 samples, including two samples from the four nearfield stations, winter and summer samples from stations I2, I6, I8, and I34, the winter sample from station I3, and the summer sample from station I21. Sediments represented by



	Cluster Group	1	2	3	4	5	6
	n	2	24	2	8	6	12
	Fines	28.8	16.3	1.7	3.9	7.4	2.6
Fine Sands	**VFSand**	24.1	56.9	0.3	1.7	25.5	3.4
	FSand	6.8	23.2	1.6	4.5	33.1	23.8
Med-Coarse Sands	**MSand**	10.0	3.3	13.9	33.4	29.0	52.8
	CSand	18.4	0.3	70.6	44.5	5.1	16.7
Coarse Particles	**VCsand**	7.4	0.0	11.9	10.4	0.0	0.7
	Granules	4.6	0.0	0.2	1.3	0.0	0.0

Figure 4.3

Results of cluster analysis of particle size sub-fraction data from SBOO benthic stations sampled during 2015. Data are presented as: (A) dendrogram of main cluster groups and (B) distribution of sediment samples as delineated by cluster analysis. Data for particle size sub-fractions are mean percentages calculated over all stations within a cluster group (n). VFSand = Very Fine Sand; FSand = Fine Sand; MSand = Medium Sand; CSand = Coarse Sand; VCSand = Very Coarse Sand.

group 6 had the highest proportions of medium sand (53% per sample) and the second highest proportion of fine sand (24% per sample).

Indicators of Organic Loading

Indicators of organic loading in benthic sediments, including sulfides, total nitrogen (TN), total organic carbon (TOC), and total volatile solids (TVS), were detected in 85 to 100% of the sediment samples collected from the South Bay outfall region during 2015 (Table 4.1). Concentrations ranged from non-detected to 9.67 ppm for sulfides, to 0.059% weight for TN, and to 1.56% weight for TOC, while TVS values ranged from 0.3 to 1.8% weight. There was no evidence of organic enrichment near the discharge site during the year. Instead, the highest concentrations of these parameters were distributed throughout the survey area (Appendix C.5). For example, the highest sulfide values (≥5.12 ppm) were recorded from stations I4, I14, I27, and I35, while the highest TOC values (≥0.44% weight) were recorded from stations I23, I28, I29, and I33 (Figure 4.4). Values of TN and TVS were also wide-ranging throughout the region in 2015, co-varying with percent fines (Table 4.2, Figure 4.5). Previous historical analyses have demonstrated that levels of organic indicators have been fairly consistent at the

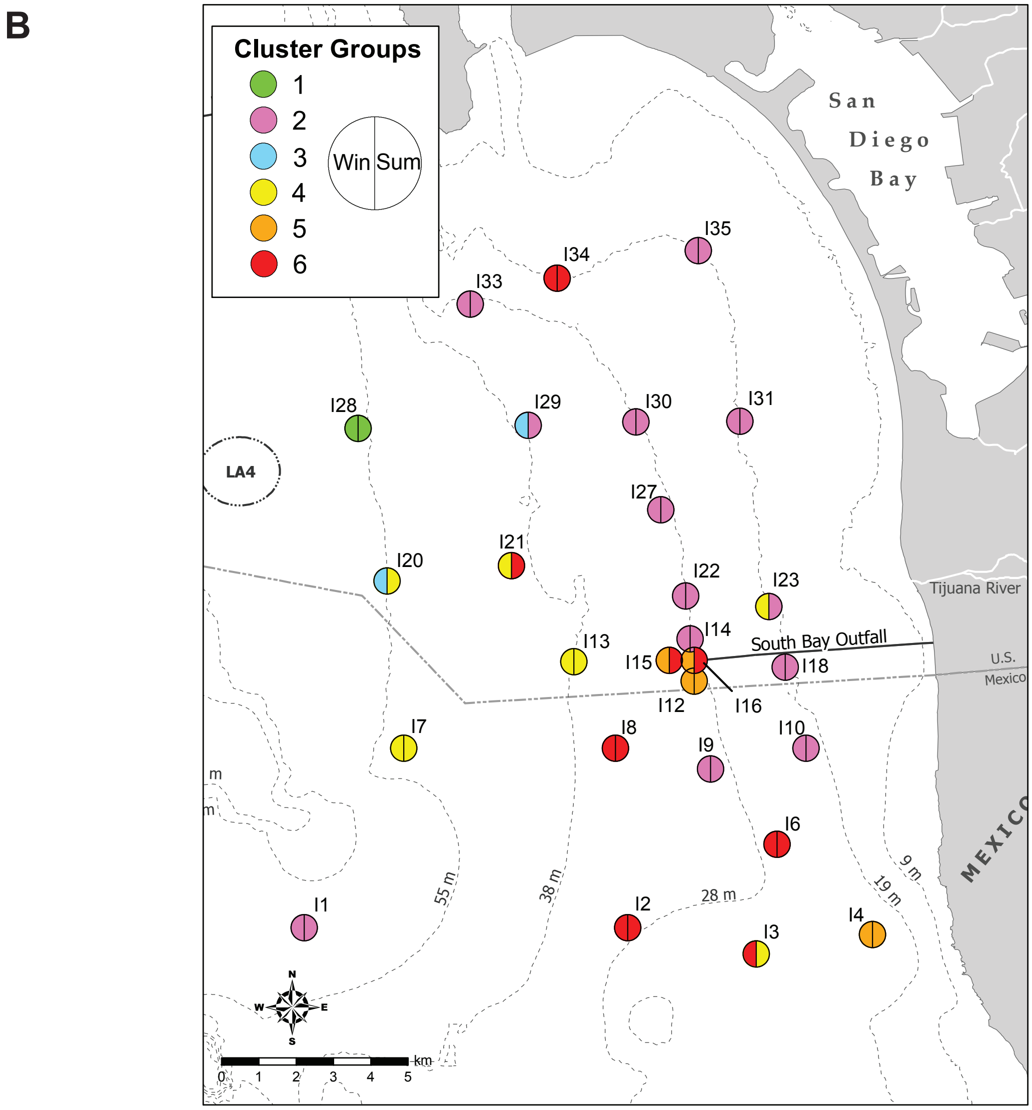


Figure 4.3 *continued*

primary core stations, with no patterns indicative of organic enrichment evident since discharge began in 1999 (City of San Diego 2014, 2015).

Trace Metals

Eight trace metals were detected in all sediment samples collected in the SBOO region during 2015, including aluminum, arsenic, barium, chromium, iron, manganese, nickel, and zinc (Table 4.1). Copper, lead, and tin were detected at a slightly lower frequency of 72 to 98%, while antimony, beryllium, cadmium, mercury, selenium, silver, and thallium were detected in ≤43% of the samples. Of the nine metals that have published ERLs and ERMs (Long et al. 1995), only arsenic was reported at levels above its ERL threshold. As in previous years, elevated arsenic was found at station I21 in both the winter and summer surveys (Figure 4.4, Appendix C.6). Most of the remaining metals were detected at levels within ranges reported prior to wastewater discharge in the South Bay outfall region and/or elsewhere in the Southern California Bight (SCB) (e.g., Dodder et al. 2016). Only barium and manganese were reported at levels higher than pre-discharge values (Table 4.1). These and the other metals varied between stations with no discernible patterns relative to the outfall. Instead, aluminum, barium,

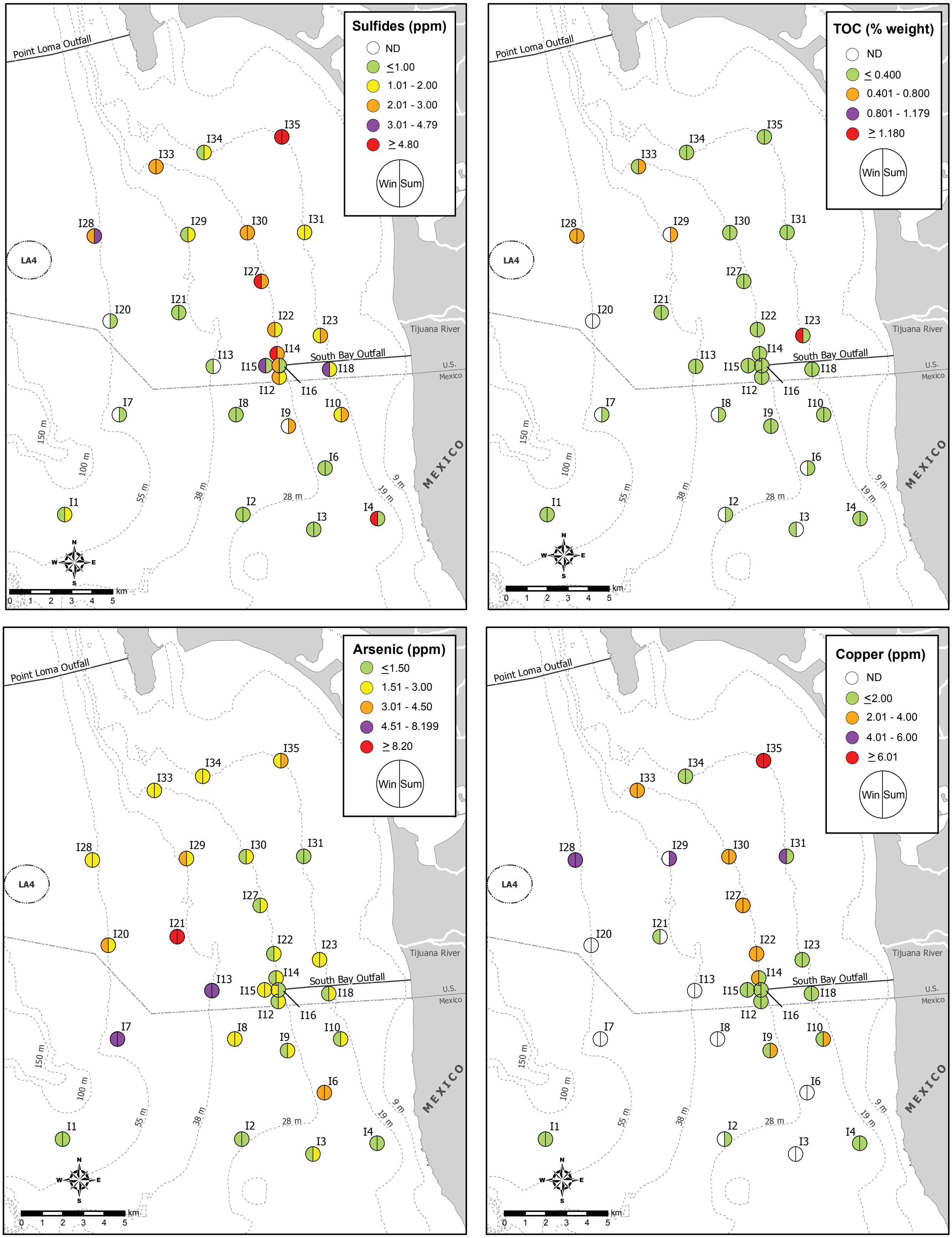


Figure 4.4

Distribution of select parameters in sediments from the SBOO region during 2015 winter and summer surveys.

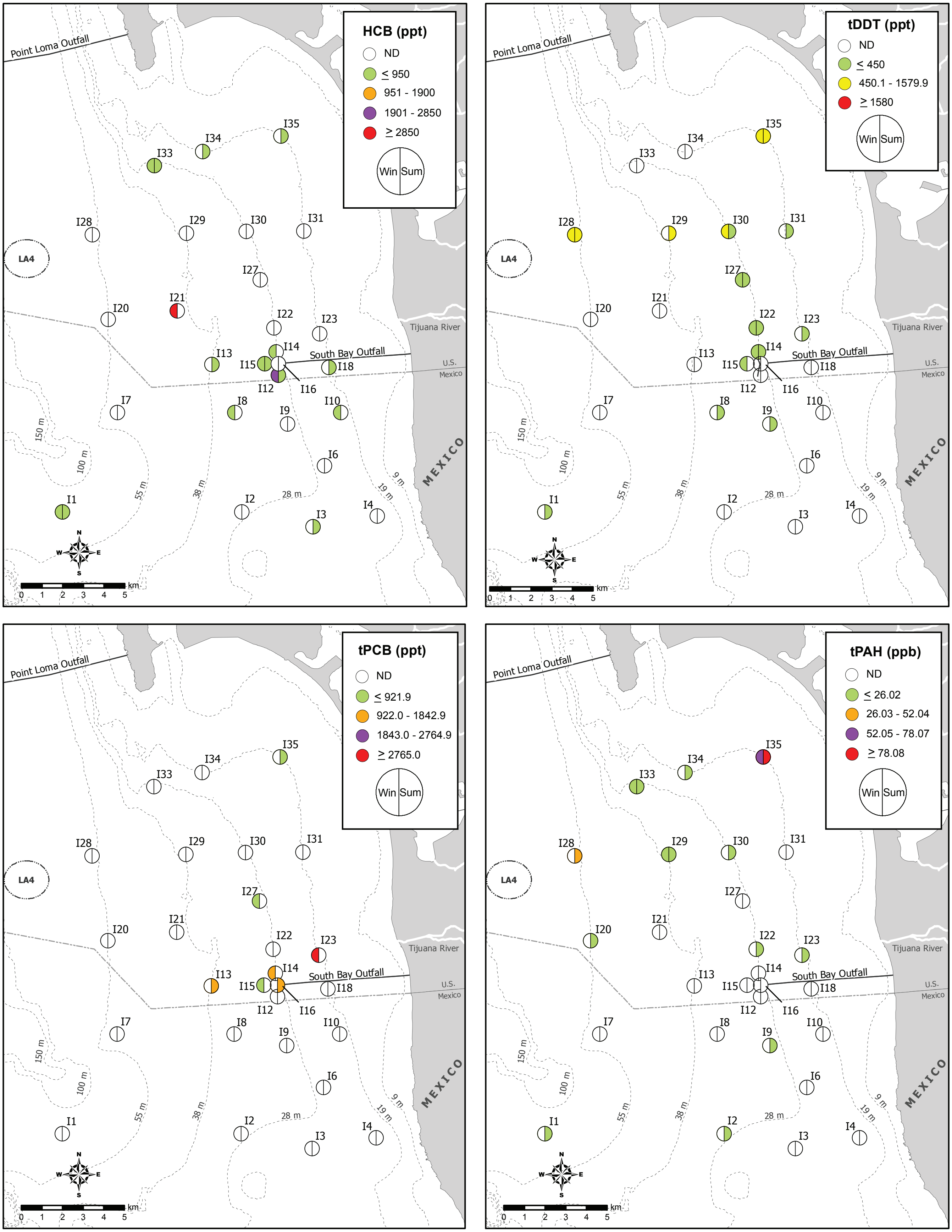


Figure 4.4 *continued*

Table 4.2

Results of Spearman rank correlation analyses of percent fines versus various sediment chemistry parameters from SBOO benthic samples collected in 2015. Shown are parameters that had correlation coefficients $r_s \geq 0.70$. For all analyses, n = the number of detected values. Select correlations with organic indicators and trace metals are illustrated graphically in Figure 4.5.

Parameter	n	r_s
Organic Indicators (% weight)		
Total Nitrogen	51	0.76
Total Volitale Solids	54	0.91
Trace Metals (ppm)		
Aluminum	54	0.87
Barium	54	0.85
Chromium	54	0.74
Copper	39	0.87
Iron	54	0.74
Manganese	54	0.85
Nickel	54	0.82
Zinc	54	0.85

chromium, copper, iron, manganese, nickel, and zinc all correlated positively with percent fines (Table 4.2, Figure 4.5) and therefore had similar distributions (see Figure 4.2, 4.4). For example, the highest concentrations of all of these metals, as well as antimony, beryllium, cadmium, lead, and mercury, occurred in sediments from station I35, which also had the highest percent fines reported during the year (Appendix C.4, C.6). On a regional basis (see Chapter 8), lead and tin were also positively correlated with percent fines. These results are consistent with long term analyses reported previously (City of San Diego 2014, 2015).

Pesticides

Three chlorinated pesticides were detected in SBOO sediments during 2015, including DDT, hexachlorobenzene (HCB), and chlordane (Table 4.1, Appendices C.3, C.7). Total DDT, composed primarily of p,p-DDE, was detected in 35% of the samples at concentrations ≤860 ppt, all of which were below the ERL and well within ranges reported prior to wastewater discharge in the South Bay outfall region and/or elsewhere in the SCB (e.g., Dodder et al. 2016). HCB was detected in 31% of the samples at concentrations up to 3800 ppt. DDT and HCB were both found at stations located throughout the survey area, with no discernable patterns relative to the outfall (Figure 4.4). Total chlordane, composed of methoxychlor, was detected in a single sample (detection rate = 2%) collected from station I12 during the winter at a concentration of 600 ppt. The pesticides hexachlorocyclohexane (HCH), aldrin, endosulfan, dieldrin, endrin, and mirex were not detected at any of the SBOO stations during 2015. Historically, chlorinated pesticides have been detected infrequently at low concentrations in the SBOO region with no patterns indicative of an outfall effect evident since sampling began (City of San Diego 2014, 2015).

PCBs

PCBs were detected in 13% of the sediment samples collected around the SBOO in 2015 at concentrations up to 3686 ppt (Table 4.1, Appendix C.7). Although no ERL or ERM thresholds exist for PCBs measured as congeners, all PCB values recorded during the year were well within ranges reported elsewhere in the SCB (Dodder et al. 2016) at stations located throughout the survey area, with no discernable patterns relative to the outfall (Figure 4.4). The PCB congeners detected during 2015 included PCB 18, PCB 28, PCB 37, PCB 44, PCB 49, PCB 52, PCB 66, PCB 70, PCB 74, PCB 101, PCB 105, PCB 110, PCB 118, PCB 138, PCB 149, PCB 153/168, and PCB 180 (Appendix C.3). As with chlorinated pesticides, PCBs have historically been detected infrequently in the SBOO region since the City started reporting the data as congeners in summer 1998, with no patterns relative to the outfall evident (City of San Diego 2014, 2015).

PAHs

PAHs were detected in 28% of the sediment samples collected from the South Bay outfall region in 2015 (Table 4.1, Appendix C.7). Concentrations of total PAH reached 104 ppb during the past year, well below the pre-discharge maximum of 636 ppb, the ERL threshold of 4022 ppb, and the Bight'13 maximum of 2900 ppb (Dodder et al. 2016). PAHs

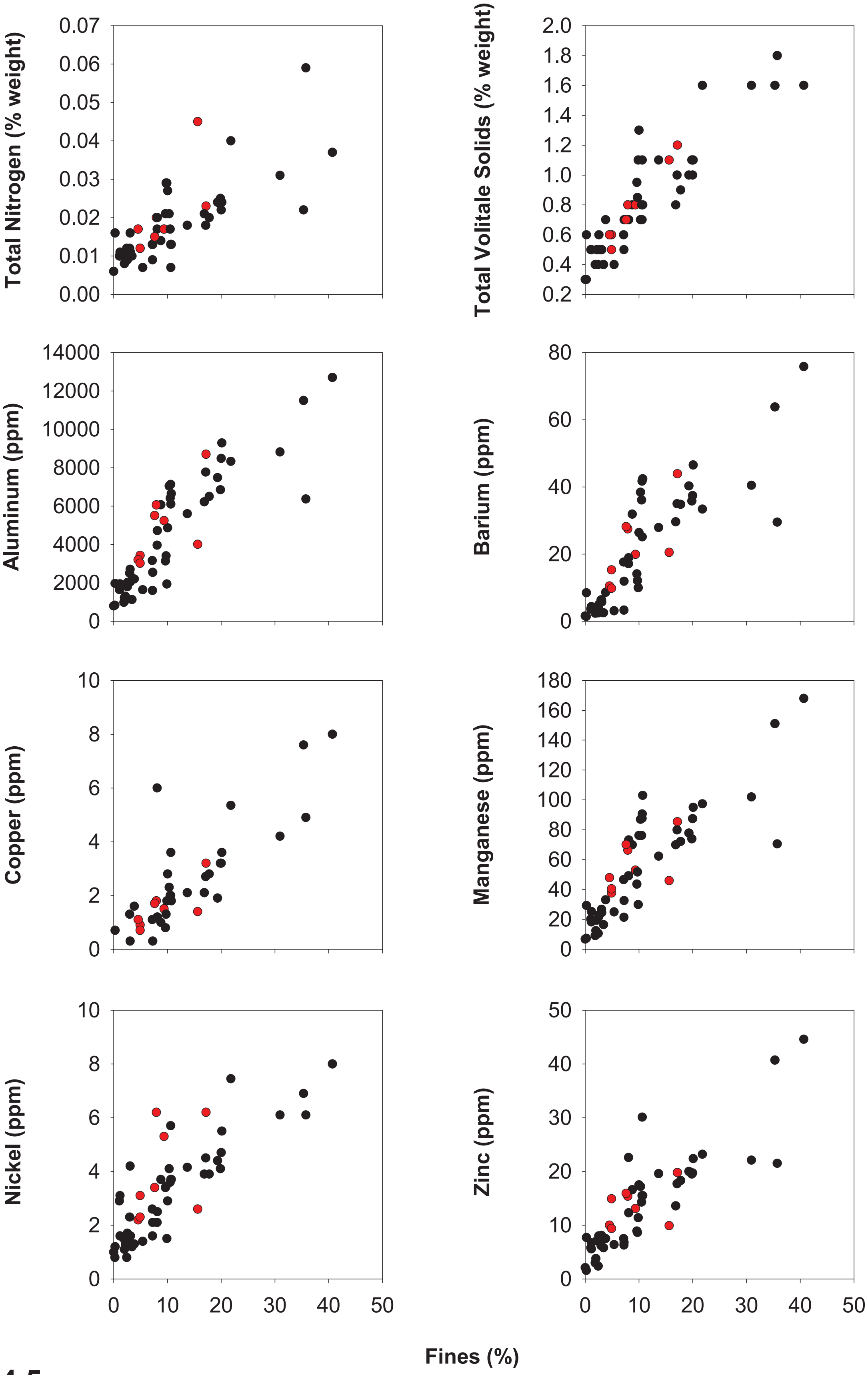


Figure 4.5
Scatterplots of percent fines versus select parameters in sediments from SBOO benthic stations sampled during 2015. Samples collected from nearfield stations are indicated in red.

were primarily detected at stations located north of the SBOO (Figure 4.4). Individual PAHs detected during the year included 2,6-dimethylnaphthalene, 3,4-benzo(B)fluoranthene, benzo[A]pyrene, benzo[e] pyrene, benzo[G,H,I]perylene, benzo[K]fluoranthene, biphenyl, chrysene, fluoranthene, indeno(1,2,3-CD) pyrene, phenanthrene, and pyrene (Appendix C.3). Historically, detection rates for tPAH have been low with all reported values less than the ERL, and no patterns indicative of a wastewater impact have been evident (City of San Diego 2014, 2015).

DISCUSSION

Particle size composition at the SBOO stations sampled in 2015 was similar to that seen historically (Emery 1960, MBC-ES 1988) and in recent survey years (e.g., City of San Diego 2007–2015). Sands made up the largest proportion of all sediments, with the relative amounts of coarser and finer particles varying among sites. No spatial relationship was evident between sediment composition and proximity to the outfall discharge site, nor has there been any substantial increase in fine sediments at nearfield stations or throughout the region since wastewater discharge began. Instead, the diversity of sediment types in the region reflects multiple geologic origins and complex patterns of transport and deposition. In particular, the presence of red relict sands at some stations is indicative of minimal sediment deposition in recent years. Several other stations are located near or within an accretion zone for sediments moving within the Silver Strand littoral cell (MBC-ES 1988, Patsch and Griggs 2007). Therefore, the higher proportions of fine sands, silts, and clays that occur at these sites are likely associated with the transport of fine materials originating from the Tijuana River, the Silver Strand beach, and to a lesser extent from San Diego Bay (MBC-ES 1988). In general, sediment composition has been highly diverse throughout the South Bay outfall region since pre-discharge sampling first began in 1995 (City of San Diego 2000).

Various organic indicators, trace metals, pesticides, PCBs, and PAHs were detected in sediment samples collected throughout the SBOO region in 2015, although concentrations were all below ERM thresholds, generally below ERL thresholds, and/or within historical ranges (City of San Diego 2014, 2015). Additionally, there have been no spatial patterns consistent with an outfall effect on sediment chemistry over the past several years, with concentrations of most contaminants at the four nearfield sites falling within the range of values at the farfield stations. Instead, relatively high values of most parameters could be found throughout the region, and several organic indicators and metals co-occurred in samples characterized by finer sediments. This association is expected due to the known correlation between particle size and concentrations of these parameters (Eganhouse and Venkatesan 1993).

The broad distribution of various contaminants in sediments throughout the SBOO region is likely derived from several sources. Mearns et al. (1991) described the distribution of contaminants such as arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB, while Brown et al. (1986) determined that there may be no coastal areas in southern California that are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent surveys of SCB continental shelf habitats (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Dodder et al. 2016). The lack of contaminant-free reference areas clearly pertains to the South Bay outfall region as demonstrated by the presence of many contaminants in sediments prior to wastewater discharge (see City of San Diego 2000). Further, historical assessments of sediments off the coast of Los Angeles have shown that as wastewater treatment has improved, sediment conditions are more likely affected by other factors (Stein and Cadien 2009). These factors may include bioturbative re-exposure of buried legacy sediments (Niedoroda et al. 1996, Stull et al. 1996), large storms that assist redistribution of legacy contaminants (Sherwood et al. 2002), and stormwater discharges (Schiff et al. 2006, Nezlin et al. 2007). Possible non-outfall sources and pathways of contaminant dispersal off San Diego include transport of contaminated sediments from

San Diego Bay via tidal exchange, offshore disposal of sediments dredged from the Bay, turbidity plumes from the Tijuana River, and surface runoff from local watersheds (e.g., Parnell et al. 2008).

In conclusion, there was no evidence of fine-particle loading related to wastewater discharge during the year or since the discharge through the SBOO began in early 1999. Likewise, contaminant concentrations at nearfield stations were within the range of variability observed throughout the region and do not appear to be organically enriched. Finally, the quality of SBOO sediments in 2015 was similar to previous years, and overall concentrations of all chemical contaminants remained relatively low compared to available thresholds and other southern California coastal areas (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009, Dodder et al. 2016).

LITERATURE CITED

Anderson, J.W., D.J. Reish, R.B. Spies, M.E. Brady, and E.W. Segelhorst. (1993). Human Impacts. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 682–766.

Brown, D.A., R.W. Gossett, G.P. Hershelman, C.G. Word, A.M. Westcott, and J.N. Cross. (1986). Municipal wastewater contamination in the Southern California Bight: Part I–metal and organic contaminants in sediments and organisms. Marine Environmental Research, 18: 291–310.

City of San Diego. (2000). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2011. City of San Diego Ocean Monitoring

Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2016). 2015 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R., R.N. Gorley, P.J. Somerfield, and R.M. Warwick. (2014). Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER-E, Plymouth, England.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Conover, W.J. (1980). Practical Nonparametric Statistics, 2^{ed}. John Wiley & Sons, Inc., New York, NY.

Cross, J.N. and L.G. Allen. (1993). Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Dodder, N., K. Schiff, A. Latker, C-L Tang. (2016). Southern California Bight 2013 Regional Monitoring Program: IV. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Eganhouse, R.P. and M.I. Venkatesan. (1993). Chemical Oceanography and Geochemistry. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 71–189.

Emery, K.O. (1960). The Sea off Southern California. John Wiley, New York, NY.

Folk, R.L. (1980). Petrology of Sedimentary Rocks. Hemphill, Austin, TX.

Gray, J.S. (1981). The Ecology of Marine Sediments: An Introduction to the Structure and Function of Benthic Communities. Cambridge University Press, Cambridge, England.

Helsel, D.R. (2005). Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc., Hoboken, NJ.

Long, E.R., D.L. MacDonald, S.L. Smith, and F.D. Calder. (1995). Incidence of adverse biological effects within ranges of chemical concentration in marine and estuarine sediments. Environmental Management, 19(1): 81–97.

Mann, K.H. (1982). The Ecology of Coastal Marine Waters: A Systems Approach. University of California Press, Berkeley, CA.

Maruya, K.A. and K. Schiff. (2009). The extent and magnitude of sediment contamination in the Southern California Bight. Geological Society of America Special Paper, 454: 399–412.

[MBC-ES] MBC Applied Environmental Sciences and Engineering-Science. (1988). Part F: Biological studies. In: Tijuana Oceanographic Engineering Study, Volume 1. Ocean Measurement Program. Prepared for the City of San Diego, CA.

Mearns, A.J., M. Matta, G. Shigenaka, D. MacDonald, M. Buchman, H. Harris, J. Golas, and G. Lauenstein. (1991). Contaminant Trends in the Southern California Bight: Inventory and Assessment. NOAA Technical Memorandum NOS ORCA 62. Seattle, WA.

Nezlin, N.P., P.M. DiGiacomo, S.B. Weisberg, D.W. Diehl, J.A. Warrick, M.J. Mengel, B.H. Jones, K.M. Reifel, S.C. Johnson, J.C. Ohlmann, L. Washburn, and E.J. Terrill. (2007). Southern California Bight 2003 Regional Monitoring Program: V. Water Quality. Southern California Coastal Water Research Project. Costa Mesa, CA.

Niedoroda, A.W., D.J.P. Swift, C.W. Reed, and J.K. Stull. (1996). Contaminant dispersal on the Palos Verdes continental margin. Science of the Total Environment, 179: 109–133.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2002). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin, 56: 1992–2002.

Parsons, T.R., M. Takahashi, and B. Hargrave. (1990). Biological Oceanographic Processes 3rd Edition. Pergamon Press, Oxford.

Patsch, K. and G. Griggs. (2007). Development of Sand Budgets for California's Major Littoral Cells. Institute of Marine Sciences, University of California, Santa Cruz, CA.

R Core Team. (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., R. Gossett, K. Ritter, L. Tiefenthaler, N. Dodder, W. Lao, and K. Maruya. (2011). Southern California Bight 2008 Regional Monitoring Program: III. Sediment Chemistry. Southern California Coastal Water Research Project, Costa Mesa, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Sherwood, C.R., D.E. Drake, P.L. Wiberg, and R.A. Wheatcroft. (2002). Prediction of the fate of p,p'-DDE in sediment on the Palos Verdes shelf, California, USA. Continental Shelf Research, 32:1025–1058.

Snelgrove, P.V.R. and C.A. Butman. (1994). Animal-sediment relationships revisited: cause versus effect. Oceanography and Marine Biology Annual Review, 32: 111–177.

Stein, E.D. and D.B. Cadien. (2009). Ecosystem response to regulatory and management actions: The Southern California experience in long-term monitoring. In: K. Schiff (ed.). Southern California Coastal Water Research Project Annual Report 2009. Southern California Coastal Water Research Project, Costa Mesa, CA.

Stull, J.K., D.J.P. Swift, and A.W. Niedoroda. (1996). Contaminant dispersal on the Palos Verdes Continental margin. Science of the Total Environment, 179: 73–90.

[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuary Protection, Washington, DC.

Wickham, H. (2007). Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL http://www.jstatsoft.org/v21/i12/.

Wickham, H. (2011). The Split-Apply-Combine Strategy for Data Analysis. Journal of Statistical Software, 40(1), 1-29. URL http://www.jstatsoft.org/v40/i01/.

Zeileis, A and G. Grothendieck (2005). zoo: S3 Infrastructure for Regular and Irregular Time Series. Journal of Statistical Software, 14(6), 1-27. URL http://www.jstatsoft.org/v14/i06/

Chapter 5
Macrobenthic Communities

Chapter 5. Macrobenthic Communities

INTRODUCTION

The City of San Diego (City) monitors communities of small benthic invertebrates (macrofauna) that live within or on the surface of soft-bottom seafloor habitats to examine potential effects of wastewater discharge on the marine benthos around the South Bay Ocean Outfall (SBOO). Benthic macrofauna are targeted for monitoring because these organisms play important ecological roles in coastal marine ecosystems off southern California and throughout the world (e.g., Fauchald and Jones 1979, Thompson et al. 1993a, Snelgrove et al. 1997). Additionally, because many benthic species live long and relatively stationary lives, they may integrate the effects of pollution or other disturbances over time (Hartley 1982, Bilyard 1987). The response of many of these species to environmental stressors is well documented, and monitoring changes in discrete populations or more complex communities can help identify locations impacted by anthropogenic inputs (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). For example, pollution-tolerant species are often opportunistic, successfully colonizing impacted areas, and can therefore displace more sensitive species. In contrast, populations of pollution-sensitive species will typically decrease in numbers in response to contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation (Gray 1979). For these reasons, the assessment of benthic community structure has become a major component of many ocean monitoring programs.

The structure of marine macrobenthic communities is influenced by naturally occurring factors such as differences in depth, sediment composition (e.g., fine versus coarse sediments), sediment quality (e.g., contaminant loads, toxicity), oceanographic conditions (e.g., temperature, dissolved oxygen, nutrient levels, currents), and biological interactions (e.g., competition, predation, bioturbation). In soft-bottom benthic habitats along the Southern California Bight (SCB) continental shelf, macrofaunal assemblages often vary along depth gradients and/or with sediment particle size (Bergen et al. 2001). Consequently, an understanding of background or reference conditions is necessary to provide the context to accurately identify whether spatial differences in populations of individual species or overall community structure may be attributable to anthropogenic activities or other factors. In the relatively nearshore environs off San Diego, past monitoring efforts for both continental shelf (<200 m) and upper slope (200–500 m) habitats have led to considerable understanding of environmental variability for the region (City of San Diego 1999, 2013, 2014a, b, Ranasinghe et al. 2003, 2007, 2010, 2012). These efforts allow for spatial and temporal comparison of the present year's monitoring data with previous surveys to determine if and where changes due to wastewater discharge may have occurred.

The City relies on a suite of ecological indices and statistical analyses to evaluate potential changes in local marine macrobenthic communities. Biological indices such as the benthic response index (BRI), Shannon diversity index, and Swartz dominance index are used as important metrics of community structure, while multivariate analyses are used to detect spatial and temporal differences among these communities (e.g., Warwick and Clarke 1993, Smith et al. 2001). The use of multiple types of analyses also provides better resolution than the evaluation of single parameters, and some include established benchmarks for determining anthropogenically-induced environmental impacts. Collectively, these data are used to determine whether invertebrate assemblages from habitats with comparable depth and sediment particle size are similar, or whether observable impacts from local ocean outfalls or other sources occur. Minor organic enrichment caused by wastewater discharge should be evident through an increase in species richness and abundance in assemblages, whereas more severe impacts should result in decreases in overall species diversity coupled with dominance by a few pollution-tolerant species (Pearson and Rosenberg 1978).

This chapter presents analysis and interpretation of macrofaunal data collected at designated benthic monitoring stations surrounding the SBOO during calendar year 2015 and includes descriptions and comparisons of the different macrobenthic communities in the region. The primary goals are to: (1) characterize and document the benthic assemblages present during the year; (2) determine the presence or absence of biological impacts on these assemblages that may be associated with wastewater discharge; (3) identify other potential natural or anthropogenic sources of variability in the local marine ecosystem.

Materials and Methods

Field Sampling

Benthic samples were collected at 27 monitoring stations in the SBOO region during the winter (January) and summer (July) of 2015 (Figure 5.1). These stations range in depth from about 18 to 60 m distributed along or adjacent to four main depth contours. Fifteen stations are located along the 19, 38, or 55-m depth contours, while 12 primary core stations are located generally along the outfall discharge depth contour of 28 m. These latter “outfall depth” stations include four nearfield monitoring sites located within 1000 m of the Y-shaped outfall diffuser structure (i.e., stations I12, I14, I15, I16), four north farfield sites located >1.2 km from the terminus of the northern diffuser leg (i.e., stations I22, I27, I30, I33), and four south farfield sites located >2.3 km from the terminus of the southern diffuser leg (i.e., stations I2, I3, I6, I9).

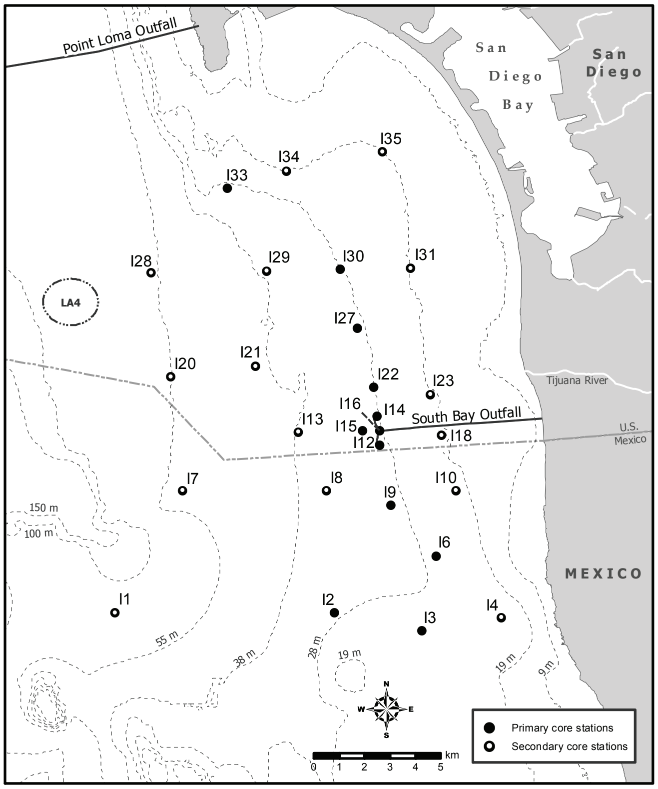


Figure 5.1
Benthic station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Samples for benthic community analysis were collected from one side of a double 0.1-m^2 Van Veen grab, while samples from the adjacent grab were used for sediment quality analyses (see Chapter 4). Criteria established by the U.S. Environmental Protection Agency (USEPA) to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were brought aboard ship, washed with seawater, and sieved through a 1.0-mm mesh screen. The organisms retained on the screen were collected, transferred to sample jars, and relaxed for 30 minutes in a magnesium sulfate solution before being fixed with buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol for final preservation. All macrofaunal organisms were separated from the raw material and sorted into five higher taxonomic groups (e.g., Annelida, Arthropoda, Mollusca, Echinodermata, and miscellaneous phyla) by a subcontract laboratory, after which they were identified to species (or the lowest taxon possible) and enumerated by City marine biologists. All identifications followed nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT 2014).

Data Analyses

The following community structure parameters were determined for each station per 0.1-m2 grab: species richness (number of taxa), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (see Swartz et al. 1986, Ferraro et al. 1994), and benthic response index (BRI; see Smith et al. 2001). Unless otherwise noted, analyses were performed using R (R Core Team 2015) and various functions within the reshape2, Rmisc, RODBC, and vegan packages (Wickham 2007, Hope 2013, Oksanen et al. 2015, Ripley and Lapsley 2015).

To examine spatial and temporal patterns among benthic communities in the SBOO region, multivariate analyses were performed using methods available in PRIMER v7 software, which included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (see Clarke et al. 2008, 2014). The Bray-Curtis measure of similarity was used as the basis for clustering, and the macrofaunal abundance data were square-root transformed to lessen the influence of overly abundant species and increase the importance (or presence) of rare species. Major ecologically-relevant clusters receiving SIMPROF support were retained, and similarity percentages analysis (SIMPER) was used to determine which species were responsible for the greatest contributions to within-group similarity (i.e., characteristic species) and between-group dissimilarity for retained clusters. To determine whether macrofaunal communities varied by sediment particle size sub-fractions, a RELATE test was used to compare patterns of rank abundance in the macrofauna Bray-Curtis similarity matrix with rank percentages in the sediment Euclidean distance matrix (see Chapter 4). A BEST test using the BIO-ENV procedure was conducted to determine which subset of sediment sub-fractions was the best explanatory variable for similarity between the two resemblance matrices.

Results and Discussion

Community Parameters

Species richness

A total of 612 taxa were identified during the 2015 SBOO surveys. Of these, 493 (81%) were identified to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although ~35% (n=211) were recorded only once. No species were reported that had not already been identified by the City's Ocean Monitoring Program.

Species richness averaged from 34 taxa per grab at station I34 to 130 taxa per grab at station I28 during the year (Table 5.1), and there were no clear patterns relative to distance from the outfall, depth, or sediment particle size (see Chapter 4). Additionally, species richness values at the different monitoring sites in 2015 (Appendix D.1) were within the range of 6–192 taxa per grab reported previously from 1995 through 2014 (City of San Diego 2000a–2015). Although long-term comparisons do not reveal any clear patterns between the nearfield and farfield stations that could be attributed to the onset of discharge in 1999 or subsequent outfall effects, it appears that variability in the number of species has been increasing generally across the SBOO region since about 2004 (Figure 5.2).

Macrofaunal abundance

A total of 30,229 macrofaunal animals were recorded in 2015. Mean abundance ranged from 117 animals per grab at station I13 to 1322 per grab at station I34 (Table 5.1). As with species richness, there were no clear patterns relative to distance from the outfall, depth, or sediment type (see Chapter 4). Abundance values during the year (Appendix D.1) were also within the historical range of 8–3216 organisms per grab reported from 1995 to 2014 (City of San Diego 2000a–2015). Long-term comparisons show that abundances remained relatively stable and similar throughout the region until around January 2007 (i.e., mean <500 per grab), after which they were higher and have been more variable (Figure 5.2). This recent high variation, especially the peaks in abundance evident during the summers of 2007, 2010, 2013, and 2015, was largely driven by region-wide increases in populations of the spionid polychaete *Spiophanes norrisi* (see Figure 5.3).

Species diversity, evenness, and dominance

Shannon diversity index (H') values averaged from 1.5 to 4.2 per grab for each station, while Pielou's evenness (J') averaged from 0.44 to 0.90 (Table 5.1).

Table 5.1

Summary of macrofaunal community parameters for SBOO benthic stations sampled during 2015. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = Pielou's evenness; Dom = Swartz dominance; BRI = benthic response index. Data for each station are expressed as annual means (n = 2 grabs). Stations are listed north to south from top to bottom for each depth contour.

	Station	SR	Abun	H'	J'	Dom	BRI
19-m Stations	I35	64	187	3.7	0.90	26	26
	I34	34	1322	1.5	0.44	5	11
	I31	62	1173	2.2	0.57	11	17
	I23	80	760	2.8	0.64	8	15
	I18	61	672	2.3	0.58	12	15
	I10	60	350	2.9	0.72	12	20
	I4	60	438	2.6	0.65	10	21
28-m Stations	I33	92	940	2.5	0.56	15	23
	I30	89	616	2.9	0.65	16	25
	I27	74	495	2.8	0.66	15	26
	I22	83	809	2.7	0.62	14	24
	I14[a]	76	642	2.5	0.59	12	26
	I16[a]	66	426	2.7	0.67	10	21
	I15[a]	68	980	2.0	0.47	8	22
	I12[a]	70	928	2.3	0.56	6	21
	I9	88	458	3.5	0.79	22	25
	I6	55	678	2.1	0.51	6	12
	I2	40	324	2.2	0.59	6	16
	I3	42	522	2.0	0.56	6	13
38-m Stations	I29	84	404	3.6	0.82	24	18
	I21	64	226	3.1	0.76	20	14
	I13	44	117	3.3	0.88	18	10
	I8	60	556	2.4	0.59	8	21
55-m Stations	I28	130	488	4.2	0.87	44	18
	I20	62	220	3.4	0.84	20	8
	I7	48	154	3.2	0.81	18	7
	I1	58	228	3.4	0.84	18	16
All Grabs	Mean	67	560	2.8	0.67	15	18
	95% CI	7	151	0.2	0.06	3	2
	Minimum	27	76	0.3	0.08	1	4
	Maximum	130	2568	4.3	0.92	46	29

[a] Nearfield station

The lowest mean diversity and evenness both occurred at station I34, while the highest respective values for these indices occurred at stations I28 and I35. Overall, these results indicate that benthic communities in the SBOO region remain characterized by relatively diverse assemblages of evenly distributed species. Swartz dominance averaged from 5 to 44 taxa per grab at each station, with the highest dominance (lowest index value) occurring at station I34 and the lowest dominance (highest index value) occurring at station I28 (Table 5.1). Values for all three of the above parameters in 2015 (Appendix D.1) were within historical ranges (City of San Diego 2000a–2015), and there continue to be no patterns evident relative to wastewater discharge, depth, or sediment particle size (see Chapter 4).

Benthic response index

The benthic response index (BRI) is an important tool for gauging anthropogenic impacts to coastal seafloor habitats throughout the SCB. BRI values below 25 are considered indicative of reference conditions, while values above 34 represent increasing levels of disturbance or environmental degradation (Smith et al. 2001). In 2015, 83% of the individual benthic grab samples collected in the SBOO region were characteristic of reference conditions (Appendix D.1), and 81% of the benthic stations sampled had mean BRI <25 (Table 5.1). Eight stations had BRI values of 25–29 that may correspond to a minor deviation from reference condition; seven of these stations occurred along the 28-m outfall discharge depth contour located from 2.3 km south to 10.3 km north of the outfall (i.e., stations I9, I14, I15, I22, I27, I30, I33), and one occurred along the 19-m contour located about 10.4 km north of the outfall (i.e., station I35). The slightly higher BRI values at these stations are not unexpected because of naturally higher levels of organic matter that may occur at depths <30 m (Smith et al. 2001). Six of these eight stations had elevated BRI values during the winter only (Appendix D.1). Historically, BRI values at the nearfield stations have been similar to values at the northern farfield stations, while BRI has been consistently lower at the southern farfield stations (Figure 5.2). Overall, there were no clear patterns in BRI results relative to wastewater discharge via the SBOO, depth, or sediment type (see Chapter 4).

Species of Interest

Dominant taxa

Polychaete worms were the dominant taxonomic group found in the SBOO region in 2015 and accounted for 46% of all taxa collected (Table 5.2). Crustaceans accounted for 21% of the taxa reported, while molluscs (17%), echinoderms (4%), and all other taxa combined (12%) accounted for the remainder. Polychaetes were also the most numerous organisms, accounting for 82% of the total abundance. Crustaceans accounted for 8% of the individuals collected, while molluscs, echinoderms, and all other taxa combined each contributed to ≤5 % of the total abundance. Overall, the percentage of taxa that occurred within each of the above major taxa and their relative abundances have remained relatively consistent since monitoring began and is similar to the rest of the Southern California Bight (see Ranasinghe et al. 2012, City of San Diego 2000a–2015).

The 10 most abundant taxa in 2015 included eight polychaetes, one bivalve, and a composite group of unidentified nematodes (Table 5.3). The dominant polychaetes were the spionids *Spiophanes norrisi* and *S. duplex*, the ampharetid *Ampharete labrops*, the capitellids *Mediomastus* sp and *Notomastus latericeus*, the cirratulid *Monticellina siblina*, the maldanid *Axiothella* sp, and the lumbrinerid *Lumbrinerides platypygos*. The dominant bivalve was *Tellina modesta*. *Spiophanes norrisi* was by far the most abundant species during the year, accounting for 55% of invertebrates collected. Overall, *S. norrisi* has been the most abundant species recorded in the SBOO region since 2007 (e.g., Figure 5.3), with up to 3009 individuals found in a single grab from station I6 during the summer of 2010 (City of San Diego 2011). *Spiophanes duplex* and *Ampharete labrops* were the next two most abundant species, averaging about 16 and 11 individuals per grab, respectively. All other species averaged fewer than 10 individuals per grab.

Spiophanes norrisi was also the most widely distributed of the above taxa in 2015, occurring in 96% of the samples with a mean abundance of ~305 individuals per grab (Table 5.3). Four of the other numerically dominant species were also found in >55% of the samples, including *Spiophanes duplex, Tellina modesta*, *Mediomastus* sp, and nematodes. The remaining five of the top 10 taxa occurred in 41–54% of the samples. Historically, *S. norrisi*, *Mediomastus* sp, *S. duplex*, *Monticellina siblina* and the maldanid polychaetes Euclymeninae sp A/B were the most numerically dominant species (Figure 5.3, Appendix D.2).

Indicator species

Several species known to be useful indicators of environmental change that occur in the SBOO region include the polychaete *Capitella teleta* (considered within the *Capitella capitata* species complex), the bivalve *Solemya pervernicosa,* and amphipods in the genera *Ampelisca* and *Rhepoxynius*. For example, increased abundances of pollution-tolerant species such as *C. teleta* and *S. pervernicosa* and

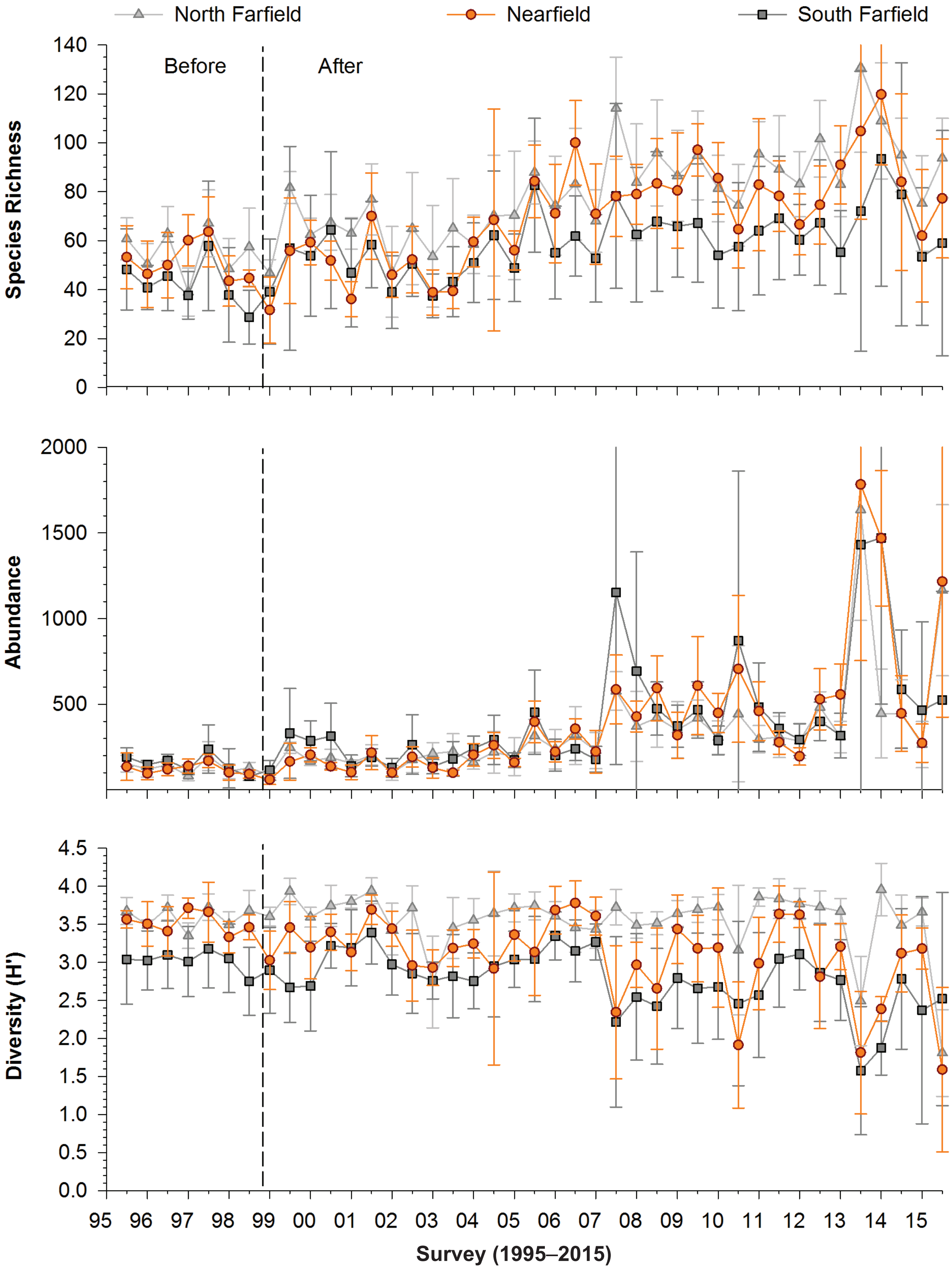


Figure 5.2

Species richness, infaunal abundance, Shannon diversity index (H'), Pielou's evenness (J'), Swartz dominance and benthic response index (BRI) at SBOO nearfield, north farfield, and south farfield primary core stations sampled from 1995 through 2015. Data for each station group are expressed as means ±95% confidence intervals per grab (n≤8). Dashed lines indicate onset of wastewater discharge.

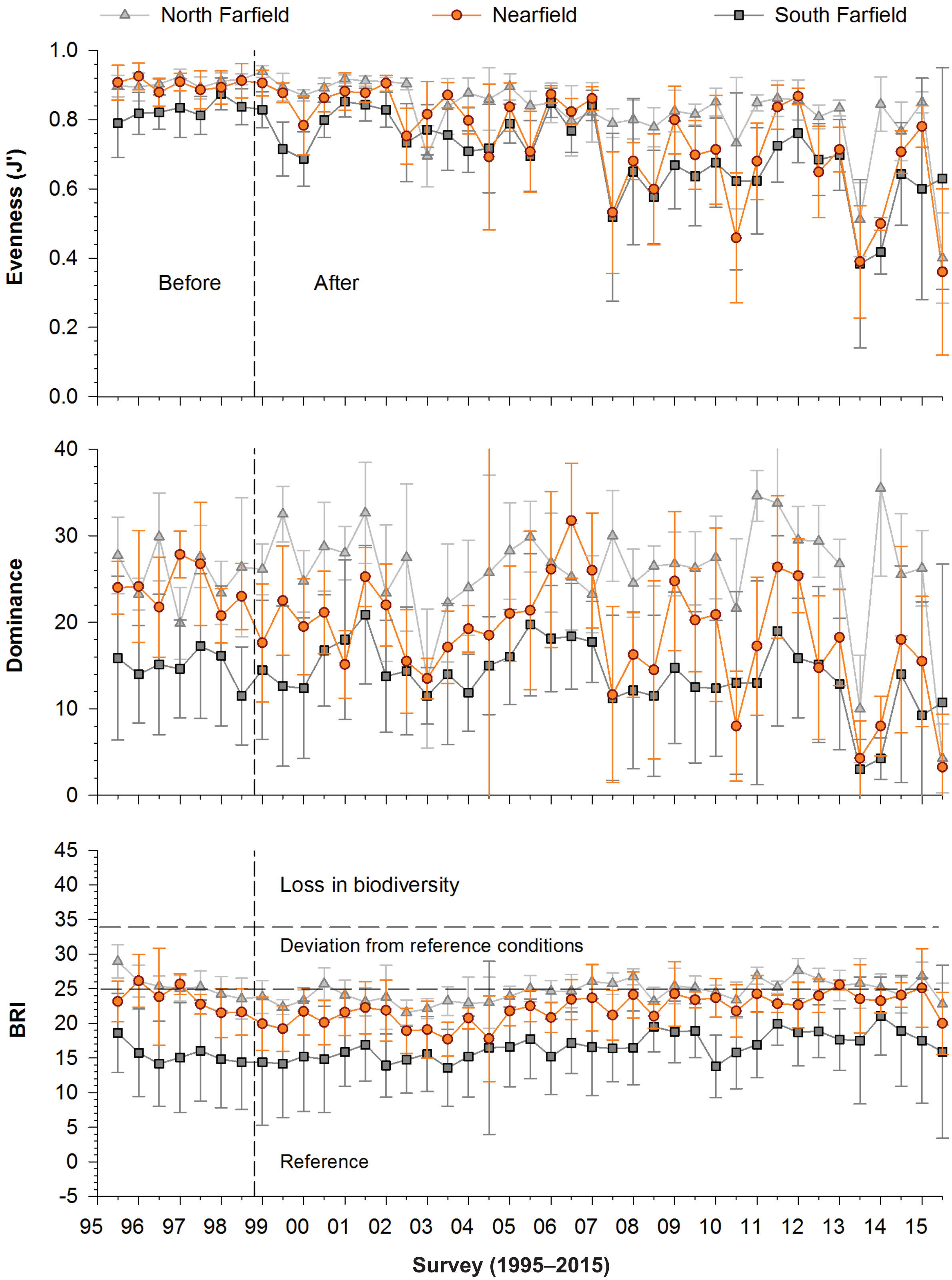


Figure 5.2 *continued*

decreased abundances of pollution-sensitive taxa such as *Ampelisca* spp and *Rhepoxynius* spp are often indicative of organic enrichment and may indicate habitats impacted by human activity (Barnard and Ziesenhenne 1961, Anderson et al. 1998, Linton and Taghon 2000, Smith et al. 2001, Kennedy et al. 2009, McLeod and Wing 2009). Only two individuals of *C. teleta* were found at station I28 and 1–13 individuals of *S. pervernicosa* were identified in samples from six stations (i.e., I1, I14, I15, I22, I27, I29) during 2015. Changes in abundances of Ampelisca and Rhepoxynius species continued to vary at all outfall depth stations, none of which were indicative of any significant wastewater impact (Figure 5.4).

Classification of Macrobenthic Assemblages

Classification (cluster) analysis was used to discriminate between macrofaunal assemblages from a total of 54 grab samples collected at 27 monitoring stations in 2015, resulting in eight ecologically relevant groups that were SIMPROF-supported at the 30% similarity level (referred to herein as cluster groups A–H), and one group (cluster group I) that split from the others at about the 12% similarity level (Figures 5.5, 5.6, Appendices D.3, D.4). These assemblages represented 1 to 20 grabs each and varied in terms of the specific taxa present, as well as their relative abundance, and occurred at sites separated by different depth and/or sediment microhabitats. For example, similar patterns of variation occurred in the benthic macrofaunal and sediment similarity/dissimilarity matrices (see Chapter 4) used to generate cluster dendrograms (RELATE ρ=0.603, p=0.001). The sediment sub-fractions that were most highly correlated to macrofaunal communities included percent fines, fine sand, coarse sand, very coarse sand, and granules (BEST ρ=0.678, p=0.001). Mean species richness ranged from 33 to 130 taxa per grab for these groups, while mean abundance ranged from 93 to 808 individuals per grab. Characteristics and differences between the nine cluster groups and their associated sediments are described below.

Table 5.2
Percent composition and abundance of major taxonomic groups in SBOO benthic grabs sampled during 2015.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	46	82
Arthropoda (Crustacea)	21	8
Mollusca	17	5
Other Phyla	12	4
Echinodermata	4	1

Cluster group A represented both the January and July assemblages in 2015 from station I28 located on the 55-m contour in the northern section of the region (Figure 5.5). This group averaged the highest species richness (130 species per grab) and

Table 5.3
The 10 most abundant macroinvertebrate taxa collected from SBOO benthic stations during 2015. Data are expressed as percent abundance (number of individuals per species/total abundance of all species), frequency of occurrence (percentage of grabs in which a species occurred) and abundance per grab (mean number of individuals per grab, n = 54).

Taxa	Taxonomic Classification	Percent Abundance	Frequency of Occurrence	Abundance per Grab
Spiophanes norrisi	Polychaeta: Spionidae	55	96	305
Spiophanes duplex	Polychaeta: Spionidae	3	59	16
Ampharete labrops	Polychaeta: Ampharetidae	2	54	11
Tellina modesta	Mollusca: Bivalvia	1	59	8
Mediomastus sp	Polychaeta: Capitellidae	1	63	6
Notomastus latericeus	Polychaeta: Capitellidae	1	48	5
Monticellina siblina	Polychaeta: Cirratulidae	1	44	4
NEMATODA	Nematoda	1	57	4
Axiothella sp	Polychaeta: Maldanidae	1	52	4
Lumbrinerides platypygos	Polychaeta: Lumbrineridae	1	41	4

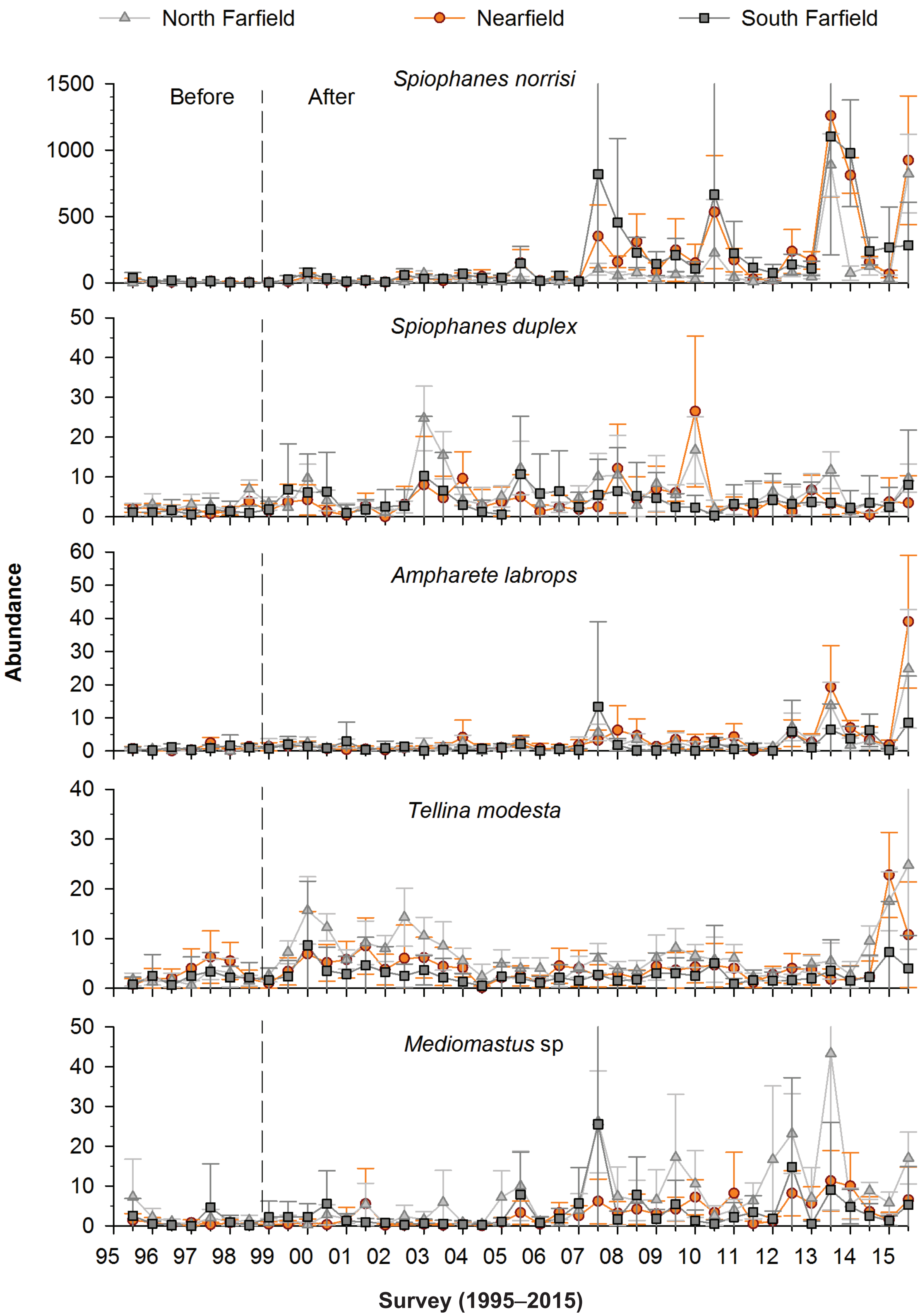


Figure 5.3

Abundances of the five most numerically dominant species (presented in order) recorded during 2015 at SBOO north farfield, nearfield, and south farfield primary core stations from 1995 through 2015. Data for each station group are expressed as means ±95% confidence intervals per grab (n≤8). Dashed lines indicate onset of wastewater discharge.

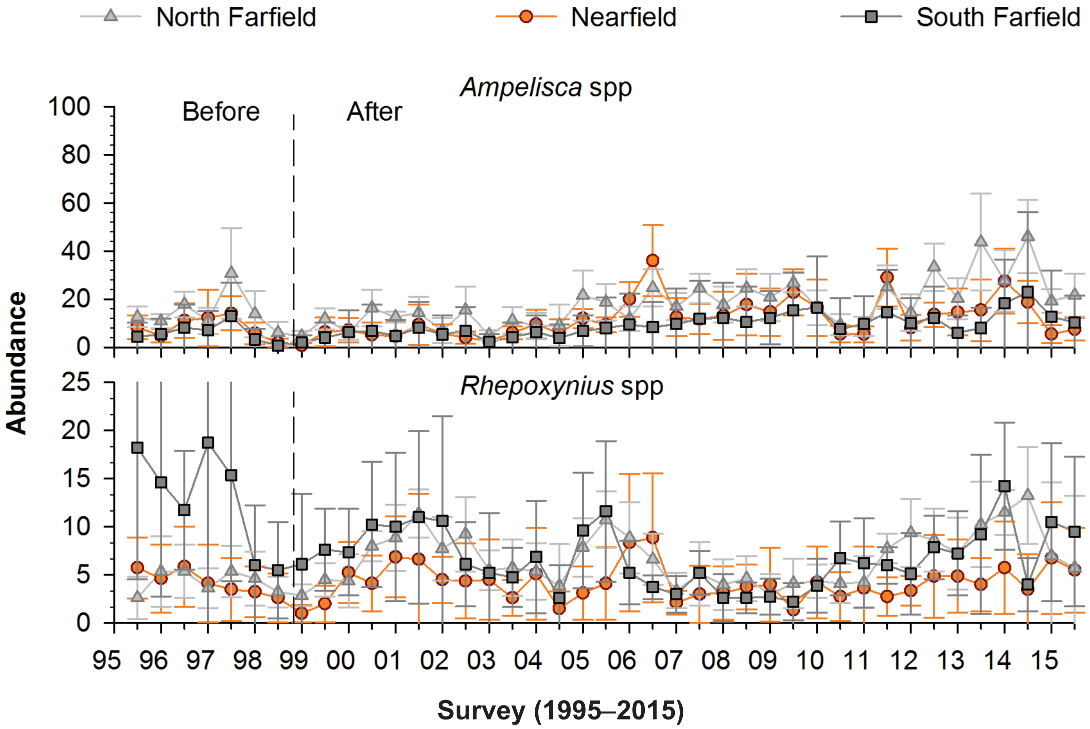


Figure 5.4
Abundances of representative ecologically important pollution-sensitive indicator taxa at SBOO north farfield, nearfield, and south farfield primary core stations from 1995 through 2015. Data for each station group are expressed as means ±95% confidence intervals per grab (n ≤ 8). Dashed lines indicate onset of wastewater discharge.

third highest abundance (488 animals per grab) of the different cluster groups. SIMPER results indicated the top five most characteristic species for group A were all polychaetes, including the sigalionid *Sthenelanella uniformis* (41 per grab), the cirratulid *Chaetozone hartmanae* (25 per grab), the maldanid Euclymeninae sp B (19 per grab), the spionid *Prionospio (Prionospio) dubia* (19 per grab), and the sabellid *Euchone incolor* (18 per grab) (Appendix D.3). Group A was also distinguished from the other SBOO assemblages by having several species unique to this cluster group including the cirratulid *Aphelochaeta tigrina* and the bivalve *Nuculana* sp A (Figure 5.6, Appendix D.3). The sediments associated with this cluster group were diverse with the highest proportion of both fines (~29%) and granules (~5%) (Appendix D.4).

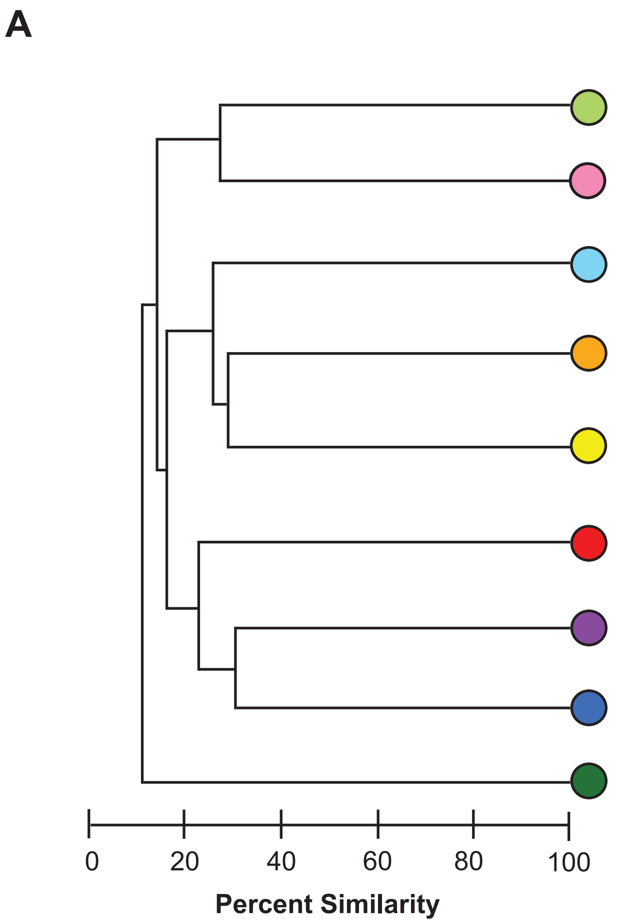
Cluster group B represented both the January and July assemblages in 2015 from station I1 located on the 55-m contour in the southwestern section of the region (Figure 5.5). Mean species richness and abundance were within the range of all other cluster groups at 59 species and 229 animals per grab, respectively. According to SIMPER analysis, this group was also characterized by its polychaete assemblage with the most characteristic species including the terebellid *Pista estevanica* (15 per grab), *Sthenelanella uniformis* (12 per grab), the chaetopterid *Spiochaetopterus costarum* Cmplx (11 per grab), the ampharetid *Anobothrus gracilis* (10 per grab), and the paraonid *Aricidea (Acmira) simplex* (7 per grab) (Appendix D.3). Group B was also distinguished by the absence or low abundance of several polychaetes common in other groups including the spionid *Spiophanes norrisi*, the cirratulid *Monticellina siblina*, and the capitellid *Mediomastus* sp (Figure 5.6). The sediments associated with this cluster group were characterized by the highest average proportion of fine sands (~49%), as well as the absence of coarse sand, very coarse sand, and granules (Appendix D.4).

Cluster group C represented the assemblages of 14 grab samples from eight different stations located along the 19–38 m depth contours during 2015 (Figure 5.5). These included both the January and July samples from three of the nearfield stations (i.e., I12, I15, I16) and three other stations located south to southwest of the discharge site at depths of about 28–38 m (i.e., stations I2, I6, I8). The remaining two samples in group C were collected in January at southern station I3 and in July at northern station I34. Mean species richness was the fourth highest while mean abundance was the highest of all cluster groups at 58 species and 808 animals per grab, respectively (Figure 5.5). Group C was distinguished from the other SBOO assemblages by having the highest mean numbers of *Spiophanes norrisi* (578 per grab) (Figure 5.6, Appendix D.3). In addition to *S. norrisi*, the remaining four of the five most characteristic species for this group according to SIMPER analysis included the capitellid *Notomastus latericeus* (14 per grab), the maldanid *Axiothella* sp (13 per grab) and the phoxocephalid amphipods *Rhepoxynius heterocuspidatus* and *Foxiphalus obtusidens* (9 and 7 per grab, respectively) (Appendix D.3). The sediments associated with this cluster group were characterized by the highest average proportion of medium sand (~47%) and the second highest proportion of fine sand (~26%) (Appendix D.4).

Cluster group D represented the January assemblages from four different stations sampled during 2015 (i.e., I4, I10, I18, I31) located along the 19-m depth contour (Figure 5.5). Species richness for this group averaged 47 species per grab, and macrofaunal abundance averaged 121 animals per grab. The five most characteristic species in this cluster group according to SIMPER analysis included *Spiophanes norrisi* (33 per grab), the bivalve *Tellina modesta* (7 per grab), the phoxocephalids *Rhepoxynius menziesi* and *Rhepoxynius variatus* (3 per grab each), and the sabellid *Dialychone veleronis* (2 per grab) (Appendix D.3). No species were unique to this cluster group. Instead, this assemblage was distinguished by lower numbers of animals that were more abundant in other groups such as the ophiuroid *Ophiura luetkenii* and the cirolanid isopod *Eurydice caudata* (Figure 5.6). The sediments associated with this cluster group averaged the highest proportion of very fine sand (~60%) and had no granules or very coarse sand (Appendix D.4).

Cluster group E was the largest group, representing the assemblages from a total of 20 grab samples collected at 13 different stations along the 19–38 m depth contours (Figure 5.5). These included both the January and July samples collected in 2015 from six stations located north of the outfall (i.e., I14, I22, I27, I30, I33, I35) and one station located south of the outfall (i.e., I9), as well as the July survey only for station I29 located north of the outfall along the 38-m depth contour and five stations arrayed along the 19-m depth contour (i.e., I4, I10, I18, I23, I31). Species richness and macrofaunal abundance for group E assemblages were widely variable (Appendix D.1). For example, species richness ranged from 55 to 125 taxa per grab with a mean of 82 species per sample, while abundance ranged from 143 to 2266 individuals per grab with a mean of 729 per sample. The five most characteristic species for this group based on SIMPER results were *Spiophanes norrisi* (401 per grab), *Spiophanes duplex* (42 per grab), *Ampharete labrops* (24 per grab), *Tellina modesta* (15 per grab), and *Mediomastus* sp (15 per grab) (Appendix D.3). In addition to the high numbers of *S. norrisi* and *S. duplex*, this group was distinguished from the other SBOO assemblages by higher numbers of *Prionospio (Prionospio) jubata*, *Monticellina siblina*, and the ampeliscid amphipod *Ampelisca cristata cristata* compared to most other groups (Figure 5.6). The sediments associated with this cluster group were characterized by the second highest proportion of fines (~18%) and very fine sand (~56%) with the lowest proportion of medium sand (~5%) (Appendix D.4).

Cluster group F represented a unique macrofaunal assemblage sampled during July 2015 at station I3 located south of the SBOO at a depth of 27 m (Figure 5.5). This assemblage had the lowest species richness (33 species) and lowest abundance (93 animals) of any cluster group. SIMPER analysis is not computed for assemblages containing only a single sample. However, the three most abundant species in this group were *Eurydice caudata* (n=20), *Spiophanes norrisi* (n=15), and the cephalochordate *Branchiostoma californiense* (n=14) which together comprised about 53% of the community (Appendix D.3). This group was also distinguished from the other SBOO assemblages by the lack of other common polychaete species such as *Spiophanes duplex*, *Mediomastus* sp, and *Ampharete labrops* (Figure 5.6, Appendix D.3). The sediments associated with cluster group F had the lowest proportions of



Cluster Group	n	Depth Range (m)	Community Metric	
			SR	Abun
A	2	55–55	130	488
B	2	60–60	59	229
C	14	19–36	58	808
D	4	18–19	47	121
E	20	18–38	82	729
F	1	27	33	93
G	4	38–41	54	172
H	4	52–55	55	187
I*	3	19–38	45	301

Figure 5.5
Results of cluster analysis of macrofaunal assemblages at SBOO benthic stations sampled during 2015. Data are presented as: (A) dendrogram of main cluster groups with community metrics presented as mean values over all stations in each group and (B) distribution of cluster groups in the SBOO region. Group I (*) is supported at 12% similarity while all other groups are supported at 30% similarity. SR = species richness; Abun = abundance.

fines, very fine sand, and fine sand (0%, 0.1%, and ~4%, respectively) and the highest proportion of coarse sand (~52%) compared to all other groups (Appendix D.4).

Cluster group G represented the January and July assemblages from all four grabs collected during 2015 at stations I13 and I21 along the 38-m depth contour (Figure 5.5). Species richness for this group averaged 54 species per grab, and macrofaunal abundance averaged 172 animals per grab. The five most characteristic species of this cluster group according to SIMPER analysis included *Spiophanes norrisi* (35 per grab), *Spiochaetopterus costarum* Cmplx (7 per grab), *Ampelisca cristata cristata* (6 per grab), the onuphid *Mooreonuphis* sp SD1 (4 per grab), and *Eurydice caudata* (3 per grab) (Appendix D.3). In addition to these five species, group G was distinguished from the other groups by the relatively high abundance of the ascidian *Agnezia septentrionalis* (Figure 5.6). The sediments associated with this cluster group averaged the second highest proportion of medium sand (~44%) and the second lowest fines (~3%) compared to other groups (Appendix D.4).

Cluster group H represented the January and July assemblages from all four grabs collected during 2015 at stations I7 and I20 along the 55-m depth contour (Figure 5.5). Species richness for this group averaged 55 species per grab, and macrofaunal abundance averaged 187 animals per grab. Group H was distinguished from the other SBOO assemblages by having high numbers of onuphids identified as either *Mooreonuphis* sp SD1 or *Mooreonuphis* sp, which combined to average about 43 worms per grab

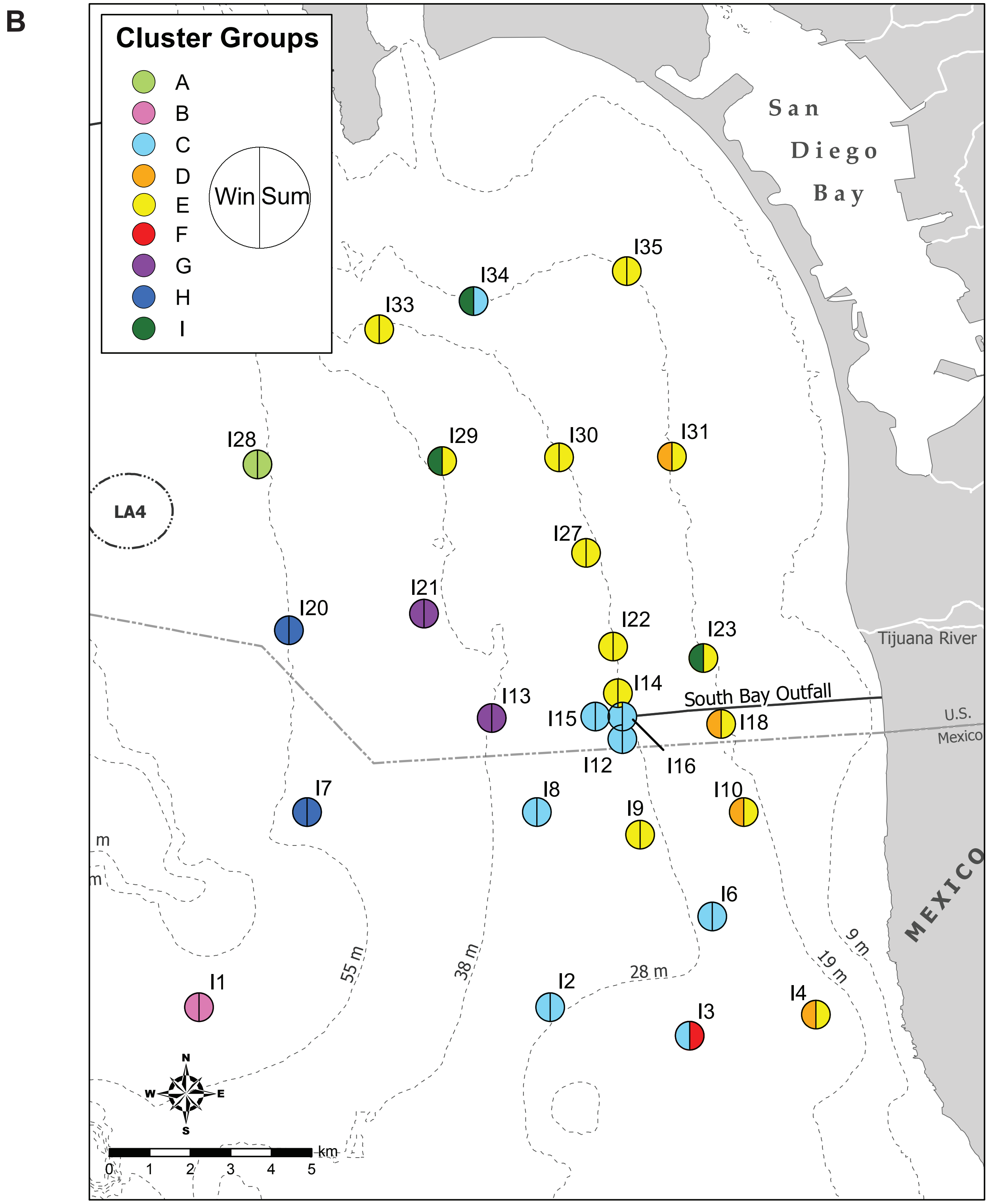


Figure 5.5 *continued*

(Appendix D.3). In contrast, these onuphids were lacking completely from groups A, D, F, and I and were only present in low numbers in the remaining groups (Figure 5.6). In addition to these *Mooreonuphis* taxa, the remaining three of the top five characteristic species for group H based on SIMPER results included the corophiid amphipod *Laticorophium baconi* (11 per grab), *Spiophanes norrisi* (10 per grab), and *Ophiura luetkenii* (5 per grab) (Appendix D.3). The sediments associated with this cluster group averaged the highest proportion of very coarse sand (~14%), and the second highest proportion of coarse sand (~50%) while having

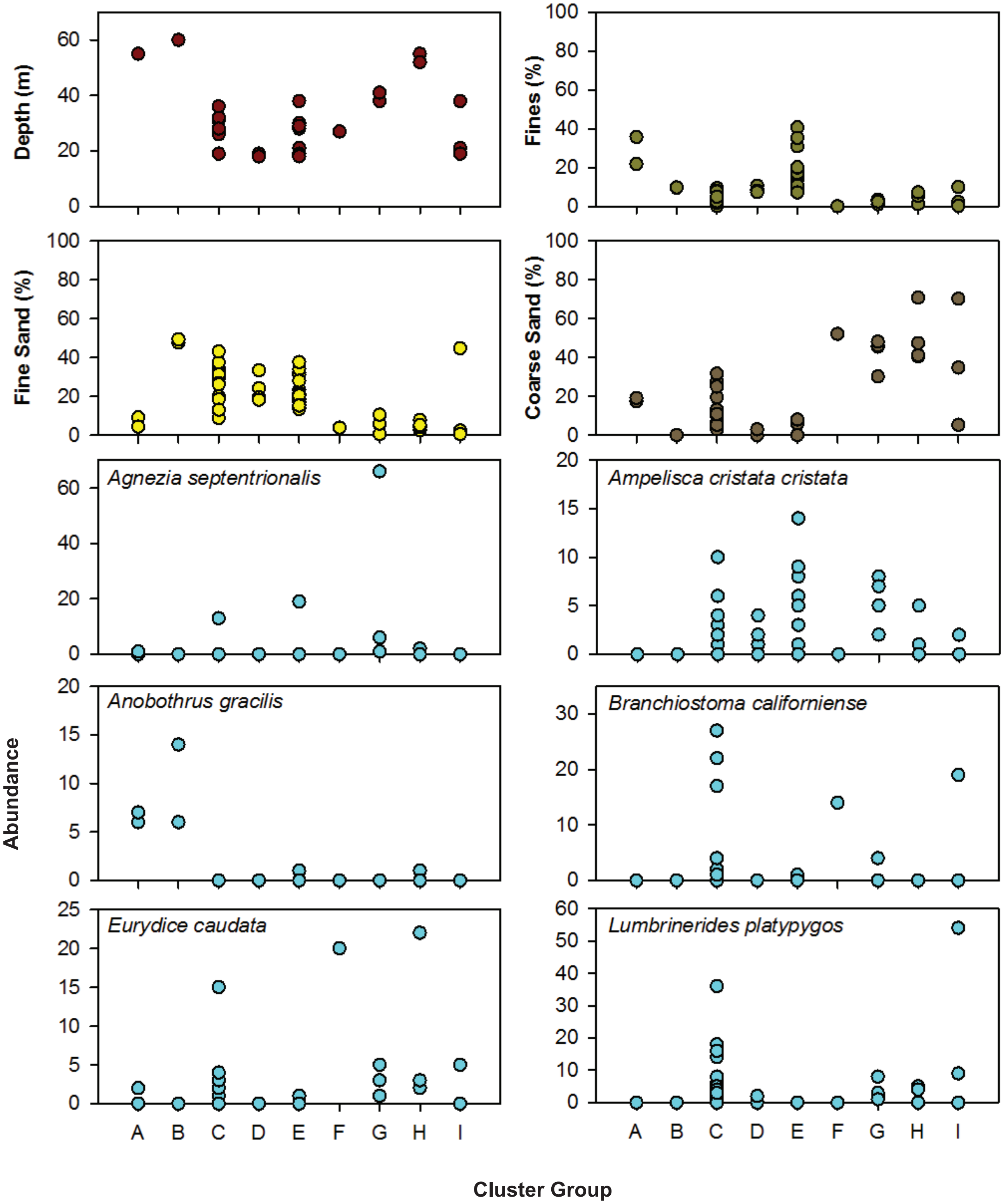


Figure 5.6
Depth, sediment composition, and abundances of select species that contributed to cluster group dissimilarities in the SBOO region during 2015 (see Figure 5.5). Each data point represents a single sediment or grab sample.

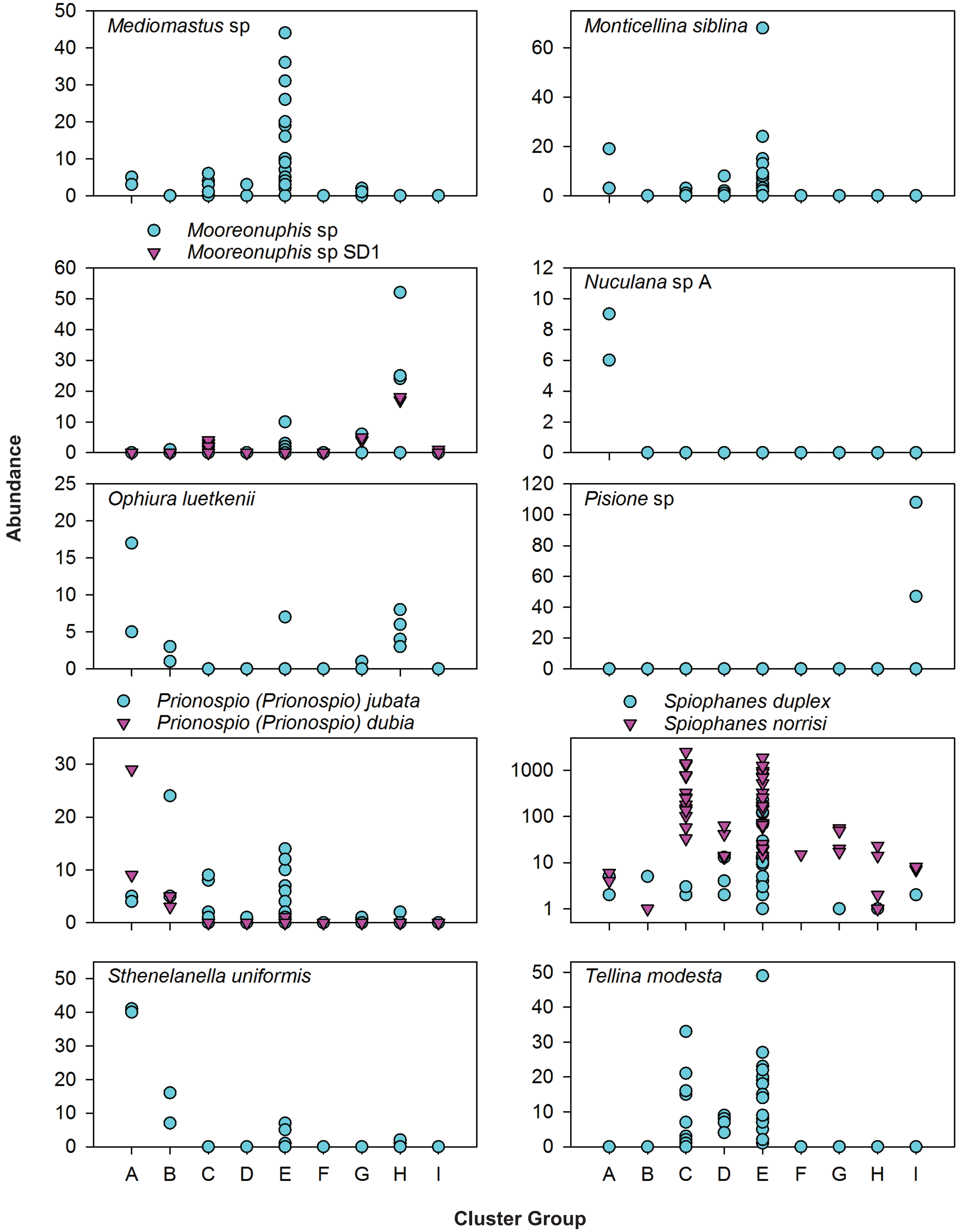


Figure 5.6 *continued*

the second lowest proportions of very fine sand (~1%) and fine sand (~5%) (Appendix D.4).

Group I represented the January assemblages from three different stations sampled during 2015 (i.e., I23, I29, I34) along the 19 and 38-m depth contours (Figure 5.5). Species richness for this group averaged 45 species per grab, and macrofaunal abundance averaged 301 animals per grab. Two of the most abundant species in this group were unique to these stations including the sigalionid *Pisione* sp (52 per grab) and the phyllodocid *Hesionura coineaui difficilis* (20 per grab) (Figure 5.6, Appendix D.3). In addition to these two polychaetes, the low numbers of *Spiophanes norrisi* (7 per grab) and high numbers of *Lumbrinerides platypygos* (21 per grab) in this group were also distinctive based on SIMPER results (Appendix D.3). The sediments associated with this cluster group averaged the second highest proportion of granules (~3%) and third highest proportion of very coarse sand (~9%) (Appendix D.4).

SUMMARY

Analyses of the 2015 macrofaunal data demonstrate that wastewater discharged through the SBOO has not negatively impacted macrobenthic communities in the region, with invertebrate assemblages located near the outfall being similar to those from the region's farfield stations. Community metrics such as species richness, macrofaunal abundance, diversity, evenness, and dominance were within historical ranges reported for the San Diego region (City of San Diego 2000a–2015), and were representative of those that occur in other sandy, shallow to mid-depth habitats throughout the SCB (Barnard and Ziesenhenne 1961, Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993b, Zmarzly et al. 1994, Diener and Fuller 1995, Bergen et al. 1998, 2000, 2001, City of San Diego 1999, Ranasinghe et al. 2003, 2007, 2010, 2012, Mikel et al. 2007). Typically, assemblages in the South Bay outfall monitoring region were indicative of the ambient sediment and/or depth characteristics, with stations of comparable physical attributes supporting similar types of benthic assemblages. Benthic response index (BRI) values determined for most sites during the year were characteristic of undisturbed habitats, with only a few stations having values suggestive of minor deviation from reference conditions. Mean BRI values at the 19-m and 28-m depth contour stations have typically been higher than along the deeper 38-m and 55-m contours since monitoring began. Higher BRI at shallower depths is not unexpected because of naturally higher levels of organic matter often occurring close to shore (Smith et al. 2001). A similar phenomenon has been reported across the SCB where Smith et al. (2001) found a pattern of lower index values at mid-depth stations (25–130 m) versus shallower (10–35 m) or deeper (110–324 m) stations.

Changes in populations of pollution-sensitive and pollution-tolerant species or other indicators of benthic condition provide little to no evidence of habitat degradation in the South Bay outfall region. For instance, populations of opportunistic species such as the polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa* were low during 2015, while populations of pollution-sensitive amphipods in the genera *Ampelisca* and *Rhepoxynius* have remained stable or increased slightly since before the onset of wastewater discharge. Additionally, although spionid polychaetes are often abundant in other areas of the world that possess naturally high levels of organic matter (Díaz-Jaramillo et al. 2008), in the SCB they are known to be a stable, dominant component of many healthy environments (Rodríguez-Villanueva et al. 2003). Thus, the presence of large populations of *Spiophanes norrisi* observed at most SBOO stations since 2007 suggest that their distribution is not indicative of habitat degradation related to wastewater discharge, but that population fluctuations of this species over the past several years likely correspond to natural changes in large-scale oceanographic conditions.

Benthic macrofaunal communities appear to be in good condition in the South Bay outfall region, remain similar to those observed prior to outfall operation, and are representative of natural indigenous communities from similar habitats on the southern California continental shelf. More than 81% of the benthic sites surveyed in 2015 were classified in reference condition based on assessments using the BRI, while the few slightly elevated BRI values that were found along and inshore of the outfall depth contour fit historical patterns that have existed since before operation of the outfall began.

Thus, no specific effects of wastewater discharge via the SBOO on the local macrobenthic community could be identified during the year.

LITERATURE CITED

Anderson, B.S., J.W. Hunt, B.M. Philips, S. Tudor, R. Fairey, J. Newman, H.M. Puckett, M. Stephenson, E.R. Long, and R.S. Tjeerdema. (1998). Comparison of marine sediment toxicity test protocols for the amphipod *Rhepoxynius abronius* and the polychaete worm *Nereis (Neanthes) arenaceodentata.* Environmental Toxicology and Chemistry. 17(5): 859–866.

Barnard, J.L. and F.C. Ziesenhenne. (1961). Ophiuroidea communities of southern Californian coastal bottoms. Pacific Naturalist, 2: 131–152.

Bergen, M., D.B. Cadien, A. Dalkey, D.E. Montagne, R.W. Smith, J.K. Stull, R.G. Velarde, and S.B. Weisberg. (2000). Assessment of benthic infaunal condition on the mainland shelf of southern California. Environmental Monitoring Assessment, 64: 421–434.

Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

Bilyard, G.R. (1987). The value of benthic infauna in marine pollution monitoring studies. Marine Pollution Bulletin, 18(11): 581–585.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000a). Final Baseline Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (1999). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2001). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2000). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2002). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2001). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2002). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental

Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2005). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014a). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014b). Point Loma Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring

Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R., R.N. Gorley, P.J. Somerfield, and R.M. Warwick. (2014). Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER-E, Plymouth, England.

Clarke, K.R., P.J. Somerfield, and R.N. Gorely. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69

Díaz-Jaramillo, M., P. Muñoz, V. Delgado-Blas, and C. Bertrán. (2008). Spatio-temporal distribution of spionids (Polychaeta-Spionidae) in an estuarine system in south-central Chile. Revista Chilena de Historia Natural, 81: 501–514.

Diener, D.R. and S.C. Fuller. (1995). Infaunal patterns in the vicinity of a small coastal wastewater outfall and the lack of infaunal community response to secondary treatment. Bulletin of the Southern California Academy of Science, 94: 5–20.

Fauchald, K. and G.F. Jones. (1979). Variation in community structures on shelf, slope, and basin macrofaunal communities of the Southern California Bight. Report 19, Series 2. In: Southern California Outer Continental Shelf Environmental Baseline Study, 1976/1977 (Second Year) Benthic Program. Principal Investigators Reports, Vol. II. Science Applications, Inc. La Jolla, CA.

Ferraro, S.P., R.C. Swartz, F.A. Cole, and W.A. Deben. (1994). Optimum macrobenthic sampling protocol for detecting pollution impacts in the Southern California Bight. Environmental Monitoring and Assessment, 29: 127–153.

Gray, J.S. (1979). Pollution-induced changes in populations. Philosophical Transactions of the Royal Society of London (Series B), 286: 545–561.

Hartley, J.P. (1982). Methods for monitoring offshore macrobenthos. Marine Pollution Bulletin, 12: 150–154.

Hope, R.M. (2013). Rmisc: Ryan Miscellaneous. R package version 1.5. http://CRAN.R-project.org/package=Rmisc.

Jones, G.F. (1969). The benthic macrofauna of the mainland shelf of southern California. Allan Hancock Monographs of Marine Biology, 4: 1–219.

Kennedy, A.J., J.A. Stevens, G.R. Lotufo, J.D. Farrar, M.R. Reiss, R.K. Kropp, J. Doi, and T.S. Bridges. (2009). A comparison of acute and chronic toxicity methods for marine sediments. Marine Environmental Research, 68: 118–127.

Linton, D.L. and G.L. Taghon. (2000). Feeding, growth, and fecundity of *Capitella* sp. I in relation to sediment organic concentration. Marine Ecology Progress Series, 205: 229–240.

McLeod, R.J. and S.R. Wing. (2009). Strong pathways for incorporation of terrestrially derived organic matter into benthic communities. Estuarine, Coastal and Shelf Science, 82: 645–653.

Mikel T.K., J.A Ranasinghe, and D.E. Montagne. (2007). Characteristics of benthic macrofauna of the Southern California Bight. Appendix F. Southern California Bight 2003 Regional Monitoring Program, SCCWRP, Costa Mesa, CA.

Oksanen, J., F. G. Blanchet, R. Kindt, P. Legendre, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens and H. Wagner. (2015). vegan: Community Ecology Package. R package version 2.3-1. http://CRAN.R-project.org/package=vegan.

Pearson, T.H. and R. Rosenberg. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review, 16: 229–311.

R Core Team. (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, and S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project, Costa Mesa, CA.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project, Westminster, CA.

Ranasinghe, J.A., K.C. Schiff, C.A. Brantley, L.L. Lovell, D.B. Cadien, T.K. Mikel, R.G. Velarde, S. Holt, and S.C. Johnson. (2012). Southern California Bight 2008 Regional Monitoring Program: VI. Benthic Macrofauna. Technical Report No. 665, Southern California Coastal Water Research Project, Costa Mesa, CA.

Ranasinghe, J.A., K.C. Schiff, D.E. Montagne, T.K. Mikel, D.B. Cadien, R.G. Velarde, and C.A. Brantley. (2010). Benthic macrofaunal community condition in the Southern California Bight, 1994–2003. Marine Pollution Bulletin, 60: 827–833.

Ripley, B. and M. Lapsley. (2015). RODBC: ODBC Database Access. R package version 1.3-12. http://CRAN.R-project.org/package=RODBC.

Rodríguez-Villanueva, V., R. Martínez-Lara, and V. Macías Zamora. (2003). Polychaete community structure of the northwestern coast of Mexico: patterns of abundance and distribution. Hydrobiologia, 496: 385–399.

[SCAMIT] Southern California Association of Marine Invertebrate Taxonomists. (2014). A taxonomic listing of benthic macro- and megainvertebrates from infaunal and epibenthic monitoring programs in the Southern California Bight, edition 9. Southern California Association of Marine Invertebrate Taxonomists, Natural History Museum of Los Angeles County Research and Collections, Los Angeles, CA.

Smith, R.W., M. Bergen, S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, J.K. Stull, and R.G. Velarde. (2001). Benthic response index for assessing infaunal communities on the southern California mainland shelf. Ecological Applications, 11(4): 1073–1087.

Snelgrove, P.V.R., T.H. Blackburn, P.A. Hutchings, D.M. Alongi, J.F. Grassle, H. Hummel, G. King, I. Koike, P.J.D. Lambshead, N.B. Ramsing, and V. Solis-Weiss. (1997). The importance of marine sediment biodiversity in ecosystem processes. Ambio, 26: 578–583.

Swartz, R.C., F.A. Cole, and W.A. Deben. (1986). Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series, 31: 1–13.

Thompson, B.E., J.D. Laughlin, and D.T. Tsukada. (1987). 1985 reference site survey. Technical Report No. 221, Southern California Coastal Water Research Project, Long Beach, CA.

Thompson, B., J. Dixon, S. Schroeter, and D.J. Reish. (1993a). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA.

Thompson, B.E., D. Tsukada, and D. O'Donohue. (1993b). 1990 reference site survey. Technical Report No. 269, Southern California Coastal Water Research Project, Long Beach, CA.

[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.

Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology, 18: 63–80.

Warwick, R.M. and K.R. Clarke. (1993). Increased variability as a symptom of stress in marine communities. Journal of Experimental Marine Biology and Ecology, 172: 215–226.

Wickham, H. (2007). Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL http://www.jstatsoft.org/v21/i12/.

Zmarzly, D.L., T.D. Stebbins, D. Pasko, R.M. Duggan, and K.L. Barwick. (1994). Spatial patterns and temporal succession in soft-bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: Relation to anthropogenic and natural events. Marine Biology, 118: 293–307.

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Chapter 6
Demersal Fishes and Megabenthic Invertebrates

Chapter 6. Demersal Fishes and Megabenthic Invertebrates

INTRODUCTION

The City of San Diego (City) collects bottom dwelling (demersal) fishes and relatively large (megabenthic) mobile invertebrates by otter trawl to examine the potential effects of wastewater discharge or other disturbances on the marine environment around the South Bay Ocean Outfall (SBOO). These fish and invertebrate communities are targeted for monitoring because they are known to play critical ecological roles on the southern California coastal shelf (e.g., Allen et al. 2006, Thompson et al. 1993a, b). Because trawled species live on or near the seafloor, they may be impacted by sediment conditions affected by both point and non-point sources such as discharges from ocean outfalls, runoff from watersheds, outflows from rivers and bays, or the disposal of dredged sediments (see Chapter 4). For these reasons, assessment of fish and invertebrate communities has become an important focus of ocean monitoring programs throughout the world, but especially in the Southern California Bight (SCB) where they have been sampled extensively on the mainland shelf for the past four decades (e.g., Stein and Cadien 2009).

In healthy ecosystems, fish and invertebrate communities are known to be inherently variable and influenced by many natural factors. For example, prey availability, seafloor topography, sediment composition, and changes in water temperatures associated with large scale oceanographic events such as El Niño can affect migration or recruitment of fish (Cross et al. 1985, Helvey and Smith 1985, Karinen et al. 1985, Murawski 1993, Stein and Cadien 2009). Population fluctuations may also be due to the mobile nature of many species (e.g., fish schools, urchin aggregations). Therefore, an understanding of natural background conditions is necessary before determining whether observed differences or changes in community structure may be related to anthropogenic activities. Pre-discharge and regional monitoring efforts by the City and other researchers since 1994 provide baseline information on the variability of demersal fish and megabenthic communities in the San Diego region critical for such comparative analyses (e.g., Allen et al. 1998, 2002, 2007, 2011, City of San Diego 2000).

The City relies on a suite of scientifically-accepted indices and statistical analyses to evaluate changes in local fish and invertebrate communities. These include univariate measures of community structure such as species richness, abundance, and diversity, while multivariate analyses are used to detect spatial and temporal differences among communities (e.g., Warwick 1993). The use of multiple analyses provides better resolution than single parameters for determining anthropogenically-induced environmental impacts. In addition, trawled fishes are inspected for evidence of physical anomalies or diseases that have previously been found to be indicators of degraded habitats (e.g., Cross and Allen 1993, Stein and Cadien 2009). Collectively, these data are used to determine whether fish and invertebrate assemblages from habitats with comparable depth and sediment characteristics are similar, or whether observable impacts from wastewater discharge or other sources have occurred.

This chapter presents analysis and interpretation of demersal fish and megabenthic invertebrate data collected during calendar year 2015, as well as long-term assessments of these communities from 1995 through 2015. The primary goals are to: (1) document assemblages present during the year; (2) determine the presence or absence of biological impacts associated with wastewater discharge; (3) identify other potential natural and anthropogenic sources of variability to the local marine ecosystem.

MATERIALS AND METHODS

Field Sampling

Trawl surveys were conducted at seven monitoring stations in the SBOO region sampled during winter (January) and summer (August) 2015 (Figure 6.1). These stations, designated SD15–SD21, are all located along the 28-m depth contour ranging from 7 km south to 8.5 km north of the SBOO. Stations SD17 and SD18 are located within 1000 m of the outfall wye, and represent the "nearfield" station group. Stations SD15 and SD16 are located > 1.8 km south of the outfall and represent the "south farfield" station group, while SD19, SD20, and SD21 are located > 1.7 km north of the outfall and represent the "north farfield" station group.

A single trawl was performed at each station during each survey using a 7.6-m Marinovich otter trawl fitted with a 1.3-cm cod-end mesh net. The net was towed for 10 minutes of bottom time at a speed of about 2.0 knots along a predetermined heading. The catch from each trawl was brought onboard the ship for sorting and inspection. All fishes and invertebrates were identified to species or to the lowest taxon possible (Eschmeyer and Herald 1998, Lawrence et al. 2013, SCAMIT 2014). If an animal could not be identified in the field, it was returned to the laboratory for identification. The total number of individuals and total biomass (kg, wet weight) were recorded for each species of fish. Additionally, each fish was inspected for the presence of physical anomalies, tumors, fin erosion, discoloration, or other indicators of disease, as well as the presence of external parasites (e.g., copepods, cymothoid isopods, leeches). The length of each fish was measured to the nearest centimeter size class; total length (TL) was measured for cartilaginous fishes and standard length (SL) was measured for bony fishes (SCCWRP 2013). For invertebrates, only the total number of individuals was recorded for each species.

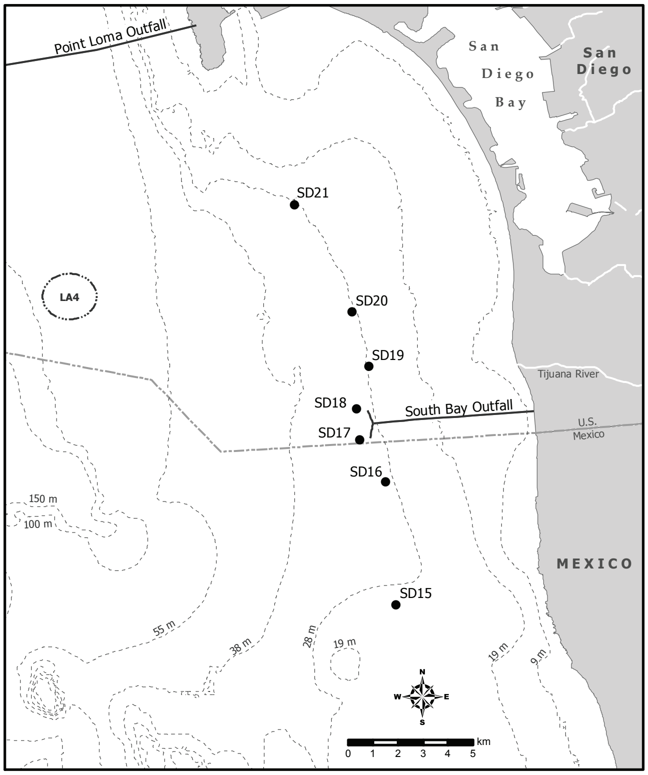


Figure 6.1
Trawl station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Data Analyses

Population characteristics of fish and invertebrate species were summarized as percent abundance (number of individuals per species/total abundance of all species), frequency of occurrence (percentage of stations at which a species was collected), mean abundance per haul (number of individuals per species/ total number sites sampled), and mean abundance per occurrence (number of individuals per species/ number of sites at which the species was collected). Additionally, the following community structure parameters were calculated per trawl for both fishes and invertebrates: species richness (number of species), total abundance (number of individuals), and Shannon diversity index (H'). Total biomass was also calculated for each fish species captured. These analyses were performed using R (R Core Team 2015) and various functions within the gtools, plyr, reshape2, RODBC, sqldf, and vegan packages (Wickham 2007, Wickham 2011, Grothendieck 2014, Oksanen et al. 2015, Ripley and Lapsley 2015, Warnes et al. 2015).

Multivariate analyses were performed in PRIMER v7 software using demersal fish and megabenthic invertebrate data collected from 1995 through 2015 (see Clarke 1993, Warwick 1993, Clarke et al. 2014). Prior to these analyses, all data were limited to summer surveys only to reduce statistical noise from natural seasonal variations evident in previous studies (e.g., City of San Diego 1997, 2013). Analyses included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). The Bray-Curtis measure of similarity was used as the basis for the cluster analysis, and abundance data were square-root transformed to lessen the influence of the most abundant species and increase the importance of rare species. Major ecologically-relevant clusters receiving SIMPROF support were retained, and similarity percentages analysis (SIMPER) was used to determine which species were responsible for the greatest contributions to within-group similarity (i.e., characteristic species).

Results and Discussion

Demersal Fishes

Community Parameters

At least 27 species of fish were collected in the SBOO monitoring region in 2015, representing 19 different families (Table 6.1, Appendices E.1, E.2). A total of 1921 individual fish were collected during the winter and summer trawls combined, which represents an average of ~137 fish per trawl. This total catch for 2015 was about 57% smaller than the catch for 2014 (see City of San Diego 2015). The three most abundant species encountered during 2015 included Speckled and Longfin Sanddabs within the family Paralichthyidae and California Lizardfish within the family Synodontidae (Table 6.1, Appendix E.1). Together these three species accounted for more than 90% of all fish captured during the year. Speckled Sanddabs continued to dominate SBOO fish assemblages, occurring in every haul and accounting for 67% of all fish collected (mean = 92 fish per haul). This average catch of Speckled Sanddabs represents about a 33% decrease compared to 2014. California Lizardfish was the second most abundant and common species present in 2015, occurring in 93% of the trawls and accounting for 16% of the fish collected (mean = 22 fish per haul). This represents about a 71% decrease in Lizardfish abundances reported for 2014. The Longfin Sanddab was the third most abundant species captured in 2015, although it occurred in only 64% of the trawls. Overall, Longfin Sanddabs accounted for about 8% of all fish collected at an average abundance of about 11 fish per trawl. Other species collected in at least 50% of the trawls, but in relatively low numbers (≤ 5 fish per haul) included California Tonguefish, Hornyhead Turbot, and California Halibut. One species not previously reported for the region by the City's monitoring program was encountered during the 2015 SBOO surveys: a single Tubesnout (*Aulorhynchus flavidus*) was collected in August at station SD16 (Appendices E.1, E.2).

More than 99% of the fishes collected in 2015 were ≤ 29 cm in length (Appendix E.1). Larger fishes included one California Skate (38 cm), two Thornback (39 cm, 53 cm), and seven California Halibut (31–68 cm). Overall, median fish lengths varied somewhat across stations and between seasons for the four most abundant species collected during the past year (Figure 6.2). Speckled Sanddabs were the most consistent in terms of size, with median lengths per haul ranging from 6 to 9 cm. The median lengths per haul for California Lizardfish ranged from 11 to 18 cm; these fish tended to be larger during the winter than in the summer, with the largest fish occurring at station SD18. Longfin Sanddab were also larger during the winter, with median lengths per haul ranging from 12 to 15 cm in January versus 5 to 9 cm in August. In contrast, California Tonguefish were larger during the summer with median lengths up to 14 cm per haul, versus the winter when median lengths ranged from 5 to 11.5 cm per haul.

Species richness and diversity were consistently low for demersal fish communities sampled in 2015, as is typical for the region (e.g., City of San Diego 2000). Species richness ranged from 6 species per haul at stations SD15 (both surveys) and SD16 (summer only) to 13 species per haul at station SD18 during the winter and station SD21 during the summer (Table 6.2). Diversity (H')

Table 6.1

Species of demersal fish collected from 14 trawls conducted in the SBOO region during 2015. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
Speckled Sanddab	67	100	92	92	Kelp Bass	<1	7	<1	4
California Lizardfish	16	93	22	23	Barred Sand Bass	<1	14	<1	1
Longfin Sanddab	8	64	11	16	California Skate	<1	14	<1	1
California Tonguefish	3	86	5	5	English Sole	<1	14	<1	1
Hornyhead Turbot	1	86	2	2	Sarcastic Fringehead	<1	14	<1	1
California Halibut	1	50	1	1	Thornback	<1	14	<1	1
Unidentified Pipefish	1	36	1	2	White Croaker	<1	14	<1	1
Calico Rockfish	<1	7	1	9	Yellowchin Sculpin	<1	14	<1	1
California Scorpionfish	<1	43	1	2	Blacksmith	<1	7	<1	1
Fantail Sole	<1	43	1	1	Ocean Whitefish	<1	7	<1	1
Plainfin Midshipman	<1	36	<1	1	Round Stingray	<1	7	<1	1
Giant Kelpfish	<1	29	<1	2	Specklefin Midshipman	<1	7	<1	1
Roughback Sculpin	<1	29	<1	2	Tubesnout	<1	7	<1	1
Curlfin Sole	<1	21	<1	2					

ranged from 0.5 to 1.4 per haul, with the lowest values recorded at stations SD15 and SD16 during the summer, and the highest values recorded at station SD15 in the winter and station SD21 in the summer. In contrast, abundance and biomass were more variable among stations and between surveys during the year. For example, total abundance ranged from 19 to 298 individuals per haul and total biomass ranged from 1.0 to 7.0 kg per haul. The smallest hauls with ≤100 individuals were from stations SD15 and SD16 during both surveys, and stations SD19 and SD20 in the summer. The largest hauls with ≥208 individuals were from stations SD19 and SD20 in the winter and station SD21 in the summer. The largest winter catches each included ≥184 Speckled Sanddabs, while the largest summer catch included 140 California Lizardfish (Appendix E.2). The heaviest trawls with ≥6.4 kg of fishes were recorded at station SD20 during the winter, and station SD21 in the summer. The large haul from station SD20 included 5.3 kg of California Halibut, while the large haul from station SD21 included 2.1 kg of California Lizardfish, 1.3 kg of Speckled Sanddab, 1.1 kg of Longfin Sanddab, and 1.0 kg of California Halibut.

Over the past 21 years, mean species richness and diversity (H') for demersal fishes have remained below 14 species per haul and 1.7 per haul, respectively, whereas there has been considerably greater variability in mean abundance (i.e., 40–624 fishes per haul) (Figure 6.3). The latter has largely been due primarily to population fluctuations of a few numerically dominant species (Figure 6.4). For example, differences in overall fish abundance primarily track changes in Speckled Sanddab populations, since this species has been numerically dominant in the SBOO region since sampling began (see following section and City of San Diego 2000). In addition, occasional spikes in abundance have been due to large hauls of other common species such as California Lizardfish, Yellowchin Sculpin, White Croaker, and Roughback Sculpin. Overall, none of the observed changes appear to be associated with wastewater discharge.

Classification of Demersal Fish Assemblages

Classification (cluster) analysis discriminated between six main types of fish assemblages present in the South Bay outfall region during the summer season over the past 21 years (Figure 6.5, Table 6.3). These assemblages (referred to herein as cluster groups A–F) represented from 1 to 45 hauls each and varied in terms of species present, as well as the relative abundances of individual species. During 2015, fish assemblages were distributed into three of the four largest cluster groups (see description of groups B, C and F below) that appear to be influenced by long-term climate-related changes in the SCB (e.g., ENSO conditions)

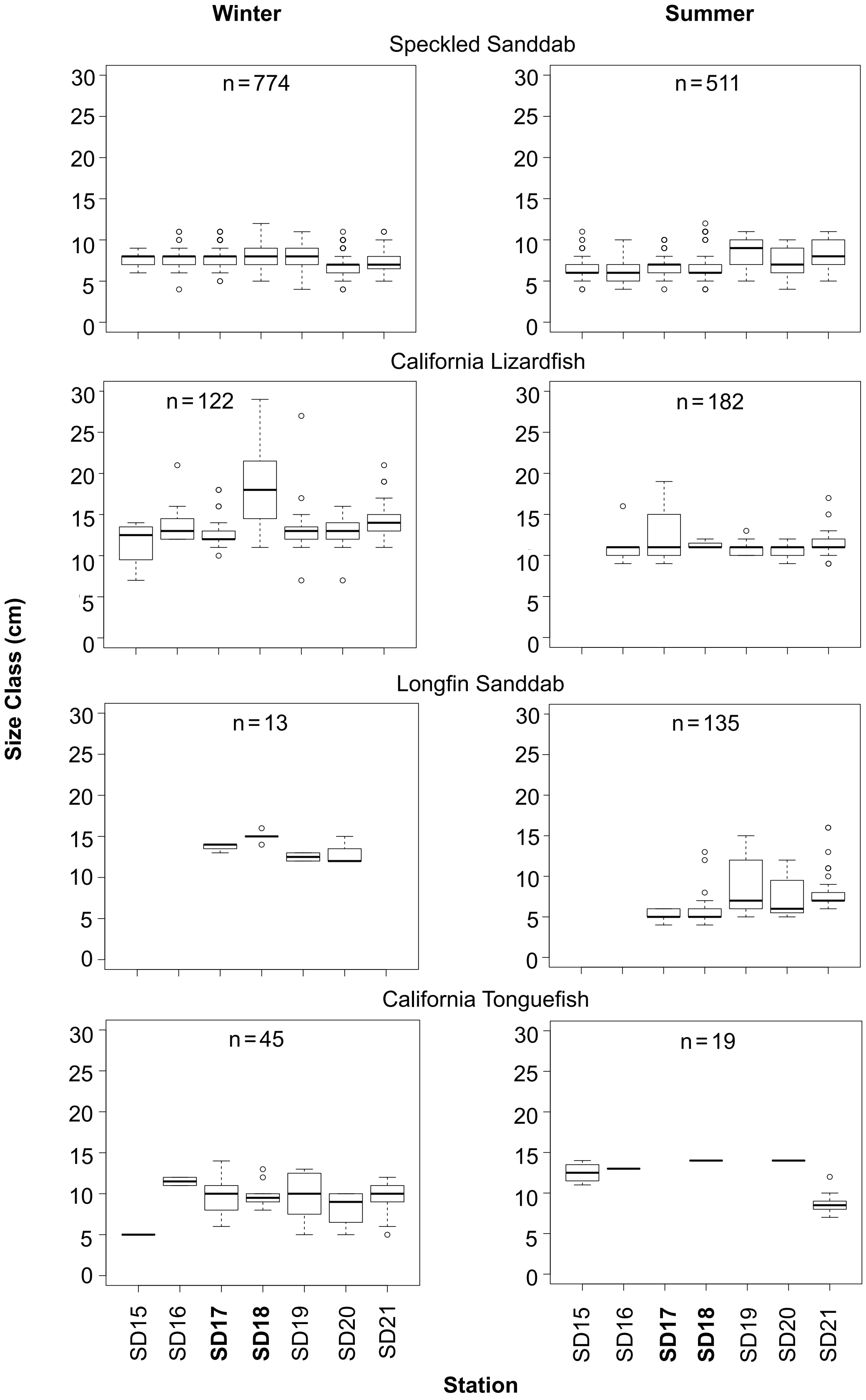


Figure 6.2

Summary of fish lengths by survey and station for the four most abundant species collected in the SBOO region during 2015. Data are median, upper and lower quartiles, 1.5 times the interquartile range (whiskers), and outliers (open circles). Stations SD17 and SD18 are considered nearfield (bold; see text).

Table 6.2

Summary of demersal fish community parameters for SBOO trawl stations sampled during 2015. Data are included for species richness, abundance, diversity (H'), and biomass (kg, wet weight). SD = standard deviation.

Station	Winter	Summer	Station	Winter	Summer
Species richness			*Abundance*		
SD15	6	6	SD15	19	98
SD16	7	6	SD16	80	100
SD17	8	8	SD17	176	116
SD18	13	8	SD18	184	136
SD19	9	8	SD19	236	64
SD20	8	11	SD20	208	86
SD21	10	13	SD21	120	298
Survey Mean	9	9	Survey Mean	146	128
Survey SD	2	2	Survey SD	71	72
Diversity			*Biomass*		
SD15	1.4	0.5	SD15	2.6	1.2
SD16	1.2	0.5	SD16	3.4	1.0
SD17	0.9	1.0	SD17	2.6	1.5
SD18	1.1	0.9	SD18	4.8	2.6
SD19	0.7	1.3	SD19	2.5	4.4
SD20	0.6	1.3	SD20	7.0	4.7
SD21	1.2	1.4	SD21	2.2	6.4
Survey Mean	1.0	1.0	Survey Mean	3.6	3.1
Survey SD	0.3	0.4	Survey SD	1.6	1.9

or unique characteristics of a specific station location. For example, cluster groups A, C and D were distinguished by very low numbers of Speckled Sanddabs (≤49 fish per haul) that coincided with or followed generally warm water conditions such as the 1994/1995 and the 1997/1998 El Niño, while groups B, E, and F had relatively high numbers of Speckled Sanddabs (≥101 fish per haul) that tended to coincide with ENSO neutral or cold water conditions associated with La Niña (see Chapter 2 and NOAA/NWS 2016). Additionally, station SD15 located farthest south of the outfall off northern Baja California often grouped apart from the remaining stations, possibly due to habitat differences such as sandier sediments (see Chapter 4). The species composition and main descriptive characteristics of each of the six cluster groups are described below.

Cluster group A represented assemblages from six trawls that included station SD15 sampled in 1997 and 1998, and stations SD15, SD16, SD17 and SD19 sampled in 2001 (Figure 6.5). This group averaged the lowest species richness (6 species per haul) and the lowest abundance (26 individuals per haul) (Table 6.3). SIMPER results indicated that the most characteristic species for group A were Speckled Sanddab (15 per haul), California Lizardfish (3 per haul), Hornyhead Turbot (2 per haul), California Scorpionfish (2 per haul), and Spotted Turbot (2 per haul).

Cluster group B was the largest group, representing the assemblages from a total of 45 trawls conducted at one to six sites sampled every summer except during 1998, 2009, 2010, 2013 and 2014 (Figure 6.5). This group included stations SD15 and SD16 sampled during 2015, 58% (n=29) of the trawls conducted at stations SD 6–SD20 from 1999 through 2004, and 65% (n=13) of the trawls conducted at station SD15 from 1995 through 2014. This assemblage type never occurred at station SD21. Assemblages represented by group B had the second lowest average species richness (7 species per haul) and the third lowest average abundance (116 individuals

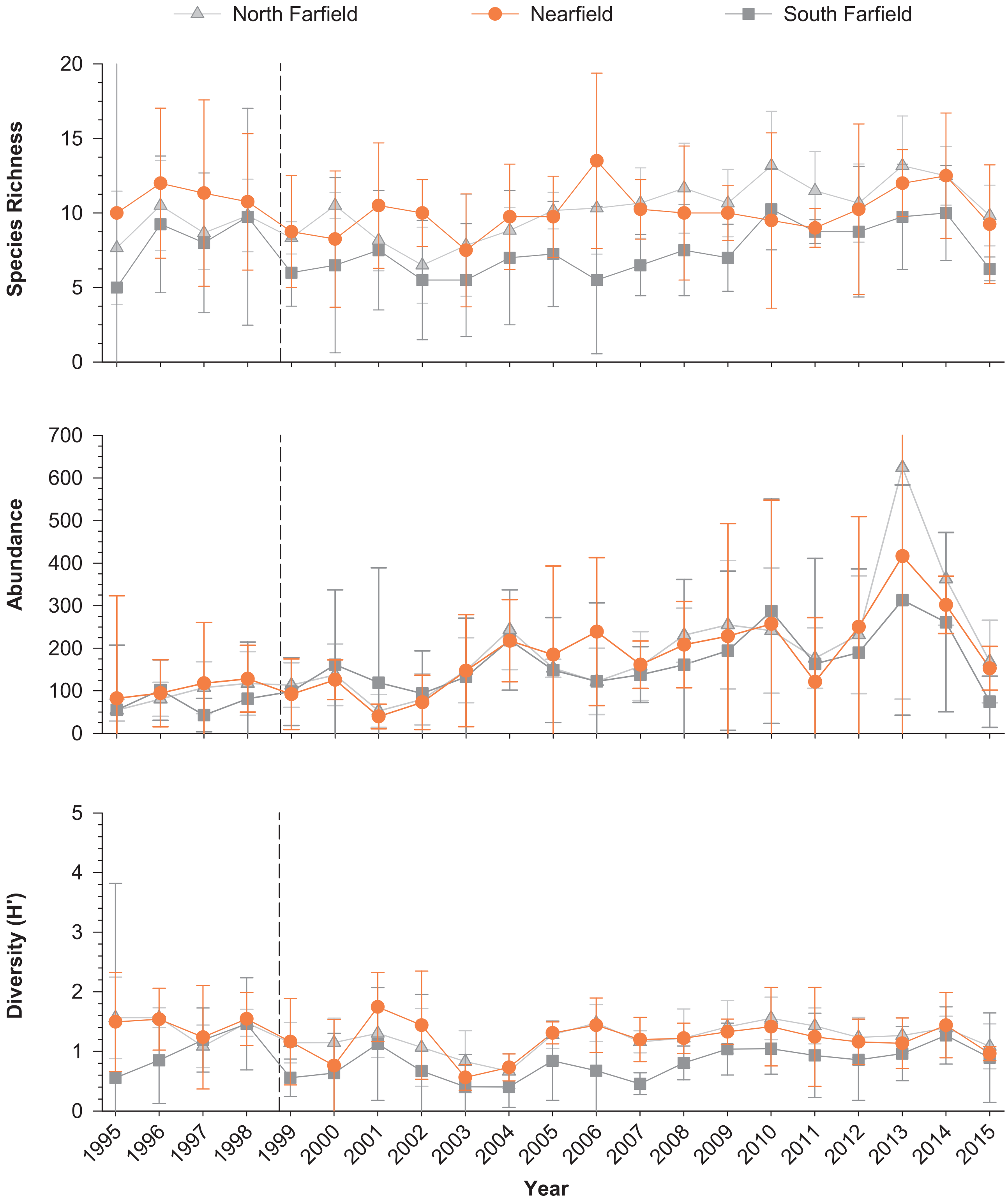


Figure 6.3
Species richness, abundance, and diversity of demersal fishes collected from SBOO trawl stations sampled from 1995 through 2015. Data are annual means with 95% confidence intervals for nearfield (n ≤ 4), north farfield (n = 6), and south farfield (n = 4) stations. Dashed lines indicate onset of wastewater discharge.

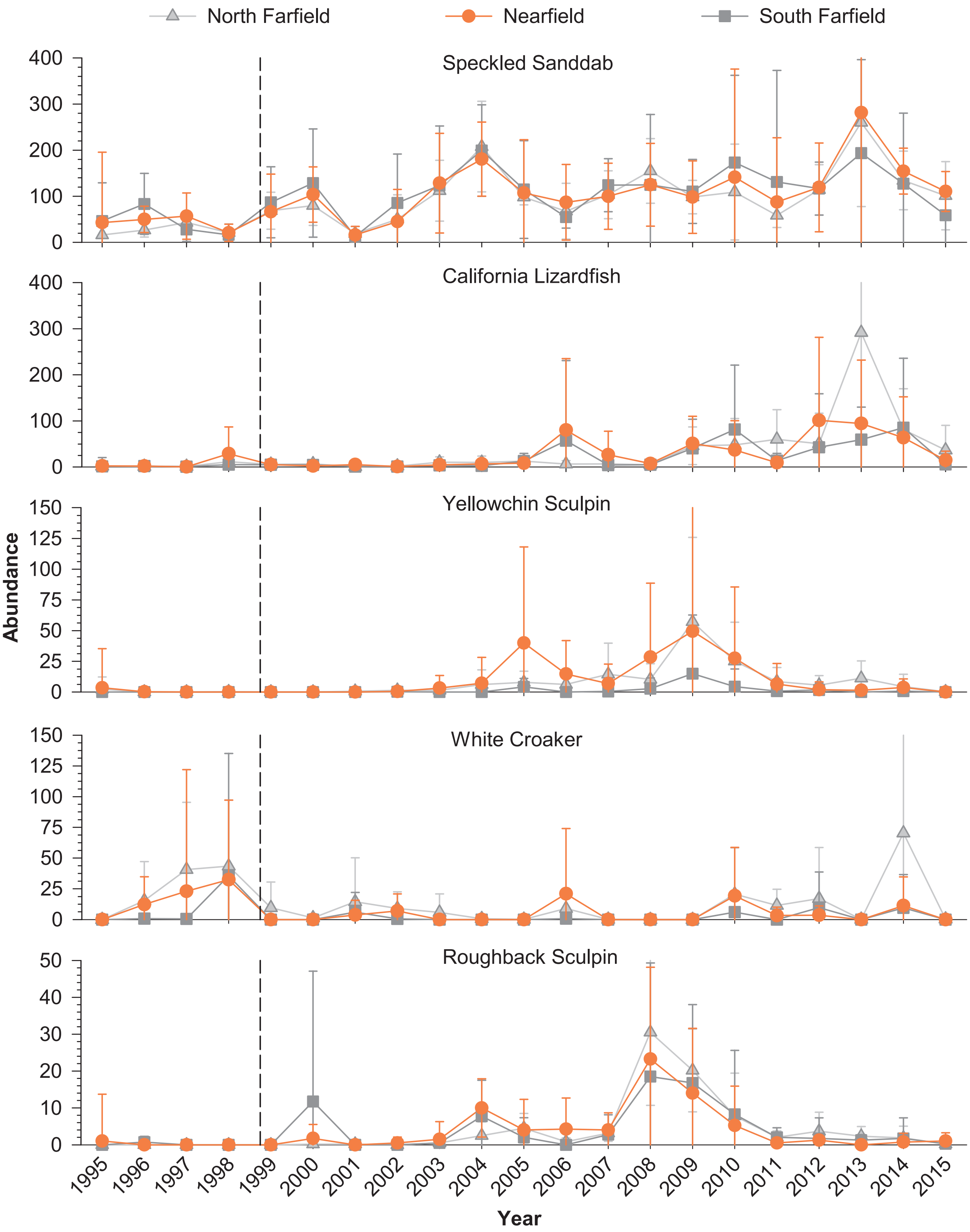


Figure 6.4

The ten most abundant fish species (presented in order) collected from SBOO trawl stations sampled from 1995 through 2015. Data are annual means with 95% confidence intervals for nearfield (n ≤ 4), north farfield (n = 6), and south farfield (n = 4) stations. Dashed lines indicate onset of wastewater discharge.

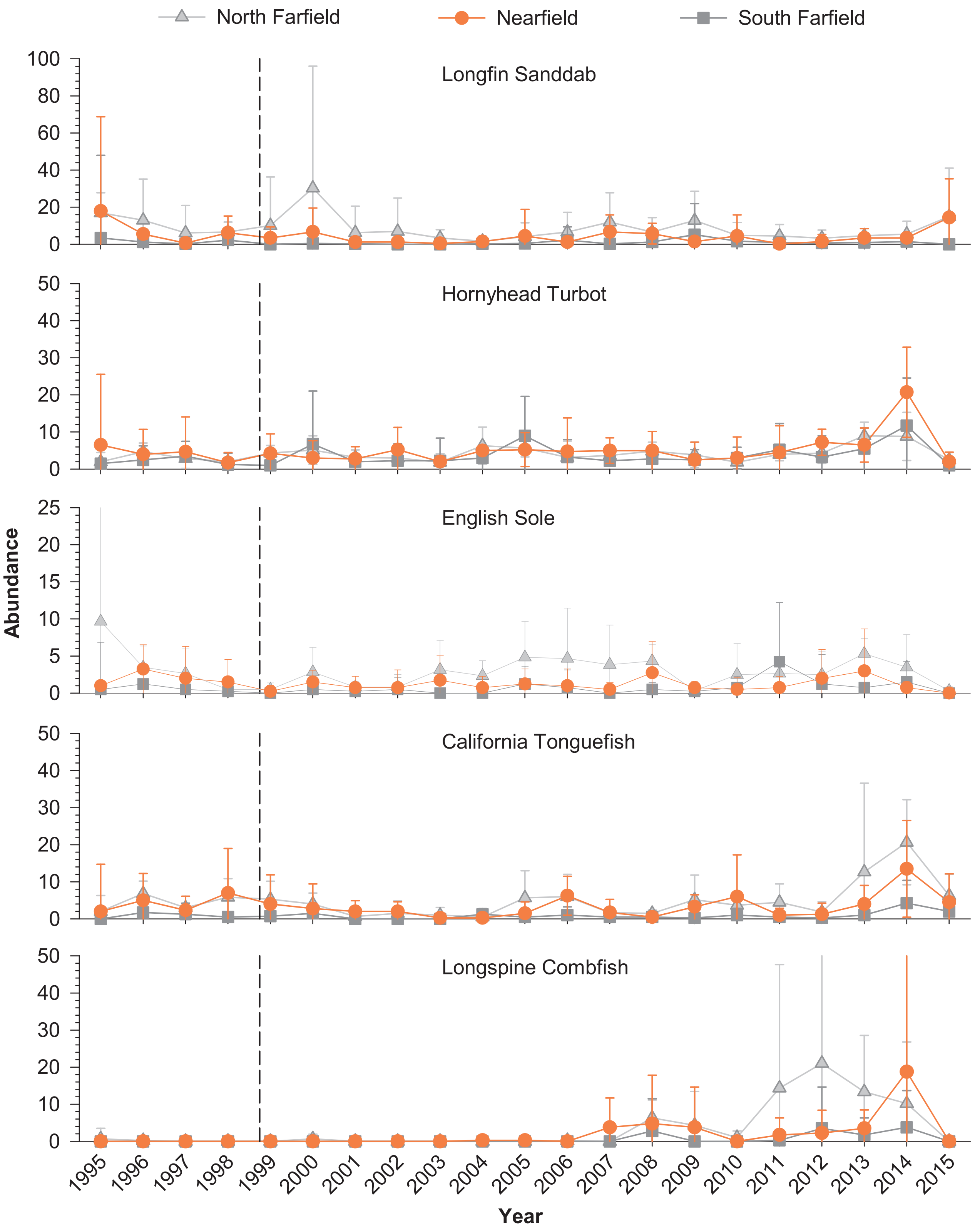


Figure 6.4 *continued*

per haul) (Table 6.3). SIMPER results indicated that the five most characteristic species for this group were Speckled Sanddabs (101 per haul), Hornyhead Turbot (4 per haul), California Lizardfish (3 per haul), Spotted Turbot (2 per haul), and California Scorpionfish (<1 per haul).

Cluster group C comprised 27 hauls, including the trawls from stations SD17–SD20 sampled in 2015, as well as the trawls from several stations sampled in other warm water years (i.e., 1995, 1996, 1998) and 83% (n=10) of the trawls from station SD21 sampled between 1995 and 2006 (Figure 6.5). This assemblage type never occurred at station SD15. Assemblages represented by group C averaged 10 species and 110 individuals per haul (Table 6.3). These assemblages had the highest average numbers of Longfin Sanddab (25 per haul) and the third lowest average number of Speckled Sanddabs (49 per haul). In addition to these two species, the remaining three of the five most characteristic species for this group according to SIMPER were California Lizardfish (11 per haul), Hornyhead Turbot (5 per haul), and California Tonguefish (5 per haul).

Cluster group D represented a unique demersal fish assemblage sampled during 2011 at station SD21 (Figure 6.5). This assemblage had the highest species richness (15 species), the second highest abundance (243 individuals), the largest number of Longspine Combfish (79 fish) and English Sole (6 fish), the second largest number of California Lizardfish (75 fish) and the second lowest number of Speckled Sanddabs (26 fish) (Table 6.3).

Cluster group E was the second largest group, representing assemblages from a total of 41 hauls that included 72% (n=39) of the trawls conducted at stations SD16−SD21 from 2003 through 2011, as well as the trawls from station SD20 in 2012 and 2014 (Figure 6.5). As with cluster group C, this assemblage type never occurred at station SD21. Group E assemblages averaged 10 species and 236 individuals per haul (Table 6.3). These assemblages had the highest average number of Yellowchin Sculpin (36 per haul) and the second highest average number of Speckled Sanddabs (140 per haul). In addition to these two species, SIMPER results indicated that the most characteristic species for group E included California Lizardfish (24 per haul), Longfin Sanddab (9 per haul), and Hornyhead Turbot (4 per haul).

Cluster group F comprised 27 hauls, including the trawl from station SD21 in 2015, three trawls from stations SD16−SD18 in 2006, the trawl from station SD15 in 2009, and 79% (n=22) of the trawls conducted across all stations during 2010, 2012, 2013, and 2014 (Figure 6.5). Assemblages represented by group F had the second highest average species richness (11 species per haul), the highest average abundance (476 individuals per haul), the highest average numbers of Speckled Sanddabs (227 per haul) and the highest average numbers of California Lizardfish (186 per haul) of any cluster group (Table 6.3). SIMPER results indicated that this group was also characterized by Hornyhead Turbot (8 per haul), Longfin Sanddab (7 per haul), and English Sole (3 per haul).

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the SBOO region during 2015. There were no incidences of fin rot or skin lesions among fishes reported during the year, while the incidences of other abnormalities were very rare (0.05%). The latter included one instance of a tumor on the caudal fin of a California Lizardfish. Evidence of parasitism was also very low (0.4%) for trawl-caught fishes in the region. These included leeches (subclass Hirudinea) reported on two Hornyhead Turbot, and the cymothoid isopod *Elthusa vulgaris* (a gill parasite) that was noted on four Speckled Sanddab and two Hornyhead Turbot. Additionally, 39 other individuals of *E. vulgaris* were identified as part of invertebrate trawl catches during the year (see Appendix E.4). Since *E. vulgaris* often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these organisms. However, *E. vulgaris* is known to be especially common on Sanddabs and California Lizardfish in southern California waters, where it may reach infestation rates of 3% and 80%, respectively (see Brusca 1978, 1981).

Megabenthic Invertebrates

Community Parameters

A total of 1718 megabenthic invertebrates (~123 per haul) representing 53 species from four phyla were collected in 2015 (Table 6.4, Appendices E.4, E.5).

Overall, the total catch in 2015 was 12% smaller than in 2014 (City of San Diego 2015), and continued to be dominated by echinoderms and crustaceans. The sea star *Astropecten californicus* was the most abundant and most frequently occurring trawl-caught invertebrate in 2015, averaging 62 individuals per haul (=51% of total abundance) and occurring in all of the trawls. The red crab *Pleuroncodes planipes* accounted for 23% of the catch, but only occurred in five trawls during the winter (FO=36%), with an average abundance of 78 individuals per occurrence. No other species contributed to more than 4% of the total catch. Other species collected during the year that occurred in at least 50% of the trawls but in low numbers (i.e., ≤4 per haul) included the crabs *Portunus xantusii* and *Pyromaia tuberculata,* the gastropod *Philine auriformis*, the shrimps *Sicyonia pencillata* and *Crangon nigromaculata*, and the cymothoid isopod *Elthusa vulgaris*. The occurrence of *P. planipes*, *P. xantusii*, and *S. pencillata* were indicative of the El Niño conditions off San Diego during 2015 (see Chapter 2). No new species were reported during the 2015 surveys.

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.5). For each haul, species richness ranged from 8 to 18 species, diversity (H') ranged from 0.4 to 2.4, and total abundance ranged from 19 to 399 individuals. During 2015, the lowest species richness values (≤10) were recorded at station SD21 in the winter and stations SD15, SD16, SD19 and SD21 in the summer. The lowest diversity values (≤1.0) and the highest abundance values (≥221 individuals) were recorded at stations SD15–SD17 in the winter and at station SD15 in the summer. The large hauls at station SD15 from both surveys reflect substantial numbers (≥312 individuals) of the sea star *Astropecten californicus,* while the two large hauls at stations SD16 and SD17 during the winter included 172 and 211 of the red crabs *Pleuroncodes planipes*.

As described for demersal fishes, large fluctuations in the abundances of a few numerically dominant species have contributed to the high variation in trawl-caught invertebrate community structure in the South Bay outfall region since 1995 (Figure 6.6, 6.7). Over the years, mean species richness and diversity have remained below 21 and 2.3 per haul, respectively, whereas there has been considerably greater variability in mean abundance (i.e., 10–516 individuals per haul) (Figure 6.6). Differences in overall invertebrate abundance has primarily tracked changes in populations of the sea star *Astropecten californicus,* the sea urchin *Lytechinus pictus*, the sand dollar *Dendraster terminalis*, the brittle star *Ophiothrix spiculata*, and the crab *Pleuroncodes planipes*. These species have all been prevalent in the SBOO region at different times. For example, fluctuations of *A. californicus* and *D. terminalis* populations have contributed greatly to changes in abundance during recent years at the south farfield stations, while large incursions of *L. pictus* during the 1995–1998 pre-discharge years influenced the total abundance at both the south farfield and nearfield stations. During 2015, *P. planipes* also influenced total abundance at the south farfield and nearfield stations (see above). Overall, none of the observed changes have appeared to be associated with wastewater discharge.

Classification Analysis of Invertebrate Assemblages

Classification (cluster) analysis discriminated between 11 main types of megabenthic invertebrate assemblages in the South Bay outfall region over the past 21 years (i.e., cluster groups A–K; Figure 6.8). These included seven small groups representing from 1 to 6 hauls each (cluster groups A–F, cluster group H) and four larger groups representing ~82% of all trawls (cluster groups G, I–K). During 2015, fish assemblages were distributed into three of the four largest cluster groups (see description of groups G, J and K below) and demonstrated no discernible patterns associated with proximity to the outfall. Instead, assemblages appear influenced by the distribution of the more abundant species or the unique characteristics of a specific station location. For example, station SD21 located the farthest north of the outfall off of Coronado and station SD15 located farthest south of the outfall off northern Baja California often grouped apart from the remaining stations. The species composition and main descriptive characteristics of each cluster group are described below.

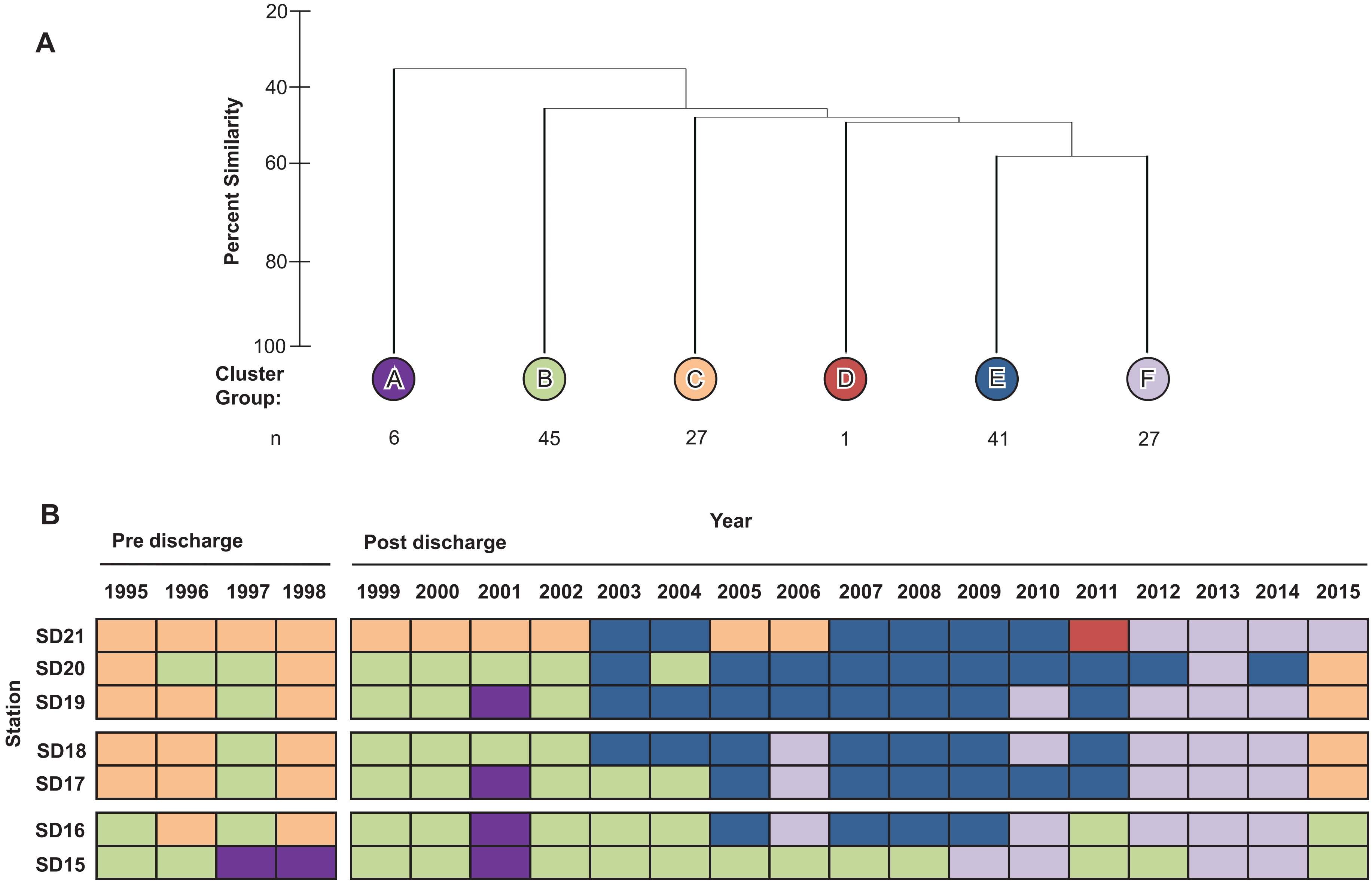


Figure 6.5
Results of cluster analysis of demersal fish assemblages from SBOO trawl stations from 1995 through 2015. Data are limited to summer surveys and presented as: (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time; n = number of hauls.

Table 6.3

Description of demersal fish cluster groups A–F defined in Figure 6.5. Highlighted/bold values indicate species that account for up to 95% within-group similarity according to SIMPER analysis; the top five most characteristic species are boxed.

	Cluster Group					
	A	B	C	D[a]	E	F
Number of Hauls	6	45	27	1	41	27
Mean Species Richness	6	7	10	15	10	11
Mean Abundance	26	116	110	243	236	476
Species	**Mean Abundance**					
Speckled Sanddab	**15**	**101**	**49**	**26**	**140**	**227**
California Lizardfish	**3**	**3**	**11**	**75**	**24**	**186**
Longspine Combfish	0	0	<1	**79**	1	10
White Croaker	0	0	3	**22**	0	0
Yellowchin Sculpin	0	<1	3	5	**36**	10
Longfin Sanddab	<1	1	**25**	**8**	**9**	**7**
Roughback Sculpin	0	<1	<1	5	**11**	4
Hornyhead Turbot	**2**	**4**	**5**	3	**4**	**8**
California Tonguefish	<1	**<1**	**4**	**6**	2	7
English Sole	<1	<1	**4**	**6**	**4**	**3**
California Scorpionfish	**2**	**<1**	<1	2	1	<1
Spotted Turbot	**2**	**2**	<1	0	<1	<1
California Halibut	<1	<1	**<1**	0	<1	<1
Fantail Sole	<1	<1	**1**	0	<1	<1

[a] SIMPER analysis only conducted on cluster groups that contained more than one trawl. Highlighted/bold values for single sample cluster groups cummulatively account for about 95% of the total abundance.

Cluster groups A, C, D, and E each represented a unique megabenthic invertebrate assemblage (Figure 6.8). The group A assemblage occurred at station SD15 in 2009 and had 8 species and 84 individuals, and the highest numbers of the brittle star *Ophiura luetkenii* (n = 72) of any cluster group (Table 6.6). The group C assemblage occurred at station SD19 in 1997 and had 6 species, 10 individuals, and the highest number of the sea star *Astropecten ornatissimus* (n = 4) compared to all other groups. The group D assemblage occurred at station SD17 in 1995 and had 12 species and 975 individuals, 951 of which were the urchin *Lytechinus pictus*. The group E assemblage occurred at station SD19 in 1998 and had the lowest species richness (n = 4) and abundance (n = 4) of all cluster groups.

Cluster group B represented assemblages from three trawls that occurred at stations SD17, SD20, and SD21 in 2000 (Figure 6.8). This group averaged 6 species and 9 individuals per haul (Table 6.6). SIMPER results indicated that the most characteristic species for group B were the crab *Loxorhynchus grandis* (1 per haul), the shrimp *Crangon nigromaculata* (1 per haul) and unidentified species of leeches (subclass Hirudinea; 1 per haul).

Cluster group F comprised four trawls, including those conducted at stations SD18 and SD20 in 2009 and those conducted at stations SD17 and SD21 in 2012 (Figure 6.8). Assemblages represented by group F averaged 8 species and 15 individuals per haul (Table 6.6). According to SIMPER results, this was one of three groups characterized by the dorid nudibranch *Acanthodoris brunnea* (2 per haul). The remaining four of five most characteristic species for this group included the sea star *Astropecten californicus* (2 per haul), the cymothoid isopod *Elthusa vulgaris* (2 per haul), the octopus *Octopus rubescens* (1 per haul), and the crab *Platymera gaudichaudii* (1 per haul).

Table 6.4

Megabenthic invertebrates collected from 14 trawls conducted in the SBOO region during 2015. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO
Astropecten californicus	51	100	62	62
Pleuroncodes planipes	23	36	28	78
Lytechinus pictus	4	36	4	12
Portunus xantusii	3	64	4	6
Sicyonia penicillata	3	79	4	5
Pyromaia tuberculata	3	64	4	6
Elthusa vulgaris	2	71	3	4
Philine auriformis	2	57	2	3
Latulambrus occidentalis	1	43	2	4
Kelletia kelletii	1	36	1	4
Crangon nigromaculata	1	64	1	2
Acanthodoris brunnea	1	29	1	3
Acanthodoris rhodoceras	1	36	1	2
Crossata ventricosa	1	36	1	2
Loxorhynchus grandis	<1	21	<1	2
Metacarcinus gracilis	<1	43	<1	1
Armina californica	<1	14	<1	2
Crassispira semiinflata	<1	21	<1	1
Dendronotus iris	<1	14	<1	2
Lovenia cordiformis	<1	14	<1	2
Ophiothrix spiculata	<1	14	<1	2
Dendronotus venustus	<1	14	<1	2
Ericerodes hemphillii	<1	21	<1	1
Megasurcula carpenteriana	<1	14	<1	2
Pagurus spilocarpus	<1	14	<1	2
Stylatula elongata	<1	21	<1	1
Calliostoma canaliculatum	<1	14	<1	1
Dendraster terminalis	<1	14	<1	1
Flabellina iodinea	<1	14	<1	1
Flabellina pricei	<1	7	<1	2
Hemisquilla californiensis	<1	14	<1	1
Heptacarpus palpator	<1	14	<1	1
Lepidozona scrobiculata	<1	7	<1	2
Luidia armata	<1	14	<1	1
Metacarcinus anthonyi	<1	14	<1	1
Aplysia californica	<1	7	<1	1
Calliostoma gloriosum	<1	7	<1	1
Calliostoma tricolor	<1	7	<1	1
Heptacarpus stimpsoni	<1	7	<1	1
Lamellaria diegoensis	<1	7	<1	1
Luidia foliolata	<1	7	<1	1
Melibe leonina	<1	7	<1	1
Nudibranchia	<1	7	<1	1
Octopus rubescens	<1	7	<1	1
Patiria miniata	<1	7	<1	1
Pteropurpura festiva	<1	7	<1	1
Pteropurpura trialata	<1	7	<1	1
Pteropurpura vokesae	<1	7	<1	1
Pugettia dalli	<1	7	<1	1
Pugettia producta	<1	7	<1	1
Randallia ornata	<1	7	<1	1
Sinum scopulosum	<1	7	<1	1
Virgularia californica	<1	7	<1	1

Cluster group G represented assemblages from 17 hauls, including trawls from four of seven stations (i.e., SD17, SD18, SD20, SD21) sampled in 2015 (Figure 6.8). This group also included nine trawls from the nearfield stations SD17 and SD18 sampled between 2005 and 2013, as well as the trawl from station SD19 during 2011, and the trawls from station SD21 during 1997, 2001, and 2011. This assemblage type never occurred at stations SD15 or SD16. Group G assemblages had the highest average species richness (14 species per haul) and 48 individuals per haul (Table 6.6). According to SIMPER results, this group was characterized by moderate numbers of *Astropecten californicus* (9 per haul), as well as the crabs *Pyromaia tuberculata* (5 per haul) and *Latulambrus occidentalis* (5 per haul), the gastropod *Philine auriformis* (5 per haul), and *Elthusa vulgaris* (2 per haul).

Cluster group H comprised six trawls, including those from station SD21 sampled in 1995, 2004, and 2007–2008, and those from station SD16 sampled in 1997 and 2009 (Figure 6.8). Assemblages represented by this group averaged 9 species and 19 individuals per haul (Table 6.6). SIMPER results indicated that Group H was characterized by the brittle star *Ophiothrix*

Table 6.5

Summary of megabenthic invertebrate community parameters for SBOO stations sampled during 2015. Data are included for species richness, abundance, and diversity (H'). SD = standard deviation.

Station	Winter	Summer
Species richness		
SD15	11	10
SD16	15	8
SD17	12	16
SD18	15	18
SD19	11	10
SD20	11	15
SD21	9	10
Survey Mean	12	12
Survey SD	2	4
Abundance		
SD15	399	339
SD16	221	19
SD17	248	47
SD18	66	73
SD19	71	37
SD20	36	63
SD21	57	42
Survey Mean	157	89
Survey SD	136	112
Diversity		
SD15	0.5	0.4
SD16	1.0	1.8
SD17	0.7	2.4
SD18	1.7	2.3
SD19	1.7	1.4
SD20	2.0	2.0
SD21	1.5	1.8
Survey Mean	1.3	1.7
Survey SD	0.6	0.7

spiculata (5 per haul), *Astropecten californicus* (3 per haul), the sea star *Pisaster brevispinus* (2 per haul), *Pyromaia tuberculata* (2 per haul), and *Octopus rubescens* (2 per haul).

Cluster group I was the second largest group, representing the assemblages from a total of 30 trawls conducted at one to five sites sampled every summer except during 1997, 2001, 2004, 2011, and 2013–2015 (Figure 6.8). This assemblage type never occurred at station SD15. Group I assemblages averaged 6 species and 17 individuals per haul (Table 6.6). SIMPER results indicated that the five most characteristic species for group I were *Astropecten californicus* (7 per haul), *Crangon nigromaculata* (2 per haul), *Pisaster brevispinus* (1 per haul), *Elthusa vulgaris* (1 per haul), and the gastropod *Kelletia kelletii* (1 per haul).

Cluster group J represented assemblages from 17 hauls, including the trawl from station SD16 sampled in 2015 (Figure 6.8). This group also included 64% (n = 7) of the trawls from station SD16 sampled from 2004 through 2014, the trawls from station SD19 sampled in 2004, 2013, and 2014, the trawls from station SD20 sampled in 2010, 2011, 2013, and 2014, and the trawls from station SD21 sampled in 2013 and 2014. This assemblage type did not occur prior to 2004, and never occurred at stations SD15, SD17, or SD18. Group J assemblages averaged 11 species and 68 individuals per haul and had the second highest average number of *Astropecten californicus* (36 per haul) (Table 6.6). In addition to *A. californicus*, the remaining four of five most characteristic species for group J according to SIMER results included *Elthusa vulgaris* (6 per haul), the crab *Metacarcinus gracilis* (3 per haul), *Octopus rubescens* (2 per haul), and *Kelletia kelletii* (1 per haul).

Cluster group K was the largest cluster group, comprising 66 hauls (~45% of all trawls conducted) (Figure 6.8). Assemblages represented by this group occurred at every station but SD21 and in all but one year throughout the course of monitoring and may represent “background” conditions in the SBOO region during the summer. This group included trawls from stations SD15 and SD19 during 2015, as well as 95% of the trawls from station SD15 sampled from 1995 through 2014. Group K assemblages averaged 8 species and 92 individuals per haul, and the highest average number of *Astropecten californicus* (59 per haul) (Table 6.8). According to SIMPER, *A. californicus*, *Lytechinus pictus*, *Pisaster brevispinus*, *Latulambrus occidentalis*, and the sand dollar *Dendraster terminalis* were the five most characteristic of these assemblages, each averaging ≤ 17 individuals per haul.

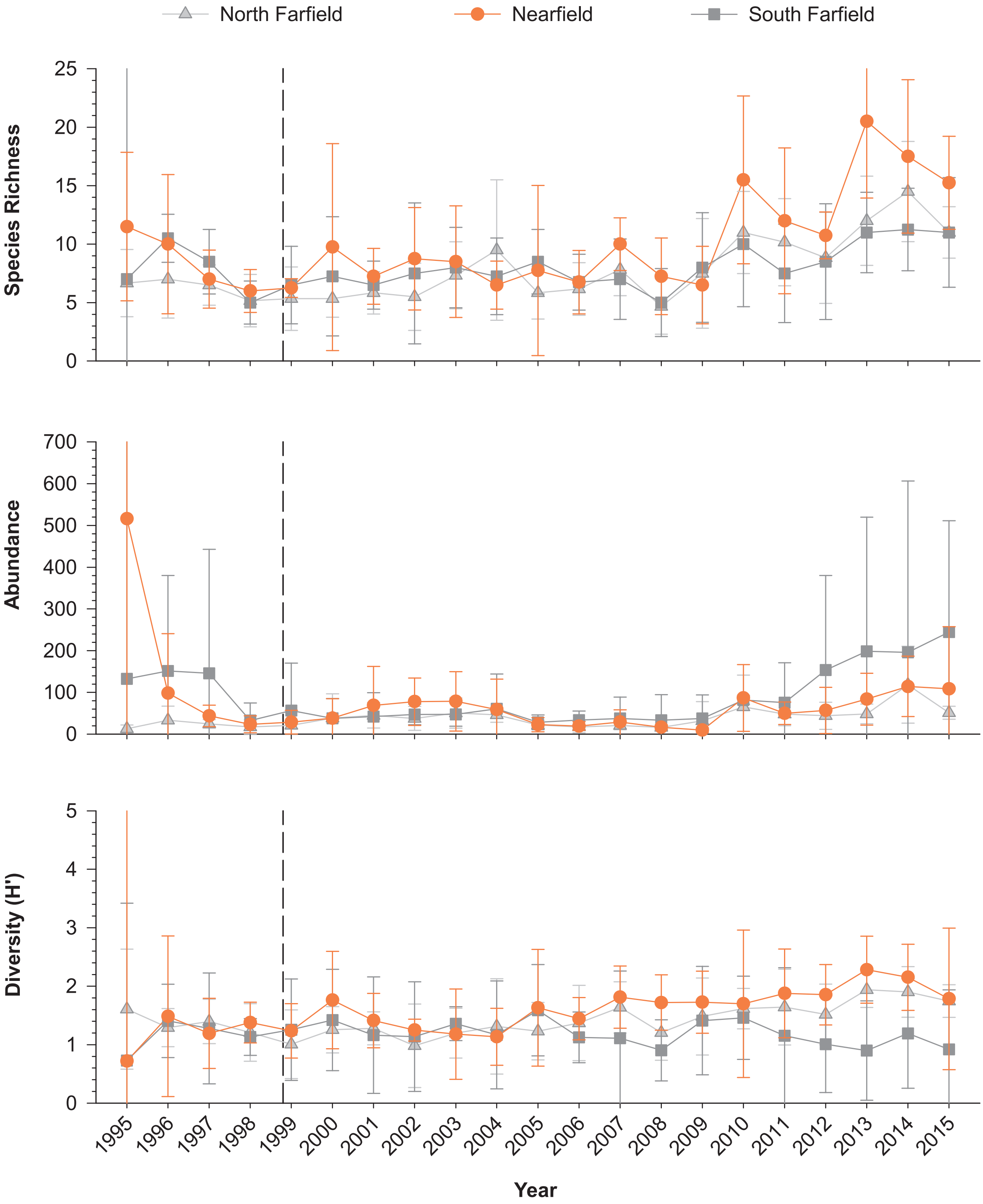


Figure 6.6
Species richness, abundance, and diversity of megabenthic invertebrates collected from SBOO trawl stations sampled from 1995 through 2015. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n=6), and south farfield (n=4) stations. Dashed lines indicate onset of wastewater discharge.

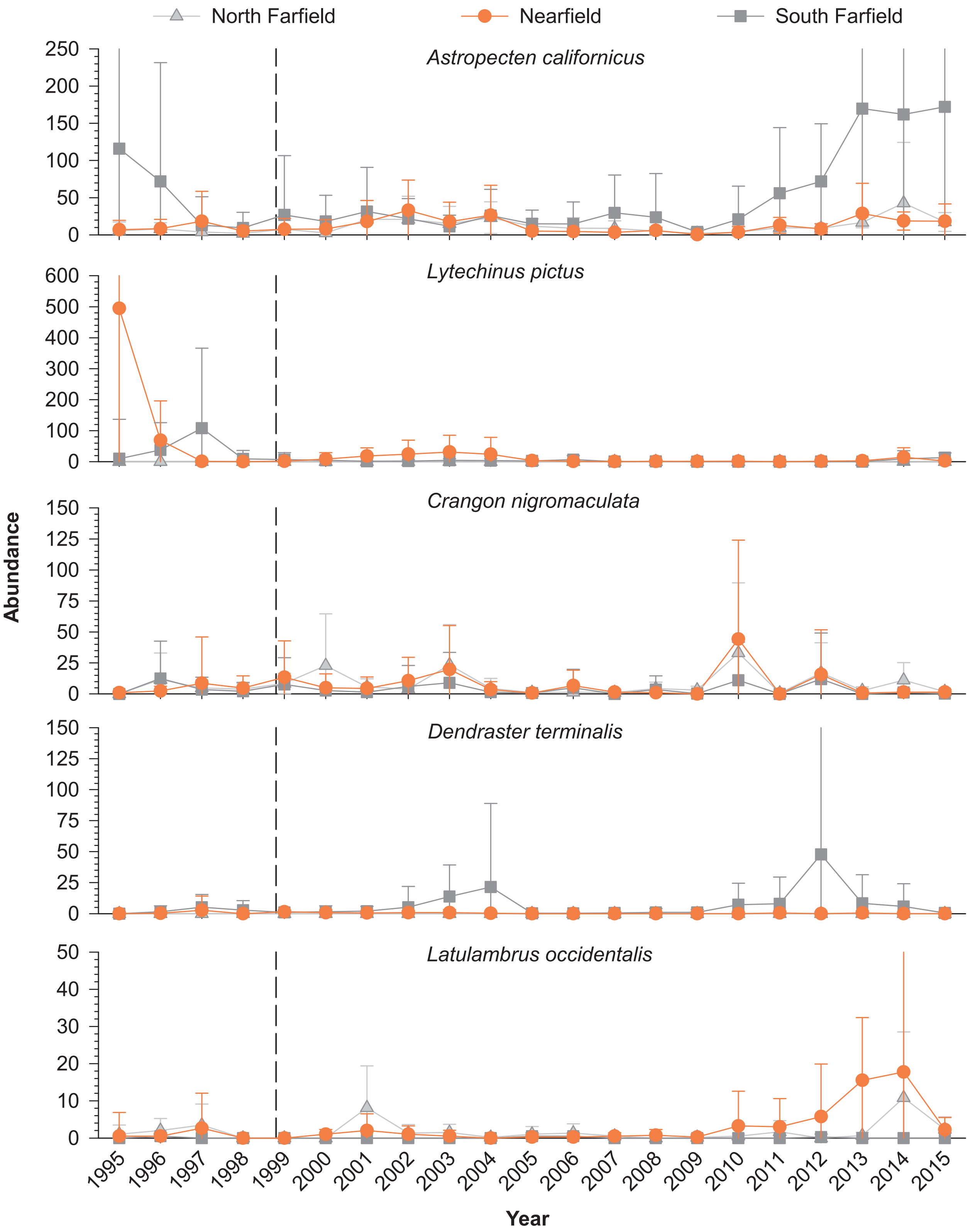


Figure 6.7
The ten most abundant megabenthic invertebrate species (presented in order) collected from SBOO trawl stations sampled from 1995 through 2015. Data are annual means with 95% confidence intervals for nearfield (n ≤ 4), north farfield (n = 6), and south farfield (n = 4) stations. Dashed lines indicate onset of wastewater discharge.

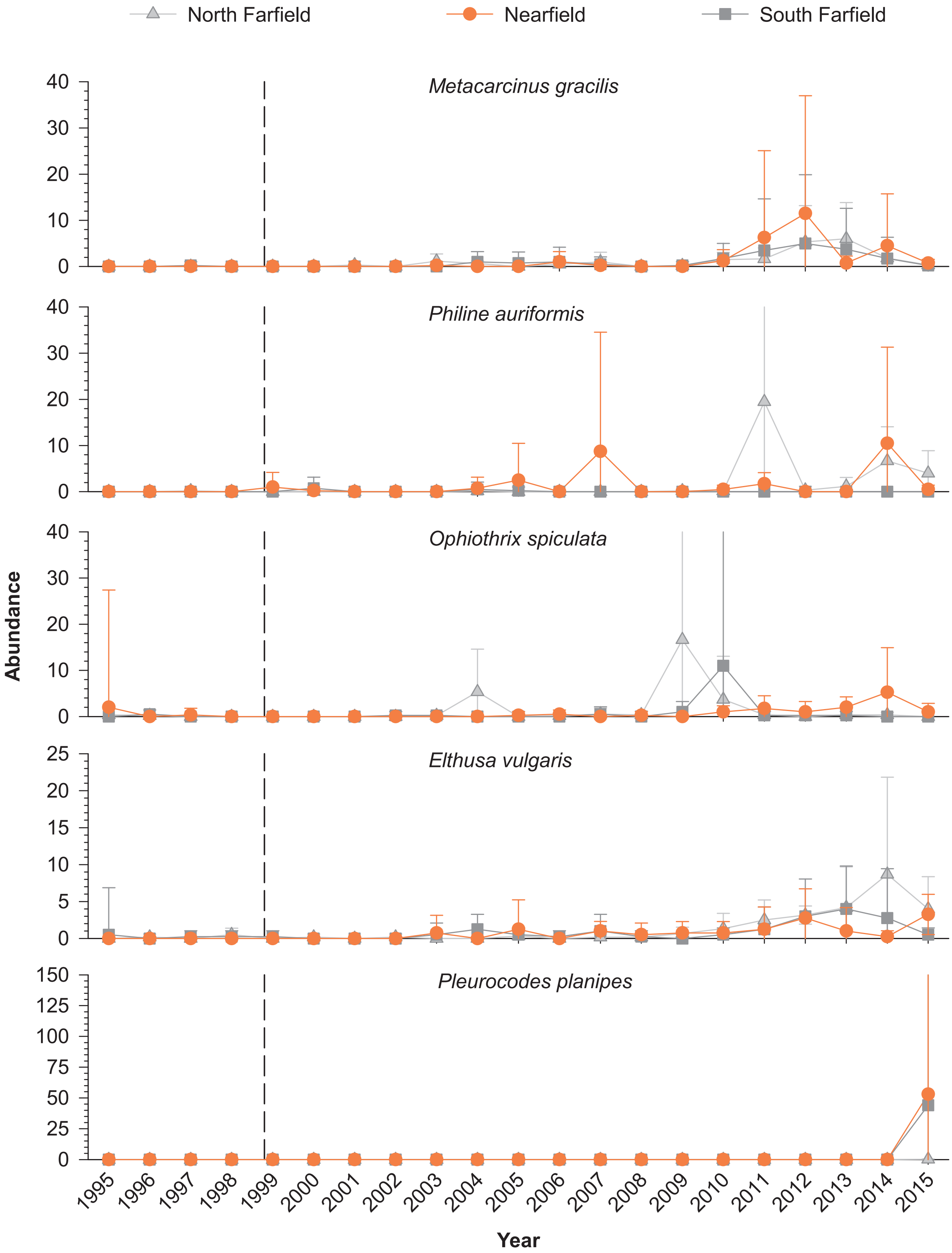


Figure 6.7 *continued*

SUMMARY

Speckled Sanddab dominated fish assemblages surrounding the SBOO in 2015 as they have since monitoring began in 1995. This species occurred in all trawls and accounted for 67% of the total catch. California Lizardfish were also prevalent during 2015, as they have been in five of the past six years. This species occurred in 93% of trawls and accounted for 16% of the total catch. Longfin Sanddab was the third most abundant species captured in 2015, although it occurred in only 64% of the trawls. Other commonly captured, but less abundant fishes, included California Tonguefish, Hornyhead Turbot, and California Halibut. Almost all fishes collected were <29 cm in length. Although the composition and structure of the fish assemblages varied among stations and surveys in 2015 as in previous years, these differences appear to be due to natural fluctuations of common species.

Assemblages of trawl-caught invertebrates in 2015 were dominated by the sea star *Astropecten californicus*, which occurred in every trawl and accounted for 51% of the total invertebrate abundance. The red crab *Pleuroncodes planipes* was collected in five trawls during the winter. Other frequently collected species included the crabs *Portunus xantusii* and *Pyromaia tuberculata*, the gastropod *Philine auriformis*, the shrimps *Sicyonia penicillata* and *Crangon nigromaculata*, and the cymothoid isopod *Elthusa vulgaris*. The occurrence of *P. planipes*, *P. xantusii*, and *S. pencillata* were indicative of the El Niño conditions off San Diego during 2015 (see Chapter 2). As with demersal fishes in the SBOO region, the composition of the trawl-caught invertebrate assemblages varied among stations and surveys, generally reflecting population fluctuations in the species mentioned above.

Overall, there is no evidence that wastewater discharged through the SBOO affected demersal fish or megabenthic invertebrate communities in 2015. Although highly variable, patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away. Instead, the high variability in these assemblages during the year was similar to that observed in previous years including the period before wastewater discharge began (City of San Diego 2000, 2006–2015). In addition, the low species richness and relatively small populations of these fish and invertebrates are consistent with expectations for the relatively shallow, sandy habitats characteristic of the SBOO region (Allen et al. 1998, 2002, 2007, 2011). Consequently, changes in local community structure of these organisms are more likely due to natural factors such as changes in ocean temperatures associated with El Niño or other large-scale oceanographic events, and the mobile nature of many resident species. Finally, the absence or low incidence of disease indicators or other physical abnormalities in local fishes suggests that populations in the region continue to be healthy.

LITERATURE CITED

Allen, L.J., D.J. Pondella II, and M.H. Horn. (2006). The Ecology of Marine Fishes: California and Adjacent Waters. University of California Press, Berkeley, CA. 660pp.

Allen, M.J., D. Cadien, E. Miller, D.W. Diehl, K. Ritter, S.L. Moore, C. Cash, D.J. Pondella, V. Raco-Rands, C. Thomas, R. Gartman, W. Power, A.K. Latker, J. Williams, J.L. Armstrong, and K. Schiff. (2011). Southern California Bight 2008 Regional Monitoring Program: Volume IV. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Costa Mesa, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

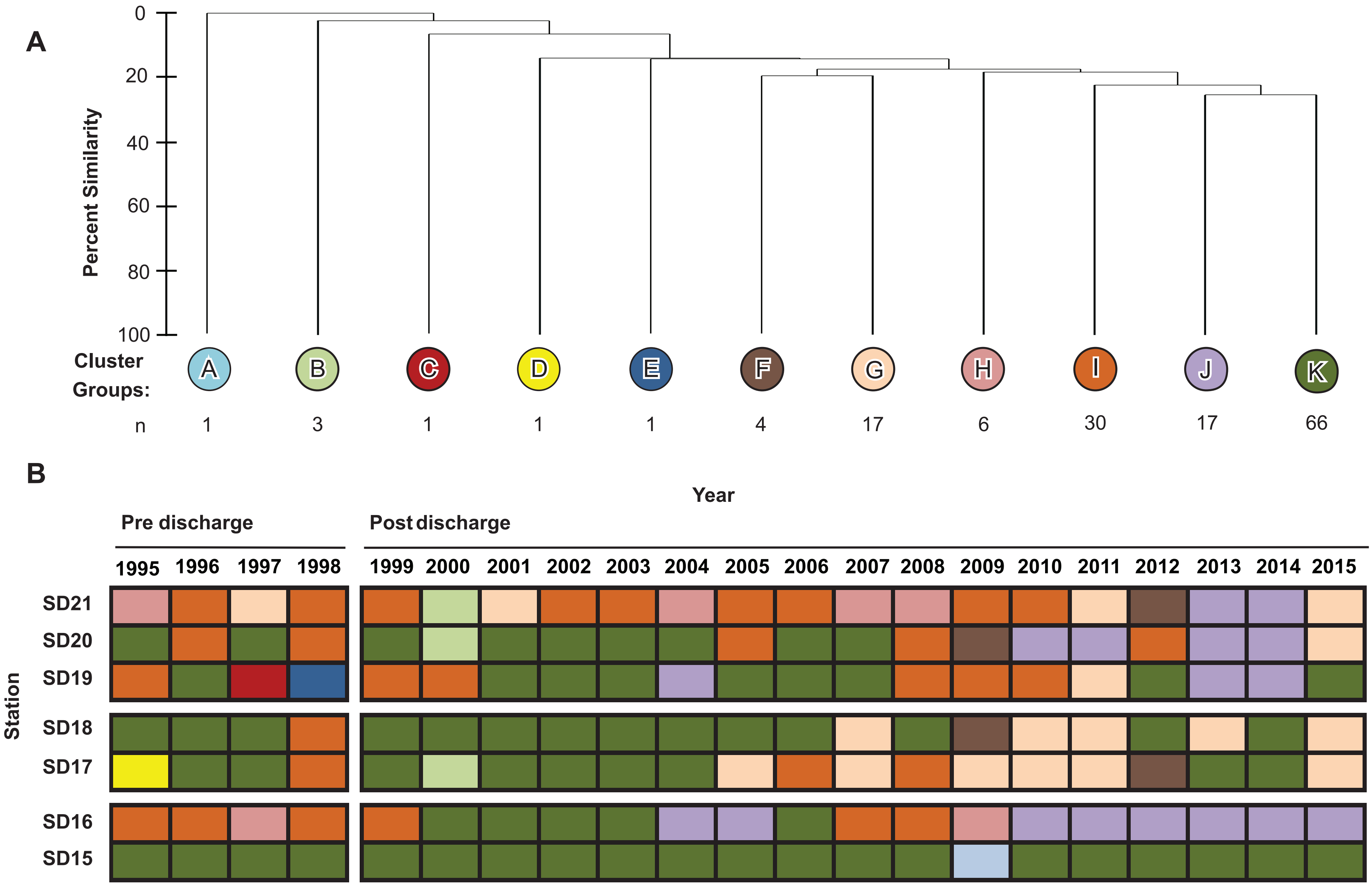


Figure 6.8
Results of cluster analysis of megabenthic invertebrate assemblages from SBOO trawl stations from 1995 through 2015. Data are limited to summer surveys and are presented as: (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time; n = number of hauls.

Table 6.6

Description of megabenthic invertebrate cluster groups A–K defined in Figure 6.8. Highlighted/bold values indicate taxa that account for up to 95% of intra-group similarity according to SIMPER analysis; the top five most characteristic species are boxed.

	Cluster Group										
	A[a]	B	C[a]	D[a]	E[a]	F	G	H	I	J	K
Number of Hauls	1	3	1	1	1	4	17	6	30	17	66
Mean Species Richness	8	6	6	12	4	8	14	9	6	11	8
Mean Abundance	84	9	10	975	4	15	48	19	17	68	92
Species	**Mean abundance**										
Astropecten californicus	0	0	0	6	**1**	**2**	**9**	**3**	**7**	**36**	**59**
Lytechinus pictus	0	1	0	**951**	0	1	<1	0	0	<1	**17**
Ophiura luetkenii	**72**	0	0	0	0	0	**2**	0	0	<1	<1
Dendraster terminalis	**3**	0	0	0	0	0	0	0	0	0	**2**
Pisaster brevispinus	0	0	**2**	2	**1**	0	**1**	**2**	**1**	<1	**1**
Ophiothrix spiculata	**3**	0	0	4	0	0	**1**	**5**	<1	2	<1
Astropecten ornatissimus	0	0	**4**	0	0	0	0	0	<1	0	0
Pyromaia tuberculata	1	1	0	4	0	1	**5**	**2**	<1	1	**<1**
Crangon nigromaculata	0	**1**	0	1	0	0	**1**	0	**2**	<1	**1**
Latulambrus occidentalis	0	<1	**1**	0	0	<1	**5**	<1	**1**	1	**2**
Octopus rubescens	1	0	0	0	0	**1**	<1	**2**	<1	2	<1
Hirudinea	0	**1**	0	0	0	0	<1	0	<1	0	<1
Loxorhynchus grandis	0	**1**	0	0	0	1	<1	<1	<1	<1	1
Elthusa vulgaris	0	<1	0	0	0	**2**	**2**	0	**1**	**6**	<1
Kelletia kelletii	0	0	0	0	0	**1**	**2**	<1	**1**	**1**	1
Acanthodoris brunnea	0	0	0	0	0	**2**	**2**	0	<1	**3**	1
Philine auriformis	0	0	0	0	0	0	**5**	<1	<1	1	<1
Platymera gaudichaudii	0	0	0	0	0	**1**	**<1**	<1	<1	<1	<1
Metacarcinus gracilis	0	0	0	0	0	**1**	<1	1	0	**3**	<1
Doryteuthis opalescens	0	0	0	1	**1**	0	0	0	<1	0	1
Crangon alba	**2**	0	0	1	0	0	0	0	0	0	<1
Luidia armata	0	0	**1**	0	0	0	<1	0	<1	**<1**	<1
Heptacarpus stimpsoni	0	0	**1**	0	0	0	1	0	<1	0	<1
Flabellina iodinea	0	0	1	0	0	0	<1	0	<1	**1**	<1
Acanthodoris rhodoceras	0	0	0	0	0	0	**1**	0	<1	<1	<1
Dendronotus iris	0	0	0	0	0	0	**1**	0	<1	2	0
Pleurobranchaea californica	0	0	0	0	0	0	**<1**	0	<1	0	<1
Pteropurpura festiva	0	0	0	0	0	<1	**<1**	<1	<1	0	<1
Pagurus spilocarpus	1	<1	0	0	0	0	**<1**	0	<1	<1	<1
Crossata ventricosa	0	0	0	0	1	0	**1**	0	<1	<1	<1
Randallia ornata	0	0	0	0	0	0	0	<1	<1	**1**	<1
Sicyonia penicillata	0	0	0	0	0	<1	1	0	0	**3**	<1

[a] SIMPER analysis only conducted on cluster groups that contained more than one trawl. Highlighted/bold values for single sample cluster groups cummulatively account for about 95% of the total abundance.

Allen, M.J., T. Mikel, D. Cadien, J.E. Kalman, E.T. Jarvis, K.C. Schiff, D.W. Diehl, S.L. Moore, S. Walther, G. Deets, C. Cash, S. Watts, D.J. Pondella II, V. Raco-Rands, C. Thomas, R. Gartman, L. Sabin, W. Power, A.K. Groce, and J.L. Armstrong. (2007). Southern California Bight 2003 Regional Monitoring Program: IV. Demersal Fishes and Megabenthic Invertebrates.

Southern California Coastal Water Research Project. Costa Mesa, CA.

Allen, M.J., S.L. Moore, K.C. Schiff, D. Diener, S.B. Weisberg, J.K. Stull, A. Groce, E. Zeng, J. Mubarak, C.L. Tang, R. Gartman, and C.I. Haydock. (1998). Assessment of demersal fish and megabenthic invertebrate assemblages on the mainland shelf of Southern California in 1994. Southern California Coastal Water Research Project, Westminster, CA.

Brusca, R.C. (1978). Studies on the cymothoid fish symbionts of the eastern Pacific (Crustacea: Cymothoidae). II. Systematics and biology of Livoneca vulgaris Stimpson 1857. Occasional Papers of the Allan Hancock Foundation. (New Series), 2: 1–19.

Brusca, R.C. (1981). A monograph on the Isopoda Cymothoidae (Crustacea) of the eastern Pacific. Zoological Journal of the Linnean Society, 73: 117–199.

City of San Diego. (1997). International Wastewater Treatment Plant Baseline Ocean Monitoring Report. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000). Final Baseline Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117–143.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Clarke, K.R., R.N. Gorley, P.J. Somerfield, and R.M. Warwick. (2014). Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER-E, Plymouth, England.

Cross, J.N. and L.G. Allen. (1993). Chapter 9. Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. pp. 459–540.

Cross, J.N., J.N. Roney, and G.S. Kleppel. (1985). Fish food habits along a pollution gradient. California Fish and Game, 71: 28–39.

Eschmeyer, W.N. and E.S. Herald. (1998). A Field Guide to Pacific Coast Fishes of North America. Houghton and Mifflin Company, New York.

Grothendieck, G. (2014). sqldf: Perform SQL Selects on R Data Frames. R package version 0.4-10. http://CRAN.R-project.org/package=sqldf

Helvey, M. and R.W. Smith. (1985). Influence of habitat structure on the fish assemblages associated with two cooling-water intake structures in southern California. Bulletin of Marine Science, 37: 189–199.

Karinen, J.B., B.L. Wing, and R.R. Straty. (1985). Records and sightings of fish and invertebrates in the eastern Gulf of Alaska and oceanic phenomena related to the 1983 El Niño event. In: W.S. Wooster and D.L. Fluharty (eds.). El Niño North: El Niño Effects in the Eastern Subarctic Pacific Ocean. Washington Sea Grant Program, WA. pp. 253–267.

Lawrence, P.M., H. Espinosa-Pérez, L.T. Findley, C.R. Gilbert, R.N. Lea, N.E. Mandrak, R.L. Mayden, and J.S. Nelson. (2013). Common and Scientific names of fishes from the United States, Canada and Mexico. Special Publication 34. The American Fisheries Society, Bethesda, MD.

Murawski, S.A. (1993). Climate change and marine fish distribution: forecasting from historical analogy. Transactions of the American Fisheries Society, 122: 647–658.

[NOAA/NWS] National Oceanic and Atmospheric Administration/National Weather Service.

(2016). Climate Prediction Center Website. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory.html.

Oksanen, J., F.G. Blanchet, R. Kindt, P. Legendre, P.R. Minchin, R.B. O'Hara, G.L. Simpson, P. Solymos, M. Henry, H. Stevens and H. Wagner. (2015). vegan:Community Ecology Package. R package version 2.3-0. http://CRAN.R-project.org/package=vegan

R Core Team. (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Ripley, B. and M. Lapsley. (2015). RODBC: ODBC Database Access. R package version 1.3-12. http://CRAN.R-project.org/package=RODBC

[SCAMIT] Southern California Association of Marine Invertebrate Taxonomists. (2014). A taxonomic listing of benthic macro- and megainvertebrates from infaunal and epibenthic monitoring programs in the Southern California Bight, edition 9. Southern California Association of Marine Invertebrate Taxonomists, Natural History Museum of Los Angeles County Research and Collections, Los Angeles, CA.

[SCCWRP] Southern California Coastal Water Research Project. (2013). Southern California Bight 2013 Regional Monitoring Program: Contaminant Impact Assessment Field Operations Manual. Southern California Coastal Water Research Project. Costa Mesa, CA.

Stein, E.D. and D.B. Cadien. (2009). Ecosystem response to regulatory and management actions: The southern California experience in long-term monitoring. Marine Pollution Bulletin, 59: 91–100.

Thompson, B.E., J. Dixon, S. Schroeter, and D.J. Reish. (1993a). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. pp. 369–458.

Thompson, B., D. Tsukada, and J. Laughlin. (1993b). Megabenthic assemblages of coastal shelves, slopes, and basins off Southern California. Bulletin of the Southern California Academy of Sciences, 92: 25–42.

Warnes, G.R., B. Bolker, and T. Lumley. (2015). gtools: Various R Programming Tools. R package version 3.4.2. http://CRAN.R-project.org/package=gtools

Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology, 18: 63–80.

Wickham, H. (2007). Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL http://www.jstatsoft.org/v21/i12/.

Wickham, H. (2011). The Split-Apply-Combine Strategy for Data Analysis. Journal of Statistical Software, 40(1), 1-29. URL http://www.jstatsoft.org/v40/i01/.

Chapter 7
Bioaccumulation of Contaminants in Fish Tissues

Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

Introduction

Bottom dwelling (i.e., demersal) fishes are collected as part of the City of San Diego's (City) Ocean Monitoring Program to evaluate if contaminants in wastewater discharged from the South Bay Ocean Outfall (SBOO) are bioaccumulating in their tissues. Anthropogenic inputs to coastal waters can result in increased concentrations of pollutants within the local marine environment, and subsequently in the tissues of fishes and their prey. This accumulation occurs through the biological uptake and retention of chemicals derived via various exposure pathways like the absorption of dissolved chemicals directly from seawater and the ingestion and assimilation of pollutants contained in different food sources (Connell 1988, Cardwell 1991, Rand 1995, USEPA 2000). In addition, demersal fishes may accumulate contaminants through the ingestion of suspended particulates or sediments because of their proximity to the seafloor. For this reason, contaminant levels in the tissues of these fish are often related to those found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

The bioaccumulation portion of the City's monitoring program consists of two components: (1) analyzing liver tissues from trawl-caught fishes; (2) analyzing muscle tissues from fishes collected by hook and line (rig fishing). Species targeted by trawling activities (see Chapter 6) are considered representative of the general demersal fish community off San Diego. The chemical analysis of liver tissues in these trawl-caught fishes is important for assessing population effects because this is the organ where contaminants typically bioaccumulate. In contrast, species targeted for capture by rig fishing represent fish that are more characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance and more directly relevant to human health concerns. Consequently, muscle samples are analyzed from these fishes because this is the tissue most often consumed by humans. All liver and muscle tissue samples collected during the year were analyzed for contaminants as specified in the NPDES discharge permits that govern monitoring requirements for the SBOO (see Chapter 1). Most of these contaminants are also sampled for the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program, which was initiated to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants of environmental concern (Lauenstein and Cantillo 1993).

This chapter presents the results of all chemical analyses performed on the tissues of fishes collected in the South Bay outfall region during calendar year 2015. The primary goals are to: (1) document levels of contaminant loading in local demersal fishes; (2) identify whether any contaminant bioaccumulation detected in fishes collected around the SBOO may be associated with the outfall discharge; (3) identify other potential natural and anthropogenic sources of pollutants to the local marine environment.

Materials and Methods

Field Collection

Fishes were collected during October 2015 from five trawl zones (TZ5–TZ9) and two rig fishing (RF3–RF4) stations (Figure 7.1). Each trawl zone represents an area centered on one or two trawl stations as specified in Chapter 6. Trawl Zone 5 includes the area located within a 1-km radius of stations SD17 and SD18 located just south and north of the SBOO, respectively. Trawl Zone 6 includes the area within 1-km radius surrounding northern stations SD19 and SD20, while Trawl Zone 7 includes the northern station SD21. Trawl Zone 8 represents the area within a 1-km radius

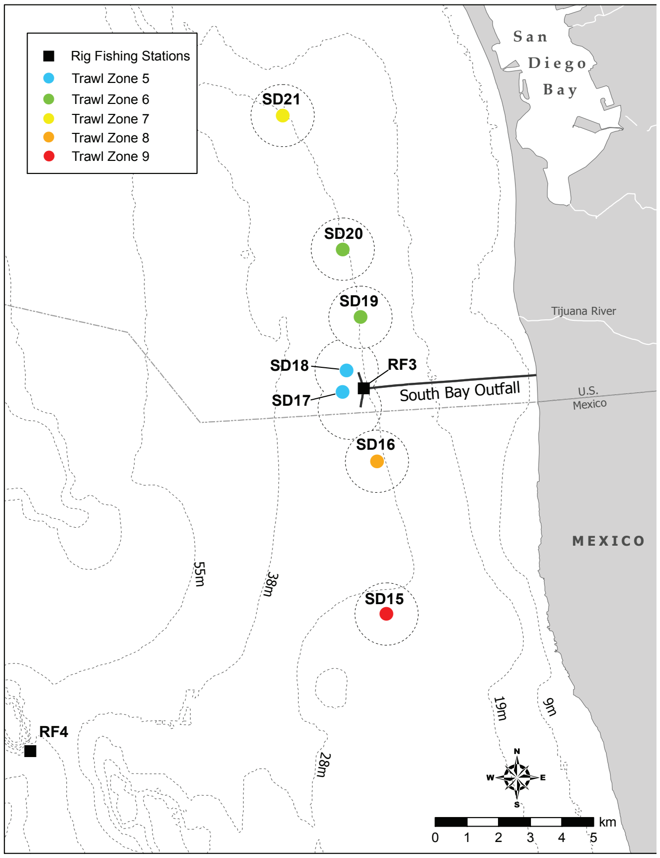


Figure 7.1
Trawl and rig fishing station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

surrounding southern station SD16, while Trawl Zone 9 represents the area within a 1-km radius surrounding southern station SD15. All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for collection methods). Efforts to collect target species at the trawl stations were limited to five 10-minute (bottom time) trawls per site. Fishes collected at the two rig fishing stations were caught within 1 km of the nominal station coordinates using standard rod and reel procedures; fishing effort was limited to 5 hours at each of these stations. Occasionally, insufficient numbers of the target species were obtained despite this effort, which resulted in inadequate amounts of tissue to complete the full suite of chemical analyses (see Table 7.1).

Three species were collected for analysis of liver tissues at the trawl stations, including Hornyhead Turbot (*Pleuronichthys verticalis*), Longfin Sanddab (*Citharichthys xanthostigma*) and Fantail Sole (*Xystreurys liolepis*) (Table 7.1). In addition, seven different species were collected for the analysis of muscle tissues at the two rig fishing stations. These species included the California Scorpionfish (*Scorpaena guttata*), Brown Rockfish (*Sebastes auriculatus*), Gopher Rockfish (*Sebastes carnatus*), Olive Rockfish (*Sebastes serranoides*), Squarespot Rockfish (*Sebastes hopkinsi*), Treefish (*Sebastes serriceps*) and Vermilion Rockfish (*Sebastes miniatus*). Only fishes with a standard length ≥ 9 cm were retained in order to facilitate collection of sufficient tissue for analysis. These fishes were sorted into three composite samples per station, with a minimum of three individuals in each composite. All fishes were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were stored at -20°C prior to dissection and tissue processing.

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis. A brief summary follows, but see City of San Diego (in prep) for additional details. Prior to dissection, each fish was partially defrosted, cleaned with a paper towel to remove loose scales and excess mucus, and the standard length (cm) and weight (g) were recorded (Appendix F.1). Dissections were carried out on Teflon® pads that were cleaned between samples. The liver or muscle tissues from each fish were removed and placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses.

All tissue chemical analyses were performed at the City of San Diego's Environmental Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2016a). Briefly, fish tissue samples were analyzed on a wet weight basis to determine concentrations of 18 trace metals, 9 chlorinated pesticides, 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs). Data were

Table 7.1

Species of fish collected from each SBOO trawl and rig fishing station during 2015.

Station	Composite 1	Composite 2	Composite 3
Rig Fishing Station 3 (RF3)	Squarespot Rockfish [a]	California Scorpionfish [a]	Mixed Rockfish [a,b]
Rig Fishing Station 4 (RF4)	Treefish [a]	Gopher Rockfish [a]	Gopher Rockfish [a]
Trawl Zone 5 (TZ5)	Longfin Sanddab [a,c]	Fantail Sole [a,c,d]	no sample [e]
Trawl Zone 6 (TZ6)	Longfin Sanddab [a]	Fantail Sole [a,c]	Hornyhead Turbot [a]
Trawl Zone 7 (TZ7)	Fantail Sole [a]	Hornyhead Turbot [a,f]	Longfin Sanddab [a,g]
Trawl Zone 8 (TZ8)	Fantail Sole [a,h]	Fantail Sole [a,h]	Hornyhead Turbot [a]
Trawl Zone 9 (TZ9)	Fantail Sole [a,c,d]	no sample [e]	no sample [e]

[a] No methoxychlor, aldrin, alpha endosulfan, beta endosulfan, dieldrin, endrin, or endrin aldehyde; [b] includes Brown, Olive, and Vermilion Rockfish; [c] no metals except Hg, Se; [d] no PAHs; [e] insufficient fish collected (see text); [f] no metals; [g] no lipids; [h] no metals except Hg

generally limited to values above the method detection limit (MDL) for each parameter (see Appendix F.2). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry.

Data Analyses

Data summaries for the various parameters included detection rate, minimum, maximum, and mean values by species. All means were calculated using detected values only; no substitutions were made for non-detects in the data (i.e., analyte concentrations < MDL). Total DDT (tDDT), total chlordane, total hexachlorocyclohexane (tHCH), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix F.3 for individual constituent values). In addition, the distribution of contaminants with detection rates ≥ 20% was assessed by comparing values in fishes collected from "nearfield" stations located within 1 km of the outfall diffuser structure (TZ5, RF3) to those from "farfield" stations located > 1.7 km away to the south (TZ9, TZ8), north (TZ6, TZ7), and southwest (RF4). Contaminant concentrations were also compared to maximum values reported during the pre-discharge period (1995–1998). Because contaminant levels can vary drastically among different species of fish, only intra-species comparisons were used for these assessments. Analyses were performed using SAS software v9.3.

Contaminant levels in fish muscle tissue samples were compared to state, national, and international limits and standards in order to address seafood safety and public health issues. These included: (1) fish contaminant goals for chlordane, DDT, methylmercury, selenium, and PCBs developed by the California Office of Environmental Health Hazard Assessment (OEHHA) (Klasing and Brodberg 2008); (2) action limits on the amount of mercury, DDT, and chlordane in seafood that is to be sold for human consumption, set by the United States Food and Drug Administration (USFDA) (Mearns et al. 1991); (3) international standards for acceptable concentrations of various metals and DDT (Mearns et al. 1991).

RESULTS

Contaminants in Trawl-Caught Fishes

Trace Metals

Ten trace metals were detected in all liver tissue samples from trawl-caught fishes collected in the South Bay outfall region during 2015 (Table 7.2). These included arsenic, cadmium, chromium, copper, iron, manganese, mercury, selenium, tin, and zinc. Aluminum, barium, beryllium, nickel, silver and thallium were also detected, but in fewer

Table 7.2

Summary of metals in liver tissues of fishes collected from SBOO trawl zones during 2015. Data include the number of detected values (n), minimum, maximum and mean[a] detected concentrations for each species, and the total number of samples, detection rate and maximum value for all species. Concentrations are expressed as parts per million (ppm); nd = not detected. See Appendix F.2 for MDLs.

	Al	**Sb**	**As**	**Ba**	**Be**	**Cd**	**Cr**	**Cu**	**Fe**	**Pb**	**Mn**	**Hg**	**Ni**	**Se**	**Ag**	**Tl**	**Sn**	**Zn**
Fantail Sole																		
n	1	0	1	1	1	1	1	1	1	0	1	6	0	4	0	1	1	1
Min	5.0	—	5.70	0.15	0.009	1.72	0.3	2.3	89.0	—	0.7	0.035	—	0.65	—	0.60	0.800	20.70
Max	5.0	—	5.70	0.15	0.009	1.72	0.3	2.3	89.0	—	0.7	0.080	—	0.97	—	0.60	0.800	20.70
Mean	5.0	—	5.70	0.15	0.009	1.72	0.3	2.3	89.0	—	0.7	0.057	—	0.77	—	0.60	0.800	20.70
Hornyhead Turbot																		
n	1	0	2	1	1	2	2	2	2	0	2	2	0	2	2	1	2	2
Min	nd	—	2.40	nd	nd	1.22	0.1	6.9	44.0	—	0.9	0.059	—	0.65	0.10	nd	0.600	45.80
Max	10.0	—	4.60	0.11	0.018	1.44	0.2	8.6	64.0	—	0.9	0.079	—	0.96	0.19	0.50	1.500	75.00
Mean	10.0	—	3.50	0.11	0.018	1.33	0.1	7.7	54.0	—	0.9	0.069	—	0.80	0.15	0.50	1.050	60.40
Longfin Sanddab																		
n	2	0	2	2	0	2	2	2	2	0	2	3	1	3	0	2	2	2
Min	5.0	—	5.90	0.10	—	0.77	0.2	2.6	87.0	—	0.7	0.046	nd	0.65	—	0.70	0.800	19.70
Max	22.0	—	7.90	0.54	—	2.21	0.4	6.3	191.0	—	0.8	0.083	0.3	1.01	—	0.80	2.500	29.80
Mean	13.5	—	6.90	0.32	—	1.49	0.3	4.4	139.0	—	0.7	0.067	0.3	0.84	—	0.75	1.650	24.75
Total Samples[b]	5	5	5	5	5	5	5	5	5	5	5	11	5	9	5	5	5	5
Detection rate (%)	80	0	100	80	40	100	100	100	100	0	100	100	20	100	40	80	100	100
Max	22.0	—	7.90	0.54	0.018	2.21	0.4	8.6	191.0	—	0.9	0.083	0.3	1.01	0.19	0.80	2.500	75.00

[a] Minimum and maximum values were calculated based on all samples, whereas means were calculated from detected values only

[b] See Table 7.1

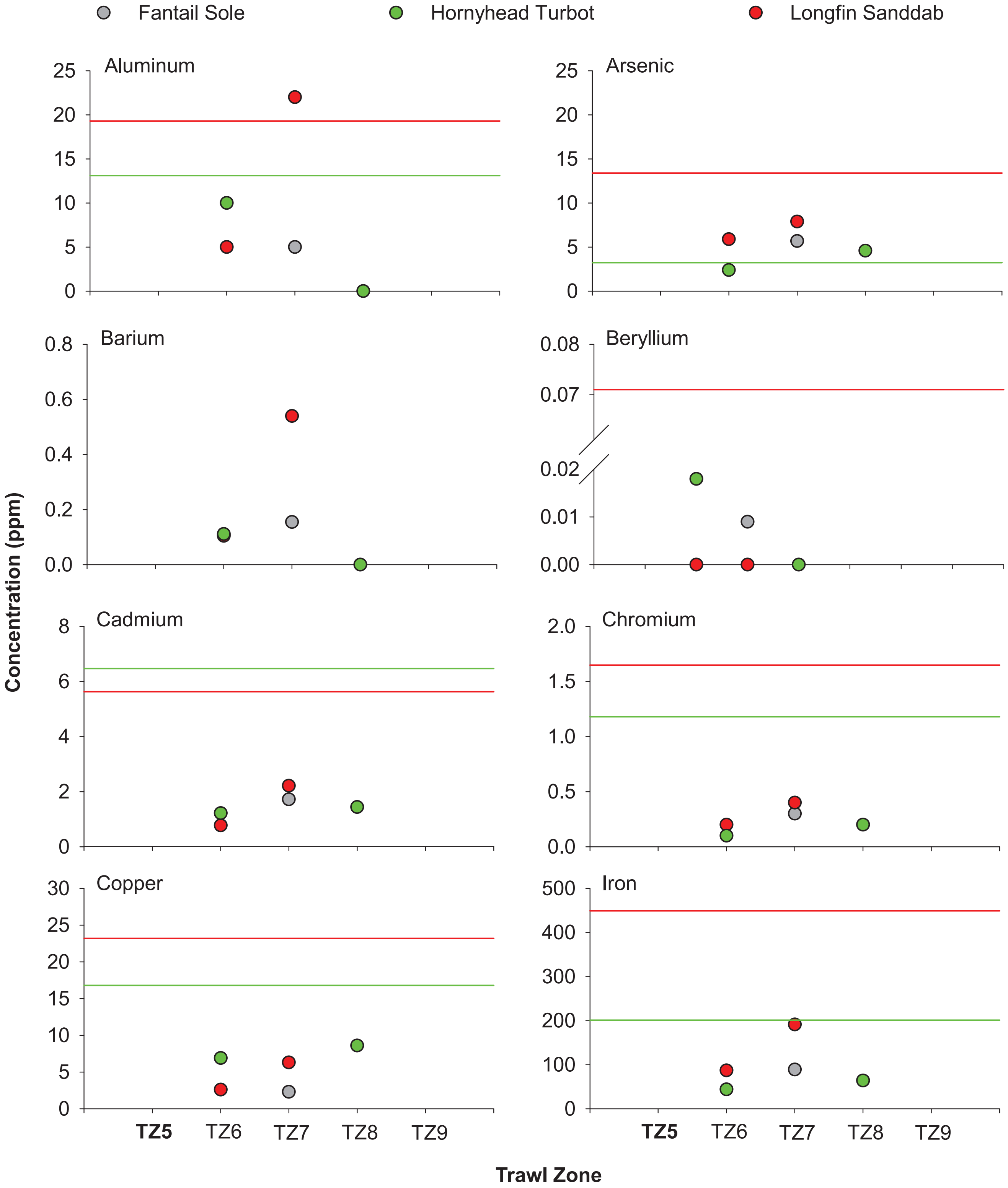


Figure 7.2

Concentrations of metals with detection rates ≥20% in liver tissues of fishes collected from each SBOO trawl zone during 2015. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate metals were not detected in that species pre-discharge. Zeros were substituted for non-detects to differentiate them from missing values (i.e., samples that were not collected; see Table 7.1). Zone TZ5 is considered nearfield (bold; see text).

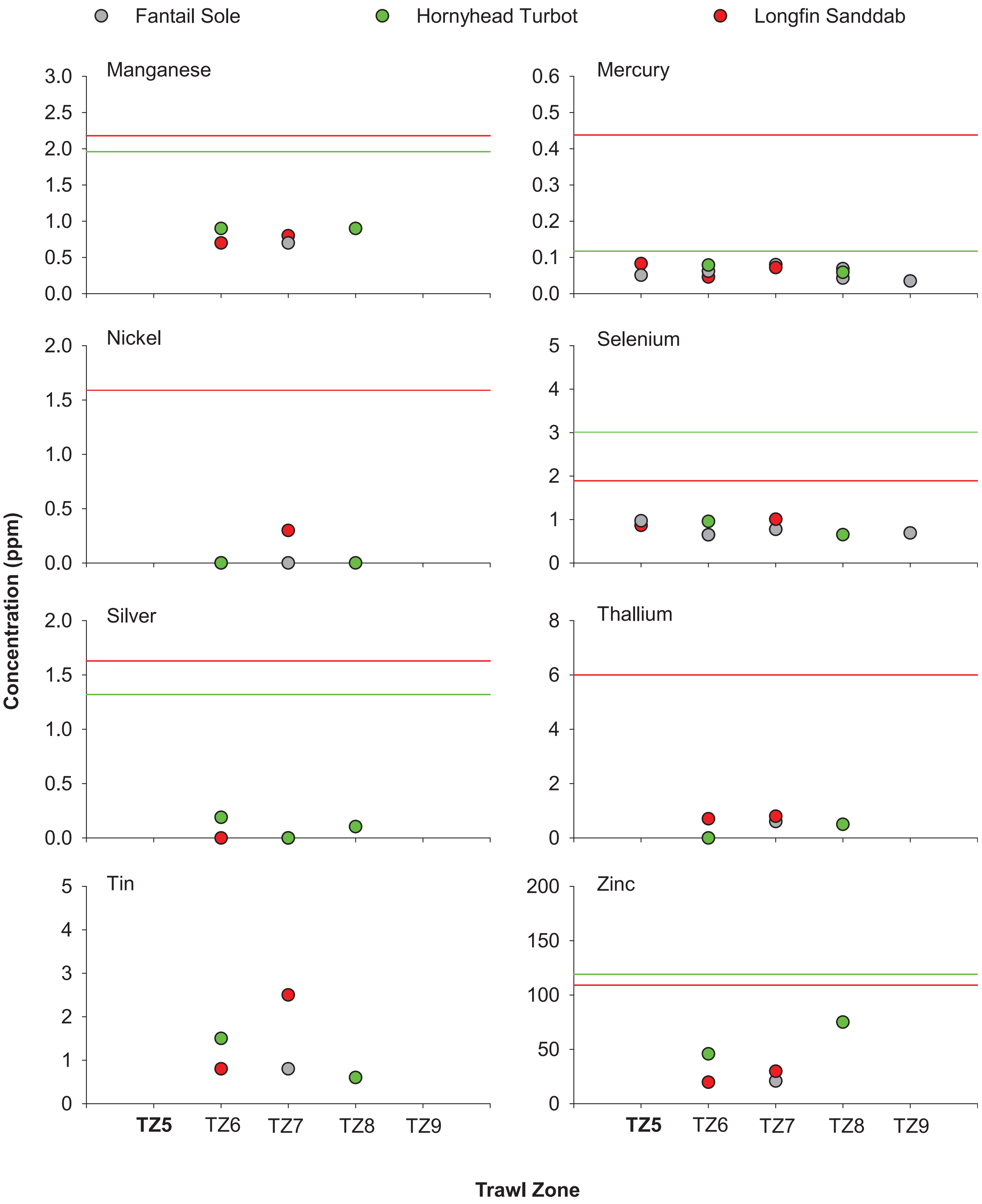


Figure 7.2 *continued*

samples (20–80%). Antimony and lead were not detected in any liver tissue samples collected in the SBOO region during the year. Most metals occurred at concentrations ≤8.6 ppm, although higher concentrations up to 22 ppm for aluminum, 75 ppm for zinc, and 191 ppm for iron were recorded. Most metals were detected at levels within ranges reported prior to wastewater discharge (e.g., City of San

Table 7.3

Summary of pesticides, total PCB, total PAH and lipids in liver tissues of fishes collected from SBOO trawl zones during 2015. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations for each species, and the total number of samples, detection rate (DR) and maximum value for all species. Concentrations are expressed in ppb for all parameters except lipids, which are % weight; nd = not detected. See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT, total chlordane (tChlor), tPCB, and tPAH.

	Pesticides					
	HCB	tDDT	tChlor	tPCB	tPAH	Lipids
Fantail Sole						
n	0	5	1	4	1	6
Min	—	nd	nd	nd	nd	1.5
Max	—	443.7	3.9	475.0	20.0	41.1
Mean	—	114.1	3.9	126.9	20.0	10.4
Hornyhead Turbot						
n	1	3	0	3	0	3
Min	nd	31.0	—	7.1	—	1.3
Max	2.3	49.0	—	16.8	—	9.5
Mean	2.3	39.0	—	13.0	—	4.4
Longfin Sanddab						
n	3	3	1	3	1	2
Min	2.1	38.0	nd	12.4	nd	6.4
Max	4.9	352.3	1.9	175.5	20.0	28.7
Mean	3.1	230.7	1.9	86.3	20.0	17.5
Tot Samples[b]	12	12	12	12	11	11
DR(%)	33	92	17	83	18	100
Max	4.9	443.7	3.9	475.0	20.0	41.1

[a] Minimum and maximum values were based on all samples, whereas means were calculated from detected values only; [b] see Table 7.1

Diego 2000). Exceptions included aluminum, which exceeded pre-discharge values in a single Longfin Sanddab sample, and arsenic, which exceeded pre-discharge values in a single Hornyhead Turbot sample (Figure 7.2). Intra-species comparisons between nearfield and farfield stations could only be made for mercury and selenium. These comparisons suggest that there was no clear relationship with proximity to the discharge site, as concentrations of both metals were similar across all zones.

Pesticides

Only three chlorinated pesticides were detected in fish liver tissue samples collected from the SBOO region during 2015 (Table 7.3). DDT was the most prevalent, occurring in all but one tissue sample (92%) at concentrations up to 443.7 ppb. This pesticide was found at extremely low levels compared to those reported during the pre-discharge period for both Hornyhead Turbot and Longfin Sanddab, with no patterns evident relative to proximity to the outfall (Figure 7.3). The tDDT metabolite p,p-DDE, was found in 92% of the samples, whereas o,p-DDE, p,p-DDD, and p,p-DDMU occurred in ≤25% of the samples (Appendix F.3). HCB was detected in samples from most zones, with an overall detection rate of 34% at concentrations up to 4.9 ppb (Table 7.3). The highest HCB value was recorded in a Longfin Sanddab sample collected from farfield zone TZ7 (Figure 7.3). Chlordane (as trans nonachlor) was found in only two samples (detection rate = 17%) at concentrations from 1.9 to 3.9 ppb. These were recorded for a Longfin Sanddab sample collected from zone TZ6 and a Fantail Sole sample collected from zone TZ7 (Appendix F.3).

PCBs and PAHs

PCBs were detected in 83% of the liver tissue samples collected from the SBOO region during 2015 (Table 7.3). Total PCB concentrations were highly variable with detected values ranging from 3 to 475 ppb. As with DDT, PCBs were found at extremely low levels compared to those reported during the pre-discharge period for both Hornyhead Turbot and Longfin Sanddab, with no patterns relative to proximity to the outfall evident (Figure 7.3). The congeners PCB 153/168 and PCB 187 occurred in 83% of the samples, while PCB 118 and PCB 149 were detected at least 50% of the time (Appendix F.3). Another 23 congeners were recorded in ≤42% of the samples. In contrast to PCBs, PAHs (composed solely of 1-methylnaphthrene) were detected in only two samples (detection rate = 18%), both at a concentration of 20 ppb. These were recorded for a Longfin Sanddab sample collected from zone TZ5 and a Fantail Sole sample collected from zone TZ6.

Contaminants in Fishes Collected by Rig Fishing

Only six trace metals occurred in all muscle tissue samples collected at the two SBOO rig fishing

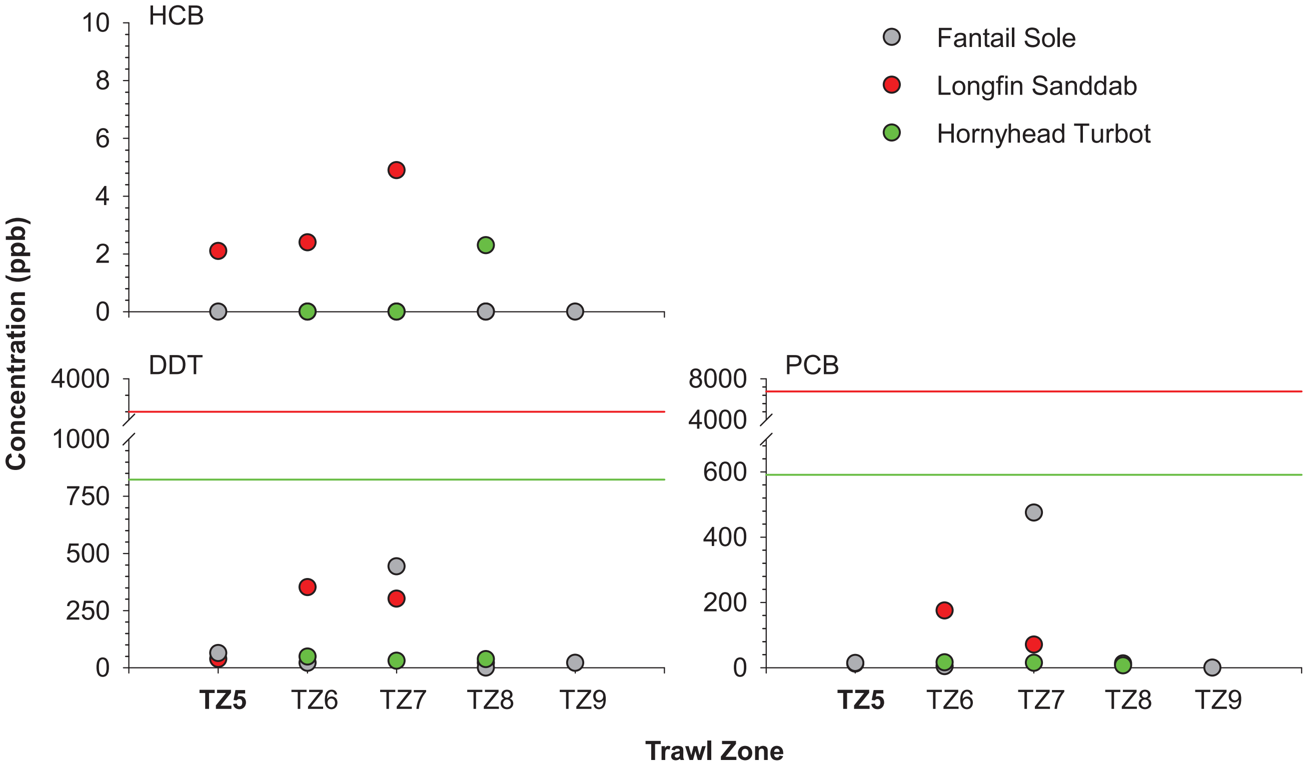


Figure 7.3
Concentrations of HCB, total DDT, and total PCB in liver tissues of fishes collected from each SBOO trawl zone during 2015. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate parameters were not detected in that species pre-discharge. Zeros were substituted for non-detects to differentiate them from missing values (i.e., samples that were not collected; see Table 7.1). Zone TZ5 is considered nearfield (bold; see text).

stations during 2015, including arsenic, chromium, mercury, selenium, tin and zinc (Table 7.4). Detection rates for five other metals (aluminum, barium, copper, iron, tin) were ≤67%, while antimony, beryllium, cadmium, lead, manganese, nickel, and silver were not detected in any of the samples. The metals present in the highest concentrations were aluminum, arsenic, iron, and zinc, although all were ≤11.2 ppm. Arsenic, iron, mercury, selenium, and zinc all occurred at concentrations that exceeded pre-discharge values in one or more samples of California Scorpionfish, Treefish, and/or mixed Rockfish (Figure 7.4). The highest concentrations of arsenic, barium and copper were found in tissue samples collected at station RF3, while the highest concentrations of chromium, iron, selenium, tin and zinc were found in tissue samples collected at station RF4. Overall, variations in the concentrations of these metals were minor and may have been due to weight, length, and/or life history differences between the different species of fish (Appendix F.1).

DDT (composed solely of p,p-DDE) and HCB were the only pesticides detected in rockfish muscle tissues collected in the SBOO region during 2015 (Table 7.5, Appendix F.3). Both of these pesticides were found in 83% of the samples at low concentrations ≤2.6 ppb. Total DDT levels were well below pre-discharge values, whereas HCB was not detected during that period. DDT and HCB levels appeared to be similar in fish tissue samples collected at the two rig fishing stations (Figure 7.4).

During 2015, PCBs (composed of PCB 153/168 and PCB 180) were detected at a rate of 67% in the SBOO muscle tissue samples, while PAHs (composed solely of naphthalene) were detected at a rate of 17% (Table 7.5, Appendix F.3). As with pesticides, total PCB and total PAH were also found at low concentrations (≤0.3 ppb

Table 7.4

Summary of metals in muscle tissues of fishes collected from SBOO rig fishing stations during 2015. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the number of samples, detection rate and maximum value for all species. Concentrations are expressed as parts per million (ppm); na = not available; nd = not detected. Highlighted values meet or exceed OEHHA fish contaminant goals, USFDA action limits, or median international standards (IS). See Appendix F.2 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Gopher Rockfish																		
n	2	0	2	1	0	0	2	1	2	0	0	2	0	2	0	1	2	2
Min	3.0	—	4.50	nd	—	—	0.20	nd	2.0	—	—	0.113	—	0.32	—	nd	0.40	4.10
Max	5.0	—	5.30	0.045	—	—	0.20	0.2	2.0	—	—	0.183	—	0.36	—	0.40	0.50	4.40
Mean	4.0	—	4.90	0.045	—	—	0.20	0.2	2.0	—	—	0.148	—	0.34	—	0.40	0.45	4.25
California Scorpionfish																		
n	0	0	1	0	0	0	1	1	0	0	0	1	0	1	0	0	1	1
Value	—	—	3.15	—	—	—	0.15	0.1	—	—	—	0.247	—	0.28	—	—	0.55	4.70
Mixed Rockfish																		
n (out of 1)	0	0	1	0	0	0	1	1	1	0	0	1	0	1	0	0	1	1
Value	—	—	11.20	—	—	—	0.20	0.4	3.0	—	—	0.053	—	0.32	—	—	0.50	5.60
Squarespot Rockfish																		
n	0	0	1	1	0	0	1	0	0	0	0	1	0	1	0	0	1	1
Value	—	—	2.03	0.087	—	—	0.25	—	—	—	—	0.015	—	0.25	—	—	0.55	4.70
Treefish																		
n	0	0	1	0	0	0	1	1	1	0	0	1	0	1	0	0	1	1
Value	—	—	1.50	—	—	—	0.30	0.2	5.0	—	—	0.207	—	0.40	—	—	0.80	6.50
Total Samples[b]	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Detection Rate (%)	33	0	100	33	0	0	100	67	67	0	0	100	0	100	0	17	100	100
Max Value	5.0	—	11.20	0.087	—	—	0.30	0.4	5.0	—	—	0.247	—	0.40	—	0.40	0.80	6.50
OEHHA[c]	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
USFDA Action Limit[d]	na	na	na	na	na	na	na	na	na	na	na	1.0	na	na	na	na	na	na
Median IS[d]	na	na	1.4	na	na	1.0	1.0	20	na	2.0	na	0.50	na	0.30	na	na	175	70

[a] Minimum and maximum values were based on all samples, whereas means were calculated from detected values only

[b] See Table 7.1

[c] From the California OEHHA (Klasing and Brodberg 2008)

[d] From Mearns et al. 1991. USFDA mercury action limits and all international standards (IS) are for shellfish, but are often applied to fish

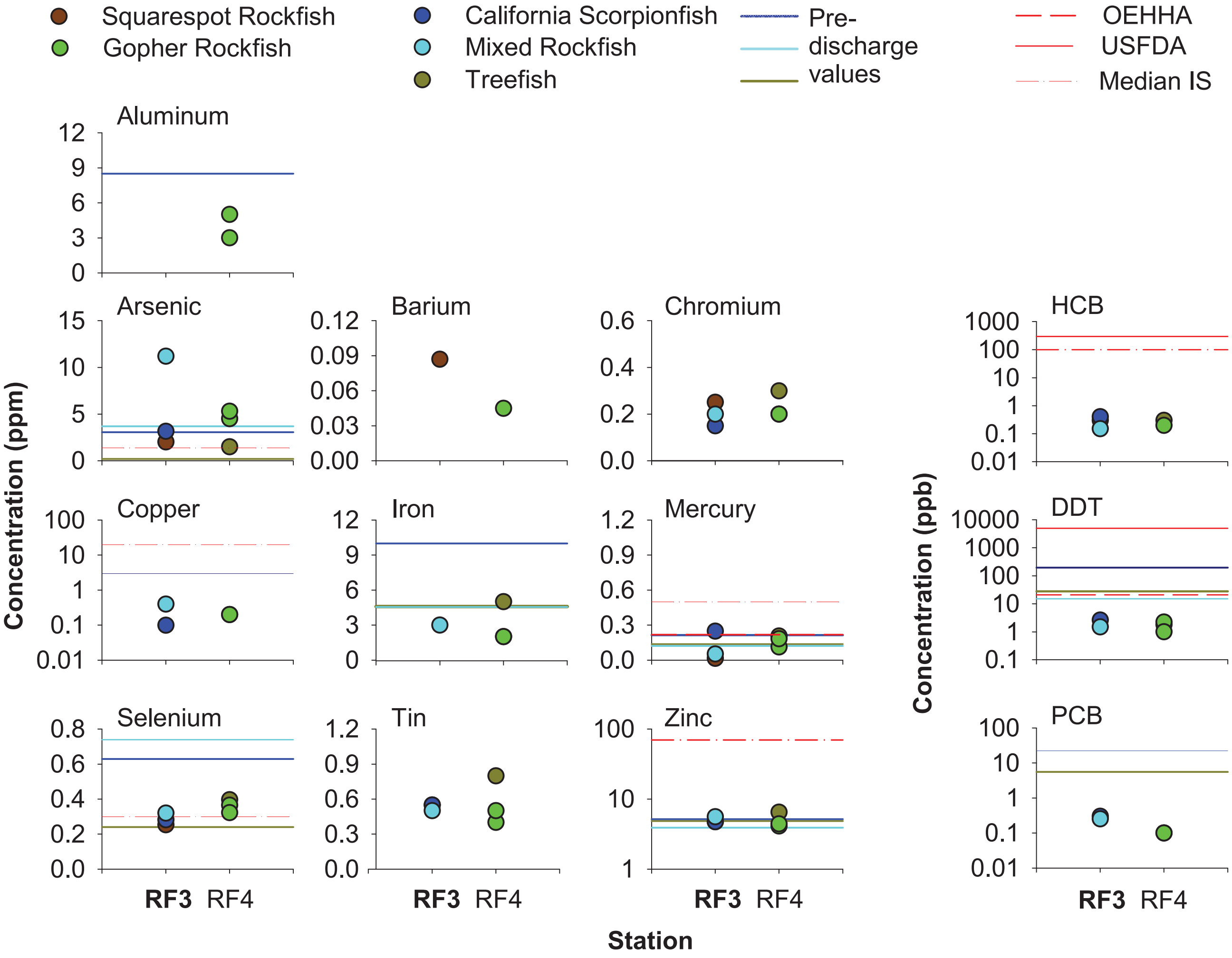


Figure 7.4

Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each SBOO rig fishing station during 2015. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate parameters were not detected in that species pre-discharge. See Tables 7.4 and 7.5 for thresholds. Missing values are non-detects. Station RF3 is considered nearfield (bold; see text).

and ≤ 35 ppb, respectively). PCBs were found at both rig fishing stations at levels below pre-discharge values (Figure 7.4). Naphthalene was found only at RF3; it was not detected during the pre-charge period (Appendix F.3).

Most contaminants detected in fish muscle tissues during 2015 occurred at concentrations below state, national, and international limits and standards (Table 7.4, 7.5, Figure 7.4). Exceptions included: (1) arsenic, which occurred at levels higher than the median international standard in every muscle sample from both station RF3 and station RF4; (2) selenium, which exceeded the median international standard in one sample of Mixed Rockfish from station RF3, one sample of Treefish, and two samples of Gopher Rockfish from station RF4; (3) mercury, which exceeded the OEHHA fish contaminant goal in one sample of California Scorpionfish from station RF3.

DISCUSSION

Several trace metals, PCB congeners, PAHs and the chlorinated pesticides DDT, HCB, and chlordane were detected in liver tissues from three different species of fish collected in the South Bay outfall region during 2015. Many of the same metals, pesticides, PCBs and PAHs were also detected

Table 7.5

Summary of pesticides, total PCB, total PAH, and lipids in muscle tissues of fishes collected from SBOO rig fishing stations during 2015. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species and the total number of samples, detection rate and maximum value for all species; na = not available; nd = not detected. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits, or median international standards (IS). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT, tPCB and tPAH.

	Pesticides				
	HCB (ppb)	tDDT (ppb)	tPCB (ppb)	tPAH (ppb)	Lipids (% wt)
Gopher Rockfish					
n (out of 2)	1	2	1	0	2
Min	nd	1.0	nd	—	0.3
Max	0.2	2.2	0.1	—	0.8
Mean	0.2	1.6	0.1	—	0.6
California Scorpionfish					
n (out of 1)	1	1	1	0	1
Value	0.4	2.6	0.3	—	0.5
Mixed Rockfish					
n (out of 1)	1	1	1	1	1
Value	0.1	1.5	0.2	35.0	0.7
Squarespot Rockfish					
n (out of 1)	1	0	0	0	1
Value	0.3	—	—	—	0.1
Treefish					
n (out of 1)	1	1	1	0	1
Value	0.3	1.8	0.1	—	0.6
Total Samples[b]					
Detection Rate (%)	83	83	67	17	100
Max Value	0.4	2.6	0.3	35.0	0.8
OEHHA[c]	na	21	3.6	na	na
U.S. FDA Action Limit[d]	300	5000	na	na	na
Median IS[d]	100	5000	na	na	na

[a] Minimum and maximum values were based on all samples, whereas means were calculated from detected values only

[b] See Table 7.1

[c] From the California OEHHA (Klasing and Brodberg 2008)

[d] From Mearns et al. 1991. USFDA action limits and all international standards (IS) are for shellfish, but are often applied to fish

in muscle tissues during the year, although often less frequently and/or in lower concentrations. Although tissue contaminant concentrations varied among different species of fish and between stations, all values were within ranges reported previously for Southern California Bight (SCB) fishes (e.g., Mearns et al. 1991, Allen et al.1998, City of San Diego 2015a). Additionally, all muscle tissue samples from sport fish collected in the region had concentrations of mercury and DDT below USFDA action limits. However, all muscle tissue samples had concentrations of arsenic above the median international standards, one or more samples had concentrations of selenium above the median international standards, and one California Scorpionfish sample exceeded the OEHHA fish contaminant goal for mercury. Elevated levels of these contaminants are not uncommon in sport fish from the SBOO region (City of San Diego 2000–2015b) or from other parts of the San Diego region (see City of San Diego 2015a and references therein). For example, muscle tissue samples from fishes collected off Point Loma since 1991 have occasionally had concentrations of contaminants such as arsenic, selenium, mercury, and PCB that exceeded different consumption limits.

The frequent occurrence of metals and chlorinated hydrocarbons in the tissues of fish captured in the SBOO region may be due to multiple factors. Many metals occur naturally in the environment, although little information is available on background levels in fish tissues. Brown et al. (1986) determined that there may be no area in the SCB sufficiently free of chemical contaminants to be considered a reference site, while Mearns et al. (1991) described the distribution of several contaminants such as arsenic, mercury, DDT and PCBs as being ubiquitous. The wide-spread distribution of contaminants in SCB fishes has been supported by more recent work regarding PCBs and DDTs (e.g., Allen et al. 1998, 2002) and is supported in the South Bay outfall region by the presence of many contaminants in fish tissues prior to the initiation of wastewater discharge in 1999 (City of San Diego 2000).

Other factors that affect contaminant loading in fish tissues include the physiology and life history of different species (see Groce 2002 and references therein). Exposure to contaminants can also vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). Fishes may be exposed to contaminants in an area that is highly polluted and then move into an area that is not. For example, California Scorpionfish tagged in Santa Monica Bay have been recaptured as far south as the Coronado Islands (Hartmann 1987, Love et al. 1987). This is of particular concern for fishes collected in the vicinity of the SBOO, as there are other point and non-point sources that may contribute to contamination in the region, including the Tijuana River, San Diego Bay, and offshore dredged material disposal sites (see Chapters 2–4) (Parnell et al. 2008). In contrast, assessments of contaminant loading in sediments surrounding the outfall have revealed no evidence to indicate that the SBOO is a major source of pollutants to the area (Chapter 4).

Overall, there was no evidence of contaminant bioaccumulation in SBOO fishes during 2015 that could be associated with wastewater discharge from the outfall. Although several muscle or liver tissue samples had concentrations of some contaminants that exceeded pre-discharge maxima, concentrations of most contaminants were generally similar to or below pre-discharge levels (see also City of San Diego 2000). In addition, most tissue samples that did exceed pre-discharge levels were widely distributed among stations and showed no spatial patterns relative to the outfall. Finally, there were no other indications of poor fish health in the region, such as the presence of fin rot, other indicators of disease, or any physical anomalies (see Chapter 6).

LITERATURE CITED

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., S.L. Moore, K.C. Schiff, D. Diener, S.B. Weisberg, J.K. Stull, A. Groce, E. Zeng, J. Mubarak, C.L. Tang, R. Gartman, and C.I. Haydock. (1998). Assessment of demersal fish and megabenthic invertebrate assemblages on the mainland shelf of Southern California in 1994. Southern California Coastal Water Research Project, Westminster, CA.

Brown, D.A., R.W. Gossett, G.P. Hershelman, C.G. Word, A.M. Westcott, and J.N. Cross. (1986). Municipal wastewater contamination in the Southern California Bight: Part I–metal and organic contaminants in sediments and organisms. Marine Environmental Research, 18: 291– 10.

Cardwell, R. D. (1991). Methods for evaluating risks to aquatic life and human health from exposure to marine discharges of municipal wastewaters. Pages 253–252 in A. G. Miskiewicz, editor. Proceedings of a Bioaccumulation Workshop: Assessment of the Distribution, Impacts, and Bioaccumulation of Contaminants in Aquatic Environments. Australian Marine Science Association, Inc./WaterBoard.

City of San Diego. (2000). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2001). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2000). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2002). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, (2001). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, (2002). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2005). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015a). Appendix D. Bioaccumulation Assessment. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements Point Loma Ocean Outfall. Volume V, Appendices C thru D. Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015b). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2016a). 2015 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2016b). Point Loma Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2015. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (in prep). Quality Assurance Project Plan for Coastal Receiving Waters Monitoring. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Connell, D. W. (1988). Bioaccumulation behavior of persistent organic chemicals with aquatic organisms. Review of Environmental Contamination and Toxicology, 101: 117– 54.

Groce, A.K. (2002). Influence of life history and lipids on the bioaccumulation of organochlorines in demersal fishes. Master's thesis. San Diego State University. San Diego, CA.

Hartmann, A.R. (1987). Movement of scorpionfishes (Scorpaenidae: Sebastes and Scorpaena) in the Southern California Bight. California Fish and Game, 73: 68– 69.

Klasing, S. and R. Brodberg (2008). Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Sport Fish: Chlordane, DDTs, Dieldrin, Methylmercury, PCBs, Selenium, and Toxaphene. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA.

Lauenstein, G.G. and A.Y. Cantillo, eds. (1993). Sampling and Analytical Methods of the NOAA National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984–1992: Vol. I–IV. Technical Memorandum NOS ORCA 71. NOAA/NOS/ORCA, Silver Spring, MD.

Love, M.S., B. Axell, P. Morris, R. Collins, and A. Brooks. (1987). Life history and fishery of the California scorpionfish, Scorpaena guttata, within the Southern California Bight. Fisheries Bulletin, 85: 99–116.

Mearns, A.J., M. Matta, G. Shigenaka, D. MacDonald, M. Buchman, H. Harris, J. Golas, and G. Lauenstein. (1991). Contaminant Trends in the Southern California Bight:

Inventory and Assessment. NOAA Technical Memorandum NOS ORCA 62. Seattle, WA.

Otway, N. (1991). Bioaccumulation studies on fish: choice of species, sampling designs, problems and implications for environmental management. In: A.G. Miskiewicz (ed.). Proceedings of a Bioaccumulation Workshop: Assessment of the Distribution, Impacts, and Bioaccumulation of Contaminants in Aquatic Environments. Australian Marine Science Association, Inc./Water Board.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin, 56: 1992–2002.

Rand, G.M., ed. (1995). Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment. 2nd ed. Taylor and Francis, Washington, D.C.

Schiff, K.C. and M.J. Allen. (1997). Bioaccumulation of chlorinated hydrocarbons in livers of flatfishes from the Southern California Bight. In: S.B. Weisberg, C. Francisco, and D. Hallock (eds.). Southern California Coastal Water Research Project Annual Report 1995–996. Southern California Coastal Water Research Project, Westminster, CA.

[USEPA] United States Environmental Protection Agency. (2000). Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment. Status and Needs. EPA-823-R-00-001. U.S. Environmental Protection Agency.

Chapter 8
San Diego Regional Survey
Sediment Conditions

Chapter 8. San Diego Regional Survey Sediment Conditions

INTRODUCTION

Ocean sediments are the primary habitat for macrobenthic invertebrate and demersal fish communities on the coastal shelf and slope. The physical and chemical conditions of these sediments can therefore influence the ecological health of marine communities by affecting the distribution and presence of various species (Gray 1981, Cross and Allen 1993, Thompson et al. 1993, Snelgrove and Butman 1994). For this reason, sediments have been sampled extensively near Southern California Bight (SCB) ocean outfalls in order to monitor benthic conditions around these and other point sources over the past several decades (Swartz et al. 1986, Anderson and Gossett 1987, Finney and Huh 1989, Stull 1995, Bay and Schiff 1997, Stein and Cadien 2009). Examples of such local assessments include the regular ongoing surveys conducted each year around the ocean outfalls operated by the four largest wastewater dischargers in the region: the City of Los Angeles, the City of San Diego, the Los Angeles County Sanitation District, and the Orange County Sanitation District (e.g., City of Los Angeles 2014, 2015, LACSD 2014, City of San Diego 2015a, b, OCSD 2015). In order to place data from these localized surveys into a broader biogeographic context, larger-scale regional monitoring efforts have also become an important tool for evaluating benthic conditions and sediment quality in southern California (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009, Bight'13 CIA 2013, Dodder et al. 2016).

The City of San Diego has also conducted annual regional benthic surveys off the coast of San Diego since 1994 (see Chapter 1). The primary objectives of these summer surveys, which typically range from offshore of Del Mar in northern San Diego southward to the USA/Mexico border, are to: (1) describe the overall condition and quality of the diverse benthic habitats that occur in the coastal waters off San Diego; (2) characterize the ecological health of the soft-bottom marine benthos in the region; (3) gain a better understanding of regional variation in order to distinguish anthropogenically-driven changes from natural fluctuations. These surveys typically occur at an array of 40 stations selected each year using a probability-based, random stratified sampling design as described in Bergen (1996), Stevens (1997), and Stevens and Olsen (2004). During 1995–1997, 1999–2002, and 2005–2007, the surveys off San Diego were restricted to continental shelf depths (<200 m); however, the area of coverage was expanded beginning in 2009 to include deeper habitats along the upper slope (200–500 m). No survey of randomly selected sites was conducted in 2004 due to sampling for a special sediment mapping project (Stebbins et al. 2004), while the surveys in 1994, 1998, 2003, 2008, and 2013 were conducted as part of larger, multi-agency surveys of the entire SCB (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009, Bight'13 CIA 2013, Dodder et al. 2016).

This chapter presents analysis and interpretation of the sediment particle size and chemistry data collected during the 2015 regional survey of the continental shelf and upper slope off San Diego. Included are descriptions of the region's sediment conditions during the year and comparisons of sediment characteristics and quality across the major depth strata defined by the SCB regional programs. Additionally, multivariate analyses of sediment data collected from the 2015 regional survey are presented. Results of macrofaunal community analyses for these same sites are presented in Chapter 9.

MATERIALS AND METHODS

Field Sampling

The July 2015 regional survey covered an area ranging north of La Jolla southward to

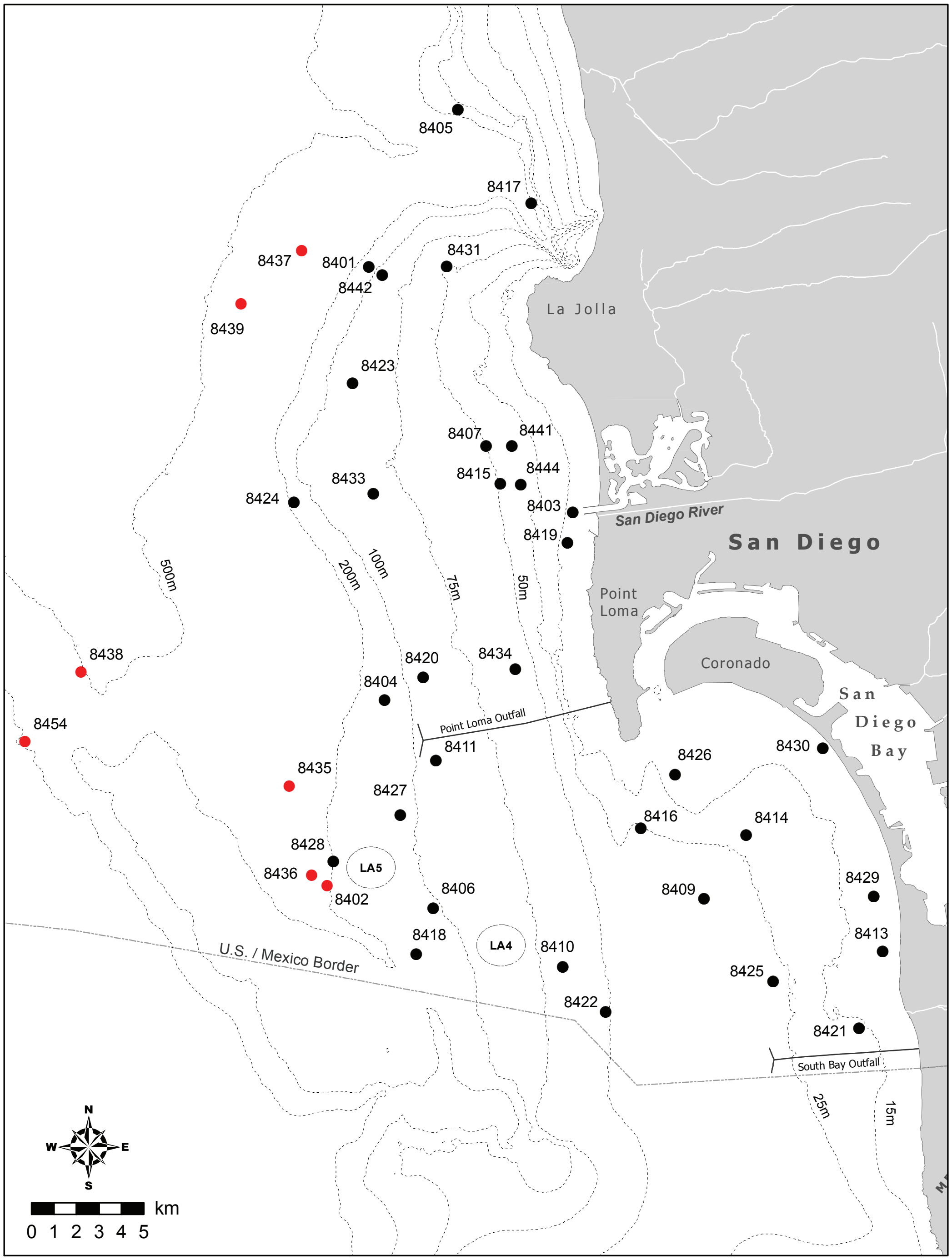


Figure 8.1
Randomly generated regional benthic survey stations sampled during July 2015 as part of the City of San Diego's Ocean Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

the USA/Mexico border (Figure 8.1). A total of 40 stations were sampled at depths ranging from 9 to 530 m spanning four distinct depth strata characterized by the SCB regional monitoring programs (Dodder et al. 2016). These included 10 stations along the inner shelf (5–30 m), 16 stations along the mid-shelf (>30–120 m), seven stations along the outer shelf (>120–200 m), and seven stations on the upper slope (>200–530 m). Each sediment sample was collected from one side of a double 0.1-m^2 Van Veen grab, while the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 9). Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines (USEPA 1987).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Environmental Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2016). Briefly, sediment sub-samples were analyzed on a dry weight basis to determine concentrations of various indictors of organic loading (i.e., total organic carbon, total nitrogen, total sulfides, total volatile solids), 18 race metals, 9 chlorinated pesticides (e.g., DDT), 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs). Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix C.1). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry.

Particle size analysis was performed using either a Horiba LA-950V2 laser scattering particle analyzer or a set of nested sieves. The Horiba measures particles ranging in size from 0.5 to 2000 µm. Coarser sediments were removed and quantified prior to laser analysis by screening samples through a 2000 µm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%, and then classified into 11 sub-fractions and 4 main size fractions based on the Wentworth scale (Folk 1980) (see Appendix C.2). When a sample contained substantial amounts of coarse sand, gravel, or shell hash that could damage the Horiba analyzer and/or where the general distribution of sediments would be poorly represented by laser analysis, a set of sieves with mesh sizes of 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, and 63 µm was used to divide the samples into seven sub-fractions.

Data Analyses

Data summaries for the various sediment parameters included detection rate, minimum, maximum, and mean values for all stations combined. Average values were also calculated for each depth stratum. All means were calculated using detected values only; no substitutions were made for non-detects in the data (i.e., analyte concentrations < MDL). Total DDT (tDDT), total hexachlorocyclohexane (tHCH), total chlordane, total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix G.1 for individual constituent values). These analyses were performed using R (R Core Team 2015) and various functions within the plyr, reshape2, and zoo packages (Zeileis and Grothendieck 2005, Wickham 2007, Wickham 2011). Contaminant concentrations were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed, while values above the ERL but below the ERM represent levels at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998).

Multivariate analyses were performed using PRIMER v7 software to examine spatial patterns in the regional particle size and sediment chemistry data collected during 2015 (Clarke et al. 2014). These included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). Prior to these analyses, proportions of silt and clay sub-fractions were combined as percent fines to accommodate sieved samples, while sediment chemistry data were normalized after non-detects (see Table 8.1) were converted to "0" values. Similarity percentages analysis (SIMPER) was used to determine which sub-fractions or sediment chemistry parameters were responsible for the greatest contributions to within-group similarity and between group dissimilarity for retained clusters. To determine whether sediment chemistry concentrations varied by sediment particle size sub-fractions, a RELATE test was used to compare patterns in the sediment chemistry Euclidean distance matrix with patterns in the particle size Euclidean distance matrix. A BEST test using the BIO-ENV procedure was

Table 8.1

Summary of particle sizes and chemistry concentrations in sediments from San Diego regional benthic stations sampled during 2015. Data include detection rate (DR), minimum, maximum, and mean values for the entire survey area, as well as mean value by depth stratum; n = number of stations; nd = not detected.

	2015 Survey Area[a]				**Depth Strata**			
Parameters	**DR (%)**	**Min**	**Max**	**Mean**	**Inner Shelf** n = 10	**Mid-Shelf** n = 16	**Outer Shelf** n = 7	**Upper Slope** n = 7
Particle Size (%)								
Coarse particles	28	0.0	22.8	1.4	0.0	2.0	3.0	0.2
Med-coarse sands	98	0.0	67.4	7.1	4.6	10.5	7.5	2.3
Fine sands	100	27.7	91.9	55.5	82.7	51.3	46.8	35.1
Fines	100	1.2	71.9	36.0	12.6	36.2	42.7	62.3
Organic Indicators								
Sulfides (*ppm*)	100	0.19	35.30	6.89	2.54	3.84	13.47	13.48
TN (*% weight*)	95	nd	0.115	0.036	0.015	0.027	0.035	0.081
TOC (*% weight*)	98	nd	5.39	1.01	0.20	0.76	1.49	2.16
TVS (*% weight*)	100	0.60	7.90	2.70	0.92	1.98	3.23	6.34
Trace Metals (*ppm*)								
Aluminum	100	1880	19,000	9194	5709	7965	11,087	15,086
Antimony	85	nd	2.6	0.8	0.5	0.6	0.7	1.4
Arsenic	100	1.27	9.03	2.76	1.80	2.74	2.83	4.11
Barium	100	4.26	156.00	52.20	35.82	39.97	57.26	98.53
Beryllium	3	nd	0.06	0.06	nd	nd	nd	0.06
Cadmium	55	nd	0.51	0.21	0.17	0.13	0.24	0.27
Chromium	100	6.4	98.2	21.4	10.7	16.7	22.3	46.4
Copper	98	nd	36.2	8.9	2.2	6.3	11.2	21.9
Iron	100	5180	40,400	13,250	7845	11,611	14,751	23,214
Lead	100	1.5	11.4	4.5	2.5	4.2	6.1	6.5
Manganese	100	19.7	188.0	105.4	84.1	96.9	122.6	136.7
Mercury	95	nd	0.179	0.031	0.007	0.025	0.050	0.057
Nickel	100	1.8	18.5	8.3	3.9	6.8	10.5	15.9
Selenium	30	nd	1.23	0.60	nd	0.27	0.33	0.81
Silver	0	—	—	—	—	—	—	—
Thallium	3	nd	0.5	0.5	nd	nd	0.5	nd
Tin	95	nd	2.0	0.9	0.5	0.8	1.1	1.3
Zinc	100	7.4	69.9	30.8	17.4	27.0	36.3	53.2
Pesticides (*ppt*)								
Total DDT	83	nd	2270	511	196	566	508	576
HCB	33	nd	1400	487	279	528	870	220
Total PCB (ppt)	33	nd	9858	1590	2338	433	1454	5026
Total PAH (ppb)	68	nd	420	62	24	30	94	102

[a] Minimum and maximum values were calculated using all samples (n = 40), whereas means were calculated on detected values only (n ≤ 40)

conducted to determine which subset of sediment sub-fractions was the best explanatory variable for the similarity between the two resemblance matrices.

Spearman rank correlations were calculated to assess if values for the various parameters co-varied in the sediments. This non-parametric analysis accounts for non-detects in the data without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in rank-based analyses may intensify with increased censoring (Conover 1980). Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis.

RESULTS AND DISCUSSION

Particle Size Composition

Ocean sediments were diverse at the benthic stations sampled during the summer 2015 regional survey off San Diego. The proportion of fine particles (i.e., silt and clay; also referred to as percent fines) ranged from ~1 to 72% per sample, while fine sands, medium-coarse sands, and coarse particles ranged from 28 to 92%, 0 to 67%, and 0 to 23% per sample, respectively (Table 8.1, Figure 8.2). Coarser particles often comprised red relict sands, black sands, and/or shell hash (Appendix G.2). Overall, sediment composition varied as expected by region and depth stratum (Table 8.1, Figures 8.2, 8.3). For example, percent fines increased from about 13% per sample at inner shelf stations, to 36 and 43% per sample at mid- and outer shelf stations, to 62% per sample at upper slope stations. Correlation analysis confirmed that percent fines tended to increase with depth (Figure 8.4). The most notable exceptions to this pattern included sediments from stations 8410, 8422, 8431, and 8427 located at depths of 63, 51, 54 and 112 m on the mid-shelf, station 8424 located at a depth of 131 m on the outer shelf, and station 8454 located at a depth of 465 m on the upper slope along the Coronado Bank (Appendix G.2). Each of these stations had lower percent fines (≤43%) than other stations at similar depths. In contrast to fine particles, fine sands decreased from 83% per sample on the inner shelf to 35% per sample on the upper slope (Table 8.1, Figure 8.3). On average, medium-coarse sands were highest on the mid-shelf, while coarse particles were very low on the upper slope and absent from the inner shelf.

Indicators of Organic Loading

Sulfides were detected in all sediment samples collected from the 2015 San Diego regional benthic stations at concentrations from 0.19 to 35.30 ppm (Table 8.1). Sulfides averaged from 2.54 ppm on the inner shelf, to 3.84 ppm on the mid-shelf, to ~13.5 ppm on the outer shelf and upper slope (Table 8.1, Figure 8.3). The highest values of this analyte (≥19.20) were recorded at stations 8405 and 8417 located at 150 and 199 m within the La Jolla canyon, and at stations 8402, 8428, and 8436 located at 195–219 m on the west side of the LA-5 dredge materials dumpsite (Appendix G.3). Sulfides did not co-vary with percent fines (Appendix G.4).

During 2015, total nitrogen (TN), total organic carbon (TOC), and total volatile solids (TVS) were detected in 95–100% of the sediments from regional stations (Table 8.1). Overall, concentrations ranged from not detected to 0.115% weight for TN, not detected to 5.39% weight for TOC, and 0.6–7.9% weight for TVS. Values of these parameters increased from the inner shelf to the upper slope (Table 8.1, Figure 8.3), likely due to differences in sediment particle composition, since all three parameters are known to co-vary with percent fines (e.g., see Figure 8.4, Appendix G.4, City of San Diego 2014).

Trace Metals

Nine trace metals were detected in sediments collected from all stations sampled during the 2015 regional survey off San Diego, including aluminum, arsenic, barium, chromium, iron, lead, manganese, nickel, and zinc (Table 8.1). Antimony, cadmium, copper, mercury and tin were detected at 55–95% of the stations, while beryllium, selenium, and thallium had much lower detection rates from 3 to 30%. Silver was not detected during this survey. Concentrations of metals were within ranges previously reported from elsewhere in the SCB (Dodder et al. 2016)

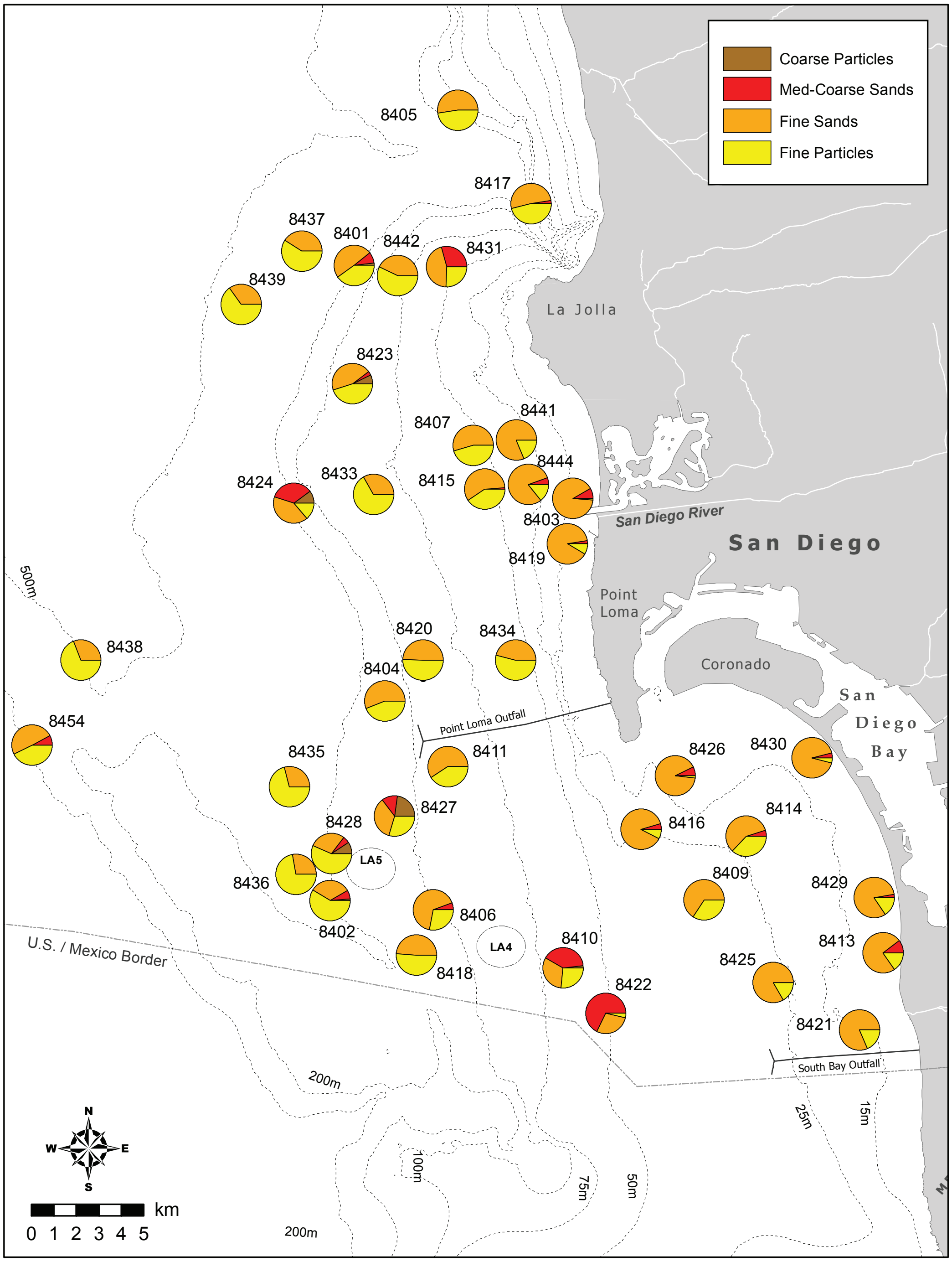


Figure 8.2
Sediment composition from regional benthic stations sampled off San Diego during July 2015.

and almost all were found at levels below both ERL and ERM thresholds (Appendix G.3). Exceptions occurred at two stations: (1) ERLs for arsenic and chromium were exceeded at station 8454 located at a depth of 465 m on the edge of the Coronado Bank; (2) ERLs for copper and mercury were exceeded at station 8428 located at a depth of 195 m adjacent to the LA-5 dredge materials dumpsite.

Concentrations of aluminum, barium, copper, iron, lead, manganese, nickel, and zinc correlated positively with the percentage of fine sediments in each sample (Appendix G.4) and therefore generally increased with depth (e.g., Figures 8.3, 8.4). Although antimony, arsenic, chromium, mercury, and selenium were not correlated as strongly with percent fines (i.e., rs <0.70), concentrations of these metals also tended to increase

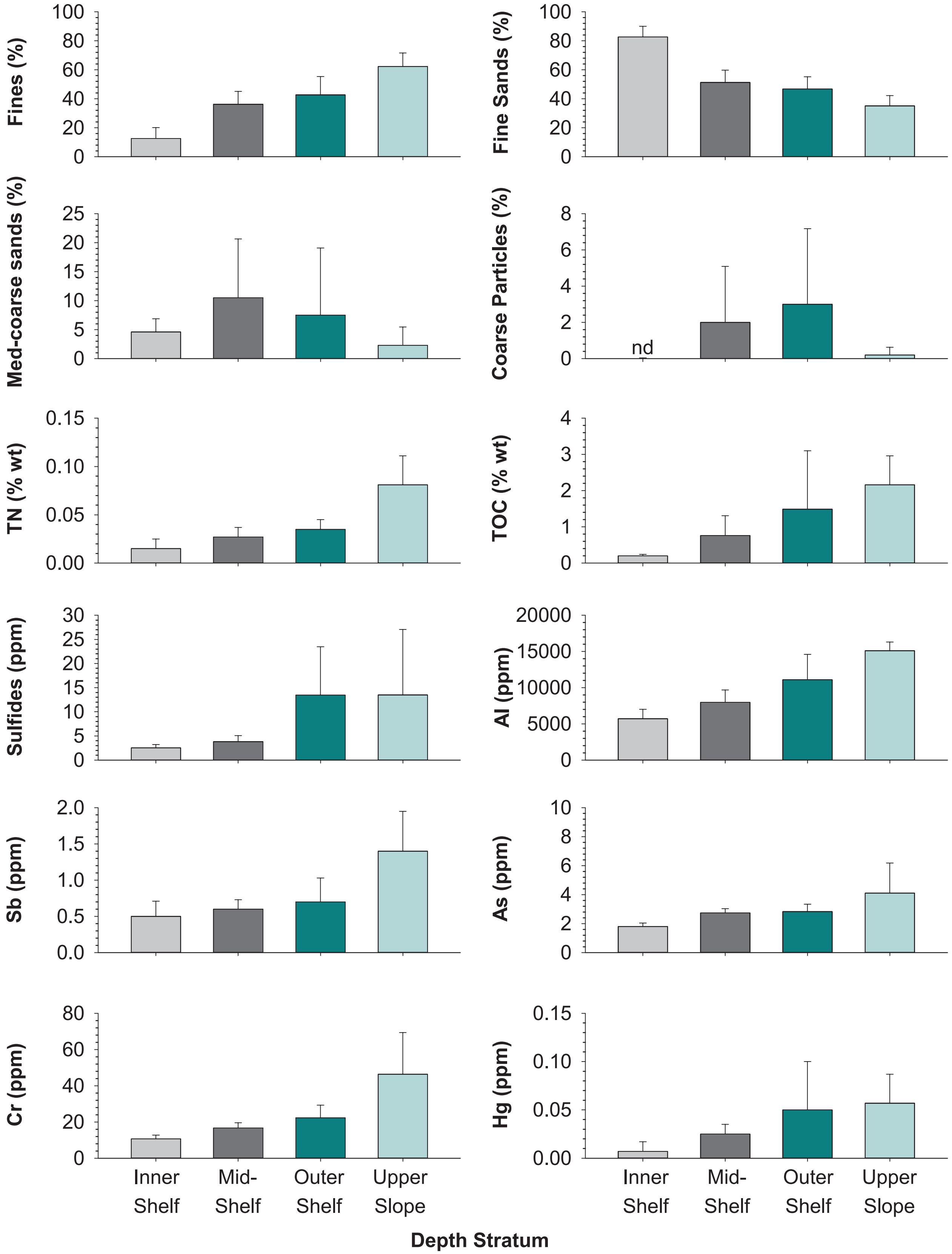


Figure 8.3

Comparison of select particle size and chemistry parameters in sediments from the four major depth strata sampled during the 2015 regional survey off San Diego. Data are expressed as means + 95% confidence intervals calculated on detected values only.

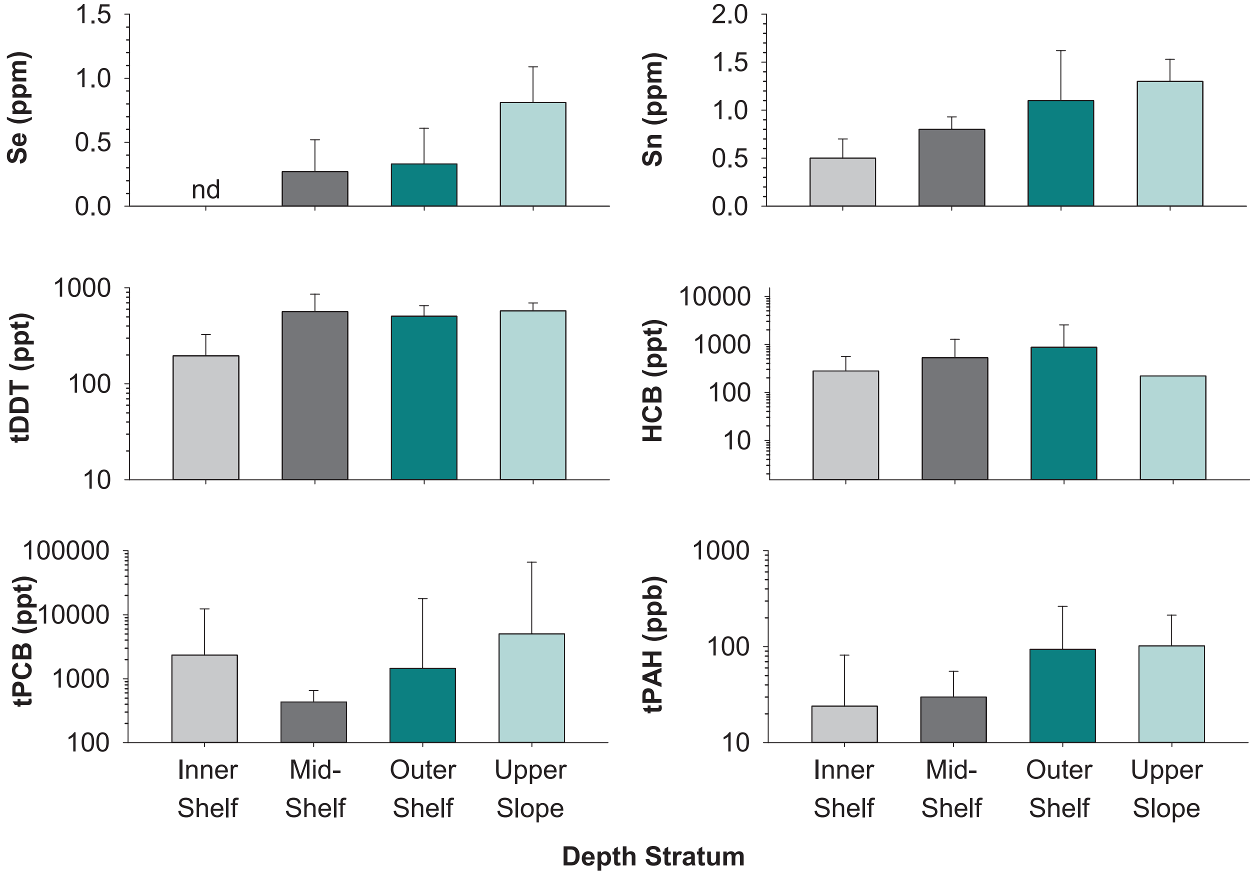


Figure 8.3 *continued*

by depth with the highest values occurring at upper slope stations (Figure 8.3). Selenium was not detected on the inner shelf, thallium was only detected on the outer shelf, and beryllium was only detected on the upper slope (Table 8.1, Appendix G.3).

Pesticides

Two chlorinated pesticides were detected in sediments collected during the 2015 regional survey off San Diego, including DDT and hexachlorobenzene (HCB) (Table 8.1, Appendix G.1, Appendix G.3). Total DDT, composed primarily of p,p-DDE, was detected at 83% of the stations at concentrations up to 2270 ppt. Mean values of DDT were lowest on the inner shelf, and fairly evenly distributed across the mid-shelf, outer shelf and upper slope (Figure 8.3). A single reported value of DDT exceeded the ERL of 1580 ppt at station 8409 located at a depth of 33 m off the Coronado Island "Silver Strand" beach (Appendix G.3). However, all values were well within ranges reported elsewhere in the SCB (e.g., Dodder et al. 2016). Detectable levels of HCB were found at 33% of the regional stations at concentrations up to 1400 ppt (Table 8.1). Average HCB values ranged from 279 ppt on the inner shelf, to 528 ppt on the mid-shelf, to 870 on the outer shelf, to 220 ppt on the upper slope (Table 8.1, Figure 8.3). This trend reflects the three highest values ≥1100 ppt that were recorded on the mid-shelf at station 8409 and on the outer shelf at stations 8401 and 8405 (Appendix G.3).

PCBs

PCBs were detected in sediments from 33% of the 2015 regional stations at concentrations up to 9858 ppt (Table 8.1). No ERL or ERM values exist for PCBs measured as congeners; however, values reported in 2015 were well within those previously reported off San Diego (City of San Diego 2013, 2014, 2015a, b) and elsewhere for the SCB (e.g., Dodder et al. 2016). PCB levels were lowest at the mid-shelf stations, averaging 433 ppt per sample, and highest at the inner

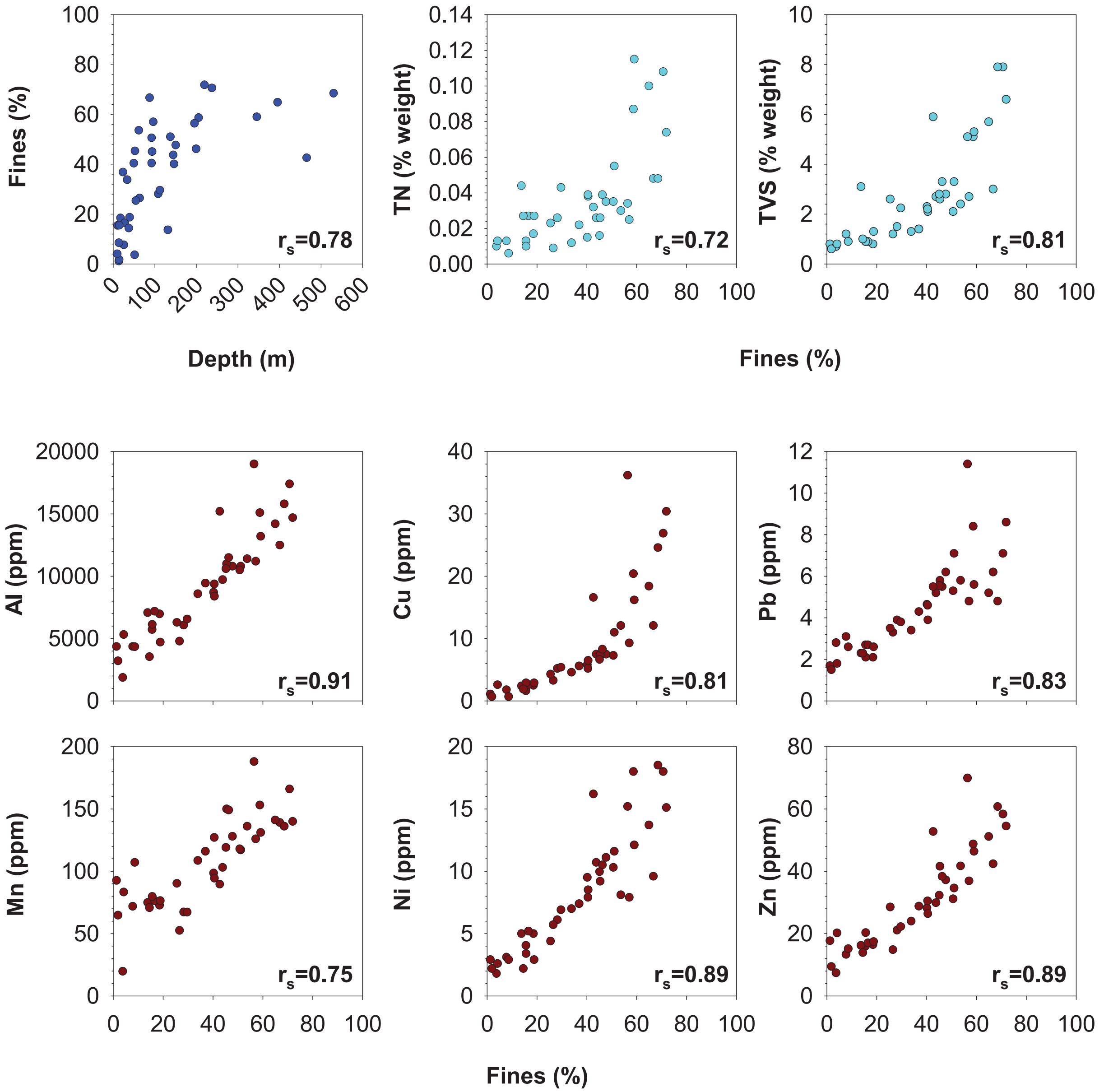


Figure 8.4

Scatterplots of percent fines versus depth and select parameters in sediments from San Diego regional benthic stations sampled during 2015. Spearman rank correlation coefficients (r_s) are included; see Appendix G.4 for other correlation results.

shelf and upper slope stations, averaging 2338 ppt and 5026 ppt per sample, respectively (Table 8.1, Figure 8.3). The hightest PCB values (≥2748 ppt) were found in sediments from stations 8402 and 8428 located adjacent to the LA-5 dredge materials dumpsite and at station 8414 located at a depth of 23 m off of the Coronado Island "Silver Strand" beach (Appendix G.3). The congener PCB 153/168 was found most frequently (detection rate=25%), while the following congeners occurred in ≤18% of the regional samples: PCB 18, PCB 28, PCB 44, PCB 49, PCB 52, PCB 66, PCB 70, PCB 74, PCB 77, PCB 87, PCB 99, PCB 101, PCB 105, PCB 110, PCB 118, PCB 128, PCB 138, PCB 149, PCB 156, PCB 158, PCB 180, PCB 183, and PCB 187 (Appendix G.1).

PAHs

PAHs were detected in sediments from 68% of the 2015 regional stations (Table 8.1, Appendices G.1, G.3). Concentrations were ≤420 ppb, well below threshold values (i.e., <4022 ppb) and within the range of those

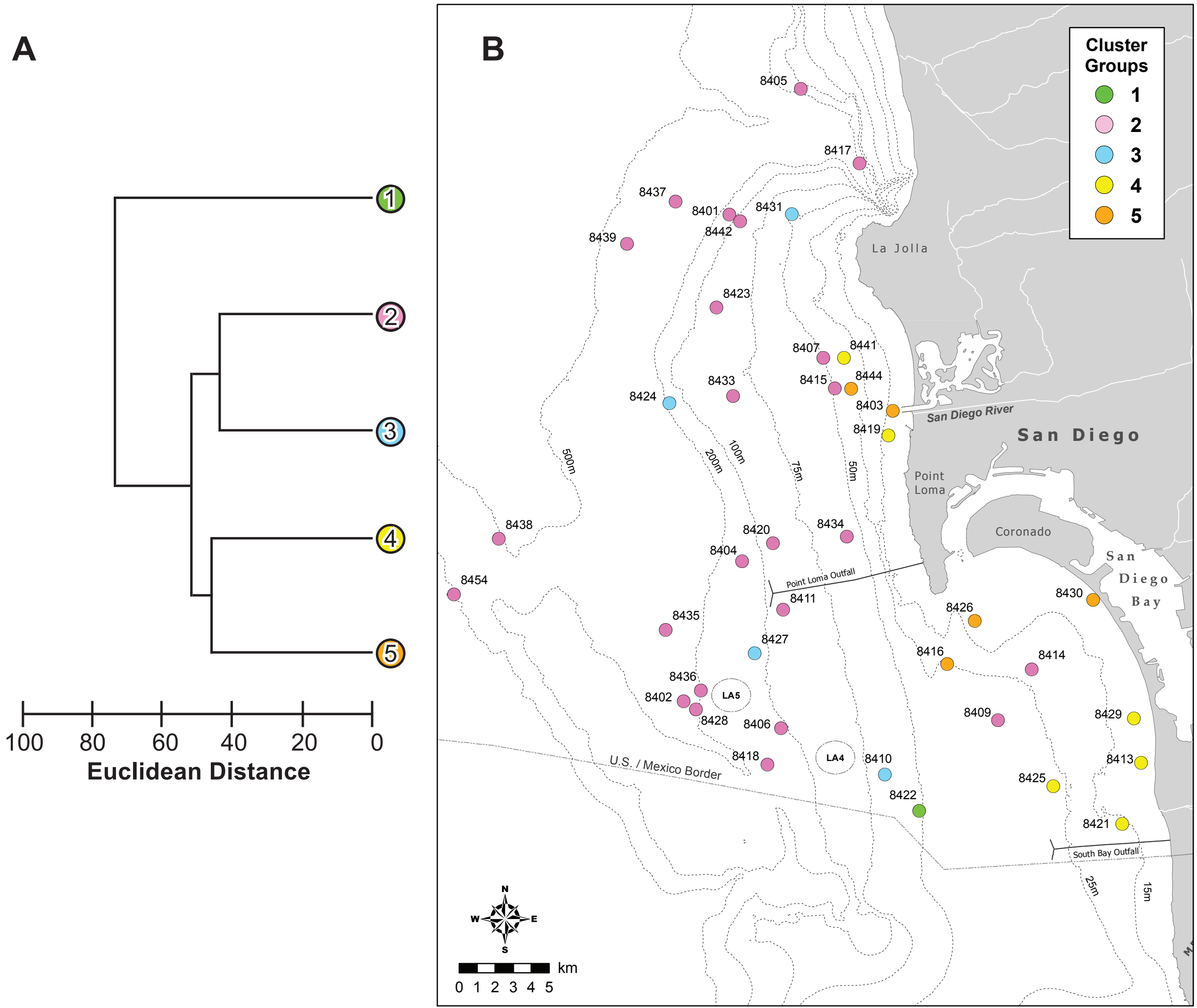


Figure 8.5
Results of cluster analysis of particle size sub-fraction data from San Diego regional benthic stations sampled during 2015. Data are presented as: (A) dendrogram of main cluster groups and (B) spatial distribution of sediments as delineated by cluster analysis.

reported elsewhere in the SCB (e.g., Dodder 2016). Mean PAH concentrations increased from 24 ppb on the inner shelf, to 30 ppb on the mid-shelf, to 94 ppb on the outer shelf, to 102 ppb per sample on the upper slope (Table 8.1, Figure 8.3). The three highest values (≥236 ppb) were found at stations 8402, 8428 and 8436, all of which were located near the LA-5 dredged materials dumpsite. During 2015, the compound 2,6-dimethylnaphthalene was detected most frequently at a rate of 50%; other compounds recorded during the year in 3–33% of the samples included 2-methylnaphthalene, 3,4-benzo(B)fluoranthene, anthracene, benzo[A]anthracene, benzo[A]pyrene, benzo[e]pyrene, benzo[G,H,I]perylene, benzo[K] fluoranthene, biphenyl, chrysene, dibenzo(A,H) anthracene, fluoranthene, indeno(1,2,3- CD)pyrene, perylene, phenanthrene, and pyrene.

Classification of Regional Shelf and Slope Sediment Conditions

Particle Size Composition

Classification (cluster) analysis of 2015 particle size sub-fraction data collected from the 40 regional stations discriminated five main cluster groups (particle size cluster groups 1–5; Figure 8.5, Table 8.2). According to SIMPER results, these five groups were primarily distinguished by proportions

Table 8.2

Summary of particle size cluster groups 1–5 (defined in Figure 8.5). Data are presented as means (ranges) calculated over all stations within a cluster group (n). VFSand = Very Fine Sand; FSand = Fine Sand; MSand = Medium Sand; CSand = Coarse Sand; VCSand = Very Coarse Sand.

Cluster Group	n	Depth Range (m)	Percent Fines	Fine Sands		Med-Coarse Sands		Coarse Particles	
				VFSand	FSand	MSand	CSand	VCSand	Granules
1	1	51	3.7	4.8	23.6	51.6	15.8	0.6	0.0
			—	—	—	—	—	—	—
2	24	(23-530)	50.8	34.0	12.2	1.7	0.4	0.3	0.5
			(28.2-71.9)	(11.9-53.8)	(4.5-32.0)	(0-7.6)	(0-5.4)	(0-3.3)	(0-5.8)
3	4	(54-131)	23.8	22.5	15.9	17.9	11.2	6.3	2.3
			(13.7-29.6)	(17.0-27.5)	(7.6-24.5)	(4.0-24.5)	(8.1-18.0)	(0.1-20.1)	(0-6.5)
4	6	(10-39)	15.6	61.4	20.0	2.3	0.7	<0.1	0.0
			(8.6-18.8)	(56.1-67.7)	(14.9-25.5)	(0.8-6.3)	(0-4.2)	(0-0.1)	—
5	5	(9-37)	5.9	35.6	52.6	5.7	0.1	<0.1	0.0
			(1.2-14.4)	(26.1-43.8)	(38.7-64.4)	(3.2-8.2)	(0-0.6)	(0-0.2)	—

of fines, very fine sand, fine sand, and medium sand. The distribution and main characteristics of each cluster group are described below.

Cluster group 1 comprised a unique sediment sample collected from station 8422, located northwest of the South Bay ocean outfall (SBOO) at a depth of 51 m (Figure 8.5). Sediments from this station had the lowest proportion of fines (4%), the lowest proportion of very fine sand (5%), the largest proportion of medium sand (52%), and the largest proportion of coarse sand (16%) (Table 8.2). There were no granules present at this station.

Cluster group 2 was the largest group, representing 24 stations that spanned the entire survey area at depths from 23 to 530 m (Table 8.2, Figure 8.5). Group 2 had the finest sediments, with the largest proportion of fines (51% per sample), 34% very fine sand, and 12% fine sand per sample. This group also had the lowest proportion of medium sand (2% per sample) and averaged <% coarse sand, very coarse sand, and granules per sample.

Cluster group 3 was also widely distributed; it comprised three mid-shelf stations (i.e., 8410, 8427, 8431) and the shallowest outer shelf station (i.e., 8424) (Figure 8.5). Group 3 sediments were distinguished from group 2 sediments by having about half the amount of fines (24% per sample), a third the amount of very fine sand (23% per sample), and greater amounts of fine sand (16% per sample), medium sand (18% per sample), coarse sand (11% per sample), very coarse sand (6% per sample), and granules (2% per sample) (Table 8.2).

Cluster group 4 comprised six stations ranging in depth from 10 to 39 m, including stations 8419 and 8441 located off of Ocean Beach and Mission Beach, and stations 8413, 8421, 8425, and 8429 located off Imperial Beach and north of the SBOO (Figure 8.5). Sediments represented by this group had the highest proportion of very fine sand (61% per sample), and averaged 16% fines, 20% fine sand, 2% medium sand, and <1% coarse and very coarse sand per sample. Granules were absent at these stations.

Cluster group 5 was very similar to group 4 in that it comprised five stations ranging in depth from 9 to 37 m, including two located off Mission Beach and Ocean Beach (i.e., stations 8403, 8444) and three located south of the entrance to San Diego Bay (i.e., stations 8416, 8426, 8430) (Figure 8.5). Group 5 sediments were distinguished from group 4 sediments by having slightly more than half of the amount of very fine sand (36% per sample), more than twice the amount of fine sand (53% per sample), less fines (6% per sample), and more medium sand (6% per sample). Similar to group 4, group 5 sediments also had < 1% coarse and very coarse sand per sample, and granules were absent at these stations.

Sediment Chemistry

Results of cluster analyses performed on sediment chemistry data collected from the 40 regional stations during 2015 discriminated five main groups (Figure 8.6). These groups (sediment chemistry cluster groups A–E) differed in relative concentrations of metals, pesticides, total PCB, and total PAH detected in sediments from each station (e.g., Figure 8.7). Overall, sediment chemistry was weakly linked to sediment particle size composition (RELATE $\rho = 0.291$, $p = 0.002$). Sediment subfractions that were most highly correlated to contaminants included percent fines and larger particles referenced herein as granules, but are described in visual observations as shell hash or gravel (BEST $\rho = 0.432$, $p = 0.006$).

The largest sediment chemistry cluster group (group E) included 78% of the stations sampled during 2015 (Figure 8.6). These shelf stations spanned the entire survey area and were located at depths from 9 to 199 m. According to SIMPER results, a wide range of analytes accounted for 43% of the within-group similarity for group E, including four organic indicators (sulfides, TN, TOC, TVS), 17 metals (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, thallium, tin, zinc), two chlorinated pesticides (HCB, DDT), and total PAH (see Figure 8.7 for select examples). It is likely that this cluster group represents background conditions on the shelf in the San Diego region.

Cluster groups C and D included seven stations located on the outer shelf and upper slope at depths from 195 to 530 m (Figure 8.6). These two groups had the finest sediments (56%–72% per station) and both were characterized by relatively high concentrations of several parameters (e.g., TN, aluminum, barium, copper, iron, lead, manganese, nickel, tin, and zinc) that were found to co-vary with percent fines (see Figure 8.7 for select examples). Group D included the three stations located just west of the LA-5 dredge materials dumpsite (i.e., 8402, 8428, 8436), and was primarily distinguished from group C by having the highest concentrations of sulfides, aluminum, copper, mercury, and total PAH (Figure 8.7).

The two remaining cluster groups each comprised one "outlier" station that differed from groups C–E primarily by having higher values of a few select contaminants (Figures 8.6, 8.7). For example, station 8454 (group A) had the highest concentrations of antimony, arsenic, chromium, and iron, the lowest concentration of sulfides, and it was the only station where beryllium was detected. This station was located on the western edge of the Coronado Bank at a depth of 465 m. Station 8409 (group B) was located at a depth of 33 m off the Coronado Island "Silver Strand" beach and had the highest concentration of total DDT and the second highest concentration of HCB.

SUMMARY

Particle size composition at the regional benthic stations sampled in 2015 was typical for the continental shelf and upper slope off the coast of southern California (Emery 1960), and consistent with results from previous surveys (e.g., City of San Diego 2008–2014, 2015a, b). Overall, sediments varied as expected by region and depth stratum. For example, regional stations sampled along the inner and middle shelf within the South Bay ocean outfall monitoring area (see Chapter 4) tended to be predominantly sand, whereas regional stations sampled along the middle and outer shelf within the Point Loma ocean outfall monitoring area (see City of San Diego 2015a) typically had much finer sediments. However, exceptions to this overall pattern occurred throughout the region,

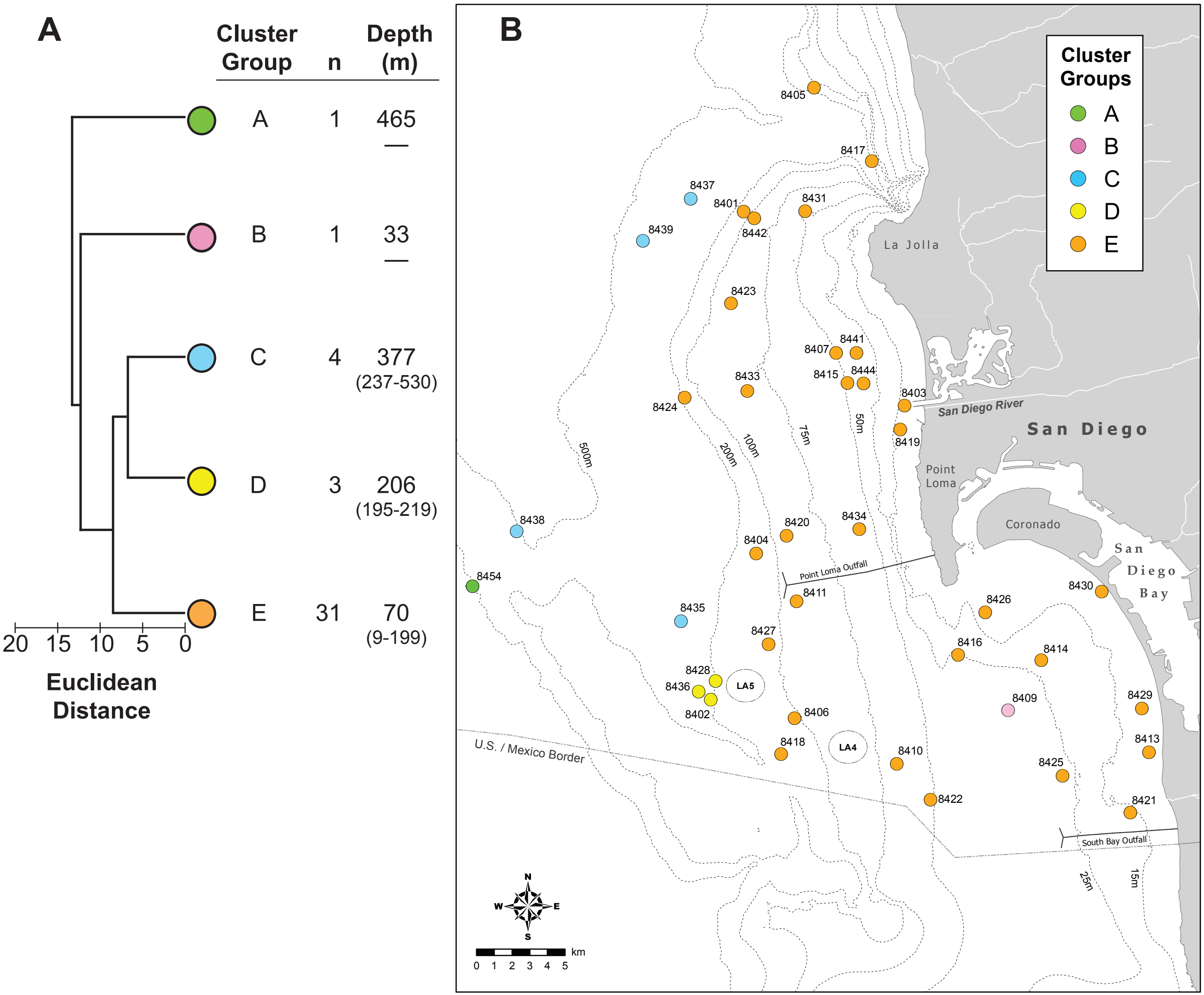


Figure 8.6

Results of cluster analysis of sediment chemistry data from San Diego regional benthic stations sampled during 2015. Data are presented as: (A) dendrogram of main cluster groups and (B) spatial distribution of sediments as delineated by cluster analysis. Depths are presented as means (ranges) calculated over all stations within a cluster group (n).

particularly along the Coronado Bank, a southern rocky ridge located southwest of Point Loma at depths of 150–170 m. Sediment composition at stations from this area were coarser than stations at similar depths located off of Point Loma and further to the north. Much of the variability in particle size composition throughout the region may be due to the complexities of seafloor topography and current patterns, both of which affect sediment transport and deposition (Emery 1960, Patsch and Griggs 2007). Additionally, several stations lie within accretion zones of coastal littoral cells and receive more frequent deposition of sands and fine sediments.

As with sediment particle size composition, regional patterns of sediment contamination in 2015 were similar to patterns seen in previous years. There was no evidence of degraded sediment quality in the general San Diego region. While various indicators of organic loading, trace metals, chlorinated pesticides, PCBs, and PAHs were detected at variable concentrations in sediment samples collected throughout the region, almost all contaminants occurred at levels below both ERL and ERM thresholds as they have in previous years (City of San Diego 2008–2014, 2015a, b). Further, there was no evidence of sediment contamination during the 2015

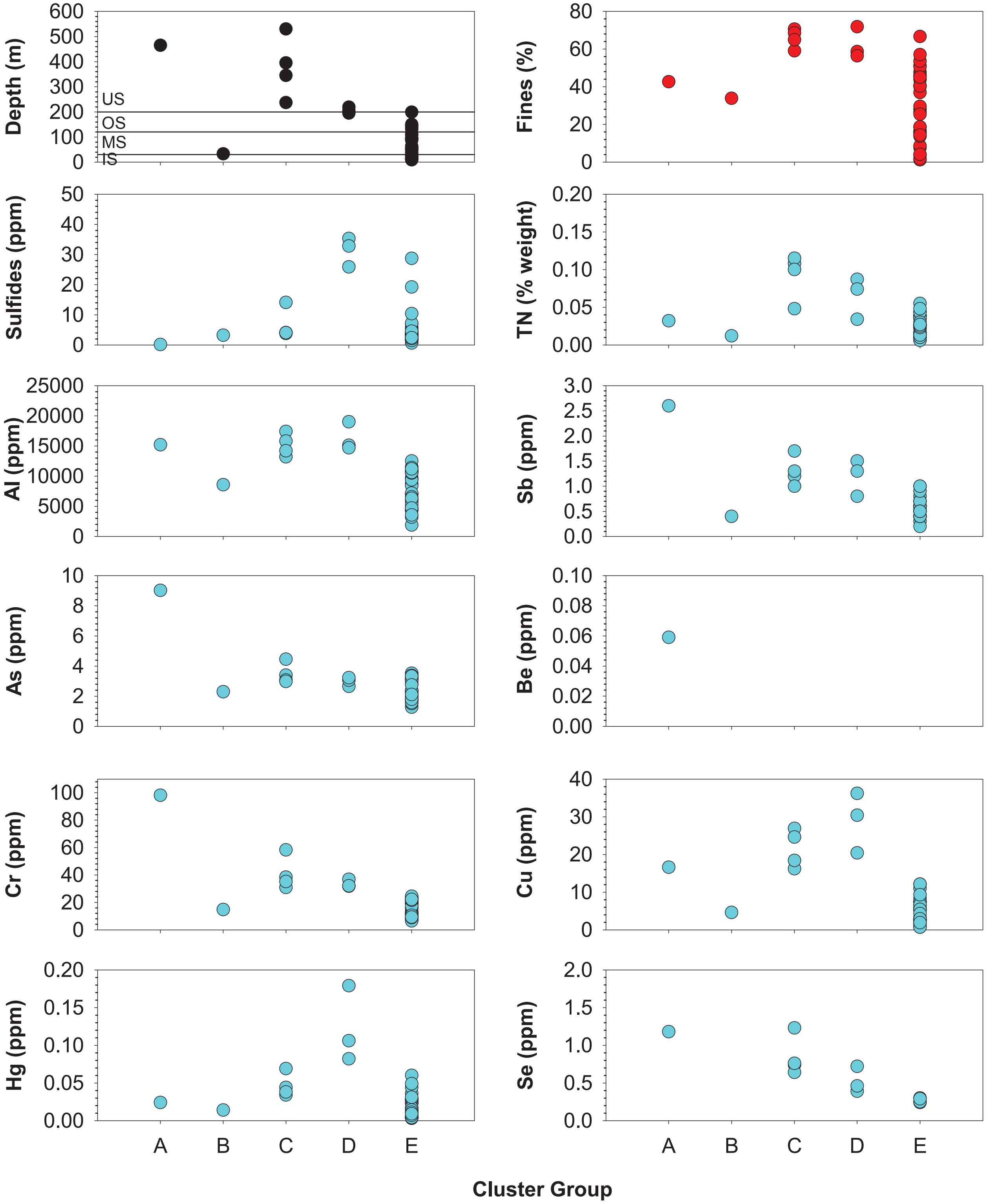


Figure 8.7
Depth, percent fines, and select sediment chemistry parameters that contributed to sediment chemistry cluster group dissimilarities. Each data point represents a single sample. IS=inner shelf, MS=mid-shelf, OS=outer shelf; US=upper slope.

regional survey that could be attributed to local wastewater discharges. Instead, concentrations of total nitrogen, total volatile solids and several trace metals were found to increase with increasing amounts of fine sediments (percent fines). Percent fines increased with depth in the

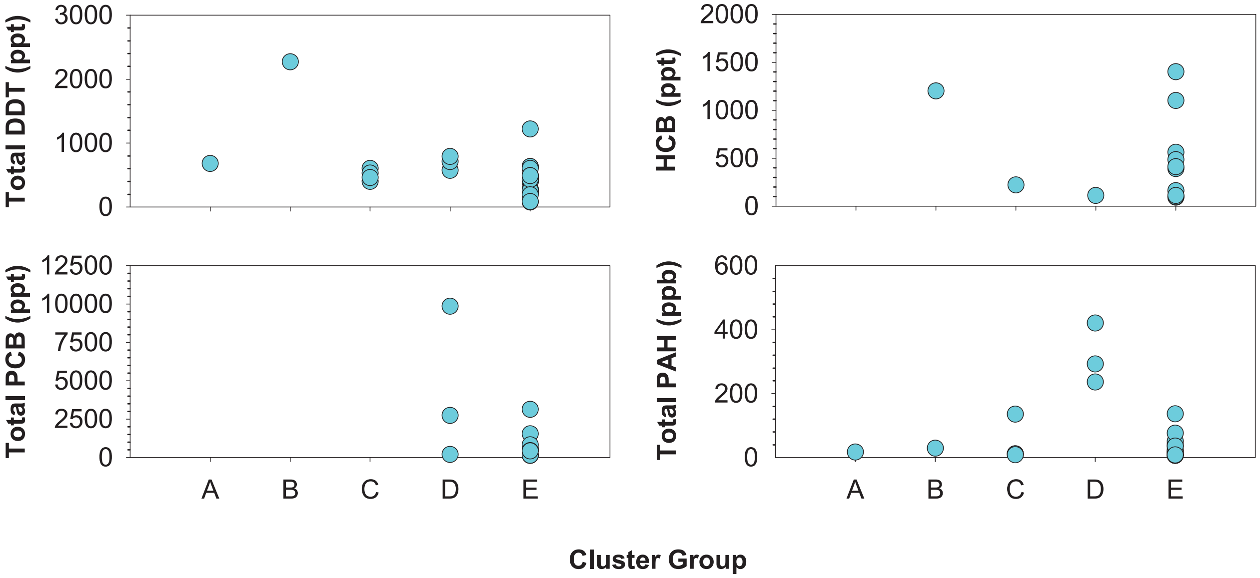


Figure 8.7 *continued*

region, and subsequently many contaminants were detected at higher concentrations in deeper strata compared to the shallow and mid-shelf regions. For example, the highest concentrations of most contaminants occurred in sediments along the upper slope, where some of the finest sediments were measured. This association is expected due to the known correlation between sediment size and concentration of organics and trace metals (Eganhouse and Venkatesan 1993). Finally, concentrations of these contaminants remained relatively low compared to many other coastal areas located off southern California (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, City of San Diego 2007, Maruya and Schiff 2009, Dodder et al. 2016).

LITERATURE CITED

Anderson, J. and R. Gossett. (1987). Polynuclear aromatic hydrocarbon contamination in sediments from coastal waters of southern California. Southern California Coastal Water Research Project, Technical Report No. 199. Long Beach, CA.

Bay, S. and K. Schiff. (1997). Impacts of stormwater discharges on the nearshore environment of Santa Monica Bay. In: S. Weisberg, C. Francisco, and D. Hallock (eds.). Southern California Coastal Water Research Project, Annual Report 1995–1996. Westminster, CA. p 105–118.

Bergen, M. (1996). The Southern California Bight Pilot Project: Sampling Design, In: M.J. Allen, C. Francisco, D. Hallock (eds.). Southern California Coastal Water Research Project: Annual Report 1994–1995. Southern California Coastal Water Research Project, Westminster, CA.

[Bight'13 CIA] Bight'13 Contaminant Impact Assessment Committee. (2013). Contaminant Impact Assessment Workplan. Southern California Coastal Water Research Project, Costa Mesa, CA.

City of Los Angeles. (2014). Santa Monica Bay Biennial Assessment Report 2012–2013. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

City of Los Angeles. (2015). Los Angeles Harbor Biennial Assessment Report 2014–2015. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

City of San Diego. (2007). Appendix E. Benthic Sediments and Organisms. In: Application for renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego,

City of San Diego. (2015a). Point Loma Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015b). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2016). 2015 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R., R.N. Gorley, P.J. Somerfield, and R.M. Warwick. (2014). Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER E, Plymouth, England.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Conover, W.J. (1980). Practical Nonparametric Statistics, 2nd ed. John Wiley & Sons, Inc., New York, NY.

Cross, J.N. and L.G. Allen. (1993). Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.).

Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Dodder, N., K. Schiff, A. Latker, C-L Tang. (2016). Southern California Bight 2013 Regional Monitoring Program: IV. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Eganhouse, R.P. and M.I. Venkatesan. (1993). Chemical Oceanography and Geochemistry. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 1–189.

Emery, K. O. (1960). The Sea Off Southern California. John Wiley, New York, NY.

Finney, B. and C. Huh. (1989). High resolution sedimentary records of heavy metals from the Santa Monica and San Pedro Basins, California. Marine Pollution Bulletin, 20(4): 181–187.

Folk, R.L. (1980). Petrology of Sedimentary Rocks. Hemphill, Austin, TX.

Gray, J.S. (1981). The Ecology of Marine Sediments: An Introduction to the Structure and Function of Benthic Communities. Cambridge University Press, Cambridge, England.

Helsel, D.R. (2005). Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc., Hoboken, NJ.

[LACSD] Los Angeles County Sanitation Districts. (2014). Joint Water Pollution Control Plant Biennial Receiving Water Monitoring Report 2012–2013. Whittier, CA. Los Angeles County Sanitation Districts, Ocean Monitoring and Research Group, Technical Services Department.

Long, E.R., D.L. MacDonald, S.L. Smith, and F.D. Calder. (1995). Incidence of adverse biological effects within ranges of chemical concentration in marine and estuarine sediments. Environmental Management, 19(1): 81–97.

Maruya, K.A. and K. Schiff. (2009). The extent and magnitude of sediment contamination in the Southern California Bight. Geological Society of America Special Paper, 454: 399–412.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2002). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

[OCSD] Orange County Sanitation District. (2015). Ocean Monitoring Annual Report, Year 2013–2014. Marine Monitoring, Fountain Valley, California.

Patsch, K. and G. Griggs. (2007). Development of Sand Budgets for California's Major Littoral Cells. Institute of Marine Sciences, University of California, Santa Cruz, CA.

R Core Team. (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: Volume III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., R. Gossett, K. Ritter, L. Tiefenthaler, N. Dodder, W. Lao, and K. Maruya. (2011). Southern California Bight 2008 Regional Monitoring Program: III. Sediment Chemistry. Southern California Coastal Water Research Project, Costa Mesa, CA.

Snelgrove, P.V.R. and C.A. Butman. (1994). Animal-sediment relationships revisited: cause versus effect. Oceanography and Marine Biology Annual Review, 32: 111–177.

Stebbins, T.D., K.C. Schiff, and K. Ritter. (2004). San Diego Sediment Mapping Study: Workplan for Generating Scientifically Defensible Maps of Sediment Conditions in the San Diego Region. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Southern California Coastal Water Research Project, Westminster, CA.

Stein, E.D. and D.B. Cadien. (2009). Ecosystem response to regulatory and management actions: The Southern California experience in long-term monitoring. In: K. Schiff (ed.). Southern California Coastal Water Research Project Annual Report 2009. Southern California Coastal Water Research Project, Costa Mesa, CA.

Stevens Jr., D.L. (1997). Variable density grid-based sampling designs for continuous spatial populations. Environmetrics, 8: 167–195.

Stevens Jr., D.L. and A.R. Olsen. (2004). Spatially-balanced sampling of natural resources in the presence of frame imperfections. Journal of the American Statistical Association, 99: 262–278.

Stull, J.K. (1995). Two decades of marine biological monitoring, Palos Verdes, California, 1972 to 1992. Bulletin of the Southern California Academy of Sciences, 94(1): 21–45.

Swartz, R.C., F.A. Cole, D.W. Schults, and W.A. DeBen. (1986). Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series, 31: 1–13.

Thompson, B.E., J. Dixon, S. Schroeter, and D.J. Reish. (1993). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 369–458.

[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection, Washington, DC.

Wickham, H. (2007). Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL http://www.jstatsoft.org/v21/i12/.

Wickham, H. (2011). The Split-Apply-Combine Strategy for Data Analysis. Journal of Statistical Software, 40(1), 1-29. URL http://www.jstatsoft.org/v40/i01/.

Zeileis, A and G. Grothendieck. (2005). zoo: S3 Infrastructure for Regular and Irregular Time Series. Journal of Statistical Software, 14(6), 1-27. URL http://www.jstatsoft.org/v14/i06/

Chapter 9
San Diego Regional Survey
Macrobenthic Communities

Chapter 9. San Diego Regional Survey Macrobenthic Communities

INTRODUCTION

Macrobenthic invertebrates (macrofauna) fulfill essential roles as nutrient recyclers and bioeroders in marine ecosystems throughout the world (Fauchald and Jones 1979, Thompson et al. 1993, Snelgrove et al. 1997). Additionally, many serve as reliable indicators of pollution or other environmental stressors by either increasing or decreasing population abundances in proportion to degree of stress (Linton and Taghon 2000, Kennedy et al. 2009, McLeod and Wing 2009). For this reason, macrofauna have been sampled extensively around Southern California Bight (SCB) ocean outfalls and other point sources at small spatial scales for the past several decades in order to detect potential changes to the environment due to wastewater discharge (Stull et al. 1986, 1996, Swartz et al. 1986, Ferraro et al. 1994, Zmarzly et al. 1994, Diener and Fuller 1995, Diener et al. 1995, Stull 1995, Stein and Cadien 2009). Examples of such local assessments include the regular ongoing surveys conducted each year around the ocean outfalls operated by the four largest wastewater dischargers in the region: the City of Los Angeles, the City of San Diego, the Los Angeles County Sanitation District, and the Orange County Sanitation District (e.g., City of Los Angeles 2014, 2015, LACSD 2014, City of San Diego 2015b, c, OCSD 2015). However, because the structure of macrobenthic communities is known to be influenced by numerous natural factors (see Chapter 5) such as depth gradients and/or sediment particle size (Bergen et al. 2001), understanding natural regional variability in their populations across the SCB is essential in order to place data from localized surveys into a broader biogeographic context. Thus, larger-scale regional monitoring efforts have also become an important tool for evaluating benthic conditions and sediment quality in southern California (Bergen et al. 1998, 2000, Schiff and Gossett 1998, Noblet et al. 2002, Hyland et al. 2003, Ranasinghe et al. 2003, 2007, 2012, USEPA 2004, Schiff et al. 2006, 2011, Bight'13 CIA 2013, Dodder et al. 2016).

The City of San Diego has also conducted annual regional benthic surveys off the coast of San Diego since 1994 (see Chapter 1). The primary objectives of these summer surveys, which typically range from offshore of Del Mar in northern San Diego County southward to the USA/Mexico border, are to: (1) describe the overall condition and quality of the diverse benthic habitats that occur in the coastal waters off San Diego; (2) characterize the ecological health of the soft-bottom marine benthos in the region; (3) gain a better understanding of regional variation in order to distinguish anthropogenically-driven changes from natural fluctuations. These surveys typically occur at an array of 40 stations selected each year using a probability-based, random stratified sampling design as described in Bergen (1996), Stevens (1997), and Stevens and Olsen (2004). During 1995–1997, 1999–2002 and 2005–2007, the surveys off San Diego were restricted to continental shelf depths (<200 m); however, the area of coverage was expanded beginning in 2009 to include deeper habitats along the upper slope (200–500 m). No survey of randomly selected sites was conducted in 2004 due to sampling for a special sediment mapping project (Stebbins et al. 2004), while the surveys in 1994, 1998, 2003, 2008, and 2013 were conducted as part of larger, multi-agency surveys of the entire SCB (Bergen et al. 1998, 2001, Ranasinghe et al. 2003, 2007, 2010, 2012, Bight'13 CIA 2013, Dodder et al. 2016).

This chapter presents analysis and interpretation of the benthic macrofaunal data collected during the 2015 regional survey of the continental shelf and upper slope off San Diego. Included are analyses of benthic community structure for the region, as well as multivariate analysis of benthic macrofaunal data collected during the year. Results of benthic sediment quality analyses for these same sites are presented in Chapter 8.

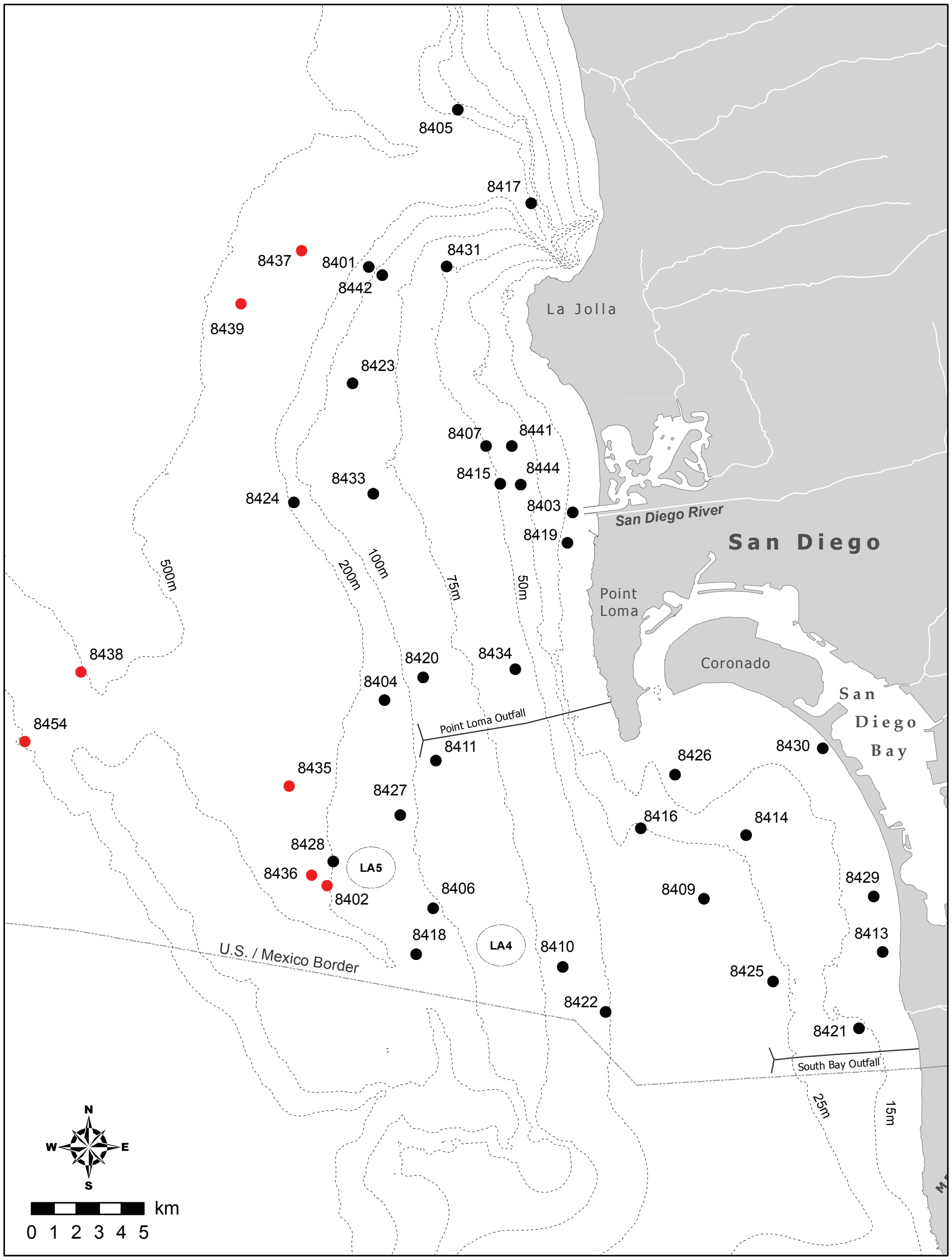


Figure 9.1
Randomly generated regional benthic survey stations sampled during July 2015 as part of the City of San Diego's Ocean Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

MATERIALS AND METHODS

Collection and Processing of Samples

The July 2015 regional survey covered an area ranging north of La Jolla southward to the USA/Mexico border (Figure 9.1). A total of 40 stations were sampled at depths ranging from 9 to 530 m spanning four distinct depth strata characterized by the SCB regional monitoring programs (Ranasinghe et al. 2012). These included 10 stations along the inner shelf (5–30 m), 16 stations along the mid-shelf (>30–120 m), seven stations along the outer shelf (>120–200 m), and seven stations on the upper slope (>200–530 m). Samples for benthic community analysis were collected from one side of a double 0.1-m^2 Van Veen grab, while samples from the adjacent grab were used for sediment quality analyses (see Chapter 8). Criteria established by the U.S. Environmental Protection Agency (USEPA) to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were brought aboard ship, washed with seawater, and sieved through a 1.0-mm mesh screen. The organisms retained on the screen were then collected, transferred to sample jars, and relaxed for 30 minutes in a magnesium sulfate solution before being fixed with buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol for final preservation. All macrofaunal organisms were separated from the raw material and sorted into five higher taxonomic groups (e.g., Annelida, Arthropoda, Mollusca, Echinodermata, and miscellaneous phyla) by a subcontract lab, after which they were identified to species (or the lowest taxon possible) and enumerated by City marine biologists. All identifications followed nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (e.g., SCAMIT 2014).

Data Analyses

The following community structure parameters were determined for each station per 0.1-m^2 grab: species richness (number of taxa), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (see Swartz et al. 1986, Ferraro et al. 1994), and benthic response index (BRI; see Smith et al. 2001). Unless otherwise noted, analyses were performed using R (R Core Team 2015) and various functions within the reshape2, Rmisc, RODBC, and vegan packages (Wickham 2007, Hope 2013, Oksanen et al. 2015, Ripley and Lapsley 2015).

To examine spatial patterns among benthic communities in the San Diego region, multivariate analyses were performed using methods available in PRIMER v7 software, which included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (see Clarke et al. 2008, 2014). The Bray-Curtis measure of similarity was used as the basis for clustering, and the macrofaunal abundance data were square-root transformed to lessen the influence of overly abundant species and increase the importance (or presence) of rare species. Major ecologically-relevant clusters receiving SIMPROF support were retained, and similarity percentages analysis (SIMPER) was used to determine which species were responsible for the greatest contributions to within-group similarity (i.e., characteristic species) and between-group dissimilarity for retained clusters. To determine whether macrofaunal communities varied by sediment particle size fractions, a RELATE test was used to compare patterns of rank abundance in the macrofauna Bray-Curtis similarity matrix with rank percentages in the sediment Euclidean distance matrix (see Chapter 8). A BEST test using the BIO-ENV procedure was conducted to determine which subset of sediment sub-fractions was the best explanatory variable for similarity between the two resemblance matrices.

RESULTS AND DISCUSSION

Community Parameters

Species richness

A total of 654 taxa were identified during the 2015 regional survey, similar to previous studies. For example, total species richness for the region has ranged from 607 to 728 taxa over the past five years (City of San Diego 2011–2015c). Of the taxa identified during 2015, 532 (81%) were identified to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although 35% (n = 228) were recorded only once. Five taxa not previously reported by the City's Ocean Monitoring Program were encountered during this survey. These included the gastropod *Lirobittium paganicum*, the cumacean *Petalosarsia* sp A, the eusirid amphipod *Rhachotropis* sp SD1, and the nemerteans Hoplonemertea sp HYP1 and Lineidae sp SD1.

Table 9.1

Macrofaunal community parameters calculated for the randomly selected regional benthic stations sampled off San Diego during 2015. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = Pielou's evenness; Dom = Swartz dominance; BRI = benthic response index; n = 1 grab per stations.

	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI[a]
Inner Shelf	8430	9	37	103	3.1	0.86	16	20
	8413	10	26	84	2.5	0.77	8	9
	8403	13	51	167	3.4	0.86	19	5
	8419	13	48	145	3.2	0.82	15	9
	8426	14	51	244	2.9	0.74	13	9
	8429	14	18	74	1.6	0.55	4	15
	8421	17	49	409	2.5	0.64	7	25
	8414	23	106	477	3.7	0.80	30	26
	8416	25	85	1420	1.3	0.30	1	23
	8425	27	77	805	1.9	0.43	4	24
Mid-shelf	8409	33	165	1334	3.1	0.61	23	26
	8444	37	87	297	3.7	0.84	29	21
	8441	39	106	315	4.1	0.87	40	21
	8415	49	107	375	4.0	0.86	30	19
	8422	51	68	287	3.5	0.84	19	11
	8407	52	94	333	3.9	0.87	32	17
	8431	54	128	475	4.2	0.87	42	18
	8434	61	66	188	3.2	0.75	23	9
	8410	63	104	432	3.9	0.84	28	12
	8433	87	60	192	3.1	0.77	20	5
	8411	92	77	290	3.7	0.86	24	17
	8420	92	75	289	3.6	0.83	21	8
	8423	93	61	157	3.6	0.87	25	6
	8442	96	51	138	3.5	0.90	21	6
	8406	108	77	177	4.1	0.94	36	13
	8427	112	84	223	4.0	0.91	36	6
Outer Shelf	8424	131	97	396	3.9	0.84	29	11
	8418	137	52	85	3.8	0.95	31	7
	8404	144	81	278	3.8	0.87	29	21
	8401	146	91	280	3.9	0.88	35	17
	8405	150	88	307	3.8	0.84	29	16
	8428	195	59	107	3.9	0.95	33	14
	8417	199	67	414	2.9	0.68	12	28
Upper Slope	8402	205	88	165	4.3	0.96	47	—
	8436	219	44	82	3.5	0.93	24	—
	8435	237	44	100	3.5	0.93	20	—
	8437	345	35	72	3.3	0.93	18	—
	8439	395	33	81	3.1	0.90	14	—
	8454	465	40	172	2.9	0.78	11	—
	8438	530	21	30	2.9	0.95	14	—

[a] BRI statistic not calculated for upper slope stations.

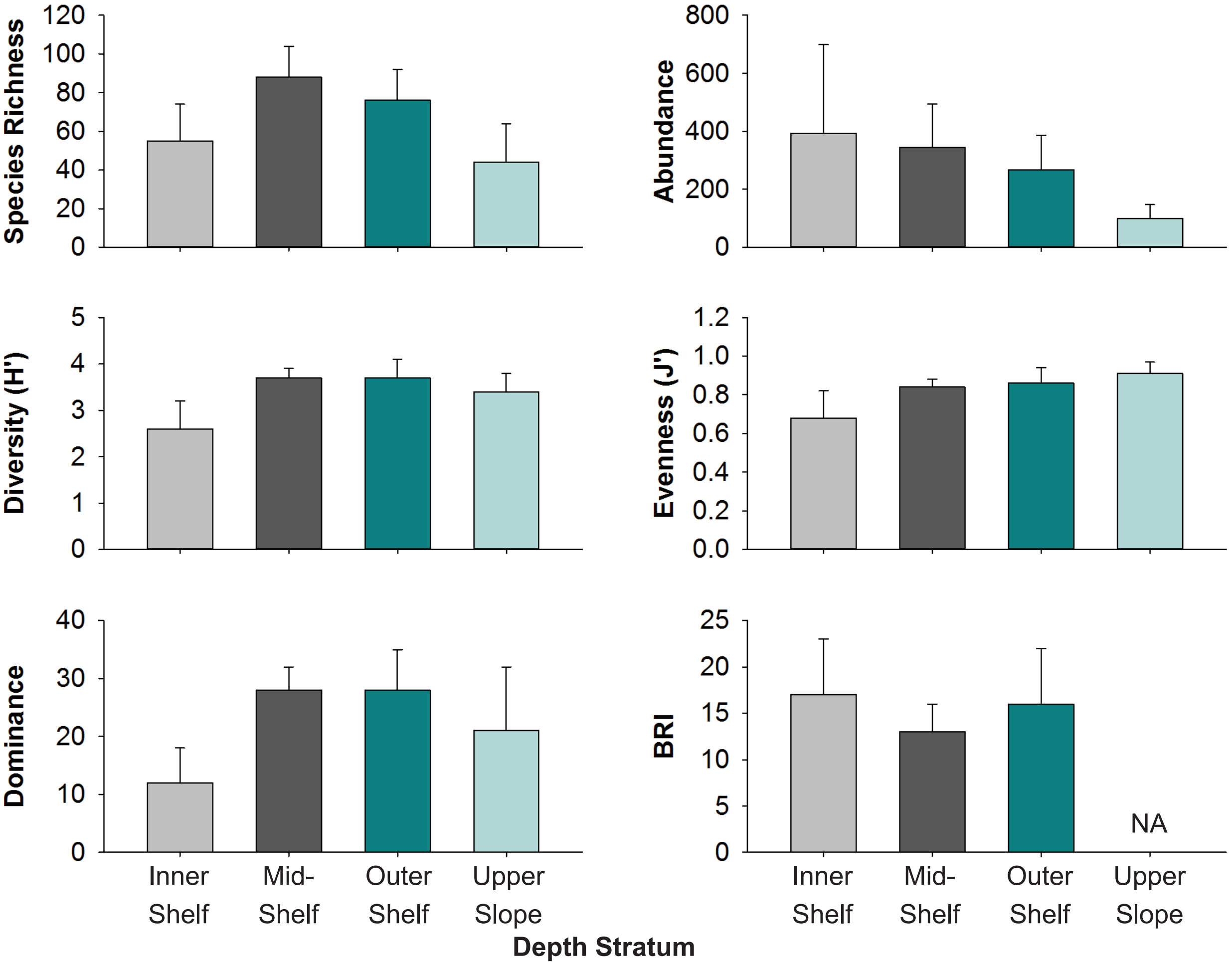


Figure 9.2

Comparison of macrofaunal community structure metrics for the four major depth strata sampled during the 2015 regional survey off San Diego. Data are expressed as means +95% confidence intervals per stratum; NA=not applicable, BRI not calculated for upper slope stations.

Species richness ranged from 18 to 165 taxa per grab across the survey area in 2015 (Table 9.1). Such a wide variation in species richness is common for the region and is consistent with values observed during previous regional surveys (City of San Diego 2015a, c). Species richness also varied between the major depth strata during this survey (Figure 9.2). For example, species richness was highest along the mid-shelf averaging 88 taxa per grab, followed by 76 taxa per grab on the outer shelf, and 55 taxa per grab on the inner shelf. The lowest species richness (44 taxa per grab) occurred at the deeper upper slope stations. This variation by depth strata corresponds with what has been reported previously for the region (City of San Diego 2015a, c).

Macrofaunal abundance

A total of 11,999 macrofaunal invertebrates were recorded during the 2015 regional survey. Abundance ranged from 30 to 1420 individuals per grab (Table 9.1), remaining within the range of values reported historically for the region (City of San Diego 2015a, c). Stations 8409, 8416, and 8425 had the largest numbers of organisms (≥805 individuals per grab). These stations were located south of the tip of Point Loma and north of the SBOO at depths between 25 and 33 m (see Figure 9.1), and each was numerically dominated by the spionid polychaete *Spiophanes norrisi* (n=1120 at station 8416, n=592 at station 8409, n=544 at station 8425). As with species richness, macrofaunal abundance varied between depth strata with the lowest average values of 100 individuals per grab occurring on the upper slope (Figure 9.2). In contrast, abundance averaged 393 individuals per grab at the inner shelf stations, 344 individuals per grab at the mid-shelf stations, and 267 individuals per grab at the outer shelf stations. This variation between strata generally corresponds with what has been reported previously for the San Diego region (City of San Diego 2015a, c).

Diversity and evenness

Shannon diversity index (H') values generally fell within historical values (City of San Diego 2015a, c), ranging from 1.3 to 4.3 at the regional stations in 2015 (Table 9.1). Further, 68% of the stations sampled in 2015 had H' values of 3.0–4.0. Diversity values ≤2.9 occurred at six inner shelf stations (i.e., 8413, 8416, 8421, 8425, 8426, 8429), one outer shelf station (8417), and two upper slope stations (i.e., 8438, 8454). Sites with H' >4.0 occurred on the mid-shelf at stations 8406, 8431, and 8441 and on the upper slope at station 8402. Historically, the lowest diversity values have been observed either on the upper slope or inner shelf (City of San Diego 2012, 2013, 2015c), similar to what was observed during 2015 (Figure 9.2).

Pielou's evenness (J') often complements diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed and that an assemblage is not dominated by a few abundant species. During 2015, J' values ranged from 0.30 to 0.96 at the regional stations (Table 9.1) with mean evenness highest on the upper slope (Figure 9.2). All J' values observed during 2015 were within historical ranges (City of San Diego 2015a, c).

Dominance

Dominance was expressed as the Swartz dominance index, which is calculated as the minimum number of taxa whose combined abundance accounts for 75% of the individuals in a sample. Therefore, lower index values reflect fewer species and indicate higher numerical dominance. Dominance values at regional shelf stations ranged from 1 to 42 taxa per grab, while values at upper slope stations ranged from 11 to 47 taxa per grab. Overall, these values fell within historical ranges (City of San Diego 2015a, c). The pattern of dominance across depth strata was generally similar between the 2015 and other recent regional surveys (Figure 9.2) (City of San Diego 2013, 2015c). For example, average dominance was higher (i.e., lower index values) along the inner shelf (12 taxa per grab) and the upper slope (21 taxa per grab) than at either the mid- or outer shelf stations (28 taxa per grab each).

Benthic response index (BRI)

The benthic response index (BRI) is an important tool for gauging anthropogenic impacts to coastal seafloor habitats throughout southern California that was originally calibrated for depths from 5 to 324 m (Smith et al. 2001). Index values below 25 are considered indicative of reference conditions, scores between 25 and 34 indicate minor deviations from reference conditions, and values above 34 represent increasing levels of disturbance or environmental degradation. During 2015, BRI ranged from 5 to 28 at the regional shelf stations (Table 9.1). Overall, 88% of these BRI values were indicative of reference conditions and 100% of the values fell within historical ranges (City of San Diego 2015a, c). Stations 8409, 8414, and 8421 had slightly higher BRI values of 25 and 26. These stations were located at relatively shallow depths ≤ 33 m where the BRI can be less reliable (Ranasinghe et al. 2010). Additionally, station 8417, located just at the outer shelf break at a depth of 199 m, had a BRI value of 28. Average BRI values varied slightly between the major depth strata, ranging from 13 per grab at mid-shelf stations to 17 per grab on the inner shelf (Figure 9.2). Index values were not calculated for the seven upper slope stations since there has been no calibration of the BRI for sites greater than 324 m depth (Ranasinghe et al. 2010).

Species of Interest

Dominant taxa

Macrofaunal communities in the San Diego region were generally dominated by polychaete worms (phylum Annelida) in 2015, although proportions of the various taxa varied between the four major depth strata (Figure 9.3). Polychaetes were the most diverse of the major taxa over all strata, accounting for 44% of all species collected. Arthropods (mostly crustaceans) and molluscs were the next two most diverse taxa, accounting for 24% and 18% of species, respectively. Echinoderms

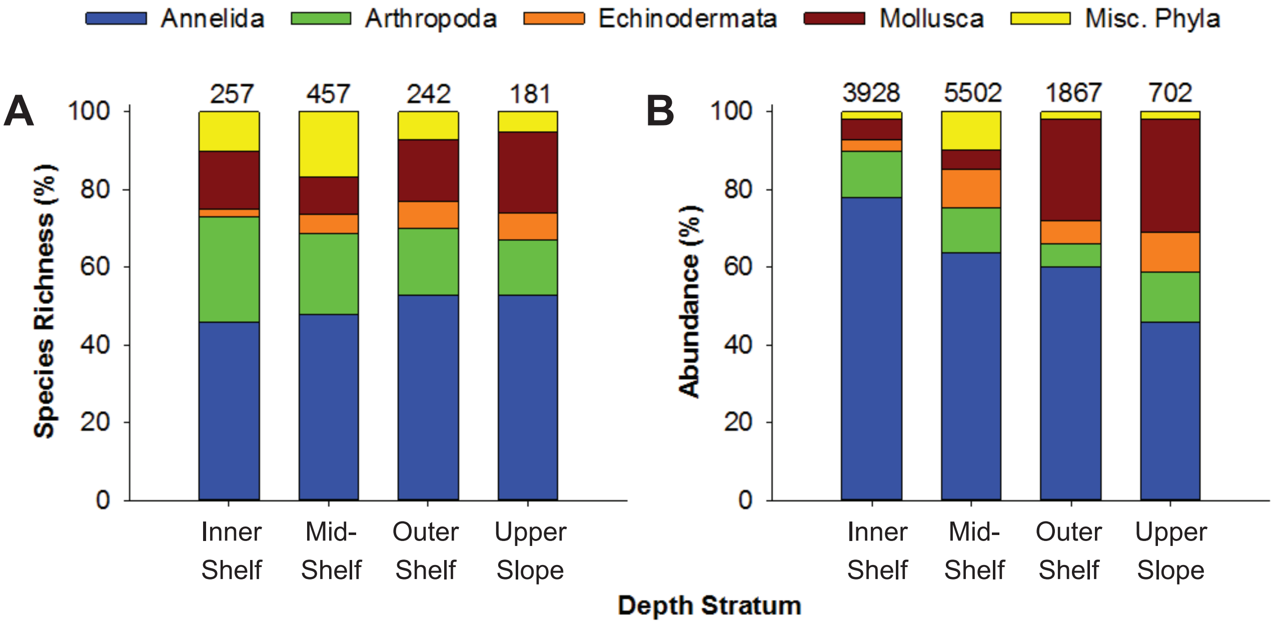


Figure 9.3
Percent contribution of major taxonomic groups (phyla) to (A) species richness and (B) abundance by depth stratum at all stations sampled during the 2015 regional survey off San Diego. Numbers above bars represent (A) total number of taxa and (B) total number of individual organisms enumerated for each stratum.

comprised 5% of all taxa, while all other phyla combined (e.g., Chordata, Cnidaria, Echiura, Nematoda, Nemertea, Phoronida, Platyhelminthes, Sipuncula) accounted for the remaining 9%. A few patterns were apparent in the proportions of the major taxa comprising the different assemblages (see Figure 9.3A). For example, the percentage of polychaetes increased across the continental shelf from 46% along the inner shelf, to 48% along the mid-shelf, to 53% along the outer shelf and upper slope. Echinoderms also increased slightly across these depths (i.e., from 2 to 7%), while the proportions of crustaceans decreased from 27 to 14%. These patterns were generally similar to those observed in previous regional surveys (City of San Diego 2011–2015a, c).

Polychaetes were also the most numerous invertebrates overall, accounting for 67% of the total abundance. Crustaceans accounted for 11% of the organisms, echinoderms 7%, molluscs 12%, and the remaining phyla 3%. Abundance patterns also varied between strata (see Figure 9.3B). For example, the proportion of polychaete abundance decreased across the shelf as species richness increased, ranging from 78% on the inner shelf, to 64% on the mid-shelf, to 60% on the outer shelf, to 46% on the upper slope. In contrast, mollusc proportions increased from 5% on the inner and mid-shelf, to 26% on the outer shelf, to 29% on the upper slope. The proportion of arthropods was lowest on the outer shelf (6%) and highest on the upper slope (13%), while echinoderms were lowest on the inner and outer shelf (3 and 6%, respectively) and highest on the mid-shelf and upper slope (both 10%). Other miscellaneous phyla comprised 2% of the total abundance at inner, outer and upper slope stations, and 10% of the total abundance at mid-shelf stations.

As expected, the numerically dominant species characteristic of the benthic assemblages off San Diego also varied between strata (Table 9.2). For example, the top 10 most abundant species along the inner shelf included six polychaetes, two crustaceans, one bivalve, and one echinoderm. Of these, the spionid polychaete *Spiophanes norrisi* was clearly dominant, accounting for 49% of all animals collected on the inner shelf, and averaging 192 animals per grab. The remaining inner shelf species accounted for ≤8% of the total abundance and averaged ≤33 animals per occurrence. *Spiophanes duplex* was the most widely distributed inner shelf species, occurring at all 10 of the sites.

Table 9.2

The 10 most abundant macroinvertebrate taxa per depth stratum collected at regional benthic stations sampled off San Diego during 2015. PA = percent abundance; FO = frequency occurrence; M/G = mean abundance per grab; M/O = mean abundance per occurrence.

Strata	Species	Taxonomic Classification	PA	FO	M/G	M/O
Inner Shelf	*Spiophanes norrisi*	Polychaeta: Spionidae	49	90	192	213
	Spiophanes duplex	Polychaeta: Spionidae	8	100	33	33
	Mediomastus sp	Polychaeta: Capitellidae	3	60	12	19
	Dendraster excentricus	Echinodermata: Echinoidea	3	60	10	17
	Diastylopsis tenuis	Arthropoda: Cumacea	2	70	6	9
	Tellina modesta	Mollusca: Bivalvia	1	70	5	7
	Monticellina siblina	Polychaeta: Cirratulidae	1	40	4	10
	Apoprionospio pygmaea	Polychaeta: Spionidae	1	60	4	6
	Ampharete labrops	Polychaeta: Ampharetidae	1	40	3	8
	Rhepoxynius menziesi	Arthropoda: Amphipoda	1	80	3	4
Mid-shelf	*Spiophanes norrisi*	Polychaeta: Spionidae	12	56	42	75
	Amphiodia urtica	Echinodermata: Ophiuroidea	6	62	20	32
	Euclymeninae	Polychaeta: Maldanidae	2	44	8	18
	Prionospio (Prionospio) dubia	Polychaeta: Spionidae	2	88	7	8
	Euchone incolor	Polychaeta: Sabellidae	2	31	7	22
	Spiophanes duplex	Polychaeta: Spionidae	2	56	6	11
	Sternaspis affinis	Polychaeta: Sternaspidae	2	81	6	7
	Praxillella pacifica	Polychaeta: Maldanidae	2	62	6	9
	Nuculana sp A	Mollusca: Bivalvia	1	50	5	10
	Sthenelanella uniformis	Polychaeta: Sigalionidae	1	38	5	13
Outer Shelf	*Axinopsida serricata*	Mollusca: Bivalvia	8	100	22	22
	Phyllochaetopterus limicolus	Polychaeta: Chaetopteridae	8	43	22	51
	Tellina carpenteri	Mollusca: Bivalvia	6	100	15	15
	Nuculana sp A	Mollusca: Bivalvia	4	86	10	11
	Euclymeninae	Polychaeta: Maldanidae	4	57	10	17
	Fauveliopsis sp SD1	Polychaeta: Fauveliopsidae	3	14	8	54
	Petaloclymene pacifica	Polychaeta: Maldanidae	3	57	7	13
	Mediomastus sp	Polychaeta: Capitellidae	2	100	5	5
	Monticellina siblina	Polychaeta: Cirratulidae	2	71	5	7
	Spiophanes kimballi	Polychaeta: Spionidae	2	71	4	6
Upper Slope	*Euphilomedes* sp	Arthropoda: Ostracoda	5	14	5	38
	Huxleyia munita	Mollusca: Bivalvia	5	14	5	32
	Adontorhina cyclia	Mollusca: Bivalvia	4	86	4	5
	Fauveliopsis glabra	Polychaeta: Fauveliopsidae	3	43	3	7
	Praxillella pacifica	Polychaeta: Maldanidae	3	57	3	5
	Tellina carpenteri	Mollusca: Bivalvia	3	71	3	4
	Amphiuridae	Echinodermata: Ophiuroidea	3	57	3	4
	Maldane sarsi	Polychaeta: Maldanidae	2	71	2	3
	Chloeia pinnata	Polychaeta: Amphinomidae	2	43	2	5
	Yoldiella nana	Mollusca: Bivalvia	2	43	2	4

The top 10 dominant taxa along the mid-shelf included eight polychaetes, one ophiuroid, and one bivalve. As on the inner shelf, *Spiophanes norrisi* was the dominant taxon, although it accounted for just 12% of the total abundance and occurred at only 56% of these stations. The brittle star *Amphiodia urtica* was also common at these depths, accounting for 6% of the total abundance, averaging about 32 animals per occurrence at 62% of the sites. All other species accounted for ≤2% of the total abundance and averaged ≤22 animals per occurrence, although some were found at up to 88% of the mid-shelf stations (e.g., the spionid *Prionospio (Prionospio) dubia*).

The top 10 species along the outer shelf included seven polychaetes and three bivalves. Densities of these species were relatively low overall with none exceeding 8% of the total abundance. The bivalves *Axinopsida serricata* and *Tellina carpenteri*, as well as the capitellid polychaete *Mediomastus* sp, occurred at all seven outer shelf stations, and averaged 22, 15, and 5 individuals per grab, respectively. The bivalve *Nuculana* sp A occurred at 86% of the stations and averaged 10 individuals per grab, while the spionid polychaete *Spiophanes kimballi* and the cirratulid polychaete *Monticellina siblina* each occurred at 71% of the stations with averages of 4–5 individuals per grab. All other species at these depths occurred at ≤57% of the outer shelf stations and averaged ≤22 individuals per grab.

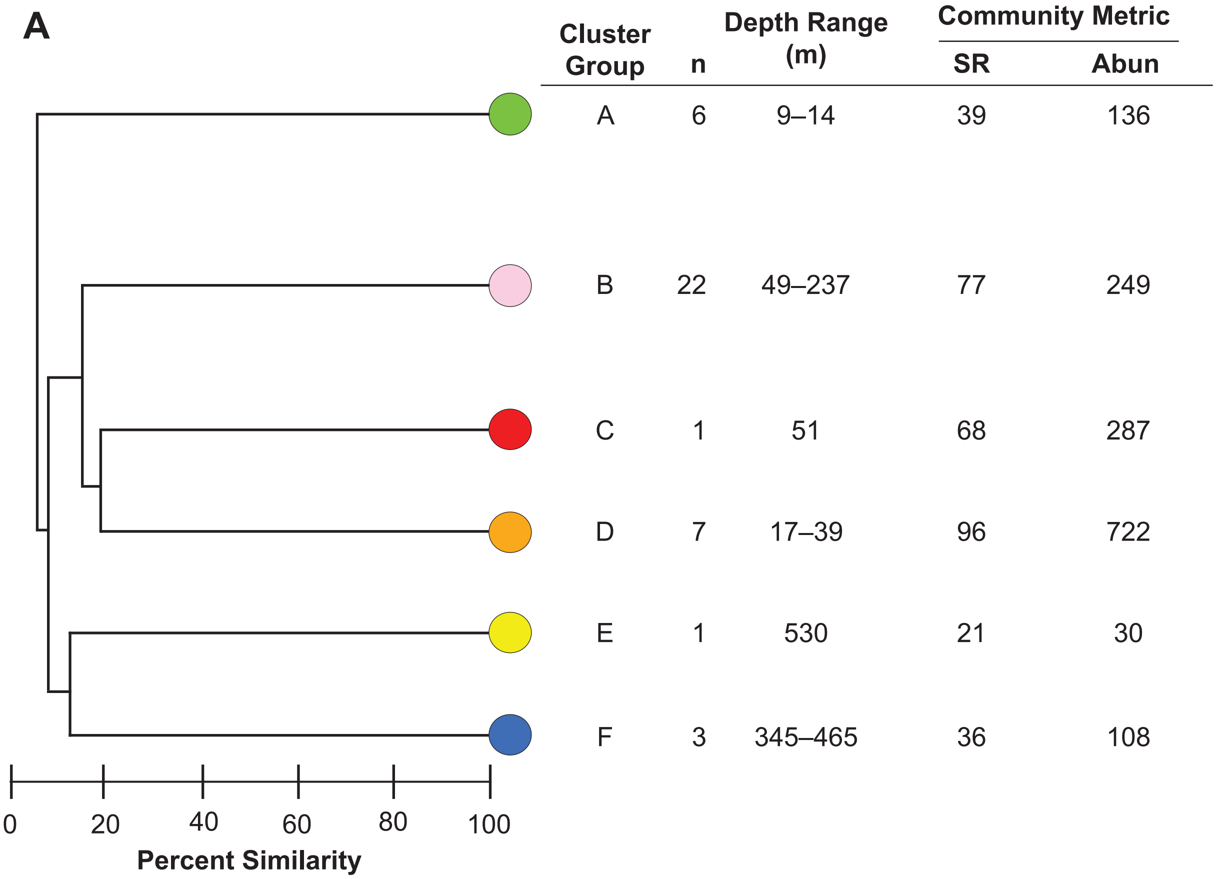
The 10 most abundant species at upper slope depths included four polychaetes, four bivalves, one ostracod and one ophiuroid. As along the outer shelf, densities at these depths were relatively low (≤5% of the total abundance). The ostracod *Euphilomedes* sp was the most abundant species on the upper slope with 38 animals per occurrence, although it occurred at only one station. The bivalve *Huxleyia munita* also had relatively high numbers (32 animals) at a single station. In contrast, the bivalves *Adontorhina cyclia* and *Tellina carpenteri*, as well as the maldanid polychaete *Maldane sarsi*, each occurred at ≥71% of the upper slope stations, but at abundances of ≤5 individuals per occurrence.

Indicator Species

Species known to be indicators of environmental change that occur in the San Diego region include the capitellid polychaete *Capitella teleta* (considered within the *Capitella capitata* species complex), the terebellid polychaete *Proclea* sp A, amphipods in the genera *Ampelisca* and *Rhepoxynius*, the bivalve *Solemya pervernicosa*, and the ophiuroid *Amphiodia urtica*. Increased abundances of *C. teleta* and *S. pervernicosa* often indicate organic enrichment, whereas decreases in numbers of pollution-sensitive species and genera such as *Proclea* sp A, *A. urtica*, *Ampelisca*, and *Rhepoxynius* may indicate habitats impacted by human activity (Barnard and Ziesenhenne 1961, Anderson et al. 1998, Linton and Taghon 2000, Smith et al. 2001, Kennedy et al. 2009, McLeod and Wing 2009). During the 2015 regional survey, abundances of pollution-sensitive indicator taxa including *Amphiodia urtica*, *Ampelisca* spp, and *Rhepoxynius* spp all were within expected natural ranges for the SCB (Smith et al. 2001), and indicate a high level of ecosystem health in shelf regions off San Diego. Additionally, abundances of *C. teleta* and *S. pervernicosa* remained low, with only three individuals of *C. teleta* and 21 individuals of *S. pervernicosa* found across the entire region.

Classification of Regional Macrobenthic Shelf and Slope Assemblages

Classification (cluster) analysis was used to discriminate between macrofaunal assemblages from grab samples collected at a total of 40 regional stations in 2015, resulting in six ecologically-relevant SIMPROF-supported groups (Figures 9.4, 9.5, Appendices H.1, H.2). These assemblages (referred to herein as cluster groups A–F) represented from 1 to 22 grabs each and varied in terms of the specific taxa present, as well as their relative abundance, and occurred at sites separated by different depth and/or sediment microhabitats. For example, similar patterns of variation occurred in the benthic macrofaunal and sediment similarity/dissimilarity matrices (see Chapter 8) used to generate cluster dendrograms (RELATE $\rho=0.531$, $p=0.001$). The sediment



Cluster Group	n	Depth Range (m)	Community Metric SR	Community Metric Abun
A	6	9–14	39	136
B	22	49–237	77	249
C	1	51	68	287
D	7	17–39	96	722
E	1	530	21	30
F	3	345–465	36	108

Figure 9.4
Results of cluster analysis of macrofaunal assemblages from San Diego regional benthic stations sampled during 2015. Data are presented as: (A) a dendrogram of main cluster groups with community metrics presented as mean values over all stations in each group (n) and (B) spatial distribution of cluster groups in the region. SR = species richness; Abun = abundance.

subfractions that were most highly correlated to macrofaunal communities included fine sands, very fine sands, and percent fines (BEST $\rho = 0.571$, $p = 0.001$). Mean species richness ranged from 21 to 96 taxa per grab for these groups, while mean abundance ranged from 30 to 722 individuals per grab (Figure 9.4). Characteristics and differences between the six cluster groups and their associated sediments are described below.

Cluster group A represented macrofaunal assemblages from six inner shelf stations located at depths ≤14 m off Mission Bay (i.e., stations 8403 and 8419), the mouth of the San Diego Bay (station 8426), the Coronado Island “Silver Strand” beach (station 8430), and Imperial Beach (i.e., stations 8429 and 8413) (Figure 9.4). These assemblages averaged 39 taxa and 136 individuals per grab. SIMPER results indicated that the species accounting for the top 45% of intragroup similarity for group A were the sand dollar *Dendraster excentricus* (17 per grab), the spionid polychaete *Spiophanes duplex* (15 per grab), and the cumacean *Diastylopsis tenuis* (10 per grab) (Appendix H.1). *Dendraster excentricus* was unique to this group (Figure 9.5). The sediments associated with this cluster group were characterized by the highest proportion of fine sand (41%) and second highest proportion of very fine sand (45%) compared to all other cluster groups (Appendix H.2).

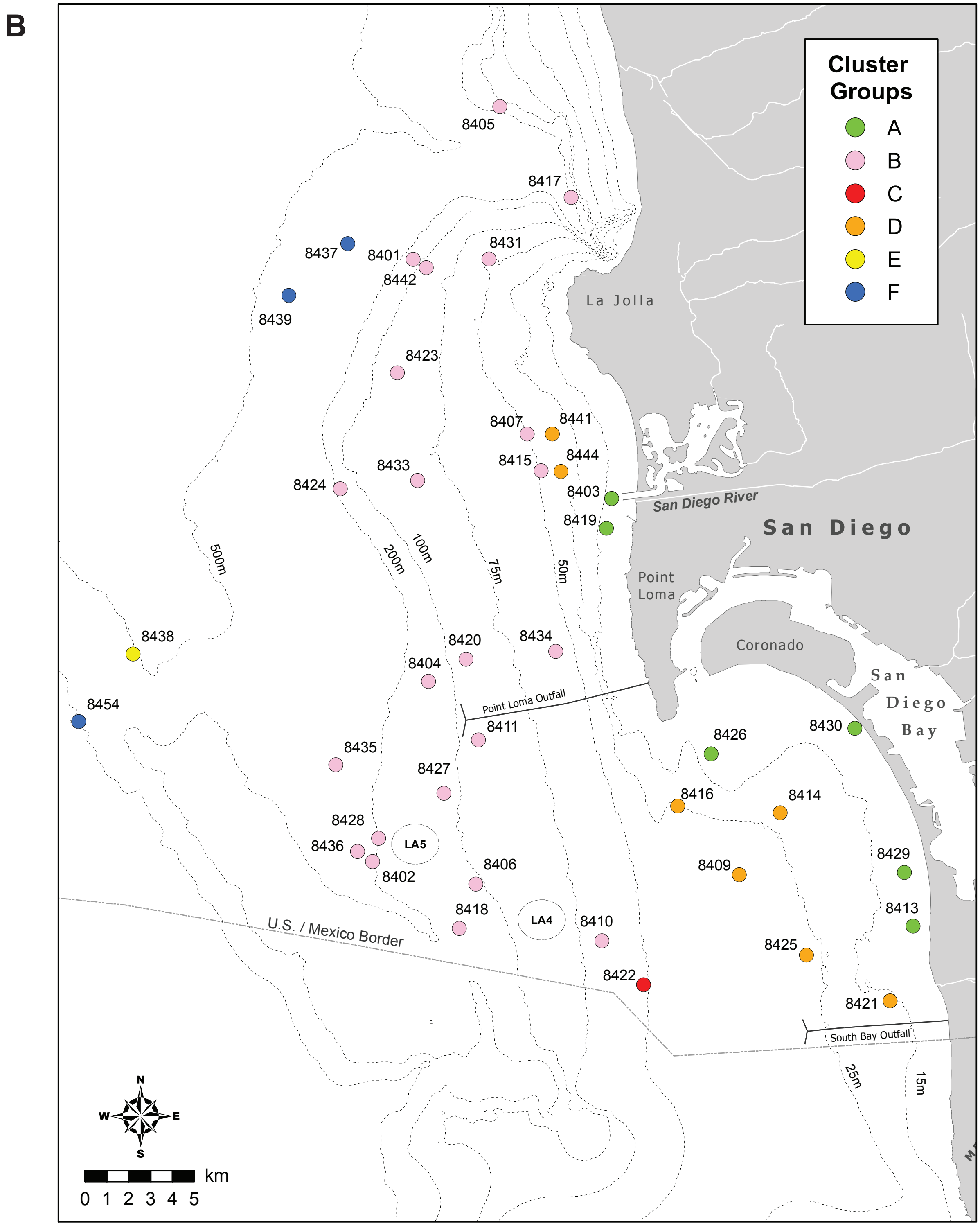


Figure 9.4 *continued*

Cluster group B was the largest group (n=22) representing assemblages from most of the mid- and outer shelf sites as well as some upper slope stations at depths ranging from 49 to 237 m (Figure 9.4). Overall, these assemblages were typical of the ophiuroid dominated community that occurs along much of the mainland shelf off southern California (see Mikel et al. 2007, City of San Diego 2015a). This group averaged 77 taxa and 249 individuals per grab, and was primarily characterized by the ophiuroid *Amphiodia urtica* (16 per grab) which was

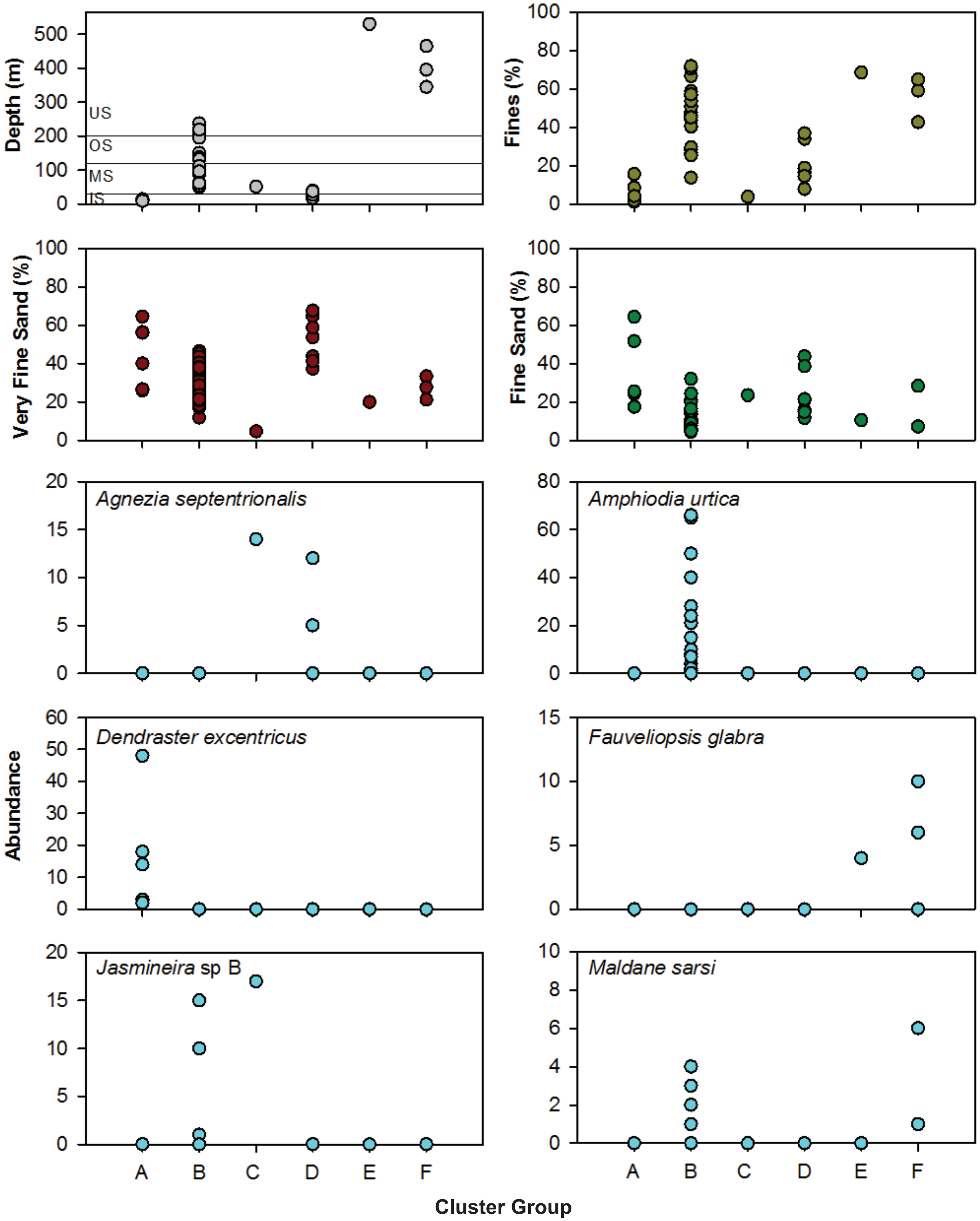


Figure 9.5

Depth, sediment composition, and abundances (# of individuals per station) of select species that contributed to cluster group dissimilarities from San Diego regional benthic stations sampled during 2015. Each data point represents a single sample or grab; IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope.

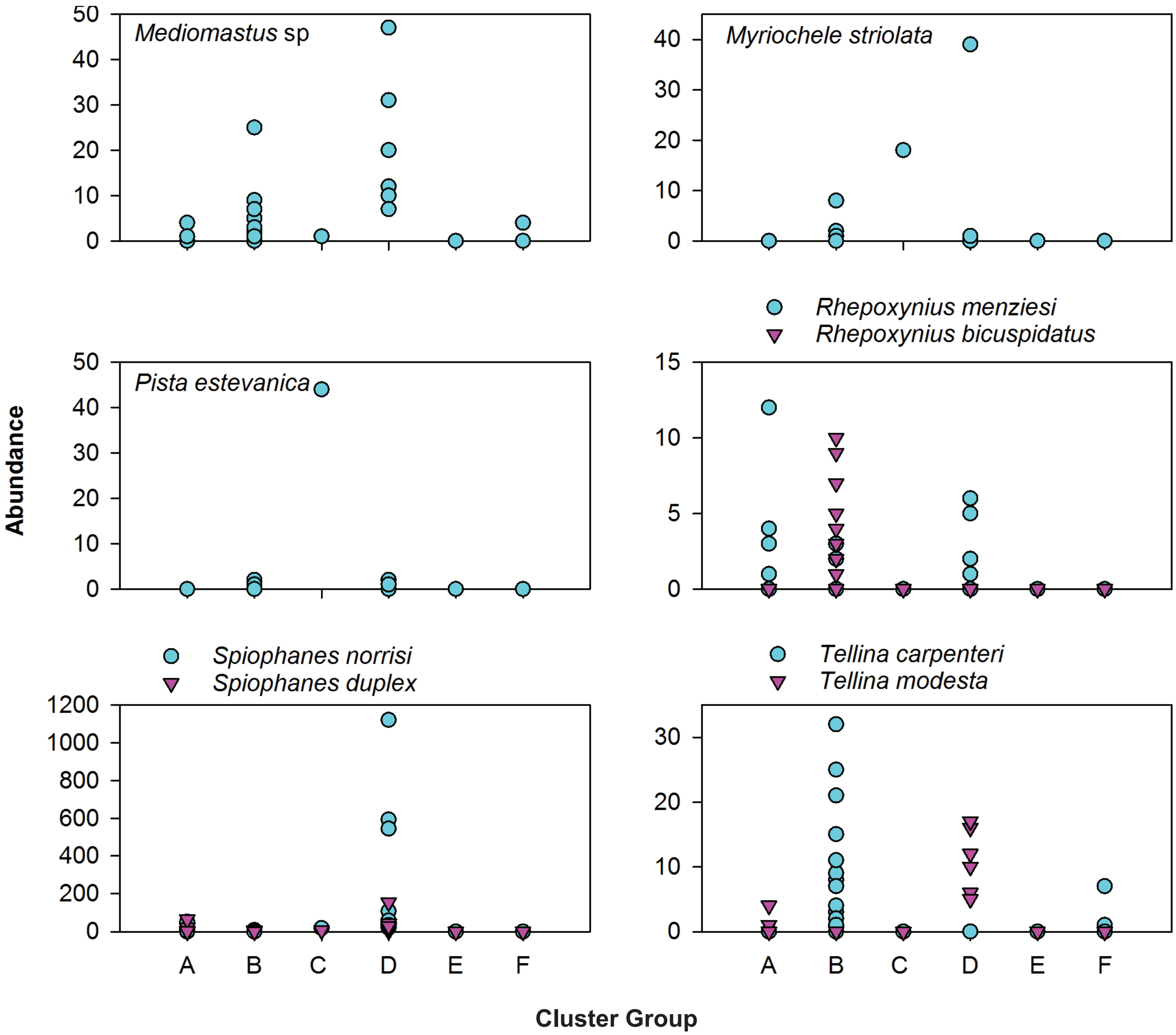


Figure 9.5 *continued*

unique to this group (Figure 9.5, Appendix H.1). In addition to *A. urtica*, the remaining four of the top five characteristic species for group B defined by SIMPER analysis included the bivalves *Axinopsida serricata* (9 per grab), *Tellina carpenteri* (7 per grab), and *Nuculana* sp A (7 per grab), and the spionid polychaete *Prionospio (Prionospio) dubia* (6 per grab). This group was also distinguished by being the only group with the phoxocephalid amphipod *Rhepoxynius bicuspidatus* and one of two groups where the sabellid polychaete *Jasmineira* sp B was present (Figure 9.5). The sediments associated with this cluster group averaged the highest proportions of very coarse sand (~2%) and granules (1%), as well as the second lowest proportion of fine sand (12%) (Appendix H.2).

Cluster group C represented a unique assemblage restricted to station 8422 located at a depth of 51 m near the USA/Mexico border (Figure 9.4). A total of 68 taxa and 287 individuals occurred in this grab. The six most abundant species in this sample, which together comprised about 45% of the organisms present, included the terebellid polychaete *Pista estevanica* (n=44), *Spiophanes norrisi* (n=18), the owenid polychaete *Myriochele striolata* (n=18), *Jasmineira* sp B (n=17), the ascidian *Agnezia septentrionalis* (n=14), and other juvenile or damaged Ascidiacea (n=14) (Appendix H.1). The relatively high number of *P. estevanica* distinguished group C from other assemblages sampled in the San Diego region during this survey (Figure 9.5). The sediments associated with this sample comprised the lowest percentages of fines (4%) and very fine sand (5%) and the highest percentages of medium sand (52%) and coarse sand (16%) of all groups (Appendix H.2).

Cluster group D represented assemblages from five stations (8409, 8414, 8416, 8421, 8425) located south of the tip of Point Loma and north of the SBOO at depths from 17 to 33 m, as well as two stations (8441, 8444) located at 39 and 37 m depth, respectively, near Mission Bay (Figure 9.4). When compared to the other cluster groups, these assemblages had the greatest number of taxa (96 taxa per grab), the largest number of animals (722 individuals per grab), and the largest numbers of *Spiophanes norrisi* (354 per grab), *Spiophanes duplex* (44 per grab), and the capitellid polychaete *Mediomastus* sp (21 per grab) (Appendix H.1). In addition to these polychaetes, the remaining two of the five most characteristic species for this group based on SIMPER results included the bivalve *Tellina modesta* (12 per grab), and the maldanid polychaete *Metasychis disparidentatus* (11 per grab) (Appendix H.1). This cluster group was distinguished from other groups by its relatively high populations of *Rhepoxynius menziesi* and *Myriochele striolata* compared to most other groups (Figure 9.5). The sediments associated with this cluster group averaged the highest proportion of very fine sand (53%) and the second highest proportion of fine sand (24%) (Appendix H.2).

Cluster group E represented a unique assemblage restricted to station 8438 located at a depth of 530 m on the northwest slope of the Coronado Bank (Figure 9.4). A total of 21 taxa and 30 individuals occurred in this grab. These low values are typical near the transition from the upper slope to lower slope communities (e.g., Ranasinghe et al. 2012). Taxa accounting for approximately 45% of the total abundance at this station included the polychaetes *Fauveliopsis glabra* (n=4) and *Eclysippe trilobata* (n=3), the bivalve *Neilonella ritteri* (n=3), and the heart urchin *Brissopsis* sp LA1 (n=2) (Appendix H.1). The sediments associated with this grab had the highest proportion of fines (69%) (Appendix H.2).

Cluster group F represented another deep water community sampled at three of the seven upper slope stations located at depths from 345 to 465 m (8437, 8439, 8454) (Figure 9.4). These assemblages had the second lowest mean number of taxa (36 per grab) and abundance (108 individuals per grab) of all cluster groups. According to SIMPER results, the most characteristic species of group F included the maldanid polychaetes *Praxillella pacifica* (5 per grab) and *Maldane sarsi* (4 per grab), the ampeliscid amphipod *Ampelisca unsocalae* (2 per grab), and the capitellid *Notomastus* sp A (1 per grab) (Appendix H.1). The numbers of *M. sarsi*, and the absence of several species such as *Spiophanes duplex*, *Spiophanes norrisi*, and *Pista estevanica*, distinguished group F from other assemblages sampled during the 2015 random survey (Figure 9.5). The sediments associated with this cluster group averaged the second highest proportion of fines (56%) (Appendix H.2).

SUMMARY

Macrofaunal communities in the San Diego region remained in good condition in 2015, with most shelf assemblages similar to those observed during regional surveys conducted from 1994 to 2014, and upper slope assemblages similar to those observed starting in 2009 (City of San Diego 2010–2013, 2014, 2015a, b, c). Benthic assemblages had expected abundances of pollution sensitive species in the amphipod genera *Ampelisca* and *Rhepoxynius*, and the brittle star *Amphiodia urtica*. In contrast, abundances of pollution tolerant species such as the polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa* were relatively low. Community parameters (i.e., species richness, abundance, Shannon diversity, evenness, dominance) for the 22 stations corresponding to the *Amphiodia* "mega-community" sampled during 2015 were within or near range of tolerance intervals calculated for this specific habitat type (see City of San Diego 2015a), suggesting that the region remains healthy.

Benthic assemblages segregated by habitat characteristics such as depth and sediment particle size, corresponding with the "patchy" habitats reported to naturally occur across the SCB (Fauchald and Jones 1979, Jones 1969, Bergen et al. 2001, Mikel et al. 2007). Several inner to mid-shelf (9–51 m depths) macrofaunal assemblages off San Diego were similar to those found in shallow habitats across southern California (Barnard 1963, Jones 1969, Thompson et al. 1987, 1992, ES Engineering Science 1988, Mikel et al. 2007). These assemblages occurred at sites characterized by sandy sediments that included populations of polychaetes such as *Spiophanes norrisi*, *Spiophanes duplex*, and *Mediomastus* sp (i.e., cluster groups A, C, D). However, each cluster group had species that clearly differentiated it from other clusters, with these organismal differences likely caused by slight differences in either sediment (e.g., shell hash, red relict sand) or depth characteristics.

The majority of the stations sampled off San Diego during 2015 were located across the mid-shelf to the upper slope and were characterized by sediments with nearly evenly balanced proportions of fines and very fine sand (i.e., cluster group B). Macrofaunal assemblages in many of these areas were dominated by the brittle star *Amphiodia urtica* that corresponds to the *Amphiodia* "mega-community" described by Barnard and Ziesenhenne (1961). Such communities are common in the Point Loma region (City of San Diego 2015b) as well as other parts of the southern California mainland shelf (Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993, Zmarzly et al. 1994, Diener and Fuller 1995, Bergen et al. 1998, 2000, 2001, Mikel et al. 2007).

Similar to patterns described in past monitoring reports (City of San Diego 2013, 2015c, Ranasinghe et al. 2012), upper slope habitats off San Diego were characterized by a high percentage of fine sediments with associated macrofaunal assemblages that were distinct from those at most shelf stations as well as lower abundances and fewer taxa per station. These macrofaunal assemblages were distinguished by their populations of the polychaetes *Eclysippe trilobata* and *Fauveliopsis glabra* and the echinoid *Brissopsis* sp LA1 (i.e., cluster groups E and F).

Although benthic communities off San Diego varied across depth and sediment gradients, there was no evidence of disturbance during the 2015 regional survey that could be attributed to wastewater discharges, disposal sites, or other point sources. Overall, benthic macrofauna appear to be in good condition throughout the region with 88% of the sites surveyed being in reference condition and the remaining 12% deviating only marginally based on assessments using the benthic response index (BRI). This result is similar to findings in Ranasinghe et al. (2010, 2012) who reported that at least 98% of the entire SCB mainland shelf is in good condition based on data from bight-wide surveys.

LITERATURE CITED

Anderson, B.S., J.W. Hunt, B.M. Philips, S. Tudor, R. Fairey, J. Newman, H.M. Puckett, M. Stephenson, E.R. Long, and R.S. Tjeerdema. (1998). Comparison of marine sediment toxicity test protocols for the amphipod *Rhepoxynius abronius* and the polychaete worm *Nereis (Neanthes) arenaceodentata*. Environmental Toxicology and Chemistry, 17(5): 859–866.

Barnard, J.L. (1963). Relationship of benthic Amphipoda to invertebrate communities of inshore sublittoral sands of southern California. Pacific Naturalist, 3: 439–467.

Barnard, J.L. and F.C. Ziesenhenne. (1961). Ophiuroidea communities of southern Californian coastal bottoms. Pacific Naturalist, 2: 131–152.

Bergen, M. (1996). The Southern California Bight Pilot Project: Sampling Design. In: M.J. Allen, C. Francisco, D. Hallock (eds.). Southern California Coastal Water Research Project: Annual Report 1994–1995. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., D.B. Cadien, A. Dalkey, D.E. Montagne, R.W. Smith, J.K. Stull, R.G. Velarde, and S.B. Weisberg. (2000). Assessment of benthic infaunal condition on the mainland shelf of southern California. Environmental Monitoring and Assessment, 64: 421–434.

Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

[Bight'13 CIA] Bight'13 Contaminant Impact Assessment Committee. (2013). Contaminant Impact Assessment Workplan. Southern California Coastal Water Research Project, Costa Mesa, CA.

City of Los Angeles. (2014). Los Angeles Harbor Biennial Assessment Report 2012–2013. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

City of Los Angeles. (2015). Santa Monica Bay Biennial Assessment Report 2013–2014. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2012). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2013). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2014). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2013. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015a). Appendix C.2. San Diego Benthic Tolerance Intervals. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume V, Appendices C & D.

Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015b). Point Loma Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2015c). South Bay Ocean Outfall Annual Receiving Waters Monitoring and Assessment Report, 2014. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R., R.N. Gorley, P.J. Somerfield, and R.M. Warwick. (2014). Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER-E, Plymouth, England.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Diener, D.R. and S.C. Fuller. (1995). Infaunal patterns in the vicinity of a small coastal wastewater outfall and the lack of infaunal community response to secondary treatment. Bulletin of the Southern California Academy of Science, 94: 5–20.

Diener, D.R., S.C. Fuller, A. Lissner, C.I. Haydock, D. Maurer, G. Robertson, and T. Gerlinger. (1995). Spatial and temporal patterns of the infaunal community near a major ocean outfall in southern California. Marine Pollution Bulletin, 30: 861–878.

Dodder, N., K. Schiff, A. Latker, C-L Tang. (2016). Southern California Bight 2013 Regional Monitoring Program: IV. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

ES Engineering Science, Inc. (1988). Tijuana Oceanographic Engineering Study (TOES) Ocean Measurement Program Summary Phases I–III (May 1986–December 1988). ES Engineering Science, Inc., San Diego, CA.

Fauchald, K. and G.F. Jones. (1979). Variation in community structures on shelf, slope, and basin macrofaunal communities of the Southern California Bight. Report 19, Series 2. In: Southern California Outer Continental Shelf Environmental Baseline Study, 1976/1977 (Second Year) Benthic Program. Principal Investigators Reports, Vol. II. Science Applications, Inc. La Jolla, CA.

Ferraro, S.P., R.C. Swartz, F.A. Cole, and W.A. Deben. (1994). Optimum macrobenthic sampling protocol for detecting pollution impacts in the Southern California Bight. Environmental Monitoring and Assessment, 29: 127–153.

Hope, R.M. (2013). Rmisc: Rmisc: Ryan Miscellaneous. R package version 1.5. http://CRAN.R-project.org/package=Rmisc.

Hyland, J.L., W.L. Balthis, V.D. Engle, E.R. Long, J.F. Paul, J.K. Summers, and R.F. Van Dolah. (2003). Incidence of stress in benthic communities along the US Atlantic and Gulf of Mexico coasts within different ranges of sediment contamination from chemical mixtures. Environmental Monitoring and Assessment, 81: 149–161.

Jones, G.F. (1969). The benthic macrofauna of the mainland shelf of southern California. Allan Hancock Monographs of Marine Biology, 4: 1–219.

Kennedy, A.J., J.A. Steevens, G.R. Lotufo, J.D. Farrar, M.R. Reiss, R.K. Kropp, J. Doi, and T.S. Bridges. (2009). A comparison of acute and chronic toxicity methods for marine sediments. Marine Environmental Research, 68: 118–127.

[LACSD] Los Angeles County Sanitation Districts. (2014). Joint Water Pollution Control Plant Biennial Ocean Monitoring Report, 2012-2013. Whittier, CA: Los Angeles County Sanitation Districts, Ocean Monitoring and Research Group, Technical Services Department.

Linton, D.L. and G.L. Taghon. (2000). Feeding, growth, and fecundity of *Capitella* sp. I in relation to sediment organic concentration. Marine Ecology Progress Series, 205: 229–240.

McLeod, R.J. and S.R. Wing. (2009). Strong pathways for incorporation of terrestrially derived organic matter into benthic communities. Estuarine, Coastal and Shelf Science, 82: 645–653.

Mikel, T.K., J.A Ranasinghe, and D.E. Montagne. (2007). Characteristics of benthic macrofauna of the Southern California Bight. Appendix F. Southern California Bight 2003 Regional Monitoring Program.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2002). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

[OCSD] Orange County Sanitation District. (2015). Annual Report, July 2013–June 2014. Marine Monitoring, Fountain Valley, California.

Oksanen, J., F. G. Blanchet, R. Kindt, P. Legendre, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens and H. Wagner. (2015). vegan: Community Ecology Package. R package version 2.3-1. http://CRAN.R-project.org/package=vegan.

R Core Team. (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, and S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

Ranasinghe, J.A., D. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., K.C. Schiff, C.A. Brantley, L.L. Lovell, D.B. Cadien, T.K. Mikel, R.G. Velarde, S. Holt, and S.C. Johnson. (2012). Southern California Bight 2008 Regional Monitoring Program:VI. Benthic Macrofauna. Technical Report No. 665, Southern California Coastal Water Research Project, Costa Mesa, CA.

Ranasinghe, J.A., K.C. Schiff, D.E. Montagne, T.K. Mikel, D.B. Cadien, R.G. Velarde, and C.A. Brantley. (2010). Benthic macrofaunal community condition in the Southern California Bight, 1994–2003. Marine Pollution Bulletin, 60: 827–833.

Ripley, B. and M. Lapsley. (2015). RODBC: ODBC Database Access. R package version 1.3-12. http://CRAN.R-project.org/package=RODBC.

[SCAMIT] Southern California Association of Marine Invertebrate Taxonomists. (2014). A taxonomic listing of benthic macro- and megainvertebrates from infaunal and epibenthic monitoring programs in the Southern California Bight, edition 9. Southern California Associations of Marine Invertebrate Taxonomists, Natural History Museum of Los Angeles County Research and Collections, Los Angeles, CA.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., R. Gossett, K. Ritter, L. Tiefenthaler, N. Dodder, W. Lao, and K. Maruya. (2011). Southern California Bight 2008 Regional Monitoring Program: III. Sediment Chemistry. Southern California Coastal Water Research Project, Costa Mesa, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Smith, R.W., M. Bergen, S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, J.K. Stull, and R.G. Velarde. (2001). Benthic response index for assessing infaunal communities on the southern California mainland shelf. Ecological Applications, 11(4): 1073–1087.

Snelgrove P.V.R., T.H. Blackburn, P.A. Hutchings, D.M. Alongi, J.F. Grassle, H. Hummel, G. King, I. Koike, P.J.D. Lambshead, N.B. Ramsing, and V. Solis-Weiss. (1997). The importance of marine sediment biodiversity in ecosystem processes. Ambio, 26: 578–583.

Stebbins, T.D., K.C. Schiff, and K. Ritter. (2004). San Diego Sediment Mapping Study: Workplan for Generating Scientifically Defensible Maps of Sediment Conditions in the San Diego Region. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Southern California Coastal Water Research Project, Westminster, CA.

Stein, E.D. and D.B. Cadien. (2009). Ecosystem response to regulatory and management actions: The Southern California experience in long-term monitoring. In: K. Schiff (ed.). Southern California Coastal Water Research Project Annual Report 2009. Southern California Coastal Water Research Project, Costa Mesa, CA.

Stevens Jr., D.L. (1997). Variable density grid-based sampling designs for continuous spatial populations. Environmetrics, 8: 167–195.

Stevens Jr., D.L. and A.R. Olsen. (2004). Spatially-balanced sampling of natural resources in the presence of frame imperfections. Journal of the American Statistical Association, 99: 262–278.

Stull, J.K. (1995). Two decades of marine environmental monitoring, Palos Verdes, California, 1972–1992. Bulletin of the Southern California Academy of Sciences, 94: 21–45.

Stull, J.K., C.I. Haydock, R.W. Smith, and D.E. Montagne. (1986). Long-term changes in the benthic community on the coastal shelf of Palos Verdes, southern California. Marine Biology, 91: 539–551.

Stull, J.K., D.J.P. Swift, and A.W. Niedoroda. (1996). Contaminant dispersal on the Palos Verdes continental margin: I. Sediments and biota near a major California wastewater discharge. Science of the Total Environment, 179: 73–90.

Swartz, R.C., F.A. Cole, and W.A. Deben. (1986). Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series, 31: 1–13.

Thompson, B.E., J. Dixon, S. Schroeter, and D.J. Reish. (1993). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 369–458.

Thompson, B., J.D. Laughlin, and D.T. Tsukada. (1987). 1985 Reference Site Survey. Technical Report No. 221, Southern California Coastal Water Research Project, Long Beach, CA.

Thompson, B., D. Tsukada, and D. O'Donohue. (1992). 1990 Reference Survey. Technical Report No. 355, Southern California Coastal Water Research Project, Long Beach, CA.

[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.

[USEPA] United States Environmental Protection Agency. (2004). National Coastal Condition Report II. US Environmental Protection Agency, Office of Research and Development, EPA-620/R-03/002, Washington, DC, USA.

Wickham, H. (2007). Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL http://www.jstatsoft.org/v21/i12/.

Zmarzly, D.L., T.D. Stebbins, D. Pasko, R.M. Duggan, and K.L. Barwick. (1994). Spatial patterns and temporal succession in soft-bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: relation to anthropogenic and natural events. Marine Biology, 118: 293–307.

Appendices

Appendix A

Supporting Data

2015 SBOO Stations

Coastal Oceanographic Conditions

Appendix A.1

Summary of temperature, salinity, DO, pH, transmissivity, and chlorophyll *a* for various depth layers as well as the entire water column from all SBOO stations during 2015. For each quarter n ≥ 358 (1–9 m), n ≥ 271 (10–19 m), n = 150 (20–28 m), n ≥ 72 (29–38 m), n ≥ 55 (39–55 m). Sample sizes differed due to slight variations in depth at individual stations.

		Depth (m)					
Temperature (°C)		**1–9**	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
February	min	15.3	14.7	14.2	13.7	12.2	12.2
	max	16.8	16.8	16.6	16.5	15.3	16.8
	mean	16.4	16.1	15.5	15.0	14.0	15.8
May	min	12.2	11.1	10.7	10.6	10.7	10.6
	max	16.5	16.1	12.5	11.7	11.2	16.5
	mean	15.1	12.9	11.5	11.0	10.9	13.1
August	min	14.8	13.2	12.9	12.6	11.9	11.9
	max	22.7	18.4	15.5	14.3	13.4	22.7
	mean	18.5	15.1	13.8	13.1	12.5	15.7
November	min	17.9	17.0	16.7	16.6	15.3	15.3
	max	21.7	21.7	21.7	21.7	20.1	21.7
	mean	19.3	19.2	18.9	18.5	17.2	19.0
Annual	min	12.2	11.1	10.7	10.6	10.7	10.6
	max	22.7	21.7	21.7	21.7	20.1	22.7
	mean	17.3	15.8	14.9	14.4	13.7	15.9

Salinity (psu)							
February	min	33.29	33.32	33.31	33.24	33.27	33.24
	max	33.44	33.44	33.41	33.40	33.40	33.44
	mean	33.39	33.38	33.35	33.34	33.34	33.37
May	min	33.18	33.22	33.31	33.37	33.43	33.18
	max	33.41	33.47	33.48	33.53	33.63	33.63
	mean	33.37	33.36	33.42	33.44	33.54	33.39
August	min	33.16	33.01	33.07	33.20	33.22	33.01
	max	33.41	33.33	33.28	33.28	33.40	33.41
	mean	33.30	33.25	33.25	33.26	33.30	33.27
November	min	33.42	33.33	33.36	33.34	33.35	33.33
	max	33.78	33.78	33.77	33.77	33.47	33.78
	mean	33.51	33.49	33.46	33.42	33.40	33.48
Annual	min	33.16	33.01	33.07	33.20	33.22	33.01
	max	33.78	33.78	33.77	33.77	33.63	33.78
	mean	33.39	33.37	33.37	33.36	33.39	33.38

Appendix A.1 *continued*

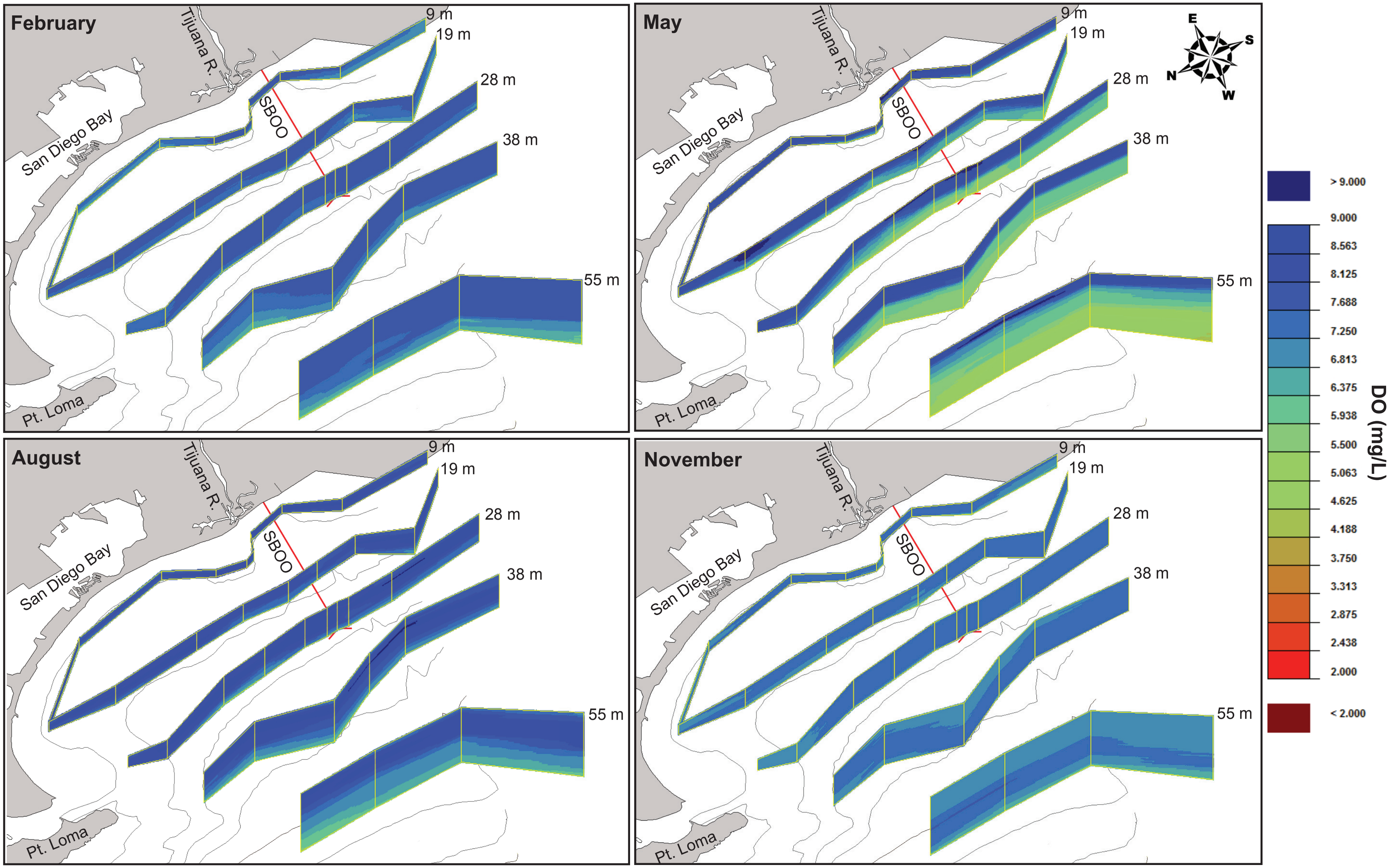
		Depth (m)					
DO (mg/L)		**1–9**	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
February	min	6.8	6.7	6.8	6.7	6.1	6.1
	max	8.0	8.1	8.1	8.0	7.8	8.1
	mean	7.8	7.7	7.6	7.4	6.9	7.6
May	min	6.7	5.1	5.3	5.1	4.6	4.6
	max	10.0	9.0	7.0	6.1	5.7	10.0
	mean	8.6	7.2	6.0	5.7	5.0	7.2
August	min	7.2	6.8	6.7	6.7	5.8	5.8
	max	9.1	9.2	8.7	8.2	7.4	9.2
	mean	8.2	8.3	7.7	7.2	6.6	7.9
November	min	6.9	6.4	6.7	6.9	6.3	6.3
	max	7.5	7.6	7.7	7.7	7.6	7.7
	mean	7.3	7.3	7.3	7.4	7.1	7.3
Annual	min	6.7	5.1	5.3	5.1	4.6	4.6
	max	10.0	9.2	8.7	8.2	7.8	10.0
	mean	8.0	7.6	7.2	6.9	6.4	7.5

pH							
February	min	8.1	8.1	8.1	8.1	8.0	8.0
	max	8.2	8.2	8.2	8.2	8.2	8.2
	mean	8.2	8.2	8.2	8.1	8.1	8.2
May	min	8.0	7.9	7.9	7.9	7.8	7.8
	max	8.2	8.2	8.0	8.0	7.9	8.2
	mean	8.2	8.1	8.0	7.9	7.9	8.1
August	min	8.0	8.0	7.9	7.9	7.8	7.8
	max	8.2	8.2	8.2	8.2	8.1	8.2
	mean	8.2	8.1	8.1	8.1	8.0	8.1
November	min	8.0	8.0	8.1	8.1	8.0	8.0
	max	8.2	8.2	8.2	8.2	8.2	8.2
	mean	8.2	8.2	8.2	8.1	8.1	8.1
Annual	min	8.0	7.9	7.9	7.9	7.8	7.8
	max	8.2	8.2	8.2	8.2	8.2	8.2
	mean	8.2	8.1	8.1	8.1	8.0	8.1

Appendix A.1 *continued*

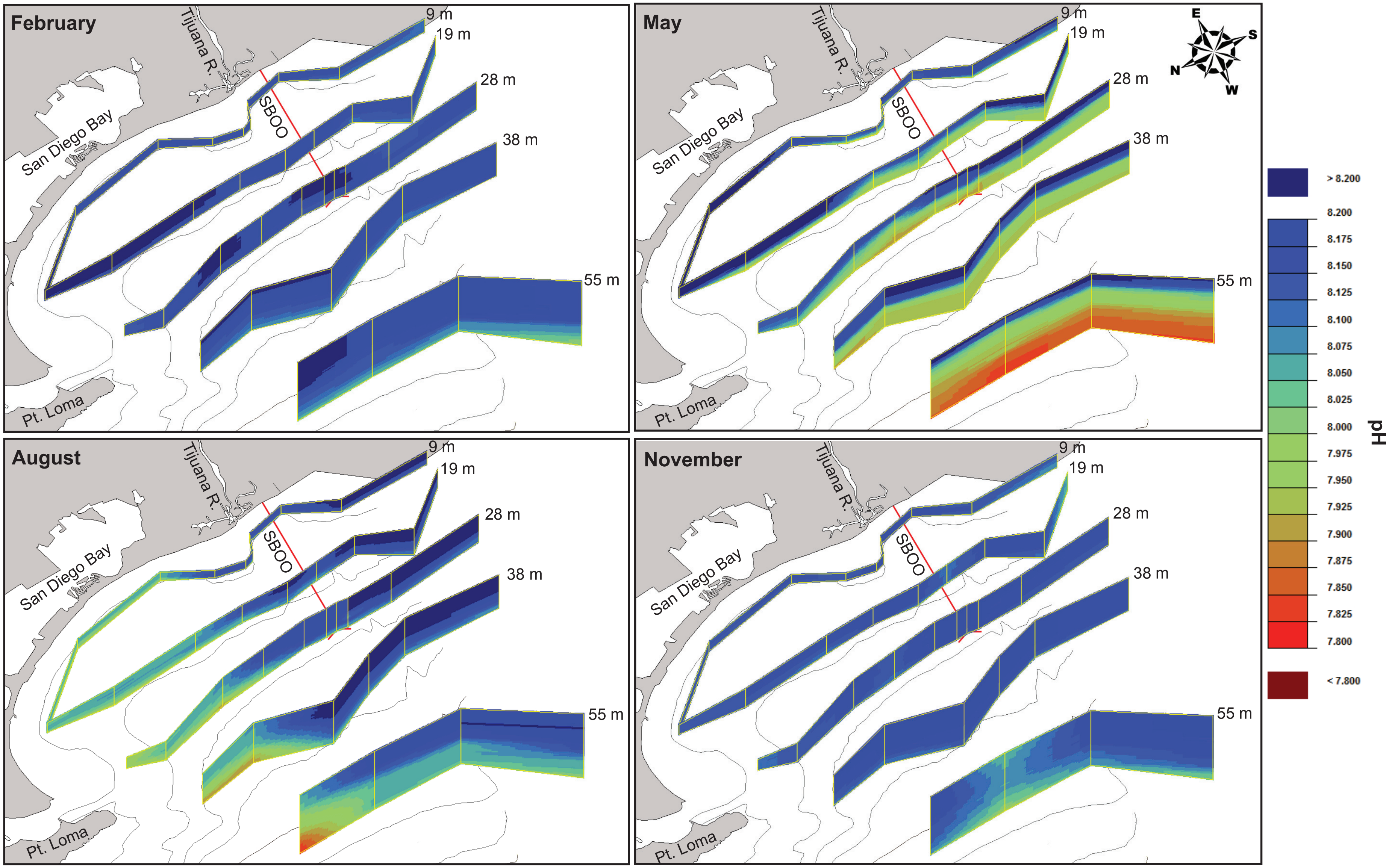
Transmissivity (%)		**Depth (m)** **1–9**	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
February	min	49	39	63	78	86	39
	max	90	90	90	89	90	90
	mean	83	85	85	87	88	85
May	min	55	38	65	69	84	38
	max	84	88	90	90	89	90
	mean	75	76	82	87	88	78
August	min	38	27	77	83	88	27
	max	90	90	89	90	90	90
	mean	84	83	85	89	90	85
November	min	61	57	67	80	86	57
	max	90	90	90	90	90	90
	mean	85	86	88	89	89	87
Annual	min	38	27	63	69	84	27
	max	90	90	90	90	90	90
	mean	82	82	85	88	89	84

Chlorophyll *a* (μg/L)							
February	min	0.2	0.3	0.4	0.6	0.5	0.2
	max	3.3	3.4	2.4	2.8	2.0	3.4
	mean	1.0	1.2	1.6	1.7	1.0	1.2
May	min	0.6	1.8	1.2	1.0	0.6	0.6
	max	32.2	14.8	5.9	3.4	1.5	32.2
	mean	3.7	5.2	2.9	1.7	0.9	3.6
August	min	0.3	0.3	0.6	1.3	0.8	0.3
	max	6.8	7.9	7.4	4.4	2.4	7.9
	mean	0.8	1.8	2.8	2.0	1.4	1.6
November	min	0.2	0.3	0.4	0.4	0.6	0.2
	max	2.8	2.8	1.9	2.2	2.1	2.8
	mean	0.8	0.9	1.0	1.1	1.3	1.0
Annual	min	0.2	0.3	0.4	0.4	0.5	0.2
	max	32.2	14.8	7.4	4.4	2.4	32.2
	mean	1.6	2.3	2.1	1.6	1.2	1.9



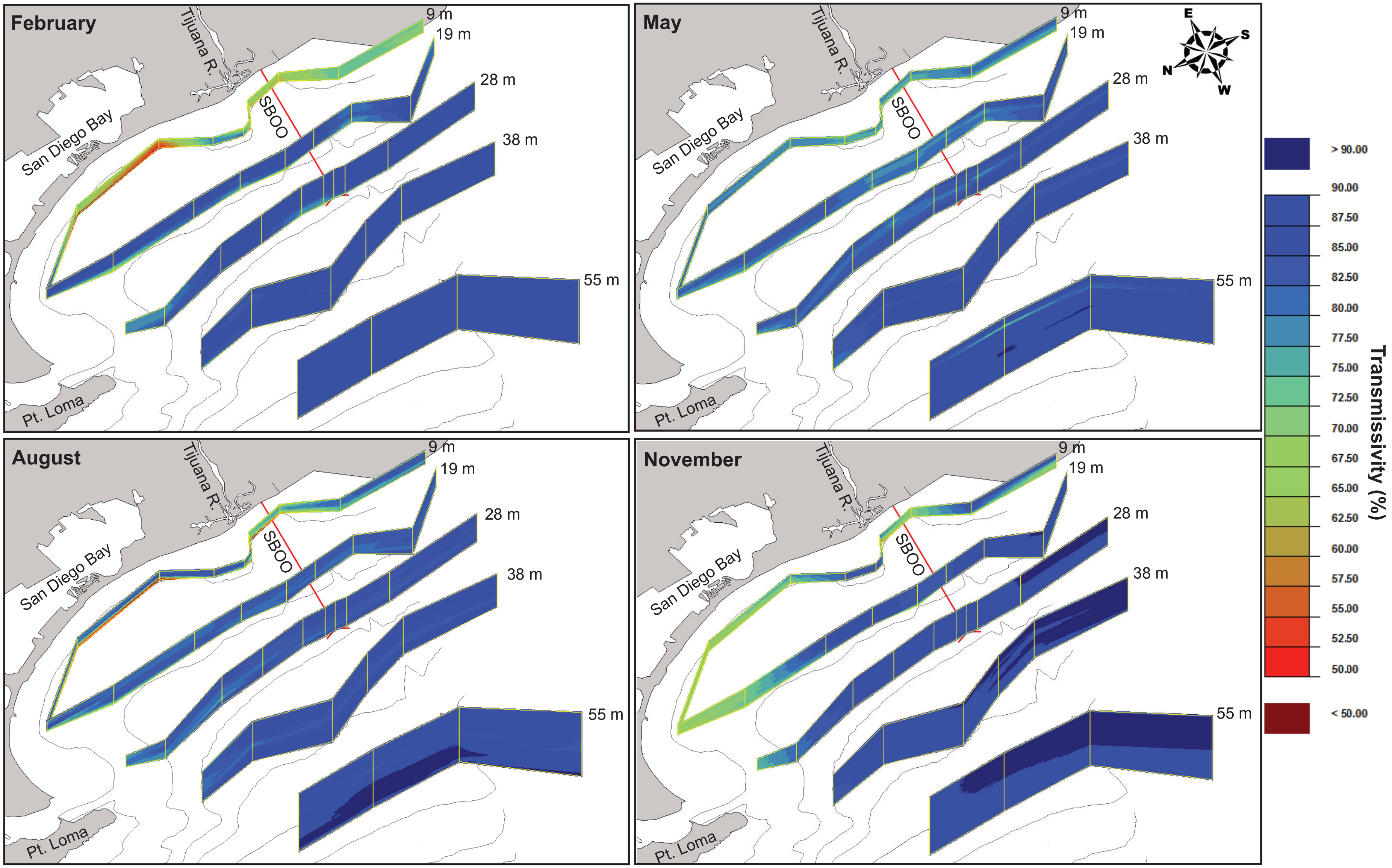
Appendix A.2

Dissolved oxygen recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2015. Data were collected over 3–5 days during each of these surveys.



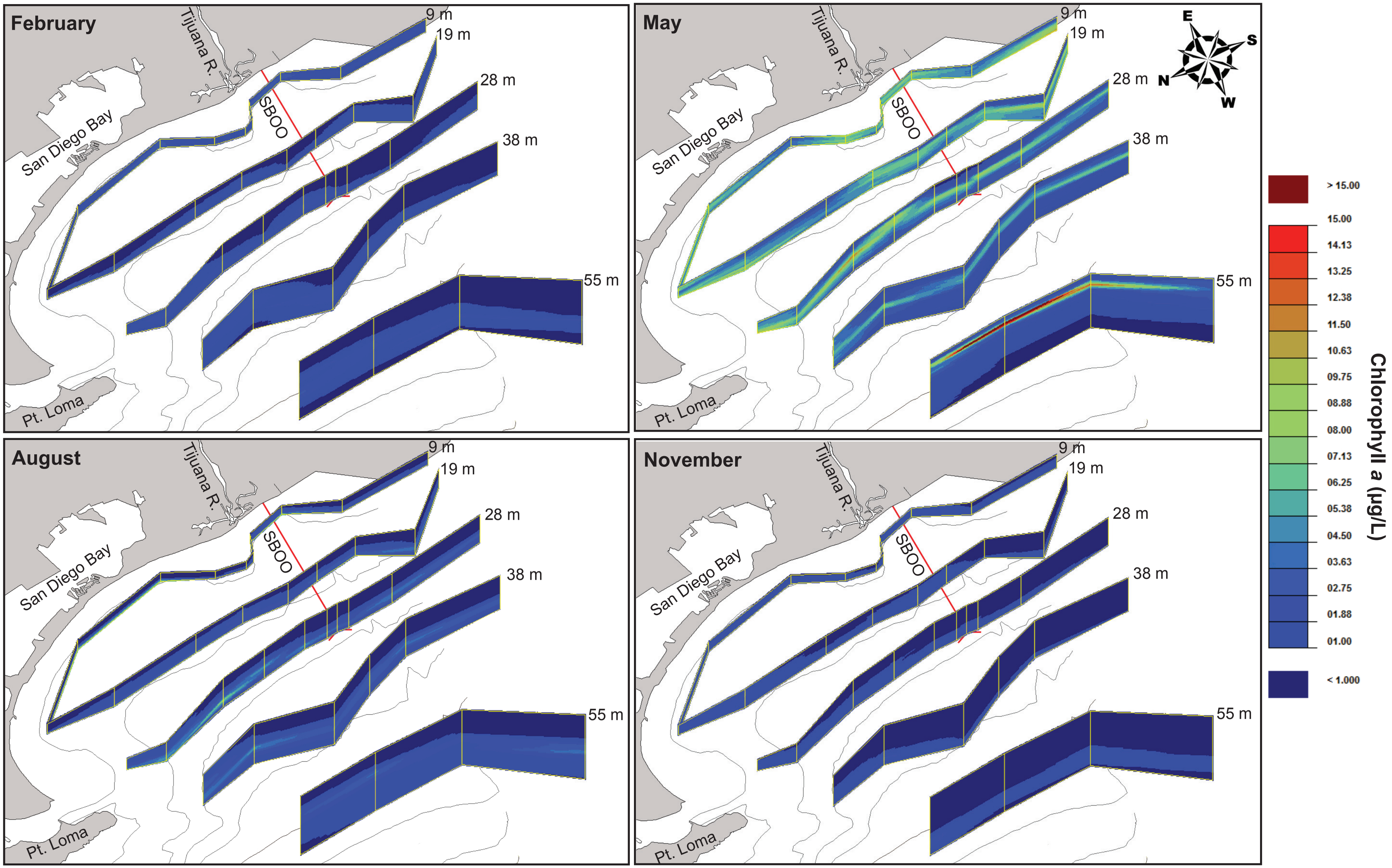
Appendix A.3

pH recorded in the SBOO region during spring (May), summer (August), and fall (November) of 2015. Data were collected over 3–5 days during each of these surveys.



Appendix A.4

Transmissivity recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2015. Data were collected over 3–5 days during each of these surveys.



Appendix A.5

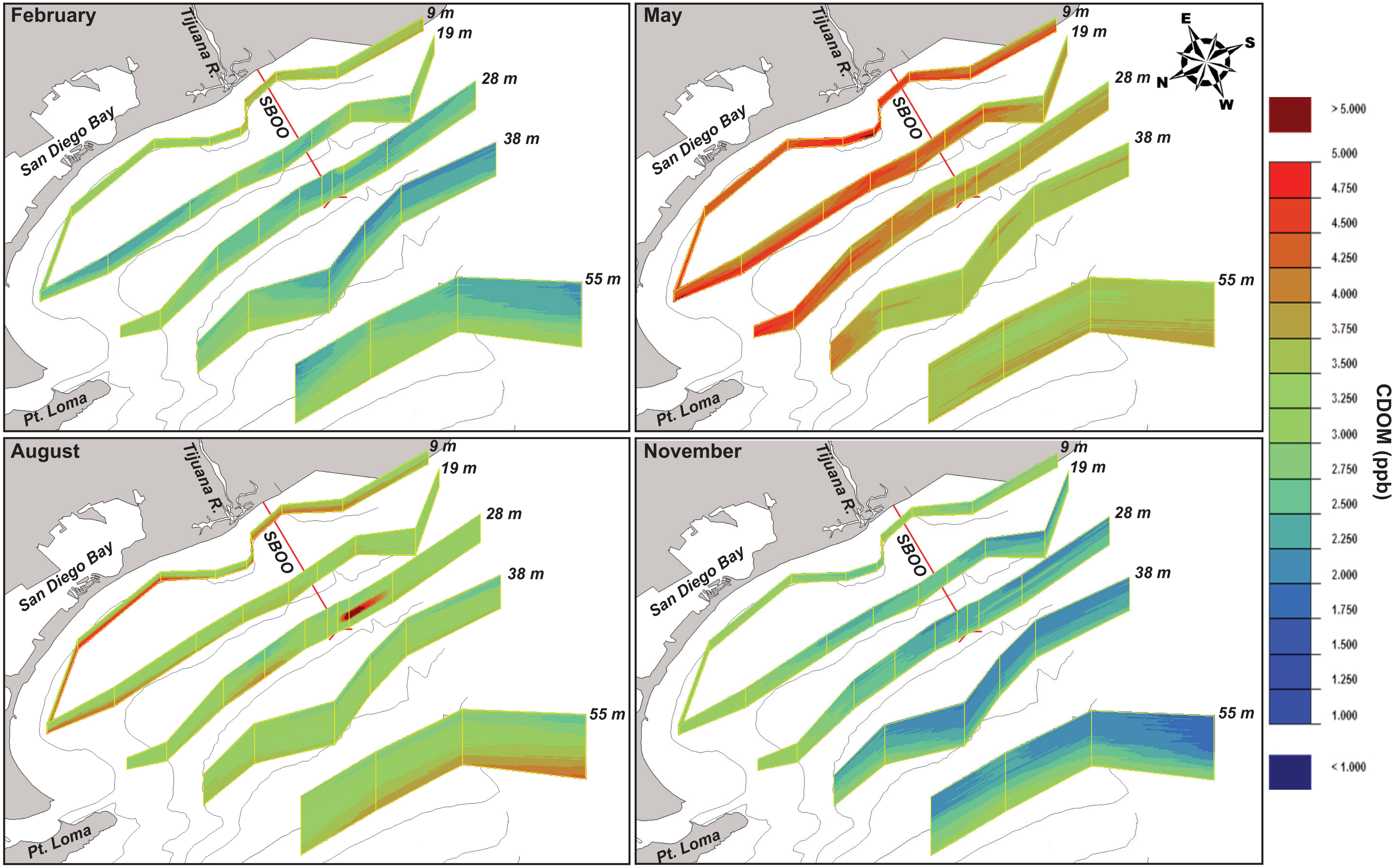
Concentrations of chlorophyll *a* recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2015. Data were collected over 3–5 days during each of these surveys.

Appendix B

Supporting Data

2015 SBOO Stations

Water Quality Compliance and Plume Dispersion



Appendix B.1

CDOM values recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2015. Data were collected over 3–5 days during each of these surveys.

Appendix B.2

Summary of SBOO reference stations used during 2015 to calculate out-of-range thresholds (see text for details).

Month	Stations
February	I13, I14, I15, I16, I17, I18, I2, I22, I27, I31, I35
May	I1, I12, I13, I14, I16, I17, I2, I20, I21, I22, I27, I28, I29, I3, I6, I7, I8, I9
August	I13, I14, I15, I16, I17, I18, I2, I22, I3, I34
November	I10, I16, I2, I22, I39

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Appendix B.3

Summary of rainfall and bacteria levels from SBOO shore stations during 2015. Total coliform, fecal coliform, and *Enterococcus* densities are expressed as mean CFU/100 mL per month. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom; n = total number of samples.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Total Rain (in):		0.42	0.28	0.93	0.02	2.39	0.04	1.72	0.01	1.24	0.43	1.55	0.89
	n	44	44	55	44	44	55	44	44	55	44	44	55
S9	*Total*	82	13	220	16	16	20	7025	25	24	16	42	2
	Fecal	18	4	17	4	2	3	1006	3	2	4	8	2
	Entero	6	4	58	2	2	6	30	7	3	2	22	2
S8	*Total*	12	6	981	8	30	20	3265	20	92	26	11	6
	Fecal	10	4	88	2	2	2	654	7	2	4	2	2
	Entero	2	3	65	2	4	3	23	5	3	4	5	2
S12	*Total*	12	4	3224	12	16	56	4210	65	176	4150	20	9
	Fecal	7	2	768	6	4	7	718	22	7	252	3	2
	Entero	20	2	1488	2	6	7	42	10	4	132	16	12
S6	*Total*	108	8	534	12	1425	16	4015	26	88	4020	61	54
	Fecal	12	4	86	6	76	4	3004	4	2	2452	5	5
	Entero	12	2	68	2	14	7	222	9	4	1604	8	11
S11	*Total*	3709	1202	3778	12	4025	20	4015	16	52	4022	16	457
	Fecal	236	32	2861	2	255	6	3003	3	2	3004	2	5
	Entero	86	9	1210	2	77	4	378	8	5	3017	6	13
S5	*Total*	4525	6765	3624	18	8040	20	4040	26	81	4036	20	4242
	Fecal	3074	3031	2469	3	1904	3	3004	7	4	3004	4	48
	Entero	3052	3008	2416	4	344	9	2758	18	8	3008	15	98
S10	*Total*	4100	7502	24	11	3056	9	36	16	56	70	82	3468
	Fecal	1554	311	4	3	116	2	4	6	2	6	18	172
	Entero	616	32	12	2	8	2	6	2	24	12	18	187
S4	*Total*	4054	4027	25	12	20	22	24	47	92	90	590	3372
	Fecal	856	84	8	2	4	2	4	2	6	7	79	50
	Entero	246	16	12	2	2	4	4	7	17	44	66	114
S3	*Total*	561	864	100	11	32	37	17	6	78	80	216	362
	Fecal	36	32	6	2	2	2	2	2	2	8	49	8
	Entero	70	14	19	2	12	2	2	2	24	30	36	17
S2	*Total*	282	11	192	2	8	17	11	446	124	196	456	592
	Fecal	30	2	22	3	2	2	2	6	2	23	52	32
	Entero	38	2	20	4	5	6	2	81	45	82	127	29
S0	*Total*	943	135	1084	1230	420	36,010	81	65	317	184	250	8584
	Fecal	70	12	62	96	44	82	10	7	14	16	31	796
	Entero	122	30	306	88	33	260	22	18	289	737	59	3681

Appendix B.4

Summary of elevated bacteria densities in samples collected from SBOO shore stations during 2015. Bold values exceed benchmarks for total coliform (> 10,000 CFU/100 mL), fecal coliform (> 400 CFU/100 mL), *Enterococcus* (> 104 CFU/100 mL), and/or the FTR criterion (total coliform > 1000 CFU/100 mL and F:T > 0.10).

Station	Date	Total	Fecal	Entero	F:T
South of USA/Mexico Border					
S0	13 Jan 15	540	30	**120**	0.06
S3	13 Jan 15	2000	100	**180**	0.05
S0	20 Jan 15	3000	240	**340**	0.08
S0	3 Mar 15	3000	120	**800**	0.04
S0	17 Mar 15	660	40	**240**	0.06
S0	24 Mar 15	1700	120	**460**	0.07
S0	7 Apr 15	3400	240	**280**	0.07
S0	16 Jun 15	**180,000**	400	**1200**	<0.01
S2	18 Aug 15	820	6	**140**	0.01
S2	25 Aug 15	940	14	**180**	0.01
S2	1 Sep 15	140	4	**120**	0.03
S0	15 Sep 15	1400	62	**1400**	0.04
S3	15 Sep 15	340	2	**110**	0.01
S0	6 Oct 15	600	56	**300**	0.09
S2	13 Oct 15	400	40	**120**	0.10
S0	20 Oct 15	78	2	**2600**	0.03
S2	20 Oct 15	260	32	**180**	0.12
S2	3 Nov 15	800	82	**440**	0.10
S0	1 Dec 15	3600	180	**1800**	0.05
S0	15 Dec 15	**>16,000**	360	**1200**	0.02
S0	21 Dec 15	**12,000**	**440**	**4400**	0.04
S0	28 Dec 15	**11,000**	**3000**	**11,000**	**0.27**
North of USA/Mexico Border					
S5[a]	2 Jan 15	ns	ns	**18,000**	—
S5[a]	4 Jan 15	ns	ns	**>12,000**	—
S11	6 Jan 15	4800	240	**110**	0.05
S5	6 Jan 15	2000	280	**110**	**0.14**
S11[a]	8 Jan 15	ns	ns	**240**	—
S5[a]	8 Jan 15	7200	**840**	**340**	**0.12**
S5[a]	9 Jan 15	200	32	**120**	0.16

[a] Resample; ns = not sampled

Appendix B.4 *continued*

Station	Date	Total	Fecal	Entero	F:T
S10	13 Jan 15	**>16,000**	**6200**	**2400**	**0.39**
S11	13 Jan 15	10,000	**700**	**220**	0.07
S4	13 Jan 15	**>16,000**	**3400**	**940**	**0.21**
S5	13 Jan 15	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10[a]	15 Jan 15	**>16,000**	**2600**	**640**	**0.16**
S11[a]	15 Jan 15	6800	260	**160**	0.04
S5[a]	15 Jan 15	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10[a]	16 Jan 15	9600	280	**160**	0.03
S5[a]	16 Jan 15	**>16,000**	**5400**	**2200**	**0.34**
S10	3 Feb 15	**>16,000**	300	14	0.02
S4	3 Feb 15	**>16,000**	320	32	0.02
S5	3 Feb 15	**11,000**	110	16	0.01
S10	24 Feb 15	**14,000**	**940**	100	0.07
S5	24 Feb 15	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10[a]	26 Feb 15	3400	**580**	ns	**0.17**
S5[a]	26 Feb 15	**>16,000**	**>12,000**	**3000**	**0.75**
S5[a]	27 Feb 15	**>16,000**	**2800**	**300**	**0.18**
S5[a]	1 Mar 15	**>16,000**	**>12,000**	**>12,000**	**0.75**
S11	3 Mar 15	**>16,000**	**14,000**	**6000**	**0.88**
S12	3 Mar 15	**>16,000**	**3800**	**7400**	**0.24**
S5	3 Mar 15	**>16,000**	**>12,000**	**>12,000**	**0.75**
S6	3 Mar 15	2600	400	**320**	**0.15**
S8	3 Mar 15	4800	**420**	**300**	0.09
S9	3 Mar 15	1000	74	**260**	0.07
S12[a]	5 Mar 15	800	200	**120**	0.25
S8[a]	5 Mar 15	ns	ns	**150**	—
S5	10 Mar 15	2000	300	30	**0.15**
S5[a]	12 Mar 15	2400	360	ns	**0.15**
S5	12 May 15	**>16,000**	**2800**	**280**	**0.18**
S10	19 May 15	**12,000**	**440**	28	0.04
S11	19 May 15	**>16,000**	**1000**	**260**	0.06
S5	19 May 15	**>16,000**	**4800**	**1000**	**0.30**
S11[a]	21 May 15	8600	**500**	48	0.06
S5[a]	21 May 15	**>16,000**	**5000**	**620**	**0.31**
S11	21 Jul 15	**>16,000**	**>12,000**	**1500**	**0.75**
S12	21 Jul 15	**>16,000**	**2800**	64	**0.18**
S5	21 Jul 15	**>16,000**	**>12,000**	**11,000**	**0.75**
S6	21 Jul 15	**>16,000**	**>12,000**	**880**	**0.75**
S8	21 Jul 15	**13,000**	**2600**	72	**0.20**
S9	21 Jul 15	**28,000**	**4000**	98	**0.14**

[a] Resample; ns = not sampled

Appendix B.4 *continued*

Station	Date	Total	Fecal	Entero	F:T
S11[a]	23 Jul 15	**13,000**	**940**	42	0.07
S5[a]	23 Jul 15	**>16,000**	**15,000**	**1600**	**0.94**
S6[a]	23 Jul 15	1200	220	4	**0.18**
S11[a]	24 Jul 15	9200	**700**	ns	0.08
S5[a]	24 Jul 15	**15,000**	**1300**	90	0.09
S6[a]	24 Jul 15	4800	**460**	ns	0.10
S11	6 Oct 15	**>16,000**	**>12,000**	**>12,000**	**0.75**
S12	6 Oct 15	**>16,000**	**980**	**500**	0.06
S5	6 Oct 15	**>16,000**	**>12,000**	**>12,000**	**0.75**
S6	6 Oct 15	**>16,000**	**9800**	**6400**	**0.61**
S4	17 Nov 15	2200	280	**120**	**0.13**
S4	24 Nov 15	120	32	**130**	0.27
S4	15 Dec 15	1600	120	**110**	0.08
S10	21 Dec 15	**>16,000**	**700**	**740**	0.04
S4	21 Dec 15	**14,000**	100	**400**	0.01
S5	21 Dec 15	**21,000**	220	**460**	0.01
S10[a]	23 Dec 15	ns	ns	**>12,000**	—
S4[a]	23 Dec 15	ns	ns	**13,000**	—
S5[a]	23 Dec 15	ns	ns	**>12000**	—
S10[a]	24 Dec 15	**11,000**	**800**	**320**	0.07
S10	28 Dec 15	800	96	**120**	0.12

[a] Resample; ns = not sampled

Appendix B.5

Summary of bacteria levels from SBOO kelp and other offshore stations during 2015. Total coliform, fecal coliform, and *Enterococcus* densities are expressed as mean CFU/100 mL for all stations along each depth contour by month; n = total number of samples per month; ns = not sampled. Rain data are from Lindbergh Field, San Diego, CA.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Rain (in):	0.42	0.28	0.93	0.02	2.39	0.04	1.72	0.01	1.24	0.43	1.55	0.89
Kelp Stations												
9-m Depth Contour												
n	90	90	90	90	90	72	90	90	90	90	90	90
Total	252	619	329	3	59	11	8	5	12	15	106	767
Fecal	19	49	27	2	7	2	4	2	2	2	15	17
Entero	13	20	6	2	15	2	2	2	3	2	5	13
19-m Depth Contour												
n	15	15	15	15	15	12	15	15	15	15	15	15
Total	7	4	3	2	2	8	3	2	2	11	16	32
Fecal	2	2	2	2	2	2	2	2	2	3	3	2
Entero	5	2	3	2	2	2	2	2	2	2	2	3
Other Offshore Stations												
9-m Depth Contour (n = 15)												
Total	ns	12	ns	ns	15	ns	ns	2	ns	ns	4	ns
Fecal	ns	3	ns	ns	3	ns	ns	2	ns	ns	2	ns
Entero	ns	2	ns	ns	3	ns	ns	2	ns	ns	2	ns
19-m Depth Contour (n = 9)												
Total	ns	8	ns	ns	10	ns	ns	2	ns	ns	2	ns
Fecal	ns	2	ns	ns	2	ns	ns	4	ns	ns	2	ns
Entero	ns	2	ns	ns	2	ns	ns	2	ns	ns	2	ns
28-m Depth Contour (n = 24)												
Total	ns	49	ns	ns	5	ns	ns	2	ns	ns	2	ns
Fecal	ns	3	ns	ns	3	ns	ns	2	ns	ns	2	ns
Entero	ns	8	ns	ns	2	ns	ns	2	ns	ns	2	ns
38-m Depth Contour (n = 9)												
Total	ns	2	ns	ns	2	ns	ns	2	ns	ns	2	ns
Fecal	ns	2	ns	ns	2	ns	ns	2	ns	ns	2	ns
Entero	ns	2	ns	ns	2	ns	ns	2	ns	ns	2	ns
55-m Depth Contour (n = 6)												
Total	ns	8	ns	ns	2	ns	ns	2	ns	ns	2	ns
Fecal	ns	2	ns	ns	2	ns	ns	2	ns	ns	2	ns
Entero	ns	2	ns	ns	2	ns	ns	2	ns	ns	6	ns

Appendix B.6

Summary of elevated bacteria densities in samples collected from SBOO kelp and other offshore stations during 2015. Bold values exceed benchmarks for total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), *Enterococcus* (>104 CFU/100 mL), and/or the FTR criterion (total coliform >1000 CFU/100 mL and F:T>0.10).

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
Kelp Stations						
I40	5 Jan 15	2	**>16,000**	**780**	**720**	0.05
I19	4 Feb 15	11	5000	60	**120**	0.01
I24	4 Feb 15	2	**20,000**	**1800**	**500**	0.09
I25	4 Feb 15	2	**>16,000**	**1200**	**760**	0.08
I40	4 Feb 15	2	1100	200	66	**0.18**
I24	7 Mar 15	6	**14,000**	**880**	86	0.06
I24	7 Mar 15	11	7600	**600**	32	0.08
I25	7 Mar 15	6	2200	240	8	**0.11**
I19	15 May 15	2	3000	260	**840**	0.09
I19	30 Nov 15	11	4400	400	**120**	0.09
I19	21 Dec 15	6	9800	**520**	**220**	0.05
I19	21 Dec 15	11	**17,000**	150	**200**	0.01
Other Offshore Stations						
I12	4 Feb 15	2	1100	20	**140**	0.02

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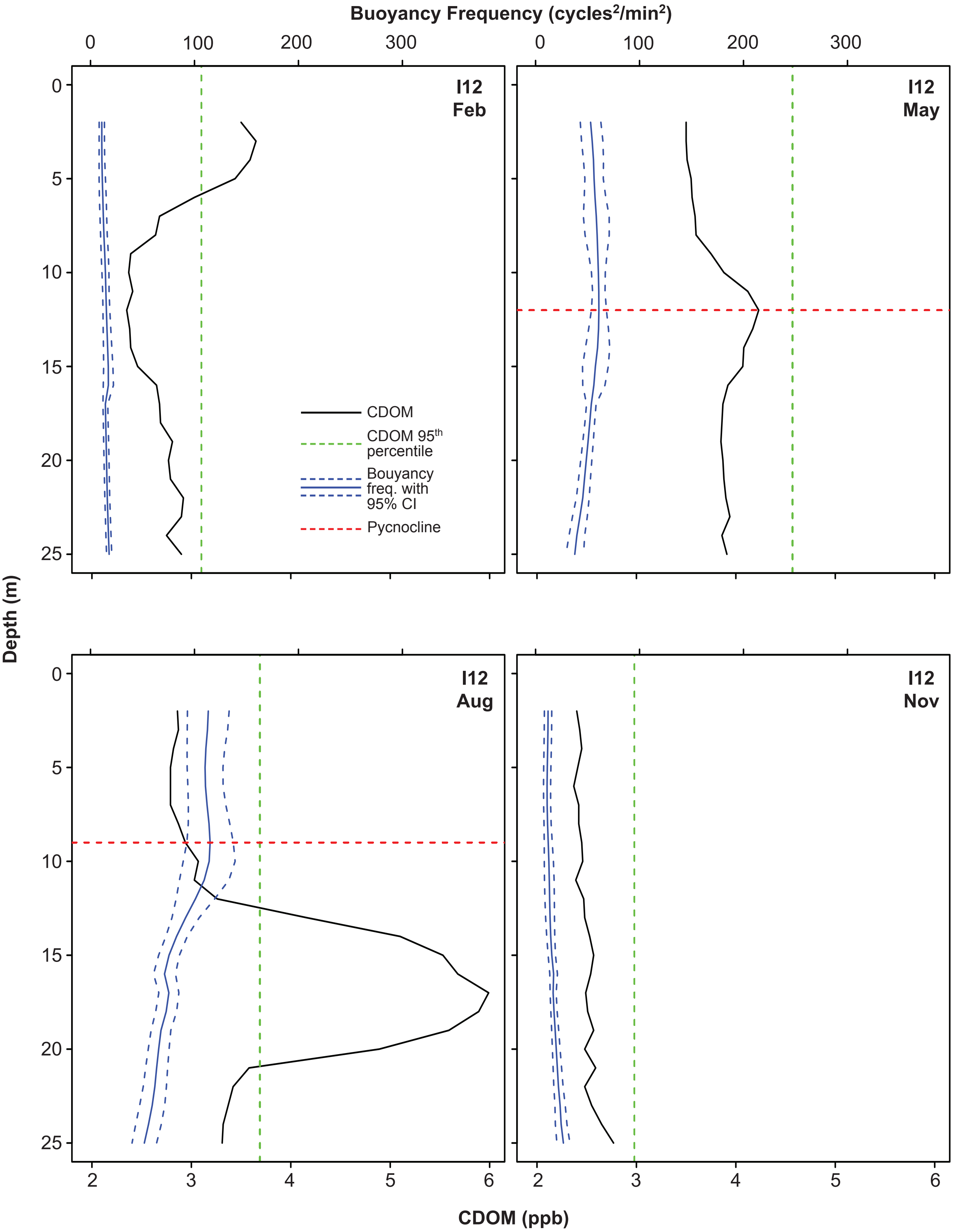
Appendix B.7

Summary of oceanographic data within potential plume at SBOO offshore stations and corresponding reference values during 2015. Highlighted/bold values indicate out-of-range values. Plume width is the number of meters in the water column where CDOM measurements exceeded the 95th percentile. DO = dissolved oxygen; XMS = transmissivity; SD = standard deviation; CI = confidence interval.

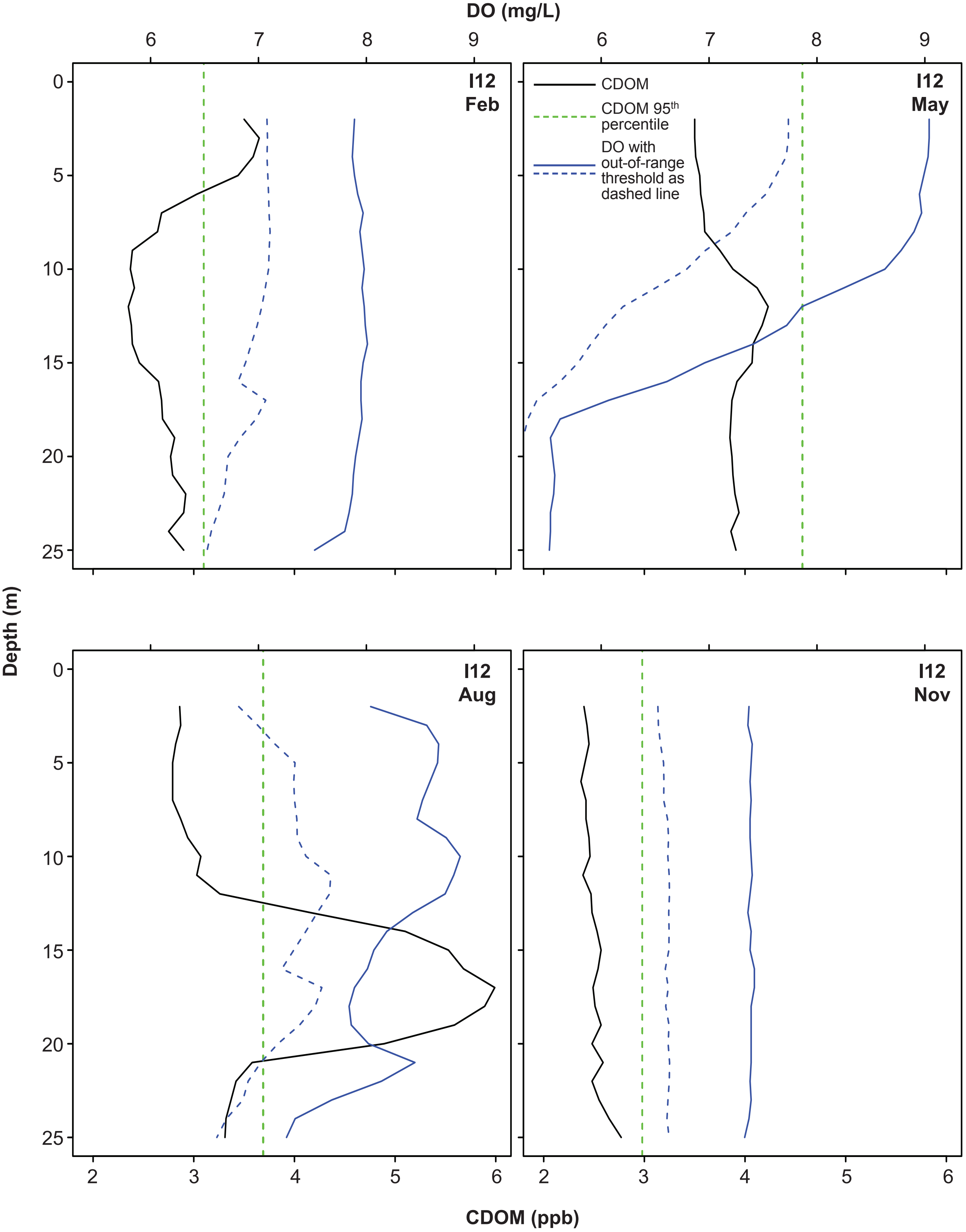
			Potential Plume			Reference		
Station	**Date**	**Plume Width (m)**	**Mean DO**	**Mean pH**	**Mean XMS**	**DO (Mean - SD)**	**pH (Mean)**	**XMS (Mean - 95% CI)**
I10	03 Feb 15	8	7.2	8.1	**81**	7.8	8.2	86
I20	03 Feb 15	4	7.6	8.2	87	7.3	8.2	77
I6	03 Feb 15	1	7.2	8.1	86	7.4	8.2	82
I12[a]	04 Feb 15	4	7.9	8.2	87	7.9	8.2	87
I34[a]	05 Feb 15	11	7.7	8.2	**79**	7.9	8.2	87
I15	06 May 15	7	6.5	8.0	78	6.3	8.0	78
I39[a]	06 May 15	5	7.9	8.1	**67**	8.2	8.2	77
I30	08 May 15	1	7.3	8.1	**74**	6.4	8.1	76
I31[a]	08 May 15	2	7.5	8.1	**74**	6.5	8.1	76
I35[a]	08 May 15	2	7.3	8.1	**71**	6.6	8.1	76
I12[a]	05 Aug 15	8	8.0	8.1	85	8.2	8.2	83
I23[a]	05 Aug 15	3	7.6	8.1	**82**	8.3	8.2	83
I27[a]	05 Aug 15	5	7.1	8.1	86	7.6	8.2	82
I35[a]	06 Aug 15	4	7.8	8.0	83	8.2	8.2	83
I9	09 Nov 15	1	7.4	8.2	89	7.4	8.2	88
I34[a]	12 Nov 15	15	7.2	8.1	**81**	7.3	8.2	88

[a] Stations located within State jurisdictional waters



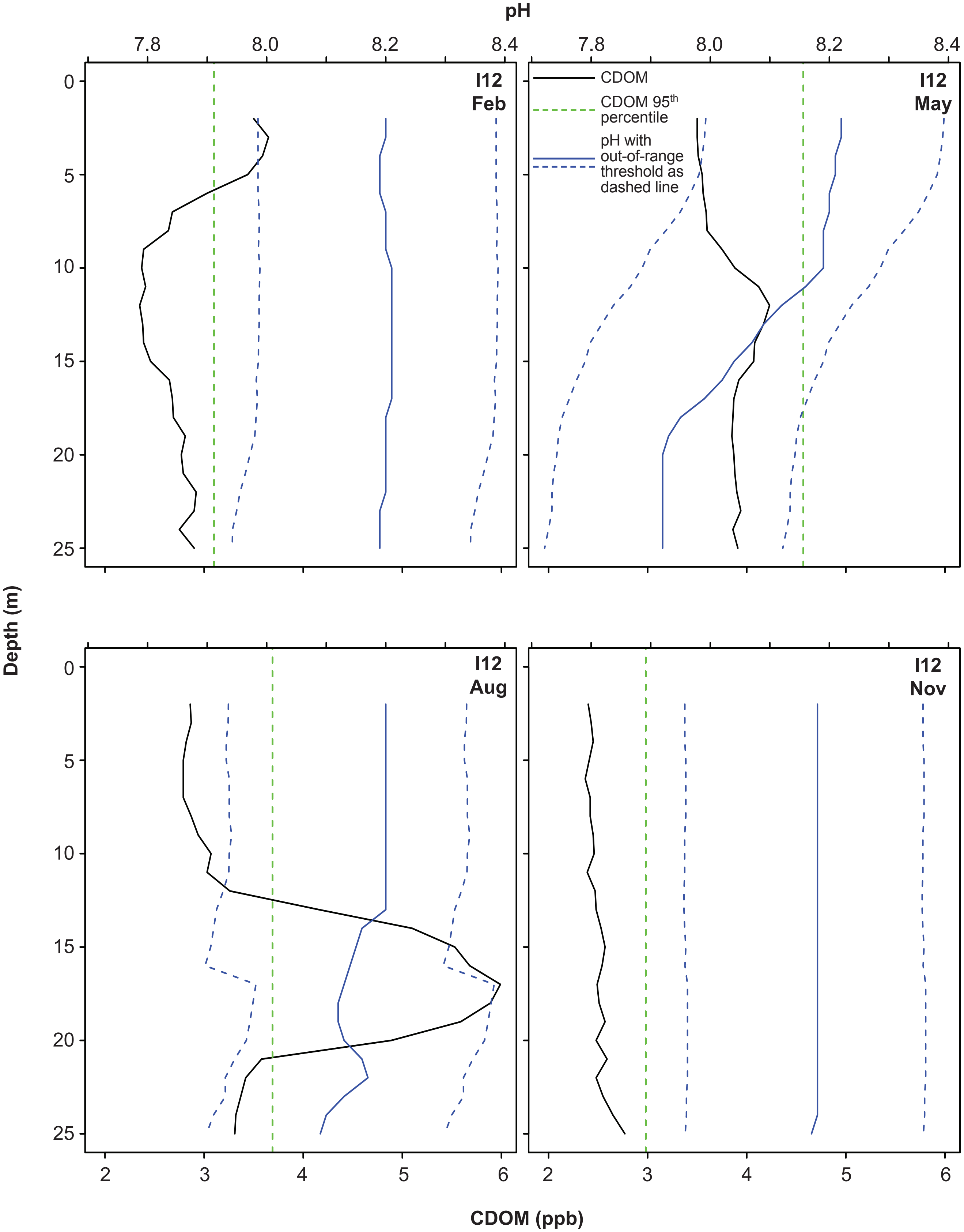
Appendix B.8

Representative vertical profiles of CDOM and buoyancy frequency from SBOO nearfield station I12 during 2015.



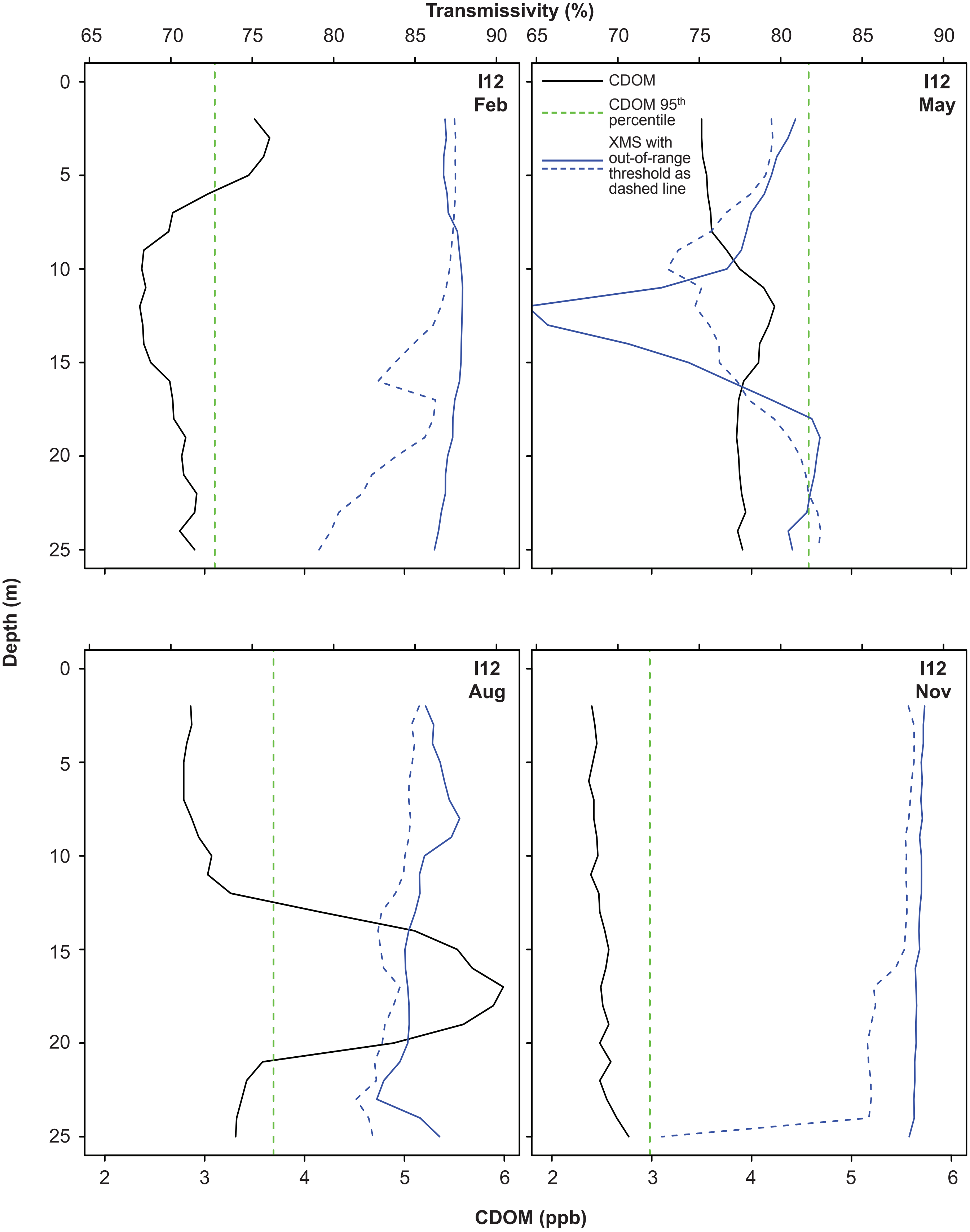
Appendix B.9

Representative vertical profiles of CDOM and dissolved oxygen (DO) from SBOO nearfield station I12 during 2015.



Appendix B.10

Representative vertical profiles of CDOM and pH from SBOO nearfiled station I12 during 2015.



Appendix B.11

Representative vertical profiles of CDOM and transmissivity from SBOO nearfield station I12 during 2015.

Appendix C

Supporting Data

2015 SBOO Stations

Sediment Conditions

Appendix C.1

Constituents and method detection limits (MDL) used for the analysis of sediments during 2015.

Parameter	MDL	Parameter	MDL
Organic Indicators			
Total Nitrogen (TN, % wt.)	0.01, 0.002[a]	Total Sulfides (ppm)	0.14
Total Organic Carbon (TOC, % wt.)	0.04	Total Volatile Solids (TVS, % wt.)	0.11
Metals (ppm)			
Aluminum (Al)	2	Lead (Pb)	0.8
Antimony (Sb)	0.3	Manganese (Mn)	0.08
Arsenic (As)	0.33	Mercury (Hg)	0.004
Barium (Ba)	0.02	Nickel (Ni)	0.1
Beryllium (Be)	0.01	Selenium (Se)	0.24
Cadmium (Cd)	0.06	Silver (Ag)	0.04
Chromium (Cr)	0.1	Thallium (Tl)	0.5
Copper (Cu)	0.2	Tin (Sn)	0.3
Iron (Fe)	9	Zinc (Zn)	0.25
Chlorinated Pesticides (ppt)			
Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	100	HCH, Delta isomer	220
HCH, Beta isomer	50	HCH, Gamma isomer	190
Total Chlordane			
Alpha (cis) Chlordane	160	Heptachlor epoxide	300
Cis Nonachlor	380	Methoxychlor	90
Gamma (trans) Chlordane	190	Oxychlordane	1200
Heptachlor	120	Trans Nonachlor	240
Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	100	p,p-DDE	90, 260[a]
o,p-DDE	60	p,p-DDMU[b]	—
o,p-DDT	110	p,p-DDT	70
p,p-DDD	160		
Miscellaneous Pesticides			
Aldrin	70	Endrin	510
Alpha Endosulfan	720	Endrin aldehyde	2400
Beta Endosulfan	780	Hexachlorobenzene (HCB)	70
Dieldrin	340	Mirex	60
Endosulfan Sulfate	1100		

[a] MDL differed from Q1 to Q3 for this parameter

[b] No MDL available for this parameter

Appendix C.1 *continued*

Parameter	MDL	Parameter	MDL
Polychlorinated Biphenyl Congeners (PCBs) (ppt)			
PCB 18	90	PCB 126	70
PCB 28	60	PCB 128	80
PCB 37	90	PCB 138	80
PCB 44	100	PCB 149	110
PCB 49	70	PCB 151	80
PCB 52	90	PCB 153/168	150
PCB 66	100	PCB 156	90
PCB 70	60	PCB 157	100
PCB 74	100	PCB 158	70
PCB 77	110	PCB 167	30
PCB 81	130	PCB 169	90
PCB 87	200	PCB 170	80
PCB 99	120	PCB 177	70
PCB 101	100	PCB 180	80
PCB 105	50	PCB 183	60
PCB 110	110	PCB 187	110
PCB 114	130	PCB 189	60
PCB 118	90	PCB 194	80
PCB 119	80	PCB 201	70
PCB 123	130	PCB 206	50
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)			
1-methylnaphthalene	20	Benzo[G,H,I]perylene	20
1-methylphenanthrene	20	Benzo[K]fluoranthene	20
2,3,5-trimethylnaphthalene	20	Biphenyl	30
2,6-dimethylnaphthalene	20	Chrysene	40
2-methylnaphthalene	20	Dibenzo(A,H)anthracene	20
3,4-benzo(B)fluoranthene	20	Fluoranthene	20
Acenaphthene	20	Fluorene	20
Acenaphthylene	30	Indeno(1,2,3-CD)pyrene	20
Anthracene	20	Naphthalene	30
Benzo[A]anthracene	20	Perylene	30
Benzo[A]pyrene	20	Phenanthrene	30
Benzo[e]pyrene	20	Pyrene	20

Appendix C.2

Particle size classification schemes (based on Folk 1980) used in the analysis of sediments during 2015. Included is a subset of the Wentworth scale presented as “phi” categories with corresponding Horiba channels, sieve sizes, and size fractions.

Wentworth Scale

Phi Size	Horiba[a] Min µm	Horiba[a] Max µm	Sieve Size	Sub-Fraction	Fraction
-1	—	—	SIEVE_2000	Granules	Coarse Particles
0	1100	2000	SIEVE_1000	Very coarse sand	Coarse Particles
1	590	1000	SIEVE_500	Coarse sand	Med-Coarse Sands
2	300	500	SIEVE_250	Medium sand	Med-Coarse Sands
3	149	250	SIEVE_125	Fine sand	Fine Sands
4	64	125	SIEVE_63	Very fine sand	Fine Sands
5	32	62.5	SIEVE_0[b]	Coarse silt	Fine Particles[c]
6	16	31	—	Medium silt	Fine Particles[c]
7	8	15.6	—	Fine silt	Fine Particles[c]
8	4	7.8	—	Very fine silt	Fine Particles[c]
9	≤	3.9	—	Clay	Fine Particles[c]

[a] Values correspond to Horiba channels; particles >2000 µm measured by sieve

[b] SIEVE_0 = sum of all silt and clay, which cannot be distinguished for samples processed by nested sieves

[c] Fine particles also referred to as percent fines

Appendix C.3

Summary of the constituents that make up total DDT, total chlordane, total PCB, and total PAH in sediments from the SBOO region during 2015; nd = not detected.

Station	Class	Constituent	Winter	Summer	Units
I-1	DDT	p,p-DDE	nd	140	ppt
I-1	PAH	Biphenyl	nd	3	ppb
I-2	PAH	Biphenyl	nd	6	ppb
I-8	DDT	p,p-DDE	nd	170	ppt
I-9	DDT	p,p-DDE	nd	210	ppt
I-9	PAH	Biphenyl	nd	6	ppb
I-12	Chlordane	Methoxychlor	600	nd	ppb
I-13	PCB	PCB 18	nd	220	ppt
I-13	PCB	PCB 28	nd	260	ppt
I-13	PCB	PCB 37	nd	140	ppt
I-13	PCB	PCB 44	nd	170	ppt
I-13	PCB	PCB 49	nd	130	ppt
I-13	PCB	PCB 52	nd	150	ppt
I-13	PCB	PCB 66	nd	170	ppt
I-13	PCB	PCB 70	nd	160	ppt
I-13	PCB	PCB 74	nd	65	ppt
I-14	DDT	p,p-DDE	330	340	ppt
I-14	PCB	PCB 110	420	nd	ppt
I-14	PCB	PCB 118	430	nd	ppt
I-14	PCB	PCB 153/168	320	nd	ppt
I-15	DDT	p,p-DDE	380	nd	ppt
I-15	PCB	PCB 49	81	nd	ppt
I-15	PCB	PCB 52	100	nd	ppt
I-16	PCB	PCB 18	nd	330	ppt
I-16	PCB	PCB 28	nd	300	ppt
I-16	PCB	PCB 37	nd	110	ppt
I-16	PCB	PCB 44	nd	170	ppt
I-16	PCB	PCB 49	nd	110	ppt
I-16	PCB	PCB 52	nd	170	ppt
I-16	PCB	PCB 66	nd	140	ppt
I-16	PCB	PCB 70	nd	170	ppt
I-16	PCB	PCB 74	nd	84	ppt

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
I-20	PAH	3,4-benzo(B)fluoranthene	nd	4	ppb
I-20	PAH	Benzo[A]pyrene	nd	3	ppb
I-20	PAH	Benzo[K]fluoranthene	nd	4	ppb
I-20	PAH	Biphenyl	nd	6	ppb
I-22	DDT	p,p-DDE	320	176	ppt
I-22	PAH	2,6-dimethylnaphthalene	nd	6	ppb
I-22	PAH	Biphenyl	nd	7	ppb
I-23	DDT	p,p-DDE	nd	160	ppt
I-23	PAH	Biphenyl	nd	7	ppb
I-23	PCB	PCB 66	99	nd	ppt
I-23	PCB	PCB 70	170	nd	ppt
I-23	PCB	PCB 74	67	nd	ppt
I-23	PCB	PCB 101	490	nd	ppt
I-23	PCB	PCB 105	220	nd	ppt
I-23	PCB	PCB 110	620	nd	ppt
I-23	PCB	PCB 118	550	nd	ppt
I-23	PCB	PCB 138	310	nd	ppt
I-23	PCB	PCB 149	270	nd	ppt
I-23	PCB	PCB 153/168	630	nd	ppt
I-23	PCB	PCB 180	260	nd	ppt
I-27	DDT	p,p-DDE	165	200	ppt
I-27	PCB	PCB 110	130	nd	ppt
I-27	PCB	PCB 118	110	nd	ppt
I-27	PCB	PCB 138	120	nd	ppt
I-28	DDT	p,p-DDE	770	540	ppt
I-28	PAH	3,4-benzo(B)fluoranthene	nd	9	ppb
I-28	PAH	Biphenyl	nd	7	ppb
I-28	PAH	Chrysene	nd	11	ppb
I-29	DDT	p,p-DDD	nd	160	ppt
I-29	DDT	p,p-DDE	nd	700	ppt
I-29	PAH	2,6-dimethylnaphthalene	8	nd	ppb
I-29	PAH	Biphenyl	nd	6	ppb
I-29	PAH	Fluoranthene	nd	8	ppb
I-29	PAH	Pyrene	nd	8	ppb
I-30	DDT	p,p-DDE	570	200	ppt
I-30	PAH	Biphenyl	nd	7	ppb

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
I-33	PAH	2,6-dimethylnaphthalene	5	8	ppb
I-33	PAH	Biphenyl	nd	7	ppb
I-34	PAH	2,6-dimethylnaphthalene	nd	6	ppb
I-34	PAH	Biphenyl	nd	6	ppb
I-35	DDT	p,p-DDD	nd	140	ppt
I-35	DDT	p,p-DDE	590	510	ppt
I-35	PAH	2,6-dimethylnaphthalene	8	11	ppb
I-35	PAH	3,4-benzo(B)fluoranthene	11	8	ppb
I-35	PAH	Benzo[A]pyrene	11	12	ppb
I-35	PAH	Benzo[e]pyrene	7	nd	ppb
I-35	PAH	Benzo[G,H,I]perylene	nd	12	ppb
I-35	PAH	Biphenyl	nd	8	ppb
I-35	PAH	Chrysene	8	8	ppb
I-35	PAH	Fluoranthene	14	17	ppb
I-35	PAH	Indeno(1,2,3-CD)pyrene	nd	8	ppb
I-35	PAH	Phenanthrene	nd	7	ppb
I-35	PAH	Pyrene	15	14	ppb
I-35	PCB	PCB 28	nd	64	ppt
I-35	PCB	PCB 49	nd	30	ppt
I-35	PCB	PCB 52	nd	69	ppt
I-35	PCB	PCB 66	nd	79	ppt
I-35	PCB	PCB 70	nd	72	ppt

Appendix C.4

Summary of particle size parameters (%) for each SBOO station sampled during winter 2015. Visual observations are from sieved “grunge” (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VCSand = Very Coarse Sand; CSand = Coarse Sand; MSand = Medium Sand; FSand = Fine Sand; VFSand = Very Fine Sand; CSilt = Coarse Silt; MSilt = Medium Silt; FSilt = Fine Silt; VFSilt = Very Fine Silt.

		Coarse Particles		Med-Coarse Sands		Fine Sands		Fine Particles					Visual Observations
		Granules	VCSand	CSand	MSand	FSand	VFSand	CSilt	MSilt	FSilt	VFSilt	Clay	
19-m Stations	I35	0.0	0.0	0.0	2.0	17.0	40.3	23.0	8.4	7.0	2.3	0.1	organic debris[b]
	I34	0.0	0.0	5.4	45.1	44.8	4.5	0.2	0.0	0.0	0.0	0.0	shell hash
	I31	0.0	0.0	0.0	0.7	18.3	72.9	5.2	0.0	0.8	1.8	0.3	
	I23[s]	9.7	12.9	34.8	27.6	2.5	2.7	9.9	—	—	—	—	shell hash
	I18	0.0	0.0	0.0	1.3	19.5	68.6	8.0	0.0	1.0	1.4	0.1	
	I10	0.0	0.0	0.0	1.8	24.2	65.2	6.1	0.0	1.0	1.5	0.1	
	I4	0.0	0.0	3.0	22.8	33.5	33.5	5.4	0.2	0.9	0.7	0.0	shell hash
28-m Stations	I33	0.0	0.0	0.0	2.8	34.0	53.2	4.3	0.8	2.5	2.3	0.1	organic debris[b], man-made fibers
	I30	0.0	0.0	0.0	0.7	13.5	66.0	14.4	1.2	2.2	1.9	0.1	organic debris[b]
	I27	0.0	0.0	0.0	0.6	13.7	67.9	13.0	0.8	1.8	2.0	0.2	organic debris[b]
	I22	0.0	0.0	0.1	9.1	32.0	45.2	8.9	1.1	2.0	1.6	0.0	organic debris[b]
	I14[a]	0.0	0.0	0.0	1.6	18.2	63.0	11.5	0.8	2.2	2.5	0.2	organic debris[b]
	I16[a]	0.0	0.0	3.0	19.4	37.5	32.2	4.6	0.8	1.5	1.0	0.0	organic debris[b]
	I15[a]	0.0	0.0	4.7	30.2	32.2	23.5	6.2	1.1	1.5	0.5	0.0	*Spio*. tubes[c], fouling hydroids
	I12[a]	0.0	0.0	6.5	39.9	32.6	16.1	2.7	0.8	1.1	0.3	0.0	shell hash, organic debris[b]
	I9	0.0	0.0	0.0	0.9	15.5	64.3	13.4	1.0	2.3	2.5	0.2	
	I6	0.0	1.6	27.6	53.6	12.8	2.5	0.8	0.2	0.7	0.1	0.0	red relict sand, organic debris[b]
	I2	0.0	0.1	9.7	53.4	31.3	3.1	0.3	0.6	1.2	0.3	0.0	organic debris[b]
	I3	0.0	1.1	19.5	59.8	18.5	0.9	0.0	0.0	0.2	0.0	0.0	
38-m Stations	I29[s]	0.4	13.3	70.3	13.0	0.6	0.3	2.2	—	—	—	—	red relict sand
	I21	0.0	7.1	48.2	34.2	5.9	1.5	0.7	0.8	1.2	0.3	0.0	red relict sand, shell hash
	I13	0.0	4.7	45.6	42.2	5.6	0.9	0.0	0.2	0.7	0.1	0.0	red relict sand, shell hash, *Spio*. tubes[c]
	I8	0.0	0.1	10.9	55.8	26.2	3.9	0.8	0.8	1.2	0.3	0.0	*Spio*. tubes[c],
55-m Stations	I28	0.0	2.9	17.5	8.7	9.2	26.0	16.5	5.5	8.5	4.9	0.4	black sand
	I20	0.0	10.4	70.9	14.8	2.6	0.2	0.0	0.4	0.8	0.0	0.0	red relict sand
	I7	0.0	9.8	47.4	37.0	4.3	0.4	0.0	0.2	0.8	0.1	0.0	red relict sand
	I1	0.0	0.0	0.0	5.4	47.7	37.4	3.3	1.0	2.9	2.3	0.1	

[a] Nearfield stations; [b] contained worm tubes; [c] *Spiochaetoperus* tubes; [s] measured by sieve (not Horiba; silt and clay fractions are indistinguishable)

Appendix C.4 *continued*

Summary of particle size parameters (%) for each SBOO station sampled during summer 2015. Visual observations are from sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VCSand = Very Coarse Sand; CSand = Coarse Sand; MSand = Medium Sand; FSand = Fine Sand; VFSand = Very Fine Sand; CSilt = Coarse Silt; MSilt = Medium Silt; FSilt = Fine Silt; VFSilt = Very Fine Silt.

		Coarse Particles		Med-Coarse Sands		Fine Sands		Fine Particles					Visual Observations
		Granules	VCSand	CSand	MSand	FSand	VFSand	CSilt	MSilt	FSilt	VFSilt	Clay	
19-m Stations	I35	0.0	0.0	0.0	3.3	20.4	41.1	19.1	7.2	6.8	2.2	0.0	organic debris[b]
	I34	0.0	0.0	5.4	42.5	43.2	5.1	0.9	0.9	1.5	0.5	0.0	shell hash, organic debris[b]
	I31	0.0	0.0	0.0	0.7	18.6	72.6	4.9	0.0	0.9	2.0	0.3	organic debris[b]
	I23[s]	0.6	0.9	5.9	18.0	14.2	50.0	10.5	—	—	—	—	shell hash
	I18	0.0	0.0	0.0	0.8	18.7	69.9	7.3	0.0	1.3	2.0	0.2	
	I10	0.0	0.0	0.0	1.5	23.4	64.9	5.9	0.1	1.9	2.3	0.2	organic debris[b]
	I4	0.0	0.1	8.1	32.7	28.0	23.9	3.7	1.1	1.7	0.6	0.0	worm sand tubes
28-m Stations	I33	0.0	0.0	0.0	4.0	37.7	47.6	3.8	0.9	3.0	2.7	0.1	organic debris[b], shell hash
	I30	0.0	0.0	0.0	1.3	15.5	63.2	13.5	1.1	2.5	2.6	0.3	organic debris[b]
	I27	0.0	0.0	0.0	0.8	15.4	66.7	10.8	0.7	2.5	2.9	0.2	organic debris[b]
	I22	0.0	0.0	0.1	8.8	31.0	43.2	9.7	1.6	3.1	2.4	0.1	organic debris[b]
	I14[a]	0.0	0.0	0.0	2.1	21.4	60.9	10.6	0.7	2.0	2.2	0.1	organic debris[b]
	I16[a]	0.0	0.1	10.6	48.5	29.4	7.0	1.6	1.1	1.5	0.3	0.0	organic debris[b], shell hash
	I15[a]	0.0	0.4	13.2	54.3	20.0	7.3	2.5	0.9	1.2	0.3	0.0	organic debris[b]
	I12[a]	0.0	0.0	5.4	28.8	34.6	23.6	4.1	1.2	1.8	0.6	0.0	shell hash, wrm snd tubes, organic debris[b]
	I9	0.0	0.0	0.0	1.4	15.3	63.2	14.4	1.0	2.2	2.3	0.2	organic debris[b]
	I6	0.0	2.3	31.7	53.9	8.9	1.3	0.6	0.6	0.7	0.0	0.0	red relict sand, shell hash
	I2	0.0	0.1	10.6	57.4	26.9	2.1	0.2	0.8	1.5	0.5	0.0	organic debris[b]
	I3	0.0	12.3	52.2	31.2	3.9	0.1	0.0	0.0	0.0	0.0	0.0	red relict sand
38-m Stations	I29	0.0	0.0	0.0	4.9	21.1	43.1	19.3	4.0	4.9	2.6	0.1	organic debris[b]
	I21	0.0	1.7	30.3	53.2	10.6	1.8	0.5	0.7	1.1	0.3	0.0	red relict sand, shell hash
	I13[s]	0.4	0.3	46.1	44.8	0.5	4.5	3.4	—	—	—	—	red relict sand, shell hash
	I8	0.0	1.4	25.0	56.5	13.1	1.4	0.2	0.7	1.3	0.3	0.0	
55-m Stations	I28[s]	9.2	11.9	19.2	11.4	4.4	22.1	21.8	—	—	—	—	black sand
	I20	0.0	17.3	40.6	26.3	7.9	1.4	0.8	1.4	2.5	0.7	0.0	red relict sand
	I7	0.0	19.0	41.2	24.0	5.3	1.8	1.1	1.9	3.4	0.9	0.0	red relict sand
	I1	0.0	0.0	0.0	5.8	49.4	35.1	3.0	1.1	3.2	2.4	0.1	algae

[a] Nearfield stations; [b] contained worm tubes; [s] measured by sieve (not Horiba; silt and clay fractions are indistinguishable)

Appendix C.5

Summary of organic indicators in sediments from SBOO stations sampled during winter and summer 2015; nd = not detected.

	Winter				Summer			
	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
19-m Stations								
I35	6.10	0.037	0.29	1.60	7.27	0.022	0.36	1.60
I34	0.80	0.016	0.08	0.60	1.30	nd	0.18	0.70
I31	1.11	0.017	0.07	0.70	1.49	0.020	0.18	0.70
I23	1.98	0.029	1.56	1.10	2.36	0.017	0.23	0.80
I18	4.75	0.013	0.09	0.70	1.35	0.013	0.19	0.80
I10	1.50	0.014	0.09	0.80	2.30	0.021	0.19	0.70
I4	9.67	0.013	0.05	0.70	0.69	0.013	0.14	0.60
28-m Stations								
I33	2.70	0.027	0.16	1.30	2.69	0.007	0.58	1.10
I30	2.26	0.025	0.15	1.10	2.52	0.022	0.24	1.00
I27	5.12	0.020	0.15	0.90	2.15	0.018	0.20	1.00
I22	2.18	0.018	0.13	1.10	1.70	0.021	0.24	0.80
I14[a]	7.09	0.023	0.17	1.20	2.32	0.045	0.22	1.10
I16[a]	2.11	0.020	0.11	0.80	0.80	0.017	0.13	0.60
I15[a]	3.39	0.017	0.09	0.80	0.56	0.012	0.12	0.50
I12[a]	2.22	0.012	0.04	0.60	1.85	0.015	0.16	0.70
I9	nd	0.024	0.13	1.00	2.61	0.024	0.22	1.10
I6	0.30	0.010	nd	0.40	0.26	0.008	0.12	0.40
I2	0.31	0.012	nd	0.40	0.50	0.012	0.13	0.50
I3	0.17	nd	0.04	0.30	0.23	0.006	nd	0.30
38-m Stations								
I29	0.21	0.011	nd	0.50	1.85	0.031	0.44	1.60
I21	0.24	0.016	0.09	0.50	0.21	0.009	0.11	0.50
I13	0.20	0.010	0.04	0.50	nd	0.010	0.10	0.40
I8	0.61	0.011	nd	0.50	0.58	nd	0.12	0.60
55-m Stations								
I28	2.46	0.059	0.52	1.80	3.97	0.040	0.54	1.60
I20	nd	0.011	nd	0.50	0.17	0.007	nd	0.40
I7	nd	0.010	nd	0.50	0.23	0.010	0.10	0.50
I1	0.40	0.021	0.12	0.95	1.69	0.029	0.20	0.85
Detection Rate (%)	89	96	78	100	96	93	93	100

[a] Nearfield stations

Appendix C.6

Concentrations of trace metals (ppm) in sediments from SBOO stations sampled during winter 2015. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted in yellow (see Table 4.1); nd=not detected.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Stations																		
I35	12,700	1.4	2.23	75.80	0.19	0.10	21.9	8.0	16,600	5.6	168.0	0.018	8.0	nd	nd	nd	2.3	44.6
I34	1970	nd	1.54	8.48	0.02	nd	4.0	0.7	3230	1.6	29.3	nd	1.2	nd	nd	nd	1.3	7.7
I31	3960	nd	0.70	17.10	0.04	nd	8.2	6.0	4100	1.7	49.1	nd	2.1	nd	nd	nd	1.4	22.6
I23	1940	nd	2.64	10.00	nd	0.08	5.5	1.8	3890	1.8	29.9	nd	1.5	nd	nd	nd	1.1	11.4
I18	7130	0.6	1.40	41.70	0.08	nd	12.1	2.0	7870	1.5	87.6	nd	5.7	nd	nd	nd	0.8	15.5
I10	6070	nd	1.41	31.90	0.10	nd	10.2	1.0	6750	1.5	69.9	nd	3.7	nd	nd	2.5	nd	16.6
I4	2550	nd	0.95	11.90	0.06	nd	6.8	0.3	3450	1.3	32.6	nd	2.1	nd	nd	0.6	nd	6.8
28-m Stations																		
I33	4870	nd	1.67	26.40	nd	nd	9.2	2.8	6860	3.1	76.2	0.012	2.9	nd	nd	nd	1.6	17.5
I30	6850	0.4	1.12	35.80	nd	nd	12.3	3.2	7560	2.2	73.9	0.004	4.1	nd	nd	nd	1.4	19.5
I27	6500	nd	1.15	34.80	nd	nd	11.2	2.8	7230	2.0	72.2	nd	3.9	nd	nd	nd	1.5	18.3
I22	5600	0.4	1.15	27.90	0.07	nd	10.1	2.1	5870	1.9	62.3	nd	4.2	nd	nd	nd	1.3	19.6
I14[a]	8700	0.4	1.22	43.90	0.10	nd	12.5	3.2	8160	1.8	85.3	nd	6.2	nd	nd	nd	0.8	19.8
I16[a]	6060	0.3	1.56	27.50	0.07	nd	9.6	1.8	6670	1.4	66.3	nd	6.2	nd	nd	nd	1.0	15.4
I15[a]	5240	nd	1.75	19.90	0.07	nd	10.9	1.5	6240	1.9	52.9	nd	5.3	nd	nd	nd	0.9	13.1
I12[a]	3430	nd	1.38	15.30	0.06	nd	6.7	0.9	4200	1.1	37.6	nd	3.1	nd	nd	nd	0.7	14.9
I9	7480	0.4	1.43	40.30	0.12	nd	11.6	1.9	7780	1.4	77.8	nd	4.4	nd	nd	2.1	nd	20.0
I6	987	nd	4.41	2.38	0.04	nd	7.8	nd	3780	1.5	9.1	nd	1.5	nd	nd	3.2	nd	3.0
I2	1150	nd	0.44	2.50	0.03	nd	5.4	nd	1340	nd	10.5	0.006	0.8	nd	nd	1.6	nd	2.4
I3	839	nd	0.63	1.42	0.03	nd	5.5	nd	1300	0.9	7.3	nd	0.8	nd	0.076	2.3	nd	1.6
38-m Stations																		
I29	1300	nd	4.23	2.53	nd	nd	7.3	nd	8110	2.4	19.4	nd	1.3	nd	nd	nd	1.4	7.1
I21	2710	0.4	9.17	6.39	0.06	nd	12.5	0.3	8840	3.6	26.7	nd	4.2	nd	nd	nd	0.7	8.1
I13	1650	nd	6.41	3.65	0.05	nd	10.5	nd	6780	2.6	20.1	nd	2.9	nd	nd	nd	0.7	5.8
I8	2060	nd	1.79	5.75	0.06	nd	9.6	nd	4300	1.5	24.5	0.003	1.6	nd	nd	2.0	nd	7.2
55-m Stations																		
I28	6370	0.4	2.14	29.50	0.11	nd	11.9	4.9	8880	3.5	70.5	0.016	6.1	nd	nd	nd	2.0	21.5
I20	1950	nd	4.27	4.26	0.05	nd	6.5	nd	5550	1.7	18.3	nd	3.1	nd	nd	nd	0.7	5.6
I7	1670	nd	4.82	4.37	0.06	nd	9.9	nd	7170	2.8	25.3	nd	1.6	nd	nd	1.6	nd	6.7
I1	3140	nd	0.71	14.10	0.11	nd	7.4	0.8	3890	1.6	43.6	0.005	3.4	nd	nd	1.8	nd	8.9
Detection Rate (%)	100	33	100	100	81	7	100	70	100	96	100	26	100	0	4	33	67	100

[a] Nearfield stations

Appendix C.6 *continued*

Concentrations of trace metals (ppm) in sediments from SBOO stations sampled during summer 2015. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted in yellow (see Table 4.1); nd = not detected.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Stations																		
I35	11,500	1.1	3.13	63.80	nd	0.09	19.1	7.6	13,200	5.8	151.0	0.030	6.9	0.09	nd	nd	0.7	40.7
I34	2200	nd	1.61	8.62	nd	nd	4.2	1.6	3330	1.9	33.1	0.006	1.3	nd	nd	nd	nd	7.5
I31	4720	nd	1.30	18.90	nd	nd	8.9	1.2	4980	1.7	73.2	nd	2.5	nd	nd	nd	0.5	12.3
I23	6410	nd	1.72	36.10	nd	nd	10.6	2.0	6720	2.0	76.2	nd	3.6	nd	nd	nd	0.5	14.3
I18	6650	0.3	2.38	42.40	nd	nd	13.4	1.8	8370	2.0	103.0	nd	3.7	nd	nd	nd	0.8	15.5
I10	7040	0.3	1.65	38.40	nd	nd	12.0	2.3	8240	2.0	87.0	0.005	4.1	0.07	nd	nd	0.9	17.2
I4	3160	nd	1.30	17.60	nd	nd	8.6	1.1	4330	1.8	46.5	nd	2.6	nd	nd	nd	0.6	7.5
28-m Stations																		
I33	6110	0.4	1.96	25.10	nd	nd	10.6	3.6	7630	3.6	90.6	0.025	3.7	0.10	nd	nd	0.7	30.1
I30	8480	0.3	1.84	37.40	nd	nd	13.5	3.2	8200	2.4	87.4	0.006	4.7	0.08	nd	nd	0.4	19.7
I27	7770	nd	1.87	35.00	nd	nd	12.2	2.7	7710	2.2	79.9	0.004	4.5	nd	nd	nd	0.7	17.7
I22	6220	0.4	2.19	29.60	nd	nd	10.9	2.1	6350	2.1	69.9	0.005	3.9	0.11	nd	nd	0.6	13.6
I14[a]	4010	nd	1.64	20.50	nd	nd	6.5	1.4	4110	1.3	45.9	nd	2.6	0.09	nd	nd	0.6	9.9
I16[a]	3200	nd	1.41	10.50	nd	nd	7.9	1.1	4770	1.7	47.9	0.004	2.2	nd	nd	nd	0.7	10.0
I15[a]	3020	nd	2.31	9.81	nd	nd	10.1	0.7	5300	2.0	40.4	0.004	2.3	nd	nd	nd	0.8	9.4
I12[a]	5510	nd	1.75	28.20	nd	nd	10.1	1.7	6910	1.7	70.1	0.001	3.4	0.09	nd	nd	0.7	15.9
I9	9290	0.4	1.84	46.50	nd	nd	13.9	3.6	9400	1.9	95.0	nd	5.5	0.09	nd	nd	0.8	22.4
I6	1230	nd	4.20	2.93	nd	nd	8.7	nd	4150	2.0	12.4	nd	1.1	nd	nd	nd	2.5	3.8
I2	2510	nd	0.77	6.35	nd	nd	11.5	1.3	2920	2.2	24.4	nd	2.3	0.07	nd	nd	1.4	6.2
I3	798	nd	1.76	1.57	nd	nd	5.3	nd	1720	0.9	6.7	nd	1.0	nd	nd	nd	0.5	2.1
38-m Stations																		
I29	8820	0.5	2.18	40.50	nd	nd	15.2	4.2	10,200	3.3	102.0	0.012	6.1	0.17	nd	nd	0.8	22.1
I21	1800	0.3	8.93	3.65	nd	nd	14.0	nd	9520	4.2	21.7	0.007	1.7	nd	nd	nd	0.5	8.0
I13	1130	nd	6.29	2.52	0.02	nd	10.2	nd	6720	3.0	16.4	nd	1.2	nd	0.04	nd	1.3	5.8
I8	2020	nd	2.61	4.99	nd	nd	9.5	nd	4440	1.6	22.9	nd	1.5	0.08	nd	nd	0.7	7.4
55-m Stations																		
I28	8330	0.5	2.26	33.40	nd	0.04	14.2	5.4	9890	4.2	97.4	0.023	7.5	0.18	0.04	nd	1.2	23.2
I20	1640	nd	2.56	3.15	nd	nd	6.1	nd	5340	2.2	24.9	nd	1.4	nd	nd	nd	0.5	6.4
I7	1600	nd	5.83	3.32	nd	nd	9.6	nd	7260	2.6	21.3	nd	1.6	nd	nd	nd	2.6	6.3
I1	3410	0.2	1.08	12.10	nd	nd	8.0	1.3	4350	1.9	51.7	0.006	3.5	0.10	nd	nd	0.6	8.7
Detection Rate (%)	100	41	100	100	4	7	100	74	100	100	100	52	100	48	7	0	96	100

[a] nearfield stations

Appendix C.7

Concentrations of total DDT, HCB, total chlordane (tChlor), total PCB, and total PAH detected in sediments from SBOO stations sampled during winter and summer 2015. Values that exceed thresholds are highlighted (see Table 4.1); nd = not detected.

	Winter					Summer				
	tDDT (ppt)	HCB (ppt)	tChlor (ppt)	tPCB (ppt)	tPAH (ppb)	tDDT (ppt)	HCB (ppt)	tChlor (ppt)	tPCB (ppt)	tPAH (ppb)
19-m Stations										
I35	590	nd	nd	nd	74	650	740	nd	314	104
I34	nd	nd	nd	nd	nd	nd	160	nd	nd	12
I31	nd	nd	nd	nd	nd	170	nd	nd	nd	nd
I23	nd	nd	nd	3686	nd	160	nd	nd	nd	7
I18	nd	nd	nd	nd	nd	nd	400	nd	nd	nd
I10	nd	280	nd	nd	nd	nd	nd	nd	nd	nd
I4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
28-m Stations										
I33	nd	170	nd	nd	5	nd	800	nd	nd	15
I30	570	nd	nd	nd	nd	200	nd	nd	nd	7
I27	165	nd	nd	360	nd	200	nd	nd	nd	nd
I22	320	nd	nd	nd	nd	176	nd	nd	nd	13
I14[a]	330	360	nd	1170	nd	340	nd	nd	nd	nd
I16[a]	nd	nd	nd	nd	nd	nd	nd	nd	1584	nd
I15[a]	380	200	nd	181	nd	nd	200	nd	nd	nd
I12[a]	nd	2400	600	nd	nd	nd	500	nd	nd	nd
I9	nd	nd	nd	nd	nd	210	nd	nd	nd	6
I6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I2	nd	nd	nd	nd	nd	nd	nd	nd	nd	6
I3	nd	nd	nd	nd	nd	nd	600	nd	nd	nd
38-m Stations										
I29	nd	nd	nd	nd	8	860	nd	nd	nd	22
I21	nd	3800	nd	nd	nd	nd	nd	nd	nd	nd
I13	nd	nd	nd	nd	nd	nd	770	nd	1465	nd
I8	nd	370	nd	nd	nd	170	nd	nd	nd	nd
55-m Stations										
I28	770	nd	nd	nd	nd	540	nd	nd	nd	27
I20	nd	nd	nd	nd	nd	nd	nd	nd	nd	16
I7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I1	nd	190	nd	nd	nd	140	700	nd	nd	3
Detect. Rate (%)	26	30	4	15	11	44	33	0	11	44

[a] Nearfield station

Appendix D

Supporting Data

2015 SBOO Stations

Macrobenthic Communities

Appendix D.1

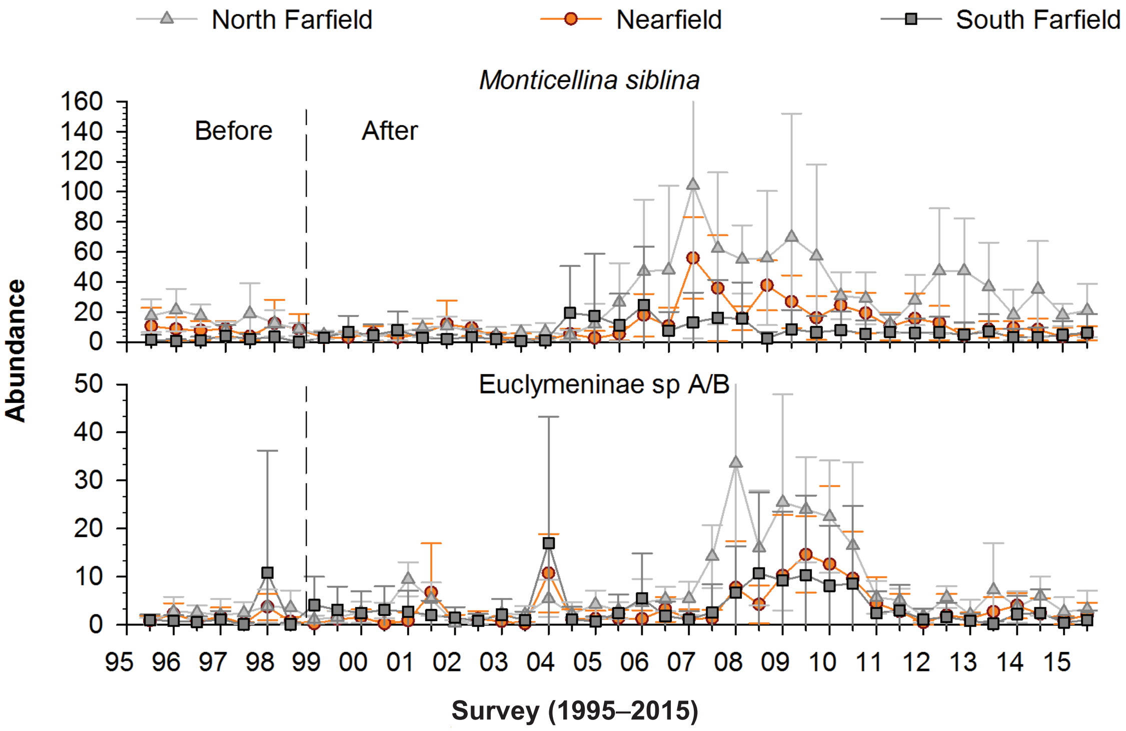
Macrofaunal community parameters by grab from SBOO benthic stations sampled during 2015 SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = Pielou's evenness; Dom = Swartz dominance; BRI = benthic response index. Stations are listed north to south from top to bottom for each depth contour.

Depth Contour	Station	Survey	SR	Abun	H'	J'	Dom	BRI
19-m	I35	winter	55	143	3.7	0.92	24	25
		summer	73	231	3.8	0.89	29	28
	I34	winter	27	76	2.7	0.81	9	13
		summer	40	2568	0.3	0.08	1	9
	I31	winter	40	80	3.3	0.89	21	19
		summer	83	2266	1.1	0.25	1	15
	I23	winter	64	617	3.0	0.73	10	10
		summer	95	904	2.5	0.56	6	19
	I18	winter	49	102	3.4	0.87	24	15
		summer	73	1243	1.3	0.29	1	15
	I10	winter	52	153	3.2	0.81	19	21
		summer	68	546	2.6	0.63	6	18
	I4	winter	45	150	2.7	0.71	13	23
		summer	74	725	2.5	0.58	6	19
28-m	I33	winter	89	347	3.8	0.84	29	26
		summer	94	1534	1.3	0.28	1	20
	I30	winter	70	208	3.7	0.88	28	27
		summer	108	1025	2.0	0.43	5	24
	I27	winter	61	177	3.5	0.86	23	29
		summer	88	813	2.1	0.47	7	24
	I22	winter	81	328	3.6	0.82	25	26
		summer	85	1290	1.9	0.42	4	22
	I14[a]	winter	73	282	3.4	0.79	22	28
		summer	78	1002	1.6	0.38	2	24
	I16[a]	winter	48	237	3.0	0.78	12	21
		summer	83	615	2.5	0.56	9	20
	I15[a]	winter	80	366	3.2	0.72	16	28
		summer	56	1595	0.8	0.21	1	17
	I12[a]	winter	47	204	3.1	0.81	12	23
		summer	92	1652	1.4	0.31	1	19
	I9	winter	76	310	3.5	0.81	20	24
		summer	100	607	3.5	0.77	25	27
	I6	winter	54	323	2.7	0.67	11	10
		summer	56	1033	1.4	0.36	2	14
	I2	winter	33	278	2.0	0.58	5	18
		summer	47	370	2.3	0.60	6	14
	I3	winter	51	951	1.3	0.33	1	18
		summer	33	93	2.8	0.80	10	8

[a] nearfield station

Appendix D.1 *continued*

Depth Contour	Station	Survey	SR	Abun	H'	J'	Dom	BRI
38-m	I29	winter	43	211	3.0	0.78	11	16
		summer	125	596	4.2	0.86	38	19
	I21	winter	45	140	2.8	0.74	15	15
		summer	82	312	3.5	0.79	25	13
	I13	winter	42	114	3.2	0.85	17	10
		summer	45	120	3.4	0.90	20	10
	I8	winter	48	419	2.0	0.52	6	22
		summer	72	694	2.8	0.66	10	21
55-m	I28	winter	130	508	4.2	0.86	43	18
		summer	130	467	4.3	0.88	46	17
	I20	winter	62	235	3.5	0.85	21	11
		summer	61	204	3.4	0.82	19	6
	I7	winter	43	155	2.8	0.74	13	4
		summer	54	153	3.5	0.89	22	9
	I1	winter	60	239	3.4	0.84	17	17
		summer	57	218	3.4	0.84	20	14



Appendix D.2

Two of the five historically most abundant species recorded from 1995 through 2015 at SBOO north farfield, nearfield, and south farfield primary core stations (*Spiophanes norrisi, S. duplex,* and *Mediomastus* sp shown in Figure 5.3). Data for each station group are expressed as means ± 95% confidence intervals per grab (n ≤ 8). Dashed lines indicate onset of wastewater discharge.

Appendix D.3

Mean abundance of the characteristic species found in each cluster group A–I (defined in Figure 5.5). Highlighted/bold values indicate taxa that account for up to 45% of intra-group similarity according to SIMPER analysis; the top five most characteristic species are boxed.

	Cluster Group								
Taxa	**A**	**B**	**C**	**D**	**E**	**F**[a]	**G**	**H**	**I**
Sthenelanella uniformis	**41**	**12**	0	0	1	0	0	1	0
Chaetozone hartmanae	**25**	0	<1	0	0	0	0	0	0
Euclymeninae sp B	**19**	4	1	1	3	0	0	4	0
Prionospio (Prionospio) dubia	**19**	4	0	0	<1	0	0	0	0
Euchone incolor	**18**	1	0	0	<1	0	0	0	0
Ophiura luetkenii	**11**	2	0	0	**<1**	0	1	**5**	0
Aphelochaeta monilaris	**10**	0	<1	0	<1	0	0	0	0
Photis californica	**8**	4	0	0	<1	0	0	1	0
Aphelochaeta tigrina	**8**	0	0	0	0	0	0	0	0
Nuculana sp A	**8**	0	0	0	0	0	0	0	0
Anobothrus gracilis	**7**	**10**	0	0	<1	0	0	<1	0
Maldanidae	**6**	1	1	0	2	4	1	1	0
Spiophanes norrisi	**5**	1	**578**	**33**	**401**	**15**	**35**	**10**	**7**
Ennucula tenuis	**5**	1	0	0	0	0	0	0	0
Prionospio (Prionospio) jubata	**5**	**15**	2	1	**5**	0	0	1	0
Jasmineira sp B	**5**	3	0	0	0	0	0	2	0
Euphilomedes carcharodonta	**4**	5	3	<1	1	0	0	0	0
Leptochelia dubia Cmplx	**4**	5	3	1	3	1	<1	<1	0
Paradiopatra parva	**4**	2	0	0	1	0	0	0	0
Pista estevanica	3	**15**	1	0	0	0	1	1	0
Spiochaetopterus costarum Cmplx	4	**11**	2	0	2	0	**7**	<1	1
Aricidea (Acmira) simplex	2	**7**	0	0	<1	0	1	0	0
Foxiphalus obtusidens	0	**5**	**7**	<1	3	4	2	**2**	0
Notomastus latericeus	0	**0**	**14**	3	4	0	0	0	0
Axiothella sp	0	0	**13**	0	1	1	1	1	<1
Rhepoxynius heterocuspidatus	0	0	**9**	0	<1	1	2	2	1
Tellina modesta	0	0	7	**7**	**15**	0	0	0	0
Rhepoxynius variatus	0	0	<1	**3**	1	0	0	0	0
Rhepoxynius menziesi	0	0	<1	**3**	2	0	0	0	<1
Dialychone veleronis	2	1	<1	**2**	4	0	0	0	0
Magelona sacculata	0	0	<1	**2**	1	0	0	0	<1
Spiophanes duplex	4	3	<1	5	**42**	0	<1	1	1
Ampharete labrops	0	0	10	0	**24**	0	1	0	<1
Mediomastus sp	4	0	2	2	**15**	0	1	0	0
Monticellina siblina	11	0	<1	3	**10**	0	0	0	0
Ampelisca brevisimulata	3	0	<1	1	**6**	0	0	0	0
Ampelisca cristata microdentata	0	0	<1	0	**5**	0	0	0	0
Nuculana taphria	0	0	<1	2	**4**	0	0	0	0

Appendix D.3 *continued*

	Cluster Group								
Taxa	**A**	**B**	**C**	**D**	**E**	**F**[a]	**G**	**H**	**I**
Eurydice caudata	1	0	2	0	< 1	**20**	**3**	**8**	2
Branchiostoma californiense	0	0	5	0	< 1	**14**	1	0	6
Ampelisca cristata cristata	0	0	4	2	3	0	**6**	2	1
Mooreonuphis sp SD1	0	0	1	0	0	0	**4**	**18**	< 1
Lumbrinerides platypygos	0	0	8	1	0	0	**4**	2	21
Mooreonuphis sp	0	1	1	0	1	0	2	**25**	0
Laticorophium baconi	0	0	< 1	0	0	0	1	**11**	3
Pisione sp	0	0	0	0	0	0	0	0	**52**
Hesionura coineaui difficilis	0	0	0	0	0	0	0	0	**20**

[a] SIMPER analysis only conducted on cluster groups that contain more than one benthic grab. Highlighted/bold values for single sample cluster groups cummulatively account for more than 45% of the total abundance.

Appendix D.4

Particle size summary for each cluster group A–I (defined in Figure 5.5). Data are presented as means (ranges) calculated over all stations within a cluster group. VF = very fine; Med = medium; VC = very coarse.

	Sediments (%)						
Cluster Group	**Fines**	**VF Sand**	**Fine Sand**	**Med Sand**	**Coarse Sand**	**VC Sand**	**Granules**
A	28.8 (21.8–35.7)	24.1 (22.1–26.0)	6.8 (4.4–9.2)	10.0 (8.7–11.4)	18.4 (17.5–19.2)	7.4 (2.9–11.9)	4.6 (0.0–9.2)
B	9.7 (9.6–9.7)	36.3 (35.1–37.4)	48.6 (44.7–49.4)	5.6 (5.4–5.8)	0.0 —	0.0 —	0.0 —
C	4.2 (0.2–9.4)	9.3 (0.9–32.2)	26.2 (8.9–43.2)	46.7 (19.4–59.8)	13.1 (3.0–31.7)	0.5 (0.0–2.3)	0.0 —
D	8.7 (7.3–10.6)	60.1 (33.5–72.9)	23.9 (18.3–33.5)	6.6 (0.7–22.8)	0.7 (0.0–3.0)	0.0 —	0.0 —
E	17.6 (7.1–40.7)	55.5 (23.9–72.6)	21.2 (13.5–37.7)	4.9 (0.6–32.7)	0.7 (0.0–8.1)	< 0.1 (0.0–0.9)	< 0.1 (0.0–0.6)
F	0.0	0.1	3.9	31.2	52.2	12.3	0.0
G	2.5 (1.0–3.4)	2.2 (0.9–4.5)	5.7 (0.5–10.6)	43.6 (34.2–53.2)	42.6 (30.3–48.2)	3.4 (0.3–7.1)	0.1 (0.0–0.4)
H	3.7 (1.2–7.2)	0.9 (0.2–1.8)	5.0 (2.6–7.9)	25.5 (14.8–37.0)	50.0 (40.6–70.9)	14.1 (9.8–19.0)	0.0 —
I	4.1 (0.2–9.9)	2.5 (0.3–4.5)	15.9 (0.6–44.8)	28.6 (13.0–45.1)	36.8 (5.4–70.3)	8.7 (0.0–13.3)	3.4 (0.0–9.7)

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Appendix E

Supporting Data

2015 SBOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Taxonomic listing of demersal fish species captured during 2015 at SBOO trawl stations. Data are number of fish (n), biomass (BM, wet weight, kg), minimum (Min), maximum (Max), and mean length (standard length, cm). Taxonomic arrangement and scientific names are of Eschmeyer and Herald (1998) and Lawrence et al. (2013).

					Length (cm)		
Taxon/Species		**Common Name**	**n**	**BM**	**Min**	**Max**	**Mean**
RAJIFORMES							
Platyrhynidae							
	Platyrhinoidis triseriata	Thornback[a]	2	1.9	39	53	46
Rajidae							
	Raja inornata	California Skate[a]	2	0.5	18	38	28
MYLIOBATIRORMES							
Urolophidae							
	Urobatis halleri	Round Stingray[a]	1	0.3	26	26	26
AULOPIFORMES							
Synodontidae							
	Synodus lucioceps	California Lizardfish	304	6.3	7	29	12
BATRACHOIDIFORMES							
Batrachoididae							
	Porichthys myriaster	Specklefin Midshipman	1	0.1	7	7	7
	Porichthys notatus	Plainfin Midshipman	7	0.5	5	22	10
GASTEROSTEIFORMES							
Syngnathidae							
	Syngnathus spp	Unidentified Pipefish	10	0.5	12	26	20
Aulorhynchidae							
	Aulorhynchus flavidus	Tubesnout	1	0.1	11	11	11
SCORPAENIFORMES							
Scorpaenidae							
	Scorpaena guttata	California Scorpionfish	9	3.3	11	23	18
Sebastidae							
	Sebastes dallii	Calico Rockfish	9	0.2	6	12	9
Cottidae							
	Chitonotus pugetensis	Roughback Sculpin	6	0.4	5	11	8
	Icelinus quadriseriatus	Yellowchin Sculpin	2	0.2	7	8	8
PERCIFORMES							
Serranidae							
	Paralabrax clathratus	Kelp Bass	4	0.1	4	8	6
	Paralabrax nebulifer	Barred Sand Bass	2	0.3	16	22	19
Malacanthidae							
	Caulolatilus princeps	Ocean Whitefish	1	0.1	3	3	3
Pomacentridae							
	Chromis punctipinnis	Blacksmith	1	0.1	7	7	7
Sciaenidae							
	Genyonemus lineatus	White Croaker	2	0.2	8	20	14
Clinidae							
	Heterostichus rostratus	Giant Kelpfish	6	0.4	9	12	11
Labrisomidae							
	Neoclinus blanchardi	Sarcastic Fringehead	2	0.2	6	11	8

[a] Length measured as total length, not standard length (see text)

Appendix E.1 *continued*

Taxon/Species	Common Name	n	BM	Length (cm) Min	Max	Mean
PLEURONECTIFORMES						
Paralichthyidae						
Citharichthys stigmaeus	Speckled Sanddab	1285	9.2	4	12	7
Citharichthys xanthostigma	Longfin Sanddab	148	2.2	4	16	8
Paralichthys californicus	California Halibut	10	12.3	22	68	37
Xystreurys liolepis	Fantail Sole	8	1.0	14	25	19
Pleuronectidae						
Parophrys vetulus	English Sole	2	0.2	9	10	10
Pleuronichthys decurrens	Curlfin Sole	5	0.4	9	18	15
Pleuronichthys verticalis	Hornyhead Turbot	27	4.6	6	21	15
Cynoglossidae						
Symphurus atricaudus	California Tonguefish	64	1.3	5	14	10

Appendix E.2

Total abundance by species and station for demersal fish at SBOO trawl stations during 2015.

	Winter 2015							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Abundance by Survey**
Speckled Sanddab	10	48	128	136	197	184	71	774
California Lizardfish	4	15	30	19	15	9	30	122
California Tonguefish	1	2	7	10	12	4	9	45
Hornyhead Turbot	1			4	6	3	2	16
Longfin Sanddab			3	5	2	3		13
Unidentified Pipefish		3		2		3	1	9
Calico Rockfish		9						9
California Halibut		2		1		1	2	6
Plainfin Midshipman			2	1			2	5
Kelp Bass			4					4
Giant Kelpfish		1	1	2				4
Roughback Sculpin	1			1	1			3
Fantail Sole			1		1	1		3
Curlfin Sole	2						1	3
White Croaker					1		1	2
Sarcastic Fringehead				1			1	2
Round Stingray				1				1
English Sole					1			1
California Skate				1				1
Survey Total	19	80	176	184	236	208	120	1023

Appendix E.2 *continued*

	Summer 2015							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Abundance by Survey**
Speckled Sanddab	87	90	76	102	35	51	70	511
California Lizardfish		5	3	7	10	17	140	182
Longfin Sanddab			31	19	12	8	65	135
California Tonguefish	4	1		1		1	12	19
Hornyhead Turbot	1	2	2	2	2	1	1	11
California Scorpionfish	1	1	1		1	3	2	9
Fantail Sole	3		1			1		5
California Halibut				1	2		1	4
Roughback Sculpin				3				3
Yellowchin Sculpin						1	1	2
Thornback			1	1				2
Plainfin Midshipman						1	1	2
Giant Kelpfish							2	2
Curlfin Sole	2							2
Barred Sand Bass					1		1	2
Tubesnout		1						1
Unidentified Pipefish						1		1
Specklefin Midshipman							1	1
Ocean Whitefish			1					1
English Sole							1	1
California Skate						1		1
Blacksmith					1			1
Survey Total	98	100	116	136	64	86	298	898
Annual Total	**117**	**180**	**292**	**320**	**300**	**294**	**418**	**1921**

Appendix E.3

Biomass (kg) by species and station for demersal fish at SBOO trawl stations during 2015.

	Winter 2015							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Biomass by Survey**
California Halibut		2.2		0.6		5.3	0.6	8.7
Speckled Sanddab	0.1	0.4	1.1	1.2	1.5	0.9	0.4	5.6
California Lizardfish	0.1	0.3	0.6	1.1	0.3	0.1	0.5	3.0
Hornyhead Turbot	2.1			0.3	0.1	0.3	0.1	2.9
California Tonguefish	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.8
Longfin Sanddab			0.1	0.3	0.1	0.1		0.6
Fantail Sole			0.3		0.1	0.1		0.5
Unidentified Pipefish		0.1		0.1		0.1	0.1	0.4
California Skate				0.4				0.4
Roughback Sculpin	0.1			0.1	0.1			0.3
Plainfin Midshipman			0.1	0.1			0.1	0.3
Giant Kelpfish		0.1	0.1	0.1				0.3
Round Stingray				0.3				0.3
White Croaker					0.1		0.1	0.2
Sarcastic Fringehead				0.1			0.1	0.2
Curlfin Sole	0.1						0.1	0.2
Calico Rockfish		0.2						0.2
Kelp Bass			0.1					0.1
English Sole					0.1			0.1
Survey Total	2.6	3.4	2.6	4.8	2.5	7.0	2.2	25.1

Appendix E.3 *continued*

	Summer 2015							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Biomass by Survey**
Speckled Sanddab	0.2	0.4	0.3	0.3	0.3	0.8	1.3	3.6
California Halibut				0.1	2.5		1.0	3.6
California Scorpionfish	0.3	0.1	0.2		0.8	1.8	0.1	3.3
California Lizardfish		0.1	0.1	0.1	0.1	0.8	2.1	3.3
Thornback			0.3	1.6				1.9
Hornyhead Turbot	0.1	0.2	0.3	0.2	0.2	0.6	0.1	1.7
Longfin Sanddab			0.1	0.1	0.2	0.1	1.1	1.6
Fantail Sole	0.3		0.1			0.1		0.5
California Tonguefish	0.1	0.1		0.1		0.1	0.1	0.5
Barred Sand Bass					0.2		0.1	0.3
Yellowchin Sculpin						0.1	0.1	0.2
Plainfin Midshipman						0.1	0.1	0.2
Curlfin Sole	0.2							0.2
Tubesnout		0.1						0.1
Unidentified Pipefish						0.1		0.1
Specklefin Midshipman							0.1	0.1
Roughback Sculpin				0.1				0.1
Ocean Whitefish			0.1					0.1
Giant Kelpfish							0.1	0.1
English Sole							0.1	0.1
California Skate						0.1		0.1
Blacksmith					0.1			0.1
Survey Total	1.2	1.0	1.5	2.6	4.4	4.7	6.4	21.8
Annual Total	**3.8**	**4.4**	**4.1**	**7.4**	**6.9**	**11.7**	**8.6**	**46.9**

Appendix E.4

Taxonomic listing of megabenthic invertebrate taxa captured during 2015 at SBOO trawl stations. Data are number of individuals (n). Taxonomic arrangement from SCAMIT (2014).

Taxon/Species				n
CNIDARIA				
	Anthozoa			
		Virgulariidae	*Stylatula elongata*	3
			Virgularia californica	1
MOLLUSCA				
	Polyplacophora			
		Ischnochitonidae	*Lepidozona scrobiculata*	2
	Gastropoda			
		Calliostomatidae	*Calliostoma canaliculatum*	2
			Calliostoma gloriosum	1
			Calliostoma tricolor	1
		Naticidae	*Sinum scopulosum*	1
		Bursidae	*Crossata ventricosa*	11
		Velutinidae	*Lamellaria diegoensis*	1
		Buccinidae	*Kelletia kelletii*	20
		Muricidae	*Pteropurpura festiva*	1
			Pteropurpura trialata	1
			Pteropurpura vokesae	1
		Pseudomelatomidae	*Crassispira semiinflata*	4
			Megasurcula carpenteriana	3
		Philinidae	*Philine auriformis*	26
		Aplysiidae	*Aplysia californica*	1
	Nudibranchia			1
		Onchidorididae	*Acanthodoris brunnea*	11
			Acanthodoris rhodoceras	11
		Arminidae	*Armina californica*	4
		Dendronotidae	*Dendronotus iris*	4
			Dendronotus venustus	3
		Tethyidae	*Melibe leonina*	1
		Flabellinidae	*Flabellina iodinea*	2
			Flabellina pricei	2
	Cephalopoda			
		Octopodidae	*Octopus rubescens*	1
ARTHROPODA				
	Malacostraca			
		Hemisquillidae	*Hemisquilla californiensis*	2
		Cymothoidae	*Elthusa vulgaris*	39
		Sicyoniidae	*Sicyonia penicillata*	51
		Hippolytidae	*Heptacarpus palpator*	2
			Heptacarpus stimpsoni	1
		Crangonidae	*Crangon nigromaculata*	18
		Paguridae	*Pagurus spilocarpus*	3
		Munididae	*Pleuroncodes planipes*	389
		Leucosiidae	*Randallia ornata*	1
		Epialtidae	*Pugettia dalli*	1
			Pugettia producta	1
			Loxorhynchus grandis	6

Appendix E.4 *continued*

Taxon/Species				n
		Inachidae	*Ericerodes hemphillii*	3
		Inachoididae	*Pyromaia tuberculata*	50
		Parthenopidae	*Latulambrus occidentalis*	23
		Cancridae	*Metacarcinus anthonyi*	2
			Metacarcinus gracilis	6
		Portunidae	*Portunus xantusii*	56
ECHINODERMATA				
	Asteroidea			
		Luidiidae	*Luidia armata*	2
			Luidia foliolata	1
		Astropectinidae	*Astropecten californicus*	868
		Asterinidae	*Patiria miniata*	1
	Ophiuroidea			
		Ophiotricidae	*Ophiothrix spiculata*	4
	Echinoidea			
		Toxopneustidae	*Lytechinus pictus*	62
		Dendrasteridae	*Dendraster terminalis*	2
		Loveniidae	*Lovenia cordiformis*	4

Appendix E.5

Total abundance by species and station for megabenthic invertebrates at the SBOO trawl stations during 2015.

	Winter 2015							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Abundance by Survey**
Astropecten californicus	358	12	5	37	35	9	10	466
Pleuroncodes planipes	4	172	211	1		1		389
Portunus xantusii	7	1	3	1	7	4	31	54
Lytechinus pictus	22	18	8	2				50
Sicyonia penicillata		4	8	3	5	7	7	34
Elthusa vulgaris			4	3	10	8	3	28
Crangon nigromaculata	1		3	2	5	2	1	14
Pyromaia tuberculata		2		9				11
Philine auriformis					2	1	2	5
Metacarcinus gracilis		1	1		1		1	4
Loxorhynchus grandis		4						4
Latulambrus occidentalis			2		2			4
Crossata ventricosa	1			1			1	3
Stylatula elongata	1					1		2
Ophiothrix spiculata				2				2
Metacarcinus anthonyi			1	1				2
Megasurcula carpenteriana	2							2
Lepidozona scrobiculata					2			2
Heptacarpus palpator		1		1				2
Hemisquilla californiensis				1	1			2
Ericerodes hemphillii	1					1		2
Calliostoma canaliculatum			1		1			2
Pugettia producta		1						1
Pugettia dalli				1				1
Pteropurpura trialata						1		1
Patiria miniata		1						1
Pagurus spilocarpus							1	1
Octopus rubescens		1						1
Luidia foliolata		1						1
Lamellaria diegoensis	1							1
Kelletia kelletii				1				1
Heptacarpus stimpsoni		1						1
Flabellina iodinea						1		1
Dendraster terminalis	1							1
Calliostoma tricolor		1						1
Armina californica			1					1
Survey Total	399	221	248	66	71	36	57	1098

Appendix E.5 *continued*

	Summer 2015							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Abundance by Survey**
Astropecten californicus	312	7	9	23	23	25	3	402
Pyromaia tuberculata	6	3	11	8	1	9	1	39
Philine auriformis			1	1	1	5	13	21
Latulambrus occidentalis			2	5	4	8		19
Kelletia kelletii		3	6	9			1	19
Sicyonia penicillata	1			1	1	1	13	17
Lytechinus pictus	12							12
Elthusa vulgaris	1	1	1	5	3			11
Acanthodoris rhodoceras			2	3	1	2	3	11
Acanthodoris brunnea			2	5		1	3	11
Crossata ventricosa			5	3				8
Lovenia cordiformis	3		1					4
Dendronotus iris				2		2		4
Crassispira semiinflata			1	2	1			4
Crangon nigromaculata				1		1	2	4
Dendronotus venustus		1				2		3
Armina californica						3		3
Portunus xantusii	1					1		2
Pagurus spilocarpus							2	2
Ophiothrix spiculata			2					2
Metacarcinus gracilis			1	1				2
Luidia armata		1	1					2
Loxorhynchus grandis	1				1			2
Flabellina pricei		2						2
Virgularia californica				1				1
Stylatula elongata			1					1
Sinum scopulosum						1		1
Randallia ornata		1						1
Pteropurpura vokesae				1				1
Pteropurpura festiva						1		1
Nudibranchia					1			1
Melibe leonina				1				1
Megasurcula carpenteriana				1				1
Flabellina iodinea			1					1
Ericerodes hemphillii						1		1
Dendraster terminalis	1							1
Calliostoma gloriosum							1	1
Aplysia californica	1							1
Survey Total	339	19	47	73	37	63	42	620
Annual Total	**738**	**240**	**295**	**139**	**108**	**99**	**99**	**1718**

Appendix F

Supporting Data

2015 SBOO Stations

Bioaccumulation of Contaminants in Fish Tissues

Appendix F.1

Lengths and weights of fishes used for each composite (Comp) tissue sample from SBOO trawl and rig fishing stations during 2015. Data are summarized as number of individuals (n), minimum, maximum, and mean values.

				Length (cm, size class)			Weight (g)		
Station/Zone	**Comp**	**Species**	**n**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Rig Fishing 3	1	Squarespot Rockfish	3	15	19	18	78	163	127
Rig Fishing 3	2	California Scorpionfish	3	25	28	27	426	584	526
Rig Fishing 3	3	Mixed Rockfish	4	18	29	23	209	638	328
Rig Fishing 4	1	Treefish	3	24	28	26	399	555	487
Rig Fishing 4	2	Gopher Rockfish	3	22	25	24	301	476	394
Rig Fishing 4	3	Gopher Rockfish	3	23	24	23	361	413	392
Trawl Zone 5	1	Longfin Sanddab	11	12	15	13	37	64	47
Trawl Zone 5	2	Fantail Sole	7	14	18	16	50	96	75
Trawl Zone 5	3	no sample[a]	—	—	—	—	—	—	—
Trawl Zone 6	1	Longfin Sanddab	12	11	14	13	24	60	42
Trawl Zone 6	2	Fantail Sole	3	15	23	19	72	234	156
Trawl Zone 6	3	Hornyhead Turbot	6	11	18	14	32	120	71
Trawl Zone 7	1	Fantail Sole	3	20	26	23	160	296	240
Trawl Zone 7	2	Hornyhead Turbot	4	12	14	13	42	67	53
Trawl Zone 7	3	Longfin Sanddab	3	9	18	14	13	60	41
Trawl Zone 8	1	Fantail Sole	4	18	24	21	123	250	189
Trawl Zone 8	2	Fantail Sole	4	16	22	18	86	192	115
Trawl Zone 8	3	Hornyhead Turbot	3	14	18	17	79	195	138
Trawl Zone 9	1	Fantail Sole	2	14	25	20	55	348	202
Trawl Zone 9	2	no sample[a]	—	—	—	—	—	—	—
Trawl Zone 9	3	no sample[a]	—	—	—	—	—	—	—

[a] Insufficient fish collected (see text)

Appendix F.2

Constituents and method detection limits (MDL) used for the analysis of liver and muscle tissues of fishes collected from the SBOO region during 2015; na = not analyzed.

	MDL			MDL	
Parameter	**Liver**	**Muscle**	**Parameter**	**Liver**	**Muscle**
Metals (ppm)					
Aluminum (Al)	1.2	1.2	Lead (Pb)	0.07	0.07
Antimony (Sb)	0.1	0.1	Manganese (Mn)	0.02	0.02
Arsenic (As)	0.12	0.12	Mercury (Hg)	0.002	0.002
Barium (Ba)	0.02	0.02	Nickel (Ni)	0.06	0.06
Beryllium (Be)	0.002	0.002	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.01	0.01	Silver (Ag)	0.03	0.03
Chromium (Cr)	0.07	0.07	Thallium (Tl)	0.1	0.1
Copper (Cu)	0.043	0.043	Tin (Sn)	0.05	0.05
Iron (Fe)	0.7	0.7	Zinc (Zn)	0.1	0.1
Chlorinated Pesticides (ppb)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	13.2	0.95	HCH, Delta isomer	2.6	0.56
HCH, Beta isomer	6.0	0.51	HCH, Gamma isomer	13.0	0.78
Total Chlordane					
Alpha (cis) chlordane	1.79	0.21	Heptachlor epoxide	4.11	0.28
Cis nonachlor	2.60	0.19	Methoxychlor	na	na
Gamma (trans) chlordane	2.41	0.24	Oxychlordane	5.24	0.48
Heptachlor	1.23	0.25	Trans nonachlor	2.24	0.20
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	1.04	0.23	p,p-DDD	2.1	0.35
o,p-DDE	1.58	0.21	p,p-DDE	2.07	0.29
o,p-DDT	2.37	0.23	p,p-DDT	1.48	0.33
p,-p-DDMU	0.87	0.25			
Miscellaneous Pesticides					
Aldrin	na	na	Endrin	na	na
Alpha endosulfan	na	na	Endrin aldehyde	na	na
Beta endosulfan	na	na	Hexachlorobenzene (HCB)	2.35	0.42
Dieldrin	na	na	Mirex	1.79	0.32
Endosulfan sulfate	28.5	2.84			

Appendix F.2 *continued*

	MDL			MDL	
Parameter	**Liver**	**Muscle**	**Parameter**	**Liver**	**Muscle**
Polychlorinated Biphenyls Congeners (PCBs) (ppb)					
PCB 18	0.89	0.22	PCB 126	1.48	0.36
PCB 28	1.12	0.18	PCB 128	1.81	0.29
PCB 37	0.29	0.15	PCB 138	2.18	0.3
PCB 44	0.77	0.09	PCB 149	1.60	0.3
PCB 49	0.45	0.16	PCB 151	2.33	0.12
PCB 52	0.77	0.15	PCB 153/168	3.49	0.56
PCB 66	0.87	0.18	PCB 156	1.24	0.23
PCB 70	0.76	0.19	PCB 157	1.00	0.14
PCB 74	0.72	0.17	PCB 158	1.24	0.13
PCB 77	1.20	0.31	PCB 167	0.74	0.17
PCB 81	1.01	0.31	PCB 169	1.15	0.23
PCB 87	1.02	0.23	PCB 170	2.12	0.41
PCB 99	1.71	0.14	PCB 177	1.75	0.49
PCB 101	2.31	0.25	PCB 180	2.49	0.42
PCB 105	2.63	0.19	PCB 183	1.56	0.46
PCB 110	2.18	0.38	PCB 187	1.25	0.47
PCB 114	2.10	0.21	PCB 189	2.04	0.36
PCB 118	2.29	0.31	PCB 194	11.40	0.61
PCB 119	1.04	0.05	PCB 201	1.69	0.21
PCB 123	1.49	0.25	PCB 206	0.67	0.14
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
1-methylnaphthalene	27.9	26.4	Benzo[K]fluoranthene	32.0	37.3
1-methylphenanthrene	17.4	23.3	Benzo[e]pyrene	41.8	40.6
2,3,5-trimethylnaphthalene	21.7	21.6	Biphenyl	38.0	19.9
2,6-dimethylnaphthalene	21.7	19.5	Chrysene	18.1	23.0
2-methylnaphthalene	35.8	13.2	Dibenzo(A,H)anthracene	37.6	40.3
3,4-benzo(B)fluoranthene	30.2	26.8	Fluoranthene	19.9	12.9
Acenaphthene	28.9	11.3	Fluorene	27.3	11.4
Acenaphthylene	24.7	9.1	Indeno(1,2,3-CD)pyrene	25.6	46.5
Anthracene	25.3	8.4	Naphthalene	34.2	17.4
Benzo[A]anthracene	47.3	15.9	Perylene	18.5	50.9
Benzo[A]pyrene	42.9	18.3	Phenanthrene	11.6	12.9
Benzo[G,H,I]perylene	27.2	59.5	Pyrene	9.1	16.6

Appendix F.3

Summary of constituents that make up total chlordane, total DDT, total PCB, and total PAH in composite (Comp) tissue samples from the SBOO region during 2015.

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
RF3	2	California Scorpionfish	Muscle	PCB	PCB 153/168	0.2	ppb
RF3	2	California Scorpionfish	Muscle	PCB	PCB 180	0.1	ppb
RF3	2	California Scorpionfish	Muscle	DDT	p,p-DDE	2.6	ppb
RF3	3	Mixed Rockfish	Muscle	PCB	PCB 153/168	0.2	ppb
RF3	3	Mixed Rockfish	Muscle	PCB	PCB 180	0.1	ppb
RF3	3	Mixed Rockfish	Muscle	DDT	p,p-DDE	1.5	ppb
RF3	3	Mixed Rockfish	Muscle	PAH	Naphthalene	35.0	ppb
RF4	1	Treefish	Muscle	PCB	PCB 153/168	0.1	ppb
RF4	1	Treefish	Muscle	DDT	p,p-DDE	1.8	ppb
RF4	2	Gopher Rockfish	Muscle	PCB	PCB 153/168	0.1	ppb
RF4	2	Gopher Rockfish	Muscle	DDT	p,p-DDE	2.2	ppb
RF4	3	Gopher Rockfish	Muscle	DDT	p,p-DDE	1.0	ppb
TZ5	1	Longfin Sanddab	Liver	PCB	PCB 99	1.4	ppb
TZ5	1	Longfin Sanddab	Liver	PCB	PCB 101	1.4	ppb
TZ5	1	Longfin Sanddab	Liver	PCB	PCB 118	2.1	ppb
TZ5	1	Longfin Sanddab	Liver	PCB	PCB 149	0.9	ppb
TZ5	1	Longfin Sanddab	Liver	PCB	PCB 153/168	4.4	ppb
TZ5	1	Longfin Sanddab	Liver	PCB	PCB 187	2.2	ppb
TZ5	1	Longfin Sanddab	Liver	DDT	p,p-DDE	38.0	ppb
TZ5	1	Longfin Sanddab	Liver	PAH	1-methylphenanthrene	20.0	ppb
TZ5	2	Fantail Sole	Liver	PCB	PCB 99	1.8	ppb
TZ5	2	Fantail Sole	Liver	PCB	PCB 149	1.5	ppb
TZ5	2	Fantail Sole	Liver	PCB	PCB 153/168	6.4	ppb
TZ5	2	Fantail Sole	Liver	PCB	PCB 183	0.9	ppb
TZ5	2	Fantail Sole	Liver	PCB	PCB 187	4.0	ppb
TZ5	2	Fantail Sole	Liver	DDT	p,p-DDE	64.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 49	1.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 52	1.2	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 66	1.9	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 74	0.9	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 99	10.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 101	5.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 105	3.6	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 110	2.4	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 118	16.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 123	2.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 138	24.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 149	6.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 151	2.8	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 153/168	46.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 158	1.6	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 167	1.4	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 170	5.6	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 177	3.7	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 180	16.0	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 183	4.4	ppb
TZ6	1	Longfin Sanddab	Liver	PCB	PCB 187	20.0	ppb
TZ6	1	Longfin Sanddab	Liver	DDT	p,p-DDD	4.3	ppb
TZ6	1	Longfin Sanddab	Liver	DDT	p,p-DDE	330.0	ppb
TZ6	1	Longfin Sanddab	Liver	DDT	p,-p-DDMU	18.0	ppb
TZ6	1	Longfin Sanddab	Liver	Chlordane	Trans Nonachlor	1.9	ppb
TZ6	2	Fantail Sole	Liver	PCB	PCB 153/168	3.1	ppb
TZ6	2	Fantail Sole	Liver	PCB	PCB 187	1.7	ppb
TZ6	2	Fantail Sole	Liver	DDT	p,p-DDE	21.0	ppb
TZ6	2	Fantail Sole	Liver	PAH	1-methylphenanthrene	20.0	ppb
TZ6	3	Hornyhead Turbot	Liver	PCB	PCB 101	1.5	ppb
TZ6	3	Hornyhead Turbot	Liver	PCB	PCB 149	1.5	ppb
TZ6	3	Hornyhead Turbot	Liver	PCB	PCB 153/168	7.7	ppb
TZ6	3	Hornyhead Turbot	Liver	PCB	PCB 180	2.9	ppb
TZ6	3	Hornyhead Turbot	Liver	PCB	PCB 187	3.2	ppb
TZ6	3	Hornyhead Turbot	Liver	DDT	p,p-DDE	49.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 28	1.9	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 49	2.2	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 52	3.3	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 66	4.9	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 70	1.1	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 74	2.4	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 99	27.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 101	10.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 105	8.8	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 110	4.7	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 118	44.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 123	3.5	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 128	7.4	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 138	85.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 149	14.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 151	6.9	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 153/168	120.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 156	5.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 167	3.9	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 177	10.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 180	38.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 183	10.0	ppb
TZ7	1	Fantail Sole	Liver	PCB	PCB 187	49.0	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ7	1	Fantail Sole	Liver	PCB	PCB 201	12.0	ppb
TZ7	1	Fantail Sole	Liver	DDT	o,p-DDE	6.7	ppb
TZ7	1	Fantail Sole	Liver	DDT	p,p-DDE	420.0	ppb
TZ7	1	Fantail Sole	Liver	DDT	p,-p-DDMU	17.0	ppb
TZ7	1	Fantail Sole	Liver	Chlordane	Trans Nonachlor	3.9	ppb
TZ7	2	Hornyhead Turbot	Liver	PCB	PCB 118	2.9	ppb
TZ7	2	Hornyhead Turbot	Liver	PCB	PCB 149	2.3	ppb
TZ7	2	Hornyhead Turbot	Liver	PCB	PCB 153/168	6.6	ppb
TZ7	2	Hornyhead Turbot	Liver	PCB	PCB 187	3.3	ppb
TZ7	2	Hornyhead Turbot	Liver	DDT	p,p-DDE	31.0	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 49	0.6	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 52	0.8	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 66	1.5	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 99	5.7	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 101	3.2	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 118	9.9	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 149	3.7	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 151	2.5	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 153/168	19.0	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 180	10.0	ppb
TZ7	3	Longfin Sanddab	Liver	PCB	PCB 187	14.0	ppb
TZ7	3	Longfin Sanddab	Liver	DDT	p,p-DDD	3.0	ppb
TZ7	3	Longfin Sanddab	Liver	DDT	p,p-DDE	290.0	ppb
TZ7	3	Longfin Sanddab	Liver	DDT	p,-p-DDMU	8.9	ppb
TZ8	1	Fantail Sole	Liver	PCB	PCB 118	3.5	ppb
TZ8	1	Fantail Sole	Liver	PCB	PCB 153/168	5.0	ppb
TZ8	1	Fantail Sole	Liver	PCB	PCB 180	1.8	ppb
TZ8	1	Fantail Sole	Liver	PCB	PCB 187	2.8	ppb
TZ8	1	Fantail Sole	Liver	DDT	p,p-DDE	21.0	ppb
TZ8	3	Hornyhead Turbot	Liver	PCB	PCB 153/168	4.7	ppb
TZ8	3	Hornyhead Turbot	Liver	PCB	PCB 187	2.4	ppb
TZ8	3	Hornyhead Turbot	Liver	DDT	p,p-DDE	37.0	ppb
TZ9	1	Fantail Sole	Liver	DDT	p,p-DDE	21.0	ppb

Appendix G

Supporting Data

2015 Regional Stations

Sediment Conditions

Appendix G.1

Summary of the constituents that make up total DDT, total PCB, and total PAH in each sediment sample collected as part of the 2015 regional survey off San Diego.

Station	Class	Constituent	Value	Units
8401	DDT	p,p-DDE	630	ppt
8401	PAH	2,6-dimethylnaphthalene	8	ppb
8401	PAH	Biphenyl	6	ppb
8402	DDT	p,p-DDE	570	ppt
8402	PAH	2,6-dimethylnaphthalene	10	ppb
8402	PAH	3,4-benzo(B)fluoranthene	33	ppb
8402	PAH	Benzo[A]anthracene	20	ppb
8402	PAH	Benzo[A]pyrene	27	ppb
8402	PAH	Benzo[e]pyrene	21	ppb
8402	PAH	Benzo[G,H,I]perylene	23	ppb
8402	PAH	Benzo[K]fluoranthene	14	ppb
8402	PAH	Biphenyl	14	ppb
8402	PAH	Chrysene	14	ppb
8402	PAH	Fluoranthene	18	ppb
8402	PAH	Indeno(1,2,3-CD)pyrene	18	ppb
8402	PAH	Pyrene	25	ppb
8402	PCB	PCB 28	82	ppt
8402	PCB	PCB 49	200	ppt
8402	PCB	PCB 52	640	ppt
8402	PCB	PCB 66	210	ppt
8402	PCB	PCB 70	440	ppt
8402	PCB	PCB 74	120	ppt
8402	PCB	PCB 87	440	ppt
8402	PCB	PCB 99	480	ppt
8402	PCB	PCB 101	1000	ppt
8402	PCB	PCB 105	450	ppt
8402	PCB	PCB 110	1100	ppt
8402	PCB	PCB 118	1100	ppt
8402	PCB	PCB 128	260	ppt
8402	PCB	PCB 138	820	ppt
8402	PCB	PCB 149	680	ppt
8402	PCB	PCB 153/168	980	ppt
8402	PCB	PCB 156	190	ppt
8402	PCB	PCB 158	120	ppt
8402	PCB	PCB 180	330	ppt
8402	PCB	PCB 183	76	ppt
8402	PCB	PCB 187	140	ppt
8404	DDT	p,p-DDE	430	ppt
8404	PAH	2,6-dimethylnaphthalene	10	ppb
8404	PAH	Biphenyl	8	ppb
8405	DDT	p,p-DDE	630	ppt
8405	PAH	2,6-dimethylnaphthalene	10	ppb
8406	DDT	p,p-DDE	275	ppt
8406	PAH	2,6-dimethylnaphthalene	6	ppb

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8406	PAH	Benzo[e]pyrene	8	ppb
8406	PAH	Benzo[G,H,I]perylene	9	ppb
8406	PAH	Indeno(1,2,3-CD)pyrene	6	ppb
8406	PAH	Pyrene	6	ppb
8406	PCB	PCB 44	23	ppt
8406	PCB	PCB 49	16	ppt
8406	PCB	PCB 52	25	ppt
8406	PCB	PCB 66	46	ppt
8406	PCB	PCB 70	23	ppt
8406	PCB	PCB 99	34	ppt
8406	PCB	PCB 101	100	ppt
8406	PCB	PCB 118	75	ppt
8406	PCB	PCB 149	120	ppt
8406	PCB	PCB 153/168	120	ppt
8407	DDT	p,p-DDE	460	ppt
8407	PAH	2,6-dimethylnaphthalene	10	ppb
8407	PAH	Benzo[e]pyrene	4	ppb
8407	PAH	Benzo[G,H,I]perylene	4	ppb
8407	PAH	Biphenyl	8	ppb
8407	PAH	Fluoranthene	8	ppb
8407	PAH	Pyrene	8	ppb
8409	DDT	p,p-DDD	270	ppt
8409	DDT	p,p-DDE	2000	ppt
8409	PAH	2,6-dimethylnaphthalene	8	ppb
8409	PAH	Benzo[e]pyrene	7	ppb
8409	PAH	Fluoranthene	5	ppb
8409	PAH	Phenanthrene	3	ppb
8409	PAH	Pyrene	6	ppb
8410	DDT	p,p-DDE	490	ppt
8410	PAH	Benzo[A]anthracene	5	ppb
8410	PAH	Benzo[A]pyrene	4	ppb
8410	PAH	Benzo[K]fluoranthene	5	ppb
8410	PAH	Chrysene	5	ppb
8411	DDT	p,p-DDE	410	ppt
8411	PAH	Biphenyl	6	ppb
8413	PCB	PCB 18	530	ppt
8413	PCB	PCB 28	380	ppt
8413	PCB	PCB 49	150	ppt
8413	PCB	PCB 66	180	ppt
8413	PCB	PCB 70	210	ppt
8413	PCB	PCB 74	99	ppt
8414	DDT	p,p-DDE	220	ppt
8414	PAH	2,6-dimethylnaphthalene	7	ppb

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8414	PAH	3,4-benzo(B)fluoranthene	10	ppb
8414	PAH	Benzo[G,H,I]perylene	10	ppb
8414	PAH	Fluoranthene	7	ppb
8414	PAH	Indeno(1,2,3-CD)pyrene	7	ppb
8414	PAH	Pyrene	10	ppb
8414	PCB	PCB 44	85	ppt
8414	PCB	PCB 49	70	ppt
8414	PCB	PCB 52	180	ppt
8414	PCB	PCB 70	130	ppt
8414	PCB	PCB 87	170	ppt
8414	PCB	PCB 99	130	ppt
8414	PCB	PCB 101	360	ppt
8414	PCB	PCB 105	150	ppt
8414	PCB	PCB 110	400	ppt
8414	PCB	PCB 118	370	ppt
8414	PCB	PCB 138	300	ppt
8414	PCB	PCB 149	230	ppt
8414	PCB	PCB 153/168	270	ppt
8414	PCB	PCB 156	68	ppt
8414	PCB	PCB 158	83	ppt
8414	PCB	PCB 180	130	ppt
8415	DDT	p,p-DDD	140	ppt
8415	DDT	p,p-DDE	460	ppt
8415	PCB	PCB 28	58	ppt
8415	PCB	PCB 49	60	ppt
8415	PCB	PCB 52	58	ppt
8415	PCB	PCB 66	73	ppt
8415	PCB	PCB 153/168	240	ppt
8416	DDT	p,p-DDD	75	ppt
8416	PAH	2,6-dimethylnaphthalene	6	ppb
8416	PAH	Biphenyl	8	ppb
8417	DDT	p,p-DDE	400	ppt
8417	PAH	2,6-dimethylnaphthalene	10	ppb
8417	PAH	Fluoranthene	7	ppb
8417	PAH	Pyrene	7	ppb
8418	DDT	p,p-DDE	490	ppt
8418	PAH	3,4-benzo(B)fluoranthene	17	ppb
8418	PAH	Benzo[A]pyrene	11	ppb
8418	PAH	Benzo[e]pyrene	10	ppb
8418	PAH	Benzo[K]fluoranthene	6	ppb
8418	PAH	Chrysene	12	ppb
8418	PAH	Fluoranthene	10	ppb
8418	PAH	Pyrene	10	ppb
8418	PCB	PCB 153/168	160	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8420	DDT	p,p-DDE	430	ppt
8420	PAH	2,6-dimethylnaphthalene	7	ppb
8420	PCB	PCB 153/168	130	ppt
8423	DDT	p,p-DDE	390	ppt
8423	PCB	PCB 153/168	140	ppt
8424	DDT	p,p-DDE	265	ppt
8425	DDT	p,p-DDE	230	ppt
8427	DDT	p,p-DDE	280	ppt
8427	PAH	2,6-dimethylnaphthalene	3	ppb
8427	PAH	3,4-benzo(B)fluoranthene	10	ppb
8427	PAH	Benzo[A]anthracene	10	ppb
8427	PAH	Benzo[A]pyrene	16	ppb
8427	PAH	Benzo[e]pyrene	15	ppb
8427	PAH	Benzo[G,H,I]perylene	6	ppb
8427	PAH	Benzo[K]fluoranthene	14	ppb
8427	PAH	Biphenyl	8	ppb
8427	PAH	Chrysene	14	ppb
8427	PAH	Fluoranthene	10	ppb
8427	PAH	Indeno(1,2,3-CD)pyrene	9	ppb
8427	PAH	Perylene	7	ppb
8427	PAH	Phenanthrene	4	ppb
8427	PAH	Pyrene	14	ppb
8427	PCB	PCB 101	120	ppt
8427	PCB	PCB 118	170	ppt
8427	PCB	PCB 138	150	ppt
8427	PCB	PCB 149	140	ppt
8427	PCB	PCB 153/168	240	ppt
8428	DDT	p,p-DDD	200	ppt
8428	DDT	p,p-DDE	510	ppt
8428	PAH	2,6-dimethylnaphthalene	10	ppb
8428	PAH	3,4-benzo(B)fluoranthene	69	ppb
8428	PAH	Anthracene	9	ppb
8428	PAH	Benzo[A]anthracene	24	ppb
8428	PAH	Benzo[A]pyrene	47	ppb
8428	PAH	Benzo[e]pyrene	37	ppb
8428	PAH	Benzo[G,H,I]perylene	39	ppb
8428	PAH	Benzo[K]fluoranthene	31	ppb
8428	PAH	Biphenyl	8	ppb
8428	PAH	Chrysene	24	ppb
8428	PAH	Dibenzo(A,H)anthracene	9	ppb
8428	PAH	Fluoranthene	29	ppb
8428	PAH	Indeno(1,2,3-CD)pyrene	29	ppb
8428	PAH	Perylene	11	ppb
8428	PAH	Phenanthrene	8	ppb

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8428	PAH	Pyrene	37	ppb
8428	PCB	PCB 18	110	ppt
8428	PCB	PCB 28	66	ppt
8428	PCB	PCB 44	68	ppt
8428	PCB	PCB 49	84	ppt
8428	PCB	PCB 52	120	ppt
8428	PCB	PCB 66	110	ppt
8428	PCB	PCB 70	90	ppt
8428	PCB	PCB 99	120	ppt
8428	PCB	PCB 101	240	ppt
8428	PCB	PCB 105	140	ppt
8428	PCB	PCB 110	270	ppt
8428	PCB	PCB 118	280	ppt
8428	PCB	PCB 138	340	ppt
8428	PCB	PCB 149	300	ppt
8428	PCB	PCB 153/168	410	ppt
8429	DDT	p,p-DDE	260	ppt
8429	PAH	Biphenyl	7	ppb
8431	DDT	p,p-DDD	41	ppt
8431	DDT	p,p-DDE	390	ppt
8431	DDT	p,p-DDMU	42	ppt
8431	PAH	2-methylnaphthalene	6	ppb
8431	PCB	PCB 28	37	ppt
8431	PCB	PCB 44	37	ppt
8431	PCB	PCB 49	31	ppt
8431	PCB	PCB 52	36	ppt
8431	PCB	PCB 66	55	ppt
8431	PCB	PCB 70	38	ppt
8431	PCB	PCB 74	36	ppt
8431	PCB	PCB 77	35	ppt
8431	PCB	PCB 99	47	ppt
8431	PCB	PCB 101	55	ppt
8431	PCB	PCB 105	35	ppt
8433	DDT	p,p-DDD	220	ppt
8433	DDT	p,p-DDE	1000	ppt
8433	PAH	Pyrene	7	ppb
8433	PCB	PCB 153/168	230	ppt
8433	PCB	PCB 180	200	ppt
8434	DDT	p,p-DDE	430	ppt
8434	PAH	2,6-dimethylnaphthalene	10	ppb
8434	PAH	Biphenyl	9	ppb
8434	PAH	Indeno(1,2,3-CD)pyrene	6	ppb
8434	PAH	Pyrene	10	ppb

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8435	DDT	p,p-DDE	400	ppt
8435	PAH	2,6-dimethylnaphthalene	12	ppb
8435	PAH	Benzo[A]pyrene	17	ppb
8435	PAH	Benzo[e]pyrene	14	ppb
8435	PAH	Benzo[G,H,I]perylene	16	ppb
8435	PAH	Benzo[K]fluoranthene	11	ppb
8435	PAH	Biphenyl	10	ppb
8435	PAH	Chrysene	12	ppb
8435	PAH	Fluoranthene	13	ppb
8435	PAH	Indeno(1,2,3-CD)pyrene	10	ppb
8435	PAH	Pyrene	20	ppb
8436	DDT	p,p-DDD	180	ppt
8436	DDT	p,p-DDE	610	ppt
8436	PAH	2,6-dimethylnaphthalene	11	ppb
8436	PAH	3,4-benzo(B)fluoranthene	57	ppb
8436	PAH	Benzo[A]pyrene	44	ppb
8436	PAH	Benzo[e]pyrene	32	ppb
8436	PAH	Benzo[G,H,I]perylene	27	ppb
8436	PAH	Benzo[K]fluoranthene	25	ppb
8436	PAH	Chrysene	26	ppb
8436	PAH	Fluoranthene	16	ppb
8436	PAH	Indeno(1,2,3-CD)pyrene	23	ppb
8436	PAH	Perylene	13	ppb
8436	PAH	Pyrene	20	ppb
8436	PCB	PCB 99	93	ppt
8436	PCB	PCB 101	100	ppt
8437	DDT	p,p-DDE	600	ppt
8437	PAH	2,6-dimethylnaphthalene	12	ppb
8438	DDT	p,p-DDE	530	ppt
8438	PAH	Biphenyl	11	ppb
8439	DDT	p,p-DDE	460	ppt
8439	PAH	2,6-dimethylnaphthalene	9	ppb
8441	DDT	p,p-DDE	190	ppt
8442	DDT	p,p-DDE	490	ppt
8442	PAH	2,6-dimethylnaphthalene	8	ppb
8444	DDT	p,p-DDE	85	ppt
8454	DDT	p,p-DDE	680	ppt
8454	PAH	2,6-dimethylnaphthalene	10	ppb
8454	PAH	Biphenyl	7	ppb

Appendix G.2

Summary of particle size parameters (%) for each San Diego regional station sampled during 2015. Visual observations are from sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VCSand = Very Coarse Sand; CSand = Coarse Sand; MSand = Medium Sand; FSand = Fine Sand; VFSand = Very Fine Sand; CSilt = Coarse Silt; MSilt = Medium Silt; FSilt = Fine Silt; VFSilt = Very Fine Silt.

			Coarse Particles		Med-Coarse Sands		Fine Sands		Fine Particles					Visual Observations
		Depth (m)	Granules	VCSand	CSand	MSand	FSand	VFSand	CSilt	MSilt	FSilt	VFSilt	Clay	
Inner Shelf	8430[s]	9	0.0	0.2	0.6	3.2	51.8	40.1	4.1	—	—	—	—	shell hash
	8413	10	0.0	0.1	4.2	6.3	17.5	56.5	13.7	0.4	0.6	0.8	0.0	
	8403	13	0.0	0.0	0.1	8.2	64.4	26.1	0.6	0.0	0.0	0.6	0.0	
	8419	13	0.0	0.0	0.0	2.5	24.4	64.6	7.9	0.0	0.0	0.6	0.1	large blade algae
	8426	14	0.0	0.0	0.0	7.1	64.4	26.7	0.6	0.0	0.3	0.9	0.1	shell hash, organic debris[a]
	8429	14	0.0	0.0	0.0	2.8	25.5	56.1	11.3	1.3	1.7	1.3	0.0	
	8421	17	0.0	0.0	0.0	0.8	15.9	64.8	13.3	1.1	2.0	2.0	0.1	shell hash, organic debris[a]
	8414	23	0.0	0.0	0.0	4.9	20.9	37.4	18.1	7.6	8.4	2.8	0.0	organic debris[a]
	8416	25	0.0	0.0	0.0	4.7	43.8	43.8	2.0	0.3	2.6	2.7	0.1	organic debris[a]
	8425	27	0.0	0.0	0.0	0.9	14.9	67.7	11.2	0.7	2.0	2.5	0.2	organic debris[a]
Mid-Shelf	8409	33	0.0	0.0	0.0	0.7	11.7	53.8	23.6	4.1	4.4	1.8	0.0	organic debris[a]
	8444	37	0.0	0.0	0.0	5.4	38.7	41.4	4.9	1.7	4.6	3.0	0.1	
	8441	39	0.0	0.0	0.0	0.8	21.6	58.8	8.3	1.7	4.9	3.7	0.2	shell hash, organic debris[a]
	8415	49	0.0	0.0	0.0	1.1	14.9	43.6	18.8	7.3	10.3	3.9	0.2	shell hash, organic debris[a]
	8422	51	0.0	0.6	15.8	51.6	23.6	4.8	1.0	0.8	1.4	0.5	0.0	red relict sand, *Spio*. tubes[b]
	8407	52	0.0	0.0	0.0	0.6	11.1	43.1	22.7	8.2	10.8	3.5	0.1	shell hash
	8431	54	0.0	0.1	8.1	21.1	24.5	20.8	8.1	4.1	7.8	5.0	0.4	shell hash, organic debris[a]
	8434	61	0.0	0.0	0.0	0.5	9.1	36.9	24.5	10.7	13.6	4.7	0.2	
	8410	63	0.0	1.7	18.0	22.0	14.9	17.0	8.1	5.1	9.3	3.8	0.1	black sand
	8433	87	0.0	0.0	0.0	0.1	4.5	28.7	30.8	14.7	16.0	5.0	0.2	
	8411	92	0.0	0.0	0.0	0.6	13.7	45.3	20.8	7.0	9.3	3.4	0.1	
	8420	92	0.0	0.0	0.0	0.2	8.7	40.6	27.4	9.1	10.5	3.5	0.1	shell hash, organic debris[a]
	8423[s]	93	5.8	1.2	1.3	2.0	6.2	38.3	45.1	—	—	—	—	black sand, black pea gravel
	8442	96	0.0	0.0	0.0	0.0	4.9	38.0	27.5	10.9	14.1	4.4	0.1	
	8406	108	0.0	0.0	0.0	5.7	32.0	34.1	9.7	4.8	8.9	4.6	0.2	red relict sand, shell hash
	8427[s]	112	2.7	20.1	8.5	4.0	7.6	27.5	29.6	—	—	—	—	black sand

[a] Contained worm tubes; [b] *Spiochaetoperis* tubes; [s] measured by sieve (not Horiba; silt and clay fractions are indistinguishable)

Appendix G.2 *continued*

			Coarse Particles		Med-Coarse Sands		Fine Sands		Fine Particles					Visual Observations
		Depth (m)	Granules	VCSand	CSand	MSand	FSand	VFSand	CSilt	MSilt	FSilt	VFSilt	Clay	
Outer	8424[s]	131	6.5	3.5	10.4	24.5	16.5	24.8	13.7	—	—	—	—	gravel, shell hash
Shelf	8418	137	0.0	0.0	0.0	0.2	10.0	38.9	20.0	9.4	15.9	5.6	0.2	
	8404	144	0.0	0.0	0.0	0.1	9.6	46.5	21.3	6.7	11.3	4.4	0.1	pea gravel, shell hash, *Spio*. tubes[b]
	8401	146	0.0	1.9	5.4	3.5	9.8	39.2	19.7	6.3	9.7	4.2	0.3	*Spio*. tubes[b]
	8405	150	0.0	0.0	0.0	0.1	9.6	42.6	19.8	8.3	14.1	5.4	0.2	shell hash, *Spio*. tubes[b]
	8428[s]	195	5.8	3.3	2.5	3.2	10.4	18.4	56.4	—	—	—	—	red relict sand, pea gravel
	8417	199	0.0	0.0	0.0	2.6	20.0	31.3	12.6	9.5	17.2	6.6	0.4	shell hash, *Spio*. tubes[b]
Upper	8402[s]	205	0.9	0.4	0.8	6.1	21.2	11.9	58.7	—	—	—	—	pea gravel, shell hash, *Spio*. tubes[b]
Slope	8436	219	0.0	0.0	0.0	0.5	6.2	21.5	20.9	17.0	26.3	7.5	0.2	red relict sand, pea gravel, *Spio*. tubes[b]
	8435	237	0.0	0.0	0.0	0.1	5.5	23.6	23.8	18.1	23.0	5.6	0.1	*Spio*. tubes[b]
	8437	345	0.0	0.0	0.0	0.1	7.4	33.4	21.6	13.2	19.1	5.1	0.1	
	8439	395	0.0	0.0	0.0	0.2	7.2	27.7	20.6	15.5	22.9	5.8	0.1	
	8454	465	0.0	0.0	0.1	7.6	28.4	21.3	10.1	9.7	17.1	5.6	0.1	pea gravel, organic debris[a]
	8438	530	0.0	0.0	0.0	0.8	10.6	20.0	12.7	15.9	30.9	8.8	0.2	

[a] Contained worm tubes; [b] *Spiochaetoperis* tubes; [s] measured by sieve (not Horiba; silt and clay fractions are indistinguishable)

Appendix G.3

Concentrations of chemical parameters in sediments from the 2015 San Diego regional stations. ERL=Effects Range Low threshold value; ERM=Effects Range Median threshold value; nd=not detected; na=not available; see Appendix C.1 for MDLs, abbreviations, and translation of periodic table symbols. Values that exceed ERL or ERM thresholds are highlighted.

	Station	Depth (m)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (%wt)	HCB (ppt)	tDDT (ppt)	tPCB (ppt)	tPAH (ppb)
Inner Shelf	8430	9	3.93	0.013	0.15	0.80	nd	nd	nd	nd
	8413	10	1.66	0.013	0.17	0.90	160	nd	1549	nd
	8403	13	3.13	nd	0.21	0.80	nd	nd	nd	nd
	8419	13	2.42	0.006	0.20	0.90	560	nd	nd	nd
	8426	14	1.51	nd	nd	0.60	nd	nd	nd	nd
	8429	14	3.80	0.010	0.15	0.90	98	260	nd	7
	8421	17	1.68	0.017	0.18	0.80	92	nd	nd	nd
	8414	23	3.44	0.022	0.31	1.40	nd	220	3126	51
	8416	25	1.99	0.013	0.20	1.20	nd	75	nd	14
	8425	27	1.87	0.027	0.21	0.90	485	230	nd	nd
Mid-Shelf	8409	33	3.22	0.012	0.33	1.30	1200	2270	nd	29
	8444	37	2.41	0.027	0.21	1.00	nd	85	nd	nd
	8441	39	2.75	0.027	0.31	1.30	410	190	nd	nd
	8415	49	3.76	0.039	0.57	2.20	nd	600	489	nd
	8422	51	0.68	0.010	0.14	0.70	nd	nd	nd	nd
	8407	52	4.33	0.026	0.61	2.60	nd	460	nd	42
	8431	54	2.19	0.023	4.55	2.60	nd	472	442	6
	8434	61	10.40	0.030	0.58	2.40	nd	430	nd	36
	8410	63	2.08	0.009	0.39	1.20	390	490	nd	18
	8433	87	3.18	0.048	0.80	3.00	nd	1220	430	7
	8411	92	7.02	0.038	0.44	2.10	nd	410	nd	6
	8420	92	3.55	0.035	0.55	2.10	nd	430	130	7
	8423	93	2.69	0.016	0.72	2.80	nd	390	140	nd
	8442	96	4.55	0.025	0.63	2.70	110	490	nd	8
	8406	108	5.11	0.026	0.37	1.50	nd	275	582	34
	8427	112	3.56	0.043	0.97	2.25	nd	280	820	137
Outer Shelf	8424	131	3.23	0.044	5.39	3.10	nd	265	nd	nd
	8418	137	7.23	0.055	0.97	3.30	nd	490	160	76
	8404	144	5.77	0.026	0.62	2.70	nd	430	nd	18
	8401	146	4.26	0.015	0.61	2.30	1100	630	nd	14
	8405	150	19.20	0.035	0.64	2.80	1400	630	nd	10
	8428	195	25.90	0.034	1.42	5.10	110	710	2748	420
	8417	199	28.70	0.039	0.78	3.30	nd	400	nd	24
Upper Slope	8402	205	35.30	0.087	1.39	5.10	nd	570	9858	236
	8436	219	32.80	0.074	1.87	6.60	nd	790	193	292
	8435	237	14.10	0.108	2.63	7.90	nd	400	nd	135
	8437	345	3.81	0.115	1.39	5.30	nd	600	nd	12
	8439	395	4.06	0.100	1.40	5.70	220	460	nd	9
	8454	465	0.19	0.032	3.55	5.90	nd	680	nd	17
	8438	530	4.12	0.048	2.87	7.90	nd	530	nd	11
		[a] **ERL**:	na	na	na	na	na	1580	na	4022
		[a] **ERM**:	na	na	na	na	na	46,100	na	44,792

[a] From Long et al. 1995

Appendix G.3 *continued*

		Depth	Metals (ppm)								
	Station	(m)	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe
Inner Shelf	8430	9	5330	0.6	1.79	38.40	nd	nd	8.9	2.6	7210
	8413	10	5720	nd	1.70	36.70	nd	nd	13.5	1.7	9890
	8403	13	4360	0.3	1.27	32.30	nd	nd	8.0	1.1	6770
	8419	13	4350	nd	1.51	60.70	nd	nd	10.8	0.7	8700
	8426	14	3220	nd	1.58	13.40	nd	nd	6.4	0.7	5180
	8429	14	6140	0.6	2.30	39.60	nd	nd	11.5	2.9	7710
	8421	17	6980	nd	1.71	33.50	nd	nd	11.7	2.5	7310
	8414	23	9440	0.7	2.36	50.10	nd	0.29	15.8	5.6	12,000
	8416	25	4360	nd	1.83	20.10	nd	nd	7.8	1.8	6000
	8425	27	7190	0.4	1.99	33.40	nd	0.06	12.2	2.6	7680
Mid-Shelf	8409	33	8590	0.4	2.29	47.50	nd	nd	14.7	4.6	9770
	8444	37	3550	0.5	2.10	17.30	nd	0.07	9.2	1.9	5940
	8441	39	4710	0.5	2.35	26.60	nd	0.13	10.5	2.9	6460
	8415	49	9380	0.4	3.08	51.00	nd	0.19	18.4	5.2	13,000
	8422	51	1880	nd	3.09	4.26	nd	nd	8.4	nd	6120
	8407	52	11,000	0.5	3.10	65.40	nd	0.19	21.4	7.4	15,200
	8431	54	6300	0.7	3.08	37.10	nd	nd	17.2	4.3	13,900
	8434	61	11,400	0.9	3.34	64.20	nd	0.20	21.5	12.1	14,100
	8410	63	4790	nd	1.76	18.80	nd	nd	9.4	3.3	6340
	8433	87	12,500	1.0	3.38	62.60	nd	nd	24.5	12.1	16,800
	8411	92	8390	0.8	2.14	37.40	nd	0.07	15.9	6.5	11,200
	8420	92	10,500	0.6	2.95	50.10	nd	nd	20.2	7.3	14,100
	8423	93	10,600	0.5	3.30	47.70	nd	nd	22.2	6.7	15,700
	8442	96	11,200	1.0	2.74	58.20	nd	0.09	22.2	9.3	14,900
	8406	108	6080	0.4	2.00	26.30	nd	nd	12.5	5.2	9350
	8427	112	6570	0.4	3.19	25.00	nd	nd	19.0	5.4	12,900
Outer Shelf	8424	131	7080	0.4	3.52	32.80	nd	nd	11.9	2.4	7360
	8418	137	10,800	0.6	2.24	49.60	nd	0.07	23.5	11.0	14,900
	8404	144	9720	0.6	2.36	41.40	nd	0.24	19.4	7.5	13,400
	8401	146	8710	0.6	2.35	38.30	nd	0.31	19.5	5.8	12,700
	8405	150	10,800	0.6	2.79	62.60	nd	0.36	23.3	7.5	15,900
	8428	195	19,000	1.5	3.06	107.00	nd	0.15	36.8	36.2	23,200
	8417	199	11,500	0.7	3.51	69.10	nd	0.33	21.8	8.3	15,800
Upper Slope	8402	205	15,100	0.8	2.65	81.70	nd	0.14	31.7	20.4	19,700
	8436	219	14,700	1.3	3.23	82.70	nd	0.16	32.1	30.4	18,500
	8435	237	17,400	1.2	3.39	95.40	nd	0.21	38.3	26.9	20,500
	8437	345	13,200	1.0	3.07	71.80	nd	0.32	30.9	16.2	17,800
	8439	395	14,200	1.3	2.98	90.10	nd	0.32	35.1	18.4	18,600
	8454	465	15,200	2.6	9.03	112.00	0.06	0.22	98.2	16.6	40,400
	8438	530	15,800	1.7	4.45	156.00	nd	0.51	58.3	24.6	27,000
	[a]ERL:		na	na	8.2	na	na	1.2	81	34	na
	[a]ERM:		na	na	70.0	na	na	9.6	370	270	na

[a] From Long et al. 1995

Appendix G.3 *continued*

			Metals (ppm)								
	Station	**Depth (m)**	**Pb**	**Mn**	**Hg**	**Ni**	**Se**	**Ag**	**Tl**	**Sn**	**Zn**
Inner Shelf	8430	9	1.8	83.3	0.007	2.6	nd	nd	nd	0.4	20.2
	8413	10	2.7	76.6	0.004	4.1	nd	nd	nd	0.5	15.9
	8403	13	1.7	92.6	nd	2.9	nd	nd	nd	nd	17.7
	8419	13	2.6	107.0	nd	2.9	nd	nd	nd	0.4	15.1
	8426	14	1.5	64.8	0.005	2.2	nd	nd	nd	nd	9.4
	8429	14	2.1	79.7	0.004	3.4	nd	nd	nd	0.4	20.3
	8421	17	2.1	72.7	0.004	5.0	nd	nd	nd	0.5	16.4
	8414	23	4.3	116.0	0.024	7.4	nd	nd	nd	1.1	28.8
	8416	25	3.1	71.8	0.010	3.1	nd	nd	nd	0.5	13.3
	8425	27	2.7	76.3	0.004	5.2	nd	nd	nd	0.4	17.0
Mid-Shelf	8409	33	3.4	nr	0.014	7.0	nd	nd	nd	0.6	24.0
	8444	37	2.3	70.8	0.009	2.2	nd	nd	nd	0.5	13.9
	8441	39	2.6	76.3	0.011	2.9	nd	nd	nd	0.5	17.4
	8415	49	4.6	127.0	0.036	7.9	nd	nd	nd	0.8	30.5
	8422	51	2.8	19.7	nd	1.8	nd	nd	nd	0.6	7.4
	8407	52	5.8	150.0	0.029	9.2	nd	nd	nd	0.9	41.6
	8431	54	3.5	90.2	0.014	4.4	nd	nd	nd	0.7	28.5
	8434	61	5.8	136.0	0.049	8.1	nd	nd	nd	1.3	41.7
	8410	63	3.3	52.5	0.016	5.7	nd	nd	nd	0.5	14.8
	8433	87	6.2	139.0	0.044	9.6	nd	nd	nd	1.3	42.4
	8411	92	3.9	94.3	0.023	8.5	nd	nd	nd	0.7	26.4
	8420	92	5.3	118.0	0.027	10.3	nd	nd	nd	0.8	31.1
	8423	93	5.6	119.0	0.029	10.0	nd	nd	nd	0.9	32.3
	8442	96	4.8	126.0	0.031	7.9	0.29	nd	nd	1.0	36.9
	8406	108	3.9	67.3	0.027	6.1	nd	nd	nd	0.7	21.1
	8427	112	3.8	67.2	0.017	6.9	0.25	nd	nd	0.7	22.2
Outer Shelf	8424	131	2.3	74.9	0.013	5.0	nd	nd	nd	0.5	16.2
	8418	137	7.1	117.0	0.060	11.6	0.30	nd	nd	1.7	34.6
	8404	144	5.2	103.0	0.027	10.7	nd	nd	0.5	0.9	29.9
	8401	146	4.7	98.5	0.023	9.5	nd	nd	nd	0.8	28.2
	8405	150	6.2	128.0	0.028	11.1	nd	nd	nd	0.8	37.2
	8428	195	11.4	188.0	0.179	15.2	0.46	nd	nd	2.0	69.9
	8417	199	5.5	149.0	0.023	10.5	0.24	nd	nd	0.7	38.3
Upper Slope	8402	205	8.4	153.0	0.082	18.0	0.39	nd	nd	1.6	48.7
	8436	219	8.6	140.0	0.106	15.1	0.72	nd	nd	1.5	54.5
	8435	237	7.1	166.0	0.069	18.0	0.74	nd	nd	1.5	58.3
	8437	345	5.6	131.0	0.044	12.1	0.64	nd	nd	1.1	46.4
	8439	395	5.2	141.0	0.038	13.7	0.76	nd	nd	1.1	51.1
	8454	465	5.5	89.6	0.024	16.2	1.18	nd	nd	1.1	52.7
	8438	530	4.8	136.0	0.034	18.5	1.23	nd	nd	1.0	60.7
		[a]**ERL:**	46.7	na	0.15	20.9	na	1.0	na	na	150
		[a]**ERM:**	218.0	na	0.71	51.6	na	3.7	na	na	410

[a] From Long et al. 1995

Appendix G.4

Results of Spearman rank correlation analyses of various sediment parameters from San Diego regional benthic samples collected during 2015. Data include the correlation coefficient (r_s) for all parameters with detection rates ≥50% (see Table 8.1). Correlation coefficients $r_s \geq 0.70$ are highlighted below; select correlations are presented graphically in Figure 8.4.

	FINES	Sulf	TN	TOC	TVS	Al	Sb	As	Ba	Cd	Cr	Cu
Sulf	0.5											
TN	0.72	0.44										
TOC	0.28	0.11	0.4									
TVS	0.81	0.49	0.79	0.61								
Al	0.91	0.57	0.69	0.4	0.88							
Sb	0.68	0.3	0.51	0.52	0.8	0.81						
As	0.43	0.07	0.29	0.6	0.6	0.55	0.8					
Ba	0.75	0.42	0.55	0.44	0.87	0.88	0.83	0.6				
Cd	0.61	0.33	0.48	0.2	0.63	0.62	0.56	0.39	0.68			
Cr	0.59	0.2	0.44	0.52	0.78	0.74	0.91	0.89	0.82	0.54		
Cu	0.81	0.64	0.68	0.39	0.9	0.91	0.77	0.44	0.83	0.52	0.67	
Fe	0.72	0.33	0.5	0.51	0.83	0.85	0.91	0.85	0.87	0.58	0.97	0.75
Pb	0.83	0.72	0.58	0.23	0.71	0.87	0.59	0.37	0.66	0.44	0.53	0.86
Mn	0.82	0.62	0.58	0.2	0.69	0.87	0.56	0.24	0.77	0.57	0.44	0.76
Hg	0	-0.05	-0.11	-0.08	-0.09	0	-0.06	-0.06	-0.01	-0.13	-0.05	-0.05
Ni	0.87	0.57	0.72	0.42	0.91	0.92	0.76	0.56	0.84	0.66	0.77	0.86
Sn	0.08	0	-0.05	-0.05	-0.03	0.08	0	-0.02	0.05	-0.09	0	0.02
Zn	0.89	0.56	0.67	0.41	0.9	0.98	0.84	0.56	0.91	0.64	0.75	0.94
tDDT	0.53	0.21	0.23	0.15	0.32	0.47	0.35	0.27	0.35	0.17	0.31	0.36
tPAH	0.43	0.75	0.37	0.16	0.49	0.57	0.36	0.1	0.41	0.1	0.26	0.76

	Fe	Pb	Mn	Hg	Ni	Sn	Zn	tDDT
Pb	0.68							
Mn	0.61	0.82						
Hg	-0.07	-0.06	0.73					
Ni	0.85	0.82	0.76	-0.24				
Sn	0	0.03	0.75	1	-0.17			
Zn	0.86	0.87	0.87	0.79	0.92	0.84		
tDDT	0.37	0.43	0.62	0.76	0.25	0.8	0.73	
tPAH	0.37	0.76	0.52	0	0.52	0.06	0.59	0.22

Appendix H

Supporting Data

2015 Regional Stations

Macrobenthic Communities

Appendix H.1

Mean abundance of the characteristic species found in each cluster group A–F (defined in Figure 9.4) from San Diego regional benthic stations sampled during 2015. Highlighted/bold values indicate taxa that account for up to 45% of intra-group similarity according to SIMPER analysis; the top five most characteristic species are boxed.

	Cluster Group					
Taxa	**A**	**B**	**C**[a]	**D**	**E**[a]	**F**
Dendraster excentricus	**17**	0	0	0	0	0
Diastylopsis tenuis	**10**	0	0	< 1	0	0
Spiophanes duplex	**15**	1	6	**44**	0	0
Mediomastus sp	1	**4**	1	**21**	0	1
Amphiodia urtica	0	**16**	0	0	0	0
Axinopsida serricata	0	**9**	0	0	0	0
Tellina carpenteri	0	**7**	0	0	0	3
Nuculana sp A	0	**7**	0	0	0	0
Prionospio (Prionospio) dubia	0	**6**	0	< 1	0	0
Sternaspis affinis	0	**4**	0	1	0	0
Chaetozone hartmanae	0	**4**	0	0	0	0
Amphiodia sp	0	**3**	0	< 1	0	0
Euclymeninae sp B	0	**3**	8	1	0	1
Prionospio (Prionospio) jubata	0	**3**	0	2	0	0
Rhepoxynius bicuspidatus	0	**3**	0	0	0	0
Amphiuridae	1	**2**	1	1	0	4
Ennucula tenuis	0	**2**	0	0	1	1
Lumbrineris sp Group I	0	**2**	0	< 1	0	0
Adontorhina cyclia	0	**2**	0	0	0	1
Parvilucina tenuisculpta	0	**2**	0	1	0	0
Nephtys ferruginea	< 1	**2**	0	< 1	0	0
Heterophoxus oculatus	0	**1**	0	0	0	0
Terebellides californica	0	**1**	0	< 1	0	0
Pista estevanica	0	1	**44**	1	0	0
Myriochele striolata	0	1	**18**	6	0	0
Jasmineira sp B	0	1	**17**	0	0	0
Agnezia septentrionalis	0	0	**14**	2	0	0
Ascidiacea	0	0	**14**	0	0	0
Spiophanes norrisi	15	1	**18**	**354**	0	0
Tellina modesta	1	0	0	**12**	0	0
Metasychis disparidentatus	0	< 1	0	**11**	0	0
Monticellina siblina	0	2	0	**9**	0	0
Ampelisca brevisimulata	< 1	1	0	**6**	0	0
Apoprionospio pygmaea	< 1	0	0	**6**	0	0
Gadila aberrans	0	< 1	2	**4**	0	0
Sigalion spinosus	2	0	0	**4**	0	0

Appendix H.1 *continued*

Taxa	A	B	C [a]	D	E [a]	F
Fauveliopsis glabra	0	0	0	0	**4**	5
Eclysippe trilobata	0	2	0	0	**3**	2
Neilonella ritteri	0	0	0	0	**3**	0
Brissopsis sp LA1	0	0	0	0	**2**	1
Praxillella pacifica	0	2	0	7	0	**5**
Maldane sarsi	0	1	0	0	0	**4**
Ampelisca unsocalae	0	0	0	0	0	**2**
Notomastus sp A	0	2	0	< 1	0	**1**

[a] SIMPER analysis only conducted on cluster groups that contain more than one benthic grab. Highlighted/bold values for single sample cluster groups cummulatively account for about 45% of the total abundance.

Appendix H.2

Sediment particle size summary for each cluster group A–F (defined in Figure 9.4) from San Diego regional benthic stations sampled during 2015. Data are presented as means (ranges) calculated over all stations within a cluster group. VF = very fine; Med = medium; VC = very coarse.

	Sediments (%)						
Cluster Group	Fines	VF Sand	Fine Sand	Med Sand	Coarse Sand	VC Sand	Granules
A	7.8 (1.2–15.6)	45.0 (26.1–64.6)	41.3 (17.5–64.4)	5.0 (2.5–8.2)	0.8 (0.0–4.2)	< 0.1 (0.0–0.2)	< 0.1 (0.0–0.02)
B	45.9 (13.7–71.9)	32.4 (11.9–46.5)	12.3 (4.5–32.0)	4.5 (0.0–24.5)	2.5 (0.0–18.0)	1.5 (0.0–20.1)	1.0 (0.0–6.5)
C	3.7	4.8	23.6	51.6	15.8	0.6	0.0
D	21.0 (7.7–36.9)	52.5 (37.4–67.7)	23.9 (11.7–43.8)	2.6 (0.7–5.4)	0.0 —	0.0 —	0.0 —
E	68.5	20.0	10.6	0.8	0.0	0.0	0.0
F	55.5 (42.6–64.9)	27.5 (21.3–33.4)	14.3 (7.2–28.4)	2.6 (0.1–7.6)	< 0.1 (0.0–0.1)	0.0 —	0.0 —