THE CITY OF SAN DIEGO

Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant) 2012

City of San Diego
Ocean Monitoring Program

Public Utilities Department
Environmental Monitoring and Technical Services Division

THE CITY OF SAN DIEGO

June 28, 2013

Mr. David Gibson, Executive Officer
San Diego Regional Water Quality Control Board
9174 Sky Park Court, Suite 100
San Diego, CA 92123

Attention: POTW Compliance Unit

Dear Sir:

Enclosed is the 2012 Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, South Bay Water Reclamation Plant as required per Order No. R9-2006-0067 (superseded by Order R9-2013-0006, effective April 4, 2013), NPDES Permit No. CA0109045. This assessment report contains data summaries, analyses and interpretations of the various portions of the ocean monitoring program conducted during calendar year 2012, including oceanographic conditions, water quality, sediment conditions, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues. 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. 96-50, 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,

Steve Meyer
Deputy Public Utilities Director

TDS/akl

cc: U.S. Environmental Protection Agency, Region 9

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Annual Receiving Waters Monitoring Report

for the

South Bay Ocean Outfall

(South Bay Water Reclamation Plant)

2012

Prepared by:

City of San Diego
Ocean Monitoring Program
Public Utilities Department
Environmental Monitoring and Technical Services Division

June 2013

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Acknowledgments:
We are grateful to the personnel of the City's Marine Biology, Marine Microbiology, and Wastewater Chemistry Services Laboratories for their assistance in the collection and/or processing of all samples, and for discussions of the results. The completion of this report would not have been possible without their continued efforts and contributions. We would especially like to thank K. Beauchamp, G. Daly, A. Davenport, W. Enright, A. Feit, K. Langan, M. Kasuya, M. Kelly, D. Olson, L. Othman, J. Pettis-Schallert, V. Rodriguez-Villanueva, R. Velarde, G. Welch, and L. Wiborg for their critical reviews of various chapters of this report. We would also like to thank Dr. E. Parnell of the Scripps Institution of Oceanography for his advice and assistance. Complete staff listings for the above labs and additional details concerning relevant QA/QC activities for the receiving waters monitoring data reported herein are available online in the 2012 Annual Receiving Waters Monitoring & Toxicity Testing Quality Assurance Report (www.sandiego.gov/mwwd/environment/reports.shtml).

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

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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 Mediam
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 for 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 Pollution 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 for 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 Quiality 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

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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 NPDES regulatory permits for the City's South Bay Water Reclamation Plant (SBWRP) and the South Bay International Wastewater Treatment Plant (SBIWTP) operated by the International Boundary and Water Commission, U.S. Section (USIBWC). Since treated effluent from these two facilities commingle before discharge to the ocean, a single monitoring and reporting program approved by the San Diego Regional Water Quality Control Board and U.S. Environmental Protection Agency 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-contact standards,
- 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 2012 was in good condition based on the comprehensive scientific assessment of the South Bay outfall 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. Shoreline monitoring at the core stations extends from Coronado, San Diego (USA) southward to Playa Blanca in northern Baja California (Mexico), while offshore monitoring occurs in adjacent 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 2012 are presented and discussed in the following nine chapters in this report. 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 2012 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, the results for 2012 which 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 colder than normal from January through July, after which they increased to above average temperatures throughout the remainder of the year. This pattern was consistent with reports from National Oceanic and Atmospheric Administration (NOAA) that the relatively cool water La Niña conditions of 2011 persisted throughout the first half of 2012 before beginning to warm. Ocean conditions indicative of coastal upwelling were observed from the beginning of spring through mid-summer, but were most evident during March and April. As is typical for the 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 generally similar to that observed during 2010–2011, with low values predominantly associated with turbidity plumes originating from the Tijuana River, re-suspension of bottom sediments due to waves or storm activity, or phytoplankton blooms. The occurrence of plankton blooms often corresponded to upwelling as described above, including a massive bloom in March that extended throughout the SBOO region and to north of Point Loma. 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 stations located west of Imperial Beach. In contrast, these standards to do not apply to the three shore stations located south of the border off northern Baja California. Overall compliance with the Ocean Plan's single sample maximum (SSM) and geometric mean standards for FIB concentrations was 97% for the shore and kelp bed stations combined in 2012, which was higher than the 91% overall compliance observed in 2011. This improvement appears related to the effect of lower rainfall, which totaled about 6.6 inches in 2012 compared to 9.1 inches in 2011. Compliance at the above shore stations was ≥71% for the three geometric mean standards and ≥66% for each of the four SSM standards. However, six of these stations (i.e., S4, S5, S6, S10, S11, S12) fall within or immediately adjacent to areas already listed by the State and U.S. EPA as impaired waters due to other 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 99.7% in 2012. Water quality was also high at the three kelp bed stations during the year, with compliance being 100% for the geometric mean standards and ≥96% for the SSMs. Compliance was generally lowest during the wet season (October–April) when rainfall was greatest due to higher levels of FIBs. For example, about 85% of all elevated FIBs occurred during the wet season. This relationship between rainfall and FIB counts in local waters has remained consistent since monitoring began in 1995 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 or nearshore recreational waters during 2012. Bacterial contamination was very low in offshore waters, with <1% of all samples collected having elevated FIBs. In fact, only a single sample with elevated FIBs was collected near the discharge site (i.e., at station I12 near the tip of the southern diffuser leg). This low rate of bacteriological contamination near the outfall is expected due to chlorination of SBIWTP effluent that typically occurs between November and April, and to the initiation of full secondary treatment at the SBIWTP that began in January 2011. Consequently, bacteriological data may no longer be useful for plume tracking in this region. Instead, other methods of plume detection along with visual observations from satellite imagery may prove more useful. For example, satellite images taken in 2012 were able to detect the SBOO plume in near-surface waters over the discharge site on several occasions during the months of January, February, and December. These findings have been supported by other high resolution satellite images that suggest the SBOO plume typically remains within about 700 m of the outfall. Further, detection of the plume using CDOM and salinity signatures was low (11.6%) during 2012, with most detections occurring at stations near the outfall. There were no images captured during the year that indicated the plume reached the Imperial Beach kelp bed or other nearshore waters.

Sediment Conditions

The composition of benthic sediments at the SBOO core stations was similar in 2012 to previous years, which varied 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 reflects multiple geological origins or complex patterns of transport and deposition from sources such as the Tijuana River and San Diego Bay.

Sediment quality was also similar in 2012 to previous years with overall contaminant loads remaining low compared to 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 and PCBs varied widely throughout the region, and there were no patterns that could be attributed to the outfall or other point sources. Instead, the distribution of contaminants in local sediments continued to be linked to natural environmental heterogeneity. For example, concentrations of total organic carbon, total nitrogen, total volatile solids, and several metals were usually higher at sites characterized by finer sediments, a pattern consistent with results from other studies. Finally, 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 either threshold in 2012 were for arsenic, which exceeded the ERL at one station during both the January and July surveys.

Macrobenthic Communities

Benthic macrofaunal assemblages surrounding the SBOO were similar in 2012 to previous years, and there were no significant differences between those occurring at nearfield and farfield sites. These assemblages were typical of those that occur in similar habitats throughout the Southern California Bight (SCB). For example, most of the relatively shallow, coarse sand sites had high abundances of *Spiophanes norrisi*, a polychaete worm characteristic of similar habitats throughout the SCB. In contrast, slightly different assemblages were found at mid-depth stations with somewhat finer sediments characteristic of much of the southern California mainland shelf.

Species richness and total abundance of the SBOO macrobenthic assemblages varied with depth and sediment type, but showed no clear patterns relative to the discharge area. Instead, spatial patterns in abundance were driven mostly by changes in *S. norrisi* populations similar to that observed over the past few years. Benthic response index (BRI) values were also mostly characteristic of non-impacted macrofaunal communities. Changes that did occur during the year were similar in magnitude to those seen previously in southern California waters and that correspond to large-scale oceanographic processes or other natural events. Overall, macrofaunal assemblages surrounding the outfall remain similar to indigenous communities characteristic of similar habitats on the southern California continental shelf. There remains no evidence that wastewater discharge has caused degradation of the marine benthos at any of the monitoring sites.

Demersal Fishes And Megabenthic Invertebrates

Speckled sanddabs dominated fish assemblages surrounding the SBOO in 2012 as they have in previous years, occurring at almost all stations and accounting for 49% of the total year's catch. Other species collected in at least half the trawls included California lizardfish, hornyhead turbot, English sole, plainfin midshipman, and California tonguefish. Although the composition and structure of the fish assemblages varied among stations and surveys, these differences appear to be due to natural fluctuations of these common species.

Trawl-caught invertebrate assemblages were dominated by the shrimp *Crangon nigromaculata* during the winter and the sea star *Astropecten californicus* during the summer. These two species occurred in 71% and 93% of trawls, respectively, and accounted for 30% and 27% of the total invertebrate abundance. Other less abundant but common species included the crabs *Metacarcinus gracilis* and *Platymera gaudichaudii*, the cymothoid isopod *Elthusa vulgaris*, and the gastropod *Kelletia kelletii*. As with fishes, the composition and structure of the invertebrate assemblages varied among stations, reflecting mostly large fluctuations in populations of the above species.

Comparisons of the 2012 surveys with results from previous surveys conducted from 1995–2011 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 2012. Although a few tissue samples had concentrations of metals 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. Additionally, exposure to contaminants can vary greatly between different species of fish 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 2012 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 an a stratified, randomized sampling design were sampled at inner shelf, mid-shelf, outer shelf, and upper slope depths ranging from 11–448 m. Included below is a summary of the sediment conditions and soft-bottom macrobenthic assemblages present during the 2012 regional survey, along with a comparison to conditions present from 2009 to 2011 for a four-year assessment.

Regional Sediments

The composition of sediments at the regional stations sampled in 2012 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 comprised 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 2012 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 have been highly variable over the past four years, there was no evidence of disturbance that could be attributed to local wastewater discharges from either the SBOO or PLOO. Instead, concentrations of chemical parameters such as total nitrogen, total volatile solids, and several trace metals were found to increase with increasing amounts of fine sediments (percent fines). As the percent fines component also increased with depth, many contaminants were detected at higher concentrations in deeper strata compared to shallower inner and mid-shelf regions. For example, the highest levels of most contaminants occurred in sediments along the upper slope where some of the finest sediments were present.

Regional Macrofauna

The SCB benthos has long been considered to be composed of heterogeneous or "patchy" habitats, with the distribution of macrobenthic invertebrate species and communities exhibiting considerable spatial variability. Results of the summer 2012 regional survey off San Diego, coupled with data from 2009 to 2011, 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 2009-2012 were similar to those found in other shallow, sandy habitats across the SCB, and were characterized by species such as the polychaete worms *Owenia* *collaris* and *Spiophanes norrisi*, and the bivalve *Tellina modesta*. 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 distinct species of polychaetes (e.g., *Aphelochaeta glandaria* Cmplx*, Monticellina siblina,* and *Chaetozone* sp SD5). 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 bivalves such as *Yoldiella nana*, *Nuculana conceptionis,* and *Tellina carpenteri*.

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2009−2012 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 89% of the shelf sites surveyed over the past four years 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 2012, as well as the summer 2012 San Diego regional benthic survey, 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 recreational waters 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 macrobenthic 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. Finally, results of the regional benthic survey conducted during the year also revealed no outfall related effects, and that benthic habitats in the region remain in good condition similar to much of the southern California continental shelf.

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 subject to the terms and conditions set forth in San Diego Regional Water Quality Control Board Order No. 96–50, Cease and Desist Order No. 96–52 (NPDES Permit No. CA0108928). Discharge from the City's SBWRP began in May 2002, and in calendar year 2012 was subject to provisions set forth in Order No. R9-2006-0067 (NPDES Permit No. CA0109045).[1] The Monitoring and Reporting Program (MRP) requirements, as specified in each of the above 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.

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 region-wide surveys off the coast of San Diego each summer since 1994 as part of regular annual monitoring requirements (e.g., see chapters 8 and 9 herein) or during participation in larger, multi-agency surveys of the Southern California Bight that occur about every five years (e.g., see Bight'08 CEC 2012). These large-scale regional surveys are especially useful for characterizing the ecological health of diverse coastal environments and in distinguishing reference from impacted sites or areas.

Additionally, 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 2012 are available in Svejkovsky (2013).

This annual assessment report presents the results of all receiving waters monitoring activities conducted during calendar year 2012 for the South Bay outfall monitoring program. Included are results from all regular core stations that compose a fixed-site monitoring grid surrounding the outfall, as well as results from the summer 2012 benthic survey of randomly selected sites that ranged from near the USA/Mexico border to northern San Diego County. Comparisons are also made to conditions found during previous years 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

[1] Order R9-2006-0067 superseded by adoption of Order R9-2013-0006 effective April 4, 2013

Communities. General background information on program design is outlined below, while details regarding sampling procedures are specified in subsequent chapters and appendices.

Core Monitoring

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 SBIWTP/SBWRP 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.

The regular 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 (Figure 1.1). The offshore monitoring sites are arranged in a grid surrounding the outfall, with each station being sampled in accordance with MRP requirements. Sampling at these grid stations includes monthly seawater measurements of physical, chemical, and bacteriological parameters

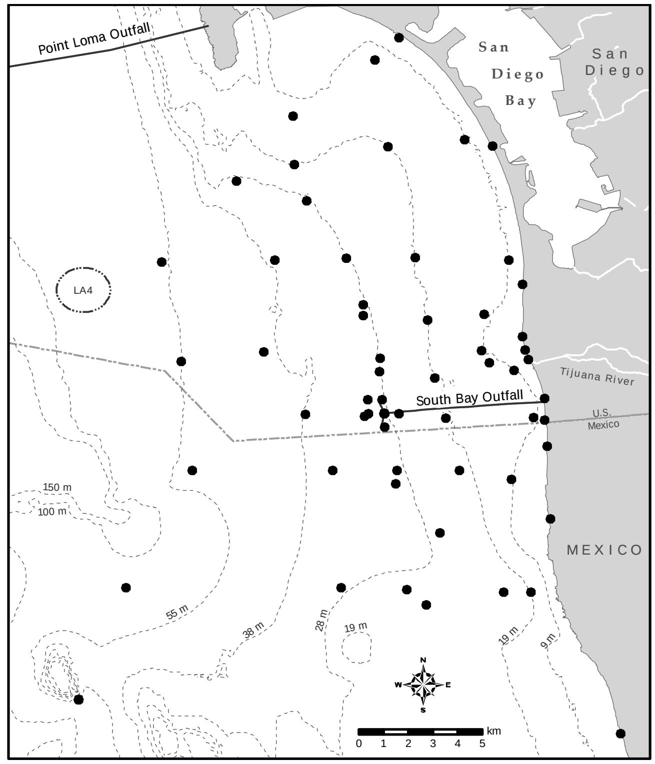

Figure 1.1
Receiving waters monitoring stations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

to document water quality conditions in the area. Benthic sediment samples are collected semiannually to evaluate macrobenthic invertebrate communities and sediment conditions. Trawl surveys are performed quarterly to monitor communities of demersal fish and large, bottom-dwelling invertebrates (megabenthos). Additionally, analyses of muscle and liver tissues from local bottom-dwelling fishes are performed semiannually to assess the bioaccumulation of chemical constituents that may have ecological or public health implications.

Regional Benthic Surveys

In addition to the core sampling described above, the monitoring requirements for the South Bay outfall program require the City to annually conduct a summer benthic survey of sites distributed throughout the entire San Diego coastal region (Figure 1.2). The regional surveys conducted in 1994, 1998, 2003, and 2008 were very broad in scope, involved organizations in addition to the City, and included sites ranging throughout most of the entire Southern California Bight (SCB) to as far north as Point Conception. These surveys included the original Southern California Bight Pilot Project (SCBPP) in 1994 and subsequent bight-wide regional monitoring efforts in 1998 (Bight'98), 2003 (Bight'03), and 2008 (Bight'08). Results of these four SCB regional surveys are available in Bergen et al. (1998, 2001), Noblet et al. (2002), Ranasinghe et al. (2003, 2007, 2012), and Schiff et al. (2006, 2011).

In most years, however, the annual regional surveys are restricted to San Diego coastal waters based on an array of stations selected by the United States Environmental Protection Agency (USEPA) using a stratified random sampling design. Results of the 13 San Diego regional surveys conducted between 1995 and 2011 are available in City of San Diego (1998, 1999, 2000b, 2001–2003, 2006–2012). The same randomized sampling design was used to target 40 new stations per year for the summer surveys conducted in 1995–1997 and 1999–2002. These stations were distributed between three main depth strata on the continental shelf, including inner shelf (5–30 m), mid-shelf (30–120 m), and outer shelf (120–200 m). Beginning in 2005, however, the City, USEPA, and the San Diego Regional Water Quality Control Board agreed that it would be valuable to revisit sites sampled 10 years earlier to facilitate comparisons of long-term changes in benthic conditions. During these follow-up surveys, some originally targeted stations could not be revisited due to the presence of rocky substrates that made it impossible to collect benthic grab samples. This resulted in 36 sites being revisited in 2005, 34 sites in 2006, and 39 sites in 2007. As indicated above, a separate San Diego survey was not conducted in 2008 due to participation in Bight'08. In 2009, sampling was conducted at the 34 shelf sites originally sampled in 1999 plus six new sites located in deeper waters on the upper continental slope (~200–500 m; see City of San Diego 2010). For the 2010–2012 regional surveys, the USEPA resumed selecting all new sites, but distributed between all four depth strata (inner, mid- and outer shelf, and upper slope). The 2012 San Diego regional survey involved sampling a total of 40 new stations at depths ranging from 11 to 448 m (see Chapters 8–9 for details).

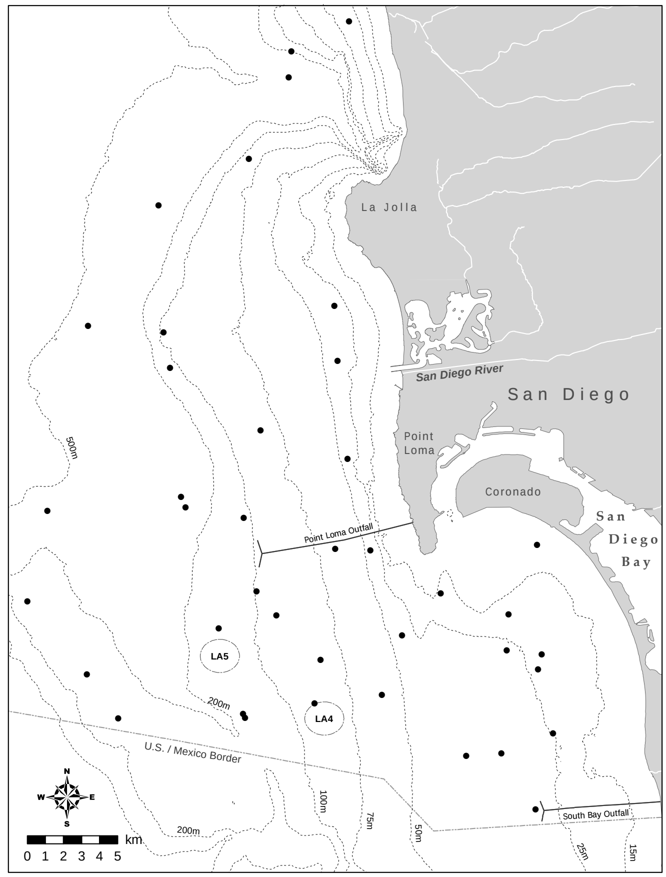

Figure 1.2
Regional benthic survey stations sampled during July 2012 as part of the City of San Diego's Ocean Monitoring Program.

Literature Cited

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

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

[Bight'08 CEC] Southern California Bight 2008 Regional Monitoring Program Coastal Ecology Committee. (2012). Coastal Ecology Synthesis Report. Southern California Coastal Water Research Project, Costa Mesa, CA.

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

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

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

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

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

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

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

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

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

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

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2008. City of San Diego Ocean

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

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

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

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

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

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

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

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

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

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

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

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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 (e.g., Skirrow 1975) that can impact marine life (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 ocean 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, NOAA/NWS 2013), (2) the California Current System coupled with local gyres that transport distinct water masses into and out of the SCB throughout the year (Lynn and Simpson 1987), and (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 and weaker stratification characterize ocean conditions during the wet season from October to April (City of San Diego 2010b, 2011b, 2012b). For example, winter storms bring higher winds, rain, and waves that 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 (Jackson 1986). 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 the seasonal patterns described above is important since they can affect the transport and distribution of wastewater, storm water, and other types of water masses (e.g., sediment or turbidity plumes). In the South Bay outfall region these include 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).

This chapter presents analyses and interpretations of the oceanographic data collected during 2012 at fixed monitoring stations surrounding the SBOO. The primary goals are to: (1) summarize oceanographic conditions in the region, (2) identify potential natural and anthropogenic sources of variability, and (3) evaluate local conditions in context with regional climate processes. Results of remote sensing observations (i.e., aerial and 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, 2013). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of remote sensing data 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 potential (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

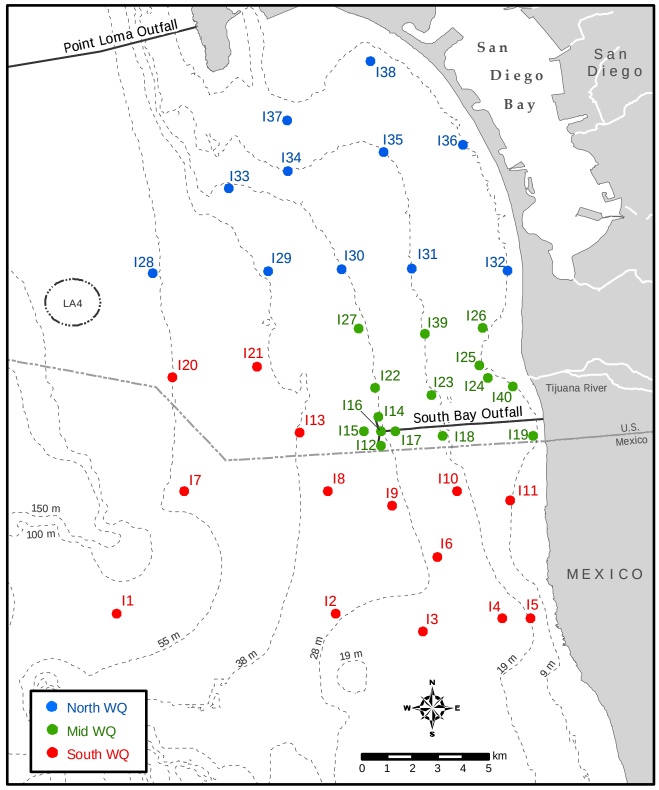

Figure 2.1
Water quality (WQ) monitoring station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Materials and Methods

Field Sampling

Oceanographic measurements were collected at 40 monitoring stations arranged in a grid surrounding the SBOO and that encompass a total area of ~300 km^2 (Figure 2.1). These stations (designated I1–I40) are located between about 3.4 and 14.6 km offshore along or adjacent to the 9, 19, 28, 38 and 55-m depth contours. Each station was sampled once per month, with sampling at all 40 stations usually completed over three consecutive days (Table 2.1). For sampling and analysis purposes the stations were grouped together as follows during each monthly survey: "North Water Quality" stations I28–I38 (n = 11); "Mid Water Quality" stations I12, I14–I19, I22–I27, I39, I40 (n = 15); "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, pH, transmissivity (a proxy for water clarity), and chlorophyll *a* (a proxy for phytoplankton). Water column profiles of each parameter were constructed for each station by averaging the data values recorded within each 1-m depth interval. This data reduction ensured that physical measurements used in subsequent analyses could 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.

Remote Sensing

Coastal monitoring of the South Bay outfall region during 2012 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite imaging data collected during the year were made available

Table 2.1

Sample dates for monthly oceanographic surveys conducted in the South Bay outfall region during 2012. Surveys were conducted over three–five consecutive days with all stations in each station group sampled on a single day (see text and Figure 2.1 for a list of stations and station locations).

Station Group	2012 Sampling Dates											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North WQ	3	6	8	20	4	7	12	14	4	1	6	5
Mid WQ	4	8	7	18	3	6	11	13	5	2	7	4
South WQ	5	7	6	19	2	5	10	15	6	5	8	3

for review and download from OI's website (Ocean Imaging 2013), while a separate report summarizing results for the year was also produced (Svejkovsky 2013). Several types of satellite imagery were analyzed during 2012, including Moderate Resolution Imaging Spectroradiometer (MODIS), Thematic Mapper TM7 color/thermal, and high resolution Rapid Eye images. While these technologies differ in terms of their capabilities, they are generally useful for revealing patterns in surface waters as deep as 12 m.

Data Analysis

Water column parameters measured in 2012 were summarized as means for each month pooled over all stations by the following depth layers: 1–9, 10–19, 20–28, 29–38, 39–55 m. Due to instrumentation issues, pH data for the months of August through October and chlorophyll *a* data for November and December were excluded from these and subsequent analyses. To identify seasonal patterns and trends, temperature, salinity, dissolved oxygen (DO) and density data from stations I2, I3, I6, I9, I12, I14, I15, I16, I17, I22, I27, I30 and I33 located along the 28-m contour (referred to as "outfall depth" stations hereafter) were averaged for each 1-m depth bin by month. Data were limited to these 13 outfall depth stations to prevent masking trends that occur when data from all depth contours are combined. Vertical density profiles were constructed for these stations to depict the pycnocline for each month and to illustrate seasonal changes in water column stratification. 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 seawater density, and dρ/dz is the density gradient (Mann and Lazier 1991). The depth of maximum BF was used as a proxy for the depth at which stratification was the greatest.

For spatial analysis of all parameters, 3-dimensional graphical views were created for each month using Interactive Geographical Ocean Data System (IGODS) software, which interpolates data between stations along each depth contour. For temperature, salinity, DO and pH, the 3-D analyses reported herein are limited to the four monthly surveys most representative of the winter (February), spring (May), summer (August), and fall (November) seasons. These surveys also corresponded to the quarterly water quality surveys conducted as part of the coordinated Point Loma Ocean Outfall and Central Bight Regional monitoring efforts (e.g., City of San Diego 2013, OCSD 2009). For transmissivity and chlorophyll *a*, specific months were chosen to depict events such as storms or phytoplankton blooms.

Additionally, time series of anomalies for temperature, salinity and DO were created to evaluate regional oceanographic events in context with larger scale processes (i.e., ENSO events). These analyses were limited to data from the 28-m outfall depth stations, with all water column depths combined. Anomalies were then calculated by subtracting the average of all 18 years combined (i.e., 1995–2012) from the monthly means for each year.

Results and Discussion

Oceanographic Conditions in 2012

Water Temperature and Density

Surface water temperatures across the entire South Bay outfall region ranged from 10.6ºC in April to 22.2ºC in September during 2012, while sub-surface temperatures ranged from 10.0ºC in April at bottom depths to 20.1ºC in October at mid-water column depths (Appendix A.1). The maximum surface temperature recorded in September was ~1.2ºC higher than in 2011 and ~2.8ºC higher than 2010 (City of San Diego 2011b, 2012b). Temperatures decreased with increasing depth during each survey. Colder waters < 12ºC, likely indicative of upwelling conditions, were recorded at the 13 outfall depth stations from March through July at depths below 20 m, with the lowest values occurring in April (Figure 2.2). Similar conditions extended across the sampling region out to the stations along the 55-m contour (e.g., Figure 2.3, May).

Thermal stratification followed expected seasonal patterns, with the greatest difference between surface and bottom waters (~10ºC) occurring during August (Figure 2.2, 2.3, Appendix A.1). In the shallower 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 month (e.g., Figure 2.4). These vertical density profiles further demonstrated how the water column ranged from well-mixed (i.e., lacking stratification) during January and February with maximum BF ≤35 cycles^2/min^2, to highly stratified in August with a maximum BF of 219 cycles^2/min^2, to weakly stratified in October, November and December with maximum BF ≤74 cycles^2/min^2. These results also illustrated how the depth of the pycnocline (i.e., depth layer where the density gradient was greatest) varied by season, with shallower depths tending to correspond with greater stratification.

Salinity

Salinities recorded in 2012 were similar to those reported previously for the SBOO region (e.g., City of San Diego 2011b, 2012b). Salinity ranged from 33.16 to 33.85 psu in surface waters and from 33.22 to 34.00 psu at sub-surface depths (Appendix A.1). As with ocean temperatures, salinity varied seasonally. For example, the narrow range of values (≤0.2 psu) during January and October reflect the well-mixed or weakly stratified conditions described in the previous section for these months. Additionally, relatively high salinity (e.g., ≥33.60 psu) was present across most of the region from March to July at depths that corresponded with the lowest water temperatures (e.g., Figure 2.2, 2.5). Taken together, low temperatures and high salinity may indicate local coastal upwelling that typically occurs during spring months (Jackson 1986) or may be due to 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 sub-surface depths throughout the SBOO region during the summer (August) and fall (November) of 2012 (Figure 2.5). For example, salinity was ≤33.37 psu between ~15 and 20 m depths at the outfall depth stations during September (Figure 2.2). It seems unlikely that this sub-surface salinity minimum layer (SSML) was related to wastewater discharge via the SBOO for several reasons. First, no evidence has ever been reported of the wastewater plume extending simultaneously in so many directions across such great distances. Instead, results of remote sensing observations (e.g., Svejkovsky 2010), field observations, and other oceanographic studies (e.g., Terrill et al. 2009) have demonstrated that the SBOO plume tends to disperse in only one direction at any given time (e.g., south, southeast, or north) or pool to a limited extent above the outfall. Second, similar SSMLs have been reported previously off San Diego and elsewhere in southern California, including

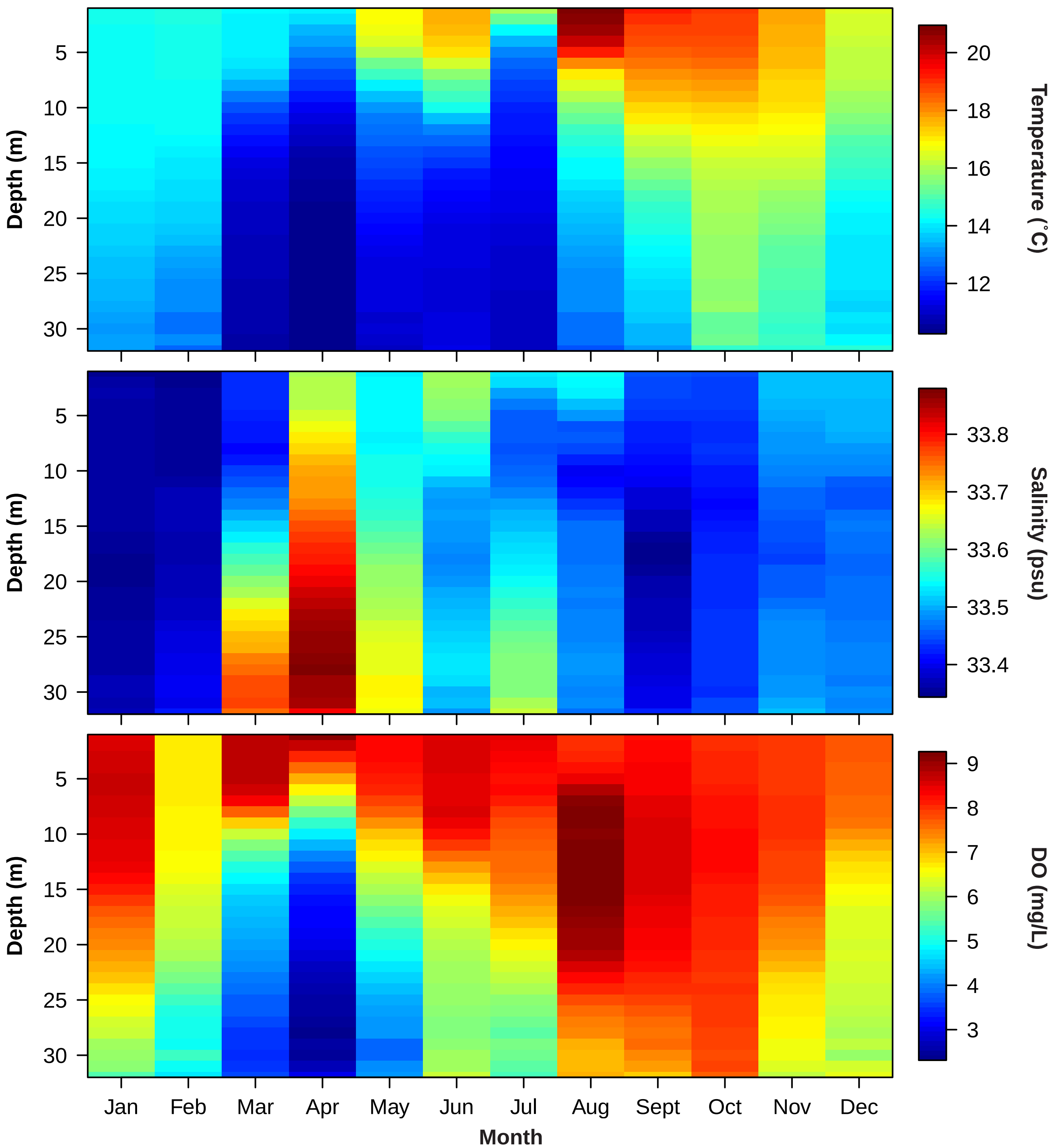

Figure 2.2
Temperature, salinity, and dissolved oxygen (DO) values recorded at SBOO outfall depth stations during 2012. Data are expressed as mean values for each 1-m depth bin, pooled over all stations.

Orange and Ventura Counties, which suggests that this phenomenon is due to a larger-scale oceanographic process (e.g., OCSD 1999, 2009, City of San Diego 2010a, 2011a, 2012a, 2013). Finally, other indicators of the wastewater plume, such as elevated levels of fecal indicator bacteria or colored dissolved organic matter, do not correspond to the SSML (see Chapter 3). Further investigation is required to determine the possible source or sources of this phenomenon.

Dissolved oxygen and pH

Overall, DO concentrations and pH levels were within historical ranges throughout the year

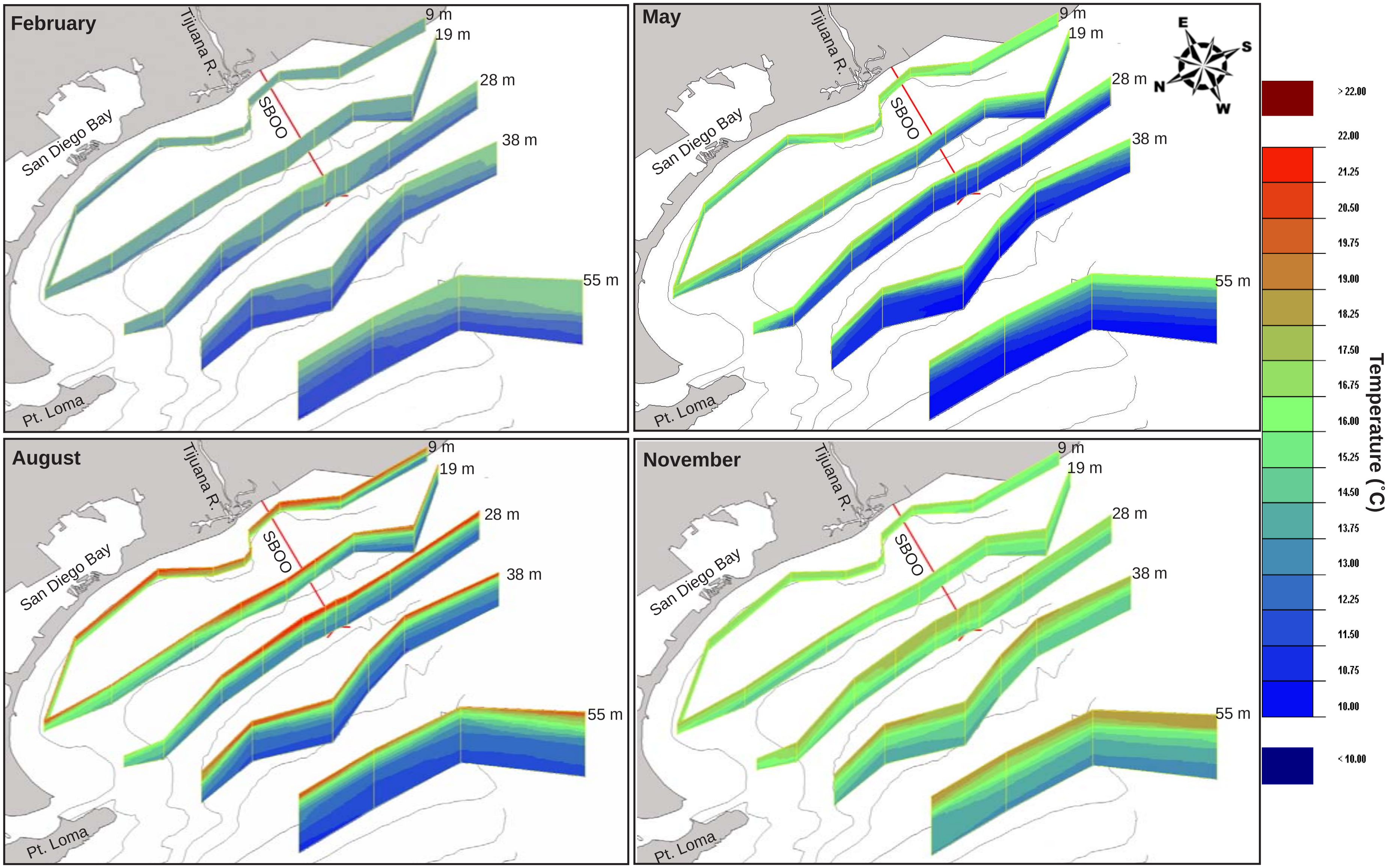

Figure 2.3
Ocean temperatures recorded in 2012 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.

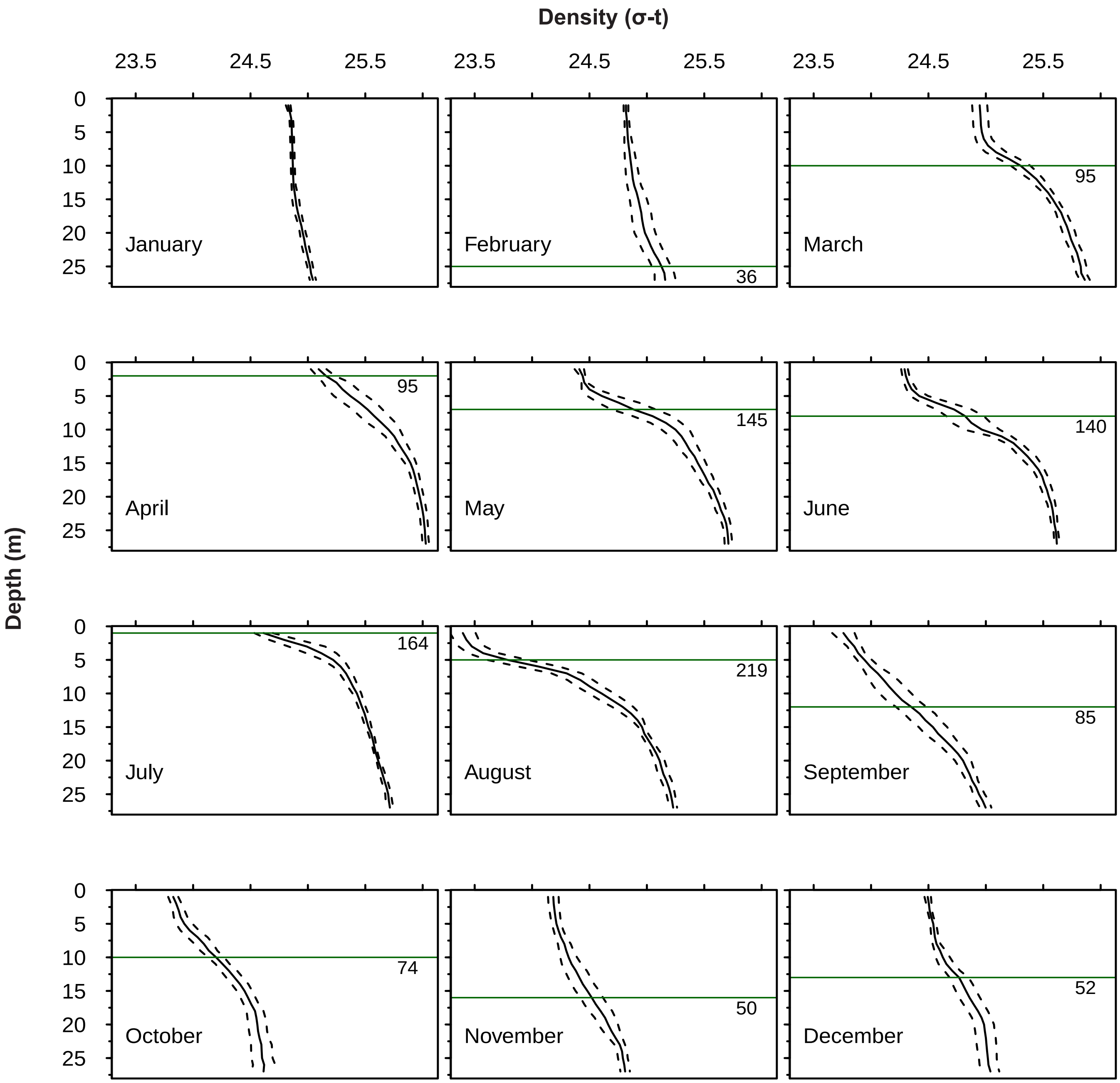

Figure 2.4
Monthly density and maximum buoyancy frequency for the outfall depth stations in the SBOO region during 2012. Solid lines are means, dotted lines are 95% confidence intervals (n = 13). Horizontal lines indicate depth and value of maximum buoyancy frequency (cycles^2/min^2). Buoyancy frequencies less than 35 cycles^2/min^2 are not shown, indicating a well mixed water column.

(e.g., City of San Diego 2011b, 2012b). DO ranged from 1.9 to 12.1 mg/L at the surface and from 1.8 to 10.6 mg/L at sub-surface depths, while pH ranged from 7.6 to 8.4 at the surface and 7.6 to 8.3 at sub-surface depths (Appendix A.1). 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). Additionally, because these parameters varied similarly across all stations, there was no evidence to indicate that the monthly surveys were not synoptic even though sampling occurred over a 3–5 day period (e.g., Appendices A.2, A.3).

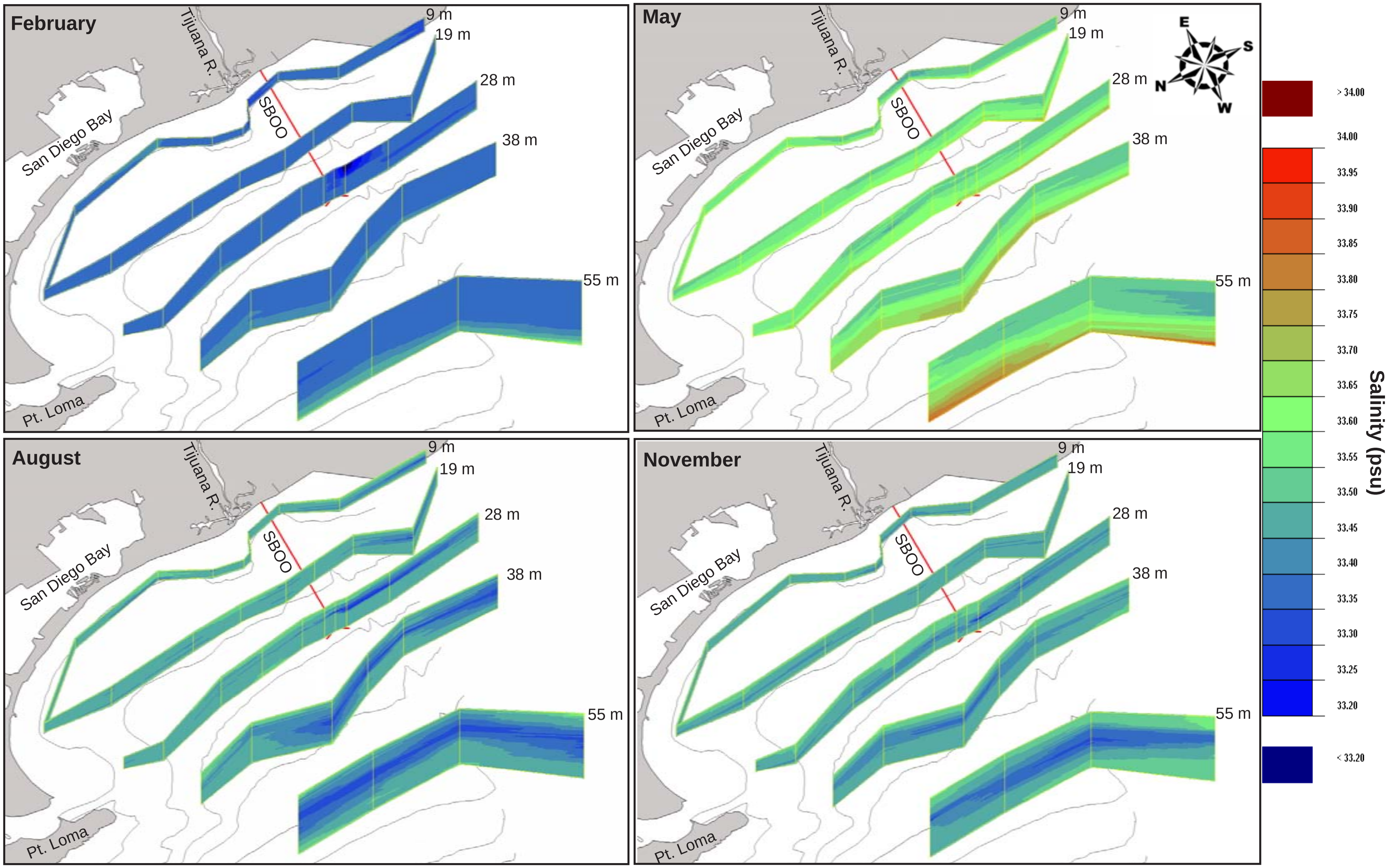

Figure 2.5

Ocean salinity recorded in 2012 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.

Figure 2.6
Rapid Eye image of the SBOO and coastal region depicting turbidity plumes in the study area following storm events on January 26, 2012 (Ocean Imaging 2013).

Changes in DO and pH followed expected patterns that corresponded to seasonal fluctuations in water column stratification and phytoplankton productivity. The greatest variation and maximum stratification occurred predominately during the spring and summer (e.g., Figure 2.2; see also Appendices A.1, A.2, A.3). Low values for DO and pH that occurred at depths below 20 m between March and July 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 in April and August were associated with phytoplankton blooms as evident by high chlorophyll *a* concentrations (e.g., surface DO = 11.7 mg/L and chlorophyll *a* = 64.0 µg/L at station I37 in April).

Transmissivity

Transmissivity levels (%) were within historical ranges for the South Bay outfall region during 2012 (e.g., City of San Diego 2011b, 2012b) with values of 12–91% at the surface and 18–92% at sub-surface depths (Appendix A.1). Water clarity was consistently greater, by as much as 80%, at the offshore stations than in nearshore waters (Appendix A.4). Reduced transmissivity at surface and 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). Low transmissivity recorded during winter months may also have been due to wave and storm activity and resultant increases in suspended sediments. For example, turbidity plumes originating from the Tijuana River (Figure 2.6) coincided with reduced transmissivity throughout the water column at the 9 and 19-m stations during January (Appendix A.4), while reduced transmissivity observed along the bottom at the 28 and 38-m stations during this survey may have been due to significant swell heights > 1.5 m recorded by offshore buoys at the time of sampling (CDIP 2013).

Chlorophyll a

Concentrations of chlorophyll *a* ranged from 0.5 to 74.6 mg/L during 2012 (Appendix A.1). Relatively high values ≥ 40 mg/L occurred during January, March, April, May, June, July, and August at depths from 1 to 38 m. As has been reported previously (e.g., Svejkovsky 2011), the highest chlorophyll *a* concentrations tended to coincide with the upwelling events described in previous sections. Further, the high concentrations recorded at mid- and deeper depths (e.g., Appendix A.4) may reflect the fact that phytoplankton tend to mass at the bottom of the pycnocline where nutrients are greatest (Lalli and Parsons 1993). Only the elevated chlorophyll *a* values reported during March corresponded to phytoplankton blooms observed by satellite (Svejkovsky 2013). These plankton blooms extended throughout the South Bay outfall region and to the north of Point Loma (Figure 2.7). Elevated chlorophyll *a* concentrations that occurred during other surveys were most likely also associated with phytoplankton blooms, but because the phytoplankton occurred at sub-surface depths, they went un-observed by remote sensing due to the depth-limitations of satellite imagery (Svejkovsky 2013).

Figure 2.7
Terra MODIS image of wide-spread phytoplankton blooms in San Diego's nearshore waters in the South Bay outfall region March 4, 2012 (Ocean Imaging 2013).

Historical Assessment of Oceanographic Conditions

A review of temperature, salinity, and DO data from all outfall depth stations sampled between 1995 and 2012 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 (Figure 2.8) (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, NOAA/NWS 2013). For example, six 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 between 1999 and 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. Temperature and salinity data for the SBOO region are consistent with all but the third of these events; while the CCS was experiencing a warming trend that lasted through 2006, the SBOO region experienced cooler than normal conditions during much of 2005 and 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 occurred after the subarctic intrusion were likely associated with increased rainfall in the region (Goericke et al. 2007, NWS 2011). During 2012, sea surface temperatures were colder than normal from January through July, after which they increased to above average temperatures throughout the remainder of the year. This pattern was consistent with reports from NOAA that the relatively cool water La Niña conditions of 2011 persisted throughout the first half of 2012 before beginning to warm (NOAA/NWS 2013).

Historical trends in local DO concentrations reflect several periods during which lower than normal DO has aligned with low water temperatures and high salinity, which is consistent with the cold, saline and oxygen-poor ocean waters that result from local coastal upwelling (e.g., 2002, 2005–2011). In addition, 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).

Summary

Sea surface temperatures were colder than normal from January through July, after which they increased to above average temperatures throughout the remainder of the year. This pattern was consistent with reports from NOAA that

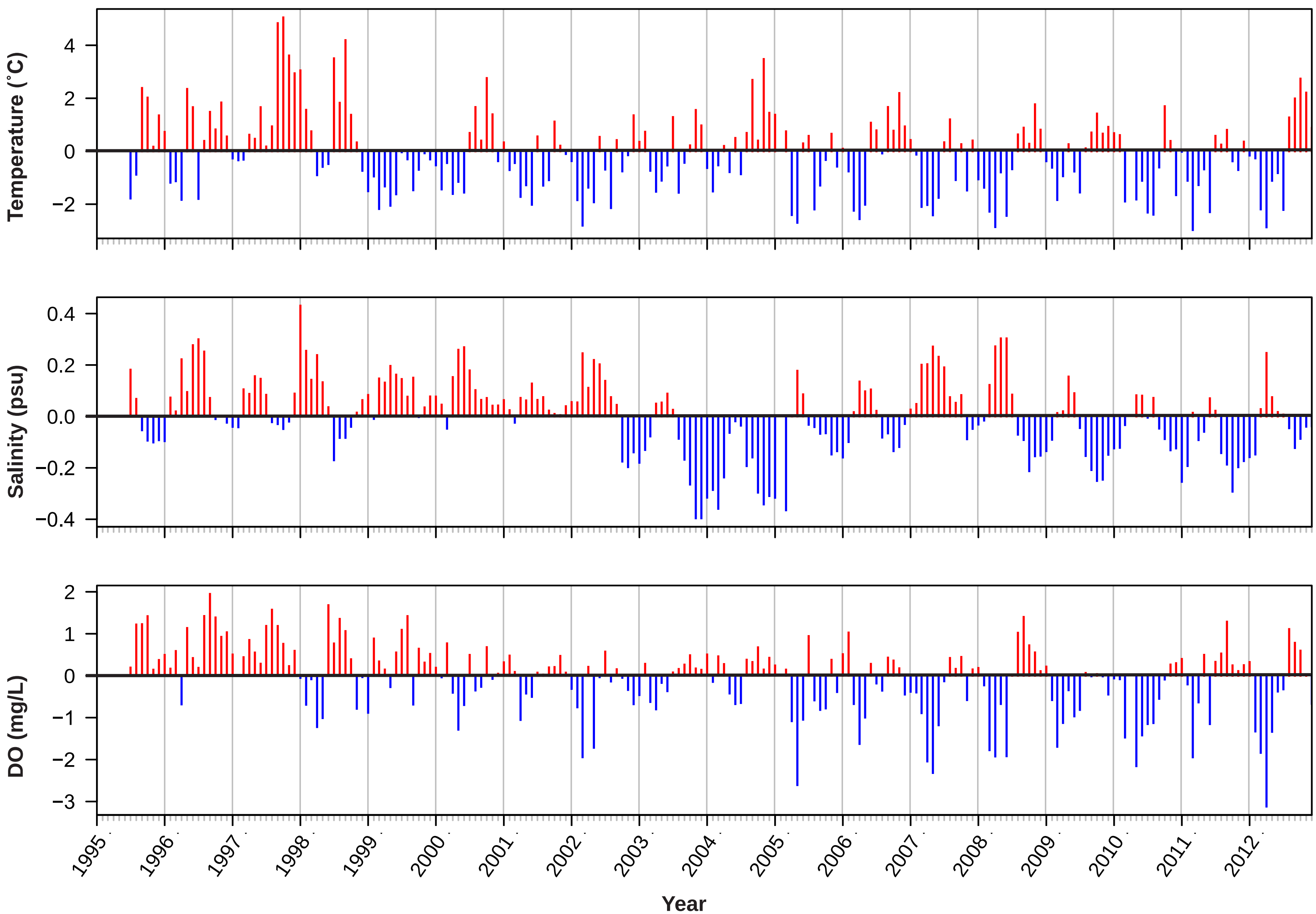

Figure 2.8
Time series of temperature, salinity, and dissolved oxygen (DO) anomalies between 1995 and 2012. Data were limited to outfall depth stations, all depths combined.

the relatively cool water La Niña conditions of 2011 persisted throughout the first half of 2012 before beginning to warm (Bjorkstedt et al. 2012, NOAA/NWS 2013). 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 from the beginning of spring through mid-summer, but were most evident during March and April. Phytoplankton blooms, indicated by high chlorophyll *a*, were present during much of the year. Due to their depth, cruise-based profiles showed that these plankton blooms covered a greater spatial and temporal extent than was evident from remote sensing alone (Svejkovsky 2013).

Overall, water column stratification in 2012 followed seasonal patterns typical for the San Diego region; maximum stratification of the water column 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, NOAA/NWS 2013) or with conditions in northern Baja California (Peterson et al. 2006). These observations suggest that most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego are explained by a combination of local (e.g., coastal upwelling, rain-related runoff) and large-scale oceanographic processes (e.g., ENSO, PDO, NPGO).

Literature Cited

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

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

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

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

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

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

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

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

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

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

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

[CDIP] Coastal Data Information Program. (2013). Repository of historical data collected by offshore buoys. http://cdip.ucsd.edu/?&nav=historic&sub=data.

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

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

Lalli, C.M. and T.R. Parsons. (1993). Biological Oceanography: an introduction. Pergamon. New York.

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

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

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

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

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

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

[NOAA/NWS] National Oceanic and Atmospheric Administration/National Weather Service. (2013). Climate Prediction Center Website. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory.html.

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

Ocean Imaging. (2013). Ocean Imaging Corporation archive of aerial and satellite-derived images. http://www.oceani.com/SanDiegoWater/index.html.

[OCSD] Orange County Sanitation District. (1999). Annual Report, July 2008 – June 1999. Marine Monitoring, Fountain Valley, CA.

[OCSD] Orange County Sanitation District. (2009). Annual Report, July 2008 – June 2009. Marine Monitoring, Fountain Valley, CA.

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

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

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

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

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

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

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

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

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

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Chapter 3
Water Quality Compliance & Plume Dispersion

Chapter 3. Water Quality Compliance & 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 (FIB), 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 addition, the City's water quality monitoring efforts in 2012 were designed to assess compliance with the water contact standards specified in the 2005 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 2005).

Multiple sources of potential bacterial contamination exist in the South Bay outfall monitoring region in addition to the outfall. Therefore, being able to separate impacts associated with a wastewater plume from other sources of contamination is often challenging. Examples of other local, but non-outfall sources of bacterial contamination include 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 wet-weather runoff from local watersheds 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, cultivating bacteria until release 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. 2012). 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 analyses and interpretations of the microbiological, water chemistry, and oceanographic data collected during 2012 at fixed water quality monitoring stations surrounding the SBOO. The primary goals are to: (1) document overall water quality conditions in the region during the year; (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 2005 Ocean Plan. Results of remote sensing data are also evaluated to provide insight into wastewater transport and the extent of significant events in surface waters during the year (e.g., turbidity plumes).

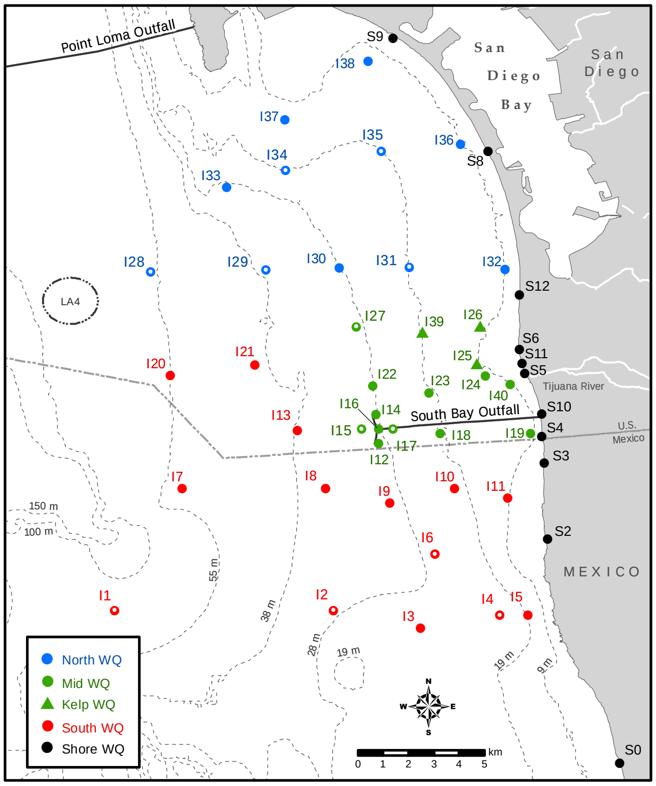

Figure 3.1

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.

Table 3.1

Depths at 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.

Materials and Methods

Field Sampling

Shore stations

Seawater samples were collected weekly at 11 shore stations to monitor 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 in northern Baja California, Mexico and are not subject to Ocean Plan requirements. Seawater samples for shore stations were collected from the surf zone in sterile 250-mL bottles. In addition, visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. 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.

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 located near the inner edge of the kelp bed along the 9-m depth contour (i.e., I25, I26), and one station located near the outer edge of the kelp bed along the 18-m depth contour (I39). An additional 25 stations located further offshore in deeper waters were sampled once a month to monitor FIB levels and 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 generally occurred over a 3-day period within each month (see Chapter 2).

Seawater samples were collected for FIB and total suspended solids (TSS) at three discrete depths (Table 3.1) at kelp stations using an array

Box 3.1

Water quality objectives for water contact areas, 2005 California Ocean Plan (SWRCB 2005).

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.

of Van Dorn bottles and at non-kelp bed offshore stations using a Sea-Bird (SBE 32C) rosette sampler fitted with Niskin bottles. 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 Wastewater Chemistry 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 monthly from these stations using a Sea-Bird (SBE 25) conductivity, temperature, and depth instrument (CTD) and included measurements of 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 1995, CDPH 2000, USEPA 2006). All bacterial analyses were performed within eight hours of sample collection and conformed to standard membrane filtration techniques (APHA 1995).

Enumeration of FIB density was performed and validated in accordance with USEPA (Bordner et al. 1978, USEPA 2006) and APHA (1995) 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 2013).

Data Analyses

Bacteriology

FIB densities were summarized as monthly means for each shore station and by depth contour for the kelp bed and non-kelp bed offshore stations. TSS concentrations were also summarized by month 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 2005 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 2005) were used as reference points to distinguish elevated FIB values (i.e., benchmark levels). Concentrations of each type of FIB are identified by sample in Appendices B.1, B.2, and B.3. Bacterial densities were compared to rainfall data from Lindbergh Field, San Diego, CA (see NOAA 2013). Fisher's Exact Tests (FET) or 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 (January–April and October–December) and dry (May–September) seasons. Satellite images of the SBOO region were provided by Ocean Imaging of Solana Beach, California (Svejkovsky 2013) 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 and the three kelp bed stations exceeded the various standards.

Plume Detection and Out-of-range Calculations

The potential presence or absence of 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.4). 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 is weak or absent (City of San Diego 2009–2012, Terrill et al. 2009). Water column stratification and pycnocline depth were quantified using calculations of buoyancy frequency (cycles^2/min^2) for each month (Chapter 2). If the water column was stratified, subsequent analyses were limited to depths below the pycnocline. Identification of a potential plume signal at a station relied on multiple criteria, including (1) high CDOM, (2) low salinity, (3) low chlorophyll *a*, and (4) visual interpretation of the overall water column profile. Detection thresholds were adaptively set for each monthly sampling period according to the following criteria: CDOM exceeding the 90th 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. Finally, water column profiles were visually interpreted to remove stations with spurious signals (e.g., CDOM signals near the benthos likely due to resuspension of sediments by wave activity).

After identifying the stations and depth-ranges where detection criteria suggested the plume was present, out-of-range thresholds were calculated for water quality parameters of interest, namely DO,

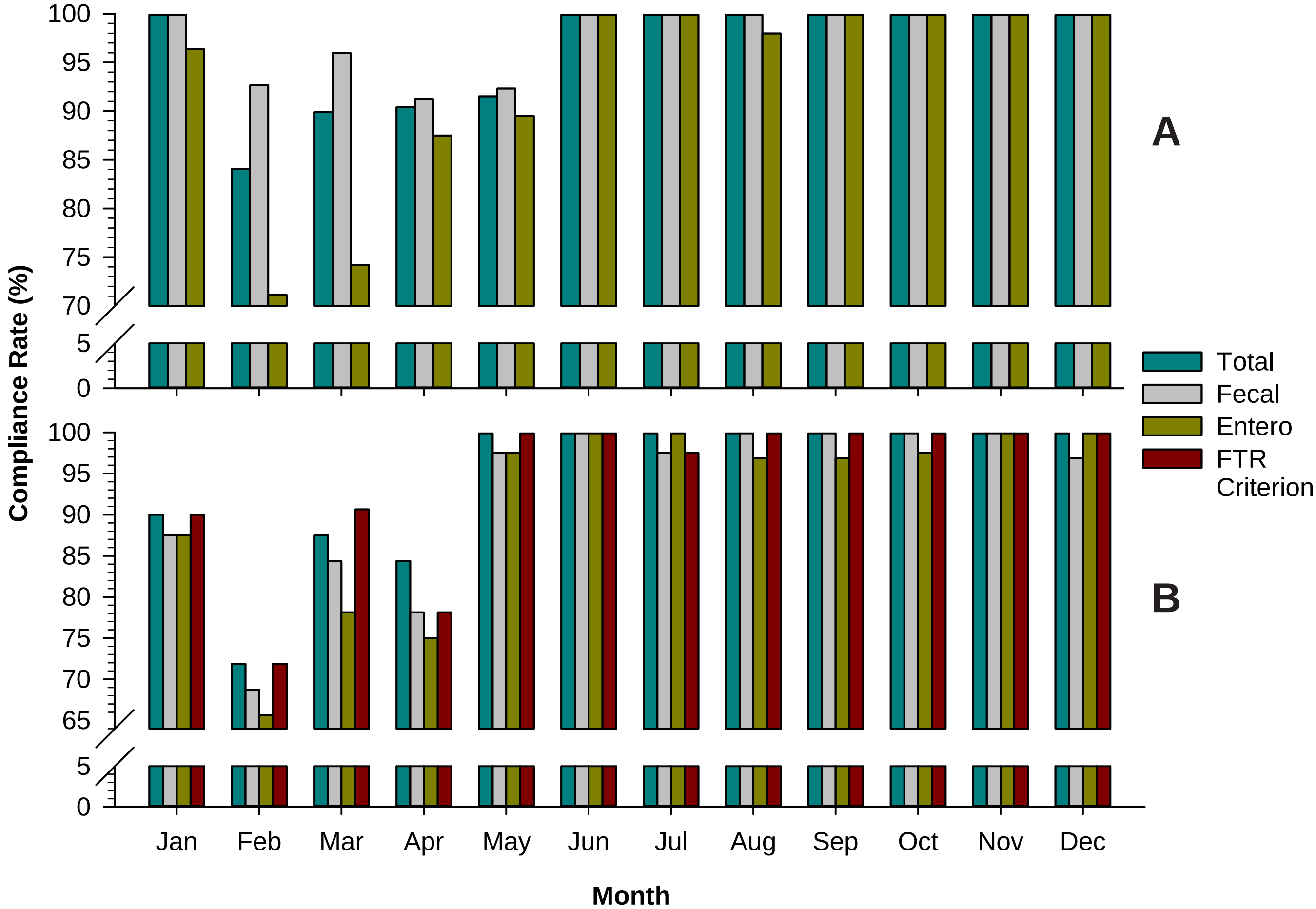

Figure 3.2
Compliance rates for (A) the three geometric mean and (B) the four single sample maximum water contact standards at SBOO shore stations during 2012. See Box 3.1 for details.

pH, and transmissivity. Any stations with CDOM below the 90th percentile were considered to lack the presence of wastewater plume and were used as non-plume reference stations for that month (Appendix B.5). Stations were designated as out-of-range if DO, pH, or transmissivity within the wastewater plume exceeded water quality standards as defined by the Ocean Plan (Box 3.1). Out-of-range (OOR) thresholds were determined by comparing geometric means for each parameter at plume stations and depths against the thresholds calculated at similar depths across all non-plume reference stations for each monthly sampling period (Appendix B.6). Thresholds for non-plume reference DO and pH (10% and 0.2 unit reductions, respectively) were applied to the mean minus one standard deviation, while transmissivity thresholds were calculated as the lower 95% confidence interval from the mean (Box 3.1).

Results and Discussion

Bacteriological Compliance and Distribution

Shore stations

During 2012, compliance for the 30-day geometric mean standards at the eight shore stations located north of the USA/Mexico border ranged from 84 to 100% for total coliforms, 91 to 100% for fecal coliforms, and 71 to 100% for *Enterococcus* (Figure 3.2A). In addition, compliance for single sample maximum (SSM) standards ranged from 72 to 100% for total coliforms, 69 to 100% for fecal coliforms, 66 to 100% for *Enterococcus*, and 72 to 100% for the fecal:total coliforms (FTR) criterion (Figure 3.2B). However, six of these stations (i.e., S4, S5, S6, S10, S11, S12) fall within or immediately adjacent to areas listed as impaired waters and are not expected to be in compliance with the various water contact standards set by the State of California and USEPA (SOC 2010). Overall compliance at the two shore stations outside these areas (i.e., S8 and S9) was 99.7% in 2012. Reduced compliance at shore stations was more prevalent during the wet season (i.e., January–April), ranging from 66 to 91% across all standards and lowest during February. Compliance levels were greater than 96% for the last two-thirds of the year (i.e., May–December).

Monthly mean FIB densities ranged from 2 to 8055 CFU/100 mL for total coliforms, 2 to 5758 CFU/100 mL for fecal coliforms, and 2 to 4137 CFU/100 mL for *Enterococcus* at the individual stations (Appendix B.7). Of the 568 shore samples analyzed during the year, 7% had elevated FIB, which is a decline from 13.6% in 2011. Bacterial exceedances occurred more often during the wet season in 2012 (10% versus 3% in the dry season; n = 568, $\chi^2 = 10.02$, $p = 0.0016$). During this period when rainfall totaled 6.54 inches (versus 0.02 inches in the dry season), 82% of the shore station samples with elevated FIB were collected (Table 3.2). This general relationship between rainfall and elevated bacterial levels has been evident from water quality monitoring in the South Bay outfall region since 1996 (Figure 3.3). Historical data indicate that collecting a sample with elevated FIB was

Table 3.2
The number of samples with elevated bacteria densities collected at SBOO shore stations during 2012. Wet = January–April and October–December; Dry = May–September; n = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

	Seasons		
Station	**Wet**	**Dry**	**% Wet**
S9	1	2	33
S8	0	1	0
S12	0	0	—
S6	0	0	—
S11	2	0	100
S5	9	1	90
S10	5	1	83
S4	4	0	100
S3	3	1	75
S2	3	0	100
S0	6	1	86
Rain (in)	6.54	0.02	
Total Counts	33	7	82
n	326	242	

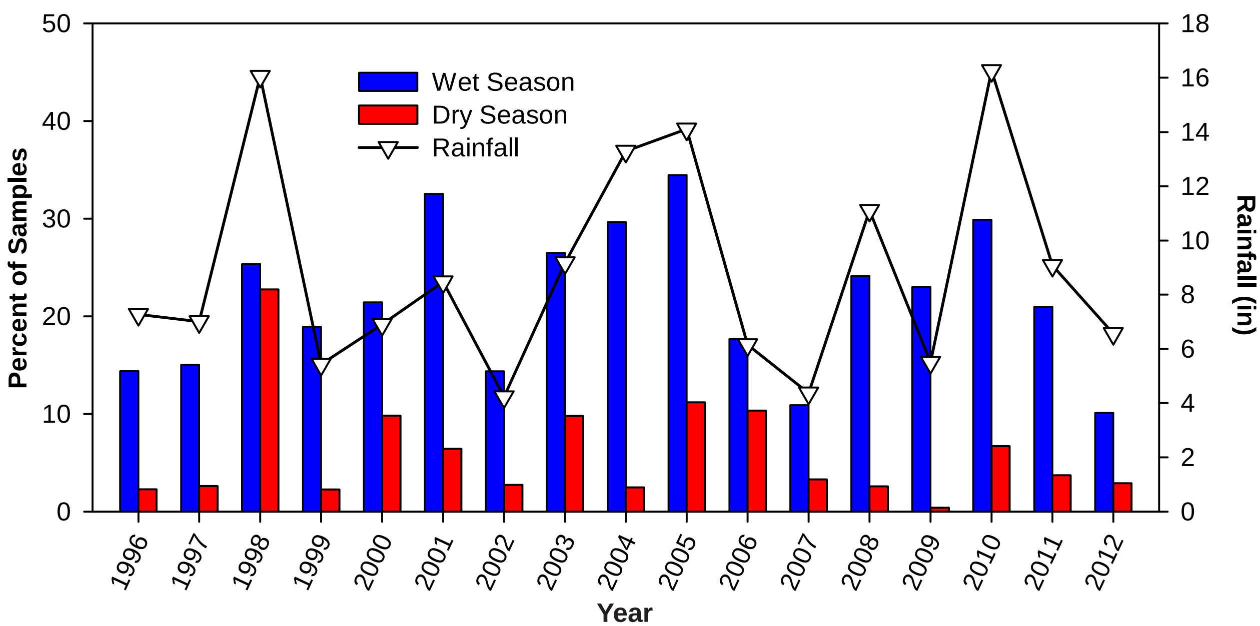

Figure 3.3
Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet versus dry seasons at SBOO shore stations between 1996 and 2012. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA. Data from 1995 were excluded as sampling did not occur the entire year.

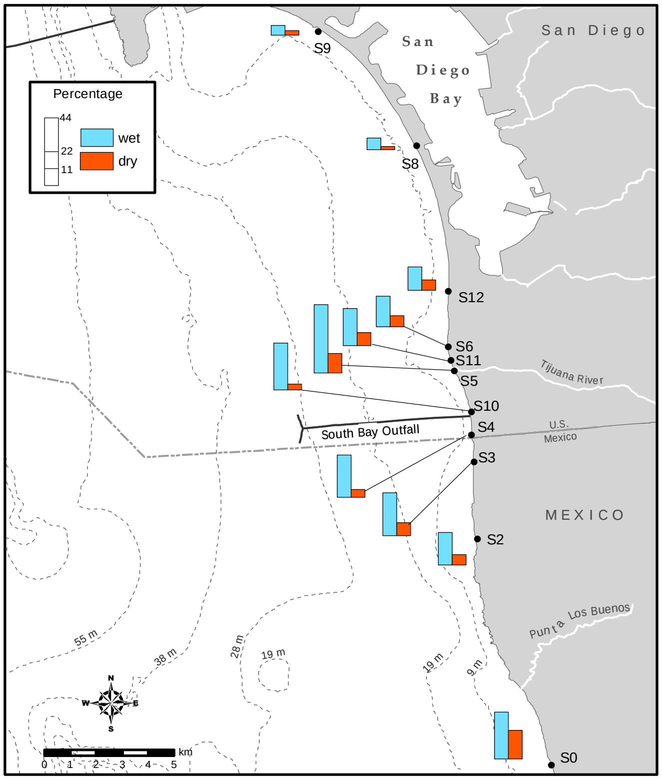

Figure 3.4
Comparison of known non-outfall sources of contamination to the percent of samples with elevated FIB densities in wet versus dry seasons at SBOO shore stations between 1995 and 2012. Wet = January–April and October–December; Dry = May–September.

significantly more likely during the wet season than during the dry (21% versus 6%, respectively; n = 10,582, $\chi^2 = 447.78$, $p < 0.0001$).

During the wet season, samples with elevated FIB were primarily collected at stations located close to the mouth of the Tijuana River (S4, S5, S10, S11) and farther south in Mexico (S0, S2, S3) (Table 3.2, Appendix B.1). Samples from some of these stations (i.e., S0, S3, S5, S10) also had high levels of bacterial contamination during dry conditions from May to September, and accounted for four of the seven dry weather samples with elevated FIB. The remaining three dry-weather samples with elevated FIB were taken at the two northernmost stations (i.e., S8 and S9), though the source of contamination at these sites remains unclear. Foam and sewage-like odors were consistently observed at various shore stations within the SBOO region, with increased occurrences during the wet season. Additionally, water running from storm drains was observed at all three stations in Mexico. Analyses of historical data, including several years prior to wastewater discharge, indicated greater frequencies of elevated FIB occurred near the Tijuana River and, to a lesser extent, south of the international border near Los Buenos Creek, especially during the wet season (Figure 3.4). Over the past several years, high FIB counts at these stations have consistently corresponded to turbidity flows from the Tijuana River and Los Buenos Creek, typically following rain events (City of San Diego 2008–2012). Shore station water quality may also be impacted via sewage spills, regardless of season. For example, three separate sewage spills with discharges ranging from 2 to 5 million gallons were reported in 2012, two in April via the Tijuana River and one in August from the Playas de Tijuana area (Svejkovsky 2013). Two of these spills corresponded with exceedances of the *Enterococcus* SSM at station S5 on April 24 and station S3 on August 28 (Appendix B.1).

Kelp bed stations
Compliance at the three kelp bed stations in the SBOO region was 100% for the 30-day total coliforms, fecal coliforms, and *Enterococcus* geometric mean standards. The SSM compliance rates were 96–100%, with standards exceeded from 2 to 5 times at these stations (Figure 3.5). The lowest compliance rates occurred in February and March, which correspond to a period of high rainfall during 2012 (Appendix B.2).

Monthly mean FIB densities at the SBOO kelp bed stations were lower than those at shore stations, ranging from 2 to 1117 CFU/100 mL for total coliforms, 2 to 244 CFU/100 mL for fecal coliforms, and 2 to 31 CFU/100 mL for *Enterococcus* (Appendix B.8). Only six of 540 samples (1.1%) analyzed during the year had elevated FIB, all of which were collected at station I25. Visual observations confirmed discolored water due to runoff from the Tijuana River at station I25 on January 25, although no bacterial exceedances occurred in this particular instance. Due to fewer high-rainfall events, coastal runoff from the Tijuana Estuary was lower in 2012 compared to previous years (Svejkovsky 2013). This may explain the decline in elevated FIB samples,

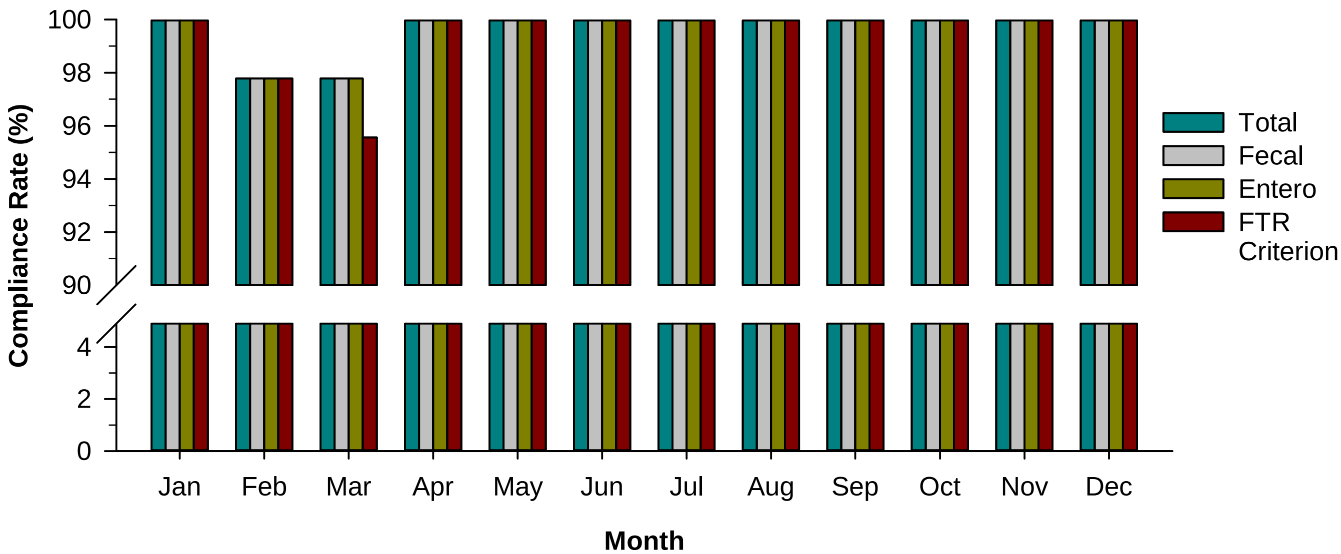

Figure 3.5
Compliance rates for the four single sample maximum water contact standards at SBOO kelp bed stations during 2012. See Box 3.1 for standard details.

down from 2.8% in 2011 (City of San Diego 2012). The highest concentrations of these bacteria occurred during the wettest months of 2012, similar to the pattern exhibited at shore stations (2% versus 0% in the dry season; $n = 540$, $p = 0.0437$, FET). For example, all of the kelp bed samples with elevated FIB were collected during the wet season (Table 3.3). These results are consistent with historical water quality monitoring data for the region (Figure 3.6), and indicate that collecting a sample with elevated FIB was significantly more likely during the wet season than during the dry season (8% versus 1%, respectively; $n = 7964$, $\chi^2 = 195.07$, $p < 0.0001$).

Oil and grease (O&G) and total suspended solids (TSS) were also measured at kelp bed stations as potential indicators of wastewater. Only one sample collected during 2012 contained detectable levels of O&G (detection limit = 0.2 mg/L), but did not coincide with elevated FIB. In contrast, TSS were detected in 97% of samples at concentrations ranging from 1.77 to 31.20 mg/L per sample (Appendix B.9). Of the 20 seawater samples with elevated TSS concentrations (≥ 8.0 mg/L), none co-occurred with elevated FIB.

Non-kelp bed stations

FIB concentrations were low in seawater samples collected from the 25 non-kelp bed offshore stations during 2012, with monthly means ranging from 2 to 908 CFU/100 mL for total coliforms, 2 to 97 CFU/100 mL for fecal coliforms, and 2 to 75 CFU/100 mL for *Enterococcus* (Appendix B.8). Only about 0.8% ($n = 7$) of the 900 samples collected at these sites contained elevated FIB (Appendix B.3). There was a coinciding decrease in rainfall and samples with elevated FIB in 2012, down from 9.08 inches and 1.3% in 2011, respectively (City of San Diego 2012). At stations located along the 9-m depth contour (i.e., I5, I40), 83% of the samples with elevated FIB were collected during the wet season. In combination with kelp bed station I25, these two stations had the highest elevated FIB detection rates throughout the year (Figure 3.7). Given the proximity of these stations to the shore, coastal runoff may drive this pattern (Chapter 2). For example, a satellite image showed a turbidity plume from the Tijuana River passing over station I40 (northeast of the outfall) five days prior to the collection of an elevated FIB water sample, and within the same image the surfacing outfall plume is visibly transported southward, impacting station I12 (Figure 3.8).

The percentage of samples collected along the 28-m offshore stations with elevated FIB was much lower in 2012 than in previous years (Figure 3.9). Only one sample with high bacteria counts was collected

Table 3.3

The number of samples with elevated bacteria collected at SBOO kelp bed and other offshore stations during 2012. Wet = January–April and October–December; Dry = May–September; n = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Missing offshore stations had no samples with elevated FIB concentrations during 2012.

	Wet	Dry	% Wet
Rain (in)	6.54	0.02	
2012 Kelp Bed Stations			
9-m Depth Contour			
I25	6	0	100
I26	0	0	—
19-m Depth Contour			
I39	0	0	—
Total Counts	6	0	100
n	315	225	
2012 Non-Kelp Bed Stations			
9-m Depth Contour			
I5	3	1	75
I40	2	0	100
28-m Depth Contour			
I12	1	0	100
Total Counts	6	1	86
n	525	375	

along this depth contour, from station I12 at a depth of 2 m (Table 3.3, Figure 3.7, 3.8, Appendix B.3). Historically, samples with elevated bacterial levels have been collected more often at the three stations closest to the SBOO south diffuser leg (i.e., I12, I14, I16) compared to other stations along the 28-m depth contour (13% versus 3%; n = 4961, $\chi^2 = 181.62$, $p < 0.0001$) (Figure 3.9). These elevated samples have predominately been collected at a depth of 18 m. Consequently, it appears likely that these FIB densities were associated with wastewater discharge from the outfall. Visual observations confirmed the surfacing of the plume at station I12 on January 4. However, the source of other surface observations, such as sewage-like odors noted at station I11 on April 11 and foam observed at station I13 on August 15, is less clear.

Oil and grease and total suspended solids were also measured at the non-kelp bed stations as potential indicators of wastewater (Appendix B.9). Of the samples collected during 2012, 2.3% contained detectable levels of O&G, with concentrations that ranged from 1.80 to 22.60 mg/L. Total suspended solids were detected in 94% of samples, with concentrations that ranged from 1.45 to 33.70 mg/L. Only one seawater sample with elevated TSS concentrations (≥8.0 mg/L) corresponded to a sample with elevated FIB, the 9-m sample at station I40 on February 8. The location of this sample, near the bottom and in close proximity to the Tijuana River mouth, suggests that this elevated measurement was likely due to re-suspension of sediments.

Wastewater Plume: Detection and Impacts

Based on detection criteria, the potential wastewater plume from the SBOO was identified at various stations in all months except January, with an overall annual detection rate of 11.6% based on 336 total profile casts (Table 3.4). The spatial distribution of plume detections fluctuated throughout the year, occurring both north and south of the outfall (Figure 3.10, Appendix B.10). This is likely due to reversals in alongshore currents in the SBOO region (Terrill et al. 2009), though subsurface current data are currently not available. The plume was most frequently detected at stations near the wastewater outfall, particularly at stations I16 and I12 (83% and 67%, respectively). Failure to detect the wastewater plume at certain times (e.g., January) was most likely a consequence of the coarse spatial scale of the fixed-grid sampling stations in the SBOO region (see Terrill et al. 2009). Plume depth also fluctuated through time; periods of weak stratification (buoyancy frequency < 32 cycles^2/min^2) allowed the plume to surface, while stronger stratification (buoyancy frequency > 32 cycles^2/min^2) restricted the plume's rise height to depths beneath the pycnocline (Appendix B.11). Detection of the wastewater plume surfacing at station I12 on February 8 was corroborated by a water sample with elevated FIB collected at a depth of 2 m (Figure 3.7, Appendix B.3). In addition, a satellite image captured five days prior to this sampling provides convincing visible evidence that the wastewater plume was in surface waters during that timeframe (Figure 3.8).

The impacts of the SBOO plume on water quality were calculated at stations and depths where it

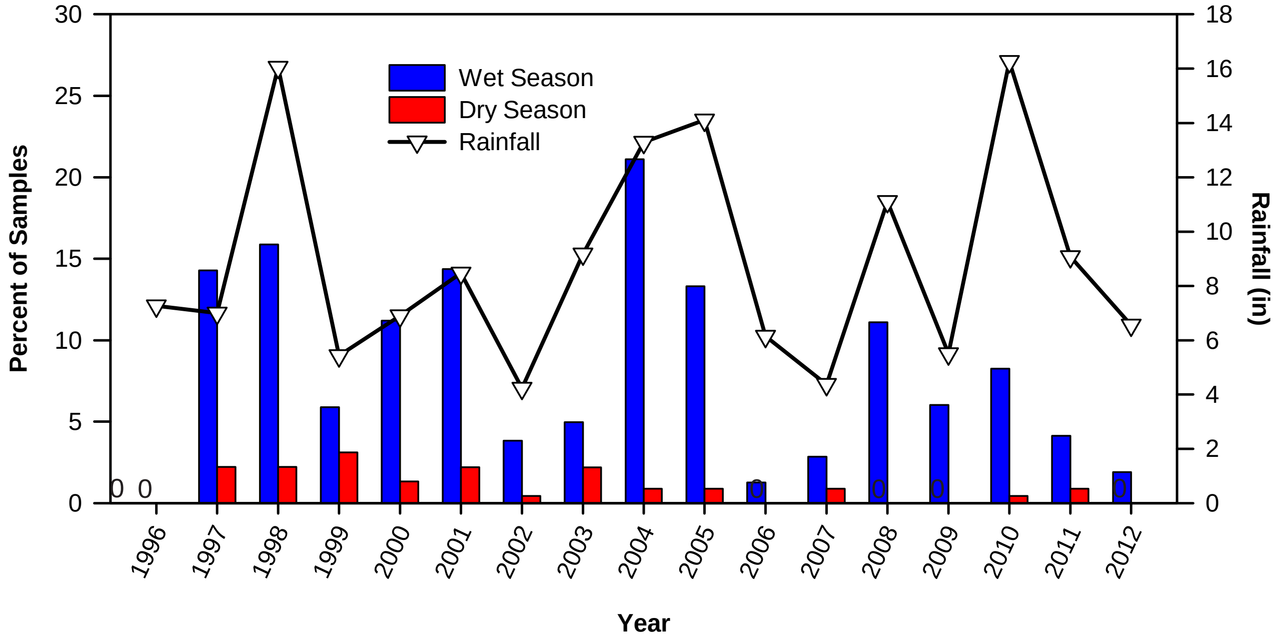

Figure 3.6

Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet versus dry seasons at SBOO kelp bed stations between 1996 and 2012. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA. Data from 1995 were excluded as sampling did not occur the entire year.

was detected. At each of these stations, mean values of DO, pH, and transmissivity within the plume were compared to thresholds within similar depths from non-plume reference stations (Appendix B.6). Of the 39 total plume detections during 2012, 31 out-of-range (OOR) events within the wastewater plume were identified, consisting of one instance for DO, no instances for pH, and 30 instances for transmissivity (Table 3.4, Appendices B.12, B.13, B.14). The OOR event for DO occurred in July at station I12 (Figure 3.11) while transmissivity OOR events happened consistently throughout the year. None of OOR events occurred at the kelp bed stations where Ocean Plan compliance standards applied at the time of sampling.

Summary

Water quality conditions in the South Bay outfall region were excellent during 2012. Overall compliance with 2005 Ocean Plan water-contact standards was ~97%, which was greater than the 91% compliance observed during the previous year (City of San Diego 2012). This improvement likely reflects lower rainfall, which totaled about 6.56 inches in 2012 versus 9.08 inches in 2011. Additionally, only 2.6% of all water samples analyzed in 2012 had elevated FIB, of which 85% occurred during the wet season. Of these elevated counts, 73% were from samples collected at the shore stations. This pattern of relatively higher contamination along the shore during the wet season is similar to that observed during previous years (e.g., City of San Diego 2012). The few samples with high bacteria counts taken during dry weather periods also tended to occur more frequently at shore stations.

There was no evidence that wastewater discharged to the ocean via the SBOO reached the shoreline or nearshore recreational waters during the year. Although elevated FIB were detected along the shore and occasionally at kelp bed or other nearshore stations, these results did not indicate shoreward transport of the wastewater plume, a conclusion consistently supported by remote sensing observations (e.g., Terrill et al. 2009, Svejkovsky 2010–2013). Instead, comparisons of FIB distribution patterns with corresponding satellite images suggest that other sources such as coastal runoff (e.g., turbidity plumes) from rivers and creeks are more likely to impact coastal

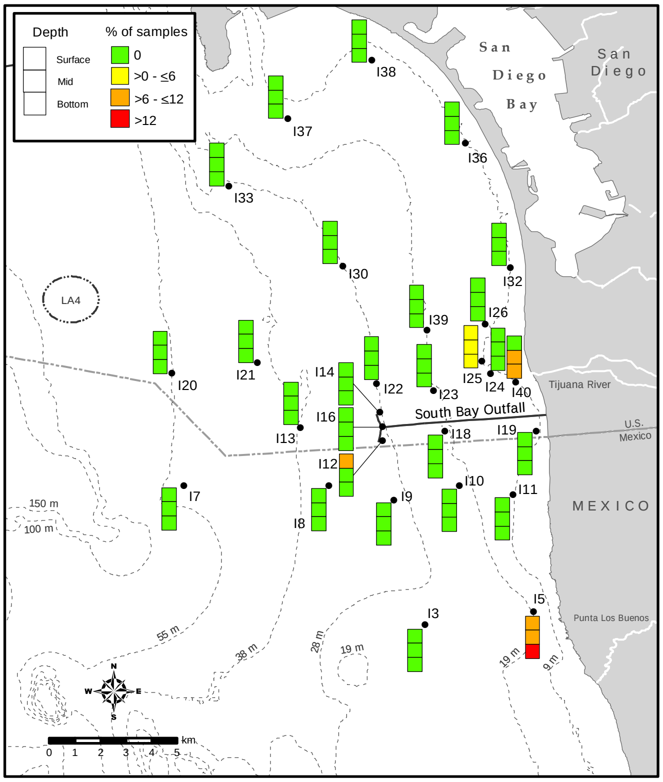

Figure 3.7

Distribution of seawater samples with elevated FIBs at kelp bed and other offshore stations during 2012. Data are the percent of samples that contained elevated bacteria densities. See text and Table 3.1 for sampling details.

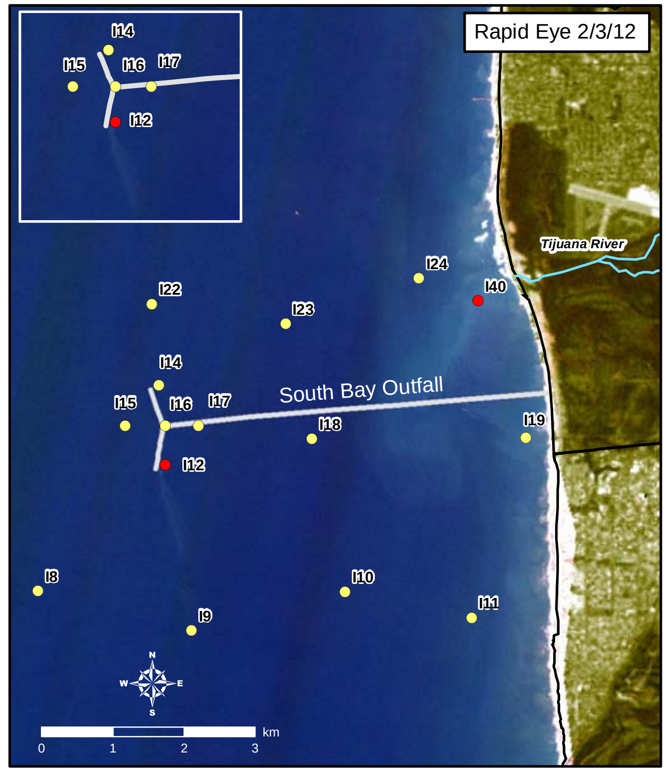

Figure 3.8

Rapid Eye satellite image showing offshore stations near the SBOO on February 3, 2012 (Ocean Imaging 2013) combined with bacteria levels sampled on February 8, 2012. Turbid waters from the Tijuana River or the surfacing effluent plume can be seen overlapping stations with elevated FIBs (red circles). See Appendix B.3 for bacterial sample details and Appendices B.10–B.13 for vertical profiles of station I12.

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 2008–2012). It is also well established that sewage-laden discharges from the Tijuana River and Los Buenos Creek are likely sources of bacteria during 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).

Finally, bacterial contamination in non-kelp offshore waters was very low in the SBOO region during 2012, with about 0.8% of all samples collected having elevated FIB. These high counts included six samples from the wet season and one sample from the dry season. Only a single sample with elevated FIB was collected near the discharge site (i.e., at station I12 near the tip of the southern diffuser leg). The low rates of bacteriological contamination detected near the outfall is likely due to chlorination of South Bay International Water Treament Plant effluent (typically between November and April) and the initiation of full secondary treatment that began in January 2011. Consequently, bacteriological data may no longer be useful for plume tracking in this region. Instead, plume detection analyses and available observations from satellite imagery may prove more insightful. For example, satellite images captured during 2012 were able to detect the signature of the SBOO wastewater plume in near-surface waters over the discharge site on several

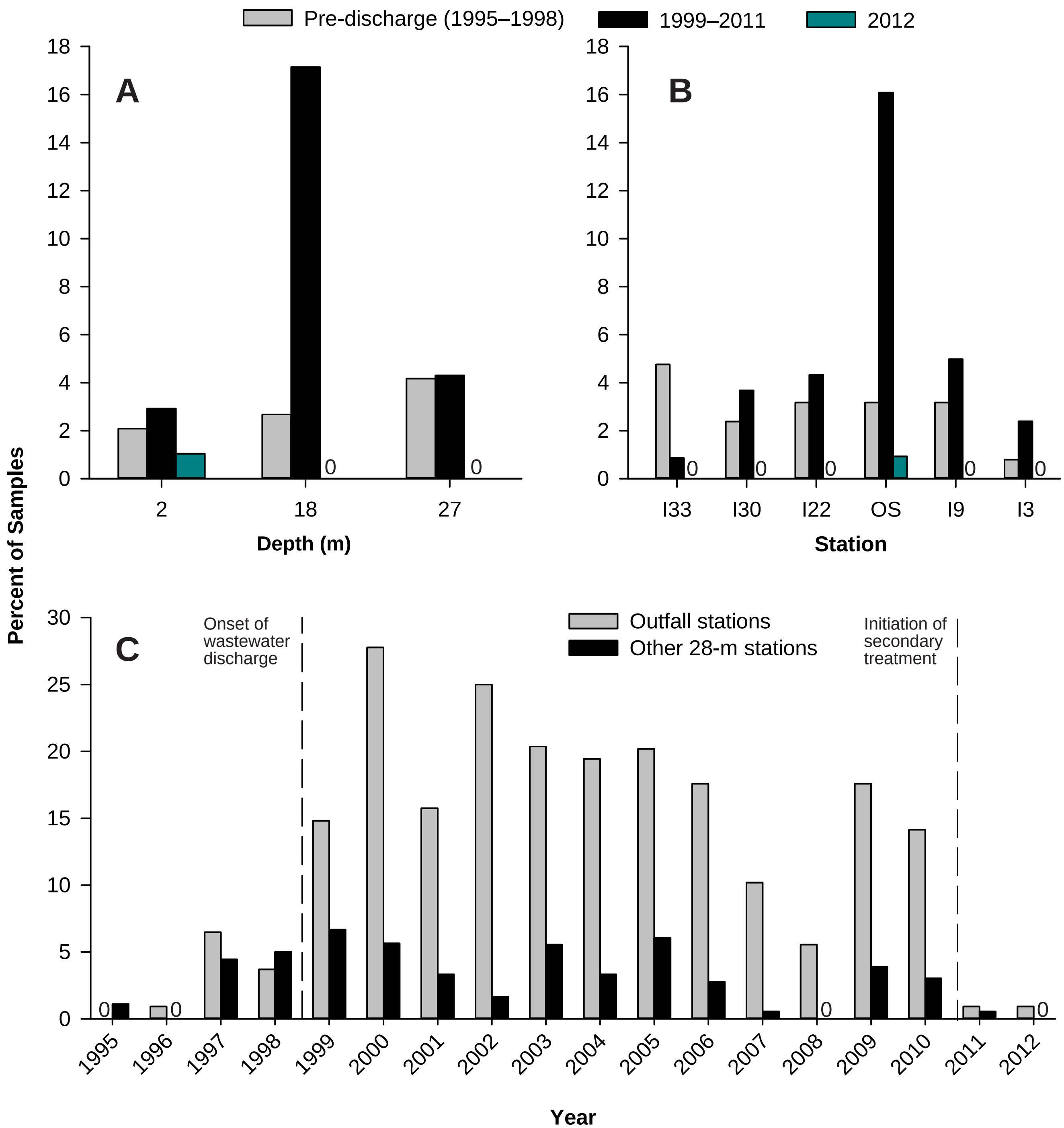

Figure 3.9

Percent of samples collected from SBOO 28-m offshore stations with elevated bacteria densities. Samples from 2012 are compared to those collected between 1995 and 2011 by (A) sampling depth, (B) station, and (C) year. Stations in part (B) listed from north to south from left to right. Dashed lines indicate the onset of wastewater discharge and the initiation of secondary treatment. OS = outfall stations (I12, I14, I16).

occasions in January, February, and December (Svejkovsky 2013). These findings have been supported by other high resolution satellite images and analyses of oceanographic data collected by the City's ocean monitoring program for the past several years that suggest the wastewater plume typically remains within approximately 700 m of the outfall (City of San Diego 2008–2012, Svejkovsky 2010–2013). Further, detection of the wastewater plume was low (11.6%) in the SBOO

Table 3.4
Summary of plume detections and out-of-range values at SBOO offshore stations during 2012. DO = dissolved oxygen; XMS = transmissivity. Data for pH are excluded for August, September, and October (see Chapter 2 for details).

		Out of Range			
Month	**Plume Detections**	**DO**	**pH**	**XMS**	**Stations**
Jan	0	0	0	0	none
Feb	2	0	0	2	I12[a], I16[a]
Mar	5	0	0	4	I6[a], I12[a], I16[a], I17[a], I23
Apr	3	0	0	1	I12[a], I15, I16
May	1	0	0	0	I27
Jun	4	0	0	2	I6[a], I9, I12, I16[a]
Jul	5	1	0	5	I9[a], I12[ab], I16[a], I17[a], I30[a]
Aug	5	0	—	3	I8, I9[a], I12[a], I15, I16[a],
Sep	5	0	—	5	I12[a], I14[a], I15[a], I16[a], I17[a]
Oct	4	0	—	3	I7, I13[a], I15[a], I16[a]
Nov	4	0	0	3	I12[a], I14[a], I15, I16[a]
Dec	1	0	0	1	I16[a]
Detection Rate (%)	11.6	0.3	0.0	8.9	
Total Count	39	1	0	30	
n	336	336	336	336	

[a] Out-of-range value for transmissivity; [b] out-of-range value for dissolved oxygen

region during 2012, with the majority of detections occurring at stations nearest to the outfall, but none occurring at the kelp bed stations where Ocean Plan compliance standards applied at the time of sampling. Within the plume, transmissivity of light was most often significantly reduced (77% OOR) while OOR events for DO and pH were either rare or not detected (2.6% and 0%, respectively).

Literature Cited

[APHA] American Public Health Association. (1995). Standard Methods for the Examination of Water and Wastewater, 19th edition. A.E. Greenberg, L.S. Clesceri, and A.D. Eaton (eds.). American Public Health Association, American Water Works Association, and Water Pollution Control Federation.

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

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

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

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

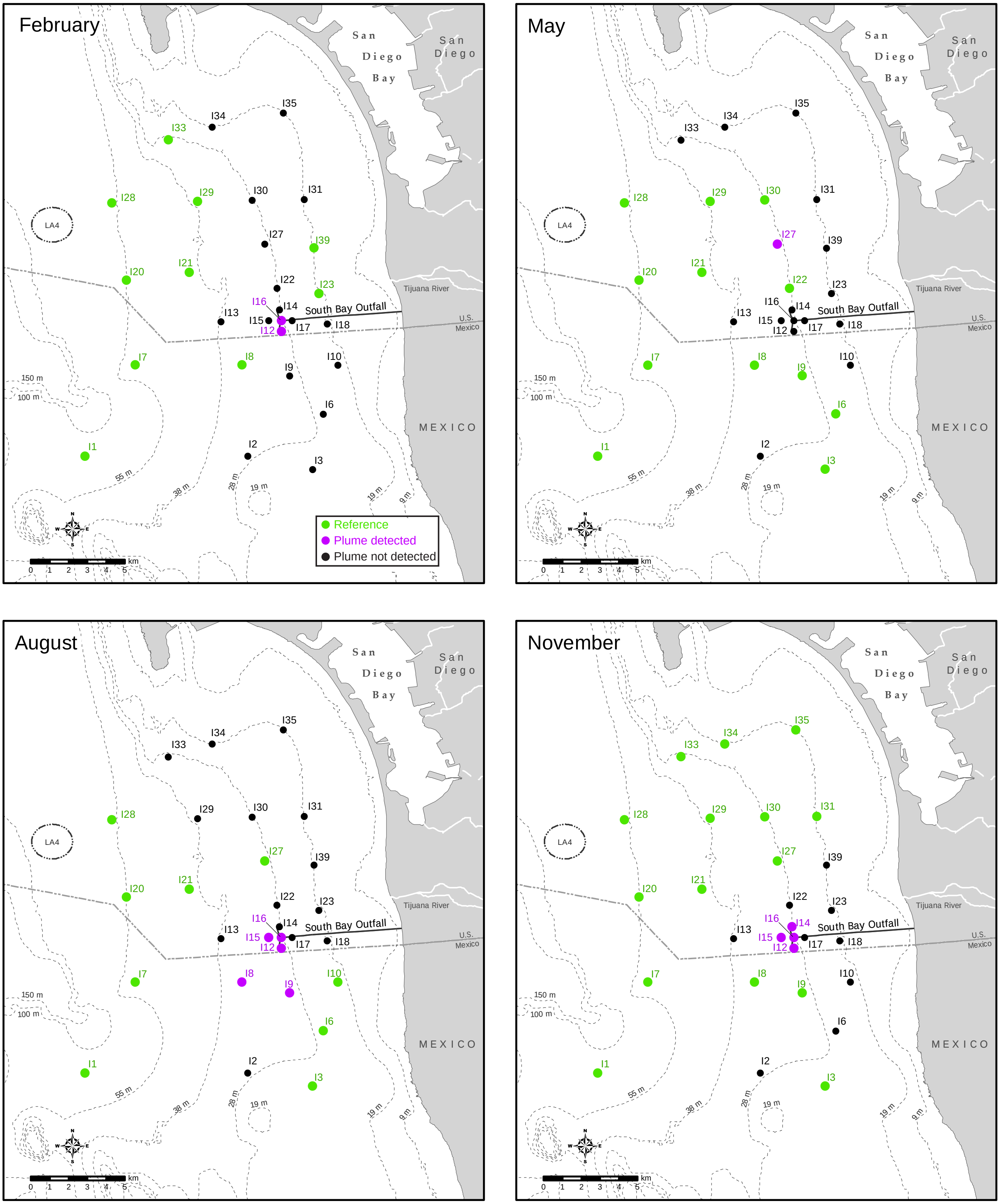

Figure 3.10

Distribution of stations with potential plume detections (purple) and those used as reference stations for water quality compliance calculations (green) during selected SBOO monthly surveys during 2012. Additional monthly distribution maps are located in Appendix B.10.

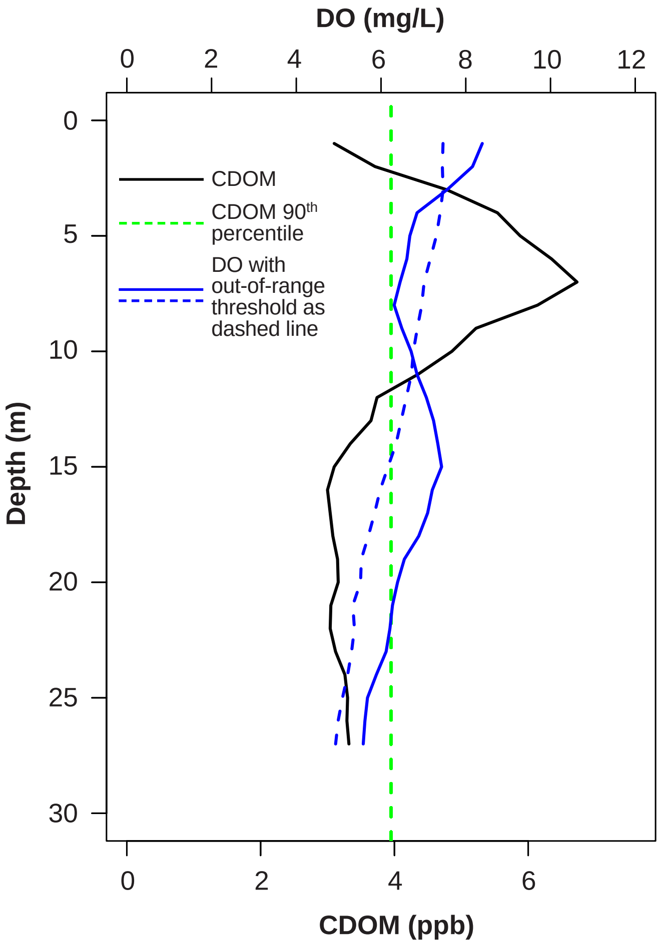

Figure 3.11

Vertical profile from station I12 on July 11, 2012 showing detection of the wastewater plume via CDOM and out-of-range dissolved oxygen (DO) values.

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

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

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

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

City of San Diego. (2013). EMTS Division Laboratory Quality Assurance Report, 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

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

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

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

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

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

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

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

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

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

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

[NOAA] National Oceanic and Atmospheric Administration. (2013). National Climatic Data Center. http://www7.ncdc.noaa.gov/CDO/cdo.

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

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

Ocean Imaging. (2013). Ocean Imaging Corporation archive of aerial and satellite-derived images. http://www.oceani.com/SanDiegoWater/index.html.

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

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

Rochelle-Newall, E.W., and T.R. Fisher. (2002). Production of chromophoric dissolved organic matter fluorescence in marine and estuarine environments: an investigation into the role of phytoplankton. Marine Chemistry 77: 7–21.

Rogowski, P., E. Terrill, M. Otero, L. Hazard, S.Y. Kim, P.E. Parnell, and P. Dayton. (2012). Point Loma Ocean Outfall Plume Behavior Study. Scripps Institution of Oceanography, University of California, San Diego, CA.

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

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

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

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

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

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

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

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

[SWRCB] California State Water Resources Control Board. (2005). California Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency, Sacramento, CA.

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

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

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

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Chapter 4
Sediment Conditions

Chapter 4. Sediment Conditions

Introduction

Ocean sediment samples are analyzed as part of the City of San Diego's Ocean Monitoring Program to examine potential effects of wastewater discharge on the marine benthos from the South Bay Ocean Outfall (SBOO). Analyses of various contaminants are conducted because anthropogenic inputs to the marine ecosystem, including municipal wastewater, can lead to increased concentrations of pollutants within the local environment. Sediment particle sizes (e.g., relative percentages of sand, silt, clay) 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 monitored 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 associated levels of organic loading affect 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 types, and also sediment chemical composition. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediment and debris from bays, rivers, and streams 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 to the sea floor. In addition, primary productivity by marine 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 by wastewater 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 analyses and interpretations of sediment particle size and chemistry data collected during 2012 at fixed benthic monitoring stations surrounding the SBOO. The primary goals are to: (1) document sediment conditions during the year, (2) identify possible effects of

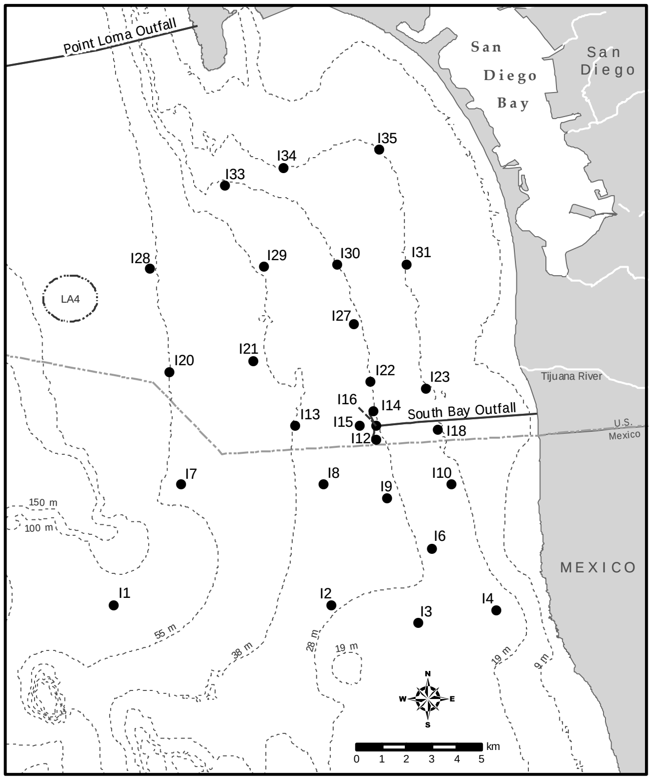


Figure 4.1
Benthic station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

wastewater discharge on sediment quality in the region, and (3) identify other potential natural and anthropogenic sources of sediment contaminants to the local marine ecosystem.

Materials and Methods

Field Sampling

Sediment samples were collected at 27 benthic stations in the SBOO region during January and July 2012 (Figure 4.1). These stations range in depth from 18 to 60 m and are distributed along or adjacent to four main depth contours. The four stations considered to represent "nearfield" conditions (i.e., I12, I14, I15, I16) are located within 1000 m of the outfall wye. Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 5) and visual observations of sediment composition. 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 Wastewater Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2013). Briefly, sediment sub-samples were analyzed 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) on a dry weight basis. 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%. 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 fractions. Sieve results and output from the Horiba were classified into size fractions (i.e., fine particles, fine sand, coarse sand, coarse particles) and sub-fractions (e.g., very fine silt, fine silt, medium silt, coarse silt) based on the Wentworth scale (Appendix C.2).

Data Analyses

Data summaries for the various sediment parameters included detection rates, minimum, median, 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 (tChlor), 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). Sediment 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 used to assess if concentrations of chemical parameters co-varied with the proportion of fine particles in each sample. 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 software to examine spatio-temporal patterns in the overall particle size composition in the South Bay outfall region (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 particle size sub-fractions were square-root transformed to limit the influence of the largest fractions, and Euclidean distance was used as the basis for the cluster analysis.

Results and Discussion

Particle Size Distribution

Ocean sediments were diverse across the South Bay outfall region in 2012. The proportion of fine particles (i.e., silt and clay; also referred to as percent fines) ranged from 0 to 40% per sample, while fine sand, coarse sand, and coarse particles ranged from 3 to 86%, 1 to 89%, and 0 to 31%, respectively (Table 4.1, Figure 4.2). Visual observations recorded for corresponding macrofaunal samples also revealed the presence of organic debris, worm tubes, coarse red relict sands, coarse black sands, gravel, and/or shell hash at different stations (Appendix C.4). Particle size composition varied within sites between the winter (January) and summer (July) surveys by as much as 75% per size fraction, with the greatest changes occurring at stations I4, I15, I16, I20, I23, and I34 (Figure 4.2, Appendix C.4). Despite this variability, some general patterns were evident: (1) sediments at most stations located just south of, near, and to the north of the outfall along the 19- and 18-m contours consisted predominantly of fine sand with variable amounts of fine particles; (2) sediments at most stations located farther south along these same contours and at several stations located along the 38- and 55-m contours were composed primarily of coarse sand with variable amounts of fine sand and fine particles (see below). Exceptions to these patterns occurred at stations I1 and I28 during both surveys, which had sediments with more fine particles and fine sand than neighboring stations, and stations I15 (in January), I23 (in January), and I34 (both surveys) that had more coarse sand than nearby areas. Overall, sediments collected from the four

Table 4.1

Summary of particle sizes and chemistry concentrations in sediments from SBOO benthic stations sampled during 2012. Data include the detection rate (DR), mean, minimum, median, 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.

	2012 Summary[a]					Pre-discharge		
Parameter	**DR (%)**	**Areal Mean**	**Min**	**Median**	**Max**	**Max**	**ERL[b]**	**ERM[b]**
Particle Size								
Coarse particles (*%*)	—	3.6	0.0	0.0	30.7	52.5	na	na
Coarse sand (*%*)	—	34.8	1.3	19.8	88.7	99.8	na	na
Fine sand (*%*)	—	49.2	2.6	57.8	86.1	97.4	na	na
Fines particles (*%*)	—	12.4	0.0	11.9	40.4	47.2	na	na
Organic Indicators								
Sulfides (*ppm*)	93	1.9	nd	1.3	10.2	222.0	na	na
TN (*% weight*)	98	0.030	nd	0.024	0.138	0.077	na	na
TOC (*% weight*)	100	0.30	0.02	0.13	4.83	0.638	na	na
TVS (*% weight*)	100	0.84	0.33	0.76	1.85	9.20	na	na
Trace Metals (ppm)								
Aluminum	100	4012	634	3300	9750	15,800	na	na
Antimony	43	0.38	nd	nd	0.52	5.60	na	na
Arsenic	100	2.3	0.6	1.7	9.9	10.90	8.2	70
Barium	100	19.8	1.7	18.9	50.8	54.30	na	na
Beryllium	100	0.082	0.011	0.076	0.190	2.14	na	na
Cadmium	28	0.09	nd	nd	0.18	0.41	1.2	9.6
Chromium	100	9.3	2.1	9.6	14.4	33.8	81	370
Copper	100	2.3	0.2	2.0	7.0	11.10	34	270
Iron	100	5579	1190	5930	10,100	17,100	na	na
Lead	100	2.99	1.01	2.88	5.26	6.80	46.7	218
Manganese	100	47.2	5.2	47.9	107.0	162.0	na	na
Mercury	37	0.011	nd	nd	0.029	0.078	0.15	0.71
Nickel	100	2.56	0.71	2.71	5.15	13.60	20.9	51.6
Selenium	4	0.32	nd	nd	0.39	0.620	na	na
Silver	2	0.19	nd	nd	0.19	nd	1.0	3.7
Thallium	0	—	—	—	—	17.00	na	na
Tin	56	0.60	nd	0.34	1.72	nd	na	na
Zinc	100	12.0	2.3	11.1	24.1	46.90	150	410
Pesticides (ppt)								
Total DDT	26	380	nd	nd	2330	23,380	1580	46,100
Total Chlordane	2	29	nd	nd	29	nd	na	na
HCB	7	95	nd	nd	140	nd	na	na
Total PCB (ppt)	20	342	nd	nd	600	na	na	na
Total PAH (ppb)	0	—	—	—	—	636.5	4022	44,792

na = not available; nd = not detected

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

[b] From Long et al. 1995.

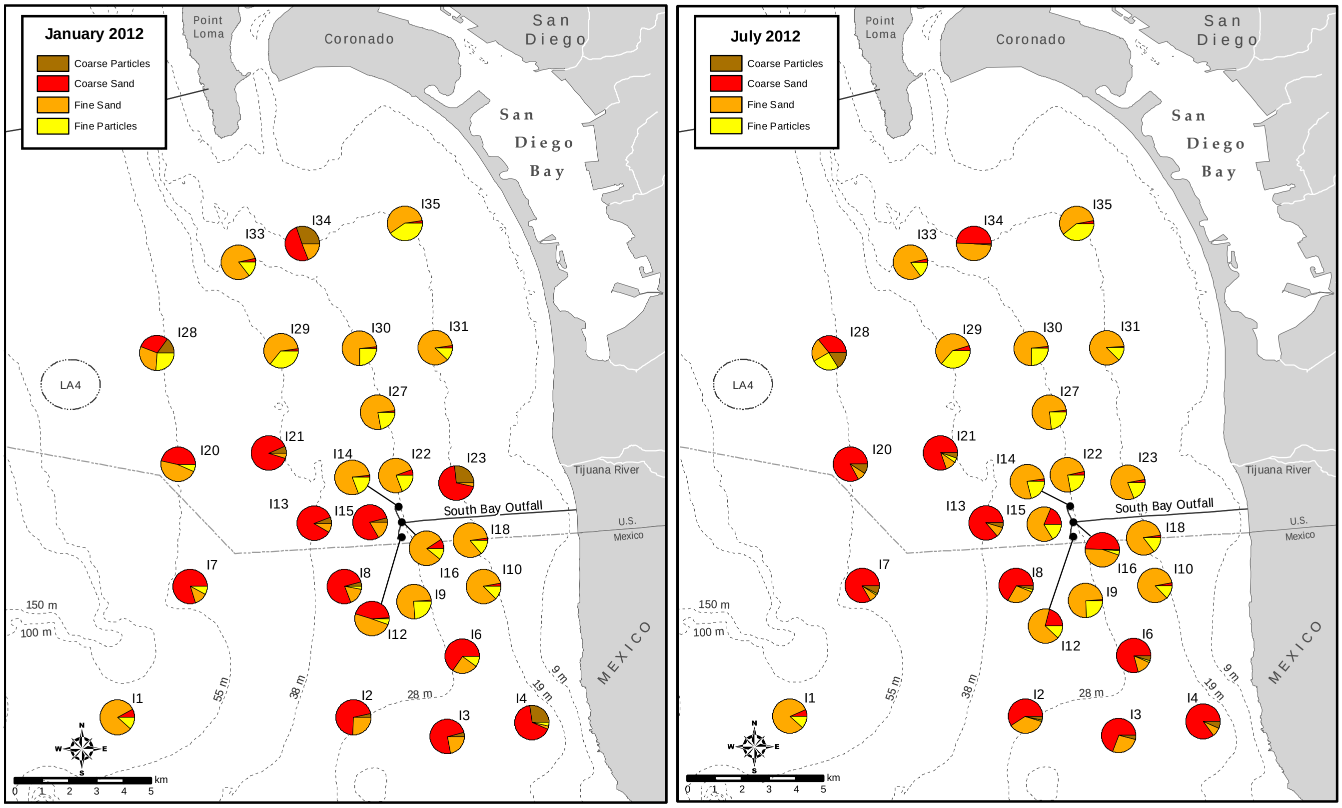


Figure 4.2
Sediment composition at SBOO benthic stations sampled in 2012 during January (left) and July (right) surveys.

nearfield stations (I12, I14, I15, I16) were similar to those from surrounding areas in containing <25% of fine particles (Appendix C.4), a pattern that has been evident since sampling began in 1995 (Figure 4.3).

Further examination of the above sediment data using classification (cluster) analysis discriminated four main cluster groups based on the particle size sub-fractions present in samples collected in 2012 (cluster groups 1–4; Figure 4.4). Group 1 comprised 52% of the samples; sediments in this group averaged 12% coarse silt, 50% very fine sand, and 26% fine sand, and corresponded to the first pattern described in the previous paragraph. Group 2 comprised the two samples collected during the year at station I28 that had sediments averaging 26% coarse silt, 22% very fine sand, 13% medium sand, and 19% coarse sand. Group 3 represented the three samples collected in January from stations I4, I23 and I34; this group had sediments with the largest percentage of coarse particles (29%). Group 4 comprised 39% of the samples collected during the year; sediments in this group averaged 19% fine sand, 42% medium sand, and 29% coarse sand, and corresponded to the second pattern described in the previous paragraph.

Historical analysis of particle size data revealed considerable temporal variability at stations such as I2, I3, I4, I10, I12, I13, I18, I20, I29 and I35 (Figure 4.5). While sediments at all of these stations predominantly consisted of sand with variable amounts of finer and coarser materials, the size of the sand particles (e.g., fine versus coarse) differed substantially. The relative composition of the sand sub-fractions and the presence of other coarse particles appeared to correspond to distributions of fine versus coarse red relict sands, coarse black sands, shell hash, and gravel that have been encountered previously. In contrast, stations such as I1, I7, I8, I9, I28 and I30 have demonstrated relative stability in their sediments over time. For example, stations I1 and I30 have been consistently dominated by fine sand, stations I7 and I8 by coarse sand, station I9 by higher percent fines than other nearby stations, and station I28 by relatively high proportions of both coarse and fine materials.

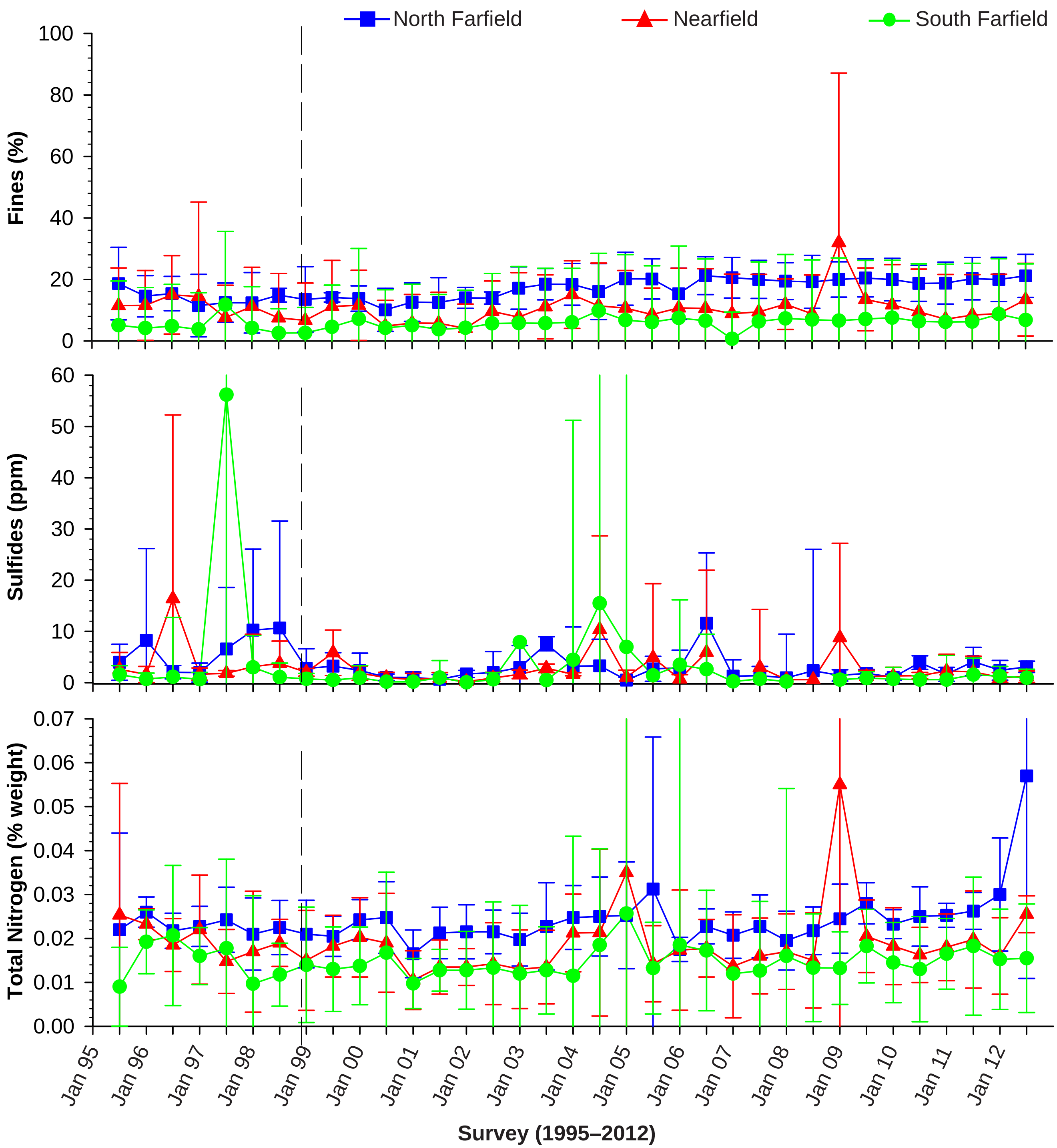


Figure 4.3

Particle size and organic loading indicators at SBOO 28-m benthic stations sampled between 1995—2012. Data are expressed as means of detected values ±95% confidence intervals for samples pooled over north farfield (I33, I30, I27, I22), nearfield (I12, I14, I15, I16) and south farfield (I9, I6, I2, I3) stations for each survey. Dashed lines indicate onset of discharge from the SBOO.

Indicators of Organic Loading

Indicators of organic loading, including sulfides, total nitrogen (TN), total organic carbon (TOC), and total volatile solids (TVS) had detection rates ≥93% in sediments from the South Bay outfall region in 2012 (Table 4.1). Overall, mean concentrations of these parameters were 1.9 ppm, 0.03% wt, 0.3% wt, and 0.84% wt, respectively. Only TN and TOC were

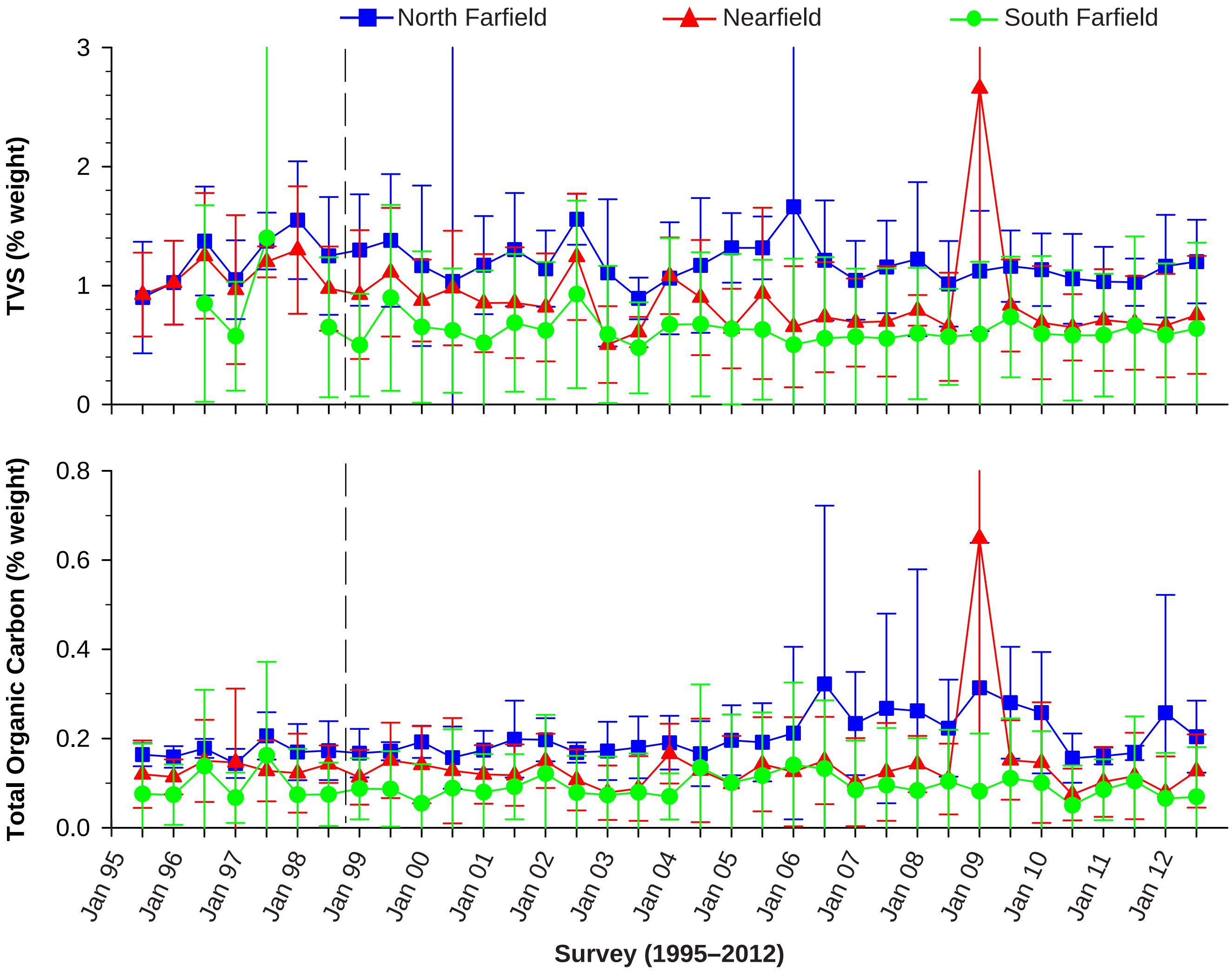


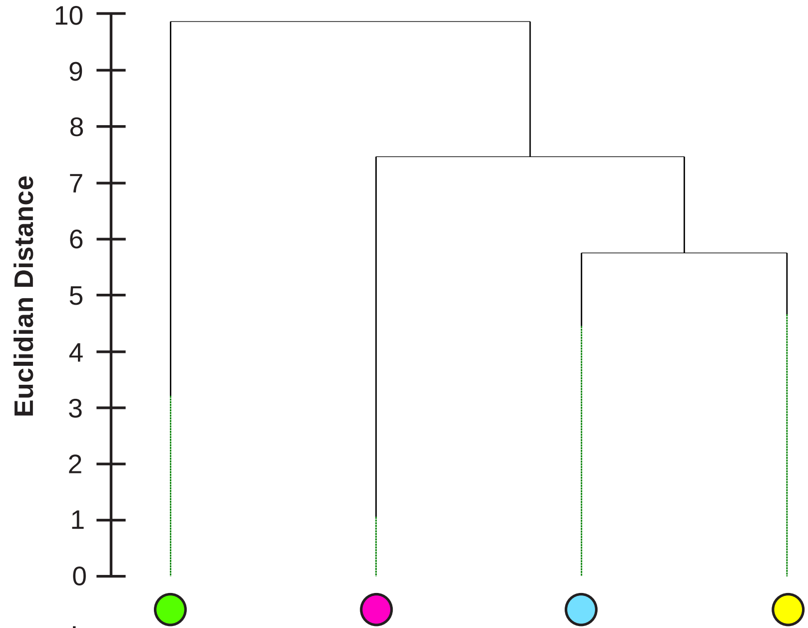
Figure 4.3 *continued*

detected at concentrations higher than the maximum values reported prior to wastewater discharge. However, there was no evidence of organic enrichment near the discharge site. Instead, TN, TOC and TVS concentrations were positively correlated with the percentage of fine sediments in each sample (Table 4.2, Figure 4.6A, B) and therefore had similar distributions throughout the region (see Figure 4.2). The highest sulfide concentrations were found north of the outfall at station I35 in January and station I33 in July (Appendix C.5). Additionally, there has been no evidence of organic enrichment at any of the nearfield or farfield 28-m depth contour stations since discharge began, despite a spike in values at nearfield stations in January 2009 (Figure 4.3). This spike was due to an anomalous sediment sample collected from station I16 during this survey that contained ~79% fines.

Trace Metals

Eleven trace metals were detected in all sediment samples collected in the SBOO region during 2012, including aluminum, arsenic, barium, beryllium, chromium, copper, iron, lead, manganese, nickel and zinc (Table 4.1, Appendix C.6). Antimony, cadmium, mercury, selenium, silver and tin were also detected, but in fewer samples (2–56%). Thallium was not detected in any samples collected during the year. Almost all metals were detected at levels below their ERL and ERM thresholds and within ranges reported prior to discharge in the South Bay outfall region and elsewhere in the Southern California Bight (SCB; Schiff et al. 2011). The only exception was arsenic, which exceeded the ERL (but not ERM) at station I21 during both

A



	Cluster Group	1	2	3	4
	n	28	2	3	21
Fine Particles	CLAY	1	0	0	<1
	VFSILT	2	0	0	<1
	FSILT	2	0	0	1
	MSILT	3	0	0	1
	CSILT	12	26	1	1
Fine Sand	VFSAND	50	22	1	3
	FSAND	26	4	8	19
Coarse Sand	MSAND	4	13	28	42
	CSAND	<1	19	34	29
Coarse Particles	VCSAND	0	10	16	4
	GRANULES	0	6	13	0

Figure 4.4
Cluster analysis of particle size sub-fraction data from SBOO benthic stations sampled during 2012. Data are presented as (A) cluster results and (B) spatial 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). VFSILT = Very Fine Silt; FSILT = Fine Silt; MSILT = Medium Silt; CSILT = Coarse Silt; VFSAND = Very Fine Sand; FSAND = Fine Sand; MSAND = Medium Sand; CSAND = Coarse Sand; VCSAND = Very Coarse Sand.

surveys. Concentrations of aluminum, barium, copper, manganese, nickel and zinc all correlated positively with the percentage of fine sediments in each sample (Table 4.2, Figure 4.6C, D) and therefore had similar distributions (see Figure 4.2). Metals that did not co-vary with percent particles were also found to be present throughout the region or were detected at stations distant to the outfall. For instance, selenium was detected only in the July samples collected at stations I31 and I33, while silver was found only at station I35 in January. As in previous years (City of San Diego 2012), no patterns indicative of an outfall effect were evident.

B

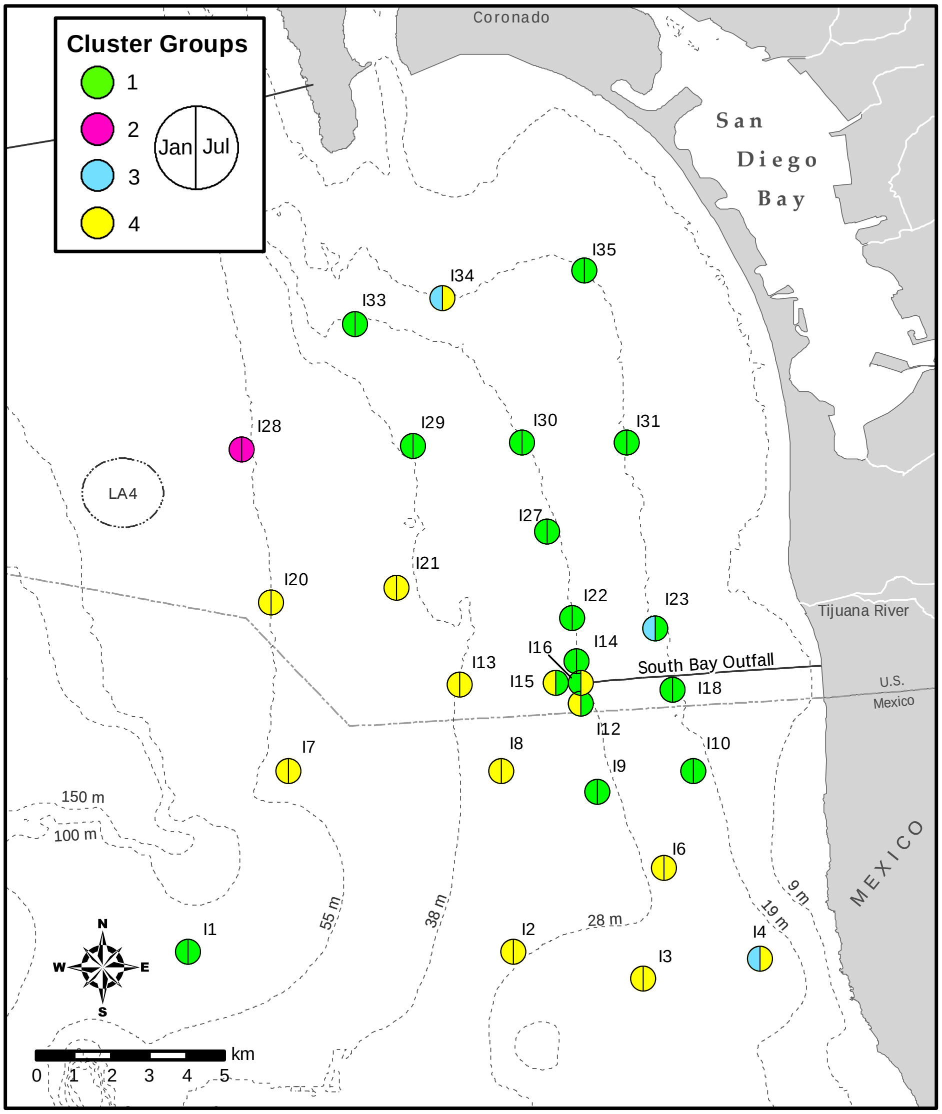


Figure 4.4 *continued*

Pesticides, PCBs, and PAHs

Chlorinated pesticides were detected infrequently in SBOO sediments during 2012, with detection rates ≤26% (Table 4.1, Appendix C.7). Detectable levels of total DDT (primarily p,p-DDE; Appendix C.3) were found in sediments from 10 of 27 stations at concentrations up to 2330 ppt. Although the highest DDT concentration exceeded its ERL threshold at station I29 in July, all DDT values were below those reported prior to wastewater discharge. Hexachlorobenzene (HCB) was detected in samples from stations I1, I4, I6 and I7 in July at levels ranging from 73 to 140 ppt. Heptachlor epoxide, an oxidation product of chlordane and heptachlor, was detected in only one sample from station I12 in July at a concentration of 29 ppt. PCBs were detected in 20% of the samples, with a maximum concentration of 600 ppt reported for station I28 in January. PAHs were not detected in any sediment samples collected during the year. No patterns indicative of an outfall effect were evident in the distribution of pesticides or PCBs during 2012.

Summary

Particle size composition at the SBOO stations sampled in 2012 was similar to that seen historically (Emery 1960, MBC-ES 1988) and in recent survey years (City of San Diego 2007–2012). Sands made

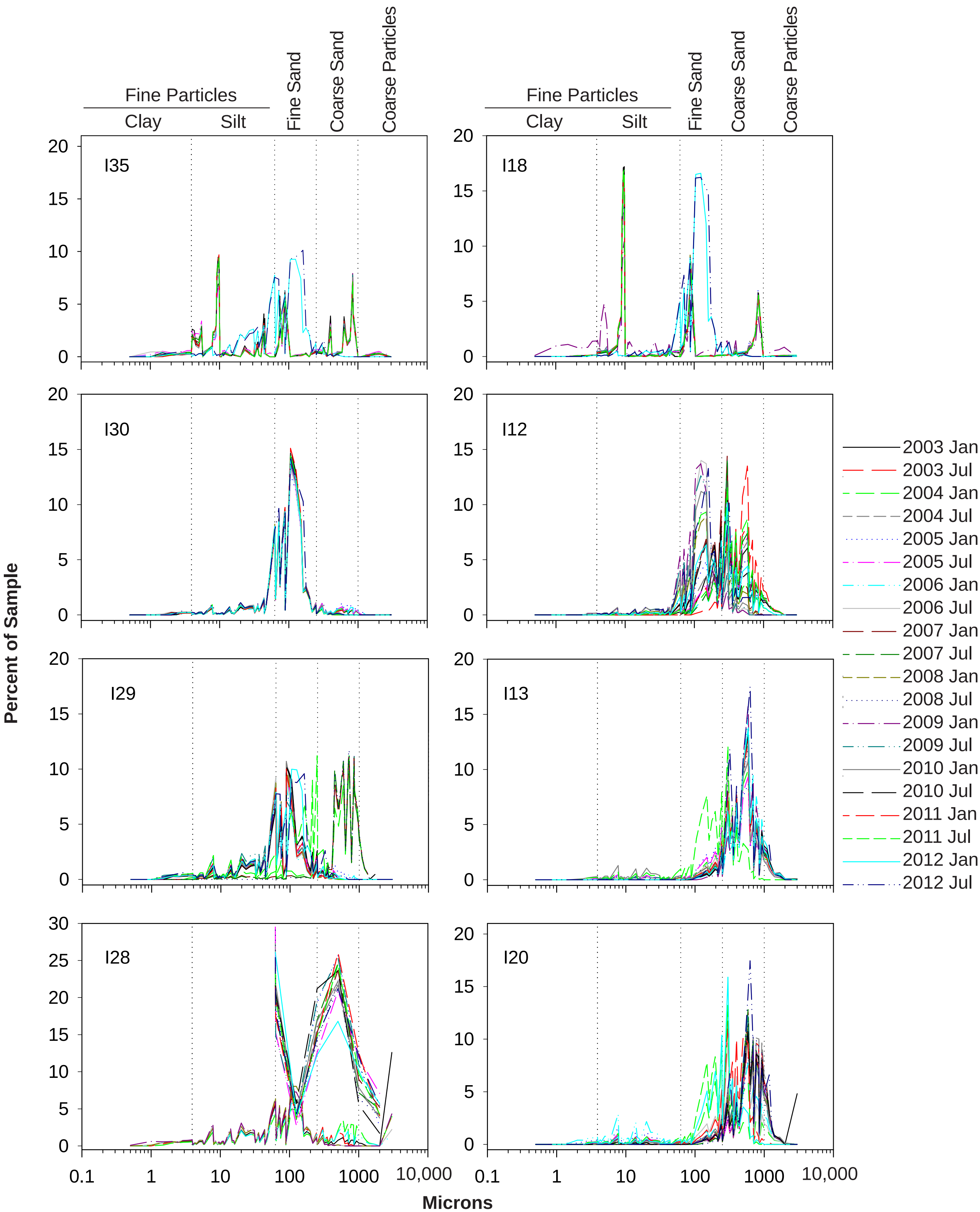


Figure 4.5
Select plots illustrating historical particle size distributions in sediments collected from the SBOO region between 2003 and 2012.

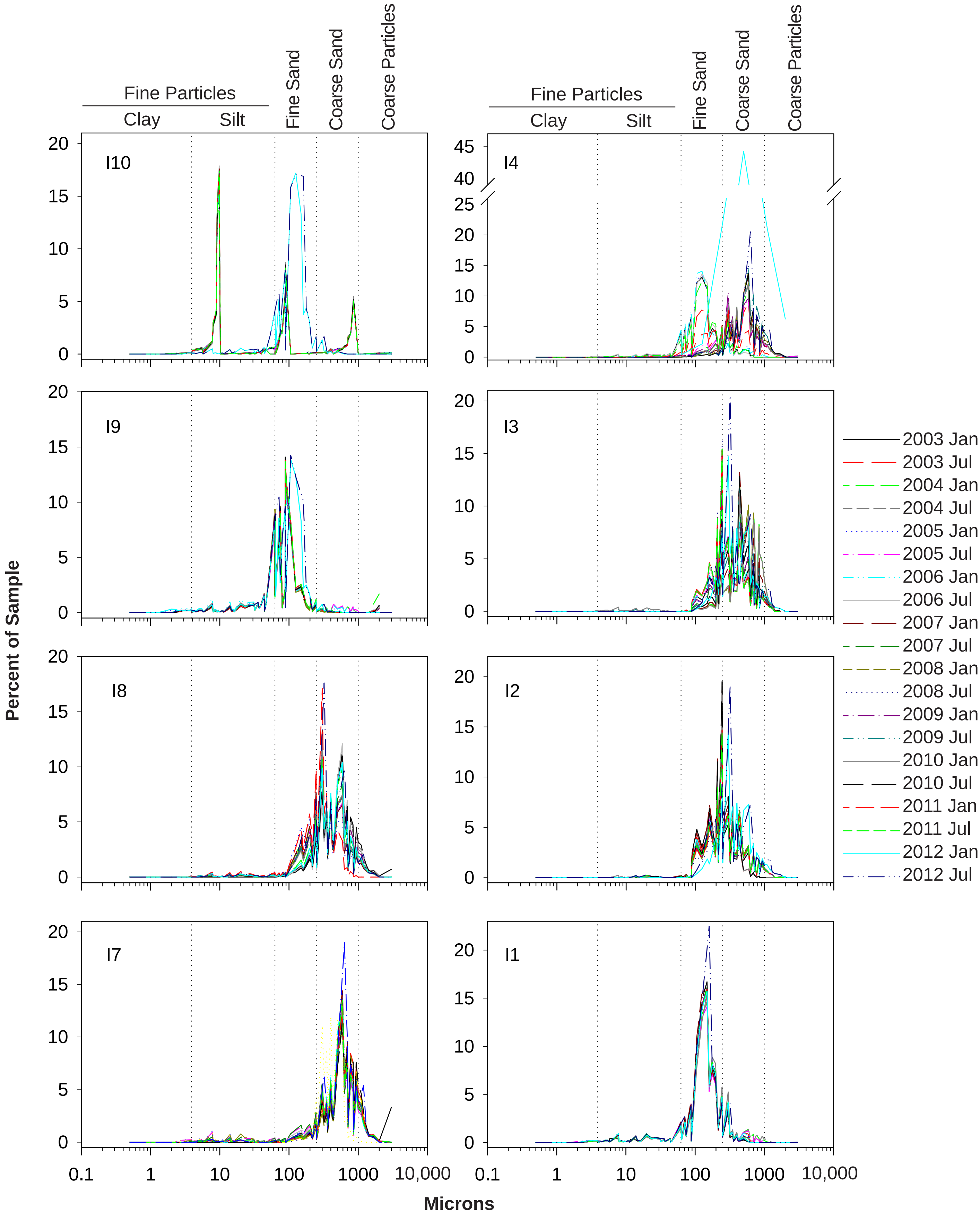


Figure 4.5 *continued*

Table 4.2

Results of Spearman rank correlation analyses of percent fines versus depth and various sediment chemistry parameters from SBOO benthic samples collected in 2012. Shown are analytes 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 4.6.

Analyte	n	r_s
Organic Indicators (% weight)		
Total Nitrogen	53	0.78
Total Organic Carbon	54	0.72
Total Volatile Solids	54	0.79
Trace Metals (ppm)		
Aluminum	54	0.76
Barium	54	0.75
Copper	54	0.75
Manganese	54	0.71
Nickel	54	0.80
Zinc	54	0.76

up the largest proportion of all samples, with the relative amounts of coarser and finer particles varying among sites. There was no evident spatial relationship 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 in 1999. 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 sampling first began in 1995 (City of San Diego 2000).

Various trace metals, pesticides, PCBs, and organic loading indicators were detected in sediment samples collected throughout the SBOO region in 2012, though concentrations were generally below either ERL and/or ERM thresholds with very few exceedances. Additionally, there have been no spatial patterns indicative of an outfall effect on sediment chemistry over the past several years, with concentrations of most contaminants at nearfield stations falling within the range of values at the farfield stations (City of San Diego 2012). Instead, relatively high values of most parameters were present throughout the region, and several co-occurred at sites characterized by finer sediments. This association is expected due to the known correlation between particle size and concentrations of organics and trace metals (Eganhouse and Venkatesan 1993).

The frequent and wide-spread occurrences of various contaminants in sediments from the SBOO region are 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 of Los Angeles have shown that as wastewater treatment has improved, sediment conditions are more likely affected by other factors (Stein and Cadien 2009). Such factors may include bioturbative re-exposure of buried legacy sediments (Niederoda 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

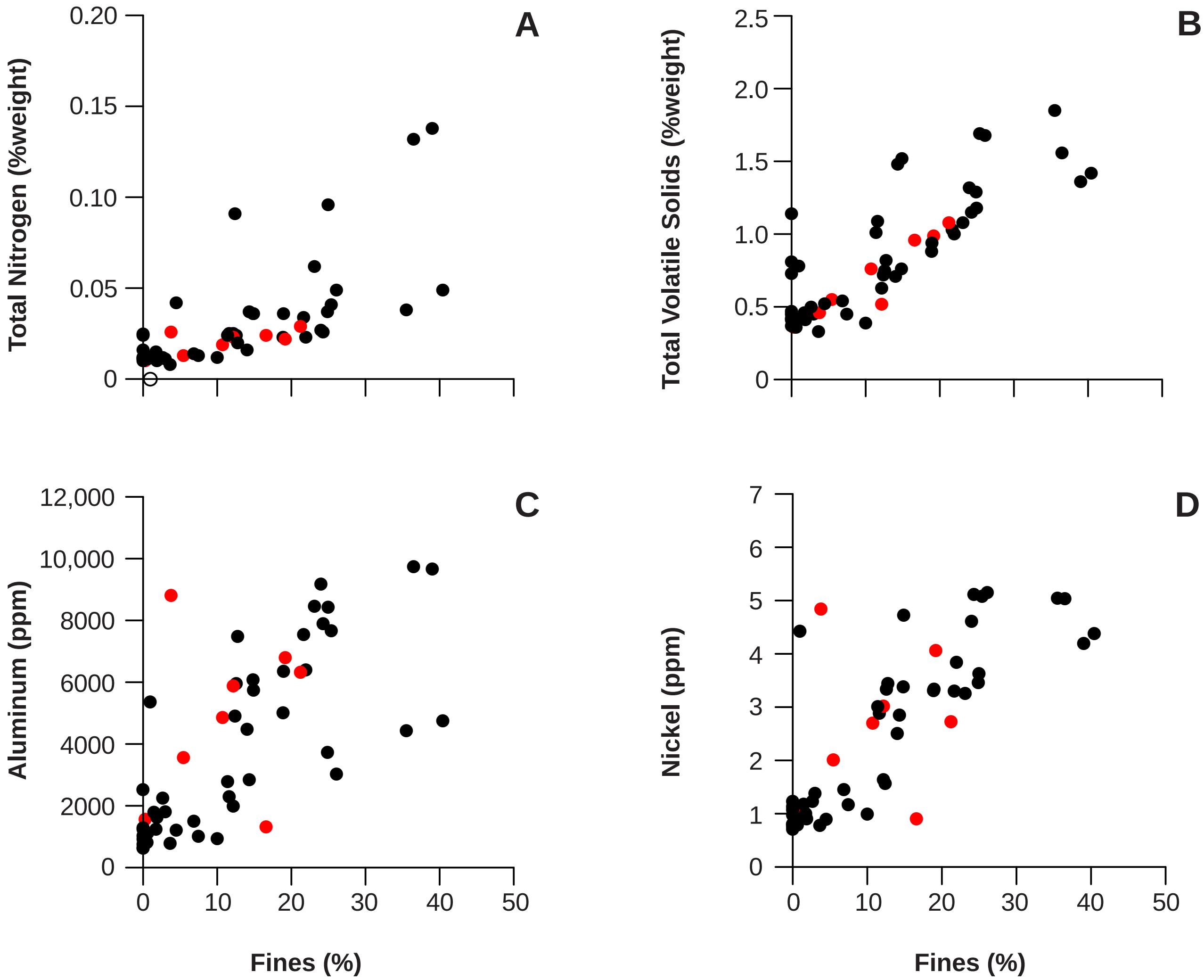


Figure 4.6

Scatterplots of percent fines versus concentrations of (A) total nitrogen, (B) total volatile solids, (C) aluminum, and (D) nickel in sediments from SBOO stations sampled during 2012. Samples collected from nearfield stations are indicated in red. Open circles indicate samples with analyte concentrations below the method detection limit.

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, sediment particle size distributions in the South Bay outfall region reflect the diverse geologic history and complex transport patterns along this section of the coast. There was no evidence of fine-particle loading related to wastewater discharge during the year. 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 2012 was similar to previous years, and overall concentrations of all chemical contaminants remained relatively low compared to other southern California coastal areas (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

Literature Cited

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

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

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

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

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

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

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

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

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

City of San Diego. (2013). 2012 Annual Reports and Summary for the South Bay Wastewater Reclamation Plant and Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R. and R.M. Warwick. (2001). Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. PRIMER-E, Plymouth.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage.

Journal of Experimental Marine Biology and Ecology, 366: 56–69.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Chapter 5
Macrobenthic Communities

Chapter 5. Macrobenthic Communities

Introduction

The City of San Diego (City) collects small invertebrates (macrofauna) that live within or on the surface of soft-bottom habitats to examine potential effects of wastewater discharge on the marine benthos around the South Bay Ocean Outfall (SBOO). These benthic macrofauna are targeted for monitoring because they are known to play critical ecological roles in marine environments along the Southern California Bight (SCB) coastal shelf (Fauchald and Jones 1979, Thompson et al. 1993a, Snelgrove et al. 1997). Additionally, because many benthic species are relatively stationary and long-lived, they integrate the effects of pollution or disturbance over time (Hartley 1982, Bilyard 1987). The response of many species to environmental stressors is well documented, and monitoring changes in discrete populations or more complex communities can help identify locations experiencing anthropogenic impacts (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). For example, pollution-tolerant species are often opportunistic and can displace others in impacted environments. In contrast, populations of pollution-sensitive species decrease in response to toxic 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 naturally influenced by factors such as ocean depth, sediment composition (e.g., percent of 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). On the SCB coastal shelf, assemblages typically vary along depth gradients and/or with sediment particle size (Bergen et al. 2001); therefore, an understanding of natural background or reference conditions provides the context necessary to identify whether spatial differences in community structure are likely attributable to anthropogenic activities. Off the coast of San Diego, past monitoring efforts for both shelf and upper slope habitats have led to considerable understanding of regional environmental variability (City of San Diego 1999, 2012a, b, Ranasinghe et al. 2003, 2007, 2010, 2012) These efforts allow for spatial and temporal comparison of the current year's monitoring data with past surveys to determine if and where changes due to wastewater discharge are occurring.

The City relies on a suite of scientifically-accepted indices and statistical analyses to evaluate potential changes in local marine invertebrate communities. The benthic response index (BRI), Shannon diversity index and Swartz dominance index are used as metrics of invertebrate community structure, while multivariate analyses are used to detect spatial and temporal differences among communities (Warwick and Clarke 1993, Smith et al. 2001). The use of multiple analyses provides better resolution than 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 characteristics are similar, or whether observable impacts from outfalls or other sources occur. Minor organic enrichment caused by wastewater discharge should be evident through an increase in species richness and abundance of 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 analyses and interpretations of macrofaunal data collected at designated benthic monitoring stations surrounding the SBOO during 2012 and includes descriptions and comparisons of the different invertebrate communities in the region. The primary goals are to: (1) document the benthic assemblages present during the year, (2) determine the presence or absence of biological impacts associated with wastewater discharge, and (3) identify other potential natural and anthropogenic sources of variability in the local marine ecosystem.

Materials and Methods

Collection and Processing of Samples

Benthic samples were collected at 27 stations in the SBOO region during January and July 2012 (Figure 5.1). These stations range in depth from about 18 to 60 m and are distributed along or adjacent to four main depth contours. The four stations considered to represent "nearfield" conditions (i.e., I12, I14, I15, I16) are located within 1000 m of the outfall wye. Stations with similar depths used for comparison to nearfield sites include four "north farfield" stations (i.e., I22, I27, I30, and I33) and four "south farfield" stations (i.e., I2, I3, I6, I9).

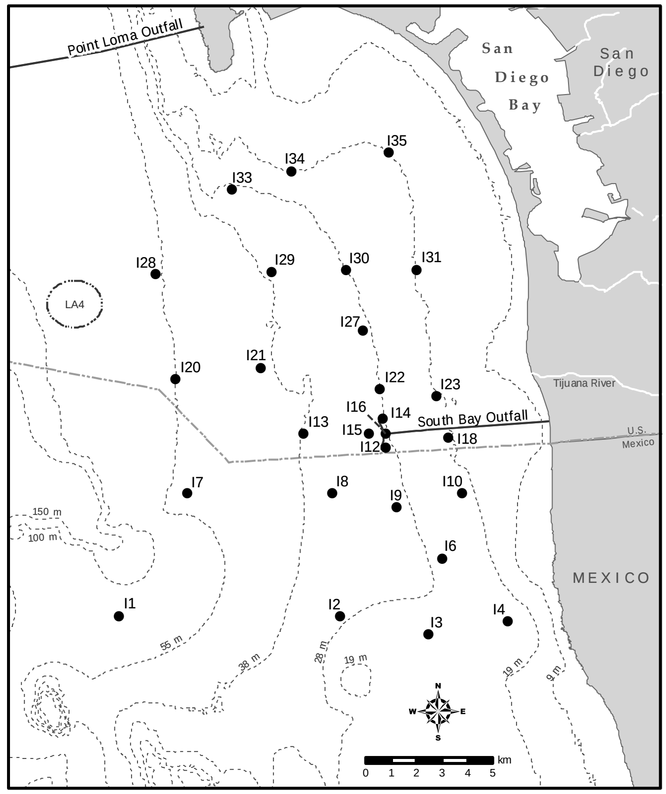


Figure 5.1
Benthic station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Two samples for benthic community analyses were collected per station during each survey using a double 0.1-m^2 Van Veen grab. The first sample was used for analysis of macrofauna, and the adjacent grab was used for sediment quality analysis (see Chapter 4). A second macrofaunal grab was then collected from a subsequent cast. Criteria established by the USEPA to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen to collect macrofaunal organisms. Benthic macrofauna retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution and then fixed with buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All macrofauna were sorted from the raw sample into major taxonomic groups by a subcontractor and then identified to species (or the lowest taxon possible) and enumerated by City marine biologists. All identifications followed nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT 2012).

Data Analyses

Each grab sample was considered an independent replicate for analysis. The following community structure parameters were calculated for each station per 0.1-m^2 grab: species richness (number of species), 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). Additionally, the total (cumulative) number of species identified from all grabs at each station during the year was calculated.

To further examine spatial patterns among benthic communities in the SBOO region, multivariate analyses were conducted on macrofaunal grabs that had a corresponding sediment sample using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). Multivariate 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 supported by SIMPROF were retained, and similarity percentages analysis (SIMPER) was used to determine which organisms 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 or other factors (e.g., increased organics), a RELATE test was used to compare patterns of rank abundance in the macrofauna Bray-Curtis similarity matrix with rank abundance in the sediment Euclidean distance matrix (see Chapter 4). When significant similarity was found, a BEST test using the BIO-ENV amalgamate was conducted to determine which subset of sediment subfractions was the best explanatory variable for similarity between the two resemblance matrices.

Results and Discussion

Community Parameters

Species richness

A total of 757 taxa were identified during the 2012 SBOO surveys. Of these, 601 (79%) were identified to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although 22% (n = 170) were recorded only once. Three species not previously reported by the City's Ocean Monitoring Program were encountered, including the nemertean Hoplonemertea sp SD4, the polychaete *Sphaerosyllis* sp SD4, and a gastropod mollusc identified to the genus *Eubranchus*. Mean species richness ranged from 43 taxa per 0.1 m^2 grab at station I4 to 150 per grab at station I28 (Table 5.1). The lowest and highest species richness values occurred at stations located 7.9 to 9.8 km from the physical structure of the SBOO, with no clear pattern in species richness relative to distance from the discharge site or depth observed. Additionally, no consistent seasonal pattern was evident between winter and summer surveys (Appendix D.1). Species richness by grab was within the historical range of 16–172 taxa reported from 1995 to 2011, with mean nearfield and farfield values at the outfall depth following similar patterns since monitoring began (Figure 5.2A).

Macrofaunal abundance

A total of 37,749 macrofaunal individuals were counted in 2012. Mean abundance per station ranged from 153 to 652 animals per grab (Table 5.1), with the lowest abundance occurring at station I18 and the highest at station I28 (the same station that also had the highest species richness). No spatial patterns in overall abundance related to distance from the outfall were observed, although mean abundance by depth contour progressively increased from 289 animals per station at 19-m depths, to ~364 at 28- and 38-m depths, to 395 at 55-m depths. This pattern is likely influenced by differences in sediment composition among depth strata. Macrofaunal abundance was often higher in grabs from the summer rather than winter surveys (Appendix D.1). During the past year, abundance was within the historical range of 39–1579 individuals per grab reported between 1995 and 2011. Variation in mean abundance observed at outfall depth stations since 2007 has primarily been associated with changes in populations of the spionid polychaete *Spiophanes norrisi* (Figures 5.2B, 5.3). Since this species has fluctuated at both nearfield and farfield sites, changes in abundance are likely a regional phenomenon that is not caused by outfall impacts.

Species diversity, evenness, and dominance

Mean Shannon diversity (H') and evenness (J') per station ranged from 2.3 to 4.3 and from 0.61 to 0.89 across the SBOO region in 2012, respectively, indicating that local benthic communities remain

Table 5.1

Summary of macrofaunal community parameters for SBOO benthic stations sampled during 2012. Tot Spp=cumulative no. taxa for the year; SR=species richness (no. taxa/0.1 m^2); Abun=abundance (no. individuals/0.1 m^2); H'=Shannon diversity index; J'=evenness; Dom=Swartz dominance; BRI=benthic response index. Data for each station are expressed as annual means (n=4 grabs) except Tot Spp (n=1). Stations are listed north to south from top to bottom.

	Station	Tot Spp	SR	Abun	H'	J'	Dom	BRI
19-m Stations	I35	156	65	416	3.2	0.77	22	27
	I34	160	52	545	2.7	0.68	14	15
	I31	130	54	198	3.2	0.80	18	22
	I23	173	64	271	3.6	0.85	24	20
	I18	109	49	153	3.4	0.86	20	21
	I10	142	66	265	3.4	0.82	21	19
	I4	112	43	176	3.0	0.80	14	8
28-m Stations	I33	202	96	450	3.6	0.78	26	28
	I30	188	90	332	3.9	0.87	32	27
	I27	162	80	302	3.7	0.84	28	25
	I22	206	103	452	3.9	0.84	32	28
	I14[a]	152	71	247	3.5	0.83	24	25
	I16[a]	159	61	288	3.0	0.74	17	24
	I15[a]	175	74	450	3.2	0.74	17	23
	I12[a]	181	76	464	3.2	0.73	22	22
	I9	197	96	393	3.9	0.85	29	26
	I6	148	66	404	3.0	0.71	13	17
	I2	91	47	231	2.8	0.72	13	19
	I3	105	45	359	2.3	0.61	7	14
38-m Stations	I29	246	104	492	3.9	0.83	28	23
	I21	122	56	246	2.9	0.72	14	12
	I13	120	52	357	2.4	0.61	8	12
	I8	112	57	364	2.8	0.69	10	23
55-m Stations	I28	289	150	652	4.3	0.86	44	17
	I20	185	84	326	3.7	0.84	27	15
	I7	191	91	357	3.9	0.86	29	12
	I1	171	79	246	3.9	0.89	30	16
All Grabs	Mean	162	73	350	3.3	0.78	22	20
	95% CI	18	5	37	0.1	0.02	2	1
	Minimum	91	29	91	1.0	0.27	1	-1
	Maximum	289	164	1074	4.4	0.94	46	32

[a] nearfield station

characterized by relatively diverse assemblages of evenly distributed species (Table 5.1). The lowest values for diversity and evenness were reported at stations I3 and I13, sites characterized by relatively high abundances of *Spiophanes norrisi*. Highest diversity and evenness occurred at 55-m stations I28 and I1, respectively. No spatial patterns relative to wastewater discharge or depth were evident for these parameters. Except for lower diversity and evenness that were associated with high densities of *S. norrisi* between 2007 and 2010 (Figures 5.2C, D, 5.3), values of both parameters recorded during the year were similar to historical values. Swartz dominance values averaged from 7 to 44 taxa per station with the lowest dominance (highest index value) occurring at station I28 and the highest dominance (lowest index value) occurring at station I3 (Table 5.1). No seasonal differences between surveys were apparent for these three parameters (Appendix D.1).

Benthic response index

The benthic response index (BRI) is an important tool for gauging possible anthropogenic impacts to marine environments throughout the SCB. Values < 25 are considered indicative of reference conditions, values 25–33 represent "a minor deviation from reference conditions," and values ≥ 34 represent increasing levels of degradation (Smith et al. 2001). In 2012, 74% of the benthic stations sampled had mean BRI values < 25 (Table 5.1). Seven stations had mean values that corresponded to a minor deviation from reference conditions (BRI = 25–28): six along the 28-m depth contour located from 2.3 km south to 10.8 km north of the outfall (i.e., stations I9, I14, I22, I27, I30, I33), and one along the 19-m contour 11.0 km north of the outfall (i.e., I35). Higher BRI at these depths is not unexpected because of naturally higher levels of organic matter often occurring close to shore (Smith et al. 2001). Although stations located along the 55-m depth contour had among the lowest mean BRI values calculated, the lowest mean occurred at 19-m contour station I4. Historically, mean BRI at the four nearfield stations in the SBOO region have been similar to mean values for the northern 28-m contour farfield stations (Figure 5.2F), suggesting no impact of the SBOO on the marine environment. No consistent seasonal pattern was evident between winter and summer surveys (Appendix D.1).

Species of Interest

Dominant taxa

Although only a subset of species encountered in the SBOO region was present in each grab, annelids (mostly polychaetes) were usually dominant, with mean percent composition and abundance of 51% and 68%, respectively (Table 5.2). Arthropods (mostly crustaceans) followed with an average percent composition of 21% and average abundance of 17%. Molluscs, echinoderms, and other phyla (i.e., cnidarians, nemerteans, echiurans, nematodes, sipunculids, phoronids, chordates, and platyhelminthes) each contributed to ≤ 13% of total invertebrate composition and ≤ 8% of total abundance. Overall, the percentage of taxa that occurred within each major taxonomic grouping and their relative abundances were similar to those observed in 2011 and have remained consistent since monitoring began in 1995 (City of San Diego 2000, 2012a).

The 10 most abundant species in 2012 included nine polychaetes and one arthropod (Table 5.3). The numerically dominant polychaetes included the spionids *Spiophanes norrisi*, *Spiophanes duplex*, *Prionospio* (*Prionospio*) *jubata*, and *Spio maculata*, the cirratulid *Monticellina siblina*, the capitellid *Mediomastus* sp, the chaetopterid *Spiochaetopterus costarum* Cmplx, the magelonid *Magelona sacculata*, and the onuphid *Mooreonuphis nebulosa*. The most dominant crustacean was the amphipod *Ampelisca cristata cristata*. *Spiophanes norrisi* was the most abundant species collected, accounting for ~23% of invertebrate abundance in the SBOO region. This species was also the most widely distributed species during the year and occurred in 94% of grabs, with mean abundance of ~87 individuals per grab. Seven of the most abundant species in 2012 were also among the most abundant in 2011 (City of San Diego 2012a). Though abundances have fluctuated through time, populations of the most abundant species were within recent historical ranges (Figure 5.3, Appendix D.2).

Four of the most abundant species collected during 2012 were also among the historically most abundant recorded (*Spiophanes norrisi*, *Spiophanes duplex*, *Monticellina siblina*, and *Mediomastus* sp). The maldanid polychaete species complex Euclymeninae sp A/B was not among the most abundant recorded during 2012 but has been historically dominant, with a recent population expansion from 2007 to 2011 (Appendix D.2).

Indicator species

Species known to be indicators of environmental change that occur in the SBOO region include the polychaete *Capitella teleta* (previously considered within the *Capitella capitata* species complex), the bivalve *Solemya pervernicosa*, and amphipods in

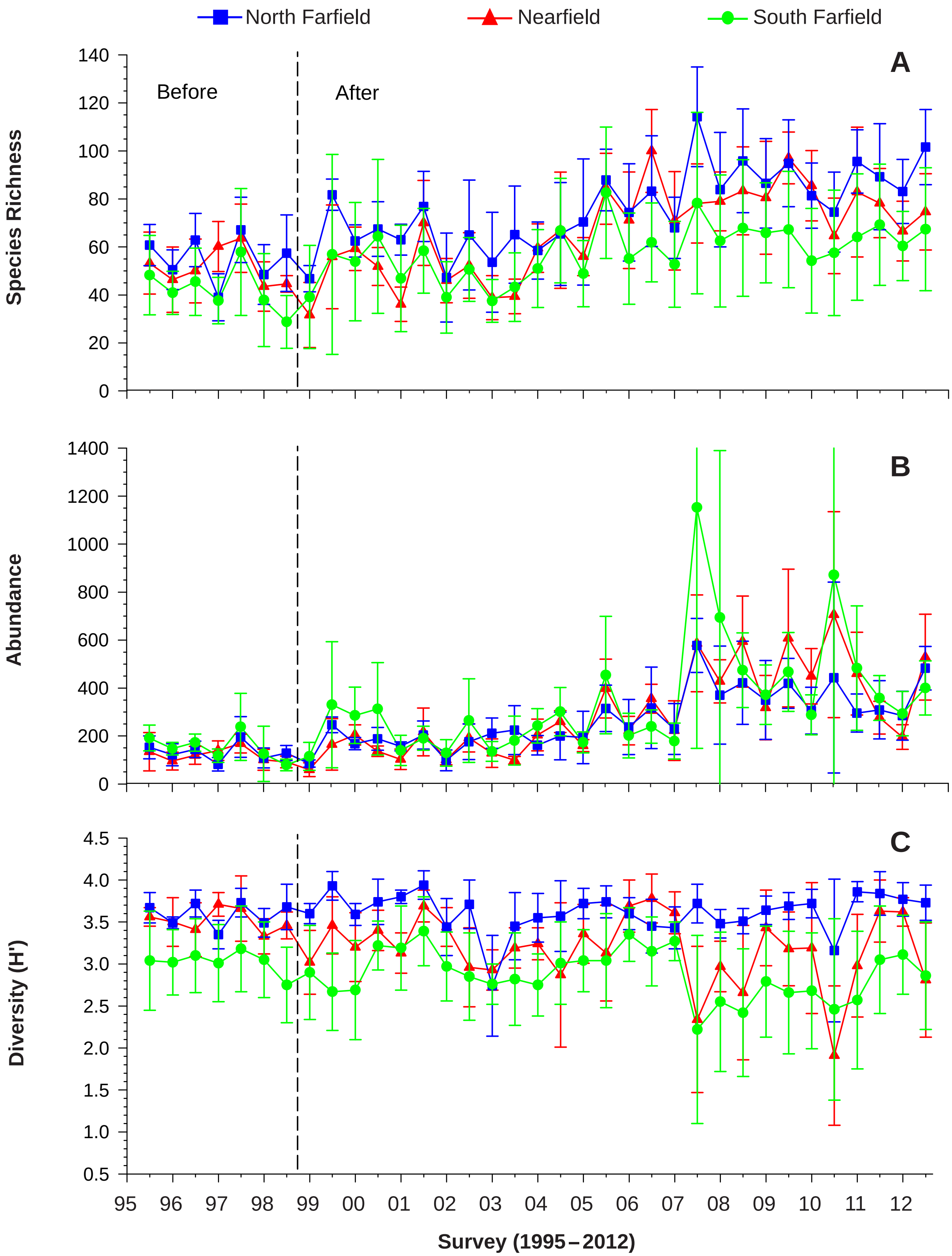


Figure 5.2

Comparison of community parameters at SBOO nearfield, north farfield, and south farfield stations along the 28-m depth contour sampled between 1995 and 2012. Parameters include: (A) species richness; (B) infaunal abundance; (C) diversity (H'); (D) evenness (J'); (E) Swartz dominance; (F) benthic response index (BRI). Data for each station group are expressed as means ±95% confidence intervals per 0.1 m^2 (n=8). Dashed lines indicate onset of wastewater discharge.

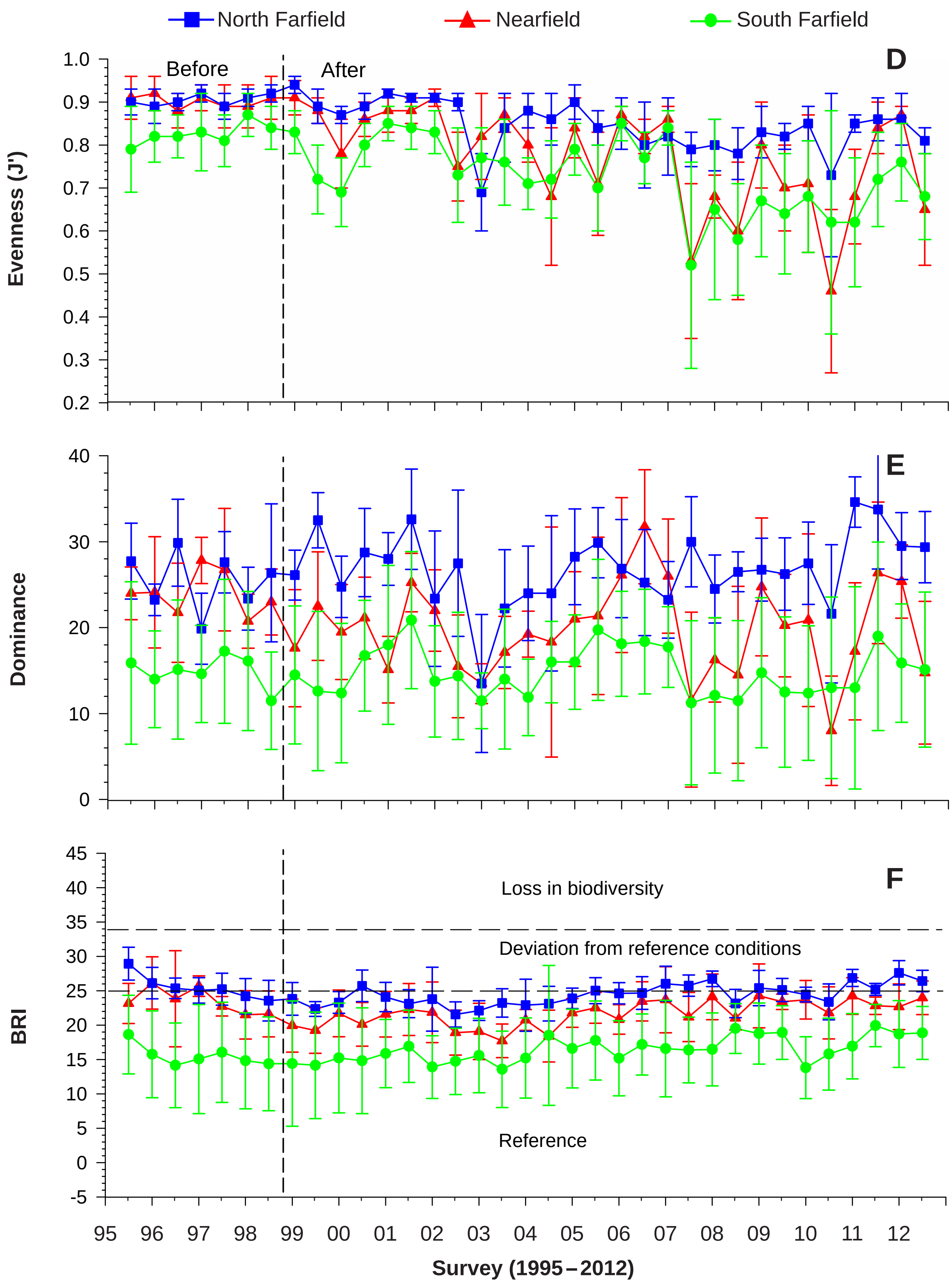


Figure 5.2 *continued*

the genera *Ampelisca* and *Rhepoxynius*. Increased abundances of *C. teleta* and *S. pervernicosa* often indicate organic enrichment, whereas decreases in numbers of pollution-sensitive genera such as *Ampelisca* and *Rhepoxynius* may indicate habitats impacted by human activity (Anderson et al. 1998, Linton and Taghon 2000, Kennedy et al. 2009, McLeod and Wing 2009).

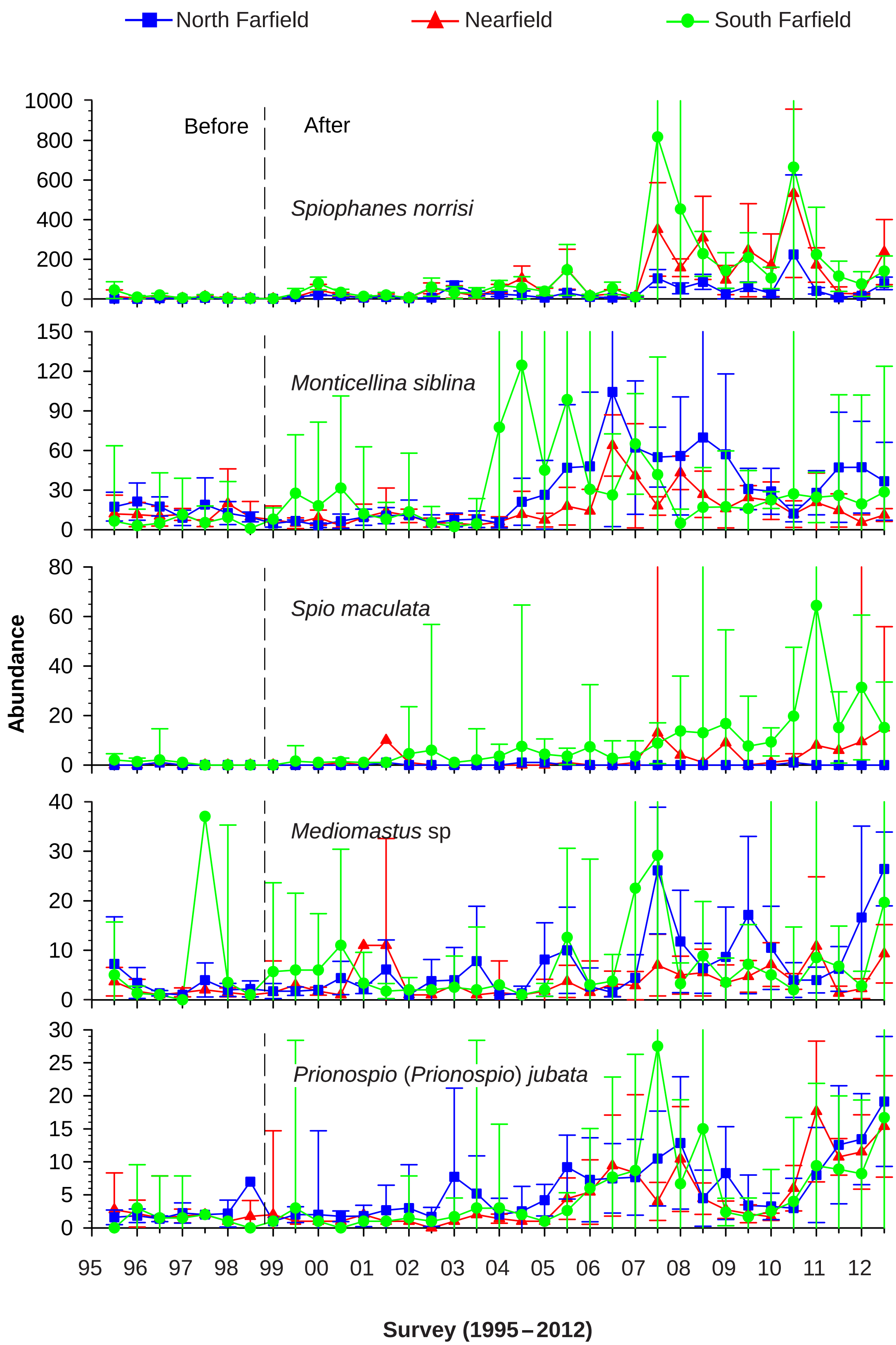


Figure 5.3
Historical abundances of the five most abundant species recorded during 2012 at SBOO north farfield, nearfield, and south farfield stations along the 28-m depth contour. Data for each station group are expressed as means ±95% confidence intervals per 0.1 m^2 (n=8). Dashed lines indicate onset of wastewater discharge.

In 2012, the relative mean abundances of each indicator species were similar at nearfield and farfield 28-m stations, suggesting that populations of these taxa were not affected by wastewater discharge (Figure 5.4). Populations of the opportunistic species *Capitella teleta* and *Solemya pervernicosa* remained low, with only 2 and 42 individuals being recorded across the entire SBOO region, respectively. Populations of pollution-sensitive taxa such as *Ampelisca* and *Rhepoxynius* remained within their historical ranges.

Classification of Macrobenthic Assemblages

Similarity of Assemblages

Classification (cluster) analysis was used to discriminate between macrofaunal assemblages from 54 individual grab samples collected at 27 stations in 2012, resulting in nine ecologically-relevant SIMPROF-supported groups (Figures 5.5, 5.6, Appendix D.3). These assemblages (referred to herein as cluster groups A–I) represented between 1 and 19 grabs each, and exhibited mean species richness ranging from 49 to 152 taxa per grab and mean abundances of 155 to 731 individuals per grab. Groups were primarily distinguished by sediment characteristics and depth as described below.

Table 5.2

Percent composition and abundance of major taxonomic groups (phyla) in SBOO benthic grabs sampled during 2012. Data are expressed as annual means (range) for all stations combined; n = 108.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	51 (34–64)	68 (38–95)
Arthropoda (Crustacea)	21 (5–35)	17 (2–44)
Mollusca	11 (0–23)	6 (0–17)
Echinodermata	5 (0–13)	2 (0–14)
Other Phyla	13 (4–25)	8 (1–39)

Cluster group A represented the macrofaunal assemblages collected in January from stations I23 and I34 located north of the SBOO on the 19-m contour (Figure 5.6). Although having the lowest species richness observed (49 taxa per grab), abundance was second highest of all cluster groups with 429 individuals per grab. The five most abundant taxa included the polychaetes *Pisione* sp,

Table 5.3

The 10 most abundant macroinvertebrate taxa collected at the SBOO benthic stations during 2012. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab. Percent occurrence = percentage of grabs in which a species occurred.

Species	Taxonomic Classification	Abundance per Sample	Percent Occurrence
Spiophanes norrisi	Polychaeta: Spionidae	87.1	94
Monticellina siblina	Polychaeta: Cirratulidae	13.5	71
Mediomastus sp	Polychaeta: Capitellidae	10.0	76
Spiochaetopterus costarum Cmplx	Polychaeta: Chaetopteridae	8.2	90
Prionospio (*Prionospio*) *jubata*	Polychaeta: Spionidae	7.5	69
Spio maculata	Polychaeta: Spionidae	6.7	26
Spiophanes duplex	Polychaeta: Spionidae	4.5	69
Ampelisca cristata cristata	Arthropoda: Amphipoda	4.5	81
Magelona sacculata	Polychaeta: Magelonidae	4.4	62
Mooreonuphis nebulosa	Polychaeta: Onuphidae	4.1	41

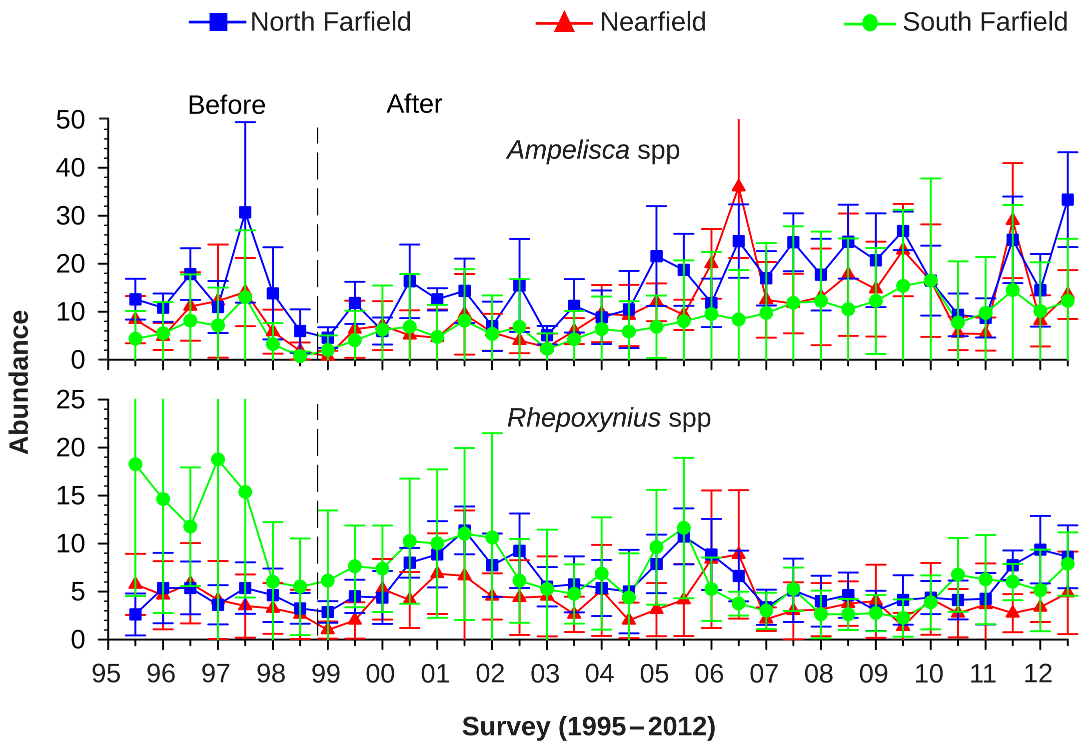


Figure 5.4
Historical abundances of ecologically important indicator species at SBOO north farfield, nearfield, and south farfield stations along the 28-m depth contour. Data for each station group are expressed as means ±95% confidence intervals per 0.1 m^2 (n=8). Dashed lines indicate onset of wastewater discharge.

Pareurythoe californica, and *Hesionura coineaui difficilis,* the chordate *Branchiostoma californiense*, and nematodes, all of which had mean abundances ranging from 40 to 54 individuals (Appendix D.3). No other taxa had mean abundances >20 individuals. Taxa contributing to 25% of within group similarity included three of the five most abundant taxa listed, *Pisione* sp, *P. californica*, and *B. californiense* (Figure 5.7). The sediments associated with this assemblage were coarse in comparison to other cluster groups, and had 0% fines. The percentage of coarse sand present was high, ranging from 51 to 70% and visual observations of grunge included shell hash. (Appendix C.4).

Cluster group B represented mid-shelf assemblages and comprised macrofauna collected from three grabs, two from station I7 and the July grab from I20. Both stations are located west of the SBOO along the 55-m contour (Figure 5.6). Mean species richness and abundance values were the second and third highest of all other cluster groups at 94 taxa and 406 individuals per grab, respectively. The five most abundant taxa were the polychaetes *Spio maculata*, *Spiophanes norrisi*, and *Mooreonuphis* sp SD1, the amphipod *Photis californica*, and nematodes, all of which had mean abundances ranging from 14 to 39 individuals. No other taxa had abundances >11 individuals. Taxa contributing to 25% of within group similarity included nematodes, and the polychaetes *S. maculata*, *S. norrisi*, *Prionospio* (*Prionospio*) *jubata* and *Lumbrineris ligulata*. Sediments associated with this assemblage contained from 0 to 8% fines. Coarse sands were dominant and ranged from 80 to 83%, though visual observations of grunge also included fine sand and fine red relict sand (Appendix C.4).

Cluster group C, located south of the SBOO, represented the assemblages from both grabs at station I4 and the January grab from I6 (Figure 5.6). Compared to other clusters, group C had a relatively low mean species richness of 50 taxa per grab and a mid-range abundance of 246 individuals per grab. The five most abundant taxa were the polychaetes *Spiophanes norrisi*, *Spio maculata*, and

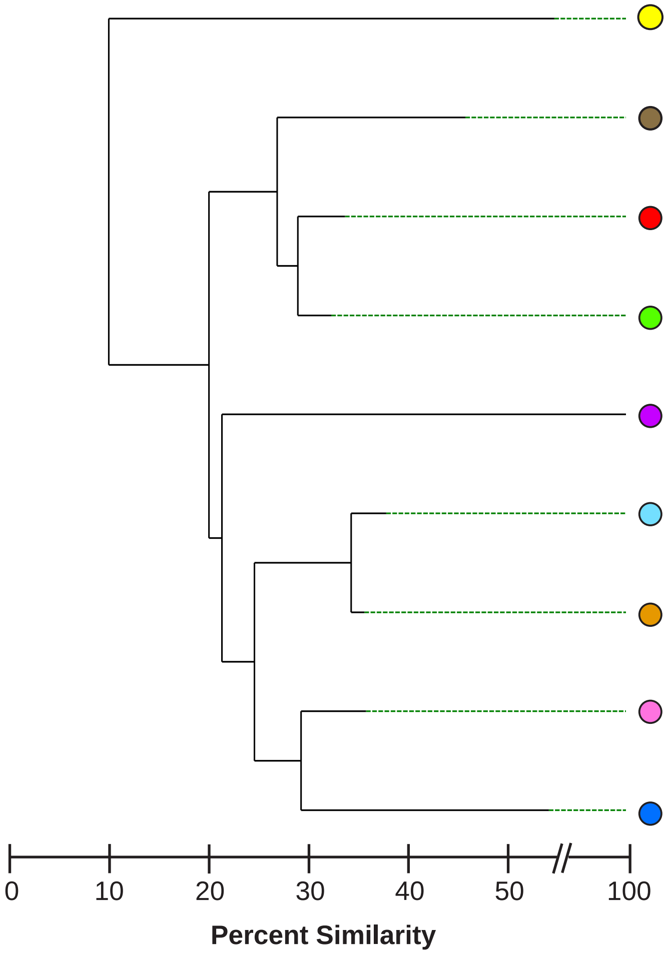
Protodorvillea gracilis, the crustacean *Anchicolurus occidentalis*, and the chordate *Branchiostoma californiense* (Figure 5.7, Appendix D.3), that averaged from 13 to 36 individuals. No other taxa had abundances >12 individuals. Taxa contributing to 25% of within group similarity included *S. norrisi, P. gracilis*, and *S. maculata*. Sediments associated with this group ranged from 1 to 10% fines, but coarse sands dominated, ranging from 66 to 85%. Visual observations of grunge included shell hash, some gravel, and organic debris (Appendix C.4).

Cluster group D comprised macrofauna from 14 grabs along the 28-m and 38-m contours including nearfield stations I12, I15, and I16 (Figure 5.6). Mean species richness and abundance were within the range of all other cluster groups at 52 taxa and 304 individuals per grab. The five most abundant taxa included the polychaetes *Spiophanes norrisi, Spio maculata, Spiochaetopterus costarum* Cmplx, *Scoloplos armiger* Cmplx, and *Lumbrinerides platypygos,* all of which had mean abundances ranging from 8 to 130 individuals (Appendix D.3). No other taxa had abundances >6 individuals. Taxa contributing to 25% of within group similarity included *S. norrisi* and *S. maculata*. Sediments from grabs in group D had only 0 to 6% fines, with coarse sands being dominant, ranging from 44 to 89%. Visual observations of grunge among grabs were varied and included: worm tubes, red relict sand, and shell hash (Appendix C.4).

Cluster group E represented the assemblage from station I16 in January, and was located less than 100 m from the SBOO wye (Figure 5.6). Although having species richness within the range of all other cluster groups (58 taxa), abundance was lowest at 155 individuals. The five most abundant taxa included the polychaetes *Spiophanes norrisi, Prionospio* (*Prionospio*) *jubata,* and *Platynereis bicanaliculata,* the mollusc *Alvania compacta*, and the ophiuroid *Ophiothrix spiculata*. These species had abundances ranging from 6 to 32 individuals and no other taxa had abundances >5 individuals (Appendix D.3). Sediments associated with this grab had a relatively high percentage of fine sand recorded (80%), and also had 11% fines. Visual observations of grunge included organic material and algae (Appendix C.4). The presence of drift algae collected along with the animals could explain the unique composition of this assemblage as *P. bicanaliculata*, *A. compacta*, and *O. spiculata* are all known to commonly occur with kelp holdfasts and other macroalgae.

Cluster group F represented the assemblages from seven grabs located along the 19-m contour (Figure 5.6). Mean species richness and abundance were within the range of all other cluster groups at 59 taxa and 225 individuals per grab. The five most abundant taxa included the polychaetes *Spiophanes norrisi, Spiophanes duplex, Mediomastus* sp, and *Ampharete labrops* and the amphipod *Ampelisca cristata cristata,* all of which had mean abundances ranging from 9 to 48 individuals (Appendix D.3). No other taxa had abundances >7 individuals. Taxa contributing to 25% of within group similarity included *S. norrisi, S. duplex, A. cristata cristata,* and *Mediomastus* sp. Sediments collected in associated grabs had from 12 to 19% fines, but fine sands were dominant, ranging from 79 to 86%. Visual observations of grunge from individual grabs included organic debris and some shell hash (Appendix C.4).

Cluster group G comprised macrofaunal assemblages collected from 19 grabs at 11 stations ranging in depth from 19 to 38 m (Figure 5.6). This group represents typical inner shelf assemblages for the SCB, and corresponds to cluster group D of the regional survey (see Chapter 9). Mean species richness and abundance were within the range of all other cluster groups at 92 taxa and 376 individuals per grab. The five most abundant taxa were polychaetes: *Spiophanes norrisi*, *Monticellina siblina*, *Prionospio* (*Prionospio*) *jubata*, *Mediomastus* sp, and *Mooreonuphis nebulosa* (Figure 5.7, Appendix D.3), that averaged from 12 to 48 individuals. No other taxa had abundances > 10 individuals. Taxa contributing to 25% of within group similarity included the polychaetes *S. norrisi, M. siblina, Mediomastus* sp, *P.* (*P.*) *jubata,* and *Spiochaetopterus costarum* Cmplx, and the amphipod *Ampelisca brevisimulata*.



Cluster Group	n	SR	Abun
A	2	49	429
B	3	94	406
C	3	50	246
D	14	52	304
E	1	58	155
F	7	59	225
G	19	92	376
H	3	78	254
I	2	152	731

Figure 5.5
Cluster analysis of macrofaunal assemblages at SBOO stations sampled during 2012. Data for species richness (SR) and infaunal abundance (Abun) are expressed as mean values per 0.1-m^2 over all stations in each group (n).

Sediments collected in associated grabs were generally finer compared to those from most other groups, and contained from 1 to 40% fines, with fine sand ranging from 49 to 82%. Visual observations of grunge mostly included organic debris such as worm tubes (Appendix C.4).

Cluster group H represented the assemblages of macrofauna collected from both grabs at station I1 and the January grab at station I20, located along the 55-m depth contour (Figure 5.6). Mean species richness and abundance were within the range of all other cluster groups at 78 taxa and 254 individuals per grab. The most abundant species were the polychaetes *Pista estevanica*, *Spiophanes norrisi, Aricidea* (*Acmira*) *simplex, Aphelochaeta* sp LA1, and *Chaetozone* sp SD5, and the tanaid *Leptochelia dubia* Cmplx, all of which averaged from 8 to 21 individuals (Appendix D.3). No other taxa had abundances >6 individuals. Taxa contributing to 25% of within group similarity included the polychaetes *P. estevanica, S. norrisi, A.* (*A.*) *simplex, Prionospio* (*Prionospio*) *jubata* and *Scoloplos armiger* Cmplx, and the ostracod *Euphilomedes carcharodonta*. Sediments associated with this group were sandy with fine sand ranging from 47 to 82%, and only 7 to 12% fines (Appendix C.4).

Cluster group I represented the assemblages from station I28 in January and July, located on the 55-m contour in the northern section of the South Bay outfall region (Figure 5.6).

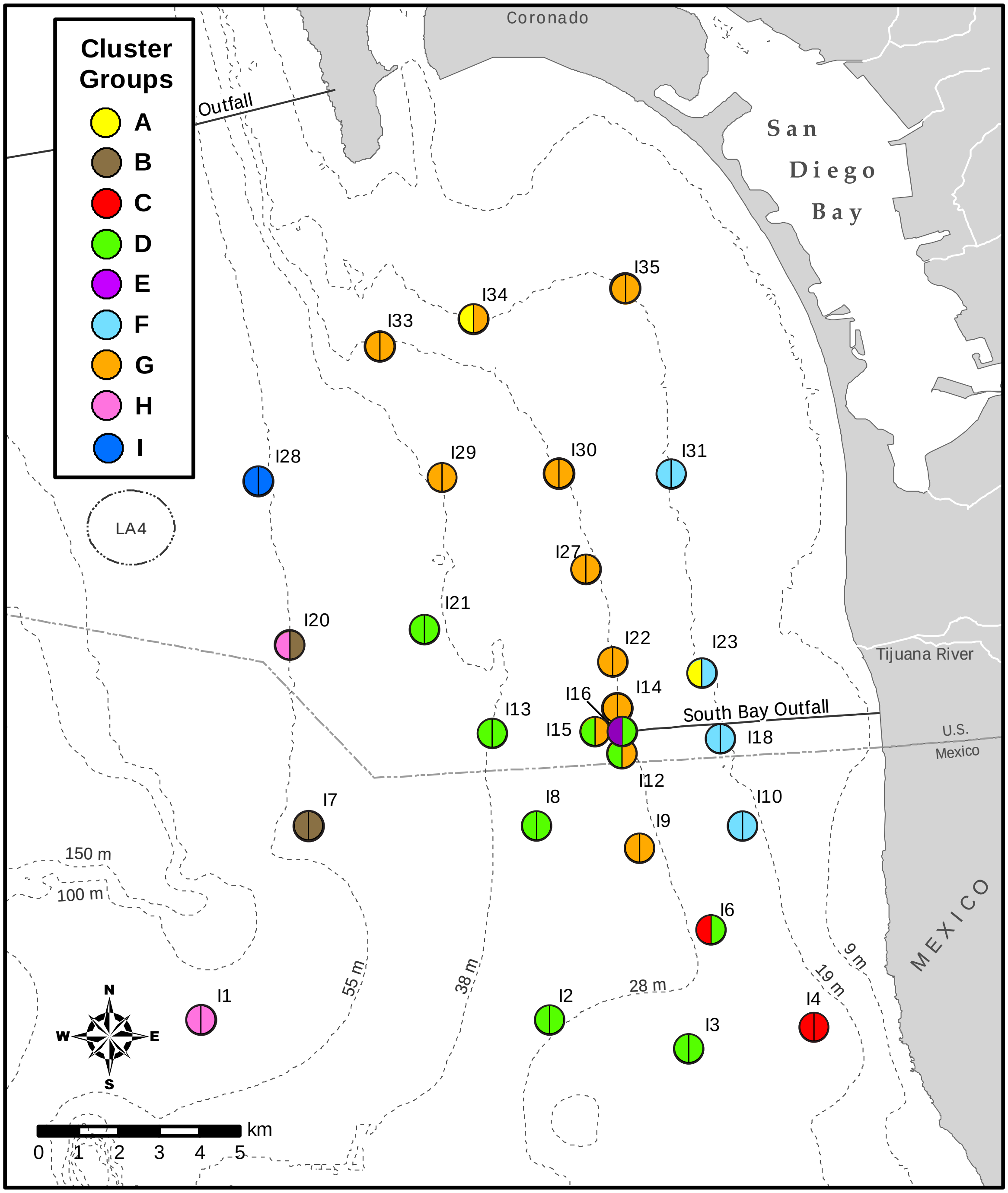


Figure 5.6
Spatial distribution of cluster groups in the SBOO region. Colors of each circle correspond to colors in Figure 5.5.

Mean species richness and abundance were the highest among all cluster groups at 152 taxa and 731 individuals per grab. The five most abundant species were the polychaetes *Spiophanes norrisi*, *Chaetozone hartmanae*, and *Prionospio* (*Prionospio*) *jubata*, the tanaid *Leptochelia dubia* Cmplx, and the amphipod *Photis californica,* all of which had mean abundances ranging from 20 to 60 individuals (Appendix D.3). No other taxa had abundances >18 individuals. Taxa contributing to 25% of within group similarity included *L. dubia* Cmplx, the polychaetes *C. hartmanae, S. norrisi, P.* (*P.*) *jubata, P. californica, Prionospio* (*Prionospio*) *dubia*, and *Sthenelanella uniformis,* and the ostracod *Euphilomedes carcharodonta*. Sediments associated with this assemblage had

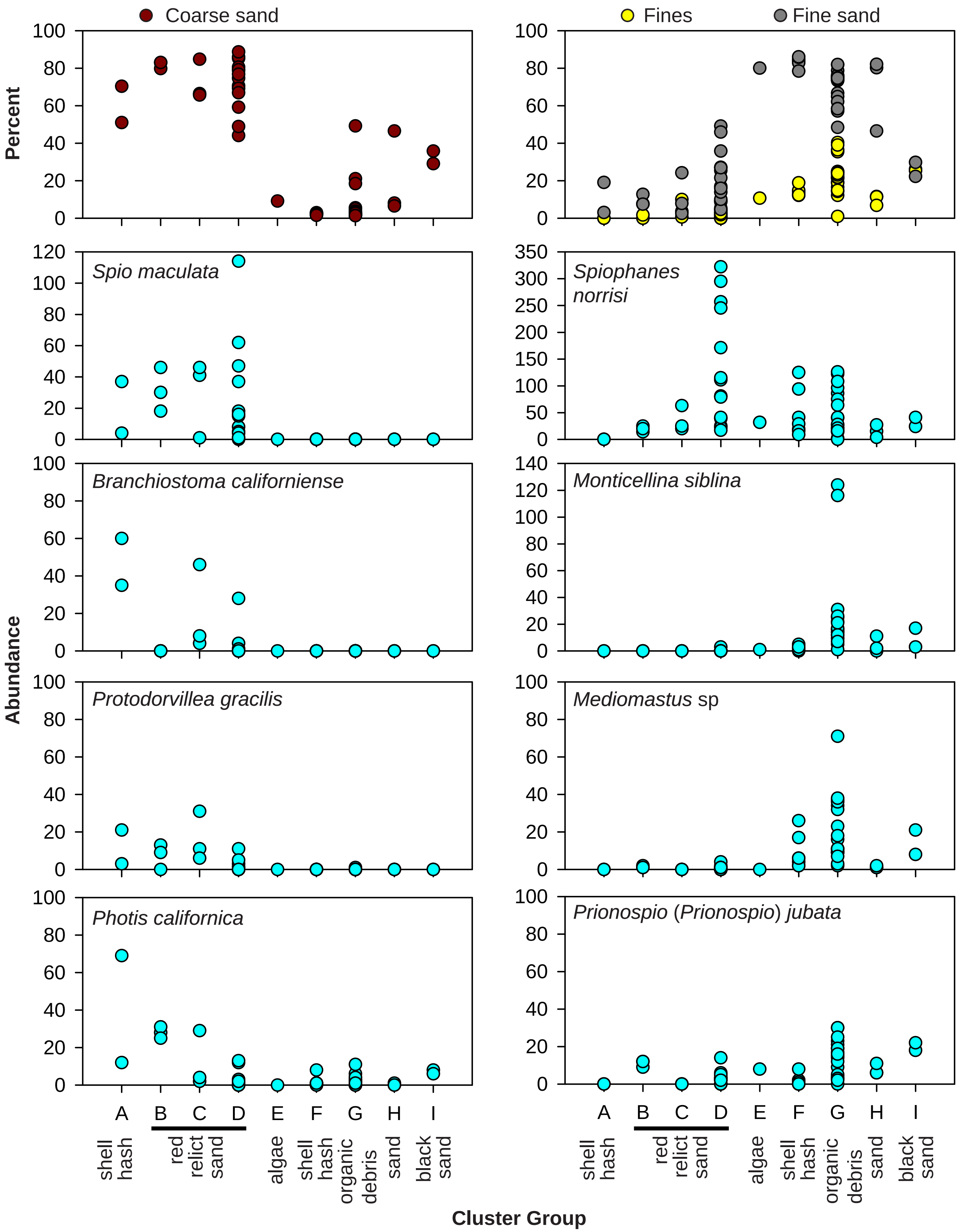


Figure 5.7

Sediment composition and abundances of select species that contributed to cluster group dissimilarities. Each data point represents a single grab. Grabs from cluster groups A and F contained shell hash, grabs from cluster groups B, C, D contained red relict sand. The grab from cluster group E contained algae, grabs from cluster group G contained organic debris. Grabs from cluster groups H and I contained sand and coarse black sand, respectively. Sediment values shown in dark red, grey, and yellow; abundance values shown in blue.

from 25 to 26% fines, with coarse sand ranging from 29 to 36%. Visual observations of grunge were unique and included coarse black sand, shell hash, and gravel (Appendix C.4).

Comparison of macrobenthic and sediment assemblages

Similar patterns of variation occurred in the benthic macrofaunal and sediment similarity/dissimilarity matrices (see Chapter 4) used to generate cluster dendrograms and confirmed that macrofaunal assemblages were correlated to sediment composition (RELATE $\rho = 0.701$, $p = 0.0001$). Sediment subfractions that were highly correlated to macrofaunal communities included clay, fine silt, coarse silt, very fine sand, fine sand, very coarse sand, and granules (BEST $\rho = 0.731$, $p = 0.001$) (Appendix C.1). Macrofaunal and sediment dendrograms (Figures 5.5 and 4.6, respectively) indicated that macrofaunal communities separate based on high percentages of coarse fractions (macrofauna cluster groups A–D, I) versus high percentages finer sediments (E–H). Macrofauna cluster group I (both grabs from station I28) exactly matched sediment cluster group 2, suggesting that these macrofaunal assemblages form primarily due to the sediment composition present. However, it is unlikely that differences in macrofaunal communities are caused solely by differences in the sediment subfractions measured. Additional factors influencing benthic assemblages may include: (1) the presence or absence of extremely coarse sediment fractions retained during screening of macrofauna (Appendix C.4), (2) differences in concentrations of organic material, trace metals, or pollutants (Appendices C.5–C.7), (3) differences in depth, (4) differences in biological factors (e.g., increased predation), or (5) differences in ephemeral habitat alteration (e.g., in the case of cluster group E, the presence of drift algae that would temporarily support a unique macrofaunal assemblage).

Summary

Analysis of the 2012 macrofaunal data do not suggest that wastewater discharged through the SBOO has affected macrobenthic communities in the region, with invertebrate assemblages located near the outfall being similar to those from neighboring farfield sites. Species richness, abundance, diversity, evenness and dominance were within historical ranges reported for the San Diego region (see Chapter 9 and City of San Diego 2000, 2012a), 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 monitoring region were indicative of the ambient sediment and/or depth characteristics present, with stations having comparable physical attributes supporting similar types of benthic assemblages. Benthic response index (BRI) values reported at 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. Since monitoring first began within the SBOO region in 1995, 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. 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 is 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 or pollution-tolerant species or other indicators of benthic condition provide little to no evidence of significant environmental degradation in the South Bay outfall region. For instance, populations of opportunistic taxa such as the polychaete *Capitella teleta* and the bivalve mollusc *Solemya pervernicosa* were low during 2012, while populations of pollution-sensitive taxa such as the genera *Ampelisca* and *Rhepoxynius* have remained stable 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 naturally possess high 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, ubiquitous, high populations of *Spiophanes norrisi* observed at most SBOO stations between 2007 and 2012 suggest that their distribution is not indicative of habitat degradation related to wastewater discharge, and that population fluctuations of this species over the past few years likely correspond to natural changes in large-scale oceanographic conditions. Likewise, although fluctuations in populations of capitellid polychaetes have been shown to be possible indicators of polluted sediments near wastewater treatment plants in certain areas of the world (Swartz et al. 1986, Rodríguez-Villanueva et al. 2003), the abundance of *Mediomastus* sp in the SBOO region in 2012 was within the natural range of variation expected, with the highest abundances occurring along the 19-m isobath inshore of the outfall. Sediments associated with relatively high *Mediomastus* sp populations had a high percentage of fine sands, a habitat type known to support motile deposit feeders including capitellids (Fauchald and Jumars 1979).

In conclusion, anthropogenic impacts in marine environments are known to have spatial and temporal dimensions that can vary depending on a range of biological and physical factors. Such impacts can be difficult to detect, and specific effects of wastewater discharge via the SBOO on the local macrobenthic community could not be identified during 2012. Furthermore, populations and communities of benthic invertebrates exhibit substantial natural spatial and temporal variability that may mask the effects of any disturbance event (Morrisey et al. 1992a, b, Otway 1995). Although some changes have occurred near the SBOO over time, benthic assemblages in the region remain similar to those observed prior to outfall operations and to natural indigenous communities characteristic of similar habitats on the southern California continental shelf.

Literature Cited

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

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

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

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

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

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

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

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

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

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

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R. and R.M. Warwick. (2001). Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. PRIMER-E, Plymouth.

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

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

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

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

Fauchald, J. and P.A. Jumars. (1979) The diet of worms: a study of polychaete feeding guilds. Oceanography and Marine Biology Annual Review, 117:193-284.

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

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

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

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

Kennedy, A.J., J.A. Steevens, G.R. Lotufo, J.D. Farrar, M.R. Reiss, R.K. Kropp, J. Doi, and T.S. Bridges. (2009). A comparison of acute and chronic toxicity methods for marine sediments. Marine Environmental Research, 68: 188–127.

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

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

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

Morrisey, D.J., L. Howitt, A.J. Underwood, and J.S. Stark. (1992a). Spatial variation in soft-sediment benthos. Marine Ecology Progress Series, 81: 197–204.

Morrisey, D.J., A.J. Underwood, L. Howitt, and J.S. Stark. (1992b). Temporal variation in soft-sediment benthos. Journal of Experimental Marine Biology and Ecology, 164: 233–245.

Otway, N.M. (1995). Assessing impacts of deepwater sewage disposal: a case study from New South Wales, Australia. Marine Pollution Bulletin, 31: 347–354.

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

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

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

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

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

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

[SCAMIT] Southern California Association of Marine Invertebrate Taxonomists. (2012). A taxonomic listing of benthic macro- and megainvertebrates from infaunal and epibenthic monitoring programs in the Southern California Bight, edition 7. Southern California Associations of Marine Invertebrate Taxonomists, Natural History Museum of Los Angeles County Research and Collections, Los Angeles, CA.

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

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

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

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

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

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

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

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

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

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

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Chapter 6
Demersal Fishes and Megabenthic Invertebrates

Chapter 6. Demersal Fishes and Megabenthic Invertebrates

Introduction

The City of San Diego (City) collects bottom dwelling (demersal) fishes and relatively large (megabenthic) mobile invertebrates by otter trawl to examine the potential effects of wastewater discharge or other disturbances on the marine environment around the South Bay Ocean Outfall (SBOO). These fish and invertebrate communities are targeted for monitoring because they are known to play critical ecological roles on the southern California coastal shelf (e.g., Allen et al. 2006, Thompson et al. 1993a, b). Because trawled species live on or near the seafloor, they may be impacted by sediment conditions affected by both point and non-point sources such as discharges from ocean outfalls and storm drains, surface runoff from watersheds, outflows from rivers and bays, or the disposal of dredge materials (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 three decades (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 of adult fish or the recruitment of juveniles into an area (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 background or reference conditions is necessary before determining whether observed differences or changes in community structure may be related to anthropogenic activities. Pre-discharge or 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 analysis (e.g., City of San Diego 2000, Allen et al. 1998, 2002, 2007, 2011).

The City relies on a suite of scientifically-accepted indices and statistical analyses to evaluate changes in local fish and invertebrate communities. These include community structure metrics such as species richness, abundance and the Shannon diversity index, 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, the data are used to determine whether fish and invertebrate populations near outfalls are similar to populations from habitats with similar depth and sediment characteristics, or whether observable impacts from wastewater discharge or other sources occur.

This chapter presents analyses and interpretations of demersal fish and megabenthic invertebrate data collected during 2012, as well as a long-term assessment of these communities from 1995 through 2012. 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, and (3) identify other potential natural and anthropogenic sources of variability to the local marine ecosystem.

Materials and Methods

Field Sampling

Trawl surveys were conducted at seven fixed monitoring stations in the SBOO region during January, April, July–August, and October 2012 (Figure 6.1). These trawl stations, designated SD15, SD16, SD17, SD18, SD19, SD20 and SD21, are located along the 28-m depth contour, and encompass an area 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 are considered to represent the "nearfield" station group. Stations SD15–SD16 and SD19–SD21 are located >1.8 km south and >1.7 km north of the SBOO, respectively, and represent "south farfield" and "north farfield" station groups. Surveys from winter, spring, and fall each took place over 2–3 days. The summer survey primarily occurred over 2 days in July; however, station SD15 was not sampled until late August due to a large abundance of squid eggs covering the benthos in July.

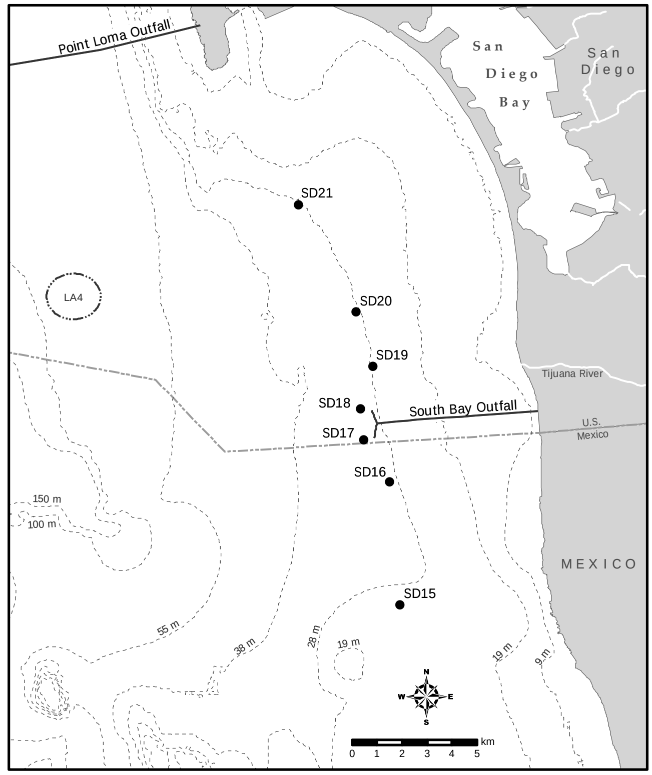

Figure 6.1
Otter trawl station locations sampled around the South Bay Ocean Outfall as part of City of San Diego's Ocean Monitoring Program.

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 total 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. If an animal could not be identified in the field, it was returned to the laboratory for further identification. For fishes, the total number of individuals and total biomass (kg, wet weight) were recorded for each species. Additionally, each individual fish was inspected for physical anomalies, indicators of disease (e.g., tumors, fin erosion, discoloration), and the presence of external parasites (e.g., copepods, cymothoid isopods). The length of each fish was measured to the nearest centimeter size class on measuring boards; total length (TL) was measured for cartilaginous fishes and standard length (SL) was measured for bony fishes. For invertebrates, the total number of individuals was recorded per species. Due to the small size of most organisms, invertebrate biomass was typically measured as a composite weight of all taxa combined, though large or exceptionally abundant taxa were weighed separately.

Data Analyses

Populations of each fish and invertebrate species were summarized as percent abundance (no. individuals per species/total abundance of all species), frequency of occurrence (percentage of stations at which a species was collected), mean abundance per haul (no. individuals per species per total number sites sampled), and mean abundance per occurrence (no. individuals per species per number of sites at which the species was collected) for the year. 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 of demersal fish and megabenthic invertebrate communities sampled in the region were performed in PRIMER using data collected from 1995 through 2012 (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). Demersal fish data were limited to those from summer surveys to reduce statistical noise from natural seasonal variations evident in previous studies (City of San Diego 1997). Megabenthic invertebrate data were limited to winter and summer surveys in order to explore seasonal variation. Spring and autumn surveys were not considered since they may represent transitional species assemblages between the warmest and coldest times of the year. For both demersal fish and invertebrate data, 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 supported by SIMPROF were retained, and similarity percentages analysis (SIMPER) was used to determine which organisms 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 (maximum number of permutations = 9999) for each set of historical data. For fish, station group (i.e., nearfield, north farfield, south farfield) and year were provided as factors. For invertebrates, station group and season (i.e., summer and winter) were tested. 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

Forty-one species of fish were collected in the area surrounding the SBOO in 2012 (Table 6.1, Appendix E.1). The total catch for the year was 5791 individuals (Appendix E.2), representing an average of ~207 fish per trawl. Of 24 families represented, five accounted for 95% of the total abundance (i.e., Hexagrammidae, Paralichthyidae, Pleuronectidae, Sciaenidae, Synodontidae). As in previous years, speckled sanddabs (Paralichthyidae) were dominant. This species occurred in every haul and accounted for 49% of all fishes collected at an average of 102 individuals per trawl. No other species contributed to more than 27% of the total catch during the year. For example, California lizardfish and hornyhead turbot also occurred at more than 90% of stations, but with fewer numbers (56 and 5 individuals per haul, respectively). Other species collected frequently (≥50% of the trawls) but in relatively low numbers (≤3 individuals per haul) included English sole, plainfin midshipman, and California tonguefish. A juvenile blacksmith collected at station SD17 in October represents a new record for the SBOO trawl surveys.

Over 99% of the fishes collected during 2012 were between 2 and 30 cm in length (Appendix E.1). Exceptions included 11 California halibut (31–82 cm), five California skate (32–42 cm), three shovelnose guitarfish (32–62 cm), and single individuals of fantail sole (31 cm), round stingray (44 cm), spotted ratfish (49 cm), spotted turbot (32 cm), starry skate (82 cm), and thornback (45 cm). Median lengths for the four most abundant fish ranged from 7 to 9 cm for speckled sanddab, 10 to 17 cm for California lizardfish, 12 to 13 cm for white croaker, and 13 to 14 cm for longspine combfish (Figure 6.2). Although no seasonal differences were observed among lengths of speckled sanddab, white croaker, or longspine combfish, a difference was observed among individuals of California lizardfish, with a higher median length occurring during winter.

Species richness ranged between 6 and 15 taxa per haul, and diversity (H') ranged between 0.4 and 1.6 (Table 6.2). Minimum species richness and diversity both occurred at southern farfield station SD15 located off northern Baja California, whereas the highest diversity occurred at both nearfield station SD18 and northern farfield

Table 6.1

Species of demersal fish collected from 28 trawls conducted in the SBOO region during 2012. 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	49	100	102	102	Curlfin sole	<1	18	<1	1
California lizardfish	27	96	56	58	Pacific sanddab	<1	4	<1	6
White croaker	10	43	21	49	California scorpionfish	<1	18	<1	1
Longspine combfish	3	29	5	19	Shiner perch	<1	11	<1	2
Hornyhead turbot	2	93	5	5	Queenfish	<1	7	<1	2
English sole	2	54	3	6	Shortspine combfish	<1	4	<1	3
Longfin sanddab	1	43	2	4	Shovelnose guitarfish	<1	11	<1	1
Yellowchin sculpin	1	21	2	8	Vermilion rockfish	<1	7	<1	2
Pacific pompano	1	25	1	6	Diamond turbot	<1	7	<1	1
Plainfin midshipman	1	57	1	2	Pacific staghorn sculpin	<1	7	<1	1
California tonguefish	1	50	1	3	Blacksmith	<1	4	<1	1
Roughback sculpin	1	36	1	4	Cabezon	<1	4	<1	1
Pygmy poacher	<1	36	1	2	Calico rockfish	<1	4	<1	1
California halibut	<1	36	1	2	California butterfly ray	<1	4	<1	1
Kelp pipefish	<1	25	1	2	Lingcod	<1	4	<1	1
Fantail sole	<1	32	1	2	Pacific jack mackerel	<1	4	<1	1
Northern anchovy	<1	11	1	5	Round stingray	<1	4	<1	1
Spotted turbot	<1	14	<1	3	Spotted ratfish	<1	4	<1	1
Barcheek pipefish	<1	4	<1	6	Starry skate	<1	4	<1	1
Basketweave cusk-eel	<1	14	<1	2	Thornback	<1	4	<1	1
California skate	<1	18	<1	1					

station SD21. Total abundance ranged from 49 to 446 fishes per haul, with highest and lowest values both occurring during the fall survey at northern farfield stations SD20 and SD21, respectively. This high variation in abundance at geographically close stations was mostly due to differences in the numbers of speckled sanddab and California lizardfish captured at each station (Appendix E.2).

Total fish biomass ranged from 1.5 to 18.3 kg per haul, with higher values coincident with either greater numbers of fishes or the presence of a few large individuals (Appendix E.3). For example, three California halibut composed about 3.6 kg of the total biomass at station SD18 in January, whereas 220 speckled sanddab, 75 California lizardfish, and one California halibut accounted for about 4.9 kg of the biomass at station SD18 in October.

Over the years, changes in demersal fish community structure in the South Bay outfall region generally reflect changes in species abundance, with no patterns related to wastewater discharge evident (Figures 6.3, 6.4). Average species richness and diversity have remained within narrow ranges (i.e., SR = 6–13 species, H' = 0.4–1.7 per station group). Conversely, the average abundance has varied considerably (i.e., 44–272 fish per station group), mostly in response to fluctuations in the populations of a few dominant species. Examples of this include: (1) an increase in speckled sanddab populations in 2003 along with a corresponding decrease in longfin sanddab populations; (2) an increase in California lizardfish and yellowchin sculpin populations in 2009; (3) a decrease in roughback sculpin populations in 2011 and 2012.

Multivariate Analyses of Fish Assemblages

Fish assemblages sampled from 1995 through 2012 (summer surveys only) differed significantly by year, but not by station group (i.e., nearfield versus north/south farfield; Table 6.3). Individual pairwise comparisons found that fish communities in 2012 were not significantly different from those recorded

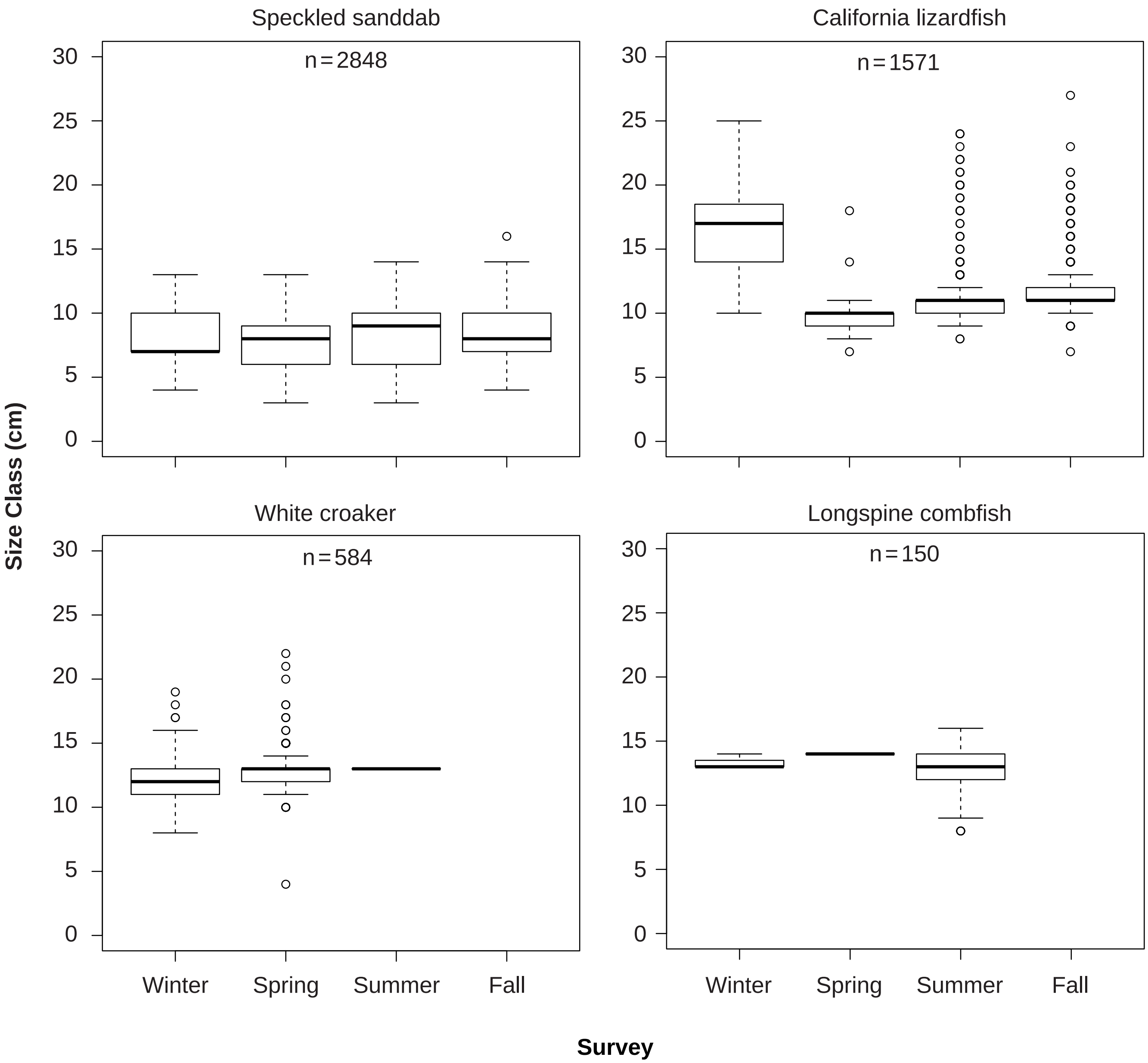

Figure 6.2
Summary of fish lengths by survey for each of the four most abundant species collected in the SBOO region during 2012. Data are median, upper and lower quartiles, 1.5 times the interquartile range (whiskers), and outliers (open circles).

in 2005, 2006, 2008, 2009 and 2011, but did differ significantly from every other year (Appendix E.4). Population fluctuations of common species such as speckled sanddab, yellowchin sculpin, hornyhead turbot and California lizardfish contributed substantially to these annual differences (Figure 6.5).

Classification (cluster) analysis discriminated four types of fish assemblages in the South Bay outfall region from 1995 to 2012 (cluster groups A–D; Figure 6.6), with fish populations from 2012 included as part of the main assemblage that has been observed since 2003. There were no discernible patterns in the distribution of assemblages that could be associated with proximity to the outfall, or the onset of wastewater discharge in 1999. Instead, assemblages appear influenced by large-scale oceanographic events (e.g., El Niño in 1998) or unique characteristics of a specific station location. For example, station SD15 located south of the outfall off northern Baja California often grouped apart from the remaining stations. The

Table 6.2

Summary of demersal fish community parameters for SBOO trawl stations sampled during 2012. Data are included for species richness, abundance, diversity (H'), and biomass (kg, wet weight). SD = standard deviation.

Station	Win	Spr	Sum	Fall	Annual Mean	Annual SD	Station	Win	Spr	Sum	Fall	Annual Mean	Annual SD
Species richness							*Abundance*						
SD15	7	6	6	7	6	1	SD15	141	139	78	165	131	37
SD16	10	11	12	10	11	1	SD16	175	125	365	222	222	103
SD17	8	10	11	8	9	2	SD17	58	157	393	166	194	142
SD18	15	11	7	13	12	3	SD18	173	235	377	324	277	91
SD19	7	10	14	9	10	3	SD19	94	120	412	254	220	146
SD20	10	7	10	8	9	2	SD20	199	108	122	446	219	157
SD21	10	12	13	8	11	2	SD21	188	131	375	49	186	138
Survey Mean	10	10	10	9			Survey Mean	147	145	303	232		
Survey SD	3	2	3	2			Survey SD	53	43	140	127		
Diversity							*Biomass*						
SD15	0.6	0.9	0.4	0.9	0.7	0.2	SD15	3.0	1.5	2.0	4.4	2.7	1.3
SD16	1.1	1.5	1.3	1.1	1.3	0.2	SD16	6.8	8.2	6.4	5.4	6.7	1.2
SD17	1.4	1.1	1.2	1.1	1.2	0.1	SD17	4.4	4.7	8.1	5.5	5.7	1.7
SD18	1.3	1.3	0.8	1.0	1.1	0.2	SD18	10.1	7.6	6.0	10.3	8.5	2.1
SD19	0.9	1.1	1.5	1.1	1.1	0.3	SD19	2.3	4.0	18.3	5.8	7.6	7.3
SD20	0.8	1.1	1.5	1.0	1.1	0.3	SD20	4.4	2.2	4.0	5.8	4.1	1.5
SD21	1.2	0.9	1.5	1.6	1.3	0.3	SD21	6.4	7.9	9.0	3.2	6.6	2.5
Survey Mean	1.0	1.1	1.2	1.1			Survey Mean	5.3	5.2	7.7	5.8		
Survey SD	0.3	0.2	0.4	0.2			Survey SD	2.7	2.8	5.2	2.2		

composition and main characteristics of each cluster group are described below (see also Table 6.4).

Cluster group A represented assemblages from all stations sampled in 1998, most stations in 1997 and 2001, and stations SD20 and SD21 in 1995. This group, which largely coincided with warm water events (e.g., El Niño years), averaged 8 species and 48 fish per haul and was characterized by speckled sanddab, California lizardfish, longfin sanddab, hornyhead turbot, and spotted turbot.

Cluster group B comprised 46% of the trawls conducted during the past 18 years, and with few exceptions represented assemblages sampled at stations SD16–SD21 from 2003 through 2012 and station SD15 from 2009 through 2011. This group averaged 10 species and 266 fish per haul, the highest abundance of all groups. Group B was numerically dominated by speckled sanddab, which was one of the most characteristic species of this group. Additional characteristic species included California lizardfish, yellowchin sculpin, roughback sculpin, and hornyhead turbot.

Group C comprised assemblages that occurred primarily at stations SD15–SD20 in 1999, 2000 and 2002, as well as station SD15 throughout most years. This group averaged 6 species and 115 fish per haul. Similar to group B, assemblages in group C were dominated by speckled sanddab and further characterized by hornyhead turbot and California lizardfish.

Cluster group D represented assemblages sampled at most stations during 1995–1996, and at station SD21 for several years between 1999–2006. This group averaged 10 species and 122 individuals per haul, equaling group B for the highest species richness. Group D was characterized by both speckled and longfin sanddab as well as hornyhead turbot, California tonguefish, and English sole.

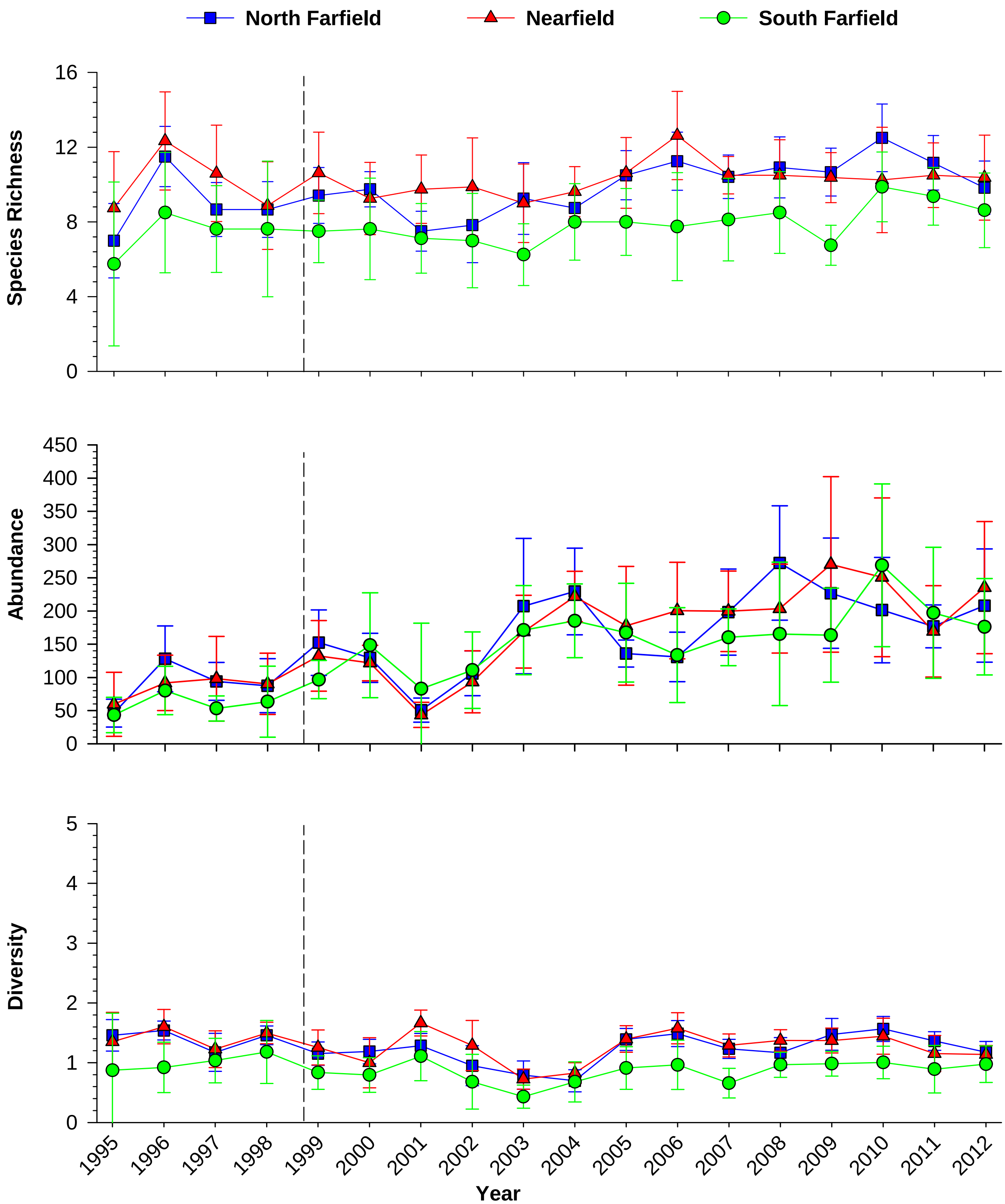

Figure 6.3

Species richness, abundance, and diversity of demersal fishes collected from SBOO trawl stations sampled between 1995 and 2012. Data are means with 95% confidence intervals for nearfield stations (SD17, SD18), north farfield stations (SD19, SD20, SD21), and south farfield stations (SD15, SD16). n=4 in 1995 (south farfield, nearfield); n=5 in 1997 (nearfield); n=6 in 1995 (north farfield); n=8 between 1996 and 2012 (south farfield, nearfield); n=12 between 1996 and 2012 (north farfield). Dashed lines indicate onset of wastewater discharge.

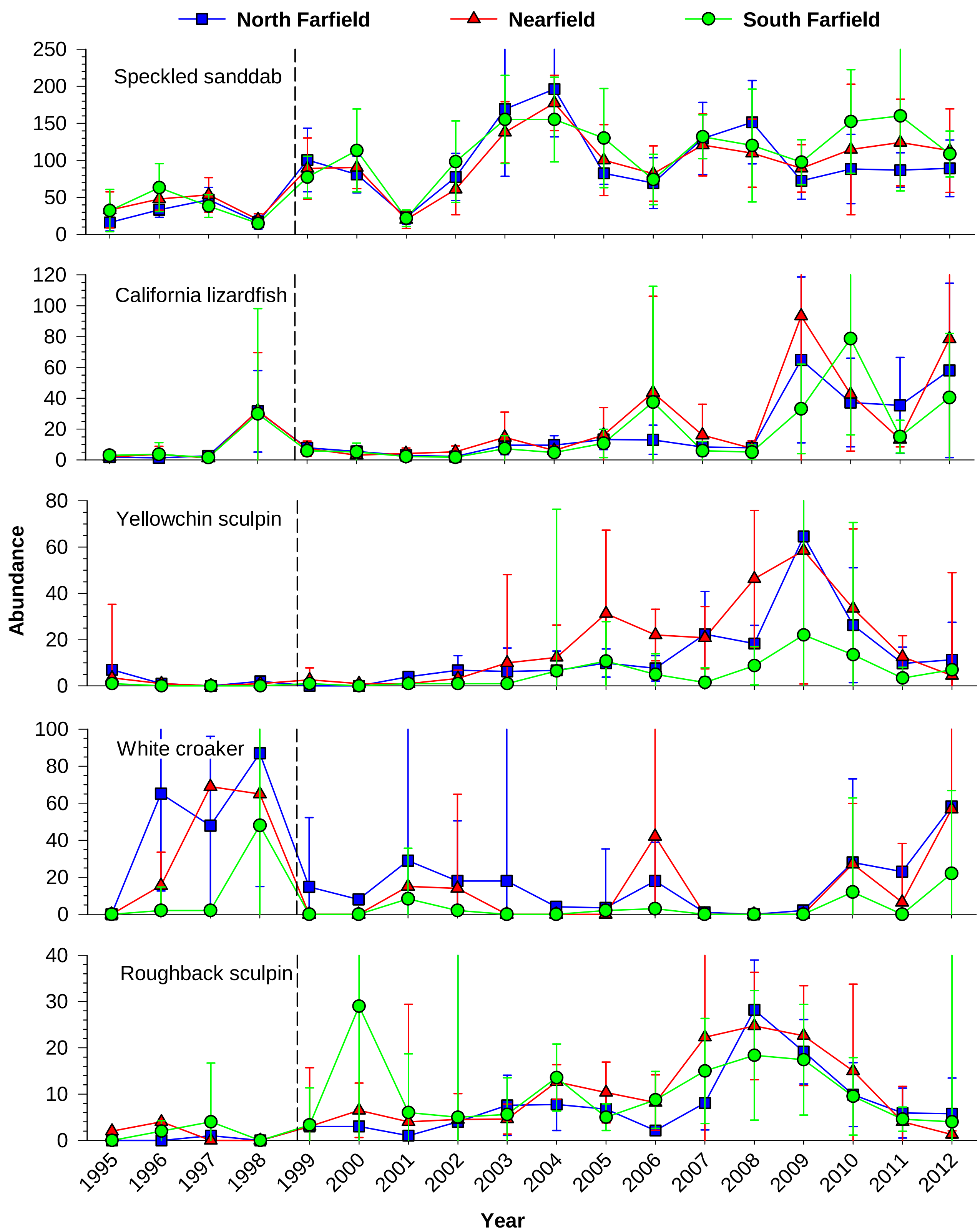

Figure 6.4

The ten most abundant fish species (presented in order) collected from SBOO trawl stations sampled between 1995 and 2012. Data are means with 95% confidence intervals for nearfield stations (SD1, SD18), north farfield stations (SD19, SD20, SD21), and south farfield stations (SD15, SD16). n = 4 in 1995 (south farfield, nearfield); n = 5 in 1997 (nearfield); n = 6 in 1995 (north farfield); n = 8 between 1996 and 2012 (south farfield, nearfield); n = 12 between 1996 and 2012 (north farfield). Dashed lines indicate onset of wastewater discharge.

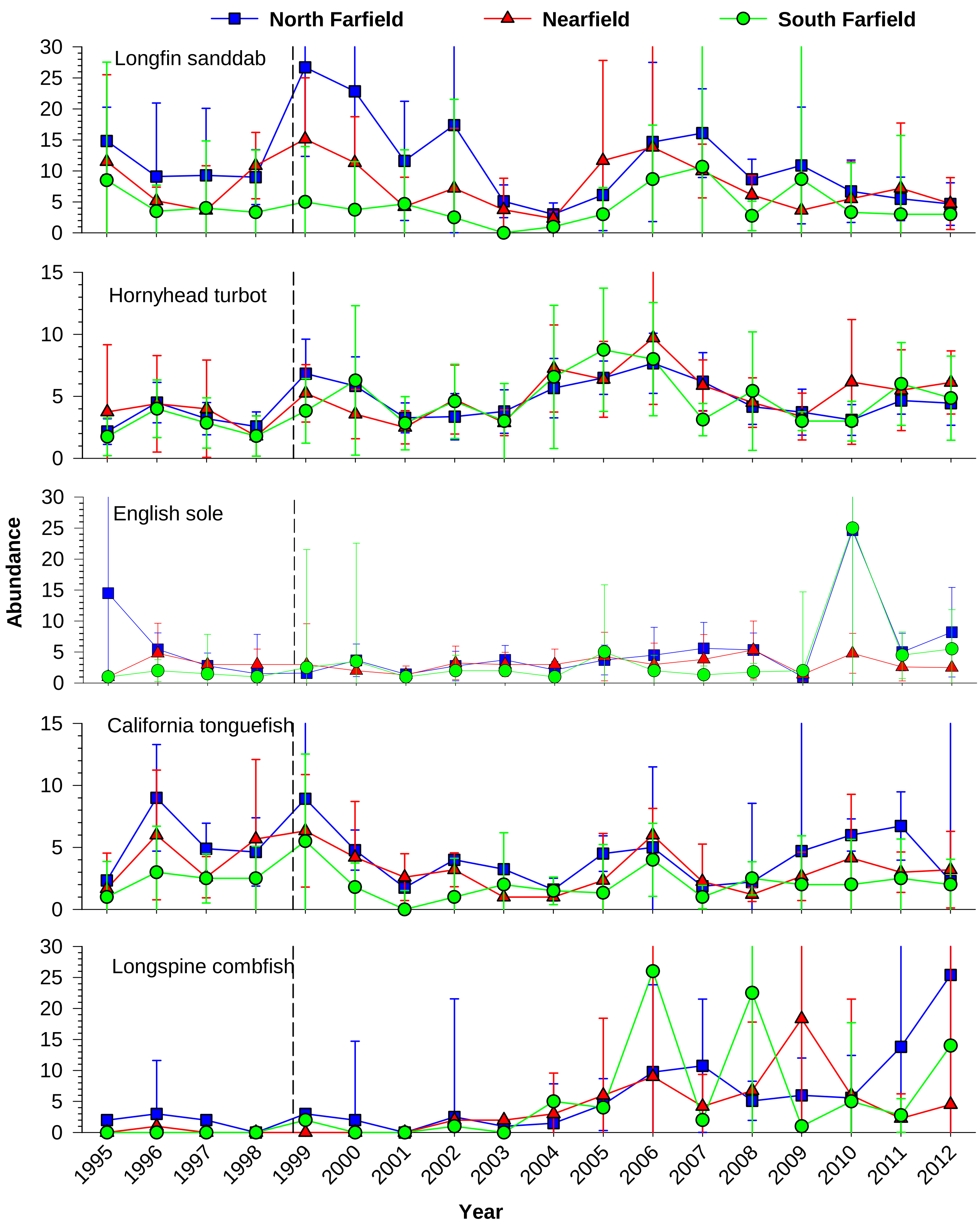

Figure 6.4 *continued*

Physical Abnormalities and Parasitism
Demersal fish populations appeared healthy in the SBOO region during 2012. There were no incidences of fin rot, discoloration, skin lesions, tumors, or any other indicators of disease among fishes collected during the year. Evidence of parasitism was also very low (<0.1%) for trawl-caught fishes in the

Table 6.3
Results of a two-way crossed ANOSIM (with replicates) for demersal fish assemblages sampled around the SBOO between 1995 and 2012. Data are limited to summer surveys.

Global Test: Factor A (station groups)	
Tests for differences between station groups (across all years)	
Sample statistic (Rho):	0.183
Significance level of sample statistic:	0.06%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Rho:	5
Global Test: Factor B (years)	
Tests for differences between years (across all station groups)	
Sample statistic (Rho):	0.535
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Rho:	0

region. Eight external parasites associated with their hosts were observed only during the October survey. These parasites included the copepod eye parasite *Phrixocephalus cincinnatus*, a leech (class Hirudinea), and the cymothoid isopod *Elthusa vulgaris*. Additionally, 58 *E. vulgaris* were identified as part of other trawl catches during the year (see Appendix E.5). Since cymothoids often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these isopods. 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 2134 megabenthic invertebrates (~76 per trawl) representing 52 taxa from 42 families were collected in 2012 (Table 6.5, Appendices E.5, E.6). Crustaceans and echinoderms dominated trawl taxa. For instance, the crangonid shrimp *Crangon nigromaculata* was the most abundant species (~23 individuals per haul), accounting for 30% of the total invertebrate abundance and occurring in 71% of the trawls. This was followed by the sea star *Astropecten californicus* (~20 individuals per haul) which accounted for 27% of the total invertebrate abundance and occurred in 93% of the trawls. Other species collected frequently (≥40% of the trawls) but with ≤8 individuals per haul included the crabs *Metacarcinus gracilis* and *Platymera gaudichaudii*, the parasitic cymothoid isopod *Elthusa vulgaris*, and the gastropod *Kelletia kelletii*. The occurrence of *Octopus bimaculatus* (Mollusca, Cephalopoda, Octopodidae) represents a new species record for the City's Ocean Monitoring Program.

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.6). Overall, species richness ranged from 3 to 14 species per trawl, while diversity (H') ranged from 0.2 to 2.3 and biomass ranged from 0.1 to 4.4 kg. Total abundance ranged from 12 to 357 individuals per trawl, with most stations having lower values during summer than other times of the year. Additionally, the two northernmost stations (i.e., SD20, SD21) had lower abundances than the more southerly stations. Generally, patterns in total invertebrate abundance at the SBOO trawl stations mirrored variation in populations of *Astropecten californicus*, the sand dollar *Dendraster terminalis*, and *Crangon nigromaculata* because of their dominance at select stations at different times of the year (Appendix E.6). For example, high numbers of invertebrates were reported at station SD15 during the winter and summer surveys primarily due to relatively large populations of *A. californicus* and *D. terminalis*, while *C. nigromaculata* dominated

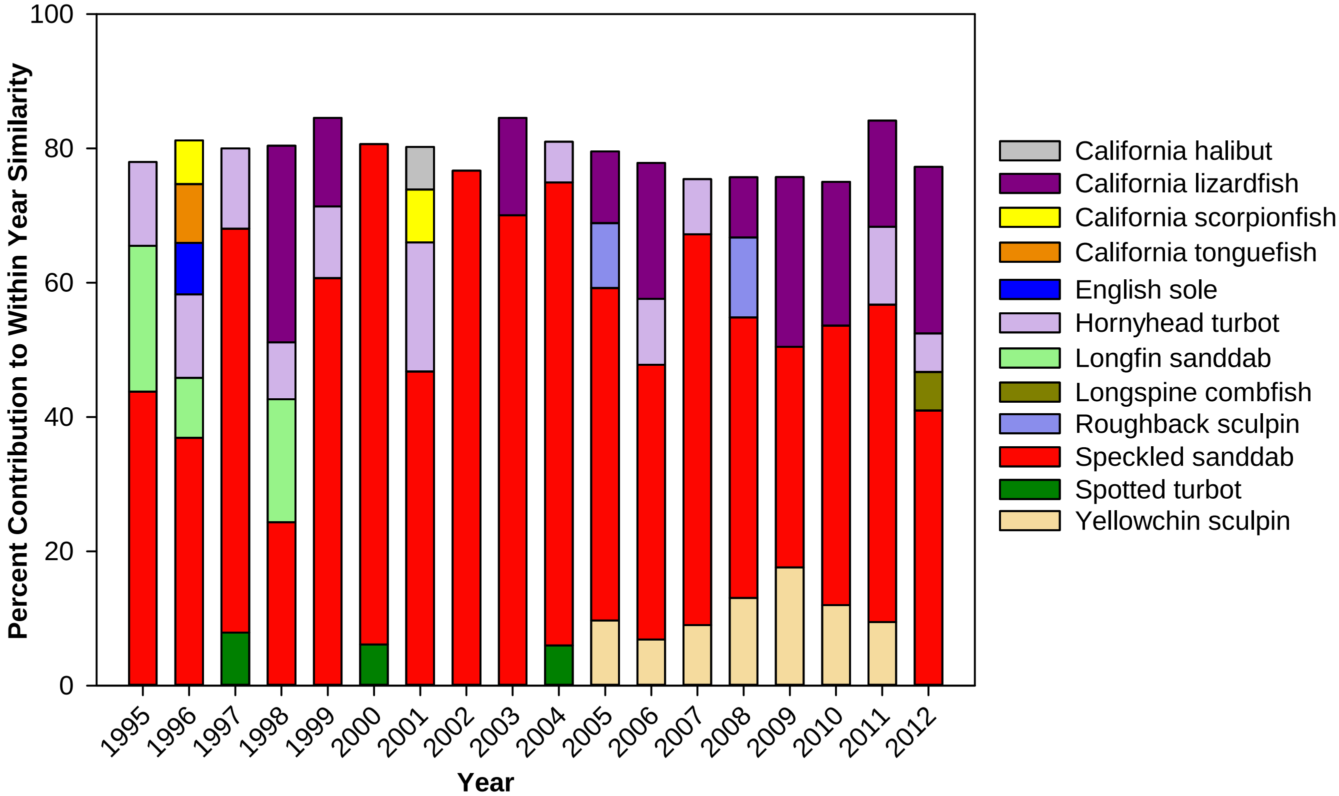

Figure 6.5
Percent contribution of individual species that cumulatively equal 75% similarity for each year group (Factor B, see Table 6.3) according to SIMPER analysis.

hauls at stations SD16 and SD17 in January and SD16–SD18 in April.

Over the years, changes in megabenthic invertebrate community structure in the South Bay outfall region generally reflect changes in species abundance, with no patterns related to wastewater discharge evident (Figures 6.7, 6.8). Average species richness and diversity have remained within narrow ranges (i.e., SR = 5–13 species, H' = 0.8–1.7 per station group, respectively). Conversely, average invertebrate abundance has varied considerably (i.e., 12–292 individuals per station group) over time, mostly in response to fluctuations in populations of a few dominant species. Examples of this include: (1) a decrease in *Astropecten californicus* in 1996; (2) a decrease in the urchin *Lytechinus pictus* in 1998; (3) an increase in *Dendraster terminalis* in 2012. Additionally, *A. californicus* and *D. terminalis* have typically been more abundant at the south farfield stations since 1995 than at the nearfield and north farfield stations.

Multivariate Analysis of Invertebrate Assemblages

Megabenthic invertebrate assemblages sampled from 1995 through 2012 (summer and winter surveys only) did not differ significantly by station group (i.e., nearfield versus north/south farfield) but did differ by season (Table 6.7). Population fluctuations of common species such as the sea star *Astropecten californicus* and the shrimp *Crangon nigromaculata* contributed substantially to seasonal differences (Figure 6.9).

Classification (cluster) analysis discriminated 10 types of invertebrate assemblages in the South Bay outfall region between 1995−2012 (i.e., cluster groups A–J; Figure 6.10). The distribution of trawl-caught invertebrate assemblages in 2012 were generally similar to those observed since 1995, with no discernible patterns associated with proximity to the outfall. Instead, most differences appear to be related to seasonal cycles or the unique

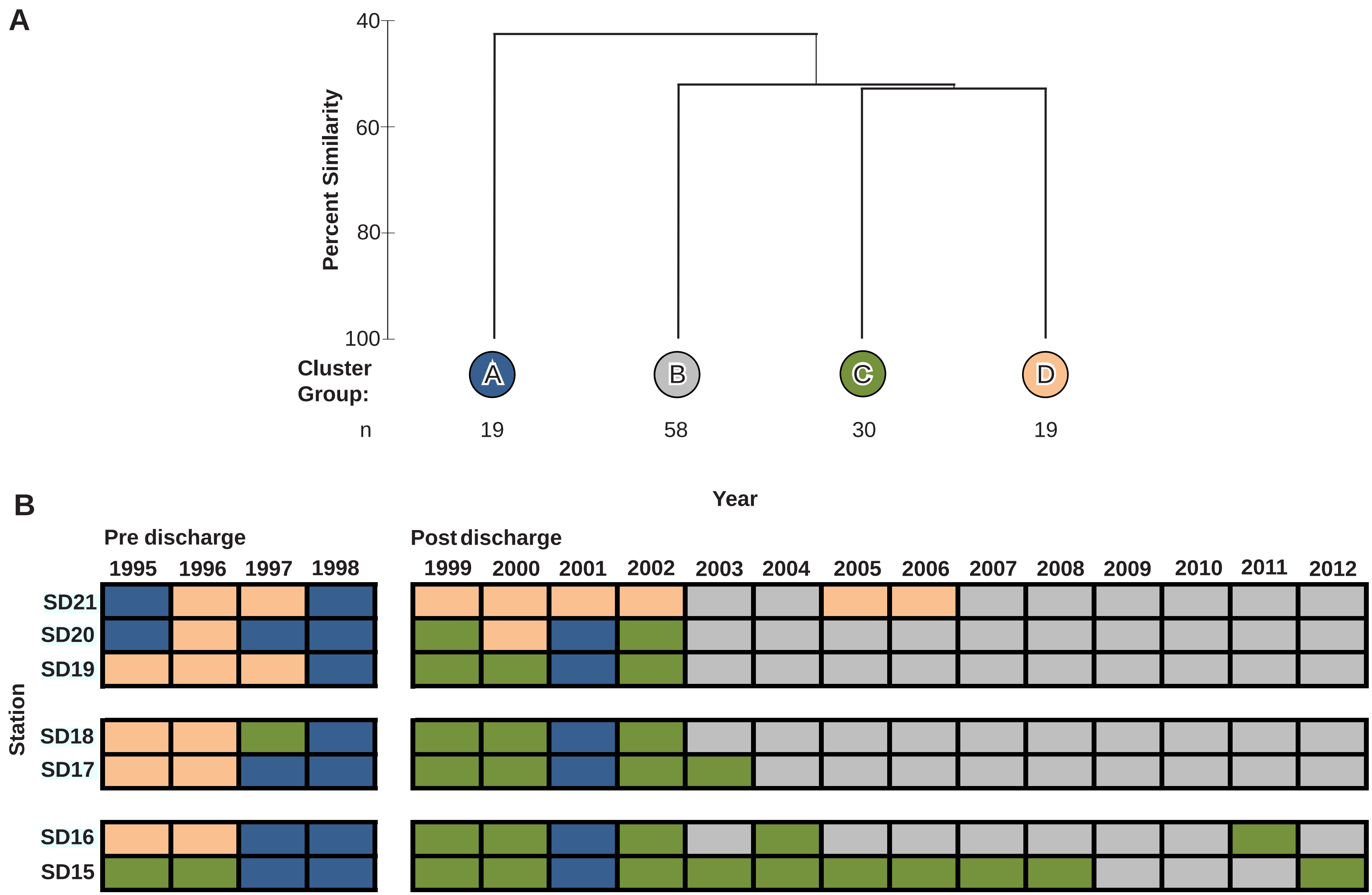

Figure 6.6
Results of cluster analysis of demersal fish assemblages from SBOO trawl stations between 1995 and 2012. Data are limited to summer surveys only and presented as (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time. Major ecologically relevant SIMPROF supported clades with <53% similarity were retained. n = number of hauls.

Table 6.4

Descriptive statistics of demersal fish cluster groups A–D defined in Figure 6.6. Species included represent the five most abundant taxa recorded for each cluster group. Bold values indicate species that were considered most characteristic of that group according to SIMPER analysis.

	Cluster Groups			
	A	B	C	D
Number of Hauls	19	58	30	19
Mean Species Richness	8	10	6	10
Mean Abundance	48	266	115	122
Taxa	**Mean taxon abundance**			
Speckled sanddab	**18**	**151**	**102**	**61**
California lizardfish	**11**	**50**	**3**	3
Longfin sanddab	**5**	7	<1	**28**
Hornyhead turbot	**3**	**4**	**4**	**6**
English sole	2	3	1	**3**
Spotted turbot	**2**	1	2	1
California tonguefish	1	2	1	**6**
California scorpionfish	1	1	1	1
Yellowchin sculpin	<1	**29**	<1	3
White croaker		<1		4
Roughback sculpin		**10**	<1	1

characteristics of a specific station location. For example, station SD15 located south of the outfall off northern Baja California almost always grouped into a single cluster. The composition and main characteristics of each cluster group are described below (see also Table 6.8).

Cluster groups A−H comprised one to nine hauls each. For these eight groups, mean species richness and abundance ranged from 6 to 14 species and 10 to 155 individuals per trawl. These assemblages typically differed from the two larger main assemblages (cluster groups I and J, described below) because of either (a) exceptionally high abundances of one or two uncommon species, or (b) exceptionally low abundance of otherwise common species. For example, the single trawl represented by group A contained 72 individuals of the brittle star *Ophiura luetkenii*, while this species was absent or present in low numbers in all other cluster groups. Similarly, group D averaged ~99 individuals of the shrimp *Crangon nigromaculata* and ~16 individuals of the crab *Portunus xantusii*, while group H averaged ~29 individuals of the opisthobranch *Philine auriformis*. Groups C and F were notable for either lacking or containing low abundances of common species such as the sea star *Astropecten californicus* and the urchin *Lytechinus pictus*.

Cluster group I comprised assemblages from 65% of the trawls from winter surveys conducted over the past 18 years, and may represent "typical" winter conditions for all stations in the South Bay outfall region except for SD15. Species richness averaged 7 taxa per haul, and total invertebrate abundance averaged 34 individuals per haul. Characteristic species included the shrimp *Crangon nigromaculata* and the sea stars *Astropecten californicus* and *Pisaster brevispinus*. Abundances of *C. nigromaculata* are known to peak during certain months of the year due to cyclical spawning events (Siegfried 1989), and it is hypothesized that the high abundances of this species in January may be linked to this natural cycle.

In contrast to group I above, cluster group J represented assemblages from 73% of the summer surveys conducted at stations SD16–SD21, as well

Table 6.5
Species of megabenthic invertebrates collected from 28 trawls conducted in the SBOO region during 2012. 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
Crangon nigromaculata	30	71	23	32	*Aphrodita armifera*	<1	4	<1	3
Astropecten californicus	27	93	20	22	*Flabellina iodinea*	<1	11	<1	1
Dendraster terminalis	14	11	10	97	*Randallia ornata*	<1	11	<1	1
Metacarcinus gracilis	10	79	8	10	*Strongylocentrotus franciscanus*	<1	11	<1	1
Elthusa vulgaris	3	68	2	3	*Euspira lewisii*	<1	4	<1	2
Crangon alba	2	11	1	13	*Halosydna latior*	<1	7	<1	1
Heterocrypta occidentalis	2	32	1	4	Hirudinea	<1	4	<1	2
Octopus rubescens	1	39	1	3	*Lamellaria diegoensis*	<1	7	<1	1
Kelletia kelletii	1	46	1	2	*Paguristes bakeri*	<1	7	<1	1
Ophiothrix spiculata	1	18	1	5	*Paguristes ulreyi*	<1	4	<1	2
Crossata californica	1	29	1	2	*Pleurobranchaea californica*	<1	7	<1	1
Hemisquilla californiensis	1	25	1	3	*Pteropurpura macroptera*	<1	4	<1	2
Acanthodoris brunnea	1	25	1	2	*Aphrodita refulgida*	<1	4	<1	1
Pisaster brevispinus	1	39	1	1	*Aphrodita* sp	<1	4	<1	1
Platymera gaudichaudii	1	46	1	1	Asteriidae	<1	4	<1	1
Lytechinus pictus	1	21	1	2	*Caesia perpinguis*	<1	4	<1	1
Loxorhynchus grandis	1	25	<1	2	*Calliostoma tricolor*	<1	4	<1	1
Pyromaia tuberculata	<1	25	<1	1	*Dendronotus iris*	<1	4	<1	1
Pagurus armatus	<1	11	<1	3	*Lepidozona scrobiculata*	<1	4	<1	1
Doryteuthis opalescens	<1	7	<1	4	*Luidia armata*	<1	4	<1	1
Heptacarpus stimpsoni	<1	7	<1	3	*Megastraea undosa*	<1	4	<1	1
Podochela hemphillii	<1	11	<1	2	*Octopus bimaculatus*	<1	4	<1	1
Heptacarpus palpator	<1	7	<1	2	*Ophiura luetkenii*	<1	4	<1	1
Luidia foliolata	<1	11	<1	1	*Pandalus danae*	<1	4	<1	1
Pagurus spilocarpus	<1	14	<1	1	*Sicyonia penicillata*	<1	4	<1	1
Philine auriformis	<1	7	<1	2	*Tritonia diomedea*	<1	4	<1	1

as 89% of the trawls conducted at station SD15 since monitoring began. This group averaged 7 taxa and 65 individuals per haul and was characterized by having the highest abundances of *Astropecten californicus* relative to the other cluster groups. Other characteristic species included *Pisaster brevispinus*, the crab *Heterocrypta occidentalis*, and *Lytechinus pictus*, although *L. pictus* has not been common in the South Bay outfall region since 1997.

Summary

Speckled sanddabs dominated fish assemblages surrounding the SBOO in 2012 as they have since monitoring began in 1995. This species occurred at all stations and accounted for 49% of the total catch. Other commonly captured, but less abundant species, included California lizardfish, hornyhead turbot, English sole, plainfin midshipman, and California tonguefish. The majority of these fishes tended to be relatively small with an average length <30 cm. Although the composition and structure of the fish assemblages varied among stations and surveys, these differences appear to be due to natural fluctuations of common species.

During 2012, assemblages of trawl-caught invertebrates were dominated by the shrimp *Crangon nigromaculata* during winter and the sea

Table 6.6

Summary of megabenthic invertebrate community parameters for SBOO stations sampled during 2012. Data are included for species richness, abundance, and diversity (H') and biomass (kg, wet weight). SD = standard deviation.

Station	Win	Spr	Sum	Fall	Annual Mean	Annual SD	Station	Win	Spr	Sum	Fall	Annual Mean	Annual SD
Species richness							*Abundance*						
SD15	10	9	5	8	8	2	SD15	357	48	83	180	167	138
SD16	12	7	7	11	9	3	SD16	141	237	34	84	124	87
SD17	11	4	11	11	9	4	SD17	107	83	26	34	62	39
SD18	9	14	12	12	12	2	SD18	47	76	47	36	52	17
SD19	13	10	11	12	12	1	SD19	67	113	31	31	60	39
SD20	11	7	3	9	8	3	SD20	46	48	14	25	33	17
SD21	9	5	6	5	6	2	SD21	92	21	14	12	35	38
Survey Mean	11	8	8	10			Survey Mean	122	89	36	57		
Survey SD	1	3	3	3			Survey SD	109	71	24	59		
Diversity							*Biomass*						
SD15	1.0	1.7	0.4	1.0	1.0	0.5	SD15	1.8	0.6	1.1	1.4	1.2	0.5
SD16	1.7	0.3	1.0	1.8	1.2	0.7	SD16	2.8	0.6	0.8	4.2	2.1	1.7
SD17	1.5	0.2	2.3	2.0	1.5	0.9	SD17	3.2	0.3	0.8	1.5	1.4	1.3
SD18	1.9	1.5	1.8	2.1	1.8	0.2	SD18	1.2	1.3	0.6	1.8	1.2	0.5
SD19	1.7	1.5	1.8	2.2	1.8	0.3	SD19	2.8	0.5	0.5	4.4	2.0	1.9
SD20	2.1	1.3	0.7	1.9	1.5	0.6	SD20	3.0	1.6	0.1	2.7	1.8	1.3
SD21	1.3	1.3	1.7	1.5	1.4	0.2	SD21	2.0	0.5	2.6	1.1	1.6	0.9
Survey Mean	1.6	1.1	1.4	1.8			Survey Mean	2.4	0.8	0.9	2.4		
Survey SD	0.4	0.6	0.7	0.4			Survey SD	0.7	0.5	0.8	1.4		

star *Astropecten californicus* during summer. These two species occurred in 71% and 93% of trawls, respectively, and accounted for 30% and 27% of the total invertebrate abundance. Other megabenthic invertebrates collected frequently included the crabs *Metacarcinus gracilis* and *Platymera gaudichaudii*, the cymothoid isopod *Elthusa vulgaris*, and the gastropod *Kelletia kelletii*. As with demersal fishes in the region, the composition and structure of the trawl-caught invertebrate assemblages varied among stations and surveys, generally reflecting population fluctuations in the species mentioned above. However, at least seasonal differences appear related, in part, to normal spawning cycles of *C. nigromaculata* (Siegfried 1989).

Overall, no evidence exists that wastewater discharged through the SBOO has affected either demersal fish or megabenthic invertebrate communities in 2012. Although highly variable, patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away, with no discernible changes in the region following the onset of wastewater discharge through the SBOO in January 1999. Instead, the high variability in fish and invertebrate assemblages during the year was similar to that observed in previous years (City of San Diego 2006–2012), including prior to outfall operation (City of San Diego 2000). In addition, low species richness and abundances of fish and invertebrates are consistent with what is expected for the relatively shallow, sandy habitats in which the SBOO trawl stations are located (Allen 2005, Allen et al. 1998, 2002, 2007, 2011). Changes in these communities appear to be more likely due to natural factors such as changes in ocean water temperatures associated with large-scale oceanographic events (e.g., El Niño), to the mobile nature of many of the resident species collected, or in the case of invertebrates, seasonality. Finally, the absence of disease or other physical abnormalities

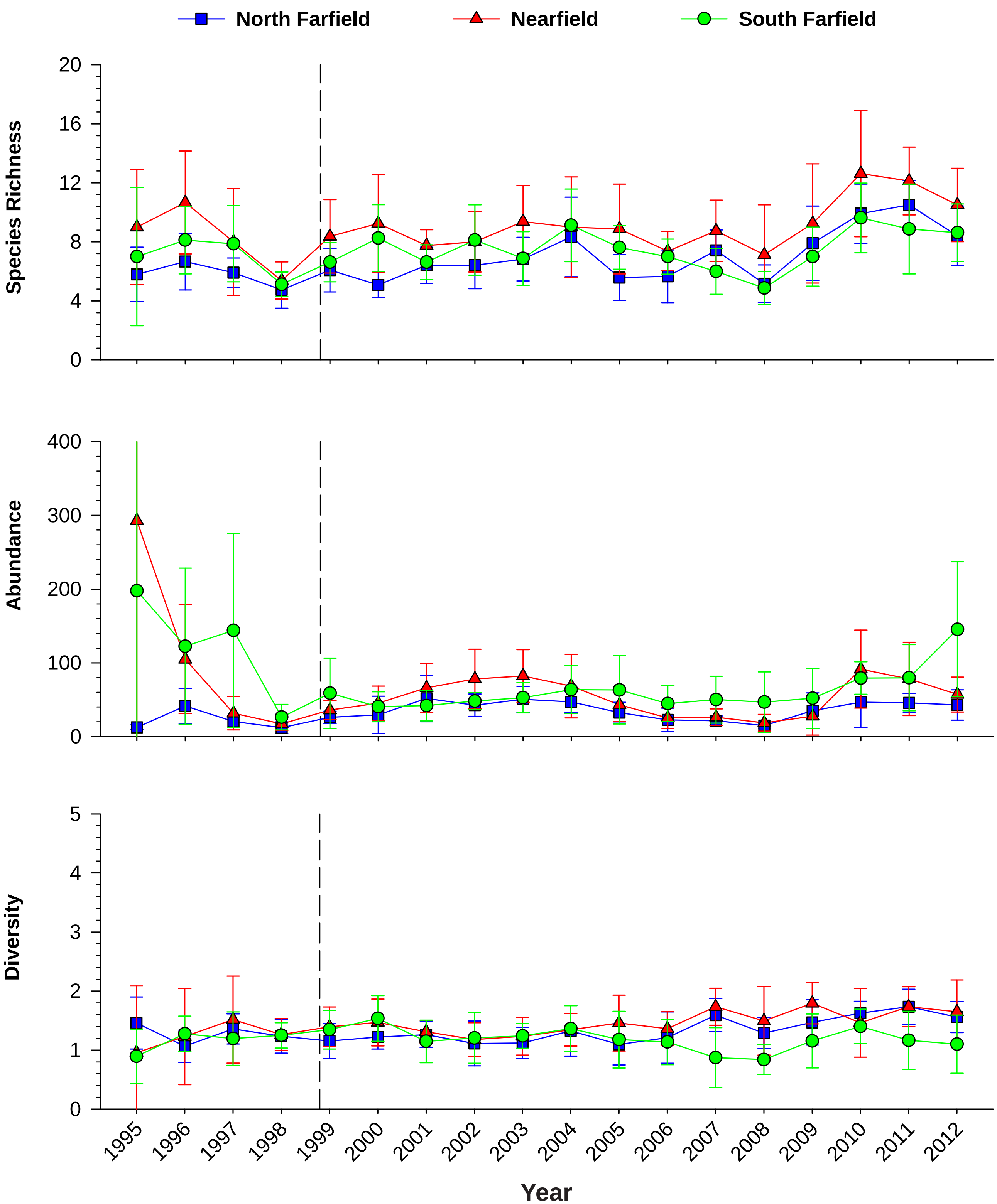

Figure 6.7
Species richness, abundance, and diversity of megabenthic invertebrates collected from SBOO trawl stations sampled between 1995 and 2012. Data are means with 95% confidence intervals for nearfield stations (SD17, SD18), north farfield stations (SD19, SD20, SD21), and south farfield stations (SD15, SD16). n=4 in 1995 (south farfield, nearfield); n=5 in 1997 (nearfield); n=6 in 1995 (north farfield); n=8 between 1996 and 2012 (south farfield and nearfield); n=12 between 1996 and 2012 (farfield stations). Dashed lines indicate onset of wastewater discharge.

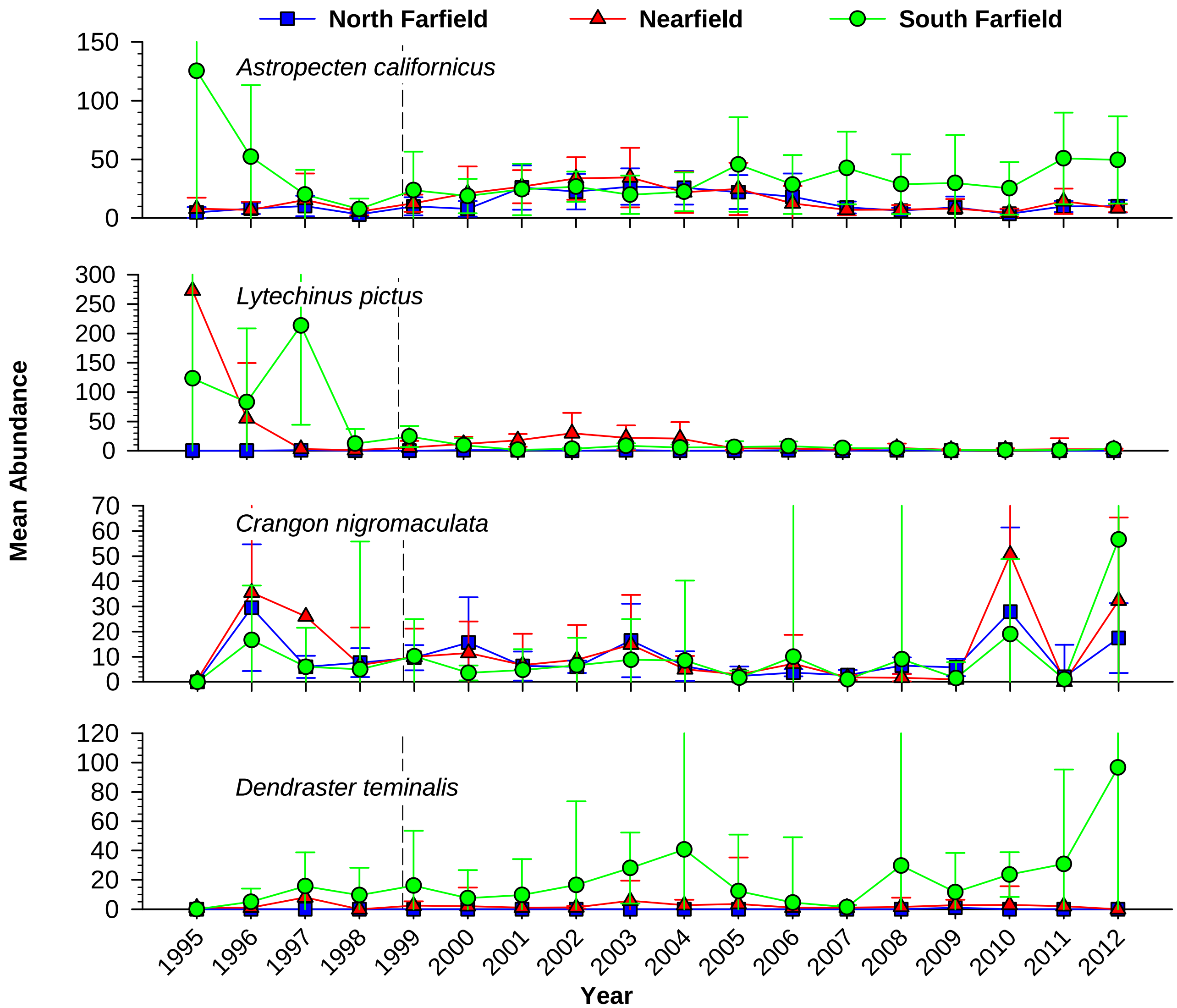

Figure 6.8
The seven most abundant megabenthic invertebrate species (presented in order) collected from SBOO trawl stations sampled between 1995 and 2012. Data are means with 95% confidence intervals for nearfield stations (SD17, SD18), north farfield stations (SD19, SD20, SD21), and south farfield stations (SD15, SD16). n = 4 in 1995 (south farfield, nearfield); n = 5 in 1997 (nearfield); n = 6 in 1995 (north farfield); n = 8 between 1996 and 2012 (south farfield, nearfield); n = 12 between 1996 and 2012 (north farfield). Dashed lines indicate onset of wastewater discharge.

in local fishes suggests that populations in the region continue to be healthy.

Literature Cited

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

Allen, M.J. (2005). The check list of trawl-caught fishes for Southern California from depths of 2–1000 m. Southern California Coastal Water Research Project, Westminster, CA.

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

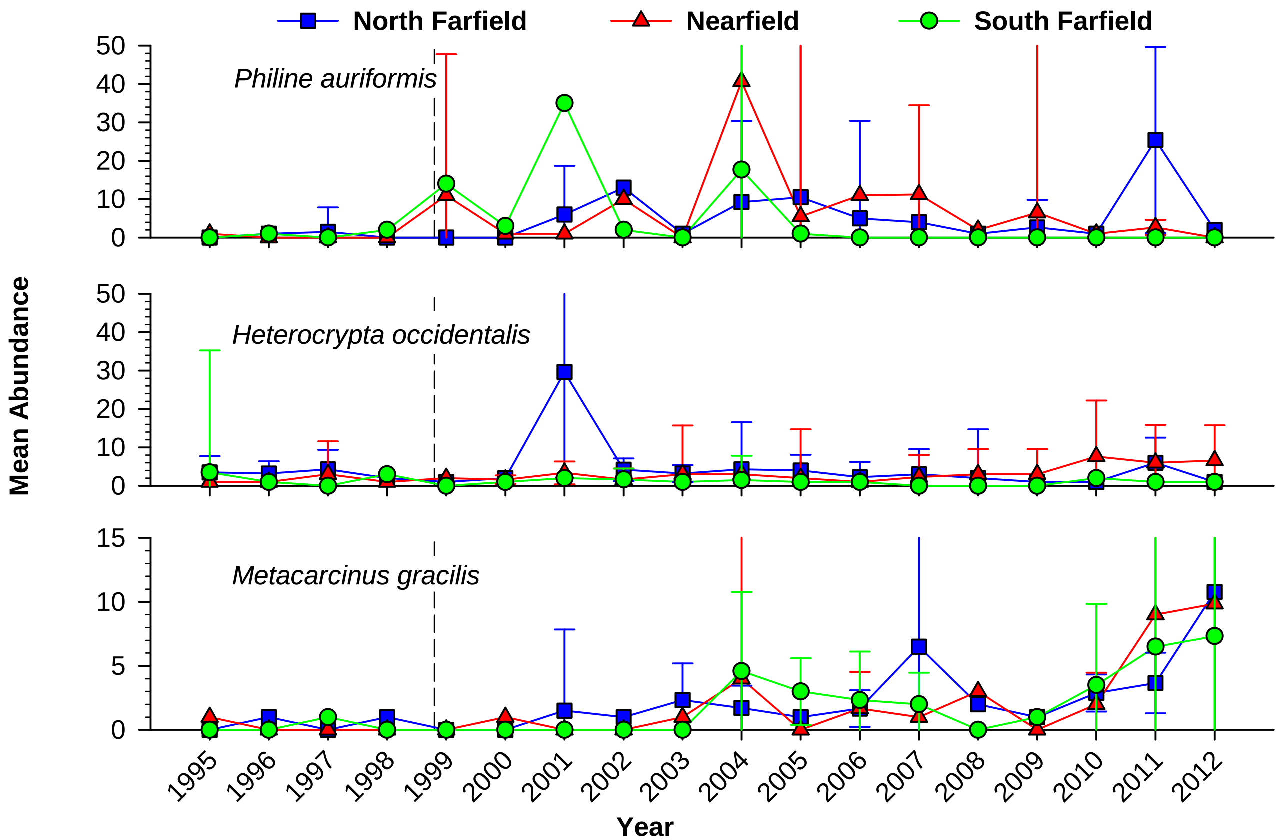

Figure 6.8 *continued*

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

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

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

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

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

City of San Diego. (1997). International Wastewater Treatment Plant Baseline Ocean

Table 6.7

Results of a two-way crossed ANOSIM (with replicates) for megabenthic invertebrates assemblages sampled around the SBOO between 1995 and 2012. Data are limited to winter and summer surveys.

Global Test: Factor A (station groups)	
Tests for differences between station groups (across all seasons)	
Sample statistic (Rho):	0.141
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Rho:	0
Global Test: Factor B (seasons)	
Tests for differences between seasons (across all station groups)	
Sample statistic (Rho):	0.317
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Rho:	0

Monitoring Report. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

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

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

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

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

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

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

City of San Diego. (2011). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2010. City of San Diego Ocean Monitoring Program, Public Utilities

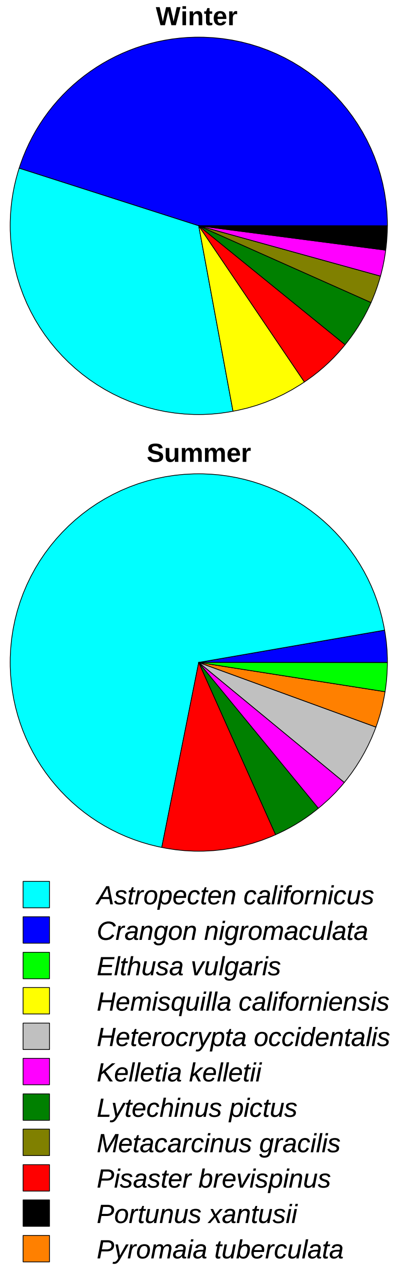

Figure 6.9
Percent contribution of individual species that cumulatively equal 90% similarity for each season (Factor B, see Table 6.7) according to SIMPER analysis.

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

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

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

Clarke, K.R. and R.N. Gorley. (2006). Primer v6: User Manual/Tutorial. PRIMER-E: Plymouth, England.

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

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

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

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

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

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

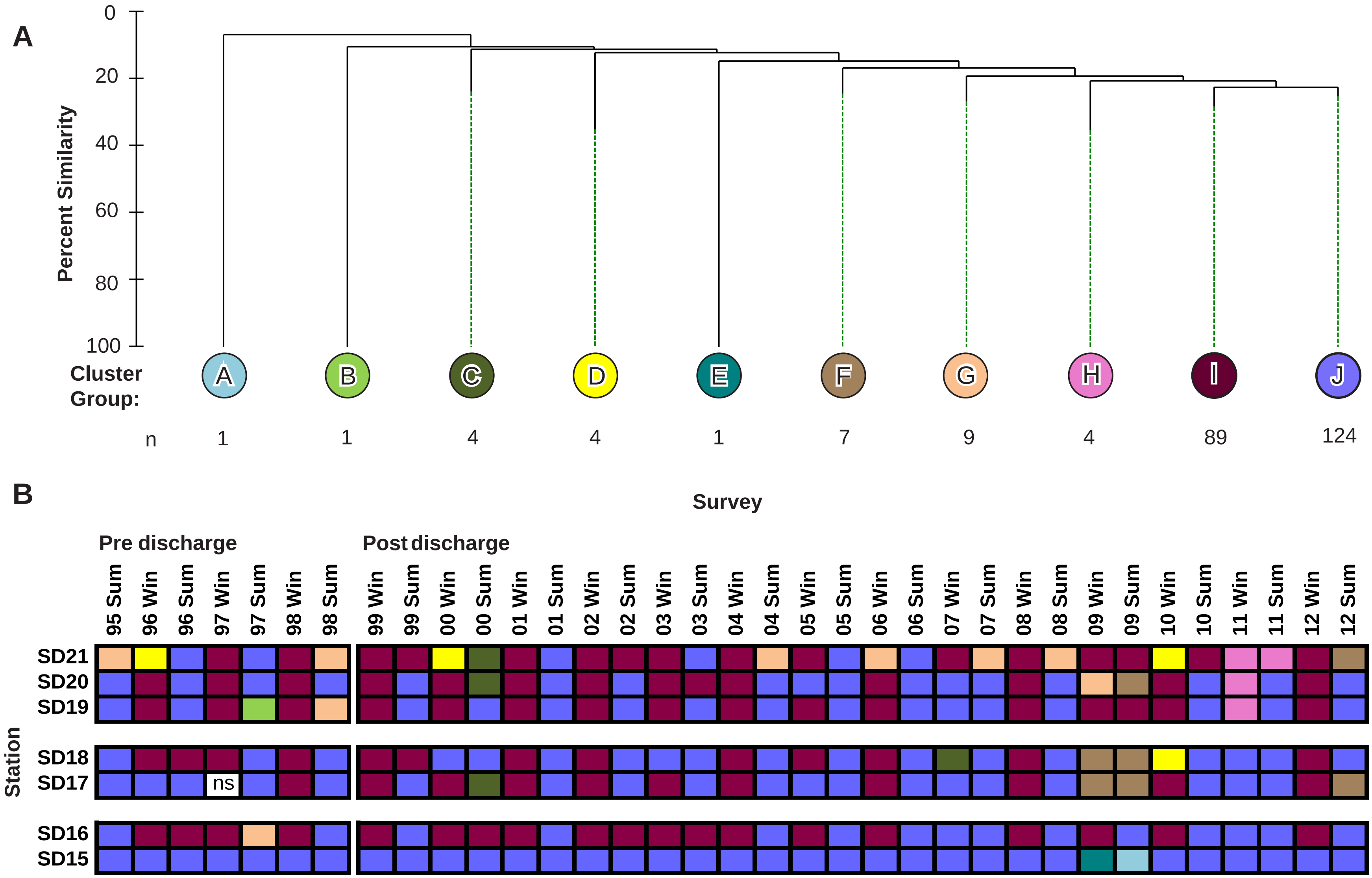

Figure 6.10
Results of cluster analysis of megabenthic invertebrate assemblages from SBOO trawl stations between 1995 and 2012. Data are limited to summer and winter surveys only and are presented as (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time. Major ecologically relevant SIMPROF supported clades with <23% similarity were retained. n = number of hauls; ns = not sampled.

Table 6.8

Descriptive statistics of megabenthic invertebrate cluster groups A–J defined in Figure 6.10. Species included represent the five most abundant taxa recorded for each cluster group. Bold values indicate species that were considered most characteristic of that group according to SIMPER analysis.

	Cluster Group									
	A[a]	B[a]	C	D	E[a]	F	G	H	I	J
Number of Hauls	1	1	4	4	1	7	9	4	89	124
Mean Species Richness	8	6	6	14	12	7	8	11	7	7
Mean Abundance	84	10	10	155	46	12	15	61	34	65
Taxa	**Mean taxon abundance**									
Ophiura luetkenii	72							<1	<1	<1
Ophiothrix spiculata	3			**6**	1		**3**	1	1	1
Dendraster terminalis	3				1				<1	4
Crangon alba	2								<1	1
Pyromaia tuberculata	1		1	1		**1**	**1**	1	<1	1
Pagurus spilocarpus	1		<1						<1	<1
Octopus rubescens	1			<1		1	**1**	1	<1	<1
Megastraea turbanica	1								<1	<1
Astropecten ornatissimus		4							<1	<1
Pisaster brevispinus		2		<1			**2**	<1	**1**	**1**
Heterocrypta occidentalis		1	<1	<1		<1	<1		<1	**2**
Heptacarpus stimpsoni		1		8	17			3	<1	<1
Flabellina iodinea		1		<1					<1	<1
Luidia armata		1							<1	<1
Farfantepenaeus californiensis			1	1					<1	<1
Hirudinea			**1**						<1	<1
Crangon nigromaculata			**1**	**99**				1	**14**	1
Lytechinus pictus			**1**	1		**1**	<1		1	**19**
Elthusa vulgaris			1			**1**		2	1	1
Heptacarpus palpator			<1		2		1	1	1	<1
Portunus xantusii				**16**					1	<1
Neocrangon zacae				6						<1
Metacarcinus gracilis				1		1	<1	**2**	2	<1
Pandalus danae				<1	5		<1		<1	<1
Heptacarpus fuscimaculatus					8					
Astropecten californicus					7	**1**	**2**	**11**	**6**	**26**
Acanthodoris brunnea						**2**		**2**	<1	<1
Platymera gaudichaudii						1			<1	<1
Philine auriformis							<1	**29**	<1	1

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

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

[SCAMIT] Southern California Association of Marine Invertebrate Taxonomists. (2012). A taxonomic listing of benthic macro- and megainvertebrates from infaunal and epibenthic monitoring programs in the

Southern California Bight, edition 7. Southern California Associations of Marine Invertebrate Taxonomists, Natural History Museum of Los Angeles County Research and Collections, Los Angeles, CA.

Siegfried, C.A. (1989). Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) – crangonid shrimp. U.S. Fish and Wildlife Service Biological Report 82(11.125). U.S. Army Corps of Engineers, TR EL-82-4.

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

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

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

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

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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 collected by trawling activities (see Chapter 6) are considered representative of the general demersal fish community off San Diego, and specific species are targeted based on their prevalence and ecological significance. 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 2012. The primary goals are to: (1) document levels of contaminant loading in local demersal fishes, (2) identify whether any contaminant bioaccumulation in fishes collected around the SBOO may be due to the outfall discharge, and (3) identify other potential natural and anthropogenic sources of pollutants to the local marine ecosystem.

Materials and Methods

Field Collection

Fishes were collected during April and October of 2012 at seven otter trawl and two rig fishing stations (Figure 7.1, Table 7.1). Four species of flatfishes were targeted for collection at the trawl stations for analysis of liver tissues, including English sole (*Parophrys vetulus*), hornyhead turbot (*Pleuronichthys verticalis*), longfin sanddab (*Citharichthys xanthostigma*), and Pacific sanddab (*Citharichthys sordidus*). In contrast, five species of roundfishes were targeted for collection at the two

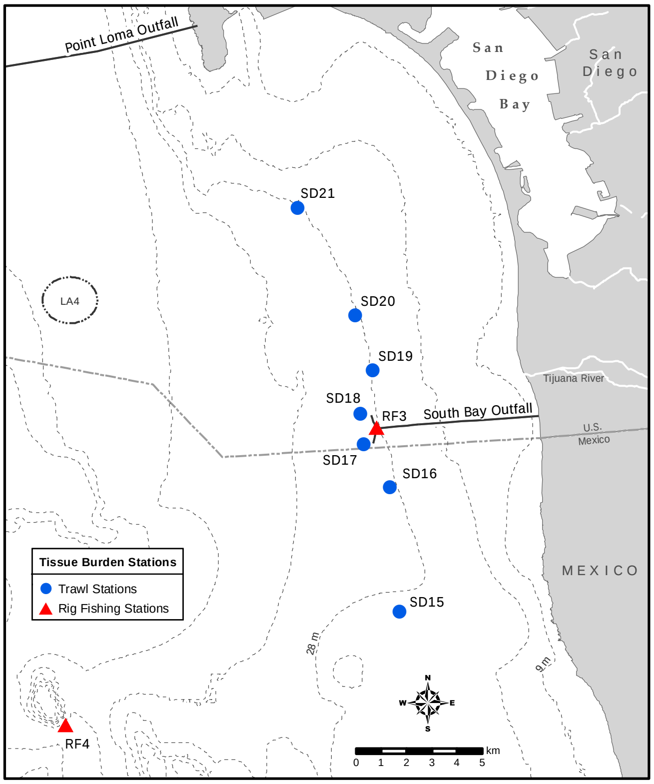

Figure 7.1
Otter trawl and rig fishing station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

rig fishing stations for the analysis of muscle tissues. These species included the bocaccio (*Sebastes paucispinis*), brown rockfish (*Sebastes auriculatus*), rosy rockfish (*Sebastes rosaceus*), vermilion rockfish (*Sebastes miniatus*), and California scorpionfish (*Scorpaena guttata*). All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for collection methods). Efforts to collect target species at the trawl stations were limited to five 10-minute (bottom time) trawls per site. Fishes collected at the two rig fishing stations were caught within 1 km of the nominal station coordinates using standard rod and reel procedures; fishing effort was limited to 5 hours at each station. Occasionally, insufficient numbers of the target species were obtained despite this effort, which resulted in a reduced number of composite samples at a particular station, or inadequate amounts of tissue to complete the full suite of chemical analyses.

Only fishes with a standard length ≥13 cm were retained in order to facilitate collection of sufficient tissue for chemical 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 -80°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 Wastewater Chemistry Services Laboratory within 10 days of dissection.

Chemical constituents were measured on a wet weight basis, and included 18 trace metals, 10 chlorinated pesticides (e.g., DDT), 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs) (see Appendix F.2). Data were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemical Services Laboratory (City of San Diego 2013a).

Data Analyses

Data summaries for each contaminant include detection rates, minimum, maximum, and mean detected values of each parameter by species. Total

Table 7.1

Species of fish collected from each SBOO trawl and rig fishing station during April and October 2012.

Survey	Station	Composite 1	Composite 2	Composite 3
April 2012	RF3	Mixed rockfish[d]	Brown rockfish	Vermilion rockfish
	RF4	California scorpionfish[a]	California scorpionfish	California scorpionfish
	SD15	No sample[c]	No sample[c]	No sample[c]
	SD16	English sole	Hornyhead turbot	No sample[c]
	SD17	English sole	Hornyhead turbot	No sample[c]
	SD18	English sole	Hornyhead turbot	Hornyhead turbot
	SD19	Hornyhead turbot	English sole	Hornyhead turbot
	SD20	Hornyhead turbot	English sole	English sole
	SD21	Hornyhead turbot	English sole	Hornyhead turbot
October 2012	RF3	Vermilion rockfish[b e]	Vermilion rockfish[b e]	Vermilion rockfish[b e]
	RF4	California scorpionfish[b e]	California scorpionfish[a b e]	California scorpionfish[b e]
	SD15	Pacific sanddab[b e]	Pacific sanddab[b e]	Pacific sanddab[b e]
	SD16	Longfin sanddab[b e]	Hornyhead turbot[b e]	Hornyhead turbot[b e]
	SD17	Longfin sanddab[b e]	Hornyhead turbot[b e]	Hornyhead turbot[b e]
	SD18	Longfin sanddab[b e]	Longfin sanddab[b e]	Longfin sanddab[b e]
	SD19	Longfin sanddab[a b e]	Hornyhead turbot[b e]	Hornyhead turbot[b e]
	SD20	Longfin sanddab[b e]	Longfin sanddab[b e]	Hornyhead turbot[b e]
	SD21	Hornyhead turbot[b e]	Hornyhead turbot[b e]	Longfin sanddab[a]

[a] No PAHs analyzed for these samples; [b] No mercury analyzed for these samples; [c] Insufficient fish collected (see text); [d] Includes rosy rockfish, bocaccio, and brown rockfish; [e] No toxaphene analyzed for these samples

DDT (tDDT), total hexachlorocyclohexane (tHCH), total chlordane (tChlor), 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 wye or diffuser legs (SD17, SD18, RF3) to those from "farfield" stations located farther 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 (1995–1999). 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 collected in 2012 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 and Discussion

Contaminants in Trawl-Caught Fishes

Trace Metals

Ten trace metals occurred in 100% of the liver tissue samples from trawl-caught fishes collected in the South Bay outfall region during 2012. These included arsenic, cadmium, chromium, copper, iron, manganese, mercury, selenium, tin, and zinc (Table 7.2). Aluminum, barium, lead, nickel, silver, and thallium were also detected but at rates between 8 and 86%. In contrast, antimony and beryllium were not detected in any liver samples collected during the year. Several metals were found at levels higher than pre-discharge values (Figure 7.2). These included aluminum, arsenic, cadmium, copper, manganese, mercury and selenium which exceeded pre-discharge values in 6–51% of the samples. However, intra-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. For example, most of the relatively high concentrations occurred in various species collected throughout the region (i.e., not just at the "nearfield" stations).

Pesticides

Seven chlorinated pesticides were detected in fish liver tissues during 2012 (Table 7.3). DDT was found in every tissue sample with tDDT concentrations ranging from 22 to 676 ppb. Hexachlorobenzene (HCB) also occurred frequently at a rate of 86%, while tHCH, tChlor, dieldrin, endrin, and mirex had low occurrence rates ≤5%. Concentrations of these pesticides tended to be much lower than tDDT. For example, HCB was found at levels ≤3.1 ppb, endrin at ≤26 ppb, tChlor at 12.1 ppb, dieldrin at 8.3 ppb, mirex at 2.0 ppb, and tHCH at 1.2 ppb. The DDT metabolite p,p-DDE was found in 100% of the samples, whereas o,p-DDE, o,p-DDD, p,p-DDD, p,p-DDMU, and p,p-DDT were detected in at least 14% of the tissue samples (Appendix F.3). The only chlordane constituents reported during the year were alpha (cis) chlordane and trans-nonachlor, while tHCH consisted solely of the delta isomer.

All tDDT concentrations measured during 2012 were below the maximum levels detected prior to wastewater discharge (Figure 7.3). This comparison could not be made for HCB since it was not detected prior to discharge. Although the highest values of both tDDT and HCB in 2012 occurred in one of three longfin sanddab samples from station SD18, these pesticides were present in samples from all stations at variable concentrations. The single occurrence of chlordane during the past year was also from station SD18, whereas HCH and mirex were found in samples from station SD17, and dieldrin and endrin were found in samples from station SD16 (data not shown).

PAHs and PCBs

PAHs were not detected in any liver tissue samples during 2012. In contrast, PCBs occurred in every sample (Table 7.3). Total PCB concentrations were highly variable, ranging from 6 to 543 ppb. PCB 153/168 occurred in all samples, while 14 other PCB congeners were detected 54–95% of the time (Appendix F.3). Almost all PCB concentrations were less than pre-discharge values (Figure 7.3). The only exception was a single Pacific sanddab sample from station SD15, which exceeded the pre-discharge value of 38 ppb. Overall, tPCB occurred at variable concentrations in samples from all stations. However, similar to the results for tDDT and HCB, the highest value of tPCB occurred in one of three longfin sanddab samples from station SD18.

Contaminants in Fishes Collected by Rig Fishing

Only five trace metals occurred in all fish muscle tissue samples collected at stations RF3 and RF4 in 2012, including arsenic, chromium, mercury, selenium, and zinc (Table 7.4). Aluminum, barium, copper, iron, manganese, thallium and tin were also detected, but at lower rates between 8 and 58%. In contrast, antimony, beryllium, cadmium, lead, nickel and silver were not detected in any samples. Intra-species comparisons between nearfield station RF3 and farfield station RF4 could not be made, however metal concentrations appeared similar in tissue samples collected from fish at the two rig fishing stations (Figure 7.4). Additionally, only two metals were found at levels higher than those recorded during the pre-discharge period. Specifically, arsenic exceeded pre-discharge levels in two California scorpionfish samples collected from station RF4, while zinc exceeded pre-discharge levels in a single mixed rockfish sample from station RF3.

Table 7.2

Summary of metals in liver tissues of fishes collected from SBOO trawl stations during 2012. 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. 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[b]	Ni	Se	Ag	Tl	Sn	Zn
English sole																		
n (out of 7)	0	0	7	1	0	7	7	7	7	7	7	7	2	7	6	7	7	7
Min	—	—	11.4	nd	—	0.68	0.20	2.0	108.0	0.24	1.6	0.047	nd	0.59	nd	0.64	0.343	26.1
Max	—	—	24.5	0.031	—	1.67	0.41	12.7	275.0	1.18	2.1	0.119	0.230	1.29	0.135	1.18	0.663	39.1
Mean	—	—	17.0	0.031	—	1.29	0.30	6.4	196.9	0.53	1.9	0.075	0.227	0.84	0.099	0.91	0.472	32.3
Hornyhead turbot																		
n (out of 18)	9	0	18	1	0	18	18	18	18	3	18	9	2	18	17	13	18	18
Min	nd	—	2.2	nd	—	1.67	0.19	4.8	24.0	nd	1.0	0.069	nd	0.34	nd	nd	0.321	33.7
Max	21.0	—	7.6	0.050	—	7.06	0.33	15.0	70.1	0.23	2.1	0.109	0.216	1.39	0.248	0.97	0.600	90.5
Mean	15.4	—	4.7	0.050	—	3.45	0.27	8.0	44.4	0.21	1.3	0.088	0.208	0.67	0.143	0.67	0.500	52.3
Longfin sanddab																		
n (out of 9)	9	0	9	1	0	9	9	9	9	4	9	na	0	9	6	9	9	9
Min	30.0	—	4.2	nd	—	0.82	0.20	5.3	33.0	nd	0.8	na	—	0.3	nd	0.60	0.600	22
Max	49.0	—	7.5	0.150	—	8.61	0.40	9.9	93.0	0.40	1.8	na	—	1.18	0.160	1.70	1.300	31.2
Mean	37.3	—	5.8	0.150	—	2.98	0.30	7.0	58.8	0.40	1.2	na	—	0.56	0.125	0.91	0.922	26.0
Pacific sanddab																		
n (out of 3)	3	0	3	0	0	3	3	3	3	0	3	na	0	3	1	3	3	3
Min	12.0	—	2.9	—	—	6.99	0.30	5.9	53.0	—	1.6	na	—	1.06	nd	0.50	0.400	31.6
Max	20.0	—	6.8	—	—	17.00	0.40	6.4	72.0	—	2.2	na	—	1.39	0.070	0.70	0.600	42.2
Mean	16.3	—	5.4	—	—	10.39	0.33	6.2	59.7	—	1.9	na	—	1.25	0.070	0.60	0.500	36.4
All species																		
Detection rate (%)	57	0	100	8	0	100	100	100	100	38	100	100	11	100	81	86	100	100
Max	49.0	—	24.5	0.150	—	17.00	0.41	15.0	275	1.18	2.2	0.119	0.230	1.39	0.250	1.70	1.3	90.5

na = not available; nd = not detected

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

[b] No mercury analyzed from October samples.

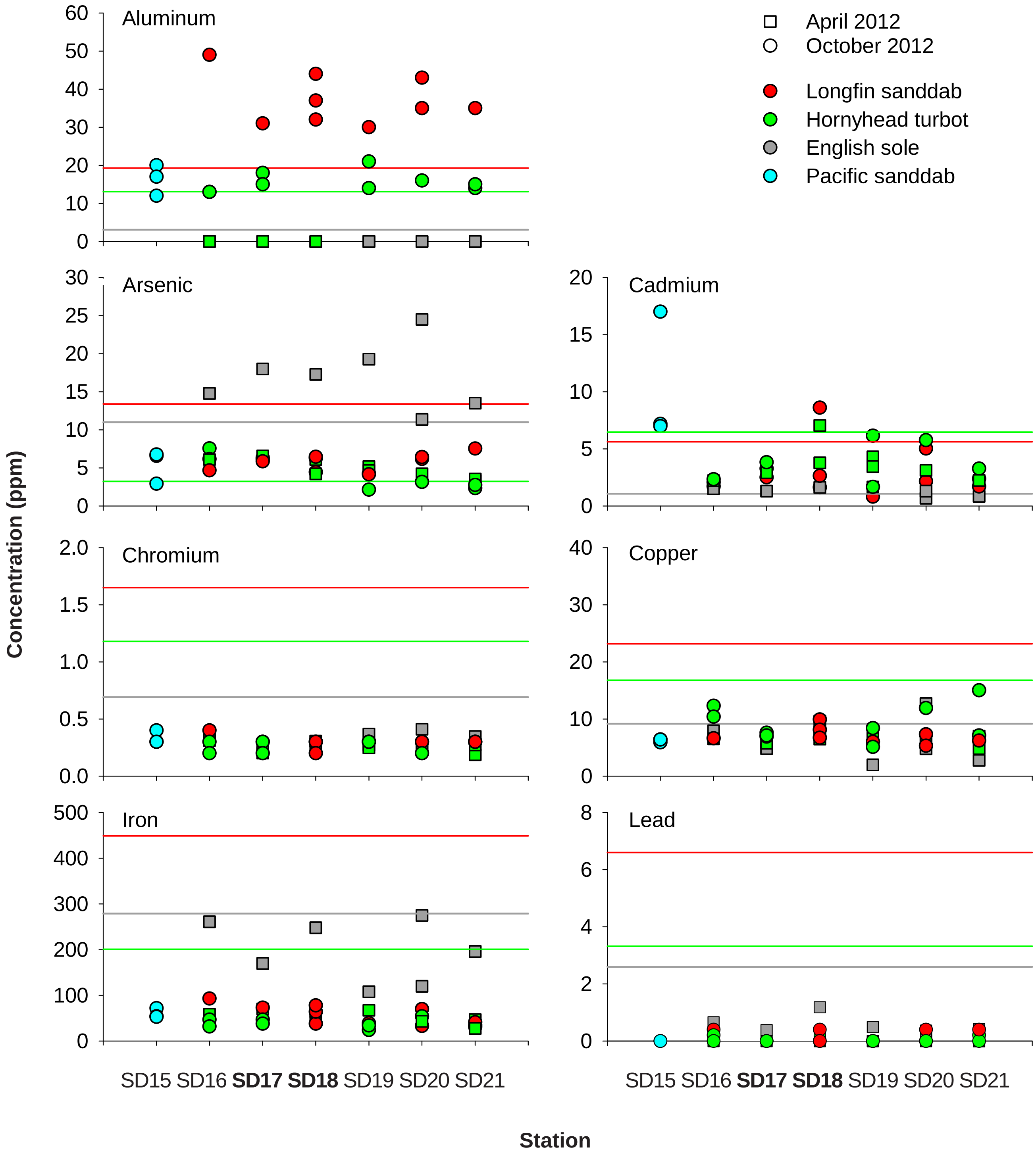

Figure 7.2

Concentrations of metals with detection rates ≥20% in liver tissues of fishes collected from each SBOO trawl station during 2012. 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. To differentiate between missing values (i.e., samples that were not collected; see Table 7.1) and non-detects, zeros were added as placeholders for non-detected values. Stations SD17 and SD18 are considered nearfield (bold; see text).

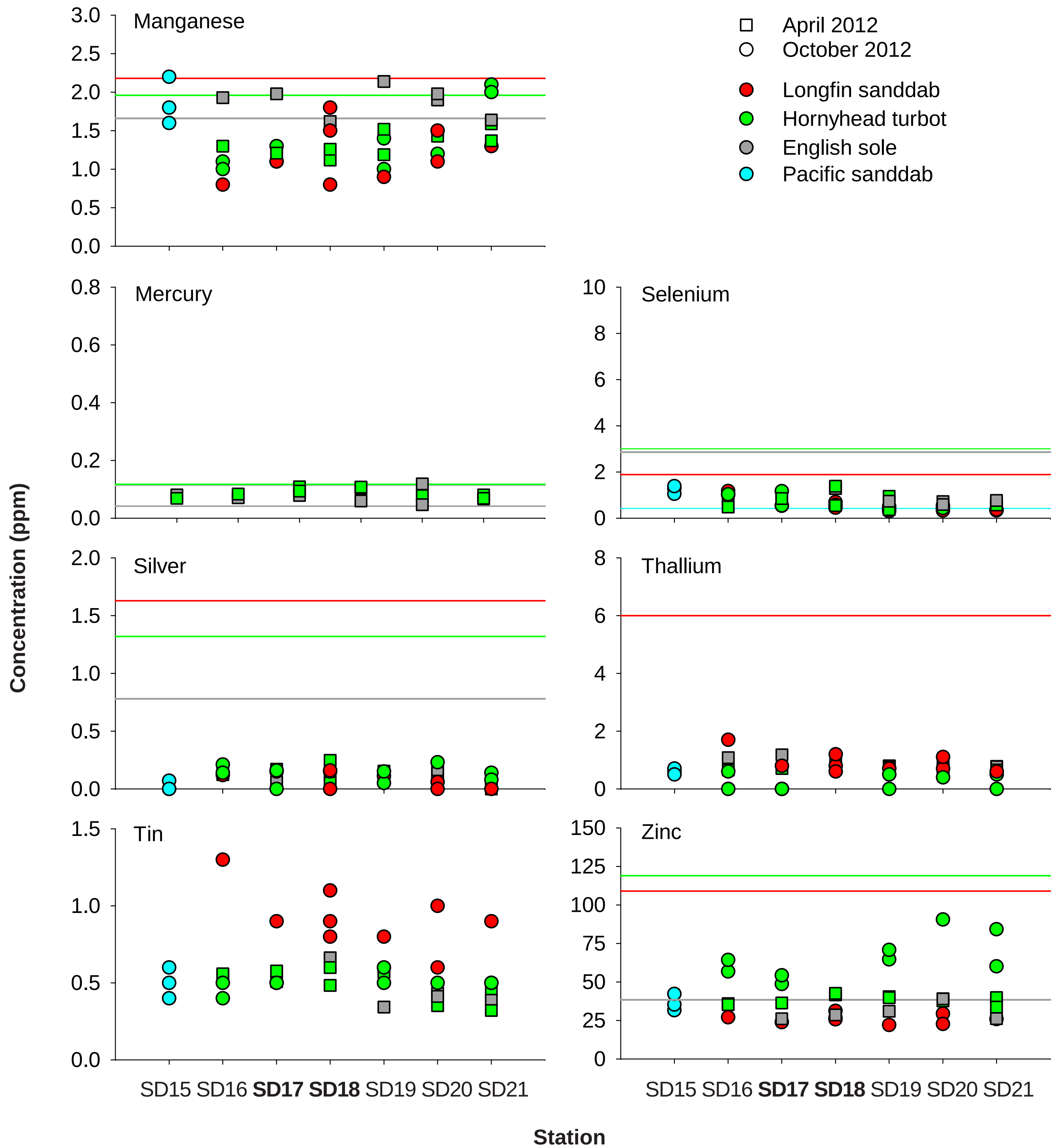

Figure 7.2 *continued*

Two different pesticides were detected in fish muscle tissues during 2012; DDT was detected in all samples, while HCB occurred in 50% of the samples (Table 7.5). The detection rate for PCBs was also high at 83%. Concentrations of all three of these contaminants were below 5 ppb. Neither tDDT nor tPCB exceeded pre-discharge values, whereas HCB was not detected during that period. Additionally, none of these parameters demonstrated a clear relationship with proximity to the outfall (Figure 7.4). Total DDT was composed primarily of p,p-DDE (Appendix F.3). PCB 153/168 was detected in 83% of the samples, while another nine PCB congeners were detected

Table 7.3

Summary of pesticides, tPCB, and lipids in liver tissues of fishes collected from SBOO trawl stations during 2012. 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. See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT, chlordane (tChlor), HCH and PCB.

	Pesticides								
	tChlor	tDDT	Dieldrin	Endrin	HCB	tHCH	Mirex	tPCB	Lipids
English sole									
n (out of 7)	0	7	0	1	6	0	0	7	7
Min	—	25.0	—	nd	nd	—	—	10.4	2.5
Max	—	124.3	—	22.0	1.6	—	—	67.9	6.1
Mean	—	65.2	—	22.0	1.2	—	—	41.1	3.8
Hornyhead turbot									
n (out of 18)	0	18	1	1	14	1	0	18	18
Min	—	27.0	nd	nd	nd	1.2	—	6.4	1.3
Max	—	95.2	8.3	26.0	2.3	1.2	—	47.6	10.1
Mean	—	54.2	8.3	26.0	1.1	1.2	—	23.1	5.9
Longfin sanddab									
n (out of 9)	1	9	0	0	9	0	1	9	9
Min	nd	158.6	—	—	1.2	—	nd	81.3	18.3
Max	12.1	676.5	—	—	3.1	—	2.0	542.9	46.3
Mean	12.1	277.1	—	—	2.3	—	2.0	188.4	30.2
Pacific sanddab									
n (out of 3)	0	3	0	0	3	0	0	3	3
Min	—	22.0	—	—	0.6	—	—	11.3	5.8
Max	—	56.6	—	—	1.1	—	—	40.1	7.8
Mean	—	34.5	—	—	0.9	—	—	21.3	7.0
All Species:									
DR(%)	3	100	3	5	86	3	3	100	100
Max	12.1	676.5	8.3	26.0	3.1	1.2	2.0	542.9	46.3

nd = not detected

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

at rates ≤58%. No PAHs were detected in muscle tissues during 2012.

Most contaminants detected in fish muscle tissues during 2012 occurred at concentrations below state, national, and international limits and standards (Tables 7.4, 7.5). Exceptions included: (a) arsenic, which exceeded its median international standard in all four samples of vermilion rockfish and five of six samples of California scorpionfish; (b) selenium, which exceeded its median international standard in all samples of vermilion rockfish, mixed rockfish and two of six samples of California scorpionfish.

Summary

Several trace metals, PCB congeners, and the chlorinated pesticides chlordane, DDT, dieldrin, endrin, HCB, HCH and mirex were detected in liver tissues from four different species of fish collected in the South Bay outfall region during 2012. Many

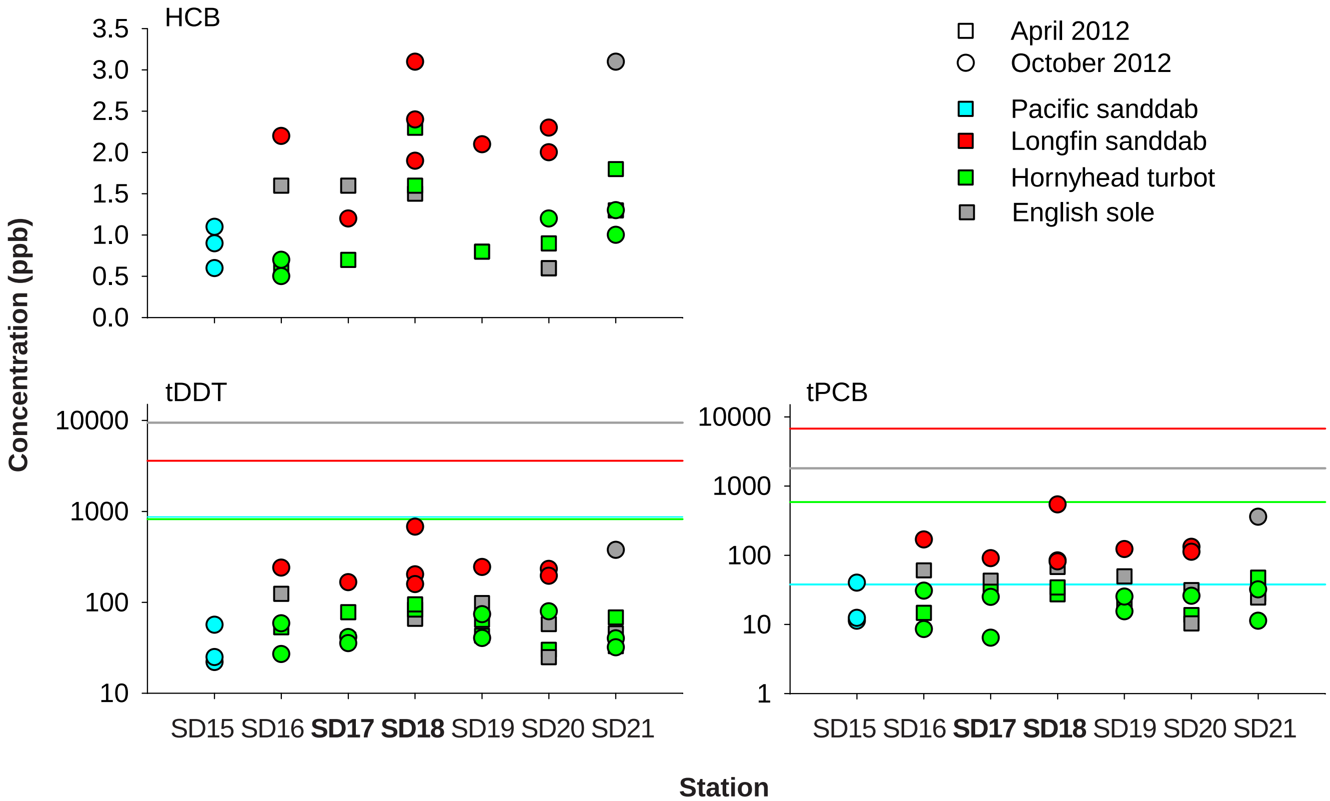

Figure 7.3

Concentrations of HCB, tDDT, and tPCBs in liver tissues of fishes collected from each SBOO trawl station during 2012. 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. All missing values are non-detects. Stations SD17 and SD18 are considered nearfield (bold; see text).

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 (see Mearns et al. 1991, Allen et al. 1998, City of San Diego 2007a). Additionally, all muscle tissue samples from sport fish collected in the region had concentrations of mercury and DDT below FDA human consumption limits. However, some tissue samples from California scorpionfish, vermilion rockfish, and “mixed rockfish” composites had concentrations of arsenic and selenium above median international standards for human consumption. Elevated levels of arsenic and selenium are not uncommon in sport fish from the SBOO survey area (City of San Diego 2000–2006, 2007b, 2008–2012) or from other parts of the San Diego region (see City of San Diego 2013b and references therein). For example, muscle tissue samples from fishes collected in the Point Loma outfall survey area 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, including arsenic, mercury, DDT, and PCBs as being ubiquitous. The wide-spread distribution of contaminants in the SCB has been supported by more recent work regarding PCBs and DDTs

Table 7.4

Summary of metals in muscle tissues of fishes collected from SBOO rig fishing stations during 2012. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations for each 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. 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[d]	Ni	Se	Ag	Tl	Sn	Zn
Brown rockfish																		
n (out of 1)	1	0	1	0	0	0	1	1	1	0	0	1	0	1	0	1	1	1
Min	4.4	—	0.5	—	—	—	0.19	0.4	2.2	—	—	0.202	—	0.23	—	0.48	0.259	3.7
Max	4.4	—	0.5	—	—	—	0.19	0.4	2.2	—	—	0.202	—	0.23	—	0.48	0.259	3.7
Mean	4.4	—	0.5	—	—	—	0.19	0.4	2.2	—	—	0.202	—	0.23	—	0.48	0.259	3.7
California scorpionfish																		
n (out of 6)	0	0	6	1	0	0	6	4	3	0	0	3	0	6	0	3	3	6
Min	—	—	1.2	nd	—	—	0.10	nd	nd	—	—	nd	—	0.18	—	nd	nd	2.7
Max	—	—	**3.9**	0.032	—	—	0.20	0.4	3.0	—	—	0.212	—	**0.35**	—	0.73	0.498	4.2
Mean	—	—	**2.6**	0.032	—	—	0.16	0.3	2.4	—	—	0.183	—	0.26	—	0.66	0.402	3.4
Mixed rockfish																		
n (out of 1)	0	0	1	0	0	0	1	1	1	0	0	1	0	1	0	1	1	1
Min	—	—	1.1	—	—	—	0.10	0.4	2.8	—	—	0.104	—	**0.37**	—	0.69	0.429	4.0
Max	—	—	1.1	—	—	—	0.10	0.4	2.8	—	—	0.104	—	**0.37**	—	0.69	0.429	4.0
Mean	—	—	1.1	—	—	—	0.10	0.4	2.8	—	—	0.104	—	**0.37**	—	0.69	0.429	4.0
Vermilion rockfish																		
n (out of 4)	0	0	4	0	0	0	4	0	1	0	3	1	0	4	0	2	1	4
Min	—	—	**2.0**	—	—	—	0.19	—	nd	—	nd	0.063	—	**0.33**	—	nd	nd	3.0
Max	—	—	**3.5**	—	—	—	0.40	—	2.4	—	0.1	0.063	—	**0.35**	—	0.57	0.380	3.9
Mean	—	—	**2.7**	—	—	—	0.26	—	2.4	—	0.1	0.063	—	**0.34**	—	0.51	0.380	3.4
All Species:																		
Detection Rate (%)	8	0	100	8	0	0	100	50	50	0	25	100	0	100	0	58	50	100
Max Value	4.4	—	**3.9**	0.032	—	—	0.40	0.4	3.0	—	0.1	0.212	—	**0.37**	—	0.73	0.498	4.2
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	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

na = not available; nd = not detected

[a] Minimum and maximum values were calculated 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.

[d] No mercury analyzed for October samples

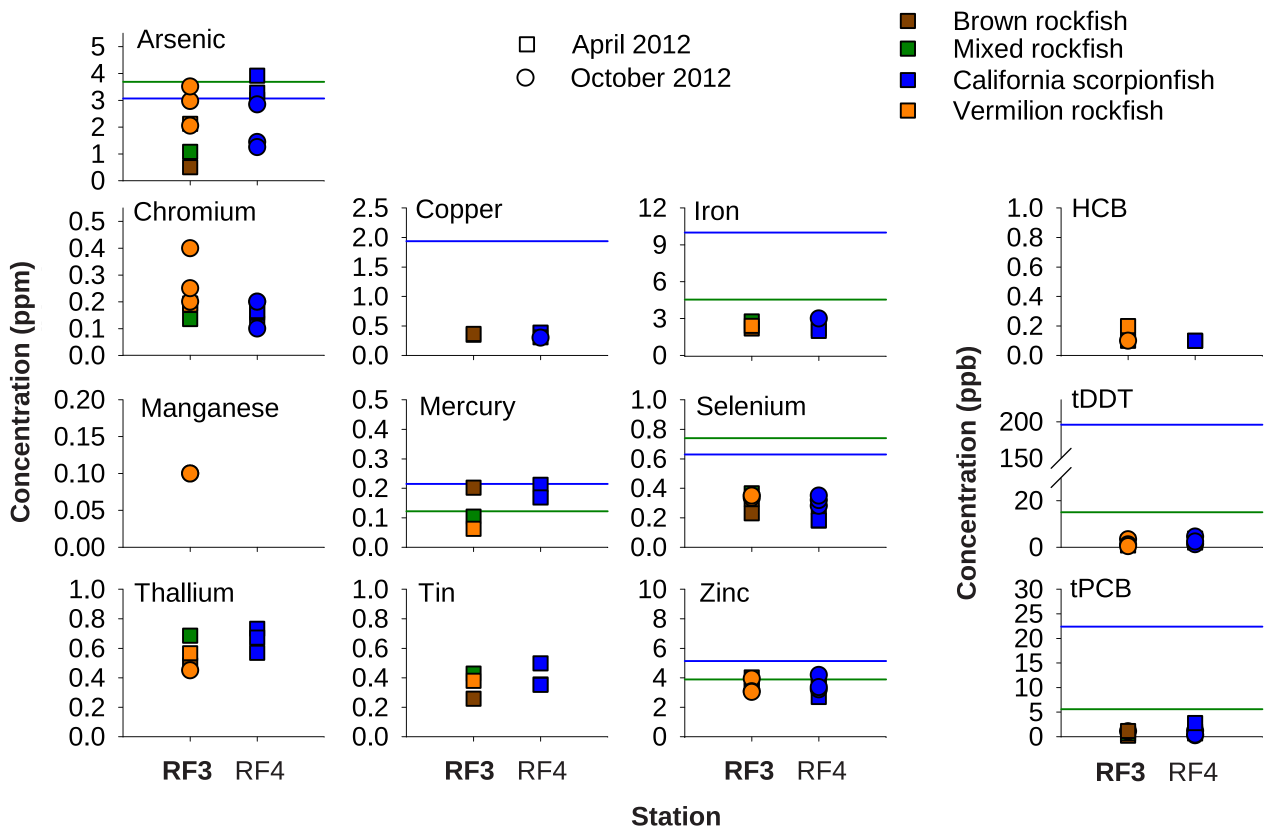

Figure 7.4
Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each SBOO rig fishing station during 2012. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate parameters were not detected in that species prior to discharge, or the species was not collected during those surveys. All missing values = non-detects. Station RF3 is considered nearfield (bold; see text).

(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 (see City of San Diego 2000).

Other factors that affect contaminant loading in fish tissues include the physiology and life history of different species (see Groce 2002 and references therein). Exposure to contaminants can also vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). Fishes may be exposed to contaminants in an area that is highly polluted and then move into an area that is not. For example, California scorpionfish tagged in Santa Monica Bay have been recaptured as far south as the Coronado Islands (Hartmann 1987, Love et al. 1987). This is of particular concern for fishes collected in the vicinity of the SBOO, as there are 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 2012 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

Table 7.5

Summary of pesticides, tPCB, and lipids in muscle tissues of fishes collected from SBOO rig fishing stations during 2012. 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. 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 total DDT and PCB.

	Pesticides			
	HCB (ppb)	tDDT (ppb)	tPCB (ppb)	Lipids (% wt)
Brown rockfish				
n (out of 1)	0	1	1	1
Min	—	2.3	1.2	0.2
Max	—	2.3	1.2	0.2
Mean	—	2.3	1.2	0.2
California scorpionfish				
n (out of 6)	3	6	6	6
Min	nd	1.3	0.3	0.2
Max	0.1	4.6	2.8	0.5
Mean	0.1	2.8	1.1	0.4
Mixed rockfish				
n (out of 1)	1	1	1	1
Min	0.1	2.0	0.7	0.2
Max	0.1	2.0	0.7	0.2
Mean	0.1	2.0	0.7	0.2
Vermilion rockfish				
n (out of 4)	2	4	2	4
Min	nd	0.4	nd	0.3
Max	0.2	3.4	1.1	0.8
Mean	0.2	1.5	0.7	0.4
All Species:				
Detection Rate (%)	50	100	83	100
Max Value	0.2	4.6	2.8	0.8
OEHHA[b]	na	21	3.6	na
U.S. FDA Action Limit[c]	300	5000	na	na
Median IS[c]	100	5000	na	na

na = not available; nd = not detected

[a] Minimum and maximum values were calculated 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.

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).

Literature Cited

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the South Bay Ocean

Outfall (South Bay Water Reclamation Plant), 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

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

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

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

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

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

Connell, D. W. (1988). Bioaccumulation behavior of persistent organic chemicals with aquatic organisms. Review of Environmental Contamination and Toxicology, 101:117–154.

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

Hartmann, A.R. (1987). Movement of scorpionfishes (Scorpaenidae: *Sebastes* and *Scorpaena*) in the Southern California Bight. California Fish and Game, 73: 68–79.

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

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

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

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

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

Environments. Australian Marine Science Association, Inc./Water Board.

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

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

Schiff, K. and M.J. Allen. (1997). Bioaccumulation of chlorinated hydrocarbons in livers of flatfishes from the Southern California Bight. In: S.B. Weisberg, C. Francisco, and D. Hallock (eds.). Southern California Coastal Water Research Project Annual Report 1995–1996. Southern California Coastal Water Research Project, Westminster, CA.

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

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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, 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). Examples of such local assessments include the regular ongoing surveys conducted each year around the ocean outfalls operated by the City of Los Angeles, the City of San Diego, the Los Angeles County Sanitation District, and the Orange County Sanitation District, the four largest wastewater dischargers in the region (City of Los Angeles 2007, 2008, City of San Diego 2012a, b, LACSD 2012, OCSD 2012). 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).

The City of San Diego has 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 south of Del Mar to the USA/Mexico border, are to (1) describe the overall condition and quality of the diverse benthic habitats that occur off San Diego, (2) characterize the ecological health of the soft-bottom marine benthos in the region, and (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 also 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), and surveys in 1994, 1998, 2003 and 2008 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).

This chapter presents analyses and interpretations of the sediment particle size and chemistry data collected during the 2012 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 2009–2012 regional surveys are presented. Although regional data exist prior to this time period, 2009 represents the first year where upper slope sites were included as a fourth depth stratum, allowing this region to be comparable to the three continental shelf strata. Results of macrofaunal community analyses for these same sites are presented in Chapter 9.

Materials and Methods

Field Sampling

The July 2012 regional survey covered an area ranging south of Del Mar in northern San Diego

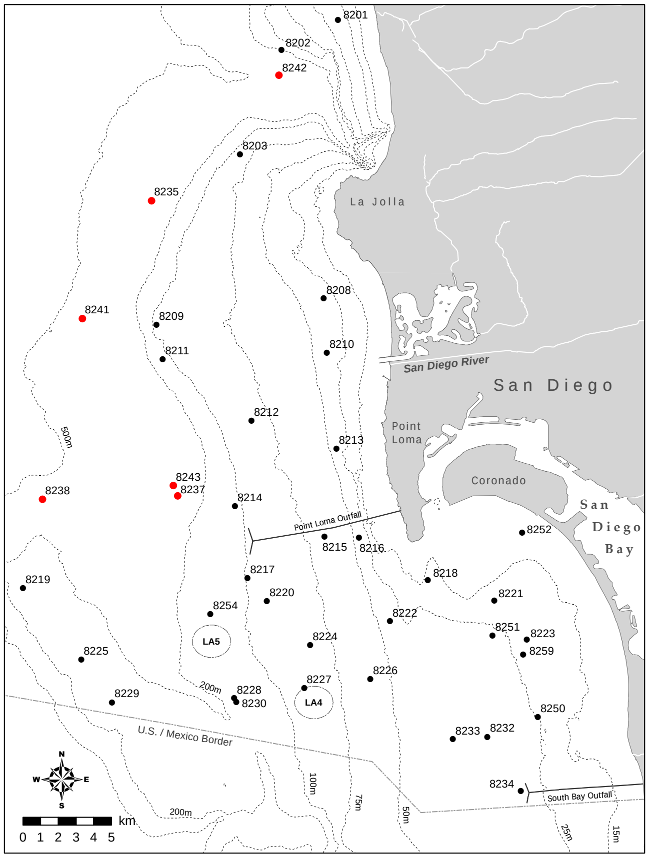


Figure 8.1
Regional benthic survey stations sampled during July 2012 as part of the City of San Diego's Ocean Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

County south to the USA/Mexico border (Figure 8.1). Overall, this survey included 40 stations ranging in depth from 11 to 448 m and spanning four distinct depth strata characterized by the SCB regional monitoring programs (Schiff et al. 2006). These included 8 stations along the inner shelf (5–30 m), 19 stations along the mid-shelf (>30–120 m), 7 stations along the outer shelf (>120–200 m), and 6 stations on the upper slope (>200–500 m). Samples for particle size and sediment chemistry analyses were collected at each station from one side of a double 0.1-m^2 Van Veen grab; the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 9) and visual observations of sediment composition. 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 Wastewater Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2013). Briefly, sediment sub-samples were analyzed 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) on a dry weight basis. Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix G.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%. 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 fractions. Sieve results and output from the Horiba were classified into size fractions (e.g., percent fines, fine sand, coarse sand) and sub-fractions (e.g., very fine silt, fine silt, medium silt, coarse silt) based on the Wentworth scale (Appendix C.2).

Data Analyses

Data summaries for the various sediment parameters included detection rates, minimum, median, 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 (tChlor), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix G.2 for individual constituent values). Sediment 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 used to assess if concentrations of chemical parameters co-varied with the proportion of fine particles in each sample collected between 2009 and 2012. 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 to examine spatial and temporal patterns in the regional particle size and sediment chemistry data collected between 2009 and 2012 (Clarke and Warwick 2001, Clarke and Gorley 2006). These analyses 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 dendrogram (Clarke et al. 2008). Prior to these analyses, proportions of particle size sub-fractions were square-root transformed to limit the influence of the largest fractions, while sediment chemistry data were normalized after non-detects (see above) were converted to “0” values to avoid data deletion issues with the clustering program. Similarity percentages (SIMPER) analysis was subsequently used to identify which sediment chemistry parameters primarily accounted for observed differences among cluster groups, as well as to identify the parameters typical of each group. Finally, a RELATE test was used to compare patterns in the particle size sub-fraction and sediment chemistry Euclidean distance matrices. When significant similarity was found, a BEST test using the BIO-ENV amalgamate was conducted to determine which subset of sediment sub-fractions were the best explanatory variables for similarity between the two resemblance matrices.

Results and Discussion

Particle Size Composition

Ocean sediments were diverse at the benthic stations sampled during the summer 2012 regional survey. The proportion of fine particles (i.e., silt and clay; also referred to as percent fines) ranged from 5 to 88% per station, while fine sand, coarse sand, and coarse particles ranged from 1 to 82%, <1 to 69%, and 0 to 59%, respectively (Table 8.1, Figure 8.2). Visual observations recorded for corresponding macrofaunal samples also revealed the presence of coarse black sands, gravel, organic debris, red relict sands, and shell hash at different stations (Appendix G.3). Overall, sediment composition varied as expected by region and depth stratum (Figure 8.2, Appendices G.3, G.4). For example, sediments from inner and middle shelf sites in the South Bay outfall region (see Chapter 4) averaged 23% fines, whereas sediments from middle and outer shelf sites in the Point Loma outfall region (see City of San Diego 2012a) averaged 46% fines, and sediments from all of the upper slope sites averaged 81% fines. The most notable exceptions

Table 8.1

Summary of particle sizes and chemistry concentrations in sediments from regional benthic stations sampled during 2012. Data include detection rate (DR), minimum, median, maximum, and mean values for the entire survey area, as well as mean value by depth stratum; n = number of stations.

	2012 Survey Area[a]					Depth Strata			
						Inner Shelf	**Mid-Shelf**	**Outer Shelf**	**Upper Slope**
	DR (%)	**Min**	**Median**	**Max**	**Mean**	n = 8	n = 19	n = 7	n = 6
Particle Size									
Coarse particles (%)	—	0	0	59.2	1.9	7.4	0.6	0.8	0.0
Coarse sand (%)	—	0.2	2.1	68.7	9.9	9.1	12.0	13.1	0.4
Fine sand (%)	—	1.3	45.2	81.9	46.6	67.3	48.9	41.0	18.1
Fines particles (%)	—	5.0	39.3	87.7	41.6	16.2	38.5	45.0	81.5
Organic Indicators									
Sulfides (*ppm*)	100	0.6	4.9	254.0	13.3	3.2	4.4	11.3	57.0
TN (*% weight*)	100	0.013	0.048	0.249	0.067	0.021	0.042	0.076	0.199
TOC (*% weight*)	100	0.09	0.68	6.49	1.28	0.34	0.77	2.69	2.52
TVS (*% weight*)	100	0.29	2.42	38.50	3.90	5.69	2.01	3.75	7.66
Trace Metals (*ppm*)									
Aluminum	100	1610	7760	26,200	9215	4602	7337	10,710	19,567
Antimony	65	nd	0.51	1.61	0.58	0.40	0.44	0.85	0.78
Arsenic	100	0.8	3.1	9.3	3.5	2.2	3.4	4.1	4.8
Barium	100	4.5	29.1	120.0	40.1	20.4	32.3	44.7	85.6
Beryllium	92	nd	0.120	0.416	0.146	0.065	0.132	0.118	0.323
Cadmium	20	nd	0.12	0.38	0.16	0.07	0.06	0.38	0.15
Chromium	100	5.3	17.4	38.0	18.9	8.1	17.4	23.4	32.9
Copper	100	0.4	9.3	26.7	9.7	3.9	7.9	12.0	20.5
Iron	100	3610	12,000	39,200	12,976	5159	13,314	15,287	19,633
Lead	100	2.43	6.16	18.50	6.67	3.21	6.26	7.27	11.90
Manganese	100	24.3	84.5	215.0	94.1	68.1	86.0	89.0	160.5
Mercury	85	nd	0.022	0.151	0.036	0.007	0.027	0.065	0.054
Nickel	100	0.77	6.53	24.00	8.00	2.89	6.41	8.53	19.23
Selenium	45	nd	0.44	1.86	0.69	0.33	0.4	0.41	1.27
Silver	8	nd	0.23	3.83	1.42	nd	0.20	nd	2.03
Thallium	0	—	—	—	—	nd	nd	nd	nd
Tin	92	nd	1.58	5.14	1.72	1.21	1.90	1.38	2.21
Zinc	100	6.3	27.5	65.4	29.4	13.4	26.3	34.2	55.1
Pesticides (*ppt*)									
HCB	15	nd	nd	200	135	nd	122	200	nd
Total DDT	68	nd	470	1100	499	nd	453	459	694
Total PCB (ppt)	82	nd	310	51,660	2689	302	929	9768	768
Total PAH (ppb)	10	nd	47.6	283.0	100.4	nd	23.4	126.1	nd

nd = not detected

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

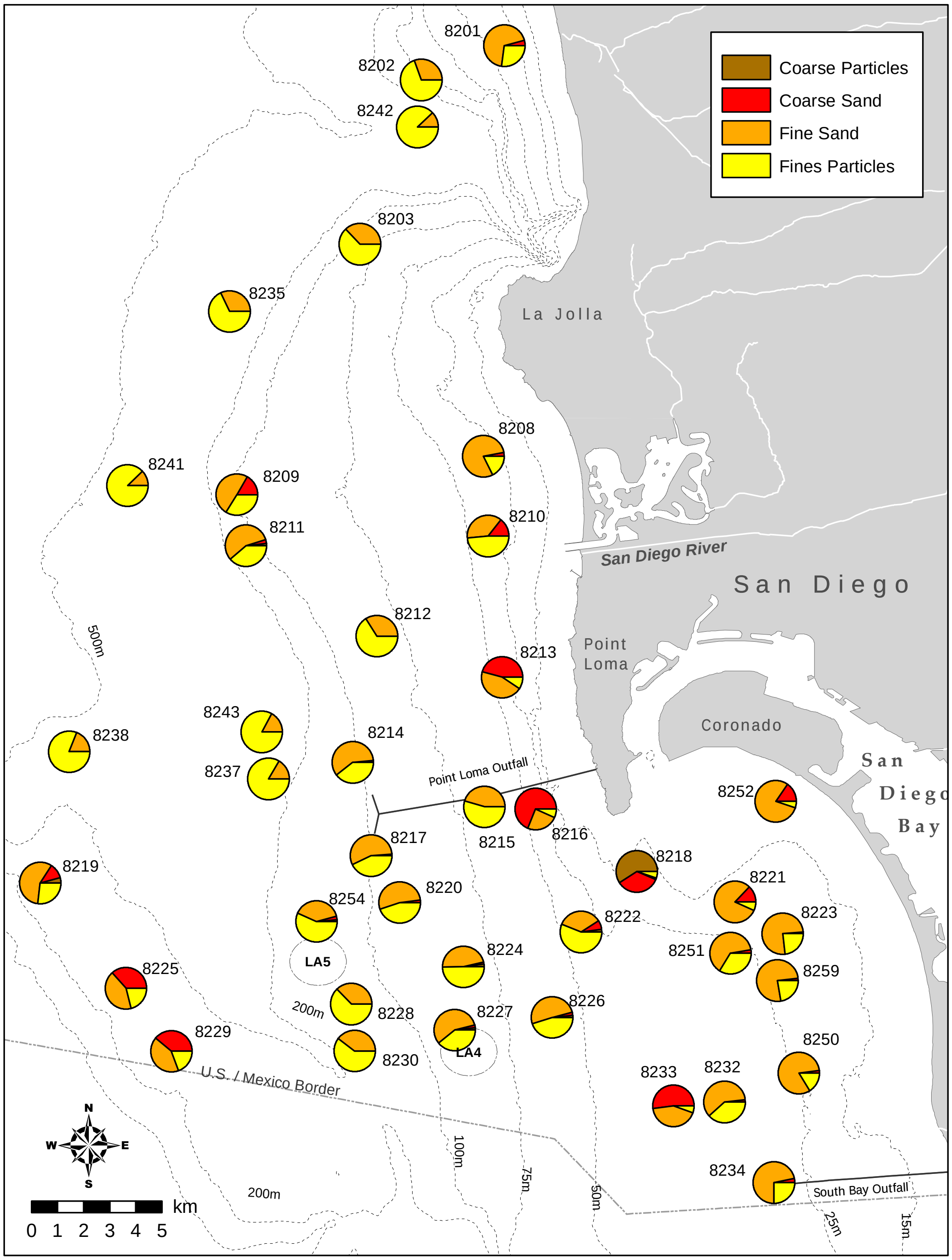


Figure 8.2
Sediment composition at regional benthic stations sampled during July 2012.

to this trend included sediments from outer shelf stations located on the Coronado Bank (8219, 8225, 8229), each of which had lower percent fines (≤27%) than other stations at similar depths (Figure 8.2, Appendices G.3, G.4). Correlation analysis of data collected between 2009 and 2012 confirmed that percent fines increased with depth (Table 8.2, Figure 8.3A). The increase in fine particles across depth strata has been consistent over the past four years (Figure 8.4A).

Indicators of Organic Loading

Sulfides were detected in all sediment samples collected from the 2012 regional benthic stations at concentrations from 0.6 to 254.0 ppm (Table 8.1).

Table 8.2
Results of Spearman rank correlation analyses of percent fines versus depth and various sediment chemistry parameters from regional benthic samples collected between 2009 and 2012. Shown are analytes 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 presented graphically in Figure 8.3.

Analyte	n	r_s
Depth	162	0.74
Organic Indicators (% weight)		
Total Nitrogen	148	0.85
Total Volatile Solids	148	0.84
Trace Metals (ppm)		
Aluminum	148	0.86
Barium	148	0.80
Beryllium	140	0.77
Chromium	148	0.78
Copper	146	0.84
Iron	148	0.74
Lead	148	0.80
Manganese	148	0.77
Mercury	122	0.79
Nickel	145	0.92
Zinc	148	0.87

Average sulfides progressively increased with depth from 3.2 ppm on the inner shelf to 57.0 ppm on the upper slope. The highest value was found at station 8242 in the La Jolla canyon, and was an order of magnitude greater than any other concentration recorded during the year for this survey or for the SBOO and PLOO fixed grid stations (see Chapter 4, City of San Diego 2012a). However, sulfides from this station were similar to those from a nearby La Jolla canyon site sampled during 2011 (City of San Diego 2012b). Without this anomalous value, sulfide concentrations on the upper slope averaged 17.6 ppm.

During 2012, total nitrogen (TN), total organic carbon (TOC) and total volatile solids (TVS) were also detected in sediments from all regional stations and generally increased with depth (Table 8.1). For example, average TN increased from 0.021% wt on the inner shelf to 0.199% wt on the upper slope, while TOC increased from 0.34% wt to 2.52% wt and TVS increased from 5.69% wt to 7.66% wt. For all stations sampled between 2009 and 2012, TN and TVS correlated positively with the percentage of fine sediments in each sample (Table 8.2, Figure 8.3B) and mirrored changes in percent fines across strata (e.g., Figure 8.4A). In contrast, TOC was not as strongly correlated with percent fines (i.e., $r_s < 0.70$); it has varied considerably within each depth stratum over this 4-year period (Figure 8.4C).

Trace Metals

Ten trace metals were detected in sediments collected from all stations sampled during the 2012 regional survey, including aluminum, arsenic, barium, chromium, copper, iron, lead, manganese, nickel, and zinc (Table 8.1). Antimony, beryllium, mercury, selenium, and tin were also detected frequently at rates from 45 to 92%, while cadmium and silver were found at ≤20% of the stations. Thallium 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.5). Exceptions included: (1) arsenic, which exceeded its ERL at stations 8209 and 8242; (2) mercury, which exceeded its ERL at station 8254; (3) nickel, which exceeded its ERL at stations 8237, 8238, 8242; (4) silver, which exceeded its ERM at station 8242. With the exception of mid-shelf station 8209, these stations were located at depths ≥160 m on the outer shelf or upper slope where sediments had high percent fines (Appendix G.3).

Concentrations of aluminum, barium, beryllium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc correlated positively with the percentage of fine sediments in each sample collected between 2009 and 2012 (Table 8.2, Figure 8.3) and generally increased with depth (e.g., Figure 8.4D, E). Although arsenic and cadmium were not correlated as strongly with percent fines (i.e., $r_s < 0.70$), their concentrations were often higher on the upper slope than at shelf depths during past surveys (Figure 8.4F, G).

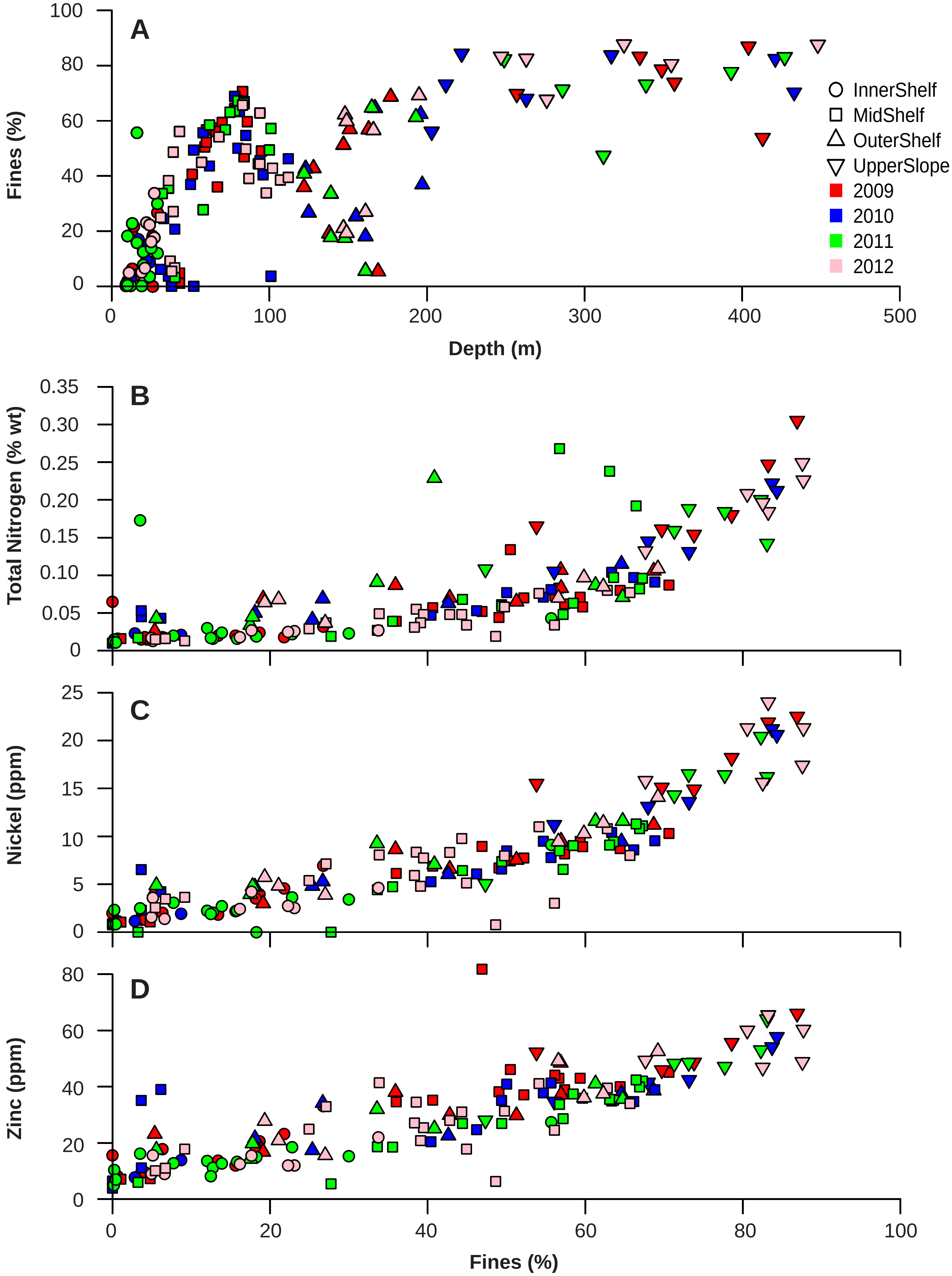


Figure 8.3

Scatterplot of percent fines versus (A) depth, (B) total nitrogen, (C) nickel, and (D) zinc in sediments from regional benthic stations sampled between 2009 and 2012.

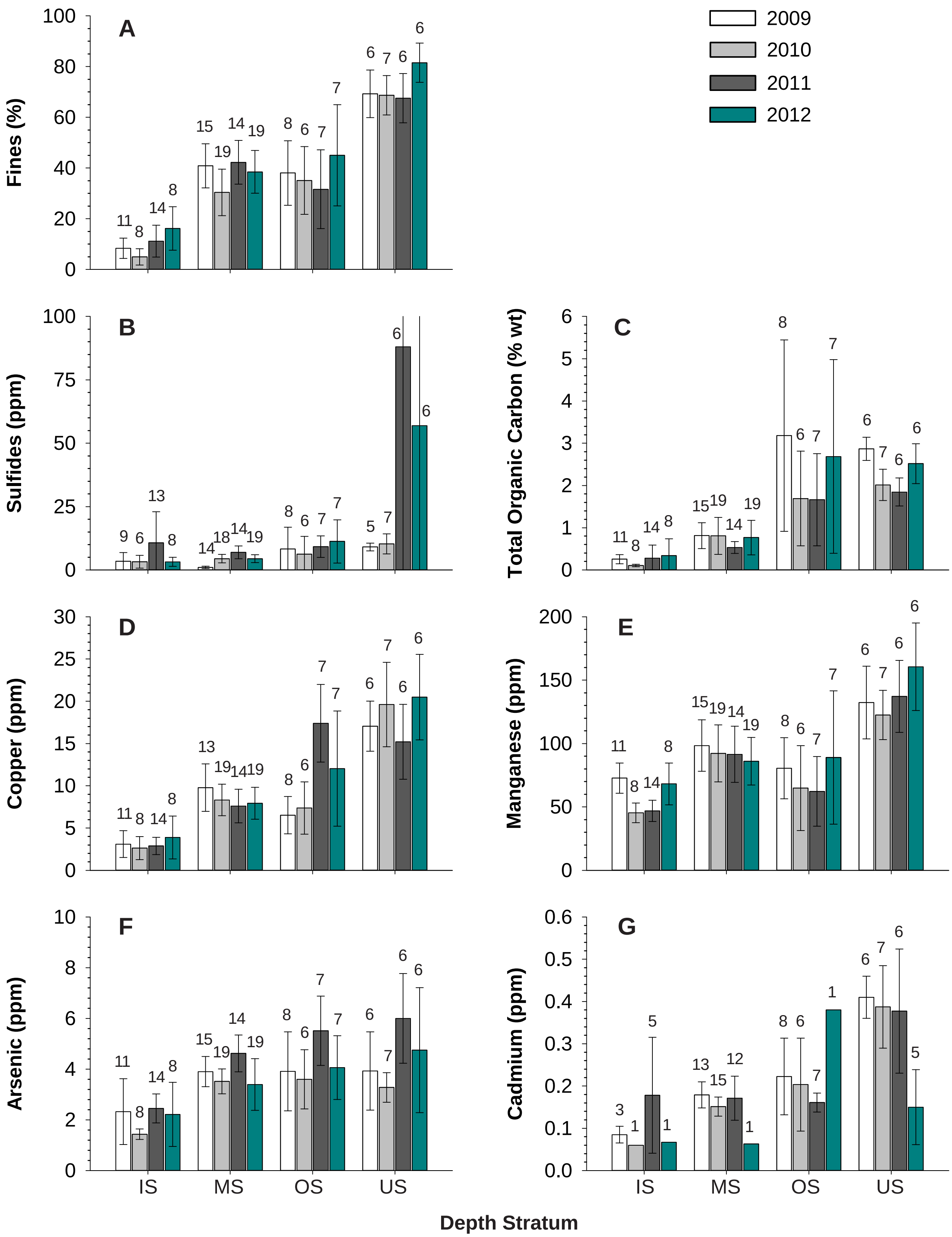


Figure 8.4

Comparison of representative particle size and chemistry parameters in sediments from the four major depth strata sampled during regional surveys between 2009 and 2012. Data are expressed as means ± 95% confidence intervals calculated on detected values only; IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope. Numbers above bars represent number of detected values.

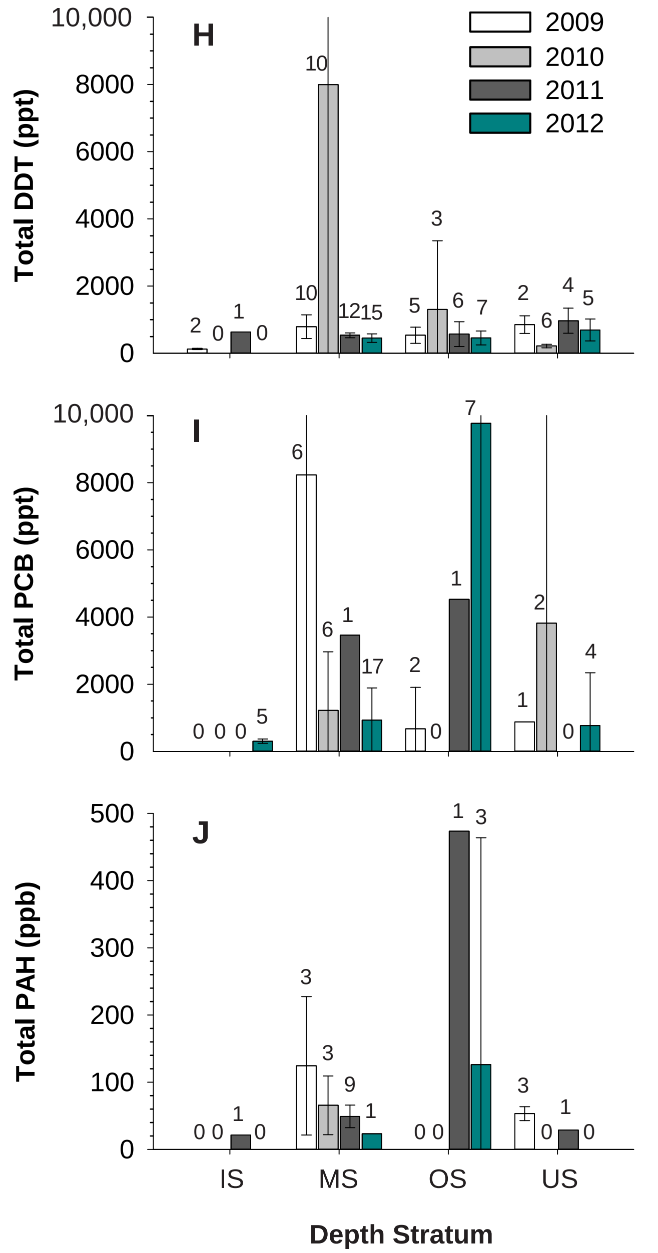


Figure 8.4 *continued*

Pesticides

Hexachlorobenzene (HCB) and DDT were the only chlorinated pesticides detected during the 2012 regional survey (Table 8.1, Appendix G.5). Detectable levels of HCB were found in sediments from just six stations (15%) at concentrations ≤200 ppt; these included the mid-shelf sites 8203, 8209, 8215, 8216, 8222 and outer shelf station 8225. Total DDT (primarily p,p-DDE; Appendix G.2) was detected at 68% of the regional stations at concentrations below threshold values (i.e., <1580 ppt) and within the range previously reported elsewhere for the SCB (Schiff et al. 2011). This pesticide was found at 79%, 100%, and 83% of the mid-shelf, outer shelf and upper slope stations, respectively. DDT was not detected at any of the inner shelf stations during the year. From 2009 to 2012, DDT levels were variable with no discernible spatial patterns except low detection rates at inner shelf stations (Figure 8.4H).

PCBs

PCBs (primarily PCB 206; Appendix G.2) were detected in sediments from 82% of the 2012 regional stations at concentrations up to 51,660 ppt (Table 8.1, Appendix G.5). The highest tPCB concentration occurred at outer shelf station 8225 located on the Coronado Bank, and was an order of magnitude higher than reported for other stations sampled during this survey or for the SBOO and PLOO fixed grid stations surveyed in 2012 (see Chapter 4, City of San Diego 2012a). No ERL or ERM values exist for PCBs measured as congeners; however, the tPCB value from station 8225 was within the range previously reported elsewhere for the SCB (Schiff et al. 2011). Excluding 8225, detected values averaged 302 ppt on the inner shelf, 929 ppt on the middle shelf, 2785 on the outer shelf, and 768 on the upper slope. As with tDDT, tPCB levels have been variable over the past four years (Figure 8.4I).

PAHs

PAHs were detected in sediments from just four (10%) of the 2012 regional stations (Table 8.1, Appendix G.5). 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 compounds fluoranthene, 3,4-benzo (B) fluoranthene, and benzo [A] pyrene were detected in two to three of these samples, whereas benzo [A] anthracene, benzo [e] pyrene, benzo [K] fluoranthene, and indeno (1,2,3-CD) pyrene were each reported only once (Appendix G.2). Three of the stations where

PAHs occurred (8228, 8230, 8254) were located on the outer shelf, while one (8220) was located on the mid-shelf. As with tDDT and tPCB, the occurrence and concentrations of tPAH have been variable over the past four years (Figure 8.4J).

Classification of Regional Shelf and Slope Sediment Conditions (2009–2012)

Particle Size Composition

Classification (cluster) analysis discriminated nine ecologically-relevant cluster groups based on the particle size sub-fractions present in sediments collected from regional stations sampled between 2009 and 2012 (Figures 8.5, 8.6). Sediments from stations sampled during 2012 did not group apart from those sampled during previous surveys. Instead, cluster groups 1–9 differed in the proportions of fine verses coarse sediments present in each sample. For instance, sediments represented by groups 1, 2, 8, and 9 had relatively high proportions of coarse sand and other coarse particles, whereas sediments represented by groups 3–7 all contained moderate to high proportions of very fine sand and/or fine particles, with very little coarse sand or other coarse particles present. Descriptions of each cluster group, including their distribution and main characteristics, are described below, with groups ordered from coarsest to finest sediments.

Cluster group 1 was characterized by having the coarsest sediments of all the groups. This group comprised ten stations that were scattered from La Jolla south to the US/Mexico border at depths ≤52 m and one station located near the LA-5 dredged material disposal site at 101 m. Sediments at these sites averaged 25% medium sand, 42% coarse sand, 15% very coarse sand, and 8% granules.

Cluster group 2 included just three stations, one located near the South Bay Ocean Outfall at 22 m, one located northwest of the LA-5 site at 128 m, and one located offshore of the San Diego River at 193 m. Sediments at these stations were primarily coarse silt (~38%) and very fine sand (~42%) but also contained relatively high proportions of coarse particles compared to groups 3–9 (~7% versus ≤1%).

Cluster group 9 comprised 15 stations that had sediments averaging 17% very fine sand, 50% fine sand, 21% medium sand, and 8% coarse sand. Ten of these sites were located near the mouth of San Diego Bay, two near the mouth of Mission Bay and one at the head of the La Jolla Canyon. These 13 stations occurred at depths ≤21 m. The remaining two stations from group 9 were located on the Coronado Bank at 161 and 169 m.

Sediments represented by group 8 were similar to those of group 9 in that they were predominantly sand, averaging 13% very fine sand, 36% fine sand, and 23% medium sand. However, they also contained moderate amounts of fine particles (~25%). Twelve of the 20 sites that comprised group 8 were located within the outer shelf/upper slope strata on the Coronado Bank; the remaining stations were scattered across the survey area at depths between 37 and 98 m.

Cluster group 3 was characterized by sediments averaging 11% coarse silt, 49% very fine sand, and 27% fine sand. This group comprised 26 stations that were located at depths between 10 and 40 m; 21 of these sites were located in the South Bay outfall region (see Chapter 4).

Group 5 comprised a single station (8170) located just off Coronado Beach at 16 m. Sediments at this station were 13% medium silt, 35% coarse silt, 33% very fine sand, and 10% fine sand.

Cluster groups 6 and 7 were the two largest groups, comprising 40 and 32 sites, respectively. Sediments represented by group 6 averaged 12% fine silt, 14% medium silt, 26% coarse silt, and 29% very fine sand. Stations in this group were located from north of La Jolla to southeast of the LA-5 disposal site at depths from 58 to 433 m. Sediments represented by group 7 averaged 18% coarse silt, 36% very fine sand, and 16% fine sand. Stations in group 7 spanned all depth strata (27–413 m), and covered more of the survey area than group 6, extending from Del Mar south to the US/Mexico border, west to the edge of the upper slope, and east into the South Bay outfall region.

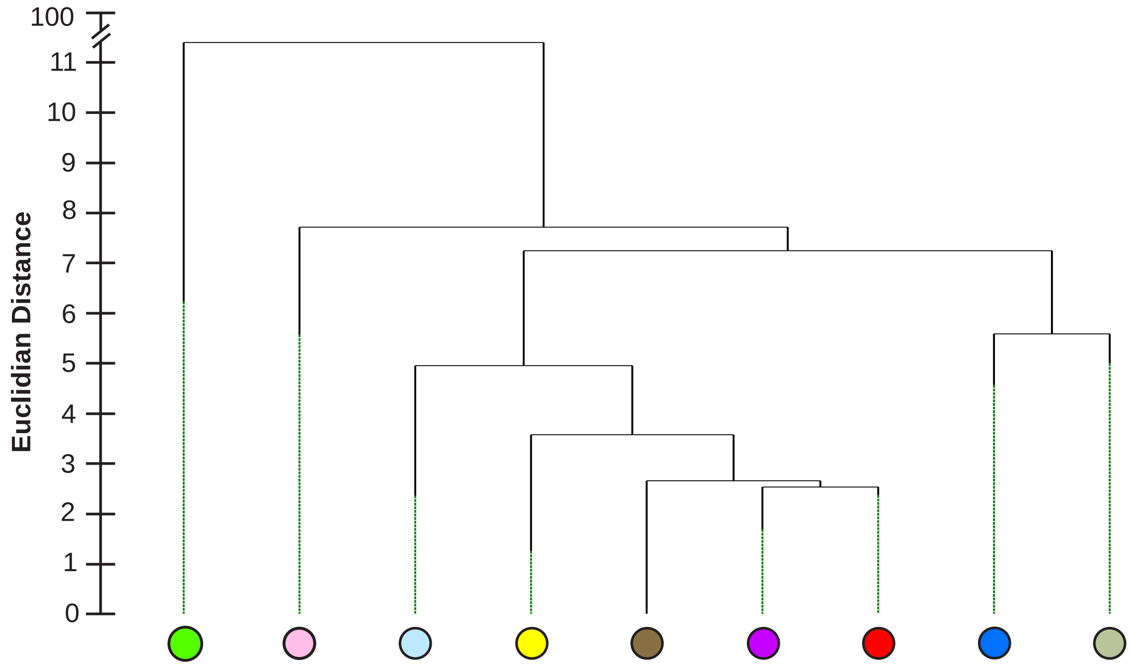
Group 4 comprised 14 stations, all located on the upper slope at depths ≥222 m. These sites had the finest sediments of all, averaging 12% very fine silt, 20% fine silt, 20% medium silt, 20% coarse silt, and 16% very fine sand.

Sediment Chemistry

Results of cluster analyses performed on sediment chemistry data collected between 2009 and 2012 discriminated 18 groups (Figures 8.7, 8.8). These groups (cluster groups A–R) differed in relative concentrations of metals, pesticides, total PCB and total PAH detected in sediments from each station (Appendices G.6, G.7). Contaminant levels present in 2012 were not distinct from previous years. Instead, sediment chemistry from all four years was linked to sediment particle size composition (RELATE $\rho=0.316$, $p=0.01$). Sediment sub-fractions that were most highly correlated to contaminants included several components of percent fines (clay, very fine silt, fine silt, medium silt) and larger particles referenced herein as granules, but are described in visual observations as shell hash or gravel (BEST $\rho=0.435$, $p=0.01$).

The three main contaminant groups (clusters L, O and P) included 83% of the 161 stations sampled, with each cluster representative of a different stratum. Group O comprised 55 stations primarily located within the SBOO monitoring region or at depths <25 m from Del Mar to Point Loma. This cluster was characterized by relatively coarse/sandy sediments as described for sites included in sediment cluster groups 1, 3, and 9 (see above). Group P had a mean depth of 88 m and comprised 57 mid-depth stations with finer sandy sediments (e.g., sediment groups 6 & 7) located in the "mud belt" of the PLOO region (see Chapter 9 and Thompson et al. 1993). Cluster group L had a mean depth of 301 m and represented outer shelf and upper slope stations where sediments were very fine (e.g., sediment groups 4 & 6). Together, these three groups represent typical background conditions for strata in the San Diego region. Contaminant levels at all stations in cluster groups O and P were below accepted thresholds; however, in group L, station 2655 exceeded the ERL for arsenic, and stations 2811, 2816, 8037, 8237, and 8238 exceeded the ERL for nickel.

The fifteen remaining cluster groups each comprised 1–6 "outlier" stations that differed from groups L, O, and P primarily by having higher values of a few select contaminants (Figure 8.8, Appendices G.6, G.7). For example, 41% of these stations had sediments with at least one contaminant that exceeded its ERL or ERM. Four outlier stations (groups A, B, E) were found along the upper slope at depths between 357 and 427 m and were characterized by the highest proportions of fine particles (58–88%). Stations 8242 (group A) and 8150 (group B) were both located at the mouth of La Jolla canyon and, together, had the highest concentrations of several metals. These included aluminum, antimony, copper, nickel, silver, and tin at station 8242, and arsenic, cadmium, and zinc at station 8150. Station 8242 also had the highest concentration of total nitrogen, while station 8150 had the highest concentration of sulfides. Sediments from stations 2812 and 2814 (group E) had the highest concentrations of chromium and selenium, and were the only sediments to contain detectable levels of chlordane. Another eight outlier stations from groups Q (2670, 8018) and R (2680, 2685, 8008, 8130, 8209, 8229) were located on the Coronado Bank or on the outer slope offshore of Mission Bay at depths between 98 and 169 m. Sediments from these stations had low percent fines (≤34%) compared to other outer shelf stations (e.g., see sediment cluster group 8), and had the highest mean concentrations of TOC, barium, and beryllium. The three outlier stations represented by groups D (8028) and H (2682, 8225) were collected at the LA-4 dredge spoils dumpsite at about 80 m or on the Coronado Bank. These had the highest concentrations of tDDTs and tPCBs, respectively, found during 2009−2012 surveys. Specifically, the ERL for tDDT was exceeded at stations 2682 and 8012, while the ERM was exceeded at station 8028. The remaining outlier stations were represented by



	Cluster Group	1	2	3	4	5	6	7	8	9
	n	11	3	26	14	1	40	32	20	15
	Depth (m)	41 (19–101)	114 (22–193)	24 (10–40)	340 (222–448)	16 —	141 (58–433)	98 (27–413)	124 (37–312)	33 (9–169)
Fine Particles (%)	CLAY	< 1	0	1	7	2	5	4	3	< 1
	VFSILT	< 1	0	2	12	2	8	6	5	< 1
	FSILT	< 1	0	3	20	4	12	8	7	< 1
	MSILT	< 1	0	4	20	13	14	9	5	< 1
	CSILT	2	38	11	20	35	26	18	5	2
Fine Sand (%)	VFSAND	2	42	49	16	33	29	36	13	17
	FSAND	6	7	27	5	10	7	16	36	50
Coarse Sand (%)	MSAND	25	4	3	1	1	1	2	23	21
	CSAND	42	3	< 1	< 1	< 1	< 1	< 1	3	8
Coarse Particles (%)	VCSAND	15	3	0	0	0	0	0	< 1	1
	GRANULES	8	4	0	0	0	0	< 1	< 1	1

Figure 8.5

Cluster analysis of particle size sub-fraction data from regional benthic stations sampled between 2009 and 2012. Data for depth and particle size sub-fractions are expressed as mean values over all stations within a cluster group (n). Depth range is also included for each group. VFSILT = Very Fine Silt; FSILT = Fine Silt; MSILT = Medium Silt; CSILT = Coarse Silt; VFSAND = Very Fine Sand; FSAND = Fine Sand; MSAND = Medium Sand; CSAND = Coarse Sand; VCSAND = Very Coarse Sand.

groups I, J, K, M, and N in the PLOO monitoring region, and by groups C, F, G, and N in the SBOO monitoring region. Sediments from these sites were characterized by concentrations of metals, organic indicators, and other contaminants that were intermediate to those characteristic of groups L, O, and P versus the outlier clusters described above.

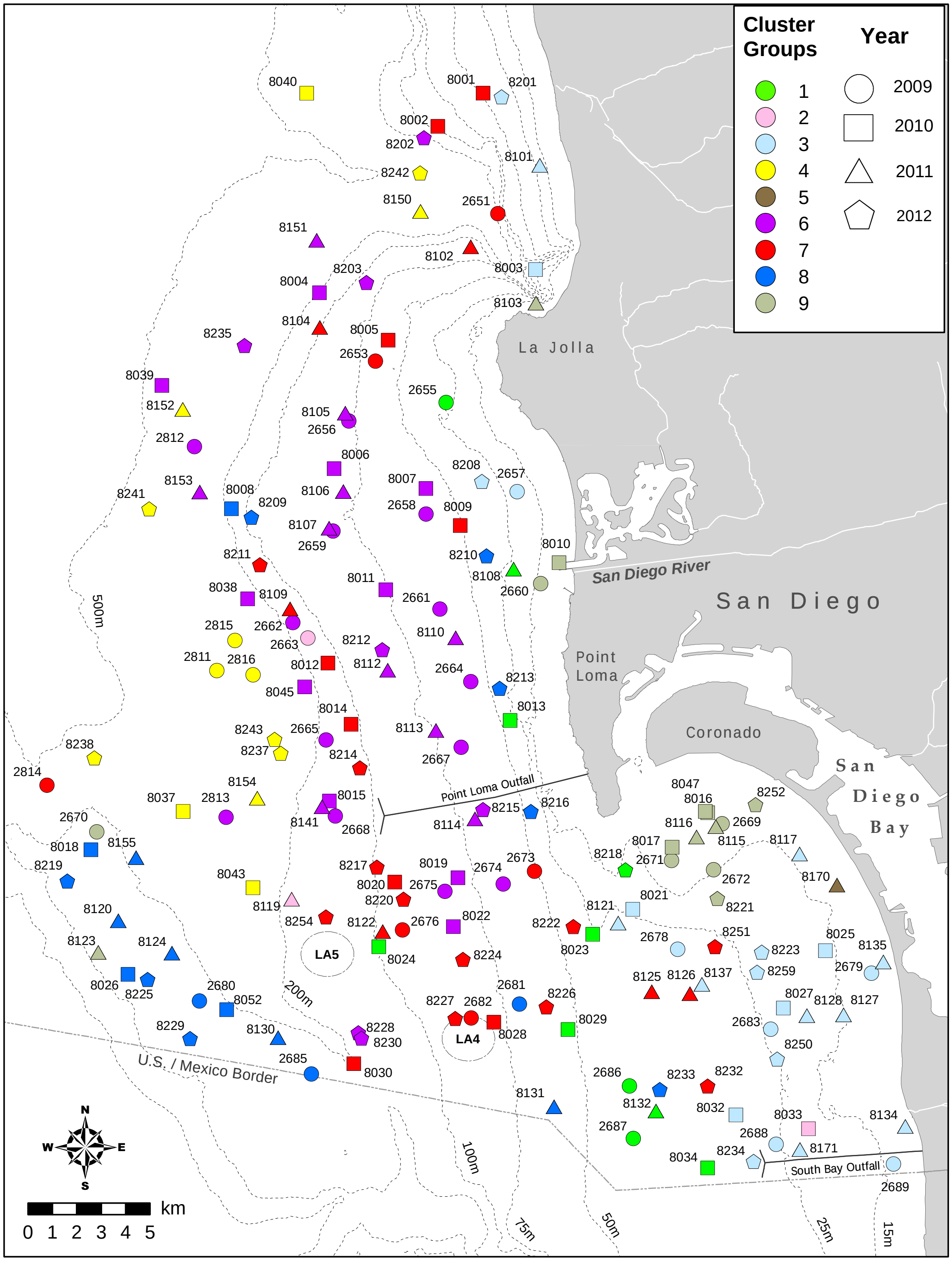


Figure 8.6
Spatial distribution of particle size cluster groups in the San Diego region. Colors of each circle correspond to colors in Figure 8.5.

Summary

Particle size composition at the regional benthic stations sampled in 2012 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 2008–2011, 2012a,b). Overall, sediments varied as expected by region and depth

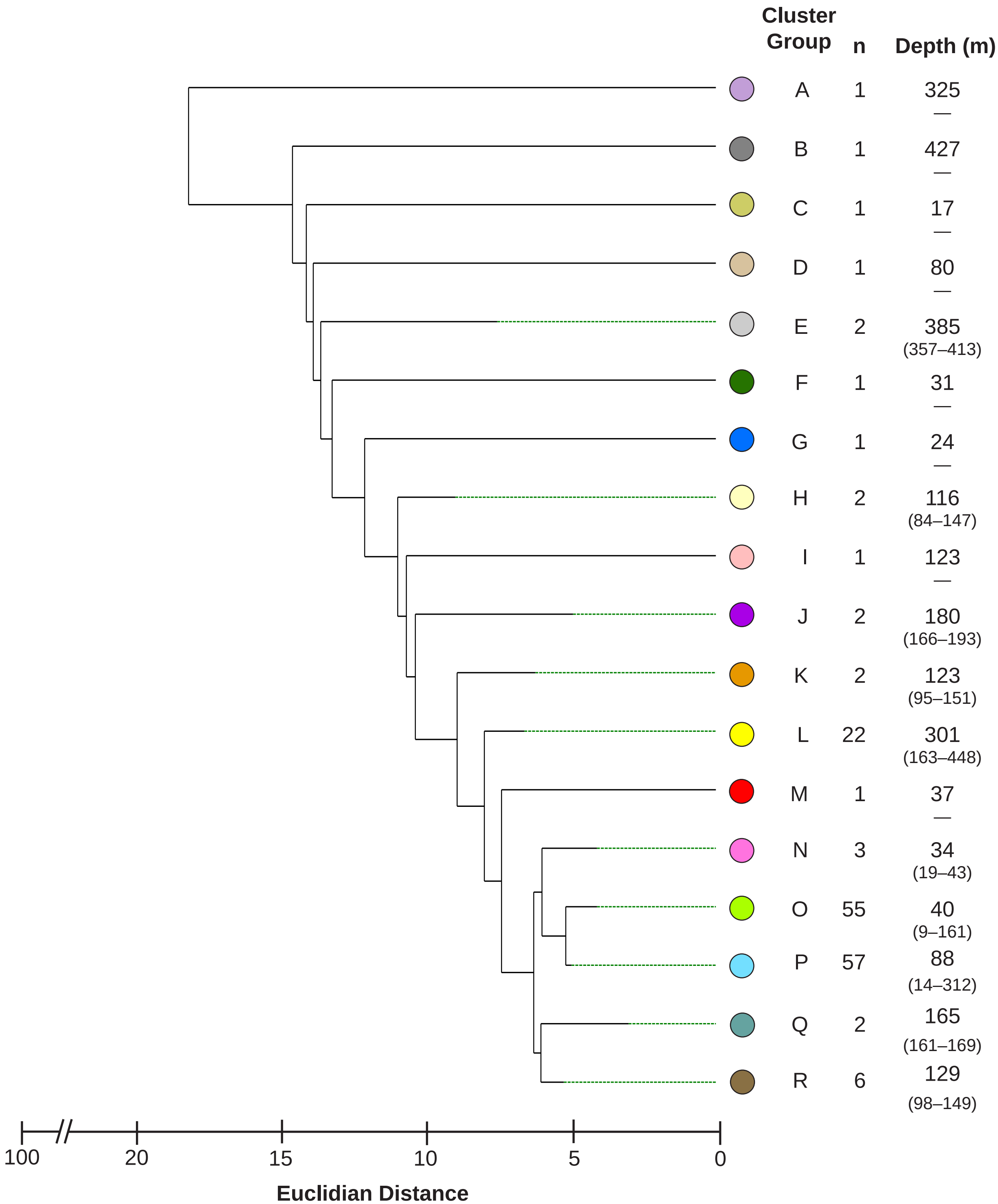


Figure 8.7

Cluster analyses of sediment chemistry data from regional benthic stations sampled between 2009−2012. Data for depth includes the mean (range) of values calculated over all stations within each group (n).

stratum. For example, regional stations sampled along the inner and middle shelf within the vicinity of SBOO fixed-grid stations (see Chapter 4) tended to be predominantly sand, whereas regional stations sampled along the middle and outer shelf within the vicinity of PLOO fixed-grid stations (see City of San Diego 2012a) typically had much finer sediments. However, exceptions to this overall

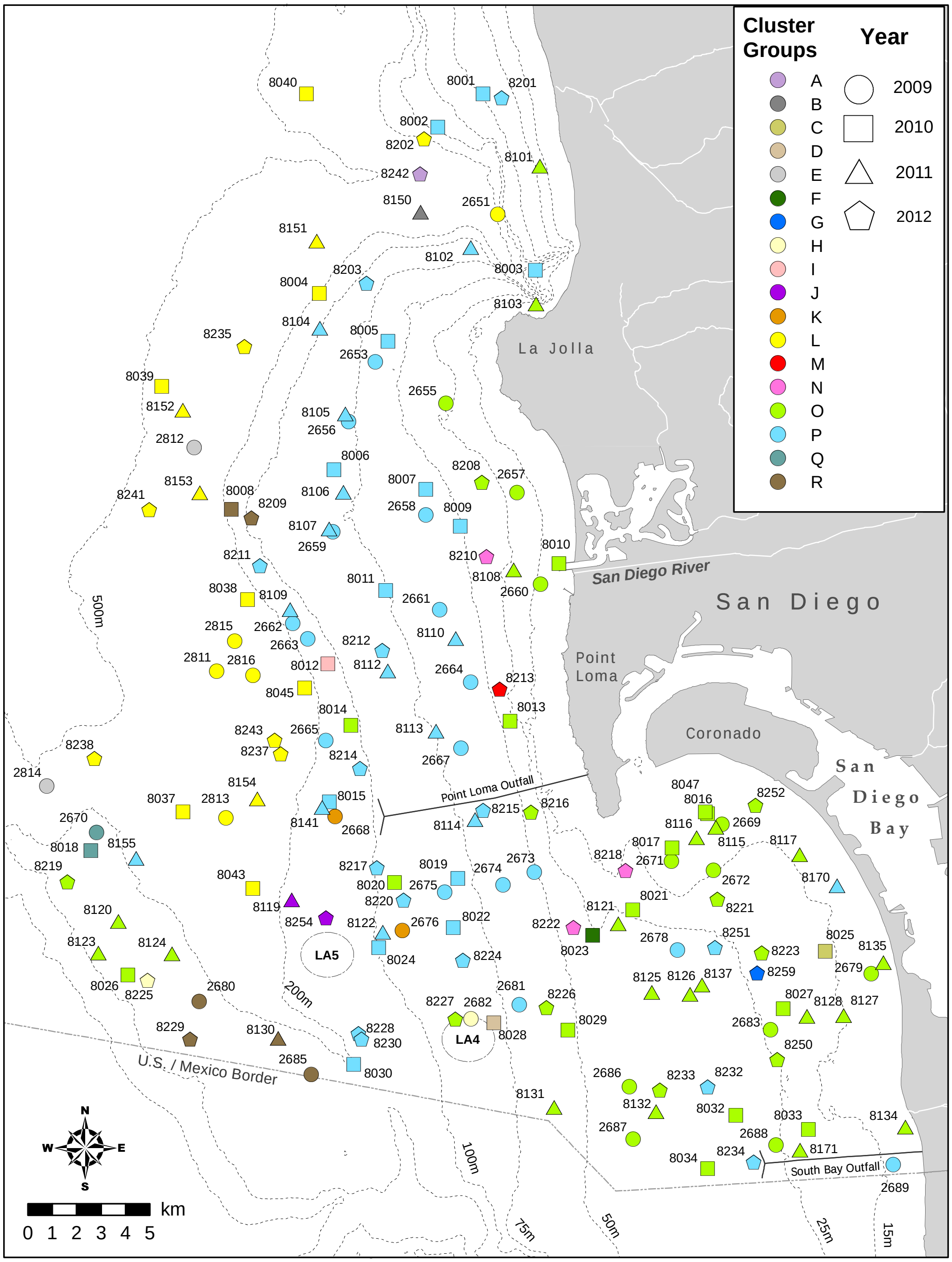


Figure 8.8

Spatial distribution of sediment chemistry cluster groups in the San Diego region. Colors of each circle correspond to colors in Figure 8.7.

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 2012 were similar to patterns seen in previous years. There was no evidence of degraded sediment quality in the general San Diego region. While various indicators of organic loading, trace metals, chlorinated pesticides, PCBs and PAHs were detected at variable concentrations in sediment samples collected throughout the region, almost all contaminants occurred at levels below both ERL and ERM thresholds, as they have in previous years (City of San Diego 2008–2011, 2012b). The only exceptions during 2012 were nickel, which exceeded its ERL at three stations, arsenic, which exceeded its ERL at two stations, mercury, which exceeded its ERL at one station, and silver, which exceeded its ERM at one station. Further, there was no evidence of sediment contamination during the 2009−2012 regional surveys that could be attributed to local wastewater discharges. Instead, concentrations of total nitrogen, total volatile solids and several trace metals were found to increase with increasing amounts of fine sediments (percent fines). Percent fines increased with depth in the 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).

Literature Cited

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

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

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

City of Los Angeles. (2007). Santa Monica Bay Biennial Assessment Report 2005–2006. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

City of Los Angeles. (2008). Los Angeles Harbor Biennial Assessment Report 2006–2007. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

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

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan

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

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

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

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

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

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

City of San Diego. (2013). 2012 Annual Reports and Summary for the South Bay Wastewater Reclamation Plant and Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R. and R.M. Warwick. (2001). Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. PRIMER-E, Plymouth.

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

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

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

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

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

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

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

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

[LACSD] Los Angeles County Sanitation Districts. (2012). Joint Water Pollution Control Plant Biennial Receiving Water Monitoring Report 2010–2011. Whittier, CA: Los Angeles County Sanitation Districts, Ocean Monitoring and Research Group, Technical Services Department.

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

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

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

[OCSD] Orange County Sanitation District. (2012). Annual Report, July 2010–June 2011. Marine Monitoring, Fountain Valley, California.

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

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

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

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

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

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

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

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

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

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

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

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

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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). Examples of such local assessments include the regular ongoing surveys conducted each year around the ocean outfalls operated by the City of Los Angeles, the City of San Diego, the Los Angeles County Sanitation District, and the Orange County Sanitation District, the four largest wastewater dischargers in the region (City of Los Angeles 2007, 2008, City of San Diego 2012a, b, LACSD 2012, OCSD 2012). 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).

The City of San Diego has 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 south of Del Mar to the USA/Mexico border, are to (1) describe the overall condition and quality of the diverse benthic habitats that occur off San Diego, (2) characterize the ecological health of the soft-bottom marine benthos in the region, and (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 also 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), and surveys in 1994, 1998, 2003 and 2008 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).

This chapter presents analyses and interpretations of the benthic macrofaunal data collected during the 2012 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 from the 2009–2012 regional surveys that describe and compare the soft-bottom macrobenthic assemblages present. Although regional data exist prior to this time period, 2009 represents the first year where upper slope sites were included as a fourth depth stratum, allowing this region to be comparable to the three continental shelf strata. Results of benthic sediment quality analyses at the same stations are presented in Chapter 8.

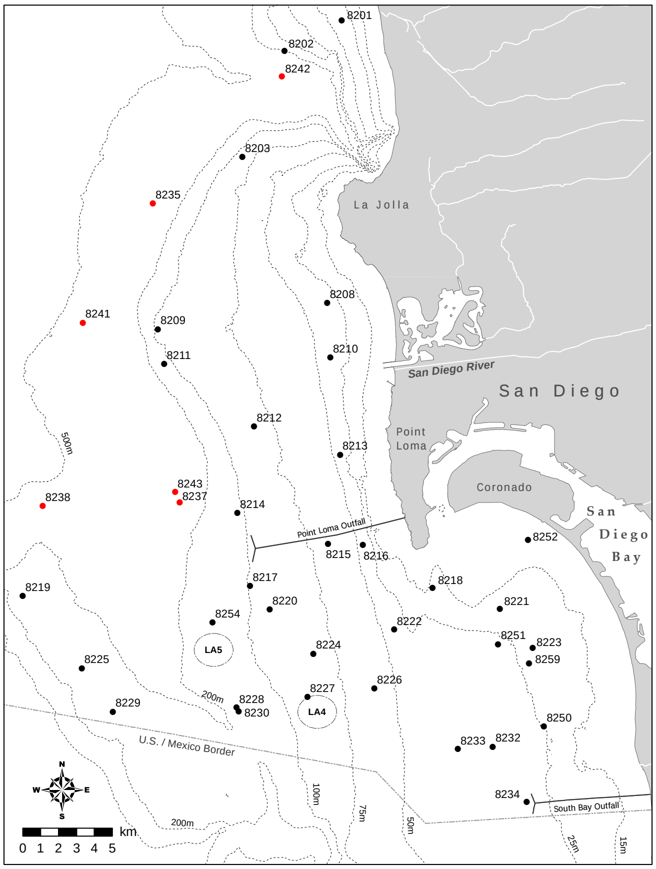


Figure 9.1
Regional benthic survey stations sampled during July 2012 as part of the City of San Diego's Ocean Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

Materials and Methods

Collection and Processing of Samples

The July 2012 regional survey covered an area ranging south of Del Mar in northern San Diego County south to the USA/Mexico border (Figure 9.1). Overall, this survey included 40 stations ranging in depth from 11 to 448 m and spanning four distinct depth strata characterized by the SCB regional monitoring programs (Ranasinghe et al. 2007). These included 8 stations along the inner shelf (5–30 m), 19 stations along the mid-shelf (>30–120 m), 7 stations along the outer shelf (>120–200 m), and 6 stations on the upper slope (>200–500 m).

Samples for benthic community analyses were collected at each station using a double 0.1-m^2 Van Veen grab; one grab from each cast was used to sample macrofauna, while the adjacent grab was used to assess sediment quality (see Chapter 8). To ensure consistency of grab samples, protocols established by the United States Environmental Protection Agency (USEPA) were followed to standardize sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen, and all debris and organisms retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution before fixing in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the grunge into major taxonomic groups by a subcontracted laboratory, and identified to species (or the lowest taxon possible) following SCAMIT (2012) nomenclature and enumerated by City of San Diego marine biologists.

Data Analyses

For 2012 data, the following community structure parameters were calculated for each station per 0.1m^2-grab: species richness (number of species), 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 in the regional benthic macrofaunal data collected from 2009 to 2012, multivariate analyses were conducted using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). These 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 supported by SIMPROF were retained, and similarity percentages analysis (SIMPER) was used to determine which organisms 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 or other factors (e.g., increased organics), a RELATE test was used to compare patterns in the macrofauna Bray-Curtis similarity and sediment Euclidean distance matrices (see Chapter 8). When significant similarity was found, a BEST test using the BIO-ENV amalgamate was conducted to determine which subset of sediment sub-fractions were the best explanatory variables for similarity between the two resemblance matrices.

Results and Discussion

Community Parameters

Species richness

A total of 628 taxa were identified during the 2012 regional surveys. Of these, 523 (83%) were identified to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although 35% (n = 221) were recorded only once. Two taxa not previously reported for the City's Ocean Monitoring Program were recorded: an amphipod identified to the subfamily Parapleustinae and an isopod in the genus *Ianiropsis.*

Species richness by station ranged from 18 to 151 taxa (Table 9.1) with the lowest values (≤26 taxa) occurring at the three deepest stations sampled (i.e., 8238, 8241, 8242), and the highest value occurring at mid-shelf station 8226 (57-m) located south of Point Loma (Figure 9.1). Mean species richness by stratum increased from 78 taxa per station on the inner shelf to a high of 88 taxa on the mid-shelf, and then decreased with depth to 55 taxa on the outer shelf and 30 taxa on the upper slope (Figure 9.2A). Species richness on the inner shelf in 2012 was higher than recorded from 2009 to 2011 (City of San Diego 2012b), and may be due to the majority of inner shelf stations from 2009 to 2011 occurring at depths ≤20 m while 2012 stations primarily occurred between 20 and 30-m depths where species richness tends to be higher. Overall, species richness from mid-shelf to upper slope strata were slightly lower than last year, but were within the 95% confidence intervals calculated for 2009–2011.

Macrofaunal abundance

A total of 10,846 macrofaunal individuals were counted during the 2012 regional surveys. Abundance by station ranged from 52 to 682 animals (Table 9.1) with the fewest individuals found at upper slope station 8238 (355-m) and the most individuals found at mid-shelf station 8226, the same site that had highest species richness (Figure 9.1). Mean abundance by stratum was similarly high on the inner and mid-shelves with 345 and 350 individuals per station, respectively, and decreased to 137 individuals per station on the outer shelf, and to 81 individuals per station on the upper slope (Figure 9.2B). High abundances on the inner and mid-shelf were due, in part, to relatively large populations of the spionid polychaete *Spiophanes norrisi*. Though the relative number of most other taxa remained similar, higher abundances of *S. norrisi* in 2012 led to higher overall macrofaunal abundance on the inner shelf than recorded from 2009 to 2011 (City of San Diego 2012b). Macrofaunal abundances from the outer shelf and upper slope were lower than last year, but were within the 95% confidence intervals calculated for 2009–2011. Although abundance has decreased temporally on the outer shelf since 2009, no reduction in any specific taxa appear responsible for this decline, and depths sampled each year are similar and do not suggest a sampling bias has occurred.

Diversity and evenness

During 2012, diversity (H') ranged from 2.0 to 4.2 (Table 9.1) with the lowest value occurring at upper slope station 8242 and the highest value occurring at inner shelf station 8251 (Figure 9.1). Mean diversity by stratum ranged from a high of 3.7 on the mid-shelf to a low of 2.9 on the upper slope, with

Table 9.1

Macrofaunal community parameters calculated per 0.1-m^2 grab at regional stations sampled during 2012. 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	8252	11	56	166	3.6	0.91	23	20
	8218	19	68	564	3.2	0.75	14	16
	8221	21	65	310	3.1	0.74	16	17
	8223	22	68	162	3.8	0.90	29	22
	8259	24	84	404	3.1	0.71	19	25
	8250	25	74	346	3.2	0.75	21	26
	8208	27	108	475	4.0	0.85	35	24
	8251	27	103	329	4.2	0.90	39	27
Mid-shelf	8234	31	89	292	3.9	0.88	32	25
	8232	36	97	373	3.9	0.86	32	21
	8213	37	90	417	3.6	0.80	24	29
	8233	38	57	286	2.5	0.62	9	21
	8201	39	97	335	4.1	0.90	37	26
	8210	39	71	413	3.2	0.74	15	27
	8216	40	101	613	3.4	0.75	19	30
	8222	43	84	326	3.8	0.85	30	24
	8226	57	151	682	3.9	0.78	42	17
	8215	68	96	438	3.5	0.77	24	16
	8212	83	80	324	3.8	0.86	28	11
	8224	85	71	285	3.2	0.74	19	8
	8227	87	73	255	3.6	0.84	26	7
	8203	94	91	256	4.0	0.89	36	9
	8220	94	77	266	3.7	0.86	29	5
	8209	98	93	276	4.1	0.90	39	13
	8217	102	82	240	3.8	0.87	28	14
	8211	107	78	229	3.9	0.89	29	13
	8214	112	97	338	4.0	0.88	35	12
Outer Shelf	8225	147	45	118	3.3	0.86	18	15
	8228	148	53	109	3.6	0.91	26	13
	8229	149	57	156	3.7	0.92	26	8
	8230	149	78	169	4.0	0.91	36	8
	8219	161	31	72	3.0	0.88	14	15
	8254	166	52	106	3.7	0.94	26	21
	8202	195	66	232	3.5	0.83	22	24
Upper Slope	8237	247	34	70	3.2	0.90	17	—
	8243	263	32	59	3.2	0.92	18	—
	8235	276	48	127	3.4	0.87	19	—
	8242	325	18	99	2.0	0.70	4	—
	8238	355	24	52	2.5	0.79	12	—
	8241	448	26	77	2.9	0.88	11	—

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

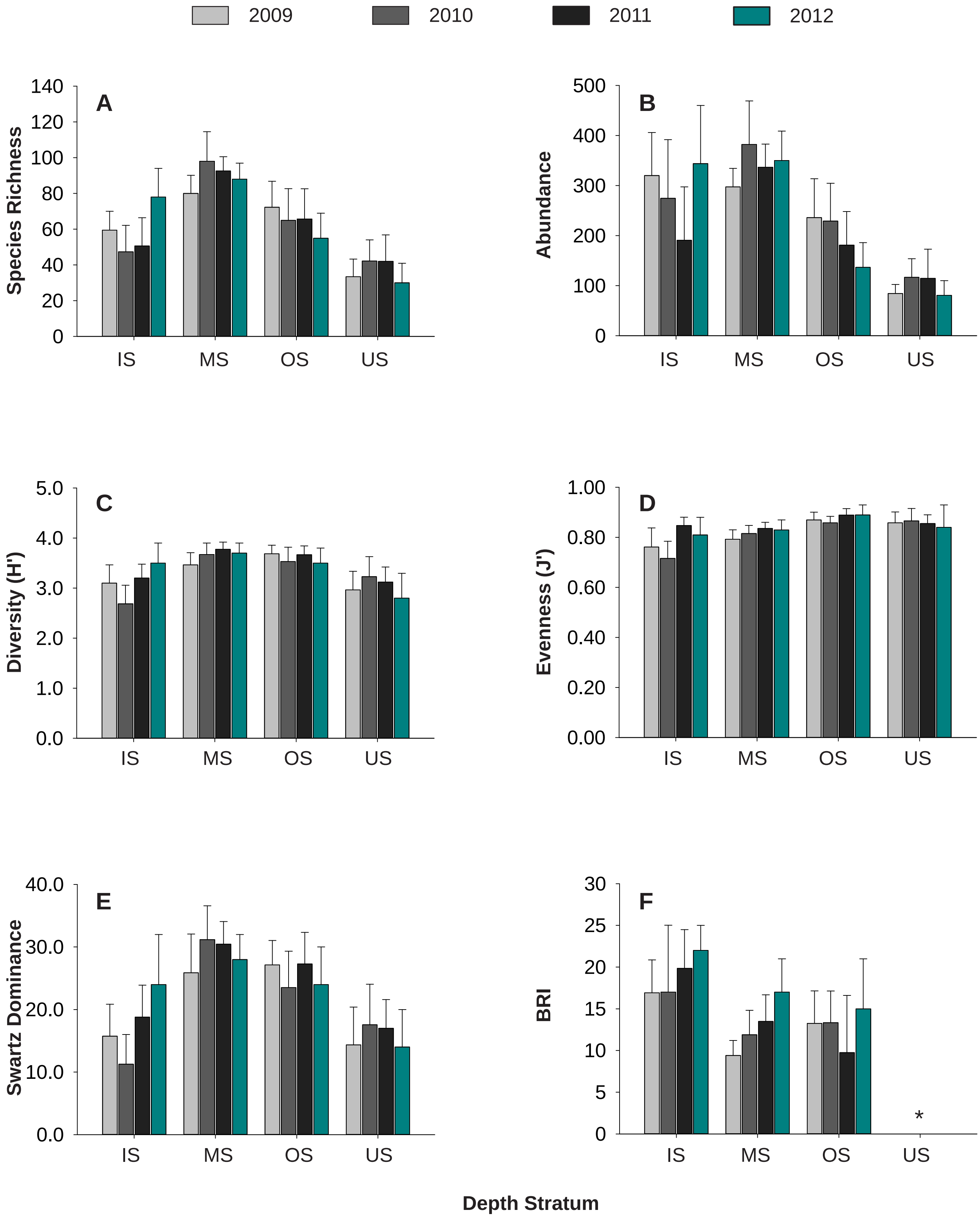


Figure 9.2

Comparison of macrofaunal community structure metrics for the four major depth strata sampled during regional surveys between 2009 and 2012. Data are expressed as means + 95% confidence interval (per 0.1 m^2). IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope. *BRI not calculated for upper slope stations.

a mid-range value of 3.5 occurring on both inner and outer shelf strata (Figure 9.2C). Evenness (J') compliments 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. J' values ranged from 0.62 to 0.94 during the year with the lowest value occurring at mid-shelf station 8233 and the highest value occurring at outer shelf station 8254. Mean evenness by stratum progressively increased from 0.81 on the inner shelf to 0.89 on the outer shelf, and then decreased to 0.84 on the upper slope (Figure 9.2D). Diversity and evenness values have remained relatively stable from 2009 to 2012, and exhibited little variability within and among strata.

Dominance

Swartz dominance values ranged between 4 and 42 taxa per station during 2012 (Table 9.1). Highest dominance (i.e., lowest index value) occurred at station 8242 on the upper slope of La Jolla Canyon where abundances of the molluscs *Lirobittium larum* and *Macoma carlottensis*, and the polychaetes *Prionospio* (*Prionospio*) *ehlersi* and *Leitoscoloplos* sp A accounted for the majority of individuals in each grab. This station also had the lowest species richness and diversity values found during the year. Lowest dominance (i.e., highest index value) occurred at mid-shelf station 8226 where numerous species co-occurred in relatively high abundances. As discussed above, station 8226 also had the highest species richness and abundance values found during the year. Mean dominance by stratum increased from 25 taxa per station on the inner shelf to 28 taxa on the mid-shelf, and then progressively decreased with depth to 14 taxa on the upper slope (Figure 9.2E). With the exception of the inner shelf, dominance in 2012 was lower on each stratum than 2011 (City of San Diego 2012b), but was within the 95% confidence intervals calculated between 2009 and 2011.

Benthic response index (BRI)

The benthic response index (BRI) is an important tool for gauging possible anthropogenic impacts to marine environments throughout the SCB. Values below 25 are considered indicative of reference conditions, values 25–33 represent "a minor deviation from reference conditions," and values ≥34 represent increasing levels of degradation (Smith et al. 2001). During 2012, BRI was only calculated for shelf stations because many upper slope stations occurred at depths outside the calibrated range (i.e., >324 m). Where calculated, BRI ranged from 5 to 30 (Table 9.1) with high and low values both occurring on the mid-shelf at stations 8216 and 8220, respectively. Overall, 76% of the stations had values indicative of reference conditions. The remaining stations had values indicating only a minor deviation from reference conditions, and all occurred at depths shallower than 40 m. Mean BRI by stratum progressively decreased from 22 on the inner shelf to 15 on the outer shelf. 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). For example, in 2012, total volatile solids were considerably higher on inner shelf strata compared to mid- and outer shelf depths (see Table 8.1 in Chapter 8). These increased organics likely led to BRI values ≥25 at shallow stations due, in part, to greater abundances of the polychaetes *Mediomastus* sp, *Spiochaetopterus costarum* Cmplx and *Magelona* spp (Table 9.2). However, all these species represent natural and expected components of inner to mid-shelf communities in the SCB and are not cause for alarm. BRI values for all shelf strata were higher in 2012 than in previous years, but most were within the 95% confidence intervals calculated between 2009 and 2011 (Figure 9.2F).

Dominant Taxa

Annelid worms (mostly polychaetes) were the largest contributors to macrofaunal diversity in the San Diego region during 2012 with 6643 individuals identified from 301 taxa (48% of all taxa recorded). Arthropods (mostly crustaceans) numbered 1892 individuals in 138 taxa (22%), followed by 921 echinoderms in 30 taxa (5%) and 762 molluscs in 100 taxa (16%). Other phyla, a group that includes cnidarians, nemerteans, echiurans, nematodes, sipunculids, phoronids, chordates, brachiopods and platyhelminthes, numbered 628 individuals

Table 9.2

The 10 most abundant macroinvertebrate taxa per depth stratum collected at regional benthic stations sampled during 2012. AS = abundance/survey; PO = percent occurrence (percent of total annual sites at which the species was collected); AO = abundance/occurrence. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample.

Strata	Species	Taxonomic Classification	AS	PO	AO
Inner Shelf	*Spiophanes norrisi*	Polychaeta: Spionidae	49.8	100	49.8
	NEMATODA	Nematoda	17.1	75	22.8
	Mediomastus sp	Polychaeta: Capitellidae	14.9	88	17.0
	Monticellina siblina	Polychaeta: Cirratulidae	11.2	75	15.0
	Spiochaetopterus costarum Cmplx	Polychaeta: Chaetopteridae	7.8	75	10.3
	Polycirrus sp SD3	Polychaeta: Terebellidae	7.2	12	58.0
	Magelona sacculata	Polychaeta: Magelonidae	6.9	75	9.2
	Photis brevipes	Arthropoda: Amphipoda	6.5	38	17.3
	Ampelisca cristata cristata	Arthropoda: Amphipoda	6.0	50	12.0
	Pareurythoe californica	Polychaeta: Amphinomidae	5.5	12	44.0
Mid-shelf	*Spiophanes norrisi*	Polychaeta: Spionidae	23.6	42	56.1
	Amphiodia urtica	Echinodermata: Ophiuroidea	22.1	63	35.0
	Prionospio (*Prionospio*) *jubata*	Polychaeta: Spionidae	12.4	95	13.1
	Spiochaetopterus costarum Cmplx	Polychaeta: Chaetopteridae	10.1	68	14.8
	Photis californica	Arthropoda: Amphipoda	8.5	32	26.8
	Amphiodia sp	Echinodermata: Ophiuroidea	7.3	63	11.5
	Pista sp	Polychaeta: Terebellidae	6.9	16	44.0
	Amphiuridae	Echinodermata: Ophiuroidea	5.8	84	6.9
	Chaetozone hartmanae	Polychaeta: Cirratulidae	5.4	63	8.6
	Euphilomedes producta	Arthropoda: Ostracoda	5.4	47	11.3
Outer Shelf	*Spiophanes kimballi*	Polychaeta: Spionidae	12.0	71	16.8
	Aphelochaeta glandaria Cmplx	Polychaeta: Cirratulidae	9.3	100	9.3
	Tellina carpenteri	Mollusca: Bivalvia	6.9	86	8.0
	Paraprionospio alata	Polychaeta: Spionidae	5.0	100	5.0
	Monticellina siblina	Polychaeta: Cirratulidae	2.9	43	6.7
	Chloeia pinnata	Polychaeta: Amphinomidae	2.9	14	20.0
	Dougaloplus amphacanthus	Echinodermata: Ophiuroidea	2.7	57	4.8
	Chaetozone sp	Polychaeta: Cirratulidae	2.4	43	5.7
	Leptochelia dubia Cmplx	Arthropoda: Tanaidacea	2.4	43	5.7
	Aphelochaeta monilaris	Polychaeta: Cirratulidae	2.3	71	3.2
Upper Slope	*Lirobittium larum*	Mollusca: Gastropoda	6.2	17	37.0
	Maldane sarsi	Polychaeta: Maldanidae	4.7	83	5.6
	Eclysippe trilobata	Polychaeta: Ampharetidae	4.3	33	13.0
	Macoma carlottensis	Mollusca: Bivalvia	4.0	33	12.0
	Tellina carpenteri	Mollusca: Bivalvia	3.8	33	11.5
	Melinna heterodonta	Polychaeta: Ampharetidae	3.7	50	7.3
	Prionospio (*Prionospio*) *ehlersi*	Polychaeta: Spionidae	3.5	50	7.0
	Paraprionospio alata	Polychaeta: Spionidae	3.3	83	4.0
	Compressidens stearnsii	Mollusca: Scaphopoda	2.5	50	5.0
	Chloeia pinnata	Polychaeta: Amphinomidae	2.2	67	3.2

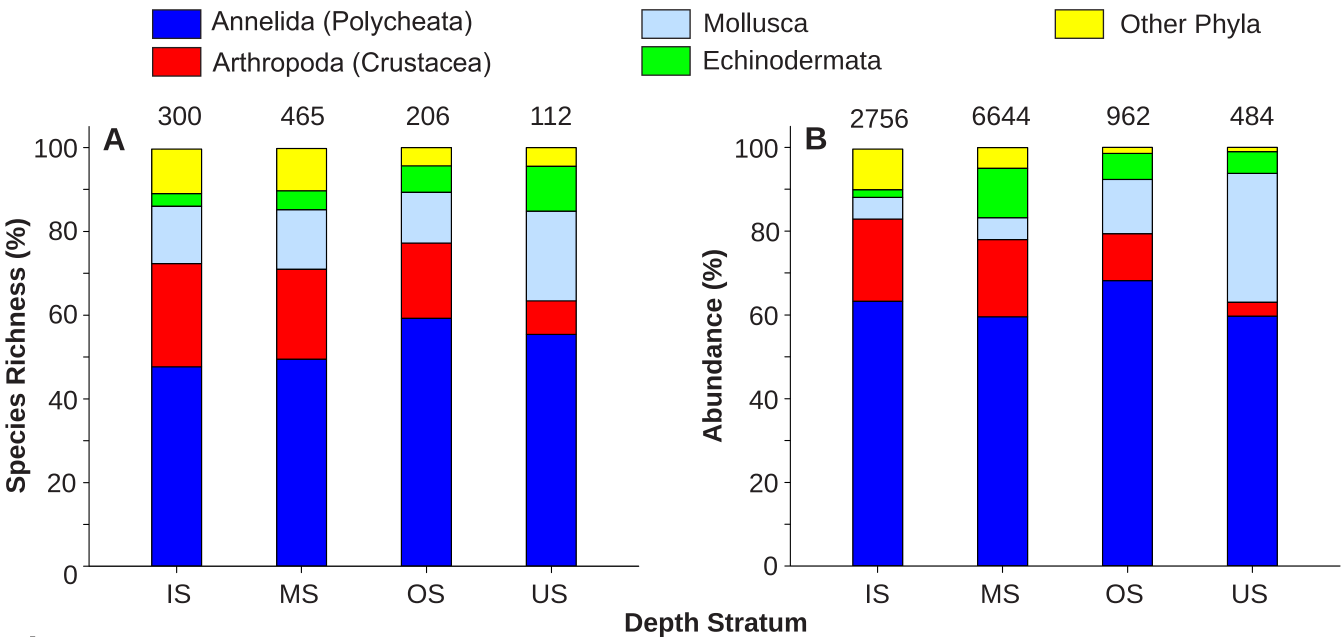


Figure 9.3
Percent contribution of major taxonomic groups (phyla) to (A) species richness and (B) abundance by depth stratum. Numbers above bars represent (A) total number of taxa and (B) total number of individual organisms enumerated for each stratum during 2012. IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope.

in 59 taxa (9%). The contribution of major taxa to species richness differed by stratum with the percentage of: (1) polychaetes increasing slightly from 48% along the inner shelf to 59% along the outer shelf, then decreasing to 55% on the upper slope, (2) echinoderms increasing with depth from 3% on the inner shelf to 11% on the upper slope, (3) molluscs increasing on the upper slope, and (4) crustaceans and other phyla decreasing with depth (Figure 9.3A). The contribution of major taxa to abundance also differed by stratum with the percentage of: (1) crustaceans and other phyla decreasing with depth, and (2) molluscs increasing by depth (Figure 9.3B). Patterns of species richness and abundance by depth strata were almost identical to those seen in 2011 (City of San Diego 2012b).

Although only a subset of the total number of species found across the San Diego region was present in each grab, polychaetes were typically dominant with mean percent composition and abundance values of 55% and 61% per grab, respectively (Table 9.3). Crustaceans followed with a mean percent composition of 19% and mean abundance of 16%. Molluscs, echinoderms, and other phyla each contributed to ≤13% of total invertebrate composition, and ≤10% of total abundance. Overall, the percentage of taxa that occurred within each major taxonomic grouping and their relative abundances were similar to those observed in 2011 (City of San Diego 2012b).

The dominant species encountered in 2012 varied among strata (Table 9.2). Within each depth stratum only 40–50% of the 10 most dominant species found in 2012 were also most dominant in 2011 (City of San Diego 2012b). The most notable change between years was the large increase in abundances of *S. norrisi* at inner to mid-shelf stations.

Along the inner shelf, the 10 most abundant taxa included seven polychaetes, two crustaceans and nematodes. Of these, the spionid polychaete *Spiophanes norrisi* was the most common and most abundant species, occurring at 100% of stations and averaging ~50 individuals per 0.1-m^2 grab. All other taxa averaged ≤17 animals per grab and occurred at ≤88% of stations. Although only occurring at single stations, high abundances of the polychaetes *Polycirrus* sp SD3 and *Pareurythoe californica* resulted in high mean abundances for these taxa on the entire stratum.

The 10 most abundant taxa along the mid-shelf included five polychaetes, three ophiuroids and two crustaceans. The most abundant species were *Spiophanes norrisi* and the ophiuroid *Amphiodia urtica*, which averaged 24 and 22 animals per grab, respectively. No other species had mean abundances >12 individuals per grab. Of the 10 taxa listed, the most common mid-shelf species was the spionid polychaete *Prionospio* (*Prionospio*) *jubata*, which occurred at 95% of stations. No other taxon occurred at >84% of stations.

On the outer shelf, the 10 most abundant species included seven polychaetes, one mollusc, one ophiuroid and one crustacean. The spionid polychaete *Spiophanes kimballi* was most abundant species, averaging 12 animals per grab, with no other species averaging >9 animals per station. The most common species were the cirratulid polychaete *Aphelochaeta glandaria* Cmplx and the spionid polychaete *Paraprionospio alata*. Both occurred at 100% of stations sampled, with no other species occurring at >86% of stations. Although common at many mid-shelf stations, the polychaete *Chloeia pinnata* only occurred at one outer shelf station but with an abundance of 20 individuals, resulting in a high overall mean abundance for this taxon.

The 10 most abundant taxa along the upper slope included six polychaetes and four molluscs. The gastropod *Lirobittium larum* occurred at one upper slope station (although it was also recorded from one mid-shelf site); however, its high abundance of 37 individuals at this location resulted in this species having the highest average abundance of any animal on the upper slope with 6 animals per grab. The most common species were *Paraprionospio alata* and the maldanid polychaete *Maldane sarsi*, both of which occurred at 83% of slope stations. No other species had mean abundances of >5 individuals per grab or occurred at more than 67% of stations.

Table 9.3
Percent composition and abundance of major taxonomic groups (phyla) for regional stations sampled during 2012. Data are expressed as means (range) for all stations combined; n = 40.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	55 (30–74)	61 (31–87)
Arthropoda (Crustacea)	19 (0–36)	16 (0–37)
Mollusca	13 (2–28)	10 (1–62)
Echinodermata	6 (0–17)	9 (0–46)
Other Phyla	9 (0–21)	5 (0–29)

Indicator Species

Species known to be indicators of environmental change that occur in the San Diego region include the polychaetes *Capitella teleta* and *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 2012 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 *Capitella teleta* and *Solemya pervernicosa* remained low, with only two individuals of *C. teleta* and eight individuals of *S. pervernicosa* found across the entire region.

Classification of Regional Macrobenthic Shelf and Slope Assemblages (2009–2012)

Similarity of Assemblages
Classification (cluster) analysis of invertebrate communities from 161 stations sampled from

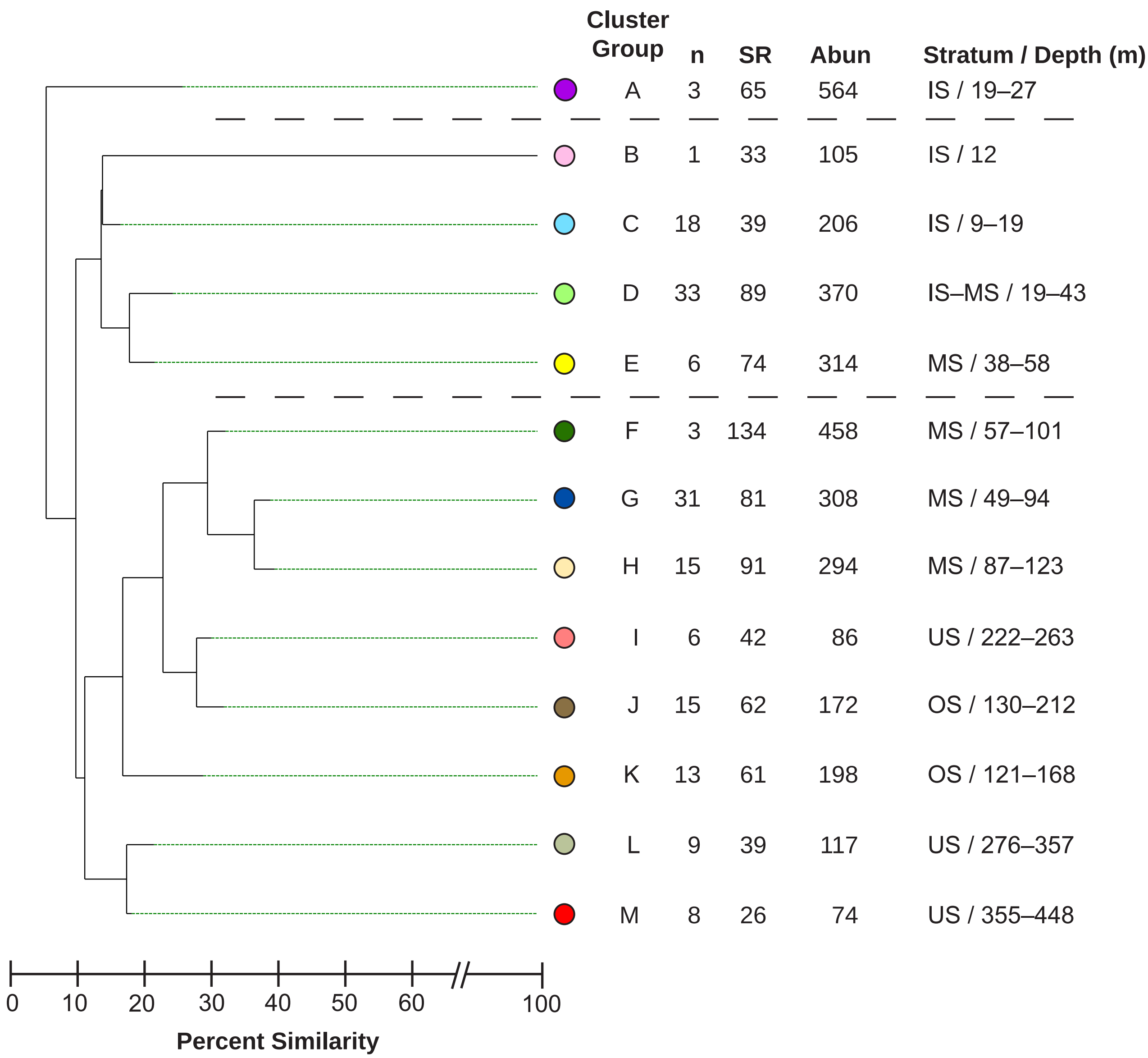


Figure 9.4
Cluster analysis of macrofaunal assemblages at regional benthic stations sampled between 2009 and 2012. Data for species richness (SR) and infaunal abundance (Abun) are expressed as mean values per 0.1 m^2 over all stations in each group (n). Dashed lines indicate delineation of megaclusters. IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope.

2009 to 2012 discriminated 13 ecologically-relevant SIMPROF-supported groups (Figures 9.4, 9.5, Appendix H.1). These "assemblages" (referred to herein as cluster groups A–M) occurred at 1–33 stations each, and exhibited mean species richness ranging from 26 to 134 taxa per station and mean abundances of 74 to 564 individuals per station. Cluster groups typically had representative stations from each survey year, with no temporal partitioning evident. As first observed during 2011 regional analyses (City of San Diego 2012b), macrofaunal communities occurring in shallow, coarse sediments (mean percent fines = 2.8%) having substantial amounts of shell hash formed a unique group that subtended two "megaclusters," each of which consist of multiple cluster groups. These megaclusters were defined primarily by depth and sediment characteristics, and included: (1) groups B–E representing stations with relatively coarse materials (mean percent fines = 16%) located at inner to mid-shelf depths between 9 and 58 m; and (2) groups F–M comprising stations with relatively

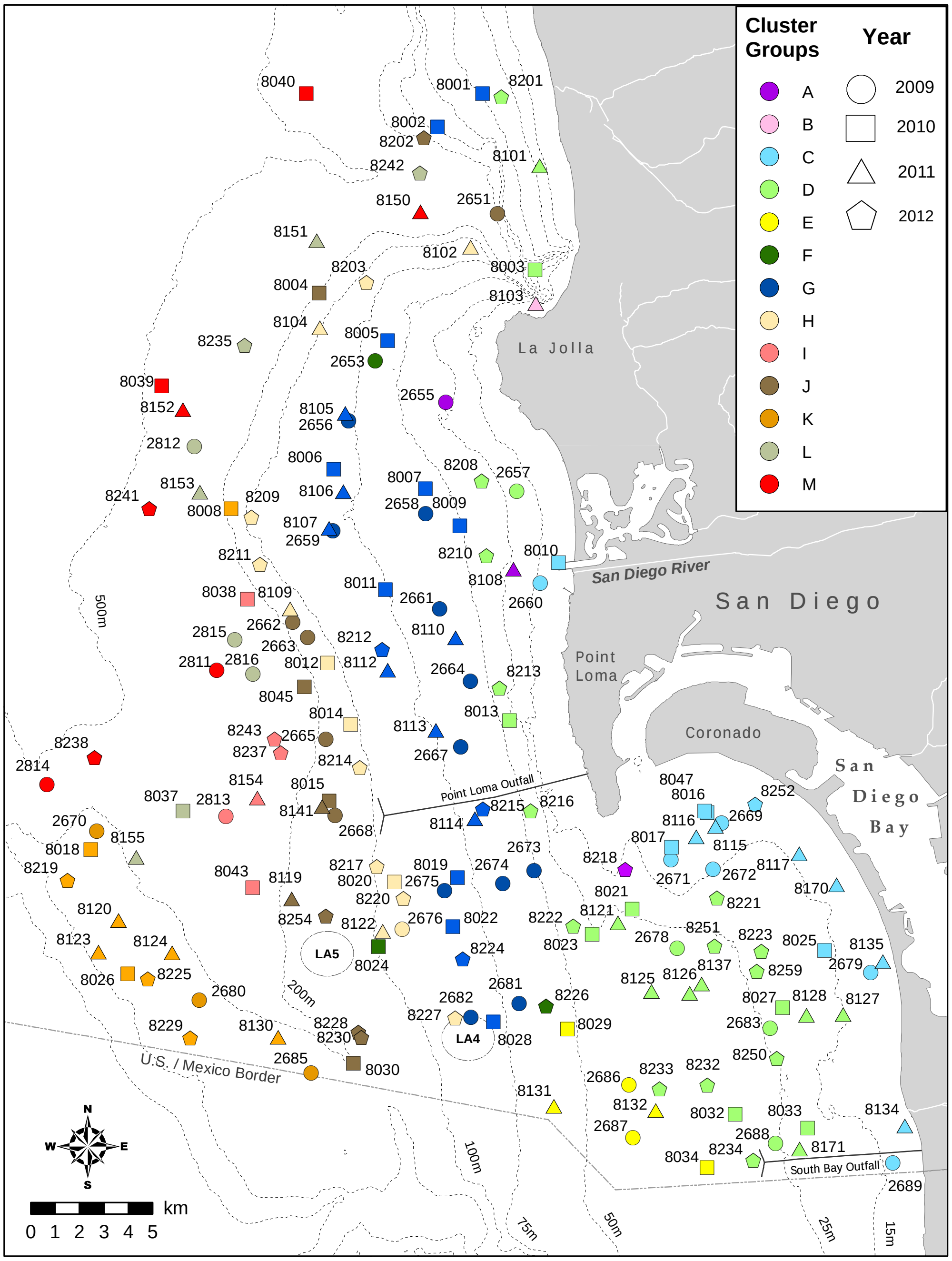


Figure 9.5

Spatial distribution of cluster groups in the San Diego region. Colors of each circle correspond to colors in Figure 9.4.

fine materials (mean percent fines = 54%) located at depths ≥49 m (see Appendix C.1 for sediment particle size classification). Group A shared only ~4% similarity with the two megaclusters. The two megaclusters shared ~9% similarity with each other. Within each megacluster, individual cluster groups were further defined by additional depth and sediment characteristics (Figure 9.6). The ecological relevance of each cluster group is described below.

<u>Shallow, shell hash assemblage</u>

Group A represented inner shelf assemblages from three stations located along the 25-m contour north and immediately south of Point Loma (Figures 9.4, 9.5). This cluster had the highest invertebrate abundance of all groups with an average of 564 individuals per station, and an average species richness of 65 taxa per station. Abundant taxa that were either uncommon or lacking in other cluster groups included nematodes

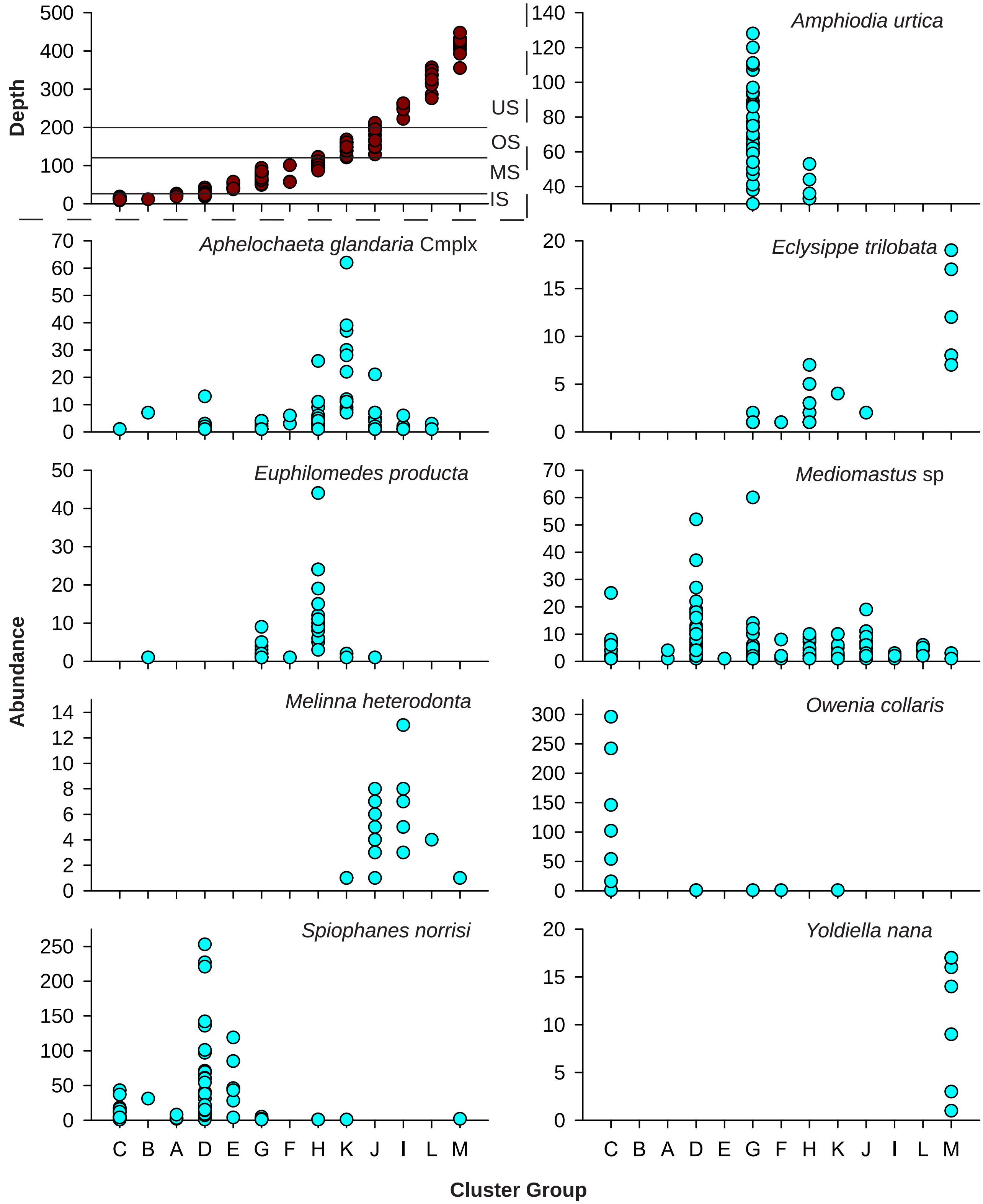


Figure 9.6

Depth (m) and abundances (# individuals per station) of select species that contributed to cluster group dissimilarities. Each data point represents a single grab. Cluster groups arranged shallowest to deepest. Depth shown in dark red; abundances shown in blue. IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope.

and the polychaetes *Pareurythoe californica*, *Pisione* sp, *Polycirrus* sp SD3 and *P. californicus* all of which averaged from 30 to 58 individuals per station (Appendix H.1). Additionally, although only averaging 12 individuals per station, the hemichordate *Branchiostoma californiense* occurred almost exclusively in group A, subsequently causing these assemblages to be termed the "*Branchiostoma* community." Taxa contributing to ≥25% of within group similarity included nematodes, *Pisione* sp and *Hesionura coineaui difficilis*. Sediments were dominated by coarse sand having substantial quantities of shell hash with only 0 to 5.1% fines.

Inner to shallow mid-shelf assemblages

With the exception of group A (above), all 58 macrofaunal grabs from inner- and shallow mid-shelf locations with sandy sediments occurred in a megacluster comprising groups B–E that shared ≥13% similarity (Figure 9.4). Many of these stations had high abundances of the spionid polychaete *Spiophanes norrisi* when compared to deeper stations with finer sediments (Figure 9.6). Sediments within this megacluster averaged 16% fine material, 62% fine sand and 21% coarse sand. Depths ranged from 9 to 58 m.

Cluster group B consisted of an assemblage restricted to a single 12 m deep station located at the head of the La Jolla Canyon (station 8103) where species richness and abundance values of 33 taxa and of 105 individuals occurred (Figures 9.4, 9.5), the second and third lowest values for these parameters, respectively. The most abundant species encountered were the polychaete *Spiophanes norrisi* and the echinoderm *Dendraster excentricus* with 31 and 16 individuals, respectively (Appendix H.1). Other relatively abundant species included the cirratulid polychaetes *Aphelochaeta glandaria* Cmplx, *Monticellina serratiseta*, *Aphelochaeta* sp SD13 and *Chaetozone commonalis*, and the bivalve *Simomactra falcata*, all with 4 to 7 individuals. No other species numbering >3 individuals was collected. Sediments consisted of 0.2% fine material, 40.9% fine sand and 58.9% coarse sand.

Cluster group C comprised assemblages from the 18 shallowest, inner shelf stations located from 9 to 19-m depths in the SBOO monitoring region and off the mouth of the San Diego River (Figures 9.4, 9.5). This cluster shared the third lowest species richness of 39 taxa per station with upper-slope cluster group L (below), but had a mean abundance of 206 individuals per station that was within the mid-range of all cluster groups. Although occurring at <50% of stations, the high abundance of the polychaete *Owenia collaris* in select locations made it the most abundant organism in the assemblage with a mean abundance of 48 individuals per station (Appendix H.1). *Owenia collaris* was rare in other cluster groups, with only single individuals reported when found (Figure 9.6). Other relatively abundant species from group C included the polychaetes *Spiophanes norrisi*, *Apoprionospio pygmaea*, *Scoletoma tetraura* Cmplx and the crustaceans *Gibberosus myersi* and *Diastylopsis tenuis*; these species averaged 5–10 individuals per station. No other species averaged >4 individuals per station. Taxa contributing to ≥25% of within group similarity included *S. norrisi*, *D. tenuis*, the bivalve *Tellina modesta* and the nemertean *Carinoma mutabilis*. Sediments at most group C stations were composed primarily of coarse and fine sand, with fine sediments ranging from 0.2 to 55.7%.

Cluster group D represented assemblages from 33 stations located between 19 and 43-m depths that spanned the entire monitoring region (Figure 9.4, 9.5). This group had the third highest species richness and abundance values of 89 taxa and 370 individuals per station, respectively. The spionid polychaete *Spiophanes norrisi* dominated many stations, with a mean abundance of 60 individuals per grab (Figure 9.6, Appendix H.1). Other abundant species included five polychaetes with mean abundances of 8 to 16 individuals per station: *Monticellina siblina*, *Mediomastus* sp, *Mooreonuphis nebulosa*, *Spiochaetopterus costarum* Cmplx and *Prionospio* (*Prionospio*) *jubata*. No other species averaged >7 individuals per station. Taxa contributing to ≥25% of within group similarity were all polychaetes and included *S. norrisi*, *Mediomastus* sp, *Phyllodoce hartmanae*, *M. siblina*, *Glycinde armigera* and *P.* (*P.*) *jubata*. Sediment composition was variable at the stations where these assemblages occurred, with fine materials ranging from 3.7 to 82.5%, fine sand ranging from 5.7 to 86.9% and coarse sand ranging from 0.4 to 75.4%. Unlike most other cluster groups, a significant coarse sediment fraction occurred at several stations (i.e., 26.3%, 12.7%, 7.0% and 2.2% for stations 8013, 8023, 8033 and 8222, respectively).

Cluster group E consisted of assemblages from six stations ranging in depth from 38 to 58 m located in the SBOO monitoring region (Figures 9.4, 9.5). Average species richness and mean abundance were 74 taxa and 314 individuals per station, respectively. As with group D, *Spiophanes norrisi* dominated many stations with a mean abundance of 54 individuals per grab (Figure 9.6, Appendix H.1). The four other most abundant species encountered were the polychaetes *Mooreonuphis* sp, *Mooreonuphis* sp SD1, *Lanassa venusta venusta* and *Spio maculata*; these species averaged between 12 and 27 individuals per station. No other species averaged > 8 individuals per station. Taxa contributing to ≥25% of within group similarity included *S. norrisi*, *Mooreonuphis* sp SD1 and *Mooreonuphis* sp. Stations where group E occurred were characterized by relatively coarse sediments having substantial quantities of red relict sand. Fine materials ranged from 0 to 27.7%, fine sand ranged from 1.8 to 50.5% and coarse sand ranged from 21.8 to 98.2%.

Middle mid-shelf to upper slope assemblages

Groups F–M shared ≥11% similarity and formed a megacluster comprising the 100 macrofaunal samples collected from the mid-shelf to upper slope stations that had relatively fine sediments (Figure 9.4). Within this megacluster, assemblages in clusters F, G, and H shared 29.7% similarity and occurred at mid-shelf stations ranging from 49 to 123 m, many of which correspond to the well-characterized "*Amphiodia urtica* zone" described previously by Barnard and Ziesenhenne (1961). This zone historically has high abundances of the ophiuroid *A. urtica*, as well as other associated taxa such as the ostracod *Euphilomedes producta* (Figure 9.6). Assemblages from cluster groups I and J shared 28.0% similarity and occurred at outer shelf to upper slope stations ranging from 130 to 263 m, whereas cluster group K represented an assemblage from outer shelf stations restricted primarily to the Coronado Bank. Assemblages from cluster groups L and M, which shared 17.0% similarity, all occurred at upper slope stations at depths ≥276 m. Cluster groups from outer shelf and upper slope depths had several species not commonly found in shallower habitats (e.g., the polychaete *Melinna heterodonta*) (Figure 9.6). Sediments from stations in this megacluster averaged 54% fine materials, 40% fine sand and 6% coarse sand. Depths ranged from 49 to 448 m (Figure 9.5).

Cluster group F comprised assemblages that occurred at three geographically disparate mid-shelf stations ranging from 57 to 101-m depths (Figures 9.4, 9.5). The mean species richness of 134 taxa and mean abundance of 458 individuals at these stations were the first and second highest values recorded for any cluster group, respectively. The most abundant species in group F included the amphipod *Photis californica* at 53 individuals per station, and the polychaete *Spiophanes kimballi* at 24 individuals per station (Appendix H.1). The polychaetes *Chloeia pinnata*, *Chaetozone hartmanae*, *Aricidea* (*Acmira*) *simplex*, and the tanaid *Leptochelia dubia* Cmplx were also relatively abundant with averages of 9 to 11 individuals per station. No other species exceeded 7 individuals per station. The taxa contributing to ≥25% of within group similarity included *L. dubia* Cmplx, the polychaetes *Prionospio* (*Prionospio*) *dubia*, *Maldane sarsi*, *C. pinnata*, *C. hartmanae*, *A.* (*A.*) *simplex*, and the amphipods *P. californica*, *Byblis millsi*, *Ampelisca careyi* and *Ampelisca* cf *brevisimulata*. Despite similarities in macrofaunal communities, stations had dissimilar sediment compositions with station 8024 having 3.7% fines and 87.5% coarse sand, and stations 2653 and 8226 having from 44.9 to 50.5% fines and coarse sand ranging from 2.2 to 4.7%.

Cluster group G represented assemblages present at 31 mid-shelf stations (49–94 m) located primarily in the PLOO monitoring region, and had mean species richness and abundance values of 81 taxa and 308 individuals, respectively. The group was dominated by the ophiuroid *Amphiodia urtica*, which averaged 75 individuals per station (Figure 9.6, Appendix H.1). Other abundant species included the bivalve *Axinopsida serricata*, unidentified brittle stars in the genus *Amphiodia* (possibly juvenile *A. urtica*), and the polychaetes *Spiophanes berkeleyorum*, *Travisia brevis* and *Pholoe glabra*; these species averaged between 6 and 15 individuals per station. No other taxon averaged >5 organisms per station. Taxa contributing to ≥25% of within group similarity included *Amphiodia* sp, *A. urtica*, the hemichordate *Stereobalanus* sp, *T. brevis* and the amphipod *Rhepoxynius bicuspidatus*. The stations in this cluster were restricted to mid-shelf depths where sediments consisted of fine sand with 36.0% to 70.6% fines (Figures 9.4, 9.5).

Cluster group H comprised 15 stations located at 87–123-m depths that represented mid-shelf assemblages (Figures 9.4, 9.5). Mean species richness of 91 taxa per station was the second highest of all cluster groups, although mean abundance of 294 individuals per station was within the mid-range of other groups. The most abundant species included the ophiuroid *Amphiodia urtica*, the ostracod *Euphilomedes producta*, and the polychaetes *Chaetozone hartmanae*, *Prionospio* (*Prionospio*) *jubata* and *Chloeia pinnata*, all of which averaged from 10 to 22 individuals per station (Appendix H.1). Taxa contributing to ≥25% of within group similarity included *A. urtica*, *E. producta*, and the polychaetes *Lumbrineris* sp GROUP I, *Paraprionospio alata*, *Sternaspis affinis, C. hartmanae, P.* (*P.*) *jubata* and *C. pinnata*. Sediments consisted of fine sand with percent fines ranging from 33.8% to 62.8%.

Cluster group I represented assemblages from six stations located on the upper slope at depths from 222 to 263 m (Figures 9.4, 9.5). Mean species richness and abundance were 42 taxa and 86 individuals, respectively. Individual species abundances were low compared to shallower cluster groups, with the most abundant species including the polychaetes *Melinna heterodonta*, *Spiophanes kimballi*, *Maldane sarsi* and *Paraprionospio alata*, and the bivalve *Tellina carpenteri*, all of which averaged between 4 and 6 individuals per station (Appendix H.1). No other taxon averaged >3 organisms per station. Taxa contributing to ≥25% of within group similarity included *P. alata*, *S. kimballi* and *M. heterodonta*. Sediments were primarily composed of 24.9 to 84.3% fines.

Cluster group J comprised 15 stations that ranged in depth from 130 to 212 m, and represented outer shelf assemblages (Figures 9.4, 9.5). Mean species richness and abundance were 62 taxa and 172 individuals per station, respectively; values higher than reported in closely-related cluster group I, and possibly due to shallower conditions. The five most abundant species included the polychaetes *Spiophanes kimballi*, *Terebellides californica* and *Mediomastus* sp, and the bivalves *Tellina carpenteri* and *Axinopsida serricata*, all of which averaged from 5 to 12 individuals per station (Appendix H.1). No other taxon averaged >4 organisms per station. Taxa contributing to ≥25% of within group similarity included the bivalves *Parvilucina tenuisculpta*, *T. carpenteri* and *A. serricata*, and the polychaetes *Paraprionospio alata*, *S. kimballi* and *Mediomastus* sp. Similar to cluster group I, sediments at the stations where this cluster group occurred were primarily composed of fine materials (i.e., 24.8 to 73.2% fines).

Cluster group K represented assemblages from outer shelf stations located on the Coronado Bank and one outer shelf station west of Mission Bay (Figures 9.4, 9.5). Mean species richness and abundance were 61 taxa and 198 individuals, respectively; values similar to outer shelf stations found in cluster group J. The most abundant taxa included the cirratulid polychaetes *Aphelochaeta glandaria* Cmplx, *Chaetozone* sp SD5, *Monticellina siblina* and *Chaetozone* sp, the bivalve *Tellina carpenteri*, and the gastropod *Micranellum crebricinctum*; these species averaged between 7 and 21 individuals per station (Appendix H.1). No other taxon averaged >5 organisms per station. Taxa contributing to ≥25% of within group similarity included *A. glandaria* Cmplx, *M. siblina*, *C.* sp SD5 and *T. carpenteri*. Unlike cluster group J, sediments consisted primarily of fine to coarse sand, with percent fines only ranging from 5.4 to 35.9%.

Cluster group L consisted of assemblages from nine upper slope stations with depths ranging from 276 to 357 m (Figures 9.4, 9.5). Mean species richness and abundance were relatively low with 39 taxa and 117 individuals per station, respectively. The most common species were the bivalve *Macoma carlottensis* and the polychaete *Maldane sarsi*, which averaged 12 and 11 individuals per station, respectively (Appendix H.1). Other relatively abundant species included the polychaete *Fauveliopsis glabra*, the scaphopod *Compressidens stearnsii*, and the bivalve *Nuculana conceptionis*, all of which averaged 4 to 6 individuals per station. No other taxon averaged >3 organisms per station. Species contributing to ≥25% of within group similarity included *M. sarsi*, *C. stearnsii* and *M. carlottensis*. Together with upper slope cluster group M (below), sediments were the finest of all groups with percent fines ranging from 47.3 to 87.7%.

Cluster group M comprised assemblages restricted to the eight deepest upper slope stations surveyed that ranged in depth from 355 to 448 m (Figures 9.4, 9.5). Mean species richness and abundance were the lowest of all cluster groups, being 26 taxa and 74 individuals per station, respectively. The most common species included the bivalves *Yoldiella nana* and *Nuculana conceptionis*, and the polychaetes *Eclysippe trilobata* and *Maldane sarsi*, all of which had mean abundance ranging from 6 to 10 individuals per station (Appendix H.1). No other taxon averaged >3 organisms per station. *Nuculana conceptionis* and *Y. nana* contributed to ≥25% of within group similarity, with *Y. nana* being unique to these stations (Figure 9.6). Sediments had percent fines ranging from 53.8 to 87.6%.

Clearly, the use of multivariate analysis has proven insightful for synthesizing species abundance data from the regional stations surveyed between 2009 and 2012, and is refining our understanding of the macrofaunal assemblages expected for the depth and sediment characteristics found at each site. However, although the groups defined through cluster analysis comprise assemblages representative of distinct depth contours and/or sediment types off San Diego, they also reveal the limitations of currently accepted cut-off depths used to define specific shelf and slope strata. For example, cluster groups H and J represent mid- and outer shelf assemblages, respectively, but the deepest stations in each cluster exceed the previously defined maximum depth limits for these strata in the SCB (Ranasinghe et al. 2007). Some "wiggle-room" exists in that depth ranges of strata are often assumed to include a ± 10% deviation (Smith et al. 2001), but concern exists that lax definitions could lead to confusion. For instance, a 212-m station cited in this report might potentially be referred to as including an outer shelf assemblage in one chapter, while being considered representative of the upper slope in another; thus it is probably more appropriate to refer to such an example as an outer shelf to upper slope "transitional" assemblage. As future invertebrate and sediment data become available for analysis, it is expected that additional insight of natural variation across the San Diego region may result in more ecologically-relevant definitions useful for describing both geographic and biological ecosystem parameters.

Comparison of Macrobenthic and Sediment Assemblages

Similar patterns of variation occurred in the benthic macrofaunal and sediment similarity/dissimilarity matrices (see Chapter 8) used to generate cluster dendrograms, confirming that macrofaunal assemblages in the San Diego region are highly correlated to sediment composition (RELATE $\rho = 0.598$, $p = 0.0001$). Sediment sub-fractions that were most highly correlated to macrofaunal communities included clay, very fine silt, fine silt, medium silt, and fine sand (BEST $\rho = 0.676$, $p = 0.001$). Macrofaunal and sediment dendrograms (Figures 9.4 and 8.6, respectively) show considerable commonality with: (a) inner to mid-shelf stations that share relatively high species richness and moderate abundance values (macrofaunal clusters A, E) having high percentages of coarse sand, very coarse sand and granules (i.e., shell hash, red relic sand) with almost no fine sediments (sediment group 1); (b) shallow (9–19m), inner shelf stations that have relatively low species richness and abundance values (macrofaunal groups B, C) having a high percentage of fine sand with almost no fines (sediment group 9); (c) inner shelf stations occurring at 19–43-m depths with relatively high species richness and abundance values (macrofaunal group D) having the highest percentage of very fine sand (sediment group 3); (d) mid-shelf to upper slope stations, including the "*Amphiodia urtica* zone," that have species richness and abundance values that fall mid-range of other cluster groups (macrofaunal clusters G, H, J) also having mid-range values for most fine and sand sediment sub-fractions (sediment clusters 6, 7); (e) outer shelf stations occurring on the Coronado Bank having lower species richness and abundances values (macrofaunal group K) than comparable outer shelf stations, and having relatively high percentages of fine and medium sand (sediment group 8); and (f) upper slope stations having low species richness and abundance values (macrofaunal groups L and M) having high percentages of clay, very fine silt, fine silt and medium silt (sediment group 4). Deviations where the macrofaunal and sediment dendrograms do not align or where several macrofaunal cluster groups co-mingle within a single sediment cluster group may indicate that additional factors other than sediment composition or depth are influencing benthic assemblages. Such factors may include: (a) the presence or absence of extremely coarse sediment fractions retained during screening of macrofauna (see visual observations in Appendix G.3), (b) differences in concentrations of organic material, trace metals, or pollutants, (c) differences in oceanographic parameters, (d) differences in biological factors (e.g., increased predation), or (e) ephemeral habitat perturbations (e.g., presence of drift algae, trawl tracks, whale feeding, deep-burrowing species).

Summary

Macrofaunal communities in the San Diego region appeared to be in good condition in 2012, with most shelf assemblages similar to those observed during regional surveys conducted from 1994 to 2011, and upper slope assemblages similar to those observed starting in 2009 (City of San Diego 2007, 2010, 2011, 2012b). No unique macrofaunal communities occurred near either the Point Loma or South Bay Ocean Outfalls, suggesting that the presence of these outfalls has not affected the large scale population dynamics of invertebrate communities. Benthic assemblages had normal 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 relatively low. Community parameters (i.e., species richness, abundance, Shannon diversity, dominance) for the 11 stations corresponding to the "*Amphiodia* mega-community" sampled during 2012 were within or near range of tolerance intervals calculated for this specific habitat type (see City of San Diego 2007), suggesting that the region remains healthy.

Benthic response index values are indicative of reference condition for 88% of regional sites surveyed from 2009 to 2012. This is not unexpected as Ranasinghe et al. (2010, 2012) recently reported that 98% of the entire SCB was in good condition based on assessment data gathered during the 1994−2003 bight-wide surveys. Benthic assemblages segregated by habitat characteristics such as depth and sediment particle size, and correspond 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). Four inner to mid-shelf (9–58-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 *Owenia collaris*, *Spiophanes norrisi*, and the bivalve *Tellina modesta* (i.e., cluster groups B–E). However, each cluster group had species that clearly differentiated it from other clusters, with these organismal differences likely caused by differences in either sediment (e.g., shell hash, red relict sand) or depth characteristics.

The majority of stations sampled off San Diego from 2009 to 2012 occurred in mid- to outer shelf areas, and were characterized by sandy sediments with a high percentage of fines (i.e., cluster groups F–H). 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 (i.e., cluster group G) 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). Deeper outer shelf stations that had coarser sediments (e.g., along the Coronado Bank) lacked high abundances of *A. urtica*, but were instead dominated by polychaete worms such as the cirratulids *Aphelochaeta glandaria* Cmplx, *Monticellina siblina* and *Chaetozone* sp SD5 (i.e., cluster group K).

Similar to patterns described in past monitoring reports (City of San Diego 2012b, 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 bivalves such as *Yoldiella nana*, *Nuculana conceptionis* and *Tellina carpenteri*.

Finally, recent advances in various types of multivariate analysis have improved our ability to describe and understand the distribution of macrofaunal assemblages off San Diego, including the relationship of these assemblages to changes in depth and sediment characteristics. This has proven to be especially useful in examining the regional station data that has been collected over many years, and that spans a wide range of depths along the continental shelf and slope as well as many distinct sediment or habitat types. For example, multivariate analyses made it possible to more clearly recognize transitional assemblages such as those that occur between the outer shelf and upper slope off San Diego. Consequently, the results of future regional surveys are expected to provide additional insight of natural variation across the San Diego region, which in turn may result in more ecologically-relevant descriptions of both geographic and biological ecosystem parameters.

Literature Cited

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

Barnard, J.L. (1963). Relationship of benthic Amphipoda to invertebrate communities of inshore sublittoral sands of southern California. Pacific Naturalist, 3: 439–467.

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

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

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

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

Southern California Coastal Water Research Project, Westminster, CA.

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

City of Los Angeles. (2007). Santa Monica Bay Biennial Assessment Report 2005–2006. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

City of Los Angeles. (2008). Los Angeles Harbor Biennial Assessment Report 2006–2007. Department of Public Works, Bureau of Sanitation, Environmental Monitoring Division, Los Angeles, CA.

City of San Diego. (2007). Attachment E.1. 10-Year San Diego Regional Benthic Assessment and Reference Tolerant Intervals. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements, Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

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

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

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

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

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R. and R.M. Warwick. (2001). Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. PRIMER-E, Plymouth.

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

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

Diener, D.R., S.C. Fuller, A. Lissner, C.I. Haydock, D. Maurer, G. Robertson, and R. Gerlinger. (1995). Spatial and temporal patterns of the infaunal community near a major ocean outfall in southern California. Marine Pollution Bulletin, 30: 861–878.

ES Engineering Science, Inc. (1988). Tijuana Oceanographic Engineering Study (TOES)

Ocean Measurement Program Summary Phases I–III (May 1986–December 1988). ES Engineering Science, Inc., San Diego, CA.

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

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

Hyland, J.L., W.L. Balthis, V.D. Engle, E.R. Long, J.F. Paul, J.K. Summers, and R.F. Van Dolah. (2003). Incidence of stress in benthic communities along the US Atlantic and Gulf of Mexico coasts within different ranges of sediment contamination from chemical mixtures. Environmental Monitoring and Assessment, 81: 149–161.

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

Kennedy, A.J., J.A. Steevens, G.R. Lotufo, J.D. Farrar, M.R. Reiss, R.K. Kropp, J. Doi, and T.S. Bridges. (2009). A comparison of acute and chronic toxicity methods for marine sediments. Marine Environmental Research, 68: 188–127.

[LACSD] Los Angeles County Sanitation Districts. (2012). Joint Water Pollution Control Plant biennial ocean monitoring report, 2010-2011. Whittier, CA: Los Angeles County Sanitation Districts, Ocean Monitoring and Research Group, Technical Services Department.

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

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

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

[OCSD] Orange County Sanitation District. (2012). Annual Report, July 2010–June 2011. Marine Monitoring, Fountain Valley, California.

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

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

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

Ranasinghe, J.A., K.C. Schiff, D.E. Montagne, T.K. Mikel, D.B. Cadien, R.G. Velarde, and

C.A. Brantley. (2010). Benthic macrofaunal community condition in the Southern California Bight, 1994–2003. Marine Pollution Bulletin, 60: 827–833.

[SCAMIT] Southern California Association of Marine Invertebrate Taxonomists. (2012). A taxonomic listing of benthic macro- and megainvertebrates from infaunal and epibenthic monitoring programs in the Southern California Bight, edition 7. Southern California Associations of Marine Invertebrate Taxonomists, Natural History Museum of Los Angeles County Research and Collections, Los Angeles, CA.

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

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

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

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

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

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

Stull, J.K., C.I. Haydock, R.W. Smith, and D.E. Montagne. (1986). Long-term changes in the benthic community on the coastal shelf of Palos Verdes, southern California. Marine Biology, 91: 539–551.

Stull, J.K., D.J.P. Swift, and A.W. Niedoroda (1996). Contaminant dispersal on the Palos Verdes continental margin: I. Sediments and biota near a major California wastewater discharge. Science of the Total Environment, 179: 73–90.

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

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

Thompson, B., J.D. Laughlin, and D.T. Tsukada. (1987). 1985 Reference Site Survey. Technical Report No. 221, Southern California Coastal Water Research Project, Long Beach, CA.

Thompson, B., D. Tsukada, and D. O’Donohue. (1992). 1990 Reference Survey. Technical Report No. 355, Southern California Coastal Water Research Project, Long Beach, CA.

[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring

Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.

[USEPA] United States Environmental Protection Agency. (2004). National Coastal Condition Report II. US Environmental Protection Agency, Office of Research and Development, EPA-620/R-03/002, Washington, DC, USA.

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

Appendices

Appendix A

Supporting Data

2012 SBOO Stations

Oceanographic Conditions

Appendix A.1

Summary of temperature, salinity, dissolved oxygen (DO), pH, transmissivity, and chlorophyll *a* for various depth layers as well as the entire water column for all SBOO stations during 2012. For each month n = 360 (1–9 m), n = 272 (10–19 m), n = 150 (20–28 m), n = 75 (29–38 m), n = 56 (39–55 m). Due to instrumentation issues, pH data from August to October and chlorophyll *a* data from November to December were excluded from analyses.

		Depth (m)					
Temperature (°C)		**1–9**	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
January	min	13.7	13.5	13.2	12.4	11.8	11.8
	max	15.2	14.7	14.6	14.2	13.1	15.2
	mean	14.2	14.2	13.8	13.2	12.4	13.9
	95% CI	0.0	0.0	0.1	0.1	0.1	0.0
February	min	12.9	12.4	12.0	11.9	11.5	11.5
	max	14.8	14.8	14.7	14.7	13.0	14.8
	mean	14.3	14.0	13.3	12.5	12.0	13.7
	95% CI	0.0	0.1	0.1	0.2	0.1	0.1
March	min	10.9	10.4	10.4	10.4	10.2	10.2
	max	14.7	14.0	11.6	10.8	10.6	14.7
	mean	13.7	11.5	10.8	10.5	10.4	12.1
	95% CI	0.1	0.1	0.0	0.0	0.0	0.1
April	min	10.6	10.2	10.1	10.0	10.0	10.0
	max	16.0	13.9	10.4	10.3	10.1	16.0
	mean	13.1	10.8	10.3	10.2	10.0	11.5
	95% CI	0.1	0.1	0.0	0.0	0.0	0.1
May	min	12.6	11.2	10.6	10.5	10.3	10.3
	max	17.5	16.9	13.4	12.2	11.2	17.5
	mean	16.1	12.8	11.4	11.0	10.5	13.6
	95% CI	0.1	0.1	0.1	0.1	0.1	0.2
June	min	12.0	11.0	10.9	10.8	10.3	10.3
	max	18.6	17.5	13.7	13.1	12.3	18.6
	mean	16.5	12.8	11.5	11.4	11.0	13.8
	95% CI	0.2	0.2	0.1	0.1	0.1	0.2

Appendix A.1 *continued*

Temperature (°C)		Depth (m) 1–9	10–19	20–28	29–38	39–55	1–55
July	min	11.4	11.0	10.6	10.5	10.3	10.3
	max	19.9	14.7	12.9	12.0	11.2	19.9
	mean	14.1	11.8	11.2	10.9	10.6	12.5
	95% CI	0.2	0.1	0.1	0.1	0.1	0.1
August	min	13.3	12.9	12.3	12.0	11.4	11.4
	max	21.6	18.0	15.2	13.2	12.5	21.6
	mean	18.4	14.5	13.1	12.4	12.0	15.5
	95% CI	0.2	0.1	0.1	0.1	0.1	0.2
September	min	14.7	13.6	13.2	13.0	12.4	12.4
	max	22.2	19.9	16.6	15.1	14.0	22.2
	mean	17.8	15.8	14.3	13.7	13.0	16.0
	95% CI	0.2	0.1	0.1	0.1	0.1	0.1
October	min	16.2	15.1	14.7	14.2	13.8	13.8
	max	20.3	20.1	16.7	15.3	15.0	20.3
	mean	18.2	16.6	15.6	15.0	14.4	16.8
	95% CI	0.1	0.1	0.1	0.0	0.1	0.1
November	min	15.7	14.7	14.1	13.8	13.4	13.4
	max	19.1	18.8	16.5	15.0	14.1	19.1
	mean	17.4	16.3	15.1	14.3	13.8	16.2
	95% CI	0.1	0.1	0.1	0.1	0.1	0.1
December	min	14.2	13.5	12.8	12.6	12.3	12.3
	max	17.2	17.2	16.7	15.5	14.7	17.2
	mean	16.0	15.0	14.4	14.2	13.7	15.2
	95% CI	0.1	0.1	0.1	0.2	0.2	0.1
Annual	min	10.6	10.2	10.1	10.0	10.0	10.0
	max	22.2	20.1	16.7	15.5	15.0	22.2
	mean	15.8	13.8	12.9	12.4	12.0	14.2
	95% CI	0.1	0.1	0.1	0.1	0.1	0.0

Appendix A.1 *continued*

Salinity (psu)		Depth (m) 1–9	10–19	20–28	29–38	39–55	1–55
January	min	33.25	33.32	33.33	33.31	33.33	33.25
	max	33.40	33.38	33.37	33.40	33.45	33.45
	mean	33.36	33.36	33.35	33.35	33.39	33.36
	95% CI	0.00	0.00	0.00	0.00	0.01	0.00
February	min	33.16	33.22	33.35	33.35	33.36	33.16
	max	33.41	33.40	33.43	33.45	33.49	33.49
	mean	33.37	33.37	33.37	33.40	33.44	33.37
	95% CI	0.00	0.00	0.00	0.01	0.01	0.00
March	min	33.35	33.32	33.45	33.65	33.73	33.32
	max	33.61	33.83	33.84	33.83	33.91	33.91
	mean	33.44	33.52	33.65	33.75	33.83	33.55
	95% CI	0.00	0.01	0.01	0.01	0.01	0.01
April	min	33.57	33.60	33.69	33.86	33.91	33.57
	max	33.85	33.88	33.92	33.94	34.00	34.00
	mean	33.68	33.77	33.85	33.89	33.95	33.77
	95% CI	0.01	0.01	0.01	0.00	0.01	0.01
May	min	33.45	33.47	33.47	33.47	33.64	33.45
	max	33.61	33.67	33.71	33.75	33.83	33.83
	mean	33.54	33.58	33.62	33.65	33.72	33.58
	95% CI	0.00	0.01	0.01	0.02	0.02	0.00
June	min	33.42	33.32	33.38	33.42	33.42	33.32
	max	33.67	33.63	33.57	33.58	33.63	33.67
	mean	33.59	33.50	33.49	33.50	33.52	33.54
	95% CI	0.00	0.01	0.01	0.01	0.02	0.00

Appendix A.1 *continued*

Salinity (psu)		Depth (m) 1–9	10–19	20–28	29–38	39–55	1–55
July	min	33.34	33.40	33.42	33.49	33.54	33.34
	max	33.60	33.57	33.63	33.67	33.69	33.69
	mean	33.50	33.50	33.55	33.57	33.63	33.52
	95% CI	0.00	0.00	0.01	0.01	0.01	0.00
August	min	33.33	33.24	33.32	33.34	33.39	33.24
	max	33.56	33.50	33.50	33.50	33.52	33.56
	mean	33.48	33.44	33.44	33.43	33.47	33.46
	95% CI	0.00	0.01	0.01	0.01	0.01	0.00
September	min	33.31	33.28	33.28	33.35	33.37	33.28
	max	33.52	33.47	33.41	33.40	33.42	33.52
	mean	33.41	33.37	33.37	33.38	33.40	33.39
	95% CI	0.00	0.00	0.00	0.00	0.00	0.00
October	min	33.33	33.33	33.36	33.41	33.39	33.33
	max	33.53	33.53	33.44	33.45	33.46	33.53
	mean	33.42	33.42	33.42	33.43	33.43	33.42
	95% CI	0.00	0.00	0.00	0.00	0.00	0.00
November	min	33.40	33.23	33.32	33.35	33.46	33.23
	max	33.56	33.56	33.50	33.50	33.54	33.56
	mean	33.49	33.45	33.45	33.46	33.49	33.47
	95% CI	0.00	0.00	0.01	0.01	0.01	0.00
December	min	33.38	33.23	33.41	33.42	33.41	33.23
	max	33.55	33.55	33.52	33.55	33.58	33.58
	mean	33.50	33.47	33.47	33.47	33.48	33.48
	95% CI	0.00	0.00	0.00	0.01	0.01	0.00
Annual	min	33.16	33.22	33.28	33.31	33.33	33.16
	max	33.85	33.88	33.92	33.94	34.00	34.00
	mean	33.48	33.48	33.50	33.52	33.56	33.49
	95% CI	0.00	0.00	0.01	0.01	0.01	0.00

Appendix A.1 *continued*

DO (mg/L)		Depth (m)					
		1–9	10–19	20–28	29–38	39–55	1–55
January	min	5.3	5.7	5.7	5.6	5.1	5.1
	max	10.5	9.4	8.4	7.9	6.7	10.5
	mean	8.4	8.0	7.4	6.6	5.8	7.8
	95% CI	0.1	0.1	0.1	0.1	0.1	0.1
February	min	4.5	4.4	3.8	3.8	3.8	3.8
	max	9.5	8.9	7.3	6.8	5.5	9.5
	mean	6.8	6.5	5.7	4.9	4.6	6.2
	95% CI	0.1	0.1	0.1	0.2	0.1	0.1
March	min	4.5	2.9	3.2	3.3	3.0	2.9
	max	9.5	8.2	5.1	4.1	3.8	9.5
	mean	8.4	5.1	4.1	3.7	3.3	6.0
	95% CI	0.1	0.1	0.0	0.1	0.1	0.1
April	min	1.9	1.8	2.1	2.2	2.0	1.8
	max	12.1	9.7	4.1	2.9	2.6	12.1
	mean	7.5	3.6	2.8	2.5	2.3	4.9
	95% CI	0.3	0.1	0.1	0.0	0.1	0.2
May	min	6.6	4.0	3.3	3.3	2.5	2.5
	max	9.4	9.4	7.9	6.6	4.5	9.4
	mean	8.2	6.6	5.0	4.3	3.7	6.6
	95% CI	0.0	0.2	0.2	0.2	0.1	0.1
June	min	5.7	5.4	5.7	5.1	5.0	5.0
	max	9.7	10.4	8.7	8.2	7.4	10.4
	mean	8.4	7.3	6.4	6.3	5.8	7.4
	95% CI	0.1	0.1	0.1	0.2	0.2	0.1

Appendix A.1 *continued*

		Depth (m)					
DO (mg/L)		**1–9**	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
July	min	6.3	5.1	5.5	5.4	5.2	5.1
	max	10.4	10.6	10.1	8.5	7.1	10.6
	mean	8.5	7.7	6.9	6.6	5.9	7.7
	95% CI	0.1	0.1	0.2	0.2	0.1	0.1
August	min	7.5	7.1	7.2	6.1	5.7	5.7
	max	9.7	9.7	9.6	8.2	7.5	9.7
	mean	8.7	9.0	8.3	7.2	6.6	8.5
	95% CI	0.1	0.1	0.1	0.1	0.1	0.1
September	min	7.5	7.3	7.0	7.2	6.6	6.6
	max	9.2	9.2	8.9	8.7	8.3	9.2
	mean	8.4	8.5	8.3	7.9	7.3	8.3
	95% CI	0.0	0.0	0.1	0.1	0.1	0.0
October	min	7.6	7.6	7.5	7.4	6.9	6.9
	max	8.6	9.0	8.6	8.2	7.9	9.0
	mean	8.2	8.2	8.1	7.8	7.5	8.1
	95% CI	0.0	0.0	0.0	0.0	0.1	0.0
November	min	7.0	6.6	6.4	6.0	5.5	5.5
	max	8.5	8.4	8.3	7.9	6.8	8.5
	mean	7.9	7.8	7.3	6.7	6.2	7.6
	95% CI	0.0	0.0	0.1	0.1	0.1	0.0
December	min	5.9	5.6	5.2	5.1	4.8	4.8
	max	8.1	8.0	7.9	7.6	7.0	8.1
	mean	7.4	6.8	6.5	6.4	6.1	6.9
	95% CI	0.1	0.1	0.1	0.1	0.2	0.0
Annual	min	1.9	1.8	2.1	2.2	2.0	1.8
	max	12.1	10.6	10.1	8.7	8.3	12.1
	mean	8.1	7.1	6.4	5.9	5.4	7.2
	95% CI	0.0	0.1	0.1	0.1	0.1	0.0

Appendix A.1 *continued*

pH		Depth (m)					
		1–9	10–19	20–28	29–38	39–55	1–55
January	min	8.0	8.0	8.0	7.9	7.9	7.9
	max	8.3	8.2	8.2	8.1	8.0	8.3
	mean	8.1	8.1	8.1	8.0	7.9	8.1
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0
February	min	8.0	8.0	7.9	7.9	7.9	7.9
	max	8.2	8.2	8.2	8.2	8.1	8.2
	mean	8.2	8.1	8.1	8.0	7.9	8.1
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0
March	min	7.9	7.7	7.8	7.8	7.7	7.7
	max	8.2	8.2	7.9	7.8	7.8	8.2
	mean	8.2	7.9	7.8	7.8	7.8	8.0
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0
April	min	7.6	7.6	7.6	7.6	7.6	7.6
	max	8.4	8.3	7.8	7.7	7.7	8.4
	mean	8.1	7.8	7.7	7.7	7.7	7.9
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0
May	min	8.0	7.8	7.8	7.8	7.7	7.7
	max	8.3	8.3	8.2	8.1	7.9	8.3
	mean	8.2	8.0	7.9	7.9	7.8	8.1
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0
June	min	7.9	7.9	7.9	7.9	7.8	7.8
	max	8.3	8.3	8.2	8.1	8.1	8.3
	mean	8.2	8.1	8.0	8.0	7.9	8.1
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0

Appendix A.1 *continued*

		Depth (m)					
pH		**1–9**	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
July	min	7.9	7.8	7.8	7.8	7.8	7.8
	max	8.3	8.2	8.2	8.0	8.0	8.3
	mean	8.1	8.0	7.9	7.9	7.9	8.0
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0
August	min	—	—	—	—	—	—
	max	—	—	—	—	—	—
	mean	—	—	—	—	—	—
	95% CI	—	—	—	—	—	—
September	min	—	—	—	—	—	—
	max	—	—	—	—	—	—
	mean	—	—	—	—	—	—
	95% CI	—	—	—	—	—	—
October	min	—	—	—	—	—	—
	max	—	—	—	—	—	—
	mean	—	—	—	—	—	—
	95% CI	—	—	—	—	—	—
November	min	8.1	8.1	8.0	8.0	8.0	8.0
	max	8.2	8.2	8.2	8.1	8.1	8.2
	mean	8.2	8.2	8.1	8.1	8.0	8.1
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0
December	min	8.0	8.0	8.0	8.0	7.9	7.9
	max	8.2	8.2	8.2	8.1	8.1	8.2
	mean	8.1	8.1	8.0	8.0	8.0	8.1
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0
Annual	min	7.6	7.6	7.6	7.6	7.6	7.6
	max	8.4	8.3	8.2	8.2	8.1	8.4
	mean	8.1	8.0	8.0	7.9	7.9	8.0
	95% CI	0.0	0.0	0.0	0.0	0.0	0.0

Appendix A.1 *continued*

Transmissivity (%)		Depth (m)					
		1–9	**10–19**	**20–28**	**29–38**	**39–55**	**1–55**
January	min	13	25	49	51	83	13
	max	90	90	90	90	90	90
	mean	75	83	85	85	88	81
	95% CI	2	1	1	2	1	1
February	min	52	46	70	74	85	46
	max	89	89	89	89	89	89
	mean	82	84	87	86	88	84
	95% CI	1	1	0	1	0	0
March	min	41	18	73	75	90	18
	max	88	90	90	91	91	91
	mean	73	84	89	89	91	81
	95% CI	1	1	0	1	0	1
April	min	23	24	69	78	82	23
	max	88	91	91	89	89	91
	mean	70	84	86	85	86	79
	95% CI	1	1	1	1	0	1
May	min	67	54	83	87	77	54
	max	91	91	92	91	91	92
	mean	84	86	87	89	90	86
	95% CI	1	1	0	0	1	0
June	min	12	48	74	73	87	12
	max	89	90	90	90	91	91
	mean	76	82	87	88	89	81
	95% CI	1	1	1	1	0	1

Appendix A.1 *continued*

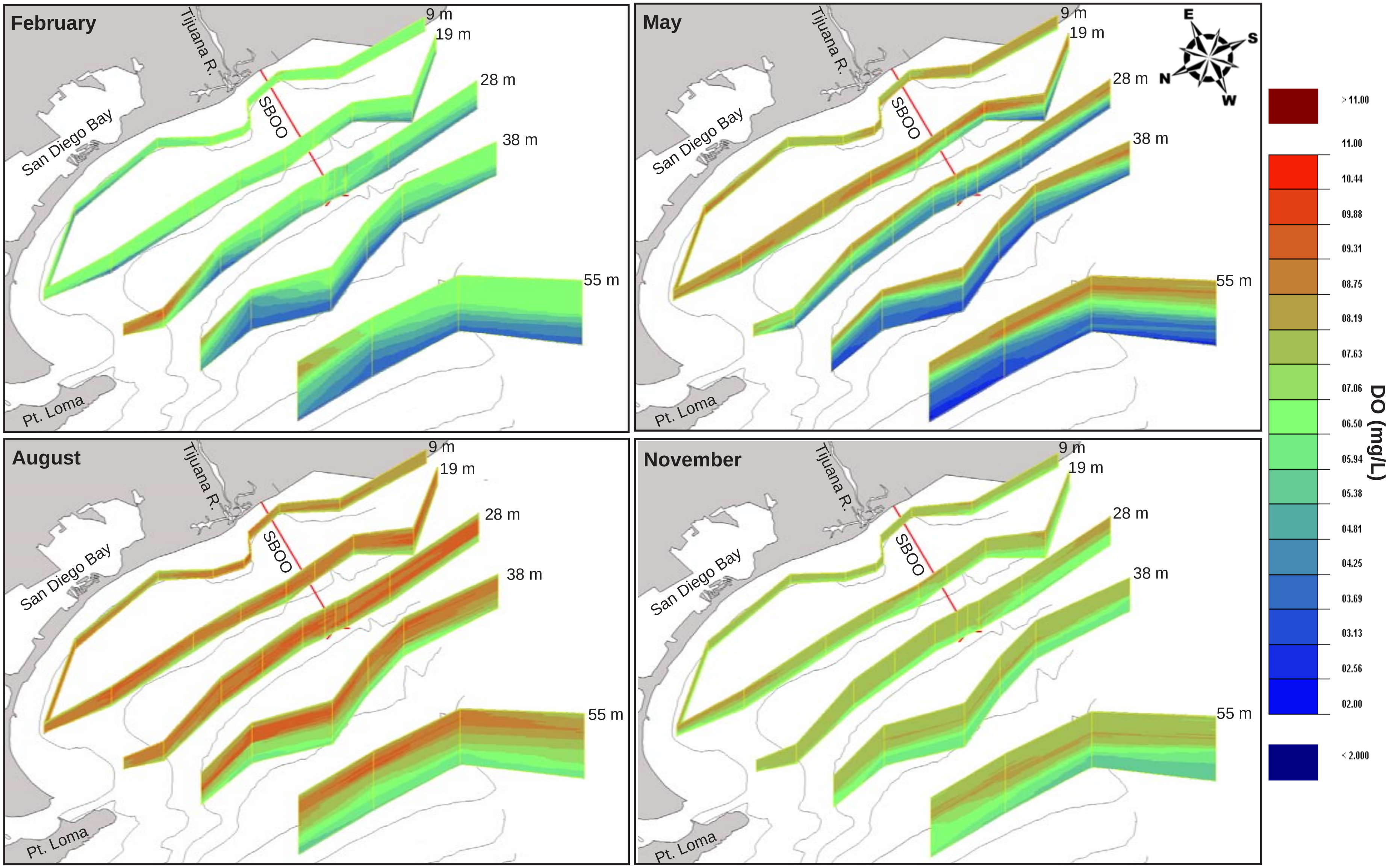
Transmissivity (%)		Depth (m) 1–9	10–19	20–28	29–38	39–55	1–55
July	min	65	49	74	81	88	49
	max	89	89	90	91	91	91
	mean	82	83	85	88	90	84
	95% CI	0	1	1	1	0	0
August	min	54	57	69	69	87	54
	max	90	90	90	90	91	91
	mean	83	85	85	87	90	84
	95% CI	1	1	1	1	0	0
September	min	56	50	63	81	86	50
	max	90	90	90	89	88	90
	mean	83	85	85	86	88	84
	95% CI	1	1	1	0	0	0
October	min	58	57	79	78	85	57
	max	91	90	89	89	89	91
	mean	85	87	85	86	88	86
	95% CI	1	1	0	1	0	0
November	min	62	50	72	80	88	50
	max	90	90	90	90	90	90
	mean	82	85	85	88	89	84
	95% CI	1	1	1	1	0	0
December	min	33	52	64	82	86	33
	max	90	90	90	90	90	90
	mean	75	83	84	87	89	81
	95% CI	1	1	1	1	0	1
Annual	min	12	18	49	51	77	12
	max	91	91	92	91	91	92
	mean	79	84	86	87	89	83
	95% CI	0	0	0	0	0	0

Appendix A.1 *continued*

Chlorophyll *a* (µg/L)		Depth (m) 1–9	10–19	20–28	29–38	39–55	1–55
January	min	1.0	1.4	2.4	2.5	1.5	1.0
	max	74.6	17.0	14.7	8.0	4.8	74.6
	mean	11.6	5.7	5.2	4.6	2.9	7.7
	95% CI	1.4	0.4	0.3	0.3	0.2	0.6
February	min	1.4	2.1	2.7	3.0	1.9	1.4
	max	19.8	20.4	10.3	7.8	5.4	20.4
	mean	5.6	6.5	5.7	4.8	3.3	5.7
	95% CI	0.4	0.4	0.3	0.3	0.2	0.2
March	min	4.2	3.0	1.9	0.5	0.5	0.5
	max	40.0	40.7	7.9	4.1	0.9	40.7
	mean	13.1	8.6	3.5	1.7	0.6	8.5
	95% CI	0.6	0.8	0.2	0.2	0.0	0.4
April	min	3.9	2.0	1.4	1.5	1.0	1.0
	max	74.6	74.6	5.8	3.1	1.7	74.6
	mean	25.5	7.8	2.8	2.1	1.4	13.1
	95% CI	2.0	1.2	0.1	0.1	0.0	1.1
May	min	0.9	1.3	2.1	2.3	1.5	0.9
	max	21.6	57.9	16.8	6.9	3.8	57.9
	mean	4.4	7.5	6.2	3.7	2.2	5.4
	95% CI	0.4	1.1	0.5	0.3	0.1	0.4
June	min	0.9	3.2	3.4	2.9	1.4	0.9
	max	53.6	65.1	16.4	10.0	9.1	65.1
	mean	9.9	12.5	6.1	5.5	3.9	9.3
	95% CI	0.8	1.1	0.4	0.5	0.5	0.5

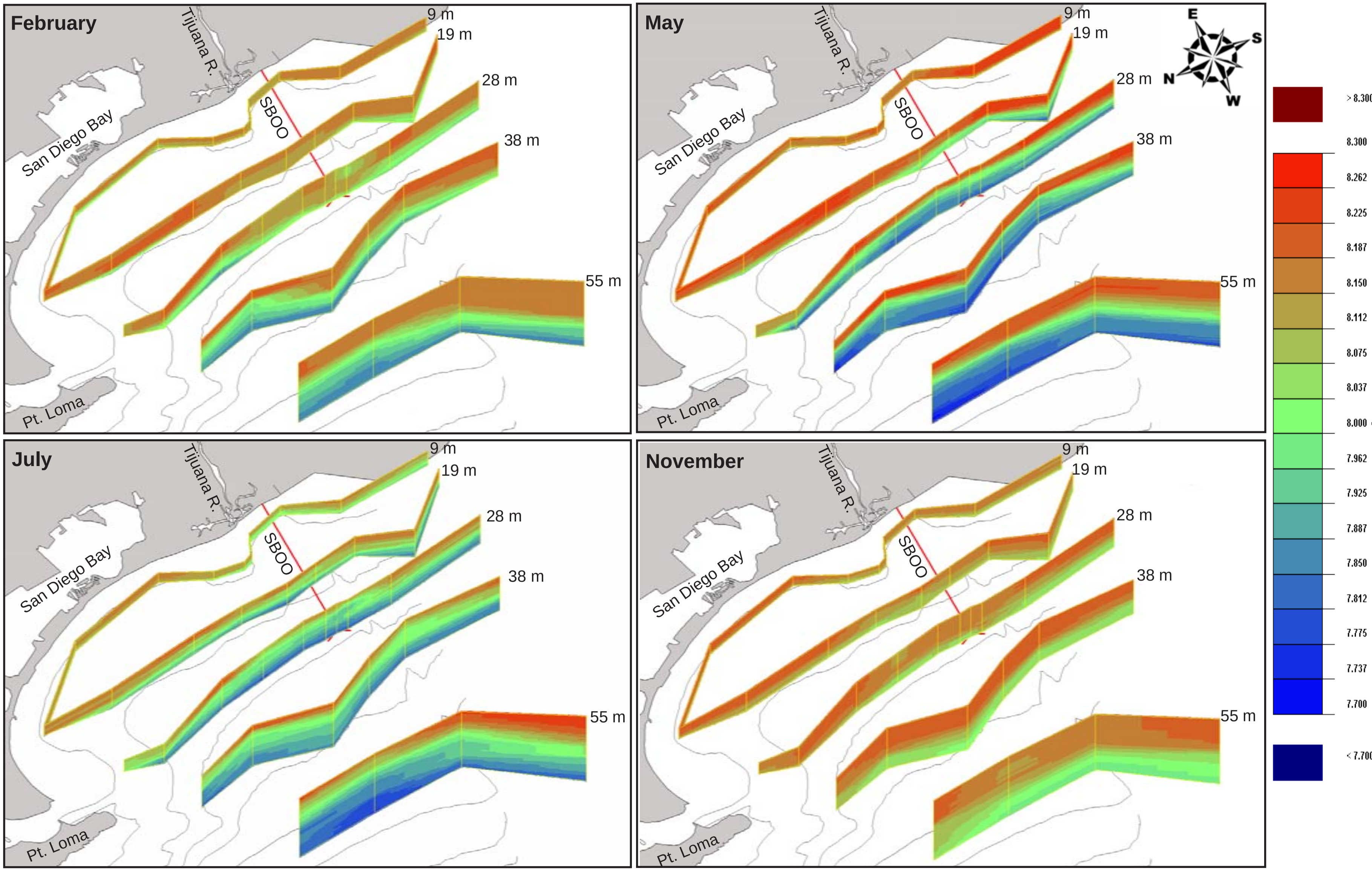
Appendix A.1 *continued*

Chlorophyll *a* (µg/L)		Depth (m) 1–9	10–19	20–28	29–38	39–55	1–55
July	min	0.8	2.0	3.8	2.2	1.8	0.8
	max	53.4	74.1	36.1	15.1	12.8	74.1
	mean	8.7	16.5	14.0	6.3	3.9	11.4
	95% CI	0.8	1.4	1.2	0.8	0.6	0.6
August	min	1.1	1.2	2.3	1.6	1.6	1.1
	max	33.4	42.1	61.1	63.4	6.5	63.4
	mean	4.1	6.2	11.4	9.4	2.9	6.3
	95% CI	0.6	0.7	1.6	2.7	0.3	0.5
September	min	0.6	0.7	1.0	1.8	2.1	0.6
	max	10.4	11.9	13.6	10.4	6.2	13.6
	mean	2.4	2.9	5.1	4.9	4.4	3.3
	95% CI	0.2	0.2	0.5	0.4	0.3	0.2
October	min	0.6	0.9	1.9	4.0	3.7	0.6
	max	12.7	14.2	18.1	15.7	10.2	18.1
	mean	2.9	3.2	6.0	7.1	5.5	4.0
	95% CI	0.3	0.3	0.5	0.8	0.4	0.2
November	min	—	—	—	—	—	—
	max	—	—	—	—	—	—
	mean	—	—	—	—	—	—
	95% CI	—	—	—	—	—	—
December	min	—	—	—	—	—	—
	max	—	—	—	—	—	—
	mean	—	—	—	—	—	—
	95% CI	—	—	—	—	—	—
Annual	min	0.6	0.7	1.0	0.5	0.5	0.5
	max	74.6	74.6	61.1	63.4	12.8	74.6
	mean	8.8	7.7	6.6	5.0	3.1	7.5
	95% CI	0.4	0.3	0.3	0.3	0.2	0.2



Appendix A.2

Dissolved oxygen recorded in 2012 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.



Appendix A.3
Measurements of pH recorded in 2012 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.

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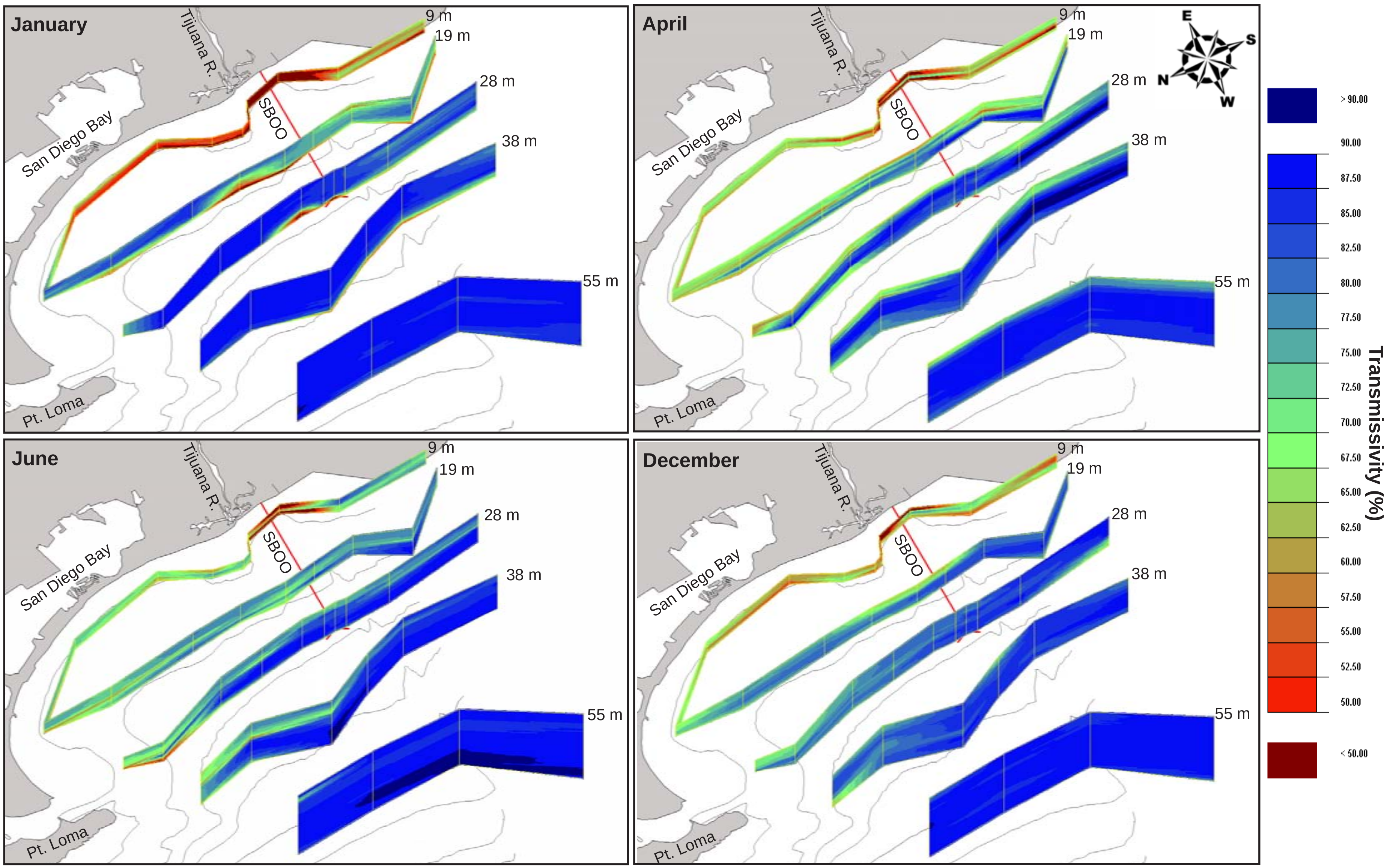

Appendix A.4

Transmissivity recorded in 2012 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.

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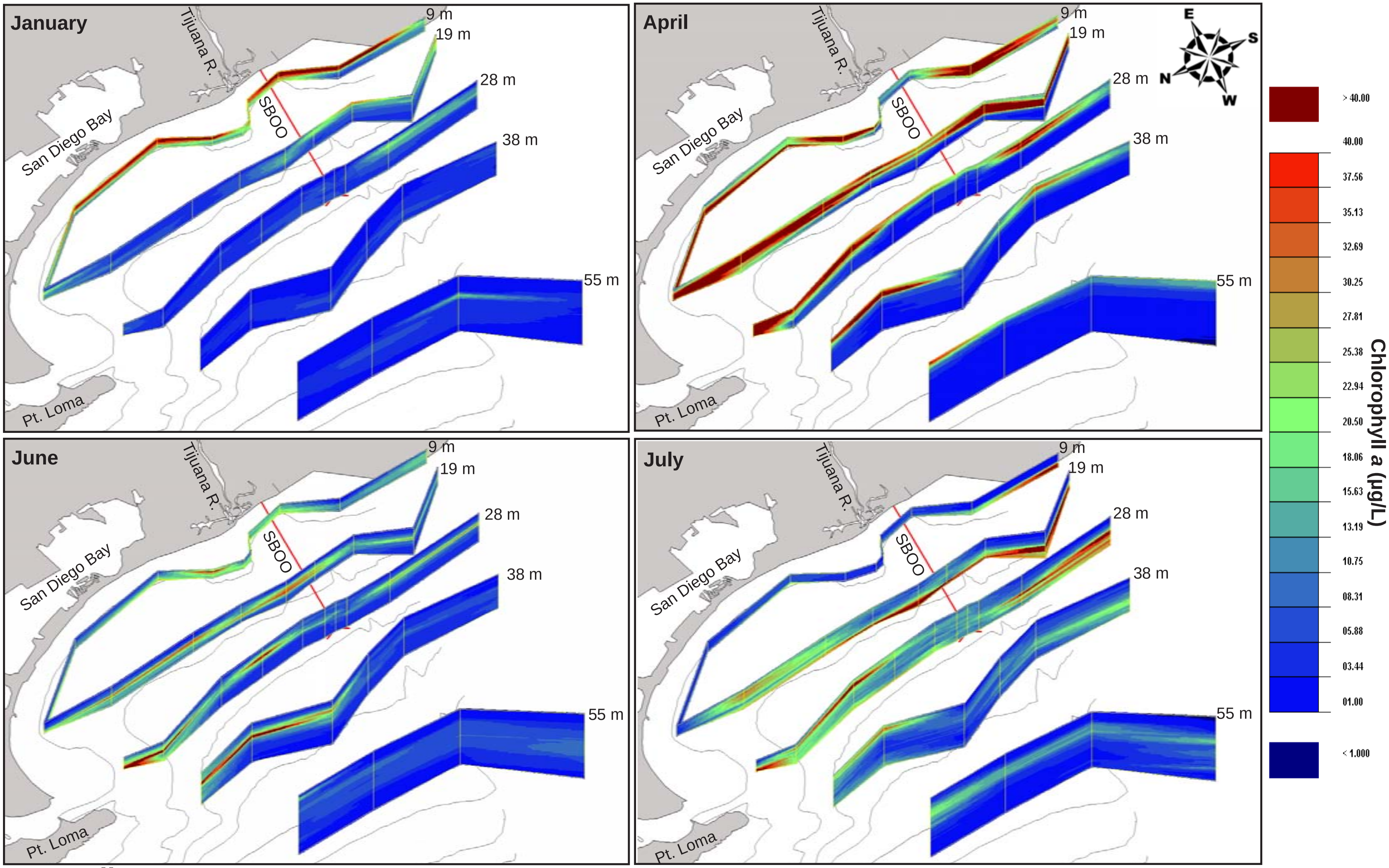


Appendix A.5

Concentrations of chlorophyll *a* recorded in 2012 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.

Appendix B

Supporting Data

2012 SBOO Stations

Water Quality

Appendix B.1

Summary of elevated bacteria densities in samples collected at SBOO shore stations during 2012. 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 coliforms >1000 CFU/100 mL and F:T>0.10).

Station	Date	Total	Fecal	Entero	F:T
S0	10 Jan 12	**>16,000**	**8400**	**6600**	**0.52**
S4	17 Jan 12	**>16,000**	**800**	**140**	0.05
S10	17 Jan 12	3800	**560**	**120**	**0.15**
S0	24 Jan 12	8200	380	**540**	0.05
S2	24 Jan 12	3800	320	**300**	0.08
S3	24 Jan 12	**>16,000**	**1200**	**2600**	0.08
S4	24 Jan 12	**>16,000**	**9800**	**7800**	**0.61**
S10	24 Jan 12	**>16,000**	**>12,000**	**10,000**	**0.75**
S5	31 Jan 12	**>16,000**	**3200**	**580**	**0.20**
S2	7 Feb 12	2000	240	100	**0.12**
S3	14 Feb 12	**>16,000**	**3200**	**2400**	**0.20**
S4	14 Feb 12	**>16,000**	**6800**	**9200**	**0.42**
S5	14 Feb 12	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10	14 Feb 12	**>16,000**	**6800**	**>12,000**	**0.42**
S0	21 Feb 12	280	38	**280**	0.14
S4	28 Feb 12	**>16,000**	**4200**	**4600**	**0.26**
S10	28 Feb 12	**>16,000**	**3800**	**3600**	**0.24**
S5	13 Mar 12	120	14	**130**	0.12
S5	20 Mar 12	**>16,000**	**>12,000**	**>12,000**	**0.75**
S11	20 Mar 12	**>16,000**	**1200**	**620**	0.08
S5	27 Mar 12	**>16,000**	**11,000**	**4400**	**0.69**
S10	27 Mar 12	60	88	**130**	1.47
S11	27 Mar 12	**>16,000**	**2800**	**500**	**0.18**
S0	3 Apr 12	6600	**1800**	**820**	**0.27**
S0	10 Apr 12	**>16,000**	**>12,000**	**>12,000**	**0.75**
S5	10 Apr 12	**>16,000**	**>12,000**	**2000**	**0.75**
S5	17 Apr 12	9000	**1300**	**140**	**0.14**
S5	24 Apr 12	2600	300	**140**	**0.12**
S5	1 May 12	6400	**440**	62	0.07
S9	8 May 12	200	8	**180**	0.04
S0	19 Jun 12	360	60	**110**	0.17
S10	17 Jul 12	1500	**1300**	22	**0.87**
S9	21 Aug 12	—	20	**300**	—
S3	28 Aug 12	9400	320	**440**	0.03
S8	18 Sep 12	200	64	**160**	0.32

Appendix B.1 *continued*

Station	Date	Total	Fecal	Entero	F:T
S2	2 Oct 12	20	4	**220**	0.20
S0	16 Oct 12	800	60	**120**	0.08
S3	16 Oct 12	200	20	**460**	0.10
S9	16 Oct 12	600	100	**140**	0.17
S5	18 Dec 12	9800	**420**	90	0.04

Appendix B.2

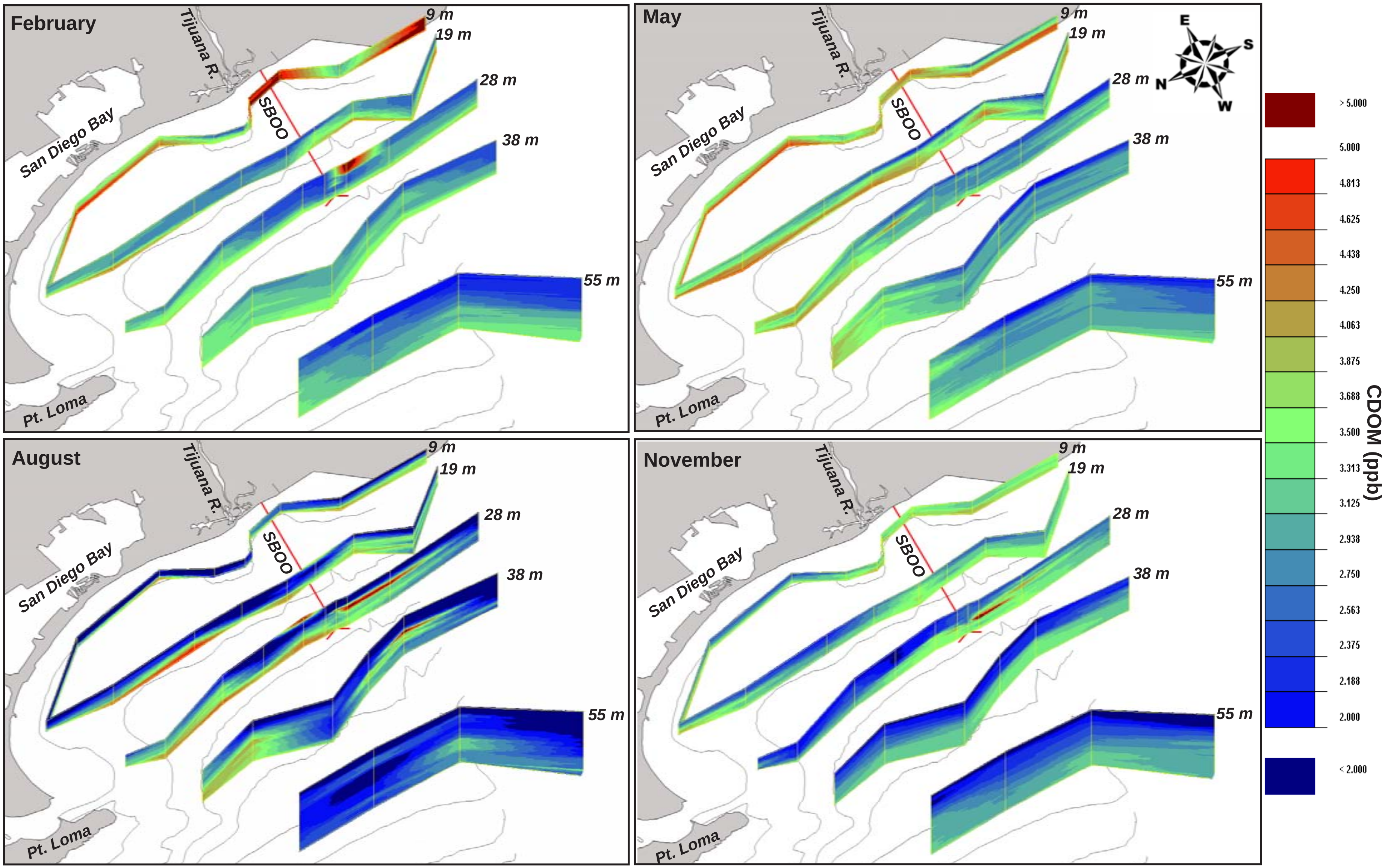
Summary of elevated bacteria densities in samples collected at SBOO kelp bed stations during 2012. Bold values exceed benchmarks for total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), *Enterococcus* (>104 CFU/100 mL), and/or the FTR criterion (total coliforms >1000 CFU/100 mL and F:T>0.10).

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
I25	15 Feb 12	2	**12,000**	**480**	**320**	0.04
I25	15 Feb 12	6	4000	**640**	**180**	**0.16**
I25	21 Mar 12	2	**>16,000**	**6400**	**240**	**0.40**
I25	21 Mar 12	6	6400	**300**	**300**	0.05
I25	21 Mar 12	9	2800	120	**110**	0.04
I25	27 Mar 12	2	1100	120	30	**0.11**

Appendix B.3

Summary of elevated bacteria densities in samples collected at SBOO non-kelp bed offshore stations during 2012. 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 coliforms > 1000 CFU/100 mL and F:T > 0.10).

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
I5	7 Feb 12	2	4400	**580**	**720**	**0.13**
I5	7 Feb 12	6	7400	**740**	**380**	0.10
I5	7 Feb 12	11	4200	**580**	**240**	**0.14**
I12	8 Feb 12	2	1200	200	**120**	**0.17**
I40	8 Feb 12	6	2000	160	**120**	0.08
I40	8 Feb 12	9	1100	160	**160**	**0.15**
I5	2 May 12	11	4200	300	**320**	0.07



Appendix B.4

CDOM values recorded in 2012 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.

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Appendix B.5

Summary of SBOO non-plume reference stations used during 2012 to calculate out-of-range thresholds for wastewater plume detection.

Month	Stations
January	I1, I3, I7, I8, I20, I21, I27, I28, I29, I34
February	I1, I7, I8, I20, I21, I23, I28, I29, I33, I39
March	I1, I3, I7, I8, I9, I20, I21, I22, I27, I28, I29, I31
April	I1, I3, I6, I7, I8, I9, I20, I21, I29
May	I1, I3, I6, I7, I8, I9, I20, I21, I22, I28, I29, I30
June	I1, I3, I7, I8, I20, I21, I22, I27, I28, I30, I31, I39
July	I1, I6, I7, I8, I10, I20, I21, I22, I23, I27, I28, I29, I33
August	I1, I3, I6, I7, I10, I20, I21, I27, I28
September	I1, I6, I7, I8, I9, I10, I20, I21, I27, I28, I29, I30, I33, I34
October	I1, I3, I6, I8, I9, I20, I22, I23, I27, I28, I29, I34, I39
November	I1, I3, I7, I8, I9, I20, I21, I27, I28, I29, I30, I31, I33, I34, I35
December	I1, I3, I6, I7, I8, I9, I10, I20, I21, I22, I23, I27, I28, I31, I34, I39

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Appendix B.6

Summary of oceanographic data from plume detections at SBOO offshore stations and corresponding non-plume reference stations during 2012. Bold values indicate out of range values. DO = dissolved oxygen; XMS = transmissivity; SD = standard deviation; CI = confidence interval. Data for pH were excluded from analyses for August, September, and October (see Chapter 2 for details).

			Plume			Reference		
Station	Date	Plume Width (m)	Mean DO	Mean pH	Mean XMS	DO (Mean - SD)	pH (Mean - SD)	XMS (Mean - 95% CI)
I12	8 Feb 12	10	5.9	8.07	**80.9**	6.3	8.15	87.1
I16	8 Feb 12	3	6.3	8.11	**84.6**	6.2	8.13	86.3
I6	6 Mar 12	1	5.0	7.91	**82.3**	4.6	7.87	85.9
I12	7 Mar 12	8	4.5	7.86	**81.5**	4.5	7.86	86.4
I16	7 Mar 12	2	4.9	7.90	**85.4**	4.6	7.88	85.4
I17	7 Mar 12	6	4.7	7.88	**84.8**	4.6	7.87	85.9
I23	7 Mar 12	1	4.6	7.88	86.1	4.6	7.87	85.9
I12	18 Apr 12	7	3.5	7.78	**83.6**	3.3	7.75	84.0
I15	18 Apr 12	1	3.4	7.77	87.6	3.3	7.75	84.2
I16	18 Apr 12	4	3.3	7.76	86.0	3.4	7.76	83.6
I27	3 May 12	3	6.1	7.97	89.8	6.2	8.01	88.1
I6	5 Jun 12	4	7.3	8.07	**82.6**	6.8	8.02	83.4
I9	5 Jun 12	2	7.2	8.05	86.5	5.9	7.94	85.1
I12	6 Jun 12	7	6.6	8.00	84.7	7.0	8.03	82.8
I16	6 Jun 12	7	6.2	7.97	**84.9**	6.3	7.97	84.1
I9	10 Jul 12	2	8.4	8.08	**84.0**	7.5	8.00	84.2
I12	11 Jul 12	9	**6.7**	7.98	**83.0**	7.9	8.05	83.0
I16	11 Jul 12	8	6.7	7.94	**83.8**	7.3	7.99	84.1
I17	11 Jul 12	7	7.3	7.99	**82.9**	7.5	8.00	83.9
I30	12 Jul 12	7	7.3	8.01	**82.7**	7.2	7.98	84.1
I12	13 Aug 12	5	8.9	—	**83.3**	8.9	—	86.7
I15	13 Aug 12	1	9.2	—	86.9	8.9	—	86.7
I16	13 Aug 12	1	9.0	—	**86.3**	8.9	—	86.7

Appendix B.6 *continued*

			Plume			Reference		
Station	Date	Plume Width (m)	Mean DO	Mean pH	Mean XMS	DO (Mean - SD)	pH (Mean - SD)	XMS (Mean - 95% CI)
I8	15 Aug 12	1	9.2	—	87.5	8.8	—	86.4
I9	15 Aug 12	1	9.1	—	**85.4**	8.9	—	86.3
I12	5 Sep 12	8	8.4	—	**84.2**	8.2	—	85.8
I14	5 Sep 12	6	8.1	—	**82.2**	7.9	—	85.0
I15	5 Sep 12	8	8.4	—	**85.1**	8.2	—	85.9
I16	5 Sep 12	5	8.3	—	**84.2**	8.1	—	85.4
I17	5 Sep 12	4	8.1	—	**82.2**	8.1	—	85.4
I7	2 Oct 12	2	8.5	—	89.4	8.0	—	85.5
I13	2 Oct 12	2	8.4	—	**85.6**	8.0	—	88.1
I15	5 Oct 12	2	8.2	—	**87.1**	8.0	—	87.6
I16	5 Oct 12	4	8.1	—	**86.0**	8.1	—	87.4
I12	7 Nov 12	1	7.5	8.12	**83.4**	6.9	8.09	83.9
I14	7 Nov 12	2	7.7	8.15	**82.8**	6.9	8.09	83.5
I15	7 Nov 12	6	7.4	8.12	84.3	6.8	8.09	84.2
I16	7 Nov 12	1	7.8	8.16	**83.7**	6.9	8.09	84.9
I16	4 Dec 12	3	6.3	8.08	**84.4**	6.2	8.06	84.4

Appendix B.7

Summary of rainfall and bacteria levels at SBOO shore stations during 2012. Total coliform, fecal coliform, and *Enterococcus* densities are expressed as mean CFU/100 mL per month and for the entire year. 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):		0.40	1.19	0.97	0.88	0.02	0.00	0.00	0.00	0.00	0.70	0.29	2.11
S9	*Total*	16	11	16	6	56	56	115	110	155	180	65	20
	Fecal	5	2	4	2	3	2	35	29	5	31	5	11
	Entero	2	2	6	2	53	2	30	96	10	46	13	2
S8	*Total*	6	16	12	6	17	6	16	16	60	13	20	92
	Fecal	2	3	2	2	2	2	2	2	18	2	8	14
	Entero	2	2	2	2	2	2	3	2	42	2	3	2
S12	*Total*	20	11	31	20	32	6	22	20	70	54	70	115
	Fecal	4	4	8	6	10	2	7	6	12	7	26	11
	Entero	13	6	12	2	6	2	4	6	8	22	26	6
S6	*Total*	17	16	206	80	44	6	13	20	20	17	20	92
	Fecal	3	2	17	4	6	2	2	2	4	4	2	2
	Entero	3	4	8	2	4	2	2	2	2	11	2	3
S11	*Total*	21	11	8016	620	56	11	16	16	30	13	35	511
	Fecal	2	3	1002	13	24	2	2	2	7	4	4	34
	Entero	3	6	290	6	5	2	2	2	2	6	4	5
S5	*Total*	3316	4006	8055	6905	1296	6	16	20	20	33	770	2486
	Fecal	643	3002	5758	3400	91	2	2	2	6	4	42	116
	Entero	120	3007	4137	571	22	2	2	2	4	6	5	32
S10	*Total*	3996	8014	1220	14	13	4	313	265	25	25	410	1006
	Fecal	2514	2652	57	5	2	2	264	24	2	2	12	46
	Entero	2030	3903	44	3	2	2	13	6	4	2	3	4
S4	*Total*	6420	8030	570	22	18	17	54	312	26	49	36	416
	Fecal	2122	2752	22	3	5	2	9	27	4	3	5	22
	Entero	1590	3457	12	6	3	2	14	9	16	4	2	14
S3	*Total*	3297	5427	1180	35	41	12	32	2606	74	63	1156	1078
	Fecal	247	1071	56	4	3	2	2	92	13	7	26	67
	Entero	534	825	20	4	4	4	3	115	10	122	44	50
S2	*Total*	886	2140	136	19	16	2	21	181	35	46	48	188
	Fecal	80	114	12	4	4	2	2	18	6	3	12	32
	Entero	83	51	12	6	2	2	3	21	20	46	18	37
S0	*Total*	4882	1247	131	5930	32	156	61	27	115	387	247	310
	Fecal	1771	59	8	3473	4	20	4	3	10	31	32	26
	Entero	1438	117	6	3212	2	38	2	2	38	29	18	33
	n	55	41	44	44	55	44	55	44	44	54	44	44
Monthly	*Total*	2080	2607	1779	1242	147	26	61	337	57	80	262	574
Means	*Fecal*	672	912	632	629	14	4	30	19	8	9	16	35
	Entero	529	1086	414	347	10	6	7	24	14	25	13	17

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Appendix B.8

Summary of bacteria levels at SBOO kelp bed and other offshore stations during 2012. 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.

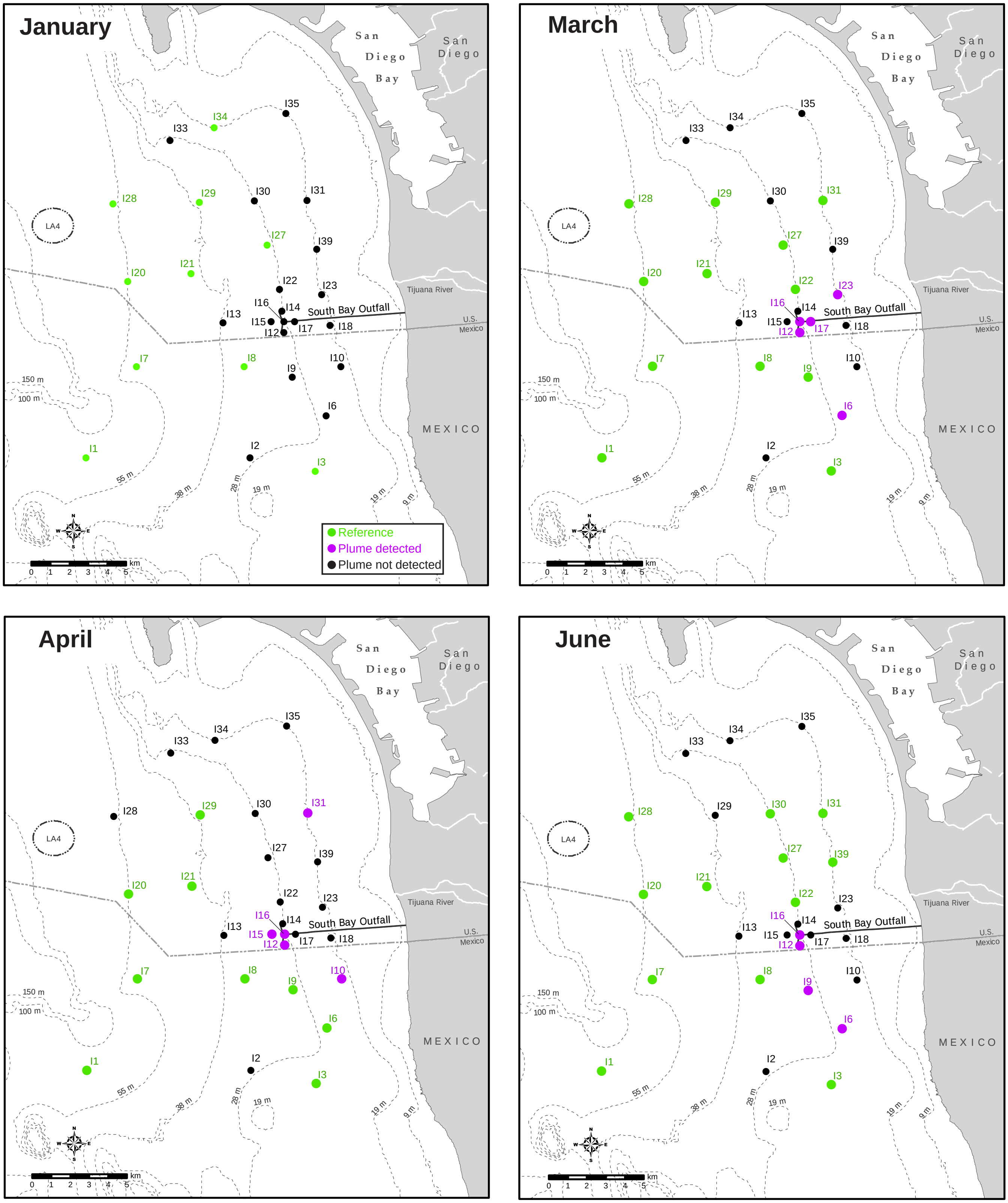
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012 Kelp Bed Stations												
9-m Depth Contour (n = 30)												
Total	36	817	1117	30	4	3	3	16	3	3	21	146
Fecal	6	57	244	5	2	2	2	2	2	2	3	23
Entero	4	31	30	2	2	2	2	2	2	2	2	3
19-m Depth Contour (n = 15)												
Total	6	64	94	10	6	2	2	42	3	2	19	8
Fecal	2	5	12	3	2	2	2	3	2	2	5	2
Entero	2	6	6	2	2	2	2	2	2	2	2	2
2012 Non-Kelp Bed Stations												
9-m Depth Contour (n = 27)												
Total	19	908	9	21	165	9	4	23	11	8	13	9
Fecal	4	97	2	2	13	2	3	2	2	2	2	2
Entero	4	75	2	2	14	2	2	2	2	2	2	2
19-m Depth Contour (n = 9)												
Total	2	40	59	5	4	2	4	10	2	2	2	9
Fecal	2	4	13	2	2	2	2	2	2	2	2	2
Entero	2	5	4	2	2	2	2	2	2	2	2	2
28-m Depth Contour (n = 24)												
Total	3	86	17	17	5	23	2	7	5	2	27	27
Fecal	2	21	3	3	3	7	2	2	2	2	5	4
Entero	2	9	2	2	2	3	2	2	2	2	2	3
38-m Depth Contour (n = 9)												
Total	2	2	8	7	2	2	2	3	4	2	2	11
Fecal	2	2	2	3	2	2	2	2	2	2	2	3
Entero	2	2	2	2	2	2	2	2	2	2	2	2
55-m Depth Contour (n = 6)												
Total	2	2	73	35	2	5	5	2	2	2	2	42
Fecal	2	2	3	3	2	2	2	2	2	2	2	4
Entero	2	2	4	3	2	2	2	2	2	2	2	3

Appendix B.9

Summary of total suspended solid (TSS) and oil and grease (O&G) concentrations in samples collected from the SBOO kelp bed and other offshore stations during 2012. Data include the number samples per month (n) and detection rate, as well as the minimum, maximum, and mean of detected concentrations for each month. The method detection limit = 0.2 mg/L for both TSS and O&G.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012 Kelp Bed Stations												
Total Suspended Solids (n = 9)												
Detection Rate (%)	100	89	100	100	100	100	100	100	78	100	100	100
Min	5.15	nd	2.14	3.27	2.94	1.77	2.48	2.48	nd	2.02	3.24	2.99
Max	31.20	8.83	9.25	19.20	10.70	9.38	12.70	5.81	3.68	6.60	5.33	9.91
Mean	14.75	4.18	4.72	7.72	4.99	5.41	4.60	3.63	2.33	3.46	4.31	5.89
Oil and Grease (n = 3)												
Detection Rate (%)	0	0	0	0	33	0	0	0	0	0	0	0
Min	—	—	—	—	nd	—	—	—	—	—	—	—
Max	—	—	—	—	1.70	—	—	—	—	—	—	—
Mean	—	—	—	—	1.70	—	—	—	—	—	—	—
2012 Non-Kelp Bed Stations												
Total Suspended Solids (n = 75)[a]												
Detection Rate (%)	84	80	88	97	99	97	99	96	87	96	93	100
Min	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.45
Max	29.30	16.40	11.50	18.00	10.90	33.70	10.40	9.06	23.20	13.50	9.90	28.70
Mean	5.69	3.90	3.73	4.74	3.90	4.77	3.39	3.21	3.81	3.35	3.40	5.04
Oil and Grease (n = 25)												
Detection Rate (%)	4	0	8	0	4	8	0	0	4	0	0	0
Min	nd	—	nd	—	nd	nd	—	—	nd	—	—	—
Max	2.50	—	4.90	—	1.80	2.90	—	—	22.60	—	—	—
Mean	2.50	—	4.50	—	1.80	2.20	—	—	22.60	—	—	—

[a] n = 74 in April; nd = not detected



Appendix B.10

Distribution of stations with potential plume detections (purple) and those used as reference stations for water quality compliance calculations (green) during selected SBOO monthly surveys during 2012.

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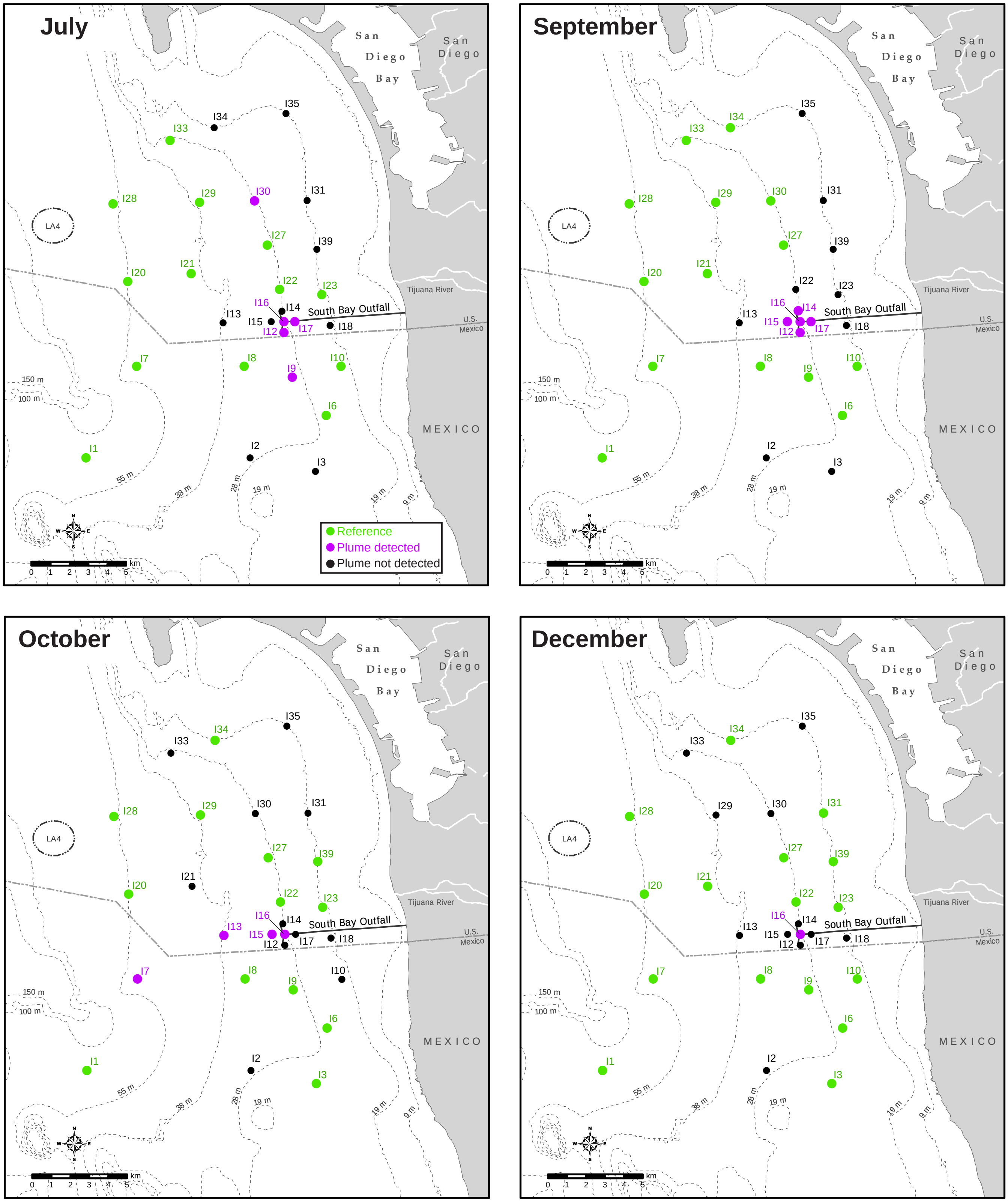

Appendix B.10 *continued*

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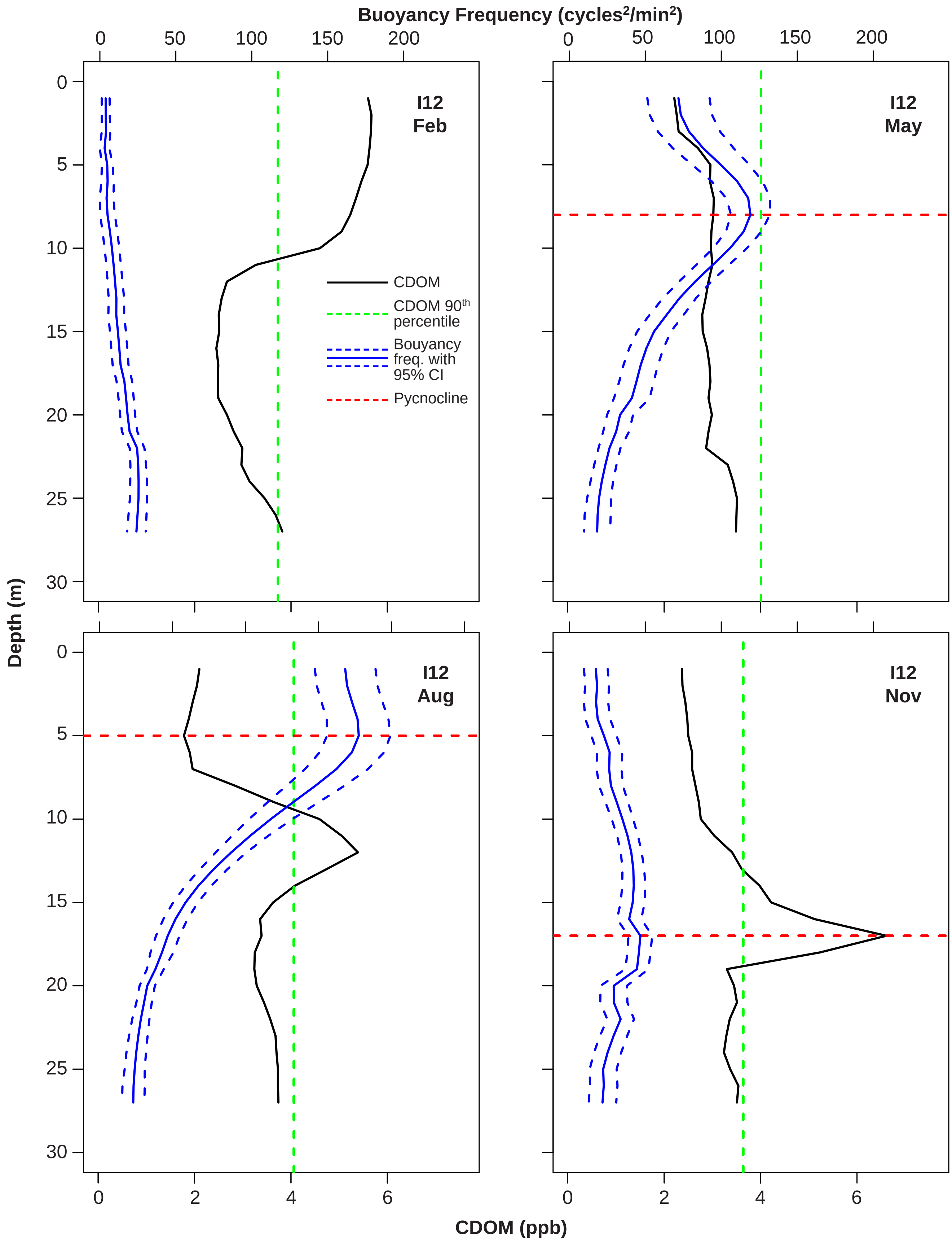
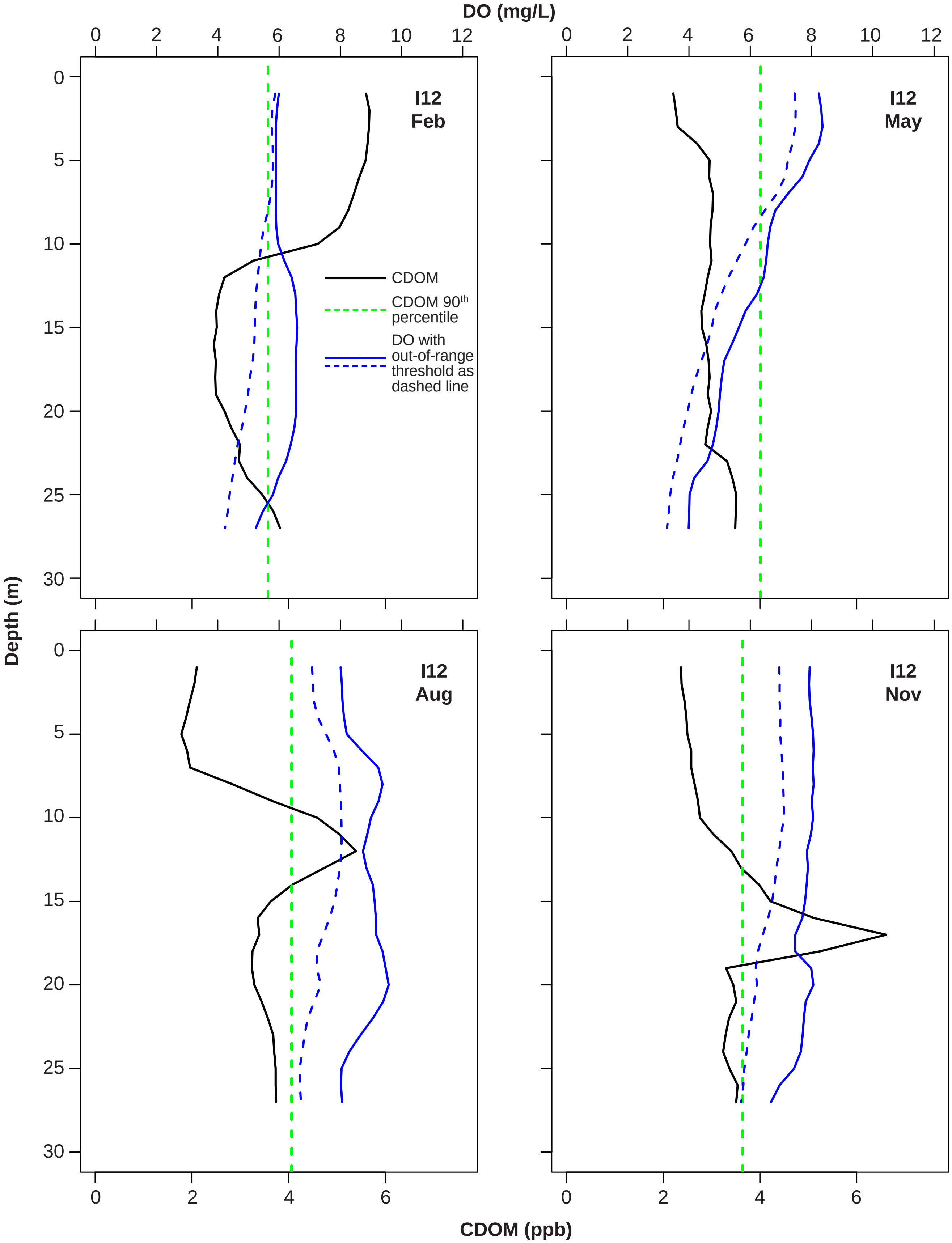


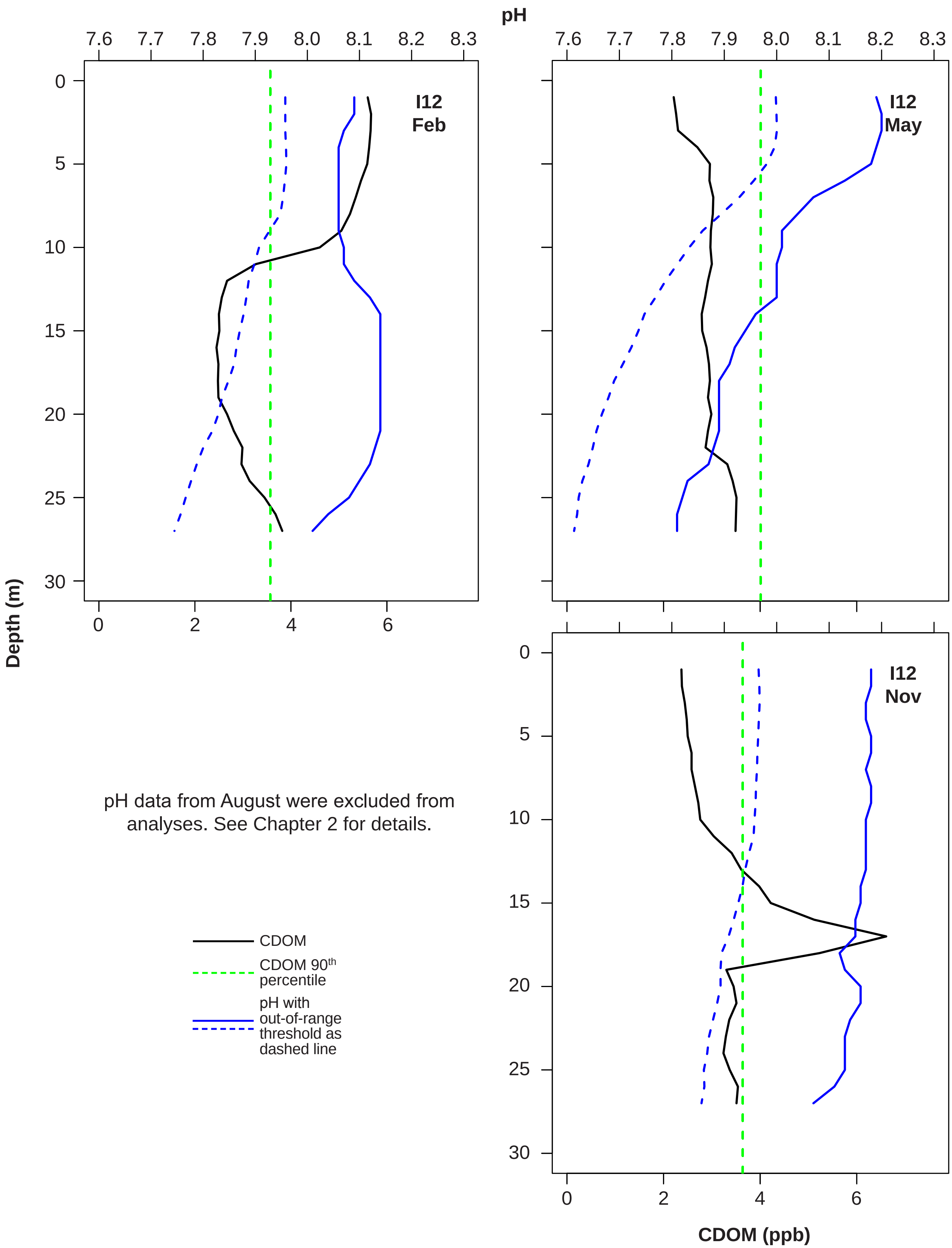
Appendix B.11

Representative vertical profiles of CDOM and buoyancy frequency from outfall station I12 during 2012.



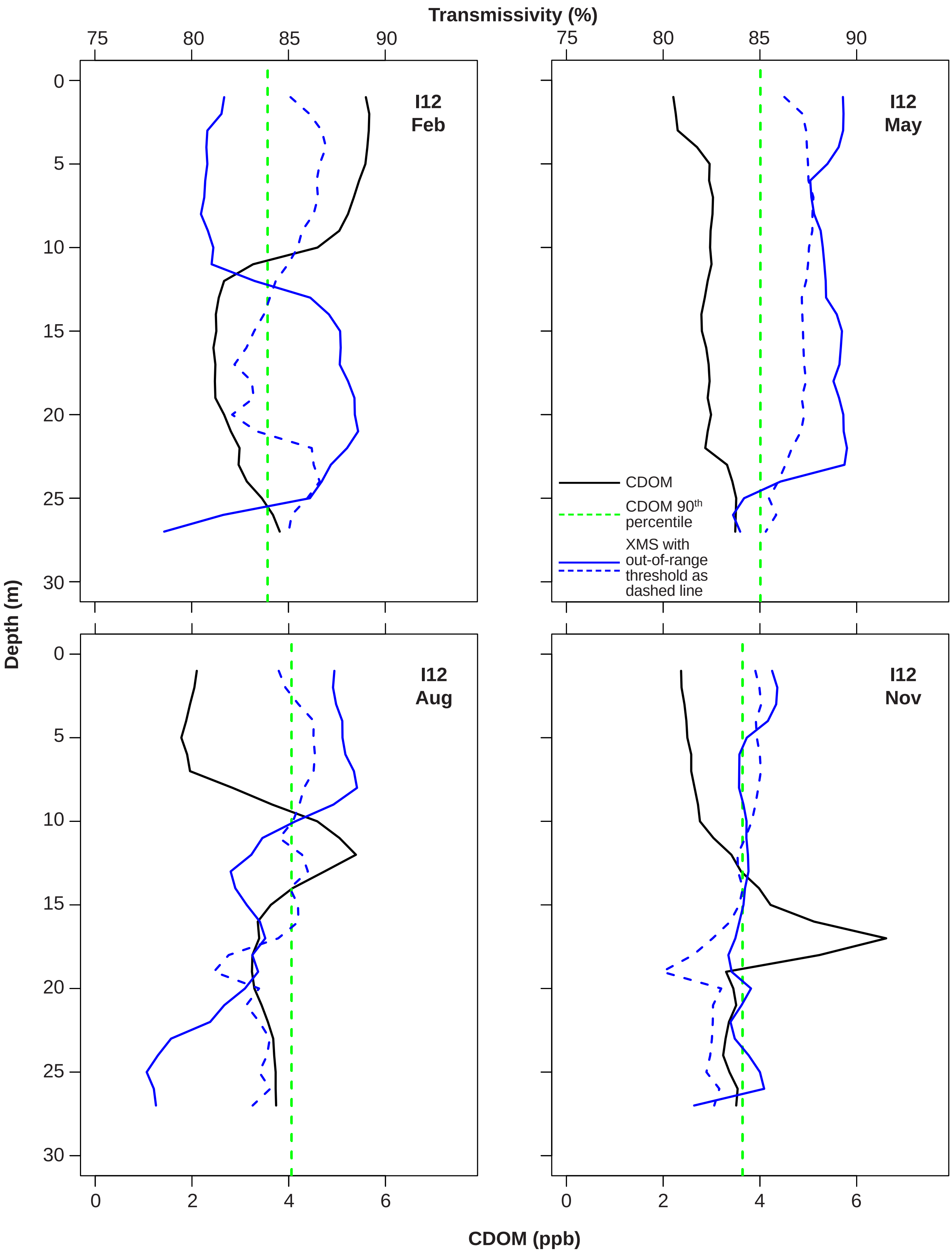
Appendix B.12

Representative vertical profiles of CDOM and dissolved oxygen (DO) from outfall station I12 during 2012.



Appendix B.13

Representative vertical profiles of CDOM and pH from outfall station I12 during 2012.



Appendix B.14

Representative vertical profiles of CDOM and transmissivity from outfall station I12 during 2012. XMS = transmissivity.

Appendix C

Supporting Data

2012 SBOO Stations

Sediment Conditions

Appendix C.1

Constituents and method detection limits (MDL) used for the analysis of sediments collected from the SBOO region during 2012.

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 (Ti)	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	150	HCH, Delta isomer	700
HCH, Beta isomer	310	HCH, Gamma isomer	260
Total Chlordane			
Alpha (cis) Chlordane	240	Heptachlor epoxide	120
Cis Nonachlor	240	Methoxychlor	1100
Gamma (trans) Chlordane	350	Oxychlordane	240
Heptachlor	1200	Trans Nonachlor	250
Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	830	p,p-DDE	260
o,p-DDE	720	p,p-DDMU [a]	—
o,p-DDT	800	p,p-DDT	800
p,p-DDD	470		
Miscellaneous Pesticides			
Aldrin	430	Endrin	830
Alpha Endosulfan	240	Endrin aldehyde	830
Beta Endosulfan	350	Hexachlorobenzene (HCB)	470
Dieldrin	310	Mirex	500
Endosulfan Sulfate	260		

[a] No MDL available for this parameter

Appendix C.1 *continued*

Parameter	MDL	Parameter	MDL
Polychlorinated Biphenyl Congeners (PCBs) (ppt)			
PCB 18	540	PCB 126	720
PCB 28	660	PCB 128	570
PCB 37	340	PCB 138	590
PCB 44	890	PCB 149	500
PCB 49	850	PCB 151	640
PCB 52	1000	PCB 153/168	600
PCB 66	920	PCB 156	620
PCB 70	1100	PCB 157	700
PCB 74	900	PCB 158	510
PCB 77	790	PCB 167	620
PCB 81	590	PCB 169	610
PCB 87	600	PCB 170	570
PCB 99	660	PCB 177	650
PCB 101	430	PCB 180	530
PCB 105	720	PCB 183	530
PCB 110	640	PCB 187	470
PCB 114	700	PCB 189	620
PCB 118	830	PCB 194	420
PCB 119	560	PCB 201	530
PCB 123	660	PCB 206	510
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 collected from the SBOO region in 2012. Included is a subset of the Wentworth scale presented as “phi” categories with corresponding Horiba channels, sieve sizes, and size fractions.

Wentworth Scale

Phi Size	Horiba[a] Min µm	Horiba[a] Max µm	Sieve Size	Sub-Fraction	Fraction
-1	—	—	SIEVE_2000	Granules	Coarse Particles
0	1100	2000	SIEVE_1000	Very coarse sand	Coarse Particles
1	590	1000	SIEVE_500	Coarse sand	Coarse Sand
2	300	500	SIEVE_250	Medium sand	Coarse Sand
3	149	250	SIEVE_125	Fine sand	Fine Sand
4	64	125	SIEVE_63	Very fine sand	Fine Sand
5	32	62.5	SIEVE_0[b]	Coarse silt	Fine Particles
6	16	31	—	Medium silt	Fine Particles
7	8	15.6	—	Fine silt	Fine Particles
8	4	7.8	—	Very fine silt	Fine Particles
9	≤	3.9	—	Clay	Fine Particles

[a] values correspond to Horiba channels; particles > 2000 µm measured by sieve
[b] sum of all silt and clay

Appendix C.3

Summary of the constituents that make up total DDT, total chlordane, and total PCB in sediments from the SBOO region during 2012.

Station	Class	Constituent	January	July	Units
I1	DDT	p,p-DDE	98	nd	ppt
I9	DDT	p,p-DDE	105	110	ppt
I12	Chlordane	Heptachlor epoxide	nd	29	ppt
I14	DDT	p,p-DDE	160	nd	ppt
I16	DDT	p,p-DDE	77	nd	ppt
I22	DDT	p,p-DDE	130	130	ppt
I22	PCB	PCB 206	nd	330	ppt
I27	DDT	p,p-DDE	nd	235	ppt
I27	PCB	PCB 206	nd	320	ppt
I28	DDT	p,p-DDE	430	355	ppt
I28	PCB	PCB 153/168	600	nd	ppt
I28	PCB	PCB 206	nd	210	ppt
I29	DDT	p,p-DDE	580	1700	ppt
I29	DDT	p,p-DDT	nd	630	ppt
I29	PCB	PCB 180	210	nd	ppt
I29	PCB	PCB 201	170	nd	ppt
I29	PCB	PCB 206	nd	290	ppt
I30	PCB	PCB 206	nd	340	ppt
I31	DDT	p,p-DDD	170	nd	ppt
I31	DDT	p,p-DDT	225	nd	ppt
I31	PCB	PCB 206	nd	380	ppt
I33	PCB	PCB 206	nd	290	ppt
I34	PCB	PCB 206	nd	290	ppt
I35	DDT	p,p-DDE	nd	180	ppt
I35	PCB	PCB 206	nd	330	ppt

nd = not detected

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Appendix C.4

Summary of particle size parameters with sub-fractions (%) for each SBOO station sampled during January 2012. Visual observations are from sieved “grunge” (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VC Sand = Very Coarse Sand; C Sand = Coarse Sand; M Sand = Medium Sand; F Sand = Fine Sand; VF Sand = Very Fine Sand; C Silt = Coarse Silt; M Silt = Medium Silt; F Silt = Fine Silt; VF Silt = Very Fine Silt.

		Coarse Particles		Coarse Sand		Fine Sand		Fine Particles					Visual Observations
		Granules	VC Sand	C Sand	M Sand	F Sand	VF Sand	C Silt	M Silt	F Silt	VF Silt	Clay	
19-m Stations	I35	0.0	0.0	0.0	2.3	17.4	39.8	23.9	9.2	3.9	2.0	1.4	organic debris/worm tubes
	I34[s]	20.9	9.8	17.5	33.5	18.4	0.7	0.0	0.0	0.0	0.0	0.0	shell hash
	I31	0.0	0.0	0.0	1.9	24.7	61.2	7.8	1.6	1.5	1.0	0.2	
	I23[s]	10.9	16.1	40.6	29.8	2.3	0.8	0.0	0.0	0.0	0.0	0.0	shell hash
	I18	0.0	0.0	0.0	2.1	24.1	59.7	9.5	1.7	1.5	1.0	0.3	organic debris/worm tubes
	I10	0.0	0.0	0.1	2.8	28.2	56.4	7.9	1.8	1.6	1.1	0.2	shell hash/organic debris/worm tubes
	I4[s]	6.2	21.0	44.3	22.2	2.2	0.4	3.6	0.0	0.0	0.0	0.0	shell hash/organic debris/worm tubes
28-m Stations	I33	0.0	0.0	0.1	3.7	36.4	45.5	6.1	2.6	2.8	2.0	0.9	organic debris/worm tubes
	I30	0.0	0.0	0.0	1.4	16.1	57.6	16.8	3.2	2.3	1.7	1.0	
	I27	0.0	0.0	0.0	1.8	17.7	58.5	15.1	2.7	2.0	1.4	0.8	
	I22	0.0	0.0	0.1	5.5	28.0	47.6	11.2	2.8	2.4	1.7	0.8	organic debris/worm tubes
	I14[a]	0.0	0.0	0.0	2.0	20.2	58.6	13.1	2.3	1.9	1.3	0.6	
	I16[a]	0.0	0.0	0.6	8.6	37.6	42.5	6.6	1.5	1.4	1.0	0.2	organic debris/algae
	I15[a]	0.0	3.8	28.2	50.7	15.4	1.5	0.3	0.0	0.0	0.0	0.0	organic debris/algae
	I12[a]	0.0	1.3	13.6	30.5	31.7	17.5	3.5	0.9	0.8	0.4	0.0	organic debris/worm tubes
	I9	0.0	0.0	0.0	1.5	16.8	57.4	17.0	2.8	2.1	1.6	0.8	organic debris/worm tubes
	I6	0.0	0.1	12.7	53.0	18.0	6.2	3.4	2.2	2.3	1.6	0.5	red relict sand/worm tubes
	I2	0.0	3.4	21.6	49.0	23.9	1.6	0.0	0.1	0.5	0.0	0.0	
	I3	0.0	3.6	23.5	51.2	20.7	0.9	0.0	0.0	0.0	0.0	0.0	red relict sand/worm tubes
38-m Stations	I29	0.0	0.0	0.0	2.2	19.1	43.1	20.7	6.2	4.1	2.8	1.8	organic debris/worm tubes
	I21	0.0	6.5	51.7	37.0	4.7	0.1	0.0	0.0	0.0	0.0	0.0	shell hash/red relict sand
	I13	0.0	5.9	44.6	40.6	7.8	1.0	0.0	0.0	0.0	0.0	0.0	shell hash/red relict sand
	I8	0.0	4.3	31.4	45.4	14.1	1.8	0.7	0.8	1.0	0.6	0.0	
55-m Stations	I28[s]	5.7	9.3	16.8	12.3	4.1	25.7	26.1	0.0	0.0	0.0	0.0	coarse black sand
	I20	0.0	0.0	5.4	41.2	39.8	6.7	1.4	1.4	2.0	1.6	0.5	
	I7	0.0	0.1	16.6	63.2	11.4	1.4	0.8	1.5	2.5	2.0	0.6	red relict sand
	I1	0.0	0.0	0.1	8.0	47.3	33.0	4.1	2.2	2.7	1.9	0.8	

[a] nearfield stations; [s] measured by sieve (not Horiba)

Appendix C.4 *continued*

Summary of particle size parameters with sub-fractions (%) for each SBOO station sampled during July 2012. Visual observations are from sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VC Sand = Very Coarse Sand; C Sand = Coarse Sand; M Sand = Medium Sand; F Sand = Fine Sand; VF Sand = Very Fine Sand; C Silt = Coarse Silt; M Silt = Medium Silt; F Silt = Fine Silt; VF Silt = Very Fine Silt.

		Coarse Particles		Coarse Sand		Fine Sand		Fine Particles					Visual Observations
		Granules	VC Sand	C Sand	M Sand	F Sand	VF Sand	C Silt	M Silt	F Silt	VF Silt	Clay	
19-m Stations	I35	0.0	0.0	0.0	2.6	18.6	39.8	22.6	8.3	4.3	2.3	1.5	organic debris/worm tubes
	I34	0.0	1.3	13.6	35.7	43.2	5.3	0.6	0.2	0.2	0.0	0.0	organic debris/shell hash/worm tubes
	I31	0.0	0.0	0.0	1.5	24.7	61.4	7.6	1.7	1.7	1.2	0.3	organic debris/worm tubes
	I23	0.0	0.0	0.1	2.5	24.2	54.3	10.4	3.2	2.9	1.8	0.6	shell hash/organic debris /worm tubes
	I18	0.0	0.0	0.1	2.3	23.8	59.1	10.2	1.9	1.5	1.0	0.2	
	I10	0.0	0.0	0.1	2.9	27.9	56.4	8.1	1.8	1.6	1.0	0.2	organic debris/worm tubes
	I4	0.0	6.7	52.2	32.6	5.3	2.6	0.6	0.0	0.0	0.0	0.0	shell hash
28-m Stations	I33	0.0	0.0	0.0	3.0	36.5	45.5	6.1	2.8	3.1	2.1	0.8	organic debris/worm tubes
	I30	0.0	0.0	0.0	1.6	16.2	57.2	15.8	3.3	2.9	2.0	0.9	organic debris/worm tubes
	I27	0.0	0.0	0.0	1.9	17.6	57.4	15.3	3.0	2.4	1.6	0.8	organic debris/worm tubes
	I22	0.0	0.0	0.1	3.2	24.1	51.0	12.5	3.4	3.0	1.9	0.8	organic debris/worm tubes
	I14[a]	0.0	0.0	0.1	2.7	20.9	55.1	13.8	2.8	2.3	1.6	0.7	organic debris/worm tubes
	I16[a]	0.0	1.2	13.2	35.8	35.8	10.2	2.0	0.8	0.7	0.2	0.0	organic debris/worm tubes
	I15[a]	0.0	0.0	1.5	17.0	34.2	30.7	10.2	2.6	2.0	1.4	0.4	organic debris/worm tubes
	I12[a]	0.0	0.0	1.9	19.2	36.7	30.0	6.8	2.0	1.8	1.2	0.3	organic debris/worm tubes
	I9	0.0	0.0	0.0	1.3	15.7	59.0	17.0	2.7	2.1	1.5	0.6	organic debris/worm tubes
	I6	0.0	4.9	35.2	44.0	12.0	2.0	0.9	0.6	0.3	0.0	0.0	shell hash/red relict sand
	I2	0.0	3.3	17.3	42.0	32.8	3.1	0.2	0.6	0.7	0.0	0.0	
	I3	0.0	3.5	21.3	48.0	25.7	1.5	0.0	0.0	0.0	0.0	0.0	
38-m Stations	I29	0.0	0.0	0.1	4.8	19.3	39.2	20.7	6.4	4.5	3.1	1.8	
	I21	0.0	4.8	38.5	42.1	8.7	1.4	0.9	1.2	1.4	1.0	0.1	
	I13	0.0	4.8	38.2	47.8	8.4	0.8	0.0	0.0	0.0	0.0	0.0	shell hash/red relict sand
	I8	0.0	3.3	21.9	45.1	23.7	3.3	0.7	0.7	0.8	0.4	0.0	
55-m Stations	I28[s]	5.5	10.9	21.2	14.7	4.3	18.0	25.4	0.0	0.0	0.0	0.0	coarse black sand/shell hash
	I20	0.0	9.2	57.1	25.9	7.3	0.5	0.0	0.0	0.0	0.0	0.0	
	I7	0.0	7.7	53.3	29.8	6.1	1.4	0.2	0.3	0.7	0.5	0.0	red relict sand
	I1	0.0	0.0	0.1	6.4	47.0	35.1	4.6	2.3	2.5	1.6	0.5	

[a] nearfield stations; [s] measured by sieve (not Horiba)

Appendix C.5

Summary of organic loading indicators in sediments from SBOO stations sampled during January and July 2012.

	January				July			
	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
19-m Stations								
I35	10.2	0.049	0.28	1.42	3.6	0.138	0.27	1.36
I34	1.2	0.025	4.83	0.73	1.8	nd	0.04	0.78
I31	3.0	0.025	0.11	0.63	2.1	0.091	0.13	0.72
I23	4.1	0.024	4.26	1.14	1.4	0.036	0.15	0.94
I18	2.2	0.016	0.08	0.71	1.6	0.036	0.12	0.76
I10	1.2	0.024	0.14	0.75	1.3	0.020	0.11	0.82
I4	nd	0.008	0.15	0.33	0.2	0.011	0.02	0.36
28-m Stations								
I33	3.3	0.037	0.50	1.48	4.1	0.036	0.26	1.52
I30	3.4	0.037	0.22	1.29	2.9	0.096	0.21	1.18
I27	2.2	0.023	0.15	1.00	2.8	0.062	0.14	1.08
I22	0.8	0.023	0.16	0.88	2.5	0.034	0.20	1.03
I14[a]	1.2	0.022	0.13	0.99	1.8	0.029	0.18	1.08
I16[a]	1.3	0.019	0.11	0.76	0.5	0.026	0.06	0.46
I15[a]	nd	0.010	0.02	0.36	1.6	0.024	0.13	0.96
I12[a]	0.6	0.013	0.05	0.55	0.7	0.023	0.13	0.52
I9	3.0	0.026	0.16	1.15	2.5	0.027	0.17	1.32
I6	1.0	0.012	0.05	0.39	0.4	0.010	0.02	0.41
I2	0.8	0.011	0.02	0.43	0.3	0.013	0.05	0.42
I3	0.4	0.012	0.03	0.37	0.4	0.012	0.04	0.41
38-m Stations								
I29	2.8	0.038	0.38	1.85	2.8	0.132	0.36	1.56
I21	2.0	0.011	0.03	0.47	0.2	0.042	0.05	0.52
I13	nd	0.011	0.03	0.45	0.2	0.010	0.03	0.81
I8	4.2	0.011	0.03	0.45	0.8	0.012	0.04	0.50
55-m Stations								
I28	3.1	0.049	0.59	1.68	1.2	0.041	0.37	1.69
I20	0.6	0.014	0.06	0.54	nd	0.016	0.02	0.42
I7	0.4	0.013	0.04	0.45	0.4	0.015	0.05	0.46
I1	2.4	0.025	0.18	1.09	0.5	0.024	0.15	1.01
Detection Rate (%)	89	100	100	100	96	96	100	100

[a] nearfield stations; nd = not detected

Appendix C.6

Concentrations of trace metals (ppm) in sediments from SBOO stations sampled during January 2012. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted in yellow (see Table 4.1).

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Stations																		
I35	4760	0.36	2.3	44.3	0.111	0.11	11.2	4.8	7600	5.26	82.6	0.017	4.38	nd	0.19	nd	0.83	24.1
I34	634	nd	1.9	4.4	0.017	nd	2.1	0.9	1610	1.74	24.3	0.005	0.71	nd	nd	nd	nd	3.6
I31	2000	nd	0.9	13.8	0.037	nd	6.1	1.3	2360	1.70	24.2	nd	1.64	nd	nd	nd	0.33	6.6
I23	1250	nd	2.0	6.0	0.049	0.07	4.2	1.1	3140	2.84	20.9	nd	1.07	nd	nd	nd	nd	6.6
I18	4480	0.32	1.4	50.8	0.066	nd	11.3	1.9	6280	2.84	54.4	nd	2.51	nd	nd	nd	0.40	11.6
I10	5960	0.39	1.4	34.3	0.085	nd	10.2	2.8	6740	3.01	68.6	0.005	3.34	nd	nd	nd	0.53	16.6
I4	792	nd	0.9	3.0	0.025	nd	4.8	0.4	1660	1.36	13.6	nd	0.78	nd	nd	nd	0.35	3.0
28-m Stations																		
I33	2840	nd	1.3	18.8	0.058	0.09	7.4	3.7	5020	3.63	55.2	0.018	2.85	nd	nd	nd	1.05	14.5
I30	3730	nd	0.9	32.7	0.068	0.09	9.3	3.1	5060	2.91	51.9	0.009	3.46	nd	nd	nd	0.46	14.9
I27	6410	0.32	1.3	34.4	0.089	nd	10.9	3.2	6570	3.62	65.2	0.006	3.84	nd	nd	nd	0.62	17.2
I22	5020	0.31	1.5	25.8	0.075	0.06	9.4	2.5	5340	3.00	50.5	0.005	3.31	nd	nd	nd	0.51	13.5
I14[a]	6800	0.47	1.3	43.0	0.111	0.18	11.1	3.6	7110	3.62	71.4	0.005	4.06	nd	nd	nd	0.73	18.9
I16[a]	4860	nd	1.3	30.4	0.078	0.07	8.8	2.5	5900	2.83	59.0	nd	2.70	nd	nd	nd	0.42	15.1
I15[a]	1560	nd	2.3	4.6	0.053	nd	8.4	0.7	3980	2.14	18.0	nd	1.08	nd	nd	nd	0.37	7.3
I12[a]	3570	nd	1.6	19.0	0.064	nd	8.0	2.1	4760	2.24	43.1	nd	2.01	nd	nd	nd	0.40	10.7
I9	7900	0.52	1.6	47.2	0.115	0.09	13.4	4.3	8750	3.68	87.5	0.005	5.12	nd	nd	nd	0.63	22.4
I6	946	0.37	3.9	3.1	0.036	nd	8.9	0.4	3920	1.65	10.2	nd	0.99	nd	nd	nd	0.36	4.2
I2	823	nd	0.8	2.2	0.021	0.07	6.1	0.5	1190	1.04	7.2	nd	0.91	nd	nd	nd	nd	2.6
I3	639	nd	1.0	1.7	0.021	nd	7.0	0.3	1260	1.01	5.2	nd	0.80	nd	nd	nd	nd	2.3
38-m Stations																		
I29	4440	0.30	2.4	37.6	0.099	0.09	11.2	4.7	7100	4.70	63.7	0.029	5.05	nd	nd	nd	0.77	19.5
I21	1030	nd	9.2	2.3	0.049	0.07	11.7	0.6	8620	3.79	15.1	nd	0.98	nd	nd	nd	0.33	7.1
I13	757	nd	5.4	2.3	0.034	nd	9.0	0.5	5410	2.51	10.5	nd	0.76	nd	nd	nd	0.34	5.3
I8	1810	nd	2.2	5.0	0.056	0.07	9.5	0.9	4690	1.96	21.4	nd	1.38	nd	nd	nd	0.44	8.4
55-m Stations																		
I28	3030	0.32	2.1	24.6	0.085	0.11	8.5	4.8	5450	4.76	45.3	0.028	5.15	nd	nd	nd	0.84	15.2
I20	1510	0.47	2.0	4.3	0.051	nd	6.2	0.9	4110	2.08	15.3	nd	1.45	nd	nd	nd	nd	7.5
I7	1020	0.40	5.6	2.8	0.046	0.07	9.6	0.6	6840	2.49	17.4	nd	1.17	nd	nd	nd	nd	6.6
I1	2300	nd	1.1	9.3	0.054	0.10	7.2	1.7	3430	2.42	31.0	0.008	2.89	nd	nd	nd	0.44	8.5
Detection Rate (%)	100	44	100	100	100	56	100	100	100	100	100	44	100	0	4	0	78	100

[a]nearfield stations; nd = not detected

Appendix C.6 *continued*

Concentrations of trace metals (ppm) in sediments from SBOO stations sampled during July 2012. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted in yellow (see Table 4.1).

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Stations																		
I35	9660	0.39	2.3	40.5	0.147	nd	13.1	5.2	10,100	4.93	107.0	0.016	4.20	nd	nd	nd	0.54	24.0
I34	5370	nd	1.9	22.7	0.086	nd	9.7	6.5	6200	4.75	79.8	0.005	4.43	nd	nd	nd	1.68	18.7
I31	4910	0.44	1.0	17.5	0.011	nd	7.9	1.4	5050	2.21	84.4	nd	1.57	0.26	nd	nd	nd	9.2
I23	6350	nd	1.4	35.5	0.112	nd	10.6	2.6	6100	3.35	71.1	nd	3.34	nd	nd	nd	nd	15.0
I18	6080	nd	1.6	26.2	0.130	nd	12.5	2.5	7440	3.96	65.2	nd	3.38	nd	nd	nd	nd	16.7
I10	7480	nd	1.6	38.0	0.151	nd	11.8	3.1	7800	3.69	82.1	nd	3.45	nd	nd	nd	nd	19.0
I4	1120	nd	1.2	3.4	0.073	nd	4.1	0.5	1860	1.58	17.8	nd	0.79	nd	nd	nd	nd	3.6
28-m Stations																		
I33	5740	0.38	1.9	23.0	0.100	nd	10.3	7.0	6750	5.02	87.0	0.015	4.73	0.39	nd	nd	1.72	20.1
I30	8430	0.31	1.5	29.8	0.131	nd	11.2	3.6	7120	3.61	71.8	0.005	3.63	nd	nd	nd	0.39	16.6
I27	8460	0.37	1.3	30.3	0.134	nd	11.0	3.4	7310	3.34	80.2	nd	3.26	nd	nd	nd	0.64	16.0
I22	7540	0.40	1.7	30.1	0.119	nd	10.6	3.3	6960	3.24	82.6	0.005	3.30	nd	nd	nd	0.40	14.6
I14[a]	6330	nd	1.7	42.2	0.114	nd	11.6	2.3	7350	3.48	84.3	nd	2.73	nd	nd	nd	nd	14.9
I16[a]	8810	0.37	1.4	43.7	0.190	nd	14.4	4.2	8470	4.48	90.8	nd	4.84	nd	nd	nd	nd	21.8
I15[a]	1320	nd	2.4	2.1	0.036	nd	5.3	0.3	4370	1.99	15.4	nd	0.91	nd	nd	nd	nd	6.5
I12[a]	5890	nd	1.6	32.1	0.120	nd	10.1	2.6	6780	3.26	66.7	nd	3.02	nd	nd	nd	nd	18.7
I9	9180	0.34	1.7	41.6	0.146	nd	12.5	4.1	8470	4.18	86.6	nd	4.61	nd	nd	nd	0.33	22.3
I6	1620	nd	4.4	4.0	0.070	nd	9.1	0.4	4300	2.27	15.9	nd	0.91	nd	nd	nd	nd	4.9
I2	1800	nd	0.6	3.3	0.069	nd	7.3	0.5	1620	1.52	12.4	nd	1.18	nd	nd	nd	nd	3.6
I3	927	nd	1.0	1.7	0.051	nd	7.3	0.3	1420	1.27	6.8	nd	1.14	nd	nd	nd	nd	2.3
38-m Stations																		
I29	9750	0.34	2.6	37.0	0.155	nd	13.6	5.8	10,100	4.79	89.1	0.016	5.04	nd	nd	nd	0.59	21.4
I21	1210	nd	9.9	2.2	0.077	nd	11.9	0.2	8490	3.76	14.1	nd	0.90	nd	nd	nd	nd	7.1
I13	1290	nd	6.0	2.8	0.104	nd	10.8	0.3	5960	2.68	16.2	nd	0.81	nd	nd	nd	nd	5.8
I8	2250	nd	2.6	5.4	0.093	nd	9.7	0.6	4630	2.10	25.6	nd	1.23	nd	nd	nd	nd	8.6
55-m Stations																		
I28	7670	0.35	2.9	27.3	0.139	nd	10.3	5.4	8260	4.21	70.1	0.023	5.08	nd	nd	nd	0.61	16.8
I20	2530	nd	3.1	7.1	0.074	nd	6.2	0.9	3890	2.02	40.8	nd	1.23	nd	nd	nd	nd	8.5
I7	1250	0.49	5.3	2.5	0.071	nd	9.2	0.3	7030	2.84	18.5	nd	1.00	nd	nd	nd	nd	6.5
I1	2790	nd	1.0	9.1	0.085	nd	7.6	1.5	3550	2.27	32.3	0.005	3.01	nd	nd	nd	nd	8.2
Detection Rate (%)	100	41	100	100	100	0	100	100	100	100	100	30	100	7	0	0	33	100

[a]nearfield stations; nd = not detected

Appendix C.7

Concentrations of total DDT, hexachlorobenzene (HCB), total chlordane (tChlor), and total PCB detected in sediments from SBOO stations sampled during January and July 2012. Values that exceed thresholds are highlighted (see Table 4.1).

	January				July			
	tDDT (ppt)	HCB (ppt)	tChlor (ppt)	tPCB (ppt)	tDDT (ppt)	HCB (ppt)	tChlor (ppt)	tPCB (ppt)
19-m Stations								
I35	nd	nd	nd	nd	180	nd	nd	330
I34	nd	nd	nd	nd	nd	nd	nd	290
I31	395	nd	nd	nd	nd	nd	nd	380
I23	nd	nd	nd	nd	nd	nd	nd	nd
I18	nd	nd	nd	nd	nd	nd	nd	nd
I10	nd	nd	nd	nd	nd	nd	nd	nd
I4	nd	nd	nd	nd	nd	73	nd	nd
28-m Stations								
I33	nd	nd	nd	nd	nd	nd	nd	290
I30	nd	nd	nd	nd	nd	nd	nd	340
I27	nd	nd	nd	nd	235	nd	nd	320
I22	130	nd	nd	nd	130	nd	nd	330
I14[a]	160	nd	nd	nd	nd	nd	nd	nd
I16[a]	77	nd	nd	nd	nd	nd	nd	nd
I15[a]	nd	nd	nd	nd	nd	nd	nd	nd
I12[a]	nd	nd	nd	nd	nd	nd	29	nd
I9	105	nd	nd	nd	110	nd	nd	nd
I6	nd	nd	nd	nd	nd	140	nd	nd
I2	nd	nd	nd	nd	nd	nd	nd	nd
I3	nd	nd	nd	nd	nd	nd	nd	nd
38-m Stations								
I29	580	nd	nd	380	2330	nd	nd	290
I21	nd	nd	nd	nd	nd	nd	nd	nd
I13	nd	nd	nd	nd	nd	nd	nd	nd
I8	nd	nd	nd	nd	nd	nd	nd	nd
55-m Stations								
I28	430	nd	nd	600	355	nd	nd	210
I20	nd	nd	nd	nd	nd	nd	nd	nd
I7	nd	nd	nd	nd	nd	93	nd	nd
I1	98	nd	nd	nd	nd	76	nd	nd
Detection Rate (%)	30	0	nd	7	22	15	4	33

[a]nearfield station; nd = not detected; na = not available

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Appendix D

Supporting Data

2012 SBOO Stations

Macrobenthic Communities

Appendix D.1

Macrofaunal community parameters by grab for SBOO benthic stations sampled during 2012. SR=species richness (no. taxa/0.1 m^2); Abun=abundance (no. individuals/0.1 m^2); H'=Shannon diversity index; J'=evenness; Dom=Swartz dominance; BRI=benthic response index. Stations are listed north to south from top to bottom.

Depth Contour	Station	Quarter	Grab	SR	Abun	H'	J'	Dom	BRI
19-m	I35	winter	1	68	194	3.8	0.90	29	29
			2	65	146	3.9	0.94	30	32
		summer	1	80	248	3.7	0.85	29	30
			2	48	1074	1.5	0.38	2	16
	I34	winter	1	48	337	3.1	0.80	12	10
			2	55	682	3.0	0.75	10	15
		summer	1	70	183	3.8	0.90	31	27
			2	33	979	1.0	0.27	1	8
	I31	winter	1	41	91	3.4	0.91	20	19
			2	52	119	3.6	0.91	23	25
		summer	1	62	287	2.7	0.66	13	25
			2	63	294	3.0	0.73	17	21
	I23	winter	1	50	520	2.8	0.70	7	14
			2	71	152	4.0	0.94	35	24
		summer	1	72	263	3.7	0.87	26	21
			2	62	149	3.7	0.90	28	22
	I18	winter	1	48	118	3.5	0.90	23	19
			2	59	198	3.6	0.87	21	21
		summer	1	39	129	3.1	0.85	16	19
			2	51	168	3.2	0.83	19	23
	I10	winter	1	70	244	3.7	0.86	24	20
			2	65	181	3.8	0.90	26	20
		summer	1	84	445	3.5	0.79	22	20
			2	43	191	2.7	0.72	11	17
	I4	winter	1	29	150	2.5	0.75	7	5
			2	52	141	3.5	0.90	23	22
		summer	1	52	219	3.1	0.79	16	7
			2	39	195	2.8	0.77	10	-1
28-m	I33	winter	1	113	525	3.5	0.74	24	30
			2	76	327	3.3	0.77	23	27
		summer	1	103	462	3.7	0.79	31	28
			2	90	484	3.7	0.83	24	28
	I30	winter	1	64	139	3.8	0.92	30	27
			2	84	226	4.0	0.90	35	29
		summer	1	120	555	3.9	0.81	34	27
			2	93	407	3.9	0.87	31	26
	I27	winter	1	69	172	3.9	0.93	33	25
			2	74	228	3.8	0.89	29	25

[a] nearfield station

Appendix D.1 *continued*

Depth Contour	Station	Quarter	Grab	SR	Abun	H'	J'	Dom	BRI
28-m	I27	summer	1	98	454	3.7	0.80	28	23
			2	81	352	3.2	0.73	22	25
	I22	winter	1	90	340	3.8	0.85	27	30
			2	95	321	4.0	0.88	35	27
		summer	1	138	708	4.0	0.81	37	29
			2	90	441	3.7	0.82	28	26
	I14[a]	winter	1	67	181	3.7	0.87	26	24
			2	62	169	3.8	0.91	27	23
		summer	1	94	377	3.6	0.79	27	26
			2	61	262	3.0	0.73	18	27
	I16[a]	winter	1	58	155	3.5	0.87	25	27
			2	57	143	3.6	0.89	25	23
		summer	1	55	450	2.1	0.54	6	20
			2	75	404	2.9	0.67	13	24
	I15[a]	winter	1	55	184	3.4	0.84	18	15
			2	79	276	3.6	0.82	23	26
		summer	1	96	500	3.7	0.80	23	27
			2	66	838	2.1	0.49	4	24
	I12[a]	winter	1	57	148	3.5	0.87	23	18
			2	98	307	4.0	0.88	36	26
		summer	1	98	544	3.6	0.78	25	23
			2	52	856	1.5	0.39	2	19
	I9	winter	1	66	249	3.6	0.86	21	25
			2	93	282	4.0	0.89	33	26
		summer	1	104	445	3.8	0.83	29	24
			2	123	597	4.0	0.83	34	28
	I6	winter	1	70	370	3.3	0.77	14	17
			2	65	362	3.1	0.75	14	16
		summer	1	61	321	2.9	0.71	14	16
			2	70	565	2.6	0.60	10	18
	I2	winter	1	48	177	3.2	0.83	17	21
			2	46	240	2.7	0.71	12	22
		summer	1	55	250	3.0	0.76	15	16
			2	40	258	2.1	0.58	7	16
	I3	winter	1	57	498	2.3	0.57	6	15
			2	38	169	2.6	0.71	10	9
		summer	1	42	456	1.8	0.47	4	16
			2	44	313	2.6	0.69	8	16

[a] nearfield station

Appendix D.1 *continued*

Depth Contour	Station	Quarter	Grab	SR	Abun	H'	J'	Dom	BRI
38-m	I29	winter	1	93	356	4.1	0.90	34	23
			2	113	510	4.2	0.88	37	20
		summer	1	121	520	4.1	0.85	32	22
			2	88	580	3.1	0.70	11	26
	I21	winter	1	47	159	3.1	0.79	13	10
			2	59	223	3.4	0.84	21	10
		summer	1	49	214	2.4	0.61	9	15
			2	68	390	2.7	0.65	13	13
	I13	winter	1	39	252	2.3	0.62	6	3
			2	59	230	3.2	0.79	16	10
		summer	1	52	469	1.7	0.43	3	19
			2	56	478	2.3	0.58	6	14
	I8	winter	1	52	281	2.9	0.73	11	17
			2	66	449	2.9	0.69	10	23
		summer	1	56	402	2.6	0.64	9	26
			2	53	325	2.7	0.68	11	26
55-m	I28	winter	1	158	775	4.4	0.87	46	16
			2	164	703	4.4	0.86	46	17
		summer	1	145	687	4.2	0.85	39	19
			2	132	443	4.2	0.87	43	16
	I20	winter	1	81	288	3.7	0.84	28	18
			2	92	358	3.9	0.87	31	17
		summer	1	81	315	3.6	0.83	24	12
			2	84	345	3.6	0.82	25	13
	I7	winter	1	90	342	3.9	0.88	30	10
			2	109	524	3.8	0.82	29	12
		summer	1	91	380	3.9	0.87	28	12
			2	74	182	3.8	0.89	29	12
	I1	winter	1	88	239	4.0	0.90	35	16
			2	92	295	4.1	0.90	36	15
		summer	1	66	235	3.7	0.88	23	15
			2	71	216	3.7	0.87	25	19

[a] nearfield station

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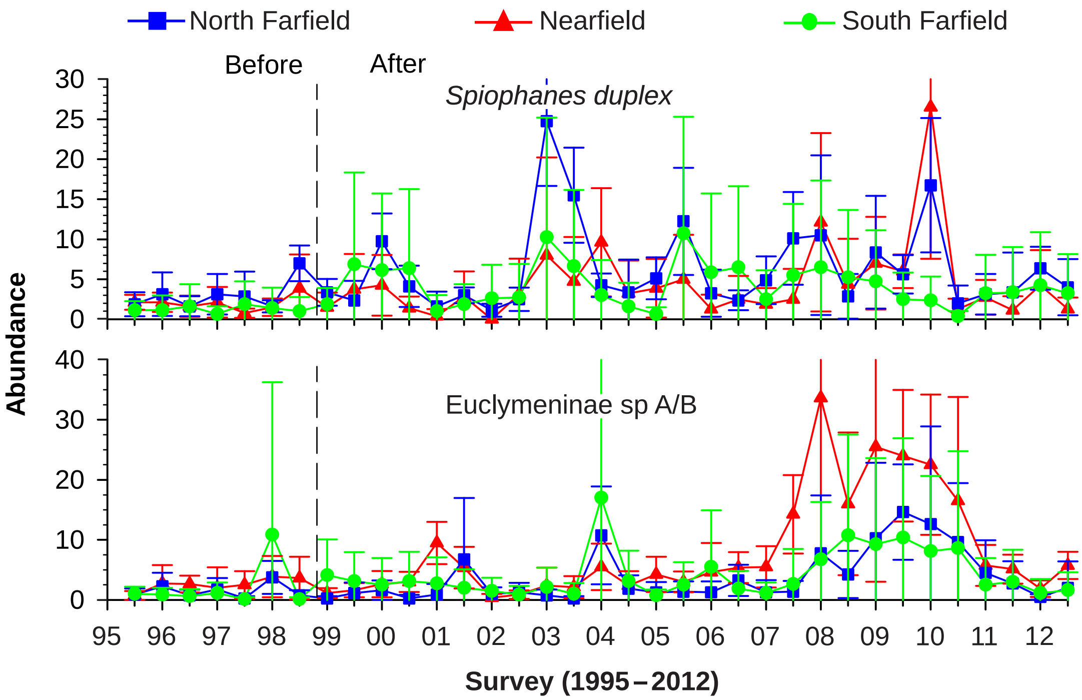

Appendix D.2

Two of the five historically most abundant species recorded from 1995 through 2012 at SBOO north farfield, nearfield, and south farfield stations along the 28-m depth contour (*Spiophanes norrisi*, *Monticellina siblina*, and *Mediomastus* sp shown in Figure 5.3). Data for each station group are expressed as means ±95% confidence intervals per 0.1 m^2 (n = 8). Dashed lines indicate onset of wastewater discharge.

Appendix D.3

Mean abundance of the 15 most common species found in each cluster group A–I (defined in Figure 5.5). Bold values indicate taxa that account for 25% of intra-group similarity according to SIMPER analysis.

	Cluster Groups								
Taxa	**A**	**B**	**C**	**D**	**E[a]**	**F**	**G**	**H**	**I**
Pisione sp	**54.0**	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pareurythoe californica	**49.5**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Branchiostoma californiense	**47.5**	0.0	19.3	2.4	0.0	0.0	0.0	0.0	0.0
Hesionura coineaui difficilis	45.5	1.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0
NEMATODA	40.5	**28.0**	11.7	2.4	0.0	1.7	2.4	0.3	7.0
Spio maculata	20.5	**31.3**	**29.3**	**23.5**	0.0	0.0	0.0	0.0	0.0
Saccocirrus sp	17.5	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Protodorvillea gracilis	12.0	7.3	**16.0**	1.6	0.0	0.0	0.1	0.0	0.0
Hemipodia borealis	9.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Micropodarke dubia	9.5	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Enopla	8.5	3.7	0.7	0.2	0.0	0.1	0.2	0.0	0.5
Leptochelia dubia Cmplx	6.0	4.3	3.0	3.9	0.0	1.6	4.0	11.0	**43.0**
Halcampa decemtentaculata	6.0	4.3	0.7	1.8	0.0	0.0	0.1	1.3	0.0
Lumbrinerides platypygos	3.0	6.7	1.0	8.5	0.0	0.0	0.2	1.3	0.0
Cirriformia sp SD2	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leptosynapta sp	2.5	0.7	0.7	0.4	0.0	0.1	0.1	1.0	0.0
Simomactra falcata	2.0	0.3	1.0	0.1	0.0	0.0	0.0	0.0	0.0
Scoloplos armiger Cmplx	1.0	1.3	3.7	7.9	1.0	0.7	2.4	**4.0**	3.0
Ampelisca cristata cristata	0.5	4.3	5.0	4.5	0.0	**9.9**	2.1	1.3	0.0
Foxiphalus obtusidens	0.5	3.0	1.7	2.2	2.0	0.3	5.0	2.7	0.0
Halistylus pupoideus	0.5	0.0	4.7	0.1	0.0	0.0	0.0	0.0	0.0
Ophelia pulchella	0.5	0.0	3.7	2.3	0.0	0.0	0.0	0.0	0.0
Amphiuridae	0.5	0.0	0.0	0.7	4.0	0.9	0.7	0.0	4.0
Photis californica	0.0	39.0	0.0	0.0	0.0	0.0	0.3	5.7	**59.5**
Spiophanes norrisi	0.0	**19.7**	**36.0**	**130.0**	32.0	**47.6**	**48.3**	**15.3**	**32.5**
Mooreonuphis sp SD1	0.0	14.3	1.7	3.8	0.0	0.0	0.0	0.7	0.0
Exogone lourei	0.0	11.0	0.0	5.6	0.0	1.7	1.1	0.0	0.0
Prionospio (*Prionospio*) *jubata*	0.0	**11.0**	0.0	3.4	8.0	1.9	**14.1**	**7.7**	**20.0**
Lumbrineris ligulata	0.0	**9.7**	0.0	0.4	0.0	0.0	0.9	0.3	7.5
Glycera oxycephala	0.0	7.3	0.0	4.2	0.0	0.3	0.6	4.3	0.0
Aricidea (*Acmira*) *cerrutii*	0.0	6.0	5.0	0.1	0.0	0.0	0.0	0.0	0.0
Pionosyllis sp SD2	0.0	5.7	0.0	0.1	0.0	0.0	0.0	0.3	0.0
Eurydice caudata	0.0	5.3	8.3	3.3	0.0	0.0	0.1	0.0	0.0
Carinoma mutabilis	0.0	3.3	1.0	0.6	5.0	1.4	1.1	0.0	3.0
Euphilomedes carcharodonta	0.0	3.0	0.3	1.6	1.0	0.7	1.1	**6.3**	**18.5**
Euclymeninae sp B	0.0	3.0	0.0	0.2	0.0	1.9	3.2	2.7	8.5
Polycirrus sp	0.0	2.7	2.7	0.0	0.0	0.0	0.1	0.0	1.5
Spiochaetopterus costarum Cmplx	0.0	2.0	2.0	8.7	1.0	3.0	**10.2**	3.3	3.5
Mediomastus sp	0.0	1.3	0.0	0.7	0.0	**9.0**	**20.4**	1.3	14.5
Pista estevanica	0.0	1.3	0.0	0.3	0.0	0.0	0.8	**21.3**	1.5
Armandia brevis	0.0	1.3	0.0	0.1	3.0	0.1	0.1	0.0	0.0
Laonice cirrata	0.0	1.0	0.0	0.0	0.0	5.1	2.0	0.0	0.0
Byblis millsi	0.0	1.0	0.0	0.0	0.0	0.0	0.6	1.0	11.5

[a] SIMPER analyses only conducted on cluster groups that contain more than one benthic grab.

Appendix D.3 *continued*

Taxa	Cluster Groups								
	A	B	C	D	E[a]	F	G	H	I
Notomastus latericeus	0.0	0.7	6.0	3.1	2.0	0.6	5.4	1.3	0.0
Solamen columbianum	0.0	0.7	5.3	1.1	0.0	0.0	0.1	0.0	0.0
Leuroleberis sharpei	0.0	0.7	1.3	0.8	4.0	0.3	0.3	0.0	0.0
Spiophanes duplex	0.0	0.7	0.0	0.1	0.0	**9.0**	7.5	4.3	14.5
Ampharete labrops	0.0	0.3	1.0	0.5	0.0	8.7	7.3	0.0	0.0
Heteronemertea sp SD2	0.0	0.3	0.3	1.4	3.0	1.3	2.5	3.0	1.0
Rhepoxynius stenodes	0.0	0.3	0.3	0.1	0.0	4.1	2.3	0.0	0.0
Aricidea (*Acmira*) *simplex*	0.0	0.3	0.3	0.1	0.0	0.0	0.1	**8.7**	13.5
Spiophanes berkeleyorum	0.0	0.3	0.0	0.5	0.0	1.4	6.8	0.7	2.5
Ampelisca careyi	0.0	0.3	0.0	0.0	0.0	0.0	1.6	7.7	1.5
Amphissa undata	0.0	0.3	0.0	0.0	0.0	0.0	0.8	0.0	10.5
Prionospio (*Prionospio*) *dubia*	0.0	0.3	0.0	0.0	0.0	0.0	0.0	1.7	**16.0**
Anchicolurus occidentalis	0.0	0.0	13.3	0.1	0.0	0.0	0.0	0.0	0.0
Axiothella sp	0.0	0.0	2.7	2.5	0.0	0.1	0.1	0.0	0.0
Rhepoxynius heterocuspidatus	0.0	0.0	1.0	2.6	1.0	0.1	0.1	0.0	0.0
Rhepoxynius menziesi	0.0	0.0	0.3	1.0	0.0	3.0	1.6	0.0	0.0
Magelona sacculata	0.0	0.0	0.3	0.5	0.0	6.1	2.1	0.0	0.0
Apoprionospio pygmaea	0.0	0.0	0.3	0.4	1.0	6.7	3.7	0.7	0.0
Nereis sp A	0.0	0.0	0.3	0.2	3.0	2.6	8.4	0.0	0.5
Sthenelanella uniformis	0.0	0.0	0.3	0.0	0.0	0.1	1.6	2.3	**14.5**
Aphelochaeta sp LA1	0.0	0.0	0.0	1.1	0.0	0.0	0.1	8.0	13.5
Chaetozone sp SD5	0.0	0.0	0.0	1.0	2.0	3.4	0.6	8.0	0.0
Glycinde armigera	0.0	0.0	0.0	1.0	1.0	3.6	3.5	1.0	0.0
Tellina modesta	0.0	0.0	0.0	0.6	3.0	3.3	3.5	0.0	0.0
Mooreonuphis nebulosa	0.0	0.0	0.0	0.3	3.0	0.0	12.3	0.3	1.5
Monticellina siblina	0.0	0.0	0.0	0.2	1.0	2.3	**26.2**	4.3	10.0
Ampelisciphotis podophthalma	0.0	0.0	0.0	0.2	1.0	0.1	6.0	1.3	0.0
Rhepoxynius lucubrans	0.0	0.0	0.0	0.2	0.0	0.3	0.1	5.3	0.0
Platynereis bicanaliculata	0.0	0.0	0.0	0.1	6.0	0.0	0.5	0.0	0.0
Ampelisca brevisimulata	0.0	0.0	0.0	0.1	0.0	1.7	**8.1**	0.7	6.0
Ophiothrix spiculata	0.0	0.0	0.0	0.1	9.0	0.0	0.2	0.0	0.0
Alvania compacta	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0
Caesia perpinguis	0.0	0.0	0.0	0.0	4.0	0.0	0.3	0.0	0.0
Astyris aurantiaca	0.0	0.0	0.0	0.0	3.0	0.0	0.3	0.0	0.0
Majoidea	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0
Chaetozone hartmanae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**26.0**
Paradoneis sp SD1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.5
Photis linearmanus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5

[a] SIMPER analyses only conducted on cluster groups that contain more than one benthic grab.

Appendix E

Supporting Data

2012 SBOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Taxonomic listing of demersal fish species captured during 2012 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 Allen (2005).

					Length	
Taxon/Species	Common Name	n	BM	Min	Max	Mean
CHIMAERIFORMES						
Chimaeridae						
Hydrolagus colliei	Spotted ratfish[a]	1	0.9	49	49	49
RAJIFORMES						
Rhinobatidae						
Rhinobatos productus	Shovelnose guitarfish[a]	3	1.2	32	62	47
Platyrhynidae						
Platyrhinoidis triseriata	Thornback[a]	1	1.0	45	45	45
Rajidae						
Raja inornata	California skate[a]	6	3.4	27	42	36
Raja stellulata	Starry skate[a]	1	3.0	82	82	82
MYLIOBATIFORNES						
Urolophidae						
Urobatis halleri	Round stingray[a]	1	1.0	44	44	44
Gymnuridae						
Gymnura marmorata	California butterfly ray[a]	1	0.7	22	22	22
CLUPEIFORMES						
Engraulidae						
Engraulis mordax	Northern anchovy	15	0.3	10	14	11
AULOPIFORMES						
Synodontidae						
Synodus lucioceps	California lizardfish	1571	24.5	7	27	12
OPHIDIIFORMES						
Ophidiidae						
Ophidion scrippsae	Basketweave cusk-eel	6	1.3	15	23	19
BATRACHOIDIFORMES						
Batrachoididae						
Porichthys notatus	Plainfin midshipman	38	3.0	3	27	13
GASTEROSTEIFORMES						
Syngnathidae						
Syngnathus californiensis	Kelp pipefish	16	0.7	15	25	20
Syngnathus exilis	Barcheek pipefish	6	0.1	19	23	22
SCORPAENIFORMES						
Scorpaenidae						
Scorpaena guttata	California scorpionfish	5	1.9	16	26	21
Sebastidae						
Sebastes dallii	Calico rockfish	1	0.1	4	4	4
Sebastes miniatus	Vermilion rockfish	3	0.2	3	4	4
Hexagrammidae						
Ophiodon elongatus	Lingcod	1	0.1	8	8	8
Zaniolepis frenata	Shortspine combfish	3	0.1	13	15	14
Zaniolepis latipinnis	Longspine combfish	150	4.4	8	16	13

[a] Length measured as total length, not standard length (see text).

Appendix E.1 *continued*

Taxon/Species			Common Name	n	BM	Length Min	Length Max	Length Mean
	Cottidae							
		Chitonotus pugetensis	Roughback sculpin	36	1.0	7	12	9
		Icelinus quadriseriatus	Yellowchin sculpin	50	0.6	6	8	7
		Leptocottus armatus	Pacific staghorn sculpin	2	0.3	13	20	16
		Scorpaenichthys marmoratus	Cabezon	1	1.2	27	27	27
	Agonidae							
		Odontopyxis trispinosa	Pygmy poacher	18	1.0	5	9	7
PERCIFORMES								
	Carangidae							
		Trachurus symmetricus	Pacific jack mackerel	1	0.2	18	18	18
	Sciaenidae							
		Genyonemus lineatus	White croaker	584	22.7	4	22	13
		Seriphus politus	Queenfish	4	0.3	9	15	13
	Embiotocidae							
		Cymatogaster aggregata	Shiner perch	5	0.3	8	9	8
	Pomacentridae							
		Chromis punctipinnis	Blacksmith	1	0.1	2	2	2
	Stromateidae							
		Peprilus simillimus	Pacific pompano	39	1.5	5	13	10
PLEURONECTIFORMES								
	Paralichthyidae							
		Citharichthys sordidus	Pacific sanddab	6	1.0	16	23	20
		Citharichthys stigmaeus	Speckled sanddab	2848	33.8	3	16	8
		Citharichthys xanthostigma	Longfin sanddab	53	4.8	9	23	15
		Paralichthys californicus	California halibut	16	22.7	18	82	38
		Xystreurys liolepis	Fantail sole	15	4.2	15	31	21
	Pleuronectidae							
		Parophrys vetulus	English sole	95	5.1	6	23	14
		Pleuronichthys decurrens	Curlfin sole	6	0.7	5	18	12
		Pleuronichthys guttulatus	Diamond turbot	2	0.6	20	21	20
		Pleuronichthys ritteri	Spotted turbot	12	3.2	15	32	22
		Pleuronichthys verticalis	Hornyhead turbot	132	12.9	4	23	13
	Cynoglossidae							
		Symphurus atricaudus	California tonguefish	36	1.6	7	17	12

Appendix E.2

Total abundance by species and station for demersal fish at SBOO trawl stations during 2012.

	Winter 2012							
Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Abundance by Survey
Speckled sanddab	123	114	33	123	73	161	64	691
White croaker	2	37	4	10	3		98	154
California lizardfish	10	9		8	4	16	4	51
Hornyhead turbot		4	9	8	5	9	4	39
Pacific pompano			7	6	7			20
California tonguefish			1	4		2	7	14
Kelp pipefish	1	2				5		8
California halibut			1	3		1	2	7
Plainfin midshipman	1	2		2		1	1	7
Barcheek pipefish							6	6
Pygmy poacher	3			1	1	1		6
Shiner perch		3		1			1	5
Queenfish				3	1			4
California skate		2				1		3
Longspine combfish				1		2		3
Fantail sole			2					2
Roughback sculpin			1	1				2
Cabezon				1				1
California butterfly ray							1	1
Longfin sanddab				1				1
Pacific jack mackerel		1						1
Pacific staghorn sculpin	1							1
Round stingray		1						1
Survey Total	141	175	58	173	94	199	188	1028

Appendix E.2 *continued*

Name	Spring 2012							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
White croaker		27	109	104	83		106	429
Speckled sanddab	73	64	20	97	18	64	11	347
California lizardfish	60	11	5	6	3	32	3	120
Hornyhead turbot	2	6	1	9	5	5	1	29
Pacific pompano		5	7	4	3			19
Northern anchovy	1	5	9					15
California tonguefish			3	7	1		1	12
English sole				1	3	4	1	9
Basketweave cusk-eel		1	1	3	1			6
Kelp pipefish			1		2		3	6
Plainfin midshipman		3			1			4
Shovelnose guitarfish		1		1		1		3
Vermilion rockfish	2					1		3
Pygmy poacher				2				2
Calico rockfish	1							1
California halibut							1	1
Curlfin sole		1						1
Lingcod							1	1
Longspine combfish						1		1
Pacific staghorn sculpin			1					1
Roughback sculpin							1	1
Spotted ratfish							1	1
Spotted turbot							1	1
Starry skate		1						1
Yellowchin sculpin				1				1
Survey Total	139	125	157	235	120	108	131	1015

Appendix E.2 *continued*

Name	Summer 2012							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	71	159	168	153	165	64	158	938
California lizardfish	1	152	183	214	152	21	107	830
Longspine combfish		14	8		37	12	75	146
Yellowchin sculpin		7	8		18	5	11	49
Roughback sculpin		7	2	1	12	7	3	32
Hornyhead turbot	1	8	8	4	4	1	3	29
English sole		5	5	3	5	7	3	28
Longfin sanddab		3	5		9	3	8	28
Fantail sole	2	1	3	1	1		1	9
Plainfin midshipman		3			2	1	3	9
Pygmy poacher		5	2				1	8
California halibut				1	2			3
California scorpionfish	1					1	1	3
California tonguefish		1			1		1	3
Curlfin sole	2		1					3
Shortspine combfish					3			3
White croaker					1			1
Survey Total	78	365	393	377	412	122	375	2122

Appendix E.2 *continued*

NAME	Fall 2012 SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Abundance by Survey
Speckled sanddab	109	156	92	220	170	101	24	872
California lizardfish	45	36	59	75	49	298	8	570
English sole		6		1	17	30	4	58
Hornyhead turbot	2	11	3	7	9		3	35
Longfin sanddab		3	6	7	1	5	2	24
Plainfin midshipman		2		1	5	6	4	18
Spotted turbot		3	3	5				11
California tonguefish		3		1		3		7
Pacific sanddab	6							6
California halibut				1	1		3	5
Fantail sole				3			1	4
California skate				1	1	1		3
California scorpionfish			1	1				2
Curlfin sole	1			1				2
Diamond turbot	1	1						2
Kelp pipefish						2		2
Pygmy poacher		1			1			2
Blacksmith			1					1
Roughback sculpin	1							1
Thornback			1					1
Survey Total	165	222	166	324	254	446	49	1626
Annual Total	**523**	**887**	**774**	**1109**	**880**	**875**	**743**	**5791**

Appendix E.3

Biomass (kg) by species and station for demersal fish at SBOO trawl stations during 2012.

	Winter 2012							
Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Biomass by Survey
Speckled sanddab	1.5	1.5	0.8	1.5	0.8	1.1	0.6	7.8
White croaker	0.3	1.5	0.3	0.7	0.2		3.2	6.2
California halibut			0.9	3.6		0.3	0.8	5.6
Hornyhead turbot		0.6	1.3	0.7	0.5	0.6	0.5	4.2
California lizardfish	0.8	0.3		0.4	0.3	1.0	0.2	3.0
California skate		1.1				0.9		2.0
Cabezon				1.2				1.2
Pacific pompano			0.4	0.4	0.3			1.1
Round stingray		1.0						1.0
Plainfin midshipman	0.1	0.4		0.2		0.1	0.1	0.9
California butterfly ray							0.7	0.7
California tonguefish			0.1	0.3		0.1	0.1	0.6
Fantail sole			0.5					0.5
Longfin sanddab				0.5				0.5
Pygmy poacher	0.1			0.1	0.1	0.1		0.4
Kelp pipefish	0.1	0.1				0.1		0.3
Queenfish				0.2	0.1			0.3
Shiner perch		0.1		0.1			0.1	0.3
Longspine combfish				0.1		0.1		0.2
Pacific jack mackerel		0.2						0.2
Roughback sculpin			0.1	0.1				0.2
Barcheek pipefish							0.1	0.1
Pacific staghorn sculpin	0.1							0.1
Survey Total	3.0	6.8	4.4	10.1	2.3	4.4	6.4	37.4

Appendix E.3 *continued*

Name	Spring 2012							Species Biomass by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
White croaker		2.3	3.5	4.0	2.7		3.9	16.4
Speckled sanddab	0.6	0.5	0.3	1.5	0.1	0.7	0.1	3.8
Starry skate		3.0						3.0
Hornyhead turbot	0.1	0.4	0.1	0.9	0.5	0.6	0.1	2.7
California halibut							1.8	1.8
Basketweave cusk-eel		1.0	0.1	0.1	0.1			1.3
California lizardfish	0.5	0.1	0.1	0.1	0.1	0.2	0.1	1.2
Shovelnose guitarfish		0.5		0.5		0.2		1.2
Spotted ratfish							0.9	0.9
English sole				0.1	0.1	0.3	0.1	0.6
Spotted turbot							0.5	0.5
California tonguefish			0.1	0.1	0.1		0.1	0.4
Pacific pompano		0.1	0.1	0.1	0.1			0.4
Kelp pipefish			0.1		0.1		0.1	0.3
Northern anchovy	0.1	0.1	0.1					0.3
Pacific staghorn sculpin			0.2					0.2
Plainfin midshipman		0.1			0.1			0.2
Vermilion rockfish	0.1					0.1		0.2
Calico rockfish	0.1							0.1
Curlfin sole		0.1						0.1
Lingcod							0.1	0.1
Longspine combfish						0.1		0.1
Pygmy poacher				0.1				0.1
Roughback sculpin							0.1	0.1
Yellowchin sculpin				0.1				0.1
Survey Total	1.5	8.2	4.7	7.6	4.0	2.2	7.9	36.1

Appendix E.3 *continued*

Name	Summer 2012							Species Biomass by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	0.6	2.2	2.1	1.3	2.3	1.0	2.2	11.7
California lizardfish	0.1	1.8	2.3	2.2	2.3	0.7	2.1	11.5
California halibut				0.6	10.5			11.1
Longspine combfish		0.4	0.1		1.0	0.5	2.1	4.1
Fantail sole	0.3	0.3	0.8	0.8	0.1		0.5	2.8
Hornyhead turbot	0.2	0.3	0.9	0.6	0.4	0.1	0.3	2.8
English sole		0.3	0.8	0.4	0.3	0.6	0.3	2.7
Longfin sanddab		0.2	0.7		0.7	0.3	0.5	2.4
Plainfin midshipman		0.5			0.2	0.3	0.3	1.3
California scorpionfish	0.5					0.3	0.3	1.1
Roughback sculpin		0.1	0.1	0.1	0.1	0.1	0.1	0.6
Yellowchin sculpin		0.1	0.1		0.1	0.1	0.1	0.5
Curlfin sole	0.3		0.1					0.4
California tonguefish		0.1			0.1		0.1	0.3
Pygmy poacher		0.1	0.1				0.1	0.3
Shortspine combfish					0.1			0.1
White croaker					0.1			0.1
Survey Total	2.0	6.4	8.1	6.0	18.3	4.0	9.0	53.8

Appendix E.3 *continued*

Name	Fall 2012 SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Biomass by Survey
Speckled sanddab	1.6	2.3	1.0	2.0	2.3	1.0	0.3	10.5
California lizardfish	0.9	0.8	1.3	1.4	1.0	3.3	0.1	8.8
California halibut				1.5	0.6		2.1	4.2
Hornyhead turbot	0.4	0.7	0.4	0.8	0.8		0.1	3.2
Spotted turbot		0.6	0.8	1.3				2.7
Longfin sanddab		0.2	0.4	0.8	0.1	0.3	0.1	1.9
English sole		0.2		0.4	0.3	0.8	0.1	1.8
California skate				0.8	0.5	0.1		1.4
Pacific sanddab	1.0							1.0
Thornback			1.0					1.0
Fantail sole				0.6			0.3	0.9
California scorpionfish			0.5	0.3				0.8
Plainfin midshipman		0.1		0.2	0.1	0.1	0.1	0.6
Diamond turbot	0.3	0.3						0.6
California tonguefish		0.1		0.1		0.1		0.3
Curlfin sole	0.1			0.1				0.2
Pygmy poacher		0.1			0.1			0.2
Blacksmith			0.1					0.1
Kelp pipefish						0.1		0.1
Roughback sculpin	0.1							0.1
Survey Total	4.4	5.4	5.5	10.3	5.8	5.8	3.2	40.4
Annual Total	**10.9**	**26.8**	**22.7**	**34.0**	**30.4**	**16.4**	**26.5**	**167.7**

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 between 1995 and 2012. Data are limited to summer surveys. Shading indicates significant difference.

		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
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	2.2	10				
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			
2010	r-value	0.977	1.000	0.953	0.884	1.000	0.884	0.93	0.884	0.907	0.721	0.395	0.651	0.721	0.419	0.14		
	sig value	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	10	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	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

Appendix E.5

Taxonomic listing of megabenthic invertebrate taxa captured during 2012 at SBOO trawl stations. Data are number of individuals (n). Taxonomic arrangement from SCAMIT (2012).

Taxon/ Species				n
MOLLUSCA				
POLYPLACOPHORA				
	Chitonida			
		Ischnochitonidae		
			Lepidozona scrobiculata	1
GASTROPODA				
		Calliostomatidae		
			Calliostoma tricolor	1
		Turbinidae		
			Megastraea undosa	1
	Hypsogastropoda			
		Naticidae		
			Euspira lewisii	2
		Bursidae		
			Crossata californica	20
		Velutinidae		
			Lamellaria diegoensis	2
		Buccinidae		
			Kelletia kelletii	26
		Nassariidae		
			Caesia perpinguis	1
		Muricidae		
			Pteropurpura macroptera	2
	Opisthobranchia	Philinidae		
			Philine auriformis	4
		Pleurobranchidae		
			Pleurobranchaea californica	2
		Onchidorididae		
			Acanthodoris brunnea	17
		Tritoniidae		
			Tritonia diomedea	1
		Dendronotidae		
			Dendronotus iris	1
		Flabellinidae		
			Flabellina iodinea	3
CEPHALOPODA				
	Teuthida			
		Loliginidae		
			Doryteuthis opalescens	8
	Octopoda			
		Octopodidae		
			Octopus bimaculatus	1
			Octopus rubescens	29

Appendix E.5 *continued*

Taxon/ Species				n
ANNELIDA				
POLYCHAETA				
	Aciculata			
		Aphroditidae		
			Aphrodita armifera	3
			Aphrodita refulgida	1
			Aphrodita sp	1
		Polynoidae		
			Halosydna latior	2
HIRUDINEA				2
ARTHROPODA				
MALACOSTRACA				
	Stomatopoda			
		Hemisquillidae		
			Hemisquilla californiensis	20
	Isopoda			
		Cymothoidae		
			Elthusa vulgaris	58
	Decapoda			
		Sicyoniidae		
			Sicyonia penicillata	1
		Hippolytidae		
			Heptacarpus palpator	5
			Heptacarpus stimpsoni	6
		Pandalidae		
			Pandalus danae	1
		Crangonidae		
			Crangon alba	40
			Crangon nigromaculata	634
		Diogenidae		
			Paguristes bakeri	2
			Paguristes ulreyi	2
		Paguridae		
			Pagurus armatus	9
			Pagurus spilocarpus	4
		Calappidae		
			Platymera gaudichaudii	16
		Leucosiidae		
			Randallia ornata	3
		Epialtidae		
			Loxorhynchus grandis	13
		Inachidae		
			Podochela hemphillii	6
		Inachoididae		
			Pyromaia tuberculata	10
		Parthenopidae		
			Heterocrypta occidentalis	37
		Cancridae		
			Metacarcinus gracilis	210

Appendix E.5 *continued*

Taxon/ Species				n
ECHINODERMATA				
	ASTEROIDEA			
	Paxillosida			
		Luidiidae		
			Luidia armata	1
			Luidia foliolata	4
		Astropectinidae		
			Astropecten californicus	569
	Forcipulatida			
		Asteriidae		1
			Pisaster brevispinus	16
	OPHIUROIDEA			
	Ophiurida			
		Ophiotricidae		
			Ophiothrix spiculata	26
		Ophiuridae		
			Ophiura luetkenii	1
	ECHINOIDEA			
	Temnopleuroida			
		Toxopneustidae		
			Lytechinus pictus	15
	Echinoida			
		Strongylocentrotidae		
			Strongylocentrotus franciscanus	3
	Clypeasteroida			
		Dendrasteridae		
			Dendraster terminalis	290

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Appendix E.6

Total abundance by species and station for megabenthic invertebrates at the SBOO trawl stations during 2012.

Name	Winter 2012							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Astropecten californicus	138	49	11	7	17	5	3	230
Crangon nigromaculata	1	47	48	15	32	12	57	212
Dendraster terminalis	191							191
Metacarcinus gracilis		19	35	8	2	11	18	93
Elthusa vulgaris	1	7		6	3	2	4	23
Crangon alba	20							20
Hemisquilla californiensis		8	2	4	2	2	1	19
Kelletia kelletii		1	1		1	4	1	8
Octopus rubescens	1		2			4		7
Acanthodoris brunnea			2	1			3	6
Crossata californica	1	2	2			1		6
Pisaster brevispinus	2				1	3		6
Heptacarpus palpator							4	4
Heterocrypta occidentalis			2	2				4
Ophiothrix spiculata	1			3				4
Lytechinus pictus		3						3
Euspira lewisii					2			2
Hirudinea					2			2
Paguristes ulreyi		2						2
Pagurus spilocarpus		1	1					2
Philine auriformis					2			2
Pyromaia tuberculata	1				1			2
Strongylocentrotus franciscanus			1	1				2
Doryteuthis opalescens		1						1
Flabellina iodinea							1	1
Halosydna latior		1						1
Ophiura luetkenii					1			1
Platymera gaudichaudii					1			1
Pleurobranchaea californica						1		1
Randallia ornata						1		1
Survey Total	357	141	107	47	67	46	92	857

Appendix E.6 *continued*

Name	Spring 2012							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Crangon nigromaculata	8	226	80	48	22	18	11	413
Astropecten californicus	8	4			28	21	5	66
Metacarcinus gracilis	2	2	1	2	50	4	3	64
Crangon alba	19							19
Heterocrypta occidentalis				8	1		1	10
Doryteuthis opalescens	7							7
Elthusa vulgaris		2			2			4
Platymera gaudichaudii	1	1		2				4
Podochela hemphillii					4			4
Aphrodita armifera				3				3
Lytechinus pictus			1	2				3
Pyromaia tuberculata				3				3
Acanthodoris brunnea					2			2
Heptacarpus stimpsoni				2				2
Kelletia kelletii						2		2
Octopus rubescens		1					1	2
Philine auriformis					2			2
Aphrodita refulgida					1			1
Aphrodita sp						1		1
Calliostoma tricolor					1			1
Dendraster terminalis	1							1
Dendronotus iris		1						1
Halosydna latior						1		1
Heptacarpus palpator				1				1
Lamellaria diegoensis	1							1
Loxorhynchus grandis				1				1
Megastraea undosa				1				1
Ophiothrix spiculata				1				1
Paguristes bakeri				1				1
Pagurus spilocarpus						1		1
Pandalus danae			1					1
Pisaster brevispinus	1							1
Strongylocentrotus franciscanus				1				1
Survey Total	48	237	83	76	113	48	21	626

Appendix E.6 *continued*

Name	Summer 2012							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Astropecten californicus	76	25	3	12	15	11	3	145
Heterocrypta occidentalis	1			19				20
Elthusa vulgaris		4	2	3	5	2	3	19
Pagurus armatus	4		3	2				9
Acanthodoris brunnea			6				2	8
Loxorhynchus grandis				1	2		4	7
Lytechinus pictus			2	4				6
Metacarcinus gracilis		1	3		1			5
Pisaster brevispinus	1			1	2	1		5
Kelletia kelletii		1	2	1				4
Platymera gaudichaudii	1	1			1			3
Pyromaia tuberculata			2				1	3
Flabellina iodinea		1		1				2
Octopus rubescens					1		1	2
Caesia perpinguis			1					1
Crangon nigromaculata					1			1
Crossata californica				1				1
Hemisquilla californiensis					1			1
Luidia foliolata				1				1
Ophiothrix spiculata				1				1
Paguristes bakeri			1					1
Podochela hemphillii			1					1
Randallia ornata		1						1
Sicyonia penicillata					1			1
Tritonia diomedea					1			1
Survey Total	83	34	26	47	31	14	14	249

Appendix E.6 *continued*

Name	Fall 2012							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Astropecten californicus	70	27	10	8	3	7	3	128
Dendraster terminalis	98							98
Metacarcinus gracilis	2	18	9	11		4	4	48
Ophiothrix spiculata		20						20
Octopus rubescens	2	2			7	7		18
Crossata californica		4		2	7			13
Elthusa vulgaris	5	2	1	2			2	12
Kelletia kelletii		5		3	2	2		12
Crangon nigromaculata		1	2	1	3	1		8
Platymera gaudichaudii	1		2	1	1	1	2	8
Loxorhynchus grandis		2			2	1		5
Heptacarpus stimpsoni			4					4
Pisaster brevispinus		1	2			1		4
Heterocrypta occidentalis				2	1			3
Luidia foliolata		2	1					3
Lytechinus pictus				3				3
Pteropurpura macroptera					2			2
Pyromaia tuberculata			1	1				2
Acanthodoris brunnea				1				1
Asteriidae			1					1
Crangon alba	1							1
Lamellaria diegoensis	1							1
Lepidozona scrobiculata					1			1
Luidia armata					1			1
Octopus bimaculatus							1	1
Pagurus spilocarpus				1				1
Pleurobranchaea californica						1		1
Podochela hemphillii			1					1
Randallia ornata					1			1
Survey Total	180	84	34	36	31	25	12	402
Annual Total	**668**	**496**	**250**	**206**	**242**	**133**	**139**	**2134**

Appendix F

Supporting Data

2012 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 April and October 2012. 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**
April 2012									
RF3	1	Mixed rockfish	3	16	30	22	142	470	264
RF3	2	Brown rockfish	3	17	27	22	160	546	344
RF3	3	Vermilion rockfish	3	23	23	23	302	310	307
RF4	1	Califorina scorpionfish	3	27	28	27	588	636	620
RF4	2	Califorina scorpionfish	3	25	27	26	522	662	592
RF4	3	Califorina scorpionfish	3	24	26	25	396	553	471
SD15	1	(no sample)	—	—	—	—	—	—	—
SD15	2	(no sample)	—	—	—	—	—	—	—
SD15	3	(no sample)	—	—	—	—	—	—	—
SD16	1	English sole	4	15	24	18	40	230	107
SD16	2	Hornyhead turbot	7	13	18	16	67	165	107
SD16	3	(no sample)	—	—	—	—	—	—	—
SD17	1	English sole	5	22	27	24	139	243	189
SD17	2	Hornyhead turbot	10	12	19	15	55	186	101
SD17	3	(no sample)	—	—	—	—	—	—	—
SD18	1	English sole	14	14	24	17	38	174	73
SD18	2	Hornyhead turbot	6	14	20	17	77	261	159
SD18	3	Hornyhead turbot	9	13	21	15	61	253	108
SD19	1	Hornyhead turbot	9	13	21	15	61	253	108
SD19	2	English sole	6	19	24	21	87	209	128
SD19	3	Hornyhead turbot	6	13	20	17	62	217	140
SD20	1	Hornyhead turbot	5	17	20	19	144	218	195
SD20	2	English sole	4	21	26	23	137	219	171
SD20	3	English sole	4	20	27	23	121	328	200
SD21	1	Hornyhead turbot	3	19	21	20	178	258	230
SD21	2	English sole	6	17	24	20	62	220	122
SD21	3	Hornyhead turbot	5	13	18	15	50	172	102

Appendix F.1 *continued*

Station	Comp	Species	n	Length (cm, size class) Min	Max	Mean	Weight (g) Min	Max	Mean
October 2012									
RF3	1	Vermilion rockfish	3	25	30	28	441	740	569
RF3	2	Vermilion rockfish	3	22	25	23	256	437	333
RF3	3	Vermilion rockfish	3	20	22	21	209	256	228
RF4	1	California scorpionfish	3	26	27	26	472	544	506
RF4	2	California scorpionfish	3	23	29	26	383	670	531
RF4	3	California scorpionfish	3	28	29	29	543	671	628
SD15	1	Pacific sanddab	5	16	24	20	68	250	164
SD15	2	Pacific sanddab	5	16	22	19	71	200	133
SD15	3	Pacific sanddab	4	21	22	22	159	228	186
SD16	1	Longfin sanddab	7	13	19	15	41	153	74
SD16	2	Hornyhead turbot	7	14	21	16	67	197	113
SD16	3	Hornyhead turbot	8	12	19	15	46	202	98
SD17	1	Longfin sanddab	4	15	22	18	79	251	128
SD17	2	Hornyhead turbot	9	13	20	16	73	235	125
SD17	3	Hornyhead turbot	7	14	21	17	57	313	148
SD18	1	Longfin sanddab	4	16	19	17	95	176	128
SD18	2	Longfin sanddab	3	16	19	18	102	183	149
SD18	3	Longfin sanddab	9	13	15	14	51	78	66
SD19	1	Longfin sanddab	4	16	18	17	75	132	104
SD19	2	Hornyhead turbot	4	19	21	20	189	272	216
SD19	3	Hornyhead turbot	8	13	18	15	61	163	106
SD20	1	Longfin sanddab	5	15	19	17	79	171	117
SD20	2	Longfin sanddab	4	15	18	17	80	164	128
SD20	3	Hornyhead turbot	5	15	20	17	83	290	168
SD21	1	Hornyhead turbot	4	15	21	18	85	326	207
SD21	2	Hornyhead turbot	3	18	22	20	167	366	253
SD21	3	Longfin sanddab	5	15	19	17	71	150	105

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 2012.

	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)	0.4	0.4
Copper (Cu)	0.1	0.1	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	24.70	2.47	HCH, Delta isomer	4.53	0.45
HCH, Beta isomer	4.68	0.47	HCH, Gamma isomer	63.40	6.34
Total Chlordane					
Alpha (cis) chlordane	4.56	0.46	Heptachlor epoxide	3.89	0.39
Cis nonachlor	4.70	0.47	Oxychlordane	7.77	0.78
Gamma (trans) chlordane	2.59	0.26	Trans nonachlor	2.58	0.26
Heptachlor	3.82	0.38			
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	2.02	0.20	p,p-DDD	3.36	0.34
o,p-DDE	2.79	0.28	p,p-DDE	2.08	0.21
o,p-DDT	1.62	0.16	p,p-DDT	2.69	0.27
p,-p-DDMU	3.29	0.33			
Miscellaneous Pesticides					
Aldrin	88.1	8.81	Hexachlorobenzene (HCB)	1.32	0.13
Alpha endosulfan	118.0	11.8	Mirex	1.49	0.15
Dieldrin	17.1	1.71	Toxaphene	342.0	34.20
Endrin	14.2	1.42			

Appendix F.2 *continued*

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Polychlorinated Biphenyls Congeners (PCBs) (ppb)					
PCB 18	2.86	0.29	PCB 126	1.52	0.15
PCB 28	2.47	0.28	PCB 128	1.23	0.12
PCB 37	2.77	0.25	PCB 138	1.73	0.17
PCB 44	3.65	0.36	PCB 149	2.34	0.23
PCB 49	5.02	0.50	PCB 151	1.86	0.19
PCB 52	5.32	0.53	PCB 153/168	2.54	0.25
PCB 66	2.81	0.28	PCB 156	0.64	0.06
PCB 70	2.49	0.25	PCB 157	2.88	0.29
PCB 74	3.10	0.31	PCB 158	2.72	0.27
PCB 77	2.01	0.20	PCB 167	1.63	0.16
PCB 81	3.56	0.36	PCB 169	2.76	0.28
PCB 87	3.01	0.30	PCB 170	1.23	0.12
PCB 99	3.05	0.30	PCB 177	1.91	0.19
PCB 101	4.34	0.43	PCB 180	2.58	0.26
PCB 105	2.29	0.23	PCB 183	1.55	0.15
PCB 110	2.50	0.25	PCB 187	2.5	0.25
PCB 114	3.15	0.31	PCB 189	1.78	0.18
PCB 118	2.06	0.21	PCB 194	1.14	0.11
PCB 119	2.39	0.24	PCB 201	2.88	0.29
PCB 123	2.64	0.26	PCB 206	1.28	0.13
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
1-methylnaphthalene	17.4	23.3	Benzo[K]fluoranthene	32.0	37.3
1-methylphenanthrene	27.9	26.4	Benzo[e]pyrene	41.8	40.6
2,3,5-trimethylnaphthalene	21.7	21.6	Biphenyl	38.0	19.9
2,6-dimethylnaphthalene	21.7	19.5	Chrysene	18.1	23.0
2-methylnaphthalene	35.8	13.2	Dibenzo(A,H)anthracene	37.6	40.3
3,4-benzo(B)fluoranthene	30.2	26.8	Fluoranthene	19.9	12.9
Acenaphthene	28.9	11.3	Fluorene	27.3	11.4
Acenaphthylene	24.7	9.1	Indeno(1,2,3-CD)pyrene	25.6	46.5
Anthracene	25.3	8.4	Naphthalene	34.2	17.4
Benzo[A]anthracene	47.3	15.9	Perylene	18.5	50.9
Benzo[A]pyrene	42.9	18.3	Phenanthrene	11.6	12.9
Benzo[G,H,I]perylene	27.2	59.5	Pyrene	9.1	16.6

Appendix F.3

Summary of constituents that make up total DDT, total chlordane (tChlor) and total PCB in composite (Comp) tissue samples from the SBOO region during April and October 2012.

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-2	RF3	1	Mixed rockfish	Muscle	PCB	PCB 118	0.1	ppb
2012-2	RF3	1	Mixed rockfish	Muscle	PCB	PCB 138	0.2	ppb
2012-2	RF3	1	Mixed rockfish	Muscle	PCB	PCB 153/168	0.2	ppb
2012-2	RF3	1	Mixed rockfish	Muscle	PCB	PCB 180	0.1	ppb
2012-2	RF3	1	Mixed rockfish	Muscle	PCB	PCB 187	0.1	ppb
2012-2	RF3	1	Mixed rockfish	Muscle	DDT	p,p-DDE	2.0	ppb
2012-2	RF3	2	Brown rockfish	Muscle	PCB	PCB 118	0.2	ppb
2012-2	RF3	2	Brown rockfish	Muscle	PCB	PCB 138	0.2	ppb
2012-2	RF3	2	Brown rockfish	Muscle	PCB	PCB 153/168	0.4	ppb
2012-2	RF3	2	Brown rockfish	Muscle	PCB	PCB 180	0.2	ppb
2012-2	RF3	2	Brown rockfish	Muscle	PCB	PCB 187	0.2	ppb
2012-2	RF3	2	Brown rockfish	Muscle	DDT	p,p-DDE	2.3	ppb
2012-2	RF3	3	Vermilion rockfish	Muscle	PCB	PCB 118	0.1	ppb
2012-2	RF3	3	Vermilion rockfish	Muscle	PCB	PCB 153/168	0.1	ppb
2012-2	RF3	3	Vermilion rockfish	Muscle	DDT	p,p-DDE	0.8	ppb
2012-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 118	0.1	ppb
2012-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 138	0.2	ppb
2012-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 153/168	0.3	ppb
2012-2	RF4	1	California scorpionfish	Muscle	PCB	PCB 187	0.1	ppb
2012-2	RF4	1	California scorpionfish	Muscle	DDT	p,p-DDE	2.0	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 118	0.3	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 128	0.1	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 138	0.4	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 149	0.1	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 153/168	0.8	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 170	0.1	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 180	0.4	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 183	0.1	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 187	0.3	ppb
2012-2	RF4	2	California scorpionfish	Muscle	PCB	PCB 99	0.2	ppb
2012-2	RF4	2	California scorpionfish	Muscle	DDT	p,-p-DDMU	0.2	ppb
2012-2	RF4	2	California scorpionfish	Muscle	DDT	p,p-DDE	3.8	ppb
2012-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 118	0.3	ppb
2012-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 138	0.2	ppb
2012-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 153/168	0.3	ppb
2012-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 180	0.1	ppb
2012-2	RF4	3	California scorpionfish	Muscle	PCB	PCB 187	0.1	ppb
2012-2	RF4	3	California scorpionfish	Muscle	DDT	p,p-DDE	2.4	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 101	3.1	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 118	4.3	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 138	6.4	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 149	3.2	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 151	1.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-2	SD16	1	English sole	Liver	PCB	PCB 153/168	15.0	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 170	1.8	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 177	2.0	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 180	4.2	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 183	2.0	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 187	7.1	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 201	3.0	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 49	1.0	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 52	0.7	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 66	0.8	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 70	0.8	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 74	0.5	ppb
2012-2	SD16	1	English sole	Liver	PCB	PCB 99	3.8	ppb
2012-2	SD16	1	English sole	Liver	DDT	o,p-DDE	2.1	ppb
2012-2	SD16	1	English sole	Liver	DDT	p,-p-DDMU	3.2	ppb
2012-2	SD16	1	English sole	Liver	DDT	p,p-DDD	2.2	ppb
2012-2	SD16	1	English sole	Liver	DDT	p,p-DDE	120.0	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 118	1.7	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 138	2.3	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 153/168	4.7	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 170	0.9	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 180	1.8	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 187	2.3	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 49	0.5	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 66	0.4	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 74	0.2	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	DDT	o,p-DDE	0.9	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	1.6	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	DDT	p,p-DDD	1.5	ppb
2012-2	SD16	2	Hornyhead turbot	Liver	DDT	p,p-DDE	51.0	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 101	3.0	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 118	3.9	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 138	4.1	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 149	2.5	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 151	0.8	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 153/168	9.0	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 158	0.5	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 170	1.1	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 180	2.8	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 183	0.8	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 187	4.1	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 194	1.1	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 201	1.6	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 206	1.1	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 49	0.5	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 52	0.6	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-2	SD17	1	English sole	Liver	PCB	PCB 66	0.5	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 70	0.7	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 74	0.3	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 87	1.2	ppb
2012-2	SD17	1	English sole	Liver	PCB	PCB 99	2.7	ppb
2012-2	SD17	1	English sole	Liver	DDT	p,-p-DDMU	1.4	ppb
2012-2	SD17	1	English sole	Liver	DDT	p,p-DDE	39.0	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 101	1.3	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 118	2.2	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 138	3.9	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 149	1.4	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 153/168	7.7	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 170	1.2	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 180	3.2	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 183	1.0	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 187	3.0	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 194	0.9	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 49	0.4	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 52	0.5	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 66	0.6	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 70	0.3	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 74	0.3	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	PCB	PCB 99	2.0	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	3.5	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	DDT	p,p-DDD	1.9	ppb
2012-2	SD17	2	Hornyhead turbot	Liver	DDT	p,p-DDE	76.0	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 101	5.3	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 118	4.8	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 128	1.8	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 138	6.7	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 149	4.1	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 151	1.5	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 153/168	14.0	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 156	0.9	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 158	2.1	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 170	1.6	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 177	1.6	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 180	3.5	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 183	1.3	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 187	5.0	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 194	1.2	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 201	1.9	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 206	0.8	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 28	0.3	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 49	1.6	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 52	1.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-2	SD18	1	English sole	Liver	PCB	PCB 66	1.1	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 70	0.8	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 74	0.4	ppb
2012-2	SD18	1	English sole	Liver	PCB	PCB 99	4.6	ppb
2012-2	SD18	1	English sole	Liver	DDT	p,-p-DDMU	2.3	ppb
2012-2	SD18	1	English sole	Liver	DDT	p,p-DDD	2.1	ppb
2012-2	SD18	1	English sole	Liver	DDT	p,p-DDE	64.0	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 101	1.6	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 118	1.9	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 138	3.5	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 149	1.2	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 153/168	6.5	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 170	1.4	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 180	2.5	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 183	0.9	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 187	2.8	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 194	0.8	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 28	0.2	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 49	0.7	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 52	0.7	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 66	0.5	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 70	0.2	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 74	0.3	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	PCB	PCB 99	1.6	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	3.8	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	DDT	p,p-DDD	2.2	ppb
2012-2	SD18	2	Hornyhead turbot	Liver	DDT	p,p-DDE	81.0	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 101	2.3	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 118	2.5	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 138	3.9	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 149	1.3	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 151	0.7	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 153/168	7.5	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 170	1.4	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 180	3.6	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 183	1.1	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 187	3.6	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 194	1.3	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 201	1.4	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 49	0.5	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 52	0.6	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 66	0.5	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 74	0.4	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	PCB	PCB 99	1.8	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	4.7	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	DDT	p,p-DDD	2.2	ppb
2012-2	SD18	3	Hornyhead turbot	Liver	DDT	p,p-DDE	93.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-2	SD19	1	Hornyhead turbot	Liver	PCB	PCB 118	2.3	ppb
2012-2	SD19	1	Hornyhead turbot	Liver	PCB	PCB 138	3.0	ppb
2012-2	SD19	1	Hornyhead turbot	Liver	PCB	PCB 149	1.0	ppb
2012-2	SD19	1	Hornyhead turbot	Liver	PCB	PCB 153/168	5.7	ppb
2012-2	SD19	1	Hornyhead turbot	Liver	PCB	PCB 170	0.9	ppb
2012-2	SD19	1	Hornyhead turbot	Liver	PCB	PCB 180	2.5	ppb
2012-2	SD19	1	Hornyhead turbot	Liver	PCB	PCB 187	2.4	ppb
2012-2	SD19	1	Hornyhead turbot	Liver	PCB	PCB 99	1.5	ppb
2012-2	SD19	1	Hornyhead turbot	Liver	DDT	p,-p-DDMU	2.0	ppb
2012-2	SD19	1	Hornyhead turbot	Liver	DDT	p,p-DDE	43.0	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 101	4.1	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 118	5.3	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 138	7.1	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 149	3.2	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 151	1.4	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 153/168	12.0	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 170	1.1	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 177	1.4	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 180	4.3	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 183	1.6	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 187	4.9	ppb
2012-2	SD19	2	English sole	Liver	PCB	PCB 99	3.5	ppb
2012-2	SD19	2	English sole	Liver	DDT	o,p-DDE	2.4	ppb
2012-2	SD19	2	English sole	Liver	DDT	p,-p-DDMU	2.6	ppb
2012-2	SD19	2	English sole	Liver	DDT	p,p-DDE	96.0	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 101	1.1	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 118	1.5	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 138	2.8	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 149	1.4	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 153/168	5.8	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 170	0.8	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 180	1.9	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 187	2.2	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 49	0.4	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 52	0.5	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 66	0.5	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	PCB	PCB 99	1.3	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	2.4	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	DDT	p,p-DDD	1.8	ppb
2012-2	SD19	3	Hornyhead turbot	Liver	DDT	p,p-DDE	62.5	ppb
2012-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 118	2.0	ppb
2012-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 138	2.1	ppb
2012-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 149	1.0	ppb
2012-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 153/168	4.1	ppb
2012-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 180	2.3	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 187	1.5	ppb
2012-2	SD20	1	Hornyhead turbot	Liver	PCB	PCB 66	0.7	ppb
2012-2	SD20	1	Hornyhead turbot	Liver	DDT	p,-p-DDMU	2.2	ppb
2012-2	SD20	1	Hornyhead turbot	Liver	DDT	p,p-DDE	30.0	ppb
2012-2	SD20	2	English sole	Liver	PCB	PCB 138	2.0	ppb
2012-2	SD20	2	English sole	Liver	PCB	PCB 149	1.2	ppb
2012-2	SD20	2	English sole	Liver	PCB	PCB 153/168	4.1	ppb
2012-2	SD20	2	English sole	Liver	PCB	PCB 180	1.3	ppb
2012-2	SD20	2	English sole	Liver	PCB	PCB 187	1.7	ppb
2012-2	SD20	2	English sole	Liver	DDT	p,-p-DDMU	0.8	ppb
2012-2	SD20	2	English sole	Liver	DDT	p,p-DDE	25.0	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 101	3.1	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 118	4.2	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 138	3.6	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 149	2.0	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 153/168	7.2	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 170	1.3	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 180	2.6	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 183	1.0	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 187	3.4	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 66	0.8	ppb
2012-2	SD20	3	English sole	Liver	PCB	PCB 99	2.3	ppb
2012-2	SD20	3	English sole	Liver	DDT	o,p-DDE	1.7	ppb
2012-2	SD20	3	English sole	Liver	DDT	p,-p-DDMU	2.3	ppb
2012-2	SD20	3	English sole	Liver	DDT	p,p-DDE	56.0	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 118	2.4	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 138	4.2	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 149	1.7	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 153/168	8.1	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 170	1.2	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 180	2.8	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 183	1.0	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 187	2.7	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 66	0.8	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	PCB	PCB 99	2.5	ppb
2012-2	SD21	1	Hornyhead turbot	Liver	DDT	p,p-DDE	33.0	ppb
2012-2	SD21	2	English sole	Liver	PCB	PCB 101	2.4	ppb
2012-2	SD21	2	English sole	Liver	PCB	PCB 118	3.0	ppb
2012-2	SD21	2	English sole	Liver	PCB	PCB 138	3.3	ppb
2012-2	SD21	2	English sole	Liver	PCB	PCB 149	1.9	ppb
2012-2	SD21	2	English sole	Liver	PCB	PCB 153/168	5.7	ppb
2012-2	SD21	2	English sole	Liver	PCB	PCB 180	2.3	ppb
2012-2	SD21	2	English sole	Liver	PCB	PCB 183	0.7	ppb
2012-2	SD21	2	English sole	Liver	PCB	PCB 187	2.7	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-2	SD21	2	English sole	Liver	PCB	PCB 66	0.8	ppb
2012-2	SD21	2	English sole	Liver	PCB	PCB 99	1.9	ppb
2012-2	SD21	2	English sole	Liver	DDT	o,p-DDE	1.6	ppb
2012-2	SD21	2	English sole	Liver	DDT	p,-p-DDMU	2.2	ppb
2012-2	SD21	2	English sole	Liver	DDT	p,p-DDE	44.0	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 101	2.6	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 118	4.9	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 138	6.7	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 149	2.4	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 153/168	12.0	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 170	1.7	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 180	5.2	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 183	1.9	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 187	5.5	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 66	1.2	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 99	3.5	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	DDT	o,p-DDE	1.4	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	3.5	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	DDT	p,p-DDD	3.9	ppb
2012-2	SD21	3	Hornyhead turbot	Liver	DDT	p,p-DDE	63.0	ppb
2012-4	RF3	1	Vermilion rockfish	Muscle	PCB	PCB 138	0.3	ppb
2012-4	RF3	1	Vermilion rockfish	Muscle	PCB	PCB 149	0.3	ppb
2012-4	RF3	1	Vermilion rockfish	Muscle	PCB	PCB 153/168	0.5	ppb
2012-4	RF3	1	Vermilion rockfish	Muscle	DDT	p,p-DDE	3.4	ppb
2012-4	RF3	2	Vermilion rockfish	Muscle	DDT	p,p-DDE	1.2	ppb
2012-4	RF3	3	Vermilion rockfish	Muscle	DDT	p,p-DDE	0.4	ppb
2012-4	RF4	1	California scorpionfish	Muscle	PCB	PCB 138	0.3	ppb
2012-4	RF4	1	California scorpionfish	Muscle	PCB	PCB 153/168	0.7	ppb
2012-4	RF4	1	California scorpionfish	Muscle	PCB	PCB 180	0.2	ppb
2012-4	RF4	1	California scorpionfish	Muscle	DDT	p,p-DDE	4.6	ppb
2012-4	RF4	2	California scorpionfish	Muscle	PCB	PCB 153/168	0.3	ppb
2012-4	RF4	2	California scorpionfish	Muscle	DDT	p,p-DDE	1.3	ppb
2012-4	RF4	3	California scorpionfish	Muscle	PCB	PCB 153/168	0.4	ppb
2012-4	RF4	3	California scorpionfish	Muscle	DDT	p,p-DDE	2.4	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 101	2.4	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 118	3.2	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 138	4.6	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 149	1.6	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 151	1.4	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 153/168	9.6	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 170	1.7	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 180	3.5	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 187	5.3	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 206	0.3	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 49	0.6	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 52	0.8	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 66	0.8	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 70	0.6	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 74	0.5	ppb
2012-4	SD15	1	Pacific sanddab	Liver	PCB	PCB 99	3.2	ppb
2012-4	SD15	1	Pacific sanddab	Liver	DDT	o,p-DDE	1.1	ppb
2012-4	SD15	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	2.6	ppb
2012-4	SD15	1	Pacific sanddab	Liver	DDT	p,p-DDD	1.5	ppb
2012-4	SD15	1	Pacific sanddab	Liver	DDT	p,p-DDE	54.0	ppb
2012-4	SD15	2	Pacific sanddab	Liver	PCB	PCB 138	2.1	ppb
2012-4	SD15	2	Pacific sanddab	Liver	PCB	PCB 153/168	4.0	ppb
2012-4	SD15	2	Pacific sanddab	Liver	PCB	PCB 180	1.8	ppb
2012-4	SD15	2	Pacific sanddab	Liver	PCB	PCB 187	1.9	ppb
2012-4	SD15	2	Pacific sanddab	Liver	PCB	PCB 49	0.5	ppb
2012-4	SD15	2	Pacific sanddab	Liver	PCB	PCB 52	0.4	ppb
2012-4	SD15	2	Pacific sanddab	Liver	PCB	PCB 66	0.4	ppb
2012-4	SD15	2	Pacific sanddab	Liver	PCB	PCB 74	0.2	ppb
2012-4	SD15	2	Pacific sanddab	Liver	DDT	p,p-DDE	22.0	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 138	2.2	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 149	1.2	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 153/168	3.7	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 187	2.1	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 49	0.3	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 52	0.5	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 66	0.4	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 70	0.3	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 74	0.4	ppb
2012-4	SD15	3	Pacific sanddab	Liver	PCB	PCB 99	1.3	ppb
2012-4	SD15	3	Pacific sanddab	Liver	DDT	p,p-DDE	25.0	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 101	5.6	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 105	3.1	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 110	2.8	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 118	9.4	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 128	3.4	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 138	20.0	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 149	6.1	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 151	3.2	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 153/168	39.0	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 156	1.7	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 158	1.4	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 167	1.3	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 170	5.2	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 177	3.4	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 180	12.0	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 183	4.7	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 187	17.0	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 194	5.4	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 201	5.4	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 206	3.9	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 49	1.0	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 52	1.3	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 66	1.7	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 70	0.9	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 74	1.1	ppb
2012-4	SD16	1	Longfin sanddab	Liver	PCB	PCB 99	9.1	ppb
2012-4	SD16	1	Longfin sanddab	Liver	DDT	o,p-DDE	4.2	ppb
2012-4	SD16	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	10.0	ppb
2012-4	SD16	1	Longfin sanddab	Liver	DDT	p,p-DDD	3.5	ppb
2012-4	SD16	1	Longfin sanddab	Liver	DDT	p,p-DDE	230.0	ppb
2012-4	SD16	1	Longfin sanddab	Liver	DDT	p,p-DDT	2.9	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 101	1.9	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 118	2.6	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 138	4.0	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 149	1.5	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 153/168	7.6	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 170	1.5	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 180	2.1	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 187	4.8	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 206	1.7	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 49	0.5	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 52	0.5	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 66	0.3	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 70	0.3	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 74	0.3	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	PCB	PCB 99	1.3	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	2.5	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	DDT	p,p-DDD	1.8	ppb
2012-4	SD16	2	Hornyhead turbot	Liver	DDT	p,p-DDE	57.0	ppb
2012-4	SD16	3	Hornyhead turbot	Liver	PCB	PCB 149	1.0	ppb
2012-4	SD16	3	Hornyhead turbot	Liver	PCB	PCB 153/168	4.0	ppb
2012-4	SD16	3	Hornyhead turbot	Liver	PCB	PCB 187	2.3	ppb
2012-4	SD16	3	Hornyhead turbot	Liver	PCB	PCB 49	0.5	ppb
2012-4	SD16	3	Hornyhead turbot	Liver	PCB	PCB 52	0.4	ppb
2012-4	SD16	3	Hornyhead turbot	Liver	PCB	PCB 66	0.4	ppb
2012-4	SD16	3	Hornyhead turbot	Liver	DDT	p,p-DDE	27.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 101	3.3	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 118	4.9	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 128	1.6	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 138	10.0	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 149	3.1	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 153/168	23.0	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 156	0.9	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 158	0.9	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 170	2.6	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 177	2.6	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 180	6.8	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 183	2.3	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 187	11.0	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 201	3.1	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 206	2.6	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 28	0.6	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 49	1.0	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 52	1.2	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 66	1.4	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 70	0.7	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 74	0.8	ppb
2012-4	SD17	1	Longfin sanddab	Liver	PCB	PCB 99	6.5	ppb
2012-4	SD17	1	Longfin sanddab	Liver	DDT	o,p-DDE	2.9	ppb
2012-4	SD17	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	7.4	ppb
2012-4	SD17	1	Longfin sanddab	Liver	DDT	p,p-DDD	3.2	ppb
2012-4	SD17	1	Longfin sanddab	Liver	DDT	p,p-DDE	160.0	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	HCH	HCH, Delta isomer	1.2	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 101	2.2	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 110	2.0	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 118	2.3	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 138	2.3	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 153/168	5.3	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 180	2.1	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 187	2.9	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 49	0.9	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 52	0.7	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 66	0.9	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 70	0.6	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 74	0.5	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	PCB	PCB 99	2.3	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	DDT	o,p-DDE	0.9	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	2.5	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	DDT	p,p-DDD	1.5	ppb
2012-4	SD17	2	Hornyhead turbot	Liver	DDT	p,p-DDE	39.0	ppb
2012-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 153/168	5.3	ppb
2012-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 52	0.4	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 66	0.4	ppb
2012-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 74	0.3	ppb
2012-4	SD17	3	Hornyhead turbot	Liver	DDT	p,p-DDE	35.5	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 101	5.0	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 118	7.0	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 128	2.1	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 138	8.6	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 149	3.6	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 151	1.5	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 153/168	20.0	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 170	2.2	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 177	2.2	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 180	7.1	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 183	1.9	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 187	9.4	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 201	2.2	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 49	0.9	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 52	1.4	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 66	1.6	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 70	0.9	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 74	0.9	ppb
2012-4	SD18	1	Longfin sanddab	Liver	PCB	PCB 99	5.5	ppb
2012-4	SD18	1	Longfin sanddab	Liver	DDT	o,p-DDD	0.8	ppb
2012-4	SD18	1	Longfin sanddab	Liver	DDT	o,p-DDE	3.9	ppb
2012-4	SD18	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	10.0	ppb
2012-4	SD18	1	Longfin sanddab	Liver	DDT	p,p-DDD	4.8	ppb
2012-4	SD18	1	Longfin sanddab	Liver	DDT	p,p-DDE	190.0	ppb
2012-4	SD18	1	Longfin sanddab	Liver	DDT	p,p-DDT	3.6	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 101	4.3	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 105	2.0	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 118	5.9	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 128	1.7	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 138	8.9	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 149	3.6	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 151	1.5	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 153/168	18.0	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 170	3.0	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 177	2.2	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 180	6.7	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 187	9.0	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 201	2.2	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 206	2.2	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 49	1.0	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 52	1.4	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 66	1.4	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 70	0.8	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 74	0.7	ppb
2012-4	SD18	2	Longfin sanddab	Liver	PCB	PCB 99	4.8	ppb
2012-4	SD18	2	Longfin sanddab	Liver	DDT	o,p-DDD	0.9	ppb
2012-4	SD18	2	Longfin sanddab	Liver	DDT	o,p-DDE	3.2	ppb
2012-4	SD18	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	9.0	ppb
2012-4	SD18	2	Longfin sanddab	Liver	DDT	p,p-DDD	4.5	ppb
2012-4	SD18	2	Longfin sanddab	Liver	DDT	p,p-DDE	150.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	tChlor	Alpha (cis) Chlordane	4.1	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 101	17.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 105	9.6	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 110	8.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 118	39.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 119	1.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 123	4.6	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 128	10.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 138	66.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 149	16.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 151	11.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 153/168	130.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 156	5.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 157	1.6	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 158	4.1	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 167	3.3	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 170	17.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 177	11.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 180	43.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 183	13.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 187	56.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 194	11.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 201	14.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 206	6.7	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 44	0.7	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 49	2.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 52	3.6	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 66	4.6	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 70	1.9	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 74	2.7	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 87	2.5	ppb
2012-4	SD18	3	Longfin sanddab	Liver	PCB	PCB 99	27.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	tChlor	Trans Nonachlor	8.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	DDT	o,p-DDD	1.6	ppb
2012-4	SD18	3	Longfin sanddab	Liver	DDT	o,p-DDE	8.7	ppb
2012-4	SD18	3	Longfin sanddab	Liver	DDT	p,-p-DDMU	24.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	DDT	p,p-DDD	9.4	ppb
2012-4	SD18	3	Longfin sanddab	Liver	DDT	p,p-DDE	650.0	ppb
2012-4	SD18	3	Longfin sanddab	Liver	DDT	p,p-DDT	6.8	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 101	5.3	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 110	3.7	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 118	8.9	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 128	2.7	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 138	12.0	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 149	6.6	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 151	2.3	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 153/168	27.0	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 167	0.9	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 170	3.5	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 177	3.2	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 180	7.4	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 183	2.5	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 187	13.0	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 194	2.8	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 201	3.3	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 206	2.6	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 49	1.4	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 52	1.8	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 66	2.2	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 70	1.2	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 74	1.1	ppb
2012-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 99	7.1	ppb
2012-4	SD19	1	Longfin sanddab	Liver	DDT	o,p-DDD	1.2	ppb
2012-4	SD19	1	Longfin sanddab	Liver	DDT	o,p-DDE	4.4	ppb
2012-4	SD19	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	14.0	ppb
2012-4	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDD	6.0	ppb
2012-4	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDE	230.0	ppb
2012-4	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDT	3.0	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 101	1.7	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 138	2.2	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 149	1.7	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 153/168	3.8	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 187	3.2	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 49	0.5	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 52	0.4	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 66	0.4	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 70	0.3	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 74	0.2	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	PCB	PCB 99	1.1	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	3.4	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	DDT	p,p-DDD	1.4	ppb
2012-4	SD19	2	Hornyhead turbot	Liver	DDT	p,p-DDE	39.0	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 101	1.8	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 118	2.2	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 138	2.7	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 149	1.6	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 153/168	6.2	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 180	2.3	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 187	3.6	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 206	1.3	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 49	0.5	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 52	0.4	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 66	0.4	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 70	0.3	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 74	0.3	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	PCB	PCB 99	1.7	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	DDT	o,p-DDE	1.0	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	2.2	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	DDT	p,p-DDD	1.7	ppb
2012-4	SD19	3	Hornyhead turbot	Liver	DDT	p,p-DDE	71.0	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 101	6.1	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 110	3.5	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 118	8.8	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 128	2.4	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 138	15.0	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 149	6.1	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 151	2.5	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 153/168	30.0	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 167	1.0	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 170	3.6	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 177	2.9	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 180	9.8	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 183	2.5	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 187	13.0	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 194	3.1	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 201	2.8	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 206	2.9	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 28	1.0	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 49	1.4	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 52	1.6	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 66	2.0	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 70	1.1	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 74	1.1	ppb
2012-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 99	7.9	ppb
2012-4	SD20	1	Longfin sanddab	Liver	DDT	o,p-DDD	1.2	ppb
2012-4	SD20	1	Longfin sanddab	Liver	DDT	o,p-DDE	4.5	ppb
2012-4	SD20	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	13.0	ppb
2012-4	SD20	1	Longfin sanddab	Liver	DDT	p,p-DDD	4.8	ppb
2012-4	SD20	1	Longfin sanddab	Liver	DDT	p,p-DDE	220.0	ppb
2012-4	SD20	1	Longfin sanddab	Liver	DDT	p,p-DDT	2.5	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 101	4.8	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 110	3.4	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 118	3.7	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 128	2.3	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 138	12.0	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 149	5.4	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 151	2.2	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 153/168	26.0	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 156	1.2	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 158	0.9	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 167	0.8	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 170	3.8	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 177	2.8	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 180	7.0	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 183	2.3	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 187	11.5	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 194	2.5	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 201	3.1	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 206	2.5	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 28	0.8	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 49	1.1	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 52	1.6	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 66	1.9	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 70	1.0	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 74	1.0	ppb
2012-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 99	6.4	ppb
2012-4	SD20	2	Longfin sanddab	Liver	DDT	o,p-DDD	1.0	ppb
2012-4	SD20	2	Longfin sanddab	Liver	DDT	o,p-DDE	4.4	ppb
2012-4	SD20	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	12.0	ppb
2012-4	SD20	2	Longfin sanddab	Liver	DDT	p,p-DDD	4.5	ppb
2012-4	SD20	2	Longfin sanddab	Liver	DDT	p,p-DDE	185.0	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 138	4.6	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 149	2.4	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 153/168	8.3	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 180	5.2	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 183	1.8	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 187	3.6	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	DDT	o,p-DDE	2.9	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	5.6	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	DDT	p,p-DDE	71.0	ppb
2012-4	SD20	3	Hornyhead turbot	Liver	DDT	p,p-DDT	5.4	ppb
2012-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 118	4.5	ppb
2012-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 138	5.6	ppb
2012-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 149	1.8	ppb
2012-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 153/168	11.0	ppb
2012-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 180	3.7	ppb
2012-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 187	4.3	ppb
2012-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 66	1.1	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2012-4	SD21	1	Hornyhead turbot	Liver	DDT	p,p-DDE	40.0	ppb
2012-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 138	2.9	ppb
2012-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 153/168	5.6	ppb
2012-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 180	2.8	ppb
2012-4	SD21	2	Hornyhead turbot	Liver	DDT	p,p-DDE	32.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 101	13.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 105	6.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 110	7.6	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 118	25.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 128	8.8	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 138	45.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 149	15.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 151	5.5	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 153/168	86.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 158	3.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 170	9.6	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 180	26.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 183	7.3	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 187	35.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 194	8.5	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 201	8.7	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 206	7.7	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 28	3.4	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 49	4.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 66	6.6	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 70	2.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 74	3.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	PCB	PCB 99	24.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	DDT	o,p-DDE	9.2	ppb
2012-4	SD21	3	Longfin sanddab	Liver	DDT	p,-p-DDMU	20.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	DDT	p,p-DDD	15.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	DDT	p,p-DDE	340.0	ppb
2012-4	SD21	3	Longfin sanddab	Liver	DDT	p,p-DDT	12.0	ppb

Appendix G

Supporting Data

2012 Regional Stations

Sediment Conditions

Appendix G.1

Constituents and method detection limits (MDL) used for the analysis of sediments collected as part of the 2009–2012 regional surveys.

Parameter	MDL 2009–2011	MDL 2012	Parameter	MDL 2009–2011	MDL 2012
Organic Indicators					
Total Nitrogen (TN, % wt.)	0.005	0.005	Total Sulfides (ppm)	0.14	0.14
Total Organic Carbon (TOC, % wt.)	0.01	0.01	Total Volatile Solids (TVS, % wt.)	0.11	0.11
Metals (ppm)					
Aluminum (Al)	2	2	Lead (Pb)	0.8	0.8
Antimony (Sb)	0.3	0.3	Manganese (Mn)	0.08	0.08
Arsenic (As)	0.33	0.33	Mercury (Hg)	0.003–0.004	0.004
Barium (Ba)	0.02	0.02	Nickel (Ni)	0.1	0.1
Beryllium (Be)	0.01	0.01	Selenium (Se)	0.24	0.24
Cadmium (Cd)	0.06	0.06	Silver (Ag)	0.04	0.04
Chromium (Cr)	0.1	0.1	Thallium (Ti)	0.5	0.5
Copper (Cu)	0.2	0.2	Tin (Sn)	0.3	0.3
Iron (Fe)	9	9	Zinc (Zn)	0.25	0.25
Chlorinated Pesticides (ppt)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	e	150	HCH, Delta isomer	e	700
HCH, Beta isomer	e	310	HCH, Gamma isomer	e	260
Total Chlordane					
Alpha (cis) Chlordane	e	240	Heptachlor epoxide	e	120
Cis Nonachlor	e	240	Methoxychlor	e	1100
Gamma (trans) Chlordane	e	350	Oxychlordane	e	240
Heptachlor	e	1200	Trans Nonachlor	e	250
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	e	830	p,p-DDE	e	260
o,p-DDE	e	720	p,p-DDMU[a]	e	—
o,p-DDT	e	800	p,p-DDT	e	800
p,p-DDD	e	470			
Miscellaneous Pesticides					
Aldrin	e	430	Endrin	e	830
Alpha Endosulfan	e	240	Endrin aldehyde	e	830
Beta Endosulfan	e	350	Hexachlorobenzene (HCB)	e	470
Dieldrin	e	310	Mirex	e	500
Endosulfan Sulfate	e	260			

[a]No MDL available for this parameter; e = values estimated regardless of MDL

Appendix G.1 *continued*

Parameter	MDL 2009–2011	MDL 2012	Parameter	MDL 2009–2011	MDL 2012
Polychlorinated Biphenyl Congeners (PCBs) (ppt)					
PCB 18	e	540	PCB 126	e	720
PCB 28	e	660	PCB 128	e	570
PCB 37	e	340	PCB 138	e	590
PCB 44	e	890	PCB 149	e	500
PCB 49	e	850	PCB 151	e	640
PCB 52	e	1000	PCB 153/168	e	600
PCB 66	e	920	PCB 156	e	620
PCB 70	e	1100	PCB 157	e	700
PCB 74	e	900	PCB 158	e	510
PCB 77	e	790	PCB 167	e	620
PCB 81	e	590	PCB 169	e	610
PCB 87	e	600	PCB 170	e	570
PCB 99	e	660	PCB 177	e	650
PCB 101	e	430	PCB 180	e	530
PCB 105	e	720	PCB 183	e	530
PCB 110	e	640	PCB 187	e	470
PCB 114	e	700	PCB 189	e	620
PCB 118	e	830	PCB 194	e	420
PCB 119	e	560	PCB 201	e	530
PCB 123	e	660	PCB 206	e	510
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
1-methylnaphthalene	20	20	Benzo[G,H,I]perylene	20	20
1-methylphenanthrene	20	20	Benzo[K]fluoranthene	20	20
2,3,5-trimethylnaphthalene	20	20	Biphenyl	30	30
2,6-dimethylnaphthalene	20	20	Chrysene	40	40
2-methylnaphthalene	20	20	Dibenzo(A,H)anthracene	20	20
3,4-benzo(B)fluoranthene	20	20	Fluoranthene	20	20
Acenaphthene	20	20	Fluorene	20	20
Acenaphthylene	30	30	Indeno(1,2,3-CD)pyrene	20	20
Anthracene	20	20	Naphthalene	30	30
Benzo[A]anthracene	20	20	Perylene	30	30
Benzo[A]pyrene	20	20	Phenanthrene	30	30
Benzo[e]pyrene	20	20	Pyrene	20	20

e = values estimated regardless of MDL

Appendix G.2

Summary of the constituents that make up total DDT, total PCB and total PAH in each sediment sample collected as part of the 2012 regional survey.

Station	Class	Constituent	Value	Units
8201	DDT	p,p-DDE	250	ppt
8201	PCB	PCB 206	290	ppt
8202	DDT	p,p-DDE	590	ppt
8202	PCB	PCB 206	270	ppt
8203	DDT	p,p-DDE	390	ppt
8203	DDT	p,p-DDT	500	ppt
8203	PCB	PCB 206	330	ppt
8208	PCB	PCB 206	310	ppt
8209	DDT	p,p-DDE	170	ppt
8209	PCB	PCB 206	250	ppt
8210	PCB	PCB 206	250	ppt
8211	DDT	p,p-DDE	270	ppt
8211	PCB	PCB 206	220	ppt
8212	DDT	p,p-DDE	460	ppt
8212	PCB	PCB 206	290	ppt
8213	PCB	PCB 206	250	ppt
8214	DDT	p,p-DDE	370	ppt
8214	PCB	PCB 206	300	ppt
8215	DDT	p,p-DDE	600	ppt
8215	PCB	PCB 138	160	ppt
8215	PCB	PCB 149	170	ppt
8215	PCB	PCB 206	350	ppt
8216	PCB	PCB 206	290	ppt
8217	DDT	p,p-DDE	310	ppt
8217	PCB	PCB 206	250	ppt
8218	PCB	PCB 206	210	ppt
8219	DDT	p,p-DDE	200	ppt
8219	PCB	PCB 206	310	ppt
8220	DDT	p,p-DDE	260	ppt
8220	PAH	Fluoranthene	23.4	ppb
8220	PCB	PCB 206	300	ppt

Appendix G.2 *continued*

Station	Class	Constituent	Value	Units
8221	PCB	PCB 206	330	ppt
8222	DDT	p,p-DDE	290	ppt
8222	PCB	PCB 101	1000	ppt
8222	PCB	PCB 105	340	ppt
8222	PCB	PCB 110	1100	ppt
8222	PCB	PCB 118	880	ppt
8222	PCB	PCB 128	280	ppt
8222	PCB	PCB 138	940	ppt
8222	PCB	PCB 153/168	1200	ppt
8222	PCB	PCB 156	180	ppt
8222	PCB	PCB 158	160	ppt
8222	PCB	PCB 180	460	ppt
8222	PCB	PCB 187	140	ppt
8222	PCB	PCB 206	310	ppt
8222	PCB	PCB 52	410	ppt
8222	PCB	PCB 70	260	ppt
8222	PCB	PCB 99	360	ppt
8223	PCB	PCB 206	350	ppt
8224	DDT	p,p-DDE	660	ppt
8224	PCB	PCB 101	280	ppt
8224	PCB	PCB 138	230	ppt
8224	PCB	PCB 149	200	ppt
8224	PCB	PCB 153/168	340	ppt
8224	PCB	PCB 52	120	ppt
8225	DDT	p,p-DDE	300	ppt
8225	PCB	PCB 101	1400	ppt
8225	PCB	PCB 110	640	ppt
8225	PCB	PCB 128	260	ppt
8225	PCB	PCB 138	3400	ppt
8225	PCB	PCB 149	5800	ppt
8225	PCB	PCB 151	2100	ppt
8225	PCB	PCB 153/168	8400	ppt
8225	PCB	PCB 156	220	ppt
8225	PCB	PCB 158	410	ppt
8225	PCB	PCB 170	3300	ppt
8225	PCB	PCB 177	2300	ppt
8225	PCB	PCB 180	10,000	ppt
8225	PCB	PCB 183	2500	ppt
8225	PCB	PCB 187	5200	ppt
8225	PCB	PCB 194	2800	ppt
8225	PCB	PCB 201	2100	ppt
8225	PCB	PCB 206	830	ppt
8226	DDT	p,p-DDE	820	ppt
8226	PCB	PCB 206	300	ppt

Appendix G.2 *continued*

Station	Class	Constituent	Value	Units
8227	DDT	p,p-DDE	620	ppt
8227	PCB	PCB 138	240	ppt
8227	PCB	PCB 149	160	ppt
8227	PCB	PCB 153/168	320	ppt
8227	PCB	PCB 180	200	ppt
8227	PCB	PCB 187	140	ppt
8227	PCB	PCB 206	370	ppt
8227	PCB	PCB 66	82	ppt
8228	DDT	p,p-DDE	470	ppt
8228	PAH	3,4-benzo(B)fluoranthene	25.7	ppb
8228	PAH	Benzo[A]pyrene	25.2	ppb
8228	PCB	PCB 206	320	ppt
8229	DDT	p,p-DDE	260	ppt
8229	PCB	PCB 206	300	ppt
8230	DDT	p,p-DDE	840	ppt
8230	PAH	3,4-benzo(B)fluoranthene	23.5	ppb
8230	PAH	Benzo[A]pyrene	20.8	ppb
8230	PCB	PCB 101	850	ppt
8230	PCB	PCB 105	310	ppt
8230	PCB	PCB 110	980	ppt
8230	PCB	PCB 118	830	ppt
8230	PCB	PCB 138	650	ppt
8230	PCB	PCB 149	520	ppt
8230	PCB	PCB 153/168	800	ppt
8230	PCB	PCB 180	320	ppt
8230	PCB	PCB 206	520	ppt
8230	PCB	PCB 28	210	ppt
8230	PCB	PCB 49	290	ppt
8230	PCB	PCB 52	520	ppt
8230	PCB	PCB 66	340	ppt
8230	PCB	PCB 70	430	ppt
8230	PCB	PCB 74	190	ppt
8230	PCB	PCB 99	450	ppt
8232	DDT	p,p-DDE	600	ppt
8232	PCB	PCB 138	130	ppt
8232	PCB	PCB 149	160	ppt
8232	PCB	PCB 153/168	250	ppt
8232	PCB	PCB 180	210	ppt
8232	PCB	PCB 206	340	ppt
8234	DDT	p,p-DDE	230	ppt
8235	DDT	p,p-DDE	520	ppt
8235	PCB	PCB 206	320	ppt

Appendix G.2 *continued*

Station	Class	Constituent	Value	Units
8237	DDT	p,p-DDE	580	ppt
8237	PCB	PCB 206	230	ppt
8238	DDT	p,p-DDE	810	ppt
8238	PCB	PCB 138	500	ppt
8238	PCB	PCB 149	360	ppt
8238	PCB	PCB 153/168	720	ppt
8238	PCB	PCB 206	510	ppt
8238	PCB	PCB 66	160	ppt
8241	DDT	p,p-DDE	460	ppt
8242	DDT	p,p-DDE	1100	ppt
8242	PCB	PCB 206	270	ppt
8250	PCB	PCB 206	310	ppt
8254	DDT	o,p-DDD	50	ppt
8254	DDT	p,p-DDD	180	ppt
8254	DDT	p,p-DDE	320	ppt
8254	PAH	3,4-benzo(B)fluoranthene	62.1	ppb
8254	PAH	Benzo[A]anthracene	29.9	ppb
8254	PAH	Benzo[A]pyrene	52.7	ppb
8254	PAH	Benzo[e]pyrene	34.2	ppb
8254	PAH	Benzo[K]fluoranthene	25.1	ppb
8254	PAH	Fluoranthene	22.4	ppb
8254	PAH	Indeno(1,2,3-CD)pyrene	30.1	ppb
8254	PAH	Pyrene	26.5	ppb
8254	PCB	PCB 101	510	ppt
8254	PCB	PCB 105	660	ppt
8254	PCB	PCB 118	560	ppt
8254	PCB	PCB 128	320	ppt
8254	PCB	PCB 138	690	ppt
8254	PCB	PCB 149	630	ppt
8254	PCB	PCB 153/168	1200	ppt
8254	PCB	PCB 177	220	ppt
8254	PCB	PCB 180	850	ppt
8254	PCB	PCB 187	520	ppt
8254	PCB	PCB 194	230	ppt
8254	PCB	PCB 44	120	ppt
8254	PCB	PCB 49	140	ppt
8254	PCB	PCB 52	240	ppt
8254	PCB	PCB 66	170	ppt
8254	PCB	PCB 70	160	ppt
8254	PCB	PCB 74	83	ppt

Appendix G.3

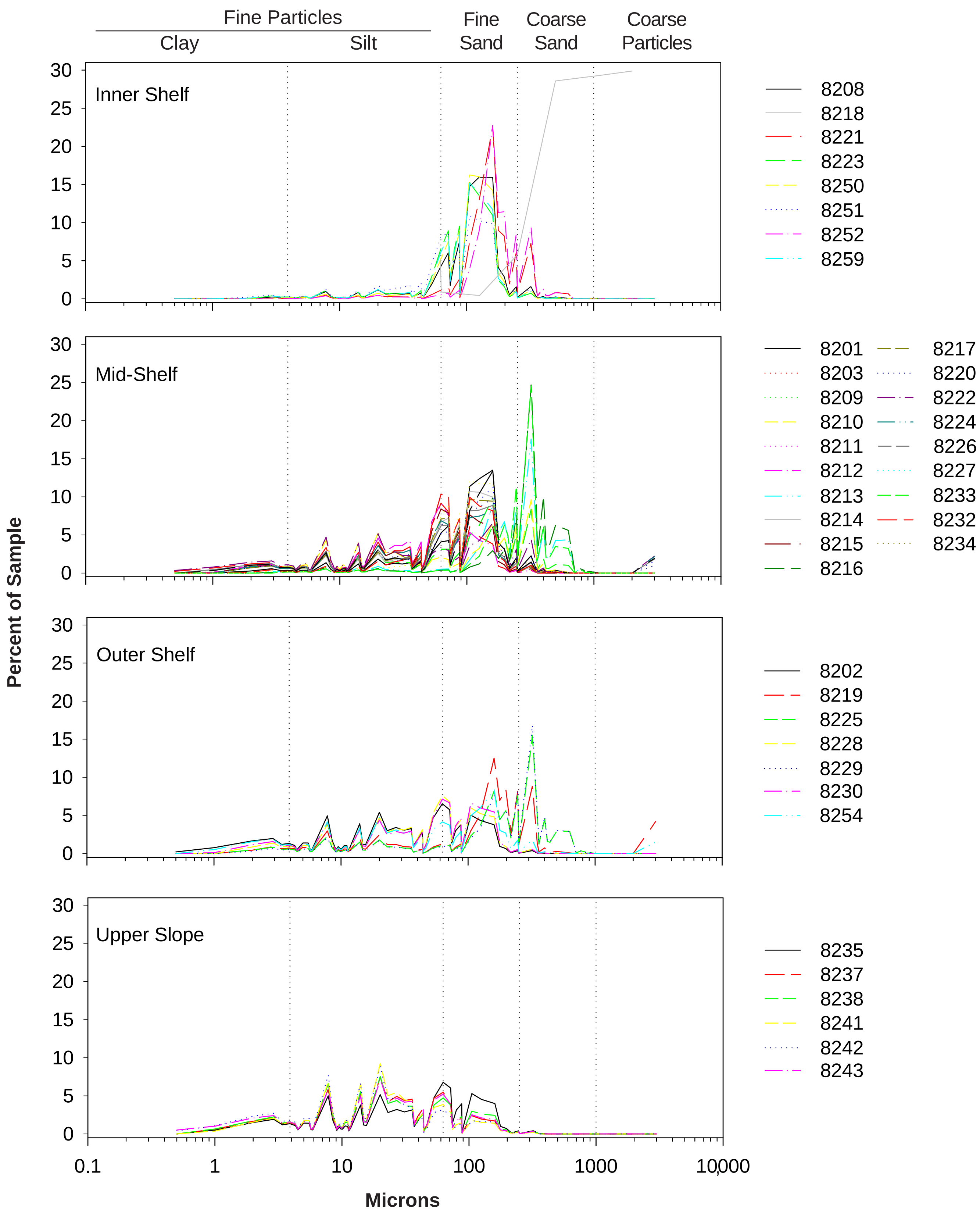
Summary of particle size parameters with sub-fractions (%) for each regional station sampled during 2012. Visual observations are from sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VC Sand=Very Coarse Sand; C Sand=Coarse Sand; M Sand=Medium Sand; F Sand=Fine Sand; VF Sand=Very Fine Sand; C Silt=Coarse Silt; M Silt=Medium Silt; F Silt=Fine Silt; VF Silt=Very Fine Silt.

			Coarse Particles		Coarse Sand		Fine Sand		Fine Particles					Visual Observations
		Depth (m)	Granules	VC Sand	C Sand	M Sand	F Sand	VF Sand	C Silt	M Silt	F Silt	VF Silt	Clay	
Inner	8252	11	0.0	0.0	0.6	14.7	63.7	16.0	1.6	1.2	1.3	0.8	0.0	shell hash/organic debris
Shelf	8218[s]	19	29.9	29.3	28.6	5.8	0.4	0.9	5.1	0.0	0.0	0.0	0.0	red relict sand/shell hash/organic debris
	8221	21	0.0	0.0	0.7	12.2	52.8	27.7	2.7	1.4	1.5	1.0	0.1	shell hash/organic debris
	8223	22	0.0	0.0	0.0	1.3	16.8	58.9	13.3	3.3	3.3	2.2	0.9	
	8259	24	0.0	0.0	0.0	1.7	18.3	57.7	12.5	3.4	3.3	2.1	1.0	organic debris/worm tubes
	8250	25	0.0	0.0	0.0	1.9	22.4	59.5	10.4	2.2	1.9	1.3	0.4	
	8208	27	0.0	0.0	0.1	2.8	26.4	53.1	8.9	3.1	3.1	1.9	0.6	
	8251	27	0.0	0.0	0.1	2.5	17.2	46.5	20.1	5.7	4.0	2.5	1.4	organic debris/worm tubes
Mid-	8234	31	0.0	0.0	0.1	3.1	21.5	50.4	16.7	3.4	2.5	1.6	0.7	organic debris/worm tubes
Shelf	8232	36	0.0	0.0	0.0	1.7	14.0	45.9	26.5	5.7	3.1	1.9	1.1	organic debris/worm tubes
	8213	37	0.0	0.0	6.6	39.1	38.1	7.1	1.8	2.1	2.7	1.9	0.6	shell hash
	8233	38	0.0	0.0	4.8	47.2	37.8	4.8	1.2	1.3	1.6	1.1	0.2	shell hash/pea gravel
	8201	39	0.0	0.0	0.1	3.9	24.9	44.0	13.1	5.3	4.4	2.8	1.5	
	8210	39	0.0	0.0	0.1	14.3	26.6	10.4	9.3	12.8	14.4	8.4	3.7	red relict sand/shell hash
	8216	40	0.0	0.0	8.2	60.5	21.3	3.3	1.4	1.4	2.0	1.5	0.4	shell hash/organic debris
	8222	43	2.2	0.0	0.1	7.0	18.8	15.9	12.7	12.9	14.8	9.5	6.2	shell hash/pea gravel
	8226	57	1.8	0.0	0.0	2.2	16.4	34.7	17.6	8.6	8.3	6.1	4.3	shell hash/pea gravel
	8215	68	0.0	0.0	0.0	0.8	9.9	35.3	25.1	11.6	8.8	5.5	3.1	
	8212	83	0.0	0.0	0.0	0.6	5.9	27.9	31.0	14.7	10.2	6.2	3.6	
	8224	85	2.2	0.0	0.0	1.5	14.6	32.1	22.0	11.2	8.3	5.2	3.1	shell hash/pea gravel
	8227	87	1.9	0.0	0.0	2.2	24.6	32.2	12.8	8.6	8.1	5.7	4.0	shell hash
	8203	94	0.0	0.0	0.0	0.4	6.0	30.8	28.1	12.3	10.2	7.0	5.2	
	8220	94	1.0	0.0	0.0	2.1	17.9	34.7	19.4	9.2	7.6	5.2	3.0	shell hash/pea gravel
	8209	98	0.0	0.0	1.2	15.4	29.0	20.5	9.8	6.8	7.9	6.0	3.5	shell hash/pea gravel
	8217	102	0.0	0.0	0.0	1.2	15.6	40.3	19.6	8.2	7.1	5.0	2.9	coarse black sand/shell hash
	8211	107	1.6	0.0	0.0	3.1	22.0	34.6	14.6	7.5	7.5	5.6	3.3	shell hash/pea gravel
	8214	112	0.0	0.0	0.0	1.3	16.0	43.2	17.8	7.4	6.8	4.8	2.7	shell hash

[s] measured by sieve (not Horiba)

Appendix G.3 *continued*

			Coarse Particles		Coarse Sand		Fine Sand		Fine Particles					Visual Observations
		Depth (m)	Granules	VC Sand	C Sand	M Sand	F Sand	VF Sand	C Silt	M Silt	F Silt	VF Silt	Clay	
Outer	8225	147	0.0	0.0	4.3	32.2	33.0	9.4	3.7	4.2	6.0	4.8	2.4	shell hash/pea gravel
Shelf	8228	148	0.0	0.0	0.0	0.8	8.1	28.7	24.6	13.8	11.9	7.9	4.1	
	8229	149	0.0	0.0	4.3	34.5	33.5	8.4	3.4	4.0	5.6	4.3	2.0	shell hash/pea gravel
	8230	149	0.0	0.0	0.0	0.7	9.0	30.4	22.1	12.4	11.9	8.5	4.9	shell hash/pea gravel
	8219	161	4.2	0.0	0.1	11.7	44.7	12.3	4.4	5.7	8.1	6.1	2.6	coarse black sand/shell hash/pea gravel
	8254	166	1.5	0.0	0.0	2.7	17.9	21.4	15.7	13.3	12.6	8.8	6.2	shell hash/pea gravel
	8202	195	0.0	0.0	0.0	0.4	6.2	24.2	22.0	14.9	14.8	10.4	7.1	organic debris/worm tubes
Upper	8237	247	0.0	0.0	0.0	0.3	3.0	13.4	23.9	21.0	19.0	12.1	7.2	organic debris/worm tubes
Slope	8243	263	0.0	0.0	0.0	0.4	3.5	13.6	22.6	20.0	18.6	12.3	9.0	organic debris/worm tubes
	8235	276	0.0	0.0	0.0	0.5	6.6	25.3	22.1	14.1	14.5	10.5	6.4	
	8242	325	0.0	0.0	0.0	0.4	3.0	8.9	15.5	21.9	24.9	15.5	9.9	organic debris/worm tubes
	8238	355	0.0	0.0	0.0	0.4	4.2	14.9	19.3	19.6	20.7	13.4	7.6	
	8241	448	0.0	0.0	0.0	0.2	2.5	9.7	19.1	24.1	23.8	13.7	6.9	



Appendix G.4

Plots illustrating particle size composition for all 2012 regional stations within each major depth stratum.

Appendix G.5

Concentrations of chemical analytes in sediments from the 2012 regional stations. ERL = Effects Range Low threshold value; ERM = Effects Range Median threshold value; see Appendix G.1 for MDLs, parameter abbreviations, and translation of periodic table symbols. Values that exceed ERL or ERM thresholds are highlighted in yellow.

	Station	Depth (m)	Sulfides (ppm)	TN (% weight)	TOC (% weight)	TVS (% weight)	tDDT (ppt)	HCB (ppt)	tPCB (ppt)	tPAH (ppb)
Inner Shelf	8252	11	7.0	0.017	0.09	0.70	nd	nd	nd	nd
	8218	19	0.9	0.013	1.50	1.04	nd	nd	210	nd
	8221	21	5.0	0.017	0.13	0.76	nd	nd	330	nd
	8223	22	2.9	0.026	0.19	0.92	nd	nd	350	nd
	8259	24	0.6	0.025	0.19	38.50	nd	nd	nd	nd
	8250	25	2.1	0.018	0.14	0.89	nd	nd	310	nd
	8208	27	2.9	0.027	0.22	1.35	nd	nd	310	nd
	8251	27	4.0	0.027	0.25	1.37	nd	nd	nd	nd
Mid-Shelf	8234	31	2.9	0.029	0.23	1.36	230	nd	nd	nd
	8232	36	4.2	0.031	0.25	1.69	600	nd	1090	nd
	8213	37	0.6	0.013	0.14	0.29	nd	nd	250	nd
	8233	38	0.7	0.015	0.31	0.87	nd	nd	nd	nd
	8201	39	1.5	0.037	0.32	1.72	250	nd	290	nd
	8210	39	0.6	0.019	0.14	0.86	nd	nd	250	nd
	8216	40	4.8	0.016	0.11	0.88	nd	100	290	nd
	8222	43	2.9	0.034	2.12	2.52	290	150	8020	nd
	8226	57	1.8	0.034	0.47	1.94	820	nd	300	nd
	8215	68	8.8	0.076	0.68	3.02	600	92	680	nd
	8212	83	7.0	0.077	0.69	2.88	460	nd	290	nd
	8224	85	2.6	0.058	0.59	2.80	660	nd	1170	nd
	8227	87	3.0	0.037	0.39	1.68	620	nd	1512	nd
	8203	94	11.6	0.080	0.77	2.97	890	130	330	nd
	8220	94	5.4	0.048	0.50	2.31	260	nd	300	23.4
	8209	98	9.8	0.049	3.27	3.23	170	140	250	nd
	8217	102	5.7	0.048	0.73	2.31	310	nd	250	nd
	8211	107	6.5	0.055	2.33	2.80	270	nd	220	nd
	8214	112	4.0	0.048	0.51	2.05	370	nd	300	nd
Outer Shelf	8225	147	17.7	0.068	6.08	3.47	300	200	51,660	nd
	8228	148	9.2	0.085	1.40	4.70	470	nd	320	50.9
	8229	149	3.2	0.064	6.49	4.06	260	nd	300	nd
	8230	149	8.0	0.097	1.26	4.20	840	nd	8210	44.3
	8219	161	1.7	0.037	1.74	2.33	200	nd	310	nd
	8254	166	10.5	0.070	0.71	3.05	550	nd	7303	283.0
	8202	195	28.5	0.109	1.12	4.43	590	nd	270	nd
Upper Slope	8237	247	21.0	0.184	2.35	7.08	580	nd	230	nd
	8243	263	15.6	0.196	2.50	7.20	nd	nd	nd	nd
	8235	276	15.9	0.132	1.79	5.22	520	nd	320	nd
	8242	325	254.0	0.226	2.48	8.59	1100	nd	270	nd
	8238	355	23.5	0.208	2.96	8.82	810	nd	2250	nd
	8241	448	11.8	0.249	3.02	9.02	460	nd	nd	nd
		[a] ERL:	na	na	na	na	1580	na	na	4022
		[a] ERM:	na	na	na	na	46,100	na	na	44,792

nd = not detected; na = not available; [a] from Long et al. 1995

Appendix G.5 *continued*

	Station	Depth (m)	Metals (ppm) Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe
Inner Shelf	8252	11	2930	nd	1.6	13.0	0.059	nd	5.3	1.0	3610
	8218	19	1770	nd	5.9	9.0	0.025	nd	6.2	9.7	5030
	8221	21	3570	nd	1.8	14.0	0.022	nd	5.5	1.4	4310
	8223	22	6070	nd	1.1	18.2	0.038	nd	9.1	2.4	5200
	8259	24	4770	0.42	1.7	19.9	0.093	nd	8.7	2.0	4480
	8250	25	6470	0.37	1.9	23.1	0.097	nd	8.8	2.9	5950
	8208	27	3760	0.31	1.6	26.6	0.034	0.07	8.8	7.0	4750
	8251	27	7480	0.52	2.2	39.5	0.150	nd	12.0	4.6	7940
Mid-Shelf	8234	31	9480	0.34	1.7	47.9	0.166	nd	14.4	4.8	9350
	8232	36	13,100	0.50	2.0	60.3	0.072	nd	16.6	6.8	11,600
	8213	37	1640	0.61	0.8	7.6	nd	nd	33.7	4.0	39,200
	8233	38	2210	nd	3.3	4.5	0.095	nd	14.0	1.2	5970
	8201	39	8320	0.46	2.1	58.2	0.120	nd	16.1	10.6	10,900
	8210	39	1610	nd	8.1	5.5	nd	nd	8.0	0.4	5840
	8216	40	2030	nd	1.7	7.6	0.015	nd	8.1	5.6	4120
	8222	43	5280	nd	6.6	27.4	nd	nd	13.3	4.5	18,000
	8226	57	7670	nd	2.5	27.1	0.041	nd	11.2	9.4	8040
	8215	68	11,800	0.55	3.5	62.2	0.165	0.06	21.2	14.0	14,100
	8212	83	7960	0.33	3.6	26.2	0.190	nd	21.2	9.5	16,700
	8224	85	9660	0.55	3.2	46.1	0.200	nd	17.4	9.7	12,300
	8227	87	6940	nd	2.1	22.7	0.031	nd	11.3	7.3	8070
	8203	94	11,300	0.46	3.3	57.9	0.180	nd	22.3	13.9	14,700
	8220	94	9300	0.43	3.1	44.6	0.150	nd	18.5	12.5	11,700
	8209	98	7850	nd	8.7	23.4	0.260	nd	31.5	6.0	26,200
	8217	102	7520	0.33	2.6	26.7	0.130	nd	15.8	11.1	10,100
	8211	107	8160	0.37	3.2	29.7	0.190	nd	20.9	10.1	16,700
	8214	112	7570	0.39	2.3	28.6	0.110	nd	14.8	9.3	9380
Outer Shelf	8225	147	5130	nd	4.6	13.2	0.033	nd	21.6	5.0	13,600
	8228	148	14,900	1.61	2.7	50.7	0.064	nd	23.3	15.3	15,400
	8229	149	6450	nd	6.6	17.9	0.040	nd	30.1	5.3	19,500
	8230	149	14,000	0.43	2.9	46.1	0.050	nd	21.3	14.4	14,600
	8219	161	4690	nd	3.8	41.6	0.091	nd	17.3	3.5	9110
	8254	166	14,600	0.72	3.3	70.5	0.290	nd	22.7	21.8	16,900
	8202	195	15,200	0.66	4.5	73.1	0.260	0.38	27.3	18.9	17,900
Upper Slope	8237	247	20,000	0.78	3.9	86.1	0.330	0.07	36.4	26.7	20,000
	8243	263	16,300	0.85	3.2	66.7	0.260	0.10	28.8	14.8	19,700
	8235	276	14,500	0.60	2.9	64.5	0.250	0.13	28.3	19.0	16,200
	8242	325	25,300	1.03	9.3	87.6	0.370	nd	36.1	21.3	20,900
	8238	355	26,200	0.65	4.1	120.0	0.416	0.25	38.0	25.2	23,600
	8241	448	15,100	0.76	5.0	88.8	0.310	0.20	29.8	16.0	17,400
		[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

nd = not detected; na = not available; [a] from Long et al. 1995

Appendix G.5 *continued*

	Station	Depth (m)	Metals (ppm)								
			Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Inner Shelf	8252	11	2.43	46.2	nd	1.57	nd	nd	nd	1.34	9.0
	8218	19	4.22	102.0	0.005	3.60	nd	nd	nd	2.67	15.6
	8221	21	2.67	49.9	0.006	1.40	nd	nd	nd	0.50	9.0
	8223	22	2.81	60.7	0.006	2.53	nd	nd	nd	0.36	12.0
	8259	24	2.83	53.0	0.004	2.75	nd	nd	nd	1.30	12.0
	8250	25	2.78	75.4	nd	2.43	0.37	nd	nd	0.32	12.5
	8208	27	3.15	69.0	0.006	4.23	0.30	nd	nd	1.58	15.5
	8251	27	4.78	88.8	0.013	4.63	nd	nd	nd	1.63	22.0
Mid-Shelf	8234	31	4.89	94.6	0.005	5.39	nd	nd	nd	nd	24.9
	8232	36	5.40	116.0	0.008	5.92	nd	nd	nd	0.56	27.1
	8213	37	6.62	180.0	nd	3.64	nd	nd	nd	1.23	17.8
	8233	38	6.49	24.3	nd	2.56	nd	nd	nd	nd	10.1
	8201	39	5.82	120.0	0.006	7.13	nd	0.20	nd	1.17	32.9
	8210	39	2.61	27.2	nd	0.77	nd	nd	nd	4.39	6.3
	8216	40	2.44	34.2	nd	3.46	nd	nd	nd	1.87	11.0
	8222	43	6.91	62.2	0.017	3.02	0.28	nd	nd	3.99	24.5
	8226	57	4.68	73.3	0.023	5.13	nd	nd	nd	0.63	17.8
	8215	68	9.65	133.0	0.046	11.00	nd	nd	nd	2.14	41.1
	8212	83	6.53	74.2	0.048	8.01	nd	nd	nd	1.42	34.0
	8224	85	8.49	101.0	0.055	7.97	0.45	nd	nd	2.14	31.3
	8227	87	5.89	68.0	0.047	4.79	0.53	nd	nd	0.82	20.8
	8203	94	9.34	129.0	0.035	10.80	nd	nd	nd	2.20	39.5
	8220	94	7.44	99.2	0.033	9.77	nd	nd	nd	1.97	31.0
	8209	98	7.62	65.9	0.018	8.06	nd	nd	nd	1.75	41.4
	8217	102	5.83	77.0	0.024	8.32	nd	nd	nd	2.89	28.0
	8211	107	6.43	75.6	0.020	8.35	nd	nd	nd	1.84	34.5
	8214	112	5.90	80.1	0.022	7.74	0.33	nd	nd	1.36	25.4
Outer Shelf	8225	147	2.64	29.0	0.011	4.84	0.41	nd	nd	0.55	20.9
	8228	148	8.72	120.0	0.098	11.40	0.38	nd	nd	1.20	37.5
	8229	149	2.67	32.9	0.010	5.74	0.55	nd	nd	nd	27.8
	8230	149	9.03	112.0	0.110	10.30	0.35	nd	nd	1.30	36.1
	8219	161	2.70	28.9	0.013	3.89	0.42	nd	nd	0.42	15.6
	8254	166	12.50	144.0	0.151	9.45	nd	nd	nd	2.40	49.2
	8202	195	12.60	156.0	0.060	14.10	0.36	nd	nd	2.39	52.6
Upper Slope	8237	247	18.50	177.0	0.089	24.00	0.94	0.23	nd	2.33	65.4
	8243	263	8.78	128.0	0.077	15.60	1.31	nd	nd	1.96	46.8
	8235	276	11.10	139.0	0.053	15.80	1.03	nd	nd	1.75	49.3
	8242	325	15.70	215.0	0.015	21.30	0.95	3.83	nd	5.14	60.3
	8238	355	10.20	168.0	0.044	21.30	1.56	nd	nd	0.67	60.0
	8241	448	7.15	136.0	0.049	17.40	1.86	nd	nd	1.42	48.8
		[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

nd = not detected; na = not available; [a] from Long et al. 1995

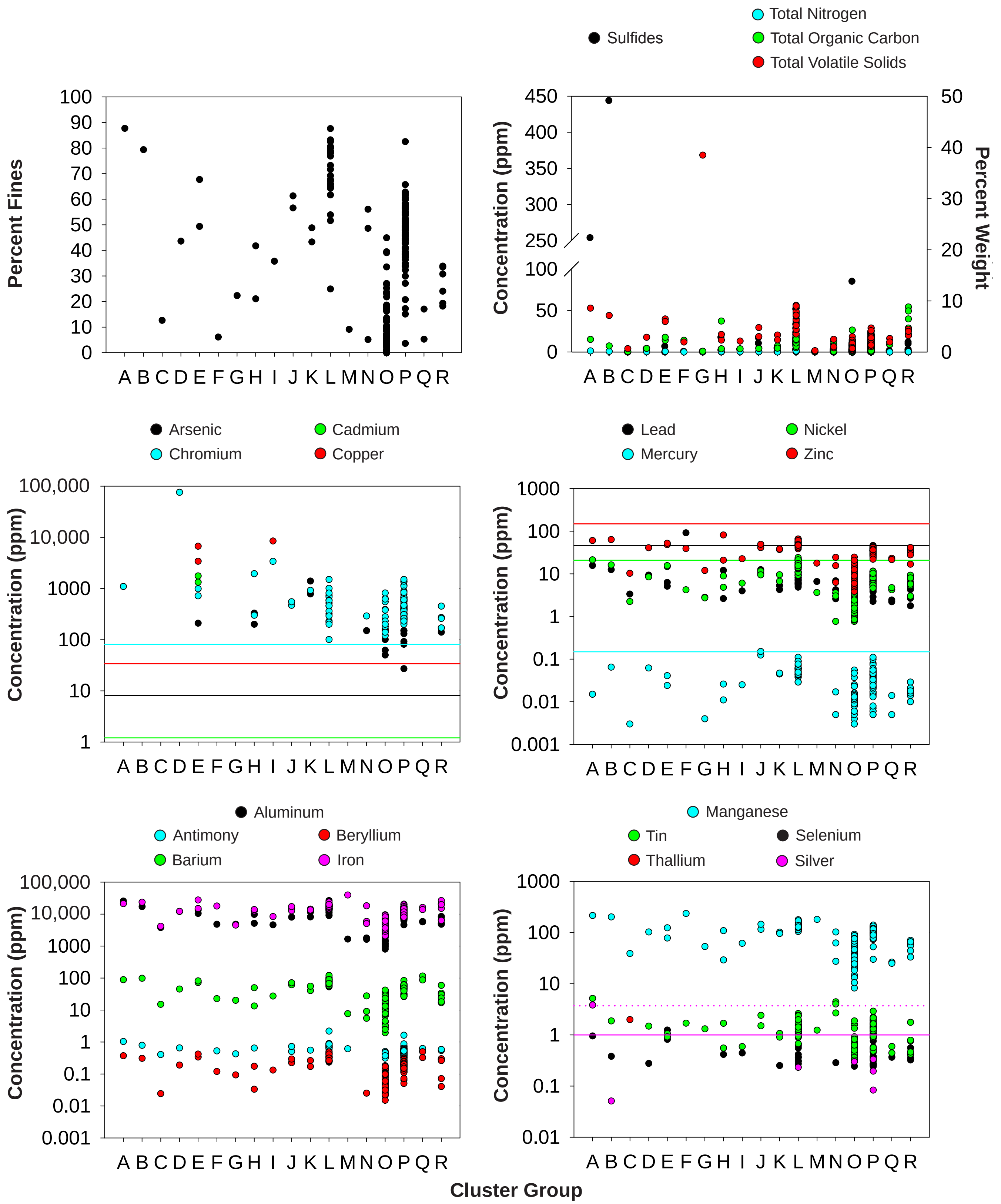
Appendix G.6

Description of sediment chemistry cluster groups A−R (as defined in Figure 8.8). Data are expressed as the average percent or concentration of each parameter for each cluster group. For groups containing more than one site, bold indicates parameters that were considered most defining for each group according to SIMPER analysis.

	Cluster Groups								
	A	B	C	D	E	F	G	H	I
Organic Indicators									
Sulfides (*ppm*)	254.0	444.0	0.2	3.9	3.4	0.7	0.6	10.1	3.3
TN (*% weight*)	0.226	0.142	0.020	0.077	0.160	0.043	0.025	0.060	0.063
TOC (*% weight*)	2.48	1.21	0.13	0.74	2.60	2.31	0.19	**3.37**	0.65
TVS (*% weight*)	8.59	7.15	0.69	2.90	6.24	1.98	38.50	2.92	2.15
Trace Metals (ppm)									
Aluminum	25,300	17,000	3780	12,000	11,900	4750	4770	7410	4560
Antimony	1.03	0.78	0.40	0.65	0	0.52	0.42	0.32	0
Arsenic	9.3	10.5	1.6	4.0	**5.3**	6.4	1.7	4.0	2.2
Barium	87.6	97.6	15.0	44.9	76.3	22.5	19.9	31.2	27.2
Beryllium	0.370	0.308	0.024	0.188	0.377	0.119	0.093	0.103	0.131
Cadmium	0	0.61	0.06	0.12	0.40	0.17	0	0.05	0.13
Chromium	36.1	30.4	9.9	18.0	**47.8**	13.3	8.7	19.9	12.2
Copper	21.3	20.4	1.3	15.7	13.9	10.4	2.0	**15.4**	6.3
Iron	20,900	23,200	4130	12,100	**21,200**	17,700	4480	13,100	8310
Lead	15.70	12.50	3.35	9.36	5.70	91.60	2.83	7.37	4.01
Manganese	215.0	201.0	38.8	102.0	100.0	235.0	53.0	68.5	61.3
Mercury	0.015	0.065	0.003	0.062	0.033	0	0.004	0.019	0.025
Nickel	21.30	16.20	2.24	8.48	15.20	4.22	2.75	6.90	6.05
Selenium	0.95	0.38	0	0.28	1.03	0	0	0.21	0.44
Silver	3.83	0.05	0	0	0	0	0	0	0
Thallium	0	0	1.97	0	0	0	0	0	0
Tin	5.14	1.87	0	1.47	0.98	1.68	1.30	1.11	0.58
Zinc	60.3	64.0	10.3	40.9	50.4	39.0	12.0	**51.4**	22.6
Chlorinated Pesticides (ppt)									
tChlor	0	0	0	0	**1550**	0	0	0	0
tHCH	0	0	0	0	**5050**	0	0	0	8500
tDDT	1100	0	0	75,920	855	0	0	1130	3390
HCB	0	0	0	0	105	0	0	265	0
Total PCB (ppt)	270	0	0	5572	0	0	0	**43,200**	0
Total PAH (ppb)	0	28.6	0	101.0	0	0	0	**82.5**	0

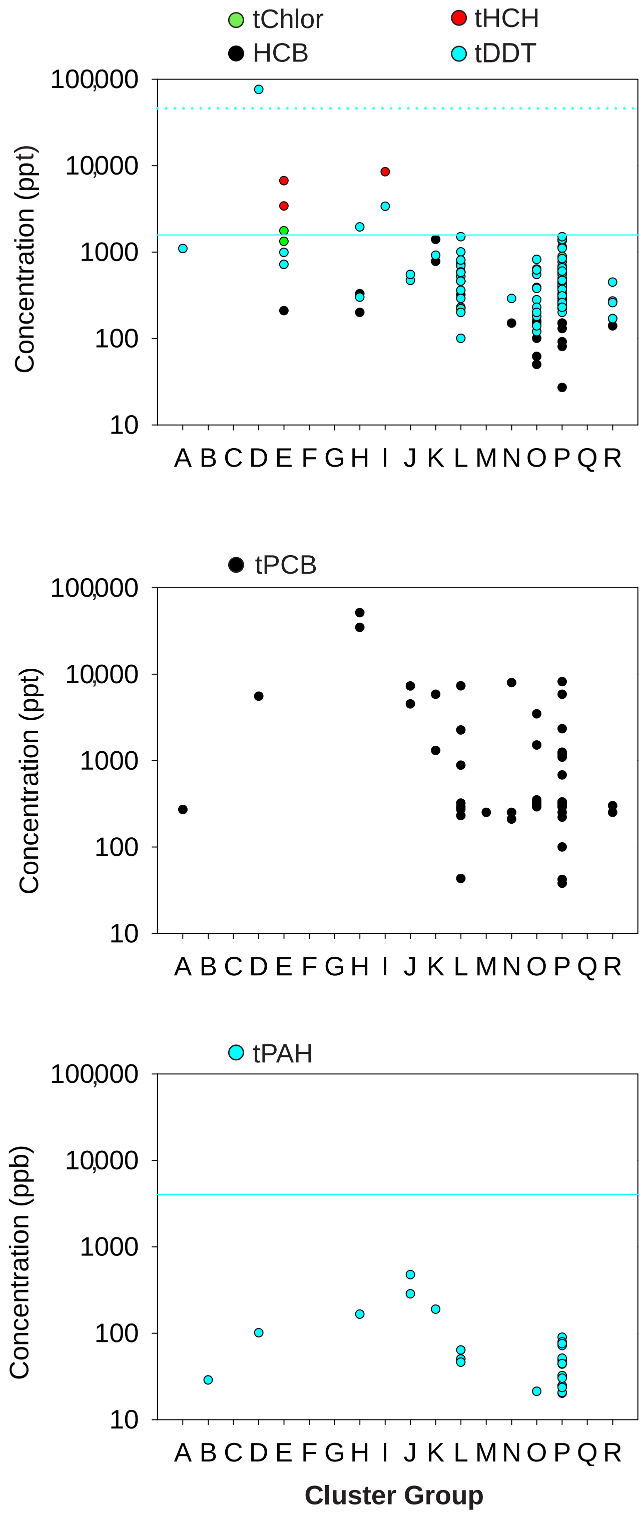
Appendix G.6 *continued*

	Cluster Groups								
	J	K	L	M	N	O	P	Q	R
Organic Indicators									
Sulfides (*ppm*)	13.9	2.6	15.5	0.6	1.5	4.3	6.0	1.6	4.9
TN (*% weight*)	0.079	0.064	0.180	0.013	0.022	0.027	**0.080**	0.038	0.072
TOC (*% weight*)	0.75	0.97	2.20	0.14	1.25	**0.42**	0.81	1.47	**5.97**
TVS (*% weight*)	3.93	2.88	6.55	0.30	1.47	1.04	2.79	2.33	3.80
Trace Metals (ppm)									
Aluminum	**11,300**	9860	15,400	1640	2890	3510	9580	5730	6230
Antimony	0.61	**0.28**	**0.64**	0.61	0	**0.10**	0.52	0.57	**0.19**
Arsenic	4.1	3.1	3.8	0.8	6.8	**2.6**	3.6	**7.2**	**6.3**
Barium	65.8	47.7	78.5	7.6	14.0	19.9	49.6	**101.0**	30.1
Beryllium	0.257	**0.215**	0.314	0	0.008	0.060	0.185	**0.407**	**0.205**
Cadmium	**0.09**	0.12	**0.36**	0	0	**0.04**	**0.13**	0.18	0.10
Chromium	21.3	17.9	29.7	33.7	9.2	8.7	18.7	**32.6**	24.3
Copper	21.1	10.0	**18.5**	4.0	**4.9**	3.0	9.4	3.0	5.4
Iron	14,800	13,800	17,900	39,200	**9620**	5570	13,300	14,800	**17,900**
Lead	11.40	4.79	8.52	6.62	4.58	2.64	6.27	2.33	4.54
Manganese	130.0	98.3	139.0	180.0	**63.8**	46.8	104.0	25.6	54.5
Mercury	**0.138**	0.046	0.057	0	0.007	0.008	**0.036**	0.010	0.018
Nickel	10.50	8.12	17.10	3.64	2.46	2.53	8.27	4.48	6.67
Selenium	0	0.13	**0.83**	0	0.10	0.05	0.12	**0.18**	0.27
Silver	0	0	0.01	0	0	0	0.01	0	0
Thallium	0	0	0	0	0	0	0	0	0
Tin	**1.95**	0.98	1.46	1.23	**3.68**	**0.46**	**1.30**	0.52	0.69
Zinc	45.2	37.7	51.8	17.8	15.5	12.7	34.4	22.4	31.7
Chlorinated Pesticides (ppt)									
tChlor	0	0	0	0	0	0	0	0	0
tHCH	0	0	0	0	0	0	0	0	0
tDDT	510	460	376	0	97	83	438	0	220
HCB	0	**1090**	36	0	50	9	**48**	0	23
Total PCB (ppt)	5920	**3590**	528	250	**2830**	130	421	0	91.7
Total PAH (ppb)	**378.0**	**94.0**	7.3	0	0	0.4	11.9	0	0



Appendix G.7

Particle size and sediment chemistry parameters by cluster group (see Figure 8.7). Solid lines are ERLs, dashed lines are ERMs (see text).



Appendix G.7 *continued*

Appendix H

Supporting Data

2012 Regional Stations

Macrobenthic Communities

Appendix H.1

Mean abundance of the most common species found in cluster groups A−M (defined in Figure 9.4). Bold values indicate taxa that account for 25% of intra-group similarity according to SIMPER analysis.

	Cluster Group												
Taxa	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
NEMATODA	**58.0**		0.1	2.8	1.3	0.3	<0.1				0.2	0.4	
Pareurythoe californica	51.3												
Pisione sp	**44.3**			<0.1	0.5								
Polycirrus sp SD3	33.3			<0.1		0.3					0.2		
Polycirrus californicus	29.7			<0.1	0.3						0.1		
Lumbrineris latreilli	25.3			3.8	2.2	1.3	0.4	0.1		0.3			
Hesionura coineaui difficilis	**21.0**				0.2								
Spio maculata	20.3			0.1	12.0		0.1						
Protodorvillea gracilis	17.3	2.0		0.5	2.2						0.1		
Lumbrinerides platypygos	14.3	2.0		0.9	2.2						0.2		
Branchiostoma californiense	12.0	1.0											
Eumida longicornuta	11.7			0.3	0.3					0.1		0.1	
Micropodarke dubia	8.3			0.9									
Eurydice caudata	5.3			0.2	4.5			0.3				0.1	
Cnemidocarpa rhizopus	4.7			0.1	1.5								
Spiophanes norrisi	4.3	31.0	**9.7**	**59.7**	**54.2**		0.5	0.1			0.1		0.3
Tiburonella viscana	3.7												
Lumbrineris sp GROUP I	2.7		0.2	0.7	0.7	3.7	2.5	**5.5**	1.0	1.5	0.1	0.2	
Mediomastus sp	1.7		3.4	**11.9**	0.3	3.7	5.3	3.5	1.0	**5.1**	3.1	1.9	0.5
Mooreonuphis sp SD1	1.7			1.1	**24.2**						0.1		
Ophelia pulchella	1.3	3.0			0.7								
Mooreonuphis sp	1.3			0.5	**27.3**			0.5		0.1	3.5		0.1
Americhelidium shoemakeri	1.0	2.0	0.8	0.6			<0.1	0.1		0.1	0.3		0.1
Ampelisca cristata cristata	1.0			3.1	3.5		<0.1	0.2					
Micranellum crebricinctum	1.0			0.1	0.2			0.1			6.6		
Simomactra falcata	0.7	4.0	0.2	<0.1	0.5								

Appendix H.1 *continued*

	Cluster Group												
Taxa	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
Phyllodoce hartmanae	0.7	2.0	0.1	**3.8**	0.8	1.0	0.3	0.3		0.1	0.1		
Exogone lourei	0.3		0.7	1.2	0.8	2.3				0.1	4.0	0.1	
Nereis sp A	0.3		0.2	3.5			0.3	0.1	0.2	0.2	0.1	0.1	
Pectinaria californiensis	0.3		0.2	0.2		1.0	0.7	0.6	0.5	1.4	0.2		0.6
Pholoe glabra	0.3			1.9	0.2	0.3	5.9	1.7		0.2	0.9		
Typosyllis sp SD2	0.3			0.6	4.0								
Eusyllis sp SD2	0.3			0.2	3.2			0.1			0.2		
Dendraster excentricus		16.0	0.3										
Aphelochaeta glandaria Cmplx		7.0	0.1	0.7		3.0	0.9	4.7	1.8	3.7	**21.2**	0.4	
Monticellina serratiseta		4.0				0.3		0.2		0.1			0.1
Aphelochaeta sp SD13		4.0					0.1	0.1			0.4		0.1
Chaetozone commonalis		4.0						0.1		1.0			
Scoloplos armiger Cmplx		2.0	0.6	1.8	0.8	1.3	1.9	2.2		0.1	0.6		
Monticellina siblina		2.0	0.3	**15.5**	0.5	5.3	0.8	2.1		1.8	**7.7**	0.1	
Hartmanodes hartmanae		2.0	0.1	1.0			0.1				0.2		
Apoprionospio pygmaea		1.0	5.3	5.7				0.1					
Glycera macrobranchia		1.0	1.1	0.5				0.1					
Amphiuridae		1.0	0.4	1.8	4.3	4.7	4.7	3.5	0.2	0.9	1.8	3.2	0.8
Aphelochaeta monilaris		1.0	0.3	0.2		3.0	1.9	1.6	1.0	3.1	1.3	1.3	0.1
Euphilomedes producta		1.0				0.3	1.1	**13.3**		0.1	0.2		
Owenia collaris			47.6	0.1		0.3	<0.1				0.1		
Gibberosus myersi			8.5	0.3	0.3								
Diastylopsis tenuis			**5.6**	0.2									
Scoletoma tetraura Cmplx			5.3	0.8		1.3	1.0	0.6	1.8	1.9		0.6	0.3
Metharpinia jonesi			4.4										
Anchicolurus occidentalis			4.0										
Tellina modesta			**3.9**	2.8									
Spiophanes duplex			3.7	6.6	1.3	5.3	2.8	0.3		0.3	0.1	0.2	

Appendix H.1 *continued*

	Cluster Group												
Taxa	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
Goniada littorea			2.7	0.1									
Carinoma mutabilis			**2.6**	1.8	1.3		<0.1	0.1		0.1	0.2		
Siliqua lucida			2.2	0.3									
Glycinde armigera			1.2	**2.9**	0.2		0.7	1.1	1.0	0.8	0.5	1.0	
Euphilomedes carcharodonta			0.9	1.3	1.0	7.0	0.3	7.5			0.3		
Chaetozone sp SD5			0.8	3.1	0.3			0.1		0.1	**11.9**		
Paradiopatra parva			0.7	0.2		2.0	1.1	2.0	0.2	2.9	0.6	0.2	
Spiochaetopterus costarum Cmplx			0.6	8.0	1.2	0.7	0.3	0.6	0.5	0.7	0.2	0.1	
Amphiodia digitata			0.4	0.5		0.7	0.1	1.5		0.9	4.3	0.4	0.3
Glycera oxycephala			0.3	1.3	5.0					0.1	1.6		
Amphiodia sp			0.3	0.8	0.2	1.0	**8.0**	7.4	0.5	0.5	1.5		
Parvilucina tenuisculpta			0.1	0.3	0.2	0.7	0.4	0.8	0.3	**3.5**	2.2	0.8	0.1
Dougaloplus amphacanthus			0.1				0.1	0.5	0.7	2.5	0.6	0.2	
Ampelisca brevisimulata			0.1	5.8	0.3	1.3	1.5	1.3	0.3	0.5	0.2		
Spiophanes berkeleyorum			0.1	4.6	0.8	2.7	6.3	2.5	0.2	1.0	0.2	0.6	
Rochefortia tumida			0.1	0.8	0.5	4.3	4.1	0.3		0.1			0.1
Ophiuroidea			0.1	0.3		1.3	<0.1	0.1			0.3	0.4	0.5
Polyschides quadrifissatus			0.1	0.2	3.5		2.5	1.5		0.2			
Nephtys ferruginea			0.1	<0.1		0.3	1.2	1.6	0.8	0.9	0.9	0.3	
Mooreonuphis nebulosa				9.3		2.7	0.2	0.1					
Prionospio (Prionospio) jubata				**7.8**	2.5	6.7	3.0	**10.7**	0.7	1.4	3.2	0.2	
Hemilamprops californicus				2.5	1.5	0.3	0.2	0.1					
Lysippe sp A				2.0	0.8	2.3	0.7	3.1		2.1	2.8		
Aphelochaeta sp LA1				1.7		5.0	0.8	0.9	0.5	1.3	1.9	0.1	
Paraprionospio alata				1.4		1.0	1.7	**5.1**	**3.7**	**4.3**	1.5	2.8	0.5
Leptochelia dubia Cmplx				1.2	1.2	**10.0**	0.6	1.7		0.3	2.9		
Petaloclymene pacifica				1.2		0.7	3.5	0.7	1.5	2.9		0.1	
Ampelisca careyi				1.0		**2.3**	1.9	3.5		1.0	3.0		

Appendix H.1 *continued*

Taxa	Cluster Group A	B	C	D	E	F	G	H	I	J	K	L	M
Chaetozone sp				0.9	0.3	1.7	<0.1	0.6		0.9	6.5	0.2	
Polycirrus sp A				0.8	3.2	1.7	1.5	6.8		1.4	1.2	0.2	
Photis californica				0.7	1.0	**52.7**	1.1						
Aricidea (Acmira) simplex				0.7	0.8	**8.7**	1.2	1.9		0.4	0.2	0.1	
Ampelisca cf brevisimulata				0.7		**2.0**	0.6	0.6					
Ophiuroconis bispinosa				0.6	7.8	2.3	0.8				0.1		
Amphiodia urtica				0.6	0.2	1.3	**74.6**	**22.2**	0.2	2.0			
Sternaspis affinis				0.5		2.3	4.8	**5.4**		1.8	0.1		
Byblis millsi				0.3	1.2	**4.0**	1.0	0.4		0.1	0.1		
Prionospio (Prionospio) dubia				0.2	0.3	**6.7**	4.4	4.7		1.0	1.0		
Stereobalanus sp				0.2	0.2	1.7	**4.5**	0.7		0.1			
Chaetozone hartmanae				0.1		**9.3**	1.7	**12.1**		0.9	1.2		
Maldane sarsi				0.1		**3.0**	1.7	1.9	4.7	1.7		**11.2**	8.6
Terebellides californica				0.1		2.0	2.9	1.5	1.0	5.9			
Tubulanidae sp B				0.1			<0.1						0.4
Lanassa venusta venusta				<0.1	12.0		0.2	0.3	0.2	0.7	0.2		
Chloeia pinnata				<0.1	0.2	**11.3**	0.2	**10.1**		0.1	4.2	1.1	0.4
Glycera nana				<0.1		1.7	1.5	2.3	0.8	2.3	0.7	0.6	0.4
Chiridota sp				<0.1		0.7	1.4	0.9	0.7	0.2		1.3	0.1
Spiophanes kimballi						23.7	1.4	3.7	**5.3**	**11.5**	0.9	1.9	
Ampelisca pacifica						6.0	2.9	3.1	0.3	0.8	0.5	0.2	
Axinopsida serricata						5.0	14.5	2.8	0.7	**7.6**	1.2	0.2	
Foxiphalus similis						4.0	0.8	0.9					
Ennucula tenuis						1.7	4.7	3.9	0.2	1.0	0.1	2.2	2.0
Amphioplus strongyloplax						1.7	0.0		0.8	0.1		1.8	0.3
Tellina carpenteri						1.3	0.4	3.1	3.8	**8.0**	**8.2**	3.4	0.3
Adontorhina cyclia						0.7	2.8	0.9	1.5	3.1	0.3	1.7	
Eyakia robusta						0.7	1.1	3.3		0.3	0.3		

Appendix H.1 *continued*

Taxa	Cluster Group												
	A	B	C	D	E	F	G	H	I	J	K	L	M
Travisia brevis						0.3	**6.0**	2.5		0.1			
Eclysippe trilobata						0.3	0.2	2.3		0.1	0.6		8.9
Compressidens stearnsii						0.3	0.1	1.2	2.7	0.7	0.3	**4.8**	0.6
Rhepoxynius bicuspidatus							**4.7**	3.3		0.7			
Heterophoxus ellisi							0.3	0.3	1.5	1.5		0.6	0.1
Macoma carlottensis							<0.1	0.3	1.5	0.7		**11.7**	0.6
Huxleyia munita								0.1			5.0		
Onuphis iridescens								0.1	1.2	0.5		0.6	0.1
Malmgreniella scriptoria								0.1		0.1			0.4
Fauveliopsis glabra								0.1				6.3	3.0
Melinna heterodonta									**6.0**	2.5	0.2	0.4	0.1
Prionospio (Prionospio) ehlersi									0.5	0.1		3.3	0.3
Limifossor fratula									0.2	0.1		0.9	0.5
Leitoscoloplos sp A									0.2	0.1		1.9	0.4
Nuculana conceptionis												3.7	**5.5**
Yoldiella nana													**9.6**
Pherusa sp SD2													2.0
Amphissa bicolor													1.5

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