THE CITY OF SAN DIEGO

South Bay Ocean Outfall
Annual Receiving Waters Monitoring & Assessment Report
2014

City of San Diego Ocean Monitoring Program

Environmental Monitoring & Technical Services Division

Public Utilities Department

THE CITY OF SAN DIEGO

June 30, 2015

Mr. 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 2014 Annual Receiving Waters Monitoring and Assessment Report for the South Bay Ocean Outfall, South Bay Water Reclamation Plant as required per Order R9-2013-0006, NPDES Permit No. CA0109045. This assessment report contains data summaries, analyses and assessments of the various portions of the ocean monitoring program conducted during calendar year 2014, 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 2014 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, NPDES Permit 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

South Bay Ocean Outfall
Annual Receiving Waters Monitoring & Assessment Report, 2014

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

Prepared by:

City of San Diego Ocean Monitoring Program

Environmental Monitoring & Technical Services Division, Public Utilities Department

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June 2015

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Landsat 8 satellite image showing the South Bay ocean monitoring region on December 19, 2014 depicting turbidity plumes from San Diego Bay, the Tijuana River, and other coastal runoff following storm events. Image provided by Ocean Imaging, Inc., www.oceani.com

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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 (Regional Water 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 2014 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 the above 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 2014 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 2014 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 2014 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, consistent with the weak El Niño that developed during 2014. 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 plumes of turbid waters originating from the Tijuana River, 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. Ocean currents flowed predominately along a north-south to northeast-southwest axis during most of the year, although these measurements excluded the influence of tidal currents and internal waves. 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 98% for the shore, kelp bed, and other offshore stations combined in 2014. Compliance at the shore stations was ≥82% 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 >99% in 2014. Water quality was also high at the three kelp bed and other offshore stations located within State waters during the year. Compliance at the kelp bed stations was 100% for the geometric mean standards and ≥78% for the SSMs, while compliance at the other offshore stations was ≥89% for the SSMs. Compliance was lowest during the wet season (October–April), when about 83% 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 2014. 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 coastal 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 discharge site. During all of 2014, just two samples with elevated FIB densities were collected from station I12 on the same day in April. This low rate of FIB contamination near the outfall is expected due to chlorination of SBIWTP effluent that typically occurs between November and April, and 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 2014 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 2014, 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 2014 were for (a) arsenic, which exceeded its ERL at a single station during both surveys, and (b) total DDT, which exceeded its ERL at a single station during January and another station during July. None of these four 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 2014 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 87% of the sites. Only four 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 2014 as they have in previous years, occurring in all trawls and accounting for 44% of the total year's catch. California Lizardfish were also prevalent as they have been in four of the past five years, occurring in 100% of trawls and accounting for 24% of the total catch. Other species collected in at least half the trawls included White Croaker, California Tonguefish, Hornyhead Turbot, Longspine Combfish, Curlfin Sole, Longfin Sanddab, Yellowchin Sculpin, English Sole, and Pygmy Poacher. 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 93% of trawls and accounted for 50% of the total invertebrate abundance. Other less abundant but common species included the sea urchin *Lytechinus pictus*, the gastropods *Acanthodoris brunnea*, *Crossata ventricosa*, *Pleurobranchaea californica*, and *Philine auriformis*, the shrimps *Sicyonia penicillata* and *Crangon nigromaculata*, the crabs *Loxorhynchus grandis*, *Metacarcinus gracilis,* and *Platymera gaudichaudii*, 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 2014 surveys with results from previous surveys conducted from 1995 through 2013 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 fishes and invertebrates are consistent with the predominantly shallow, sandy habitat of the region. Patterns in the abundance and distribution of individual species were similar at stations located near the SBOO and 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 2014. 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 2014 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 12 to 449 m. Included below is a summary of the sediment conditions and soft-bottom macrobenthic assemblages present during the 2014 regional survey.

REGIONAL SEDIMENTS

The composition of sediments at the regional stations sampled in 2014 was typical for continental shelf and upper slope benthic habitats off southern California, and consistent with results from previous surveys. Overall, sediments varied by region and depth as expected. For example, stations sampled within the region bounded by the SBOO core 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 2014 was similar to previous years, and there was no evidence of 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 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 2014 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 2014 were similar to those found in other shallow, sandy habitats across the SCB, and were characterized by species such as the polychaete worms *Spiophanes norrisi*, *Spiochaetopterus costarum* Cmplx, *Euclymeninae* sp B, *Lumbrinerides platypygos*, and *Lumbrineris latreilli*. 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. Deeper outer shelf stations with coarser sediments, such as along the Coronado Bank, were instead dominated by other species of polychaete worms such as *Monticellina siblina* and *Mooreonuphis* sp, and the ophiuroid *Ophiura luetkenii*. Similar to patterns described in previous 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 *Maldane sarsi* and *Pectinaria californiensis*, and the molluscs *Cadulus californicus* and *Nuculana conceptionis*.

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2014 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 95% 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 2014 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 2014 in support of these requirements can be found in City of San Diego (2015). 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, 2010–2013) 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). 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 2014 are available in Svejkovsky (2015).

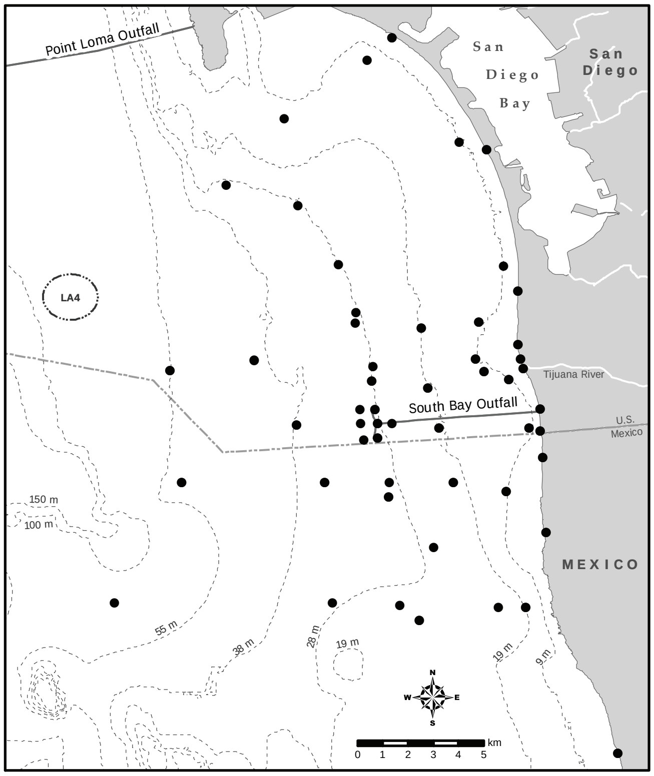

Figure 1.1
Receiving waters monitoring stations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

This annual assessment report presents the results of all receiving waters monitoring activities conducted during calendar year 2014 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 2014 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 2014) 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.

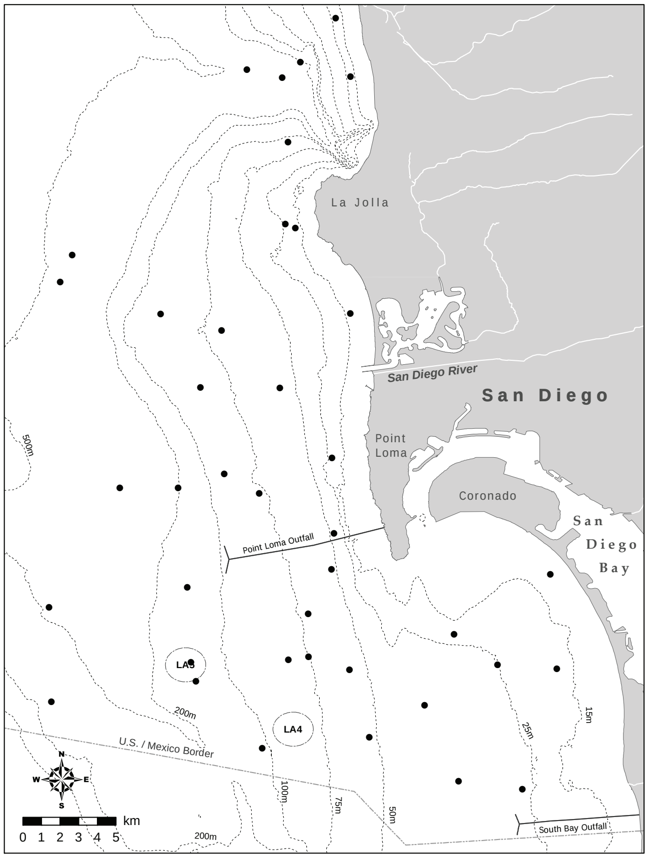

Figure 1.2
Regional benthic survey stations sampled during July 2014 as part of the City of San Diego's Ocean Monitoring Program.

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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 ocean 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 the 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 2015); (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., City of San Diego 2014b). 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).

This chapter presents analysis and interpretation of the oceanographic monitoring data collected during calendar year 2014 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. Data from current meters and thermistor strings are included to examine the dynamics and strength of the thermocline and ocean currents in the area (see Storms et al. 2006, Terrill et al. 2009). 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, 2015). 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 4–7).

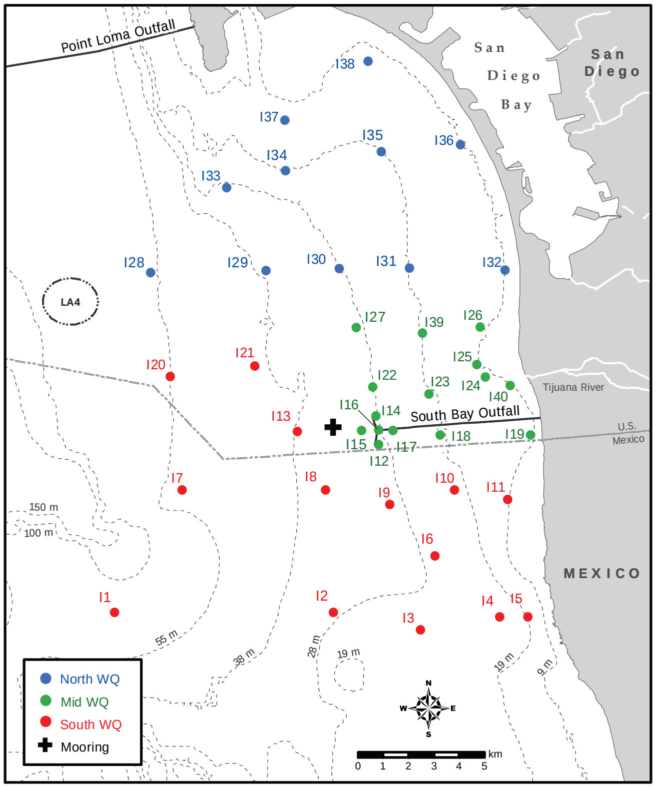

Figure 2.1

Locations of water quality (WQ) monitoring stations where CTD casts are taken and moored instruments (i.e., ADCP, thermistor) are placed 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 km^2 (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 three consecutive days (Table 2.1). The stations were grouped together as follows for sampling and analytical 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) 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.

Moored Instrument Data Collection

Moored oceanographic instruments were deployed at 36 m just offshore of the end of the SBOO in order to provide nearly continuous measurements of ocean currents and water temperature for

Table 2.1

Sample dates for quarterly oceanographic surveys conducted in the South Bay outfall region during 2014. Surveys were conducted within three days with all stations in each station group sampled on a single day (see Figure 2.1 for stations and locations).

Station Group	Feb	May	Aug	Nov
	2014 Sampling Dates			
North WQ	5	13	7	19
Mid WQ	7	15	6	18
South WQ	6	14	5	17

the area (Figure 2.1). Ocean current data were collected from a seafloor-mounted Teledyne RDI Acoustic Doppler Current Profiler (ADCP). The ADCP data were recorded every five minutes and then averaged into depth bins of 4 m. This resulted in 9 bins with midpoints ranging in depth from just below the surface to 32 m. However, the top two bins were excluded from all analyses due to surface backscatter interference. Additional details regarding ADCP data processing and analyses are presented below under 'Data Analysis.'

Temperature data were collected from a vertical series of temperature sensors (thermistors) every 10 minutes from duplicate arrays. Eight thermistors (Onset Tidbit temperature loggers) were deployed on mooring lines starting at 2 m above the seafloor and extending through the water column every 4 m to within 6 m of the surface. Additional details for both thermistor and ADCP specifications are available in Storms et al. (2006).

Remote Sensing

Coastal monitoring of the San Diego region during 2014 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 2015), while a separate report summarizing results for the year was also produced (Svejkovsky 2015). Several 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 2014 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. Due to instrumentation issues, pH data for February were excluded from these and subsequent analyses. For spatial analysis, 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.

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 13 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 $d\rho/dz$ 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 plots of anomalies for temperature, salinity, and DO data were created to evaluate regional oceanographic events in context with larger scale processes (i.e., ENSO events). These analyses were also limited to data from the

13 outfall depth stations combined over all depths. Anomalies were then calculated by subtracting the average of all 20 years combined (i.e., 1995–2014) from the monthly means for each year.

Summary statistics for seasonal ocean current data were generated for each depth bin and prevailing current modes were examined by empirical orthogonal function (EOF) analysis using singular value decomposition (Anderson et al. 1999). Since ocean currents in southern California typically vary seasonally (Winant and Bratkovich 1981), ADCP data were subset by season prior to subsequent analyses: winter (December–February); spring (March–May); summer (June–August); and fall (September–November). Although the winter season for 2014 included non-continuous months (i.e., January–February and December), preliminary analysis suggested that the current regimes for these three months were similar enough to justify pooling them together. In addition, since tidal currents are not likely to result in net water mass transport (Rogowski et al. 2012, City of San Diego 2015), their effects were removed prior to analyses using the PL33 filter (Alessi et al. 1984).

RESULTS AND DISCUSSION

Oceanographic Conditions in 2014

Water Temperature and Density

Surface water temperatures (1–9 m) across the South Bay outfall monitoring region ranged from 11.4 to 22.6ºC during 2014 (Appendix A.1). Subsurface water temperatures ranged from 10.8 to 21.3ºC at 10–19 m, 10.5 to 19.5ºC at 20–28 m, 10.5 to 18.5ºC at 29–38 m, and 10.5 to 16.2ºC at 39–55 m. The maximum surface temperature occurred in August and was ~1.5ºC higher than in 2013 when it occurred in July (City of San Diego 2014b). Although ocean temperatures varied seasonally as expected, warmer mean temperatures extended later into the year with November's mean surface temperature of 18.7ºC being ~3ºC higher than November 2013 (Figure 2.2, Appendix A.1). Seawater colder than 12ºC, possibly indicative of local upwelling, reached near-surface waters from February through June (Figure 2.3). Conversely, waters warmer than 18ºC, likely indicative of downwelling, reached bottom waters periodically from mid-September to mid-December. Thermal stratification also followed typical seasonal patterns, with the greatest difference between surface and bottom waters (10.9ºC) 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 2.4). These vertical density profiles also demonstrated how the water column ranged from well-mixed during February with a maximum BF $\leq$32 cycles^2/min^2, to stratified in May and August reaching a maximum BF of 158 cycles^2/min^2. The values observed from May to November were greater than those observed during the corresponding months in 2013 (City of San Diego 2014b). As expected, the depth of the pycnocline also varied by season, with shallower pycnocline depths (<10 m) occurring during quarters with greater stratification.

Salinity

Salinities recorded in 2014 were similar to those reported previously for the SBOO region (e.g., City of San Diego 2012b, 2013b, 2014b). Surface salinity ranged from 33.29 to 33.75 psu at 1–9 m (Appendix A.1). Subsurface salinity ranged from 33.24 to 33.63 psu at 10–19 m, 33.24 to 33.70 psu at 20–28 m, 33.20 to 33.71 psu at 29–38 m, and 33.25 to 33.70 psu at 39–55 m. As with ocean temperatures, salinity varied seasonally. For example, the highest values of the year were recorded in surface waters across the region in August. This was most likely due to evaporation during an extended period of warm temperatures along the San Diego area coast (NWS 2015). Additionally, relatively high salinity $\geq$33.6 psu was present across most of the region during

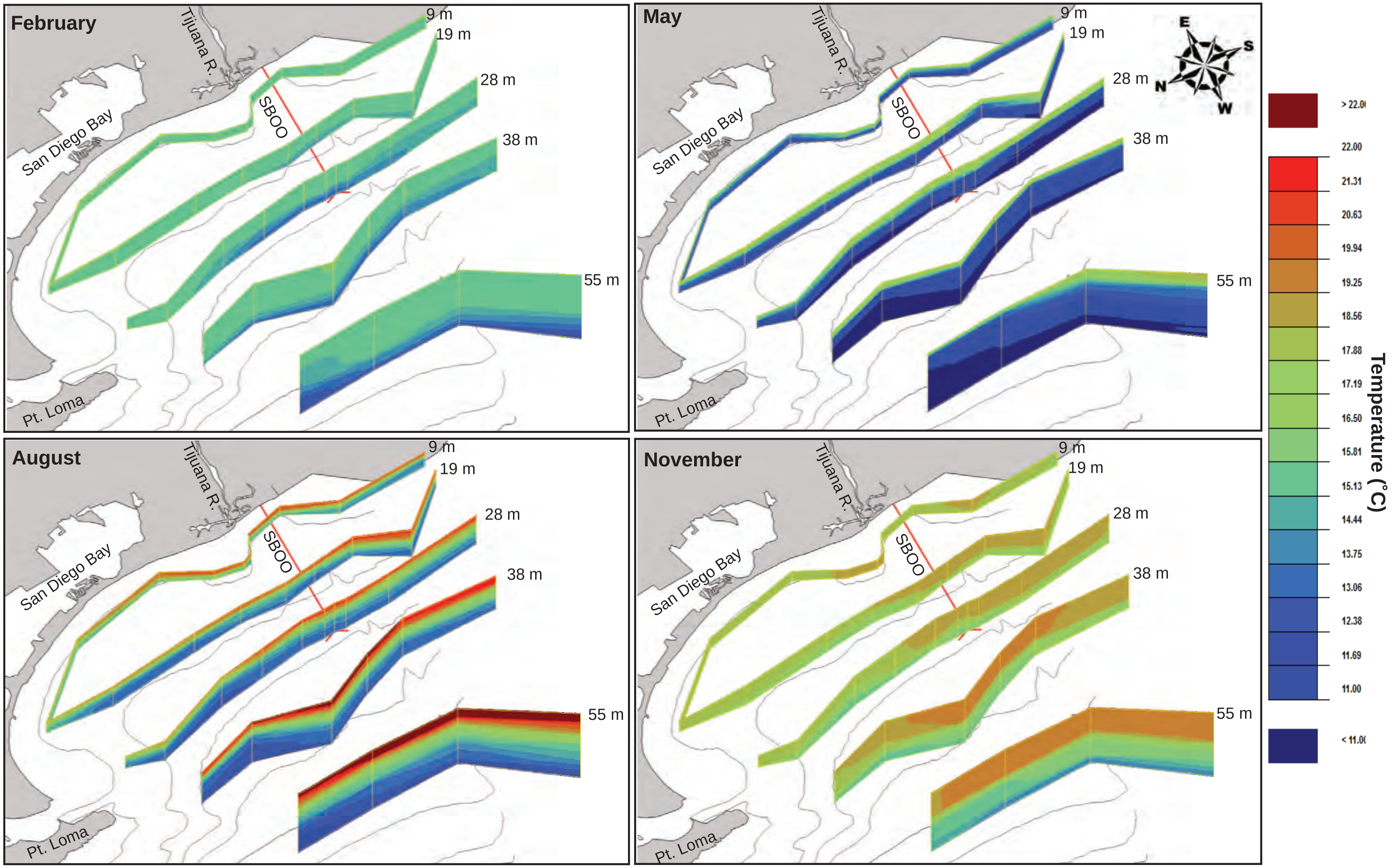

Figure 2.2
Ocean temperatures recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2014. Data were collected over three consecutive days during each of these surveys.

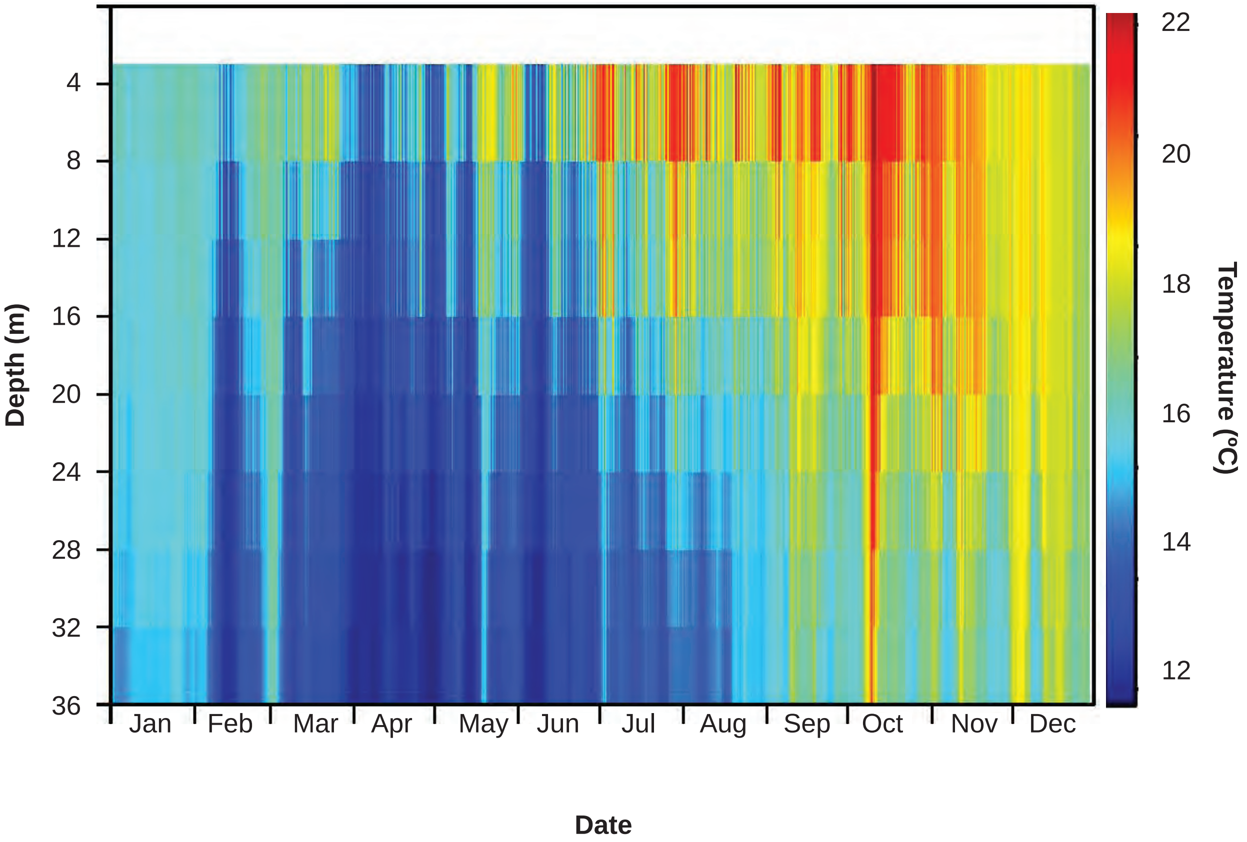

Figure 2.3

Temperature data collected at the SBOO 36-m thermistor site from January through December 2014. Data were collected every 10 minutes.

May at depths that corresponded with the lowest water temperatures (e.g., Figures 2.2, 2.5). 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 2.5, 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, results of remote imaging (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., OCSD 2012, City of San Diego 2010a-2014a). 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.

Dissolved oxygen and pH

Overall, DO and pH levels were within historical ranges throughout the year, with ranges of values observed in 2014 narrower than those of 2013

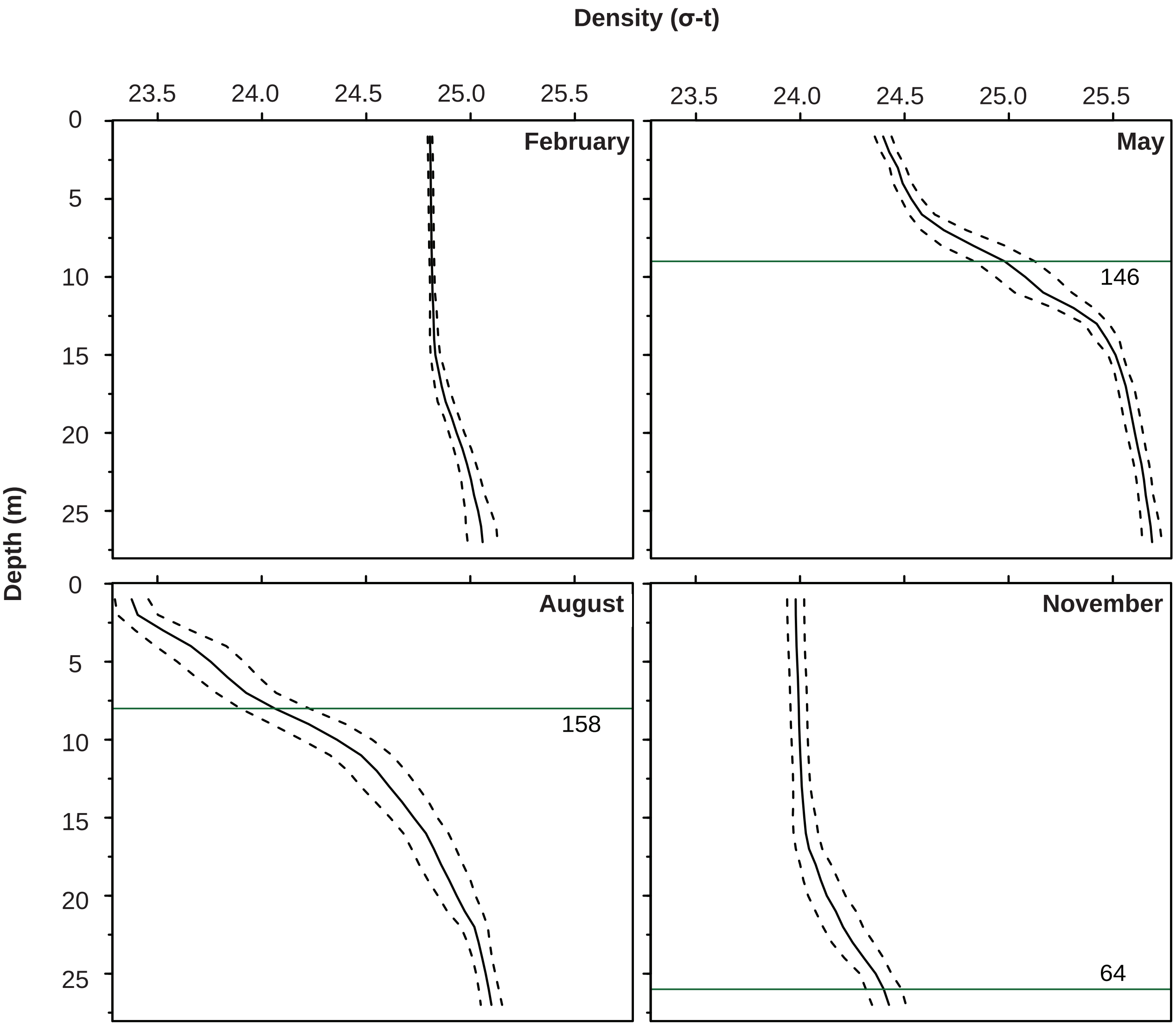

Figure 2.4

Density and maximum buoyancy frequency (BF) for each quarter at outfall depth stations sampled in the SBOO region during 2014. 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.

(City of San Diego 2014b). Surface DO ranged from 4.9 to 11.3 mg/L at 1–9 m (Appendix A.1). Subsurface DO ranged from 4.3 to 11.2 mg/L at 10–19 m, 4.0 to 8.7 mg/L at 20–28 m, 4.0 to 8.6 mg/L at 29–38 m, and 4.0 to 8.5 mg/L at 39–55 m. Surface pH ranged from 7.9 to 8.2 at 1–9 m. Subsurface pH ranged from 7.8 to 8.3 at 10–19 m, and from 7.8 to 8.2 at 20–28 m, 29–38 m, and 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 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 near the bottom 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, high DO concentrations (> 10 mg/L) in the SBOO region

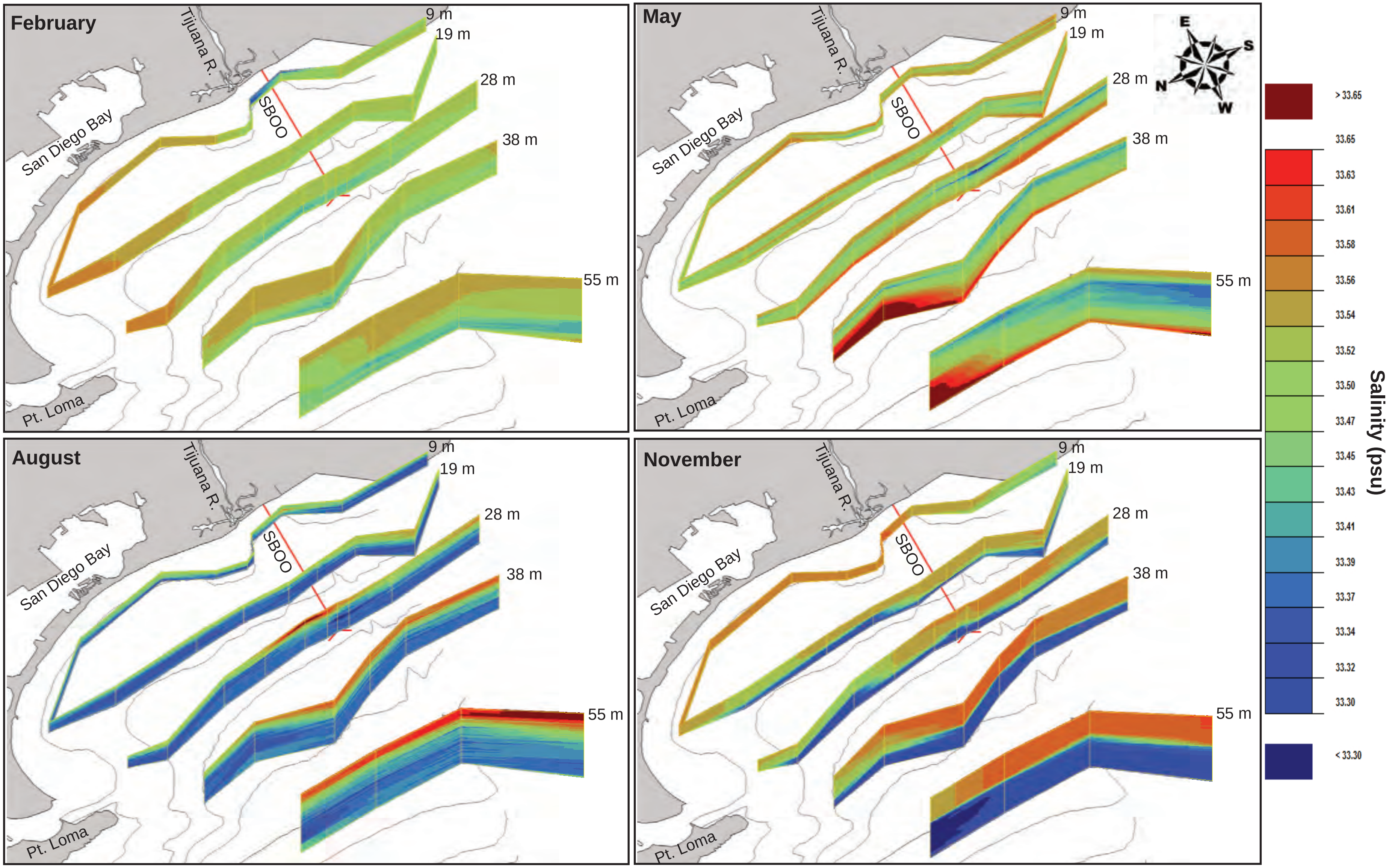

Figure 2.5
Ocean salinity recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2014. Data were collected over three consecutive days during each of these surveys.

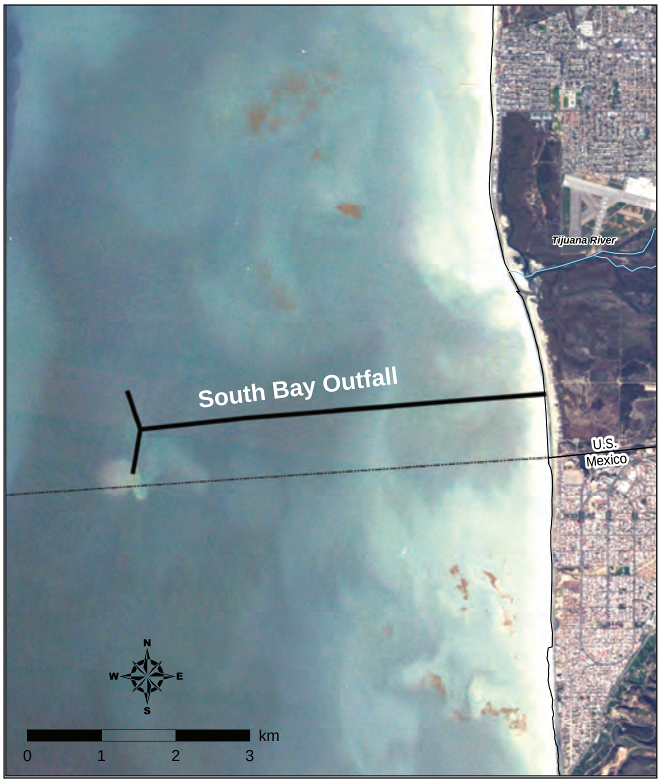

Figure 2.6
Rapid Eye image of the SBOO and coastal region acquired February 1, 2014 (Ocean Imaging 2015) depicting turbidity plumes from coastal runoff and the Tijuana River following rain events.

during May were associated with phytoplankton blooms, evident by relatively high chlorophyll *a* concentrations in the nearshore area.

Transmissivity

Overall, water clarity was within historical ranges for the SBOO region during 2014 (e.g., City of San Diego 2013b, 2014b). Surface transmissivity ranged from 26 to 90% at 1–9 m (Appendix A.1). Subsurface transmissivity ranged from 14 to 90% at 10–19 m, from 63 to 90% at 20–28 m, from 56 to 90% at 29–38 m, and from 48 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). This was especially evident in February when high surf (>1.5 m) coincided with a rainfall event (CDIP 2015, NWS 2015) and resultant increases in suspended sediments and turbidity plumes were observed via remote sensing (Figure 2.6).

Chlorophyll a

Concentrations of chlorophyll *a* ranged from 0.1 to 41.7 mg/L during 2014 (Appendix A.1). All relatively high values ≥11 mg/L occurred during May which is in contrast to 2013 when high values were observed during both the spring and summer (City of San Diego 2014b). As has been reported previously (e.g., Svejkovsky 2011), the highest chlorophyll *a* concentrations coincided with the upwelling events described in previous sections. Further, the high chlorophyll *a* concentrations recorded at mid- and bottom depths (e.g., Appendix A.5) reflect the fact that phytoplankton tend to mass at the bottom of the pycnocline where nutrients are available and light is not yet limited (Lalli and Parsons 1993).

Summary of Ocean Currents in 2014

Current patterns varied by season and depth in the SBOO region during 2014 with maximum speeds observed near the surface during summer (Appendix A.6). The general axis of variability in the current flow across the water column, as indicated by the dominant mode (EOF 1), was within ±20° of a north-south axis in all seasons at all depths (Figure 2.7). This is generally comparable to results obtained during previous studies (e.g., Terrill et al. 2009). Current direction differed with both depth and time of year (Figure 2.8A). Coherent southward flow (i.e., currents moving in the same direction throughout the entire water column) was more common from late April through mid-August. Three of these coherent southerly events corresponded to time periods when upper water column velocities were greater than 200 mm/s (Figure 2.8B). Northward flows were generally associated with very low velocities. However, during October mid-column northward velocities approached 200 mm/s over the course of several days, coinciding with an observed warming event when bottom temperatures at the 36-m mooring exceeded 21°C (Figure 2.3).

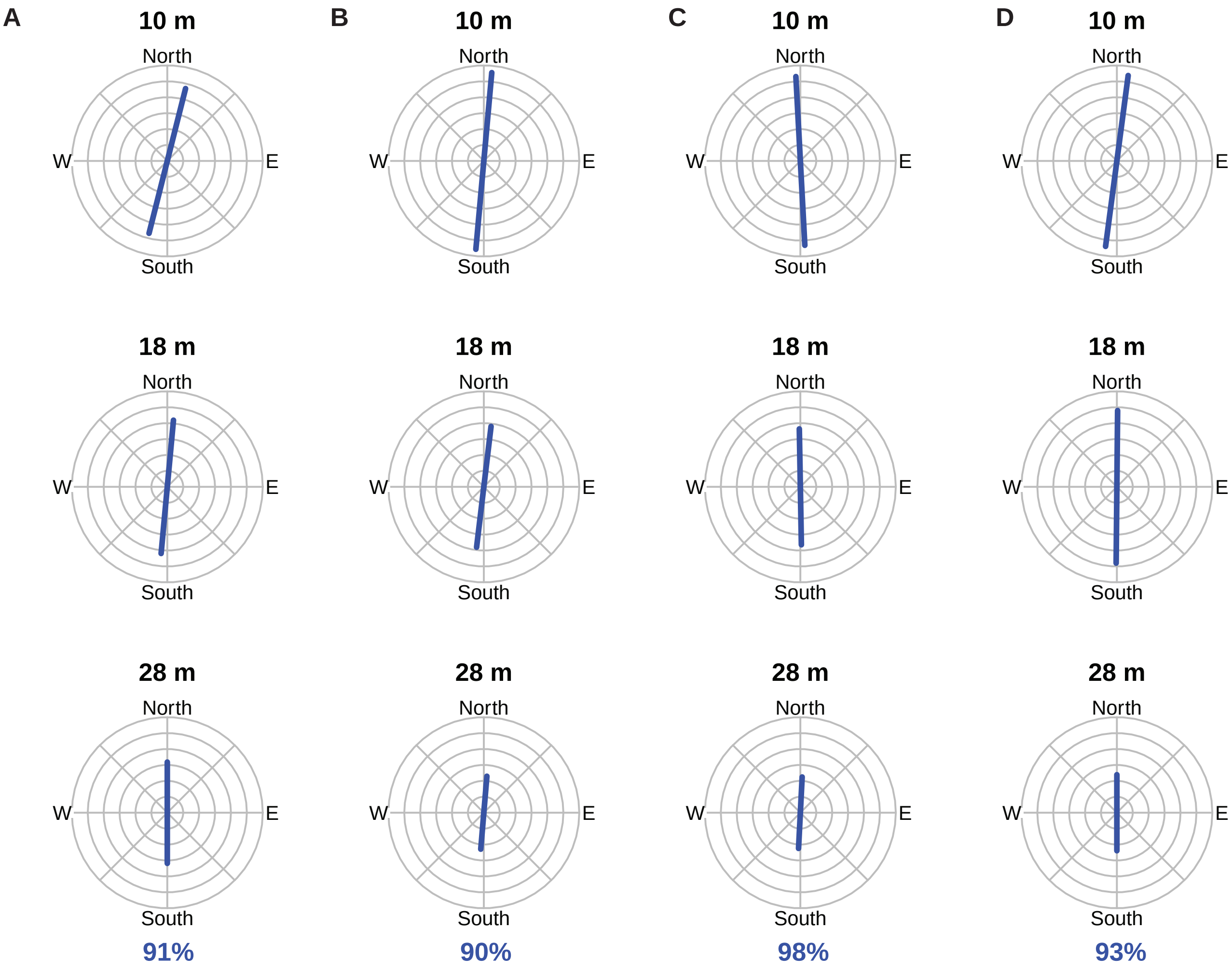

Figure 2.7
Dominant current modes (EOF 1) for (A) winter, (B) spring, (C) summer, and (D) fall in 2014 from the SBOO 36-m ADCP site for selected depth bins. Percentages indicate fraction of the total variance accounted for by the EOF for each season. Line length indicates magnitude. Each concentric ring is 0.1 mm/s.

Historical Assessment of Oceanographic Conditions

A review of temperature, salinity, and DO data from all outfall depth stations sampled from 1995 through 2014 (Figure 2.9) indicated 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, NOAA/NWS 2015). 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. Temperature and salinity data for the SBOO

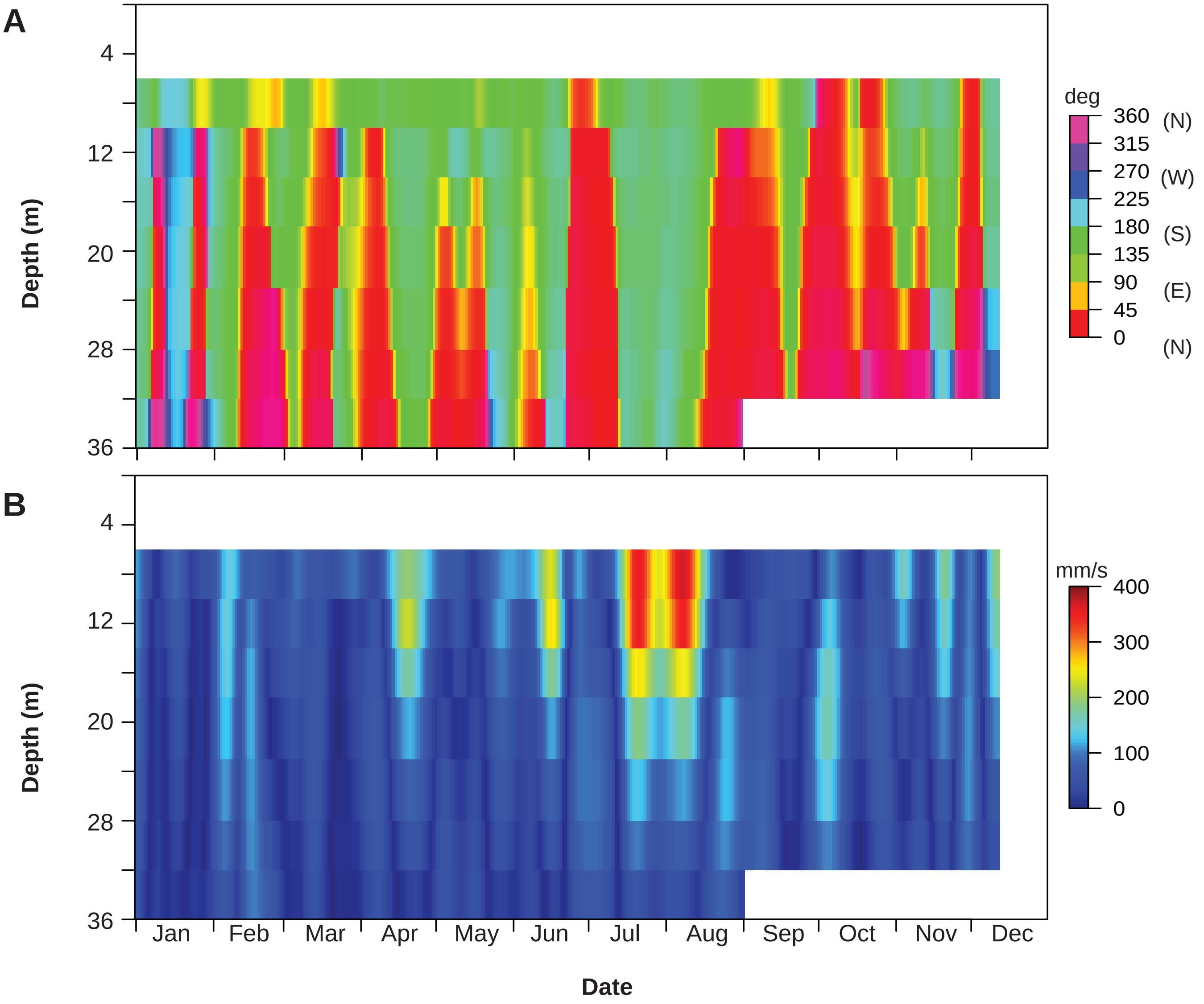

Figure 2.8

ADCP data collected at the SBOO 36-m site showing daily average (A) direction, and (B) horizontal velocity of currents from January through December 2014. Missing data (white areas) are the result of interference with the doppler signal near the surface or instrumentation issues. N = North, W = West, S = South, E = East.

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 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 2014, 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 weak El Niño that developed in 2014 (NOAA/NWS 2015).

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

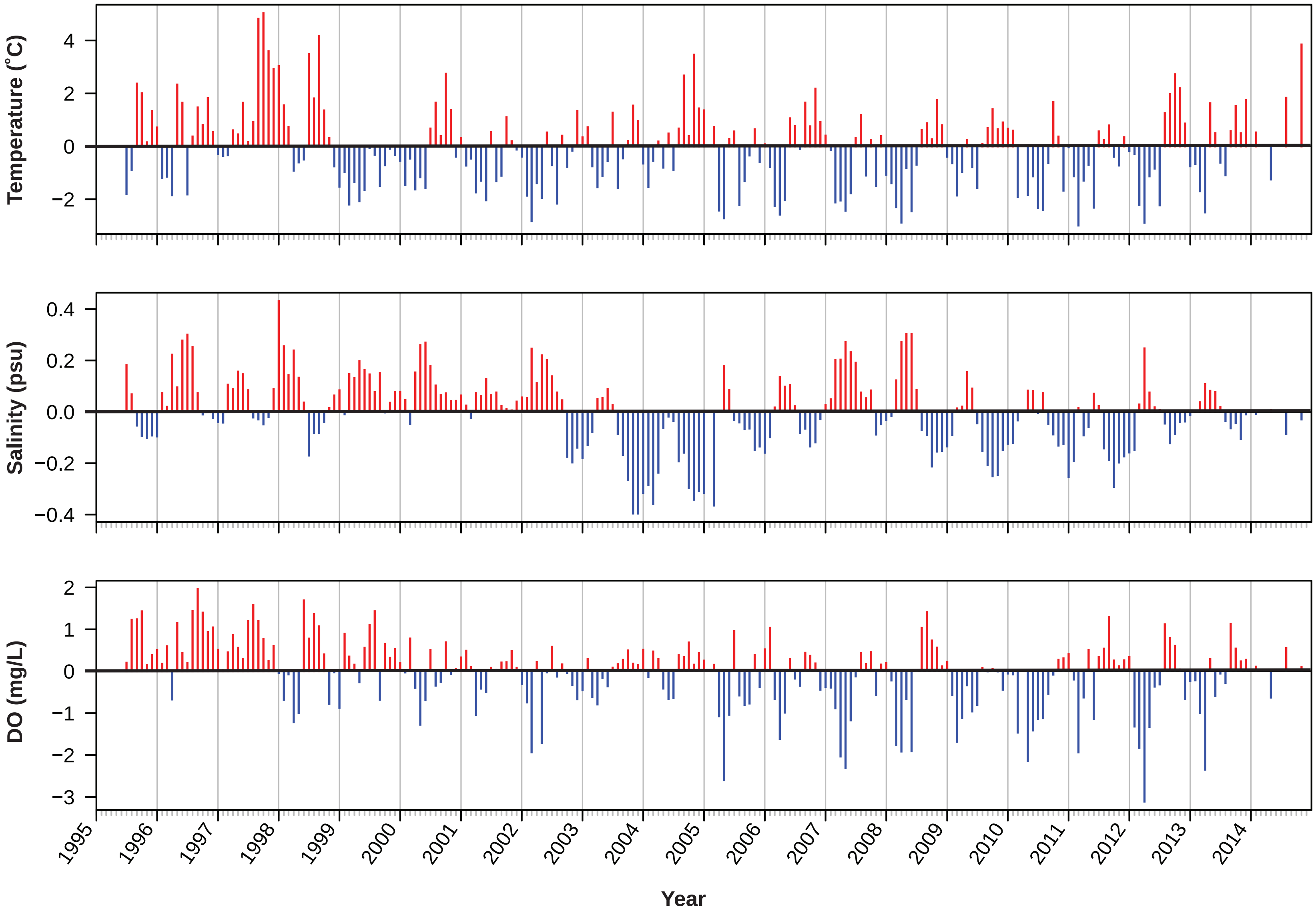

Figure 2.9
Time series of temperature, salinity, and dissolved oxygen (DO) anomalies from 1995 through 2014 at the 13 outfall depth stations sampled in the SBOO region, with all depths combined.

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, apart from May, DO anomalies were positive in 2014.

SUMMARY

Oceanographic data collected in the South Bay outfall region during 2014 were consistent with reports from NOAA that the ENSO-neutral conditions that began in mid-2012 have shifted to ENSO-positive with warmer conditions persisting through the end of 2014 (Leising et al. 2014, NOAA/NWS 2015). Conditions indicative of local coastal upwelling, such as relatively cold, dense, saline waters with low DO and pH at mid-depths and below, were observed during May although thermistor data indicated that periods of upwelling may have occurred episodically between late February and early June. Subsurface phytoplankton blooms, indicated by high chlorophyll *a* concentrations, were only observed during May. These blooms were unobserved with remote sensing instrumentation due to their depth (Svejkovsky 2015).

Overall, water column stratification in 2014 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, NOAA/NWS 2015) 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).

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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 2012 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 effects or 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, Griffith et al. 2010, Sercu et al. 2009). Moreover, beach wrack (e.g., kelp, seagrass), storm drains impacted by tidal flushing, and beach sediments can act as reservoirs for bacteria until released into nearshore waters by returning tides, rainfall, and/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 a natural chemical tracer 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). By combining measurements of CDOM with additional metrics that may characterize outfall-derived waters (e.g., low salinity, low chlorophyll *a*), multiple criteria can be applied to improve the reliability of detection and facilitate the focused 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 2014 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 2012 Ocean Plan. Results of remote sensing data for the region are also evaluated to provide insight into wastewater transport and the extent of

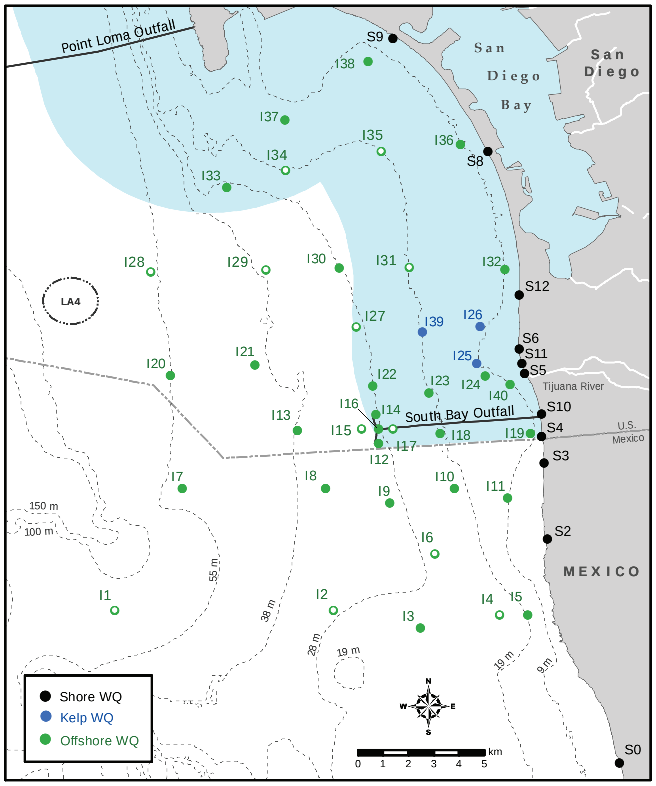

Figure 3.1

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 bed and other offshore stations.

Station Contour	Sample Depth (m) 2	6	9/11	12	18	27	37	55
Kelp Bed								
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. The samples were then 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 SDRWQCB (e.g., City of San Diego 2014b).

Kelp bed and other offshore stations

Three stations located in nearshore waters within the Imperial Beach kelp forest 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 included two stations (I25, I26) located near the inner edge of the kelp bed along the 9-m depth contour, and one station (I39) located near the outer edge of the kelp bed along the 18-m depth contour. Three other offshore stations near the terminus of the SBOO (I12, I14, I16) were sampled monthly in conjunction with a kelp sampling event. An additional 22 stations were sampled quarterly (i.e., February, May, August,

Box 3.1

Water quality objectives for water contact areas, 2012 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.

November) to monitor FIB levels and to estimate the spatial extent of the wastewater plume. These non-kelp offshore stations are arranged in a grid surrounding the discharge site along the 9, 19, 28, 38, and 55-m depth contours (Figure 3.1). Sampling of these offshore stations was completed over a 3-day period each quarter (see Chapter 2).

During quarterly sampling, seawater samples for FIB and total suspended solids (TSS) were collected at three discrete depths at each of the kelp and non-kelp bed stations using either an array of Van Dorn bottles or a rosette sampler fitted with Niskin bottles (Table 3.1). Additional samples 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. Visual observations of weather and sea conditions, and human and/or animal activity were also recorded at the time of sampling. Oceanographic data were collected from these stations using a CTD to measure temperature, conductivity (salinity), pressure (depth), chlorophyll *a*, CDOM, dissolved oxygen (DO), pH, and transmissivity (see Chapter 2).

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 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 2015a).

Data Analyses

Bacteriology

FIB densities were summarized as monthly means for each shore station and by depth contour for the kelp bed and other offshore stations. During non-quarterly months offshore station means included only the three 28-m depth contour stations I12, I14, and I16. TSS and O&G concentrations were also summarized by quarter for the offshore stations. To assess temporal and spatial trends, the bacteriological data were summarized as counts of samples in which FIB concentrations exceeded benchmark levels. For this report, water contact limits defined in the 2012 Ocean Plan for densities of total coliforms, fecal coliforms, and *Enterococcus* in individual samples (i.e., single sample maxima, see Box 3.1 and SWRCB 2012) were used as reference points or benchmarks to distinguish elevated FIB values. Bacterial densities were compared to rainfall data from Lindbergh Field, San Diego, CA (see NOAA 2015). 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 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 2015) 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 month that each of the eight shore stations located north of the USA/Mexico border, the three kelp bed stations, and the other offshore stations located within State jurisdictional waters (i.e., within 3 nautical miles of shore) exceeded the various standards.

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. All stations along the 9-m depth contour were excluded from analyses due to a strong CDOM signal near shore, which was likely caused by coastal runoff or nearshore sediment resuspension (Appendix B.1). Previous monitoring has consistently found that the SBOO plume is trapped below the pycnocline during seasonal water column stratification, but may rise to the surface when stratification breaks down (City of San Diego 2010–2014a, 2015b, 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). 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 determined by comparing mean values of DO, pH, and transmissivity within the possible plume to thresholds calculated for similar depths from reference stations. Any stations with CDOM 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) for DO, pH, and transmissivity 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., in prep). February compliance for pH was not calculated due to calibration issues with the instrument (see Chapter 2).

RESULTS AND DISCUSSION

Bacteriological Compliance and Distribution

Shore stations

During 2014, compliance for the 30-day geometric mean standards at the eight shore stations located north of the USA/Mexico border ranged from 92 to 100% for total coliforms, 84 to 100% for fecal coliforms, and 82 to 100% for *Enterococcus* (Figure 3.2A). In addition, compliance with the single sample maximum (SSM) standards ranged from 84 to 100% for total coliforms, 73 to 100% for fecal coliforms, 67 to 100% for *Enterococcus*, and 77 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 >99% in 2014. Reduced compliance at shore stations was more prevalent during the wet season, with the lowest values for all standards occurring in either March or December following significant rain events (NWS 2015). In contrast, all standards were in compliance 100% of the time during the dry weather months from June through September.

Monthly mean FIB densities ranged from 6 to 6156 CFU/100 mL for total coliforms, 2 to 2636 CFU/100 mL for fecal coliforms, and 2 to 2451 CFU/100 mL 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=64) had elevated FIB (Appendix B.4), which is slightly higher than the 8% observed in 2013 (City of San Diego 2014a). A majority (83%) of the shore samples with elevated FIB were collected during the wet season when rainfall totaled 7.69 inches, versus 0.08 inches in the dry season (Table 3.2). This general relationship between rainfall and elevated bacterial levels has been evident from water quality monitoring in the region

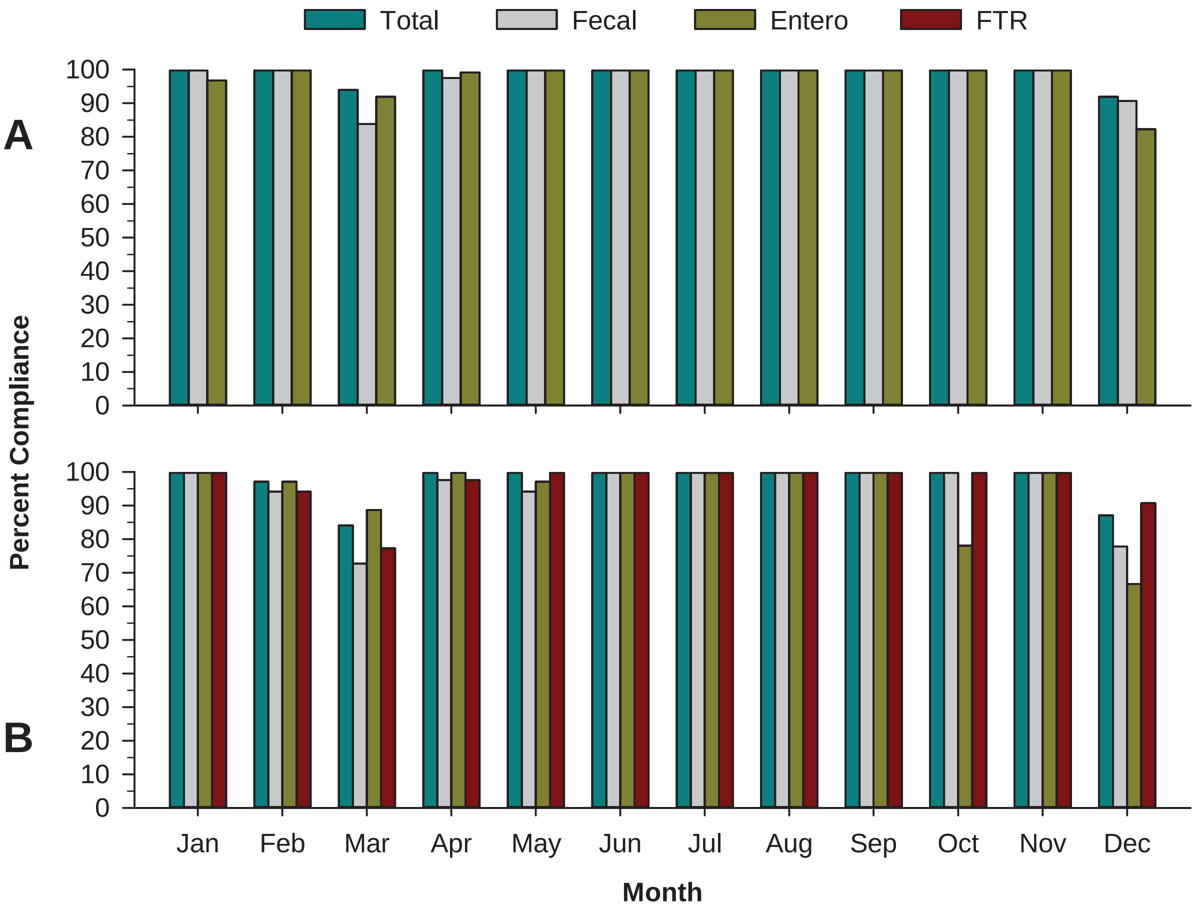

Figure 3.2

Compliance rates for (A) the three geometric mean and (B) the four single sample maximum water contact standards from SBOO shore stations during 2014.

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; $n=11{,}741$, $\chi^2=450.90$, $p<0.0001$).

During the wet season in 2014, elevated FIB were primarily detected at 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). Samples from three of these stations, S0, S2, and S3, also had high FIB counts during dry conditions from May to September, and accounted for 10 of the 11 dry weather samples with elevated FIB. An additional elevated FIB sample was collected during May at station S4 following an unusually late rain event. 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 2008–2014). Foam and sewage-like odors were also consistently observed at various shore stations within the SBOO region, with increased occurrences during the wet season. Additionally, storm drain runoff was often observed at all three stations located in Mexico.

Kelp bed stations

During 2014, compliance at the three SBOO kelp bed stations was 100% for all water contact standards from January through November. In contrast, compliance rates for the four SSM standards dropped to 78%–98% during December (Figure 3.5), corresponding to a period of high rainfall (i.e., 4.50 inches compared to ≤1.28 inches in all other months). Satellite imagery during this time shows numerous turbidity plumes including one originating from the Tijuana River (Figure 3.6).

Monthly mean FIB densities at the kelp bed stations were lower than those at shore stations, ranging from 2 to 950 CFU/100 mL for total coliforms, 2 to 110 CFU/100 mL for fecal coliforms, and 2 to 71 CFU/100 mL for *Enterococcus* (Appendix B.5). Nothing of sewage origin was observed at these stations. Of the 531 kelp bed samples analyzed during the year (not including resamples), 2% (n = 11) had elevated FIB, all of which were collected in December (Appendix B.6). Due to fewer high-rainfall events, coastal runoff from the Tijuana Estuary was low in 2014 compared to previous years (Svejkovsky 2015) and contributed to the low incidence of elevated FIB detections throughout the year (Table 3.3). 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 (7% versus 1%, respectively; $n = 9035$, $\chi^2 = 206.77$, $p < 0.0001$).

No seawater samples collected from the kelp bed stations in 2014 contained detectable levels of O&G

Table 3.2

Number of samples with elevated FIB (eFIB) densities collected from SBOO shore stations during wet and dry seasons in 2014. 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	2	0	100
S8	0	0	—
S12	1	0	100
S6	2	0	100
S11	2	0	100
S5	7	0	100
S10	6	0	100
S4	4	1	80
South of USA/Mexico Border			
S3	5	2	71
S2	4	3	57
S0	20	5	80
Rain (in)	7.69	0.08	99
Total eFIB	53	11	83
Total Samples	330	242	58

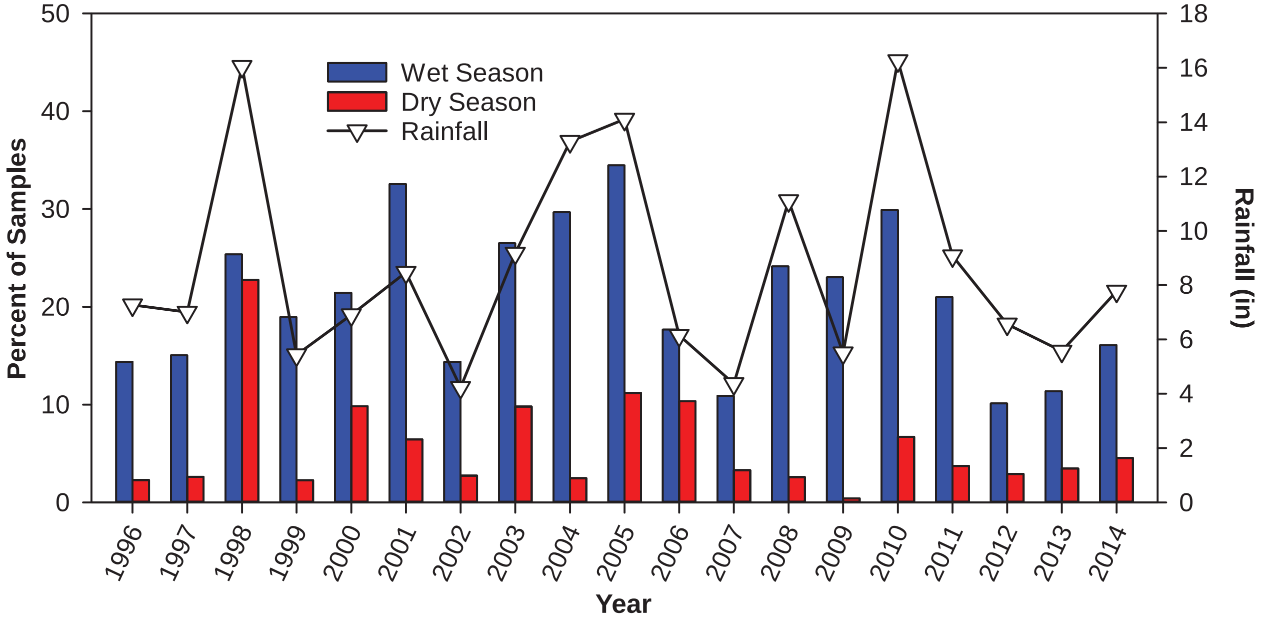

Figure 3.3

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 2014. Rain data are from Lindbergh Field, San Diego, CA. Data from 1995 were excluded as sampling did not occur the entire year.

(detection limit=0.2 mg/L; Appendix B.7). Detection rates for TSS were higher, ranging from 0% in November to 100% in May, with concentrations ≤8.0 mg/L. Only one seawater sample had an elevated TSS concentration of 8.0 mg/L. There were no elevated FIB densities associated with this sample.

Non-kelp bed stations

Compliance with the SSM water contact standards at the 14 offshore stations located within State jurisdictional waters (i.e., I12, I14, I16, I18, I19, I22–I24, I32, I33, I36–I38, I40) was ≥89% during 2014 (Figure 3.8). Monthly mean FIB concentrations in seawater samples collected from these and the other 11 non-kelp bed offshore stations ranged from 2 to 1386 CFU/100 mL for total coliforms, 2 to 238 CFU/100 mL for fecal coliforms, and 2 to 32 CFU/100 mL for *Enterococcus* (Appendix B.5). Only five (~1%) of the 372 samples collected within State waters had elevated FIB, three of which were collected from stations I19 and I40 located along the 9-m depth contour following a rain event (Appendix B.6). These two sites, in combination with the three kelp bed stations, were the only non-outfall stations with elevated FIB throughout the year in the SBOO region (Figure 3.9). Given the proximity of these stations to shore, coastal runoff may be responsible for these elevated FIB levels (see Chapter 2).

During 2014, water quality was very high at the three stations closest to the SBOO south diffuser leg (i.e., outfall stations I12, I14, I16). Only two out of 108 samples (~2%) collected from these stations had elevated FIB (Table 3.3, Figure 3.9, Appendix B.6). These two samples were collected from station I12 on April 4. Historically, samples with elevated bacterial levels have been collected more often at the three outfall stations when compared to other stations along the 28-m depth contour (8% versus 2%; n=5417, $\chi^2 = 100.11$, $p < 0.0001$) (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 dropped 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.

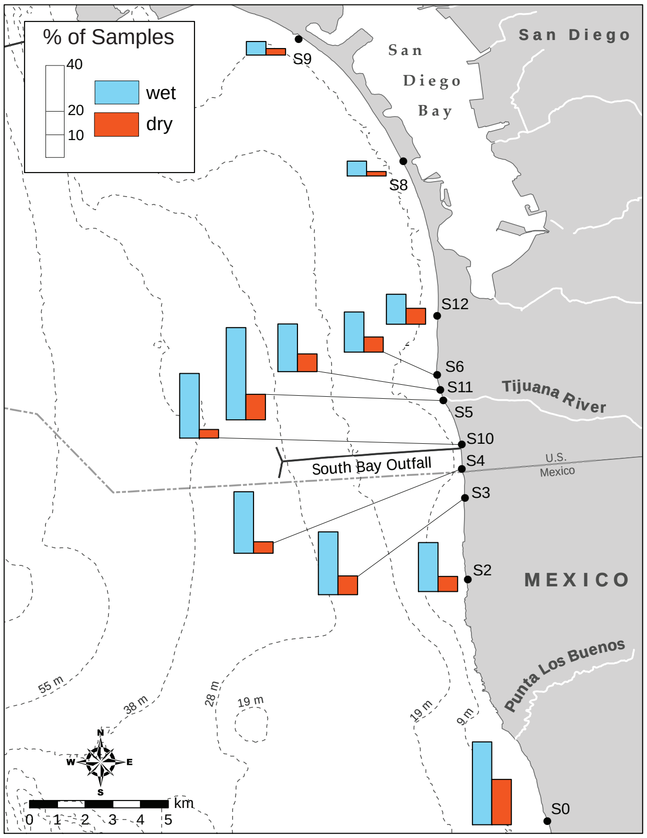

Figure 3.4
Proportion of samples with elevated FIB densities in wet versus dry seasons at SBOO shore stations from 1995 through 2014.

Of the 124 samples collected during 2014, three (~2%) contained detectable levels of O&G, with concentrations that ranged from 1.4 to 3.1 mg/L (Appendix B.7). Total suspended solids were detected in 210 of 412 samples (51%), with concentrations that ranged from 2.2 to 18.6 mg/L. None of the seawater samples with elevated TSS concentrations (≥8.0 mg/L) corresponded to 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 was assessed using the results from 112 CTD profile casts performed during 2014. Based on the

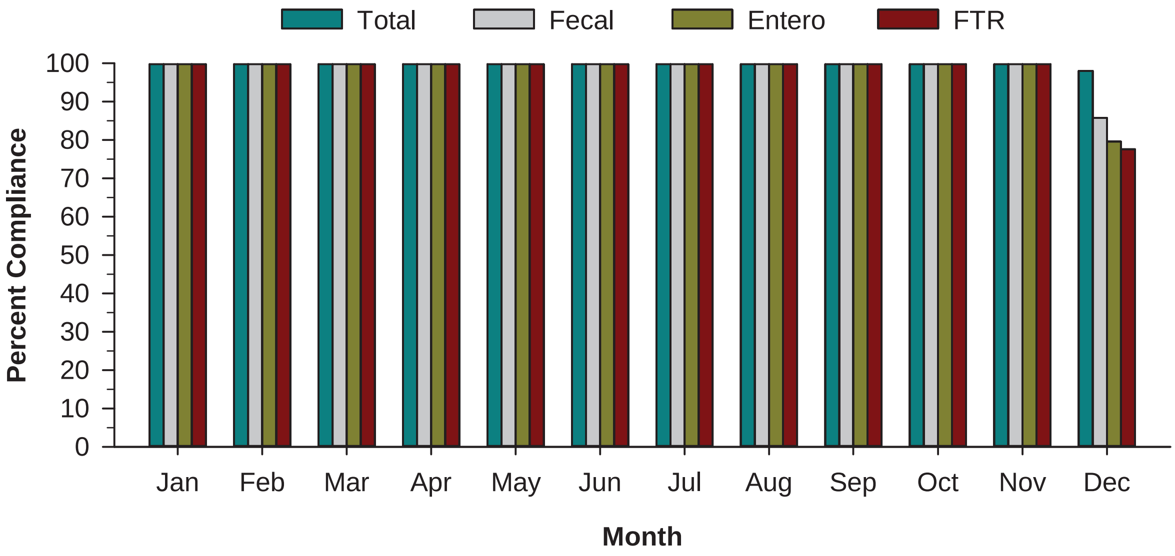

Figure 3.5
Compliance rates for the four single sample maximum water contact standards from SBOO kelp bed stations during 2014. See Box 3.1 for details.

criteria described in the Materials and Methods section, potential evidence of the plume was detected a total of 14 times from 10 different stations throughout the year (Figure 3.11, Table 3.4), while 5–13 stations were identified as reference sites during each quarterly survey (Appendix B.2). No stations were identified with potential plume characteristics in February due to the lack of a salinity signal. Eight of the possible detections (~75%) occurred at stations I12, I16, I23, and I35 in both May and August (Figure 3.11, Appendix B.8). Two of these sites, stations I12 and I16, are located near the outfall wye. The other two stations are located inshore and north of the SBOO along the 19-m contour. The identification of station I35 as having a potential plume signal may be spurious due to its proximity to San Diego Bay and the influence of tidal pumping of organic matter from inside the bay. In November, five stations located south of the USA/Mexico border along the 28 and 19-m contours showed potential plume characteristics. The detection of potential plume at these stations corresponds with near-surface dispersion patterns observed by satellites under typical southward flow conditions (Svejkovsky 2010). However, none of the plume detections were associated with elevated FIB.

The effects of the SBOO wastewater plume on the three physical water quality indicators mentioned above were calculated for each station and depth where it was detected. For each of these, mean values for natural light (% transmissivity), DO, and pH within the plume were compared to thresholds within similar depths from non-plume reference stations (see Appendix B.8). Of the 14 potential plume detections that occurred during 2014, a total of seven out-of-range (OOR) events were identified at various stations for transmissivity; no OOR events were identified for DO or pH (Table 3.4, Appendices B.9–B.12). Four of these seven OOR events occurred at stations within State jurisdictional waters where Ocean Plan compliance standards apply.

SUMMARY

Water quality conditions in the South Bay outfall region were excellent during 2014. Overall compliance with 2012 Ocean Plan water-contact standards was ~98%, which was similar to what was observed during the previous year (City of San Diego 2014a). This continued level of high compliance likely reflects another year of low rainfall, which totaled about 8 inches in 2014, in contrast to 2010, when rainfall totaled about 16 inches and overall compliance was 87% (City of San Diego 2011). Additionally, only ~5% of all water samples analyzed in 2014 had elevated FIB, of

Figure 3.6
Rapid Eye satellite image showing stations near the SBOO on December 19, 2014 (Ocean Imaging 2015) combined with bacteria levels sampled at shore and kelp bed stations on December 16 and 19, respectively. Turbid waters from the Tijuana River, caused by several rain events during the month, can be seen overlapping stations with elevated FIB (red circles). See Appendices B.4 and B.6 for bacterial sample details.

which 83% occurred during the wet season. Of these high counts, 80% were from samples collected at the shore stations. This pattern of higher contamination along the shore, especially during the wet season, is similar to that observed during previous years and is likely due to runoff from point and non-point sources (e.g., City of San Diego 2014a). The few samples with high bacteria counts taken during dry weather periods were exclusively at shore stations, most from stations south of the USA/Mexico border.

Table 3.3
Number of samples with elevated FIB (eFIB) densities collected at SBOO kelp bed and other offshore stations during wet and dry seasons in 2014. Rain data are from Lindbergh Field, San Diego, CA. Missing offshore stations had no samples with elevated FIB concentrations during 2014.

	Wet	Dry	% Wet
Rain (in)	7.69	0.08	99
Kelp Bed Stations			
9-m Depth Contour			
I25	5	0	100
I26	3	0	100
18-m Depth Contour			
I39	3	0	100
Total eFIB	11	0	100
Total Samples	315	216	
Non-Kelp Bed Stations			
9-m Depth Contour			
I19	1	0	100
I40	2	0	100
28-m Depth Contour			
I12	2	0	100
Total eFIB	5	0	100
Total Samples	195	177	

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 six 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 2010–2015). 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 the wet season. 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 2008–2014). 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. 2004, Terrill et al. 2009, Svejkovsky 2010). Further, the general relationship between rainfall and elevated bacterial levels in the SBOO region existed before wastewater discharge began in 1999 (see also City of San Diego 2000).

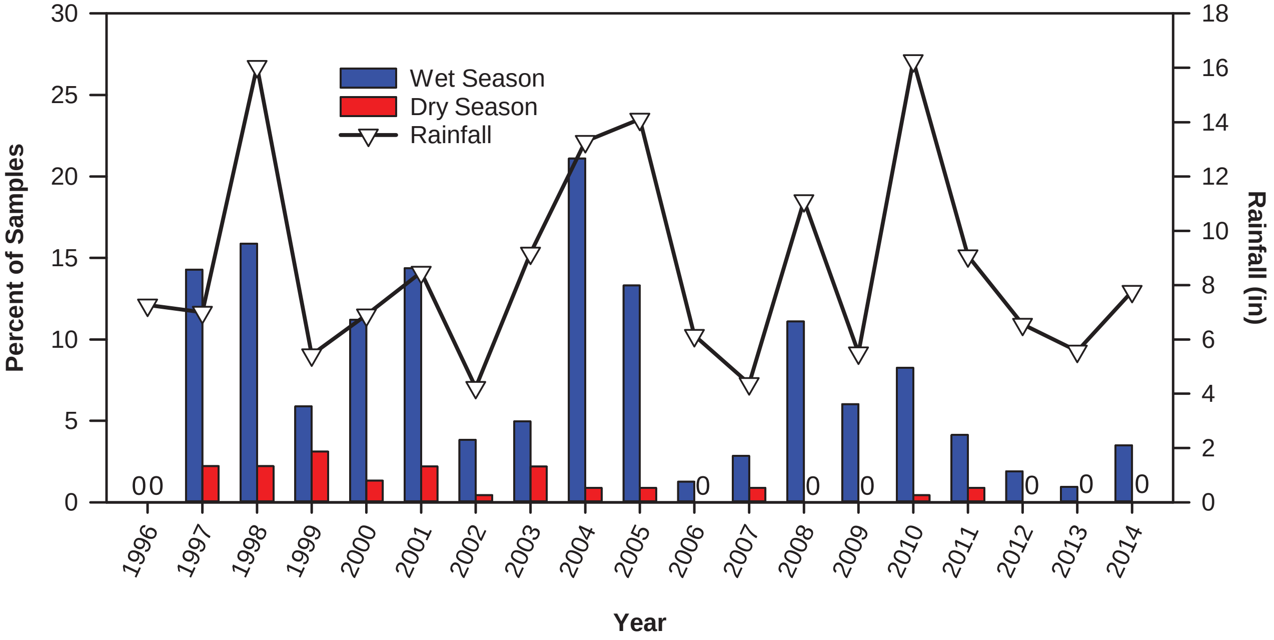

Figure 3.7

Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet versus dry seasons at SBOO kelp bed stations from 1996 through 2014. Rain data are from Lindbergh Field, San Diego, CA. Data from 1995 were excluded as sampling did not occur the entire year.

Finally, there was little indication of bacterial contamination in the offshore waters of the SBOO region during 2014, with only about 1% of all samples collected within State jurisdictional waters having elevated FIB. Additionally, these few high counts were generally either from stations located near the Tijuana River and the USA/Mexico border or very close to the active diffuser at the SBOO. The very low number of elevated FIB samples near the outfall is likely related to chlorination of South Bay International Water Treatment Plant effluent (November–April) and the initiation of full secondary treatment that began in January 2011. Further, potential detection of the wastewater plume and its effects on natural water quality indicators was low during the year.

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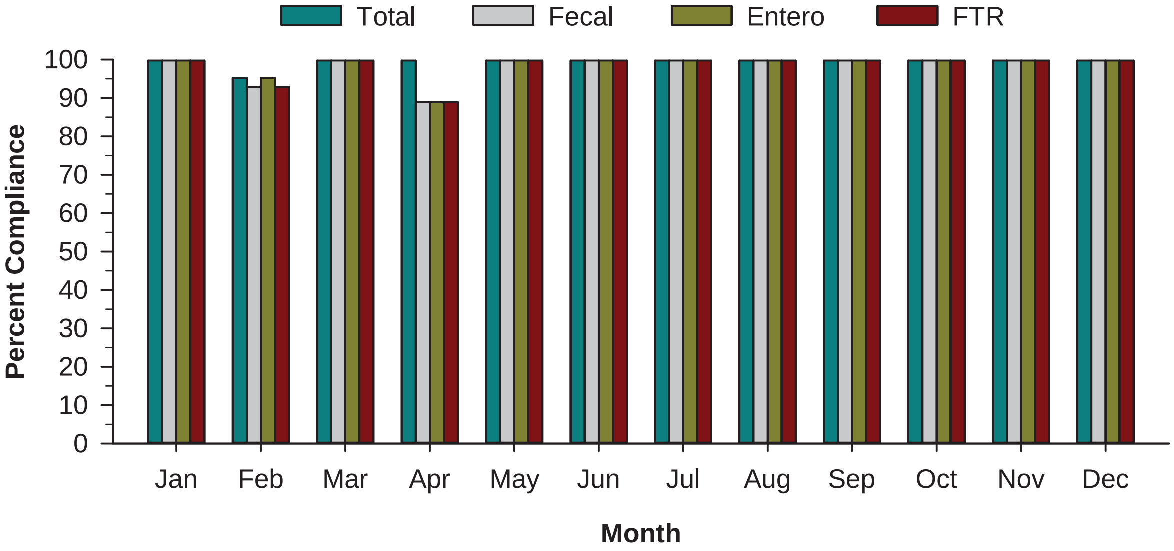

Figure 3.8
Compliance rates for the four single sample maximum water contact standards at SBOO other offshore stations during 2014. See Box 3.1 for details. During non-quarterly months sampling was limited to I12, I14, and I16.

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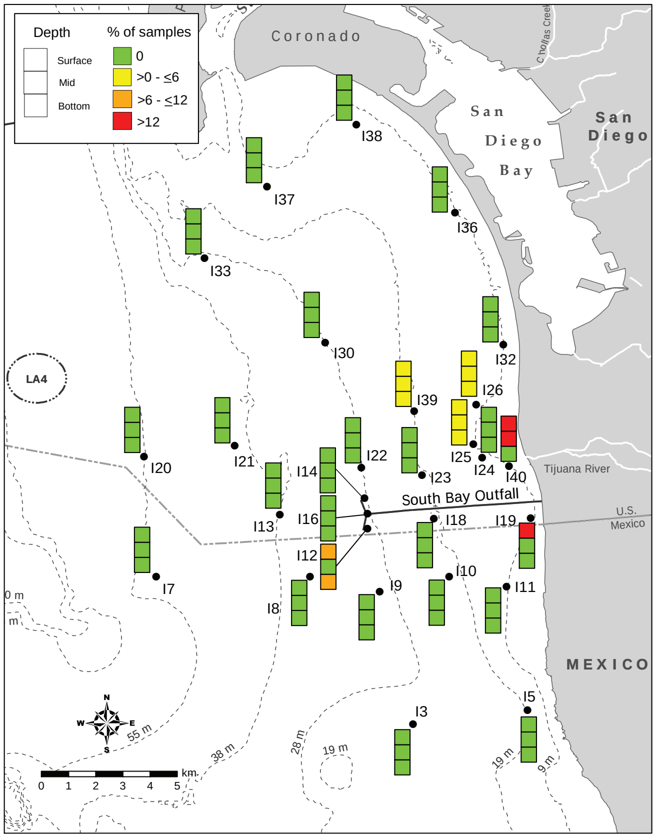

Figure 3.9

Distribution of samples with elevated FIB collected from kelp bed and other offshore stations during 2014. Data are the percent of samples that contained elevated bacteria densities. See text and Table 3.1 for sampling details.

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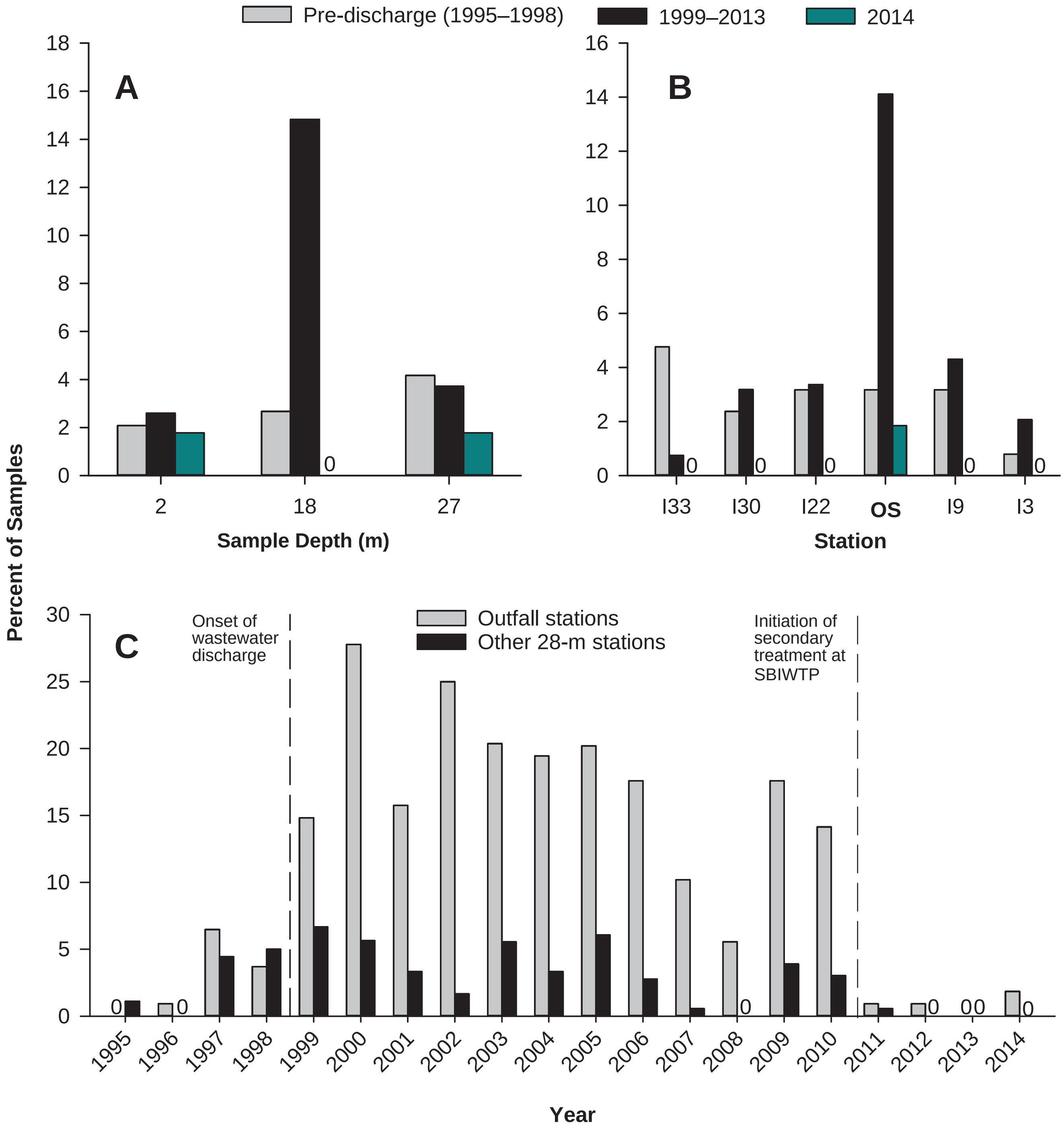

Figure 3.10
Percent of samples collected from SBOO 28-m offshore stations with elevated bacteria densities. Samples from 2014 are compared to those collected from 1995 through 2013 by (A) sampling depth, (B) station listed north to south from left to right, and (C) year. OS = outfall stations (I12, I14, I16).

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Table 3.4

Summary of potential wastewater plume detections and out-of-range values at SBOO offshore stations during 2014. Stations within State jurisdictional waters are in bold. DO = dissolved oxygen; XMS = transmissivity.

	Potential	Out of Range			
Month	**Plume Detections**	**DO**	**pH**	**XMS**	**Stations**
Feb	0	0	—	0	
May	4	0	0	0	**I12**, **I16**, **I23**, **I35**
Aug	5	0	0	4	**I12**, **I16**[a], **I23**[a], **I35**[a],**I39**[a]
Nov	5	0	0	3	I2, I3, I6[a], I9[a], I10[a]
Detection Rate (%)	12.5	0.0	0.0	6.2	
Total Count	14	0	0	7	
Total Samples	112	112	84	112	

[a] Out-of-range value for transmissivity

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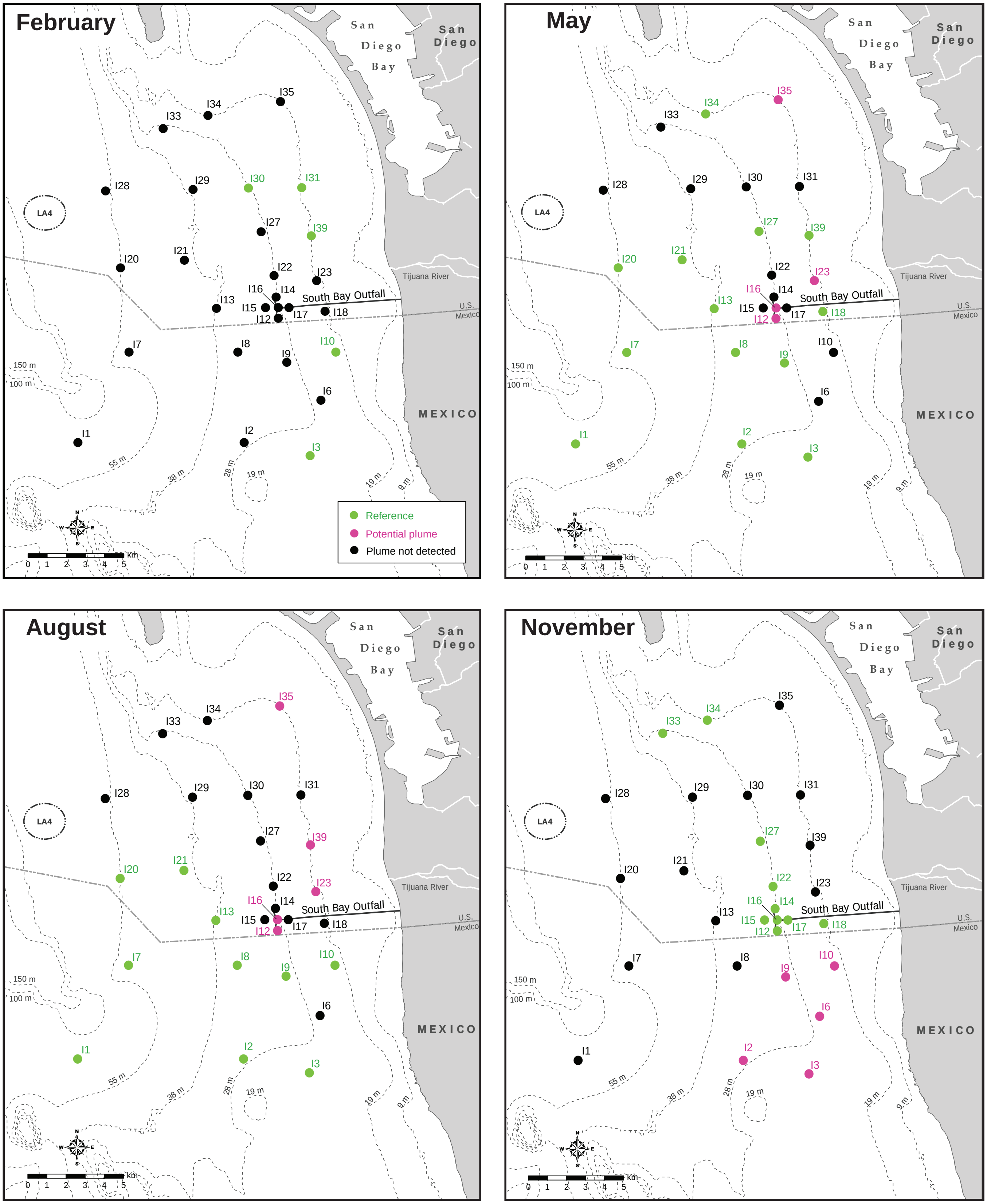

Figure 3.11

Distribution of stations where SBOO plume was potentially detected (pink) and those used as reference stations (green) during quarterly surveys in 2014.

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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 2014. The primary goals are to: (1) document sediment conditions; (2) identify possible effects of wastewater discharge on sediment

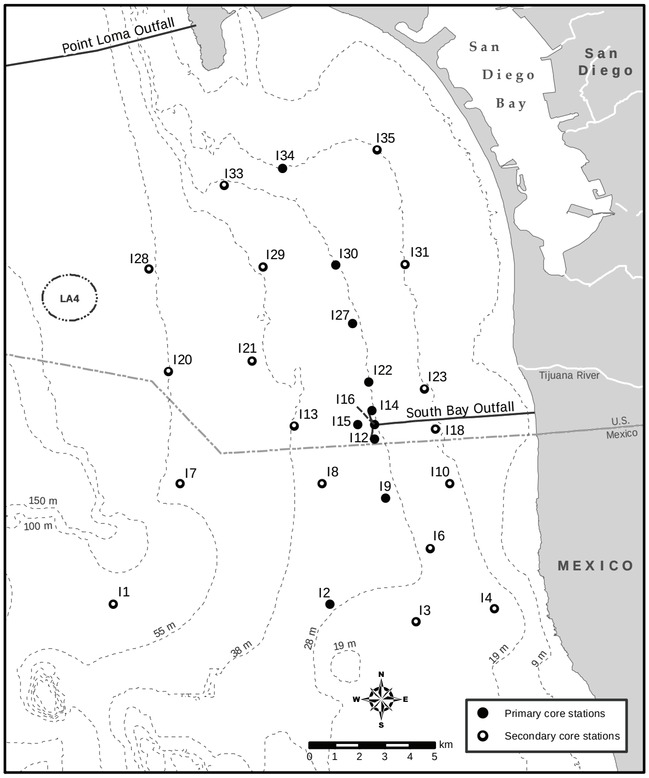


Figure 4.1
Benthic station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

quality in the region; (3) identify other potential 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 2014 (Figure 4.1). These stations range in depth from about 18 to 60 m and are 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 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 (2015). 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 presence of the specific constituent was verified by mass-spectrometry.

Particle size analysis was performed using either a Horiba LA-920 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). 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 v6 software to examine spatio-temporal patterns in the overall particle size composition in the South Bay outfall region (see Clarke and Warwick 2001, Clarke and Gorley 2006). 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 2014. The percent fines component (i.e., silt and clay) ranged from 0 to 38% per sample, while fine sands ranged from 3 to 92%, medium-coarse sands ranged from <1 to 90%, and coarse particles ranged from 0 to 54% (Table 4.1, Figure 4.2). Coarser particles often comprised red relict sands, black sands, gravel, and/or shell hash (Appendix C.4). Particle size composition varied within sites between the winter and summer surveys by as much as 70% per size fraction, with the greatest differences occurring at stations I3, I4, I12, and I34. 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 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 other sources of sediment plumes (e.g., San Diego Bay, Tijuana River; City of San Diego 2014).

Classification (cluster) analysis of the 2014 particle size sub-fraction data discriminated five main

Table 4.1

Summary of particle sizes and chemistry concentrations in sediments from SBOO benthic stations sampled during 2014. 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.

	2014 Summary[a]				Pre-discharge		
Parameter	**DR (%)**	**Mean**	**Min**	**Max**	**Max**	**ERL[b]**	**ERM[b]**
Particle Size							
Coarse Particles (%)	—	3.2	0.0	53.6	52.5	na	na
Med-Coarse sands (%)	—	34.7	0.5	89.6	99.8	na	na
Fine Sands (%)	—	50.9	2.6	91.9	97.4	na	na
Fines (%)	—	11.2	0.0	38.1	47.2	na	na
Organic Indicators							
Sulfides (*ppm*)	100	2.19	0.16	10.30	222.0	na	na
TN (*% weight*)	100	0.024	0.008	0.057	0.077	na	na
TOC (*% weight*)	100	0.19	0.04	0.85	0.64	na	na
TVS (*% weight*)	100	0.85	0.37	1.90	9.20	na	na
Trace Metals (ppm)							
Aluminum	100	4238	597	11,700	15,800	na	na
Antimony	65	0.6	nd	1.7	5.6	na	na
Arsenic	98	2.74	nd	10.80	10.9	8.2	70
Barium	100	20.58	1.39	52.40	54.3	na	na
Beryllium	37	0.09	nd	0.17	2.14	na	na
Cadmium	2	0.08	nd	0.08	0.41	1.2	9.6
Chromium	100	9.3	4.0	15.8	33.8	81	370
Copper	50	1.5	nd	4.4	11.1	34	270
Iron	100	6283	1190	13,600	17,100	na	na
Lead	96	2.0	nd	4.3	6.8	46.7	218
Manganese	100	73.1	5.4	350.0	162.0	na	na
Mercury	41	0.009	nd	0.027	0.078	0.15	0.71
Nickel	100	2.9	0.7	8.5	13.6	20.9	51.6
Selenium	15	0.15	nd	0.20	0.6	na	na
Silver	0	nd	nd	nd	nd	1.0	3.7
Thallium	18	0.9	nd	2.0	17.0	na	na
Tin	50	0.7	nd	1.6	nd	na	na
Zinc	100	13.3	2.3	34.4	46.9	150	410
Pesticides (ppt)							
HCB	11	248	nd	440	nd	na	na
Total DDT	30	735	nd	2380	23,380	1580	46,100
Total Chlordane	2	675	nd	675	nd	na	na
Total HCH	6	1283	nd	1850	nd	na	na
Total PCB (ppt)	4	487	nd	758	na	na	na
Total PAH (ppb)	20	14	nd	40	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

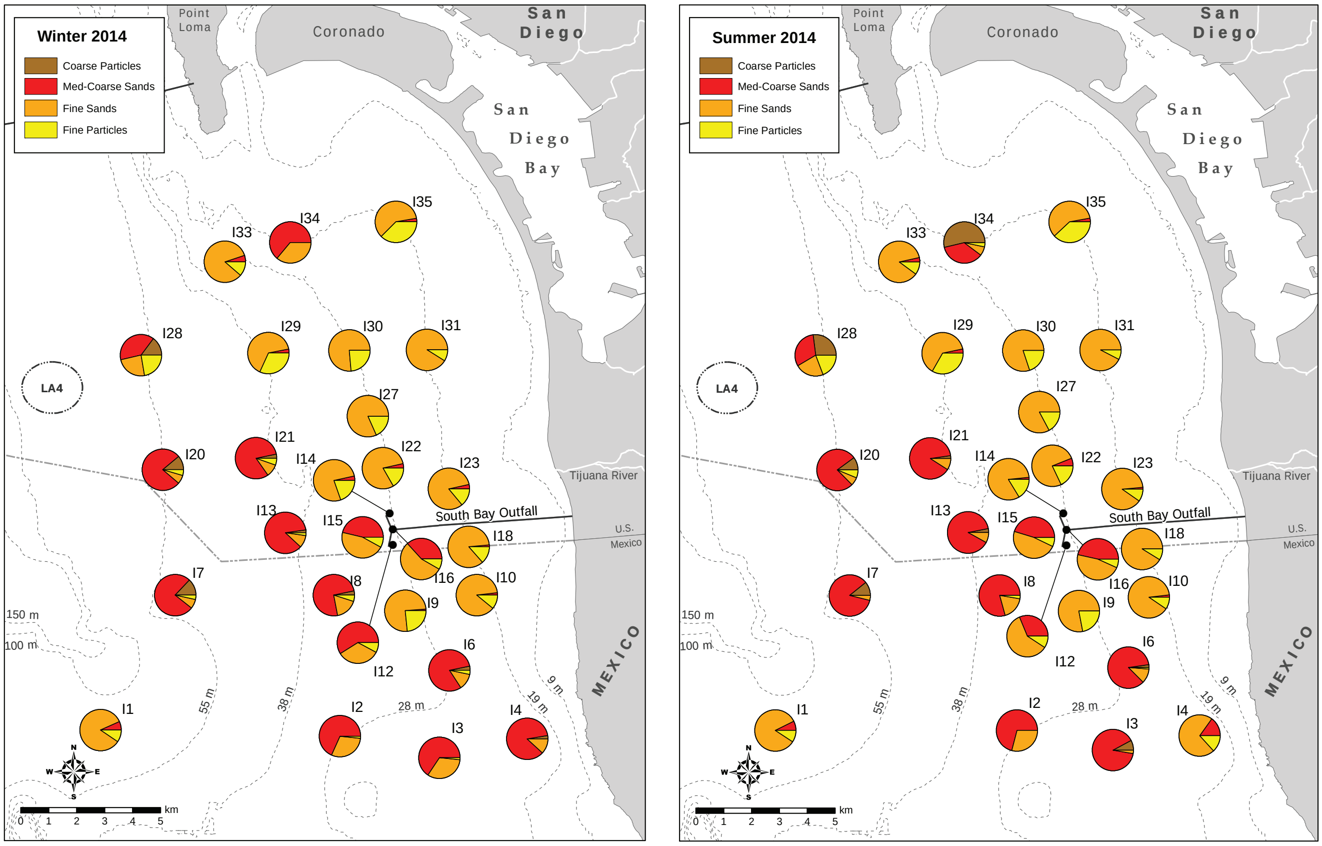


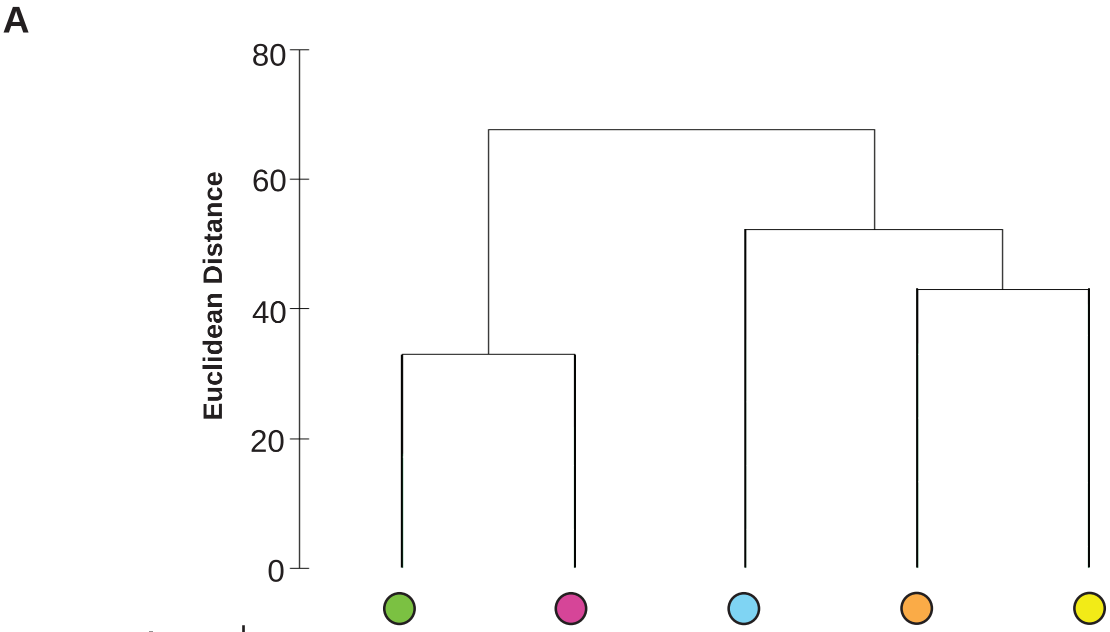
Figure 4.2

Sediment composition at SBOO benthic stations sampled in 2014 during winter and summer surveys.

cluster groups (cluster groups 1–5) (Figure 4.3). According to SIMPER results, these five groups were primarily distinguished by proportions of very fine sand, fine sand, and coarse sand. Cluster group 1 included winter and summer samples from station I1. Sediments in these samples had the largest proportion of fine sand (50% per sample) and second largest proportion of very fine sand (33% per sample). Cluster group 2 comprised 25 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 (58% per sample), as well as 18% fines, 21% fine sand, and just 3% medium sand per sample. Cluster group 3 comprised 19 samples collected primarily from sites located east and south of the SBOO along the 19, 28, and 38-m depth contours, including six of the eight samples from the four nearfield stations. These sediments had the largest proportions of medium sand (47% per sample), and the second lowest proportions of fines and very fine sand (4% and 7% per sample, respectively). Cluster group 4 comprised five samples, four of which were collected during the winter and summer surveys at stations I7 and I20, while the remaining sample was collected from station I3 during the summer. These sediments had the lowest proportions of fines and very fine sand (3% and <1% per sample, respectively), the second highest proportions of medium and very coarse sand (22% and 11% per sample, respectively), and the highest proportion of coarse sand (60% per sample). Cluster group 5 comprised both the winter and summer samples from station I28 and the summer sample from station I34. These were the coarsest sediments sampled during 2014, averaging 15% fines, 14% very fine sand, 4% fine sand, 12% medium sand, 24% coarse sand, 14% very coarse sand, and 18% granules 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



	Cluster Group	1	2	3	4	5
	n	2	25	19	5	3
	Fines	9.4	18.1	3.8	3.0	14.9
Fine Sands	**VFSand**	33.4	57.9	6.5	0.9	13.8
	FSand	50.1	21.3	21.0	4.4	4.0
Med-Coarse Sands	**MSand**	7.0	2.6	47.3	21.5	11.8
	CSand	0.0	0.1	20.0	59.6	23.7
Coarse Particles	**VCsand**	0.0	0.0	1.3	10.6	14.0
	Granules	0.0	0.0	0.0	0.0	17.7

Figure 4.3
Results of cluster analysis of particle size sub-fraction data from SBOO benthic stations sampled during 2014. 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.

detected in all sediments collected in the South Bay outfall region during 2014 (Table 4.1). Sulfide concentrations ranged from 0.16 to 10.30 ppm, while TN ranged from 0.008 to 0.057% weight, TOC ranged from 0.04 to 0.85% weight, and TVS ranged from 0.37 to 1.90% 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 region (Appendix C.5). For example, the highest sulfide values (≥4.80 ppm) were recorded from stations I9, I18, I22, I33, and I35 (see Figure 4.4), while the highest TN values (≥0.034% weight) were recorded from stations I9, I22, I28, I29, and I35, the highest TOC values (≥0.36% weight) were recorded from stations I18, I28, I29, and I33, and the highest TVS values (≥1.47% weight) were recorded from stations I28, I29, and I35. Although only TN and TVS correlated with percent fines during 2014 (Table 4.2, Figure 4.5), it has been shown that variable concentrations of TN, TOC, and TVS may be tied to regional differences in sediment particle

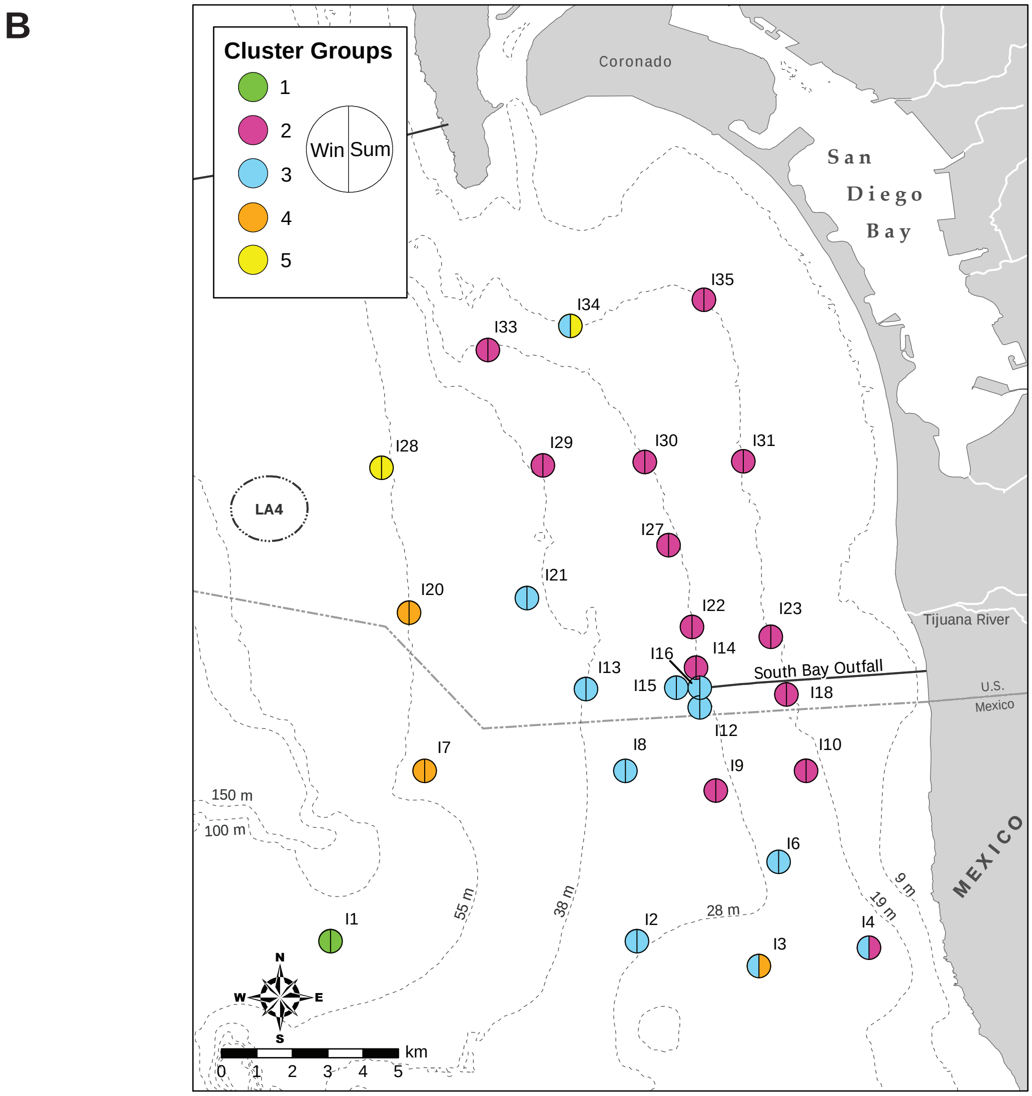


Figure 4.3 *continued*

composition, since all three parameters have been previously shown to co-vary with percent fines (City of San Diego 2014). Previous historical analyses have also demonstrated that levels of organic indicators have been fairly consistent at the primary core stations, with no patterns indicative of organic enrichment evident since discharge began in 1999 (City of San Diego 2014).

Trace Metals

Seven trace metals were detected in all sediment samples collected in the SBOO region during 2014, including aluminum, barium, chromium, iron, manganese, nickel, and zinc (Table 4.1). Antimony, arsenic, beryllium, cadmium, copper, lead, mercury, selenium, thallium, and tin were also detected, but in fewer samples (2–98%). Silver was not detected in any SBOO sediment samples collected during the year. 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). The majority 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., Schiff et al. 2011). Only manganese was

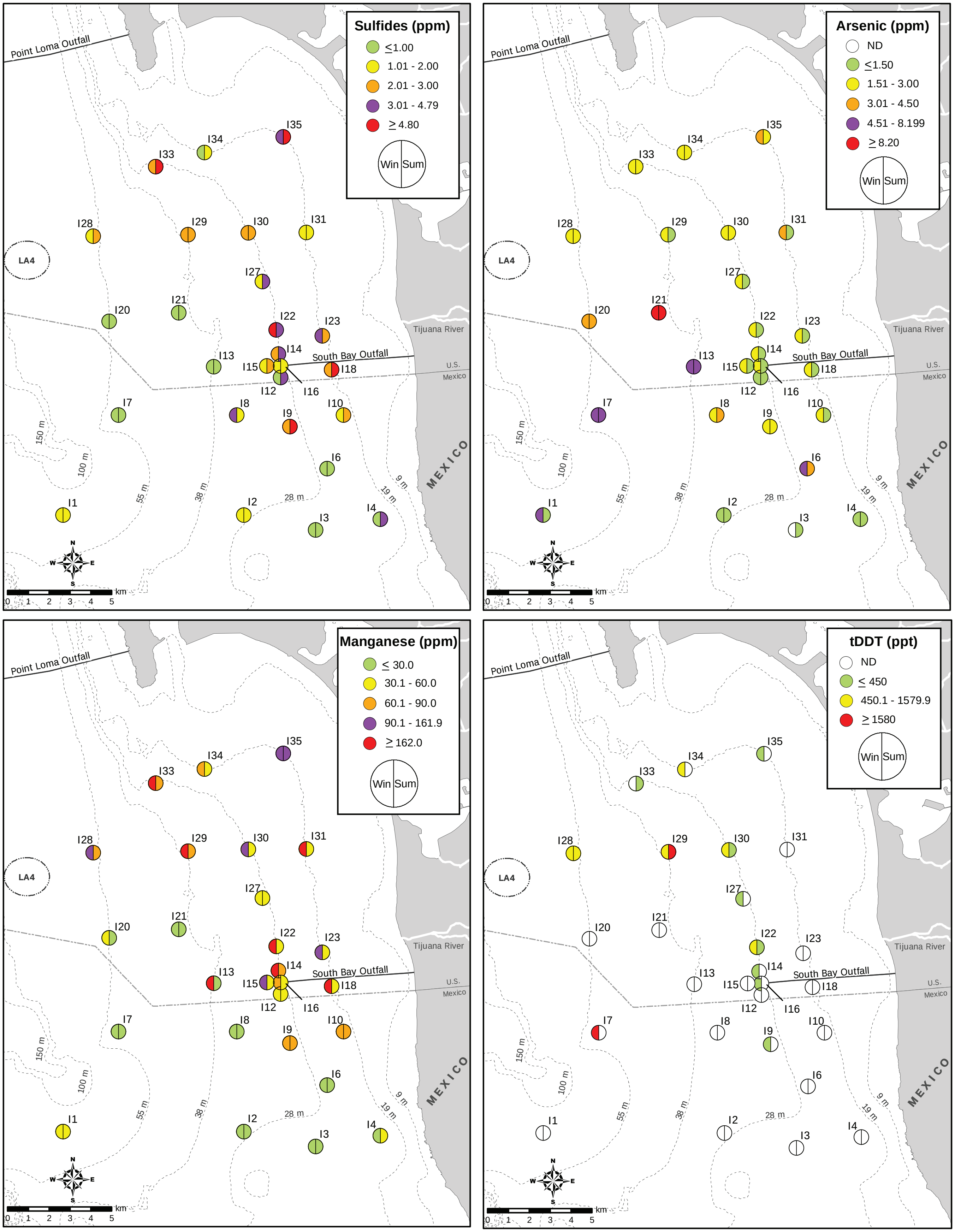


Figure 4.4

Distribution of select parameters in sediments from the SBOO region during 2014 winter and summer surveys.

Table 4.2

Results of Spearman rank correlation analyses of percent fines versus various sediment chemistry parameters from SBOO benthic samples collected in 2014. 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	54	0.76
Total Volatile Solids	54	0.85
Trace Metals (ppm)		
Aluminum	54	0.85
Barium	54	0.81
Chromium	54	0.71
Nickel	54	0.90
Zinc	54	0.87

reported at levels higher than pre-discharge values (Figure 4.4, Appendix C.6). Metal concentrations varied between stations with no discernible patterns relative to the outfall. Instead, aluminum, barium, chromium, nickel, and zinc all correlated positively with percent fines (Table 4.2, Figure 4.5) and therefore had similar distributions (see Figure 4.2). On a regional basis (see Chapter 8), beryllium, copper, iron, 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).

Pesticides

Four chlorinated pesticides were detected in SBOO sediments during 2014, including DDT, hexachlorobenzene (HCB), HCH, and chlordane (Table 4.1, Appendix C.3, Appendix C.7). Total DDT, composed primarily of p,p-DDE, was detected in 30% of the samples at concentrations up to 2490 ppt. Two samples, collected at station I7 during the winter and I29 during the summer, had total DDT values in exceedance of the ERL threshold of 1580 ppt (Figure 4.4). HCB was detected in 11% of the samples at concentrations up to 440 ppt. Total chlordane, composed of alpha (cis) chlordane, gamma (trans) chlordane, and methoxychlor, was detected in a single sample (detection rate = 2%) collected from station I7 during the winter at a concentration of 675 ppt. HCH (as the beta isomer) was detected at concentrations up to 1850 ppt in 6% of the SBOO samples, all collected during the winter survey from stations I7, I27, and I34. The pesticides aldrin, endosulfan, dieldrin, endrin, and mirex were not detected at SBOO stations during 2014. 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).

PCBs

PCBs were detected in only two of the sediment samples (i.e., 4%) collected around the SBOO in 2014 (Table 4.1, Appendix C.7). During the summer, a total PCB value of 216 ppt was reported for station I6 and a value 758 ppt was reported for station I28. Although no ERL or ERM thresholds exist for PCBs measured as congeners, all PCB values recorded during the year were within ranges reported previously for the SCB (e.g., Schiff et al. 2011). The PCB congeners detected during 2014 included PCB 49, PCB 66, PCB 70, PCB 74, PCB 99, PCB 101, PCB 138, and PCB 153/168 (Appendix C.3). Historically, PCBs have been detected in just 7% of the sediment samples collected in the SBOO region since the City started reporting the data as congeners in summer 1998, with most detected values ≤1520 ppt and no evident patterns relative to the outfall (City of San Diego 2014).

PAHs

PAHs were detected in 20% of the sediment samples collected from the South Bay outfall region in 2014 (Table 4.1, Appendix C.7). Concentrations of total PAH reached 40 ppb during the past year, well below the pre-discharge maximum of 636 ppb, the ERL threshold of 4022 ppb, and the Bight'08 maximum of 14,065 ppb (Schiff et al. 2011). Individual PAHs detected during the year included 2,6-dimethylnaphthalene, 3,4-benzo(B)fluoranthene, benzo[A]pyrene, benzo[G,H,I]perylene, chrysene, fluoranthene, and pyrene (Appendix C.3). Historically, the detection

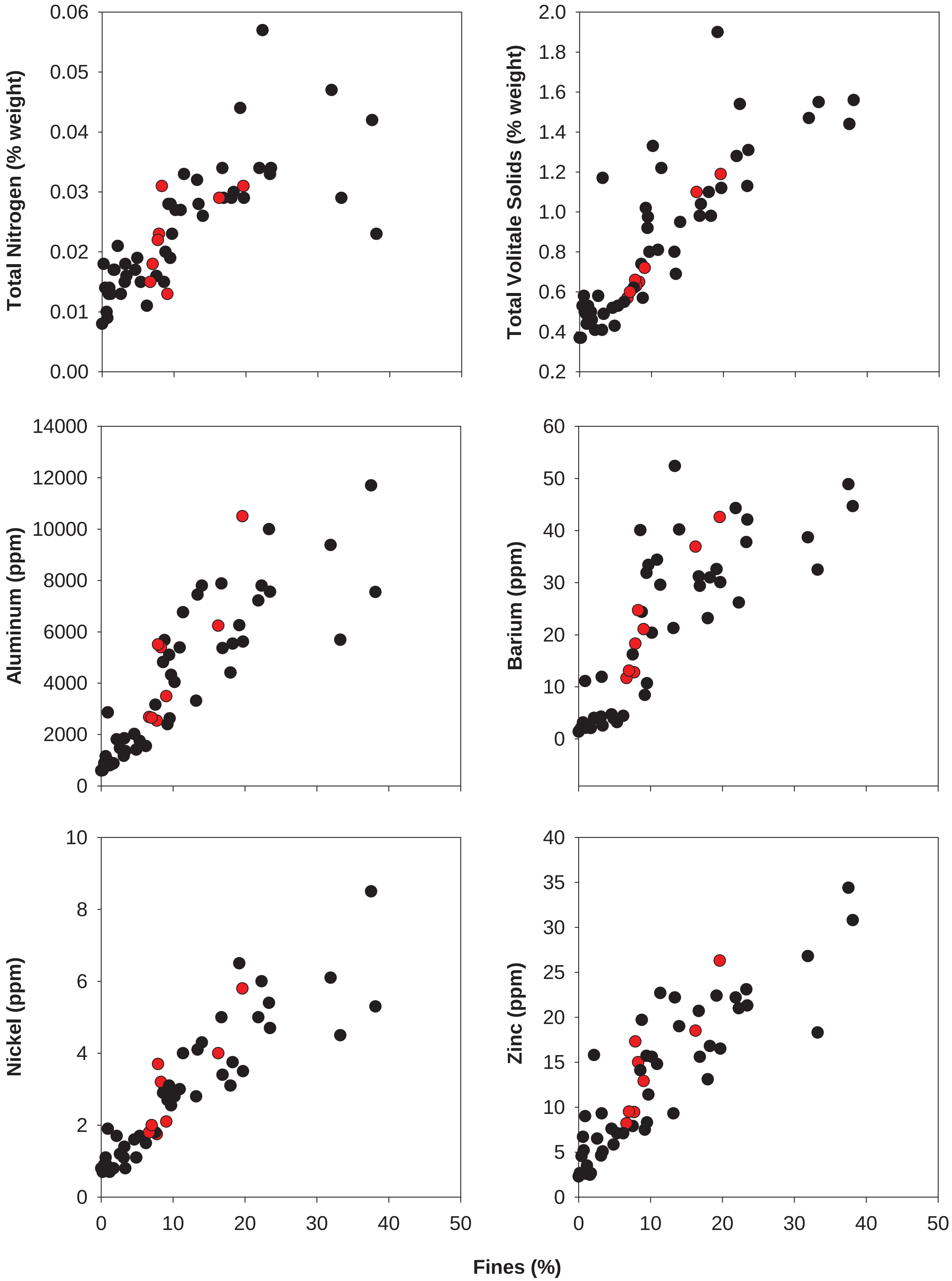


Figure 4.5

Scatterplots of percent fines versus select parameters in sediments from SBOO benthic stations sampled during 2014. Samples collected from nearfield stations are indicated in red.

rate for tPAH has been just 23%, with all reported values below the ERL, and no patterns indicative of a wastewater impact at the primary core stations (City of San Diego 2014).

DISCUSSION

Particle size composition at the SBOO stations sampled in 2014 was similar to that seen historically (Emery 1960, MBC-ES 1988) and in recent survey years (e.g., City of San Diego 2007–2014). 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 2014, although concentrations were all below ERM thresholds, generally below ERL thresholds, and/or within historical ranges (City of San Diego 2014). 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). 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 2014 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).

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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 and can therefore displace more sensitive species in impacted areas. 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 of 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, 2013a, b, 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 have occurred.

The City relies on a suite of ecological indices and statistical analyses to evaluate potential changes in local marine macrobenthic communities. For example, 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 (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 2014 and includes descriptions and comparisons of the different 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 2014 (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 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).

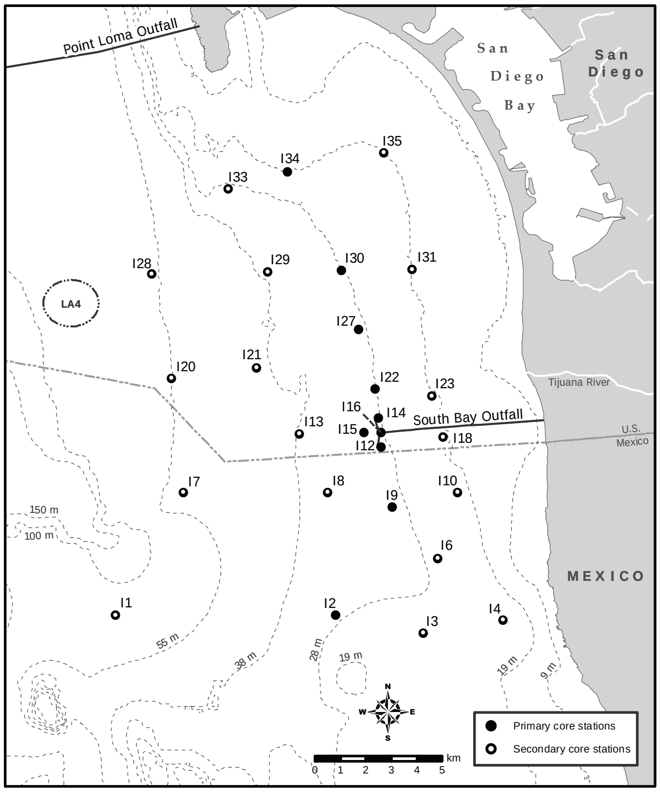

Figure 5.1
Benthic station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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 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 sorted from the raw material into several 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 (e.g., SCAMIT 2013).

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).

To examine spatial and temporal patterns among benthic communities in the SBOO region, multivariate analyses were performed using methods available in PRIMER v6 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 and Warwick 2001, Clarke and Gorley 2006, Clarke et al. 2008). 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 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 686 taxa were identified during the 2014 SBOO surveys. Of these, 553 (81%) were identified to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although 29% (n = 201) were recorded only once. Five species not previously reported by the City's Ocean Monitoring Program were encountered during these surveys. These included two polychaete worms in the family Polynoidae (*Arcteobia* sp LA1, and an unidentified species in the subfamily Lepidonotinae), one amphipod (*Ampelisca cristoides*), one nemertean (Tubulanidae sp C), and one enteropneust (Enteropneusta sp SD1).

Species richness averaged from 53 taxa per grab at station I2 to 146 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 2014 (Appendix D.1) were within the range of 6–192 taxa per grab reported previously from 1995 through 2013 (City of San Diego 2000–2014a). 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 the number of species has generally been trending upwards across the SBOO region since about 2004 (Figure 5.2).

Macrofaunal abundance

A total of 35,324 macrofaunal animals were recorded in 2014. Mean abundance ranged from 169 animals per grab at station I35 to 1292 per grab at station I9 (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 animals per grab reported from 1995 to 2013 (City of San Diego 2000–2014a). 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 much more variable, especially at both the nearfield and farfield stations (Figure 5.2). This recent high variation, especially the peaks in abundance evident during the summers of 2007, 2010, and 2013, was largely driven by region-wide changes in populations of the spionid polychaete *Spiophanes norrisi* (see Figure 5.3).

Table 5.1

Summary of macrofaunal community parameters for SBOO benthic stations sampled during 2014. SR = species richness; Abun = abundance; H' = Shannon diversity; J' = 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	72	169	3.9	0.91	30	27
	I34	56	752	2.4	0.64	6	13
	I31	59	244	2.9	0.71	16	21
	I23	81	256	3.9	0.89	30	20
	I18	72	512	2.5	0.58	12	22
	I10	88	690	2.7	0.60	13	19
	I4	98	792	2.4	0.53	12	14
28-m Stations	I33	100	292	4.0	0.87	38	25
	I30	100	484	3.6	0.79	28	24
	I27	92	405	3.5	0.78	26	24
	I22	116	601	3.7	0.78	30	26
	I14[a]	108	932	2.6	0.58	12	24
	I16[a]	118	1126	3.0	0.62	17	24
	I15[a]	78	717	2.6	0.59	8	23
	I12[a]	102	1055	2.8	0.62	14	23
	I9	129	1292	2.8	0.57	15	25
	I6	90	896	2.3	0.51	9	18
	I2	53	658	1.9	0.49	5	20
	I3	73	1272	2.3	0.56	8	17
38-m Stations	I29	137	832	3.7	0.75	28	21
	I21	104	605	3.2	0.69	20	19
	I13	96	578	3.5	0.77	23	16
	I8	68	890	2.2	0.51	6	22
55-m Stations	I28	146	566	4.2	0.85	48	16
	I20	84	490	3.4	0.77	20	12
	I7	72	288	3.5	0.83	24	13
	I1	70	267	3.6	0.85	21	19
All Grabs	Mean	91	654	3.1	0.69	19	20
	95% CI	8	125	0.2	0.04	3	1
	Minimum	24	103	1.5	0.36	2	6
	Maximum	162	2191	4.4	0.93	53	31

[a] nearfield station

Species diversity, evenness, and dominance

Shannon diversity index (H') values averaged from 1.9 to 4.2 per grab for each station, while mean evenness (J') ranged from 0.49 to 0.91 (Table 5.1). The lowest mean diversity and evenness both occurred at station I2, while the highest respective values for these two 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 48 taxa per grab at each station, with the highest dominance (lowest index value) occurring at station I2 and the lowest dominance (highest index value) occurring at station I28 (Table 5.1). Values for all three of the above parameters in 2014 (Appendix D.1) were within historical ranges (City of San Diego 2000–2014a), 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 2014, 87% of the individual benthic grab samples collected in the SBOO region were characteristic of reference conditions (Appendix D.1), and 85% of the benthic stations sampled had mean BRI < 25 (Table 5.1). Four stations had BRI values of 25–27 that may correspond to a minor deviation from reference condition; three 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, I22, 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 often occurring at depths < 30 m (Smith et al. 2001). No consistent seasonal pattern was evident between the winter and summer surveys (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 2014 and accounted for 46% of all taxa collected (Table 5.2). Crustaceans accounted for 23% of the taxa reported, while molluscs (16%), echinoderms (4%), and all other taxa combined (11%) accounted for the remainder. Polychaetes were also the most numerous animals, accounting for 75% of the total abundance. Crustaceans accounted for 13% of the animals collected, while molluscs, echinoderms, and all other taxa combined each contributed to ≤7% 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 (City of San Diego 2000, 2001–2014a).

The 10 most abundant taxa in 2014 included seven polychaetes, one crustacean, one nemertean, and unidentified nematodes (Table 5.3). The dominant polychaetes were the spionids *Spiophanes norrisi* and *Prionospio (Prionospio) jubata*, the chaetopterid *Spiochaetopterus costarum* Cmplx, the maldanid *Axiothella* sp, the capitellids *Mediomastus* sp and *Notomastus latericeus*, and the cirratulid *Monticellina siblina*. The dominant crustacean was the ampeliscid amphipod *Ampelisca cristata cristata*, while the dominant nemertean was *Carinoma mutabilis*. *Spiophanes norrisi* was by far the most abundant species during the year, accounting for 42% of invertebrates collected. Overall, this species 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. *Spiochaetopterus costarum* Cmplx and *P. (P.) jubata* were the next two most abundant species, averaging about 26 and 15 individuals per grab, respectively. All other species averaged fewer than 10 individuals per grab.

Spiophanes norrisi was the most widely distributed of the above taxa in 2014, occurring in 98% of the samples with a mean abundance of ~272 individuals per grab (Table 5.3). Four of the other numerically dominant species were also found in ≥76% of the samples, including *Spiochaetopterus costarum* Cmplx, *Prionospio (Prionospio) jubata*, *Mediomastus* sp, and *Ampelisca cristata cristata*. The remaining five taxa occurred in 44–70% of the samples. Historically, *S. norrisi*, *Mediomastus* sp, *Monticellina siblina*, the spionid polychaete *Spiophanes duplex* 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*

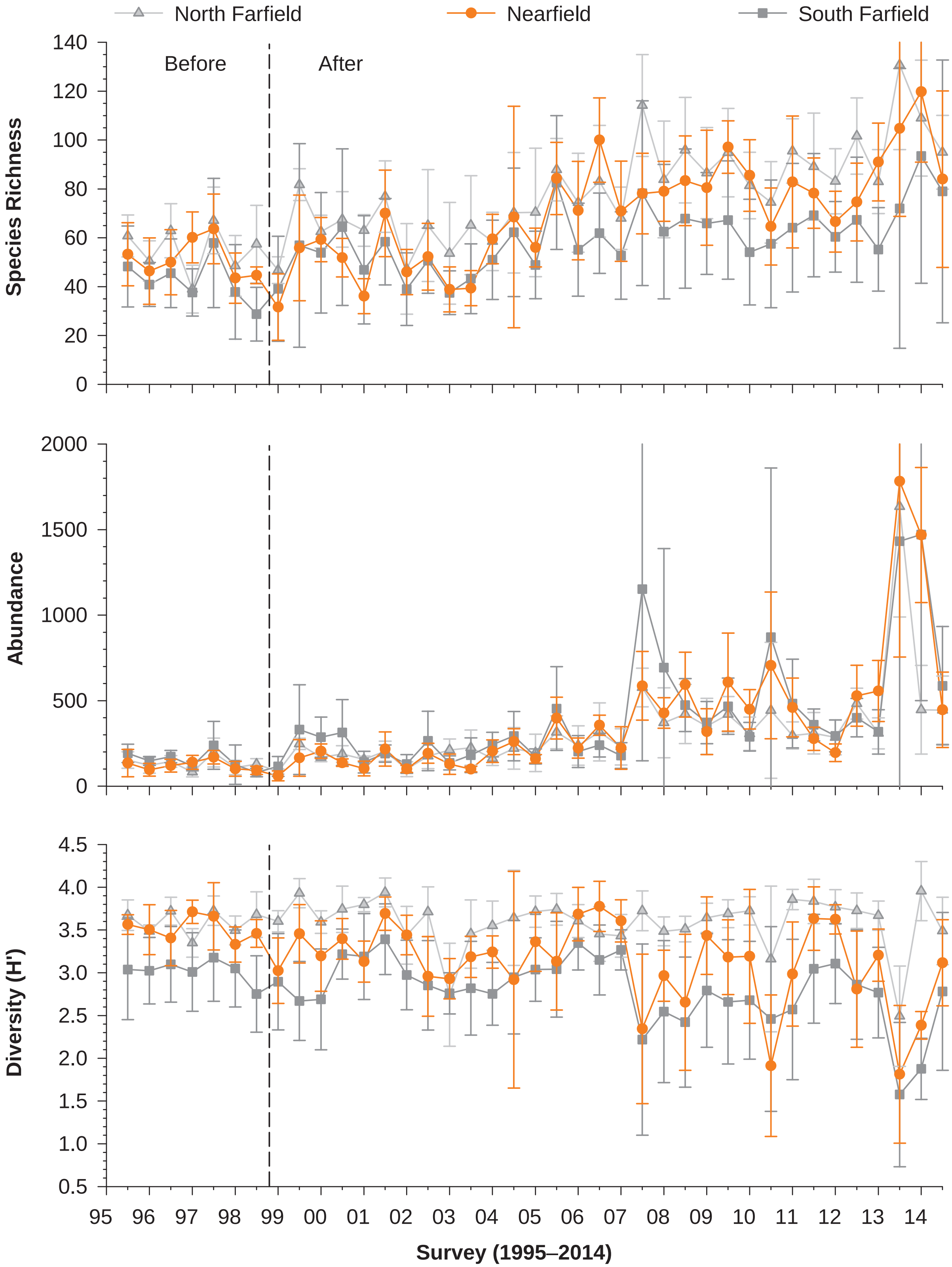

Figure 5.2

Species richness, infaunal abundance, diversity (H'), evenness (J'), Swartz dominance and benthic response index (BRI) at SBOO nearfield, north farfield, and south farfield primary core stations sampled from 1995 through 2014. Data for each station group are expressed as means ±95% confidence intervals per grab (n≤8). Dashed lines indicate onset of wastewater discharge.

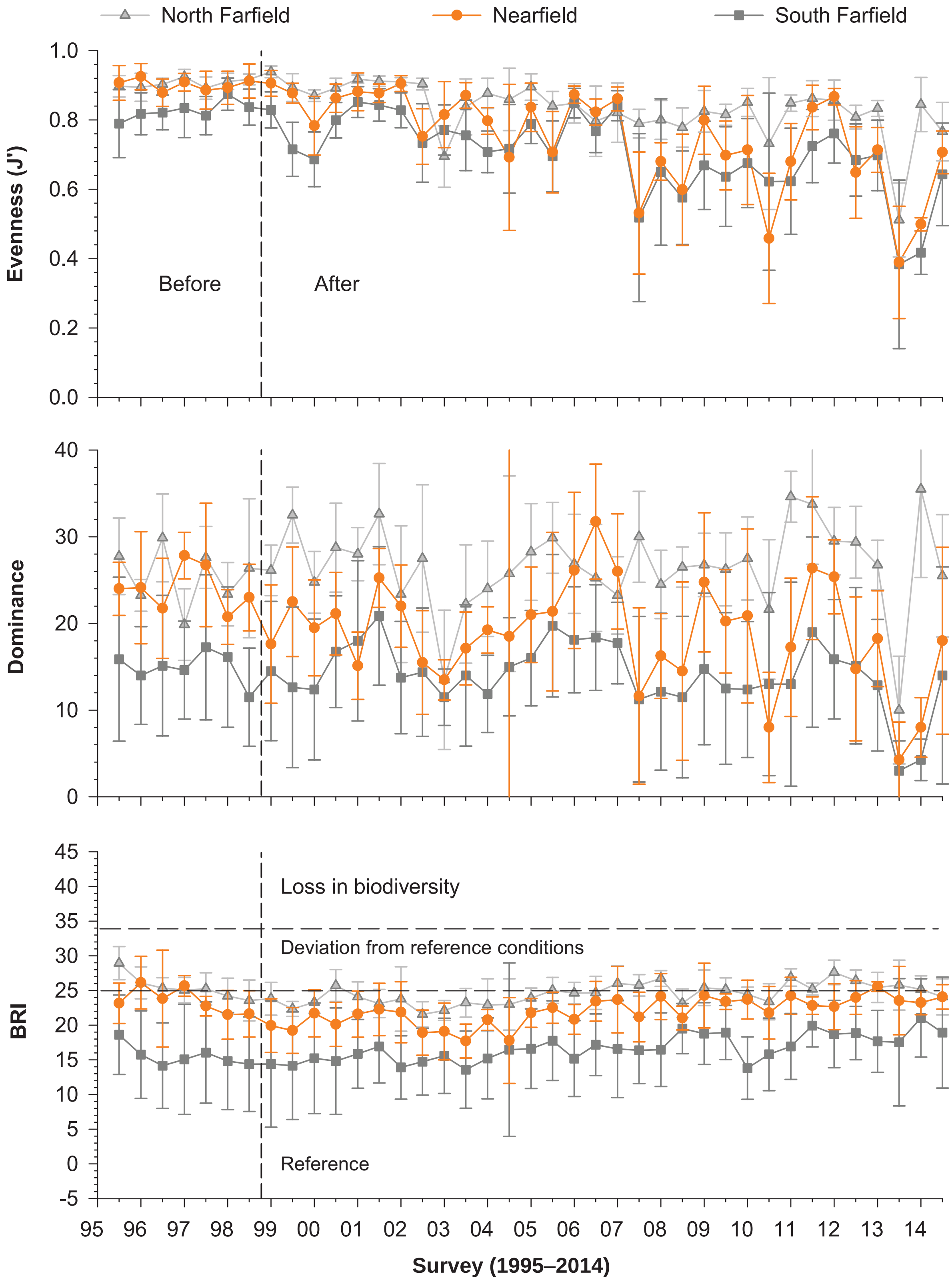

Figure 5.2 *continued*

(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 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 a single specimen of *C. teleta* was found in a grab from station I28 and 2–10 individuals of *S. pervernicosa* were identified in samples from three stations (i.e., I14, I22, I29) during 2014. Changes in abundances of *Ampelisca* and *Rhepoxynius* 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 2014, resulting in six ecologically relevant SIMPROF-supported groups (Figures 5.5, 5.6, Table 5.4, Appendix D.3). These assemblages (referred to herein as cluster groups A–F) represented from 1 to 25 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 $\rho = 0.634$, $p = 0.0001$). The sediment subfractions that were most highly correlated to macrofaunal communities included percent fines, fine sand, medium sand, coarse sand, very coarse sand, and granules (BEST $\rho = 0.668$, $p = 0.0001$). Mean species richness ranged from 24 to 146 taxa per grab for these groups, while mean abundance ranged from 103 to 877 individuals per grab. Characteristics and differences between the six 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 2014.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	46	75
Arthropoda (Crustacea)	23	13
Mollusca	16	3
Echinodermata	4	2
Other Phyla	11	7

Table 5.3

The 10 most abundant macroinvertebrate taxa collected from SBOO benthic stations during 2014. 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	42	98	272
Spiochaetopterus costarum Cmplx	Polychaeta: Chaetopteridae	4	91	26
Prionospio (Prionospio) jubata	Polychaeta: Spionidae	2	83	15
Notomastus latericeus	Polychaeta: Capitellidae	1	70	9
NEMATODA	Nematoda	1	67	9
Ampelisca cristata cristata	Arthropoda: Amphipoda	1	83	9
Monticellina siblina	Polychaeta: Cirratulidae	1	65	7
Mediomastus sp	Polychaeta: Capitellidae	1	76	6
Axiothella sp	Polychaeta: Maldanidae	1	56	6
Carinoma mutabilis	Nemertea: Palaeonemertea	1	44	6

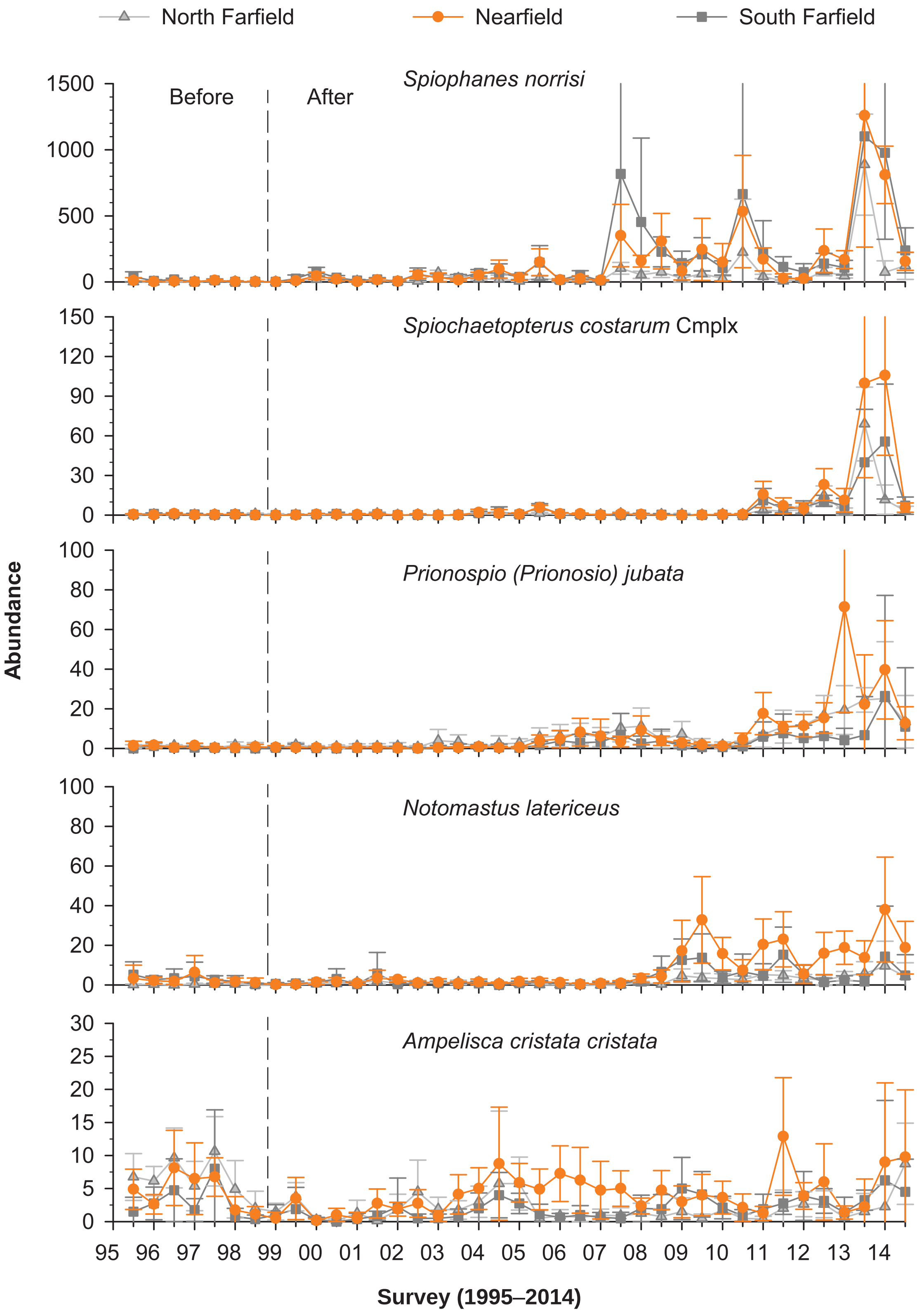

Figure 5.3

Abundances of the five most numerically dominant species (presented in order) recorded during 2014 at SBOO north farfield, nearfield, and south farfield primary core stations from 1995 through 2014. Data for each station group are expressed as means ±95% confidence intervals per grab (n≤8). Dashed lines indicate onset of wastewater discharge.

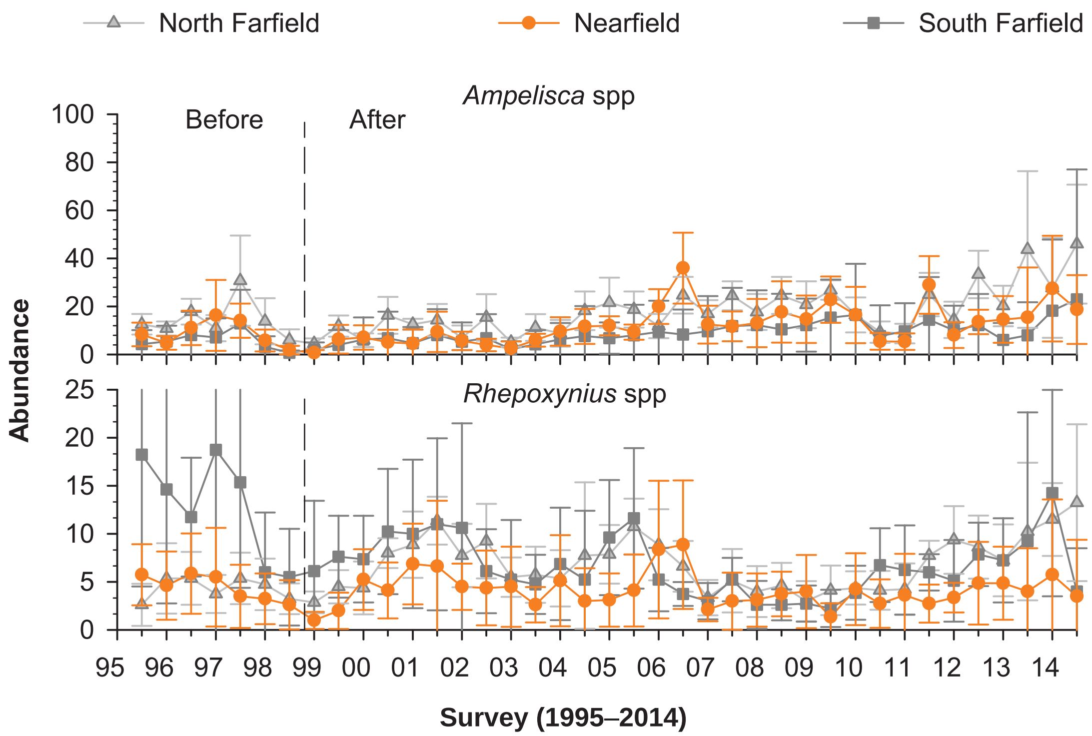

Figure 5.4
Abundances of representative ecologically important pollution-sensitive indicator taxa at SBOO north farfield, nearfield, and south farfield primary core stations from 1995 through 2014. Data for each station group are expressed as means ±95% confidence intervals per grab (n≤8). Dashed lines indicate onset of wastewater discharge.

Cluster group A represented a unique macrofaunal assemblage sampled during January 2014 at station I34 located north of the SBOO at a depth of 19 m (Figure 5.5). This assemblage had the lowest species richness (24 species per grab) and lowest abundance (103 animals per grab) of any cluster group (Table 5.4). The two most abundant species in this group were the nemertean *Carinoma mutabilis* (n = 33) and the magelonid polychaete *Magelona sacculata* (n = 25), which together comprised more than 56% of the animals (Appendix D.3). Group A was also distinguished from the other SBOO assemblages by having the largest numbers of the gastropod *Callianax baetica*, as well as by the absence of several species of polychaete worms common to the other groups; these polychaetes included the chaetopterid *Spiochaetopterus costarum* Cmplx, the cirratulids *Chaetozone hartmanae* and *Monticellina siblina*, the sigalionid *Sthenelanella uniformis*, the spionid *Spiophanes duplex*, and the terebellid *Lanassa venusta venusta* (Figure 5.6). The sediments associated with this single sample were characterized by the lowest proportion of silt and clay (<1% fines), about 36% fine sands and 63% medium-coarse sands, and less than 0.5% coarser particles (Table 5.4).

Cluster group B represented both the January and July assemblages in 2014 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 (146 species per grab) and third highest abundance (566 animals per grab) of the different cluster groups (Table 5.4). SIMPER results indicated the top five most characteristic species for group B were all polychaetes, including *Sthenelanella uniformis* (30 per grab), *Monticellina siblina* (19 per grab), the lumbrinerid *Lumbrineris* Group II (12 per grab), the spionid *Prionospio (Prionospio) dubia* (12 per grab), and the maldanid Euclymeninae sp B (11 per grab) (Appendix D.3). In addition to the highest number of *S. uniformis*, group B was also distinguished from the other SBOO assemblages by having the highest numbers of *Chaetozone hartmanae* (13 per grab), as well as the photid amphipod *Photis californica* (28 per grab) (Figure 5.6). Other species unique to this cluster group included the ampeliscid amphipod *Ampelisca*

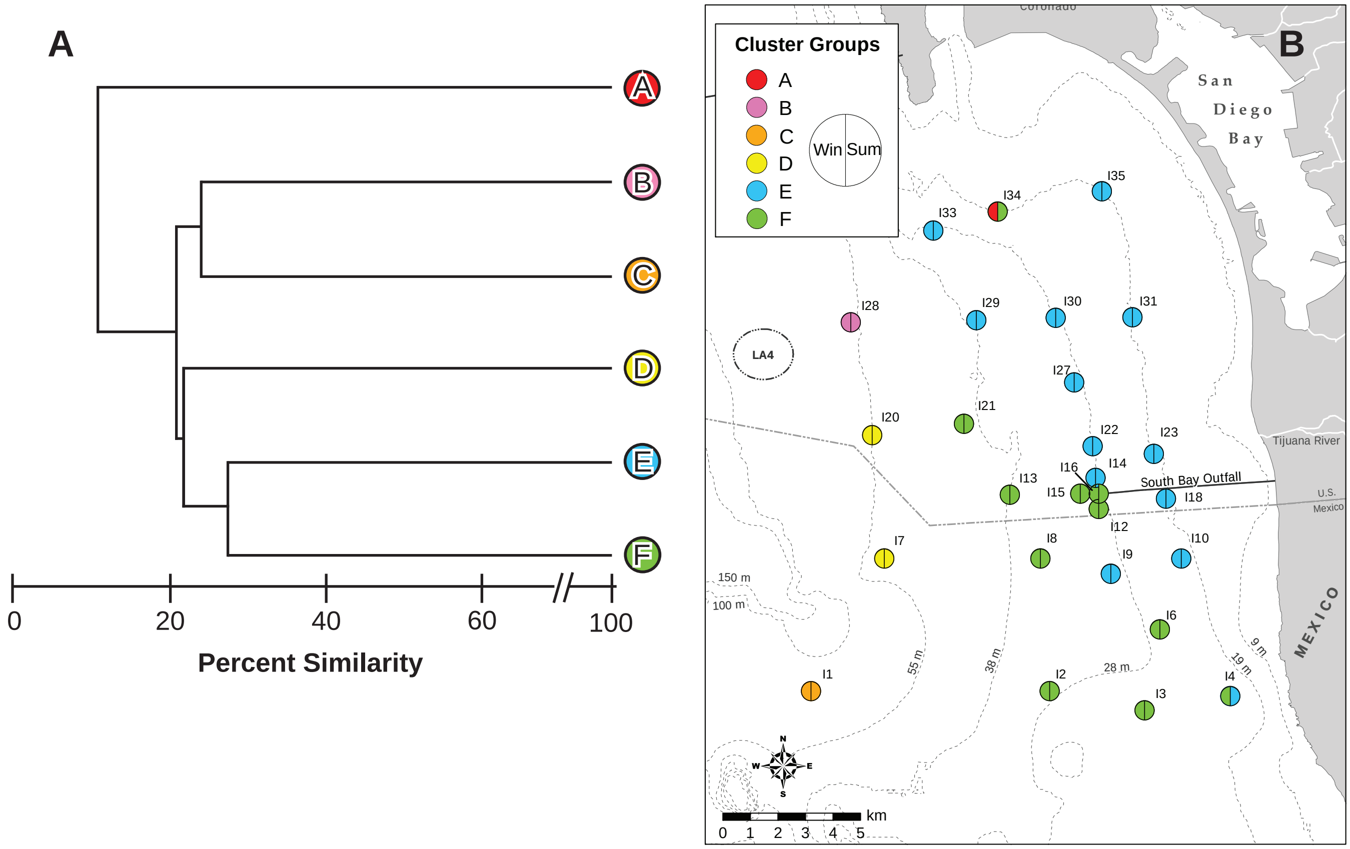

Figure 5.5

Results of cluster analysis of macrofaunal assemblages at SBOO benthic stations sampled during 2014. Data are presented as: (A) dendrogram of main cluster groups and (B) distribution of cluster groups in the SBOO region.

indentata and the photid amphipod *Photis linearmanus*. The sediments associated with this cluster group were characterized by the highest proportions of both silt and clay (~21% fines) and coarse fractions (~21%), as well as about 23% fine sands and 35% medium-coarse sands (Table 5.4).

Cluster group C represented the January and July 2014 assemblages from station I1 located southwest of the outfall along the 55-m depth contour (Figure 5.5). Mean species richness and abundance were within the range of all other cluster groups at 70 species and 267 animals per grab, respectively (Table 5.4). Group C was distinguished from the other SBOO assemblages by having the highest numbers of two crustaceans, the ostracod *Euphilomedes carcharodonta* (24 per grab) and the amphipod *Ampelisca careyi* (15 per grab) (Figure 5.6). In addition to *E. carcharodonta* and *A. careyi*, the remaining three of the five most characteristic species for this group included the spionid polychaete *Prionospio* (*Prionospio*) *jubata* (22 per grab), *Spiochaetopterus costarum* Cmplx (22 per grab) and *Sthenelanella uniformis* (13 per grab) (Appendix D.3). The sediments associated with this cluster group were characterized by the highest proportion of fine sands (~84%), and low percentages of both medium-coarse sands and fines (Table 5.4).

Cluster group D represented the January and July assemblages from all four grabs collected during 2014 at stations I7 and I20 along the 55-m depth contour (Figure 5.5). Species richness for this group averaged 78 species per grab, and macrofaunal abundance averaged 389 animals per grab (Table 5.4). Group D was distinguished from the other SBOO assemblages by having high numbers of onuphid polychaetes identified as either *Mooreonuphis* sp SD1 or *Mooreonuphis* sp, which combined to average about 64 worms per grab (i.e., 32 per grab each) (Figure 5.6). In contrast, these

Table 5.4

Community metric and particle size summary for each cluster group A–F (defined in Figure 5.5). Data are presented as means (ranges) calculated over all stations within a cluster group (n). MC = medium-coarse.

Cluster Group	n	Depth Range (m)	Community Metric		Sediments			
			SR	Abund	Fines	Fine Sands	MC Sands	Coarse
A	1	19	24	103	0.9	35.6	63.1	0.4
B	2	55	146 (130–162)	566 (370–762)	20.7 (19.2–22.3)	23.2 (22.4–24.0)	35.2 (31.4–39.0)	20.9 (14.7–27.0)
C	2	60	70 (59–81)	267 (201–333)	9.4 (9.2–9.5)	83.5 (83.4–83.7)	7.1 (6.8–7.3)	0.0 —
D	4	52-54	78 (50–118)	389 (207–773)	3.7 (0.7–6.2)	6.0 (3.8–7.2)	79.0 (76.4–84.7)	11.3 (10.1–13.1)
E	25	18-38	98 (58–154)	578 (145–1740)	18.1 (7.5–38.1)	79.2 (58.9–91.9)	2.7 (0.5–15.0)	0.0 —
F	20	18-41	86 (45–123)	877 (320–2191)	3.7 (0–9.1)	24.8 (2.6–59.7)	67.1 (31.2–89.6)	4.3 (0–53.6)

onuphids were lacking completely from groups A, B, C, and E and were only present in low numbers in group F. In addition to these *Mooreonuphis* taxa, the remaining three of the top five characteristic species for group D based on SIMPER results included *Spiophanes norrisi* (54 per grab), *Lanassa venusta venusta* (21 per grab), and the corophiid amphipod *Laticorophium baconi* (11 per grab) (Appendix D.3). The sediments associated with this cluster group averaged the highest proportion of medium-coarse sands (79%), lowest proportion of fine sands (6%), second highest proportion of the coarsest fraction (~11%), and < 4% fines (Table 5.4).

Cluster group E was the largest group, representing the assemblages from a total of 25 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 2014 from nine stations located north of the outfall (i.e., I14, I22, I23, I27, I29, I30, I31, I33, I35) and three stations located south of the outfall (i.e., I9, I10, I18), as well as the July survey only for station I4 located furthest to the southeast of the outfall. Species richness and macrofuanal abundance for group E assemblages were widely variable (Table 5.4). For example, species richness varied from 58 to 154 taxa per grab with a mean of 98 species per sample, while abundance ranged from 145 to 1740 animals per grab with a mean of 578 per sample. The five most characteristic species for this group based on SIMPER results were *Spiophanes norrisi* (214 per grab) and *Prionospio (Prionospio) jubata* (17 per grab), *Monticellina siblina* (12 per grab), the capitellid polychaete *Mediomastus* sp (11 per grab), and the ampeliscid amphipod *Ampelisca brevisimulata* (11 per grab) (Appendix D.3). In addition to *S. norrisi* and *M. siblina*, this group was also distinguished from the other SBOO assemblages by relative numbers of *Spiochaetopterus costarum* Cmplx and the ampeliscid amphipod *Ampelisca careyi* (Figure 5.6). The sediments associated with this cluster group were characterized by the second highest proportion of fines (~18%), second highest proportion of fine sands (~79%), lowest proportion of medium-coarse sands (~3%), and no coarse fraction (Table 5.4).

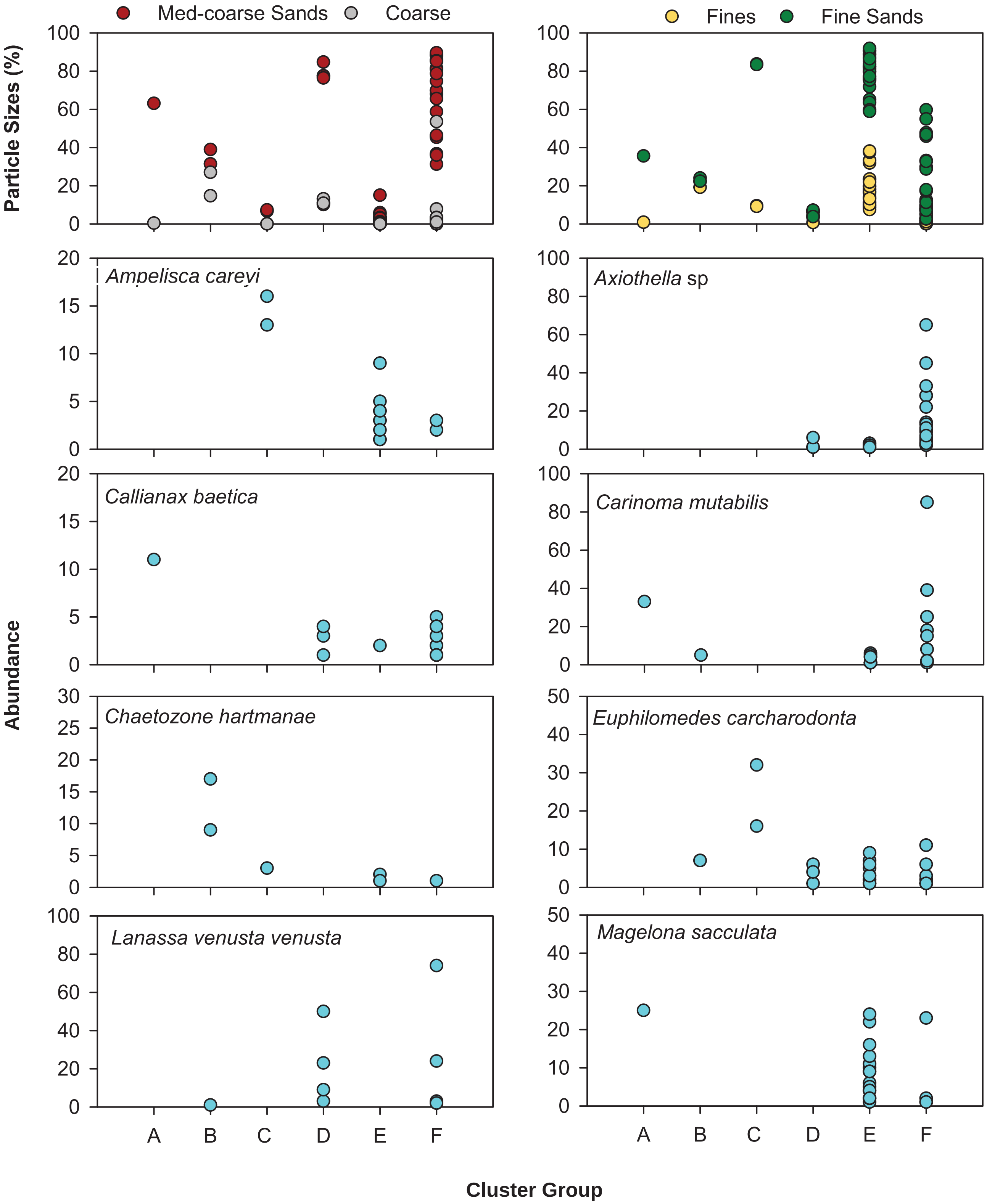

Figure 5.6
Particle sizes and abundances of select species that contributed to cluster group dissimilarities in the SBOO region during 2014 (see Figure 5.5). Each data point represents a single sediment or grab sample.

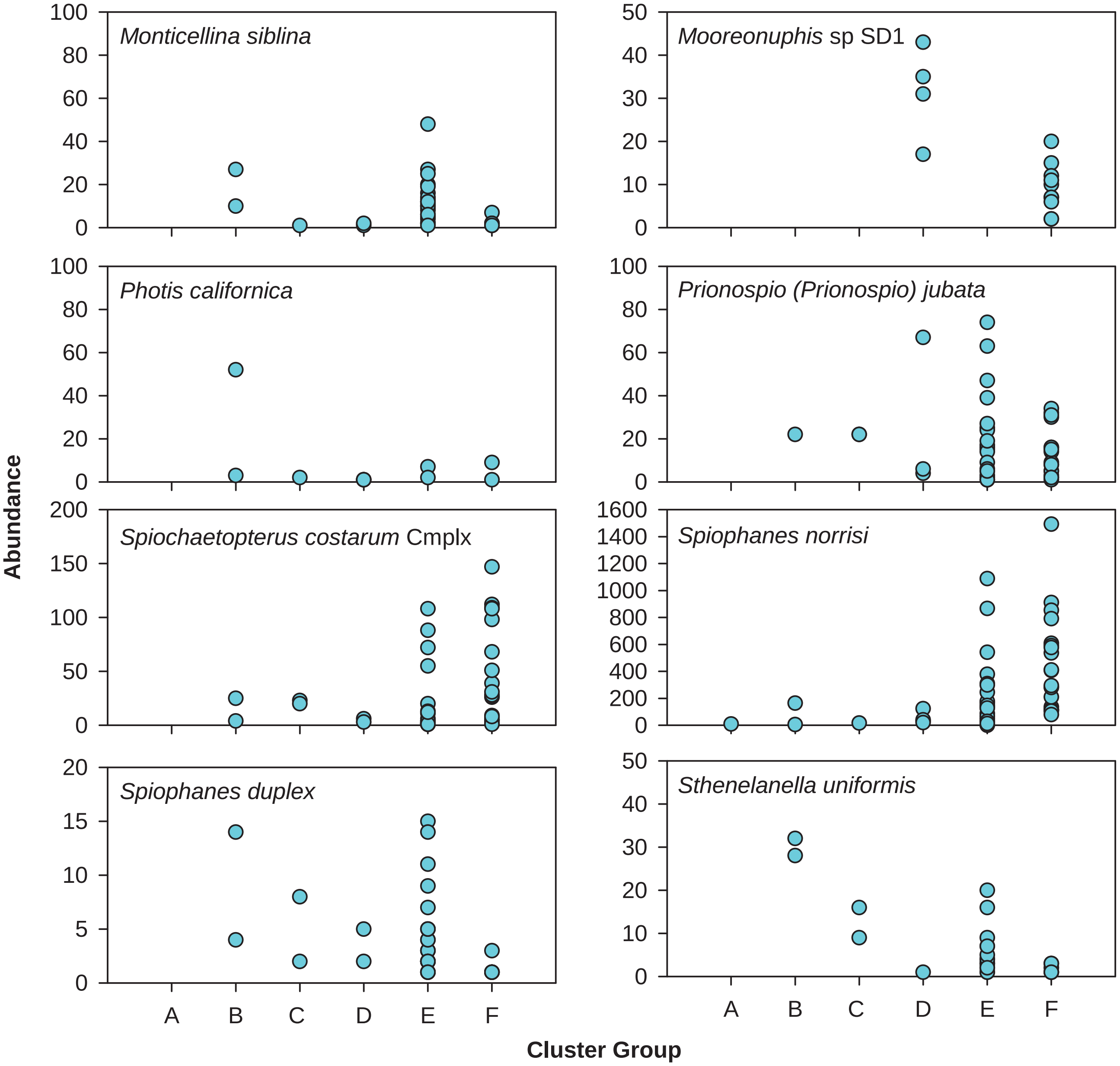

Figure 5.6 *continued*

Cluster group F represented the assemblages from a total of 20 grab samples collected at 11 different stations along the 19–38 m depth contours during 2014 (Figure 5.5). These included both the January and July samples from three of the nearfield stations (i.e., I12, I15, I16) and two other stations located west to northwest of the discharge site at depths of about 38 m (i.e., stations I13 and I21), as well as four stations located south of the outfall in Mexican waters (i.e., I2, I3, I6, I8). The remaining two samples in group E were collected in January at southern station I4 and in July at northern station I34. Similar to cluster group E, species richness and macrofaunal abundance for the group F assemblages varied widely (Table 5.4). For example, species richness values for group F ranged from 45 to 123 taxa per grab with a mean of 86 species per sample, while abundance ranged from 320 to 2191 animals per grab with a mean of 877 per sample. Four of the five most characteristic species for group F based on SIMPER results were polychaetes, including *Spiophanes norrisi* (446 per grab), *Spiochaetopterus costarum* Cmplx (44 per grab), the maldanid polychaete

Axiothella sp (16 per grab), and the capitellid *Notomastus latericeus* (18 per grab). The fifth most characteristic species was the ampeliscid amphipod *Ampelisca cristata cristata* (9 per grab) (Appendix D.3). This group was also mostly distinguished from the other SBOO assemblages by the relative numbers of *Axiothella* sp, *S. costarum* Cmplx, *S. norrisi*, *Mooreonuphis* sp SD1, and *Ampelisca careyi* (Figure 5.6). The sediments associated with cluster group F were characterized by about 4% fines, 25% fine sands, 67% medium-coarse sands, and 4% coarser particles (Table 5.4).

SUMMARY

Analyses of the 2014 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 2000–2014a), 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 possible 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 ever 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 2014, 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 have been observed to form extensive communities in other areas of the world that possess naturally high levels of organic matter (Díaz-Jaramillo et al. 2008), they are known to be a stable dominant component of many healthy environments in the SCB (Rodríguez-Villanueva et al. 2003). Thus, the presence of large populations of *Spiophanes norrisi* observed at most SBOO stations from 2007 through 2014 suggest that their distribution is not indicative of habitat degradation related to wastewater discharge, but that population fluctuations of this species over the past few 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 85% of the benthic sites surveyed in 2014 were classified in reference condition based on assessments using the BRI, while the few slightly elevated BRI values that were found south or to the far north of the outfall 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.

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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, bottom 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 2014, as well as long-term assessments of these communities from 1995 through 2014. 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 environment.

Materials and Methods

Field Sampling

Trawl surveys were conducted at seven monitoring stations in the SBOO region sampled during winter (January) and summer (July) 2014 (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 captured were identified to species or to the lowest taxon possible (Eschmeyer and Herald 1998, Lawrence et al. 2013, SCAMIT 2013). 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. Due to the small size of most invertebrate species, biomass was typically measured as a composite weight of all taxa combined, though large or exceptionally abundant species were weighed separately.

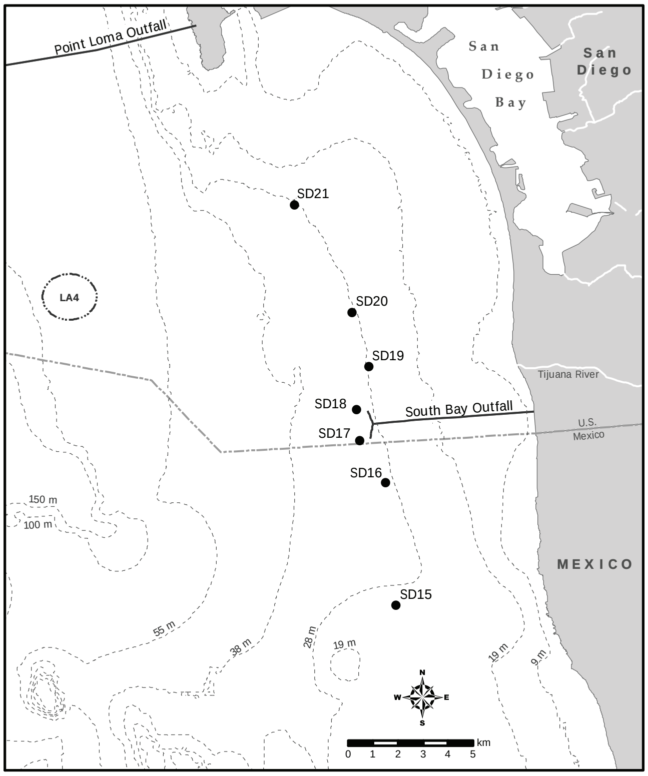

Figure 6.1
Trawl station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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 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), Shannon diversity index (H'), and total biomass.

Multivariate analyses were performed in PRIMER v6 using demersal fish and megabenthic invertebrate data collected from 1995 through 2014 (see Clarke 1993, Warwick 1993, Clarke and Gorley 2006). Prior to these analyses, all data were limited to summer surveys 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). Additionally, a 2-way crossed analysis of similarity (ANOSIM) was conducted (max. no. permutations = 9999) for each set of historical data where station group (i.e., nearfield, north farfield, south farfield) and year were provided as factors. SIMPER analyses were subsequently used to identify which species were most characteristic for each factor level when significant differences were found.

RESULTS AND DISCUSSION

Demersal Fishes

Community Parameters

Thirty species of fish were collected in the area surrounding the SBOO in 2014 (Table 6.1, Appendix E.1). The total catch for the year was 4430 individuals (Appendix E.2), representing an average of ~316 fish per trawl. Of the 18 families of fish represented, six accounted for 97% of the total abundance (i.e., Cynoglossidae, Hexagrammidae, Paralichthyidae, Pleuronectidae, Sciaenidae, Synodontidae). Overall, the total catch for winter and summer was ~33% smaller in 2014 than in 2013. Speckled Sanddab continued to dominate fish assemblages in the South Bay outfall region, occurring in every haul and accounting for 44% of all fish collected at an average of 138 individuals per trawl (Table 6.1). California Lizardfish were also prevalent in 2014, occurring in all trawls and accounting for 24% of all fish collected (~77 per haul). No other species contributed to more than 11% of the total catch. For example, Hornyhead Turbot also occurred in every trawl, but averaged only 13 individuals per occurrence. Other species collected in at least 50% of the trawls, but in relatively low numbers (≤36 per haul), included White Croaker, California Tonguefish, Longspine Combfish, Curlfin Sole, Longfin Sanddab, Yellowchin Sculpin, English Sole, and Pygmy Poacher. No new species were reported during the 2014 surveys.

More than 99% of the fishes collected in 2014 were < 30 cm in length (Appendix E.1). Larger fishes included one Shovelnose Guitarfish (45 cm), one Longnose Skate (45 cm), one Big Skate (42 cm), one California Skate (31 cm), two Thornback (46, 59 cm), and two California Halibut (32, 35 cm). Overall, median fish lengths varied little across stations and between seasons for three of the four most abundant species collected during the past year. Median lengths per haul ranged from 7 to 10 cm for Speckled Sanddab, 11 to 14 cm for California Lizardfish, and 9 to 12 cm for California Tonguefish (Figure 6.2). Median lengths per haul for White Croaker also varied little across stations (12 to 15 cm), however this species was only collected during the winter.

Species richness and diversity were consistently low for demersal fish communities sampled during 2014. Species richness ranged from 9 to 16 species per haul, with the minimum value recorded at station SD16 in the winter and at station SD15 in the winter and summer (Table 6.2). Diversity (H') ranged from 1.0 to 1.8, with the lowest value recorded at station SD16 in the summer and the highest value recorded at station SD17 in the winter. In contrast, abundance and biomass were much more variable among stations and between surveys during the year. For example, total abundance ranged from 115 to 485 individuals per haul and total biomass ranged from 2.9 to 10.4 kg per haul. The smallest hauls with ≤ 183 individuals were from stations SD15 and SD16 in the winter. The largest hauls with ≥ 405 individuals were from

Table 6.1

Species of demersal fish collected from 14 trawls conducted in the SBOO region during 2014. 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	44	100	138	138	Pacific Sanddab	<1	7	1	11
California Lizardfish	24	100	77	77	Plainfin Midshipman	<1	29	1	3
White Croaker	11	50	36	72	Fantail Sole	<1	43	1	2
California Tonguefish	4	93	14	15	California Skate	<1	43	<1	1
Hornyhead Turbot	4	100	13	13	Basketweave Cusk-eel	<1	14	<1	2
Longspine Combfish	3	64	11	17	Specklefin Midshipman	<1	21	<1	1
Queenfish	1	29	5	16	California Halibut	<1	14	<1	1
Curlfin Sole	1	86	4	5	Sarcastic Fringehead	<1	14	<1	1
Longfin Sanddab	1	57	4	7	Thornback	<1	7	<1	2
Yellowchin Sculpin	1	57	3	6	Big Skate	<1	7	<1	1
English Sole	1	57	2	4	Longnose Skate	<1	7	<1	1
Kelp Pipefish	<1	36	2	4	Pacific Pompano	<1	7	<1	1
Roughback Sculpin	<1	43	2	4	Round Stingray	<1	7	<1	1
Pygmy Poacher	<1	64	1	2	Shovelnose Guitarfish	<1	7	<1	1
Northern Anchovy	<1	7	1	12	Unidentified Pipefish	<1	7	<1	1

station SD21 in the summer, which included 232 California Lizardfish, and from station SD19 during both surveys, which included 201 White Croaker in the winter and 225 Speckled Sanddab in the summer (Appendix E.2). These large numbers contributed to the high biomass values (i.e., ≥7.6 kg) at these sites (Appendix E.3). Fish biomass was also high at stations SD18 and SD21 in the winter, reflecting a 2.1 kg Thornback and 7.9 kg of White Croaker, respectively.

Over the years, mean species richness and diversity have remained within narrow ranges (i.e., SR = 5–14 species per haul, H' = 0.4–1.7), despite considerable variability in abundance (i.e., 40–624 fishes per haul) (Figure 6.3). Differences in 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). Additionally, occasional spikes in total fish abundance have been due to large hauls of other species such as California Lizardfish, Yellowchin Sculpin, White Croaker, Roughback Sculpin, California Tonguefish, and Longspine Combfish (Figure 6.4). Overall, none of the observed changes appear to be associated with wastewater discharge.

Multivariate Analyses of Fish Assemblages

A long-term analysis of demersal fish assemblages from a total of 140 trawls conducted at seven monitoring stations during summer surveys from 1995 through 2014 showed significant differences by year, but not between nearfield, north farfield, or south farfield stations groups (Table 6.3). Pairwise comparisons demonstrated that the 2014 assemblages differed from those present in all other years except 2010–2012 (Appendix E.4). Species that contributed to these temporal differences included some of the dominant species mentioned above, including Speckled Sanddab, California Lizardfish, Yellowchin Sculpin, California Tonguefish, Longspine Combfish, and Roughback Sculpin, as well as California Halibut, English Sole, Hornyhead Turbot, Longfin Sanddab, Spotted Turbot, and California Scorpionfish (Figure 6.5).

Classification (cluster) analysis discriminated between six main types of fish assemblages in the South Bay outfall region over the past 20 years (Figure 6.6, Table 6.4). These assemblages (referred to herein as cluster groups A–F) represented from 1 to 43 hauls each and varied in terms of specific species present, as well as their relative abundance. The distribution of assemblages in 2014 (see description of groups E and F below)

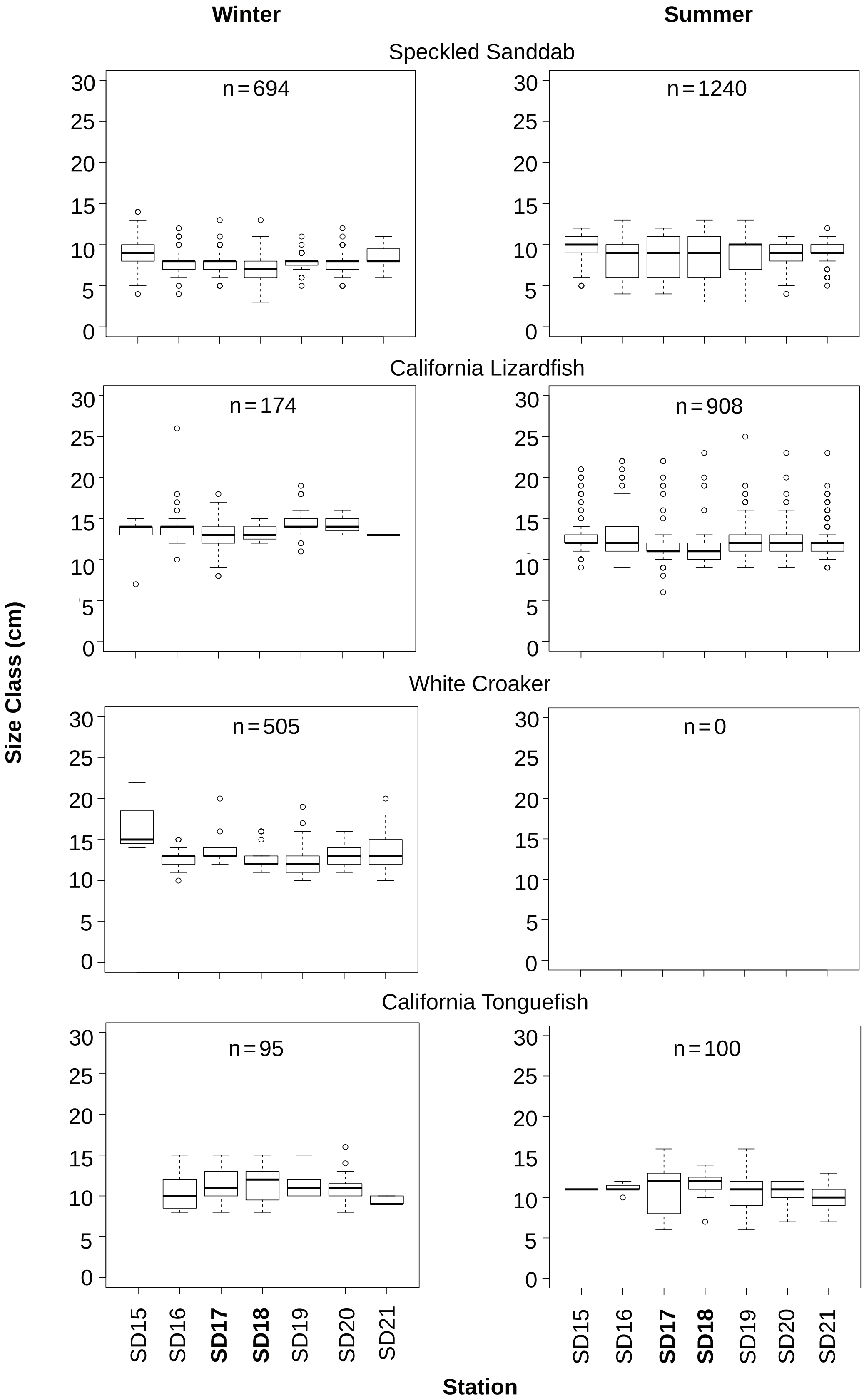

Figure 6.2

Summary of fish lengths by survey and station for the four most abundant species collected in the SBOO region during 2014. 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 2014. 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	9	9	SD15	115	376
SD16	9	13	SD16	183	371
SD17	13	11	SD17	245	320
SD18	16	10	SD18	344	299
SD19	10	13	SD19	444	405
SD20	12	11	SD20	200	337
SD21	14	15	SD21	306	485
Survey Mean	12	12	Survey Mean	262	370
Survey SD	3	2	Survey SD	111	62
Diversity			*Biomass*		
SD15	1.3	1.1	SD15	5.3	7.4
SD16	1.7	1.0	SD16	3.8	7.1
SD17	1.8	1.2	SD17	4.8	6.1
SD18	1.7	1.1	SD18	7.8	6.2
SD19	1.6	1.2	SD19	9.2	7.6
SD20	1.3	1.6	SD20	2.9	6.2
SD21	1.1	1.5	SD21	9.7	10.4
Survey Mean	1.5	1.2	Survey Mean	6.2	7.3
Survey SD	0.2	0.2	Survey SD	2.7	1.5

was generally similar to those observed since 2012, and there were no discernible patterns associated with proximity to the outfall. Instead, assemblages appear influenced by long-term climate-related changes in the SCB (e.g., El Niño/La Niña) or unique characteristics of a specific station location. For example, cluster groups A, B, and D were distinguished by very low numbers of Speckled Sanddab (≤47 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 C, E, and F had relatively high numbers of Speckled Sanddab (≥119 fish per haul) that tended to coincide with ENSO neutral or cold water conditions associated with La Niña (see Chapter 2 and CPC 2014). Additionally, station SD15 located 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 cluster group are described below.

Cluster group A represented assemblages from 11 trawls that included stations SD15–SD17 and SD20 sampled in 1997, station SD15 sampled in 1998, and stations SD15–SD20 sampled in 2001 (Figure 6.6). This group averaged the second lowest species richness (7 species per haul) and the lowest abundance (36 individuals per haul) (Table 6.4). SIMPER results indicated that the most characteristic species for group A were Speckled Sanddab (23 per haul), Hornyhead Turbot (3 per haul), California Lizardfish (2 per haul), California Scorpionfish (2 per haul), Spotted Turbot (2 per haul), and California Halibut (< 1 per haul).

Cluster group B comprised 27 hauls from one to six stations sampled from 1995 to 2002 and 2005 to 2006 (Figure 6.6). This group included all of the trawls conducted at stations SD16–SD21 during 1995, 1996, and 1998. It never occurred at station SD15. The assemblages represented by group B averaged 10 species, 105 individuals, and 47 Speckled Sanddab per haul, and had the highest numbers of

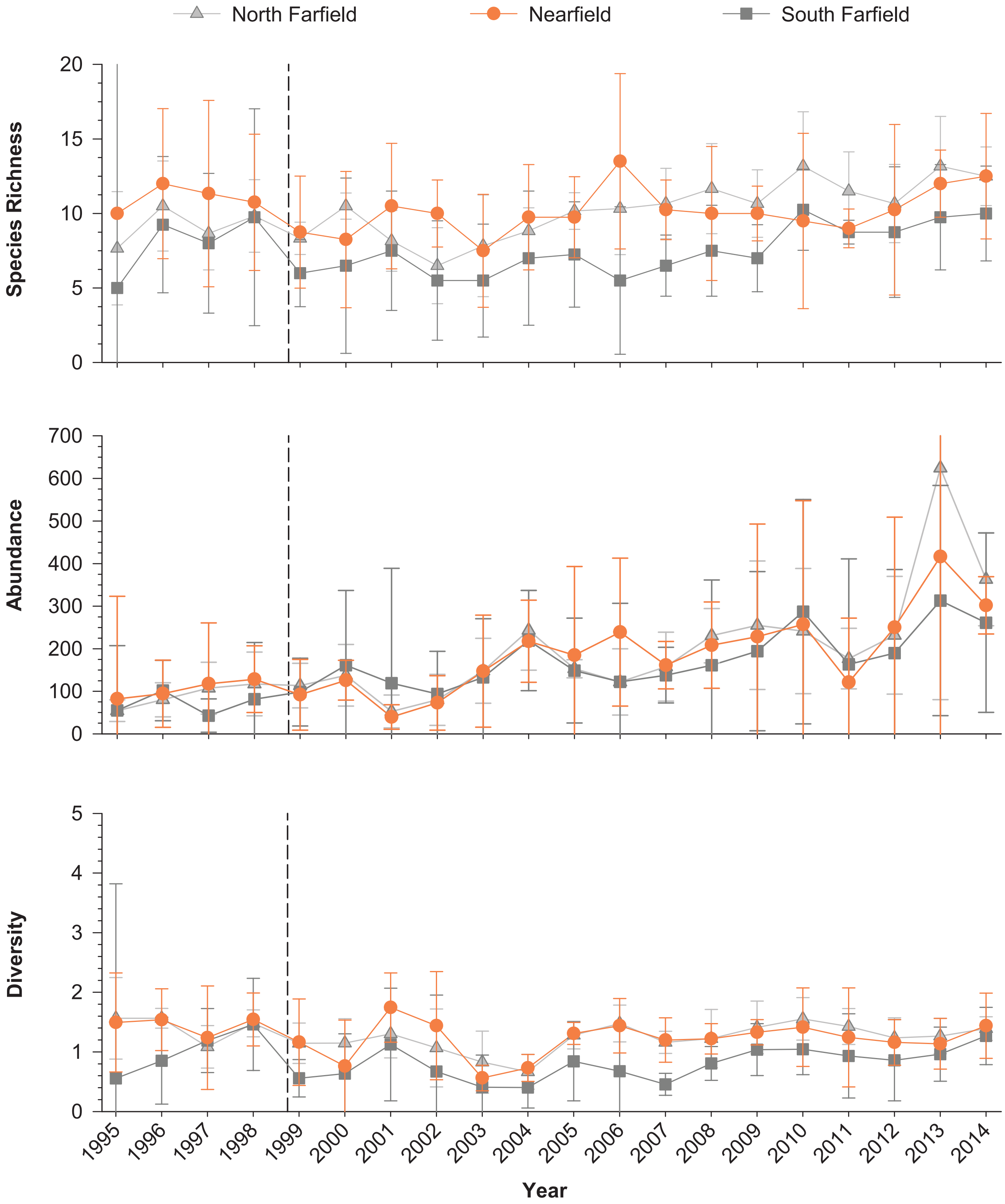

Figure 6.3
Species richness, abundance, and diversity of demersal fishes collected from SBOO trawl stations sampled from 1995 through 2014. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤6), and south farfield (n≤4) stations. Dashed lines indicate onset of wastewater discharge.

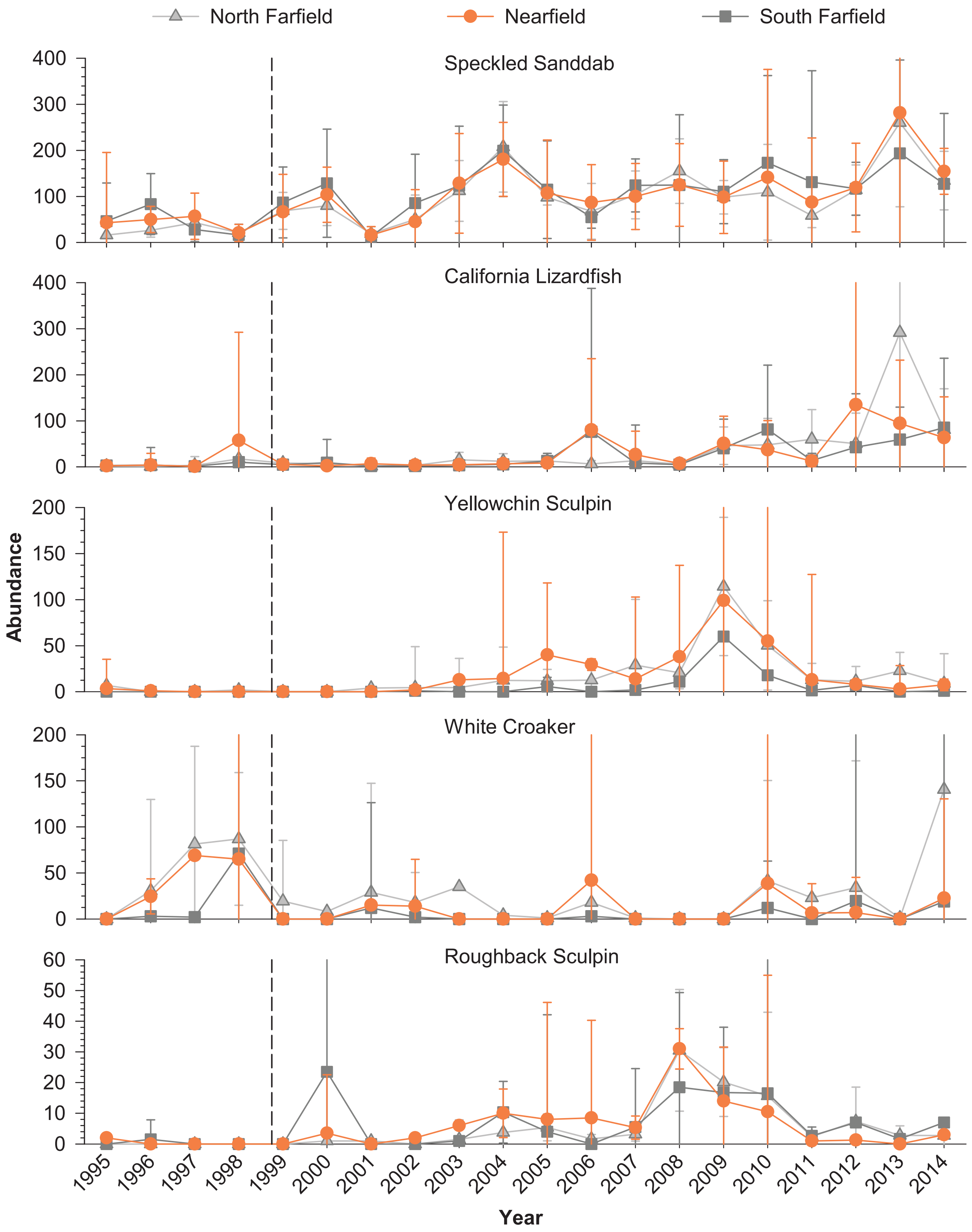

Figure 6.4
The ten most abundant fish species (presented in order) collected from SBOO trawl stations sampled from 1995 through 2014. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤6), and south farfield (n≤4) stations. Dashed lines indicate onset of wastewater discharge.

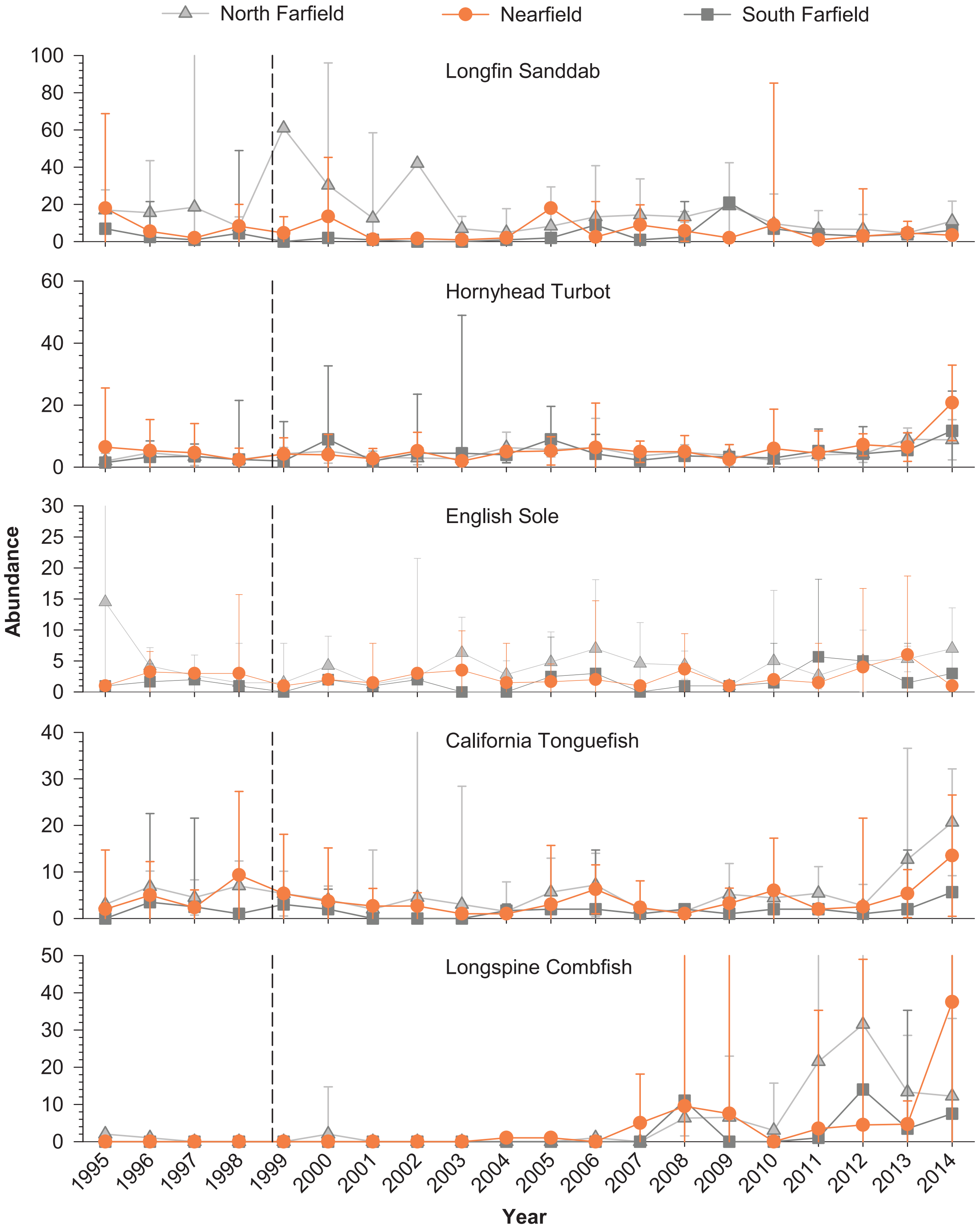

Figure 6.4 *continued*

Longfin Sanddab (23 per haul) (Table 6.4). Other characteristic species for this group included California Lizardfish (10 per haul), Hornyhead Turbot (5 per haul), California Tonguefish (5 per haul), English Sole (4 per haul), Fantail Sole (1 per haul), and Bigmouth Sole (<1 per haul).

Table 6.3

Results of 2-way crossed ANOSIM (with replicates) for demersal fish assemblages sampled around the SBOO from 1995 through 2014. Data were limited to summer surveys.

Global Test: Factor A (station groups)	
Tests for differences between station groups (across all years)	
Sample statistic (Global R):	0.203[a]
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0
Global Test: Factor B (years)	
Tests for differences between years (across all station groups, see Appendix E.4)	
Sample statistic (Global R):	0.589[a]
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0

[a] Test is considered not significant when Global R < 0.25; if Global R is 0.25–0.749 and the significance level is < 5%, significance is assumed (Clarke and Gorley 2006).

Cluster group C comprised 32 hauls from one to six stations sampled every summer except during 1998, 2001, 2009, 2010, 2013, and 2014 (Figure 6.6). This group included 60% of the trawls conducted at stations SD16–SD20 during 1999–2004, and 65% of the trawls conducted at station SD15 over the past 20 years. It never occurred at station SD21. Assemblages represented by group C had the lowest average species richness (6 species per haul) (Table 6.4). This group was also characterized by 133 individuals, 119 Speckled Sanddab, 4 Hornyhead Turbot, and 3 California Lizardfish per haul.

Cluster group D represented a unique demersal fish assemblage sampled during 2011 at station SD21 (Figure 6.6). This assemblage had the highest species richness (15 species), the second highest abundance (243 individuals), the largest number of Longspine Combfish (79 fish), White Croaker (22 fish), and English Sole (6 fish), the second largest number of California Lizardfish (75 fish), and the second lowest number of Speckled Sanddab (26 fish) (Table 6.4).

Cluster group E was the largest group, representing assemblages from a total of 43 hauls that included 74% (n = 40) of the trawls conducted at stations SD16−SD21 from 2003 through 2011, as well as the trawl from station SD18 in 2002, and the trawls from station SD20 in 2012 and 2014 (Figure 6.6). As with cluster group B, group E never occurred at station SD15. These assemblages averaged 10 species, 230 individuals, and 137 Speckled Sanddab per haul (Table 6.4). In addition to Speckled Sanddab, SIMPER results indicated that the most characteristic species for group E included Yellowchin Sculpin (35 per haul), California Lizardfish (23 per haul), Roughback Sculpin (10 per haul), Longfin Sanddab (9 per haul), Hornyhead Turbot (4 per haul), and English Sole (3 per haul).

Cluster group F comprised 26 hauls, including three trawls from stations SD16−SD18 in 2006, the trawl from station SD15 in 2009, and 79% (n = 22) of the trawls conducted during 2010, 2012, 2013, and 2014 (Figure 6.6). Assemblages represented by group F had the second highest species richness (11 species per haul), the highest abundance (483 individuals per haul), the highest numbers of Speckled Sanddab (233 per haul), and the highest numbers of California Lizardfish (187 per haul) of any cluster group (Table 6.4). This group was also characterized by Yellowchin Sculpin (10 per haul), Hornyhead Turbot (8 per haul), California Tonguefish (7 per haul), Longfin Sanddab (5 per haul), Roughback Sculpin (4 per haul), and English Sole (3 per haul).

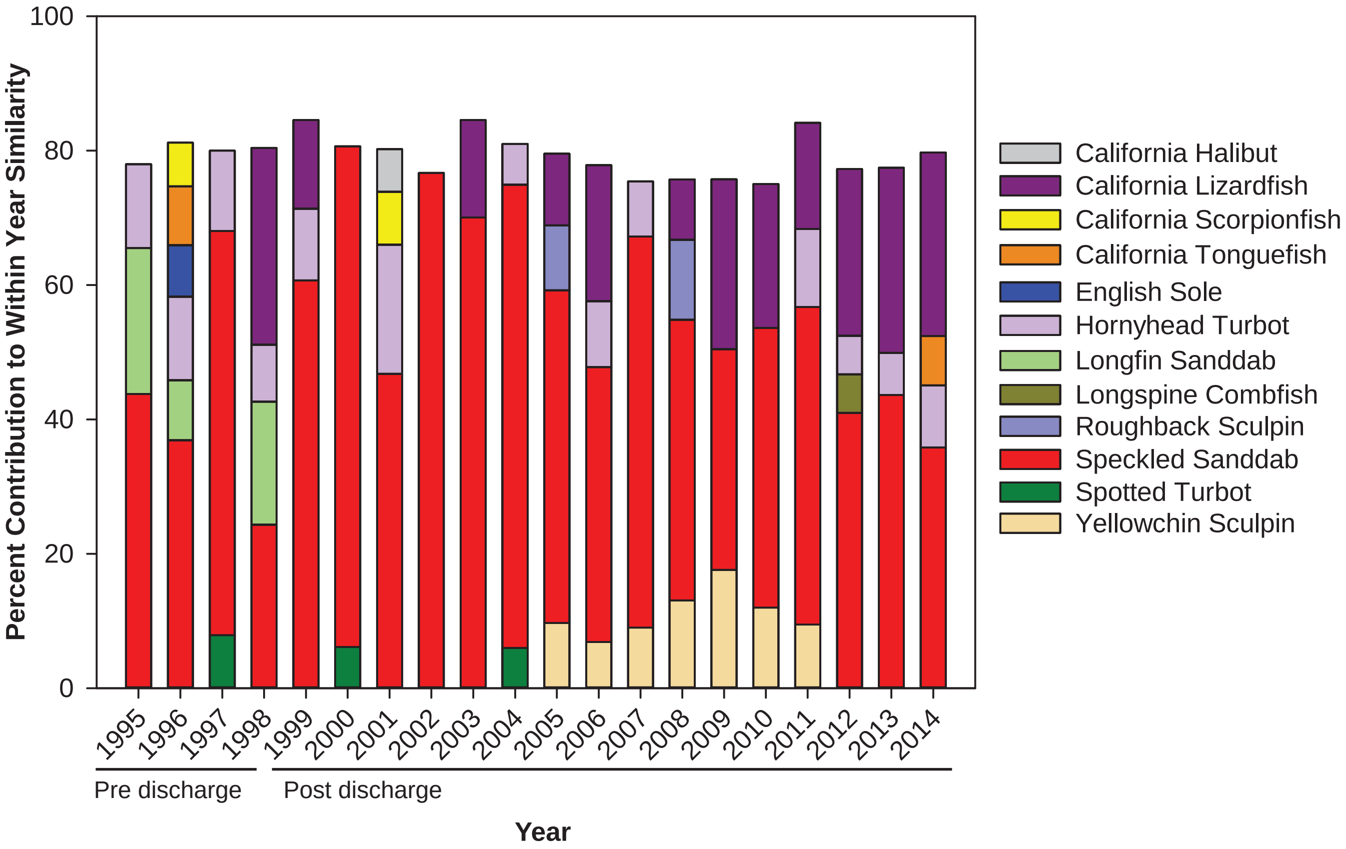

Figure 6.5

Characteristic demersal fish species collected from SBOO trawl stations sampled during summer surveys from 1995 through 2014 that contribute up to 85% of within group similarity for each year (Factor B, see Table 6.3) according to SIMPER analysis.

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the SBOO region during 2014. There were no incidences of fin rot or skin lesions among fishes collected during the year, and incidences of other abnormalities were very rare (0.07%). The latter included two instances of ambicoloration recorded on Curlfin Soles (one from each survey) and one tumor recorded on a Speckled Sanddab. Evidence of parasitism was also very low (0.3%) for trawl-caught fishes in the region. These included several leeches (subclass Hirudinea) reported from three Hornyhead Turbot and one Longnose Skate, and the cymothoid isopod *Elthusa vulgaris* (a gill parasite) that was noted on three Speckled Sanddab, two English Sole, and a single Curlfin Sole. Additionally, 64 more *E. vulgaris* were identified as part of invertebrate trawl catches during the year (see Appendix E.5). 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 1953 megabenthic invertebrates (~140 per haul) representing 51 species from five phyla were collected in 2014 (Table 6.5, Appendices E.5, E.6). Overall, the total catch in winter and summer was 38% larger in 2014 than in 2013, and continued to be dominated by echinoderms and crustaceans. The sea star *Astropecten californicus* was the most abundant and most frequently occurring trawl invertebrate in 2014, averaging 70 individuals per haul (=50% of total abundance) and occurring in 93% of the trawls. No other species contributed to more than 7% of the total catch. For example,

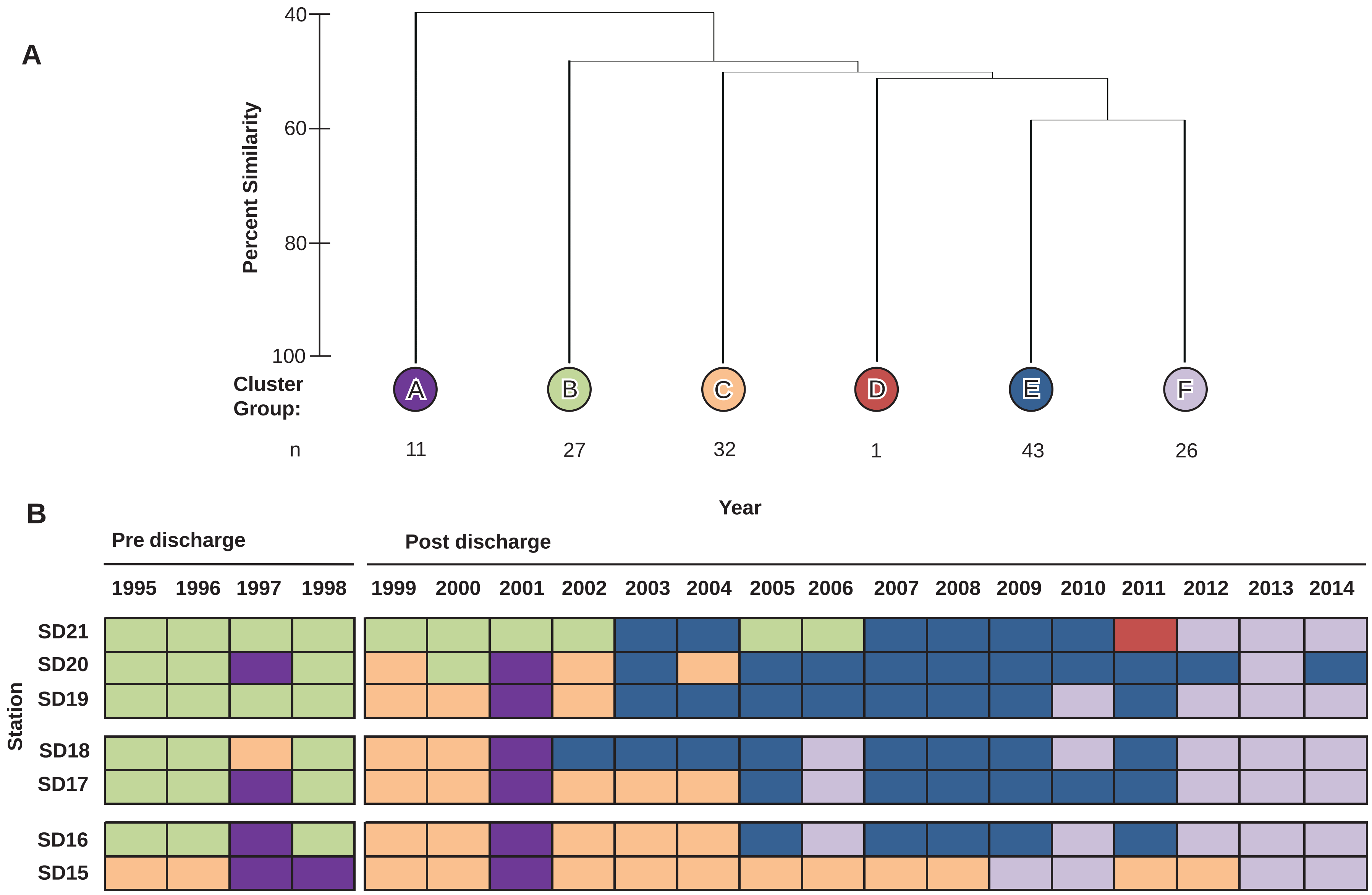

Figure 6.6
Results of cluster analysis of demersal fish assemblages from SBOO trawl stations from 1995 through 2014. Data are limited to summer surveys and presented as: (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time; n=number of hauls.

Table 6.4

Description of demersal fish cluster groups A–F defined in Figure 6.6. Highlighted/bold values indicate taxa that account for up to 95% of intra-group similarity according to SIMPER analysis.

	Cluster Group					
	A	B	C	D[a]	E	F
Number of Hauls	11	27	32	1	43	26
Mean Species Richness	7	10	6	15	10	11
Mean Abundance	36	105	133	243	230	483
Species	**Mean Abundance**					
Speckled Sanddab	**23**	**47**	**119**	26	**137**	**233**
California Lizardfish	**2**	**10**	**3**	75	**23**	**187**
Longspine combfish	0	<1	0	79	<1	10
White croaker	0	3	0	22	0	0
Yellowchin Sculpin	0	**3**	<1	5	**35**	**10**
Hornyhead Turbot	**3**	**5**	**4**	3	**4**	**8**
California Tonguefish	<1	**5**	<1	6	2	**7**
Longfin Sanddab	<1	**23**	<1	8	**9**	**5**
Roughback Sculpin	0	<1	1	5	**10**	**4**
English Sole	<1	**4**	<1	6	**3**	**3**
Fantail Sole	<1	**1**	<1	0	<1	1
California Scorpionfish	**2**	<1	<1	2	1	<1
California Halibut	**<1**	<1	<1	0	1	<1
Spotted Turbot	**2**	<1	2	<1	1	<1
Bigmouth Sole	<1	**<1**	<1	0	<1	<1

[a] SIMPER analysis only conducted on cluster groups that contained more than one trawl

the cephalopod *Octopus rubescens* also occurred in 93% of the trawls conducted during 2014, but only averaged 4 individuals per haul. Other species collected during the year that occurred in at least 50% of the trawls but in low numbers (i.e., ≤10 per haul) included the crabs *Latulambrus occidentalis*, *Loxorhynchus grandis*, *Metacarcinus gracilis*, and *Platymera gaudichaudii*, the sea urchin *Lytechinus pictus*, the gastropods *Acanthodoris brunnea*, *Crossata ventricosa*, *Pleurobranchaea californica*, and *Philine auriformis*, the shrimps *Sicyonia penicillata* and *Crangon nigromaculata*, and the cymothoid isopod *Elthusa vulgaris*. No new species were reported in the 2014 surveys.

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.6). For each haul, species richness ranged from 9 to 22 species, diversity (H') ranged from 0.4 to 2.5, total abundance ranged from 46 to 582 individuals, and biomass ranged from 0.8 to 5.6 kg. During 2014, the lowest species richness values of ≤10 were recorded at stations SD15 and SD16 in the winter and at station SD21 in the summer, while the lowest diversity values of ≤1.2 were recorded at station SD19 in the summer and at station SD15 during both surveys. The lowest biomass was recorded at station SD15 in the winter and at stations SD16 and SD17 in the summer, while the highest biomass occurred at station SD18 in the winter. The two largest hauls with ≥292 individuals were collected from stations SD15 and SD19 in the summer. The big size of these two hauls was largely due to the capture of 530 and 200 *Astropecten californicus*, respectively (Appendix E.6).

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 6.7, 6.8). Over the years, mean diversity and species

Table 6.5

Megabenthic invertebrates collected from 14 trawls conducted in the SBOO region during 2014. PA=percent abundance; FO=frequency of occurrence; MAH=mean abundance per haul; MAO=mean abundance per occurrence.

Species	PA	FO	MAH	MAO
Astropecten californicus	50	93	70	75
Latulambrus occidentalis	7	57	10	17
Acanthodoris brunnea	5	64	7	11
Lytechinus pictus	5	57	7	12
Philine auriformis	4	57	6	10
Crangon nigromaculata	4	64	6	9
Elthusa vulgaris	3	64	5	7
Octopus rubescens	3	93	4	4
Sicyonia penicillata	3	64	4	6
Metacarcinus gracilis	2	57	3	4
Pleurobranchaea californica	2	50	2	5
Loxorhynchus grandis	1	50	2	4
Dendraster terminalis	1	7	2	23
Kelletia kelletii	1	29	2	6
Ophiothrix spiculata	1	36	2	5
Platymera gaudichaudii	1	50	1	2
Crossata ventricosa	1	50	1	2
Aphrodita refulgida	1	21	1	4
Ophiura luetkenii	1	36	1	2
Pyromaia tuberculata	1	43	1	2
Randallia ornata	<1	43	1	1
Sicyonia ingentis	<1	36	1	2
Pisaster brevispinus	<1	14	<1	2
Pagurus armatus	<1	21	<1	1
Stylatula elongata	<1	21	<1	1
Ericerodes hemphillii	<1	21	<1	1
Hemisquilla californiensis	<1	14	<1	2
Pandalus danae	<1	14	<1	2
Amphissa undata	<1	14	<1	1
Aphrodita armifera	<1	14	<1	1
Armina californica	<1	14	<1	1
Calliostoma tricolor	<1	7	<1	2
Farfantepenaeus californiensis	<1	14	<1	1
Metacarcinus anthonyi	<1	14	<1	1
Pagurus spilocarpus	<1	14	<1	1
Panulirus interruptus	<1	14	<1	1
Portunus xantusii	<1	7	<1	2
Pugettia dalli	<1	7	<1	2
Calliostoma canaliculatum	<1	7	<1	1
Crangon alba	<1	7	<1	1
Crassispira semiinflata	<1	7	<1	1
Lepidozona scrobiculata	<1	7	<1	1
Lovenia cordiformis	<1	7	<1	1
Luidia armata	<1	7	<1	1
Paguristes ulreyi	<1	7	<1	1
Pteropurpura festiva	<1	7	<1	1
Pteropurpura macroptera	<1	7	<1	1
Scyra acutifrons	<1	7	<1	1
Sinum scopulosum	<1	7	<1	1
Strongylocentrotus franciscanus	<1	7	<1	1
Tritonia tetraquetra	<1	7	<1	1

richness have remained within narrow ranges (i.e., H' = 0.7–2.3, SR = 5–21 species per haul), despite considerable variability in mean abundance (i.e., 10–516 individuals per haul). Differences in overall invertebrate abundance primarily tracked changes in populations of the sea star *Astropecten californicus*, the urchin *Lytechinus pictus*, and the sand dollar *Dendraster terminalis*. 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 at the south farfield stations, while large incursions of *L. pictus* during pre-discharge years influenced the total abundance at both the north farfield and nearfield stations. Overall, none of the observed changes appear to be associated with wastewater discharge.

Multivariate Analysis of InvertebrateAssemblages

A long-term analysis of trawl-caught invertebrate assemblages from a total of 140 trawls conducted at seven monitoring stations during summer surveys from 1995 through 2014 showed significant differences by year, but not between nearfield, north farfield, or south farfield stations groups (Table 6.7). Pairwise comparisons demonstrated that the 2014 assemblages differed from those present in all other years except 1995 and 2013 (Appendix E.7). Species such as the sea stars *Astropecten californicus*

Table 6.6

Summary of megabenthic invertebrate community parameters for SBOO stations sampled during 2014. Data are included for species richness, abundance, and diversity (H') and biomass (kg, wet weight). SD = standard deviation.

Station	Winter	Summer	Station	Winter	Summer
Species richness			*Abundance*		
SD15	9	12	SD15	86	582
SD16	10	14	SD16	46	71
SD17	18	12	SD17	117	72
SD18	22	18	SD18	92	177
SD19	21	13	SD19	127	292
SD20	15	11	SD20	65	70
SD21	17	10	SD21	76	80
Survey Mean	16	13	Survey Mean	87	192
Survey SD	5	3	Survey SD	28	191
Diversity			*Biomass*		
SD15	1.1	0.4	SD15	0.8	2.3
SD16	1.8	1.5	SD16	1.5	0.8
SD17	1.9	1.8	SD17	3.5	0.8
SD18	2.5	2.4	SD18	5.6	2.3
SD19	2.2	1.2	SD19	1.1	1.2
SD20	2.4	1.9	SD20	1.3	1.1
SD21	2.1	1.7	SD21	1.1	0.9
Survey Mean	2.0	1.6	Survey Mean	2.1	1.3
Survey SD	0.5	0.6	Survey SD	1.8	0.7

and *Pisaster brevispinus*, the crabs *Latulambrus occidentalis* and *Pyromaia tuberculata*, the urchin *Lytechinus pictus*, the gastropod *Kelletia kelletii*, and the shrimp *Crangon nigromaculata* contributed to these temporal differences (Figure 6.9).

Classification (cluster) analysis discriminated between 11 main types of megabenthic invertebrate assemblages in the South Bay outfall region over the past 20 years (i.e., cluster groups A–K; Figure 6.10). These included eight small groups representing from 1 to 7 hauls each (cluster groups A–H) and three larger groups representing ~82% of all trawls (cluster groups I–K). The distribution of assemblages in 2014 (see description of groups H, J, and K below) was generally similar to those observed last year and there were 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 Beach often grouped apart from the remaining stations. The species composition and main descriptive characteristics of each cluster group are described below.

Cluster groups A, C, E, and F each represented a unique megabenthic invertebrate assemblage (Figure 6.10). The assemblage represented by group A occurred at station SD15 in 2009 and had 8 species and 84 individuals, and the highest number of the brittle star *Ophiura luetkenii* (n = 72) of any cluster group (Table 6.8). The assemblage represented by group C occurred at station SD19 in 1997 and had 6 species, 10 individuals, and the highest number of the sea star *Astropecten ornatissimus* (n = 4). The assemblage represented by group E occurred at station SD19 in 1998, and had the lowest species richness (n = 4) and abundance (n = 4). The assemblage represented by group F occurred at station SD21 in 2011, and had 17 species, 62 individuals, 11 *Astropecten californicus*, and the largest number of the

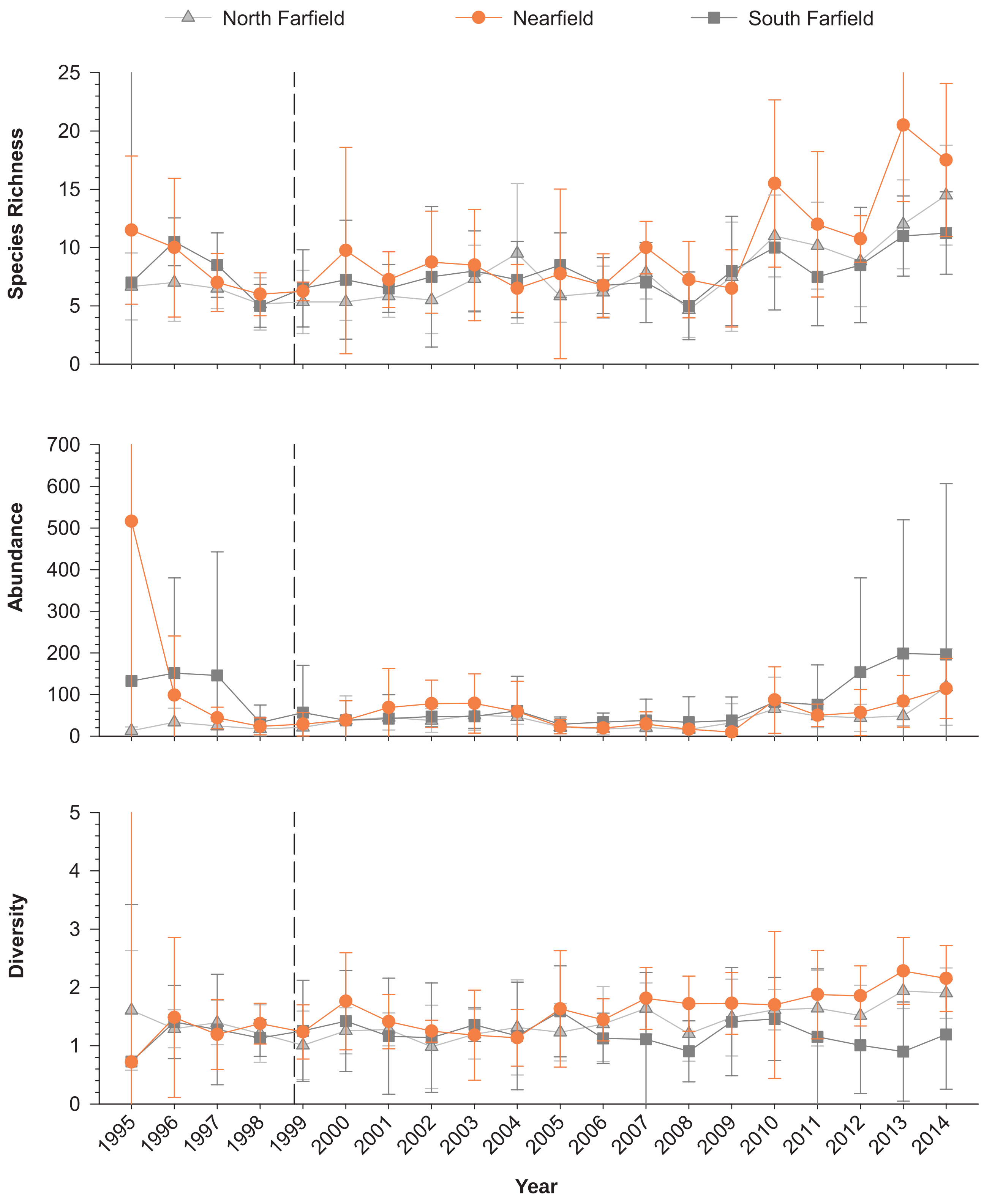

Figure 6.7

Species richness, abundance, and diversity of megabenthic invertebrates collected from SBOO trawl stations sampled from 1995 through 2014. 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.

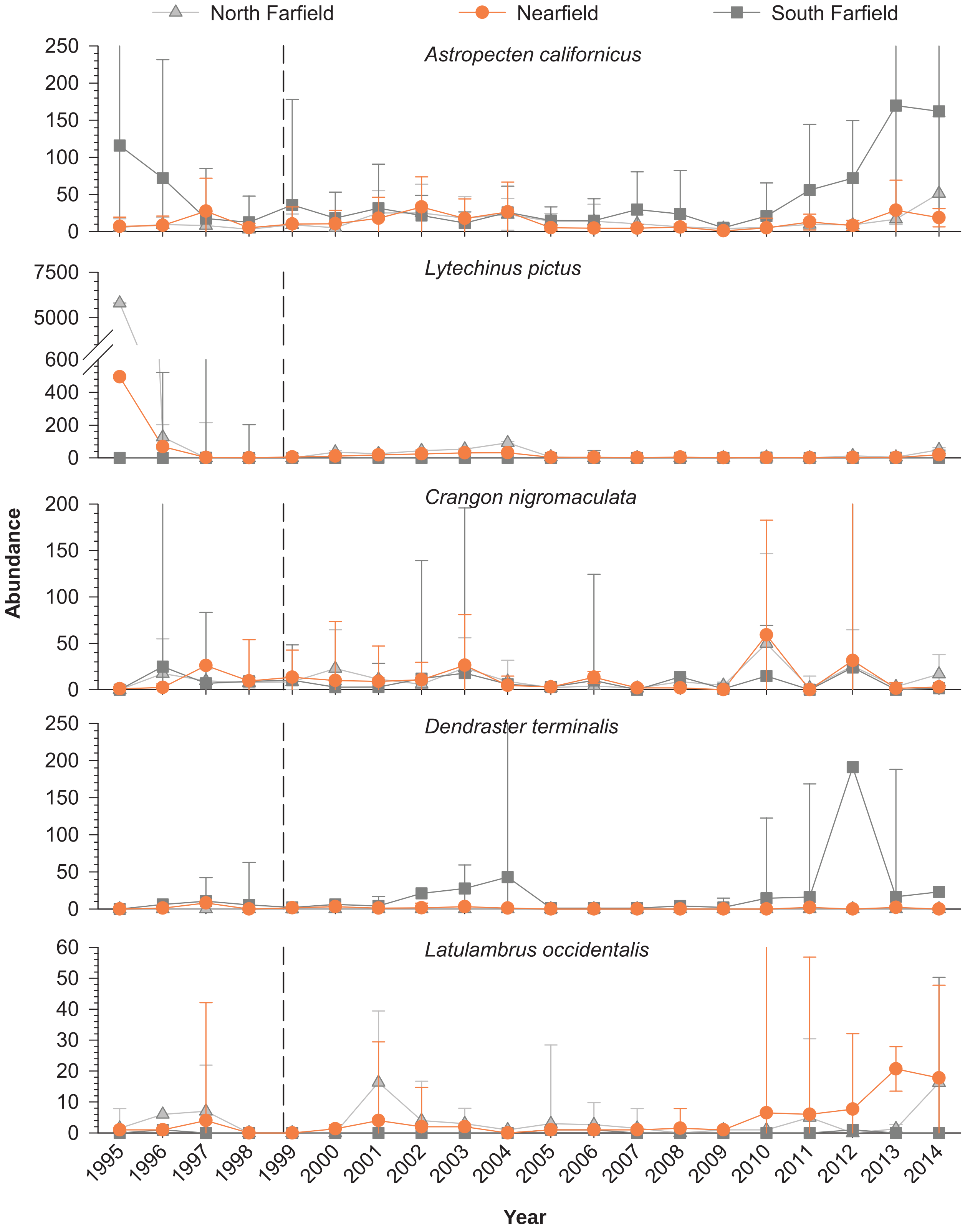

Figure 6.8

The ten most abundant megabenthic invertebrate species (presented in order) collected from SBOO trawl stations sampled from 1995 through 2014. 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.

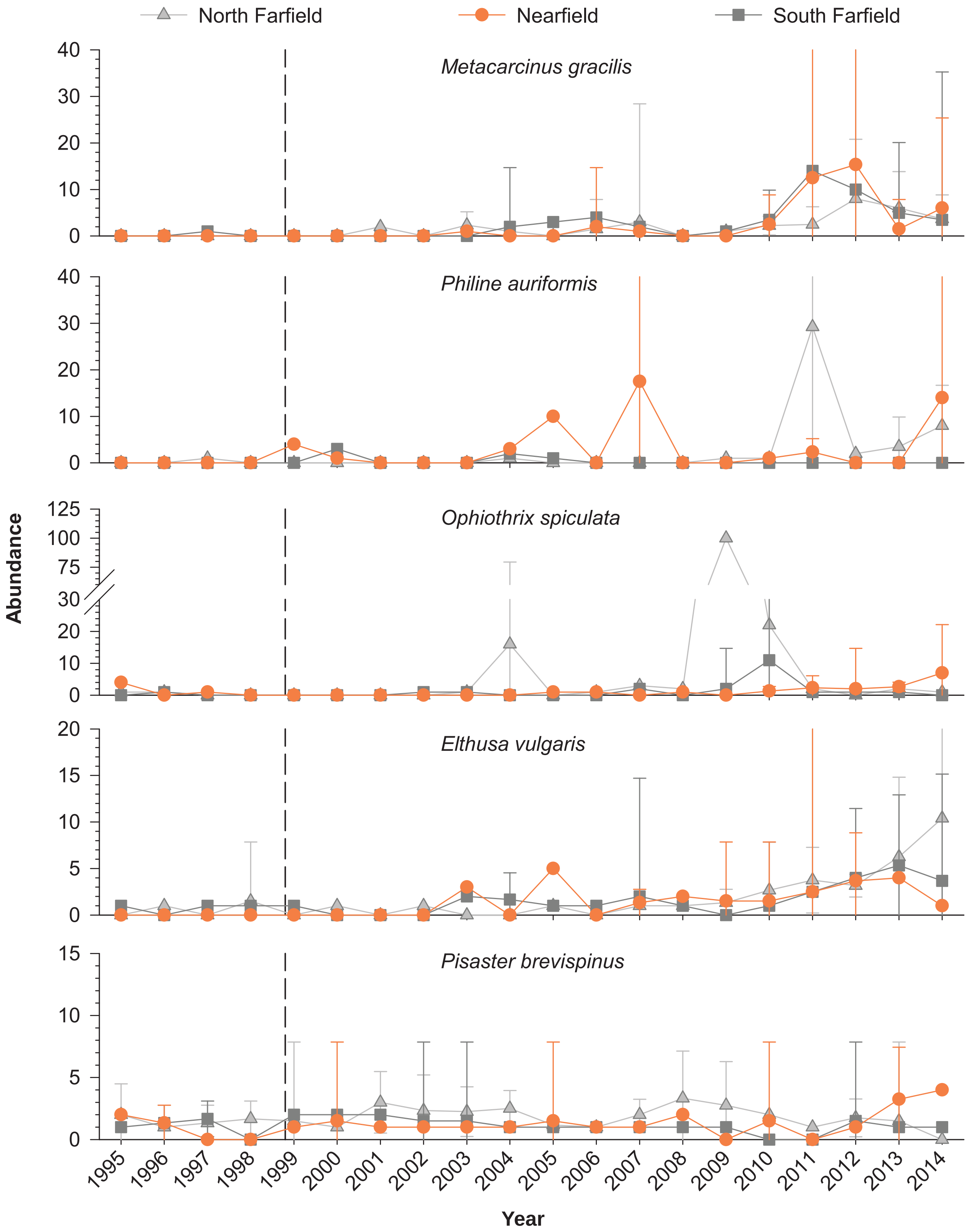

Figure 6.8 *continued*

shrimp *Heptacarpus stimpsoni* (n = 12), the gastropod *Philine auriformis* (n = 12), and the sea star *Luidia foliolata* (n = 8).

Cluster group B represented assemblages from three trawls that occurred at stations SD17, SD20, and SD21 in 2000 (Figure 6.10). Species richness for this

Table 6.7

Results of 2-way crossed ANOSIM (with replicates) for megabenthic invertebrate assemblages sampled around the SBOO from 1995 through 2014. Data were limited to summer surveys.

Global Test: Factor A (station groups)	
Tests for differences between station groups (across all years)	
Sample statistic (Global R):	0.242[a]
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0
Global Test: Factor B (years)	
Tests for differences between years (across all station groups, see Appendix E.7)	
Sample statistic (Global R):	0.307[a]
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0

[a] Test is considered not significant when Global R<0.25; if Global R is 0.25–0.749 and the significance level is <5%, significance is assumed (Clarke and Gorley 2006).

group averaged 6 species per haul and abundance averaged 9 individuals per haul (Table 6.8). SIMPER results indicated that the most characteristic species for group B were the crab *Loxorhynchus grandis* (1 per haul), *Crangon nigromaculata* (1 per haul), and unidentified leeches (subclass Hirudinea; 1 per grab).

Cluster group D comprised three trawls conducted at stations SD17, SD18, and SD20 in 2009 and two trawls conducted at stations SD17 and SD21 in 2012 (Figure 6.10). Assemblages represented by group D averaged 8 species and 14 individuals per haul (Table 6.8). This was one of two groups characterized by *Acanthodoris brunnea* (3 per haul). Other characteristic species for this group included *Astropecten californicus* (2 per haul), *Elthusa vulgaris* (1 per haul), *Kelletia kelletii* (1 per haul), *Octopus rubescens* (<1 per haul), *Pyromaia tuberculata* (<1 per haul), and the crab *Platymera gaudichaudii* (<1 per haul).

Cluster group G represented assemblages from six trawls, including those from station SD21 sampled in 1995, 2004, 2007, and 2008, and those from station SD16 sampled in 1997 and 2009 (Figure 6.10). These assemblages averaged 9 species and 19 individuals per haul (Table 6.8). SIMPER results indicated that the most characteristic species for group G were the brittle star *Ophiothrix spiculata* (5 per haul), *Astropecten californicus* (3 per haul), *Pisaster brevispinus* (2 per haul), *Pyromaia tuberculata* (2 per haul), and *Octopus rubescens* (2 per haul).

Cluster group H comprised seven trawls, including those from station SD15 sampled in 1995−1997, 1999, 2013, and 2014, and those from station SD17 sampled in 1995 (Figure 6.10). Assemblages represented by this group averaged 11 species and 463 individuals per haul, and had the highest number of *Astropecten californicus* (225 per haul) and *Lytechinus pictus* (213 per haul) (Table 6.8). Other characterstic species for group H included the sand dollar *Dendraster terminalis* (7 per haul), the urchin *Lovenia cordiformis* (4 per haul), and the sea pen *Stylatula elongata* (1 per haul).

Cluster group I was the second largest cluster group, representing assemblages from 21 hauls that included: station SD16 sampled in 1996; station SD17 sampled from 2006−2008, 2010, and 2011; station SD18 sampled in 2007, 2010, and 2011; station SD19 sampled in 2005 and 2009−2011; station SD21 sampled in 1996−1999, 2001–2002, 2006, and 2009 (Figure 6.10). These assemblages averaged 10 species and 32 individuals per haul (Table 6.8). SIMPER results indicated that the most characteristic

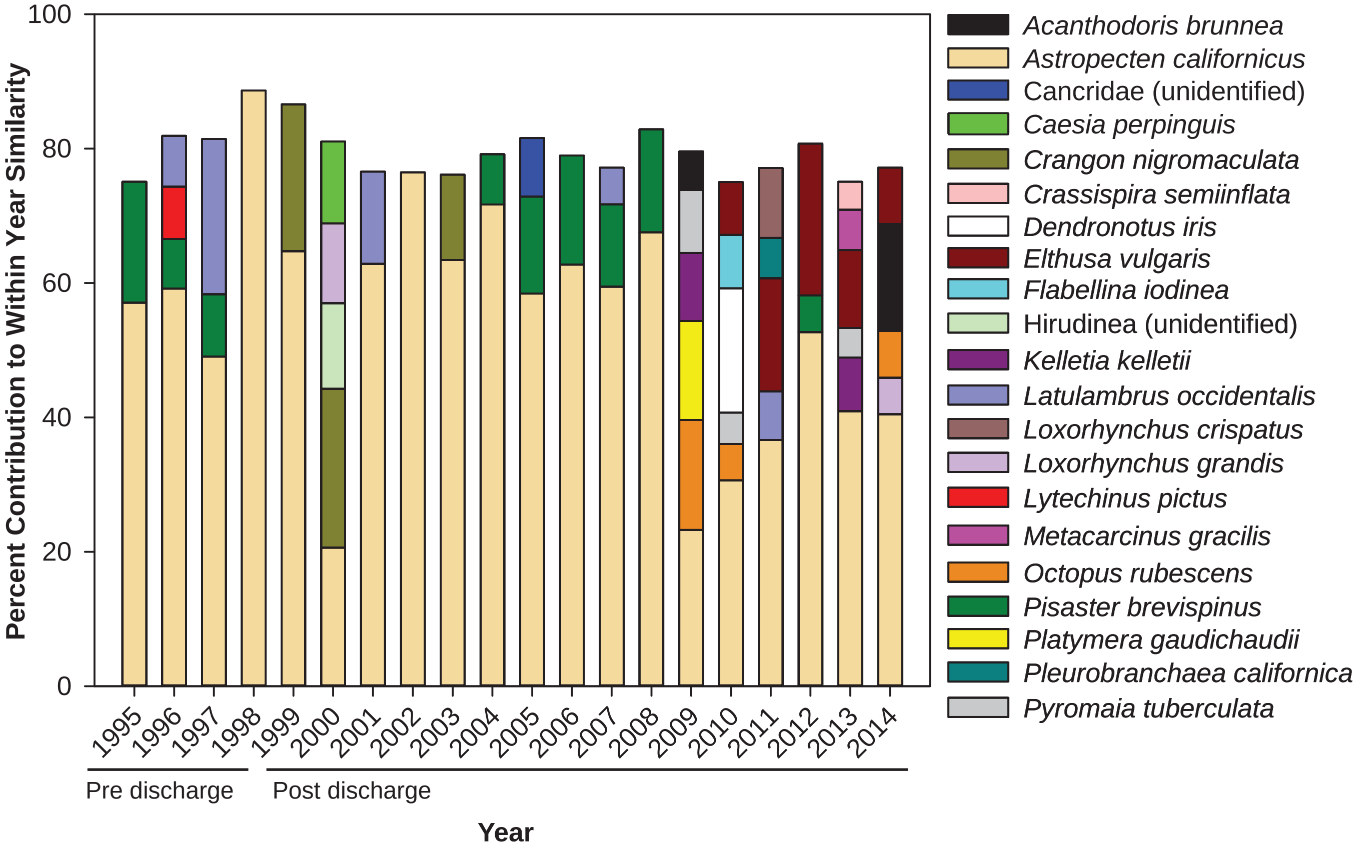

Figure 6.9
Characteristic megabenthic invertebrate species collected from SBOO trawl stations sampled during summer surveys from 1995 through 2014 that contribute up to 89% of within group similarity for each year (Factor B, see Table 6.7) according to SIMPER analysis.

species for group I were *Astropecten californicus* (6 per haul), *Latulambrus occidentalis* (4 per haul), *Crangon nigromaculata* (3 per haul), *Philine auriformis* (3 per haul), *Pyromaia tuberculata* (2 per haul), *Pisaster brevispinus* (1 per haul), *Kelletia kelletii* (1 per haul), *Elthusa vulgaris* (1 per haul), *Platymera gaudichaudii* (<1 per haul), *Ophiothrix spiculata* (<1 per haul), *Octopus rubescens* (<1 per haul), the sea slug *Flabellina iodinea* (<1 per haul), and the hermit crab *Pagurus spilocarpus* (<1 per haul).

Cluster group J was the third largest cluster group, representing assemblages from 16 hauls that included: station SD16 sampled in 2004–2005 and 2010–2014; station SD19 sampled in 2004 and 2013–2014; station SD20 sampled in 2010–2011 and 2013–2014; station SD21 sampled in 2013–2014 (Figure 6.10). These assemblages averaged 11 species and 72 individuals per haul and had the second highest number of *Astropecten californicus* (38 per haul) (Table 6.8). Other characteristic species for group J were *Elthusa vulgaris* (6 per haul), *Acanthodoris brunnea* (3 per haul), the shrimp *Sicyonia penicillata* (3 per haul), the crabs *Metacarcinus gracilis* (3 per haul) and *Randallia ornata* (<1 per haul), *Octopus rubescens* (2 per haul), the sea slug *Dendronotus iris* (2 per haul), *Kelletia kelletii* (1 per haul), *Pyromaia tuberculata* (<1 per haul), and *Flabellina iodinea* (<1 per haul).

Cluster group K was the largest cluster group, comprising 78 hauls (~56% of all trawls conducted) (Figure 6.10). Assemblages represented by this group occurred at every station and in all but one year throughout the course of monitoring, and may represent "background" conditions in the SBOO region during the summer. Group K averaged 7 species and 49 individuals per haul, and had the third

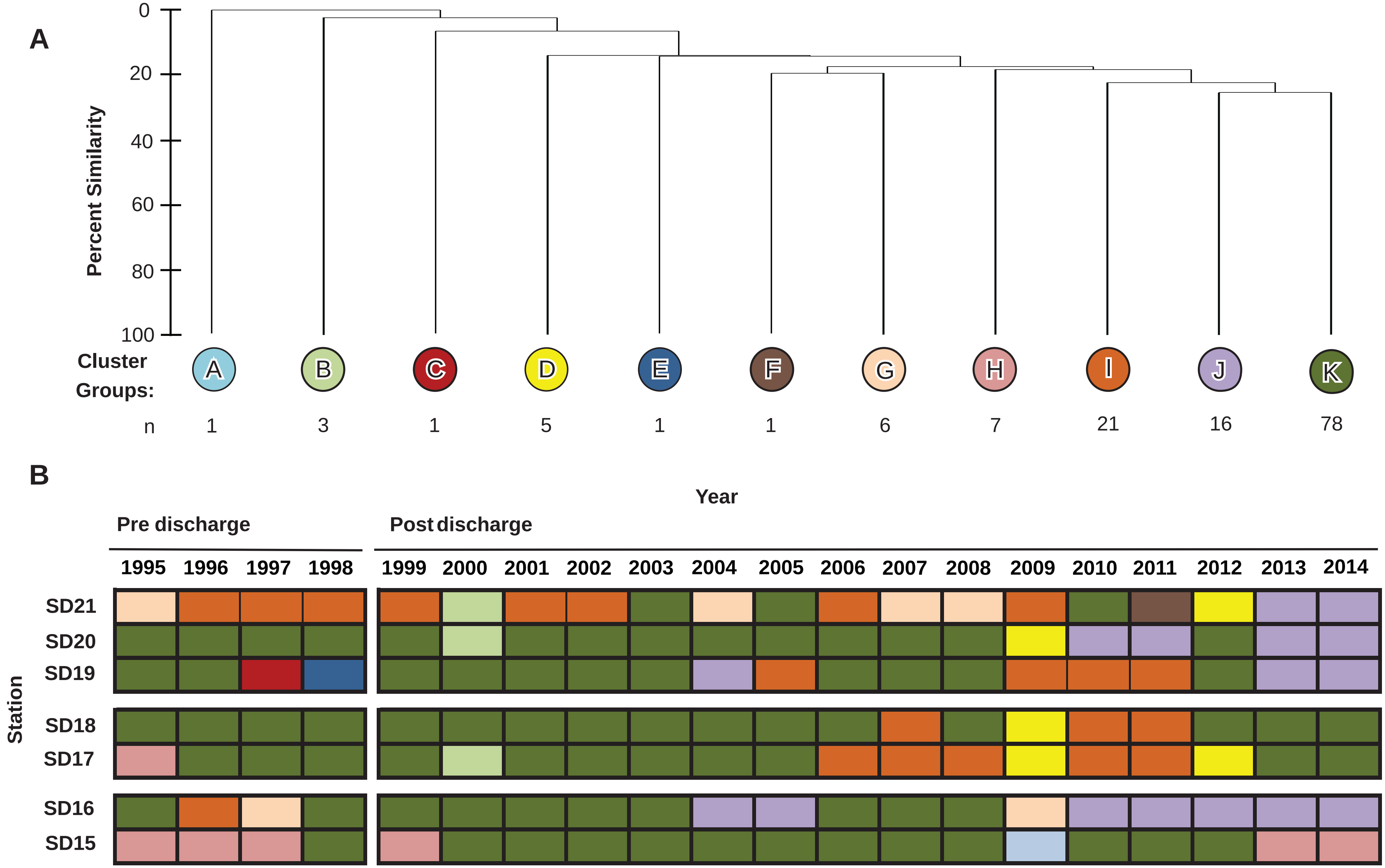

Figure 6.10
Results of cluster analysis of megabenthic invertebrate assemblages from SBOO trawl stations from 1995 through 2014. Data are limited to summer surveys and are presented as: (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time; n = number of hauls.

Table 6.8

Description of megabenthic invertebrate cluster groups A–K defined in Figure 6.10. Highlighted/bold values indicate taxa that account for up to 95% of intra-group similarity according to SIMPER analysis.

	Cluster Group										
	A[a]	B	C[a]	D	E[a]	F[a]	G	H	I	J	K
Number of Hauls	1	3	1	5	1	1	6	7	21	16	78
Mean Species Richness	8	6	6	8	4	17	9	11	10	11	7
Mean Abundance	84	9	10	14	4	62	19	463	32	72	49
Species	**Mean abundance**										
Astropecten californicus	0	0	0	**2**	1	11	**3**	**225**	**6**	**38**	**27**
Lytechinus pictus	0	<1	0	<1	0	0	0	**213**	<1	<1	**7**
Dendraster terminalis	3	0	0	0	0	0	0	**7**	0	0	1
Lovenia cordiformis	0	0	0	0	0	0	0	**4**	<1	0	<1
Ophiura luetkenii	72	0	0	0	0	1	0	0	2	<1	<1
Elthusa vulgaris	0	<1	0	**1**	0	3	0	1	**1**	**6**	**<1**
Stylatula elongata	0	0	0	0	0	0	0	**1**	<1	<1	<1
Crangon alba	2	0	0	0	0	0	0	1	0	0	<1
Loxorhynchus grandis	0	**1**	0	<1	0	1	<1	1	<1	<1	<1
Pisaster brevispinus	0	0	2	0	1	0	**2**	<1	**1**	<1	**<1**
Ophiothrix spiculata	3	0	0	0	0	2	**5**	<1	**<1**	3	<1
Pyromaia tuberculata	1	1	0	**<1**	0	2	**2**	<1	**2**	**<1**	<1
Octopus rubescens	1	0	0	**<1**	0	1	**2**	<1	**<1**	**2**	<1
Crangon nigromaculata	0	**1**	0	0	0	0	0	<1	**3**	<1	**<1**
Randallia ornata	0	0	0	0	0	0	<1	<1	0	**<1**	<1
Kelletia kelletii	0	0	0	**1**	0	0	<1	<1	**1**	**1**	**<1**
Latulambrus occidentalis	0	<1	1	<1	0	0	<1	<1	**4**	1	**2**
Acanthodoris brunnea	0	0	0	**3**	0	0	0	0	1	**3**	<1
Metacarcinus gracilis	0	0	0	<1	0	0	<1	0	<1	**3**	<1
Sicyonia penicillata	0	0	0	<1	0	0	0	0	0	**3**	<1
Dendronotus iris	0	0	0	<1	0	0	0	0	<1	**2**	<1
Philine auriformis	0	0	0	0	0	12	<1	0	**3**	1	<1
Flabellina iodinea	0	0	1	0	0	0	0	0	**<1**	**<1**	<1
Platymera gaudichaudii	0	0	0	**<1**	0	0	<1	0	**<1**	<1	<1
Pagurus spilocarpus	1	<1	0	0	0	0	0	0	**<1**	<1	<1
Luidia foliolata	0	0	0	0	0	8	0	0	<1	<1	<1
Hirudinea	0	**1**	0	0	0	0	0	0	<1	0	<1
Heptacarpus stimpsoni	0	0	1	0	0	12	0	0	<1	0	<1
Calliostoma tricolor	0	0	0	0	0	2	0	0	0	0	<1
Astropecten ornatissimus	0	0	4	0	0	0	0	0	0	0	<1
Crossata ventricosa	0	0	0	0	1	0	0	<1	<1	<1	<1
Doryteuthis opalescens	0	0	0	0	1	0	0	<1	0	0	1

[a] SIMPER analysis only conducted on cluster groups that contained more than one trawl

highest number of *Astropecten californicus* (27 per haul) (Table 6.8). According to SIMPER, *Pisaster brevispinus*, *Lytechinus pictus*, *Elthusa vulgaris*, *Crangon nigromaculata*, *Latulambrus occidentalis*, and *Kelletia kelletii* were also characteristic of these assemblages, each with ≤7 individuals per haul.

SUMMARY

Speckled Sanddab dominated fish assemblages surrounding the SBOO in 2014 as they have since monitoring began in 1995. This species occurred in all trawls and accounted for 44% of the total catch. California Lizardfish were also prevalent during 2014, as they have been in four of the past five years. This species occurred in 100% of trawls and accounted for 24% of the total catch. Other commonly captured, but less abundant species, included Hornyhead Turbot, California Tonguefish, Curlfin Sole, Longspine Combfish, White Croaker, Longfin Sanddab, Yellowchin Sculpin, English Sole, and Pygmy Poacher. Almost all fishes collected were <30 cm in length. Although the composition and structure of the fish assemblages varied among stations and surveys in 2014 as in previous years, these differences appear to be due to natural fluctuations of common species.

Assemblages of trawl-caught invertebrates in 2014 were dominated by the sea star *Astropecten californicus*, which occurred in 93% of trawls and accounted for 50% of the total invertebrate abundance. Other frequently collected species included the crabs *Latulambrus occidentalis*, *Metacarcinus gracilis*, *Platymera gaudichaudii*, and *Loxorhynchus grandis*, the gastropods *Crossata ventricosa*, *Philine auriformis*, *Pleurobranchaea californica* and *Acanthodoris brunnea*, the shrimps *Crangon nigromaculata* and *Sicyonia penicillata*, the sea urchin *Lytechinus pictus*, the cephalopod *Octopus rubescens*, and the cymothoid isopod *Elthusa vulgaris*. 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 2014. 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, 2006–2014). 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 is 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.

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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 due to their numerical dominance. 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 are 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 calender year 2014. 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 due to 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 2014 at seven otter trawl and two rig fishing stations (Figure 7.1). 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

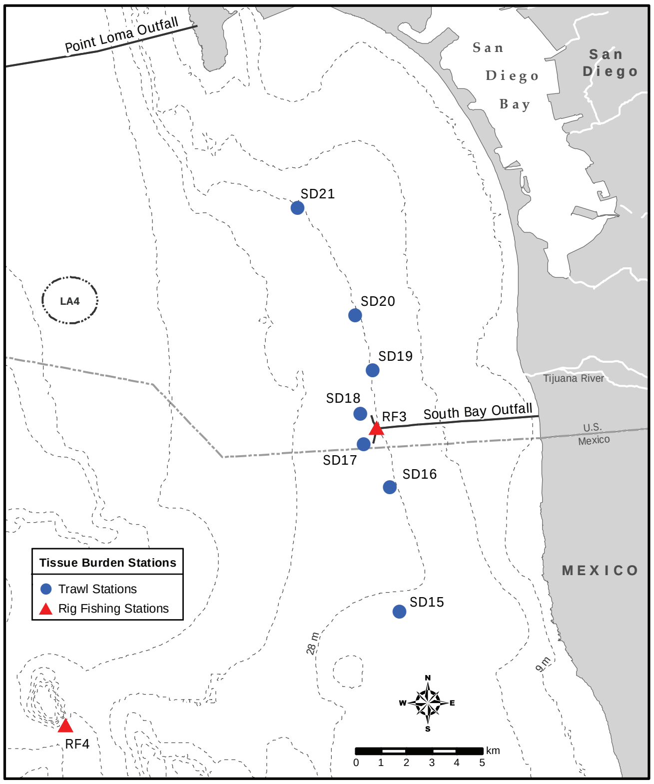

Figure 7.1

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.

and reel procedures; fishing effort was limited to 5 hours at each station. 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.

Two species were collected for analysis of liver tissues at the trawl stations, including Hornyhead Turbot (*Pleuronichthys verticalis*) and Longfin Sanddab (*Citharichthys xanthostigma*) (Table 7.1). In addition, two different species were collected for the analysis of muscle tissues at the two rig fishing stations. These species included the California Scorpionfish (*Scorpaena guttata*) and Vermilion Rockfish (*Sebastes miniatus*). Only fishes with a standard length ≥ 11 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 samples were subsequently delivered to the City's Environmental Chemistry Services Laboratory within 10 days of dissection.

All tissue 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 (2015b). 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 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

Table 7.1

Species of fish collected from each SBOO trawl and rig fishing station during 2014.

Station	Composite 1	Composite 2	Composite 3
RF3	Vermilion Rockfish	Vermilion Rockfish	California Scorpionfish
RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
SD15	Hornyhead Turbot	no sample	no sample
SD16	Hornyhead Turbot	no sample	no sample
SD17	Hornyhead Turbot	Hornyhead Turbot	no sample
SD18	Hornyhead Turbot	Hornyhead Turbot	Longfin Sanddab
SD19	Hornyhead Turbot	no sample	no sample
SD20	Longfin Sanddab	Hornyhead Turbot	no sample
SD21	Hornyhead Turbot	Hornyhead Turbot	Longfin Sanddab

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 1000 m of the outfall diffuser structure (SD17, SD18, RF3) to those from “farfield” stations located >1.7 m away to the south (SD15, SD16), north (SD19–SD21), and west (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.

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, including: (1) the California Office of Environmental Health Hazard Assessment (OEHHA), which has developed fish contaminant goals for chlordane, DDT, methylmercury, selenium, and PCBs (Klasing and Brodberg 2008); (2) the United States Food and Drug Administration (USFDA), which has set limits on the amount of mercury, DDT, and chlordane in seafood that is to be sold for human consumption (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

Nine trace metals were detected in all liver tissue samples from trawl-caught fishes collected in the South Bay outfall region during 2014 (Table 7.2). These included arsenic, cadmium, copper, iron, manganese, mercury, selenium, silver, and zinc. Aluminum, antimony, barium, beryllium, chromium, lead, and nickel were also detected, but in fewer samples (8–92%). Thallium and tin were not detected in any SBOO liver tissue samples collected during the year. Most metals occurred at concentrations ≤5.08 ppm, although higher concentrations up to ~16 ppm for copper, 25 ppm for arsenic, 154 ppm for iron, and 163 ppm for zinc were recorded. The majority of metals were detected at levels within ranges reported prior to wastewater discharge in the SBOO region (e.g., City of San Diego 2000). Exceptions included arsenic, mercury, and zinc, which exceeded pre-discharge values in 60%, 90%, and 10% of the Hornyhead Turbot samples, respectively (Figure 7.2). In contrast, all metal concentrations were below pre-discharge values in Longfin Sanddab liver tissues. Intra-

Table 7.2

Summary of metals in liver tissues of fishes collected from SBOO trawl stations during 2014. Data include the number of detected values (n), minimum, maximum and mean[a] detected concentrations for each species, and the detection rate (DR) and maximum value for all species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses; nd = not detected. See Appendix F.2 for MDLs.

	Hornyhead Turbot (n out of 10)				Longfin Sanddab (n out of 3)				All Species	
Parameter	**n**	**Min**	**Max**	**Mean**	**n**	**Min**	**Max**	**Mean**	**DR (%)**	**Max**
Aluminum	9	nd	3.0	2.0	3	1.8	3.0	2.3	92	3.0
Antimony	0	—	—	—	1	nd	0.1	0.1	8	0.1
Arsenic	10	1.69	25.00	5.43	3	5.33	9.24	6.65	100	25.00
Barium	1	nd	0.02	0.02	0	—	—	—	8	0.02
Beryllium	4	nd	0.003	0.003	2	nd	0.005	0.004	46	0.005
Cadmium	10	0.41	4.35	1.93	3	0.72	5.08	3.27	100	5.08
Chromium	5	nd	0.3	0.1	1	nd	0.1	0.1	46	0.3
Copper	10	5.7	15.9	8.4	3	3.6	8.1	6.1	100	15.9
Iron	10	22.5	111.0	59.3	3	63.4	154.0	122.1	100	154.0
Lead	7	nd	0.2	0.1	3	0.1	0.3	0.2	77	0.3
Manganese	10	0.3	1.6	1.1	3	0.8	1.2	1.0	100	1.6
Hg	10	0.083	0.344	0.220	3	0.107	0.245	0.193	100	0.344
Nickel	1	nd	0.2	0.2	0	—	—	—	8	0.2
Selenium	10	0.51	1.56	0.86	3	0.62	1.38	1.01	100	1.56
Silver	10	0.04	0.45	0.16	3	0.05	0.19	0.11	100	0.45
Thallium	0	—	—	—	0	—	—	—	0	—
Tin	0	—	—	—	0	—	—	—	0	—
Zinc	10	47.80	163.00	76.43	3	19.60	26.70	23.70	100	163.00

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

species comparisons between nearfield and farfield stations suggest that there was no clear relationship between metal concentrations in fish liver tissues and proximity to the outfall, with most of the relatively high values occurring throughout the region (i.e., not just at the "nearfield" stations). For example, arsenic levels were highest in a Hornyhead Turbot sample from station SD15, while beryllium levels were highest in two Longfin Sanddab samples from stations SD20 and SD21, copper levels were highest in a Hornyhead Turbot sample from station SD19, and zinc levels were highest in a Hornyhead Turbot sample from station SD21.

Pesticides

DDT and hexachlorobenzene (HCB) were the only two chlorinated pesticides detected in fish liver tissue samples from the South Bay outfall region during 2014 (Table 7.3). DDT was the most prevalent, occurring in every tissue sample at concentrations up to 678 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 DDT metabolite p,p-DDE was found in 100% of the samples, whereas p,p-DDD, p,p-DDMU, p,p-DDT, and o,p-DDE were detected in ≤ 38% of the samples (Appendix F.3). HCB also occurred frequently at a rate of 92%, with concentrations up to 7.3 ppb. HCB was detected in liver samples from all stations; however, the two highest values were recorded from nearfield stations SD17 and SD18 (Figure 7.3). HCB was not detected prior to discharge.

PCBs and PAHs

PCBs were detected in 92% of the liver tissue samples collected from the South Bay outfall region during 2014 (Table 7.3). Total PCB concentrations

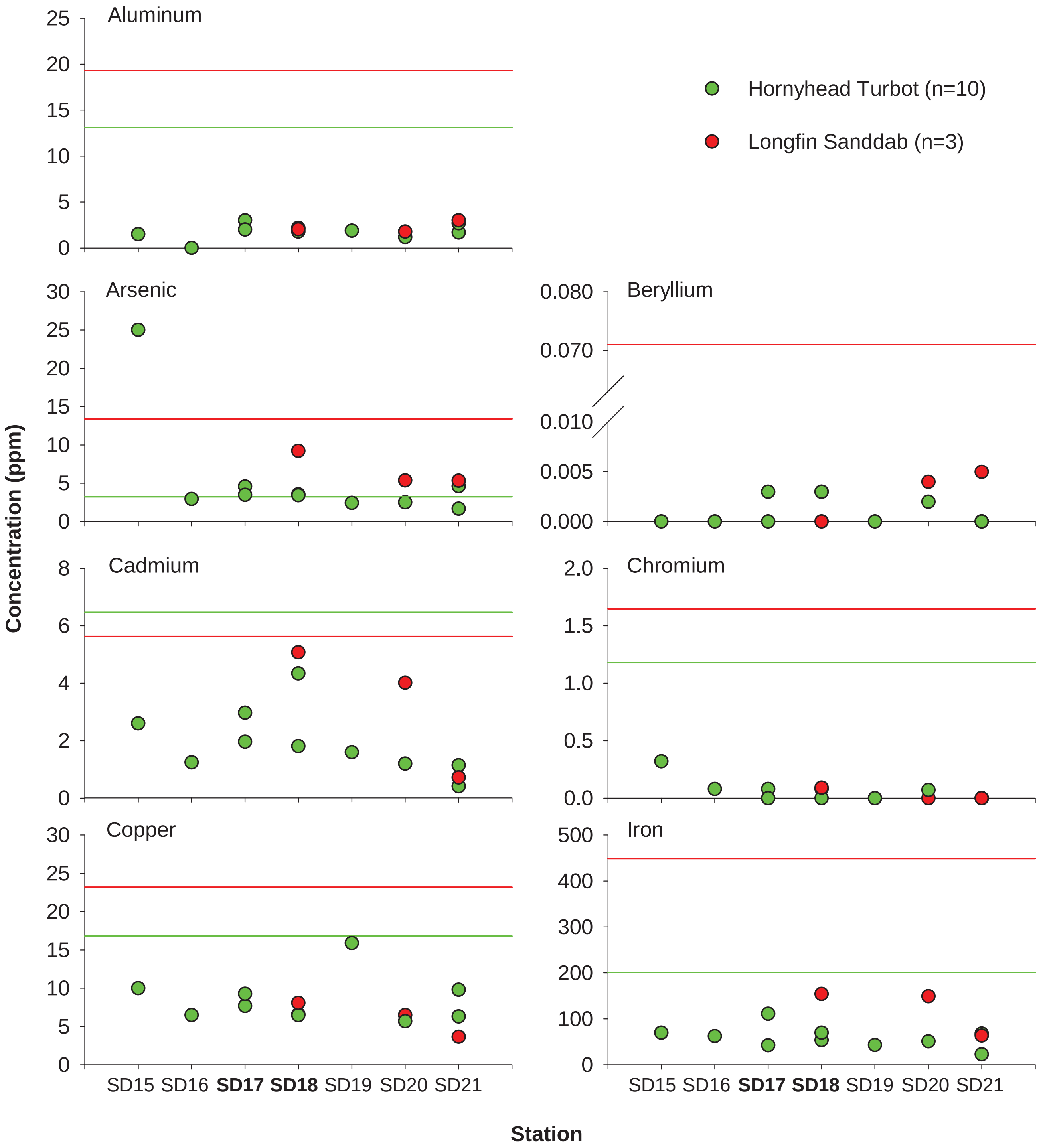

Figure 7.2

Concentrations of metals with detection rates ≥20% in liver tissues of fishes collected from each SBOO trawl station during 2014. 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 added as placeholders to differentiate between missing values (i.e., samples that were not collected; see Table 7.1) and non-detects. Stations SD17 and SD18 are considered nearfield (bold; see text).

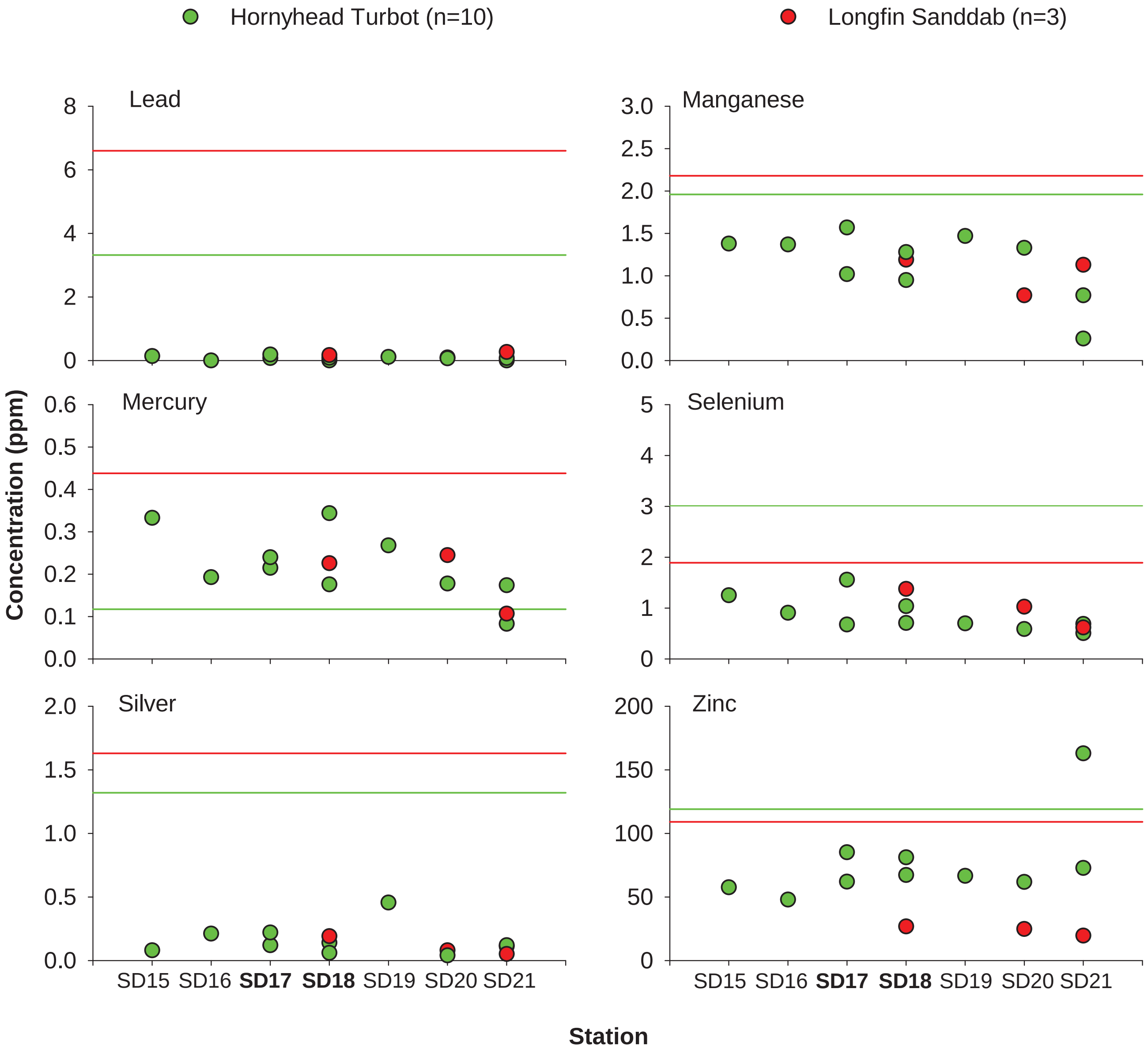

Figure 7.2 *continued*

were variable with concentrations up to 438.2 ppb. The congeners PCB 153/168 and PCB 187 both occurred in 92% of the samples, while PCB 66, PCB 138, and PCB 180 were detected at least 54% of the time (Appendix F.3). PCB concentrations during the year were below pre-discharge values and did not demonstrate a clear relationship with proximity to the outfall (Figure 7.3). The highest values of total PCB occurred in the three Longfin Sanddab samples from stations SD18, SD20, and SD21. In contrast to PCBs, PAHs (comprised solely of 2,6-dimethylnaphthalene) were only detected in one sample (detection rate = 8%), at a concentration of 50 ppb.

Contaminants in Fishes Collected by Rig Fishing

Only seven trace metals occurred in all rockfish muscle tissue samples collected at the SBOO rig fishing stations during 2014, including arsenic, cadmium, copper, manganese, mercury, selenium, and zinc (Table 7.4). Aluminum, beryllium, iron, and lead were also detected, but at rates ≤67%. In contrast, antimony, barium, chromium, nickel, silver, thallium, and tin were not detected in any muscle tissue samples. The metals present in the highest concentrations

Table 7.3

Summary of pesticides, total PCB, total PAH and lipids in liver tissues of fishes collected from SBOO trawl stations during 2014. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations for each species, and the detection rate (DR) and maximum value for all species. Concentrations are expressed in ppb for all parameters except lipids, which are % weight; the number of samples per species is indicated in parentheses; nd = not detected. See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT, tPCB, and tPAH.

	Pesticides				
	HCB	**tDDT**	**tPCB**	**tPAH**	**Lipids**
Hornyhead Turbot					
n (out of 10)	9	10	9	1	10
Min	nd	11.00	nd	nd	3.1
Max	7.30	105.70	89.40	50.0	21.7
Mean	2.41	50.29	25.39	50.0	11.3
Longfin Sanddab					
n (out of 3)	3	3	3	0	3
Min	2.80	407.20	336.50	—	7.4
Max	3.90	678.00	438.20	—	44.3
Mean	3.20	573.67	371.37	—	29.9
All Species:					
DR(%)	92	100	92	8	100
Max	7.30	678.00	438.20	50.0	44.3

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

were aluminum, arsenic, iron, mercury, and zinc, however all were ≤3.8 ppm, and only mercury exceeded pre-discharge values. These exceedances occurred in all four of the California Scorpionfish samples (Figure 7.4). The highest concentrations of aluminum, arsenic, and manganese were found in one or two samples from station RF3, while the highest concentration of mercury was found in a sample 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 two different species (or individual specimens of each species).

Half of the rockfish muscle tissue samples collected during 2014 contained detectable levels of DDT (comprised solely of p,p-DDE), while detection rates for HCB and PCB (comprised solely of PCB 153/168) were ≤33% and PAHS were not detected (Table 7.5). Concentrations of total DDT, HCB, and total PCB were below 8 ppb. Neither total DDT nor total PCB exceeded pre-discharge values, whereas HCB was not detected during that period. As with metals, DDT and HCB levels appeared to be similar in fish tissue samples collected at the two rig fishing stations (Figure 7.4).

Most contaminants detected in fish muscle tissues during 2014 occurred at concentrations below state, national, and international limits and standards (Figure 7.4, Tables 7.4, 7.5). Exceptions included: (1) arsenic, which occurred at levels higher than the median international standard in one California Scorpionfish and two Vermilion Rockfish samples from station RF3, and two California Scorpionfish samples from station RF4; (2) selenium, which exceeded the median international standard in one sample of California Scorpionfish from station RF3 and one from RF4; (3) mercury, which exceeded OEHHA fish contaminant goals in one sample of Vermilion Rockfish from station RF3 and two samples of California Scorpionfish from station RF4, as well as the median international standard in one California Scorpionfish sample from station RF3 and the USFDA action limit in one California Scorpionfish sample from station RF4.

DISCUSSION

Several trace metals, PCB congeners, PAHs and the chlorinated pesticides DDT and HCB were detected in liver tissues from two different species of fish collected in the South Bay outfall region during 2014. Many of the same metals, DDT, HCB, and PCBs were also detected 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 2015c). Additionally, all muscle tissue samples from sport fish collected in the region had concentrations of DDT below

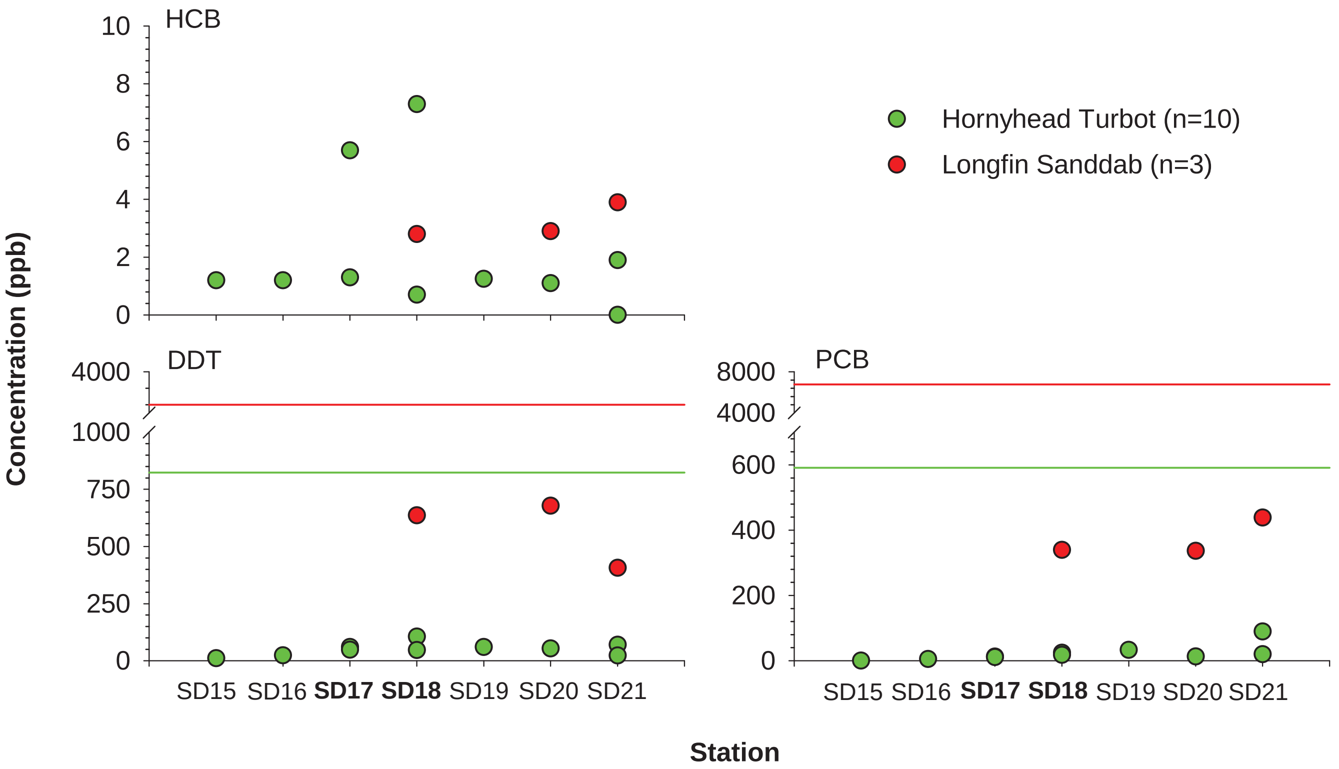

Figure 7.3
Concentrations of HCB, total DDT, and total PCB in liver tissues of fishes collected from each SBOO trawl station during 2014. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate parameters were not detected in that species pre-discharge. Zeros were added as placeholders to differentiate between missing values (i.e., samples that were not collected; see Table 7.1) and non-detects. Stations SD17 and SD18 are considered nearfield (bold; see text).

USFDA action limits. However, some composite tissue samples from California Scorpionfish and Vermilion Rockfish had concentrations of arsenic and selenium above median international standards for human consumption, and some had concentrations of mercury that exceeded OEHHA fish contaminant goals, median international standards, or the USFDA action limit. Elevated levels of these contaminants are not uncommon in sport fish from the SBOO survey area (City of San Diego 2000–2014) 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

Table 7.4

Summary of metals in muscle tissues of fishes collected from SBOO rig fishing stations during 2014. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the detection rate and maximum value for all species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses; 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 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
California Scorpionfish																		
n (out of 4)	4	0	4	0	1	4	0	4	2	1	4	4	0	4	0	0	0	4
Min	1.2	—	1.24	—	nd	0.03	—	0.1	nd	nd	0.0	**0.380**	—	0.25	—	—	—	2.70
Max	2.5	—	**2.96**	—	0.002	0.06	—	0.2	1.2	0.1	0.1	**1.540**	—	**0.32**	—	—	—	2.70
Mean	1.7	—	**2.35**	—	0.002	0.05	—	0.2	1.0	0.1	0.1	**0.802**	—	0.29	—	—	—	2.70
Vermilion Rockfish																		
n (out of 2)	0	0	2	0	0	2	0	2	2	0	2	2	0	2	0	0	0	2
Min	—	—	**3.52**	—	—	0.07	—	0.2	1.2	—	0.1	0.150	—	0.27	—	—	—	2.50
Max	—	—	**3.77**	—	—	0.07	—	0.2	1.8	—	0.1	**0.330**	—	**0.30**	—	—	—	3.20
Mean	—	—	**3.64**	—	—	0.07	—	0.2	1.5	—	0.1	**0.240**	—	0.28	—	—	—	2.85
All Species:																		
Detection Rate (%)	67	0	100	0	17	100	0	100	67	17	100	100	0	100	0	0	0	100
Max Value	2.5	—	**3.77**	—	0.002	0.07	—	0.2	1.8	0.1	0.1	**1.540**	—	**0.32**	—	—	—	3.20
OEHHA[b]	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
USFDA Action Limit[c]	na	na	na	na	na	na	na	na	na	na	na	1.0	na	na	na	na	na	na
Median IS[c]	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] From the California OEHHA (Klasing and Brodberg 2008)

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

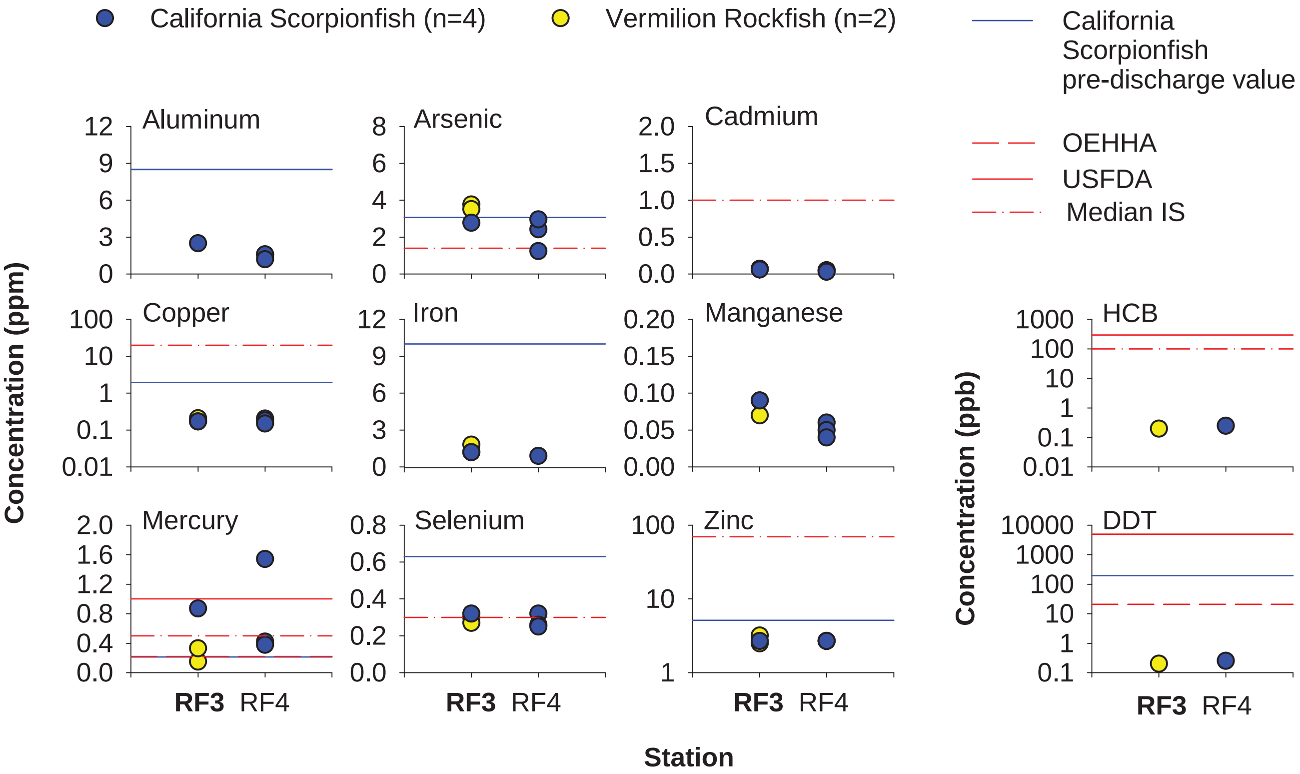

Figure 7.4

Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each SBOO rig fishing station during 2014. See Tables 7.4 and 7.5 for thresholds. Missing values are non-detects. Station RF3 is considered nearfield (bold; see text).

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 many 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 2014 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 outfall-related spatial patterns. 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).

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Table 7.5

Summary of pesticides, total PCB, and lipids in muscle tissues of fishes collected from SBOO rig fishing stations during 2014. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species and the detection rate and maximum value for all species. The number of samples per species is indicated in parentheses; 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 and tPCB.

	Pesticides			
	HCB (ppb)	**tDDT (ppb)**	**tPCB (ppb)**	**Lipids (% wt)**
California Scorpionfish				
n (out of 4)	1	3	1	4
Min	nd	nd	nd	0.1
Max	0.25	8.05	0.20	0.3
Mean	0.25	3.48	0.20	0.2
Vermilion Rockfish				
n (out of 2)	1	0	0	2
Min	nd	—	—	0.3
Max	0.20	—	—	0.3
Mean	0.20	—	—	0.3
All Species:				
Detection Rate (%)	33	50	17	100
Max Value	0.25	8.05	0.20	0.3
OEHHA[b]	na	21	3.6	na
U.S. FDA Action Limit[c]	300	5000	na	na
Median IS[c]	100	5000	na	na

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

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

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

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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 (City of Los Angeles 2013, 2014, City of San Diego 2014a, b, LACSD 2014, 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).

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).

This chapter presents analysis and interpretation of the sediment particle size and chemistry data collected during the 2014 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 2014 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 2014 regional survey covered an area ranging north of La Jolla southward to the USA/Mexico border (Figure 8.1). Overall, this survey included 40 stations ranging in

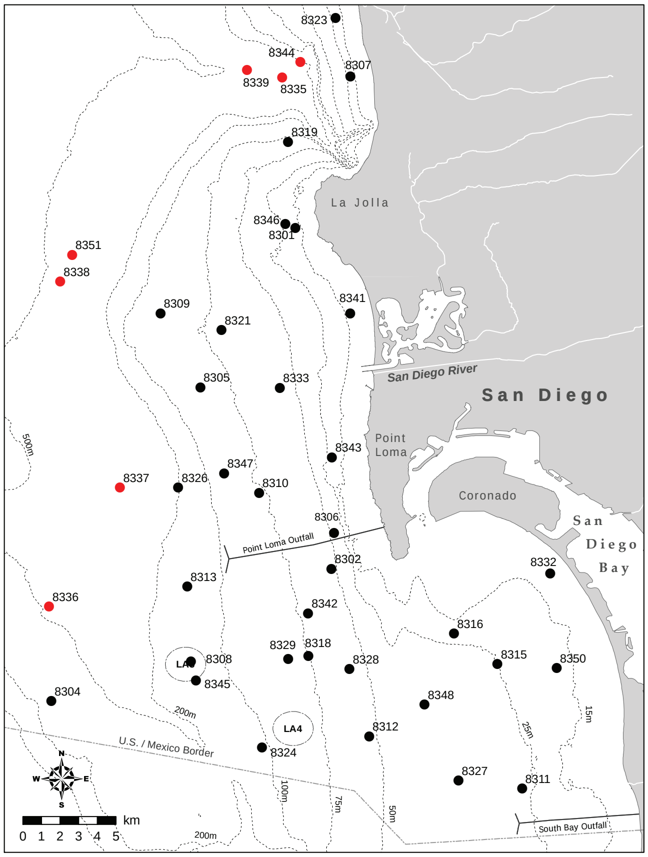

Figure 8.1

Regional benthic survey stations sampled during July 2014 as part of the City of San Diego's Ocean Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

depth from 12 to 449 m spanning four distinct depth strata characterized by the SCB regional monitoring programs (Schiff et al. 2011). These included 11 stations along the inner shelf (5–30 m), 17 stations along the mid-shelf (>30–120 m), 5 stations along the outer shelf (>120–200 m), and 7 stations on the upper slope (>200–500 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 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 (2015). 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 presence of the specific constituent was verified by mass-spectrometry.

Particle size analysis was performed using either a Horiba LA-920 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). 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).

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.

Multivariate analyses were performed using PRIMER v6 software to examine spatial patterns in the regional particle size and sediment chemistry data collected during 2014 (see Clarke and Warwick 2001, Clarke and Gorley 2006). These included hierarchical agglomerative clustering (cluster analysis) with group-average linking based on Euclidean distance and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrograms (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 above) 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 conducted to determine which subset of sediment sub-fractions was the best explanatory variable for the similarity between the two resemblance matrices.

RESULTS AND DISCUSSION

Particle Size Composition

Ocean sediments were diverse at the benthic stations sampled during the summer 2014 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 85% per sample, while fine sands, medium-coarse sands, and coarse particles (e.g., shell hash, gravel, pebbles) ranged from 0 to 92%, 0 to 92%, and 0 to 13% per sample, respectively (Table 8.1, Figure 8.2). Coarser particles often comprised shell hash, algae debris, gravel, rocks, black sand, organic debris, and worm tubes (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 9% on average at inner shelf stations, to 42 and 45% at mid- and outer shelf stations, to 74% at upper slope stations. Correlation analysis confirmed that percent fines tended to increase with depth (Figure 8.4). In contrast, fine and medium-coarse sands decreased from 61% and 29% on the inner shelf to 22% and 4% on the upper slope, respectively. The most notable exceptions to these patterns included sediments from station 8304 located at a depth of 146 m on the outer shelf and station 8336 located at a depth of 378 m on the upper slope of the Coronado Bank, each of which had lower percent fines (≤46%) than other stations at similar depths.

Indicators of Organic Loading

Sulfides were detected in all sediment samples collected from the 2014 San Diego regional benthic stations at concentrations from 0.57 to 249.00 ppm (Table 8.1). The highest values of this analyte were recorded on the upper slope within the La Jolla canyon at stations 8335, 8339, and 8344,

Table 8.1

Summary of particle sizes and chemistry concentrations in sediments from San Diego regional benthic stations sampled during 2014. 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.

	2014 Survey Area[a]				**Depth Strata**			
Parameters	**DR (%)**	**Min**	**Max**	**Mean**	**Inner Shelf** n = 11	**Mid-Shelf** n = 17	**Outer Shelf** n = 5	**Upper Slope** n = 7
Particle Size (%)								
Coarse particles	—	0.0	13.2	1.3	1.5	1.6	0.1	1.0
Med-coarse sands	—	0.0	92.0	15.3	28.5	11.1	16.5	3.7
Fine sands	—	0.0	92.1	44.5	61.2	44.8	38.7	21.6
Fines	—	0.8	85.2	38.9	8.8	42.4	44.7	73.7
Organic Indicators								
Sulfides (*ppm*)	100	0.57	249.00	21.37	4.42	6.08	11.91	91.89
TN (*% weight*)	98	nd	0.098	0.042	0.020	0.044	0.065	0.049
TOC (*% weight*)	100	0.11	0.96	0.39	0.24	0.50	0.61	0.19
TVS (*% weight*)	100	0.49	9.39	2.88	0.88	2.34	3.48	6.92
Trace Metals (*ppm*)								
Aluminum	100	1210	37,800	15,169	6224	14,403	18,510	28,700
Antimony	98	nd	3.2	1.5	1.0	1.3	1.4	2.5
Arsenic	100	0.98	8.70	3.23	2.40	2.81	4.10	4.96
Barium	100	6.83	136.00	56.48	28.76	49.78	65.36	109.94
Beryllium	98	nd	0.68	0.27	0.12	0.24	0.34	0.53
Cadmium	20	nd	0.49	0.29	nd	0.07	0.12	0.36
Chromium	100	4.3	49.5	21.2	9.7	19.2	26.7	40.2
Copper	75	nd	35.5	10.4	0.7	5.9	17.5	19.0
Iron	100	3660	33,000	15,458	7570	14,839	20,380	25,843
Lead	88	nd	15.4	5.3	2.3	4.7	6.0	9.0
Manganese	100	46.6	312.0	194.9	158.1	193.7	188.8	259.9
Mercury	68	nd	0.044	0.012	nd	0.012	0.016	0.010
Nickel	100	1.1	29.1	9.7	2.6	8.3	11.3	23.1
Selenium	53	nd	1.16	0.43	0.19	0.20	0.30	0.83
Silver	0	—	—	—	—	—	—	—
Thallium	38	nd	2.2	1.2	1.6	0.9	1.3	0.5
Tin	68	nd	2.5	1.0	0.8	0.8	0.7	1.5
Zinc	100	8.2	103.0	42.6	17.8	38.9	57.7	79.9

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

where values ranged from 98.10 to 249.00 ppm (Appendix G.3). In contrast, average sulfides ranged from 4.42 to 11.91 ppm on the inner, mid- and outer shelf (Table 8.1, Figure 8.3). Sulfides did not co-vary with percent fines (Appendix G.4).

During 2014, total nitrogen (TN), total organic carbon (TOC), and total volatile solids (TVS) were detected in 98–100% of the sediments from regional stations (Table 8.1). Overall, concentrations ranged from not detected to 0.098% weight for TN,

Table 8.1 *continued*

	2014 Survey Area[a]				Depth Strata			
Parameters	DR (%)	Min	Max	Mean	Inner Shelf n = 11	Mid-Shelf n = 17	Outer Shelf n = 5	Upper Slope n = 7
Pesticides (*ppt*)								
Total DDT	78	nd	7110	1134	194	1571	1348	745
Total chlordane	5	nd	920	690	nd	460	920	nd
HCB	23	nd	500	201	161	211	nd	220
Mirex	3	nd	150	150	nd	nd	150	nd
Total PCB (ppt)	38	nd	10,750	1911	10,750	807	3608	209
Total PAH (ppb)	70	nd	547	69	8	40	294	34

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

0.11–0.96% weight for TOC, and 0.49–9.39% weight for TVS. The highest concentrations of TVS occurred on the upper slope, likely due to being correlated strongly with percent fines (Appendix G.4). In contrast, TN and TOC values were highest at outer shelf stations (Figure 8.3). These results differ from previous findings where TN and TOC were found to co-vary with percent fines (e.g., City of San Diego 2014b).

Trace Metals

Eight trace metals were detected in sediments collected from all stations sampled during the 2014 regional survey off San Diego, including aluminum, arsenic, barium, chromium, iron, manganese, nickel, and zinc (Table 8.1). Antimony, beryllium, copper, lead, mercury, selenium, and tin were detected at ≥53% of the stations, while cadmium and thallium had detection rates from 20 to 38%. Silver was not detected during this survey. Concentrations of metals were within ranges previously reported from elsewhere in the SCB (e.g., Schiff et al. 2011) and almost all were found at levels below both ERL and ERM thresholds (Appendix G.3). Exceptions included: (1) arsenic, which exceeded its ERL at station 8304; (2) copper, which exceeded its ERL at station 8345; (3) nickel, which exceeded its ERL at stations 8335, 8337, 8338, 8339, and 8351. All of these stations were located at depths ≥146 m and all but one (station 8304) had sediments with percent fines ≥69%. Station 8304 was located on the Coronado Bank, while stations 8335 and 8339 were located within the La Jolla canyon, station 8345 was located near the LA-5 dumpsite, stations 8351 and 8338 were located on the upper slope off of Pacific Beach/La Jolla, and station 8337 was located on the upper slope off of Point Loma.

Concentrations of aluminum, barium, beryllium, chromium, copper, iron, lead, nickel, tin, and zinc correlated positively with the percentage of fine sediments in each sample (Appendix G.4) and therefore generally increased with depth (e.g., Figure 8.4). Although antimony, arsenic, manganese, and selenium were not correlated as strongly with percent fines (i.e., $r_s < 0.70$), their concentrations also tended to increase by depth with the highest values occurring at upper slope stations (Figure 8.3). Additionally, cadmium was detected almost exclusively at upper slope stations (Appendix G.3). In contrast, mean concentrations of thallium were highest on the inner shelf (Table 8.1), while mean concentrations of mercury were highest on the outer shelf (Table 8.1, Figure 8.3).

Pesticides

Four chlorinated pesticides were detected in sediments collected during the 2014 regional survey off San Diego, including DDT, hexachlorobenzene (HCB), chlordane, and mirex (Table 8.1, Appendix G.1,

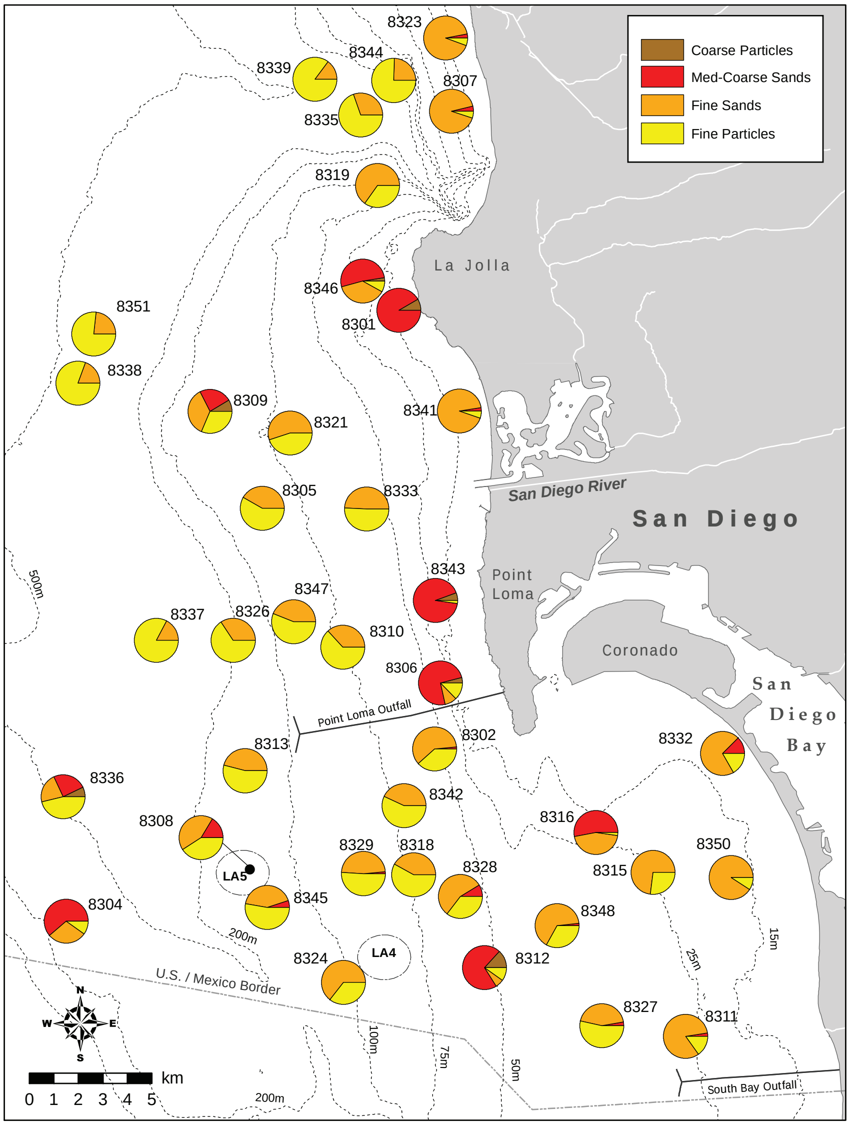

Figure 8.2

Sediment composition from regional benthic stations sampled off San Diego during July 2014.

Appendix G.3). Total DDT, composed primarily of p,p-DDE, was detected at 78% of the stations at concentrations up to 7110 ppt. The highest concentrations occurred on the mid- and outer shelf and included five stations that had total DDT values in exceedance of the ERL (Figure 8.3, Appendix G.3). Four of these mid-shelf stations, 8309, 8318, 8327, and 8348, were located throughout the region, while station 8326 was located on the outer shelf off of Point Loma. Detectable levels of HCB were found in sediments from nine stations (detection rate = 23%) located across the survey area at concentrations up to 500 ppt; these included inner shelf stations 8307 and 8343, mid-shelf stations 8302, 8305, 8306, 8309, 8327, and 8319, and upper slope station 8351. HCB was not detected on the outer shelf (Figure 8.3). Detected levels of chlordane as alpha (cis) chlordane, gamma (trans) chlordane, and/or trans nonachlor were limited to stations 8309 and 8326 at concentrations up to 920 ppt. Mirex was only recorded at station 8326 (detection rate = 3%) at a concentration of 150 ppt.

PCBs

PCBs (primarily PCB 153/168; Appendix G.1) were detected in sediments from 38% of the 2014 regional stations at concentrations up to 10,750 ppt (Table 8.1, Appendix G.3). No ERL or ERM values exist for PCBs measured as congeners; however, values

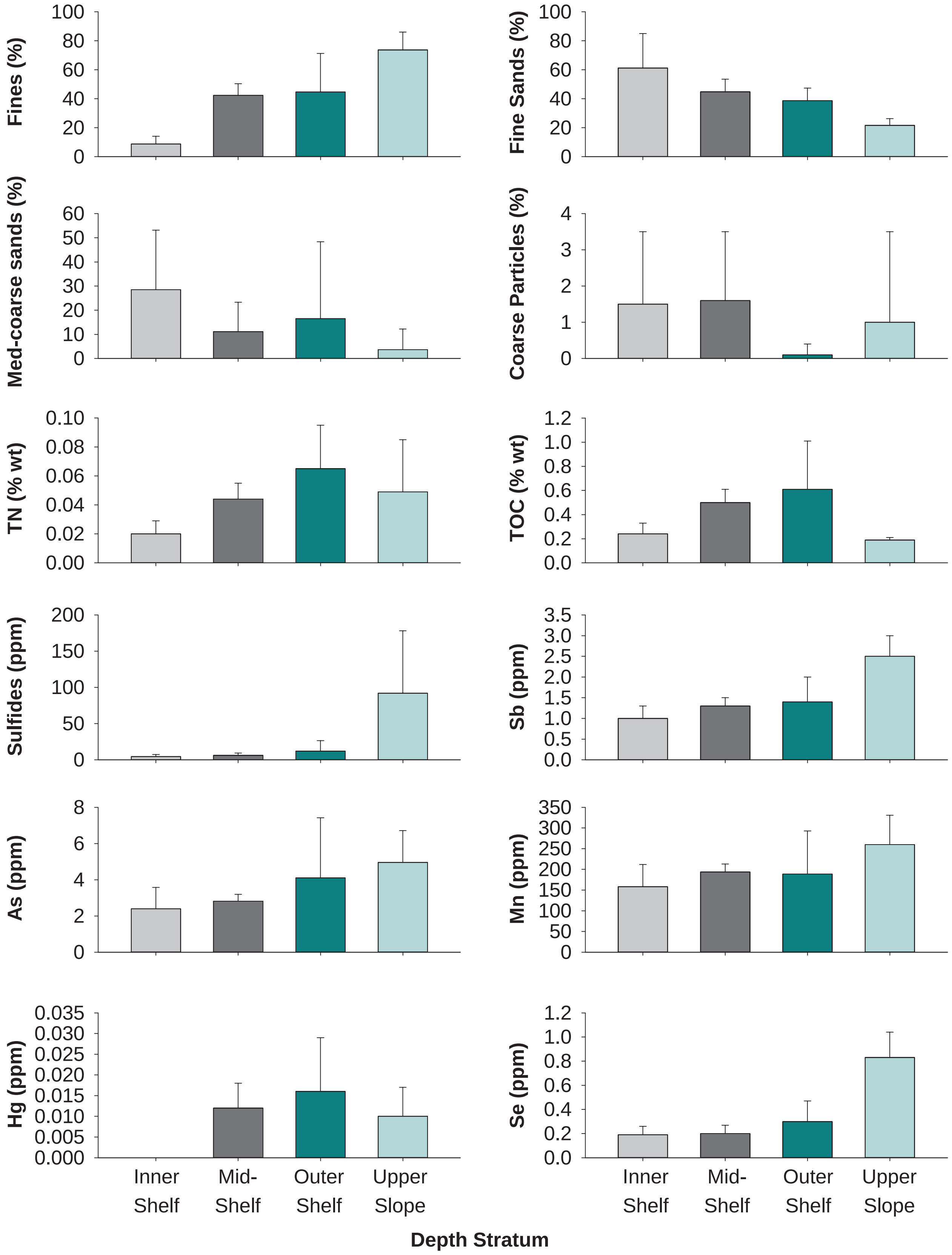

Figure 8.3

Comparison of select particle size and chemistry parameters in sediments from the four major depth strata sampled during the 2014 regional survey off San Diego. Data are expressed as means + 95% confidence intervals calculated on detected values only.

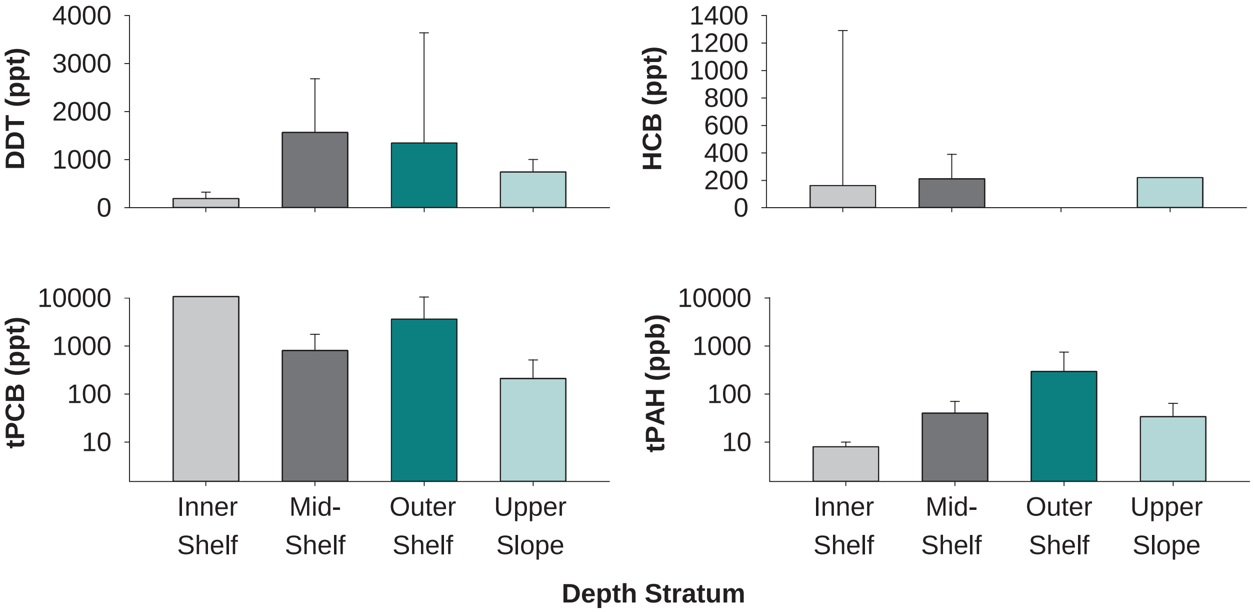

Figure 8.3 *continued*

reported in 2014 were well within those previously reported off San Diego (City of San Diego 2013, 2014b) and elsewhere for the SCB (Schiff et al. 2011). The highest total PCB concentration was recorded at inner shelf station 8332 located just off the shoreline of Coronado's Silver Strand beach area. PCB levels were much lower at other depths, averaging 807 ppt at mid-shelf stations, 3608 ppt at outer shelf stations, and 209 ppt at upper slope stations (Table 8.1, Figure 8.3).

PAHs

PAHs were detected in sediments from 70% of the 2014 regional stations (Table 8.1, Appendices G.1, G.3). Concentrations were below threshold values (i.e., < 4022 ppb) and within the range of those reported elsewhere in the SCB (Schiff et al. 2011). The two highest values (≥ 535 ppb) were found at stations 8308 and 8345, both located near the LA-5 dredged materials dumpsite. Mean PAH concentrations were lowest on the inner shelf and highest on the outer shelf (Table 8.1, Figure 8.3). During 2014, the compound 2,6-dimethylnaphthalene was detected most frequently at a rate of 67%; other compounds recorded during the year in 2–30% of the samples included 2,3,5-trimethylnaphthalene, 3,4-benzo(B)fluoranthene, acenaphthylene, anthracene, benzo[A]anthracene, benzo[A]pyrene, benzo[e]pyrene, benzo[G,H,I]perylene, benzo[K]fluoranthene, biphenyl, chrysene, 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 2014 particle size sub-fraction data collected from the 40 regional stations discriminated eight main cluster groups (particle size cluster groups 1–8; Figure 8.5, Table 8.2). According to SIMPER results, these eight groups were primarily distinguished by proportions of fines, very fine sand, medium sand, and coarse sand. The distribution and main characteristics of each cluster group are described below.

Cluster group 1 comprised stations 8301 and 8343, located at depths of 20 and 22 m off La Jolla and Point Loma, respectively (Figure 8.5). Compared to the other groups, sediments from these two stations had the lowest proportion of fines (2% per sample) and the largest proportion of coarse sand (84% per sample), with ≤8% medium and very coarse sand per sample, and no very fine sand, fine sand, or granules present (Table 8.2).

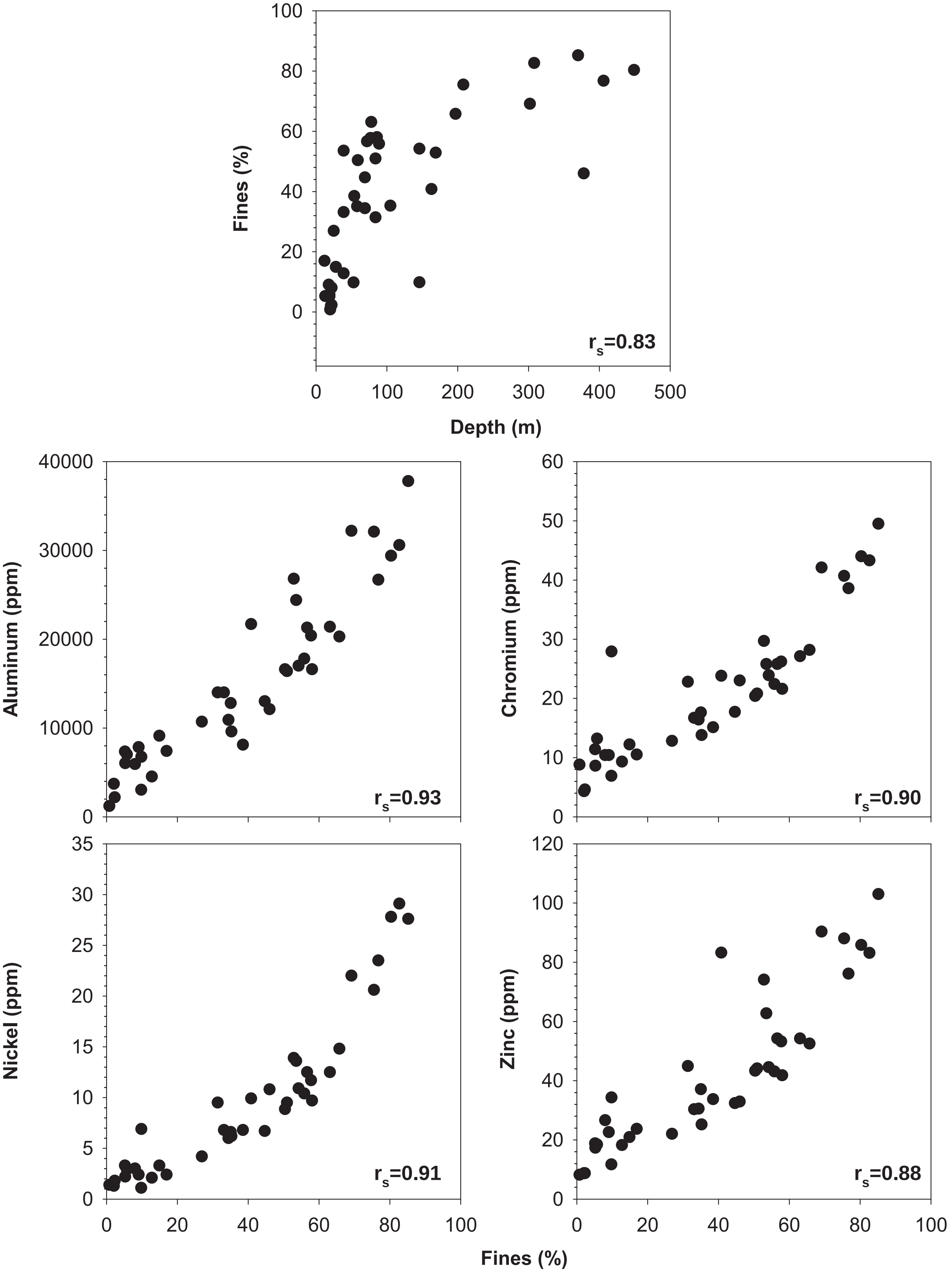

Figure 8.4

Scatterplots of percent fines versus depth and select metals in sediments from San Diego regional benthic stations sampled during 2014. Spearman rank correlation coefficients (r_s) are included; see Appendix G.4 for other correlation results.

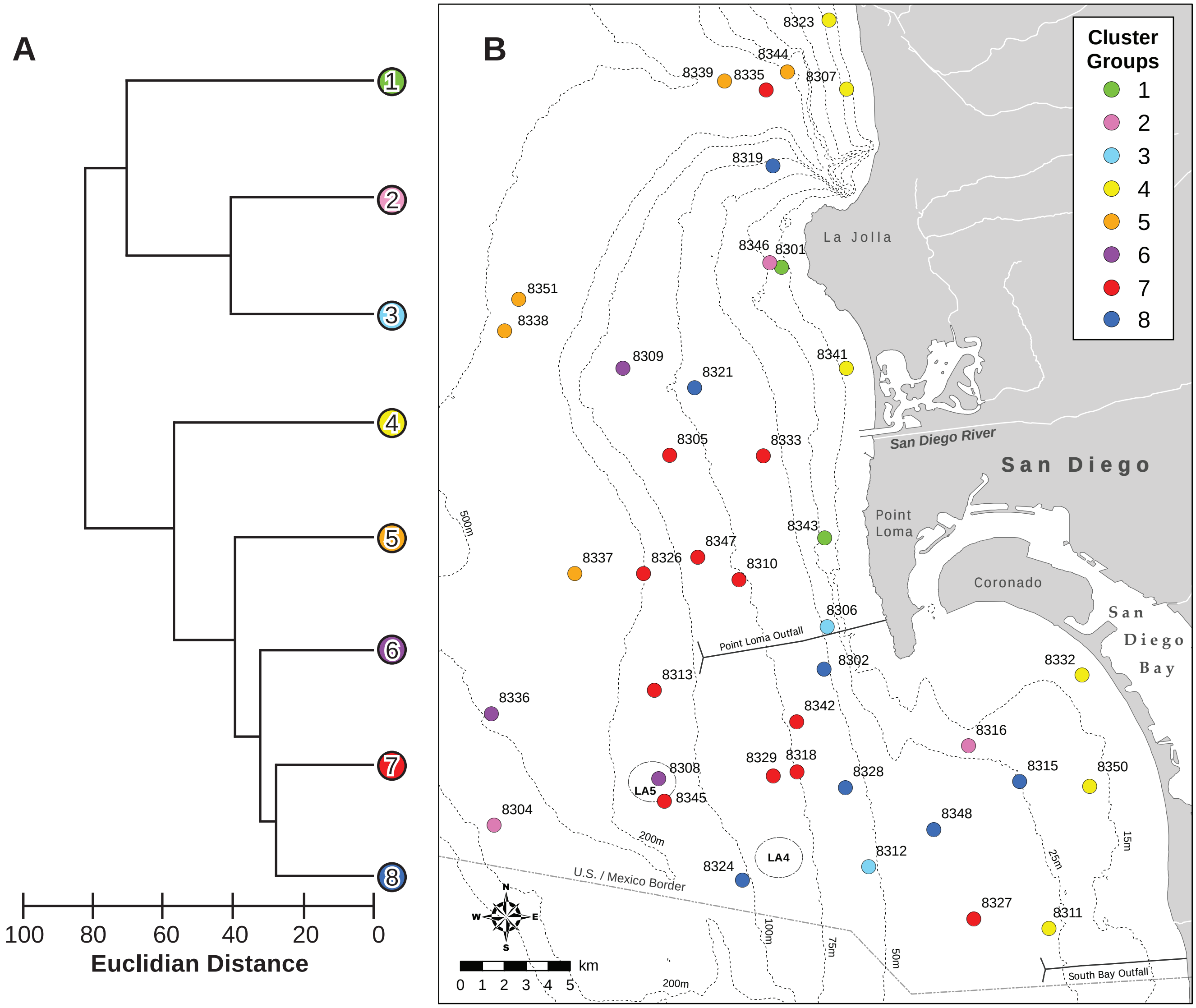

Figure 8.5

Results of cluster analysis of particle size sub-fraction data from San Diego regional benthic stations sampled during 2014. Data are presented as: (A) dendrogram of main cluster groups and (B) spatial distribution of sediments as delineated by cluster analysis.

Cluster group 2 comprised three stations, including station 8304 located at 146 m on the Coronado Bank, station 8316 located at 21 m south of the entrance to San Diego Bay, and station 8346 located at 22 m off of Point La Jolla (Figure 8.5). This group had the largest proportions of fine and medium sand (31% and 41% per sample; Table 8.2). It also averaged about 7% fines, 6% very fine sand, and 14% coarse sand per sample, with no granules present.

Cluster group 3 comprised stations 8306 and 8312, located at depths of 39 and 53 m off of Point Loma and west of the LA-4 dredged materials dumpsite, respectively (Figure 8.5). Sediments represented by this group had the highest proportion of very coarse sand with about 9% per sample (Table 8.2). These sediments also had the second largest proportions of medium (32% per sample) and coarse sand (41% per sample), and averaged 11% fines, 2% very fine sand, and 5% fine sand per sample. Granules were not present at the group 3 stations.

Cluster group 4 comprised six inner shelf stations (i.e., 8307, 8311, 8323, 8332, 8341, 8350) that spanned the entire survey area (Figure 8.5). This group had the largest proportion of very fine sand (58% per sample). It also averaged about 10% fines,

Table 8.2

Summary of particle size cluster groups 1–8 (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	2	20-22	1.6	0.0	0.0	7.8	83.6	7.1	0.0
			(0.8-2.3)	—	—	(7.0-8.6)	(83.4-83.8)	(5.7-8.4)	—
2	3	21-146	6.6	6.4	30.8	41.2	13.9	1.1	0.0
			(2.1-9.8)	(5.3-8.6)	(23.5-39.6)	(34.0-44.9)	(8.3-17.5)	(0.1-2.7)	—
3	2	39-53	11.3	2.0	5.4	31.5	40.9	8.6	0.0
			(9.8-12.8)	(1.8-2.2)	(4.4-6.5)	(24.4-38.7)	(35.9-45.9)	(4.0-13.2)	—
4	6	12-28	9.5	58.0	28.3	4.0	0.2	0.0	0.0
			(5.2-16.9)	(44.1-72.5)	(17.8-37.9)	(0.7-11.2)	(0-1.3)	—	—
5	5	208-449	80.1	15.9	3.9	0.1	0.0	0.0	0.0
			(75.5-85.2)	(11.3-19.2)	(2.3-5.2)	(0-0.1)	—	—	—
6	3	84-378	39.4	17.5	16.1	13.5	8.1	3.6	1.6
			(31.4-46.0)	(11.5-23.7)	(10.4-25.6)	(10.7-15.0)	(1.5-13.8)	(0-7.2)	(0-4.9)
7	12	39-302	57.3	31.7	9.9	1.0	0.0	0.0	0.0
			(50.4-69.1)	(20.5-38.0)	(5.3-18.6)	(0.1-5.1)	—	—	—
8	7	25-105	35.4	45.8	16.5	1.6	0.5	0.1	0.0
			(26.9-44.7)	(39.9-60.3)	(12.3-20.8)	(0.5-5.0)	(0-3.7)	(0-0.9)	—

28% fine sand, 4% medium sand, and < 1% coarse sand per sample (Table 8.2). Very coarse sand and granules were absent from these sediments.

Cluster group 5 comprised five upper slope stations (i.e., 8337, 8338, 8339, 8344, 8351) located at depths from 208 to 449 m (Figure 8.5). These stations had the finest sediments sampled during the 2014 regional survey, averaging 80% fines per sample (Table 8.2). Sediments at these stations also contained about 16% very fine sand, 4% fine sand, and < 1% medium sand per sample.

Cluster group 6 comprised three stations ranging in depth from 84 to 378 m, including station 8308 located within the LA-5 dumpsite, station 8309 located offshore of Mission Beach, and station 8336 located along the Coronado Bank (Figure 8.5). This was the only cluster group to have granules present (~ 2% per sample); it also averaged about 39% fines, 18% very fine sand, 16% fine sand, 14% medium sand, 8% coarse sand, and 4% very coarse sand per sample (Table 8.2).

Cluster group 7 was the largest group, representing 12 stations (i.e., 8305, 8310, 8313, 8318, 8326, 8327, 8329, 8333, 8342, 8345, 8347, 8335) that spanned the entire survey area at depths from 39 to 302 m (Figure 8.5). Similar to group 5, this group also had relatively fine sediments, averaging

57% fines, 32% very fine sand, 10% fine sand, and 1% medium sand per sample (Table 8.2).

Cluster group 8 was the second largest group, comprising seven stations (i.e., 8302, 8315, 8319, 8321, 8324, 8328, 8348) that generally overlapped group 7 at depths from 25 to 105 m (Figure 8.5). This group was characterized by about 35% fines, 46% very fine sand, 17% fine sand, 2% medium sand, < 1% coarse sand, and < 1% very coarse sand per sample (Table 8.2). Granules were not present at group 8 stations.

Sediment Chemistry

Results of cluster analyses performed on sediment chemistry data collected from the 40 regional stations during 2014 discriminated seven main groups (Figure 8.6). These groups (sediment chemistry cluster groups A–G) 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 $\rho = 0.310$, $p = 0.002$). Sediment sub-fractions 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 $\rho = 0.555$, $p = 0.002$).

The main sediment chemistry cluster group (group E) included 70% of the stations sampled during 2014 (Figure 8.6). These stations spanned the entire survey area and were located at depths from 13 to 378 m. According to SIMPER results, a wide range of analytes accounted for 51% of the within-group similarity for contaminant group E, including two organic indicators (sulfides, TVS), 14 metals (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, nickel, selenium, tin, zinc), two chlorinated pesticides (chlordane, DDT), total PCB, and total PAH (see Figure 8.7 for select examples). It is likely that this contaminant cluster group represents background conditions on the shelf in the San Diego region.

The second largest sediment chemistry cluster group (group G) included six stations located on the upper slope at depths from 208 to 449 m (Figure 8.6). Group G had the finest sediments (69%–85% per station) and was characterized by relatively high concentrations of several metals that were found to co-vary with percent fines (i.e., aluminum, barium, beryllium, chromium, copper, iron, lead, nickel, tin, zinc), as well as some analytes that tended to be highest at upper slope stations (e.g., sulfides, antimony, manganese, selenium) (see Figure 8.7 for select examples).

The five remaining cluster groups each comprised 1–2 “outlier” stations that differed from groups E and G primarily by having higher values of a few select contaminants (Figures 8.6, 8.7). For example, station 8326 (group A) had the highest concentration of chlordane, and was the only station where mirex was detected. This station was located offshore of Point Loma at a depth of 197 m. Station 8327 (group B) was located at a depth of 39 m northwest of the South Bay ocean outfall and had the highest concentration of total DDT. Station 8332 (group C) was located at 12 m off the Coronado Island “Silver Strand” beach and had the highest concentration of total PCB. This station also had high TOC relative to percent fines. Station 8304 (group D) was located on the Coronado Bank at a depth of 146 m and had the highest concentrations of arsenic and thallium. Group F comprised two stations (8308 and 8345) located at the LA-5 dredged materials dumpsite and had the highest concentration of total PAH.

SUMMARY

Particle size composition at the regional benthic stations sampled in 2014 were 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 2008–2013, 2014a,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

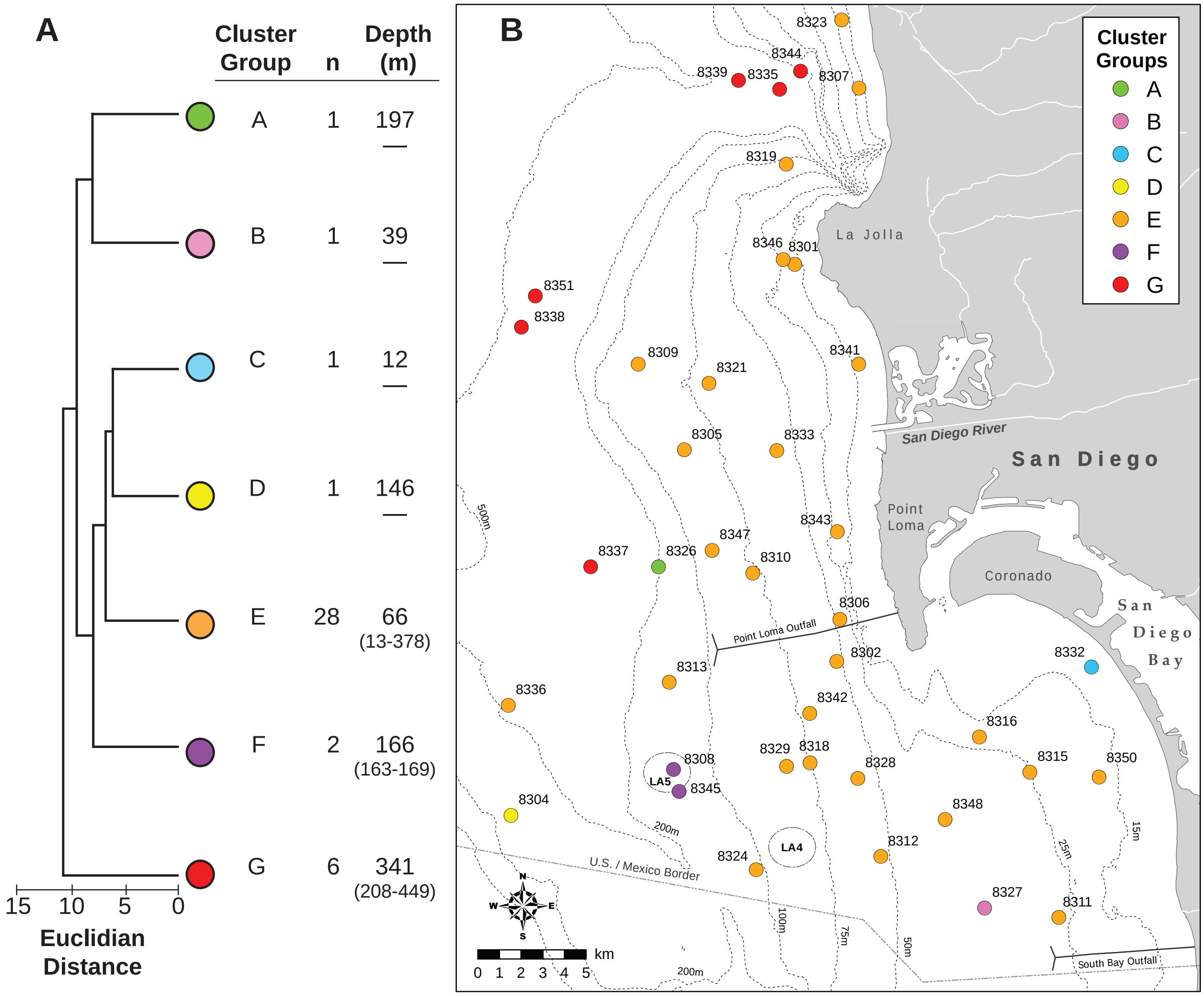

Figure 8.6
Results of cluster analysis of sediment chemistry data from San Diego regional benthic stations sampled during 2014. Data are presented as: (A) dendrogram of main cluster groups and (B) spatial distribution of sediments as delineated by cluster analysis. Depths are presented as means (ranges) calculated over all stations within a cluster group (n).

outer shelf within the Point Loma ocean outfall monitoring area (see City of San Diego 2014a) typically had much finer sediments. However, exceptions to this overall pattern occurred throughout the region, 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 2014 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,

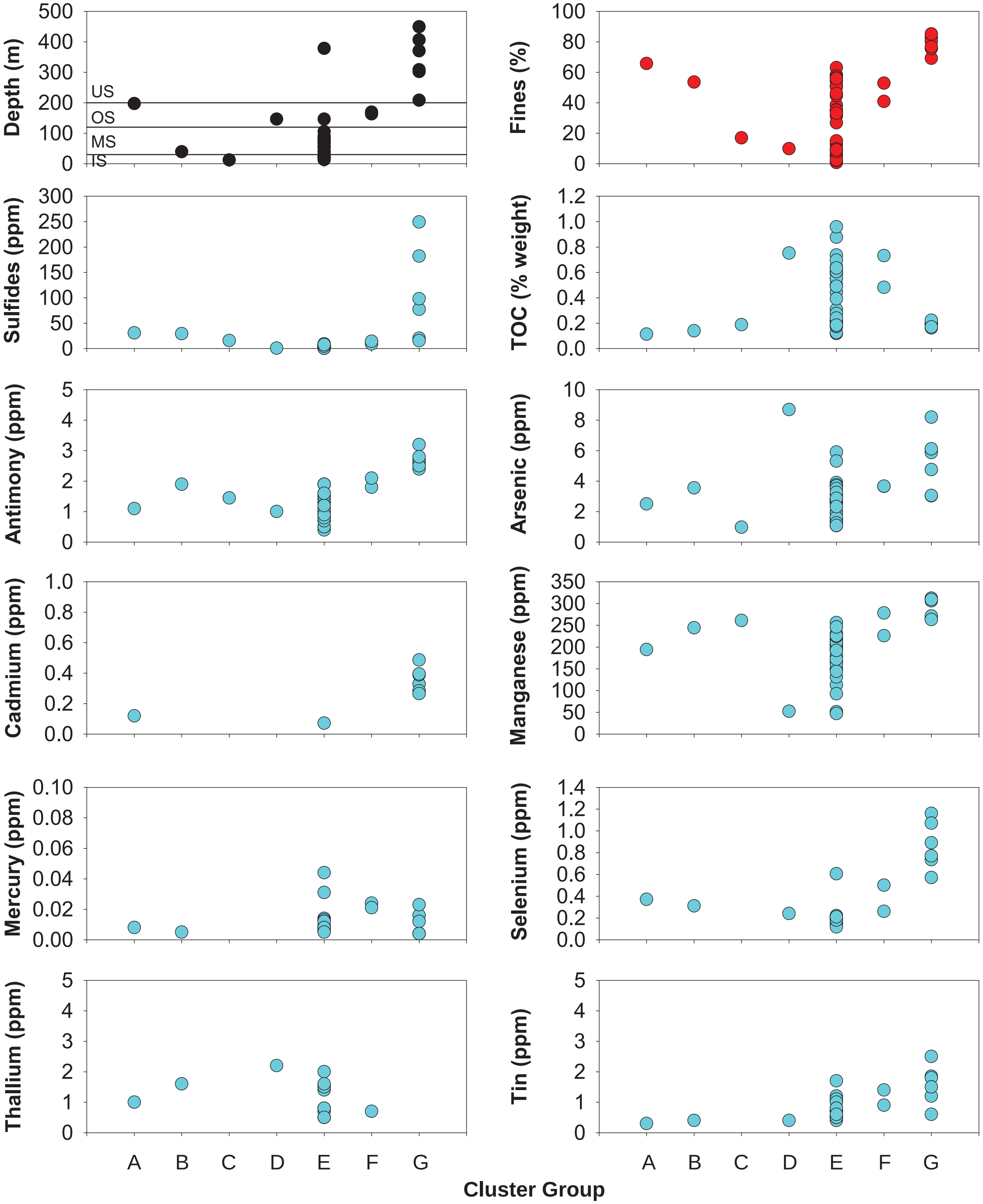

Figure 8.7

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.

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 2008–2013,

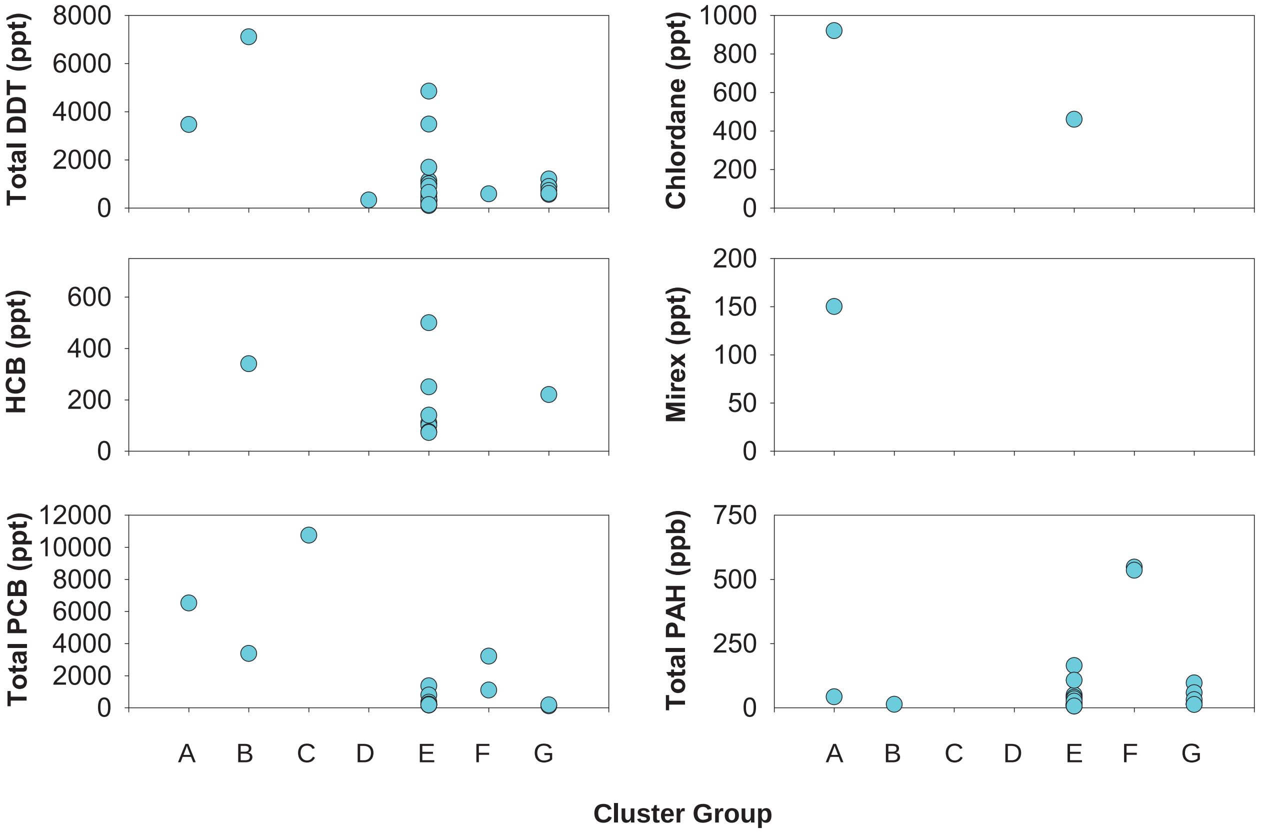

Figure 8.7 *continued*

2014a, b). Further, there was no evidence of sediment contamination during the 2014 regional survey that could be attributed to local wastewater discharges. Instead, concentrations of 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 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).

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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 monitor 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 (City of Los Angeles 2013, 2014, City of San Diego 2014a, b, LACSD 2014, 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 macrobenthic monitoring efforts have also become an important tool for evaluating benthic conditions and sediment quality in southern California (Bergen et al. 1998, 2000, Hyland et al. 2003, Ranasinghe et al. 2003, 2007, 2012, USEPA 2004, Bight'13 CIA 2013).

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).

This chapter presents analysis and interpretation of the benthic macrofaunal data collected during the 2014 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.

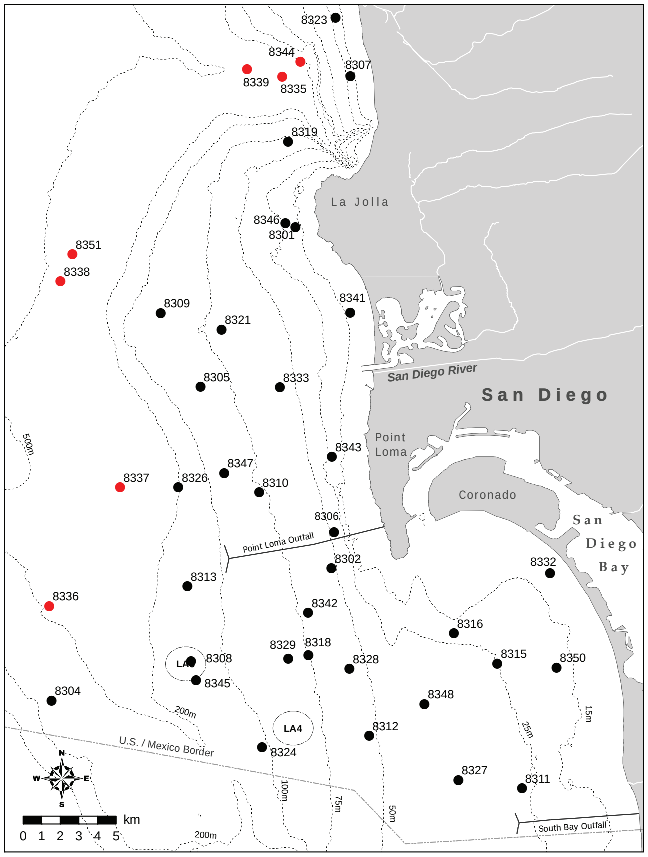

Figure 9.1

Regional benthic survey stations sampled during July 2014 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 2014 regional survey covered an area ranging north of La Jolla southward to the USA/Mexico border (Figure 9.1). Overall, this survey included 40 stations ranging in depth from 12 to 449 m and spanning four distinct depth strata characterized by the SCB regional monitoring programs (Ranasinghe et al. 2012). These included 11 stations along the inner shelf (5–30 m), 17 stations along the mid-shelf (>30–120 m), 5 stations along the outer shelf (>120–200 m), and 7 stations on the upper slope (>200–500 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 sorted from the raw material into several 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 2013).

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).

To examine spatial patterns among benthic communities in the San Diego region, multivariate analyses were performed using methods available in PRIMER v6 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 and Warwick 2001, Clarke and Gorley 2006, Clarke et al. 2008). 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 607 taxa were identified during the 2014 regional survey. Of these, 508 (84%) were identified to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although 37% (n = 223) were recorded only once. Five taxa not previously reported for the City's Ocean Monitoring Program were encountered during this survey. These included the bivalve *Policordia* sp OC1, the mysid *Holmesimysis costata*, the sabellid polychaete *Dialychone* sp, the cirratulid polychaete *Aphelochaeta* sp HYP4, and the capitellid polychaete *Dodecaseta oraria*.

Overall, species richness ranged from 10 to 127 taxa per grab across the survey area in 2014 (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 2015). 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 80 taxa per grab, followed by 69 taxa per grab on the outer shelf, and 59 taxa per grab on the inner shelf. In contrast, considerably fewer species (30 taxa per grab) occurred at the deeper upper slope stations. This variation by depth strata matches what has been reported previously for the region (City of San Diego 2013).

Macrofaunal abundance

A total of 9,593 macrofaunal animals were recorded during the 2014 regional survey. Abundance ranged from 23 to 726 individuals per grab (Table 9.1), remaining within the range of values reported historically for this survey area (City of San Diego 2015). Stations 8311, 8316, and 8327 had the largest number of animals (≥691 individuals per grab); these stations were all located at depths ≤39 m within the South Bay ocean outfall monitoring region (see Chapter 5), and each were numerically dominated by a single polychaete species. For example, 281 individuals of the spionid polychaete *Spiophanes norrisi* were collected at station 8311, 454 *S. norrisi* were collected from station 8316, and 114 individuals of the chaetopterid polychaete *Spiochaetopterus costarum* Cmplx were collected from station 8327. As with species richness, abundance varied between depth strata with the lowest average values of 87 individuals per grab occurring on the upper slope (Figure 9.2). In contrast, abundance averaged 280 individuals per grab at inner shelf stations, 295 individuals per grab at mid-shelf stations, and 180 individuals per grab at outer shelf stations. This variation by depth strata corresponds with what has been reported previously for the region (City of San Diego 2013).

Diversity and evenness

Shannon diversity index (H') values generally fell within values recorded historically (City of San Diego 2015), ranging from 1.2 to 4.2 at regional stations in 2014 (Table 9.1). Further, 80% of the stations sampled in 2014 had diversity values of 3.0–4.0; exceptions ≤2.8 occurred at three inner shelf stations (i.e., 8301, 8316, 8343) and four upper slope stations (i.e., 8337, 8338, 8339, 8351). The only site with diversity greater than 4.0 occurred on the mid-shelf at station 8309; this station had a H' value of 4.2 and was located at

Table 9.1

Macrofaunal community parameters calculated for regional stations sampled off San Diego during 2014. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; n = 1.

	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI[a]
Inner Shelf	8332	12	68	266	3.5	0.82	21	26
	8341	13	39	76	3.4	0.92	21	8
	8350	18	70	223	3.6	0.84	26	18
	8307	19	54	160	3.5	0.87	22	23
	8323	19	67	145	3.9	0.92	31	17
	8301	20	21	122	2.3	0.74	6	6
	8316	21	52	726	1.7	0.44	3	12
	8343	22	26	79	2.7	0.83	10	10
	8346	22	50	153	3.4	0.88	18	22
	8315	25	101	436	4.0	0.87	34	26
	8311	28	98	691	3.1	0.67	18	25
Mid-shelf	8306	39	64	262	3.1	0.75	15	22
	8327	39	127	705	3.8	0.78	31	21
	8348	39	99	412	3.8	0.84	31	19
	8312	53	58	152	3.6	0.88	24	9
	8302	54	96	317	4.0	0.88	40	21
	8328	58	112	352	4.0	0.86	42	13
	8333	59	73	267	3.6	0.84	24	15
	8319	69	74	208	3.7	0.87	29	17
	8321	69	59	198	3.0	0.74	18	13
	8342	72	78	354	3.4	0.78	20	19
	8318	77	74	248	3.5	0.81	24	14
	8310	78	65	286	3.2	0.76	17	11
	8309	84	97	237	4.2	0.91	43	10
	8329	84	68	250	3.1	0.73	17	8
	8305	86	56	214	3.0	0.75	15	7
	8347	89	63	287	3.0	0.73	15	9
	8324	105	91	258	4.0	0.90	37	7
Outer Shelf	8304	146	43	100	3.1	0.81	19	4
	8313	146	74	211	3.9	0.90	31	15
	8308	163	88	226	4.0	0.89	38	12
	8345	169	85	218	4.0	0.91	35	16
	8326	197	56	146	3.6	0.88	24	22
Upper Slope	8344	208	44	132	3.2	0.83	19	—
	8335	302	32	67	3.1	0.90	16	—
	8337	308	17	23	2.8	0.97	12	—
	8339	370	10	35	1.2	0.53	2	—
	8336	378	66	218	3.5	0.84	21	—
	8351	406	20	61	2.2	0.75	6	—
	8338	449	22	72	2.3	0.74	6	—

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

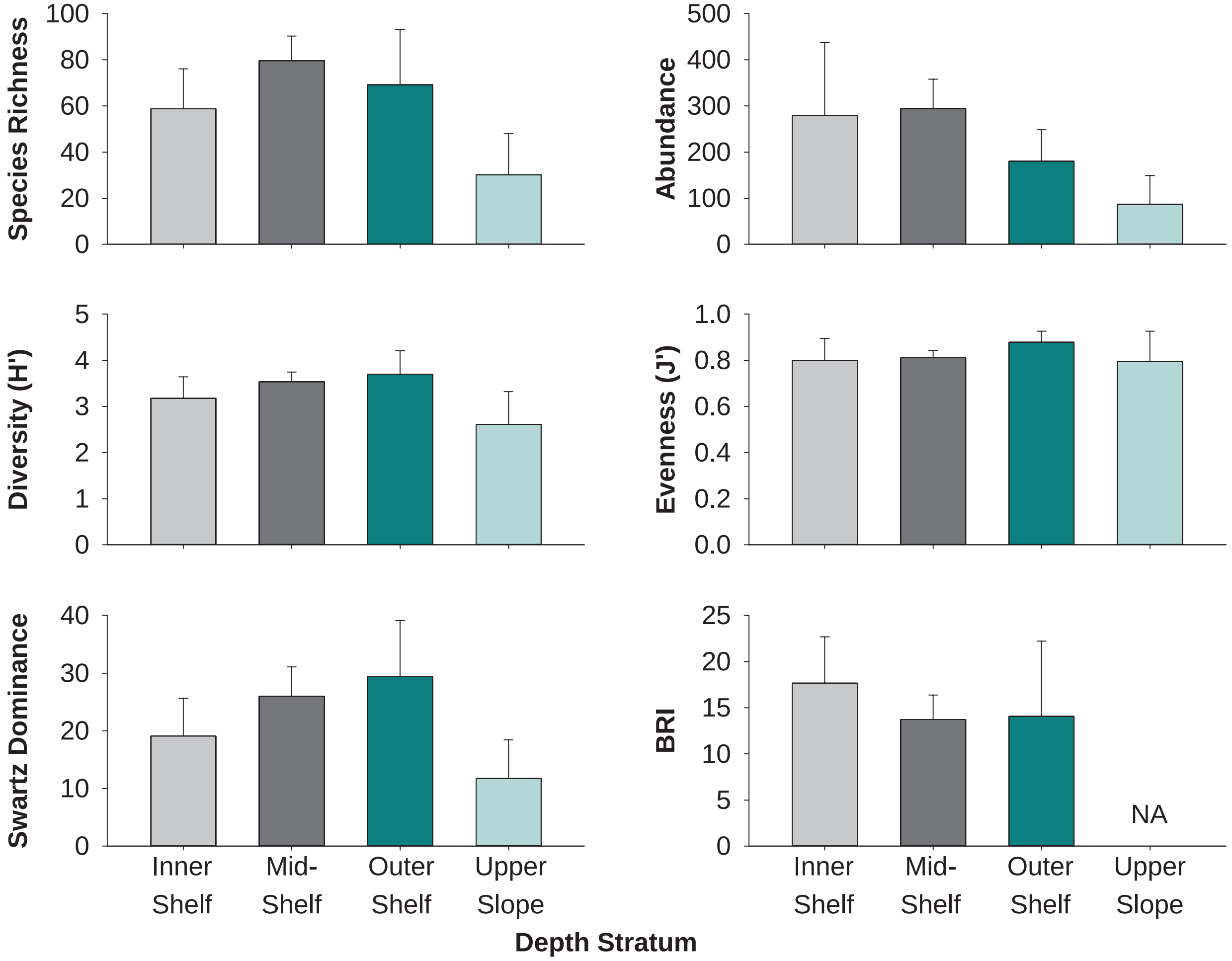

Figure 9.2

Comparison of macrofaunal community structure metrics for the four major depth strata sampled during the 2014 regional survey off San Diego. Data are expressed as means + 95% confidence interval per grab; NA = not applicable, BRI not calculated for upper slope stations.

a depth of 84 m off of Pacific Beach. The pattern of diversity across depth strata, with the upper slope being the least diverse, was generally similar to patterns reported previously for the region (City of San Diego 2013). Evenness (J') 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 2014, J' values ranged from 0.44 to 0.97 at regional stations (Table 9.1), with spatial patterns similar to those seen for diversity (Figure 9.2). These values were within historical ranges (City of San Diego 2015).

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. Values at regional shelf stations ranged from 3 to 43 taxa per grab, while values at upper slope stations ranged from 2 to 21 taxa per grab. Overall, these values fell within historical ranges (City of San Diego 2015). The pattern of dominance across depth strata was generally similar between the 2014 and other recent regional surveys (Figure 9.2) (City of San Diego 2013). For example, average dominance was notably higher (i.e., lower index values) along the inner shelf (19 taxa per grab) than at either the mid- or outer shelf stations (26 and 29 taxa per grab, respectively). Average dominance at the upper slope stations was even higher than observed along the inner shelf, with only 12 taxa per grab. As expected, dominance values tracked diversity values.

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, while values above 34 represent increasing levels of disturbance or environmental degradation. During 2014, BRI ranged from 4 to 26 at the regional shelf stations (Table 9.1). Thus, 95% of the BRI values in the San Diego region were indicative of reference conditions during the year, and 100% of the BRI values fell within historical ranges (City of San Diego 2015). Only two stations (8315 and 8332) had slightly higher BRI values of 26, and these occurred at shallow depths along the inner shelf where BRI can be less reliable (Ranasinghe et al. 2010). Average BRI values varied slightly between the major depth strata, ranging from 14 per grab at mid- and outer shelf stations to 18 per grab on the inner shelf (Figure 9.2). Index values were not calculated for the seven deeper 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 2014, 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 40% of all species collected. Arthropods (mostly crustaceans) and molluscs were the next two most diverse taxa, accounting for 25% and 20% of species, respectively. Echinoderms comprised 5% of all taxa, while all other phyla combined (e.g., Chordata, Cnidaria, Nematoda, Nemertea, Phoronida, Platyhelminthes, Sipuncula) accounted for the remaining 10%. 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 39% along the inner shelf, to 45% along the mid-shelf, to 54% along the outer shelf. Echinoderms also increased slightly across these depths (i.e., from 4 to 6%), while the proportions of crustaceans decreased from 24 to 16% and the other phyla decreased from 13 to 5%. The greatest difference occurred along the upper slope where the percentage of molluscs increased sharply to comprise about 26% of taxa. Echinoderms also accounted for a larger proportion of species at upper slope sites than on the shelf, while the proportions of polychaetes and crustaceans decreased compared to the outer shelf.

Polychaetes were also the most numerous invertebrates overall, accounting for 50% of the total abundance. Crustaceans accounted for 16% of the animals, echinoderms 15%, molluscs 13%, and the remaining phyla 7%. Abundance patterns also varied between strata (see Figure 9.3B). For example, the proportion of polychaetes was lower at the mid-shelf and upper slope stations (i.e., 42–45%) than along either the outer or inner shelf (i.e., 57−58%). The lower proportion of polychaetes along the mid-shelf and upper slope corresponded to considerably higher numbers of echinoderms (mostly ophiuroids) at mid-shelf depths (i.e., 24%) and molluscs at the deeper slope stations (i.e., 37%). As with the proportion of taxa, the percentage of crustaceans decreased from 20% of the abundance at inner shelf stations to 6% of the abundance at upper slope 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 five polychaetes, two molluscs, one amphipod, one nemertean, and phoronids. Of these, the spionid polychaete *Spiophanes norrisi* was clearly dominant, accounting for 28% of all animals collected on the inner shelf, and averaging 79 animals per grab. The remaining inner shelf species accounted for ≤3% of

Table 9.2

The 10 most abundant macroinvertebrate taxa per depth stratum collected at regional benthic stations sampled off San Diego during 2014. 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	28	100	79	79
	Mediomastus sp	Polychaeta: Capitellidae	3	73	7	10
	Monticellina siblina	Polychaeta: Cirratulidae	2	55	7	13
	Ampelisca brevisimulata	Arthropoda: Amphipoda	2	27	6	22
	Axiothella sp	Polychaeta: Maldanidae	2	9	5	52
	Ampharete labrops	Polychaeta: Ampharetidae	2	36	5	13
	Phoronis sp	Phoronida	2	18	5	26
	Tellina modesta	Mollusca: Bivalvia	2	64	5	7
	Carinoma mutabilis	Nemertea: Palaeonemertea	2	45	4	10
	Halistylus pupoideus	Mollusca: Gastropoda	2	18	4	24
Mid-shelf	*Amphiodia urtica*	Echinodermata: Ophiuroidea	15	94	45	48
	Spiochaetopterus costarum Cmplx	Polychaeta: Chaetopteridae	4	41	11	28
	Spiophanes norrisi	Polychaeta: Spionidae	4	53	11	21
	Amphiodia sp	Echinodermata: Ophiuroidea	3	82	9	11
	Sthenelanella uniformis	Polychaeta: Sigalionidae	2	76	7	9
	Amphiuridae	Echinodermata: Ophiuroidea	2	100	6	6
	Photis californica	Arthropoda: Amphipoda	2	18	5	31
	Nuculana sp A	Mollusca: Bivalvia	2	76	5	6
	Sternaspis affinis	Polychaeta: Sternaspidae	2	88	5	5
	Rhepoxynius bicuspidatus	Arthropoda: Amphipoda	2	65	5	7
Outer Shelf	*Tellina carpenteri*	Mollusca: Bivalvia	6	100	10	10
	Axinopsida serricata	Mollusca: Bivalvia	4	80	7	9
	Spiochaetopterus costarum Cmplx	Polychaeta: Chaetopteridae	4	60	7	12
	Monticellina siblina	Polychaeta: Cirratulidae	4	40	7	17
	Spiophanes kimballi	Polychaeta: Spionidae	3	60	6	10
	Adontorhina cyclia	Mollusca: Bivalvia	3	80	5	7
	Mediomastus sp	Polychaeta: Capitellidae	3	80	5	7
	Scoletoma tetraura Cmplx	Polychaeta: Lumbrineridae	3	80	5	6
	Aphelochaeta glandaria Cmplx	Polychaeta: Cirratulidae	2	100	4	4
	Petaloclymene pacifica	Polychaeta: Maldanidae	2	80	4	5
Upper Slope	*Maldane sarsi*	Polychaeta: Maldanidae	6	57	5	9
	Axinopsida serricata	Mollusca: Bivalvia	5	14	4	30
	Chloeia pinnata	Polychaeta: Amphinomidae	5	43	4	10
	Ophiuroidea	Echinodermata: Ophiuroidea	4	14	4	25
	Lirobittium calenum	Mollusca: Gastropoda	4	14	4	25
	Phoronis sp	Phoronida	4	14	3	24
	Macoma carlottensis	Mollusca: Bivalvia	4	57	3	6
	Tellina carpenteri	Mollusca: Bivalvia	4	29	3	12
	Paraprionospio alata	Polychaeta: Spionidae	3	57	3	5
	Fauveliopsis glabra	Polychaeta: Fauveliopsidae	3	43	3	6

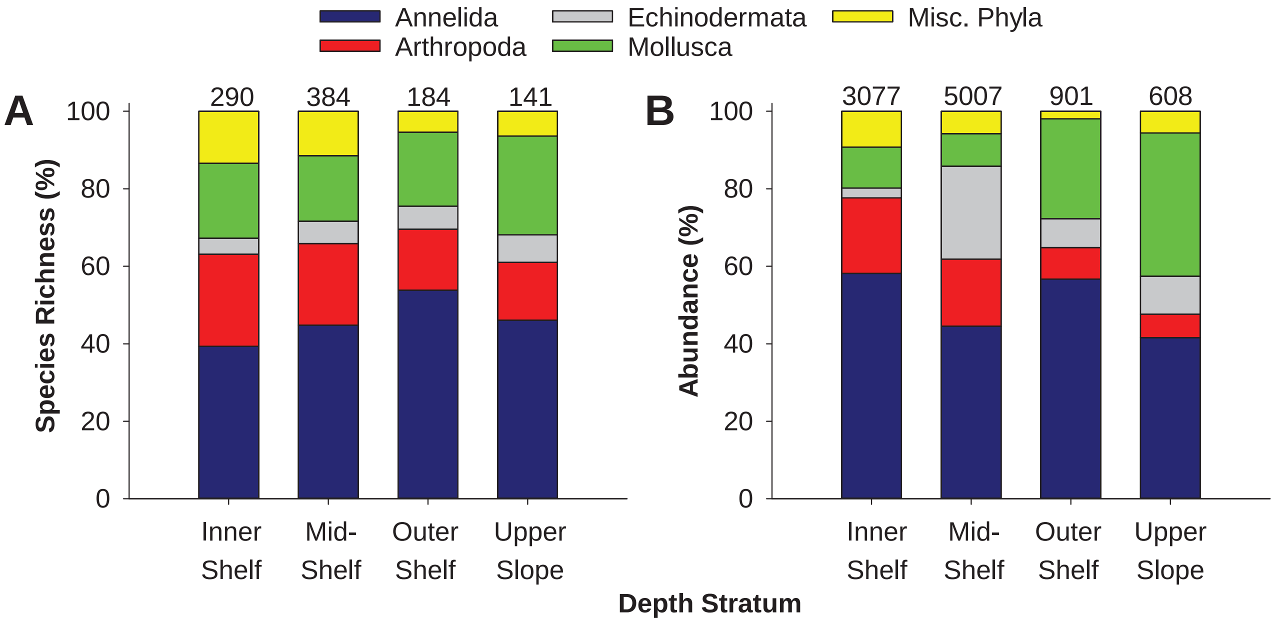

Figure 9.3

Percent contribution of major taxonomic groups (phyla) to (A) species richness and (B) abundance by depth stratum. Numbers above bars represent (A) total number of taxa and (B) total number of individual organisms enumerated for each stratum during 2014.

the total abundance and averaged ≤52 animals per occurrence. Additionally, *S. norrisi* was the most widely distributed of these species occurring at all 11 of the inner shelf sites.

The top 10 dominants along the mid-shelf included four polychaetes, three ophiuroid taxa, two amphipods, and one bivalve. The brittle star *Amphiodia urtica* was by far the most common invertebrate at these depths, accounting for 15% of the total abundance, averaging about 48 animals per occurrence at 94% of the sites. Additionally, it is likely that two of the other "dominant" ophiuroid taxa reported here (i.e., *Amphiodia* sp and Amphiuridae) represent mostly juvenile *A. urtica* that could not be identified to species. Thus, if total *A. urtica* abundance is adjusted to include putative *A. urtica* juveniles, then the estimated density would increase to about 60 brittle stars per grab. All other species at these depths accounted for ≤4% of the total abundance and averaged ≤31 animals per occurrence, although some were found at up to 88% of the mid-shelf stations (e.g., the sternaspid polychaete *Sternaspis affinis*).

The top 10 species along the outer shelf included seven polychaetes and three bivalves. However, densities were relatively low with none of the most abundant species on the outer shelf such as the cirratulid polychaete *Monticellina siblina*, the chaetopterid polychaete *Spiochaetopterus costarum* Cmplx, the spionid polychaete *Spiophanes kimballi*, or the bivalve *Tellina carpenteri*, exceeding mean densities of 17 animals per occurrence or accounting for more than 6% of the total abundance.

The 10 most abundant species at upper slope depths included four polychaetes, three bivalves, one gastropod, one ophiuroid and phoronids. The bivalve *Axinopsida serricata* was the most abundant species on the upper slope, averaging about 30 animals per occurrence. This species only occurred at about 14% of the stations at these depths. In contrast, the maldanid polychaete *Maldane sarsi*, the spionid polychaete *Paraprionospio alata*, and the bivalve *Macoma carlottensis* each occurred at 57% of the upper slope stations, but at abundances less than 9 animals 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 2014 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 no individuals of *C. teleta* and only 4 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 2014, resulting in 10 ecologically-relevant SIMPROF-supported groups (Figures 9.4, 9.5, Table 9.3, Appendix H.1). These assemblages (referred to herein as cluster groups A–J) represented from 1 to 13 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 $\rho = 0.659$, $p = 0.0001$). The sediment subfractions that were most highly correlated to macrofaunal communities included coarse sand and percent fines (BEST $\rho = 0.696$, $p = 0.001$). Mean species richness ranged from 24 to 106 taxa per grab for these groups, while mean abundance ranged from 79 to 726 individuals per grab. Characteristics and differences between the 10 cluster groups and their associated sediments are described below.

Cluster group A represented macrofaunal assemblages from stations 8301 and 8343, located at depths of 20 and 22 m off Point La Jolla and Point Loma, respectively (Figure 9.4). Assemblages at these two sites averaged 24 taxa and 101 individuals per grab (Table 9.3). SIMPER results indicated that these assemblages were characterized by the gastropod *Halistylus pupoideus* (24 per grab) and the phoxocephaloid amphipod *Tiburonella viscana* (9 per grab) (Appendix H.1). Group A was associated with very coarse sediments (e.g., ~91% medium-coarse sands and 7% coarser particles; Table 9.3).

Cluster group B represented a unique assemblage restricted to station 8332 located at a depth of 12 m off the Coronado Island "Silver Strand" beach (Figure 9.4). A total of 68 taxa and 266 individuals occurred in this grab (Table 9.3). Five of the most abundant species in this sample, which together comprised about 45% of the animals, included the ampharetid polychaete *Ampharete labrops* (n = 41), the cirratulid polychaete *Monticellina cryptica* (n = 38), the capitellid polychaete *Mediomastus* sp (n = 17), the spionid polychaete *Polydora cirrosa* (n = 15), and the caprellid amphipod *Caprella californica* (n = 12) (Appendix H.1). The relatively high number of *A. labrops* distinguished group B from other assemblages sampled in the San Diego region during this survey (Figure 9.5). The sediments associated with this sample comprised 71% fine sands (Table 9.3).

Cluster group C represented assemblages from station 8306 located at a depth of 39 m off Point Loma, station 8312 located at a depth of 53 m east of the LA-4 dumpsite, and station 8346 located at a depth of 22 m off Point La Jolla (Figure 9.4). These assemblages averaged 57 taxa and 189 individuals per grab (Table 9.3), and according to SIMPER were characterized by three polychaetes, including the spionid *Spiophanes norrisi* (40 per grab), and the lumbrinerids *Lumbrinerides platypygos* (10 per grab) and *Lumbrineris latreilli* (8 per grab), as

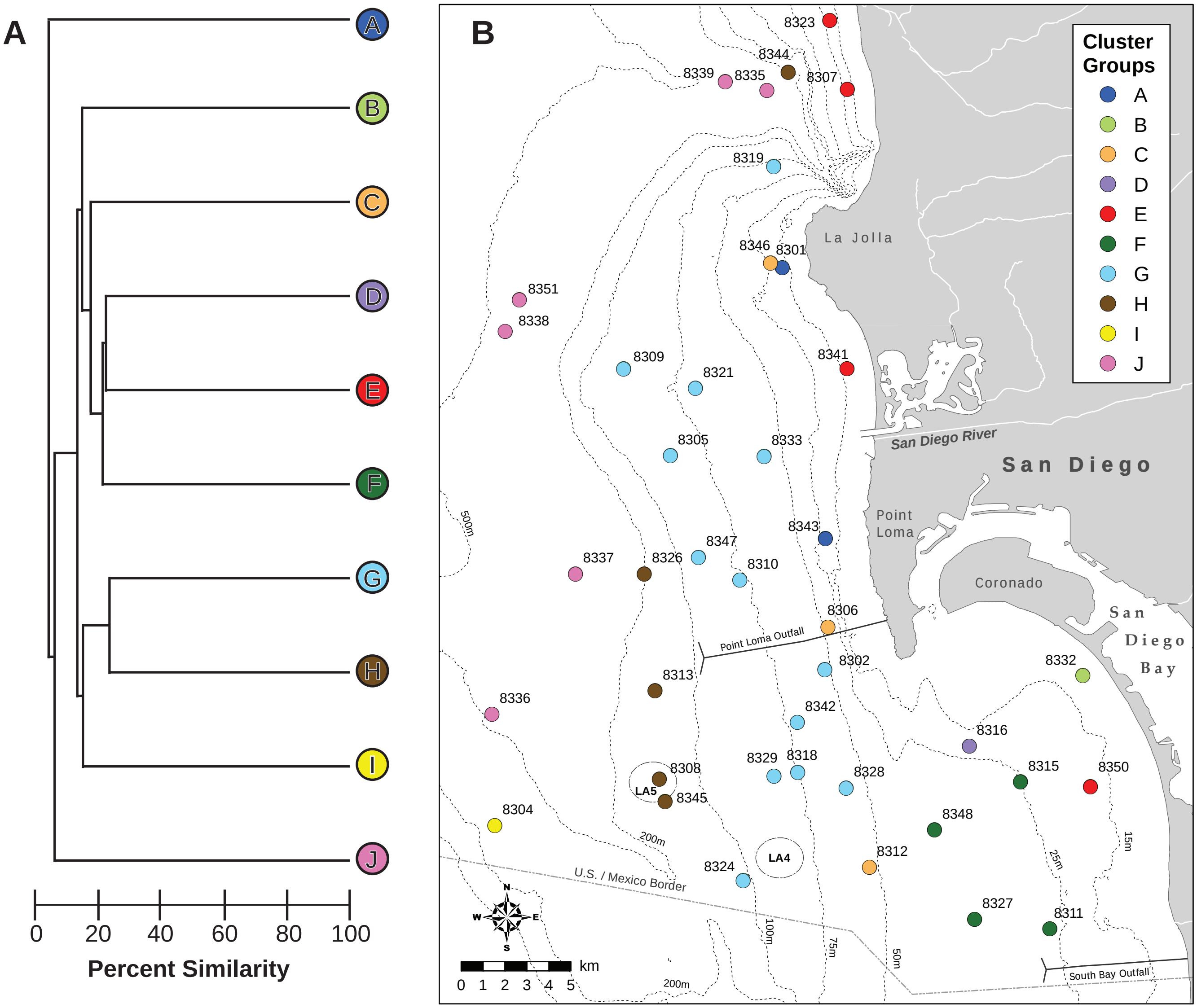

Figure 9.4

Results of cluster analysis of macrofaunal assemblages from San Diego regional benthic stations sampled during 2014. Data are presented as: (A) a dendrogram of main cluster groups and (B) spatial distribution of cluster groups in the region.

well as the sipunculid *Apionsoma misakianum* (12 per grab) (Appendix H.1). The presence of the enteropneust *Balanoglossus* sp (2 per grab), the ampeliscid amphipod *Ampelisca cristata cristata* (5 per grab), *Ampharete labrops* (<1 per grab), the maldanid polychaete Euclymeninae sp B (2 per grab), and the spionid polychaetes *Spiophanes duplex* (2 per grab) and *Prionospio* (*Prionospio*) *jubata* (2 per grab) distinguished group C from other groups (Figure 9.5). The sediments associated with this group were characterized primarily by medium-coarse sands (~66% per station), along with 18% fine sands, 10% fines, and 7% coarse particles (Table 9.3).

Cluster group D represented a unique assemblage restricted to station 8316 located at a depth of 21 m south of the entrance to San Diego Bay (Figure 9.4). A total of 52 taxa and 726 individuals occurred in this grab (Table 9.3), 454 of which were *Spiophanes norrisi* (Appendix H.1). The large number of *S. norrisi* in this assemblage distinguished it from all other assemblages sampled during this survey (Figure 9.5). The sediments associated with this sample comprised 45% fine sands and 53% medium-coarse sands (Table 9.3).

Cluster group E represented assemblages from four inner shelf stations located at depths ≤19 m

Table 9.3

Community metric and particle size summary for each cluster group A–J (defined in Figure 9.4). Data are presented as means (ranges) calculated over all stations within a cluster group (n). MC = medium-coarse.

Cluster Group	n	Depth Range (m)	Community Metric		Sediments			
			SR	Abund	Fines	Fine Sands	MC Sands	Coarse
A	2	20-22	24 (21-26)	101 (79-122)	1.6 (0.8-2.3)	0.0 —	91.4 (90.8-92.0)	7.1 (5.7-8.4)
B	1	12	68	266	16.9	70.6	12.5	0.0
C	3	22-53	57 (50-64)	189 (152-262)	10.2 (8.0-12.8)	17.6 (6.2-37.9)	65.5 (51.5-74.6)	6.6 (2.7-13.2)
D	1	21	52	726	2.1	44.9	53.0	0.1
E	4	13-19	58 (39-70)	151 (76-223)	6.3 (5.2-9.0)	91.2 (90.3-92.1)	2.5 (0.7-3.8)	0.0 —
F	4	25-39	106 (98-127)	561 (412-705)	32.1 (14.9-53.5)	65.9 (43.5-82.6)	1.9 (0.5-2.9)	0.0 —
G	13	54-105	77 (56-112)	267 (198-354)	47.1 (31.4-63.1)	49.1 (36.1-64.8)	3.1 (0.1-23.9)	0.7 (0-8.6)
H	5	146-208	69 (44-88)	187 (132-226)	57.8 (40.8-75.5)	37.8 (24.4-45.7)	4.4 (0.1-16.4)	0.0 —
I	1	146	43	100	9.8	28.8	60.9	0.5
J	6	302-449	28 (10-66)	79 (23-218)	73.3 (46.0-85.2)	21.1 (14.7-30.2)	4.3 (0-24.5)	1.2 (0-7.2)

off north La Jolla (i.e., stations 8307 and 8323), Pacific Beach (station 8341), and the Silver Strand (station 8350) (Figure 9.4). These assemblages averaged 58 taxa and 151 individuals per grab (Table 9.3). SIMPER results indicated that the top five most characteristic species for group E were *Spiophanes norrisi* (15 per grab), the bivalve *Tellina modesta* (8 per grab), the phoxocephalid amphipod *Rhepoxynius menziesi* (5 per grab), the sigalion polychaete *Sigalion spinosus* (3 per grab), and *Balanoglossus* sp (3 per grab) (Appendix H.1). This group was also distinguished from other groups by the presence of species such as the ampeliscid amphipod *Ampelisca agassizi* (3 per grab), *Ampelisca cristata cristata* (3 per grab), Euclymeninae sp B (<1 per grab), and the brachiopod *Glottidia albida* (8 per grab) (Figure 9.5). The sediments associated with this cluster group were characterized by the highest proportion of fine sands (91%) compared to all other cluster groups (Table 9.3).

Cluster group F represented assemblages from four stations (8311, 8315, 8327, 8348) located

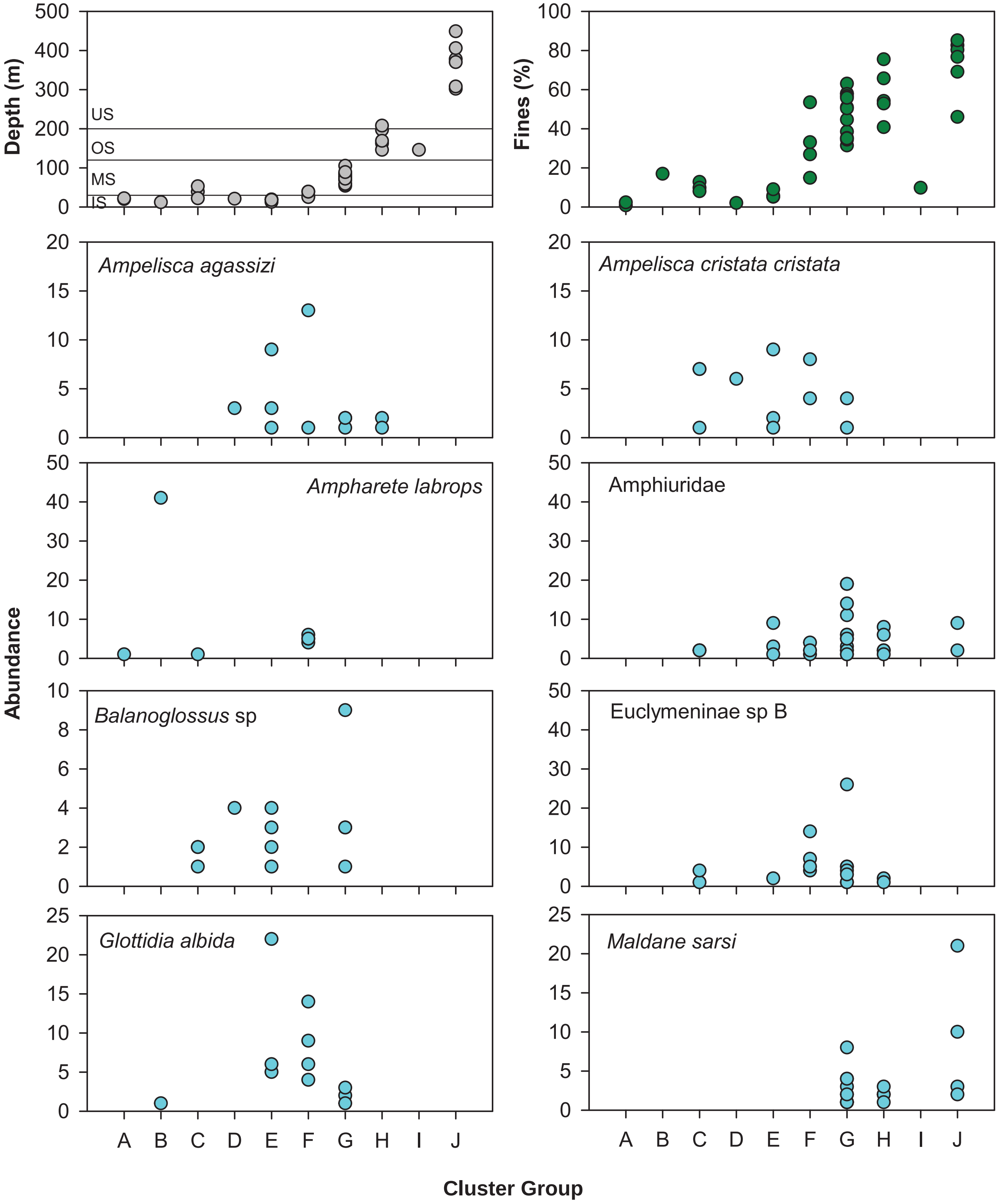

Figure 9.5

Depth, percent fines, and abundances (# of individuals per station) of select species that contributed to cluster group dissimilarities. Each data point represents a single sample or grab; IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope.

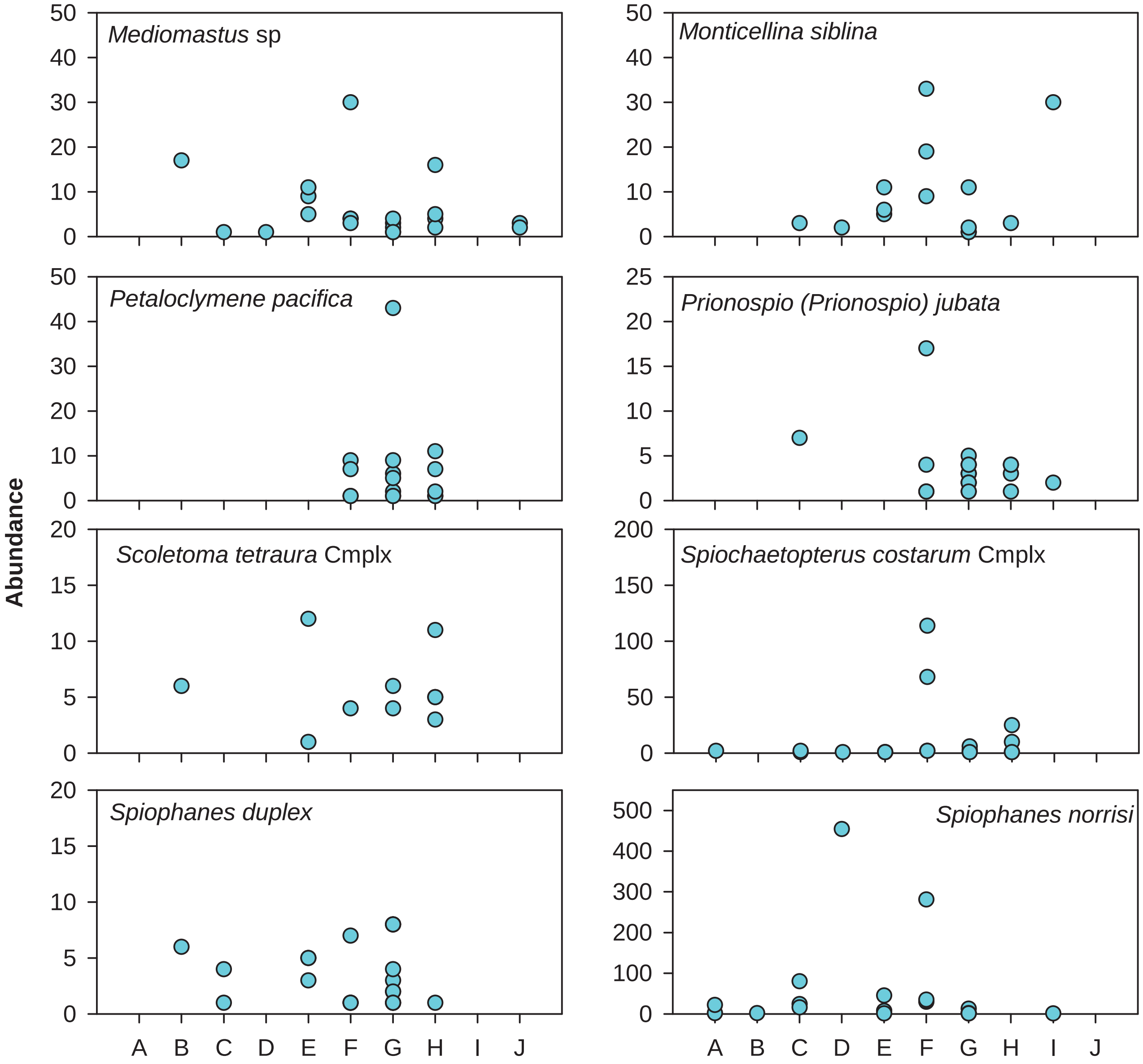

Figure 9.5 *continued*

at depths from 25 to 39 m within the South Bay ocean outfall monitoring region (see Chapter 5) (Figure 9.4). When compared to the other cluster groups, these assemblages had the greatest number of taxa (106 taxa per grab), the second largest number of animals (561 individuals per grab), and the second largest number of *Spiophanes norrisi* (95 per grab) (Table 9.3, Appendix H.1). In addition to *S. norrisi*, the remaining four of the five most characteristic species for this group based on SIMPER results included the chaetopterid polychaete *Spiochaetopterus costarum* Cmplx (47 per grab), Euclymeninae sp B (8 per grab), the ampeliscid amphipod *Ampelisca brevisimulata* (20 per grab), and *Glottidia albida* (8 per grab) (Appendix H.1). Group F was also distinguished by being one of three cluster groups, along with groups G and H, which had the maldanid polychaete *Petaloclymene pacifica* (5 per grab) present (Figure 9.5). The sediments associated with this cluster group averaged 66% fine sands and 32% fines (Table 9.3).

Cluster group G represented assemblages from most of the mid-shelf sites (n = 13) that ranged in depth from 54 to 105 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 2014a). This group averaged 77 taxa and 267 individuals per grab (Table 9.3), and was primarily characterized by the ophiuroids *Amphiodia urtica* (59 per grab) and juvenile *Amphiodia* (i.e., individuals identified as either Amphiuridae or *Amphiodia* sp, about 18 per grab combined) (Appendix H.1). In addition to these ophiuroids, the remaining two of the top five characteristic species for group G included the bivalve *Nuculana* sp A (5 per grab) and the spionid polychaete *Prionospio (Prionospio) dubia* (5 per grab). As mentioned above, this group was distinguished by being one of three groups with *Petaloclymene pacifica* present (5 per grab) (Figure 9.5). It was also distinguished by being one of three groups, along with groups H and J, which had the maldanid polychaete *Maldane sarsi* present (2 per grab). The sediments associated with this cluster group averaged 47% fines and 49% fine sands (Table 9.3).

Cluster group H represented assemblages from five stations, including four outer shelf stations at depths of 146–197 m (8308, 8313, 8326, 8345), as well as the shallowest upper slope station at 208 m (8344) (Figure 9.4). These assemblages averaged 69 taxa and 187 individuals per grab (Table 9.3). According to SIMPER results, the five most characteristic species for group H were the bivalve *Axinopsida serricata* (13 per grab), the spionid polychaete *Paraprionospio alata* (4 per grab), the cirratulid polychaete *Aphelochaeta glandaria* Cmplx (4 per grab), and the ophiuroids *Dougaloplus amphacanthus* (3 per grab) and specimens within the family Amphiuridae (4 per grab) (Appendix H.1). Group H was distinguished from most of the other assemblages in the region by the presence of *Petaloclymene pacifica* (4 per grab) and *Maldane sarsi* (2 per grab), as well as the absence of *Spiophanes norrisi* (Figure 9.5). The sediments associated with this cluster group were characterized by having slightly more fines (58% per station) and slightly less fine sands (38% per station) than found at stations in cluster group G (Table 9.3).

Cluster group I represented a unique assemblage restricted to station 8304 located at a depth of 146 m on top of the Coronado Bank (Figure 9.4). A total of 43 taxa and 100 individuals occurred in this grab (Table 9.3), 30 of which were the terebellid polychaete *Monticellina siblina* (Appendix H.1). This sample also contained eight individuals of the ophiuroid *Ophiura luetkenii* and seven of the onuphid polychaete *Mooreonuphis* sp. The relatively high number of *M. siblina*, and the absence of many other species present on the outer shelf (e.g., group H), distinguished this assemblage from other assemblages sampled in the San Diego region during this survey (Figure 9.5). The sediments associated with this grab comprised 61% medium-coarse sands and 29% fine sands (Table 9.3).

Cluster group J represented the deepest assemblages sampled at six of the seven upper slope stations located at depths from 302 to 449 m (8335, 8336, 8337, 8338, 8339, 8351) (Figure 9.4). These assemblages had the second lowest number of taxa (28 per grab) and lowest average abundance of all cluster groups (79 individuals per grab) (Table 9.3). According to SIMPER results, the top five most characteristic species of group J included *Maldane sarsi* (6 per grab), the pectinariid polychaete *Pectinaria californiensis* (2 per grab), the scaphopod *Cadulus californicus* (2 per grab), and the bivalve *Nuculana conceptionis* (<1 per grab) (Appendix H.1). The relatively high number of *M. sarsi*, and the absence of several other species such as the spionid polychates *Spiophanes duplex*, *Spiophanes norrisi*, *Monticellina siblina*, and *Spiochaetopterus costarum* Cmplx, distinguished group J from other assemblages sampled during this survey (Figure 9.5). The sediments associated with this cluster group averaged the highest proportion of percent fines (73%; Table 9.3).

SUMMARY

Macrofaunal communities in the San Diego region remained in good condition in 2014, with most shelf assemblages similar to those observed during regional surveys conducted from 1994 to 2012, and upper slope assemblages similar to those observed starting in 2009 (City of San Diego 2010–2013, 2014a, b, 2015).

Benthic assemblages had expected abundances of pollution sensitive species in the amphipod genera *Ampelisca* and *Rhepoxynius*, and especially the brittle star *Amphiodia urtica*. In contrast, abundances of pollution tolerant species such as the polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa* were absent or relatively low. Community parameters (i.e., species richness, abundance, Shannon diversity, evenness, dominance) for the 13 mid-shelf stations corresponding to the *Amphiodia* "mega-community" sampled during 2014 were within or near range of tolerance intervals calculated for this specific habitat type (see City of San Diego 2015), 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). Six inner to mid-shelf (12–53 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 relatively coarse, sandy sediments that included populations of polychaetes such as *Spiophanes norrisi*, *Spiochaetopterus costarum* Cmplx, Euclymeninae sp B, *Lumbrinerides platypygos*, and *Lumbrineris latreilli* (i.e., cluster groups A–F). 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.

Several of the stations sampled off San Diego during 2014 were located on the mid-shelf and were characterized by sandy sediments with a high percentage of fines (i.e., cluster group G). 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 2014a) 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, City of San Diego 2012a, b). Outer shelf and shallow upper slope sites sampled in 2014 (i.e., cluster group H) also had sandy sediments with slightly more fines. However, in contrast to the mid-shelf sites, these assemblages were dominated by the bivalve *Axinopsida serricata*, the polychaetes *Paraprionospio alata* and *Aphelochaeta glandaria* Cmplx, and the ophiuroid *Dougaloplus amphacanthus*. The outer shelf station located on the Coronado Bank had coarser sediments and was instead dominated by the polychaete worms *Monticellina siblina* and *Mooreonuphis* sp and the ophiuroid *Ophiura luetkenii* (i.e., cluster group I).

Similar to patterns described in past monitoring reports (City of San Diego 2013, 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. These macrofaunal assemblages typically had relatively high abundances of the polychaetes *Maldane sarsi* and *Pectinaria californiensis* and the molluscs *Cadulus californicus* and *Nuculana conceptionis* (i.e., cluster group J).

Although benthic communities off San Diego varied across depth and sediment gradients, there was no evidence of disturbance during the 2014 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 95% of the sites surveyed being in reference condition and the remaining 5% deviating only marginally based on assessments using the benthic response index (BRI). This agrees with 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.

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Appendices

Appendix A

Supporting Data

2014 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 2014. 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. February pH data were excluded due to instrumentation issues.

		Depth (m)					
Temperature (°C)		**1–9**	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
February	min	14.9	13.9	13.0	13.1	12.1	12.1
	max	15.7	15.4	15.3	15.3	15.1	15.7
	mean	15.2	15.0	14.3	14.2	13.3	14.8
May	min	11.4	10.8	10.5	10.5	10.5	10.5
	max	18.1	16.7	13.2	12.4	11.4	18.1
	mean	15.2	11.9	11.2	11.0	10.8	12.8
August	min	13.8	13.0	12.5	12.4	11.7	11.7
	max	22.6	21.3	18.5	15.8	14.9	22.6
	mean	19.1	15.5	14.0	13.6	12.9	16.1
November	min	17.8	16.0	15.4	15.1	13.8	13.8
	max	19.6	19.6	19.5	18.5	16.2	19.6
	mean	18.7	18.4	17.4	16.2	15.2	17.9
Annual	min	11.4	10.8	10.5	10.5	10.5	10.5
	max	22.6	21.3	19.5	18.5	16.2	22.6
	mean	17.0	15.2	14.2	13.7	13.0	15.4
Salinity (psu)							
February	min	33.29	33.42	33.41	33.42	33.41	33.29
	max	33.58	33.58	33.55	33.55	33.52	33.58
	mean	33.53	33.52	33.49	33.48	33.45	33.51
May	min	33.38	33.24	33.38	33.40	33.45	33.24
	max	33.59	33.63	33.70	33.71	33.70	33.71
	mean	33.52	33.49	33.54	33.57	33.58	33.52
August	min	33.31	33.27	33.33	33.31	33.33	33.27
	max	33.75	33.61	33.50	33.42	33.44	33.75
	mean	33.49	33.40	33.38	33.38	33.39	33.43
November	min	33.46	33.31	33.24	33.20	33.25	33.20
	max	33.61	33.61	33.61	33.41	33.35	33.61
	mean	33.56	33.51	33.40	33.33	33.31	33.48
Annual	min	33.29	33.24	33.24	33.20	33.25	33.20
	max	33.75	33.63	33.70	33.71	33.70	33.75
	mean	33.53	33.48	33.45	33.44	33.43	33.49

Appendix A.1 *continued*

		Depth (m)					
DO (mg/L)		**1–9**	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
February	min	7.2	6.7	6.2	6.4	5.6	5.6
	max	8.2	8.2	8.2	8.2	8.1	8.2
	mean	8.0	7.8	7.3	7.2	6.6	7.7
May	min	4.9	4.3	4.0	4.0	4.0	4.0
	max	11.3	11.2	8.3	7.4	6.1	11.3
	mean	8.5	6.7	5.5	5.2	5.0	6.9
August	min	6.7	7.1	7.1	6.8	6.0	6.0
	max	8.8	8.8	8.7	8.6	8.5	8.8
	mean	7.9	8.2	8.1	7.9	7.3	8.0
November	min	7.0	6.9	7.3	7.3	6.9	6.9
	max	7.7	7.9	8.3	8.2	8.0	8.3
	mean	7.5	7.5	7.7	7.8	7.6	7.6
Annual	min	4.9	4.3	4.0	4.0	4.0	4.0
	max	11.3	11.2	8.7	8.6	8.5	11.3
	mean	8.0	7.6	7.1	7.0	6.6	7.5

pH							
February	min	—	—	—	—	—	—
	max	—	—	—	—	—	—
	mean	—	—	—	—	—	—
May	min	7.9	7.8	7.8	7.8	7.8	7.8
	max	8.2	8.3	8.1	8.0	7.9	8.3
	mean	8.2	8.0	7.9	7.9	7.8	8.0
August	min	8.1	8.1	8.1	8.0	8.0	8.0
	max	8.2	8.2	8.2	8.2	8.2	8.2
	mean	8.2	8.1	8.1	8.1	8.1	8.1
November	min	8.1	8.1	8.1	8.1	8.0	8.0
	max	8.2	8.2	8.2	8.2	8.1	8.2
	mean	8.2	8.2	8.1	8.1	8.1	8.1
Annual	min	7.9	7.8	7.8	7.8	7.8	7.8
	max	8.2	8.3	8.2	8.2	8.2	8.3
	mean	8.1	8.1	8.0	8.0	8.0	8.1

Appendix A.1 *continued*

		Depth (m)					
Transmissivity (%)		**1–9**	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
February	min	56	59	71	78	84	56
	max	89	89	89	89	88	89
	mean	81	84	85	86	87	83
May	min	26	14	63	56	48	14
	max	89	89	90	89	89	90
	mean	79	78	85	84	74	80
August	min	62	53	81	84	86	53
	max	90	90	90	90	90	90
	mean	85	86	87	88	88	86
November	min	63	53	77	79	84	53
	max	89	89	89	89	88	89
	mean	84	85	86	86	87	85
Annual	min	26	14	63	56	48	14
	max	90	90	90	90	90	90
	mean	82	83	86	86	84	84

Chlorophyll *a* (µg/L)							
February	min	0.4	0.6	0.9	0.7	0.4	0.4
	max	3.4	2.7	2.7	2.2	1.9	3.4
	mean	1.4	1.6	1.5	1.3	1.0	1.5
May	min	0.3	0.4	0.5	0.4	0.4	0.3
	max	25.1	41.7	13.0	4.8	1.5	41.7
	mean	2.1	6.6	2.3	1.0	0.8	3.3
August	min	0.1	0.2	0.2	0.4	0.6	0.1
	max	4.0	6.7	2.7	2.9	2.2	6.7
	mean	0.7	1.0	1.3	1.6	1.4	1.0
November	min	0.2	0.2	0.3	0.8	0.6	0.2
	max	2.3	3.0	2.1	2.3	1.7	3.0
	mean	0.8	0.9	1.1	1.6	1.2	1.0
Annual	min	0.1	0.2	0.2	0.4	0.4	0.1
	max	25.1	41.7	13.0	4.8	2.2	41.7
	mean	1.2	2.5	1.5	1.4	1.1	1.7

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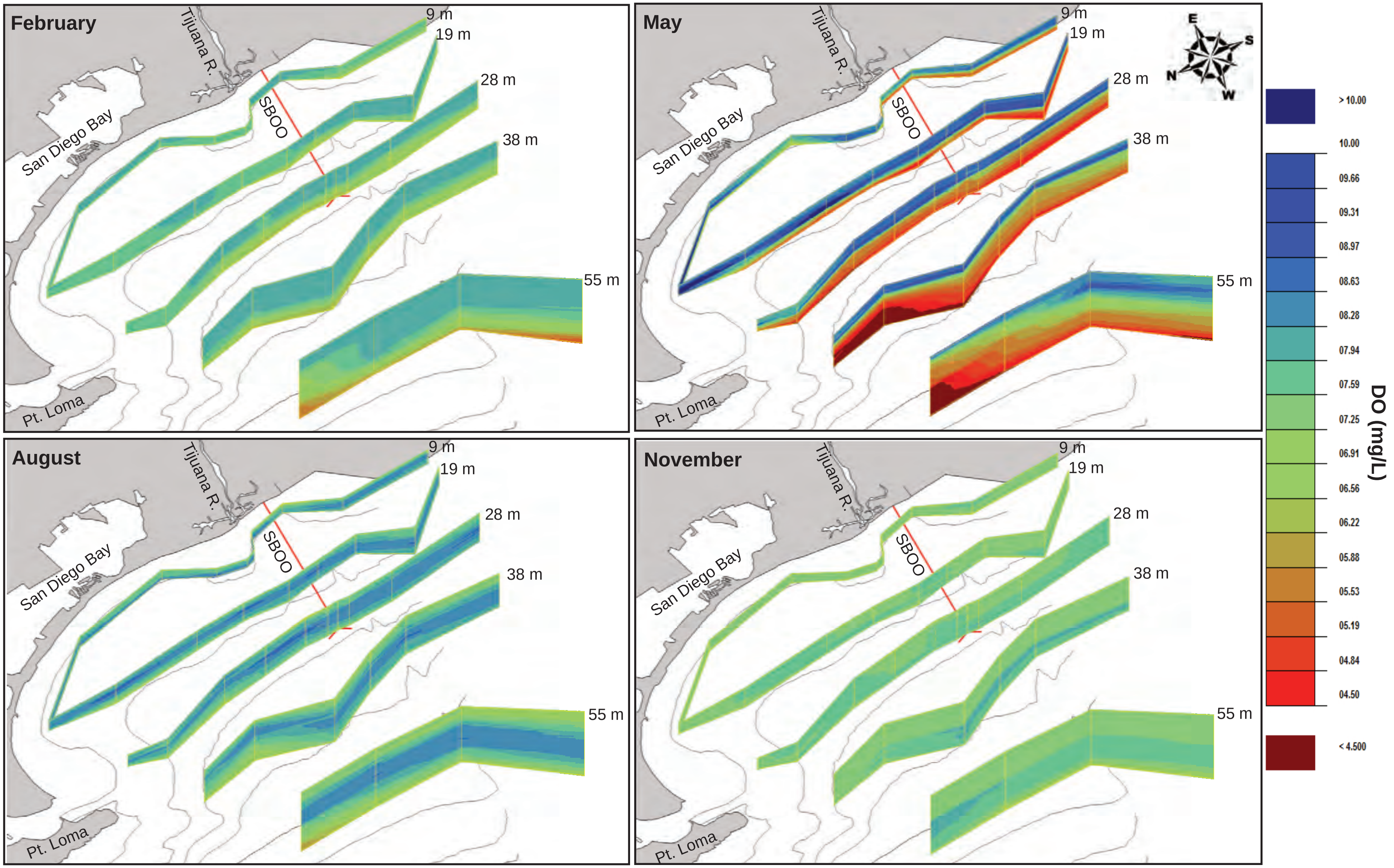
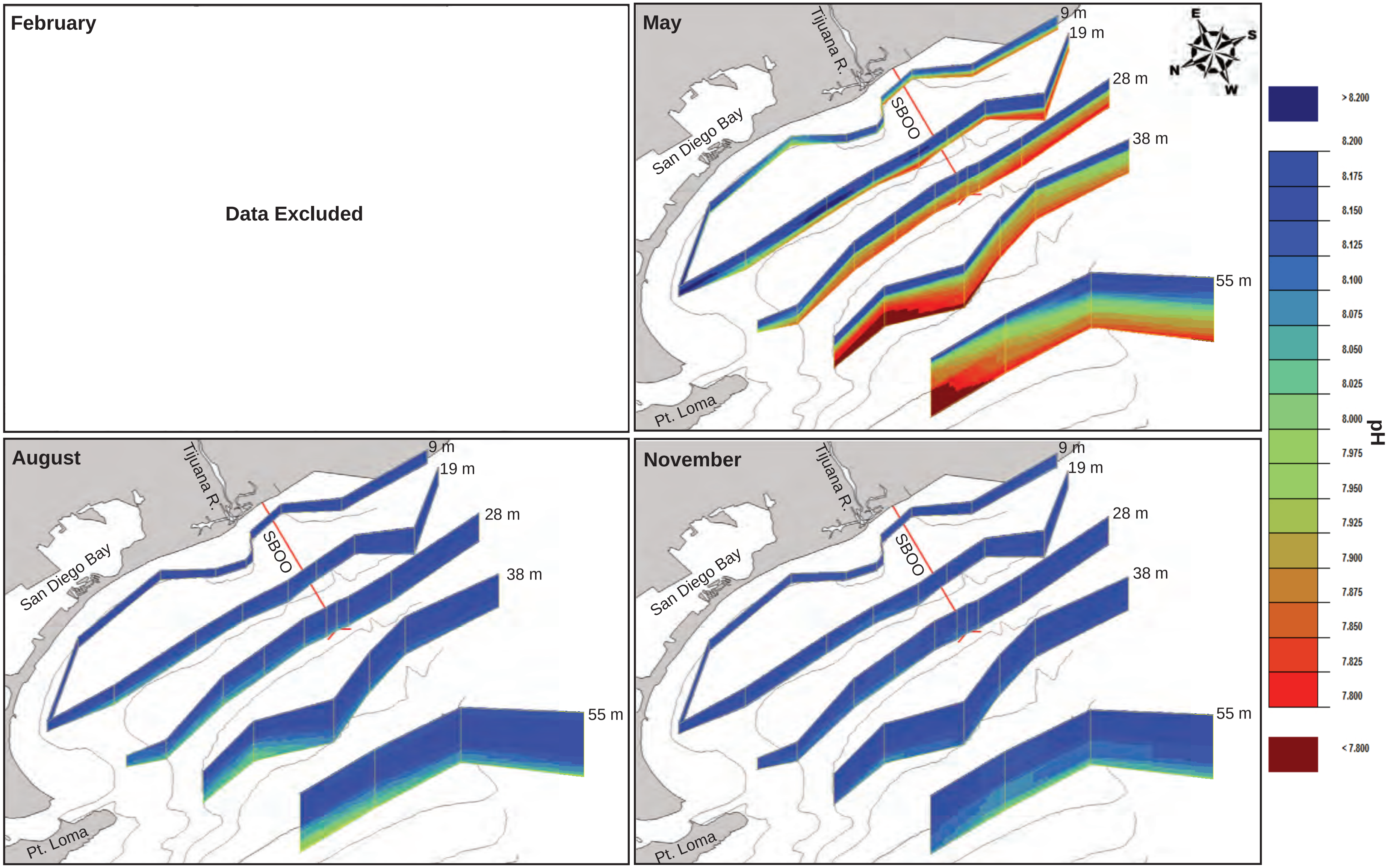


Appendix A.2

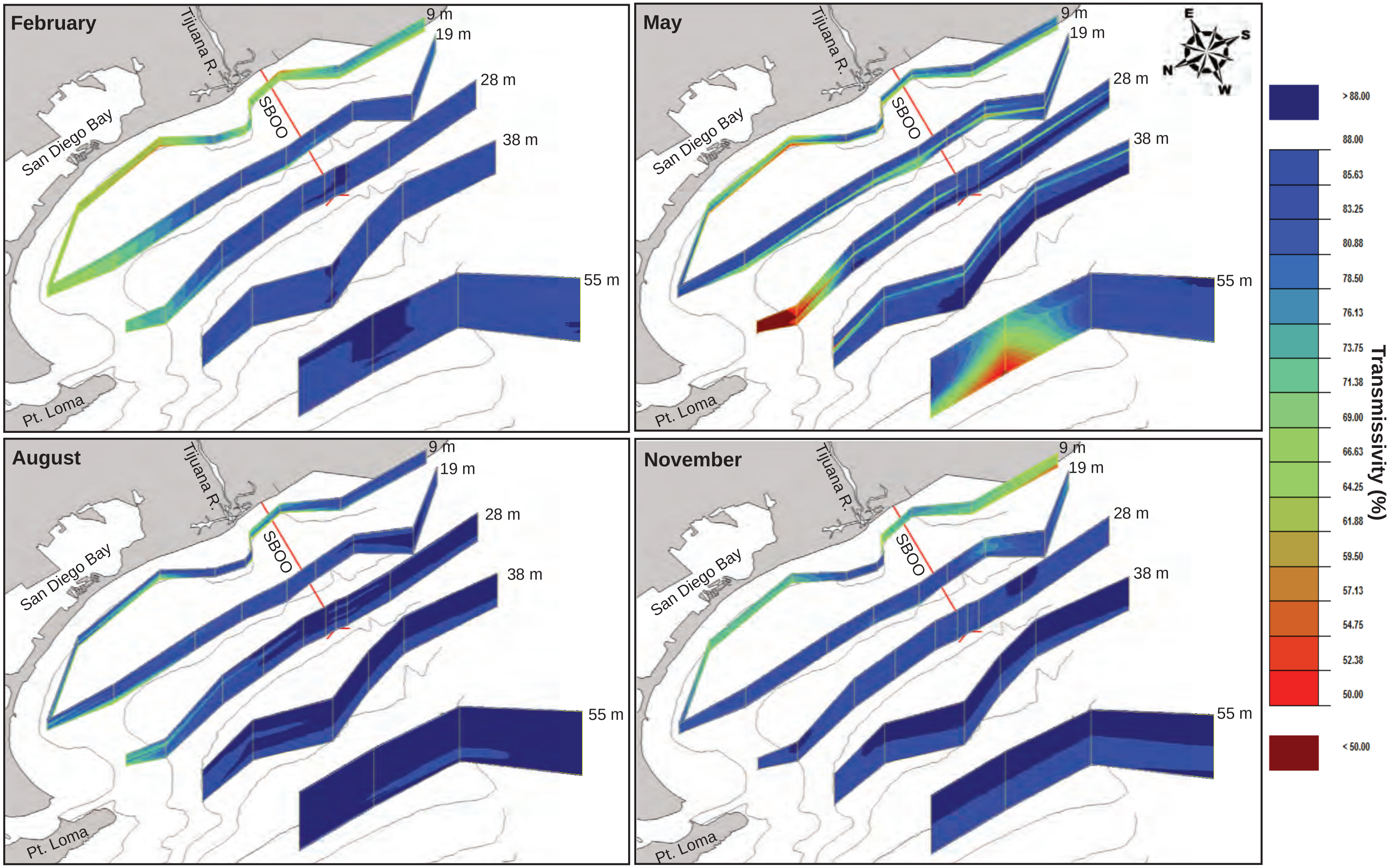
Dissolved oxygen recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2014. Data were collected over three consecutive days during each of these surveys.



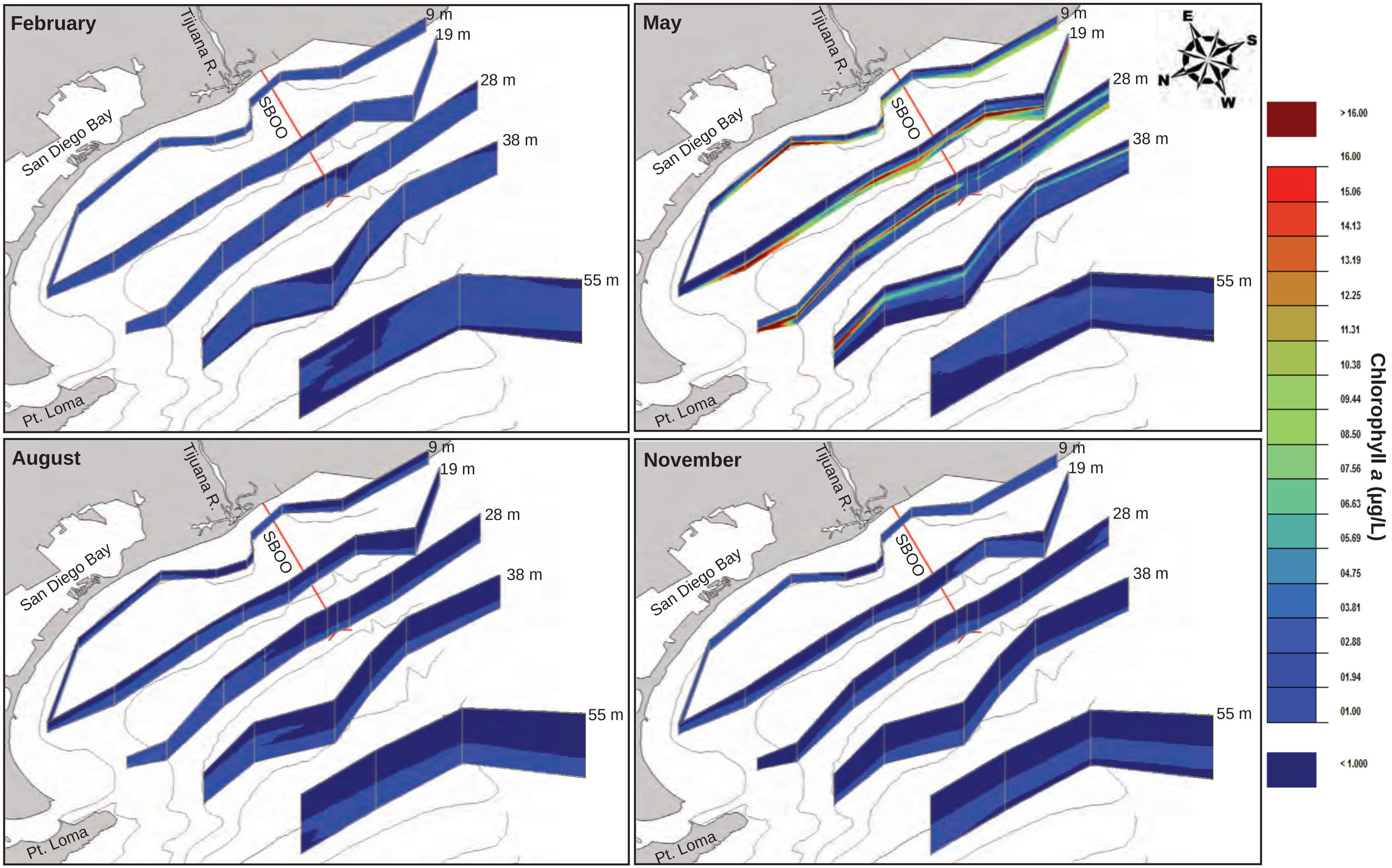
Appendix A.3

pH recorded in the SBOO region during spring (May), summer (August), and fall (November) of 2014. Data were collected over three consecutive days during each of these surveys. Data from February are exluded due to instrumentation issues.

Appendix A.4



Transmissivity recorded in the SBOO region during winter (February), spring (May), summer (August), and fall (November) of 2014. Data were collected over three consecutive 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 2014. Data were collected over three consecutive days during each of these surveys.

Appendix A.6

Summary of current velocity magnitude and direction from the SBOO 36-m ADCP in 2014. Data are presented as seasonal means with 95% confidence intervals. Minimum and maximum angles of velocity are not shown due to the circular nature of the measurement.

		Magnitude (mm/s)				Angle (°)	
	Depth (m)	Min	Max	Mean	95% CI	Mean	95% CI
Winter	6	13	196	72	2	130	43
	10	5	175	63	2	150	42
	14	0	149	58	2	138	42
	18	1	130	50	2	128	44
	24	1	112	46	2	95	48
	28	0	107	42	1	324	51
	32	4	98	38	1	321	50
Spring	6	22	194	84	2	130	51
	10	6	227	67	2	147	45
	14	3	174	55	2	128	42
	18	1	118	44	1	104	41
	24	1	78	37	1	68	40
	28	1	62	31	1	28	40
	32	0	54	24	1	1	44
Summer	6	5	369	167	5	146	46
	10	6	349	151	5	153	46
	14	5	260	119	3	145	46
	18	4	191	95	2	134	44
	24	1	136	74	1	109	42
	28	2	105	58	1	64	40
	32	1	80	40	1	20	41
Fall	6	4	180	66	2	122	42
	10	10	161	65	2	76	42
	14	15	163	66	2	39	43
	18	11	169	61	2	12	46
	24	2	143	54	2	353	44
	28	3	103	46	1	339	43
	32	36	124	79	4	346	44

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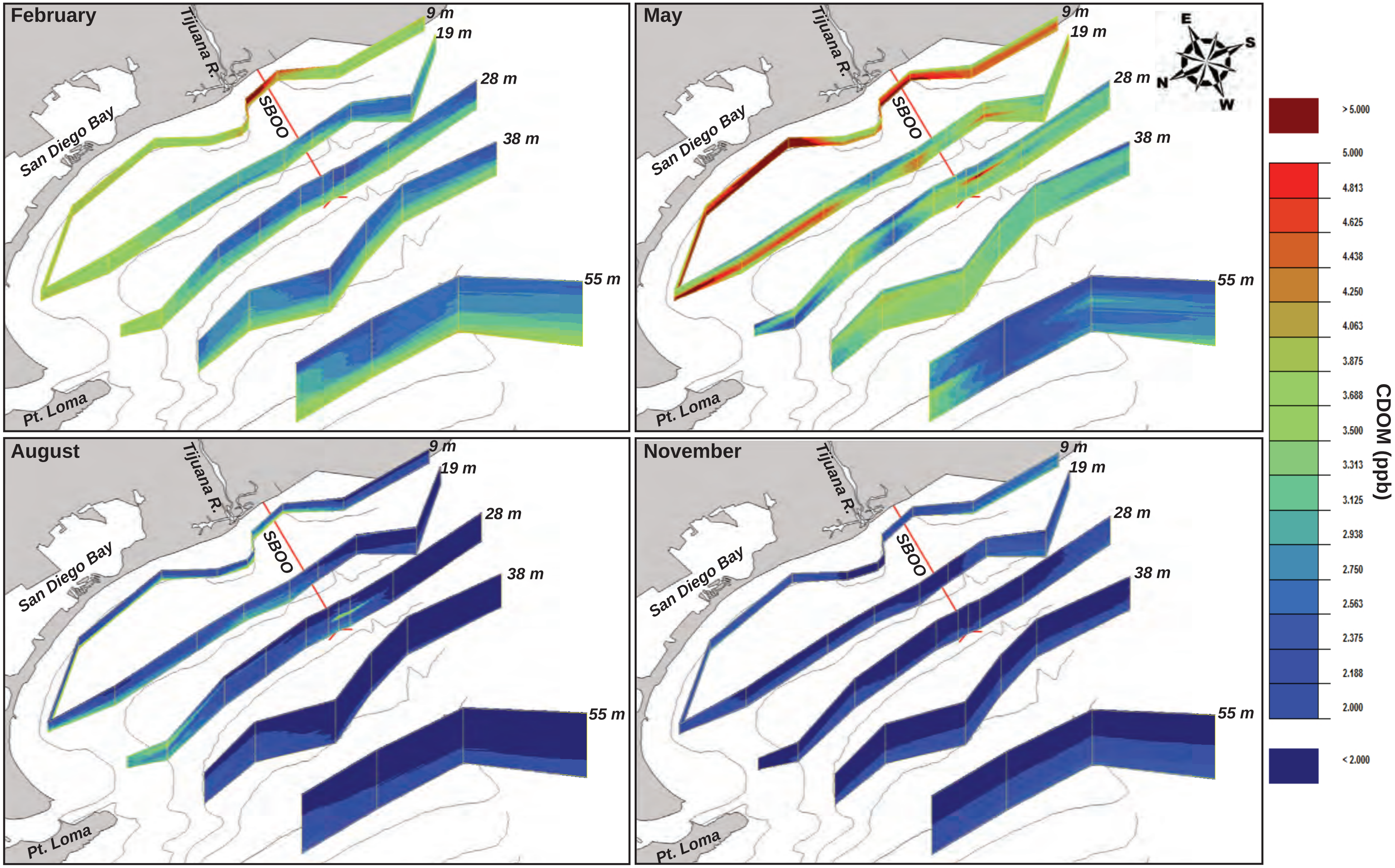
Appendix B

Supporting Data

2014 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 2014. Data were collected over three consecutive days during each of these surveys.

Appendix B.2

Summary of SBOO reference stations used during 2014 to calculate out-of-range thresholds (see text for details).

Month	Stations
February	I3, I10, I30, I31, I39
May	I1, I2, I3, I7, I8, I9, I13, I18, I20, I27, I34, I39, I21
August	I1, I2, I3, I7, I8, I9, I10, I13, I20, I21
November	I12, I14, I15, I16, I17, I18, I22, I27, I33, I34

Appendix B.3

Summary of rainfall and bacteria levels from SBOO shore stations during 2014. 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):		0.01	1.00	1.28	0.53	0.00	0.00	0.00	0.08	0.00	0.00	0.37	4.50
	n	44	44	44	55	44	44	55	44	55	44	44	55
S9	*Total*	20	11	162	56	6	65	92	65	56	16	15	28
	Fecal	3	2	30	7	2	3	6	6	3	4	16	7
	Entero	4	4	36	3	18	2	2	18	3	36	2	8
S8	*Total*	6	6	36	140	11	65	20	20	53	61	20	18
	Fecal	4	2	11	8	2	3	7	2	2	10	2	4
	Entero	2	2	18	13	2	2	2	5	4	31	5	6
S12	*Total*	7	36	40	29	16	25	24	25	60	108	16	28
	Fecal	4	16	36	2	8	11	5	8	4	8	2	13
	Entero	6	4	26	2	2	4	3	8	11	40	3	11
S6	*Total*	11	14	56	32	16	20	17	20	56	1615	12	891
	Fecal	4	18	11	8	2	2	3	2	2	43	5	181
	Entero	3	2	12	2	4	2	3	2	2	149	2	29
S11	*Total*	8	13	98	17	16	16	20	16	16	2015	8	1492
	Fecal	4	4	15	3	2	2	7	2	2	82	2	120
	Entero	6	2	12	3	4	2	2	2	2	163	2	52
S5	*Total*	8	4061	6156	300	16	16	24	20	24	1012	85	385
	Fecal	2	583	2153	286	2	2	2	2	9	52	38	2422
	Entero	3	106	155	23	3	2	4	4	2	149	4	2451
S10	*Total*	8	846	4706	108	11	16	18	11	20	1056	68	3587
	Fecal	2	216	501	15	2	6	2	2	4	36	13	2425
	Entero	9	18	46	4	5	2	4	2	7	107	2	1068
S4	*Total*	22	261	586	149	175	60	16	25	21	1615	31	3545
	Fecal	4	86	102	16	154	3	8	5	6	46	11	2234
	Entero	8	15	14	7	65	2	15	4	34	204	4	1044
S3	*Total*	12	1200	1460	457	16	1006	10	20	56	2786	660	650
	Fecal	3	134	146	6	2	187	2	2	6	41	28	104
	Entero	24	56	22	3	7	302	6	6	28	232	14	66
S2	*Total*	46	1824	130	730	16	865	6	160	369	960	105	61
	Fecal	12	240	66	48	2	112	2	26	11	26	18	49
	Entero	7	71	18	8	2	138	6	192	48	246	88	47
S0	*Total*	5745	2585	5935	4440	309	3216	3152	112	133	3335	2664	3820
	Fecal	864	588	588	2636	48	85	193	25	18	234	234	597
	Entero	350	333	242	2439	8	352	762	14	20	1516	341	1056

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Appendix B.4

Summary of elevated bacteria densities in samples collected from SBOO shore stations during 2014. 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	14 Jan 14	6000	**1000**	**600**	**0.17**
S0	21 Jan 14	**>16,000**	**2200**	**720**	**0.14**
S0	4 Feb 14	4600	**1100**	**280**	**0.24**
S2	4 Feb 14	6200	**700**	**240**	**0.11**
S3	4 Feb 14	4400	**480**	**180**	**0.11**
S0	11 Feb 14	3200	**920**	**520**	**0.29**
S0	18 Feb 14	2400	220	**520**	0.09
S3	4 Mar 14	1600	200	26	**0.12**
S0	18 Mar 14	6800	**420**	**240**	0.06
S0	25 Mar 14	**>16,000**	**1800**	**700**	**0.11**
S0	1 Apr 14	**>16,000**	**>12,000**	**>12,000**	**0.75**
S0	22 Apr 14	5600	**1100**	**160**	**0.20**
S0	6 May 14	1200	180	22	**0.15**
S0	3 Jun 14	840	96	**300**	0.11
S2	10 Jun 14	3400	**440**	**540**	**0.13**
S3	10 Jun 14	4000	**740**	**1200**	**0.18**
S0	17 Jun 14	**12,000**	240	**1100**	0.02
S0	15 Jul 14	**10,600**	**640**	**3400**	0.06
S0	22 Jul 14	5000	300	**380**	0.06
S2	19 Aug 14	600	98	**760**	0.16
S2	9 Sep 14	1600	30	**160**	0.02
S3	9 Sep 14	180	20	**120**	0.11
S2	7 Oct 14	3800	80	**940**	0.02
S3	7 Oct 14	**11,000**	100	**880**	0.01
S0	14 Oct 14	40	8	**200**	0.20
S0	21 Oct 14	**13,000**	**900**	**5400**	0.07
S0	28 Oct 14	220	20	**400**	0.09
S0	4 Nov 14	8000	**540**	**840**	0.07
S0	12 Nov 14	34	34	**300**	1.00
S2	12 Nov 14	80	40	**340**	0.50
S0	25 Nov 14	2600	360	**220**	**0.14**

[a] Resample; ns = not sampled

Appendix B.4 *continued*

Station	Date	Total	Fecal	Entero	F:T
S0	2 Dec 14	2400	84	**600**	0.04
S0	9 Dec 14	1200	80	**240**	0.07
S0	16 Dec 14	10,000	**2400**	**3400**	**0.24**
S2	16 Dec 14	ns	180	**120**	—
S3	16 Dec 14	ns	240	**140**	—
S0	23 Dec 14	4200	**400**	**520**	0.10
S3	23 Dec 14	2000	240	**160**	**0.12**
S0	30 Dec 14	1300	20	**520**	0.02
North of US/Mexico Border					
S10	11 Feb 14	3200	**680**	32	**0.21**
S5	11 Feb 14	**>16,000**	**2200**	**380**	**0.14**
S10	4 Mar 14	**10,000**	**1400**	**150**	**0.14**
S4	4 Mar 14	1400	340	42	**0.24**
S5	4 Mar 14	8600	**1200**	54	**0.14**
S9	4 Mar 14	600	110	**120**	0.18
S10[a]	6 Mar 14	**>16,000**	**4400**	**520**	**0.28**
S4[a]	6 Mar 14	8600	**660**	ns	0.08
S5[a]	6 Mar 14	**>16,000**	**>12,000**	ns	**0.75**
S10[a]	8 Mar 14	**>16,000**	**>12,000**	**2000**	**0.75**
S4[a]	8 Mar 14	ns	**4200**	ns	—
S5[a]	8 Mar 14	**>16,000**	**>12,000**	ns	**0.75**
S10[a]	10 Mar 14	**>16,000**	**3400**	34	**0.21**
S5[a]	10 Mar 14	**>16,000**	**>12,000**	ns	**0.75**
S10	11 Mar 14	8800	**600**	32	0.07
S5	11 Mar 14	**>16,000**	**7400**	**560**	**0.46**
S5	8 Apr 14	1400	**1400**	84	**1.00**
S4	20 May 14	640	**600**	**200**	0.94
S4[a]	22 May 14	ns	**2000**	58	—
S10	7 Oct 14	4200	140	**420**	0.03
S11	7 Oct 14	8000	320	**640**	0.04
S12	7 Oct 14	400	10	**140**	0.02
S4	7 Oct 14	6400	140	**780**	0.02
S5	7 Oct 14	4000	200	**580**	0.05
S6	7 Oct 14	6400	160	**580**	0.02
S10[a]	9 Oct 14	ns	ns	**140**	—
S4[a]	9 Oct 14	ns	ns	**150**	—
S9	21 Oct 14	20	8	**120**	0.40
S10	16 Dec 14	**>16,000**	**>12,000**	**5200**	**0.75**
S11	16 Dec 14	7200	**560**	**200**	0.08
S4	16 Dec 14	**>16,000**	**11,000**	**5000**	**0.69**

[a] Resample; ns = not sampled

Appendix B.4 *continued*

Station	Date	Total	Fecal	Entero	F:T
S5	16 Dec 14	ns	**>12,000**	**>12,000**	—
S6	16 Dec 14	4400	**880**	**120**	**0.20**
S10[a]	18 Dec 14	**>16,000**	**7000**	**4000**	**0.44**
S4[a]	18 Dec 14	**>16,000**	**1000**	**1200**	0.06
S5[a]	18 Dec 14	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10[a]	19 Dec 14	6200	**460**	**380**	0.07
S4[a]	19 Dec 14	3600	240	**460**	0.07
S5[a]	19 Dec 14	ns	**>12,000**	**>12,000**	—
S10[a]	21 Dec 14	**>16,000**	**1200**	**2000**	0.08
S4[a]	21 Dec 14	**11,000**	**1000**	**600**	0.09
S5[a]	21 Dec 14	580	94	**120**	0.16
S10	23 Dec 14	1600	110	**120**	0.07
S4	23 Dec 14	1400	110	**120**	0.08
S5	30 Dec 14	1100	40	**200**	0.04
S5[a]	31 Dec 14	ns	ns	**4600**	—

[a] Resample; ns = not sampled

Appendix B.5

Summary of bacteria levels from SBOO kelp bed and other offshore stations during 2014. 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.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Rain (in):	0.01	1.00	1.28	0.53	0.00	0.00	0.00	0.08	0.00	0.00	0.37	4.50
Kelp Bed Stations												
9-m Depth Contour (n = 30)												
Total	2	12	39	7	2	3	22	22	6	2	3	950
Fecal	2	6	7	3	2	2	2	3	2	2	2	110
Entero	2	2	5	4	2	5	3	2	2	2	2	71
19-m Depth Contour (n = 15)												
Total	2	5	30	10	2	2	30	3	5	2	5	714
Fecal	2	3	8	5	2	2	2	2	2	2	2	87
Entero	2	2	5	2	2	2	2	2	2	2	2	52
Non-Kelp Bed Stations												
9-m Depth Contour (n = 27)												
Total	ns	1386	ns	ns	2	ns	ns	6	ns	ns	4	ns
Fecal	ns	238	ns	ns	2	ns	ns	2	ns	ns	2	ns
Entero	ns	32	ns	ns	5	ns	ns	2	ns	ns	2	ns
19-m Depth Contour (n = 9)												
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	2	ns
28-m Depth Contour (n = 9[a])												
Total	55	14	20	414	5	20	18	5	42	7	2	14
Fecal	17	2	4	64	2	3	2	2	5	2	2	2
Entero	3	2	2	29	2	2	2	2	3	2	2	3
38-m Depth Contour (n = 9)												
Total	ns	54	ns	ns	2	ns	ns	2	ns	ns	2	ns
Fecal	ns	5	ns	ns	2	ns	ns	2	ns	ns	2	ns
Entero	ns	3	ns	ns	2	ns	ns	2	ns	ns	2	ns
55-m Depth Contour (n = 6)												
Total	ns	88	ns	ns	2	ns	ns	2	ns	ns	2	ns
Fecal	ns	14	ns	ns	2	ns	ns	2	ns	ns	2	ns
Entero	ns	4	ns	ns	19	ns	ns	2	ns	ns	2	ns

[a] n = 24 during February, May, August, and November; non-quarterly months include only stations I12, I14, and I16

Appendix B.6

Summary of elevated bacteria densities in samples collected from SBOO kelp bed and other offshore stations during 2014. 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 Bed Stations						
I25	16 Dec 14	2	1400	260	66	**0.19**
I25	16 Dec 14	6	4400	**460**	**110**	**0.10**
I25	16 Dec 14	9	3000	**640**	**120**	**0.21**
I26	16 Dec 14	6	2000	240	60	**0.12**
I25[a]	18 Dec 14	2	**15,000**	**3200**	ns	**0.21**
I25[a]	18 Dec 14	6	6200	**860**	**940**	**0.14**
I25[a]	18 Dec 14	9	5600	**780**	**1400**	**0.14**
I25	19 Dec 14	6	5200	**440**	**540**	0.08
I25	19 Dec 14	9	3600	280	**600**	0.08
I26	19 Dec 14	6	1200	140	100	**0.12**
I26	19 Dec 14	9	1600	280	**160**	**0.18**
I39	19 Dec 14	2	2600	380	**110**	**0.15**
I39	19 Dec 14	12	5800	**640**	**460**	**0.11**
I39	19 Dec 14	18	900	140	**120**	0.16
Other Offshore Stations						
I19	7 Feb 14	2	4000	**480**	24	**0.12**
I40	7 Feb 14	2	**14,000**	**2800**	**440**	**0.20**
I40	7 Feb 14	6	**>16,000**	**2600**	**280**	**0.16**
I12	4 Apr 14	2	3600	**540**	2	**0.15**
I12	4 Apr 14	27	4	2	**240**	0.50

[a] Resample; ns = not sampled

Appendix B.7

Summary of total suspended solids (TSS) and oil and grease (O&G) concentrations in samples collected from the SBOO kelp bed and other offshore stations during 2014. Data include the number of samples per month (n) and detection rate, as well as the minimum, maximum, and mean[c] of detected concentrations for each month. The method detection limit = 0.2 mg/L for both TSS and O&G; nd = not detected; ns = not sampled.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014 Kelp Bed Stations												
Total Suspended Solids (n = 9)												
Detection Rate (%)	—	89	—	—	100	—	—	11	—	—	0	—
Min	ns	nd	ns	ns	3.6	ns	ns	nd	ns	ns	—	ns
Max	ns	7.1	ns	ns	8.0	ns	ns	3.5	ns	ns	—	ns
Mean	ns	4.7	ns	ns	5.2	ns	ns	3.5	ns	ns	—	ns
Oil and Grease (n = 3)												
Detection Rate (%)	—	0	—	—	0	—	—	0	—	—	0	—
Min	ns	—	ns	ns	—	ns	ns	—	ns	ns	—	ns
Max	ns	—	ns	ns	—	ns	ns	—	ns	ns	—	ns
Mean	ns	—	ns	ns	—	ns	ns	—	ns	ns	—	ns
2014 Non-Kelp Bed Stations												
Total Suspended Solids (n = 9[a])												
Detection Rate (%)	100	85	89	67	95	44	100	17	33	0	17	0
Min	2.2	nd	nd	nd	nd	nd	3.4	nd	nd	—	nd	—
Max	10.7	16.3	6.5	8.5	18.6	5.4	11.3	8.1	4.1	—	7.6	—
Mean	4.7	4.7	4.2	4.9	5.2	3.6	5.0	4.1	3.7	—	3.5	—
Oil and Grease (n = 3[b])												
Detection Rate (%)	0	8	0	0	0	0	0	0	0	0	0	33
Min	—	nd	—	—	—	—	—	—	—	—	—	nd
Max	—	2.5	—	—	—	—	—	—	—	—	—	3.1
Mean	—	2.0	—	—	—	—	—	—	—	—	—	3.1

[a] n = 75 during February, May, August, and November; non-quarterly months include only stations I12, I14, and I16

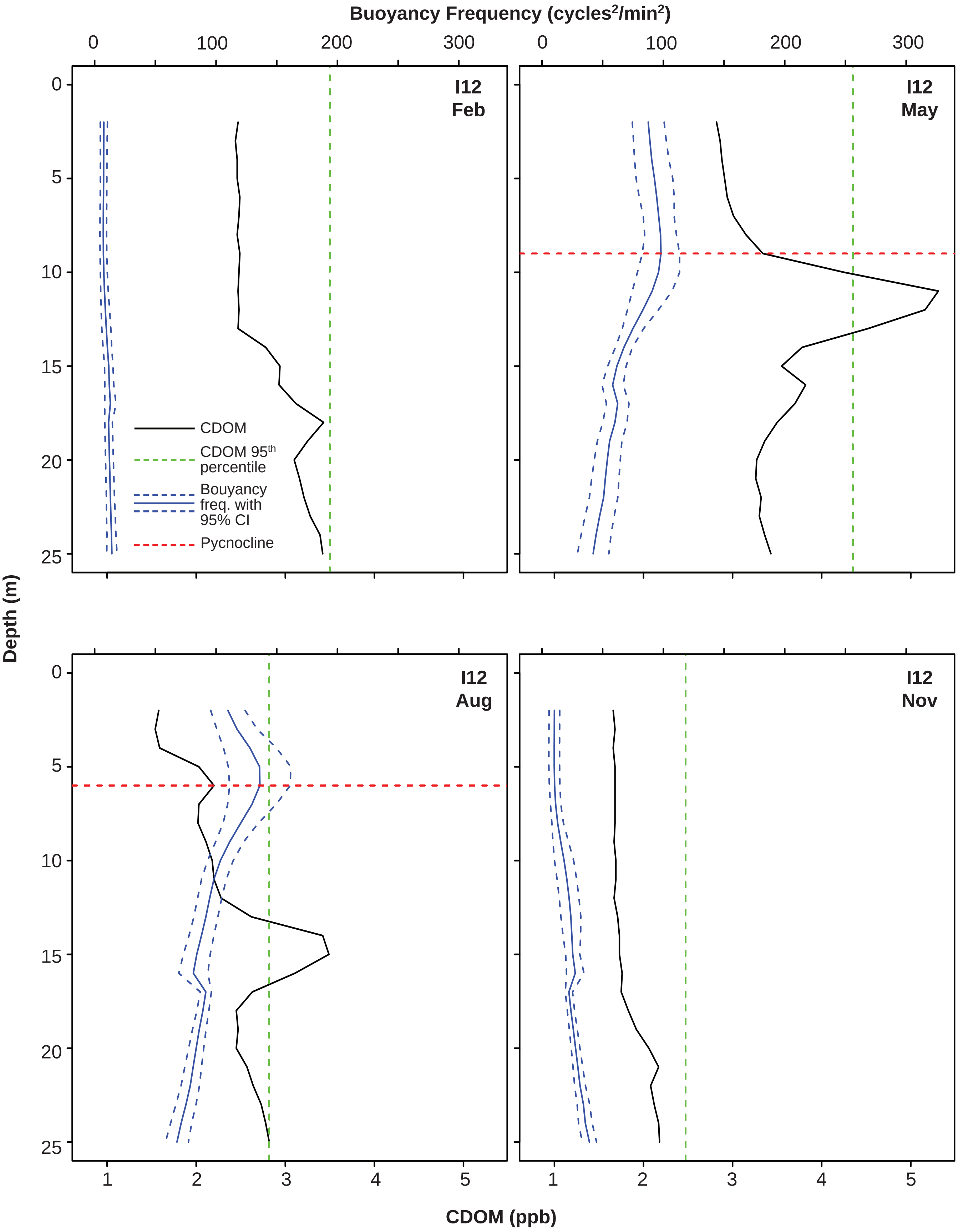
[b] n = 25 during February, May, August, and November; non-quarterly months include only stations I12, I14, and I16

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

Appendix B.8

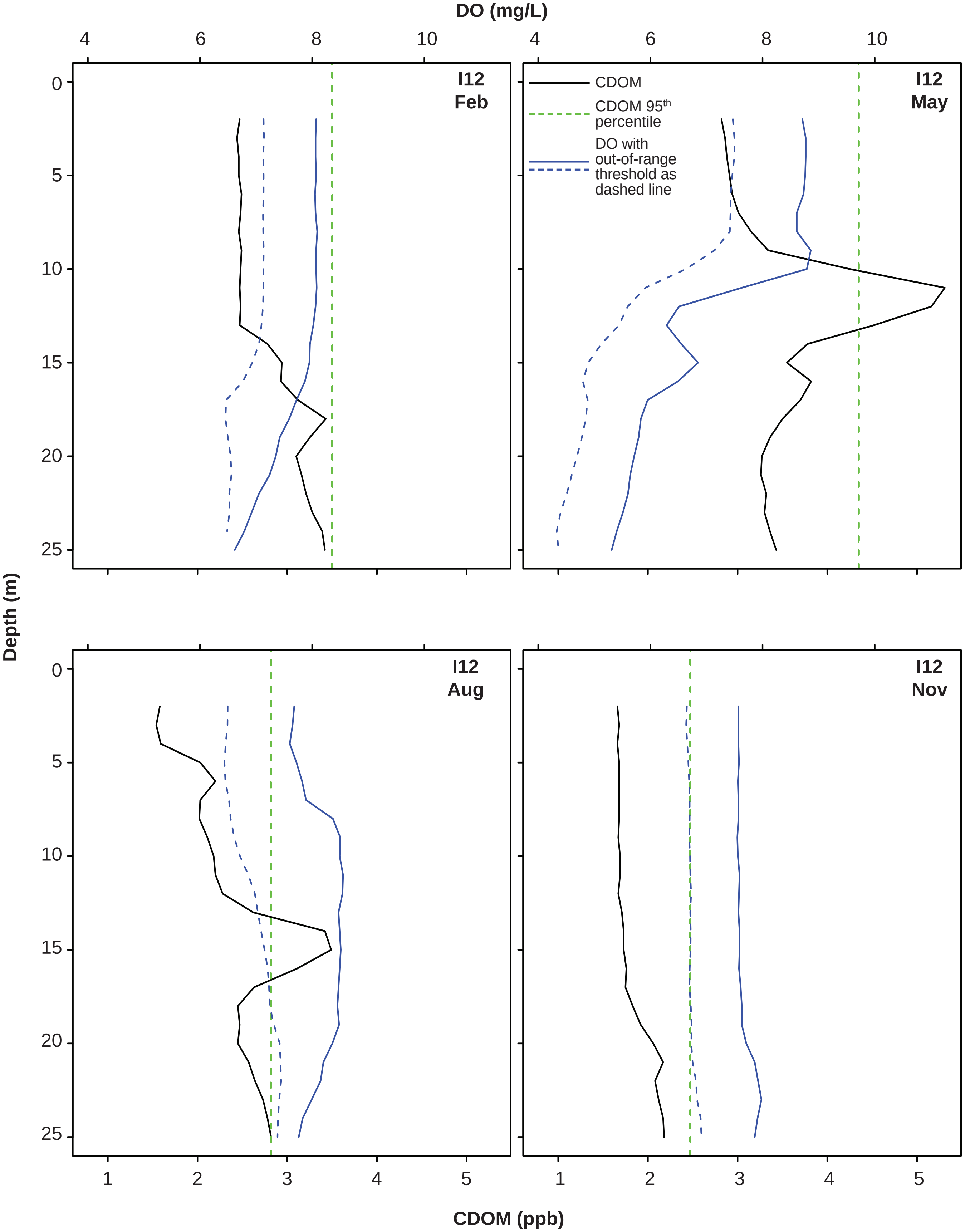
Summary of oceanographic data within potential plume at SBOO offshore stations and corresponding reference values during 2014. Highlighted values indicate out-of-range values. Plume width is the number of meters in the water column where CDOM measurements exceeded the 95th percentile. DO = dissolved 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)**
I35	13 May 14	5	7.9	8.1	82	6.4	8.1	72
I12	15 May 14	3	6.8	8.0	85	6.3	8.1	72
I16	15 May 14	1	6.6	8.1	84	6.0	8.0	72
I23	15 May 14	5	8.0	8.1	73	6.4	8.1	72
I12	06 Aug 14	3	8.5	8.2	88	7.9	8.2	88
I16	06 Aug 14	5	8.3	8.1	**88**	8.0	8.2	88
I23	06 Aug 14	2	8.1	8.1	**84**	8.0	8.2	89
I39	06 Aug 14	4	8.2	8.1	**84**	7.9	8.2	88
I35	07 Aug 14	4	7.6	8.1	**77**	7.9	8.2	88
I2	17 Nov 14	2	7.7	8.1	88	7.5	8.2	86
I3	17 Nov 14	5	7.7	8.1	86	7.6	8.1	85
I6	17 Nov 14	5	7.7	8.1	**83**	7.5	8.2	86
I9	17 Nov 14	1	7.8	8.1	**82**	7.5	8.1	86
I10	17 Nov 14	9	7.5	8.2	**78**	7.5	8.2	86



Appendix B.9

Representative vertical profiles of CDOM and buoyancy frequency from SBOO nearfield station I12 during 2014.



Appendix B.10

Representative vertical profiles of CDOM and dissolved oxygen (DO) from SBOO nearfield station I12 during 2014.

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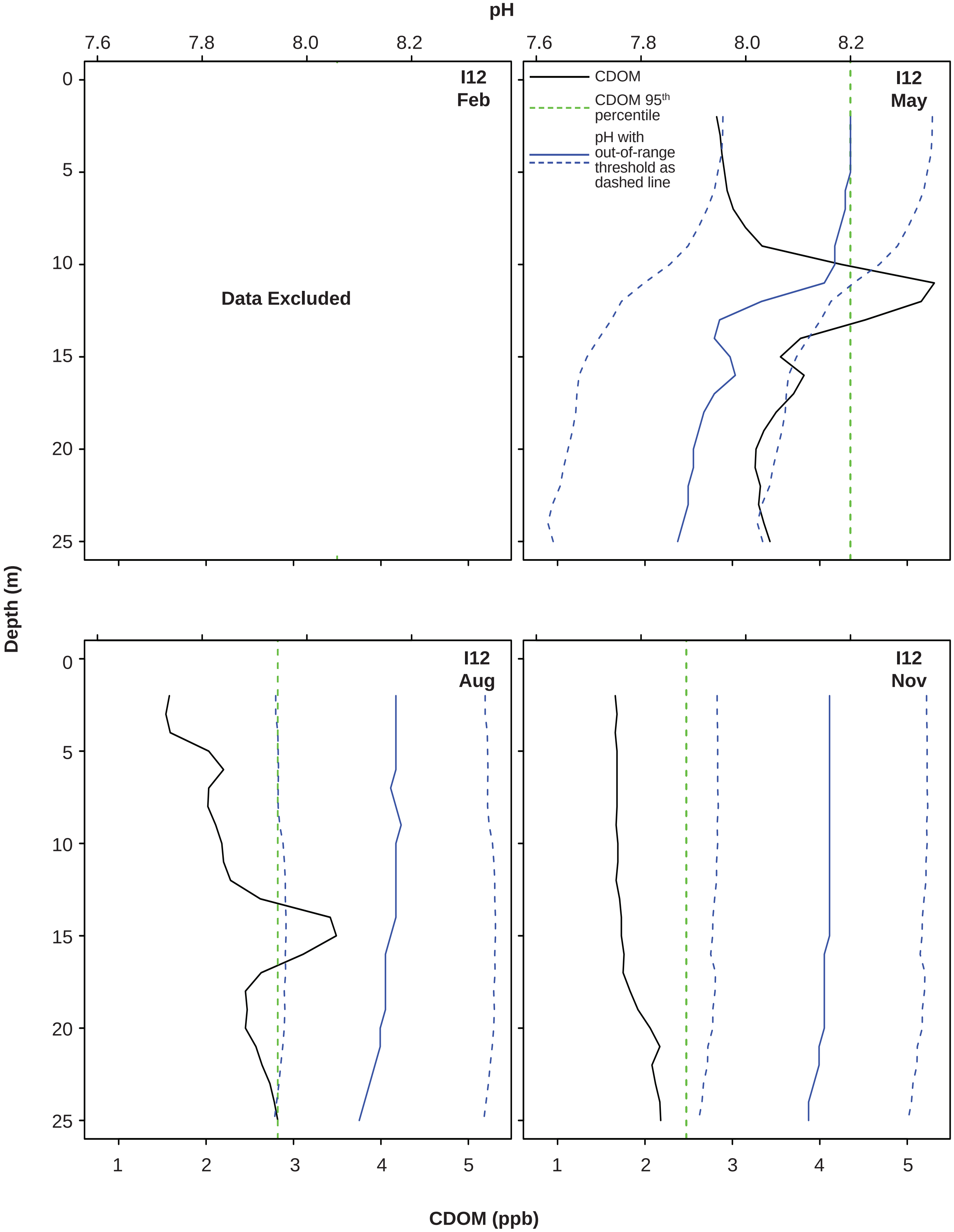
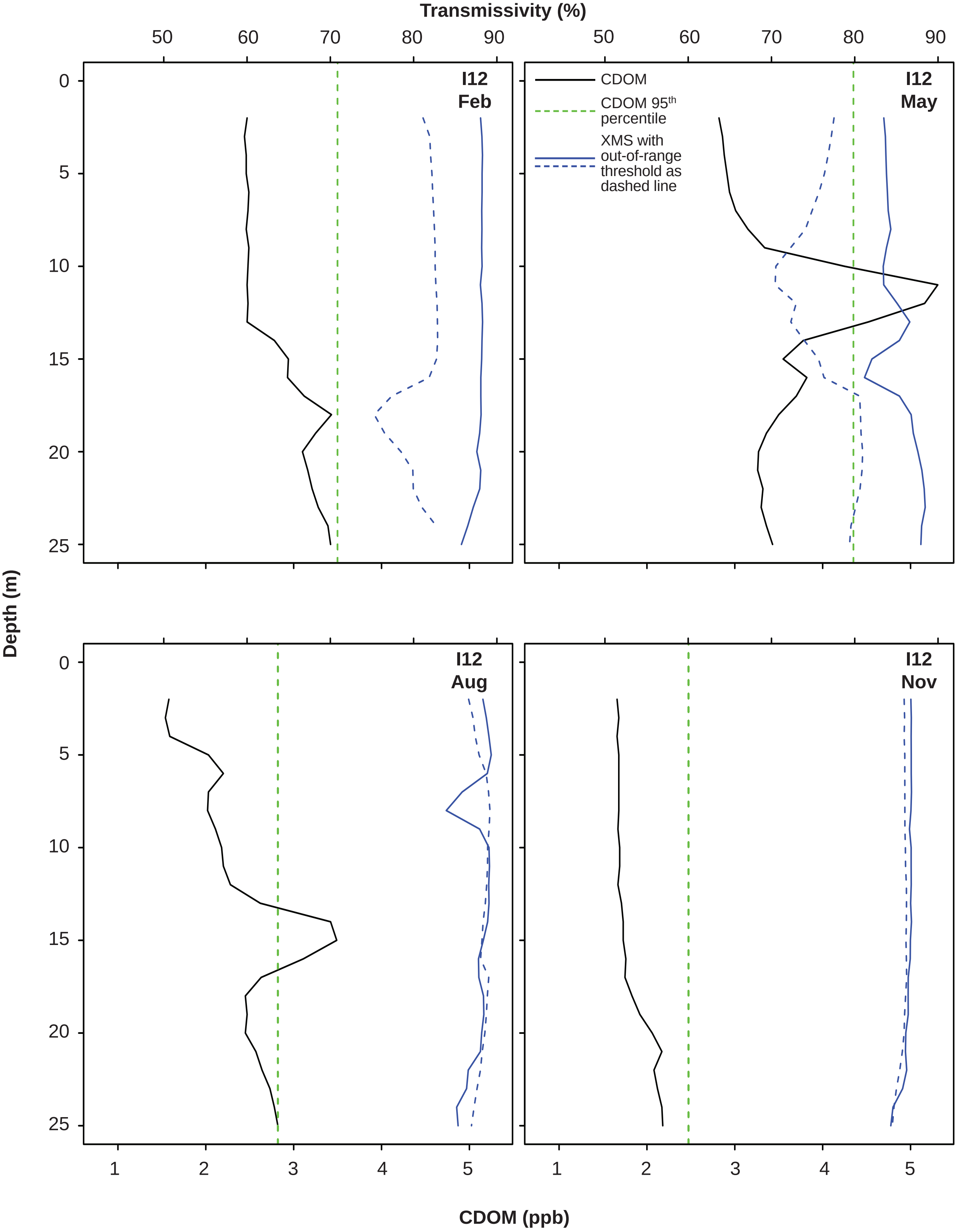


Appendix B.11

Representative vertical profiles of CDOM and pH from SBOO nearfiled station I12 during 2014. Data for February excluded due to instrumentation issues.



Appendix B.12

Representative vertical profiles of CDOM and transmissivity from SBOO nearfield station I12 during 2014.

Appendix C

Supporting Data

2014 SBOO Stations

Sediment Conditions

Appendix C.1

Constituents and method detection limits (MDL) used for the analysis of sediments during 2014.

Parameter	MDL	Parameter	MDL
Organic Indicators			
Total Nitrogen (TN, % wt.)	0.005	Total Sulfides (ppm)	0.14
Total Organic Carbon (TOC, % wt.)	0.01	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
o,p-DDE	60	p,p-DDMU[a]	—
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] 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 2014. Included is a subset of the Wentworth scale presented as "phi" categories with corresponding Horiba channels, sieve sizes, and size fractions.

Wentworth Scale

	Horiba[a]				
Phi Size	**Min µm**	**Max µm**	**Sieve Size**[b]	**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	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

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Appendix C.3

Summary of the constituents that make up total DDT, total HCH, total chlordane, total PCB, and total PAH in sediments from the SBOO region during 2014; nd = not detected.

Station	Class	Constituent	Winter	Summer	Units
I-6	PCB	PCB 66	nd	88	ppt
I-6	PCB	PCB 70	nd	65	ppt
I-6	PCB	PCB 74	nd	63	ppt
I-7	HCH	HCH, Beta isomer	1850	nd	ppt
I-7	Chlordane	Alpha (cis) Chlordane	295	nd	ppt
I-7	Chlordane	Gamma (trans) Chlordane	205	nd	ppt
I-7	Chlordane	Methoxychlor	175	nd	ppt
I-7	DDT	p,p-DDD	650	nd	ppt
I-7	DDT	p,p-DDE	480	nd	ppt
I-7	DDT	p,p-DDT	500	nd	ppt
I-9	DDT	p,p-DDE	270	nd	ppt
I-9	PAH	2,6-dimethylnaphthalene	nd	8	ppb
I-12	PAH	2,6-dimethylnaphthalene	6	nd	ppb
I-14	DDT	p,p-DDE	250	nd	ppt
I-16	DDT	p,p-DDE	100	nd	ppt
I-18	PAH	2,6-dimethylnaphthalene	10	nd	ppb
I-20	PAH	2,6-dimethylnaphthalene	8	nd	ppb
I-22	DDT	p,p-DDE	1400	240	ppt
I-22	PAH	2,6-dimethylnaphthalene	8	nd	ppb
I-27	HCH	HCH, Beta isomer	1000	nd	ppt
I-27	DDT	p,p-DDE	360	nd	ppt
I-28	DDT	p,p-DDE	550	920	ppt
I-28	PAH	2,6-dimethylnaphthalene	nd	9	ppb
I-28	PCB	PCB 49	nd	64	ppt
I-28	PCB	PCB 66	nd	64	ppt
I-28	PCB	PCB 99	nd	130	ppt
I-28	PCB	PCB 101	nd	190	ppt
I-28	PCB	PCB 138	nd	110	ppt
I-28	PCB	PCB 153/168	nd	200	ppt
I-29	DDT	o,p-DDT	nd	190	ppt

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
I-29	DDT	p,p-DDE	810	1800	ppt
I-29	DDT	p,-p-DDMU	nd	110	ppt
I-29	DDT	p,p-DDT	nd	390	ppt
I-29	PAH	2,6-dimethylnaphthalene	9	nd	ppb
I-30	DDT	o,p-DDE	nd	69	ppt
I-30	DDT	p,p-DDE	380	250	ppt
I-30	DDT	p,p-DDT	450	110	ppt
I-30	PAH	2,6-dimethylnaphthalene	11	nd	ppb
I-33	DDT	p,p-DDE	nd	100	ppt
I-33	DDT	p,p-DDT	nd	150	ppt
I-34	HCH	HCH, Beta isomer	1000	nd	ppt
I-34	DDT	p,p-DDD	420	nd	ppt
I-34	DDT	p,p-DDE	250	nd	ppt
I-34	DDT	p,p-DDT	440	nd	ppt
I-35	DDT	p,p-DDE	230	nd	ppt
I-35	PAH	2,6-dimethylnaphthalene	12	4	ppb
I-35	PAH	3,4-benzo(B)fluoranthene	8	nd	ppb
I-35	PAH	Benzo[A]pyrene	8	5	ppb
I-35	PAH	Benzo[G,H,I]perylene	nd	4	ppb
I-35	PAH	Chrysene	nd	4	ppb
I-35	PAH	Fluoranthene	8	10	ppb
I-35	PAH	Pyrene	nd	11	ppb

Appendix C.4

Summary of particle size parameters (%) for each SBOO station sampled during winter 2014. 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	2.8	18.3	41.4	20.9	7.3	7.0	2.3	0.0	organic debris[b]
	I34	0.0	0.4	10.8	52.3	32.6	3.0	0.2	0.0	0.6	0.1	0.0	shell hash
	I31	0.0	0.0	0.0	0.6	18.7	71.9	5.0	0.0	1.3	2.2	0.3	—
	I23	0.0	0.0	0.0	3.4	25.0	57.5	7.9	1.1	2.7	2.2	0.1	shell hash, organic debris[b]
	I18	0.0	0.0	0.0	1.5	20.7	64.4	8.3	0.8	2.2	2.0	0.1	—
	I10	0.0	0.0	0.0	2.0	25.3	61.9	6.3	0.7	2.0	1.8	0.1	organic debris[b], shell hash
	I4	0.0	2.7	32.7	52.7	10.0	1.8	0.2	0.0	0.0	0.0	0.0	shell hash
28-m Stations	I33	0.0	0.0	0.0	5.0	38.0	45.6	4.0	1.2	3.4	2.6	0.1	organic debris (algae)
	I30	0.0	0.0	0.0	0.9	15.2	60.6	14.3	2.0	4.1	2.8	0.1	—
	I27	0.0	0.0	0.0	0.6	14.4	66.7	11.9	0.9	2.6	2.6	0.1	—
	I22	0.0	0.0	0.0	3.6	26.6	53.1	10.0	1.4	3.1	2.2	0.0	organic debris[b]
	I14[a]	0.0	0.0	0.0	3.3	21.6	55.4	12.4	1.6	3.3	2.3	0.1	organic debris[b], Chaetopterid tubes
	I16[a]	0.0	0.0	5.1	31.6	38.4	16.6	3.4	1.9	2.4	0.6	0.0	organic debris[b], Chaetopterid tubes
	I15[a]	0.0	0.0	5.9	40.3	32.4	13.5	3.8	1.5	2.0	0.6	0.0	Chaetopterid tubes
	I12[a]	0.0	0.4	11.8	46.9	22.6	10.6	3.5	1.6	2.1	0.5	0.0	organic debris[b], Chaetopterid tubes
	I9	0.0	0.0	0.0	1.2	15.6	59.7	15.4	2.3	3.7	2.1	0.0	organic debris[b], Chaetopterid tubes
	I6	0.0	3.3	32.3	48.6	10.6	2.0	0.9	0.9	1.1	0.3	0.0	red relict sand, shell hash
	I2	0.0	0.5	13.0	55.0	27.2	2.7	0.2	0.5	0.9	0.1	0.0	Chaetopterid tubes
	I3	0.0	0.1	10.2	55.4	30.5	2.2	0.2	0.5	0.8	0.1	0.0	—
38-m Stations	I29	0.0	0.0	0.0	3.1	20.3	44.8	18.7	4.2	5.8	3.1	0.1	organic debris[b]
	I21	0.0	3.2	37.0	44.5	8.3	1.7	1.0	1.7	2.3	0.4	0.0	red relict sand/shell hash/Chaet. tubes
	I13	0.0	2.3	33.7	52.1	8.4	1.3	0.3	0.6	1.0	0.3	0.0	red relict sand/shell hash/Chaet. tubes
	I8	0.0	3.3	28.7	46.0	14.4	2.8	1.1	1.4	1.9	0.4	0.0	Chaetopterid tubes
55-m Stations	I28[s]	4.4	10.3	25.4	13.6	3.5	20.5	22.3	—	—	—	—	black sand/shell hash
	I20	0.0	11.1	61.9	15.7	5.5	1.2	0.8	1.3	2.0	0.6	0.0	—
	I7	0.0	13.1	44.5	31.9	6.0	1.2	0.5	1.0	1.6	0.3	0.0	red relict sand
	I1	0.0	0.0	0.0	6.7	50.3	33.4	3.1	1.3	3.2	1.9	0.0	—

[a] nearfield stations; [b] contained worm 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 2014. 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	3.0	18.9	40.0	21.2	8.0	6.9	2.0	0.0	organic debris[b]
	I34[s]	35.3	18.3	25.0	11.0	5.6	1.6	3.2	—	—	—	—	shell hash/pea gravel
	I31	0.0	0.0	0.0	0.5	18.0	73.9	4.7	0.0	0.9	1.8	0.2	—
	I23	0.0	0.0	0.0	1.4	22.3	66.6	5.8	0.1	1.6	2.0	0.1	organic debris[b]
	I18	0.0	0.0	0.0	0.8	19.1	71.5	6.3	0.0	0.7	1.3	0.3	—
	I10	0.0	0.0	0.0	2.0	25.5	63.1	5.9	0.1	1.5	1.8	0.1	organic debris[b]
	I4	0.0	0.0	1.5	13.5	24.8	47.0	7.9	1.1	2.4	1.8	0.0	organic debris[b]
28-m Stations	I33	0.0	0.0	0.0	3.3	34.7	51.8	4.2	0.9	2.7	2.3	0.1	—
	I30	0.0	0.0	0.0	0.6	13.7	66.0	13.9	1.2	2.4	2.1	0.1	—
	I27	0.0	0.0	0.0	0.8	14.4	68.0	12.1	0.5	1.7	2.3	0.3	organic debris[b]
	I22	0.0	0.0	0.0	5.9	29.5	46.7	10.1	2.0	3.6	2.2	0.0	organic debris[b]/shell hash
	I14[a]	0.0	0.0	0.0	1.6	17.5	64.6	11.3	0.7	1.8	2.3	0.2	organic debris[b]
	I16[a]	0.0	0.1	9.5	36.9	31.1	15.7	2.8	1.3	1.9	0.6	0.0	organic debris[b]/shell hash
	I15[a]	0.0	0.0	5.8	39.5	33.3	14.4	3.7	1.2	1.6	0.5	0.0	organic debris[b]
	I12[a]	0.0	0.0	4.6	26.6	31.7	28.0	5.9	1.0	1.5	0.6	0.0	organic debris[b]/shell hash
	I9	0.0	0.0	0.0	0.8	14.8	62.5	14.8	1.6	3.1	2.2	0.1	organic debris[b]
	I6	0.0	2.3	32.5	52.7	9.7	1.6	0.5	0.2	0.5	0.0	0.0	organic debris[b]/shell hash
	I2	0.0	0.4	13.2	56.7	26.5	2.2	0.1	0.2	0.7	0.0	0.0	organic debris[b]
	I3	0.0	7.8	69.2	20.4	2.6	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	3.2	19.7	43.9	17.3	5.4	7.7	2.9	0.0	organic debris[b]
	I21	0.0	2.3	34.7	53.4	8.0	1.0	0.0	0.0	0.5	0.0	0.0	red relict sand/shell hash/Chaet. tubes
	I13	0.0	3.1	38.3	50.2	7.0	0.9	0.0	0.0	0.3	0.0	0.0	red relict sand/shell hash
	I8	0.0	1.0	21.0	57.7	16.0	1.8	0.3	0.8	1.2	0.3	0.0	forganic debris[b]
55-m Stations	I28[s]	13.5	13.5	20.7	10.7	3.0	19.4	19.2	—	—	—	—	black sand
	I20	0.0	10.1	59.5	17.9	4.8	1.5	1.2	1.7	2.6	0.7	0.0	—
	I7	0.0	10.8	63.1	21.6	3.3	0.5	0.0	0.0	0.6	0.1	0.0	red relict sand
	I1	0.0	0.0	0.0	7.3	49.9	33.5	3.1	1.0	2.8	2.2	0.1	—

[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 2014.

	Winter				Summer			
	Sulfides (ppm)	**TN (% wt)**	**TOC (% wt)**	**TVS (% wt)**	**Sulfides (ppm)**	**TN (% wt)**	**TOC (% wt)**	**TVS (% wt)**
19-m Stations								
I35	3.45	0.042	0.31	1.44	6.79	0.023	0.33	1.56
I34	0.70	0.013	0.06	0.49	1.33	0.018	0.16	1.17
I31	1.55	0.020	0.14	0.57	1.98	0.016	0.18	0.62
I23	4.62	0.026	0.15	0.95	2.38	0.023	0.17	0.80
I18	2.87	0.028	0.14	0.69	10.30	0.015	0.85	0.74
I10	1.31	0.027	0.15	0.81	2.80	0.019	0.18	0.92
I4	0.18	0.018	0.05	0.37	3.09	0.032	0.21	0.80
28-m Stations								
I33	2.94	0.033	0.21	1.22	6.85	0.027	0.36	1.33
I30	2.01	0.033	0.23	1.13	2.97	0.029	0.24	1.12
I27	1.70	0.030	0.20	0.98	3.10	0.029	0.20	1.04
I22	4.80	0.034	0.22	0.98	3.16	0.029	0.23	1.10
I14[a]	2.60	0.031	0.18	1.19	3.30	0.029	0.23	1.10
I16[a]	1.26	0.031	0.17	0.65	1.81	0.015	0.16	0.57
I15[a]	1.54	0.023	0.12	0.63	2.91	0.018	0.17	0.60
I12[a]	0.82	0.022	0.09	0.66	3.67	0.013	0.17	0.72
I9	2.08	0.034	0.20	1.31	4.84	0.034	0.24	1.28
I6	0.26	0.015	0.04	0.41	0.27	0.013	0.13	0.53
I2	1.10	0.017	0.06	0.46	1.42	0.014	0.13	0.44
I3	0.39	0.017	0.06	0.50	0.23	0.008	0.11	0.37
38-m Stations								
I29	2.69	0.047	0.36	1.47	2.67	0.029	0.37	1.55
I21	0.49	0.015	0.03	0.53	0.31	0.010	0.13	0.58
I13	0.16	0.021	0.08	0.41	0.27	0.014	0.13	0.53
I8	3.15	0.019	0.08	0.43	1.34	0.013	0.14	0.58
55-m Stations								
I28	1.39	0.057	0.48	1.54	2.07	0.044	0.59	1.90
I20	0.30	0.017	0.05	0.52	0.76	0.011	0.16	0.55
I7	0.30	0.016	0.05	0.49	0.27	0.009	0.11	0.50
I1	1.35	0.028	0.17	0.97	1.27	0.028	0.25	1.02
Detection Rate (%)	100	100	100	100	100	100	100	100

[a] nearfield stations

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Appendix C.6

Concentrations of trace metals (ppm) in sediments from SBOO stations sampled during winter 2014. 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	11,700	0.7	3.84	48.90	0.17	nd	15.8	2.6	12,400	3.6	156.0	0.027	8.5	nd	nd	nd	0.6	34.4
I34	2860	0.3	2.83	11.10	0.04	nd	4.9	nd	4340	2.1	64.4	0.005	1.9	nd	nd	nd	1.3	9.0
I31	5680	1.1	3.97	24.40	nd	nd	10.3	nd	8930	nd	268.0	0.005	3.0	nd	nd	nd	nd	19.7
I23	7800	0.6	2.17	40.20	0.11	nd	11.5	nd	8090	1.6	127.0	0.005	4.3	nd	nd	nd	0.3	19.0
I18	7450	1.1	2.33	52.40	0.12	nd	15.6	nd	11,500	1.2	232.0	nd	4.1	nd	nd	nd	nd	22.2
I10	5390	0.4	1.87	34.40	nd	nd	10.1	0.7	6620	1.6	60.4	0.004	3.0	0.18	nd	nd	0.4	14.8
I4	607	0.3	1.10	1.75	nd	nd	4.0	nd	1540	1.5	8.0	nd	0.7	nd	nd	nd	0.3	2.7
28-m Stations																		
I33	6760	0.8	2.77	29.60	0.11	nd	10.5	nd	9260	2.4	217.0	0.017	4.0	nd	nd	nd	nd	22.7
I30	10,000	0.5	2.40	37.80	nd	nd	13.1	1.0	8650	1.4	108.0	0.009	5.4	0.07	nd	nd	0.5	23.1
I27	5540	nd	1.93	31.00	0.08	nd	10.2	1.4	6110	1.8	57.5	0.008	3.8	nd	nd	nd	1.1	16.8
I22	7880	0.9	2.16	31.20	0.13	nd	12.4	nd	8970	1.6	166.0	0.007	5.0	0.14	nd	nd	nd	20.7
I14[a]	10,500	0.7	1.72	42.60	0.15	nd	14.0	nd	10,500	1.3	172.0	0.006	5.8	nd	nd	nd	nd	26.3
I16[a]	5400	0.3	2.65	24.70	0.08	nd	8.7	nd	6430	1.2	88.3	0.004	3.2	nd	nd	nd	nd	15.0
I15[a]	5510	0.7	2.67	18.30	0.10	nd	11.1	nd	8310	1.8	145.0	0.006	3.7	0.07	nd	nd	0.4	17.3
I12[a]	2540	nd	1.10	12.80	0.05	nd	6.4	0.5	4070	1.6	32.7	0.014	1.8	nd	nd	nd	0.8	9.4
I9	7560	0.4	1.94	42.10	nd	nd	12.3	1.7	8350	1.6	78.6	0.007	4.7	nd	nd	nd	0.3	21.3
I6	1170	0.5	5.55	4.27	nd	nd	8.5	nd	4300	2.3	15.0	nd	1.1	nd	nd	nd	0.6	4.6
I2	879	nd	1.42	2.08	nd	nd	5.1	nd	1200	1.2	6.8	0.004	0.8	nd	nd	nd	0.6	2.6
I3	862	nd	nd	2.23	nd	nd	6.3	nd	1490	1.2	7.3	nd	0.8	0.17	nd	nd	0.5	2.5
38-m Stations																		
I29	9380	1.0	2.80	38.70	nd	nd	14.6	nd	11,300	2.2	191.0	0.015	6.1	nd	nd	nd	nd	26.8
I21	1750	nd	10.80	3.20	0.06	nd	12.0	nd	8620	3.5	22.6	nd	1.7	nd	nd	nd	0.5	7.1
I13	1810	1.7	4.52	4.05	0.07	nd	11.9	nd	13,600	2.2	350.0	nd	1.7	0.15	nd	nd	nd	15.8
I8	1410	nd	2.55	3.92	nd	nd	7.3	nd	3240	1.1	17.0	nd	1.1	nd	nd	nd	0.5	5.8
55-m Stations																		
I28	7800	0.6	2.59	26.20	nd	nd	11.3	1.6	8690	2.8	121.0	0.018	6.0	0.20	nd	nd	0.4	21.0
I20	2020	nd	3.39	4.70	0.06	nd	5.8	nd	5350	1.6	42.9	nd	1.6	nd	nd	nd	0.4	7.6
I7	1350	nd	6.12	2.59	nd	nd	8.8	nd	6370	2.5	14.9	nd	0.8	0.18	nd	nd	0.7	5.1
I1	2630	0.3	8.01	10.70	nd	nd	7.0	0.7	3700	1.8	35.3	0.008	2.9	nd	nd	nd	0.4	8.3
Detection Rate (%)	100	70	96	100	52	0	100	30	100	96	100	67	100	30	0	0	70	100

[a] nearfield stations

Appendix C.6 *continued*

Concentrations of trace metals (ppm) in sediments from SBOO stations sampled during summer 2014. 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	7550	0.5	2.85	44.70	0.11	nd	13.9	3.6	10,800	3.7	99.2	0.008	5.3	nd	nd	nd	1.0	30.8
I34	1850	0.6	2.64	11.90	nd	nd	4.1	1.5	3920	2.1	50.3	nd	1.4	nd	nd	nd	0.8	9.3
I31	3160	0.4	0.80	16.20	0.02	nd	6.7	0.4	3420	1.4	35.7	nd	1.8	nd	nd	0.6	0.6	7.9
I23	4320	0.5	0.62	33.40	nd	nd	8.3	0.9	4820	1.4	49.7	nd	2.5	nd	nd	nd	nd	11.4
I18	4820	0.5	0.57	40.10	nd	nd	10.6	0.8	6380	2.0	57.9	nd	2.9	nd	nd	nd	nd	14.1
I10	5100	nd	1.04	31.90	nd	nd	9.5	1.5	6440	1.7	61.7	nd	3.1	nd	nd	0.7	nd	15.7
I4	3310	nd	1.30	21.30	nd	nd	7.3	0.8	4290	1.2	41.4	nd	2.8	nd	nd	1.3	nd	9.3
28-m Stations																		
I33	4040	0.5	1.55	20.40	0.08	nd	7.7	1.9	5800	2.8	60.9	0.009	2.8	nd	nd	1.2	0.6	15.6
I30	5620	0.7	1.64	30.10	0.06	nd	10.5	1.7	6370	2.2	59.2	nd	3.5	nd	nd	nd	1.1	16.5
I27	5370	0.4	1.03	29.40	nd	nd	9.5	1.6	5910	2.2	57.1	nd	3.4	nd	nd	nd	nd	15.6
I22	4410	nd	1.03	23.20	nd	nd	8.9	1.2	5110	1.5	47.9	nd	3.1	nd	nd	nd	nd	13.1
I14[a]	6240	0.7	0.94	36.90	nd	0.08	11.0	1.8	7250	2.0	68.9	nd	4.0	nd	nd	nd	0.5	18.5
I16[a]	2680	nd	1.22	11.70	nd	nd	6.4	0.4	3550	1.3	31.0	nd	1.8	nd	nd	nd	nd	8.2
I15[a]	2650	nd	1.31	13.10	nd	nd	9.1	0.3	4810	1.7	32.8	nd	2.0	nd	nd	nd	nd	9.5
I12[a]	3490	nd	0.99	21.10	nd	nd	7.2	0.8	4860	1.3	44.6	nd	2.1	nd	nd	nd	nd	12.9
I9	7220	nd	1.91	44.30	nd	nd	12.1	2.4	8430	2.0	81.3	nd	5.0	nd	nd	nd	nd	22.2
I6	796	nd	3.79	2.25	nd	nd	7.9	nd	3640	1.3	7.8	nd	0.7	nd	nd	0.6	nd	3.5
I2	953	nd	0.56	2.15	nd	nd	5.2	nd	1190	nd	8.6	nd	0.8	nd	nd	2.0	nd	2.6
I3	597	0.3	1.15	1.39	nd	nd	5.3	nd	1760	1.1	5.4	nd	0.8	nd	nd	nd	nd	2.3
38-m Stations																		
I29	5690	0.7	1.44	32.50	0.09	nd	11.7	2.7	7610	2.9	63.3	0.004	4.5	nd	nd	0.9	1.6	18.3
I21	1150	0.4	8.65	3.16	nd	nd	11.9	nd	8210	3.6	13.1	nd	1.1	nd	nd	nd	nd	6.7
I13	882	0.4	6.52	2.22	nd	nd	9.2	nd	5540	2.5	11.6	nd	0.9	nd	nd	nd	nd	4.5
I8	1470	nd	3.62	3.95	nd	nd	8.2	nd	3840	1.5	16.5	nd	1.2	nd	nd	nd	nd	6.5
55-m Stations																		
I28	6260	0.9	2.10	32.60	0.11	nd	11.9	4.4	8850	4.3	68.0	0.007	6.5	nd	nd	nd	1.0	22.4
I20	1550	0.6	3.22	4.43	nd	nd	5.8	nd	5050	2.1	19.8	nd	1.5	nd	nd	0.7	nd	7.1
I7	1030	0.4	6.76	2.45	nd	nd	8.2	nd	6280	2.4	17.8	nd	0.9	nd	nd	0.6	nd	5.2
I1	2400	nd	0.75	8.43	nd	nd	6.3	0.8	3210	1.6	30.3	nd	2.7	nd	nd	0.6	nd	7.5
Detection Rate (%)	100	59	100	100	22	11	100	70	100	96	100	15	100	0	0	41	33	100

[a] nearfield stations

Appendix C.7

Concentrations of total DDT, HCB, total HCH, total chlordane (tChlor), total PCB, and total PAH detected in sediments from SBOO stations sampled during winter and summer 2014. Values that exceed thresholds are highlighted (see Table 4.1); nd = not detected

	Winter						Summer					
	tDDT (ppt)	HCB (ppt)	tHCH (ppt)	tChlor (ppt)	tPCB (ppt)	tPAH (ppb)	tDDT (ppt)	HCB (ppt)	tHCH (ppt)	tChlor (ppt)	tPCB (ppt)	tPAH (ppb)
19-m Stations												
I35	230	nd	nd	nd	nd	35	nd	nd	nd	nd	nd	40
I34	1110	nd	1000	nd	nd	nd	nd	nd	nd	nd	nd	nd
I31	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I23	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I18	nd	nd	nd	nd	nd	10	nd	nd	nd	nd	nd	nd
I10	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
28-m Stations												
I33	nd	nd	nd	nd	nd	nd	250	nd	nd	nd	nd	nd
I30	830	nd	nd	nd	nd	11	429	nd	nd	nd	nd	nd
I27	360	nd	1000	nd	nd	nd	nd	nd	nd	nd	nd	nd
I22	1400	nd	nd	nd	nd	8	240	nd	nd	nd	nd	nd
I14[a]	250	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I16[a]	100	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I15[a]	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I12[a]	nd	nd	nd	nd	nd	6	nd	nd	nd	nd	nd	nd
I9	270	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	8
I6	nd	nd	nd	nd	nd	nd	nd	190	nd	nd	216	nd
I2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I3	nd	410	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
38-m Stations												
I29	810	440	nd	nd	nd	9	2490	75	nd	nd	nd	nd
I21	nd	nd	nd	nd	nd	nd	nd	81	nd	nd	nd	nd
I13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
I8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
55-m Stations												
I28	550	nd	nd	nd	nd	10	920	295	nd	nd	758	9
I20	nd	nd	nd	nd	nd	8	nd	nd	nd	nd	nd	nd
I7	1630	nd	1850	675	nd	nd	nd	nd	nd	nd	nd	nd
I1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Detect. Rate (%)	41	7	11	4	0	30	19	15	0	0	7	11

[a] nearfield station

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Appendix D

Supporting Data

2014 SBOO Stations

Macrobenthic Communities

Appendix D.1

Macrofaunal community parameters by grab from SBOO benthic stations sampled during 2014. SR=species richness; Abun=abundance; H'=Shannon diversity index; J'=evenness; Dom=Swartz dominance; BRI=benthic response index. Stations are listed north to south from top to bottom for each depth contour.

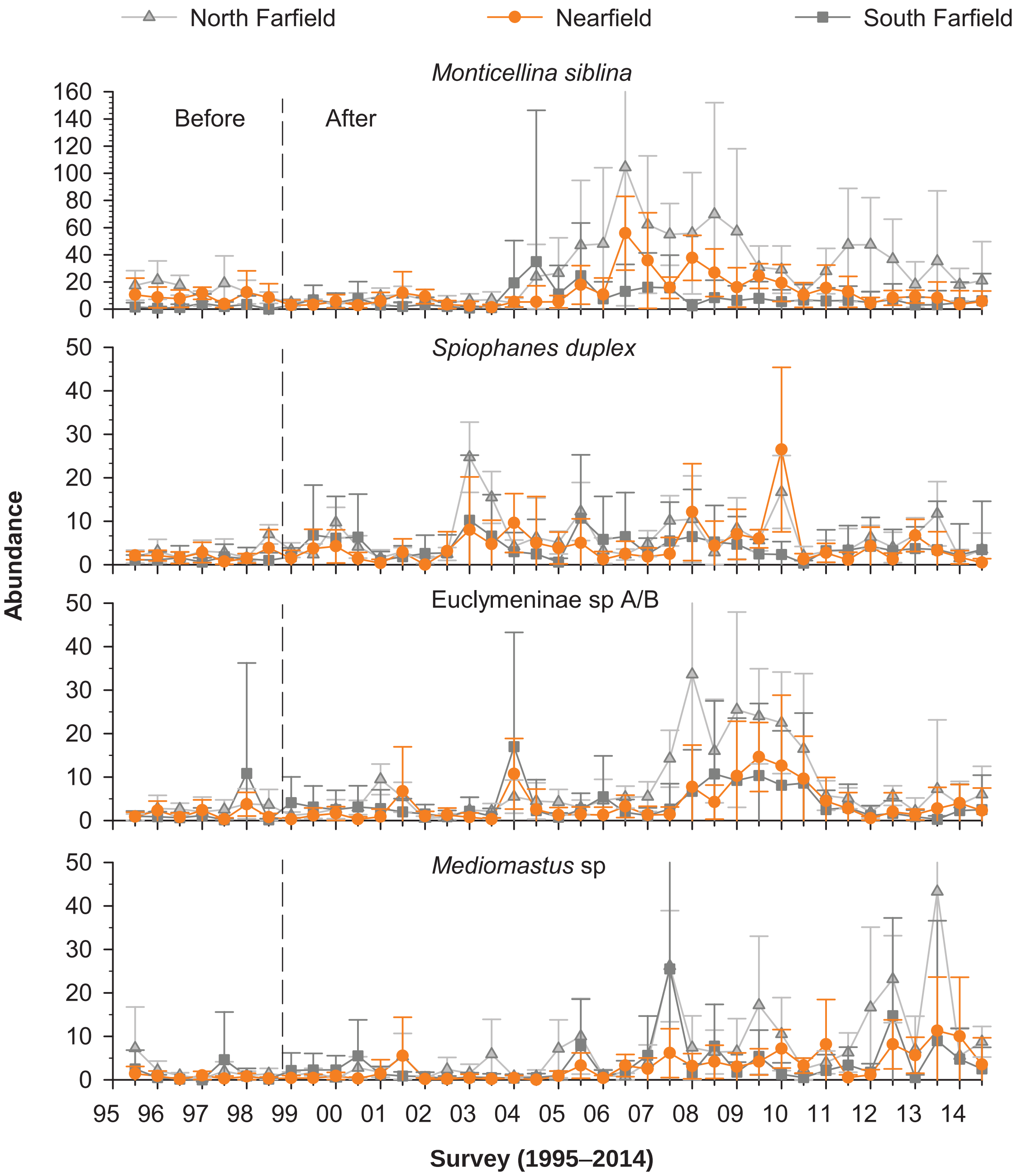
Depth Contour	Station	Survey	SR	Abun	H'	J'	Dom	BRI
19-m	I35	winter	70	145	4.0	0.93	34	24
		summer	73	193	3.8	0.89	27	31
	I34	winter	24	103	2.2	0.70	4	6
		summer	88	1401	2.6	0.58	8	19
	I31	winter	58	192	3.0	0.75	19	20
		summer	60	297	2.8	0.68	14	21
	I23	winter	87	246	4.2	0.93	37	21
		summer	75	266	3.7	0.85	24	18
	I18	winter	65	604	2.0	0.48	6	23
		summer	79	421	3.0	0.68	17	20
	I10	winter	97	926	2.3	0.51	11	21
		summer	80	454	3.1	0.70	15	18
	I4	winter	59	544	1.5	0.36	2	6
		summer	136	1039	3.4	0.70	21	22
28-m	I33	winter	110	308	4.3	0.91	45	24
		summer	89	276	3.7	0.83	31	25
	I30	winter	112	535	3.9	0.84	33	24
		summer	87	434	3.3	0.74	23	23
	I27	winter	89	311	3.8	0.85	31	25
		summer	96	499	3.3	0.71	21	23
	I22	winter	125	632	3.8	0.79	33	27
		summer	108	570	3.7	0.78	27	26
	I14[a]	winter	141	1486	2.4	0.49	11	23
		summer	76	378	2.8	0.66	14	24
	I16[a]	winter	123	1614	2.5	0.52	8	24
		summer	114	639	3.5	0.73	26	24
	I15[a]	winter	97	1114	2.3	0.49	6	24
		summer	60	320	2.8	0.70	11	22
	I12[a]	winter	118	1662	2.4	0.49	7	22
		summer	86	448	3.3	0.74	21	25
	I9	winter	139	1740	2.2	0.44	6	25
		summer	119	843	3.3	0.70	24	24
	I6	winter	86	1111	1.7	0.38	3	17
		summer	94	681	2.9	0.63	15	19
	I2	winter	61	843	1.9	0.46	5	21
		summer	45	472	2.0	0.52	5	20
	I3	winter	88	2191	1.7	0.39	3	21
		summer	58	354	2.9	0.73	12	12

[a] nearfield station

Appendix D.1 *continued*

Depth Contour	Station	Survey	SR	Abun	H'	J'	Dom	BRI
38-m	I29	winter	154	982	3.7	0.73	30	20
		summer	120	681	3.7	0.77	25	21
	I21	winter	110	620	3.6	0.77	25	15
		summer	97	590	2.7	0.60	14	22
	I13	winter	117	802	3.8	0.80	26	18
		summer	74	353	3.2	0.74	20	14
	I8	winter	76	1061	2.2	0.51	6	23
		summer	60	720	2.1	0.51	6	22
55-m	I28	winter	162	762	4.0	0.79	42	17
		summer	130	370	4.4	0.90	53	15
	I20	winter	118	773	3.7	0.78	25	14
		summer	50	207	3.0	0.77	14	9
	I7	winter	63	224	3.6	0.86	24	15
		summer	80	353	3.5	0.80	23	10
	I1	winter	81	333	3.7	0.84	23	21
		summer	59	201	3.5	0.86	19	17

[a] nearfield station



Appendix D.2

Four of the five historically most abundant species recorded from 1995 through 2014 at SBOO north farfield, nearfield, and south farfield primary core stations (*Spiophanes norrisi* 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–F (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[a]**	**B**	**C**	**D**	**E**	**F**
Spiophanes norrisi	9	**85**	9	**54**	**214**	**446**
Prionospio (Prionospio) jubata	0	11	**22**	19	**17**	**12**
Monticellina siblina	0	**19**	<1	<1	**12**	<1
Ampelisca cristata cristata	0	0	5	1	**11**	**9**
Ampelisca brevisimulata	0	2	<1	0	**11**	<1
Mediomastus sp	0	2	<1	1	**11**	2
Nereis sp A	0	<1	0	0	**7**	6
Magelona sacculata	**25**	0	0	0	**6**	1
Tellina modesta	0	0	0	0	**6**	<1
Phyllodoce hartmanae	0	0	0	1	**5**	**9**
Spiophanes duplex	0	**9**	5	2	**4**	<1
Rhepoxynius menziesi	0	0	0	0	**4**	<1
Rhepoxynius stenodes	0	0	1	0	**4**	<1
Paraprionospio alata	0	0	0	<1	**3**	<1
Carinoma mutabilis	**33**	3	0	0	1	13
Sthenelanella uniformis	0	**30**	**13**	<1	4	<1
Photis californica	0	**28**	1	<1	<1	<1
Chaetozone hartmanae	0	**13**	2	0	<1	<1
Lumbrineris sp Group II	0	**12**	0	3	<1	<1
Prionospio (Prionospio) dubia	0	**12**	0	0	0	0
Euclymeninae sp B	0	**11**	2	3	4	2
Ampelisca indentata	0	**10**	0	0	0	0
Photis brevipes	0	**10**	0	<1	2	2
Amphiodia urtica	0	**10**	<1	0	<1	1
Leptochelia dubia Cmplx	0	**9**	2	1	4	10
Euphilomedes carcharodonta	0	**7**	**24**	3	2	2
Photis linearmanus	0	**7**	0	0	0	0
Dialychone trilineata	0	**6**	0	0	0	<1
Amphissa undata	0	**6**	0	2	2	<1
Paradiopatra parva	0	**6**	0	<1	<1	<1
Spiochaetopterus costarum Cmplx	0	**15**	**22**	2	**17**	**44**
Ampelisca careyi	0	0	**15**	0	1	<1
Aricidea (Acmira) simplex	0	4	**8**	1	0	0
Mooreonuphis sp	0	0	0	**32**	0	4
Mooreonuphis sp SD1	0	0	0	**32**	0	5
Lanassa venusta venusta	0	<1	0	**21**	0	5
Eurydice caudata	0	<1	<1	**18**	<1	7
Laticorophium baconi	0	0	0	**11**	0	3

Appendix D.3 *continued*

Taxa	Cluster Group A[a]	B	C	D	E	F
Glycera oxycephala	1	0	0	**5**	<1	12
NEMATODA	0	2	0	11	3	**19**
Axiothella sp	0	0	0	2	<1	**16**
Notomastus latericeus	0	0	2	<1	6	**18**

[a] SIMPER analysis only conducted on cluster groups that contain more than one benthic grab. Highlighted values for single sample cluster groups cummulatively account for about 45% of the total abundance.

Appendix E

Supporting Data

2014 SBOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Taxonomic listing of demersal fish species captured during 2014 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).

Taxon/Species			Common Name	n	BM	Length (cm) Min	Max	Mean
RAJIFORMES								
	Rhinobatidae							
		Rhinobatos productus	Shovelnose Guitarfish[a]	1	0.4	45	45	45
	Platyrhynidae							
		Platyrhinoidis triseriata	Thornback[a]	2	2.1	46	59	52
	Rajidae							
		Raja binoculata	Big Skate[a]	1	0.6	42	42	42
		Raja inornata	California Skate[a]	7	0.8	25	31	28
		Raja rhina	Longnose Skate[a]	1	0.6	45	45	45
MYLIOBATIFORMES								
	Urolophidae							
		Urobatis halleri	Round Stingray[a]	1	0.2	28	28	28
CLUPEIFORMES								
	Engraulidae							
		Engraulis mordax	Northern Anchovy	12	0.1	9	11	10
AULOPIFORMES								
	Synodontidae							
		Synodus lucioceps	California Lizardfish	1082	16.7	6	26	12
OPHIDIIFORMES								
	Ophidiidae							
		Ophidion scrippsae	Basketweave Cusk-eel	4	0.2	17	21	20
BATRACHOIDIFORMES								
	Batrachoididae							
		Porichthys myriaster	Specklefin Midshipman	3	0.3	15	22	18
		Porichthys notatus	Plainfin Midshipman	11	0.6	4	24	12
GASTEROSTEIFORMES								
	Syngnathidae							
		Syngnathidae	Unidentified Pipefish	1	0.1	11	11	11
		Syngnathus californiensis	Kelp Pipefish	21	0.5	14	29	23
SCORPAENIFORMES								
	Hexagrammidae							
		Zaniolepis latipinnis	Longspine Combfish	151	3.6	4	15	13
	Cottidae							
		Chitonotus pugetensis	Roughback Sculpin	21	0.6	8	13	10
		Icelinus quadriseriatus	Yellowchin Sculpin	45	0.8	6	9	7
	Agonidae							
		Odontopyxis trispinosa	Pygmy Poacher	17	0.9	4	10	6
PERCIFORMES								
	Sciaenidae							
		Genyonemus lineatus	White Croaker	505	16.3	10	22	13
		Seriphus politus	Queenfish	65	1.3	9	15	11

[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
	Labrisomidae							
		Neoclinus blanchardi	Sarcastic Fringehead	2	0.2	6	8	7
	Stromateidae							
		Peprilus simillimus	Pacific Pompano	1	0.1	11	11	11
PLEURONECTIFORMES								
	Paralichthyidae							
		Citharichthys sordidus	Pacific Sanddab	11	0.7	7	21	14
		Citharichthys stigmaeus	Speckled Sanddab	1934	20.4	3	14	8
		Citharichthys xanthostigma	Longfin Sanddab	53	2.9	6	22	14
		Paralichthys californicus	California Halibut	2	1	32	35	34
		Xystreurys liolepis	Fantail Sole	10	1.3	8	24	17
	Pleuronectidae							
		Parophrys vetulus	English Sole	30	3.9	6	27	18
		Pleuronichthys decurrens	Curlfin Sole	58	3.8	5	19	11
		Pleuronichthys verticalis	Hornyhead Turbot	183	11.3	4	25	13
	Cynoglossidae							
		Symphurus atricaudus	California Tonguefish	195	2.2	6	16	11

Appendix E.2

Total abundance by species and station for demersal fish at SBOO trawl stations during 2014.

	Winter 2014							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Abundance by Survey**
Speckled Sanddab	76	54	112	176	84	132	60	694
White Croaker	3	35	14	31	201	16	205	505
California Lizardfish	10	50	31	8	59	15	1	174
Longspine Combfish	2	13	21	54		6	1	97
California Tonguefish		7	22	19	25	15	7	95
Hornyhead Turbot	3	20	24	30	9	5	2	93
Queenfish		2		2	54		7	65
Kelp Pipefish	4				9	4	2	19
Curlfin Sole	9	1	4	2		2		18
Pygmy Poacher			7	2	1	2	1	13
Northern Anchovy							12	12
Roughback Sculpin	7		3			1		11
Yellowchin Sculpin	1			7				8
Plainfin Midshipman				5			3	8
Longfin Sanddab			3	2				5
California Skate			2	1	1			4
Basketweave Cusk-eel					1		3	4
Fantail Sole				2			1	3
Thornback				2				2
Unidentified Pipefish		1						1
Shovelnose Guitarfish				1				1
Sarcastic Fringehead			1					1
Round Stingray							1	1
Pacific Pompano						1		1
English Sole			1					1
California Halibut						1		1
Survey Total	115	183	245	344	444	200	306	1837

Appendix E.2 *continued*

Name	Summer 2014							Species Abundance by Survey
	SD15	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	
Speckled Sanddab	112	267	150	180	225	179	127	1240
California Lizardfish	224	57	133	82	117	63	232	908
California Tonguefish	2	8	6	7	31	12	34	100
Hornyhead Turbot	7	17	14	15	7	10	20	90
Longspine Combfish					5	7	42	54
Longfin Sanddab		6	4	5	9	16	8	48
Curlfin Sole	15	4	1	6	1	6	7	40
Yellowchin Sculpin	1	1	8		1	24	2	37
English Sole	3	3	1	1	5	10	6	29
Pacific Sanddab	11							11
Roughback Sculpin					1	8	1	10
Fantail Sole		4	1		1		1	7
Pygmy Poacher		1	1	1			1	4
Specklefin Midshipman		1	1		1			3
Plainfin Midshipman					1		2	3
California Skate	1	1		1				3
Kelp Pipefish						2		2
Sarcastic Fringehead							1	1
Longnose Skate		1						1
California Halibut							1	1
Big Skate				1				1
Survey Total	376	371	320	299	405	337	485	2593
Annual Total	**491**	**554**	**565**	**643**	**849**	**557**	**791**	**4430**

Appendix E.3

Biomass (kg) by species and station for demersal fish at SBOO trawl stations during 2014.

	Winter 2014							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Biomass by Survey**
White Croaker	0.2	1.2	0.6	0.2	5.6	0.6	7.9	16.3
Speckled Sanddab	2.8	0.3	0.8	0.8	0.4	0.7	0.4	6.2
Hornyhead Turbot	0.1	0.6	1.2	1.7	0.5	0.3	0.1	4.5
California Lizardfish	0.1	1.0	0.5	0.1	1.1	0.2	0.1	3.1
Longspine Combfish	0.1	0.3	0.6	1.3		0.1	0.1	2.5
Thornback				2.1				2.1
Curlfin Sole	1.7	0.1	0.1	0.1		0.1		2.1
Queenfish		0.1		0.1	1.0		0.1	1.3
California Tonguefish		0.1	0.1	0.3	0.2	0.1	0.1	0.9
Pygmy Poacher			0.1	0.1	0.1	0.1	0.1	0.5
California Skate			0.2	0.2	0.1			0.5
Shovelnose Guitarfish				0.4				0.4
Longfin Sanddab			0.3	0.1				0.4
Kelp Pipefish	0.1				0.1	0.1	0.1	0.4
California Halibut						0.4		0.4
Roughback Sculpin	0.1		0.1			0.1		0.3
Fantail Sole				0.1			0.2	0.3
Yellowchin Sculpin	0.1			0.1				0.2
Round Stingray							0.2	0.2
Plainfin Midshipman				0.1			0.1	0.2
Basketweave Cusk-eel					0.1		0.1	0.2
Unidentified Pipefish		0.1						0.1
Sarcastic Fringehead			0.1					0.1
Pacific Pompano						0.1		0.1
Northern Anchovy							0.1	0.1
English Sole			0.1					0.1
Survey Total	5.3	3.8	4.8	7.8	9.2	2.9	9.7	43.5

Appendix E.3 *continued*

	Summer 2014							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Biomass by Survey**
Speckled Sanddab	1.4	2.8	1.5	1.9	2.7	2.3	1.6	14.2
California Lizardfish	3.7	0.8	1.8	1.1	1.9	1.0	3.3	13.6
Hornyhead Turbot	0.3	0.7	1.7	1.7	0.6	0.3	1.5	6.8
English Sole	0.7	0.7	0.1	0.1	0.7	0.9	0.6	3.8
Longfin Sanddab		0.1	0.4	0.3	0.6	0.9	0.2	2.5
Curlfin Sole	0.3	0.3	0.1	0.2	0.1	0.2	0.5	1.7
California Tonguefish	0.1	0.1	0.1	0.1	0.4	0.1	0.4	1.3
Longspine Combfish					0.1	0.2	0.8	1.1
Fantail Sole		0.6	0.1		0.1		0.2	1.0
Pacific Sanddab	0.7							0.7
Yellowchin Sculpin	0.1	0.1	0.1		0.1	0.1	0.1	0.6
Longnose Skate		0.6						0.6
California Halibut							0.6	0.6
Big Skate				0.6				0.6
Pygmy Poacher		0.1	0.1	0.1			0.1	0.4
Plainfin Midshipman					0.1		0.3	0.4
Specklefin Midshipman		0.1	0.1		0.1			0.3
Roughback Sculpin					0.1	0.1	0.1	0.3
California Skate	0.1	0.1		0.1				0.3
Sarcastic Fringehead							0.1	0.1
Kelp Pipefish						0.1		0.1
Survey Total	7.4	7.1	6.1	6.2	7.6	6.2	10.4	51.0
Annual Total	**12.7**	**10.9**	**10.9**	**14.0**	**16.8**	**9.1**	**20.1**	**94.5**

Appendix E.4

Pairwise r- and significance values for all year comparisons (Factor B) from the SBOO two-way crossed ANOSIM for demersal fish assemblages sampled from 1995 through 2014. Data are limited to summer surveys. Shading indicates significant difference (see Table 6.3).

		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1996	r-value	0.488																		
	sig-value	3.3																		
1997	r-value	0.326	0.116																	
	sig-value	10	26.7																	
1998	r-value	0.326	0.628	0.465																
	sig-value	8.9	2.2	2.2																
1999	r-value	0.837	0.744	0.070	0.721															
	sig-value	1.1	1.1	38.9	1.1															
2000	r-value	0.512	0.419	-0.163	0.605	0.116														
	sig-value	2.2	5.6	83.3	1.1	34.4														
2001	r-value	0.535	0.372	-0.116	0.372	0.488	0.395													
	sig-value	5.6	5.6	63.3	6.7	2.2	8.9													
2002	r-value	0.674	0.651	0.023	0.791	0.047	0.047	0.465												
	sig-value	1.1	1.1	47.8	1.1	44.4	47.8	4.4												
2003	r-value	1.000	1.000	0.674	0.767	0.698	0.628	0.930	0.605											
	sig-value	1.1	1.1	1.1	1.1	6.7	2.2	1.1	2.2											
2004	r-value	1.000	1.000	0.698	0.814	0.395	0.488	0.837	0.233	0.279										
	sig-value	1.1	1.1	1.1	1.1	6.7	4.4	1.1	17.8	6.7										
2005	r-value	0.674	0.721	0.512	0.767	0.628	0.558	0.791	0.488	0.558	0.233									
	sig-value	3.3	3.3	1.1	2.2	3.3	2.2	1.1	4.4	5.6	13.3									
2006	r-value	0.651	0.698	0.535	0.674	0.674	0.628	0.791	0.605	0.744	0.395	0.140								
	sig-value	3.3	3.3	3.3	2.2	3.3	1.1	1.1	1.1	1.1	1.1	33.3								
2007	r-value	0.744	0.744	0.581	0.814	0.488	0.605	0.814	0.605	0.744	0.093	0.163	0.372							
	sig-value	2.2	2.2	1.1	1.1	6.7	1.1	1.1	2.2	3.3	36.7	24.4	6.7							
2008	r-value	0.698	0.860	0.791	0.721	0.744	0.791	0.814	0.721	0.907	0.465	-0.023	0.558	0.233						
	sig-value	3.3	2.2	1.1	1.1	2.2	1.1	1.1	1.1	2.2	1.1	60.0	2.2	10.0						
2009	r-value	0.953	1.000	0.884	0.837	0.907	0.884	0.907	0.884	0.953	0.814	0.349	0.535	0.628	0.372					
	sig-value	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	13.3	8.9	5.6	10.0					
2010	r-value	0.977	1.000	0.953	0.884	1.000	0.884	0.930	0.884	0.907	0.721	0.395	0.651	0.721	0.419	0.140				
	sig-value	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	10.0	2.2	1.1	2.2	28.9				
2011	r-value	0.721	0.628	0.326	0.581	0.442	0.395	0.581	0.279	0.535	0.326	0.023	0.349	0.209	0.302	0.349	0.488			
	sig-value	1.1	1.1	3.3	1.1	1.1	1.1	1.1	11.1	1.1	4.4	44.4	10.0	16.7	6.7	2.2	2.2			
2012	r-value	0.744	0.767	0.744	0.698	0.814	0.721	0.884	0.698	0.767	0.628	0.488	0.581	0.628	0.535	0.512	0.395	0.233		
	sig-value	3.3	3.3	1.1	2.2	2.2	2.2	1.1	3.3	3.3	2.2	7.8	5.6	4.4	7.8	5.6	4.4	16.7		
2013	r-value	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.907	0.953	0.907	0.860	0.907	0.907	0.814	0.581	0.535	0.512	
	sig-value	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	2.2	1.1	1.1	3.3	4.4	6.7	4.4	
2014	r-value	1.000	1.000	0.884	0.837	1.000	0.837	0.953	0.907	1.000	0.977	0.791	0.744	0.860	0.884	0.744	0.442	0.442	0.233	0.721
	sig-value	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	5.6	6.7	11.1	3.3

Appendix E.5

Taxonomic listing of megabenthic invertebrate taxa captured during 2014 at SBOO trawl stations. Data are number of individuals (n). Taxonomic arrangement from SCAMIT (2013).

Taxon/Species				**n**
CNIDARIA				
	Anthozoa			
		Virgulariidae	*Stylatula elongata*	4
MOLLUSCA				
	Polyplacophora			
		Ischnochitonidae	*Lepidozona scrobiculata*	1
	Gastropoda			
		Calliostomatidae	*Calliostoma canaliculatum*	1
			Calliostoma tricolor	2
		Naticidae	*Sinum scopulosum*	1
		Bursidae	*Crossata ventricosa*	15
		Buccinidae	*Kelletia kelletii*	23
		Columbellidae	*Amphissa undata*	2
		Muricidae	*Pteropurpura festiva*	1
			Pteropurpura macroptera	1
		Pseudomelatomidae	*Crassispira semiinflata*	1
		Philinidae	*Philine auriformis*	82
		Pleurobranchidae	*Pleurobranchaea californica*	34
		Onchidorididae	*Acanthodoris brunnea*	100
		Arminidae	*Armina californica*	2
		Tritoniidae	*Tritonia tetraquetra*	1
	Cephalopoda			
		Octopodidae	*Octopus rubescens*	58
ANNELIDA				
	Polychaeta			
		Aphroditidae	*Aphrodita armifera*	2
			Aphrodita refulgida	13
ARTHROPODA				
	Malacostraca			
		Hemisquillidae	*Hemisquilla californiensis*	3
		Cymothoidae	*Elthusa vulgaris*	64
		Penaeidae	*Farfantepenaeus californiensis*	2
		Sicyoniidae	*Sicyonia ingentis*	8
			Sicyonia penicillata	56
		Pandalidae	*Pandalus danae*	3
		Crangonidae	*Crangon alba*	1
			Crangon nigromaculata	78
		Palinuridae	*Panulirus interruptus*	2
		Diogenidae	*Paguristes ulreyi*	1
		Paguridae	*Pagurus armatus*	4
			Pagurus spilocarpus	2
		Calappidae	*Platymera gaudichaudii*	17
		Leucosiidae	*Randallia ornata*	8
		Epialtidae	*Pugettia dalli*	2
			Loxorhynchus grandis	26
			Scyra acutifrons	1
		Inachidae	*Ericerodes hemphillii*	3

Appendix E.5 *continued*

Taxon/Species				n
		Inachoididae	*Pyromaia tuberculata*	10
		Parthenopidae	*Latulambrus occidentalis*	136
		Cancridae	*Metacarcinus anthonyi*	2
			Metacarcinus gracilis	36
		Portunidae	*Portunus xantusii*	2
ECHINODERMATA				
	Asteroidea			
		Luidiidae	*Luidia armata*	1
		Astropectinidae	*Astropecten californicus*	980
		Asteriidae	*Pisaster brevispinus*	5
	Ophiuroidea			
		Ophiuridae	*Ophiura luetkenii*	10
		Ophiotricidae	*Ophiothrix spiculata*	23
	Echinoidea			
		Toxopneustidae	*Lytechinus pictus*	98
		Strongylocentrotidae	*Strongylocentrotus franciscanus*	1
		Dendrasteridae	*Dendraster terminalis*	23
		Loveniidae	*Lovenia cordiformis*	1

Appendix E.6

Total abundance by species and station for megabenthic invertebrates at the SBOO trawl stations during 2014.

	Winter 2014							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Abundance by Survey**
Latulambrus occidentalis			55	2	44	9	2	112
Astropecten californicus	54	20	15	10	6	4		109
Crangon nigromaculata	1	3	3	3	24	11	31	76
Philine auriformis			1	28	15	5	1	50
Octopus rubescens	3	1	7	9	3	3	14	40
Pleurobranchaea californica	1	4	3	3	9	13		33
Metacarcinus gracilis		6	15	1	2	6	3	33
Dendraster terminalis	23							23
Sicyonia penicillata	1	7		1	3	4	5	21
Aphrodita refulgida				2	7		4	13
Platymera gaudichaudii			2	2	1	2	2	9
Ophiura luetkenii				6	1	1	1	9
Ophiothrix spiculata			3	4	1		1	9
Acanthodoris brunnea			4	4	1			9
Pyromaia tuberculata			2	2	1	3		8
Sicyonia ingentis			1		1	1	4	7
Lytechinus pictus	1			3	1		2	7
Randallia ornata			1	1	2	1	1	6
Pisaster brevispinus				4				4
Elthusa vulgaris		1		1		1	1	4
Pandalus danae					2	1		3
Loxorhynchus grandis			1	2				3
Hemisquilla californiensis		2	1					3
Crossata ventricosa			1	2				3
Portunus xantusii							2	2
Panulirus interruptus		1			1			2
Farfantepenaeus californiensis					1		1	2
Aphrodita armifera					1		1	2
Tritonia tetraquetra	1							1
Strongylocentrotus franciscanus			1					1
Pagurus spilocarpus		1						1
Metacarcinus anthonyi				1				1
Ericerodes hemphillii			1					1
Crangon alba	1							1
Calliostoma canaliculatum				1				1
Survey Total	86	46	117	92	127	65	76	609

Appendix E.6 *continued*

Name	Summer 2014							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Astropecten californicus	530	44	27	23	200	26	21	871
Lytechinus pictus	34	2	13	42				91
Acanthodoris brunnea		1	15	26	17	13	19	91
Elthusa vulgaris	1	9			33	9	8	60
Sicyonia penicillata					5	7	23	35
Philine auriformis				13	16	3		32
Latulambrus occidentalis			6	8	10			24
Loxorhynchus grandis	6	4	3	9		1		23
Kelletia kelletii		1	1	18	3			23
Octopus rubescens	3		1	4	1	5	4	18
Ophiothrix spiculata				14				14
Crossata ventricosa	1	1	1	6	3			12
Platymera gaudichaudii				5		3		8
Stylatula elongata	2					1	1	4
Pagurus armatus		2		1	1			4
Metacarcinus gracilis		1	2					3
Randallia ornata		2						2
Pyromaia tuberculata				1		1		2
Pugettia dalli				2				2
Ericerodes hemphillii	1	1						2
Crangon nigromaculata		1			1			2
Calliostoma tricolor				2				2
Armina californica	1		1					2
Amphissa undata				1			1	2
Sinum scopulosum							1	1
Sicyonia ingentis		1						1
Scyra acutifrons			1					1
Pteropurpura macroptera					1			1
Pteropurpura festiva				1				1
Pleurobranchaea californica	1							1
Pisaster brevispinus	1							1
Pagurus spilocarpus							1	1
Paguristes ulreyi		1						1
Ophiura luetkenii				1				1
Metacarcinus anthonyi							1	1
Luidia armata						1		1

Appendix E.6 *continued*

Name	Summer 2014 *continued*							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Lovenia cordiformis	1							1
Lepidozona scrobiculata					1			1
Crassispira semiinflata			1					1
Survey Total	582	71	72	177	292	70	80	1344
Annual Total	**668**	**117**	**189**	**269**	**419**	**135**	**156**	**1953**

Appendix E.7

Pairwise r- and significance values for all year comparisons (Factor B) from the SBOO two-way crossed ANOSIM for megabenthic invertebrate assemblages sampled from 1995 through 2014. Data are limited to summer surveys. Shading indicates significant difference (see Table 6.7).

		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1996	r-value	-0.279																		
	sig-value	94.4																		
1997	r-value	-0.047	0.047																	
	sig-value	60	41.1																	
1998	r-value	-0.047	0.302	0.186																
	sig-value	53.3	14.4	22.2																
1999	r-value	0.349	-0.116	0.326	0.442															
	sig-value	8.9	73.3	10.0	8.9															
2000	r-value	0.419	0.419	0.488	0.419	0.465														
	sig-value	7.8	8.9	6.7	5.6	5.6														
2001	r-value	0.349	0.186	0.163	0.651	0.605	0.535													
	sig-value	5.6	12.2	24.4	3.3	3.3	5.6													
2002	r-value	-0.070	-0.186	0.093	0.419	0.163	0.279	-0.070												
	sig-value	63.3	80.0	36.7	7.8	25.6	15.6	66.7												
2003	r-value	0.023	-0.163	0.07	0.442	-0.023	0.349	0.093	-0.302											
	sig-value	44.4	93.3	34.4	6.7	55.6	10.0	32.2	91.1											
2004	r-value	-0.047	0.140	0.326	0.326	0.442	0.512	0.419	-0.279	-0.047										
	sig-value	60.0	26.7	8.9	12.2	4.4	4.4	5.6	86.7	57.8										
2005	r-value	0.256	0.023	0.233	0.256	0.372	0.605	0.651	0.209	0.163	0.279									
	sig-value	15.6	50.0	12.2	12.2	10.0	2.2	3.3	22.2	20.0	11.1									
2006	r-value	0.093	-0.070	0.116	0.186	0.140	0.535	0.302	0.023	0.186	0.256	0.070								
	sig-value	31.1	66.7	26.7	18.9	27.8	4.4	10.0	48.9	20.0	12.2	41.1								
2007	r-value	-0.070	0.093	0.279	0.233	0.326	0.372	0.349	0.023	-0.093	0.093	0.279	0.116							
	sig-value	57.8	37.8	13.3	20.0	8.9	10.0	8.9	46.7	65.6	37.8	8.9	35.6							
2008	r-value	-0.163	0.070	0.198	-0.081	0.163	0.291	0.233	0.081	0.233	0.186	0.047	-0.023	0.047						
	sig-value	75.6	33.3	16.7	68.9	24.4	14.4	7.8	38.9	11.1	21.1	46.7	58.9	42.2						
2009	r-value	0.395	0.349	0.442	0.581	0.419	0.535	0.605	0.326	0.209	0.442	0.395	0.488	0.000	-0.070					
	sig-value	3.3	10.0	3.3	2.2	3.3	3.3	3.3	4.4	8.9	2.2	5.6	2.2	55.6	70.0					
2010	r-value	0.605	0.581	0.512	0.767	0.558	0.721	0.814	0.488	0.651	0.395	0.605	0.558	0.512	0.209	-0.209				
	sig-value	3.3	3.3	4.4	2.2	5.6	2.2	2.2	5.6	3.3	6.7	4.4	2.2	4.4	16.7	84.4				
2011	r-value	0.279	0.163	0.326	0.488	0.628	0.791	0.512	0.279	0.605	0.279	0.558	0.535	0.140	0.186	0.140	0.349			
	sig-value	16.7	25.6	6.7	7.8	2.2	2.2	2.2	14.4	2.2	17.8	2.2	2.2	32.2	26.7	25.6	11.1			
2012	r-value	0.349	0.326	0.465	0.442	0.488	0.349	0.767	0.186	0.419	0.372	0.442	0.442	0.070	-0.047	0.209	0.349	0.047		
	sig-value	10.0	6.7	2.2	3.3	3.3	6.7	2.2	27.8	4.4	8.9	3.3	3.3	38.9	55.6	13.3	5.6	43.3		
2013	r-value	0.535	0.628	0.674	0.860	0.837	0.814	0.907	0.605	0.953	0.698	0.907	0.977	0.442	0.419	0.372	0.465	0.349	0.372	
	sig-value	4.4	2.2	2.2	2.2	1.1	1.1	1.1	1.1	1.1	2.2	1.1	1.1	1.1	4.4	2.2	3.3	12.2	2.2	
2014	r-value	0.628	0.605	0.628	0.860	0.791	0.674	0.907	0.581	0.767	0.814	0.86	0.767	0.651	0.465	0.558	0.698	0.581	0.581	0.419
	sig-value	6.7	3.3	2.2	1.1	2.2	3.3	1.1	1.1	1.1	3.3	1.1	3.3	1.1	3.3	1.1	3.3	2.2	2.2	6.7

Appendix F

Supporting Data

2014 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 2014. Data are summarized as number of individuals (n), minimum, maximum, and mean values.

				Length (cm, size class)			Weight (g)		
Station	**Comp**	**Species**	**n**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
RF3	1	Vermilion Rockfish	3	19	22	21	197	279	232
RF3	2	Vermilion Rockfish	3	20	26	24	245	514	416
RF3	3	California Scorpionfish	3	26	28	27	532	694	622
RF4	1	California Scorpionfish	3	27	32	30	570	873	718
RF4	2	California Scorpionfish	3	25	27	26	431	624	507
RF4	3	California Scorpionfish	3	26	27	26	521	556	534
SD15	1	Hornyhead Turbot	3	14	21	17	60	176	127
SD15	2	No sample	—	—	—	—	—	—	—
SD15	3	No sample	—	—	—	—	—	—	—
SD16	1	Hornyhead Turbot	8	12	19	15	42	167	90
SD16	2	No sample	—	—	—	—	—	—	—
SD16	3	No sample	—	—	—	—	—	—	—
SD17	1	Hornyhead Turbot	3	15	19	18	101	224	177
SD17	2	Hornyhead Turbot	6	13	19	15	49	164	84
SD17	3	No sample							
SD18	1	Hornyhead Turbot	3	16	21	19	113	263	200
SD18	2	Hornyhead Turbot	7	14	20	17	69	192	131
SD18	3	Longfin Sanddab	7	14	20	16	52	141	82
SD19	1	Hornyhead Turbot	5	12	22	16	37	255	120
SD19	2	No sample	—	—	—	—	—	—	—
SD19	3	No sample	—	—	—	—	—	—	—
SD20	1	Longfin Sanddab	6	12	16	14	36	86	54
SD20	2	Hornyhead Turbot	4	11	17	14	30	154	74
SD20	3	No sample	—	—	—	—	—	—	—
SD21	1	Hornyhead Turbot	3	16	20	19	89	242	184
SD21	2	Hornyhead Turbot	5	18	20	19	153	205	170
SD21	3	Longfin Sanddab	7	13	16	14	46	84	61

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 2014.

	MDL			MDL	
Parameter	**Liver**	**Muscle**	**Parameter**	**Liver**	**Muscle**
Metals (ppm)					
Aluminum (Al)	3.0	3.0	Lead (Pb)	0.2	0.2
Antimony (Sb)	0.2	0.2	Manganese (Mn)	0.1	0.1
Arsenic (As)	0.24	0.24	Mercury (Hg)	0.002	0.002
Barium (Ba)	0.03	0.03	Nickel (Ni)	0.2	0.2
Beryllium (Be)	0.006	0.006	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.06	0.06	Silver (Ag)	0.05	0.05
Chromium (Cr)	0.1	0.1	Thallium (Tl)	0.1	0.1
Copper (Cu)	0.3	0.3	Tin (Sn)	0.2	0.2
Iron (Fe)	2.0	2.0	Zinc (Zn)	0.15	0.15
Chlorinated Pesticides (ppb)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	17.4	1.74	HCH, Delta isomer	6.32	0.63
HCH, Beta isomer	10.3	1.03	HCH, Gamma isomer	50.4	5.04
Total Chlordane					
Alpha (cis) chlordane	2.02	0.2	Heptachlor epoxide	3.79	0.38
Cis nonachlor	1.91	0.19	Methoxychlor	12.1	1.21
Gamma (trans) chlordane	3.07	0.31	Oxychlordane	2.92	0.29
Heptachlor	2.1	0.21	Trans nonachlor	1.44	0.14
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	1.98	0.2	p,p-DDD	2.86	0.29
o,p-DDE	2.52	0.25	p,p-DDE	4.94	0.49
o,p-DDT	2.05	0.2	p,p-DDT	2.76	0.28
p,-p-DDMU	1.82	0.18			
Miscellaneous Pesticides					
Aldrin	25.3	2.53	Endrin	30.3	3.03
Alpha endosulfan	24.7	2.47	Endrin aldehyde	10.20	1.02
Dieldrin	12.6	1.26	Hexachlorobenzene (HCB)	2.29	0.23
Endosulfan sulfate	58.3	5.83	Mirex	1.77	0.18

Appendix F.2 *continued*

	MDL			MDL	
Parameter	**Liver**	**Muscle**	**Parameter**	**Liver**	**Muscle**
Polychlorinated Biphenyls Congeners (PCBs) (ppb)					
PCB 18	1.49	0.15	PCB 126	1.93	0.19
PCB 28	1.47	0.15	PCB 128	2.28	0.23
PCB 37	2.03	0.2	PCB 138	1.93	0.19
PCB 44	1.88	0.19	PCB 149	1.92	0.19
PCB 49	1.67	0.17	PCB 151	1.52	0.15
PCB 52	1.66	0.17	PCB 153/168	3.76	0.38
PCB 66	1.86	0.19	PCB 156	2.33	0.23
PCB 70	2.05	0.2	PCB 157	2.77	0.28
PCB 74	2.11	0.21	PCB 158	2.55	0.26
PCB 77	3.32	0.33	PCB 167	2.05	0.21
PCB 81	1.91	0.19	PCB 169	1.41	0.14
PCB 87	1.95	0.19	PCB 170	2.16	0.22
PCB 99	1.54	0.15	PCB 177	1.96	0.2
PCB 101	1.7	0.17	PCB 180	2.89	0.29
PCB 105	2.28	0.23	PCB 183	2.06	0.21
PCB 110	2.13	0.21	PCB 187	2.25	0.23
PCB 114	2.77	0.28	PCB 189	1.78	0.18
PCB 118	2.56	0.26	PCB 194	3.41	0.34
PCB 119	2.72	0.27	PCB 201	2.76	0.28
PCB 123	3.04	0.3	PCB 206	1.84	0.18
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
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 DDT, total chlordane, total PCB, and total PAH in composite (Comp) tissue samples from the SBOO region during 2014.

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
RF3	3	California Scorpionfish	Muscle	DDT	p,p-DDE	0.7	ppb
RF4	1	California Scorpionfish	Muscle	DDT	p,p-DDE	7.3	ppb
RF4	1	California Scorpionfish	Muscle	DDT	p,-p-DDMU	0.8	ppb
RF4	1	California Scorpionfish	Muscle	PCB	PCB 153/168	0.2	ppb
RF4	3	California Scorpionfish	Muscle	DDT	p,p-DDE	1.7	ppb
SD15	1	Hornyhead Turbot	Liver	DDT	p,p-DDE	11.0	ppb
SD16	1	Hornyhead Turbot	Liver	DDT	p,p-DDE	24.0	ppb
SD16	1	Hornyhead Turbot	Liver	PCB	PCB 153/168	3.7	ppb
SD16	1	Hornyhead Turbot	Liver	PCB	PCB 187	1.8	ppb
SD17	1	Hornyhead Turbot	Liver	DDT	p,p-DDE	55.0	ppb
SD17	1	Hornyhead Turbot	Liver	DDT	p,-p-DDMU	4.8	ppb
SD17	1	Hornyhead Turbot	Liver	PCB	PCB 138	2.5	ppb
SD17	1	Hornyhead Turbot	Liver	PCB	PCB 153/168	5.1	ppb
SD17	1	Hornyhead Turbot	Liver	PCB	PCB 180	2.4	ppb
SD17	1	Hornyhead Turbot	Liver	PCB	PCB 187	2.7	ppb
SD17	2	Hornyhead Turbot	Liver	DDT	p,p-DDE	48.0	ppb
SD17	2	Hornyhead Turbot	Liver	PCB	PCB 138	2.5	ppb
SD17	2	Hornyhead Turbot	Liver	PCB	PCB 149	1.4	ppb
SD17	2	Hornyhead Turbot	Liver	PCB	PCB 153/168	5.3	ppb
SD17	2	Hornyhead Turbot	Liver	PCB	PCB 187	2.4	ppb
SD18	1	Hornyhead Turbot	Liver	DDT	p,p-DDE	99.0	ppb
SD18	1	Hornyhead Turbot	Liver	DDT	p,-p-DDMU	6.7	ppb
SD18	1	Hornyhead Turbot	Liver	PCB	PCB 118	3.8	ppb
SD18	1	Hornyhead Turbot	Liver	PCB	PCB 138	3.8	ppb
SD18	1	Hornyhead Turbot	Liver	PCB	PCB 153/168	8.4	ppb
SD18	1	Hornyhead Turbot	Liver	PCB	PCB 180	3.5	ppb
SD18	1	Hornyhead Turbot	Liver	PCB	PCB 187	5.1	ppb
SD18	2	Hornyhead Turbot	Liver	DDT	p,p-DDE	47.0	ppb
SD18	2	Hornyhead Turbot	Liver	PCB	PCB 138	3.9	ppb
SD18	2	Hornyhead Turbot	Liver	PCB	PCB 153/168	8.1	ppb
SD18	2	Hornyhead Turbot	Liver	PCB	PCB 180	3.0	ppb
SD18	2	Hornyhead Turbot	Liver	PCB	PCB 187	3.0	ppb
SD18	2	Hornyhead Turbot	Liver	PAH	2,6-dimethylnaphthalene	50.0	ppb
SD18	3	Longfin Sanddab	Liver	DDT	o,p-DDE	6.4	ppb
SD18	3	Longfin Sanddab	Liver	DDT	p,p-DDD	6.4	ppb
SD18	3	Longfin Sanddab	Liver	DDT	p,p-DDE	600	ppb
SD18	3	Longfin Sanddab	Liver	DDT	p,-p-DDMU	14.0	ppb
SD18	3	Longfin Sanddab	Liver	DDT	p,p-DDT	9.0	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
SD18	3	Longfin Sanddab	Liver	PCB	PCB 101	9.4	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 105	5.0	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 110	4.2	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 118	21.0	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 123	2.9	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 128	6.6	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 138	41.0	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 149	9.1	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 151	8.1	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 153/168	90.0	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 156	3.0	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 158	2.6	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 167	2.1	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 170	12.0	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 180	27.0	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 183	8.9	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 187	39.0	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 194	8.2	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 201	12.0	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 206	5.1	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 66	2.8	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 74	1.4	ppb
SD18	3	Longfin Sanddab	Liver	PCB	PCB 99	18.0	ppb
SD19	1	Hornyhead Turbot	Liver	DDT	p,p-DDD	3.8	ppb
SD19	1	Hornyhead Turbot	Liver	DDT	p,p-DDE	53.5	ppb
SD19	1	Hornyhead Turbot	Liver	DDT	p,p-DDT	3.2	ppb
SD19	1	Hornyhead Turbot	Liver	PCB	PCB 118	4.6	ppb
SD19	1	Hornyhead Turbot	Liver	PCB	PCB 138	5.5	ppb
SD19	1	Hornyhead Turbot	Liver	PCB	PCB 149	2.6	ppb
SD19	1	Hornyhead Turbot	Liver	PCB	PCB 153/168	9.7	ppb
SD19	1	Hornyhead Turbot	Liver	PCB	PCB 180	3.8	ppb
SD19	1	Hornyhead Turbot	Liver	PCB	PCB 187	4.3	ppb
SD19	1	Hornyhead Turbot	Liver	PCB	PCB 49	1.3	ppb
SD19	1	Hornyhead Turbot	Liver	PCB	PCB 66	1.3	ppb
SD20	1	Longfin Sanddab	Liver	DDT	o,p-DDE	6.8	ppb
SD20	1	Longfin Sanddab	Liver	DDT	p,p-DDD	5.6	ppb
SD20	1	Longfin Sanddab	Liver	DDT	p,p-DDE	64.0	ppb
SD20	1	Longfin Sanddab	Liver	DDT	p,-p-DDMU	20.0	ppb
SD20	1	Longfin Sanddab	Liver	DDT	p,p-DDT	5.6	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 28	1.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 49	1.7	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 66	3.2	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 74	2.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 99	21.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 101	9.3	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 105	5.6	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
SD20	1	Longfin Sanddab	Liver	PCB	PCB 110	3.5	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 118	22.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 123	3.2	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 128	7.6	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 138	40.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 149	11.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 151	5.9	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 153/168	75.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 156	3.5	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 158	2.5	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 167	2.1	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 170	12.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 177	7.7	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 180	25.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 183	9.2	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 187	38.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 194	8.2	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 201	11.0	ppb
SD20	1	Longfin Sanddab	Liver	PCB	PCB 206	5.3	ppb
SD20	2	Hornyhead Turbot	Liver	DDT	p,p-DDE	54.0	ppb
SD20	2	Hornyhead Turbot	Liver	PCB	PCB 66	0.7	ppb
SD20	2	Hornyhead Turbot	Liver	PCB	PCB 138	4.2	ppb
SD20	2	Hornyhead Turbot	Liver	PCB	PCB 153/168	5.6	ppb
SD20	2	Hornyhead Turbot	Liver	PCB	PCB 187	2.7	ppb
SD21	1	Hornyhead Turbot	Liver	DDT	p,p-DDD	3.0	ppb
SD21	1	Hornyhead Turbot	Liver	DDT	p,p-DDE	67.0	ppb
SD21	2	Hornyhead Turbot	Liver	PCB	PCB 66	0.7	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 101	5.5	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 118	8.1	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 138	14.0	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 149	5.0	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 153/168	20.0	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 170	3.0	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 180	6.4	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 183	3.2	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 187	9.8	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 49	2.7	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 66	2.1	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 70	1.1	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 74	0.9	ppb
SD21	1	Hornyhead Turbot	Liver	PCB	PCB 99	7.6	ppb
SD21	2	Hornyhead Turbot	Liver	DDT	p,p-DDE	23	ppb
SD21	2	Hornyhead Turbot	Liver	PCB	PCB 138	5.4	ppb
SD21	2	Hornyhead Turbot	Liver	PCB	PCB 153/168	8.0	ppb
SD21	2	Hornyhead Turbot	Liver	PCB	PCB 180	2.7	ppb
SD21	2	Hornyhead Turbot	Liver	PCB	PCB 187	3.6	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
SD21	3	Longfin Sanddab	Liver	DDT	o,p-DDE	6.1	ppb
SD21	3	Longfin Sanddab	Liver	DDT	p,p-DDD	8.6	ppb
SD21	3	Longfin Sanddab	Liver	DDT	p,p-DDE	37.0	ppb
SD21	3	Longfin Sanddab	Liver	DDT	p,-p-DDMU	18.0	ppb
SD21	3	Longfin Sanddab	Liver	DDT	p,p-DDT	4.5	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 49	4.3	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 52	4.3	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 66	5.8	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 70	1.30	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 74	2.9	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 99	32.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 101	15.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 105	7.1	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 110	6.6	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 118	31.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 128	9.7	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 138	49.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 149	16.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 151	5.9	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 153/168	94.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 156	3.7	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 158	3.4	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 167	2.7	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 170	14.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 177	9.5	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 180	32.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 183	9.7	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 187	47.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 194	10.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 201	14.0	ppb
SD21	3	Longfin Sanddab	Liver	PCB	PCB 206	7.3	ppb

Appendix G

Supporting Data

2014 Regional Stations

Sediment Conditions

Appendix G.1

Summary of the constituents that make up total chlordane, total DDT, total PCB, and total PAH in each sediment sample collected as part of the 2014 regional survey off San Diego.

Station	Class	Constituent	Value	Units
8302	DDT	p,p-DDE	100	ppt
8302	DDT	p,p-DDT	77	ppt
8302	PAH	2,6-dimethylnaphthalene	14	ppb
8304	DDT	p,p-DDE	330	ppt
8305	DDT	p,p-DDD	160	ppt
8305	DDT	p,p-DDE	870	ppt
8305	DDT	p,p-DDT	100	ppt
8308	DDT	p,p-DDD	220	ppt
8308	DDT	p,p-DDE	290	ppt
8308	DDT	p,p-DDT	81	ppt
8308	PAH	2,6-dimethylnaphthalene	11	ppb
8308	PAH	3,4-benzo(B)fluoranthene	100	ppb
8308	PAH	Acenaphthylene	8	ppb
8308	PAH	Anthracene	15	ppb
8308	PAH	Benzo[A]anthracene	30	ppb
8308	PAH	Benzo[A]pyrene	80	ppb
8308	PAH	Benzo[e]pyrene	50	ppb
8308	PAH	Benzo[G,H,I]perylene	40	ppb
8308	PAH	Benzo[K]fluoranthene	40	ppb
8308	PAH	Chrysene	40	ppb
8308	PAH	Fluoranthene	30	ppb
8308	PAH	Indeno(1,2,3-CD)pyrene	40	ppb
8308	PAH	Perylene	13	ppb
8308	PAH	Pyrene	50	ppb
8308	PCB	PCB 28	120	ppt
8308	PCB	PCB 49	170	ppt
8308	PCB	PCB 66	160	ppt
8308	PCB	PCB 101	280	ppt
8308	PCB	PCB 110	320	ppt
8308	PCB	PCB 118	300	ppt
8308	PCB	PCB 128	87	ppt
8308	PCB	PCB 138	330	ppt
8308	PCB	PCB 149	280	ppt
8308	PCB	PCB 153/168	710	ppt
8308	PCB	PCB 180	270	ppt
8308	PCB	PCB 187	180	ppt
8309	Chlordane	Alpha (cis) Chlordane	270	ppt
8309	Chlordane	Gamma (trans) Chlordane	190	ppt
8309	DDT	o,p-DDD	250	ppt
8309	DDT	o,p-DDE	250	ppt
8309	DDT	p,p-DDD	800	ppt
8309	DDT	p,p-DDE	1200	ppt
8309	DDT	p,p-DDT	980	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8310	DDT	p,p-DDE	170	ppt
8310	DDT	p,p-DDT	110	ppt
8310	PAH	2,6-dimethylnaphthalene	12	ppb
8310	PAH	3,4-benzo(B)fluoranthene	12	ppb
8310	PAH	Fluoranthene	9	ppb
8310	PAH	Pyrene	11	ppb
8311	DDT	p,p-DDE	120	ppt
8311	PAH	2,6-dimethylnaphthalene	8	ppb
8313	DDT	p,p-DDE	1000	ppt
8313	PAH	2,6-dimethylnaphthalene	3.5	ppb
8313	PAH	Benzo[A]pyrene	10	ppb
8313	PAH	Benzo[e]pyrene	8.5	ppb
8313	PAH	Benzo[G,H,I]perylene	9.5	ppb
8313	PAH	Fluoranthene	7	ppb
8313	PAH	Indeno(1,2,3-CD)pyrene	3.5	ppb
8313	PAH	Pyrene	8	ppb
8315	DDT	p,p-DDE	270	ppt
8315	PAH	2,6-dimethylnaphthalene	11	ppb
8318	DDT	p,p-DDD	390	ppt
8318	DDT	p,p-DDE	1300	ppt
8318	PAH	2,6-dimethylnaphthalene	15	ppb
8318	PAH	3,4-benzo(B)fluoranthene	20	ppb
8318	PAH	Benzo[A]pyrene	20	ppb
8318	PAH	Benzo[e]pyrene	14	ppb
8318	PAH	Benzo[G,H,I]perylene	15	ppb
8318	PAH	Benzo[K]fluoranthene	9	ppb
8318	PAH	Biphenyl	9	ppb
8318	PAH	Chrysene	12	ppb
8318	PAH	Fluoranthene	18	ppb
8318	PAH	Indeno(1,2,3-CD)pyrene	12	ppb
8318	PAH	Pyrene	20	ppb
8318	PCB	PCB 66	120	ppt
8318	PCB	PCB 70	91	ppt
8318	PCB	PCB 118	330	ppt
8318	PCB	PCB 138	200	ppt
8318	PCB	PCB 149	240	ppt
8318	PCB	PCB 153/168	380	ppt
8319	DDT	p,p-DDE	580	ppt
8319	PAH	2,6-dimethylnaphthalene	10	ppb
8321	DDT	p,p-DDE	530	ppt
8321	DDT	p,p-DDT	97	ppt
8321	PCB	PCB 153/168	200	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8324	DDT	p,p-DDE	250	ppt
8324	DDT	p,p-DDT	73	ppt
8324	PAH	2,6-dimethylnaphthalene	8	ppb
8326	Chlordane	Gamma (trans) Chlordane	250	ppt
8326	Chlordane	Trans Nonachlor	670	ppt
8326	DDT	o,p-DDD	190	ppt
8326	DDT	o,p-DDE	360	ppt
8326	DDT	o,p-DDT	210	ppt
8326	DDT	p,p-DDD	340	ppt
8326	DDT	p,p-DDE	2000	ppt
8326	DDT	p,-p-DDMU	380	ppt
8326	DDT	p,p-DDT	370	ppt
8326	PAH	2,6-dimethylnaphthalene	13	ppb
8326	PAH	3,4-benzo(B)fluoranthene	9	ppb
8326	PAH	Fluoranthene	10	ppb
8326	PAH	Pyrene	10	ppb
8326	PCB	PCB 18	140	ppt
8326	PCB	PCB 28	260	ppt
8326	PCB	PCB 37	270	ppt
8326	PCB	PCB 66	150	ppt
8326	PCB	PCB 74	310	ppt
8326	PCB	PCB 77	240	ppt
8326	PCB	PCB 81	320	ppt
8326	PCB	PCB 87	420	ppt
8326	PCB	PCB 99	390	ppt
8326	PCB	PCB 101	450	ppt
8326	PCB	PCB 105	220	ppt
8326	PCB	PCB 110	470	ppt
8326	PCB	PCB 114	250	ppt
8326	PCB	PCB 118	360	ppt
8326	PCB	PCB 119	240	ppt
8326	PCB	PCB 123	290	ppt
8326	PCB	PCB 126	150	ppt
8326	PCB	PCB 138	240	ppt
8326	PCB	PCB 149	210	ppt
8326	PCB	PCB 151	300	ppt
8326	PCB	PCB 153/168	570	ppt
8326	PCB	PCB 167	130	ppt
8326	PCB	PCB 170	140	ppt
8327	DDT	o,p-DDD	260	ppt
8327	DDT	o,p-DDE	130	ppt
8327	DDT	o,p-DDT	250	ppt
8327	DDT	p,p-DDD	670	ppt
8327	DDT	p,p-DDE	4600	ppt
8327	DDT	p,-p-DDMU	270	ppt
8327	DDT	p,p-DDT	1200	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8327	PAH	2,6-dimethylnaphthalene	13	ppb
8327	PCB	PCB 87	300	ppt
8327	PCB	PCB 101	560	ppt
8327	PCB	PCB 110	650	ppt
8327	PCB	PCB 118	510	ppt
8327	PCB	PCB 128	150	ppt
8327	PCB	PCB 138	420	ppt
8327	PCB	PCB 149	270	ppt
8327	PCB	PCB 151	90	ppt
8327	PCB	PCB 156	81	ppt
8327	PCB	PCB 158	100	ppt
8327	PCB	PCB 180	160	ppt
8327	PCB	PCB 187	87	ppt
8328	DDT	p,p-DDE	340	ppt
8328	PAH	2,6-dimethylnaphthalene	12	ppb
8328	PCB	PCB 138	85	ppt
8328	PCB	PCB 180	90	ppt
8329	DDT	p,p-DDE	1000	ppt
8329	PAH	2,6-dimethylnaphthalene	9	ppb
8329	PAH	3,4-benzo(B)fluoranthene	16	ppb
8329	PAH	Benzo[A]pyrene	14	ppb
8329	PAH	Benzo[e]pyrene	9	ppb
8329	PAH	Benzo[G,H,I]perylene	10	ppb
8329	PAH	Chrysene	11	ppb
8329	PAH	Fluoranthene	13	ppb
8329	PAH	Indeno(1,2,3-CD)pyrene	9	ppb
8329	PAH	Pyrene	16	ppb
8329	PCB	PCB 66	89	ppt
8329	PCB	PCB 70	81	ppt
8329	PCB	PCB 149	220	ppt
8329	PCB	PCB 153/168	400	ppt
8332	PCB	PCB 49	130	ppt
8332	PCB	PCB 52	520	ppt
8332	PCB	PCB 66	130	ppt
8332	PCB	PCB 70	380	ppt
8332	PCB	PCB 87	680	ppt
8332	PCB	PCB 99	560	ppt
8332	PCB	PCB 101	1400	ppt
8332	PCB	PCB 105	470	ppt
8332	PCB	PCB 110	1600	ppt
8332	PCB	PCB 118	1100	ppt
8332	PCB	PCB 128	310	ppt
8332	PCB	PCB 138	1100	ppt
8332	PCB	PCB 149	740	ppt
8332	PCB	PCB 153/168	1300	ppt
8332	PCB	PCB 156	170	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8332	PCB	PCB 158	160	ppt
8333	DDT	p,p-DDE	440	ppt
8333	PAH	2,6-dimethylnaphthalene	13	ppb
8333	PAH	Biphenyl	7	ppb
8333	PAH	Fluoranthene	9	ppb
8333	PAH	Pyrene	11	ppb
8335	DDT	p,p-DDE	560	ppt
8335	PAH	2,6-dimethylnaphthalene	40	ppb
8335	PAH	Benzo[e]pyrene	14	ppb
8335	PAH	Benzo[G,H,I]perylene	13	ppb
8335	PAH	Perylene	13	ppb
8335	PAH	Pyrene	16	ppb
8336	DDT	p,p-DDE	250	ppt
8336	DDT	p,p-DDT	85	ppt
8336	PAH	2,6-dimethylnaphthalene	12	ppb
8336	PCB	PCB 101	88	ppt
8336	PCB	PCB 110	66	ppt
8336	PCB	PCB 118	82	ppt
8336	PCB	PCB 153/168	110	ppt
8337	DDT	p,p-DDE	580	ppt
8337	DDT	p,p-DDT	324	ppt
8337	PAH	2,6-dimethylnaphthalene	15	ppb
8338	DDT	o,p-DDE	190	ppt
8338	DDT	p,p-DDD	240	ppt
8338	DDT	p,p-DDE	630	ppt
8338	DDT	p,p-DDT	140	ppt
8338	PAH	2,6-dimethylnaphthalene	14	ppb
8338	PCB	PCB 110	110	ppt
8339	DDT	p,p-DDE	890	ppt
8339	PAH	2,6-dimethylnaphthalene	30	ppb
8339	PAH	Fluoranthene	15	ppb
8339	PAH	Pyrene	13	ppb
8341	PAH	2,6-dimethylnaphthalene	6.5	ppb
8342	DDT	p,p-DDE	900	ppt
8342	PAH	2,6-dimethylnaphthalene	10	ppb
8342	PAH	Benzo[A]pyrene	8	ppb
8342	PAH	Fluoranthene	7	ppb
8342	PAH	Pyrene	9	ppb
8342	PCB	PCB 66	72	ppt
8342	PCB	PCB 101	150	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8343	DDT	p,p-DDE	340	ppt
8344	DDT	p,p-DDE	630	ppt
8344	DDT	p,p-DDT	96	ppt
8344	PAH	2,6-dimethylnaphthalene	19	ppb
8344	PAH	Fluoranthene	12	ppb
8344	PCB	PCB 153/168	170	ppt
8345	PAH	2,6-dimethylnaphthalene	13	ppb
8345	PAH	3,4-benzo(B)fluoranthene	90	ppb
8345	PAH	Acenaphthylene	10	ppb
8345	PAH	Anthracene	14	ppb
8345	PAH	Benzo[A]anthracene	30	ppb
8345	PAH	Benzo[A]pyrene	70	ppb
8345	PAH	Benzo[e]pyrene	50	ppb
8345	PAH	Benzo[G,H,I]perylene	40	ppb
8345	PAH	Benzo[K]fluoranthene	40	ppb
8345	PAH	Biphenyl	8	ppb
8345	PAH	Chrysene	50	ppb
8345	PAH	Fluoranthene	30	ppb
8345	PAH	Indeno(1,2,3-CD)pyrene	40	ppb
8345	PAH	Phenanthrene	10	ppb
8345	PAH	Pyrene	40	ppb
8345	PCB	PCB 66	98	ppt
8345	PCB	PCB 101	220	ppt
8345	PCB	PCB 138	200	ppt
8345	PCB	PCB 149	240	ppt
8345	PCB	PCB 153/168	340	ppt
8346	DDT	p,p-DDE	100	ppt
8346	PAH	2,6-dimethylnaphthalene	7	ppb
8347	DDT	p,p-DDE	645	ppt
8347	PAH	2,3,5-trimethylnaphthalene	8	ppb
8347	PCB	PCB 66	53	ppt
8347	PCB	PCB 138	110	ppt
8348	DDT	o,p-DDD	130	ppt
8348	DDT	o,p-DDE	120	ppt
8348	DDT	o,p-DDT	120	ppt
8348	DDT	p,p-DDD	510	ppt
8348	DDT	p,p-DDE	3400	ppt
8348	DDT	p,-p-DDMU	280	ppt
8348	DDT	p,p-DDT	570	ppt
8348	PAH	2,6-dimethylnaphthalene	12	ppb
8348	PAH	Fluoranthene	6	ppb
8348	PAH	Pyrene	7	ppb
8348	PCB	PCB 153/168	170	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
8350	DDT	p,p-DDE	140	ppt
8350	PAH	2,6-dimethylnaphthalene	6	ppb
8351	DDT	p,p-DDE	600	ppt
8351	PAH	2,6-dimethylnaphthalene	12	ppb

Appendix G.2

Summary of particle size parameters (%) for each San Diego regional station sampled during 2014. 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	8332	12	0.0	0.0	1.3	11.2	26.5	44.1	10.3	2.1	2.8	1.7	0.0	shell hash, algae debris
	8341	13	0.0	0.0	0.0	2.6	29.8	62.3	3.3	0.0	0.5	1.3	0.1	—
	8350	18	0.0	0.0	0.0	0.7	17.8	72.5	5.8	0.0	1.2	1.9	0.2	—
	8307	19	0.0	0.0	0.0	3.8	37.9	53.1	2.5	0.0	1.0	1.5	0.1	—
	8323	19	0.0	0.0	0.0	3.0	35.0	56.3	3.0	0.0	1.0	1.5	0.1	—
	8301	20	0.0	8.4	83.8	7.0	0.0	0.0	0.0	0.5	0.3	0.0	0.0	gravel, rocks, shell hash
	8316	21	0.0	0.1	8.3	44.7	39.6	5.3	0.6	0.3	0.9	0.3	0.0	shell hash
	8343	22	0.0	5.7	83.4	8.6	0.0	0.0	0.3	1.2	0.7	0.0	0.0	gravel, shell hash
	8346	22	0.0	2.7	17.5	34.0	29.3	8.6	2.0	1.9	3.2	0.8	0.0	mud-gravel, mud-rock, shell hash
	8315	25	0.0	0.0	0.0	0.5	12.3	60.3	17.7	3.1	4.3	1.8	0.0	organic debris (worm tubes)
	8311	28	0.0	0.0	0.0	2.5	23.1	59.5	9.1	0.9	2.4	2.3	0.1	organic debris (worm tubes)
Mid-Shelf	8306	39	0.0	4.0	35.9	38.7	6.5	2.1	1.8	3.3	6.0	1.7	0.0	shell hash
	8327	39	0.0	0.0	0.0	2.9	15.1	28.4	24.8	11.5	12.2	4.7	0.4	crusty sediment worm tubes
	8348	39	0.0	0.0	0.0	1.9	17.7	47.3	18.7	5.0	6.6	2.7	0.1	Spiochaetopterid worm tubes
	8312	53	0.0	13.2	45.9	24.4	4.4	1.8	1.5	2.6	4.6	1.1	0.0	black sand
	8302	54	0.0	0.0	0.0	1.5	17.5	42.5	17.0	7.3	10.4	3.7	0.1	—
	8328	58	0.0	0.9	3.7	5.0	15.4	39.9	16.5	6.3	9.0	3.2	0.1	gravel
	8333	59	0.0	0.0	0.0	0.7	11.0	38.0	23.5	10.1	12.7	4.0	0.1	—
	8319	69	0.0	0.0	0.0	0.7	17.5	47.3	14.5	5.8	10.0	3.9	0.1	shell hash
	8321	69	0.0	0.0	0.0	0.7	14.4	40.3	19.4	9.1	12.0	4.0	0.1	—
	8342	72	0.0	0.0	0.0	0.7	9.3	33.4	25.7	11.8	14.3	4.7	0.2	—
	8318	77	0.0	0.0	0.0	0.2	8.1	33.9	27.4	12.1	13.9	4.2	0.1	shell hash
	8310	78	0.0	0.0	0.0	0.1	5.3	31.6	29.7	13.2	15.2	4.8	0.2	—
	8309[s]	84	4.9	3.7	8.9	15.0	12.4	23.7	31.4	—	—	—	—	shell hash
	8329	84	0.0	0.0	0.0	1.3	12.5	35.2	23.7	10.5	12.5	4.1	0.1	—
	8305	86	0.0	0.0	0.0	0.2	8.5	33.2	26.2	12.3	14.7	4.7	0.1	—
	8347	89	0.0	0.0	0.0	0.1	7.1	37.0	29.3	10.6	11.9	3.9	0.1	—
	8324	105	0.0	0.0	0.0	0.8	20.8	43.0	12.2	6.0	11.4	5.4	0.3	—

[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 Shelf	8304	146	0.0	0.5	16.0	44.9	23.5	5.3	1.6	2.1	4.5	1.6	0.0	gravel, rocks, shell hash
	8313	146	0.0	0.0	0.0	0.1	8.1	37.6	21.9	10.2	16.3	5.6	0.2	organic debris (worm tubes)
	8308	163	0.0	0.0	1.5	14.9	25.6	17.2	12.7	9.1	12.2	6.4	0.5	gravel, rocks, shell hash
	8345	169	0.0	0.0	0.0	5.1	18.6	23.4	15.1	12.6	19.2	5.8	0.1	gravel, shell hash
	8326	197	0.0	0.0	0.0	0.1	5.4	28.8	25.4	13.4	19.1	7.3	0.6	Spiochaetopterid worm tubes
Upper Slope	8344	208	0.0	0.0	0.0	0.1	5.2	19.2	19.8	18.9	28.4	8.1	0.3	organic debris (worm tubes)
	8335	302	0.0	0.0	0.0	0.8	9.7	20.5	17.0	19.2	27.1	5.8	0.0	—
	8337	308	0.0	0.0	0.0	0.0	2.3	15.1	19.6	21.0	32.9	8.9	0.2	—
	8339	370	0.0	0.0	0.0	0.1	3.4	11.3	16.0	23.5	36.0	9.4	0.3	—
	8336	378	0.0	7.2	13.8	10.7	10.4	11.5	10.0	12.1	18.8	5.0	0.1	gravel
	8351	406	0.0	0.0	0.0	0.1	4.4	18.7	19.3	18.0	28.9	9.9	0.7	—
	8338	449	0.0	0.0	0.0	0.1	4.1	15.4	18.9	22.3	32.0	7.0	0.1	—

Appendix G.3

Concentrations of chemical parameters in sediments from the 2014 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)	Mirex (ppt)	tChlor (ppt)	tDDT (ppt)	tPCB (ppt)	tPAH (ppb)
Inner Shelf	8332	12	15.90	0.018	0.19	0.96	nd	nd	nd	nd	10,750	nd
	8341	13	3.70	nd	0.22	0.72	nd	nd	nd	nd	nd	7
	8350	18	7.80	0.016	0.18	0.77	nd	nd	nd	140	nd	6
	8307	19	2.26	0.013	0.18	0.72	250	nd	nd	nd	nd	nd
	8323	19	2.68	0.008	0.17	0.72	nd	nd	nd	nd	nd	nd
	8301	20	0.62	0.050	0.60	1.12	nd	nd	nd	nd	nd	nd
	8316	21	1.95	0.009	0.13	0.66	nd	nd	nd	nd	nd	nd
	8343	22	0.60	0.011	0.17	0.49	72	nd	nd	340	nd	nd
	8346	22	6.48	0.018	0.24	1.44	nd	nd	nd	100	nd	7
	8315	25	4.52	0.036	0.28	1.16	nd	nd	nd	270	nd	11
	8311	28	2.14	0.020	0.22	0.93	nd	nd	nd	120	nd	8
Mid-Shelf	8306	39	1.73	0.015	0.21	0.74	140	nd	nd	nd	nd	nd
	8327	39	29.20	0.049	0.14	3.43	340	nd	nd	7110	3378	13
	8348	39	4.53	0.038	0.39	2.10	nd	nd	nd	4850	170	25
	8312	53	0.57	0.010	0.12	0.51	nd	nd	nd	nd	nd	nd
	8302	54	3.98	0.049	0.55	2.10	110	nd	nd	177	nd	14
	8328	58	5.05	0.034	0.49	1.64	nd	nd	nd	340	175	12
	8333	59	3.21	0.029	0.64	2.36	nd	nd	nd	440	nd	40
	8319	69	9.18	0.029	0.50	2.00	500	nd	nd	580	nd	10
	8321	69	2.94	0.037	0.44	2.13	nd	nd	nd	627	200	nd
	8342	72	7.43	0.068	0.69	3.05	nd	nd	nd	900	222	34
	8318	77	5.13	0.094	0.74	3.13	nd	nd	nd	1690	1361	164
	8310	78	5.21	0.066	0.88	3.20	nd	nd	nd	280	nd	44
	8309	84	7.29	0.052	0.31	3.97	75	nd	460	3480		nd
	8329	84	3.85	0.068	0.61	2.50	nd	nd	nd	1000	790	107
	8305	86	4.30	0.044	0.59	2.53	100	nd	nd	1130	nd	nd
	8347	89	4.85	0.027	0.63	2.34	nd	nd	nd	645	163	8
	8324	105	4.99	0.038	0.55	1.99	nd	nd	nd	323	nd	8
Outer Shelf	8304	146	0.82	0.047	0.75	3.19	nd	nd	nd	330	nd	nd
	8313	146	4.30	0.075	0.96	3.37	nd	nd	nd	1000	nd	50
	8308	163	9.22	0.036	0.48	2.37	nd	nd	nd	591	3207	547
	8345	169	14.30	0.097	0.73	3.70	nd	nd	nd	nd	1098	535
	8326	197	30.90	0.072	0.11	4.76	nd	150	920	3470	6520	42
Upper Slope	8344	208	98.10	0.095	0.16	6.47	nd	nd	nd	726	170	31
	8335	302	182.00	0.047	0.19	6.59	nd	nd	nd	560	nd	96
	8337	308	77.40	0.012	0.20	8.17	nd	nd	nd	904	nd	15
	8339	370	249.00	0.098	0.22	9.39	nd	nd	nd	890	nd	58
	8336	378	0.80	0.069	0.20	3.75	nd	nd	nd	335	346	12
	8351	406	15.60	0.012	0.17	6.50	220	nd	nd	600	nd	12
	8338	449	20.30	0.013	0.19	7.59	nd	nd	nd	1200	110	14
		[a] **ERL**:	na	na	na	na	na	na	na	1580	na	4022
		[a] **ERM**:	na	na	na	na	na	na	na	46,100	na	44,792

[a] from Long et al. 1995

Appendix G.3 *continued*

	Station	Depth (m)	Metals (ppm)								
			Al	**Sb**	**As**	**Ba**	**Be**	**Cd**	**Cr**	**Cu**	**Fe**
Inner Shelf	8332	12	7400	1.4	0.97	24.80	0.13	nd	10.5	nd	10,500
	8341	13	6030	1.6	1.25	29.40	0.11	nd	8.6	nd	8110
	8350	18	7830	1.6	1.09	19.40	0.13	nd	10.4	nd	8950
	8307	19	7330	1.0	1.57	34.60	0.11	nd	11.4	nd	7720
	8323	19	7010	0.9	1.08	43.80	0.10	nd	13.2	nd	8710
	8301	20	1210	0.4	5.91	8.49	nd	nd	8.8	0.3	4520
	8316	21	3710	nd	2.66	11.30	0.05	nd	4.3	0.4	4050
	8343	22	2190	0.9	5.32	15.90	0.13	nd	4.6	nd	3660
	8346	22	5930	1.2	3.25	64.30	0.12	nd	10.4	nd	9510
	8315	25	10,700	0.5	1.89	30.60	0.15	nd	12.8	1.3	8460
	8311	28	9120	0.9	1.39	33.80	0.14	nd	12.2	nd	9080
Mid-Shelf	8306	39	4520	1.3	1.37	18.30	0.10	nd	9.3	nd	9900
	8327	39	24,400	1.9	3.56	105.00	0.40	nd	25.8	9.6	21,100
	8348	39	14,000	1.9	2.33	42.80	0.21	nd	16.7	2.6	12,300
	8312	53	3030	1.5	1.56	6.83	0.10	nd	6.9	nd	9550
	8302	54	8100	0.7	3.10	46.10	0.13	nd	15.1	6.4	11,900
	8328	58	12,800	1.5	2.56	38.70	0.20	nd	17.6	4.3	12,100
	8333	59	16,600	1.4	2.74	55.10	0.28	nd	20.4	5.5	16,200
	8319	69	10,900	0.5	2.83	46.80	0.20	0.07	16.4	2.3	11,300
	8321	69	13,000	0.7	2.82	38.90	0.21	nd	17.7	3.1	12,900
	8342	72	21,300	1.9	3.51	73.80	0.35	nd	25.8	9.2	19,800
	8318	77	20,400	1.3	3.75	75.80	0.31	nd	26.2	9.3	18,200
	8310	78	21,400	1.4	3.91	73.00	0.34	nd	27.1	9.2	19,800
	8309	84	14,000	1.1	3.72	41.30	0.29	nd	22.8	6.3	18,100
	8329	84	16,400	1.0	2.82	54.40	0.27	nd	20.8	7.5	16,000
	8305	86	16,600	1.4	2.66	49.60	0.28	nd	21.6	5.5	16,400
	8347	89	17,800	1.9	2.87	53.40	0.30	nd	22.4	5.6	17,000
	8324	105	9600	0.8	1.62	26.40	0.17	nd	13.8	2.4	9710
Outer Shelf	8304	146	6750	1.0	8.70	17.20	0.36	nd	27.9	3.2	20,000
	8313	146	17,000	1.0	1.97	47.60	0.30	nd	23.9	8.0	16,300
	8308	163	21,700	1.8	3.66	93.20	0.31	nd	23.8	30.7	22,500
	8345	169	26,800	2.1	3.67	105.00	0.40	nd	29.7	35.5	25,900
	8326	197	20,300	1.1	2.51	63.80	0.32	0.12	28.2	9.9	17,200
Upper Slope	8344	208	32,100	2.5	6.12	112.00	0.59	0.39	40.7	18.1	29,200
	8335	302	32,200	2.6	5.88	119.00	0.58	0.33	42.1	19.9	29,900
	8337	308	30,600	2.4	4.75	111.00	0.53	0.28	43.3	21.2	26,100
	8339	370	37,800	3.2	8.20	136.00	0.68	0.26	49.5	26.3	33,000
	8336	378	12,100	1.5	3.69	54.60	0.28	nd	23.0	10.1	13,500
	8351	406	26,700	2.8	3.06	106.00	0.48	0.39	38.6	17.0	23,800
	8338	449	29,400	2.7	3.04	131.00	0.52	0.49	44.0	20.7	25,400
		[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*

	Station	Depth (m)	Metals (ppm)								
			Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Inner Shelf	8332	12	nd	261.0	nd	2.4	nd	nd	nd	nd	23.7
	8341	13	nd	224.0	nd	2.2	nd	nd	nd	nd	17.3
	8350	18	nd	246.0	nd	2.4	nd	nd	nd	nd	22.6
	8307	19	0.9	149.0	nd	3.3	nd	nd	nd	nd	18.8
	8323	19	nd	217.0	nd	2.9	0.21	nd	1.4	nd	18.4
	8301	20	2.4	50.1	nd	1.4	0.16	nd	1.5	nd	8.2
	8316	21	2.0	51.0	nd	1.3	nd	nd	2.0	nd	8.7
	8343	22	2.5	46.6	nd	1.8	0.21	nd	1.6	0.8	8.7
	8346	22	4.7	172.0	nd	3.0	nd	nd	nd	0.8	26.6
	8315	25	1.2	131.0	nd	4.2	nd	nd	nd	nd	22.0
	8311	28	nd	191.0	nd	3.3	nd	nd	nd	nd	20.9
Mid-Shelf	8306	39	2.1	199.0	0.008	2.1	nd	nd	nd	nd	18.2
	8327	39	6.6	244.0	0.005	13.6	0.31	nd	1.6	0.4	62.7
	8348	39	2.9	192.0	0.005	6.8	nd	nd	nd	0.6	30.3
	8312	53	1.6	206.0	nd	1.1	nd	nd	0.5	nd	11.7
	8302	54	5.4	113.0	0.031	6.8	0.22	nd	0.5	1.7	33.7
	8328	58	4.8	179.0	0.013	6.6	nd	nd	nd	0.5	37.1
	8333	59	5.4	210.0	0.012	8.8	nd	nd	nd	1.0	43.3
	8319	69	3.3	150.0	0.006	6.0	nd	nd	0.8	nd	30.5
	8321	69	3.2	162.0	0.006	6.7	nd	nd	0.8	0.7	32.4
	8342	72	6.6	256.0	0.012	12.5	0.18	nd	nd	1.0	54.2
	8318	77	7.1	212.0	0.014	11.7	nd	nd	0.7	1.2	53.2
	8310	78	6.3	232.0	0.044	12.5	nd	nd	nd	0.7	54.2
	8309	84	5.4	166.0	0.007	9.5	0.19	nd	nd	0.7	44.9
	8329	84	7.7	197.0	0.013	9.5	0.12	nd	nd	0.5	44.1
	8305	86	4.6	205.0	0.008	9.7	nd	nd	nd	0.5	41.8
	8347	89	4.0	226.0	0.008	10.4	nd	nd	nd	0.5	43.1
	8324	105	2.6	144.0	0.006	6.2	0.20	nd	1.5	nd	25.2
Outer Shelf	8304	146	4.1	51.9	nd	6.9	0.24	nd	2.2	0.4	34.3
	8313	146	4.6	194.0	0.009	10.9	0.14	nd	nd	0.4	44.5
	8308	163	8.4	226.0	0.024	9.9	0.26	nd	0.7	0.9	83.2
	8345	169	8.3	278.0	0.021	13.9	0.50	nd	nd	1.4	74.1
	8326	197	4.5	194.0	0.008	14.8	0.37	nd	1.0	0.3	52.5
Upper Slope	8344	208	10.5	309.0	0.012	20.6	0.57	nd	nd	1.5	88.0
	8335	302	11.0	306.0	0.016	22.0	0.73	nd	nd	1.8	90.3
	8337	308	7.8	266.0	0.004	29.1	1.16	nd	nd	1.8	83.1
	8339	370	15.4	312.0	0.023	27.6	0.77	nd	nd	2.5	103.0
	8336	378	3.8	92.2	0.008	10.8	0.60	nd	0.5	1.1	32.9
	8351	406	6.3	263.0	0.004	23.5	0.89	nd	nd	0.6	76.1
	8338	449	8.3	271.0	0.004	27.8	1.07	nd	nd	1.2	85.8
		[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 2014. 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	Be	Cr	Cu
Sulf	0.52											
TN	0.54	0.36										
TOC	0.17	-0.26	0.47									
TVS	0.86	0.72	0.44	-0.08								
Al	0.93	0.67	0.53	0.05	0.90							
Sb	0.68	0.63	0.21	-0.19	0.76	0.81						
As	0.33	0.57	0.48	0.15	0.58	0.43	0.33					
Ba	0.85	0.64	0.43	-0.05	0.86	0.95	0.81	0.42				
Be	0.88	0.70	0.51	0.03	0.94	0.95	0.81	0.59	0.90			
Cr	0.90	0.67	0.50	0.06	0.97	0.94	0.79	0.57	0.90	0.98		
Cu	0.73	0.53	0.50	0.09	0.76	0.85	0.71	0.45	0.86	0.80	0.80	
Fe	0.86	0.67	0.55	0.11	0.89	0.95	0.81	0.56	0.90	0.97	0.96	0.86
Pb	0.80	0.72	0.63	0.16	0.83	0.87	0.68	0.67	0.86	0.88	0.86	0.83
Mn	0.63	0.52	0.17	-0.11	0.56	0.75	0.81	-0.03	0.72	0.65	0.62	0.58
Hg	0.52	0.27	0.57	0.49	0.32	0.48	0.26	0.27	0.45	0.40	0.41	0.53
Ni	0.91	0.65	0.39	-0.04	0.98	0.94	0.80	0.49	0.91	0.95	0.97	0.79
Se	0.65	0.57	0.17	-0.29	0.88	0.71	0.70	0.47	0.76	0.77	0.81	0.72
Sn	0.70	0.57	0.52	0.08	0.77	0.74	0.64	0.63	0.76	0.77	0.75	0.74
Zn	0.88	0.67	0.50	0.05	0.90	0.97	0.81	0.50	0.95	0.95	0.95	0.90
tDDT	0.29	0.06	0.24	-0.10	0.23	0.30	0.18	0.05	0.27	0.26	0.23	0.10
tPAH	0.20	0.05	0.37	0.29	0.11	0.35	0.23	0.12	0.38	0.24	0.22	0.71

	Fe	Pb	Mn	Hg	Ni	Se	Sn	Zn	tDDT
Pb	0.89								
Mn	0.70	0.52							
Hg	0.50	0.60	0.30						
Ni	0.91	0.83	0.63	0.36					
Se	0.71	0.64	0.41	0.12	0.87				
Sn	0.76	0.86	0.42	0.56	0.75	0.65			
Zn	0.97	0.91	0.71	0.51	0.93	0.75	0.78		
tDDT	0.25	0.20	0.15	-0.01	0.24	0.09	0.06	0.24	
tPAH	0.38	0.39	0.27	0.45	0.17	0.14	0.30	0.43	-0.05

Appendix H

Supporting Data

2014 Regional Stations

Macrobenthic Communities

Appendix H.1

Mean abundance of the characteristic species found in each cluster group A–J (defined in Figure 9.4). 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[a]**	**C**	**D[a]**	**E**	**F**	**G**	**H**	**I[a]**	**J**
Halistylus pupoideus	**24**	0	0	0	0	0	0	0	0	0
Tiburonella viscana	**9**	0	<1	0	0	0	0	0	0	0
Ampharete labrops	<1	**41**	<1	0	0	**5**	0	0	0	0
Monticellina cryptica	0	**38**	0	0	0	2	<1	2	0	0
Mediomastus sp	0	**17**	<1	1	**6**	**10**	<1	**5**	0	<1
Polydora cirrosa	0	**15**	0	0	0	0	0	0	0	0
Caprella californica	0	**12**	0	0	0	0	0	0	0	0
Spiophanes norrisi	12	2	**40**	**454**	**15**	**95**	1	0	1	0
Apionsoma misakianum	0	0	**12**	0	0	<1	0	<1	0	0
Lumbrinerides platypygos	<1	0	**10**	0	0	0	0	0	0	0
Lumbrineris latreilli	0	0	**8**	0	0	0	<1	0	0	0
Glottidia albida	0	1	0	0	**8**	**8**	<1	0	0	0
Tellina modesta	0	4	2	0	**8**	3	0	0	0	0
Rhepoxynius menziesi	0	0	0	0	**5**	1	<1	0	0	0
Sigalion spinosus	0	0	0	0	**3**	<1	<1	0	0	0
Balanoglossus sp	0	0	2	4	**3**	0	1	0	0	0
Hartmanodes hartmanae	0	0	0	0	**2**	2	0	0	0	0
Spiochaetopterus costarum Cmplx	1	0	1	1	<1	**47**	<1	7	0	0
Ampelisca brevisimulata	0	0	0	1	0	**20**	3	<1	0	0
Monticellina siblina	0	0	1	2	6	**15**	1	<1	**30**	0
Ampelisciphotis podophthalma	0	0	0	0	0	**15**	0	0	0	0
Euclymeninae sp B	0	0	2	0	<1	**8**	3	<1	0	0
Amphideutopus oculatus	0	0	0	1	0	**7**	0	0	0	0
Metasychis disparidentatus	0	0	<1	0	0	**6**	<1	<1	0	0
Hemilamprops californicus	0	0	0	2	<1	**5**	<1	0	0	0
Ampelisca pugetica	0	0	0	0	<1	**5**	2	0	0	0
NEMATODA	0	0	0	2	<1	**4**	<1	0	0	<1
Nereis sp A	0	0	0	2	0	**3**	<1	<1	0	0
Amphiodia urtica	0	0	1	0	3	2	**59**	<1	0	0
Amphiodia sp	0	1	0	0	<1	1	**11**	1	1	0
Amphiuridae	0	0	2	0	3	2	**7**	**4**	0	2
Rhepoxynius bicuspidatus	0	0	0	0	0	0	**6**	0	0	0
Nuculana sp A	0	0	0	0	0	2	**5**	4	0	0
Prionospio (Prionospio) dubia	0	0	<1	0	0	<1	**5**	0	0	0
Sternaspis affinis	0	0	0	0	0	3	**5**	<1	0	<1
Euphilomedes carcharodonta	0	1	<1	0	<1	3	**5**	0	0	0

Appendix H.1 *continued*

Taxa	Cluster Group A	B[a]	C	D[a]	E	F	G	H	I[a]	J
Travisia brevis	0	0	0	0	<1	0	**4**	<1	0	0
Heterophoxus oculatus	0	0	0	0	0	<1	**3**	0	0	0
Prionospio (Prionospio) jubata	0	0	2	0	0	6	**3**	2	2	0
Axinopsida serricata	0	0	0	0	<1	<1	2	**13**	0	0
Tellina carpenteri	0	0	0	0	0	0	<1	**10**	1	4
Adontorhina cyclia	0	0	0	0	0	0	<1	**5**	0	1
Scoletoma tetraura Cmplx	0	6	0	0	3	1	<1	**5**	0	0
Petaloclymene pacifica	0	0	0	0	0	5	5	**4**	0	0
Paraprionospio alata	0	2	<1	0	<1	3	1	**4**	2	<1
Aphelochaeta glandaria Cmplx	0	0	1	0	0	<1	<1	**4**	2	0
Dougaloplus amphacanthus	0	0	0	0	0	0	<1	**3**	1	0
Heterophoxus ellisi	0	0	0	0	0	0	0	**2**	0	<1
Parvilucina tenuisculpta	0	0	<1	0	0	0	<1	**2**	1	1
Ophiura luetkenii	0	0	1	0	<1	4	1	<1	**8**	0
Mooreonuphis sp	0	0	<1	0	0	0	0	0	**7**	0
Maldane sarsi	0	0	0	0	0	0	2	2	0	**6**
Pectinaria californiensis	0	3	0	0	0	2	1	<1	0	**2**
Cadulus californicus	0	0	0	0	0	0	0	<1	1	**2**
Nuculana conceptionis	0	0	0	0	0	0	0	0	0	**<1**

[a] SIMPER analysis only conducted on cluster groups that contain more than one benthic grab. Highlighted values for single sample cluster groups cummulatively account for about 45% of the total abundance.