THE CITY OF SAN DIEGO

Point Loma Ocean Outfall

Annual Receiving Waters Monitoring & Assessment Report

2014

City of San Diego Ocean Monitoring Program

Environmental Monitoring & Technical Services Division

Public Utilities Department

THE CITY OF SAN DIEGO

June 30, 2015

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

Attention: POTW Compliance Unit

Dear Mr. Gibson:

Enclosed is the 2014 Annual Receiving Waters Monitoring and Assessment Report for the Point Loma Ocean Outfall as required per Order No. R9-2009-0001, NPDES Permit No. CA0107409. This assessment report contains data summaries, analyses and interpretations of all portions of the ocean monitoring program conducted during calendar year 2014, including oceanographic conditions, water quality, sediment conditions, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues.

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

Sincerely,

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

TDS/akl

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

DIVERSITY

Point Loma Ocean Outfall

Annual Receiving Waters Monitoring & Assessment Report, 2014

(Order No. R9-2009-0001; NPDES No. CA0107409)

Prepared by:

City of San Diego Ocean Monitoring Program

Environmental Monitoring & Technical Services Division, Public Utilities Department

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June 2015

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

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Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
ANOSIM	Analysis of Similarity
APHA	American Public Health Association
APT	Advanced Primary Treatment
AUV	Automated Underwater Vehicle
BACIP	Before-After-Control-Impact-Paired
BEST	Bio-Env + Stepwise Tests
BIO-ENV	Biological/Environmental
BOD	Biochemical Oxygen Demand
BRI	Benthic Response Index
CalCOFI	California Cooperative Fisheries Investigation
CCS	California Current System
CDIP	Coastal Data Information Program
CDOM	Colored Dissolved Organic Matter
CDPH	California Department of Public Health
CFU	Colony Forming Units
cm	centimeter
CSDMML	City of San Diego Marine Microbiology Laboratory
CTD	Conductivity, Temperature, Depth instrument
DDT	Dichlorodiphenyltrichloroethane
df	degrees of freedom
DO	Dissolved Oxygen
ELAP	Environmental Laboratory Accreditation Program
EMAP	Environmental Monitoring and Assessment Program
EMTS	Environmental Monitoring and Technical Services
ENSO	El Niño Southern Oscillation
ERL	Effects Range Low
ERM	Effects Range 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 Pollutant Discharge Elimination System
NPGO	North Pacific Gyre Oscillation
NWS	National Weather Service
O&G	Oil and Grease
OCSD	Orange County Sanitation District
OEHHA	California Office of Environmental Health Hazard Assessment
OI	Ocean Imaging
OOR	Out-of-range
p	probability
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PDO	Pacific Decadal Oscillation
pH	Acidity/Alkalinity value
PLOO	Point Loma Ocean Outfall
PLWTP	Point Loma Wastewater Treatment Plant
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PRIMER	Plymouth Routines in Multivariate Ecological Research
psu	practical salinity units
r	ANOSIM test value that examines 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
SCCWRP	Southern California Coastal Water Research 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 Point Loma Ocean Outfall (PLOO). The data collected are used to determine compliance with receiving water conditions as specified in the National Pollutant Discharge Elimination System (NPDES) regulatory permit for the City's Point Loma Wastewater Treatment Plant (PLWTP).

The primary objectives of ocean monitoring for the Point Loma outfall region are to:

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

Overall, the state of San Diego's coastal waters in 2014 was in good condition based on the comprehensive scientific assessment of the Point Loma outfall monitoring region. This report details the methods, scope, results and evaluation of the ocean monitoring program.

Regular (core) monitoring sites that are sampled on a weekly, quarterly or semiannual basis are arranged in a grid surrounding the PLOO, which terminates approximately 7.2 km offshore of the PLWTP at a discharge depth of about 100 m. Monitoring at the shoreline stations extends from Mission Beach southward to the tip of Point Loma, while regular monitoring in the Point Loma Kelp Forest and further offshore occurs in waters overlying the continental shelf at depths of about 9 to 116 m. In addition to the above core monitoring, a broader geographic survey of benthic conditions is typically 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 Point Loma region is also available from a baseline study conducted by the City over a 2½ year period prior to wastewater discharge.

Details of the results and conclusions of all receiving waters monitoring activities conducted from January through December 2014 are presented and discussed in the following seven chapters. Chapter 1 represents a general introduction and overview of the City's ocean monitoring program, while chapters 2–7 include results of all monitoring at the regular core stations conducted during the year. In Chapter 2, data characterizing oceanographic conditions and water mass transport for the region are evaluated. Chapter 3 presents the results of shoreline and offshore water quality monitoring, including measurements of fecal indicator bacteria and oceanographic data to evaluate potential movement and dispersal of the plume and assess compliance with water contact standards defined in the Ocean Plan. Assessments of benthic sediment quality and the status of macrobenthic invertebrate communities are presented in Chapters 4 and 5, respectively. Chapter 6 presents the results of trawling activities designed to monitor communities of bottom dwelling (demersal) fishes and megabenthic invertebrates. Bioaccumulation assessments to measure contaminant loads in the tissues of local fishes are presented in Chapter 7. In addition to the above activities, the City and International Boundary and Water Commission, U.S. Section (USIBWC) support other projects relevant to assessing the quality and movement of ocean waters in the region. One such project involves satellite imaging of the San Diego/Tijuana coastal region, of which the 2014 results are incorporated into Chapters 2 and 3. A summary of the main findings for each of the above components is included below.

Coastal Oceanographic Conditions

Sea surface temperatures off Point Loma in 2014 were cooler than the long-term averages during the winter and spring, while waters were warmer than normal during the summer and fall. Ocean conditions indicative of coastal upwelling were most evident during the February winter survey, although thermistor data indicated that periods of upwelling may have occurred episodically through mid-August. As is typical for the Point Loma outfall region, maximum stratification or layering of the water column occurred during mid-summer, while waters were more mixed during the winter. Water clarity (% transmissivity) during the year was within historical ranges for the region, with low values usually being associated with turbidity plumes near the shore or kelp beds, re-suspension of bottom sediments due to waves or storm activity, or the presence of phytoplankton blooms. Ocean currents off Point Loma flowed along a predominantly north-south to northwest-southeast axis during most of the year, although these measurements excluded the influence of tidal currents and internal waves. Overall, ocean conditions during the year were consistent with well documented patterns for southern California and northern Baja California. These findings suggest that natural factors such as upwelling of deep ocean waters and changes due to climatic events such as El Niño/La Niña oscillations continue to explain most of the temporal and spatial variability observed in the coastal waters off southern San Diego.

Water Quality Compliance and Plume Dispersion

Water quality conditions were excellent in the Point Loma region during 2014. Overall compliance with the Ocean Plan's single sample maximum and geometric mean standards for fecal indicator bacteria (FIB) was >99% for the shore, kelp bed and other offshore stations located within State waters. Compliance was also very high with Ocean Plan objectives for natural light (i.e., water clarity or transmissivity), pH, and dissolved oxygen in Point Loma coastal waters where the plume is likely to occur (see below).

There was no evidence that wastewater discharged to the ocean via the PLOO reached the shore or nearshore kelp forests during 2014. These results are consistent with satellite imagery observations, as well as findings from a recent plume behavior study that showed the PLOO waste field is highly unlikely to surface and that plume dispersion is typically directed away from the Point Loma kelp beds. Elevated FIB densities were detected at six shore stations (11 samples) and at one kelp station (1 sample) during the year. FIB densities were also generally low at all offshore stations during each quarterly survey, with only 2% (n=11) of the samples from these stations having elevated *Enterococcus* levels. All 11 of these samples were collected from depths of 60 m or deeper from stations located along the 80 or 100-m depth contours. The low rate of bacterial contamination near the outfall may be due to chlorination of PLWTP effluent that has occurred since late 2008. Because bacteriological data may no longer be a good indicator of plume presence in the region, other oceanographic measurements such as high colored dissolved organic matter (CDOM) values may be more useful detecting and tracking the plume. For example, waters with a CDOM-characteristic plume signature were detected about 17% of the time off Point Loma, with most detections occurring beyond State waters at depths below 40 m. Overall, the results from 2014 are consistent with other data that indicate the PLOO plume remains restricted to relatively deep, offshore waters throughout the year.

Sediment Conditions

Ocean sediments surrounding the PLOO in 2014 were composed primarily of fine sands and finer particles, which is similar to patterns seen in previous years. There were no changes in the amount of fine sediments that could be attributed to wastewater discharge, nor was there any other apparent relationship between particle size distributions and proximity to the outfall. Instead, most differences between monitoring sites are probably due to factors such as offshore disposal of dredged sediments, deposition of detrital materials, presence of residual construction materials near the outfall, and the geological history and origins of different sediment types.

As in previous years, sediment quality was very high in 2014, with overall contaminant loads remaining relatively low compared to available thresholds and other southern California coastal areas. The potential for environmental degradation by various contaminants was evaluated using the effects-range low (ERL) and effects-range median (ERM) sediment quality guidelines when available. The only exceedances of these thresholds in 2014 were for total DDT, which was found in excess of its ERL at two northern farfield stations during July. Additionally, there was no evidence of contaminant accumulation associated with wastewater discharge. Concentrations of the various organic loading indicators, trace metals, pesticides, PCBs and PAHs varied widely throughout the region, and there were no patterns that could be attributed to the outfall or other point sources. Instead, the highest concentrations of several contaminants occurred in sediments collected from the northern-most or southern-most stations. The occurrence of elevated levels of pesticides, PCBs and PAHs south of the outfall is consistent with other studies that have suggested that sediment contamination in the area is probably related to short dumps of dredged materials destined originally for the USEPA designated LA-5 disposal site. The only evidence of possible organic enrichment in Point Loma sediments was slightly higher sulfide and BOD levels at a few stations located within 200 m of the zone of initial dilution (ZID).

Macrobenthic Communities

Benthic macrofaunal communities surrounding the PLOO were similar in 2014 to previous years. These communities remained dominated by polychaete worm and ophiuroid (brittle star) assemblages that occur in similar habitats throughout the Southern California Bight. Specifically, the brittle star *Amphiodia urtica* was the most abundant species off Point Loma, although its populations have shown a region-wide decrease since monitoring began 24 years ago. The spionid polychaete *Prionospio (Prionospio) dubia* was the most widespread benthic invertebrate. There have been some minor changes in macrofaunal assemblages located within ~200 m of the discharge zone that would be expected near large ocean outfalls. For example, some descriptors of benthic community structure (e.g., infaunal abundance, species richness) or populations of indicator species (e.g., *A. urtica*) have shown changes over time between reference areas and sites located nearest the outfall. Despite these changes, however, benthic response index (BRI) results for 95% of the samples remained characteristic of undisturbed habitats. Only the BRI values for two grab samples collected at near-ZID station E14 indicated a possible minor deviation from reference condition. In addition, changes documented during the year were similar in magnitude to those reported previously for the region and elsewhere off southern California. Overall, macrofaunal assemblages off Point Loma remain similar to natural indigenous communities that are characteristic of similar habitats on the southern California continental shelf. There was no evidence that wastewater discharge has caused degradation of the marine benthos at any of the monitoring stations.

Demersal Fishes and Megabenthic Invertebrates

Comparisons of the 2014 trawl survey results with previous surveys indicate that demersal fish and megabenthic invertebrate communities in the region remain unaffected by wastewater discharge. Although highly variable, patterns in the abundance and distribution of individual species were similar at stations located near the outfall and farther away. Pacific Sanddab and California Lizardfish dominated Point Loma fish assemblages during

2014, with both species occurring at all stations and each accounting for about 34% of the year's catch. Other common species off Point Loma included Bigmouth Sole, California Skate, California Tonguefish, Dover Sole, English Sole, Halfbanded Rockfish, Hornyhead Turbot, Pink Seaperch, Plainfin Midshipman, Shortspine Combfish, Stripetail Rockfish, and Yellowchin Sculpin. Trawl-caught invertebrate assemblages were dominated by the sea urchin *Lytechinus pictus*, which also occurred in all trawls and accounted for 76% of all invertebrates captured. The sea star *Luidia foliolata* and the brittle star *Ophiura luetkenii* were also collected at all stations, although usually in fairly low numbers at most sites. Other common, but far less abundant invertebrates included the sea urchin *Strongylocentrotus fragilis*, the sea stars *Astropecten californicus* and *Luidia asthenosoma*, the sea cucumber *Parastichopus californicus*, the opisthobranch *Pleurobranchaea californica*, the cephalopod *Octopus rubescens*, the sea pen *Acanthoptilum* sp, and the cymothoid isopod *Elthusa vulgaris*. Finally, external examinations of the fish captured during the year indicated that local fish populations remain healthy, with <1% of all fish having external parasites or any evidence of disease.

Contaminants in Fish Tissues

The accumulation of chemical contaminants in local fishes was assessed by analyzing liver tissues from trawl-caught flatfish and muscle tissues from rockfish captured by hook and line. Results from both analyses indicated no evidence that contaminant loads in Point Loma fishes were affected by wastewater discharge in 2014. Although several metals, pesticides, and PCB congeners were detected in both tissue types, these contaminants occurred in fishes distributed throughout the region with no patterns that could be attributed to wastewater discharge. While several rockfish muscle samples exceeded state or international standards for a few contaminants, all samples were within federal (USFDA) action limits. Furthermore, concentrations of all contaminants were within ranges reported previously for southern California fishes. The occurrence of some 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 marine fishes include differences in physiology and life history traits of various species. In addition, exposure 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 PLOO, as there are many other potential point and non-point sources of contamination.

Conclusions

The findings and conclusions for the ocean monitoring efforts conducted for the Point Loma outfall region during calendar year 2014 were consistent with previous years. Overall, there were few changes to local receiving waters, benthic sediments, or marine invertebrate and fish communities that could be attributed to human activities. Coastal water quality conditions and compliance with Ocean Plan standards were excellent, and there was no evidence that the wastewater plume from the outfall surfaced or was transported inshore to recreational waters along the shore or in the Point Loma kelp beds. There were also no clear outfall related patterns in sediment contaminant distributions, or in differences between invertebrate and fish assemblages at the different monitoring sites. The lack of physical anomalies or other symptoms of disease or stress in local fishes, as well as the low level of contaminants in fish tissues, was also indicative of a healthy marine environment. Finally, benthic habitats in the Point Loma region remain in good condition similar to much of the southern California continental shelf.

Chapter 1
General Introduction

Chapter 1. General Introduction

The City of San Diego (City) Point Loma Wastewater Treatment Plant (PLWTP) discharges advanced primary treated effluent to the Pacific Ocean through the Point Loma Ocean Outfall (PLOO) in accordance with requirements set forth in Order No. R9-2009-0001, National Pollutant Discharge Elimination System (NPDES) Permit No. CA0107409. This Order was adopted by the San Diego Regional Water Quality Control Board (Regional Water Board) on June 10, 2009, became effective August 1, 2010, and expires July 31, 2015. The Monitoring and Reporting Program (MRP) in this order specifies the requirements for monitoring ambient receiving waters conditions off Point Loma, San Diego, including field sampling design and frequency, compliance criteria, types of laboratory analyses, and data analysis and reporting guidelines, although some monitoring requirements were modified by the Regional Water Board for calendar years 2013 and 2014 as part of a resource exchange agreement to allow City participation in the Bight'13 regional monitoring program.

The main objectives of the City's Ocean Monitoring Program for the PLOO region are to: 1) provide data that satisfy NPDES permit requirements, 2) demonstrate compliance with California Ocean Plan (Ocean Plan) provisions and water contact standards, 3) detect dispersion and transport of the waste field (plume), and 4) identify any environmental changes that may be associated with wastewater discharge via the outfall.

Background

The City began operation of the PLWTP and original ocean outfall off Point Loma in 1963, at which time treated effluent (wastewater) was discharged approximately 3.9 km offshore at a depth of about 60 m. From 1963 to 1985, the plant operated as a primary treatment facility, removing approximately 60% of the total suspended solids (TSS) by gravity separation. The City began upgrading the process to advanced primary treatment (APT) in mid-1985, with full APT status being achieved by July 1986. This improvement involved the addition of chemical coagulation to the treatment process which increased the removal of TSS to about 75%. Since 1986, treatment has been further enhanced with the addition of several more sedimentation basins, expanded aerated grit removal, and refinements in chemical treatment. These enhancements have further reduced mass emissions from the plant. TSS removals are now consistently greater than the 80% required by the permit. Finally, the City began testing disinfection of PLWTP effluent using a sodium hypochlorite solution in September 2008 following adoption of Addendum No. 2 to previous Order No. R9-2002-0025. Partial chlorination continued throughout 2014.

The physical structure of the PLOO was modified in the early 1990s when it was extended approximately 3.3 km farther offshore to prevent intrusion of the wastewater plume into nearshore waters and to increase compliance with Ocean Plan standards for water-contact sports areas. Discharge from the original 60-m terminus was discontinued in November 1993 following completion of the outfall extension. The present deepwater outfall extends approximately 7.2 km offshore to a depth of about 94 m, where the main pipeline splits into a Y-shaped multiport diffuser system. The two diffuser legs extend an additional 762 m to the north and south, each terminating at a depth of about 98 m.

The average daily flow of effluent through the PLOO in 2014 was 139.2 million gallons per day (mgd), ranging from a low of about 124 mgd on November 28, 2014 to a high of about 181 mgd on March 1, 2014. Overall, this represents about a 3.2% decrease from the average flow rate in 2013. TSS removal averaged about 92% in 2014, while total mass emissions for the year were approximately 5,204 metric tons (see City of San Diego 2015a).

Receiving Waters Monitoring

The core monitoring area off Point Loma extends from stations along the shore seaward to a depth of about 116 m and encompasses an area of approximately 184 km^2 (Figure 1.1). A total of 82 core monitoring sites surrounding the outfall are sampled for various parameters in accordance with a prescribed schedule as specified in the MRP. A summary of the results for quality assurance procedures performed in 2014 in support of these requirements can be found in City of San Diego (2015c). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the Regional Water Board and U.S. Environmental Protection Agency (USEPA) throughout the year are available online at the City's website (www.sandiego.gov/mwwd/environment/oceanmonitor.shtml).

Prior to 1994, the City conducted an extensive ocean monitoring program off Point Loma surrounding the original 60-m discharge site. This program was subsequently expanded with the construction and operation of the deeper outfall. Data from the last year of regular monitoring near the original discharge site are presented in City of San Diego (1995a), while the results of a three-year "recovery study" are summarized in City of San Diego (1998). From 1991 through 1993, the City also conducted a "pre-discharge" study in order to collect baseline data prior to wastewater discharge into these deeper waters (City of San Diego 1995a, b). Results of NPDES mandated monitoring for the extended PLOO from 1994 to 2013 are available in previous annual receiving waters monitoring reports (e.g., City of San Diego 2014). In addition, the City has conducted annual region-wide surveys off the coast of San Diego since 1994 either as part of regular South Bay outfall monitoring requirements (e.g., City of San Diego 1999, 2015c) or as part of larger, multi-agency surveys of the entire Southern California Bight (SCB). The latter include the 1994 Southern California Bight Pilot Project (Allen et al. 1998, Bergen et al. 1998, 2001, Schiff and Gossett 1998) and subsequent Bight'98, Bight'03, Bight'08, and Bight'13 programs in 1998, 2003, 2008, and 2013 respectively (Allen et al. 2002, 2007, 2011, Noblet et al. 2002, Ranasinghe et al. 2003, 2007, 2012, Schiff et al. 2006, 2011, Bight'13 CIA 2013). These large-scale surveys are useful for characterizing the ecological health of diverse coastal areas and in distinguishing reference sites from those impacted by wastewater or storm water discharges, urban runoff, or other sources of contamination. In addition to the above activities, the City participates as a member of the Region Nine Kelp Survey Consortium to fund aerial surveys of all the major kelp beds in San Diego and Orange Counties (e.g., MBC Applied Environmental Sciences 2014).

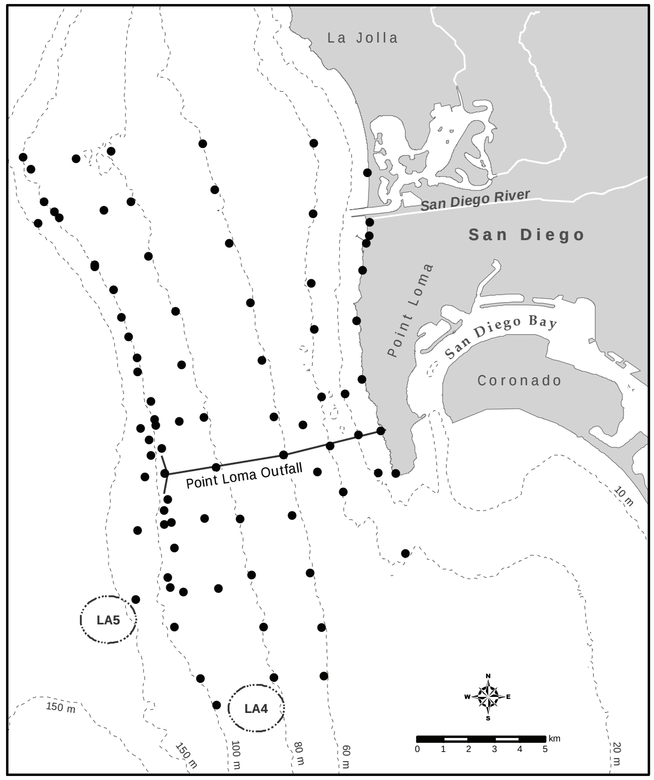

Figure 1.1
Receiving waters monitoring stations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Enhanced Monitoring

The City has also been actively working on, collaborating with other researchers or agencies, or supporting a large number of important special projects or enhanced ocean monitoring studies over the past 10 years or more. Many of these projects were identified as the result a scientific review of the City's Ocean Monitoring Program and environmental monitoring needs for the region that was conducted by a team of scientists from the Scripps Institution of Oceanography (SIO) and several other institutions (SIO 2004), as well as in consultation with staff from the Regional Water Board, USEPA, Southern California Coastal Water Research Project (SCCWRP), and others. Examples of special projects or enhanced monitoring efforts that have been recently completed, are presently underway, or that are just being initiated include:

Point Loma Ocean Outfall Plume Behavior Study
This project was designed to determine the characteristic fates of the PLOO wastewater plume in the coastal waters off Point Loma using a combination of observational and modeling approaches. The study was successfully completed in 2012 and resulted in several important conclusions and recommendations (see Rogowski et al. 2012a, b, 2013, and Appendix F in City of San Diego 2015d). The City is currently in the process of implementing the major recommendations of this study (see next project below).

Real-Time Observing Systems for the Point Loma and South Bay Ocean Outfalls
This project addresses the primary recommendation of the Point Loma Ocean Outfall plume behavior study described above, as well as similar study completed several years ago for the South Bay outfall region. The study involves design and installation of a real-time ocean observing system that will span both outfall regions. The project is expected to begin in late 2015 with installation of the mooring system scheduled to be completed during 2016. This project is being conducted in partnership between the City and the Ocean Time Series Group of SIO who presently operate a similar mooring system off Del Mar. The project is expected to significantly enhance the City's environmental monitoring capabilities in order to address current and emerging issues relevant to the health of San Diego's coastal waters, including plume dispersion, subsurface current patterns, ocean acidification, hypoxia, nutrient sources, and coastal upwelling.

Deep Benthic Habitat Assessment Study:
This project represents an ongoing, long-term project designed to assess the condition of deeper (>200 m) continental slope habitats off San Diego. A summary report of the current status of this project for data collected from 2003 through 2013 is included in Appendix C.5 of City of San Diego (2015d).

San Diego Sediment Mapping Study
This represents a two-phased project conducted in collaboration with SCCWRP in which sampling was conducted in 2004 for Phase 1 and in 2012 for Phase 2. Phase 1 was designed to estimate spatial variance in sediment quality and macrobenthic community condition over an area spanning both the PLOO and SBOO monitoring regions (>400 km^2). In contrast, the goal of Phase 2 was to utilize an optimal resolution (spacing) of sample sites derived in part from Phase 1 results to generate a completed map of sediment chemistry conditions within a more restricted 30 km^2 area surrounding the PLOO. The findings for Phase 1 and the preliminary results from Phase 2 are included as a summary report in Appendix C.4 of City of San Diego (2015d).

Remote Sensing of the San Diego/Tijuana Coastal Region
This project represents a long-term effort funded jointly by the City and the International Boundary and Water Commission since 2002 to utilize satellite and aerial imagery observations to better understand regional water quality conditions off San Diego. The project is conducted by Ocean Imaging (Solana Beach, CA), and is focused on detecting and tracking the dispersion of wastewater plumes from local ocean outfalls and nearshore sediment plumes originating from storm water runoff or outflows from local bays and rivers. Results from this project for calendar year 2014 are available in Svejkovsky (2015), while a comprehensive multi-year report and peer-reviewed publication are expected to be completed in 2016.

San Diego Kelp Forest Ecosystem Monitoring Project
This project represents continuation of a long-term commitment by the City to support this important research conducted by the Scripps Intuition of Oceanography. Overall, this work is essential to assessing the health of San Diego's kelp forests and to monitoring the effects of wastewater discharge on

the local coastal ecosystem relative to other factors. The final project report for the most recent 4-year agreement (2010–2014) with SIO is available in Parnell et al. (2014), while work on a new 5-year agreement through June 2019 is currently underway.

This report presents the results of all regular core receiving waters monitoring activities conducted off Point Loma from January through December 2014. The major components of the monitoring program are covered in the following six chapters: Coastal Oceanographic Conditions, Water Quality Compliance and Plume Dispersion, Sediment Conditions, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, and Bioaccumulation of Contaminants in Fish Tissues.

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

In nearshore coastal waters of the Southern California Bight (SCB) such as the region surrounding the PLOO, ocean conditions are influenced by multiple factors. These include: (1) large scale climate processes such as the El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and North Pacific Gyre Oscillation (NPGO) that can affect long-term trends (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, NOAA/NWS 2015); (2) the California Current System coupled with local gyres that transport distinct water masses into and out of the SCB (Lynn and Simpson 1987, Leising et al. 2014); (3) seasonal changes in local weather patterns (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Seasonality is responsible for the main stratification patterns observed in the coastal waters off San Diego and the rest of southern California (Terrill et al. 2009, Rogowski et al. 2012a, b, 2013). Relatively warm waters and a more stratified water column are typically present during the dry season from May to September while cooler waters coupled with greater mixing and weaker stratification characterize ocean conditions during the wet season from October through April (e.g., City of San Diego 2014a). For example, winter storms bring higher winds, rain, and waves that typically result in a well-mixed, non-stratified water column (Jackson 1986). Surface waters begin to warm by late spring and are then subjected to increased surface evaporation. Once the water column becomes stratified, minimal mixing conditions typically remain throughout the summer and into early fall. Toward the end of the year, surface water cooling along with increased storm frequency returns the water column to well-mixed conditions.

Understanding changes in oceanographic conditions due to natural processes such as seasonal patterns is important since they can affect the transport and distribution of wastewater, storm water, and other types of plumes. In the Point Loma outfall region these include sediment or turbidity plumes associated with outflows from local bays, major rivers, lagoons and estuaries, discharges from storm drains or other point sources, surface runoff from local watersheds, seasonal upwelling, and variable ocean currents or eddies. For example, outflows from the San Diego River, San Diego Bay, and the Tijuana River, which are fed by 1140 km^2, 1165 km^2, and 4483 km^2 of watersheds, respectively (Project Clean Water 2012), can contribute significantly to patterns of nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009, Svejkovsky 2010, 2015).

This chapter presents analysis and interpretation of the oceanographic monitoring data collected during calendar year 2014 for the coastal waters surrounding the PLOO. The primary goals are to: (1) summarize coastal oceanographic conditions in the region; (2) identify natural and anthropogenic sources of variability; (3) evaluate local conditions off Point Loma within the context of regional climate processes. Data from current meters and temperature sensor (thermistor) strings are included to examine the dynamics and strength of the thermocline and ocean currents in the area (see Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010, Rogowski et al. 2012a, b, 2013). Additionally, results of remote sensing observations (e.g., satellite imagery) are combined with measurements of physical oceanographic parameters to provide further insight on the horizontal transport of surface waters in the region (Pickard and Emery 1990, Svejkovsky 2010, 2015). The results reported herein are also referred to in subsequent chapters to explain patterns of fecal indicator bacteria distributions and plume dispersion (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

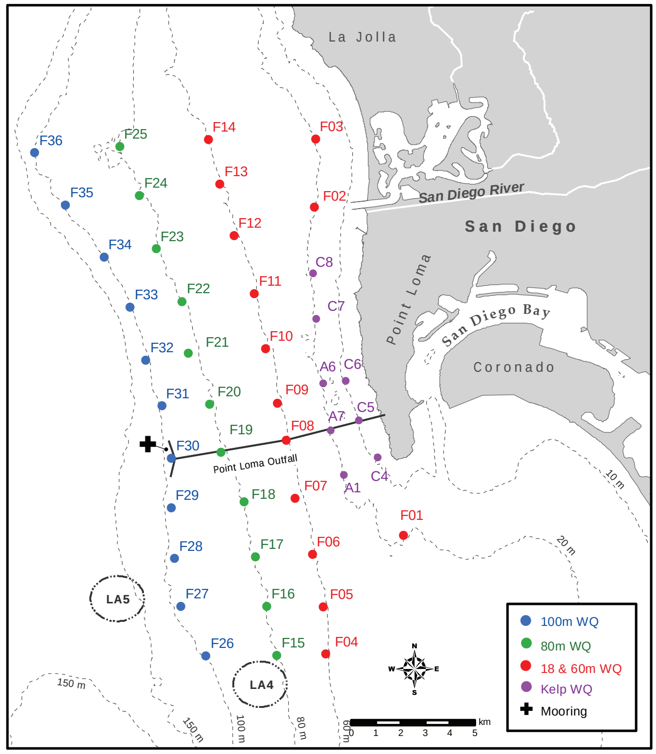

Figure 2.1
Locations of water quality (WQ) monitoring stations where CTD casts are taken and moored instruments (i.e., ADCP, thermistor) are placed around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Materials and Methods

Field Sampling

Oceanographic measurements were collected at 44 water quality monitoring stations arranged in a grid surrounding the PLOO that encompass a total area of ~146 km^2 (Figure 2.1). These include 36 offshore stations (designated F01–F36) located between 1.7 and 10.2 km offshore of Point Loma along or adjacent to the 18, 60, 80, and 100-m depth contours, and eight kelp bed stations (A1, A6, A7, C4–C8) distributed along the inner (9 m) and outer (18 m) edges of the Point Loma kelp forest. Monitoring at the offshore "F" stations occurred quarterly (February, May, August, November). For sampling and analysis purposes, the 36 quarterly sites were grouped by depth contour as follows: (1) "100-m WQ" = stations F26–F36 (n = 11); (2) "80-m WQ" = stations F15–F25 (n = 11); (3) "18 & 60-m WQ" = stations F01–F14 (n = 14). All stations within each of these groups were sampled on a single day during each quarterly survey. Sampling at the eight kelp bed stations ("Kelp WQ") was conducted five times per month to meet monitoring requirements for fecal indicator bacteria (see Chapter 3). However, only Kelp WQ data collected within one week of the quarterly stations are analyzed in this chapter (see Table 2.1).

Oceanographic data were collected using a SeaBird (SBE 25) conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, conductivity (used to calculate salinity), pressure (used to calculate depth), dissolved oxygen (DO), pH, transmissivity (a proxy for water clarity), and chlorophyll *a* (a proxy for phytoplankton). Vertical profiles of each parameter were constructed for each station by averaging the data values recorded within each 1-m depth bin. This data reduction ensured that physical measurements used in subsequent analyses

Table 2.1
Sample dates for quarterly oceanographic surveys conducted in the Point Loma outfall region during 2014. All stations in each station group were sampled on a single day (see Figure 2.1 for stations and locations).

	2014 Sampling Dates			
Station Group	Feb	May	Aug	Nov
18 & 60-m WQ	12	23	13	4
80-m WQ	11	22	12	5
100-m WQ	10	21	11	6
Kelp WQ	18	20	14	7

would correspond to the discrete sampling depths required for fecal indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Moored Instrument Data Collection

Moored oceanographic instruments (e.g., current meters, thermistors) were deployed at 100 m near the end of the PLOO (Figure 2.1). Ocean current data were collected from a seafloor-mounted Teledyne RDI Acoustic Doppler Current Profiler (ADCP). The ADCP data were recorded every five minutes and then averaged into depth bins of 4 m. This resulted in 25 bins with midpoints ranging in depth from just below the ocean surface to 95 m. However, the top three bins were excluded from all analyses due to surface backscatter interference. Additional details regarding ADCP data processing and analyses are presented below under 'Data Analysis.'

Temperature data were collected from a vertical series of thermistors (Onset Tidbit temperature loggers) every 10 minutes from duplicate arrays. Twenty-four thermistors were deployed on mooring lines ranging in depth from 6 to 98 m with equal 4-m spacing. Additional details for both thermistor and ADCP specifications are available in Storms et al. (2006).

Remote Sensing

Coastal monitoring of the Point Loma outfall region during 2014 included remote imaging analyses performed by Ocean Imaging of Solana Beach, CA. All satellite imaging data acquired during the year were made available for review and download from Ocean Imaging's website (Ocean Imaging 2015), while a separate report summarizing results for the year was also produced (Svejkovsky 2015). Several different types of satellite imagery were analyzed, including Moderate Resolution Imaging Spectroradiometer (MODIS), Thematic Mapper TM7 color/thermal, and high resolution Rapid Eye images. While these technologies differ in terms of their capability and resolution, all are generally useful for revealing patterns in surface waters as deep as 12 m.

Data Analysis

Water column parameters measured in 2014 were summarized as quarterly means pooled over all stations by the following depth layers: 1–20 m, 21–60 m, 61–80 m, 81–100 m. The top layer is herein referred to as surface water while the subsurface layers account for mid and bottom waters. For spatial analysis of all parameters, 3-dimensional graphical views were created for each survey using Interactive Geographical Ocean Data System (IGODS) software, which interpolates data between stations along each depth contour (Ocean Software 2009).

Vertical density profiles were constructed to depict the pycnocline (i.e., depth layer where the density gradient was greatest) for each survey and to illustrate seasonal changes in water column stratification. Data for these density profiles were limited to the 11 outfall depth stations (i.e., F26–F36) to prevent masking trends that occur when data from multiple depth contours are combined. Buoyancy frequency (BF), a measure of the water column's static stability, was used to quantify the magnitude of stratification for each survey and was calculated as follows:

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

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

Additionally, time series of anomalies for temperature, salinity, and DO were calculated to evaluate regional oceanographic events in context with larger scale processes (i.e., ENSO events). These analyses were also limited to data from the 100-m outfall depth stations, with all water column depths combined. Anomalies were then calculated by subtracting the average of all 24 years combined (i.e., 1991–2014) from the monthly means for each year.

Summary statistics for seasonal ocean current data were generated for each depth bin and prevailing current modes were examined by empirical orthogonal function (EOF) analysis using singular value decomposition (Anderson et al. 1999). Since ocean currents in southern California typically vary seasonally (Winant and Bratkovich 1981), ADCP data were subset by season prior to subsequent analyses: winter (January–February); spring (March–May); summer (June–August). Fall data were not analyzed due to instrumentation issues from September through December. In addition, since tidal currents are not likely to result in net water mass transport (Rogowski et al. 2012a), tides were removed prior to analyses using the PL33 filter (Alessi et al. 1984).

Results and Discussion

Oceanographic Conditions in 2014

Water Temperature and Density

Surface water temperatures (1–20 m) across the Point Loma outfall region ranged from 11.2 to 23.4°C during 2014. Subsurface water temperatures ranged from 10.3 to 19.9°C at 21–60 m, 10.1 to 14.1°C at 61–80 m, and 9.9 to 12.4°C at 81–100 m (Appendix A.1). The maximum surface temperature, recorded in August, was ~3.1°C higher than in 2013 (City of San Diego 2014a). Warmer water persisted late into the year with all subsurface maxima occurring in November along each depth contour (Figure 2.2). Ocean temperatures varied seasonally as expected. Some of the lowest temperatures in the 21–60 m layer (< 11ºC) occurred during February and May along the 60, 80, and 100-m depth contours (Figure 2.2, Appendix A.1). Shoaling of these cold waters into shallower depths may be indicative of spring upwelling. Thermal stratification also followed expected seasonal patterns, with the greatest differences (12.6°C) between surface and bottom depth layers occurring during August. Continuous temperature data from the thermistor strings yielded similar results, indicating potential upwelling events from late February through August (Figure 2.3).

In shallow coastal waters of southern California and elsewhere, density is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, seasonal changes in thermal stratification were mirrored by the density stratification of the water column during each survey (Figure 2.4). These vertical density profiles further demonstrated how the water column ranged from well-mixed during February with a maximum BF < 32 cycles^2/min^2, to stratified in May and August with a maximum BF of 87 and 144 cycles^2/min^2, respectively, to moderately stratified again in November with a maximum BF of 67 cycles^2/min^2. The values observed in August and November were greater than observed during the same months in 2013 (City of San Diego 2014b). As expected, the depth of the pycnocline also varied by season, with shallower pycnocline depths (< 10 m) corresponding to greater stratification.

Salinity

Salinities recorded in 2014 were similar to those reported previously in the PLOO region (e.g., City of San Diego 2013a, 2014a). Surface salinities ranged from 33.24 to 33.68 psu at 1–20 m. Subsurface salinities ranged from 33.17 to 33.87 psu at 21–60 m, 33.31 to 33.93 psu at 61–80 m, and 33.42 to 33.96 psu at 81–100 m (Appendix A.1). As with ocean temperatures, salinity varied seasonally. For example, relatively high salinity > 33.85 psu was present across most of the region during February at depths that corresponded with the lowest water temperatures

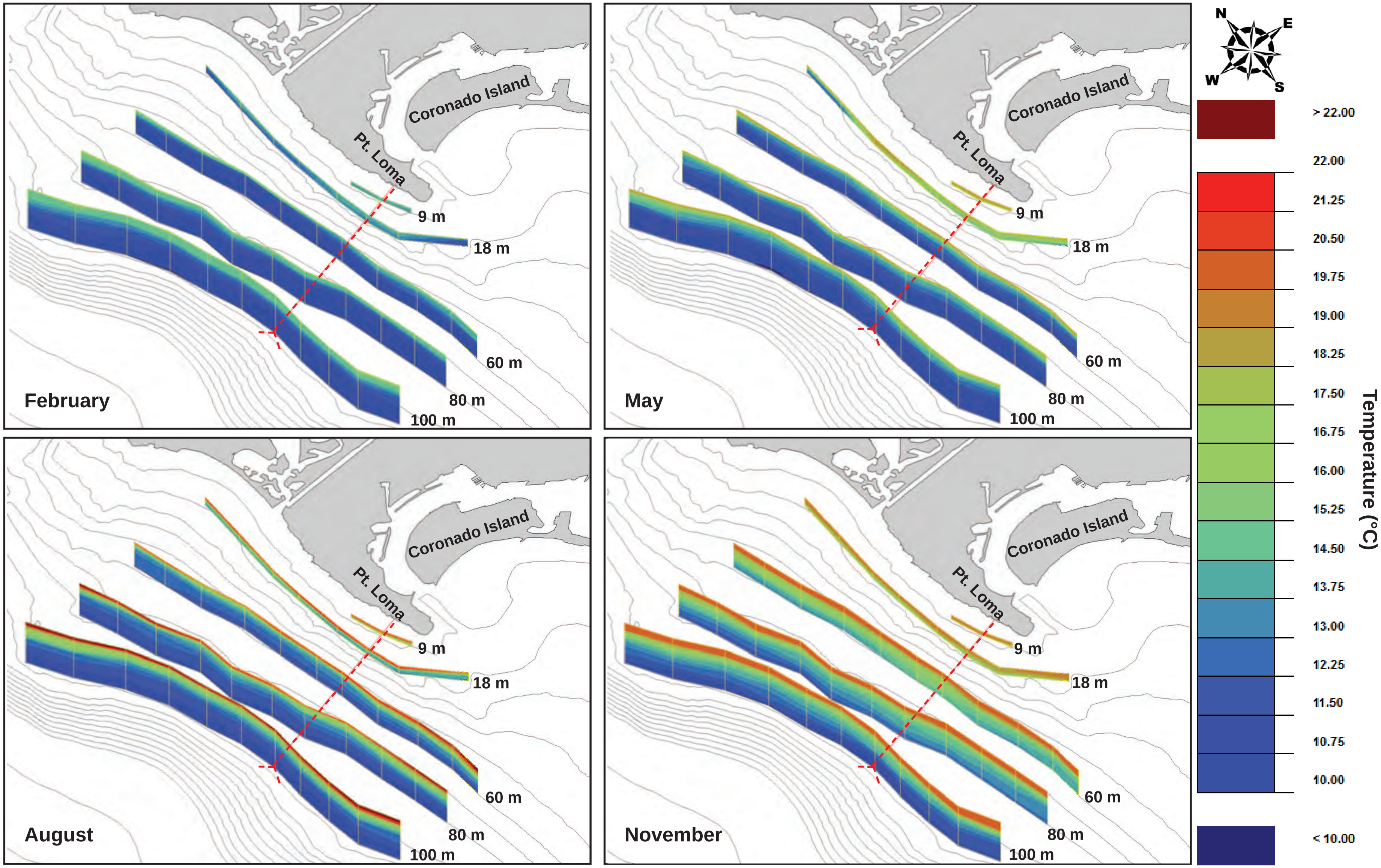

Figure 2.2
Ocean temperatures recorded in the PLOO region during 2014. Data were collected over 4–9 days during each quarterly survey.

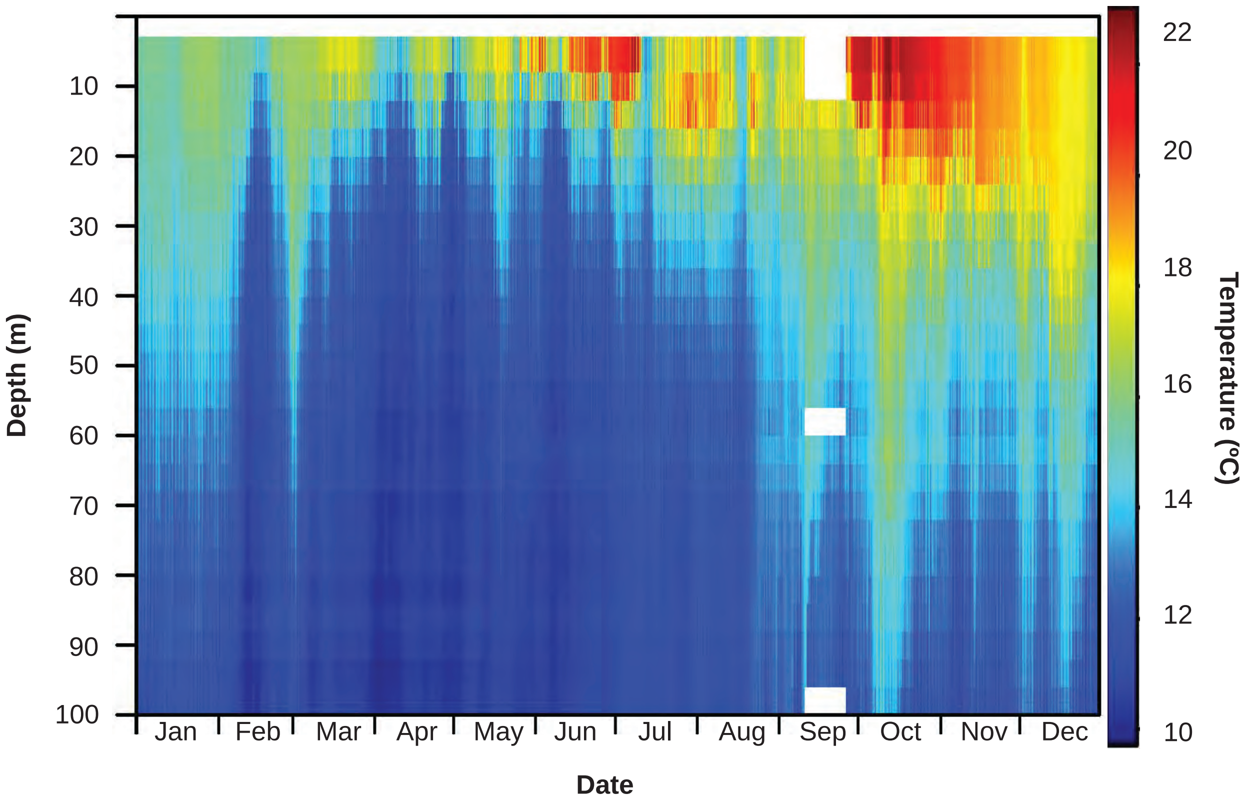

Figure 2.3
Temperature data collected at the 100-m thermistor site off Point Loma from January through December 2014. Data were collected every 10 minutes. Missing data shown as white spaces.

for that survey (Figures 2.2, 2.5). Taken together, low temperatures and high salinity may indicate local coastal upwelling (Jackson 1986).

As in previous years, a layer of relatively low salinity water was evident at sub-surface depths from 10 to 60 m at various stations in the PLOO region throughout the year (Figure 2.5). This subsurface salinity minimum layer (SSML) was most apparent at offshore stations along the 80-m and 100-m depth contours. However, it is unlikely that this SSML is related to wastewater discharge via the PLOO. First, a recently published study of the PLOO effluent plume demonstrated that the plume disperses in one direction at any given time and has a very weak salinity signature (Rogowski et al. 2012a, b, 2013). Second, similar SSMLs have been reported previously off San Diego and elsewhere in southern California, including Orange and Ventura Counties, which suggests that this phenomenon is due to a larger-scale oceanographic process (e.g., OCSD 2012, City of San Diego 2011a, b, 2012a, b, 2013a, b, 2014b). Finally, other potential indicators of wastewater, such as elevated levels of fecal indicator bacteria or colored dissolved organic matter (CDOM), did not correspond to the SSML (see Chapter 3). Further investigation is required to determine the sources of this phenomenon.

Dissolved Oxygen and pH

Overall, DO and pH levels were within historical ranges throughout the year for the Point Loma region (e.g., City of San Diego 2013a, 2014a). Surface DO ranged from 4.8 to 9.5 mg/L at 1–20 m. Subsurface DO ranged from 3.5 to 8.9 mg/L at 21–60 m, 3.3 to 7.7 mg/L at 61–80 m, and 3.2 to 6.3 mg/L at 81–100 m. Changes in pH and DO were closely linked since both parameters reflect fluctuations in dissolved carbon dioxide associated with biological activity in coastal waters (Skirrow 1975). Surface pH ranged from 7.8 to 8.3 at 1–20 m. Subsurface pH ranged from 7.7 to 8.2 at 21–60 m, 7.6 to 8.1 at 61–80 m,

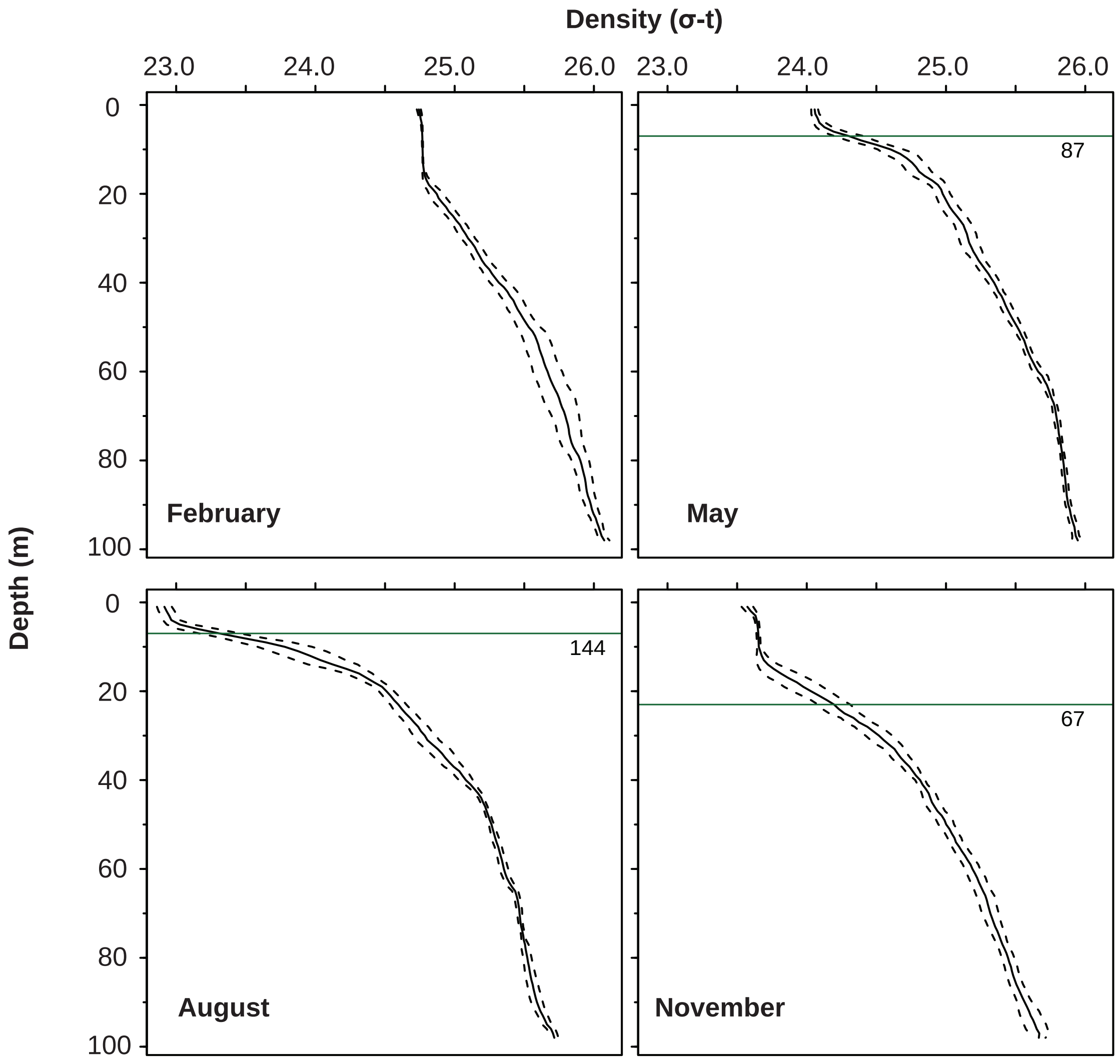

Figure 2.4

Density and maximum buoyancy frequency (BF) for each quarter at outfall depth stations sampled in the PLOO region during 2014. Solid lines are means, dotted lines are 95% confidence intervals (n = 11). Horizontal lines indicate depth of maximum BF with the number indicating the value in cycles^2/min^2. BF values less than 32 cycles^2/min^2 indicate a well-mixed water column and are not shown.

and 7.7 to 8.0 at 81–100 m. (Appendix A.1). These parameters varied similarly across all stations yielding no evidence to indicate that the quarterly surveys were not synoptic even though February's sampling occurred over a 9-day period (e.g., Appendices A.2, A.3).

Changes in DO and pH also followed expected patterns that corresponded to seasonal fluctuations in water masses and phytoplankton productivity. The greatest difference between surface and 81–100-m depth layer values occurred during February (Appendices A.2, A.3). Low values for DO and pH that occurred at depths deeper than 20 m during February were likely due to upwelling of cold, saline, oxygen poor water moving inshore as described above for temperature and salinity. Conversely, higher DO and pH concentrations during the year were often associated with phytoplankton, evident from relatively high chlorophyll *a* concentrations.

Transmissivity

Overall, water clarity was within historical ranges throughout the year for the Point Loma region during 2014 (e.g., City of San Diego 2013a, City of San Diego 2014a). Surface transmissivity ranged from 17 to 91% at 1–20 m. Subsurface

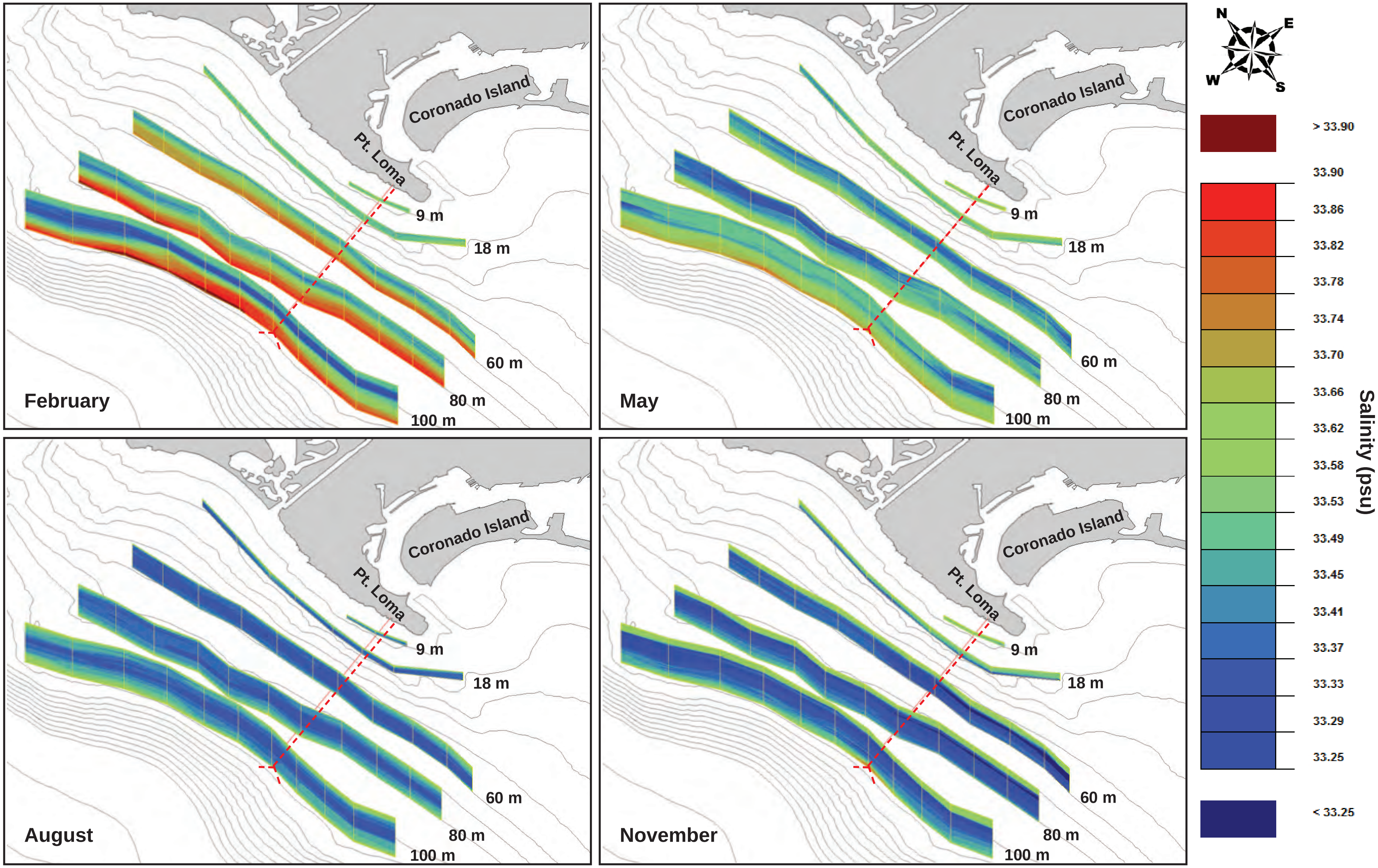

Figure 2.5
Ocean salinity recorded in the PLOO region during 2014. Data were collected over 4–9 days during each quarterly survey.

Figure 2.6
Rapid Eye image of the Point Loma region acquired February 14, 2014 (Ocean Imaging 2015) depicting the dispersion of turbidity plumes from the San Diego River and San Diego Bay.

transmissivity ranged from 75 to 91% at 21–60 m, 73 to 91% at 61–80 m, and 79 to 90% at 81–100 m. (Appendix A.1). Transmissivity was lowest along the kelp bed at the 9 and 18-m stations during February and at the 9-m stations in May (Appendix A.4). February's low values coincided with elevated chlorophyll *a* concentrations (see following section and Appendices A.1, A.4, A.5). However, remote sensing imagery from the area shows how turbidity from the San Diego River may be restricted shoreward of the kelp forest, possibly also contributing to these low values (Figure 2.6).

Chlorophyll a

Concentrations of chlorophyll *a* off Point Loma ranged from 0.1 to 11.5 μg/L during 2014 (Appendix A.1). The highest concentrations of chlorophyll *a* occurred at stations along the 9 and 18-m depth contours in February (Appendix A.5). Thin, patchy layers of elevated chlorophyll *a* concentrations also occurred at subsurface depths during May, August, and November along the 60, 80, and 100-m depth contours. These results reflect the tendency for phytoplankton to accumulate along isopycnals where nutrients are available and light is not limiting (Lalli and Parsons 1993).

Summary of Ocean Currents in 2014

Current patterns varied by season and depth in the PLOO region during 2014 with the highest mean speeds occurring near the surface (i.e., the 11-m bin) and decreasing with depth in all three seasons (Appendix A.6). Surface mean speeds increased from winter to summer during the year. Peak velocities in spring of 2014 were ~90mm/s (24%) faster than in spring of 2013 (City of San Diego 2014a). The general axis of variability in the current flow across the water column, as indicated by the dominant current mode (EOF 1), was most commonly along a northwest-southeast axis at all depths in winter and spring (Figure 2.7). Summer currents were less consistent during 2014 than in previous years with only 52% of the variability accounted for by EOF 1. The axis of variability was more directly north-south than in the winter or spring. The second mode (EOF 2) accounted for 29% of the observed variability and was characterized by a strong shift from northwest-southeast to north/northeast-south/southwest currents between the 15 and 31-m bins. These results are generally comparable to those obtained during previous studies (e.g., City of San Diego 2015, Parnell and Rasmussen 2010, Rogowski et al. 2012a, b, 2013).

Current direction differed by both depth and season (Figure 2.8A). During the winter, the entire water column often flowed in the same direction. However, beginning in mid-March periods of high shear, (i.e., adjacent layers of water moving in distinctly different directions and/or speeds), occurred more frequently. In the upper 40 m, southward velocities periodically exceeded 300 mm/s, especially from February to April (Figure 2.8B). At depths below 60 m, current velocities were generally slower than 100 mm/s. However, from late July to early August, mid-column northward velocities exceeded 200 mm/s.

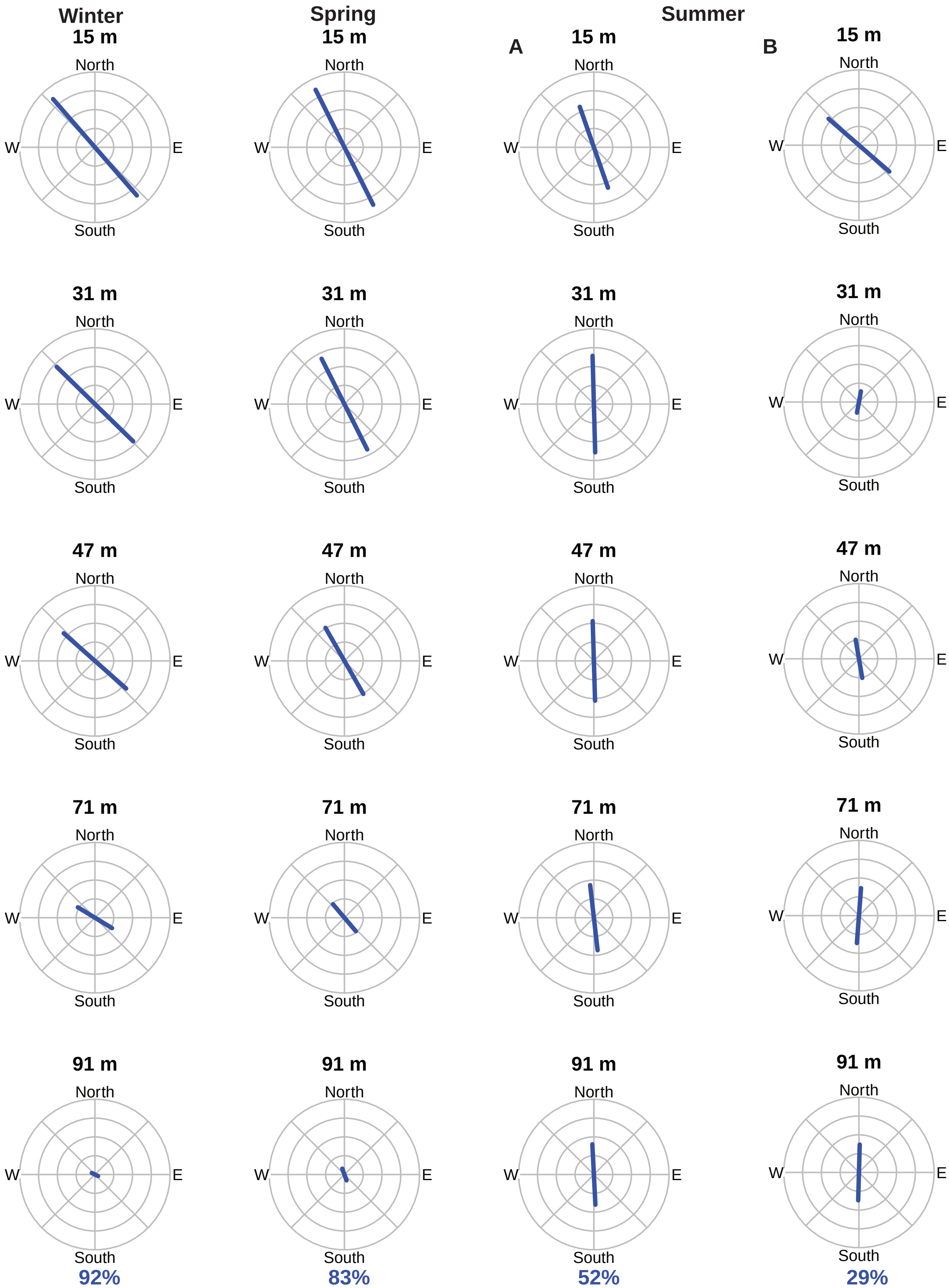

Figure 2.7
Dominant current modes (EOF 1) for winter, spring, and summer (A) during 2014 at the 100-m ADCP site off Point Loma for selected depth bins. The second mode (EOF 2) is also shown for summer (B). Percentages indicate fraction of the total variance accounted for by the EOF for each season. Line length indicates magnitude. Each concentric ring is 0.1 mm/s. Fall data were not collected due to instrumentation issues.

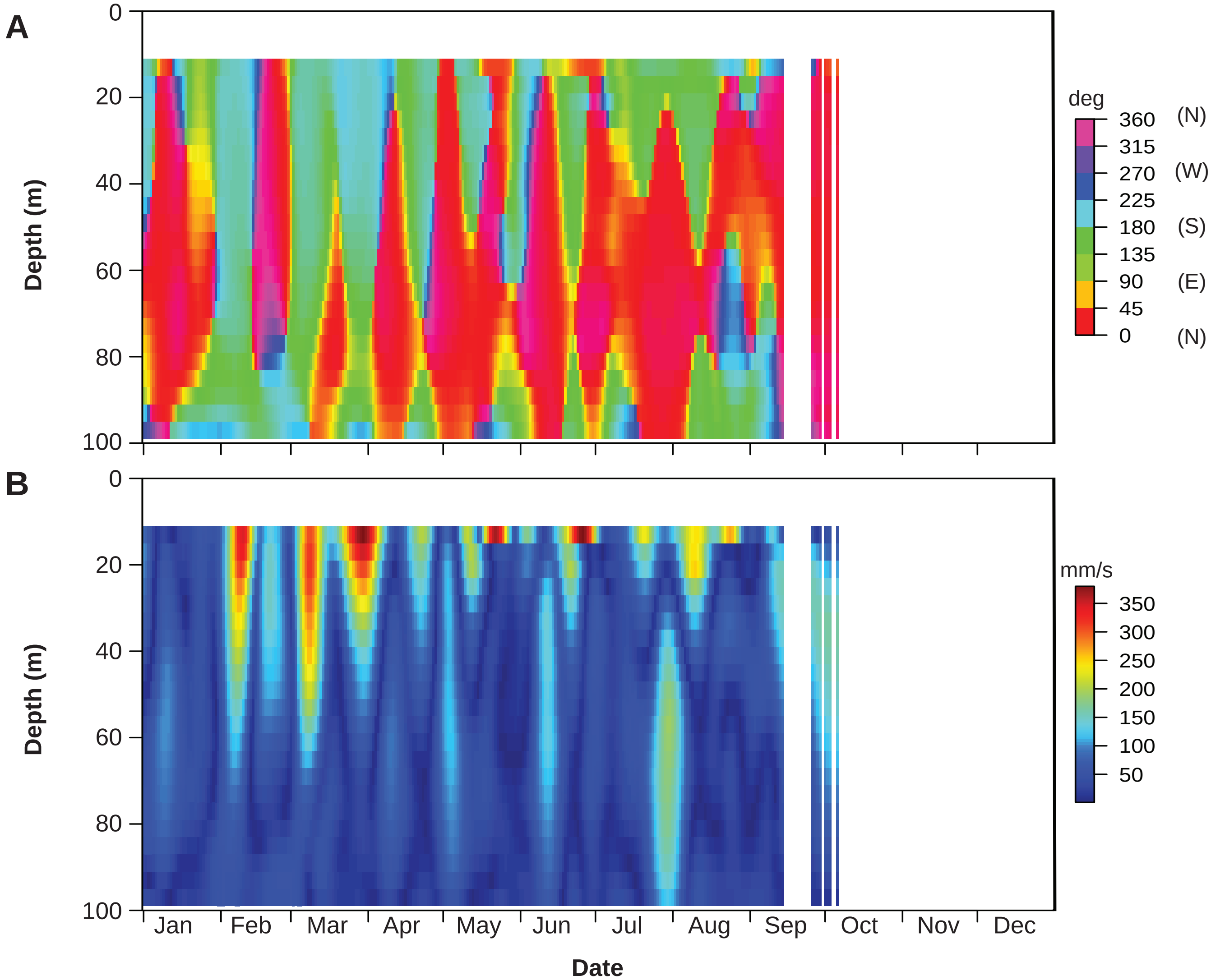

Figure 2.8

ADCP data collected at the 100-m site off Point Loma showing daily average (A) direction, and (B) horizontal velocity of currents from January through October 2014. Missing data (white areas) are the result of interference with the doppler signal near the surface or instrumentation issues. N = north, S = south, E = east, W = west.

Historical Assessment of Oceanographic Conditions

A review of temperature, salinity, and DO data from all outfall depth stations sampled from 1991 through 2014 indicated how the PLOO coastal region has responded to long-term climate-related changes in the SCB (Figure 2.9). Overall, these results are consistent with large-scale temporal patterns in the California Current System (CCS) associated with ENSO, PDO, and NPGO events (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, Leising et al. 2014, NOAA/NWS 2015). For example, seven major events have affected SCB coastal waters during the last two decades: (1) the 1997–98 El Niño; (2) a shift to cold ocean conditions reflected in ENSO and PDO indices between 1999 and 2002; (3) a subtle but persistent return to warm ocean conditions in the 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

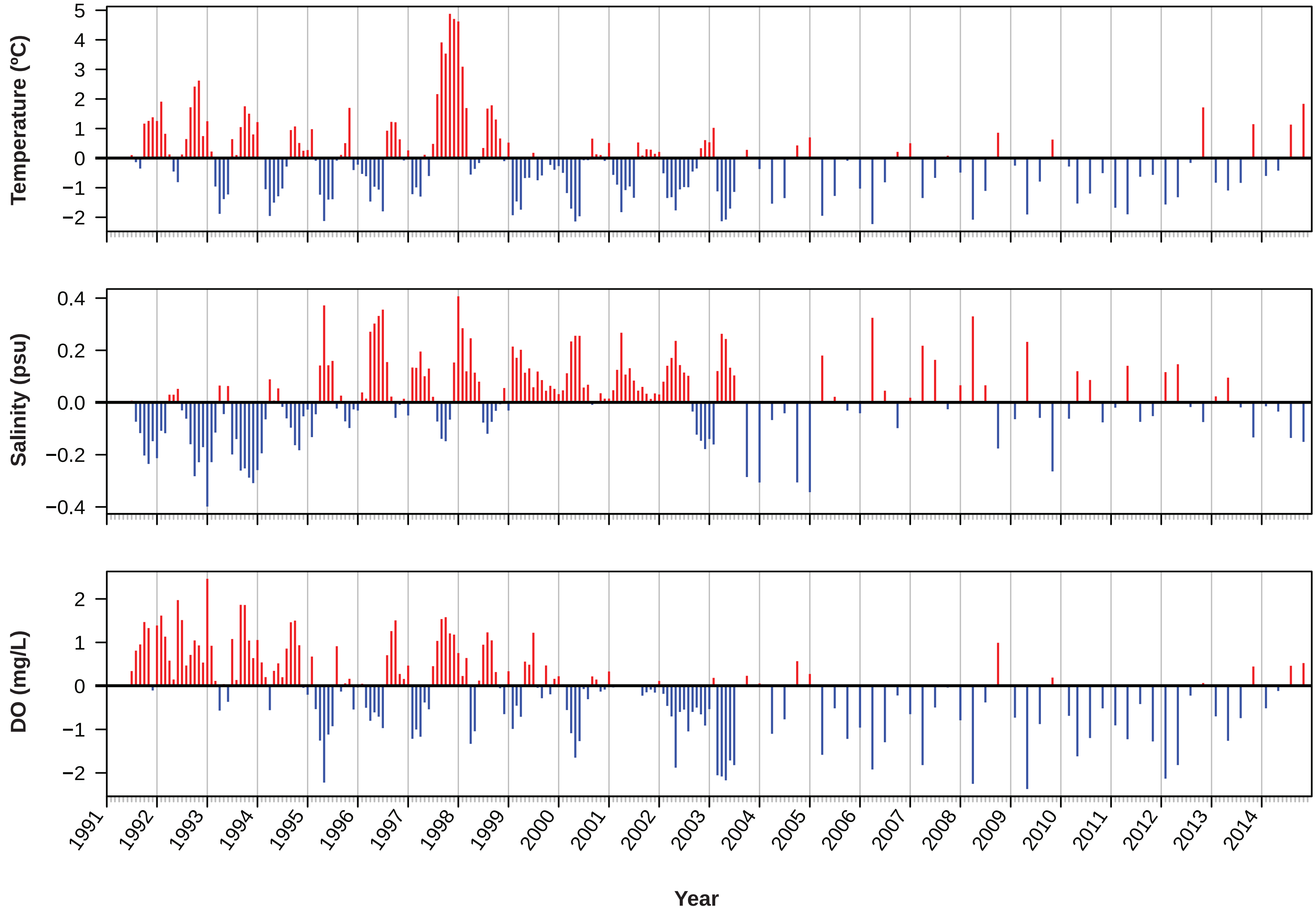

Figure 2.9
Time series of temperature, salinity, and dissolved oxygen (DO) anomalies from 1991 through 2014 at the 11 outfall depth stations sampled in the PLOO region with all depths combined.

flow of cold, nutrient-rich water from the north; (6) development of another La Niña starting in May 2010; (7) a region-wide warming beginning in the winter of 2013/2014 when the PDO, NPGO, and MEI (Multivariate ENSO Index) all changed phase. Temperature and salinity data for the PLOO region are consistent with all but the third of these CCS events; while the CCS was experiencing a warming trend that lasted through 2006, the PLOO region experienced cooler than normal conditions during much of 2005 and 2006. The conditions in 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). In 2014, temperature anomalies remained negative compared to the long-term average in February and May before warming in August and November. The increased positive temperature anomalies in the latter half of the year are consistent with the weak El Niño that developed in 2014 (NOAA/NWS 2015). Although the latter half of 2014 saw a return to positive anomalies, the overall decrease in DO in the PLOO 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

Oceanographic data collected in the Point Loma outfall region were consistent with reports from NOAA that the mild ENSO-neutral conditions that began in mid-2012 have shifted to ENSO-positive with warmer conditions persisting through the end of 2014 (Leising et al. 2014, NOAA/NWS 2015). Conditions indicative of local coastal upwelling, such as relatively cold, dense, saline waters with low DO and pH at mid-depths and below, were most evident during February although thermistor data indicated that periods of upwelling may have occurred episodically through mid-August. Phytoplankton blooms, indicated by relatively high chlorophyll *a* concentrations, were observed during February and confirmed by remote sensing (Svejkovsky 2015). Subsequent observations of elevated chlorophyll *a* concentrations during May, August, and November were unobserved with remote sensing instrumentation due to their depth.

Overall, water column stratification in 2014 followed seasonal patterns typical for the San Diego region. Maximum stratification occurred in August, while well-mixed waters were present during February. Further, oceanographic conditions were either consistent with long-term trends in the SCB (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, Leising et al. 2014, NOAA/NWS 2015) or with conditions typically seen 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 driven by a combination of local (e.g., coastal upwelling, rain-related runoff) and large-scale oceanographic processes (e.g., ENSO, PDO, NPGO).

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Chapter 3
Water Quality Compliance & Plume Dispersion

Chapter 3. Water Quality Compliance & Plume Dispersion

Introduction

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

Multiple sources of potential bacterial contamination exist in the Point Loma outfall monitoring region. Therefore, being able to separate any effects or impacts associated with the discharge of wastewater from the PLOO or other sources of contamination is often challenging. Examples of other sources of contamination include outflows from San Diego Bay and the Tijuana and San Diego Rivers (Nezlin et al. 2007, Svejkovsky 2015). Likewise, storm water discharges and runoff from local watersheds during wet weather can also flush contaminants seaward (Noble et al. 2003, Reeves et al. 2004, Sercu et al. 2009, Griffith et al. 2010). Moreover, beach wrack (e.g., kelp, seagrass), storm drains impacted by tidal flushing, and beach sediments can act as reservoirs for bacteria until release into nearshore waters by returning tides, rainfall, or other disturbances (Gruber et al. 2005, Martin and Gruber 2005, Noble et al. 2006, Yamahara et al. 2007, Phillips et al. 2011). Further, the presence of birds and their droppings has been associated with bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2010).

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

This chapter presents analysis and interpretation of the microbiological, water chemistry, and oceanographic data collected during calendar year 2014 at water quality monitoring stations surrounding the PLOO. The primary goals are to: (1) document overall water quality conditions in the region; (2) distinguish between the PLOO wastewater plume and other sources of bacterial contamination; (3) evaluate potential movement and dispersal of the plume; (4) assess compliance with water-contact standards defined in the Ocean Plan. Results of remote sensing data for the region are also evaluated to provide insight into wastewater transport and the extent of significant events in surface waters during the year (e.g., turbidity plumes).

Materials and Methods

Field Sampling

Shore stations

Seawater samples were collected five times per month at eight shore stations (i.e., D4, D5, D7–D12)

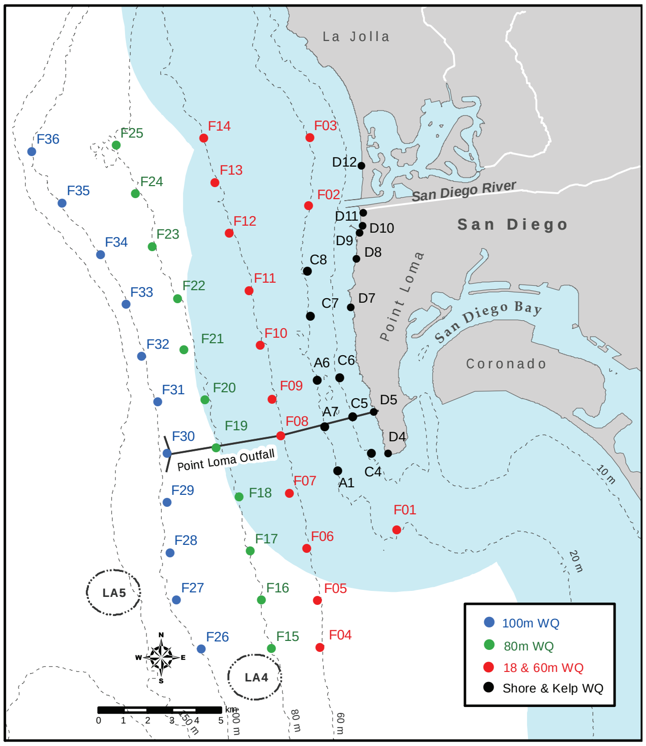

Figure 3.1
Water quality (WQ) monitoring station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program. Light blue shading represents State jurisdictional waters.

located from Mission Beach southward to the tip of Point Loma to monitor fecal indicator bacteria (FIB) concentrations in waters adjacent to public beaches (Figure 3.1) and to evaluate compliance with Ocean Plan water contact standards (see Box 3.1). Seawater samples were collected from the surf zone at each shore station in sterile 250-mL bottles, transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML), and analyzed to determine concentrations of total coliform, fecal coliform, and *Enterococcus* bacteria. In addition, water temperature and visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. These observations were previously reported in monthly receiving waters monitoring reports submitted to the San Diego Regional Water Quality Control Board (SDRWQCB) (e.g., City of San Diego 2015a).

Kelp bed and other offshore stations

Eight stations located in nearshore waters within the Point Loma 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 stations C4, C5, and C6 located near the inner edge of the kelp bed along the 9-m depth contour and stations A1, A6, A7, C7, and C8 located near the outer edge of the kelp bed along the 18-m depth contour (Figure 3.1). Weekly monitoring at each of the kelp bed sites consisted of collecting seawater samples to determine concentrations of the same three types of fecal indicator bacteria as at the shore stations. Samples were also collected to assess ammonia levels at these kelp stations according to the offshore water quality sampling schedule described below.

An additional 36 offshore stations were sampled quarterly in order to monitor *Enterococcus* levels and to estimate dispersion of the wastewater plume. These offshore "F" stations are arranged in a grid surrounding the discharge zone along or adjacent to the 18, 60, 80, and 100-m depth contours (Figure 3.1). These quarterly offshore stations were monitored during February, May, August and November in 2014 over a 3-day period (see Table 2.1 in Chapter 2). Monitoring for ammonia occurred at the same discrete depths where bacteria samples were collected at the 15 "F" stations located within State jurisdictional waters.

Seawater samples for bacterial analyses were collected at three discrete depths at the kelp stations and 18-m and 60-m offshore stations, four depths at the 80-m offshore stations, and five depths at the 100-m offshore stations (Table 3.1). These samples were collected using an array of Van Dorn bottles for sampling in the kelp forest or a rosette sampler fitted with Niskin bottles when sampling the "F" stations. Aliquots for ammonia and bacteriological analyses were drawn into sterile sample bottles and refrigerated prior to processing at the City's Toxicology and Marine Microbiology Laboratories, respectively. Visual observations of weather, sea conditions, and human and/or animal activity were also recorded at the time of sampling. Oceanographic data were collected from these stations using a CTD to measure temperature, conductivity (salinity),

Box 3.1

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

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

(a) *30-day Geometric Mean* – The following standards are based on the geometric mean of the five most recent samples from each site:
1) Total coliform density shall not exceed 1000 CFU/100 mL.
2) Fecal coliform density shall not exceed 200 CFU/100 mL.
3) *Enterococcus* density shall not exceed 35 CFU/100 mL.

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

B. Physical Characteristics

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

C. Chemical Characteristics

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

pressure (depth), chlorophyll *a*, CDOM, dissolved oxygen (DO), pH, and light transmissivity (see Chapter 2). Measurements of CDOM were only taken at offshore "F" stations; therefore subsequent plume detection analyses were limited to these stations.

Laboratory Analyses

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

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

Quality assurance tests were performed routinely on seawater samples to ensure that analyses and sampling variability did not exceed acceptable limits. Bacteriological laboratory and field duplicate samples were processed according to method requirements to measure analyst precision and variability between samples, respectively. Results of these procedures were reported under separate cover (City of San Diego 2015b).

Table 3.1
Depths from which seawater samples are collected for bacteriological analysis from the PLOO kelp bed and offshore stations.

Station Contour	Sample Depth (m)								
	1	3	9	12	18	25	60	80	98
Kelp Bed									
9-m	x	x	x						
18-m	x			x	x				
Offshore									
18-m	x			x	x				
60-m	x					x	x		
80-m	x					x	x	x	
100-m	x					x	x	x	x

Additional seawater samples were analyzed by the City's Toxicology Laboratory to determine ammonia (nitrogen) concentrations using a Hach DR850 colorimeter and the Salicylate Method (Bower and Holm-Hansen 1980). Quality assurance tests for these analyses were performed using sample blanks.

Data Analyses

Bacteriology

FIB densities (total coliforms, fecal coliforms, *Enterococcus*) were summarized as monthly means for each shore station and by depth contour and month for each of the kelp bed stations. For the offshore stations where only *Enterococcus* was measured, densities were summarized as quarterly means. In order to assess temporal and spatial trends, the data were summarized as the number of samples in which FIB concentrations exceeded benchmark levels. For this report, the single sample maximum and 30 day geometric mean standards defined in the Ocean Plan for total coliforms, fecal coliforms, and *Enterococcus* were used as benchmarks to distinguish elevated FIB values at all stations located within State jurisdictional waters (see Box 3.1 and SWRCB 2012). Bacterial densities were compared to rainfall data from Lindbergh Field, San Diego, CA (see NOAA 2015). Chi-squared Tests (χ^2) were conducted to determine if the frequency of samples with elevated FIB counts differed at the shore stations between wet (October–April) and dry (May–September) seasons and to determine if elevated FIB counts at kelp bed stations differed before and after the completion of the outfall extension over 20 years ago. Additional χ^2 tests were conducted to determine whether elevated FIB counts differed at outfall stations (i.e., F29, F30, F31) compared to other stations along the 100-m contour as well as whether elevated counts differed at these stations before and after the initiation of effluent chlorination in 2008. Satellite images of the San Diego coastal region were provided by Ocean Imaging of Solana Beach, California (Svejkovsky 2015) and used to aid in the analysis and interpretation of water quality data (see Chapter 2 for remote sensing details). Finally, compliance with Ocean Plan water-contact standards was summarized as the number of times per sampling period that each shore, kelp, and offshore station within State jurisdictional waters exceeded the various standards.

Wastewater Plume Detection and Out-of-Range Calculations

The potential presence or absence of the wastewater plume was determined at each station using a combination of oceanographic parameters (i.e., detection criteria). If present, a strong alongshore CDOM signal due to coastal runoff could interfere with plume detection. However, pre-screening of CDOM data revealed no such signal within the PLOO region (Appendix B.1), and all 36 offshore "F" stations were therefore included in the analyses. Previous monitoring has consistently found that the PLOO plume is trapped below the pycnocline with no evidence of surfacing throughout the year (City of San Diego 2010–2015c, Rogowski et al. 2012a, b, 2013). Water column stratification and pycnocline depth were quantified using calculations of buoyancy frequency (cycles^2/min^2) for each quarterly survey (see Chapter 2). For the purposes of the plume dispersion analysis, buoyancy frequency calculations included data from those stations that would be most likely to demonstrate the potential plume trapping depth (i.e., all stations located along the 18, 60, 80, and 100-m depth contours).

If the water column was stratified (i.e., maximum buoyancy frequency >32 cycles^2/min^2), subsequent analyses were limited to depths below the pycnocline. Identification of a potential plume signal at a station was based on: (1) high CDOM; (2) low chlorophyll *a*; (3) visual interpretation of the water column profile. Detection thresholds were adaptively set for each quarterly survey according to the following criteria: CDOM exceeding the 95th percentile and chlorophyll *a* 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 off Point Loma and are thus constrained to use within the region. Finally, water column profiles were visually interpreted to remove stations with spurious signals (e.g., CDOM signals near the sea floor that were likely caused by resuspension of sediments). Exclusion of stations using the chlorophyll *a* criterion was confirmed as part of the visual interpretation of the profiles.

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

Results and Discussion

Bacteriological Compliance and Distribution

Shore stations

During 2014, compliance at the eight shore stations in the PLOO region was 100% for the 30-day total coliform and fecal coliform geometric mean standards while compliance with the 30-day *Enterococcus* geometric mean standard was 95–100%. Compliance with the single sample maximum (SSM) standards was 98–100% for total coliforms, fecal coliforms, and the fecal:total coliform (FTR) criterion, and 95–100% for *Enterococcus* (Figure 3.2). Sewage-like odors and surface scum on the water were rarely observed along the shore during the year (City of San Diego 2015a). Monthly mean FIB densities ranged from 6 to 3810 CFU/100 mL for total coliforms, 2 to 2825 CFU/100 mL for fecal coliforms, and 2 to 158 CFU/100 mL for *Enterococcus* (Appendix B.3). The highest mean values for all three parameters occurred at station D8 in October. Of the 488 shore samples collected during the year (not including resamples), only 11 (~2.3%) had elevated FIB (Table 3.2, Appendix B.4). This represents a slight increase from the five samples with elevated FIB counts in 2013 but the same amount as in 2012. A general relationship between rainfall and elevated bacterial levels at the shore stations has been evident since water quality monitoring began in the Point Loma outfall region (Figure 3.3). Historical analysis indicates that the occurrence of a sample with elevated FIB is significantly more likely to occur during the wet season than during the dry season (6% versus 2%, respectively; n=8166, χ^2=99.44, p<0.0001). Contrary to this historical trend, no seasonal effect has been observed for FIB exceedances for the last several years, possibly due to continued low rainfall.

Kelp bed stations

During 2014, compliance at the eight kelp bed stations was 100% for all 30-day geometric mean water contact standards. Compliance with the single sample maximum (SSM) standards was 100% for total coliforms and fecal coliforms while the standards for *Enterococcus* and the FTR criterion

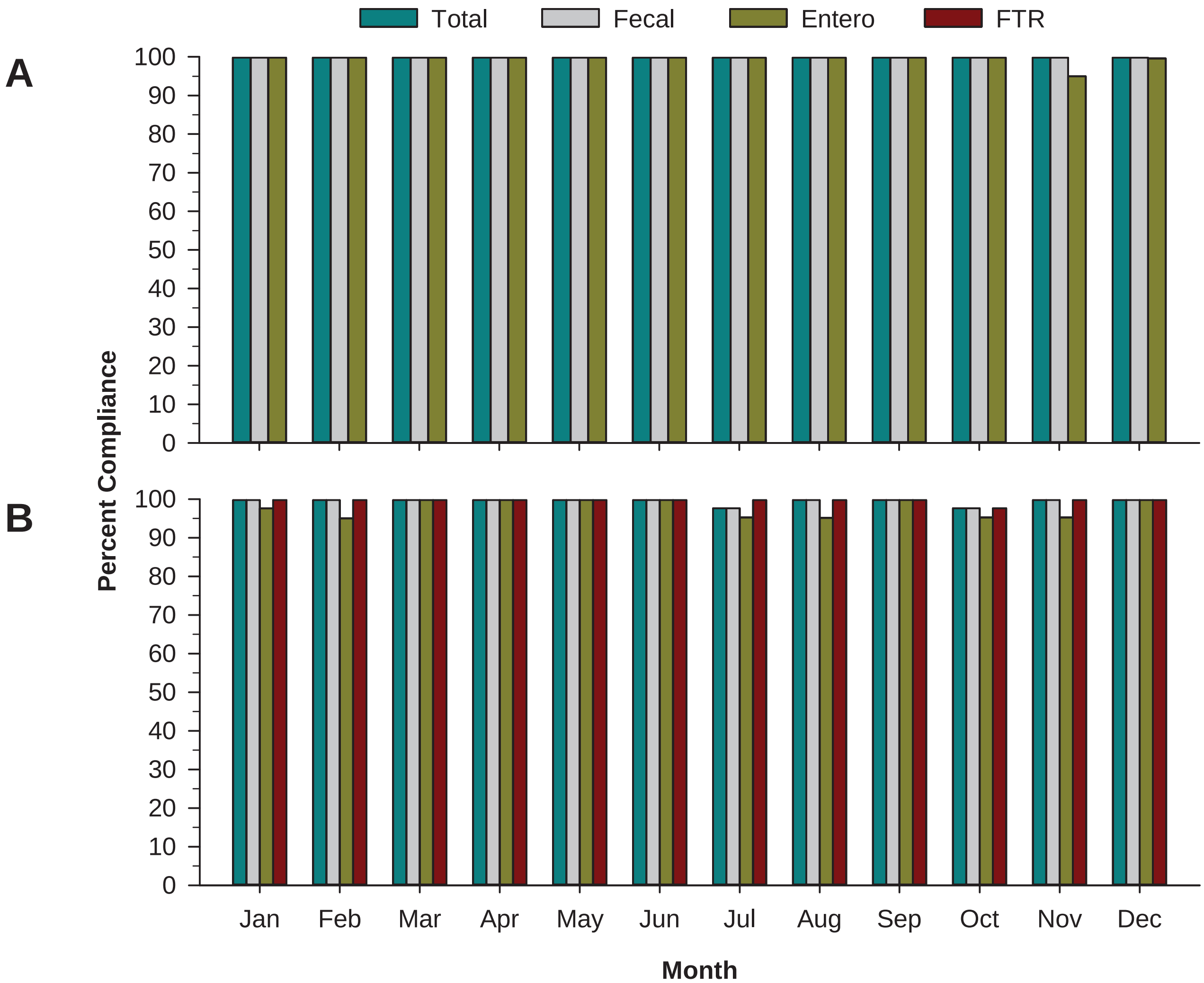

Figure 3.2
Compliance rates for (A) the three geometric mean and (B) the four single sample maximum water contact standards from PLOO shore stations during 2014.

were 99–100%. These results are only slightly lower than those for 2013 when compliance rates were 100% for all standards (City of San Diego 2014). Monthly mean FIB densities at the kelp stations were lower than those along the shore, ranging from 2 to 110 CFU/100 mL for total coliforms, 2 to 13 CFU/100 mL for fecal coliforms, and 2 to 6 CFU/100 mL for *Enterococcus* throughout the year (Appendix B.5). This low incidence of elevated FIB is consistent with water quality results dating back to 1994 after the outfall was extended to its present discharge site (Figure 3.4). In contrast, the likelihood of encountering elevated FIB concentrations was significantly higher at the kelp bed stations prior to the outfall extension (13% versus <1%; n=43,917, $\chi^2=3680.6$, $p<0.0001$). No relationship between rainfall and elevated FIB levels has been evident at these stations over the years, as the proportion of samples with high FIBs is similar between wet and dry seasons (~4% for both). No signs of wastewater (e.g., foam, sewage-like odor) were observed at any of the kelp stations in 2014. Satellite imagery showed that runoff from the San Diego River in 2014 was typically restricted to the area between the shore and inside of the kelp forest (Svejkovsky 2015).

Offshore stations

The maximum concentration of *Enterococcus* at the offshore stations was 640 CFU/100 mL in 2014 (Appendix B.4). Eleven of 564 offshore samples (~2%) had elevated *Enterococcus* densities >104 CFU/100 mL. However, all of these elevated samples were from 60 m or greater depths from

Table 3.2
The number of samples with elevated FIB (eFIB) densities collected at PLOO shore stations during the wet and dry seasons in 2014. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

Station	Seasons: Wet	Seasons: Dry	% Wet
D12	0	1	0
D11	1	1	50
D10	1	0	100
D9	0	0	—
D8	3	1	75
D7	0	1	0
D5	2	0	100
D4	0	0	—
Rain (in)	7.69	0.08	99
Total eFIB	7	4	64
Total Samples	288	200	59

stations located along the 80 or 100-m depth contours (Figure 3.5). Only two of these exceedances occurred in State jurisdictional waters (i.e., stations F18 and F19) resulting in ≥99% compliance with the *Enterococcus* SSM standard for these stations in 2014. These results suggest that the wastewater plume from the PLOO was restricted to relatively deep, offshore waters throughout the year. Additionally, there were no signs of wastewater at any of these 36 stations based on visual observations of the surface (City of San Diego 2015a). This conclusion is consistent with remote sensing observations that provided no evidence of the plume reaching surface waters in 2014 (Svejkovsky 2015). These findings are also consistent with historical results, which revealed that <1% of the samples collected from 1991 through 2014 from depths ≤25 m at the stations located along the 100-m discharge depth contour had elevated levels of *Enterococcus* (Figure 3.6A). Over this time period, detection of elevated FIB was significantly more likely at the three stations located near the discharge zone (i.e., F29, F30, F31) than at any other 100-m site (15% versus 5%, respectively; $n = 5240$, $\chi^2 = 161.75$, $p < 0.0001$) (Figure 3.6B). Following the initiation of partial chlorination in 2008 (City of San Diego 2009), the number of samples with elevated *Enterococcus* also dropped significantly at these three stations (17% before versus 7% after, $n = 1781$, $\chi^2 = 21.11$, $p < 0.0001$), as well as at the other 100-m stations (6% before versus <1% after; $n = 3459$, $\chi^2 = 45.88$, $p < 0.0001$) (Figure 3.6C).

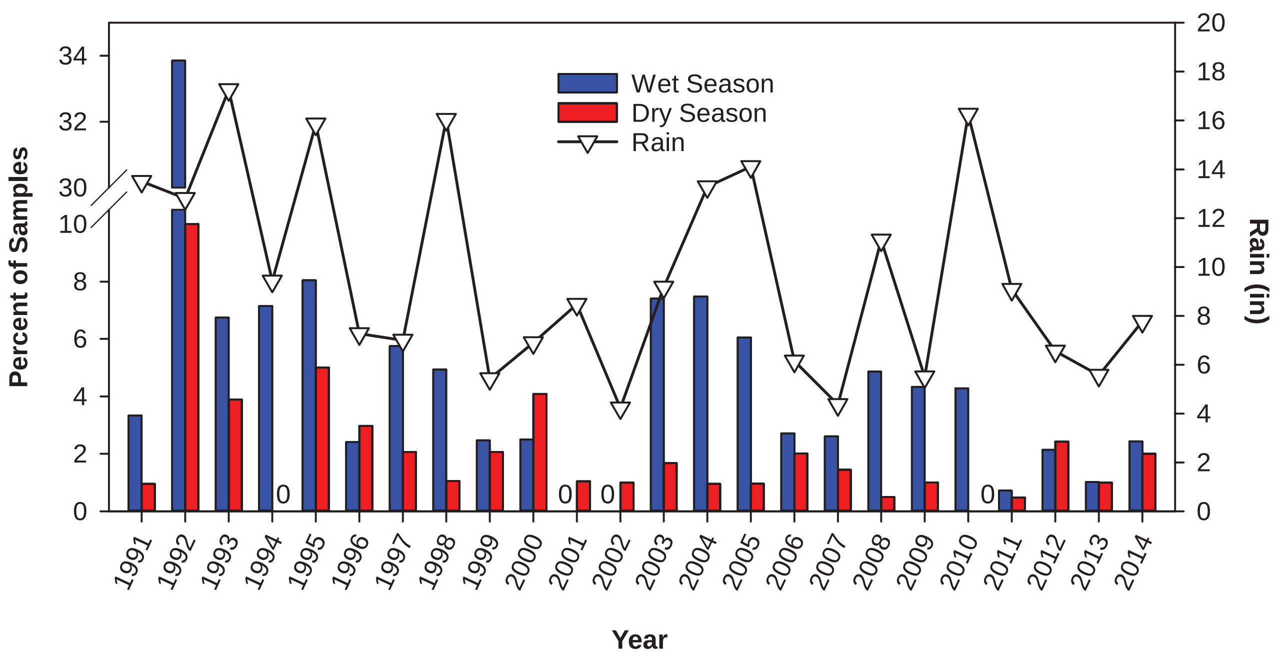

Figure 3.3
Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet versus dry seasons at PLOO shore stations from 1991 through 2014. Rain data are from Lindbergh Field, San Diego, CA.

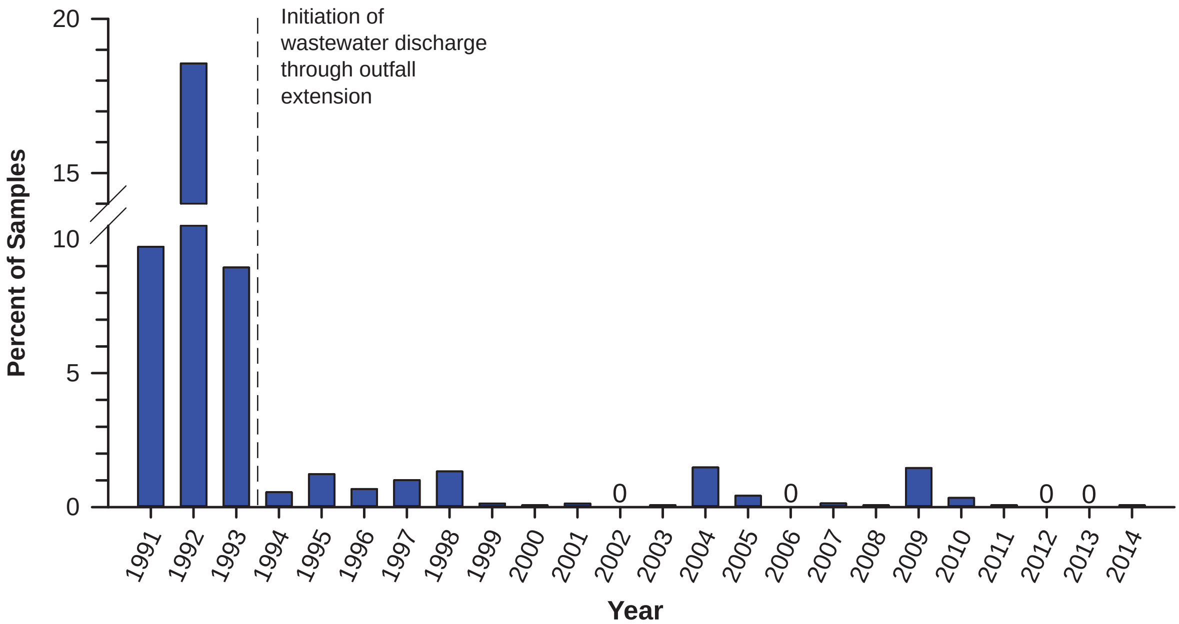

Figure 3.4
Percent of samples with elevated FIB densities at PLOO kelp bed stations from 1991 through 2014.

Ammonia

Ammonia was detected in ~19% of the 276 samples collected during 2014. This parameter was found at 21 of the 23 stations sampled and was recorded during each of the quarterly surveys except August at concentrations up to 0.17 mg/L (Figure 3.7, Table 3.3). These levels are an order of magnitude lower than the water quality objectives for ammonia defined in the Ocean Plan (i.e., instant maximum of 6.0 mg/L, daily maximum of 2.4 mg/L; SWRCB 2012). Ammonia is considered a possible wastewater plume indicator (e.g., LACSD 2014), however only one sample collected from station F18 at 80 m during November had detectable levels of ammonia that coincided with elevated densities of *Enterococcus*, whereas other chemical and physical criteria (i.e., CDOM, transmissivity) at this station were not indicative of a plume signature (see following section, City of San Diego 2015a).

Plume Dispersion and Effects

The dispersion of the wastewater plume from the PLOO and its effects on natural light, DO and pH levels were assessed by evaluating the results of 144 CTD profile casts performed during 2014. Based on the criteria described in the Materials and Methods section, potential evidence of a plume signal was detected a total of 24 times during the year from 17 different stations, while 6–17 stations were identified as reference sites during each quarterly survey (Figure 3.9, Table 3.4, Appendix B.2). Although a plume signal was detected during all four quarters at station F30 located near the center of the zone of initial dilution (ZID), dispersion away from the discharge zone appeared to vary seasonally. Twenty-five percent of possible detections occurred in February (n=6) when in addition to station F30, presence of a plume signal was restricted to four sites located about 2–8 km north of the outfall along the 80-m depth contour (i.e., stations F20, F21, F22, F23), as well as station F11 located further inshore along the 60-m depth contour. However, the results for station F11 should be interpreted cautiously due to the potential influence of outflows from the nearby San Diego River. About 17% of the potential detections occurred during May (n=4), when the plume signal was observed near or over the outfall at stations F30 and F19, as well as at stations F31 and F32 located about 2–4 km north of the discharge zone along the 100-m depth contour. About 46% of the possible detections (n=11) occurred during August when the plume appeared to be dispersed from about 4 km north of the discharge zone to about 8 km south of the outfall along the outer 80 and 100-m depth contours.

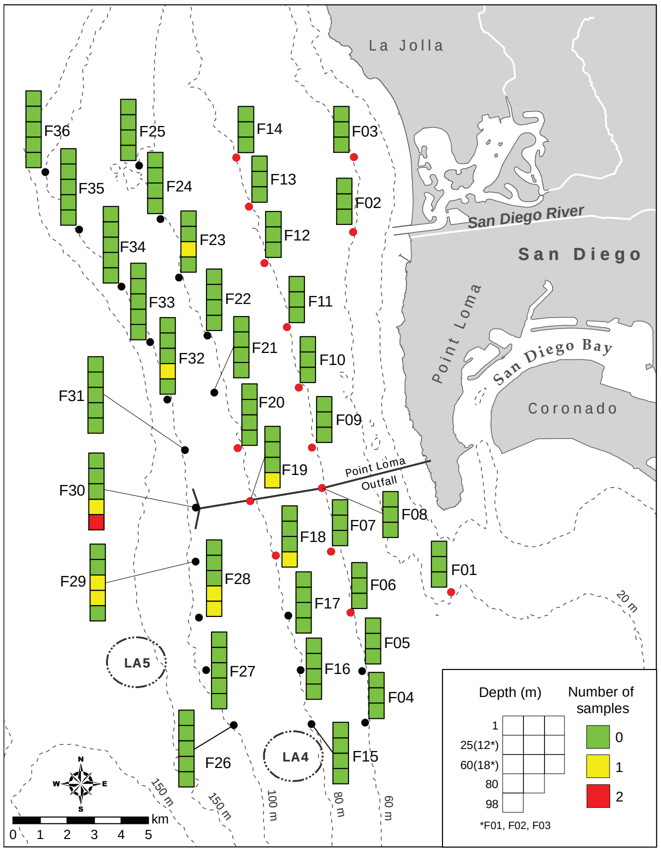

Figure 3.5

Distribution of samples with elevated *Enterococcus* collected at PLOO offshore stations during 2014. Data are number of samples that exceeded concentrations >104 CFU/100 mL. Red circles indicate stations sampled within State jurisdictional waters. See text and Table 3.1 for sampling details.

The possible presence of a plume signal at station F12 located to the north and west of the San Diego River mouth is considered unlikely for reasons similar to those described above for station F11 during the February survey. Reliable detection of the plume in November was limited to stations F28–F30 located along the 100-m depth contour within 4 km of the outfall. Overall, the variation in plume dispersion observed off Point Loma in 2014 was similar to flow-mediated dispersal patterns reported previously for the region (Rogowski et al. 2012a, b, 2013).

The width and rise height of the PLOO wastewater plume varied between stations throughout the year (Appendix B.6). Despite fluctuations in the depth of the pycnocline, the plume remained below 50 m even during periods of weak water column stratification (Appendix B.7). This finding is in agreement with satellite imagery observations that showed no visual evidence of the plume surfacing during 2014 (Svejkovsky 2015). Near-ZID station F30 was the only site where presence of the plume was corroborated by seawater samples with elevated *Enterococcus* densities. These samples were collected in February and August at a depth of 98 m, and in November at a depth of 80 m (see Figure 3.6, Appendix B.4).

The effects of the PLOO wastewater plume on the three physical water quality indicators mentioned above were calculated for each station and depth where a plume signal was indicated. For each of these detections, mean values for natural light (% transmissivity), DO, and pH within the estimated plume were compared to thresholds within similar depths from non-plume reference stations (Appendix B.6). Of the 24 potential plume signals that occurred during 2014, a total of 17 out-of-range (OOR) events were identified, which consisted of 14 OOR events for natural light at various stations throughout the year, and three OOR events for DO (Table 3.4, Appendices B.7, B.8, B.9, and B.10). There were no OOR events for pH. Only two of the 17 OOR events, all for natural light, occurred at stations located clearly within State jurisdictional waters where Ocean Plan compliance standards apply (i.e., stations F11, F12), while two other OOR events also for natural light occurred at stations F18 and F20 located very near the 3 nautical mile State waters boundary. Additionally, the OOR events for stations F11 and F12 are more likely to be influenced by outflows from the nearby San Diego River than to inshore dispersion of the wastewater plume from the PLOO.

Summary

Water quality conditions in the Point Loma outfall region were excellent during 2014. Overall compliance with Ocean Plan water-contact standards was >99%, which was similar to that observed during the previous year (City of San Diego 2014). In addition, there was no evidence that wastewater discharged into the ocean via the PLOO reached

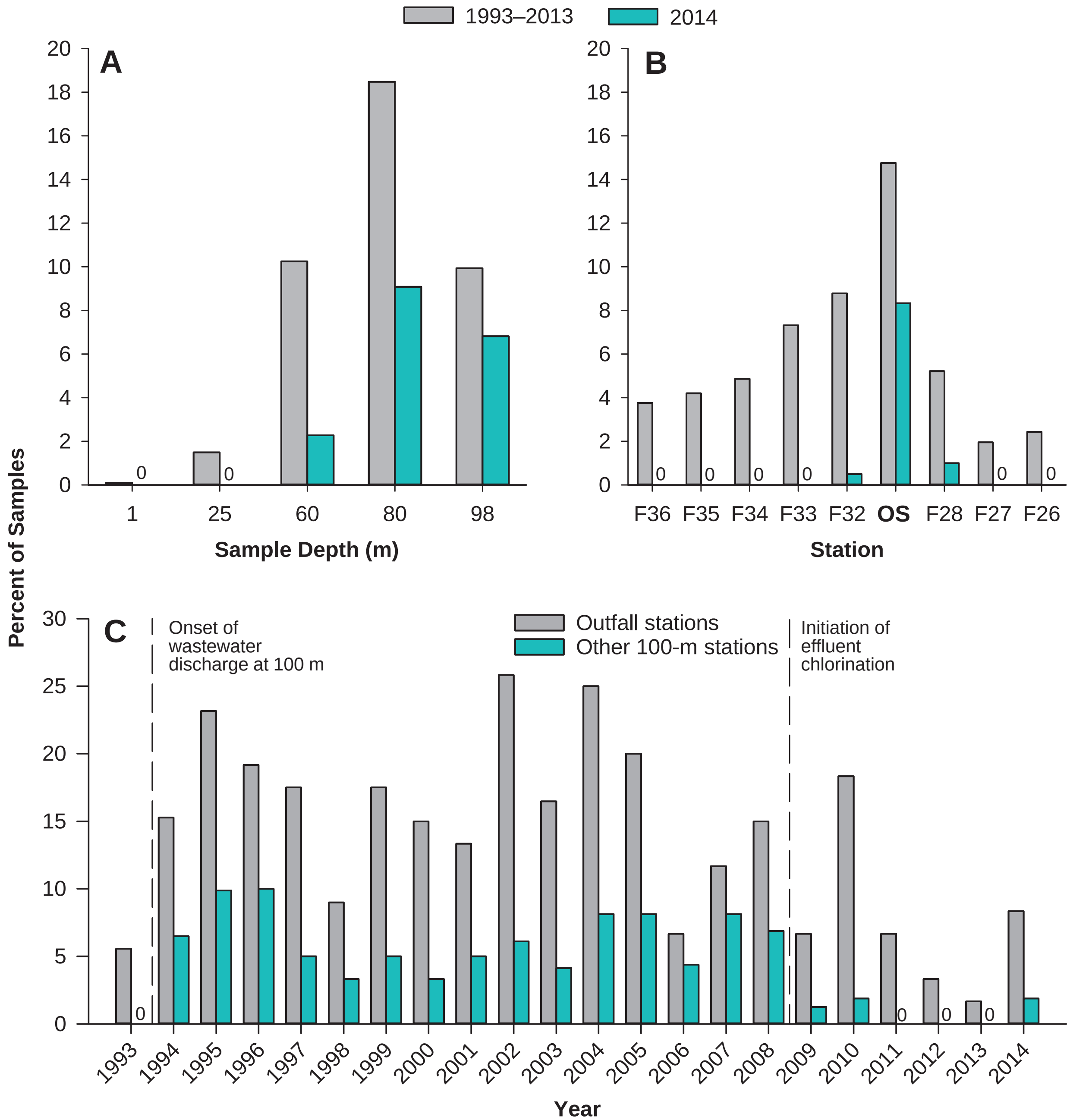

Figure 3.6

Percent of samples collected from PLOO 100-m offshore stations with elevated *Enterococcus* densities. Samples from 2014 are compared to those collected from 1993 through 2013 by (A) sampling depth, (B) stations listed north to south from left to right, and (C) year. OS = outfall stations (F29, F30, F31).

inshore of the 60-m stations. Elevated FIB densities were detected in 11 samples collected from six of the eight shoreline stations sampled during the year, while elevated bacterial counts were detected from a single sample at the kelp bed stations. Historically, elevated FIB counts along the shore or at the kelp bed stations have typically been associated with rainfall, heavy recreational use, the presence of seabirds, or decaying kelp or surfgrass (e.g., City of San Diego 2009–2014). The main exception to this pattern occurred during a few months in 1992 following a catastrophic break of the outfall that occurred within the Point Loma kelp bed (e.g., Tegner et al. 1995).

There were few instances of elevated FIB concentrations at the 36 offshore water quality stations sampled in the PLOO region during 2014. Eight of 11 samples with elevated levels of

Table 3.3
Summary of ammonia concentrations in samples collected from the 23 PLOO kelp bed and offshore stations located within State jurisdictional waters during 2014. Data include the number of samples per month (n) and detection rate, as well as the minimum, maximum, and mean[a] detected concentrations for each month. The method detection limit for ammonia = 0.01 mg/L; nd = not detected.

	Feb	May	Aug	Nov
9-m Depth Contour (n = 9)				
Detection Rate (%)	0	11	0	33
Min	—	nd	—	nd
Max	—	0.01	—	0.03
Mean	—	0.01	—	0.02
18-m Depth Contour (n = 24)				
Detection Rate (%)	0	42	0	29
Min	—	nd	—	nd
Max	—	0.17	—	0.03
Mean	—	0.05	—	0.02
60-m Depth Contour (n = 27)				
Detection Rate (%)	7	81	0	7
Min	nd	nd	—	nd
Max	0.04	0.12	—	0.03
Mean	0.03	0.05	—	0.02
80-m Depth Contour (n = 12)				
Detection Rate (%)	0	25	0	8
Min	—	nd	—	nd
Max	—	0.03	—	0.01
Mean	—	0.02	—	0.01

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

Enterococcus were collected from a depth of 80 m or greater from stations located along the 100-m depth contour. Only two of the samples with elevated *Enterococcus* were collected from stations located within State jurisdictional waters. Additionally, detection of the PLOO wastewater plume and its effects on physical water quality indicators was low during the year.

These results are consistent with previous studies that have indicated the PLOO wastefield typically remains offshore and submerged in deep waters ever since the extension of the outfall was completed in late 1993 (e.g., City of San Diego 2007–2015c, Rogowski et al. 2012a, b, 2013). The deepwater location of the discharge site may be the dominant factor that inhibits the plume from reaching surface waters. For example, wastewater released into these deep, cold and dense waters does not appear to mix with the upper 25 m of the water column (Rogowski et al. 2012a, b, 2013). Further, it appears that not only is the plume being trapped below the pycnocline, but now that effluent is undergoing partial chlorination prior to discharge, densities of fecal indicator bacteria have dropped significantly at all offshore stations along the discharge depth contour, including those nearest the outfall.

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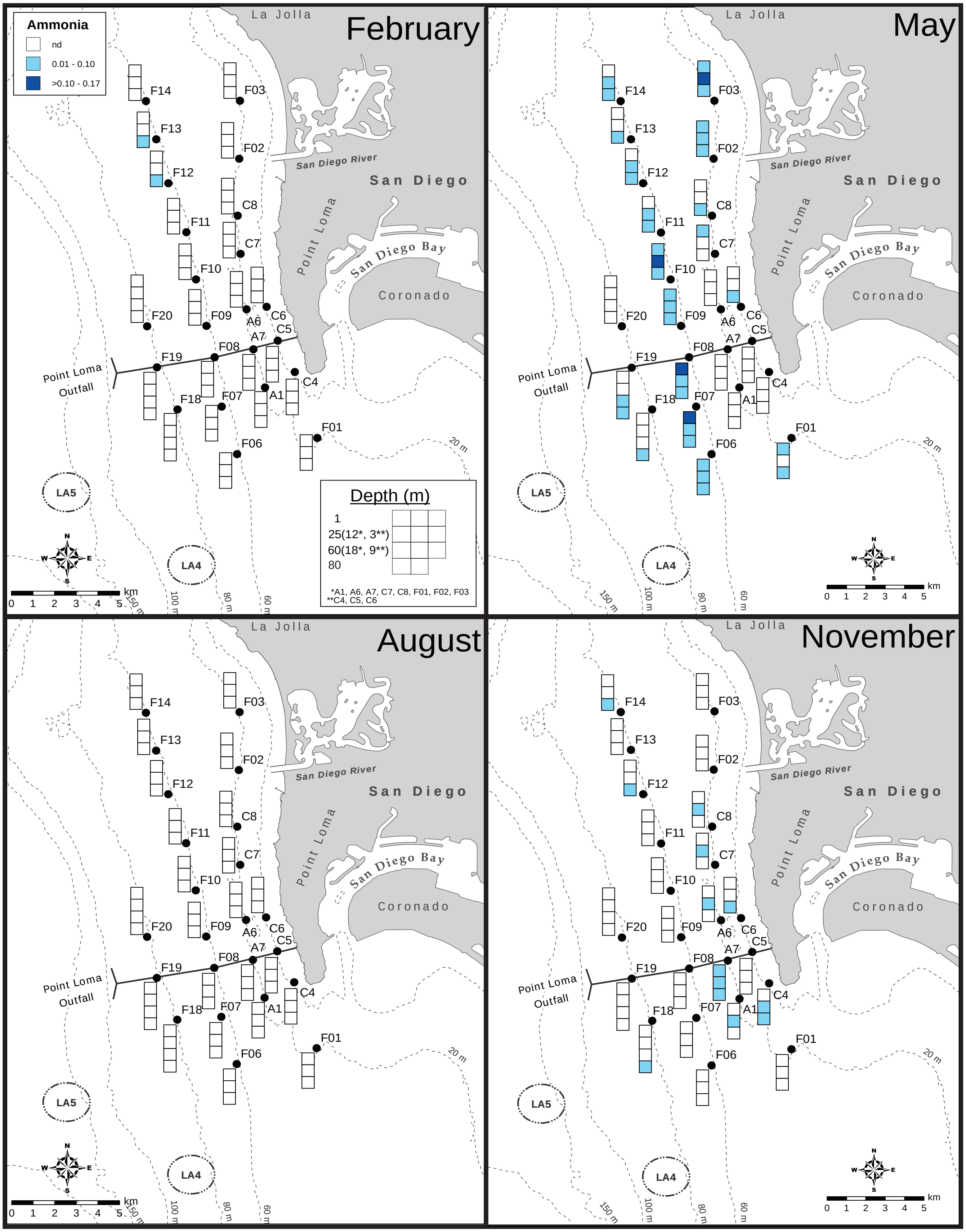

Figure 3.7

Distribution of ammonia (as nitrogen, mg/L) in seawater samples collected during the PLOO quarterly surveys in 2014. See text and Table 3.1 for sampling details; nd = not detected.

Table 3.4
Summary of potential wastewater plume detections and out-of-range values at PLOO offshore stations during 2014. Stations within State jurisdictional waters are in bold. DO = dissolved oxygen; XMS = transmissivity.

	Potential	Out of Range			
Month	**Plume Detections**	**DO**	**pH**	**XMS**	**Stations**
Feb	6	0	0	5	**F11**[b], **F20**[b], F21[b], F22[b], F23, F30[b]
May	4	0	0	1	**F19**, F30[b], F31, F32
Aug	11	0	0	6	**F12**[b], F16, F17[b], **F18**[b], F26, F27, F28[b], F29[b], F30[b], F31, F32
Nov	3	3	0	2	F28[a], F29[ab], F30[ab]
Detection Rate (%)	16.7	2.1	0.0	9.7	
Total Count	24	3	0	14	
n	144	144	144	144	

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

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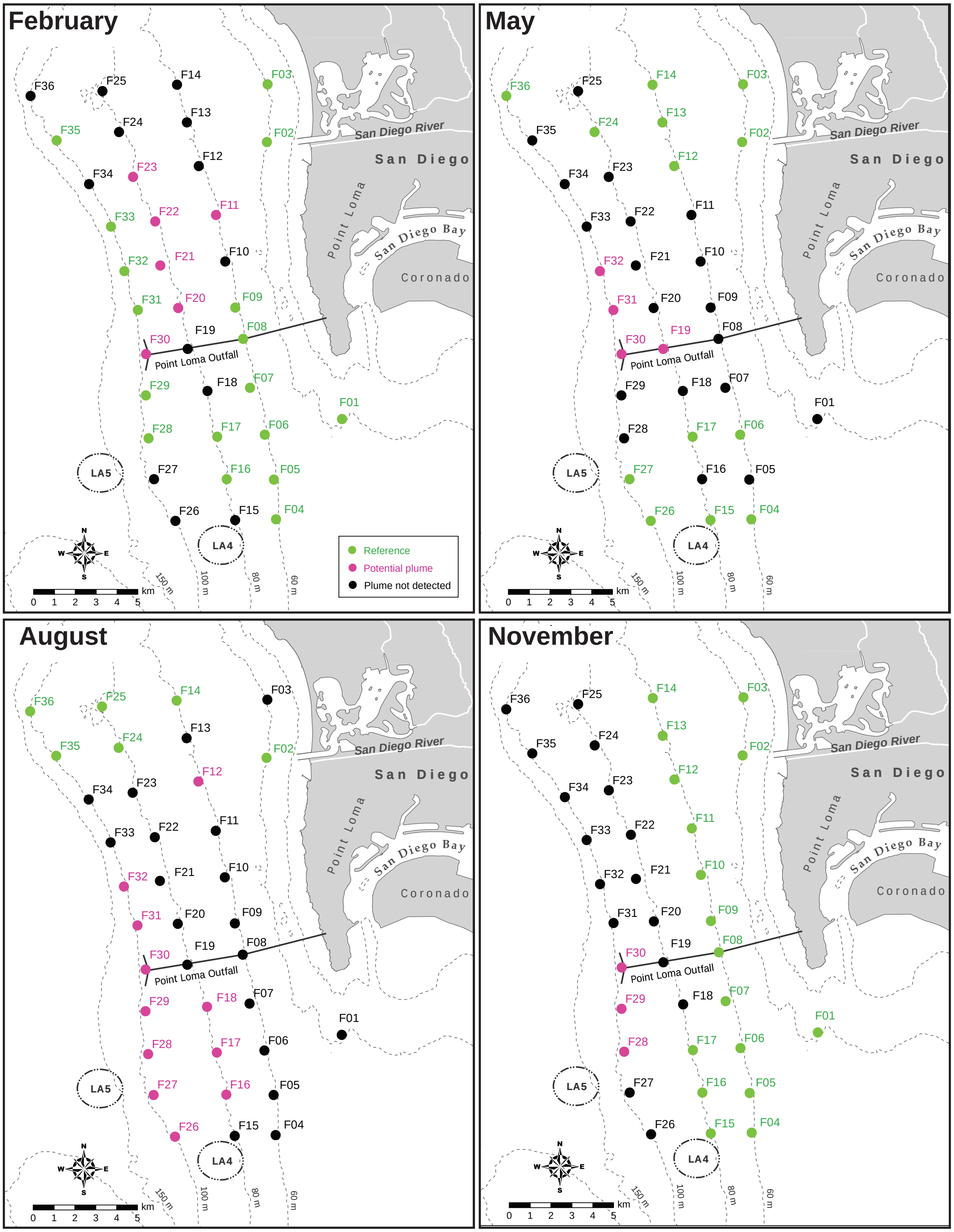

Figure 3.8

Distribution of stations where potential wastewater plume was detected and those used as reference stations for water quality compliance calculations during the PLOO quarterly surveys in 2014.

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Chapter 4
Sediment Conditions

Chapter 4. Sediment Conditions

Introduction

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

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

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

This chapter presents analysis and interpretation of sediment particle size and chemistry data collected at monitoring stations surrounding the PLOO during calendar year 2014. The primary goals are to: (1) document sediment conditions; (2) identify possible effects of wastewater discharge on sediment quality in the region; (3) identify other potential natural and anthropogenic sources of sediment contaminants to the local marine environment.

Materials and Methods

Field Sampling

Sediment samples were collected at 22 monitoring stations in the PLOO region during winter (January) and summer (July) of 2014 (Figure 4.1). These stations are distributed along or adjacent to three main depth contours, with the primary core stations located along the 98-m contour (i.e., outfall discharge depth), and the secondary core stations located along the 88-m or 116-m contours. These farfield sites include 18 'E' stations ranging from ~5 km south to ~8 km north of the outfall, and five 'B' stations located ~10–12 km north of the tip of the northern diffuser leg (see Chapter 1). The three stations located closest (i.e., within 200 m) to the boundary of the zone of initial dilution (ZID) are considered to represent near-ZID conditions (i.e., stations E11, E14, E17).

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

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Environmental Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2015a). Briefly, sediment sub-samples were analyzed on a dry weight basis to determine concentrations of various indictors of organic loading (i.e., biochemical oxygen demand, total organic carbon, total nitrogen, total sulfides, total volatile solids), 18 trace metals, 9 chlorinated pesticides, 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs). Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix C.1). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry.

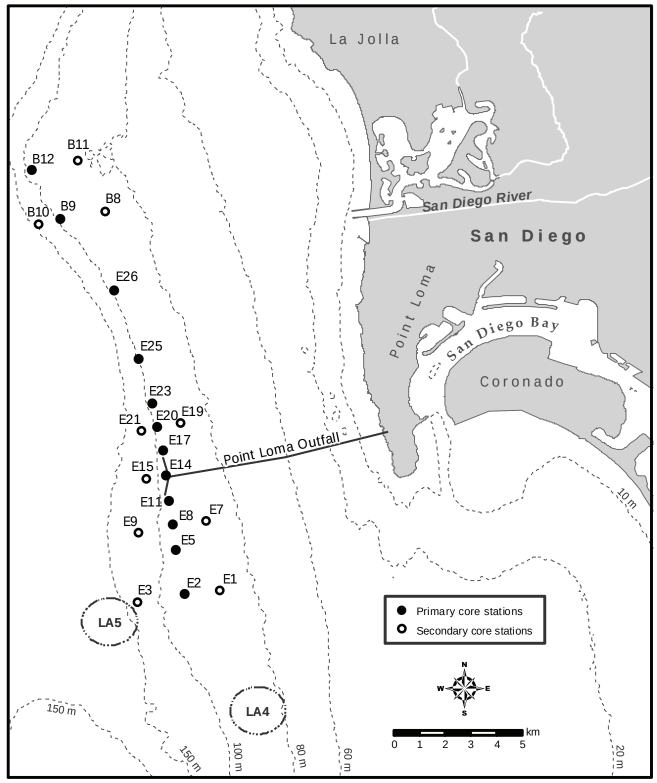


Figure 4.1
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of nested sieves. The Horiba measures particles ranging in size from 0.5 to 2000 µm. Coarser sediments were removed and quantified prior to laser analysis by screening samples through a 2000 µm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%, and then classified into 11 sub-fractions and 4 main size fractions based on the Wentworth scale (Folk 1980) (see Appendix C.2). When a sample contained substantial amounts of coarse sand, gravel, or shell hash that could damage the Horiba analyzer and/or where the general distribution of sediments would be poorly represented by laser analysis, a set of sieves with mesh sizes of 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, and 63 µm was used to divide the samples into seven sub-fractions.

Data Analyses

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

Multivariate analyses were performed using PRIMER v6 software to examine spatio-temporal patterns in the overall particle size composition in the Point Loma outfall region (see Clarke and Warwick 2001, Clarke and Gorley 2006). These included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). Proportions of silt and clay sub-fractions were combined as percent fines to accommodate sieved samples and Euclidean distance was used as the basis for the cluster analysis. Similarity percentages analysis (SIMPER) was used to determine which sub-fractions were responsible for the greatest contributions to within-group similarity and between group dissimilarity for retained clusters.

Results

Particle Size Distribution

Ocean sediments sampled off Point Loma were composed primarily of fine particles (i.e., silt and clay; also referred to as percent fines) and fine sands during 2014. Percent fines ranged from 14 to 63% per sample, while fine sands ranged from 37 to 83%, medium-coarse sands ranged from < 1 to 32%, and coarse particles ranged from 0 to 7% per sample (Table 4.1, Figure 4.2). Coarser particles often included black sand, gravel, pea gravel, rock, and/or shell hash (Appendix C.4). Particle size composition varied within sites between the winter and summer surveys by as much as 20% per size fraction, with the greatest intra-station differences occurring at northern stations B10 and B11. Overall, there were no spatial patterns in sediment composition relative to the PLOO discharge site. For example, sediments collected from nearfield stations ranged from 31 to 41% fines and 59 to 68% fine sands per sample, while sediments > 1000 m from the outfall ranged from 14 to 63% fines and 37 to 83% fine sands per sample. These results are consistent with the findings from long term analyses reported previously (City of San Diego 2014a, 2015b).

Classification (cluster) analysis of the 2014 particle size sub-fraction data discriminated five main cluster groups (cluster groups 1–5; Figure 4.3). SIMPER results indicated that these five groups were primarily distinguished by proportions of fines, very fine sand, and medium sand. Cluster group 1 included the summer sample from northern station B10. Sediments in this sample had the largest proportion of very fine sand (70%), the smallest proportion of percent fines (14%), and it was one of three groups with coarse sand, very coarse sand, and granules present. Cluster group 2 comprised four samples, including both winter and summer samples from northern station B12 and southern station E3. These sediments had the lowest proportion of very fine sand (16% per

Table 4.1

Summary of particle sizes and chemistry concentrations in sediments from PLOO benthic stations sampled during 2014. Data include the detection rate (DR), mean, minimum, and maximum values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1991–1993) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold; na = not available; nd = not detected.

	2014 Summary[a]				Pre-discharge		
Parameter	**DR (%)**	**Mean**	**Min**	**Max**	**Max**	**ERL[b]**	**ERM[b]**
Particle Size							
Coarse Particles(%)	—	0.8	0.0	7.3	26.4	na	na
Med-Coarse Sands (%)	—	5.4	0.1	31.6	41.6	na	na
Fine sands (%)	—	54.1	36.7	82.8	72.6	na	na
Fines (%)	—	39.7	13.9	63.2	74.4	na	na
Organic Indicators							
BOD (ppm)	100	291	140	610	656	na	na
Sulfides (ppm)	100	8.75	1.15	68.20	20.0	na	na
TN (% weight)	100	0.043	0.005	0.085	0.074	na	na
TOC (% weight)	100	0.51	0.16	1.39	1.24	na	na
TVS (% weight)	100	2.23	1.60	3.55	4.0	na	na
Trace Metals (*ppm*)							
Aluminum	100	8281	5030	14,500	na	na	na
Antimony	100	0.7	0.3	1.2	6.0	na	na
Arsenic	100	2.85	1.41	6.41	5.6	8.2	70
Barium	100	36.42	20.00	80.40	na	na	na
Beryllium	32	0.13	nd	0.22	2.01	na	na
Cadmium	34	0.08	nd	0.12	6.10	1.2	9.6
Chromium	100	15.7	10.1	26.9	43.6	81	370
Copper	100	4.9	2.1	11.8	34.0	34	270
Iron	100	12,133	7560	24,900	26,200	na	na
Lead	100	4.5	2.2	8.3	18.0	46.7	218
Manganese	100	94.1	54.8	162.0	na	na	na
Mercury	100	0.020	0.004	0.062	0.096	0.15	0.71
Nickel	100	7.2	4.7	10.2	14.0	20.9	51.6
Selenium	23	0.18	nd	0.42	0.90	na	na
Silver	0	nd	nd	nd	4.00	1.0	3.7
Thallium	30	0.9	nd	1.8	113.0	na	na
Tin	100	1.1	0.6	1.6	na	na	na
Zinc	100	30.3	18.5	43.4	67.0	150	410
Pesticides (*ppt*)							
Total DDT	98	960	nd	17,830	13,200	1580	46,100
HCB	9	599	nd	1600	nd	na	na
Total chlordane	2	610	nd	610	nd	na	na
Total PCB (*ppt*)	30	3558	nd	22,690	na	na	na
Total PAH (*ppb*)	89	81	nd	1173	199	4022	44,792

[a] Minimum and maximum values were based on all samples (n = 44), whereas means were calculated on detected values only (n ≤ 44)

[b] From Long et al. 1995

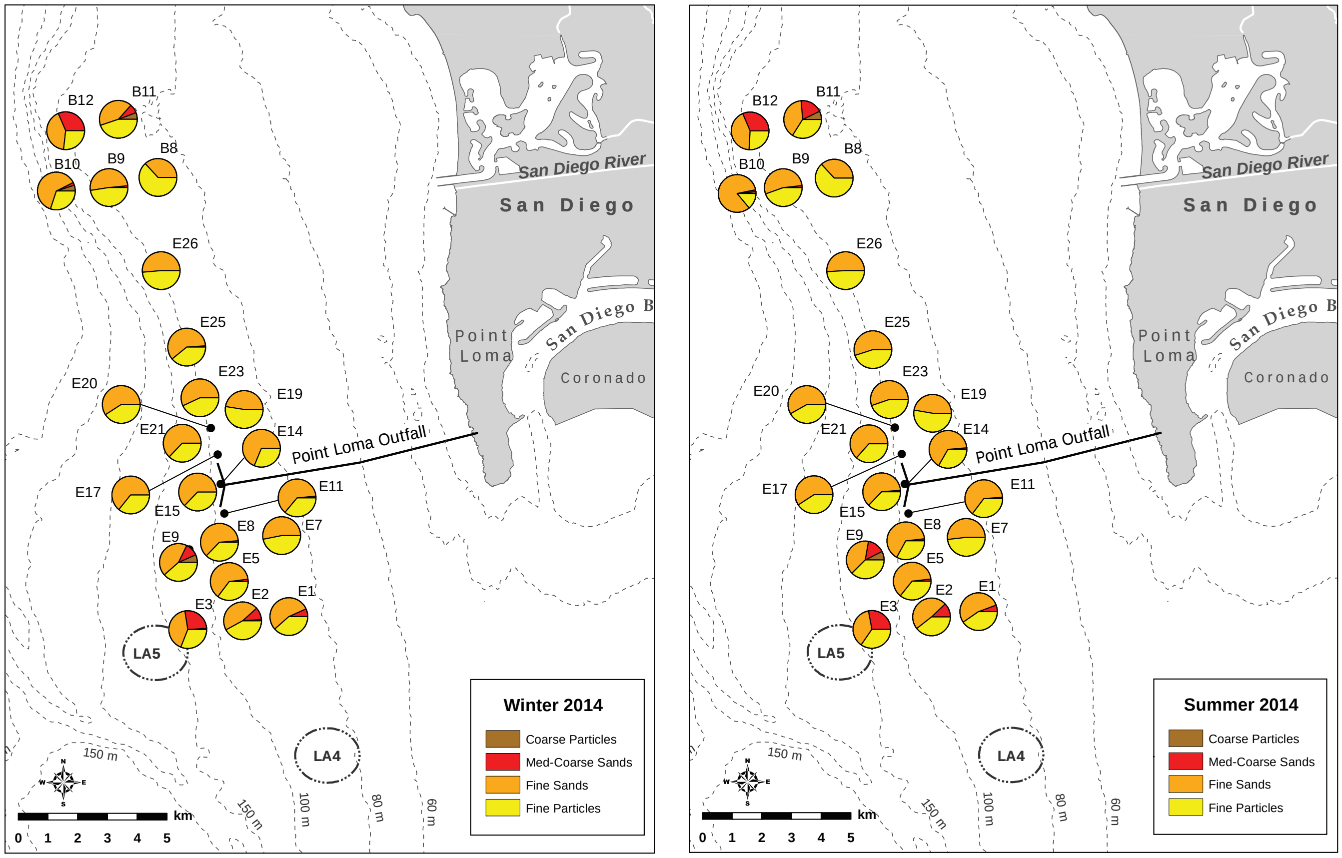


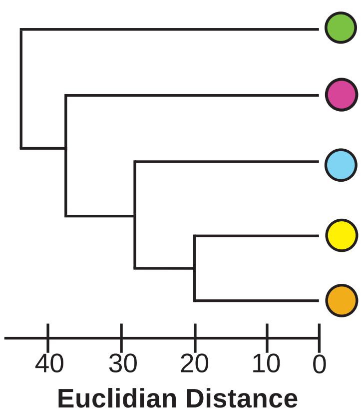
Figure 4.2
Sediment composition at PLOO benthic stations sampled in 2014 during winter and summer surveys.

sample), and the highest proportions of fine sand (25% per sample), medium sand (23% per sample), and coarse sand (7% per sample). This group also had trace amounts of very coarse sand and granules present. Cluster group 3 included winter and summer samples from northern station B8. Sediments in these samples had the largest proportion of fines (63% per sample), the smallest proportion of medium sand (0.1% per sample), as well as 31% very fine sand and 6% fine sand per sample. Coarse sand, very coarse sand, and granules were absent from these group 3 sediments. Cluster group 4 comprised eight samples, including the winter and summer samples from northern station B11 and southern stations E1, E2, and E9. Sediments at these stations averaged 39% fines, 29% very fine sand, 17% fine sand, 7% medium sand, 4% coarse sand, 2% very coarse sand, and 1% granules per sample. Cluster group 5 represented the remaining 29 samples collected during the year, including all 6 samples from the three near-ZID stations. Sediments in these samples averaged 40% fines, 44% very fine sand, 15% fine sand, and 1% medium sand per sample. Coarse sand, very coarse sand, and granules were absent from these sediments.

Indicators of Organic Loading

Indicators of organic loading in benthic sediments, including biochemical oxygen demand (BOD), sulfides, total nitrogen (TN), total organic carbon (TOC), and total volatile solids (TVS), were detected in all sediment samples collected from the Point Loma outfall region during 2014 (Table 4.1). BOD concentrations ranged from 140 to 610 ppm, while sulfides ranged from 1.15 to 68.20 ppm, TN ranged from 0.005 to 0.085% weight, TOC ranged from 0.16 to 1.39% weight, and TVS ranged from 1.60 to 3.55% weight. Of these five indicators only sulfides, TN, and TOC were detected at concentrations higher than observed

A



Cluster Group	n	Percent Fines	Fine Sands: VFSand	Fine Sands: FSand	Med-Coarse Sands: MSand	Med-Coarse Sands: CSand	Coarse Particles: VCSand	Coarse Particles: Granules
1	1	13.9	70.4	12.4	1.2	0.5	0.6	1.0
2	4	29.6	16.0	24.7	22.8	6.5	0.1	0.3
3	2	63.2	31.1	5.7	0.1	0.0	0.0	0.0
4	8	39.4	29.0	17.0	7.3	3.7	2.4	1.0
5	29	40.4	43.6	14.9	1.0	0.0	0.0	0.0

B

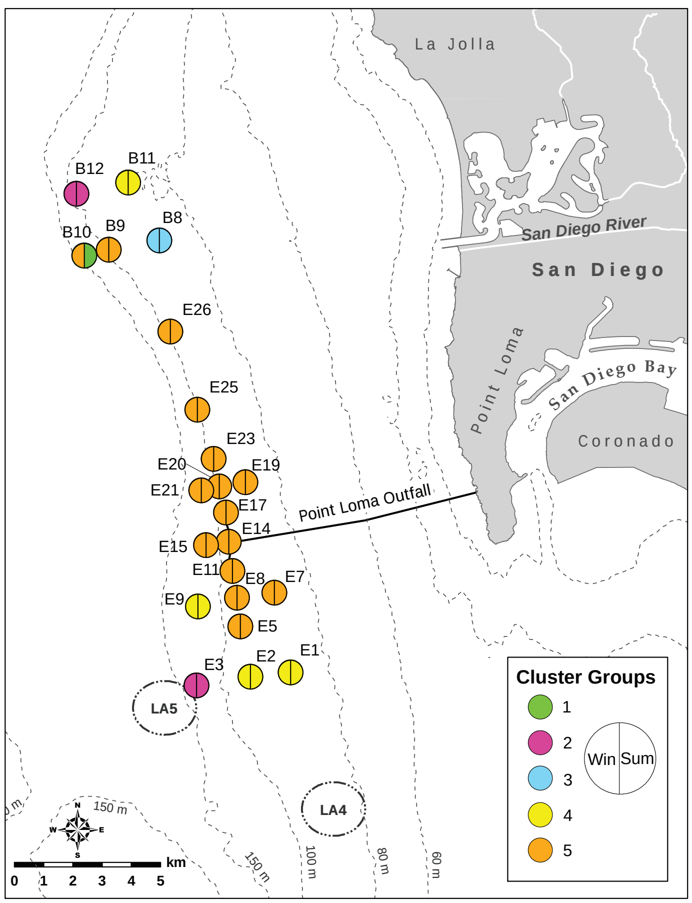


Figure 4.3

Results of cluster analysis of particle size sub-fraction data from PLOO benthic stations sampled during 2014. Data are presented as: (A) dendrogram of main cluster groups and (B) distribution of sediment samples as delineated by cluster analysis. Data for particle size sub-fractions are mean percentages calculated over all stations within a cluster group (n). VFSand = Very Fine Sand; FSand = Fine Sand; MSand = Medium Sand; CSand = Coarse Sand; VCSand = Very Coarse Sand.

before wastewater discharge began. The highest TN (≥0.066% weight), TOC (≥0.74% weight), and TVS (≥3.13% weight) concentrations occurred at the northern 'B' stations located at least 10 km north of the outfall (e.g., Figure 4.4, Appendix C.5). In contrast, the highest sulfide and BOD concentrations occurred at near-ZID station E14 located nearest the discharge zone (Figure 4.4). In general, only sulfide and BOD concentrations have shown changes near the outfall that appear consistent with possible organic enrichment (City of San Diego 2014a, 2015b).

Trace Metals

Thirteen trace metals were detected in all sediment samples collected in the PLOO region during 2014, including aluminum, antimony, arsenic, barium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, and zinc (Table 4.1, Appendix C.6). Beryllium, cadmium, selenium, and thallium were also detected, but in fewer samples (23–34%). Silver was not detected in any PLOO sediment samples collected during the year. Each of the nine metals with published ERLs and ERMs (see Long et al. 1995) were reported at levels below these thresholds. Additionally, the majority of metals were detected at levels within ranges reported prior to wastewater discharge off Point Loma, and/or elsewhere in the Southern California Bight (SCB) (e.g., Schiff et al. 2011, City of San Diego 2015b). Only arsenic was reported at levels higher than pre-discharge values. In addition to being low overall, metal concentrations varied between stations with no discernible patterns relative to the outfall. Instead, the highest levels of several metals occurred in sediments from one or more of the northern 'B' stations or southern 'E' stations. For example, the highest concentrations of barium (≥50.6 ppm) occurred at stations B9, B11, E2, and E3, while the highest concentrations of chromium (≥21.3 ppm) occurred at stations B8, B11, and B12, the highest concentrations of copper (≥9.5 ppm) occurred at stations E2, E3, and E9, the highest concentrations of lead (≥6.6 ppm) occurred at stations B8, B11, and E3, and the highest concentrations of zinc (≥38.9 ppm) occurred at stations B11, B12, and E5 (e.g., Figure 4.4). These results are consistent with the findings from long term analyses reported previously (City of San Diego 2014a, 2015b).

Pesticides

Three chlorinated pesticides were detected in PLOO sediments during 2014, including DDT, hexachlorobenzene (HCB), and chlordane (Table 4.1, Appendix C.3, C.7). Total DDT, composed primarily of p,p-DDE, was detected in 98% of the sediment samples at concentrations up to 17,830 ppt. Two samples, collected at stations B9 and B10 in summer, had total DDT values in excess of the ERL threshold of 1580 ppt (Figure 4.4). However, neither of these samples exceeded the ERM threshold. HCB was detected in four sediment samples from stations B11, E15, E20, and E23 during the summer of 2014 at concentrations up to 1600 ppt. Total chlordane, composed of heptachlor and trans nonachlor, was found in a single sediment sample collected from station E9 during the summer at a concentration of 610 ppt. The pesticides HCH, aldrin, endosulfan, dieldrin, endrin, and mirex were not detected during 2014. These results are consistent with the findings from long term analyses reported previously (City of San Diego 2014a, 2015b).

PCBs

PCBs were detected in 30% of the sediment samples collected around the PLOO in 2014 (Table 4.1). Total PCB had a maximum concentration of 22,690 ppt, reported from station E2 during the winter (Figure 4.4, Appendix C.7). The most commonly detected PCB congeners that occurred in ≥18% of the samples were PCB 101, PCB 110, PCB 118, PCB 138, and PCB 153/168 (Appendix C.3). Although no ERL or ERM thresholds exist for PCBs measured as congeners, all PCB values recorded during the year were within ranges reported previously for the SCB (e.g., Schiff et al. 2011). Historically, PCBs have been detected infrequently at low concentrations in the PLOO region with no evident patterns relative to the outfall (City of San Diego 2014a, 2015b). Instead, PCBs have been detected most frequently at the southern 'E' stations.

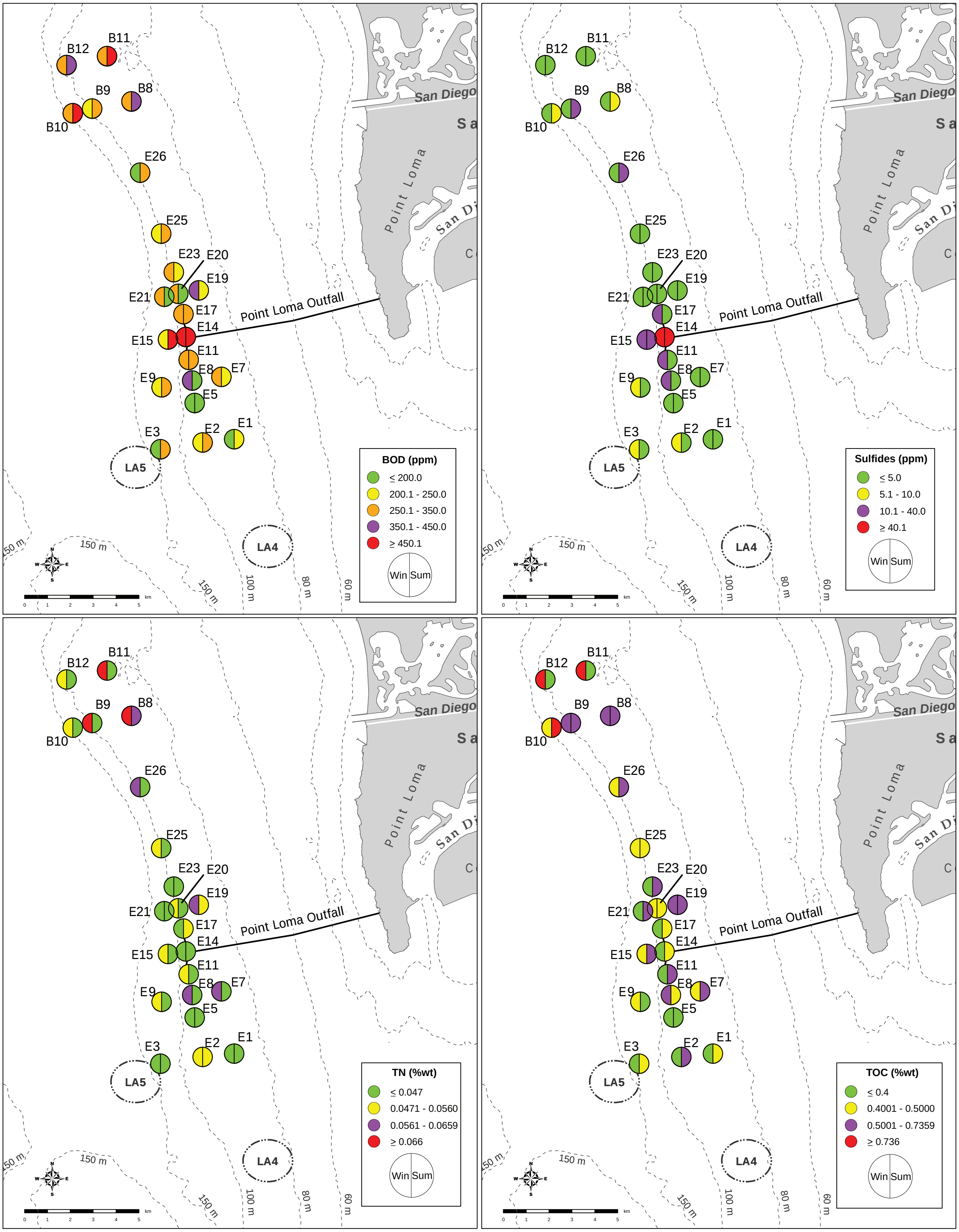


Figure 4.4

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

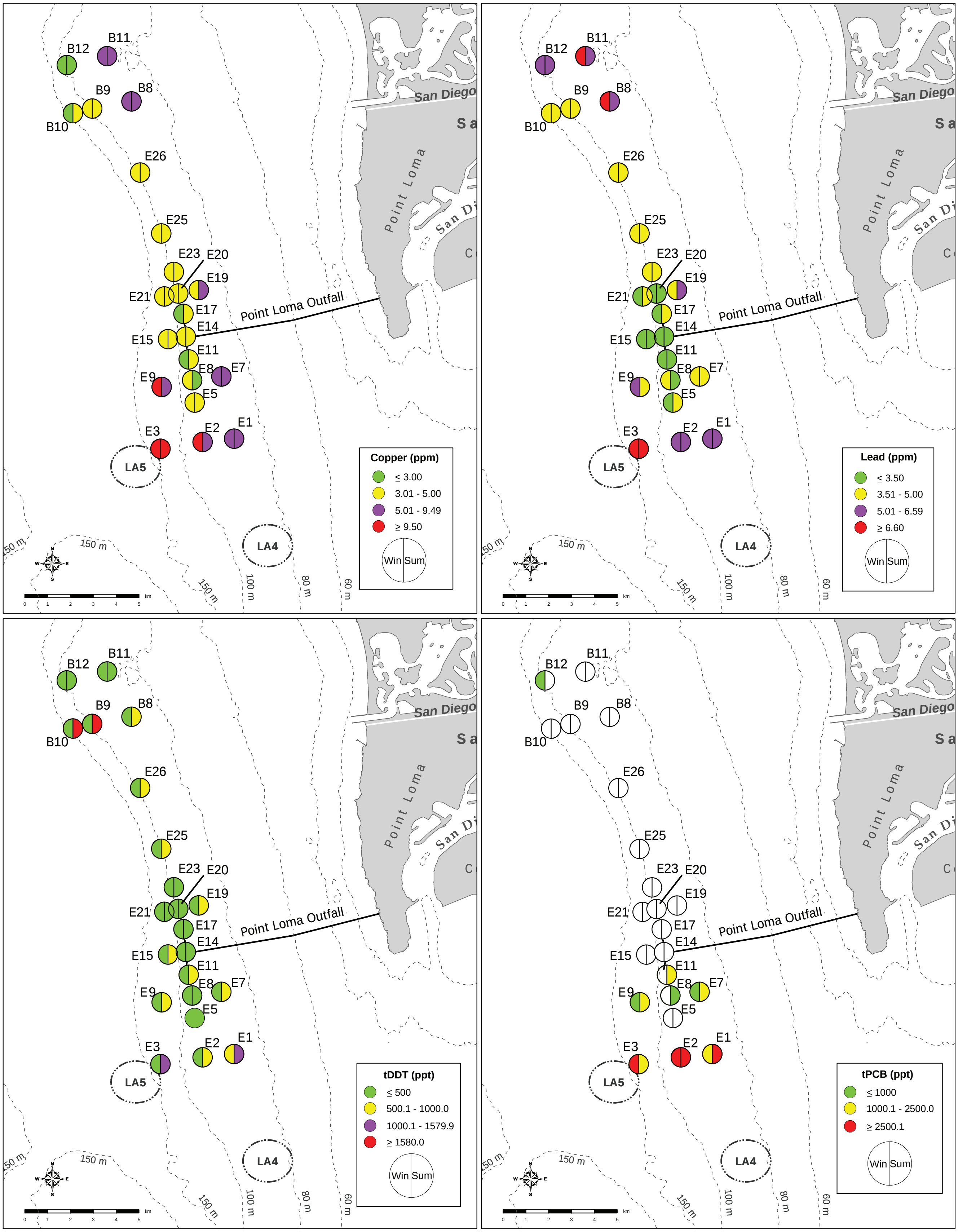


Figure 4.4 *continued*

PAHs

PAHs were detected in 89% of the sediment samples collected from the Point Loma outfall region in 2014 (Table 4.1, Appendix C.3, C.7). Concentrations of total PAH reached 1173 ppb during the year, above the pre-discharge maximum of 199 ppb but well below the ERL threshold of 4022 ppb and the Bight'08 maximum of 14,065 ppb (Schiff et al. 2011). The most frequently recorded compound was 2,6-dimethylnaphthalene; it occurred in 97% of the samples with detectable levels of PAHs. Other individual PAHs found during the year included 1-methylnaphthalene, 2-methylnaphthalene, 3,4-benzo(B)fluoranthene, benzo[A]anthracene, acenaphthene, acenaphthylene, anthracene, benzo[e]pyrene, benzo[G,H,I]perylene, benzo[K] fluoranthene, biphenyl, chrysene, dibenzo(A,H) anthracene, fluoranthene, fluorene, indeno(1,2,3-CD)pyrene, perylene, phenanthrene, and pyrene. Over the past 24 years, PAHs have been detected infrequently, with all reported values below the ERL, and there have been no patterns indicative of a wastewater impact at the primary core stations (Appendix C.7, City of San Diego 2014a, 2015b). As with PCBs, PAHs have been detected most frequently at the southern 'E' stations.

Discussion

Particle size composition at the PLOO stations was similar in 2014 to that reported during recent years (City of San Diego 2014a, 2015b), with percent fines (silt and clay) and fine sands composing the largest proportion of all sediments. No spatial relationship was evident between sediment composition and proximity to the outfall discharge site, nor has there been any substantial increase in percent fines at near-ZID stations or throughout the region since wastewater discharge began. Overall, variability in the composition of sediments off Point Loma is likely affected by both anthropogenic and natural influences, including outfall construction materials, offshore disposal of dredged materials, multiple geologic origins of different sediment types, and recent deposition of sediment and detrital materials (Emery 1960, Parnell et al. 2008, City of San Diego 2015b). The Point Loma outfall lies within the Mission Bay littoral cell (Patsch and Griggs 2007), with natural sources of sediments including outflows from Mission Bay, the San Diego River, and San Diego Bay. However, fine particles may also travel in suspension across littoral cell borders up and down the coast (e.g., Farnsworth and Warrick 2007, Svejkovsky 2013), thus widening the range of potential sediment sources to the region.

Various organic indicators, trace metals, pesticides, PCBs, and PAHs were detected in sediment samples collected throughout the PLOO region in 2014, though concentrations were all below ERM thresholds, mostly below ERL thresholds, and/or within historical ranges (City of San Diego 2014a, 2015b). Additionally, values for most sediment parameters remained within ranges typical for other areas of the southern California continental shelf (see Schiff and Gossett 1998, City of San Diego 2000, 2014b, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

There have been few spatial patterns consistent with an outfall effect on sediment chemistry over the past several years, with concentrations of most contaminants at the three near-ZID sites falling within the range of values at the farfield stations. The only exceptions were slightly higher sulfide and BOD levels near the outfall (City of San Diego 2014a, 2015b). Instead, the highest concentrations of several organic indicators, trace metals, pesticides, PCBs, and PAHs have been found in sediments from the southern and/or northern farfield stations. Historically, concentrations of contaminants have been higher in sediments at southern sites such as stations E1–E3, E5, and E7–E9 than elsewhere off San Diego (City of San Diego 2014a, 2015b). This pattern may be due in part to the dumping of dredged materials destined originally for the LA-5 dumpsite (Anderson et al. 1993, Steinberger et al. 2003, Parnell et al. 2008).

The broad distribution of various contaminants in sediments throughout the PLOO region is likely derived from several sources. Mearns et al. (1991) described the distribution of contaminants such as arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB, while Brown et al. (1986) determined that there may be no coastal areas in southern California that are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent surveys of SCB continental shelf habitats (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011). The lack of contaminant-free reference areas clearly pertains to the Point Loma outfall region as demonstrated by the presence of many contaminants in sediments prior to wastewater discharge (see City of San Diego 2015b). Further, historical assessments of sediments off the coast of Los Angeles have shown that as wastewater treatment has improved, sediment conditions are more likely affected by other factors (Stein and Cadien 2009). These factors may include bioturbative re-exposure of buried legacy sediments (Niedoroda et al. 1996, Stull et al. 1996), large storms that assist redistribution of legacy contaminants (Sherwood et al. 2002), and stormwater discharges (Schiff et al. 2006, Nezlin et al. 2007). Possible non-outfall sources and pathways of contaminant dispersal off San Diego include transport of contaminated sediments from San Diego Bay via tidal exchange, offshore disposal of sediments dredged from the Bay, and surface runoff from local watersheds (Parnell et al. 2008).

Overall, there is little evidence of contaminant loading or organic enrichment in sediments throughout the PLOO region after 21 years of wastewater discharge. For example, concentrations of most indicators continue to occur at low levels below available thresholds and within the range of variability typical for the San Diego region (e.g., see City of San Diego 2014a, 2015b). The only sustained effects have been restricted to a few sites located within about 300 m of the outfall (i.e., nearfield stations E11, E14, E17). These effects include measurable increases in sulfide and BOD concentrations (City of San Diego 2015b). However, there is no evidence to suggest that wastewater discharge is affecting the quality of benthic sediments in the region to the point that it will degrade the resident marine biota (e.g., see Chapters 5 and 6).

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Chapter 5
Macrobenthic Communities

Chapter 5. Macrobenthic Communities

Introduction

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

The structure of marine macrobenthic communities is influenced by naturally occurring factors such as differences in depth, sediment composition (e.g., fine versus coarse sediments), sediment quality (e.g., contaminant loads, toxicity), oceanographic conditions (e.g., temperature, dissolved oxygen, nutrient levels, currents), and biological interactions (e.g., competition, predation, bioturbation). In soft-bottom benthic habitats along the Southern California Bight (SCB) continental shelf, macrofaunal assemblages often vary along depth gradients and/or with sediment particle size (Bergen et al. 2001). Consequently, an understanding of background or reference conditions is necessary to provide the context to accurately identify whether spatial differences in populations of individual species or overall community structure may be attributable to anthropogenic activities or other factors. In the relatively nearshore environs off of San Diego, past monitoring efforts for both continental shelf (<200 m) and upper slope (200−500 m) habitats have led to considerable understanding of environmental variability for the region (City of San Diego 1999, 2013, 2015a, b, Ranasinghe et al. 2003, 2007, 2010, 2012). These efforts allow for spatial and temporal comparison of the present year's monitoring data with previous surveys to determine if and where changes due to wastewater discharge have occurred.

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

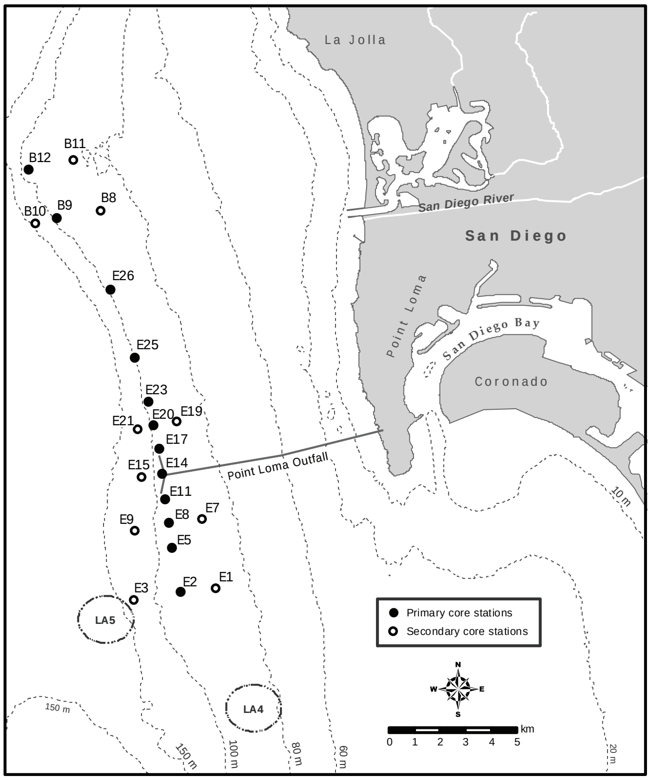

Figure 5.1
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

diversity coupled with dominance by a few pollution-tolerant species (Pearson and Rosenberg 1978).

This chapter presents analysis and interpretation of macrofaunal data collected at designated benthic monitoring stations surrounding the PLOO during calendar year 2014 and includes descriptions and comparisons of the different communities in the region. The primary goals are to: (1) characterize and document the benthic assemblages present during the year; (2) determine the presence or absence of biological impacts on these assemblages that may be associated with wastewater discharge; (3) identify other potential natural or anthropogenic sources of variability in the local marine ecosystem.

Materials and Methods

Collection and Processing of Samples

Benthic samples were collected at 22 monitoring stations in the PLOO region during winter (January) and summer (July) of 2014 (Figure 5.1). These stations are distributed along or adjacent to three main depth contours, with the primary core stations located along the 98-m contour (i.e., outfall discharge depth), and the secondary core stations located along the 88-m or 116-m contours. These farfield sites include 18 ‘E’ stations ranging from ~5 km south to ~8 km north of the outfall, and five ‘B’ stations located ~10–12 km north of the tip of the northern diffuser leg (see Chapter 1). The three stations located closest (i.e., within 200 m) to the boundary of the zone of initial dilution (ZID) are considered to represent near-ZID conditions (i.e., stations E11, E14, E17).

Samples for benthic community analysis were collected from one side of a double 0.1-m^2 Van Veen grab, while samples from the adjacent grab were used for sediment quality analyses (see Chapter 4). During 2014, only one macrofaunal grab was collected from each station during each survey due to a Bight’13 resource exchange agreement (see Chapter 1). Criteria established by the U.S. Environmental Protection Agency (USEPA) to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were brought aboard ship, washed with seawater, and sieved through a 1.0-mm mesh screen. The organisms retained on the screen were then collected, transferred to sample jars, and relaxed for 30 minutes in a magnesium sulfate solution before being fixed with buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol for final preservation. All macrofaunal organisms were sorted from the raw material into several higher taxonomic groups (i.e., Annelida, Arthropoda, Mollusca, Echinodermata, and miscellaneous phyla) by a subcontract lab, after which they were identified to species (or the lowest taxon possible) and enumerated by City marine biologists. All identifications followed nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT 2013).

Data Analyses

The following community structure parameters were determined for each station per 0.1-m^2 grab:

species richness (number of taxa), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (see Swartz et al. 1986, Ferraro et al. 1994), and benthic response index (BRI; see Smith et al. 2001).

To examine spatial and temporal patterns among benthic communities in the PLOO region, multivariate analyses were performed using methods available in PRIMER v6 software, which included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (see Clarke and Warwick 2001, Clarke and Gorley 2006, Clarke et al. 2008). The Bray-Curtis measure of similarity was used as the basis for clustering, and the macrofaunal abundance data were square-root transformed to lessen the influence of overly abundant species and increase the importance (or presence) of rare species. Major ecologically-relevant clusters receiving SIMPROF support were retained, and similarity percentages analysis (SIMPER) was used to determine which species were responsible for the greatest contributions to within-group similarity (i.e., characteristic species) and between-group dissimilarity for retained clusters. To determine whether macrofaunal communities varied by sediment particle size fractions, a RELATE test was used to compare patterns of rank abundance in the macrofauna Bray-Curtis similarity matrix with rank percentages in the sediment Euclidean distance matrix (see Chapter 4). A BEST test using the BIO-ENV procedure was conducted to determine which subset of sediment sub-fractions was the best explanatory variable for similarity between the two resemblance matrices.

A Before-After-Control-Impact-Paired (BACIP) statistical model was used to test the null hypothesis that there have been no changes in community parameters due to operation of the PLOO (Bernstein and Zalinski 1983, Stewart-Oaten et al. 1986, 1992, Osenberg et al. 1994). The BACIP model compares differences between control (reference) and impact stations at times before and after an impact event. The analyses presented in this report are based on 2.5 years (10 quarterly surveys) of before-impact data from July 1991–October 1993 and 21 years (61 quarterly or semi-annual surveys) of after-impact data from January 1994 through July 2014. The 'E' stations, located ~0.1–8 km from the outfall, are considered most likely to be affected by wastewater discharge (Smith and Riege 1994), whereas the 'B' stations located >10 km north of the outfall were originally designed to be control sites. However, benthic communities differed between the 'B' and 'E' stations prior to discharge (Smith and Riege 1994, City of San Diego 1995). Station E14 was selected as the impact site for all analyses due to its proximity to the boundary of the ZID making it most susceptible to impact. Stations E26 and B9 were selected to represent separate control sites in the BACIP tests. Station E26 is located 8 km north of the outfall and is considered the 'E' station least likely to be impacted, and previous analyses have suggested that station B9 was the most appropriate 'B' station for comparison with the 'E' stations (Smith and Riege 1994, City of San Diego 1995). Six dependent variables were analyzed, including number of species (species richness), macrofaunal abundance, the benthic response index (BRI), and abundances of three taxa considered sensitive to organic enrichment. These indicator taxa include ophiuroids in the genus *Amphiodia* (mostly *A. urtica*), and amphipods in the genera *Ampelisca* and *Rhepoxynius*. All BACIP analyses were interpreted using one-tailed paired t-tests with a type I error rate of $\alpha = 0.05$.

Results and Discussion

Community Parameters

Species richness

A total of 454 taxa were identified during the 2014 PLOO surveys. Of these, 377 (83%) were identified to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although 33% (n = 151) were recorded only once. One species not previously reported by the City's Ocean Monitoring Program was encountered, the pachynid amphipod *Prachynella oculata.*

Table 5.1

Summary of macrofaunal community parameters for PLOO benthic stations sampled during 2014. SR = species richness; Abun = abundance; H' = Shannon diversity; J' = evenness; Dom = Swartz dominance; BRI = benthic response index. Data for each station are expressed as annual means (n = 2). Stations are listed north to south from top to bottom for each depth contour.

	Station	SR	Abun	H'	J'	Dom	BRI
88-m Depth Contour	B11	106	254	4.2	0.90	45	11
	B8	66	197	3.3	0.80	24	10
	E19	84	340	3.5	0.80	24	12
	E7	85	308	3.8	0.85	30	14
	E1	81	336	3.4	0.78	24	12
98-m Depth Contour	B12	95	265	4.1	0.90	40	16
	B9	83	226	3.9	0.88	32	12
	E26	69	194	3.6	0.85	28	11
	E25	77	278	3.6	0.84	26	12
	E23	84	286	3.7	0.83	28	15
	E20	77	332	3.6	0.83	22	14
	E17[a]	79	325	3.6	0.83	24	17
	E14[a]	79	286	3.6	0.83	24	28
	E11[a]	94	407	3.8	0.84	27	17
	E8	89	312	3.9	0.86	32	14
	E5	82	297	3.7	0.84	26	14
	E2	91	270	3.9	0.87	35	13
116-m Depth Contour	B10	105	332	4.1	0.88	38	14
	E21	75	270	3.6	0.84	22	13
	E15	87	313	3.8	0.85	30	10
	E9	93	254	4.1	0.91	38	13
	E3	111	306	4.2	0.90	44	8
All Grabs	Mean	86	290	3.8	0.85	30	14
	95% CI	4	20	0.1	0.01	2	1
	Min	59	179	3.1	0.77	19	6
	Max	131	410	4.4	0.92	53	30

[a] near-ZID stations

Species richness averaged from 66 taxa per grab at station B8 located 9.8 km north of the outfall wye to 111 taxa per grab at station E3 located 4.2 km south of the wye (Table 5.1), and there were no clear patterns relative to the discharge site, depth, or sediment particle size (see Chapter 4). Additionally, species richness values at the different monitoring sites in 2014 (Appendix D.1) were within the range of 33–174 taxa per grab reported from 1991 through 2013 (City of San Diego 2015a), and all but one sample were within the tolerance interval range of 60–145 taxa per grab calculated for the region over an 18-year period (City of San Diego 2015b).

BACIP t-test results indicated a net change in the mean difference of species richness between impact station E14 and both control stations following the onset of wastewater discharge (Table 5.2). This change appears driven by increased variability and higher numbers of species at E14 during most surveys beginning in 1994 (Figure 5.2A);

Table 5.2

Results of BACIP t-tests for species richness (SR), infaunal abundance, BRI, and abundance of several indicator taxa around the PLOO (1991–2014). Critical t-value = 1.67 for $\alpha = 0.05$ (one-tailed t-tests, df = 69); ns = not significant.

Variable	Control vs. Impact	t	p
SR	E26 vs E14	-3.27	<0.001
	B9 vs E14	-3.20	0.001
Abundance	E26 vs E14	-1.74	0.044
	B9 vs E14	-2.79	0.003
BRI	E26 vs E14	-13.40	<0.001
	B9 vs E14	-10.10	<0.001
Amphiodia spp	E26 vs E14	-6.38	<0.001
	B9 vs E14	-4.32	<0.001
Ampelisca spp	E26 vs E14	-2.19	0.016
	B9 vs E14	-1.88	0.032
Rhepoxynius spp	E26 vs E14	-0.47	ns
	B9 vs E14	-0.65	ns

however, the cause of increased species richness near the discharge site remains unclear. For example, species richness has not co-varied with the concentrations of sulfides, total organic carbon, or total nitrogen present in the sediments at station E14 over the years (Appendix D.2), and sediment composition has remained somewhat consistent at this station, with no evidence that the proportion of fine particles has increased since wastewater discharge began (City of San Diego 2014, 2015a).

Macrofaunal abundance

A total of 12,780 macrofaunal individuals were recorded in 2014. Mean abundance ranged from 194 animals per grab at farfield station E26 to 407 per grab at nearfield station E11 (Table 5.1). Overall, no spatial patterns in abundance were observed related to discharge site, depth, or sediment particle size (see Chapter 4). During the past year, macrofaunal abundance at all stations was within the range of 70–1509 individuals per grab reported from 1991 through 2013 (see Appendix D.1 and City of San Diego 2015a). Additionally, 82% of grabs were within the tolerance interval range of 223–603 individuals per grab calculated for the region (City of San Diego 2015b). A total of eight samples collected from six of the farfield monitoring sites (stations E2, E3, E9, E26, B8, B9) had abundance values below the lower tolerance interval bound, while no samples exceeded the upper bound (Appendix D.1).

BACIP t-test results indicated a net change in macrofaunal abundance between impact station E14 and both control stations following the onset of wastewater discharge (Table 5.2). Although historical trends in abundance differ among all three stations, particularly from 1999 to present, differences typically appear to be less between stations E14 and E26 than between E14 and B9 (Figure 5.2B). As with species richness, the cause of the general increase in total numbers of macrobenthic invertebrates nearest the discharge site remains unclear, but does not appear to be linked to changes in organics or sediment particle size (see Appendix D.2 and City of San Diego 2015a).

Species diversity, evenness, and dominance

Shannon diversity (H') index values averaged from 3.3 to 4.2 per grab for each station while evenness (J') averaged from 0.78 to 0.91 per grab, indicating that local benthic communities remain characterized by relatively diverse assemblages of evenly distributed species (Table 5.1). No clear patterns relative to the discharge site, depth, or sediment particle size (see Chapter 4) were evident. For example, the highest mean H' values of 4.2 were reported for both the northernmost farfield site along the 88-m contour (station B11) and the southernmost farfield site along the 116-m contour (station E3), while the lowest mean H' occurred at another northern farfield site along the 88-m contour (station B8). During the past year, diversity and evenness values were also generally similar to historical values (Figures 5.2C, D). Additionally, all individual grab samples had diversity and evenness values within the regional tolerance intervals of 2.5−4.4 for H' and 0.58–0.92 for J' (see Appendix D.1 and City of San Diego 2015b).

Swartz dominance averaged from 22 to 45 species per grab, with the lowest dominance (highest index value) occurring at northern farfield station B11 and the highest dominance (lowest index value)

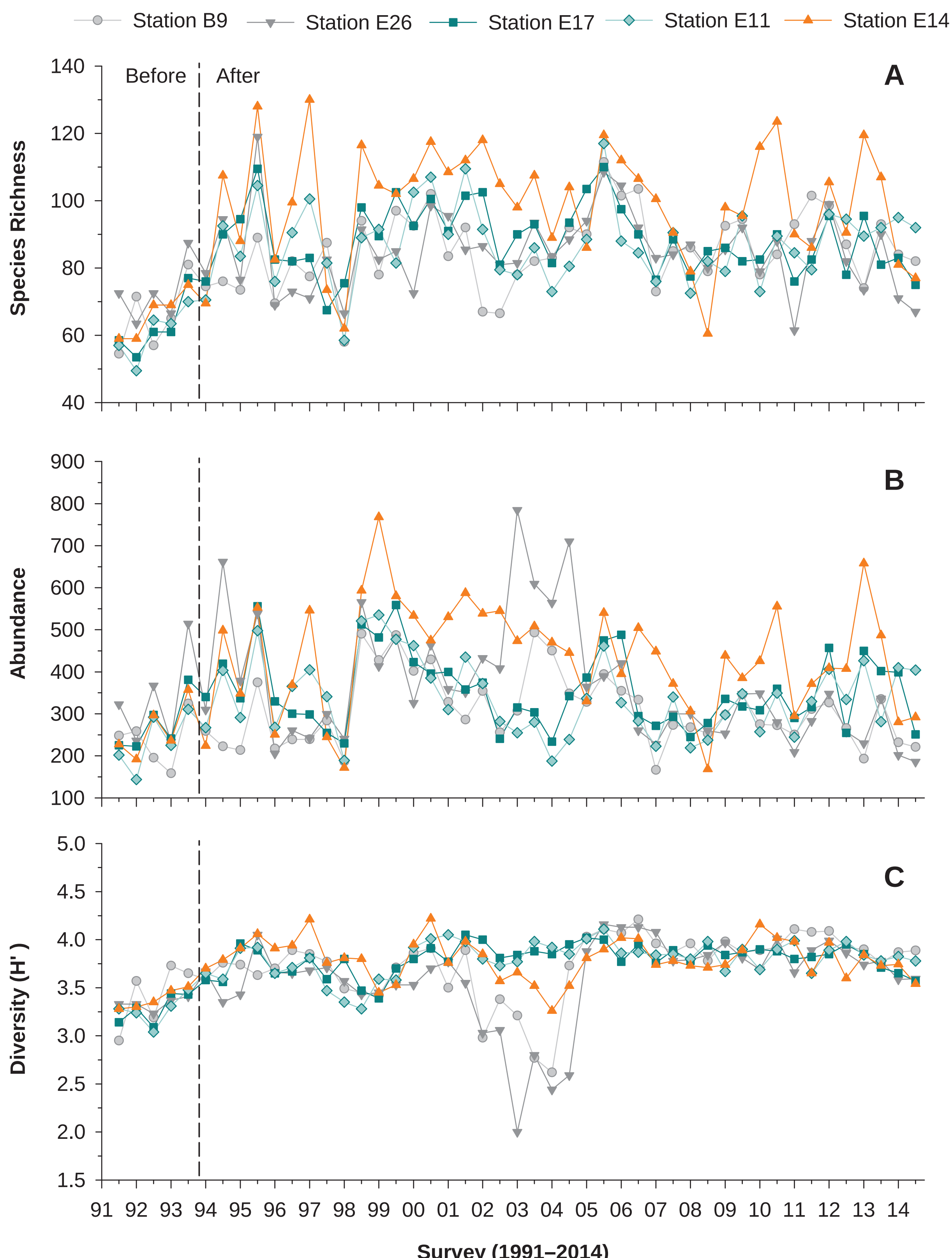

Figure 5.2
Comparison of community parameters at PLOO near-ZID stations E11, E14, and E17, and farfield stations E26 and B9 sampled from 1991 through 2014. Parameters include: (A) species richness; (B) infaunal abundance; (C) diversity (H'); (D) evenness (J'); (E) Swartz dominance; (F) benthic response index (BRI). Data for each station are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.

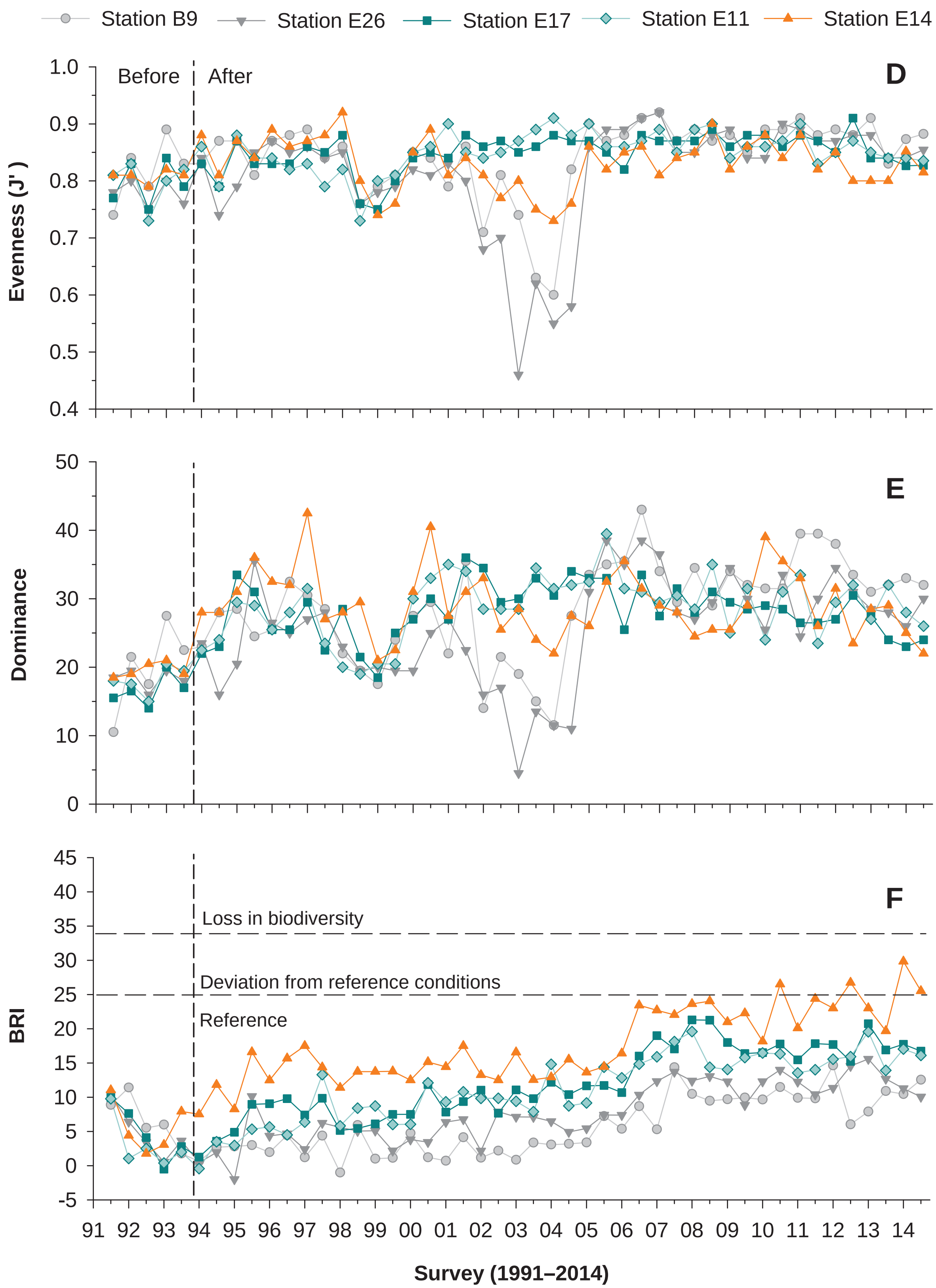

Figure 5.2 *continued*

occurring at farfield stations E20 and E21 (Table 5.1). No patterns relative to the outfall, depth, or sediment particle size were evident. During the past year, all but one grab sample was within the regional tolerance interval range of 7–49 per grab (City of San Diego 2015b); the only exception occurred at northern farfield station B11, which had a dominance value of 53 in the summer (Appendix D.1).

Benthic response index

The benthic response index (BRI) is an important tool for gauging anthropogenic impacts to coastal seafloor habitats throughout the SCB. BRI values below 25 are considered indicative of reference conditions, while values above 34 represent increasing levels of disturbance or environmental degradation (Smith et al. 2001). In 2014, 95% of the individual benthic samples collected off Point Loma were characteristic of reference conditions (Appendix D.1). Only the single grab samples collected at near-ZID station E14 during the winter (BRI = 30) and summer (BRI = 26) surveys had BRI scores indicative of a possible minor deviation in benthic condition (BRI = 25−34). Although the three primary core stations closest to the discharge zone (i.e., near-ZID stations E11, E14, E17) had slightly higher BRI values than sites located farther away, no other spatial patterns relative to depth or sediments were observed.

When compared to historical data, BACIP t-test results indicated a net change in the mean difference of BRI values between impact site E14 and both control sites following the onset of wastewater discharge (Table 5.2). These changes are due to higher index values at station E14 since 1994 (Figure 5.2F), which has been largely driven by a long-term decline in resident brittle star populations (i.e., *Amphiodia urtica*; see Figure 5.3) as well as temporary increases in populations of opportunistic species such as *Capitella teleta* (Figure 5.4). Although these results are consistent with an outfall related pattern, the effect appears minor, restricted to this near-ZID site, and not linked to changes in organics or sediment particle size (see Appendix D.2 and City of San Diego 2015a).

Species of Interest

Dominant taxa

Polychaete worms were the dominant taxonomic group found in the PLOO region in 2014 and accounted for 44% of all taxa collected (Table 5.3). Crustaceans accounted for 24% of the taxa reported, while the remainder comprised 16% molluscs, 6% echinoderms, and about 10% all other taxa combined. Polychaetes were also the most numerous animals, accounting for 43% of the total macrofaunal abundance. Crustaceans accounted for 27% of the animals collected, while molluscs, echinoderms, and all other taxa combined each contributed to ≤16% of the total abundance. Overall, the percentage of taxa that occurred within each of the above major taxonomic groupings and their relative abundances has remained relatively consistent since monitoring began in 1991 (City of San Diego 1995, City of San Diego 2015a).

The 10 most abundant species in 2014 included four polychaetes, two crustaceans, two echinoderms, and two molluscs (Table 5.4). Together these species accounted for about 42% of all invertebrates identified during the year. The numerically dominant polychaetes included the amphinomid *Chloeia pinnata*, the spionids *Prionospio (Prionospio) jubata* and *P. (P.) dubia*, and the cirratulid *Chaetozone hartmanae*. The dominant crustaceans included the ostracods *Euphilomedes carcharodonta* and *E. producta*, while the ophiuroids *Amphiodia urtica* and *Amphiodia* sp[1] were the dominant echinoderms. The dominant molluscs were the bivalves *Nuculana* sp A and *Tellina carpenteri*. *Amphiodia urtica* was the most abundant species during the year, accounting for ~10% of all invertebrates collected, and occurring in 98% of grabs with a mean abundance of ~28 individuals per grab. *Prionospio (Prionospio) dubia* was slightly more widespread, occurring in all samples from all sites; however, this polychaete accounted for only 2% of all macrobenthic invertebrates collected during the year with an average abundance of ~5 worms per grab. The remaining eight species occurred in 86–98% of the grabs collected during 2014 and averaged ≤18 individuals per grab.

With the exception of *A. urtica*, the top five species have occurred sporadically or have become more abundant in the region during recent years (Figure 5.3). *Amphiodia urtica* remains the

[1] *Amphiodia* sp likely represents unidentifiable juvenile specimens of *A. urtica* or *A. digitata* that are missing necessary diagnostic characters.

most abundant invertebrate in the Point Loma outfall region after 21 years of outfall operation (Figure 5.3), although it comprised at least 75% of all echinoderms sampled during the pre-discharge period compared to only about 53% during the post-discharge period (City of San Diego 2015a). The other top four historically dominant species were all polychaetes, including the terebellids *Proclea* sp A and *Phisidia sanctaemariae*, the spionid *Spiophanes duplex*, and the oweniid *Myriochele striolata* (Figure 5.4, Appendix D.3).

Indicator species

Several species known to be useful indicators of environmental change that occur in the PLOO region include the capitellid polychaete *Capitella teleta*, amphipods in the genera *Ampelisca* and *Rhepoxynius*, the bivalve *Solemya pervernicosa*, as well as the terebellid polychaete *Proclea* sp A and the brittle star *Amphiodia urtica*. For example, increased abundances of pollution-tolerant species such as *C. teleta* and *S. pervernicosa* and decreased abundances of pollution-sensitive taxa such as *Proclea* sp A, *A. urtica*, *Ampelisca* spp, and *Rhepoxynius* spp are often indicative of organic enrichment and may indicate habitats impacted by human activity (Barnard and Ziesenhenne 1961, Anderson et al. 1998, Linton and Taghon 2000, Smith et al. 2001, Kennedy et al. 2009, McLeod and Wing 2009).

In 2014, indicator species with similar abundances at nearfield and farfield stations included *Proclea* sp A and *Rhepoxynius* spp (Figure 5.4). Abundances of *Proclea* sp A and *Rhepoxynius* spp have followed similar patterns off Point Loma since monitoring began, and have remained within tolerance intervals calculated for the region (City of San Diego 2015b), which suggests little to no impact associated with the outfall discharge. Further, the results of BACIP analyses examining mean differences in abundances of *Rhepoxynius* spp demonstrated that no net change has occurred between "impact" station E14 and "control" stations E26 and B9 (Table 5.2). In contrast, abundances of *Ampelisca* spp were slightly lower at near-ZID station E14 during both surveys in 2014 (Figure 5.4), and BACIP results did indicate a net change in *Ampelisca* spp abundance between E14 and both farfield stations (Table 5.2). However, caution should be exercised in interpreting these results given the relatively low abundances and natural population fluctuations of *Ampelisca* spp, and that the average number of *Ampelisca* spp per station (including near-ZID site E14) has remained within regional tolerance intervals of 2–31 amphipods per grab (City of San Diego 2015b).

The abundance of *Amphiodia urtica* was lower at nearfield station E14 than other stations in 2014 (Figure 5.3), and is one of the factors driving the relatively higher BRI values for station E14 (Table 5.1, Appendix D.1). Results of BACIP t-tests indicated a significant change in the difference in abundances between "impact" station E14 and both of the "control" stations E26 and B9 between the 2.5 year pre-discharge and 21 year post-discharge periods (Table 5.2). For example, average *Amphiodia* abundances have decreased about 78% at E14 compared to much smaller changes at E26 and B9. Although this pattern is consistent with the predicted effects of organic enrichment, predation by fish predators (e.g., sea basses and surfperch) attracted to the outfall pipe may also contribute to reduced brittle star numbers in nearby areas such as station E14 (see Davis et al. 1982, Ambrose and Anderson 1990, Posey and Ambrose 1994). For example, *Amphiodia* abundances at near-ZID stations E11 and E17 appear much less affected by the wastewater discharge. Whether or not these population changes are due to wastewater discharge, increased predation pressure, or some other factor, abundances of *Amphiodia* near the outfall and elsewhere are still within the range of natural variability seen at similar depths throughout the SCB (e.g., Bergen et al. 1998, 2001; Ranasinghe et al. 2003, 2007, 2012).

Opportunistic species such as *Capitella teleta* and *Solemya pervernicosa* typically increase in abundance in areas having high organic content (Linton and Taghon 2000, McLeod and Wing 2009). Between 2013 and the 2014 surveys, populations of *C. telata* decreased from the highest ever recorded at the PLOO stations (i.e., 140 individuals in a grab from E14 in winter 2013) to ≤6 worms per grab at both stations E14 and E11. *Solemya*

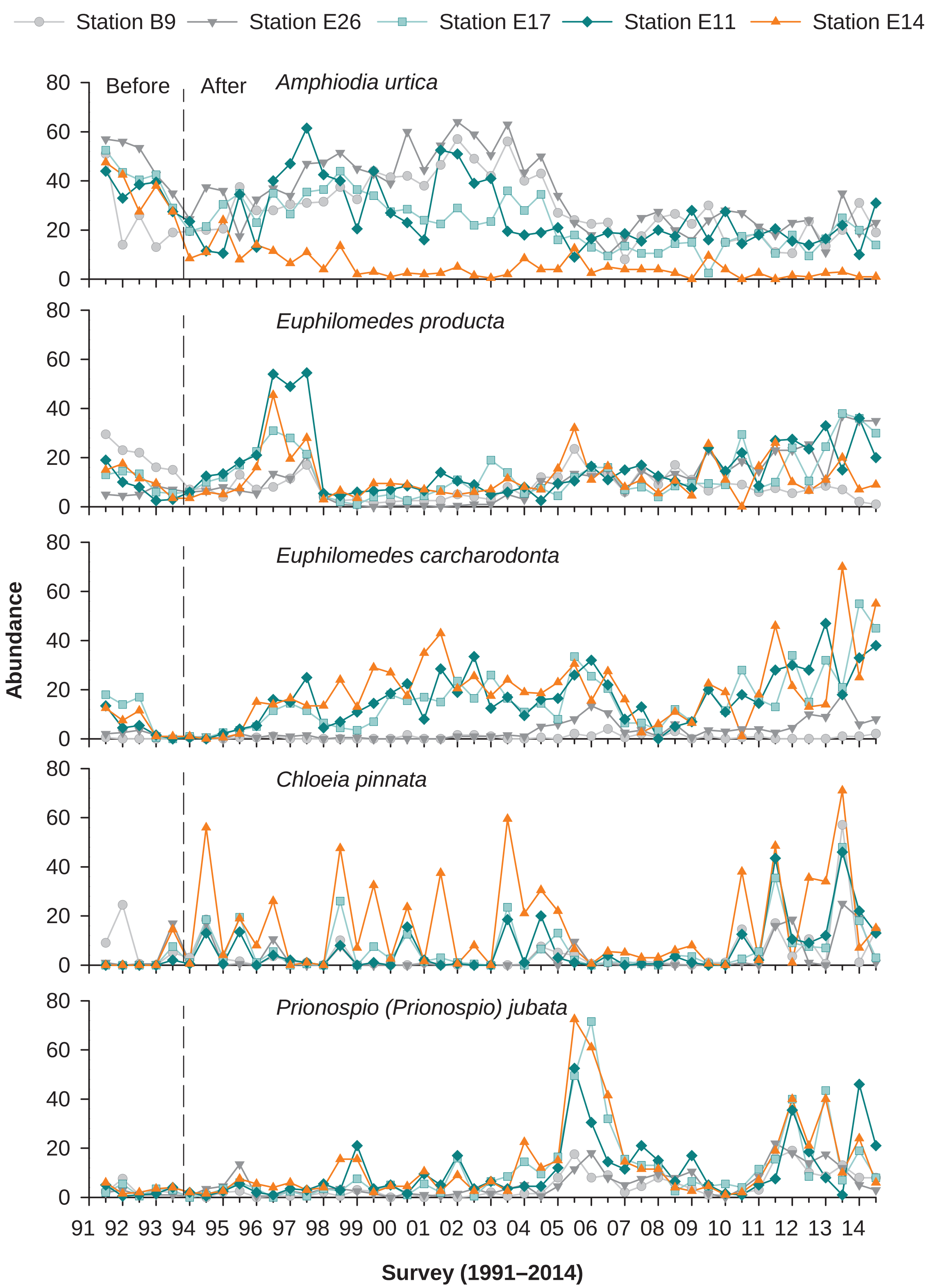

Figure 5.3
Abundances of the five most numerically dominant species recorded during 2014 (presented in order) at PLOO near-ZID stations E11, E14, and E17 and farfield stations E26 and B9. Data for each station are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.

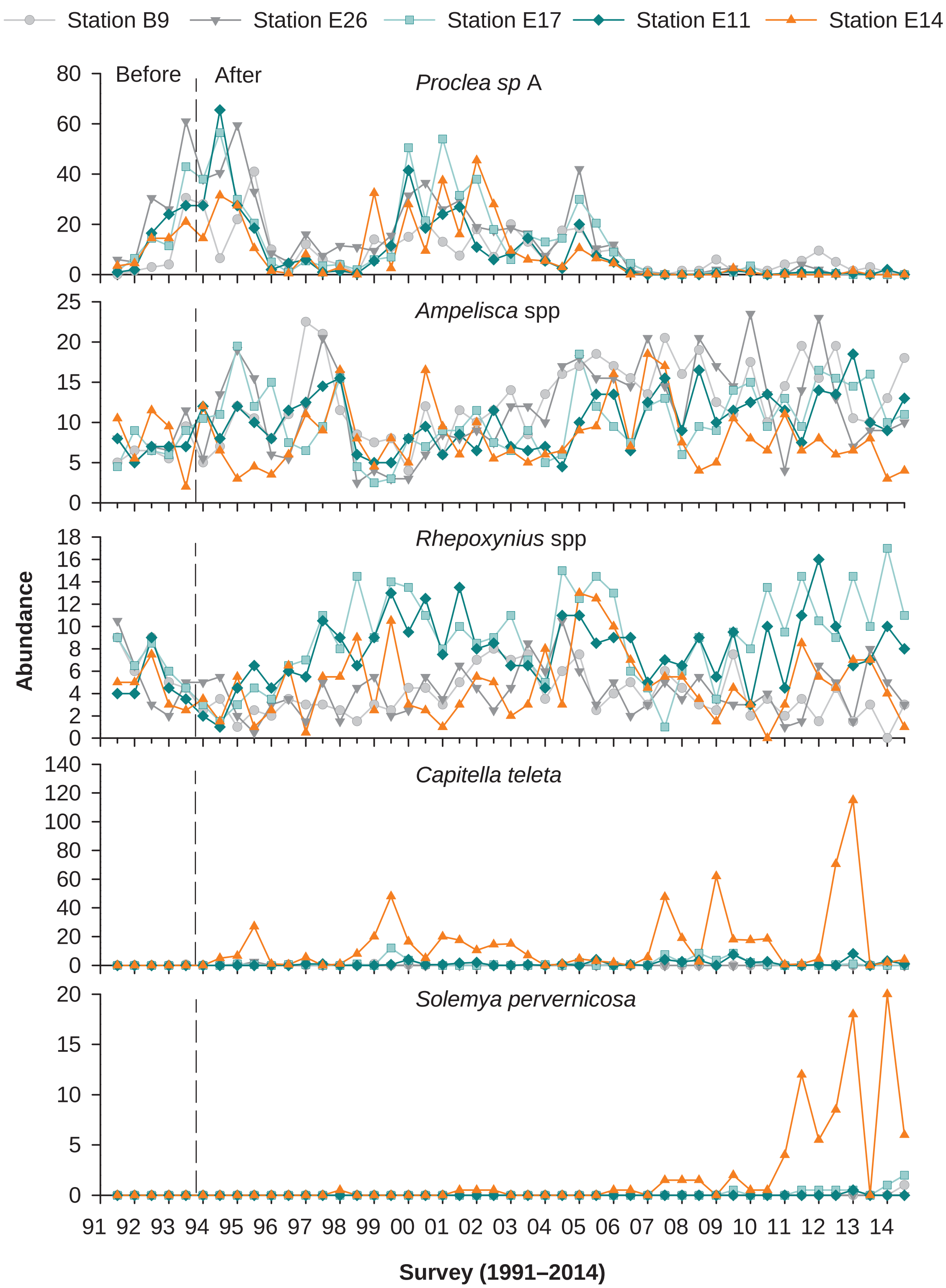

Figure 5.4
Abundances of representative ecologically important indicator taxa at PLOO near-ZID stations E11, E14, and E17 and farfield stations E26 and B9 sampled from 1991 through 2014. Data for each station are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.

pervernicosa reached 20 individuals per grab in the winter at station E14, but had low numbers (≤6 per grab) at station E17 during both winter and summer, and at stations B9, E14, and E15 during the summer. Despite occasionally exceeding regional tolerance intervals of 0–1 individuals per grab (City of San Diego 2015b), abundances of these two species remained characteristic of relatively undisturbed habitats. For example, *C. teleta* commonly reaches densities as high as 500 individuals per 0.1-m^2 grab in polluted sediments (Reish 1957; Swartz et al. 1986).

Table 5.3
Percent composition and abundance of major taxonomic groups in PLOO benthic grabs sampled during 2014.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	44	43
Arthropoda (Crustacea)	24	27
Mollusca	16	14
Echinodermata	6	16
Other Phyla	10	2

Classification of Macrobenthic Assemblages

Classification (cluster) analysis was used to discriminate between macrofaunal assemblages from a total of 44 grab samples collected at 22 PLOO monitoring stations in 2014, resulting in six ecologically relevant SIMPROF-supported groups (Figures 5.5, 5.6, Table 5.5, Appendix D.4). These assemblages (referred to herein as cluster groups A–F) represented 1–32 grabs each and varied in terms of the specific taxa present, as well as their relative abundance, and occurred at sites separated by different sediment microhabitats. For example, similar patterns of variation occurred in the benthic macrofaunal similarity matrix and sediment dissimilarity matrix (see Chapter 4) used to generate their respective cluster dendrograms, thus confirming that the local PLOO assemblages were correlated to sediment composition (RELATE $\rho = 0.724$, $p = 0.0001$). The sediment sub-fractions that were most highly correlated to the macrofaunal assemblages included gravel, very coarse sand, coarse sand, medium sand, very fine sand, and fines (BEST $\rho = 0.73$, $p = 0.0001$). The main characteristics of each of these six assemblages and their associated sediments are described below.

Cluster group A represented macrofaunal assemblages from both the winter and summer grabs collected at station E3 in 2014, the southernmost station located nearest the LA-5 dredged materials disposal site (Figure 5.5). The mean species richness of 111 taxa per grab and mean abundance of 306 individuals per grab were the highest of all cluster groups (Table 5.5). The five most characteristic species of group A according to SIMPER results included the spionid polychaete *Prionospio (Prionospio) jubata* (23 per grab), the amphinomid polychaete *Chloeia pinnata* (21 per grab), the ophiuroid *Amphiodia digitata* (10 per grab), the ampeliscid amphipod *Ampelisca brevisimulata* (9 per grab), and the bivalve *Tellina carpenteri* (8 per grab) (Appendix D.4). This assemblage was distinguished from groups D, E, and F by the above relatively high numbers of *A. digitata*, as well as by very low numbers of its congener *Amphiodia urtica* (<1 per grab). The sediments associated with these two samples from station E3 averaged 33% fines, 39% fine sands, 27% medium-coarse sands, and <1% coarser particles; the medium-coarse sand component was the highest of all six cluster groups (Table 5.5). Gravel, pea gravel, and shell hash were also observed in sediments from this station (Appendix C.4).

Cluster group B represented assemblages from five samples, including the winter and summer grabs collected at northern farfield stations B10 and B12, as well the winter grab from southern station E9 (Figure 5.5). Species richness for this assemblage averaged 98 taxa per grab, while macrofaunal abundance averaged 283 individuals per grab (Table 5.5). The five most characteristic species in group B according to SIMPER results included three species that were also characteristic of group A above: *Chloeia pinnata* (22 per grab), *Prionospio (Prionospio) jubata* (7 per grab), and *Amphiodia digitata* (7 per grab) (Appendix D.4). The remaining two most characteristic species of group B were

Table 5.4

The 10 most abundant macroinvertebrate taxa collected from PLOO benthic stations during 2014. Data are expressed as percent abundance (number of individuals per species/total abundance of all species), frequency of occurrence (percentage of grabs in which a species occurred) and abundance per grab (mean number of individuals per grab, n = 44).

Species	Taxonomic Classification	Percent Abundance	Frequency of Occurrence	Abundance per Grab
Amphiodia urtica	Echinodermata: Ophiuroidea	10	98	28.4
Euphilomedes producta	Arthropoda: Ostracoda	6	91	18.0
Euphilomedes carcharodonta	Arthropoda: Ostracoda	6	95	18.0
Chloeia pinnata	Polychaeta: Amphinomidae	4	93	13.0
Prionospio (Prionospio) jubata	Polychaeta: Spionidae	4	95	10.2
Chaetozone hartmanae	Polychaeta: Cirratulidae	3	98	9.3
Nuculana sp A	Mollusca: Bivalvia	3	95	8.5
Amphiodia sp	Echinodermata: Ophiuroidea	2	86	6.2
Tellina carpenteri	Mollusca: Bivalvia	2	93	6.0
Prionospio (Prionospio) dubia	Polychaeta: Spionidae	2	100	4.9

the cirratulid polychaete *Chaetozone hartmanae* (18 per grab) and the bivalve *Nuculana* sp A (8 per grab). Similar to group A, this assemblage was distinguished from groups D, E, and F by having relatively lower numbers of *Amphiodia urtica* (i.e., 2 per grab) and higher numbers of *A. digitata* (i.e., 7 per grab). The sediments associated with this cluster group averaged about 27% fines, 55% fine sands, 16% medium-coarse sands, and 2% coarser particles; the percent fines component was the lowest of all six cluster groups (Table 5.5). Gravel, rock, and shell hash were also observed in sediments from these stations (Appendix C.4).

Cluster group C represented the macrofaunal assemblages from the winter and summer grabs collected at near-ZID station E14 in 2014 (Figure 5.5). Assemblages at this site are the most likely to be impacted by wastewater discharge or other factors associated with the outfall structure. Species richness averaged 79 taxa per grab, while macrofaunal abundance averaged 286 individuals per grab (Table 5.5). The assemblages at this station were the only ones where BRI values were slightly higher than normal for reference conditions (i.e., 26–30; see Appendix D.1). The five most characteristic species of group C according to SIMPER results were the ostracod *Euphilomedes carcharodonta* (40 per grab), *Nuculana* sp A (17 per grab), *Tellina carpenteri* (10 per grab), the capitellid polychaete *Notomastus* sp A (22 per grab) and the lumbrinerid polychaete *Lumbrineris cruzensis* (14 per grab) (Appendix D.4). The presence of at least six individuals of the pollution-tolerant bivalve *Solemya pervernicosa* in each of these two samples also helped distinguish these assemblages from those in the other cluster groups (Figure 5.6). Cluster group C was also distinguished from groups D, E, and F by low numbers of the brittle star *Amphiodia urtica* (~1 per grab). The sediments associated with these two samples averaged 32% fines, 67% fine sands, 1% medium-coarse sands, and no coarser particles; the fine sand component was the highest of all six cluster groups (Table 5.5). The presence of black sands and shell hash (winter only) were also observed in sediments from station E14 (AppendixC.4).

Cluster group D represented the macrofaunal assemblages from the winter and summer grabs collected at northern farfield station B11 during 2014 (Figure 5.5). Species richness for these assemblages averaged 107 taxa per grab, which was the second highest of the six cluster groups (Table 5.5), while the mean abundance of 254 individuals per grab was the second lowest of all the groups. The five most characteristic “species” of group D according to SIMPER results included three ophiuroid taxa,

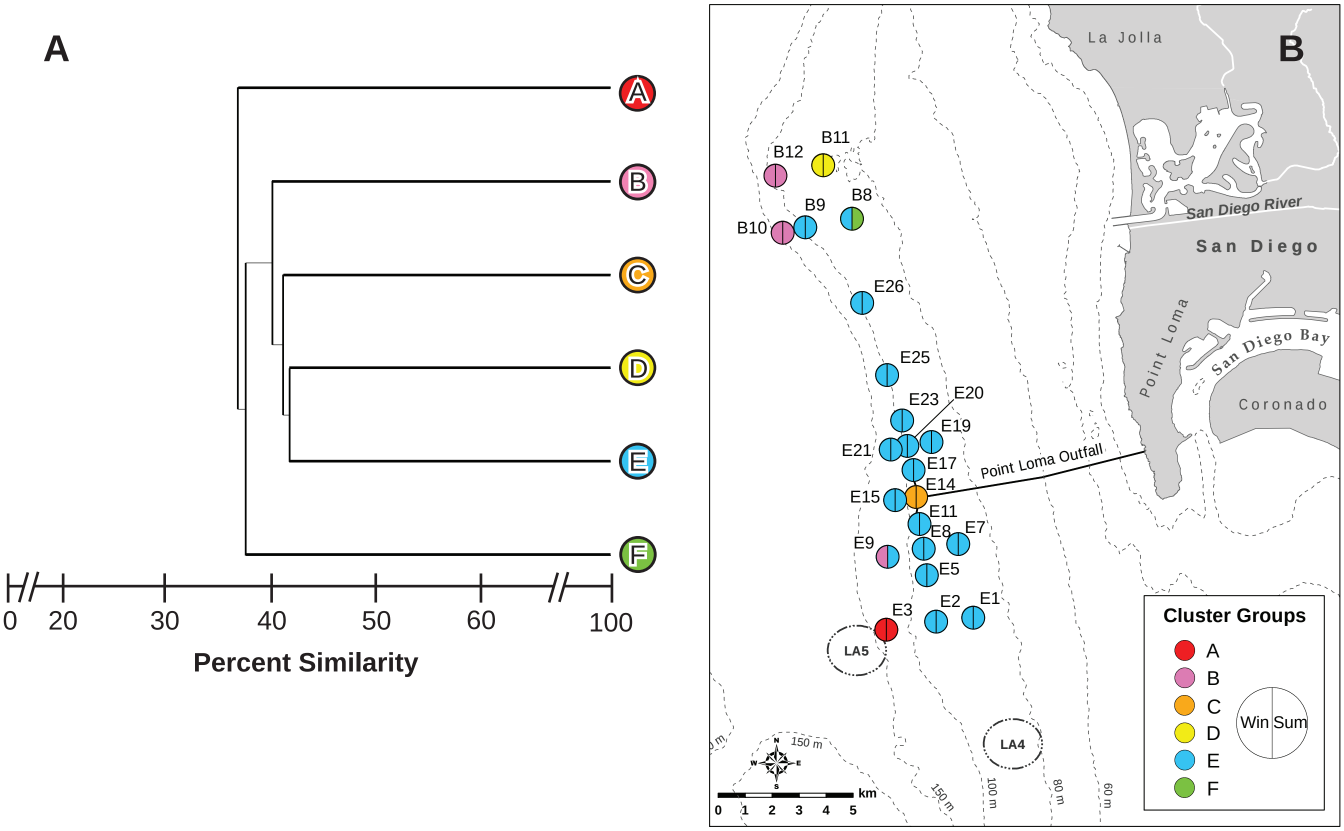

Figure 5.5

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

one polychaete, and one bivalve (Appendix D.4). The characteristic ophiuroid taxa were *Amphiodia urtica* (20 per grab), and juvenile brittle stars that could be identified only to genus as *Amphiodia* sp (11 per grab) or to family as Amphiuridae (8 per grab). The other two top five species were *Chaetozone hartmanae* (10 per grab) and the bivalve *Adontorhina cyclia* (10 per grab). Sediments associated with these two samples from station B11 averaged 39% fines, 41% fine sands, 14% medium-coarse sands, and 6% coarser particles; the coarse particle fraction component was the highest of all six cluster groups (Table 5.5). Shell hash, pea gravel, gravel, and larger rocks were also observed at this station (Appendix C.4).

Cluster group E represented the main group of macrofaunal assemblages present in the PLOO region during 2014, comprising about 73% of the samples collected during the year from 17 different monitoring stations (Figure 5.5). These included both the winter and summer samples from all primary core stations located along the 98-m discharge depth contour except for near-ZID station E14 and northern farfield station B12 (i.e., 20 grabs from 10 stations), a total of seven grab samples from stations E1, E7, E19, and B8 located along the inner 88-m depth contour, and a total of five grab samples from stations E9, E15, and E21 located along the outer 116-m depth contour. Compared to the other cluster groups, the group E assemblages averaged the fourth highest species richness of about 83 taxa per grab and the second highest abundance of about 297 animals per grab (Table 5.5). The five most characteristic species according to SIMPER results were *Amphiodia urtica* (36 per grab), *Euphilomedes producta* (23 per grab), *Euphilomedes carcharodonta* (21 per grab), *Chloeia pinnata* (12 per grab), and *Chaetozone hartmanae* (9 per grab) (Appendix D.4). Overall, the characteristics of the cluster group E assemblages are comparable to background conditions for the PLOO monitoring region that have been described over many years (City of San Diego 2015a, b) and

Table 5.5

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

Cluster Group	n	Depth Range (m)	Community Metric		Sediments			
			SR	Abund	Fines	Fine Sands	MC Sands	Coarse
A	2	116–116	111.0	306.0	32.7	39.4	27.0	0.8
			(91–131)	(214–398)	(31.0–34.5)	(37.2–41.6)	(26.3–27.8)	(0.5–1.2)
B	5	98–116	97.6	283.2	27.0	54.7	15.7	1.6
			(88–111)	(221–377)	(13.9–38.5)	(41.8–82.8)	(1.7–31.6)	(0–6.6)
C	2	98–98	79.0	286.0	32.1	66.8	1.1	0.0
			(77–81)	(280–292)	(30.9–33.3)	(65.4–68.2)	(0.9–1.2)	—
D	2	88–88	106.5	254.0	39.4	40.8	13.6	6.3
			(91–122)	(230–278)	(33.9–44.8)	(39.7–41.8)	(7.7–19.4)	(5.6–7.0)
E	32	88–116	82.6	296.7	41.9	55.6	2.3	0.3
			(67–105)	(186–410)	(33.1–63.2)	(36.8–65.3)	(0.1–14.8)	(0–7.3)
F	1	88	59.0	179.0	63.2	36.7	0.1	0.0

are generally characteristic of similar mid-shelf soft-bottom habitats in the SCB. The sediments associated with this cluster group averaged about 42% fines, 56% fine sands, 2% medium-coarse sands, and < 1% coarser particles; the percent fines and fine sands components were the second highest compared to the other five cluster groups (Table 5.5). Shell hash and other types of organic debris were also observed in these sediments (Appendix C.4).

Cluster group F represented the macrofaunal assemblage present at northern farfield station B8 during the summer survey (Figure 5.5). This assemblage had the lowest species richness (59 taxa per grab) and lowest abundance (179 animals per grab) of the six cluster groups (Table 5.5). Since SIMPER results cannot be calculated for a single sample, the five most abundant taxa for group F included the ophiuroids *Amphiodia urtica* (n = 56), *Amphiodia* sp (n = 13), and Amphiuridae (n = 16), as well as the phoxocephalid amphipods *Heterophoxus oculatus* (n = 6) and *Rhepoxynius bicuspidatus* (n = 5). The three ophiuroid taxa together (probably all representing *A. urtica*) comprised about 47% of this assemblage. This assemblage was also distinguished from those in the other five cluster groups by the absence of species such as the tanaid *Leptochelia dubia* Cmplx, and the polychaetes *Prionospio (Prionospio) jubata*, *Chloeia pinnata*, and *Chaetozone hartmanae* (Figure 5.6). Compared to the other cluster groups, the sediments associated with the group F assemblage had the highest percent fines (63%), lowest fine sands (37%), lowest medium-coarse sands (< 1%), and no coarser particles (Table 5.5).

Summary

Analysis of the 2014 macrofaunal data do not suggest that wastewater discharged through the PLOO has affected macrobenthic communities in the region other than a minor deviation from reference conditions that may be occurring at near-ZID station E14. Benthic communities off Point Loma in 2014 were similar to those encountered previously, including the 2.5 year pre-discharge monitoring period (City of San Diego 1995, 2015a).

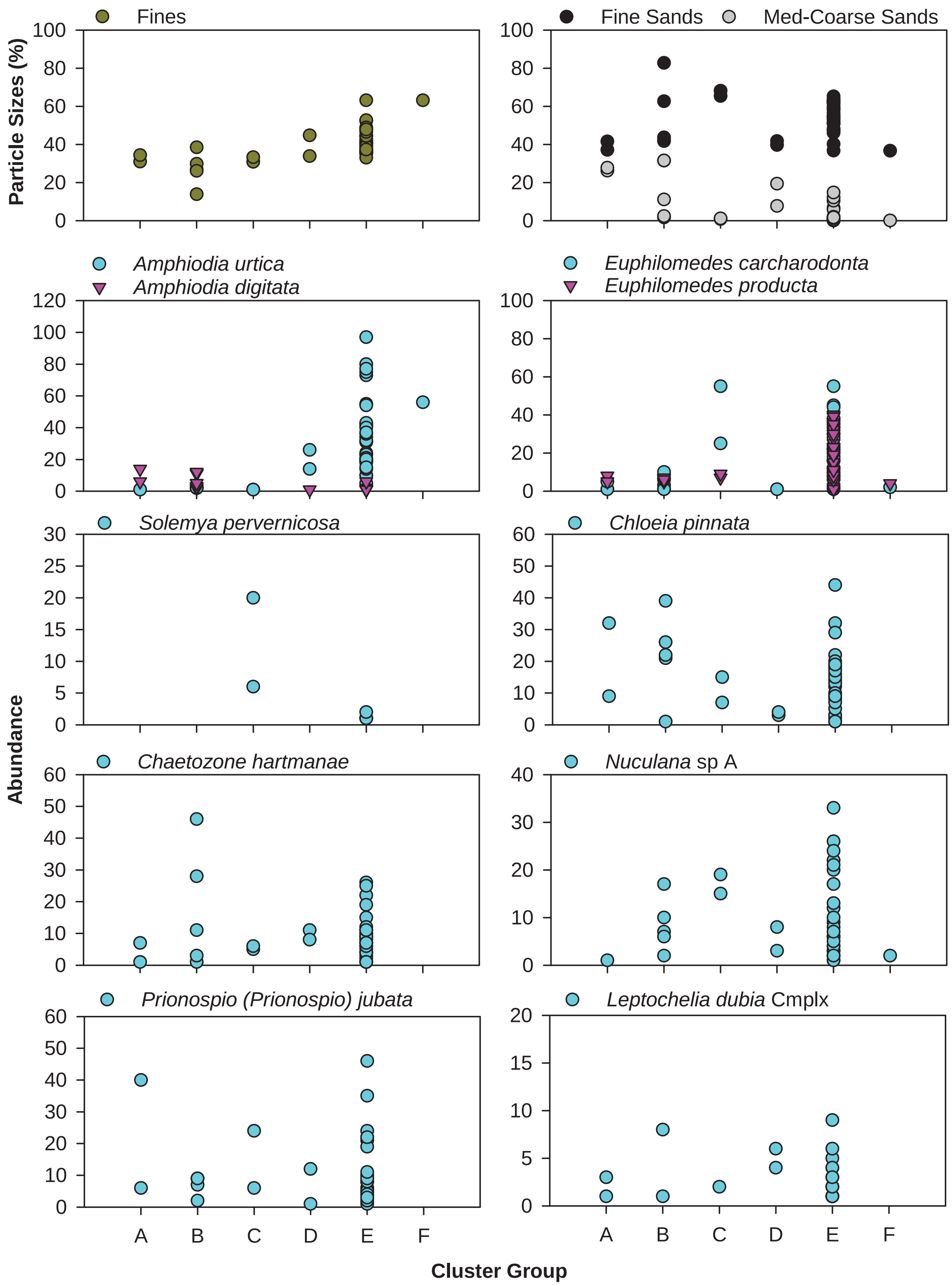

Figure 5.6
Sediment composition and abundances of select species that contributed to cluster group dissimilarities in the PLOO region during 2014 (see Figure 5.5). Each data point represents a single sediment or grab sample.

Overall, these communities remain dominated by ophiuroid-polychaete based assemblages. As in past years, the brittle star *Amphiodia urtica* was the most abundant species off Point Loma, although its population abundances have generally decreased since monitoring began in 1991. Of the 10 most abundant species recorded during 2014, the spionid polychaete *Prionospio* (*Prionospio*) *dubia* was the most widespread and occurred at every station. Additionally, abundance and dominance of most species were typically within historical ranges (City of San Diego 2015a). As previously reported, most of the primary core stations along the 98-m contour had sandy sediments with a high fraction of fines that supported similar types of benthic communities. Most of the variability in individual species populations occurred at stations located several kilometers to the north and south of the outfall that had slightly higher fractions of coarse sediments. Put into a broader biogeographical context, most values for species richness, macrofaunal abundance, diversity, evenness, and dominance off Point Loma were indicative of natural ranges reported for the San Diego region (City of San Diego 2015b) and the entire 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, Ranasinghe et al. 2003, 2007, 2010, 2012).

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 off Point Loma. For instance, the brittle star *Amphiodia urtica* is a well-known dominant of mid-shelf, mostly fine sediment habitats in the SCB that is sensitive to changes near wastewater outfalls. Although BACIP tests reveal that populations of *A. urtica* have decreased significantly over time near the discharge site (i.e., station E14), there has also been a concomitant decrease in this species region-wide. Although long-term changes in *A. urtica* populations at near-ZID station E14 may be related to organic enrichment, factors such as increased predation pressure near the outfall may also be important. Regardless of the cause of these changes, abundances of *A. urtica* off Point Loma remain within the range of natural variation in SCB populations. Other important indicator species in the SCB are the opportunistic polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa*. During 2014, total abundances of these two species were ≤ 20 per grab. Historically, abundances of *C. teleta* and *S. pervernicosa* have been ephemeral and remained relatively low at the nearfield stations when compared to other SCB dischargers (e.g., LACSD 2012, OCSD 2012). For example, *C. teleta* is known to reach densities as high as 500 per 0.1 m^2 in polluted sediments (e.g., Reish 1957, Swartz et al. 1986). Further, no difference in variability in populations of pollution-sensitive phoxocephalid amphipods in the genus *Rhepoxynius* have occurred at the nearfield sites compared to farfield sites, suggesting that wastewater discharge has had little to no effect on these species.

Benthic macrofaunal communities appear to be healthy and in good condition off Point Loma, with about 95% of the assemblages surveyed in 2014 classified in reference condition based on assessments using the BRI. This agrees with findings in Ranasinghe et al. (2010, 2012) who reported that at least 98% of the entire SCB mainland shelf was in good condition based on data from bight-wide surveys. Most communities near the PLOO remain similar to natural indigenous assemblages characteristic of the San Diego region (City of San Diego 2015b), although some minor changes in component species or community structure have appeared near the outfall. However, it is not currently possible to definitively determine whether these observed changes are due to habitat alteration related to organic enrichment, physical structure of the outfall, or a combination of factors. In addition, abundances of soft bottom marine invertebrates exhibit substantial natural spatial and temporal variability that may mask the effects of disturbance events (Morrisey et al. 1992a, 1992b, Otway 1995), and the effects associated with the discharge of advanced primary treated sewage may be difficult to detect in areas subjected to strong currents that facilitate rapid dispersion of the wastewater plume (Diener and Fuller 1995).

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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 Point Loma Ocean Outfall (PLOO). These fish and invertebrate communities are targeted for monitoring because they are known to play critical ecological roles on the southern California coastal shelf (e.g., Allen et al. 2006, Thompson et al. 1993a, b). Because trawled species live on or near the seafloor, they may be impacted by sediment conditions affected by both point and non-point sources such as discharges from ocean outfalls, runoff from watersheds, outflows from rivers and bays, or the disposal of dredged sediments (see Chapter 4). For these reasons, assessment of fish and invertebrate communities has become an important focus of ocean monitoring programs throughout the world, but especially in the Southern California Bight (SCB) where they have been sampled extensively on the mainland shelf for the past four decades (e.g., Stein and Cadien 2009).

In healthy ecosystems, fish and invertebrate communities are known to be inherently variable and influenced by many natural factors. For example, prey availability, bottom topography, sediment composition, and changes in water temperatures associated with large scale oceanographic events such as El Niño can affect migration or recruitment of fish (Cross et al. 1985, Helvey and Smith 1985, Karinen et al. 1985, Murawski 1993, Stein and Cadien 2009). Population fluctuations may also be due to the mobile nature of many species (e.g., fish schools, urchin aggregations). Therefore, an understanding of natural background conditions is necessary before determining whether observed differences or changes in community structure may be related to anthropogenic activities. Pre-discharge and regional monitoring efforts by the City and other researchers since 1994 provide baseline information on the variability of demersal fish and megabenthic communities in the San Diego region critical for such comparative analyses (e.g., Allen et al. 1998, 2002, 2007, 2011, City of San Diego 1995, 1998).

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

This chapter presents analysis and interpretation of demersal fish and megabenthic invertebrate data collected during calendar year 2014, as well as long-term assessments of these communities from 1991 through 2014. The primary goals are to: (1) document assemblages present during the year; (2) determine the presence or absence of biological impacts associated with wastewater discharge; (3) identify other potential natural and anthropogenic sources of variability to the local marine ecosystem.

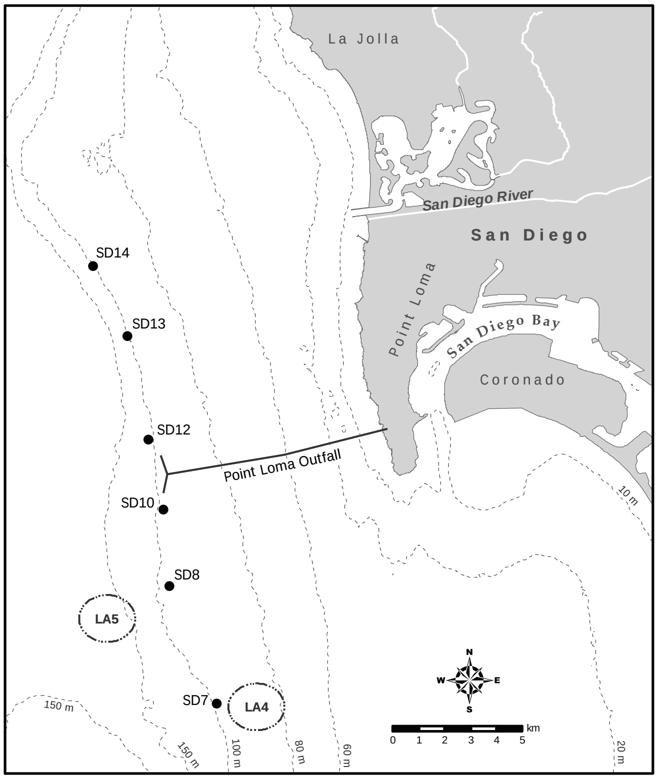

Figure 6.1
Trawl station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Materials and Methods

Field Sampling

Trawl surveys were conducted at six monitoring stations in the PLOO region sampled during winter (January) and summer (July) 2014 (Figure 6.1). These stations, designated SD7–SD14, are all located along the 100-m depth contour ranging from 9 km south to 8 km north of the PLOO. Stations SD10 and SD12 are located within 1000 m of the outfall wye, and represent the "nearfield" station group. Stations SD7 and SD8 are located >3.6 km south of the outfall and represent the "south farfield" station group, while SD13 and SD14 are located >4.7 km north of the outfall and represent the "north farfield" station group.

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

Data Analyses

Population characteristics of all fish and invertebrate species were summarized as percent abundance (number of individuals per species/total abundance of all species), frequency of occurrence (percentage of stations at which a species was collected), mean abundance per haul (number of individuals per species/total number of sites sampled), and mean abundance per occurrence (number of individuals per species/number of sites at which the species was collected). Additionally, the following community structure parameters were calculated per trawl for both fishes and invertebrates: species richness (number of species), total abundance (number of individuals), and Shannon diversity index (H'). Total biomass was also calculated for each fish species captured.

Multivariate analyses were performed in PRIMER v6 software using demersal fish and megabenthic invertebrate data collected from 1991 through 2014 (see Clarke 1993, Warwick 1993, Clarke and Gorley 2006). Prior to these analyses, all data were limited to summer surveys only to reduce statistical noise from natural seasonal variations

Table 6.1

Demersal fish species collected from 12 trawls conducted in the PLOO region during 2014. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
California Lizardfish	34	100	146	146	Spotfin Sculpin	<1	17	1	4
Pacific Sanddab	34	100	144	144	Spotted Cusk-eel	<1	42	<1	1
Longspine Combfish	11	100	47	47	Pacific Argentine	<1	8	<1	4
Halfbanded Rockfish	8	67	33	50	Greenstriped Rockfish	<1	17	<1	2
Stripetail Rockfish	3	83	14	17	Unidentified Rockfish	<1	17	<1	2
Shortspine Combfish	2	92	8	9	Roughback Sculpin	<1	17	<1	2
Pink Seaperch	2	83	8	10	Blackbelly Eelpout	<1	17	<1	1
Dover Sole	1	92	4	5	Cowcod	<1	8	<1	2
Plainfin Midshipman	1	83	4	5	Fringed Sculpin	<1	8	<1	2
English Sole	1	67	3	5	Rosethorn Rockfish	<1	17	<1	1
California Tonguefish	<1	58	2	3	Slender Sole	<1	8	<1	2
Hornyhead Turbot	<1	67	2	2	Blacktip Poacher	<1	8	<1	1
California Skate	<1	67	1	2	Bluebanded Ronquil	<1	8	<1	1
Yellowchin Sculpin	<1	50	1	3	Curlfin Sole	<1	8	<1	1
Bigmouth Sole	<1	58	1	2	Kelp Pipefish	<1	8	<1	1
California Scorpionfish	<1	33	1	3	Starry Skate	<1	8	<1	1
Chilipepper	<1	8	1	10	Swell Shark	<1	8	<1	1
Flag Rockfish	<1	8	1	7					

evident in previous studies (e.g., City of San Diego 1997, 2013). Analyses included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). The Bray-Curtis measure of similarity was used as the basis for the cluster analysis, and abundance data were square-root transformed to lessen the influence of the most abundant species and increase the importance of rare species. Major ecologically-relevant clusters receiving SIMPROF support were retained, and similarity percentages analysis (SIMPER) was used to determine which species were responsible for the greatest contributions to within-group similarity (i.e., characteristic species). Additionally, a 2-way crossed analysis of similarity (ANOSIM) was conducted (max. no. permutations = 9999) for each set of historical data where station group (i.e., nearfield, north farfield, south farfield) and year were provided as factors. SIMPER analyses were subsequently used to identify which species were most characteristic for each factor level when significant differences were found.

Results and Discussion

Demersal Fishes

Community Parameters

Thirty-five species of fish were collected in the area surrounding the PLOO during 2014 (Table 6.1, Appendix E.1). The total catch for the year was 5109 individuals (Appendix E.2), representing an average of ~426 fish per trawl. Of the 17 families represented, seven accounted for 98% of the total abundance (i.e., Batrachoididae, Embiotocidae, Hexagrammidae, Paralichthyidae, Pleuronectidae, Scorpaenidae, Synodontidae). Overall, the total catch was ~7% smaller in 2014 than in 2013. Pacific Sanddab and California Lizardfish dominated Point Loma fish assemblages during 2014, with both species occurring at all stations and each accounting for about 34% of the year's catch. No other species contributed to more than 11% of the total catch. For example, Longspine Combfish also occurred in every trawl, but averaged only 47 individuals per occurrence. Other species collected in at least 50% of the trawls, but in relatively low numbers

(≤33 per haul), included Bigmouth Sole, California Skate, California Tonguefish, Dover Sole, English Sole, Halfbanded Rockfish, Hornyhead Turbot, Pink Seaperch, Plainfin Midshipman, Shortspine Combfish, Stripetail Rockfish, and Yellowchin Sculpin. No new species were reported during the 2014 surveys.

More than 99% of the fishes collected in 2014 were <20 cm in length (Appendix E.1). Larger fishes included one Swell Shark (27 cm), one Starry Skate (38 cm), one California Scorpionfish (27 cm), one California Lizardfish (30), and ten California Skates (28–55 cm). Overall, median fish lengths varied little across stations and between seasons for two of the four most abundant species collected during the past year (Figure 6.2). Median lengths per haul ranged from 11 to 13 cm for California Lizardfish and from 10 to 12 cm for Halfbanded Rockfish. Median fish lengths were more variable for Pacific Sanddab, which ranged from 6 cm at station SD7 to 11 cm at station SD14 during the summer, and for Longspine Combfish, which ranged from 7 cm at station SD12 to 14 cm at station SD8 during the winter.

Species richness and diversity were consistently low for demersal fish communities sampled during 2014. Species richness ranged from 9 species per haul at station SD13 in the summer to 20 species per haul at station SD7 in the winter (Table 6.2). Diversity (H') ranged from 0.8 at station SD13 in the summer to 1.9 at station SD10 in the winter. In contrast, abundance and biomass were much more variable among stations and between surveys during the year. For example, total abundance ranged from 227 to 723 individuals per haul and total biomass ranged from 5.0 to 14.2 kg. The smallest hauls occurred during the summer at stations SD7 and SD8; these hauls had ≤259 individuals. The largest hauls with ≥717 individuals were from station SD7, which included 300 Halfbanded Rockfish and 187 Pacific Sanddab, and from station SD14, which included 259 California Lizardfish, 207 Longspine Combfish, and 174 Pacific Sanddab. Both of these trawls occurred during the winter, and they corresponded to the highest biomass values (≥10.7 kg per haul).

Over the past 24 years, mean species richness and diversity for demersal fishes have remained within narrow ranges (i.e., SR = 11–23 species per haul, H' = 1.1–1.8), whereas there has been considerable variability in mean abundance (i.e., 97–1065 fishes per haul) (Figure 6.3). The latter has largely been due to population fluctuations of a few numerically dominant species (Figure 6.4). For example, differences in overall fish abundance primarily track changes in Pacific Sanddab populations, since this species has been numerically dominant in the PLOO region since sampling began (see following section and City of San Diego 2015). In addition, occasional spikes in abundance have been due to large hauls of other common species such as California Lizardfish, Yellowchin Sculpin, Halfbanded Rockfish, Longspine Combfish, Stripetail Rockfish and Longfin Sanddab. Overall, none of the observed changes appear to be associated with wastewater discharge.

Multivariate Analyses of Fish Assemblages

A long-term analysis of demersal fish assemblages from a total of 142 trawls conducted at six monitoring stations during summer surveys from 1991 through 2014 showed significant differences among the nearfield, north farfield, and south farfield station groups and by year (Table 6.3). Pairwise comparisons showed that assemblages at the south farfield stations differed from those at the north farfield stations (Table 6.3), while 2014 assemblages differed from those present in all other years except for 2009, 2010, and 2012 (Appendix E.4). Species that contributed to these spatial and temporal differences included some of the dominant species mentioned above, such as Pacific Sanddab, California Lizardfish, Yellowchin Sculpin, Halfbanded Rockfish, Longspine Combfish, Stripetail Rockfish and Longfin Sanddab, as well as Bay Goby, California Tonguefish, Dover Sole, Greenblotched Rockfish, Pacific Argentine, Pink Seaperch, Plainfin Midshipman, Shortspine Combfish, Slender Sole, and Stripetail Rockfish (Figure 6.5).

Classification (cluster) analysis discriminated between 11 main types of fish assemblages in the

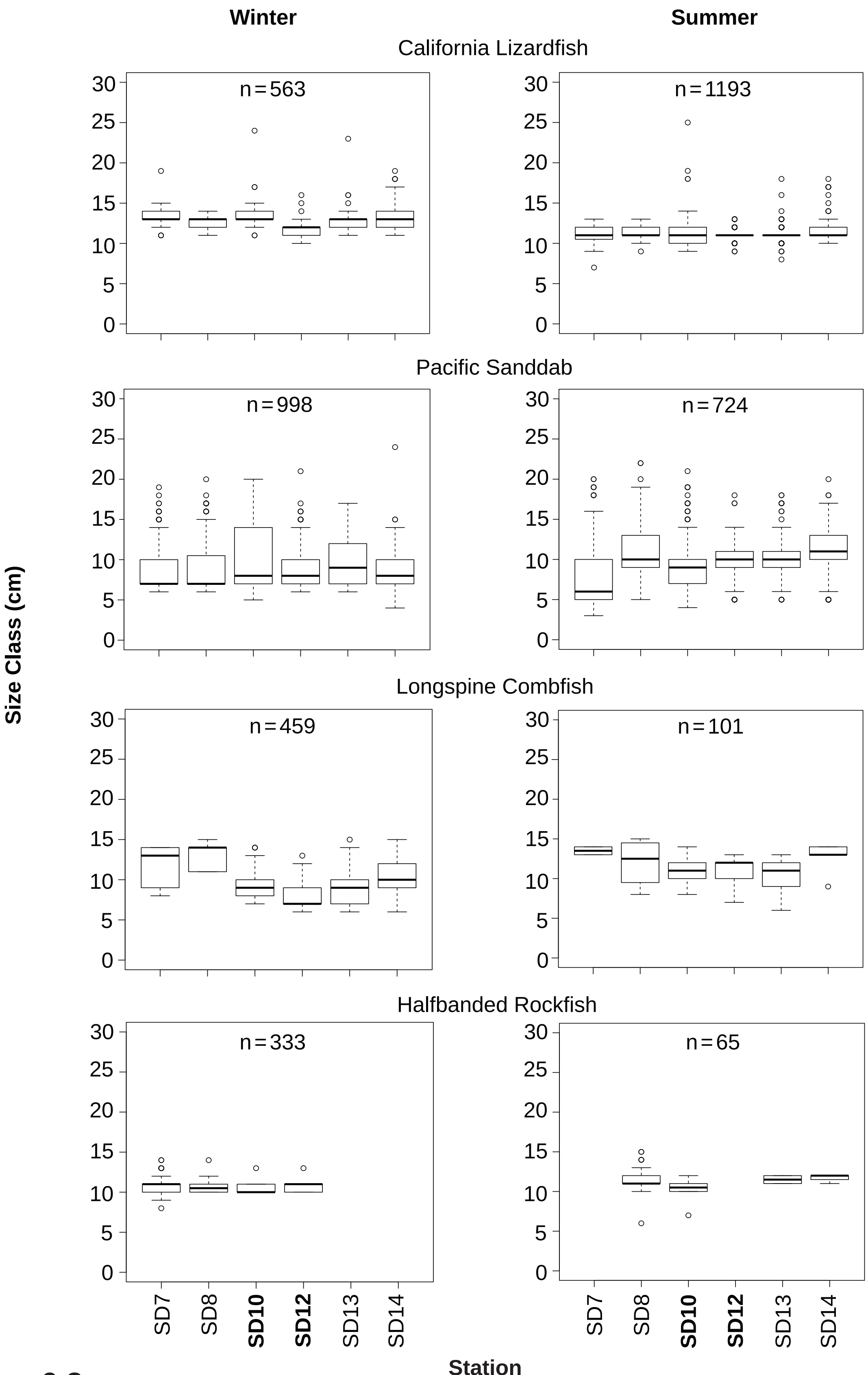

Figure 6.2

Summary of fish lengths by survey and station for each of the four most abundant species collected in the PLOO region during 2014. Data are median, upper and lower quartiles, 1.5 times the interquartile range (whiskers), and outliers (open circles). Stations SD10 and SD12 are considered nearfield (bold; see text).

Table 6.2
Summary of demersal fish community parameters for PLOO trawl stations sampled during 2014. Data are included for species richness, abundance, diversity (H'), and biomass (kg, wet weight). SD = standard deviation.

Station	Winter	Summer
Species Richness		
SD7	20	15
SD8	17	14
SD10	14	17
SD12	16	13
SD13	12	9
SD14	14	12
Survey Mean	16	13
Survey SD	3	3
Abundance		
SD7	723	259
SD8	353	227
SD10	305	507
SD12	369	368
SD13	337	431
SD14	717	513
Survey Mean	467	384
Survey SD	197	122
Diversity		
SD7	1.8	1.3
SD8	1.2	1.6
SD10	1.9	1.6
SD12	1.6	1.1
SD13	1.5	0.8
SD14	1.5	1.0
Survey Mean	1.6	1.3
Survey SD	0.3	0.3
Biomass		
SD7	14.2	5.3
SD8	5.6	5.4
SD10	8.5	8.1
SD12	5.4	6.5
SD13	5.0	5.8
SD14	10.7	9.1
Survey Mean	8.2	6.7
Survey SD	3.7	1.6

Point Loma outfall region over the past 24 years (cluster groups A–K; Figure 6.6, Table 6.4). These included seven small groups representative of one to nine hauls each (groups A–D, F, H, I), and four larger groups ranging from 17 to 40 hauls each and representing ~82% of all trawls (groups E, G, J, K). The distribution of assemblages in 2014 (see description of groups D and G below) was generally similar to those observed in 2009, and there were no discernible patterns associated with proximity to the outfall. Instead, assemblages appear influenced by the distribution of the more abundant species or the unique characteristics of a specific station location. For example, assemblages from stations SD7 and SD8 located south of the outfall often grouped apart from the remaining stations between 1993 and 2007. The species composition and main descriptive characteristics of each cluster group are described below.

Cluster groups A–C and F each represented a unique demersal fish assemblage sampled at one of the nearfield stations (Figure 6.6). The assemblage represented by group A occurred at station SD10 in 1997 and had the lowest number of species (n = 7 species), lowest total abundance (n = 44 individuals), and the lowest number of Pacific Sanddab of any cluster group (n = 23 fish) (Table 6.4). The assemblage represented by group B occurred at station SD12 in 1998 and had 16 species and 261 individuals, and the highest numbers of Plainfin Midshipman (n = 116 fish) and Dover Sole (n = 36 fish) of any group. The assemblage represented by group C occurred at station SD12 in 1997 and had the highest species richness (n = 19 species), 231 individuals, and the highest number of Halfbanded Rockfish (n = 60 fish). The assemblage represented by group F occurred at station SD12 in 2011 and had 13 species, 190 individuals, the second lowest number of Pacific Sanddab (n = 68 fish), and the second highest number of Stripetail Rockfish (n = 20 fish) and Longspine Combfish (n = 17 fish).

Cluster group D represented assemblages from nine hauls collected at stations SD7–SD10 and SD13 in 2009, as well as stations SD7–SD8 and SD12–SD14 in 2014 (Figure 6.6). This group averaged 13 species and 267 individuals per haul and had the highest number of California Lizardfish (125 fish per haul) relative to the other cluster groups (Table 6.4). SIMPER results indicated that Pacific Sanddab, Longspine Combfish, and Dover Sole, which averaged 6–95 individuals per haul, were also characteristic of group D.

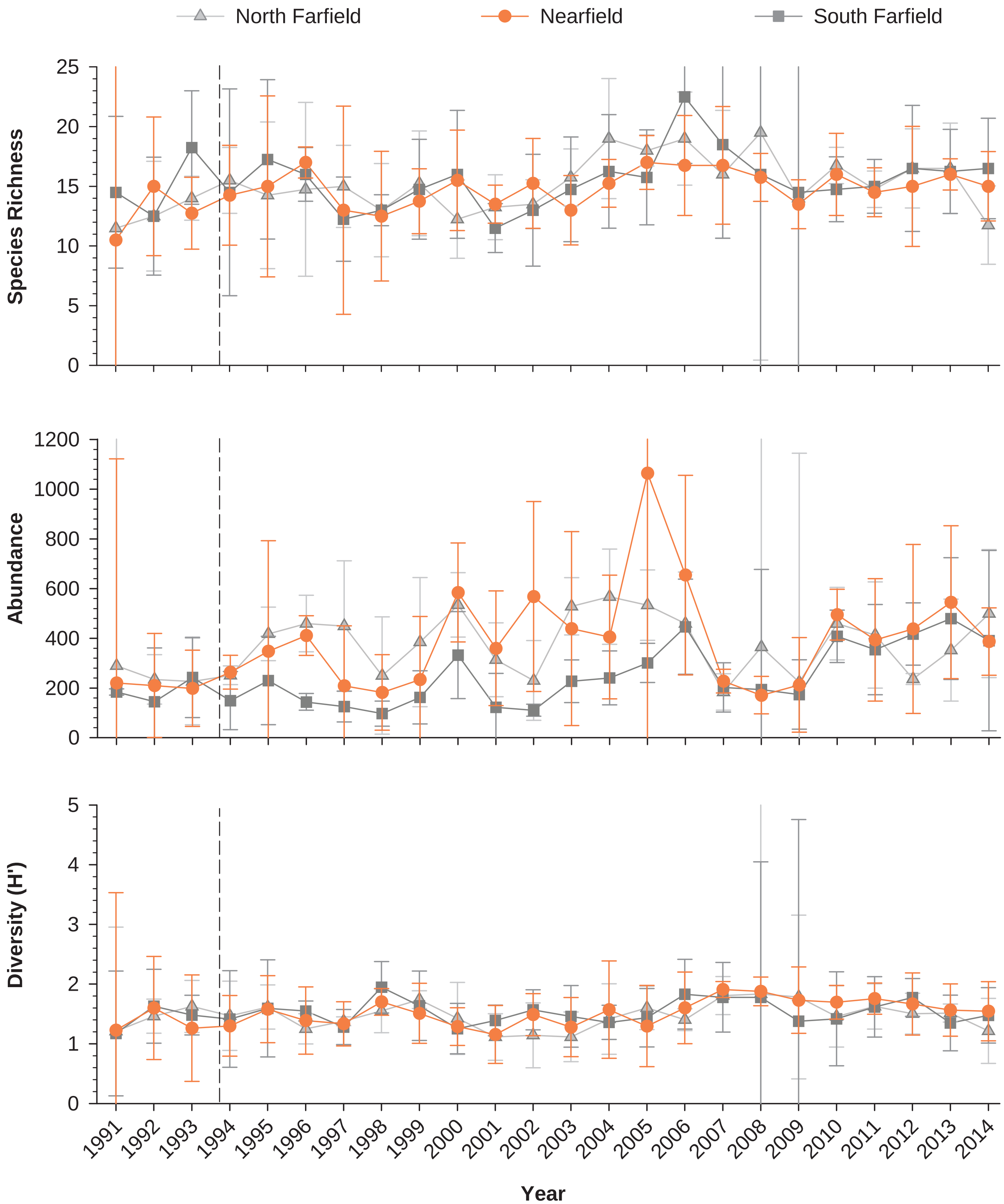

Figure 6.3
Species richness, abundance, and diversity of demersal fishes collected from PLOO trawl stations sampled from 1991 through 2014. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤4), and south farfield stations (n≤4). Dashed lines indicate onset of wastewater discharge.

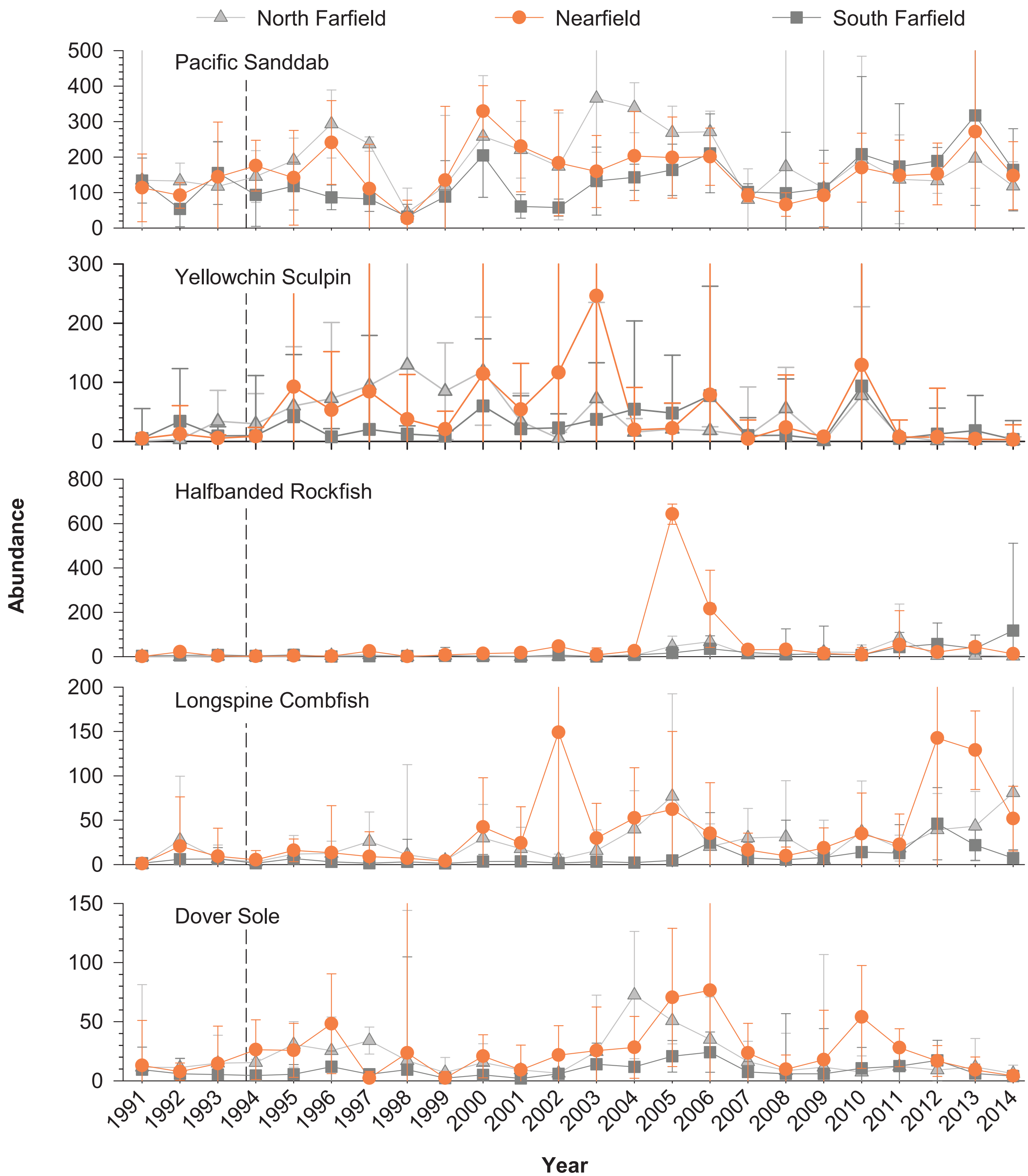

Figure 6.4
The ten most abundant fish species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2014. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤4), and south farfield stations (n≤4). Dashed lines indicate onset of wastewater discharge.

Cluster group E comprised 15 hauls, including five trawls from station SD8 sampled in 2003–2007, two trawls from station SD10 sampled in 2007–2008, five trawls from station SD12 sampled in 2003–2008, two trawls from station SD13 sampled in 2006–2007, and the trawl from station SD14 sampled in 2007 (Figure 6.6). Assemblages represented by group E averaged 16 species and 250 individuals per haul

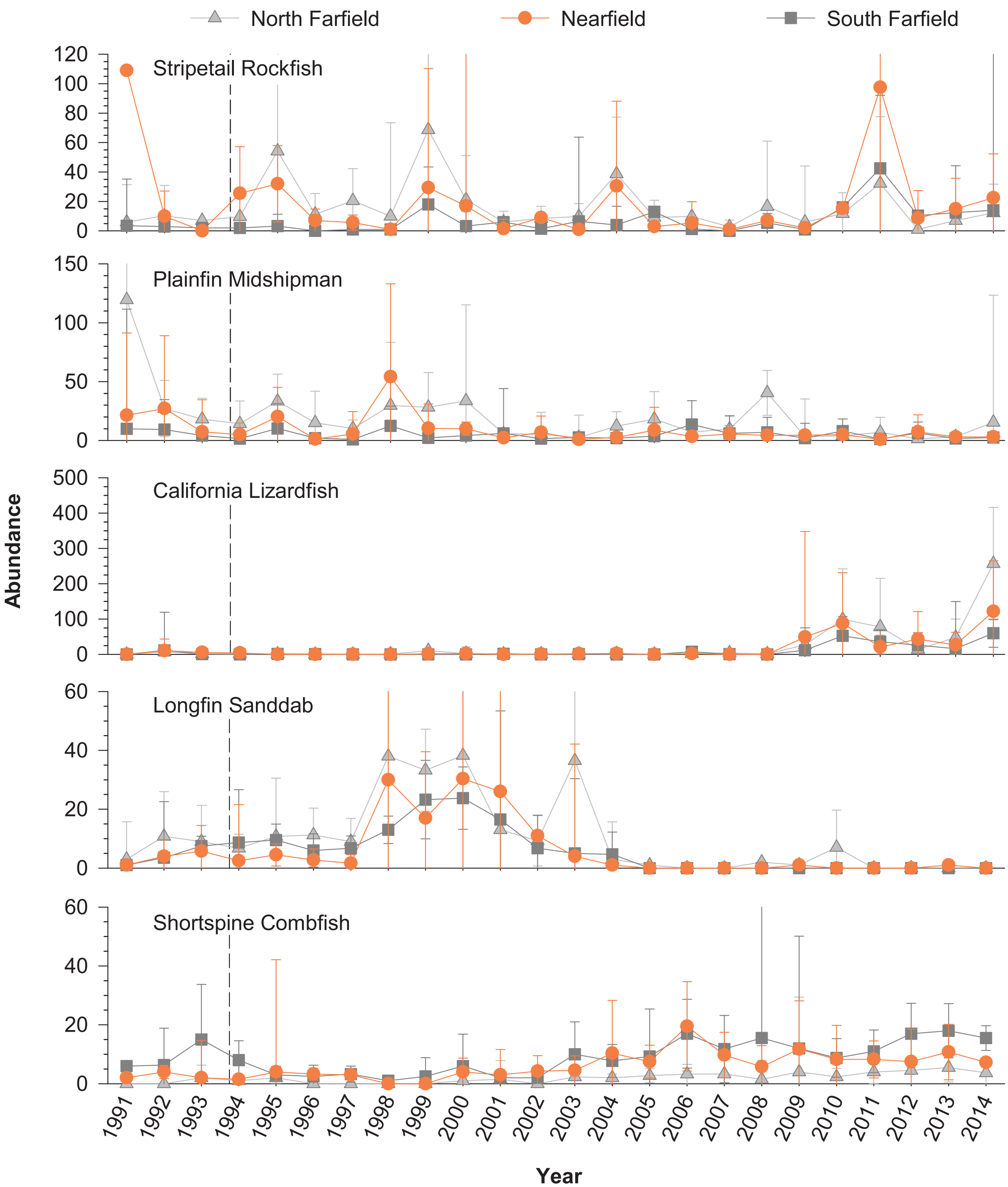

Figure 6.4 *continued*

(Table 6.4). SIMPER results indicated that the most characteristic species for this group included Pacific Sanddab (136 per haul), Halfbanded Rockfish (25 per haul), Dover Sole (24 per haul), Longspine Combfish (12 per haul), Shortspine Combfish (12 per haul), and Slender Sole (8 per haul).

Cluster group G was the third largest cluster group, representing assemblages from a total of 28 hauls that included 96% (n = 23) of the trawls conducted at all stations sampled from 2010 through 2013, as well as the trawls from station SD10 and station SD14 in 2006, the trawls from station SD12 and station SD14

Table 6.3

Results of 2-way crossed ANOSIM (with replicates) for demersal fish assemblages sampled around the PLOO from 1991 through 2014. Data were limited to summer surveys.

Global Test: Factor A (station groups)

Tests for differences between station group (across all years)

Sample statistic (Global R):	0.357 [a]
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0

Pairwise Tests: Factor A

Tests for pairwise differences between individual station groups across all years: r values (p values)

	Nearfield	South Farfield
North Farfield	0.207 (1.0)	0.674 (0.01)
South farfield	0.239 (0.2)	

Global Test: Factor B (years)

Tests for differences between years (across all station groups, see Appendix E.4)

Sample statistic (Global R):	0.670 [a]
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0

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

in 2009, and the trawl from station SD10 in 2014 (Figure 6.6). These assemblages averaged 16 species and 459 individuals per haul (Table 6.4). Group G was one of two groups (with group J) that had the highest number of Pacific Sanddab at 252 fish per haul. Other characteristic species included Halfbanded Rockfish (57 per haul), California Lizardfish (41 per haul), Longspine Combfish (38 per haul), and Dover Sole (22 per haul).

Cluster group H comprised the assemblages from three hauls collected at station SD10, SD13 and SD14 during 1999 (Figure 6.6). This group had the second highest species richness (17 species per haul) and highest abundance (495 fish per haul), and the second highest number of Pacific Sanddab (248 per haul) (Table 6.4). Group H also had the highest number of Longfin Sanddab (32 per haul), Stripetail Rockfish (102 per haul), and Yellowchin Sculpin (31 per haul) of any cluster group. Other characteristic species included Plainfin Midshipman (26 per haul) and Halfbanded Rockfish (7 per haul).

Cluster group I represented assemblages from seven trawls that included station SD7 sampled in 2003–2006, station SD8 sampled in 1991–1992, and station SD10 sampled in 2001 (Figure 6.6). These assemblages averaged 15 species of fish, 223 individuals, and 149 Pacific Sanddab per haul (Table 6.4). In addition to Pacific Sanddab, SIMPER results indicated that the most characteristic species for group I included Yellowchin Sculpin (20 per haul), Dover Sole (16 per haul), Shortspine Combfish (7 per haul), and Plainfin Midshipman (3 per haul).

Cluster group J was the largest group, representing assemblages from a total of 40 hauls that included 75% (n = 39) of the trawls conducted at stations SD10–SD14 from 1993 through 2005, as well as the trawl conducted at station SD7 in 2000 (Figure 6.6). Group J averaged 15 species and 375 individuals per haul, and had the highest number of Pacific Sanddab (252 per haul) with group G (Table 6.4). Other species characteristic of these assemblages included Dover Sole (33 per haul), Longspine

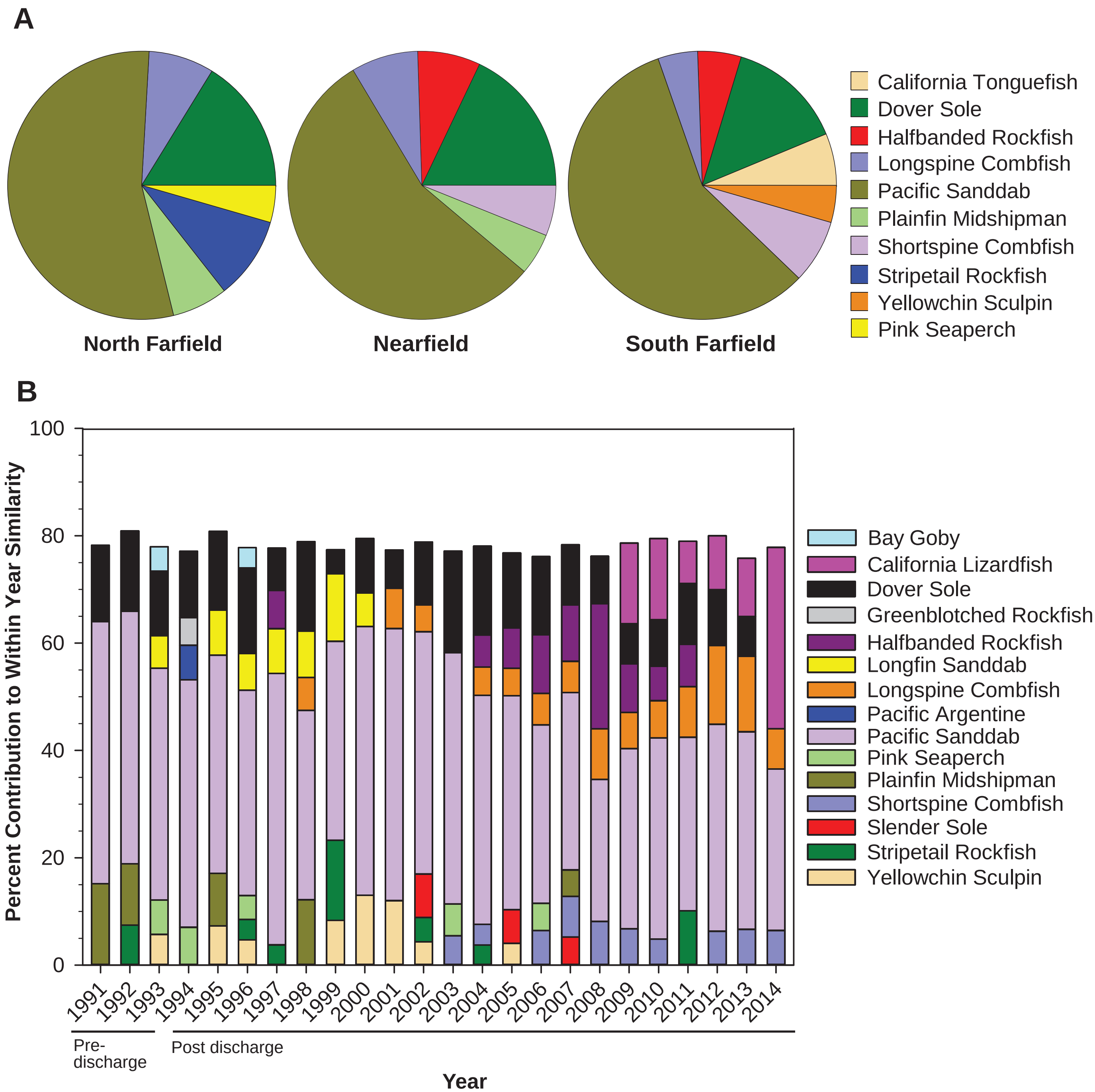

Figure 6.5
Characteristic demersal fish species collected from PLOO trawl stations sampled from 1991 through 2014 that contribute up to 81% of within group similarity for (A) each station group (Factor A during summer surveys), and (B) each year group (Factor B) according to SIMPER analysis (see Table 6.3).

Combfish (17 per haul), Yellowchin Sculpin (15 per haul), and Stripetail Rockfish (8 per haul).

Cluster group K was the second largest group, representing assemblages from a total of 34 hauls that included 88% (n = 21) of the trawls conducted at south farfield stations SD7 and SD8 from 1991–2002 (Figure 6.6). This group also included all of the trawls from stations SD10–SD14 sampled in 1991 and 1992, the trawls from stations SD10 and SD12 sampled in 1995, the trawls from stations SD10 and SD14 sampled in 1998, and the trawl from station SD7 sampled in 2007. These assemblages averaged 13 species, 151 individuals, and 91 Pacific Sanddab

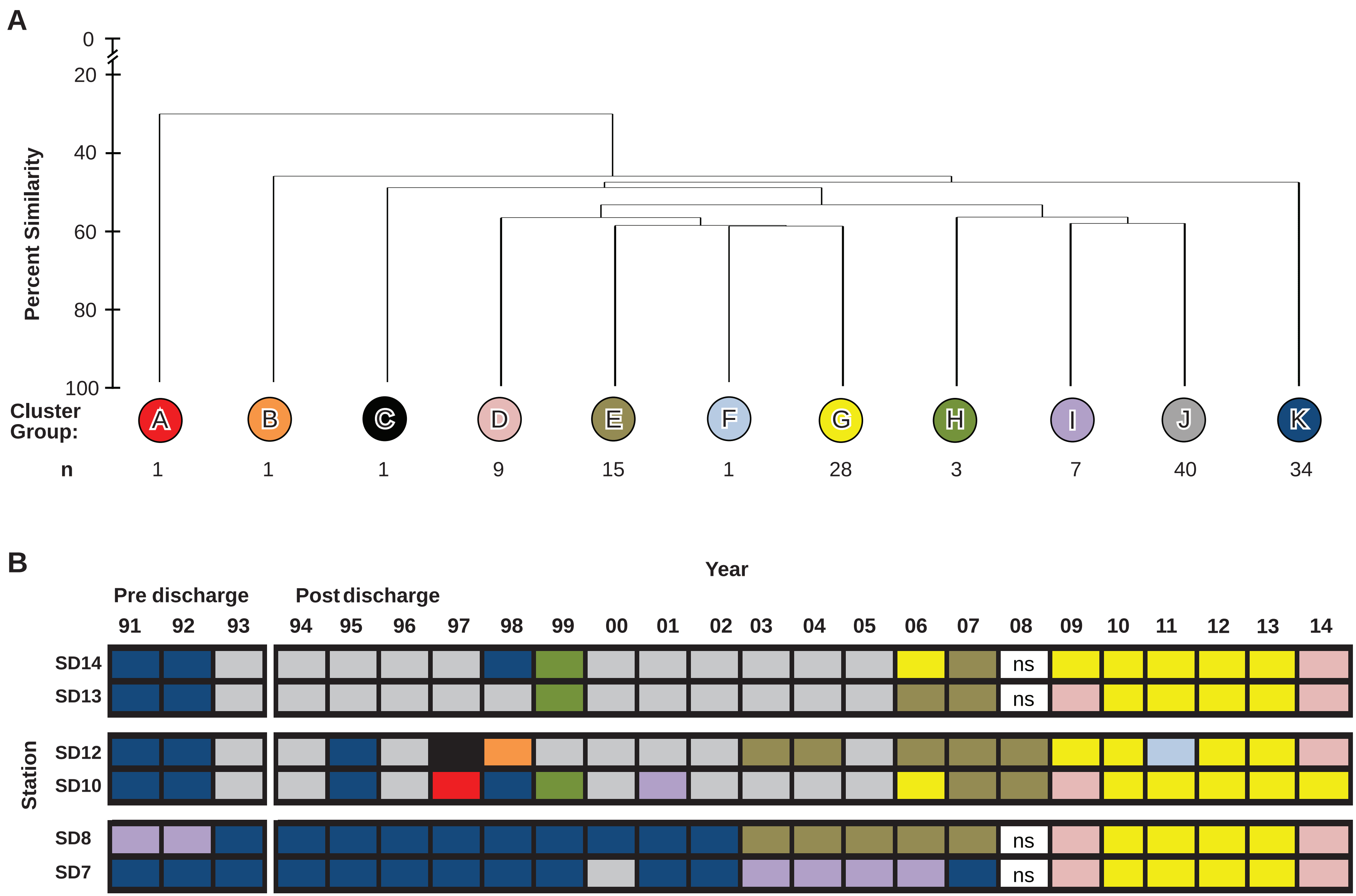

Figure 6.6
Results of cluster analysis of demersal fish assemblages from PLOO trawl stations sampled from 1991 through 2014. Data are limited to summer surveys and are presented as (A) a dendrogram of main cluster groups and (B) a matrix showing distribution of cluster groups over time; n=number of hauls; ns=not sampled.

Table 6.4

Description of demersal fish cluster groups A–K defined in Figure 6.6. Bold values indicate species that were considered most characteristic of that group contributing up to 80% within-group similarity according to SIMPER analysis.

	Cluster Group										
	A[a]	B[a]	C[a]	D	E	F[a]	G	H	I	J	K
Number of Hauls	1	1	1	9	15	1	28	3	7	40	34
Mean Species Richness	7	16	19	13	16	13	16	17	15	15	13
Mean Abundance	44	261	231	267	250	190	459	495	223	375	151
Species	**Mean Abundance**										
Pacific Sanddab	23	75	110	**95**	**136**	68	**252**	**248**	**149**	**252**	**91**
Halfbanded Rockfish	16	0	60	11	**25**	0	**57**	**7**	6	7	2
Longfin Sanddab	1	0	0	0	<1	0	<1	**32**	0	5	**6**
Plainfin Midshipman	0	116	4	1	4	0	2	**26**	**3**	9	**13**
Dover Sole	0	36	1	**6**	**24**	31	**22**	5	**16**	**33**	**9**
Longspine Combfish	0	7	2	**7**	**12**	17	**38**	5	4	**17**	1
Stripetail Rockfish	0	1	5	3	2	20	10	**102**	<1	**8**	8
Slender Sole	0	2	0	1	**8**	2	2	6	2	6	1
Shortspine Combfish	0	0	3	8	**12**	7	10	0	**7**	2	2
California Tonguefish	0	0	1	<1	2	0	<1	3	1	<1	**3**
California Lizardfish	0	0	0	**125**	<1	18	**41**	6	<1	0	<1
Yellowchin Sculpin	0	0	0	<1	<1	0	2	**31**	**20**	**15**	3

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

per haul (Table 6.4). Other species characteristic of group K included Plainfin Midshipman (13 per haul), Dover Sole (9 per haul), Longfin Sanddab (6 per haul), and California Tonguefish (3 per haul).

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the PLOO region during 2014. There were no incidences of fin rot, skin lesions, or tumors during the year, and incidences of other abnormalities were very rare (0.04%). The latter included one Spotted Cusk-eel with lumpy skin and one Pacific Sanddab with ambicoloration. Evidence of parasitism was also very low (<1.0%) for trawl-caught fishes in the region. The copepod *Phrixocephalus cincinnatus* infected 2.2% of the Pacific Sanddab (38 individuals) collected during the year; this eye parasite was found on fish from all stations. In addition, two Pacific Sanddab were observed with attached specimens of the cymothoid isopod gill parasite *Elthusa vulgaris*. Finally, 15 individuals of *E. vulgaris* were identified as part of the trawl invertebrate catches during the year (see Appendix E.5). Since *E. vulgaris* often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these organisms. However, *E. vulgaris* is known to be especially common on Sanddab 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 20,338 megabenthic invertebrates (~1695 per trawl) representing 43 taxa from six phyla were collected in 2014 (Table 6.5, Appendix E.5, Appendix E.6). Overall, the total catch was 36% smaller in 2014 than in 2013, and continued to be dominated by echinoderms. The sea urchin *Lytechinus pictus* was the most abundant and most frequently occurring trawl invertebrate, averaging 1280 individuals per haul (76% of total abundance), and occurring in every

Table 6.5

Megabenthic invertebrates collected from 12 trawls conducted in the PLOO region during 2014. PA=percent abundance; FO=frequency of occurrence; MAH=mean abundance per haul; MAO=mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
Lytechinus pictus	76	100	1280	1280	*Metridium farcimen*	<1	17	<1	1
Ophiura luetkenii	20	100	339	339	*Ophiopholis bakeri*	<1	8	<1	2
Strongylocentrotus fragilis	3	33	44	132	*Pandalus danae*	<1	17	<1	1
Florometra serratissima	<1	33	8	25	*Philine alba*	<1	8	<1	2
Luidia foliolata	<1	100	4	4	*Podochela lobifrons*	<1	8	<1	2
Acanthoptilum sp	<1	50	3	6	*Schmittius politus*	<1	8	<1	2
Parastichopus californicus	<1	83	2	3	*Antiplanes catalinae*	<1	8	<1	1
Astropecten californicus	<1	67	2	2	Asteriidae	<1	8	<1	1
Ophiothrix spiculata	<1	17	2	9	*Barbarofusus barbarensis*	<1	8	<1	1
Octopus rubescens	<1	83	1	2	*Calliostoma turbinum*	<1	8	<1	1
Elthusa vulgaris	<1	58	1	2	*Cancellaria crawfordiana*	<1	8	<1	1
Pleurobranchaea californica	<1	67	1	2	*Enallopaguropsis guatemoci*	<1	8	<1	1
Thesea sp B	<1	33	1	3	*Ericerodes hemphillii*	<1	8	<1	1
Acanthodoris brunnea	<1	33	1	3	*Euspira draconis*	<1	8	<1	1
Luidia asthenosoma	<1	58	1	1	*Lepidozona* sp	<1	8	<1	1
Sicyonia ingentis	<1	25	<1	2	*Megasurcula carpenteriana*	<1	8	<1	1
Paguristes turgidus	<1	25	<1	1	*Paguristes bakeri*	<1	8	<1	1
Spatangus californicus	<1	17	<1	2	*Philine auriformis*	<1	8	<1	1
Suberites latus	<1	25	<1	1	*Platymera gaudichaudii*	<1	8	<1	1
Arctonoe pulchra	<1	8	<1	2	*Pteropurpura macroptera*	<1	8	<1	1
Calinaticina oldroydii	<1	17	<1	1	*Tritonia tetraquetra*	<1	8	<1	1
Hinea insculpta	<1	17	<1	1					

trawl. No other species contributed to more than 20% of the total catch. For example, the brittle star *Ophiura luetkenii* and the sea star *Luidia foliolata* also occurred in every haul, but averaged just 339 and 4 individuals per haul, respectively. Other species collected during the year that occurred in at least 50% of the trawls but in low numbers (i.e., ≤3 per haul) included the sea stars *Astropecten californicus* and *Luidia asthenosoma*, the sea cucumber *Parastichopus californicus*, the opisthobranch *Pleurobranchaea californica*, the cephalopod *Octopus rubescens*, the sea pen *Acanthoptilum* sp, and the cymothoid isopod *Elthusa vulgaris*. No new species were reported in the 2014 surveys.

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.6). For each haul, species richness ranged from 8 to 24 species and total abundance ranged from 56 to 4253 individuals. During 2014, the lowest species richness values of ≤10 were recorded at stations SD8, SD12, SD13 and SD14 during the winter and at station SD14 during the summer. Patterns of total invertebrate abundance mirrored variation in populations of *Lytechinus pictus* because of the overwhelming dominance of this sea urchin (Appendix E.6). For example, high invertebrate abundances with ≥2414 individuals per haul reflected large hauls of *L. pictus* (i.e., 2081–3913 per haul) recorded at stations SD7 and SD10 during the winter and at stations SD7 and SD8 during the summer. In addition, large numbers of *Ophiura luetkenii* (i.e., 1794–2070 per haul) contributed to high abundances at station SD14 in the winter and at station SD7 in the summer. The low diversity values (≤1.5) observed throughout the PLOO region during 2014 were caused by the numerical dominance of one or both of these two species.

Table 6.6

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

Station	Winter	Summer
Species Richness		
SD7	14	16
SD8	10	24
SD10	12	13
SD12	10	13
SD13	8	11
SD14	9	9
Survey Mean	10	14
Survey SD	2	5
Abundance		
SD7	2414	4253
SD8	2577	2703
SD10	3949	887
SD12	56	268
SD13	538	394
SD14	2021	278
Survey Mean	1926	1464
Survey SD	1427	1651
Diversity		
SD7	0.2	0.8
SD8	0.2	0.1
SD10	0.1	0.2
SD12	1.5	0.5
SD13	0.9	1.0
SD14	0.5	0.9
Survey Mean	0.6	0.6
Survey SD	0.6	0.4

As described for demersal fishes, mean trawl-caught invertebrate diversity and species richness have remained within narrow ranges (i.e., H' = 0.1–1.4, SR = 7–24 species per haul) off Point Loma since 1991 (Figure 6.7). In contrast, there has been considerable variability in abundance (i.e., 79–5613 individuals per haul) over the years, largely due to population fluctuations of a few numerically dominant species (Figure 6.8). For example, differences in overall invertebrate abundance, especially at nearfield and south farfield stations, primarily track changes in *Lytechinus pictus* populations, since this species has been numerically dominant in the PLOO region since sampling began (see following section and City of San Diego 2015). Other influential species include the sea pen *Acanthoptilum* sp, the sea urchin *Strongylocentrotus fragilis*, and more recently the brittle star *Ophiura luetkenii*. For example, fluctuations of *S. fragilis* populations have contributed greatly to changes in total abundance at the north farfield stations. These results are likely due to differences in sediment composition between the north and south regions of the PLOO survey area (see Chapter 4) and to the narrowness of the continental shelf in the north region that may allow deep-water *S. fragilis* to move into shallower depths. Overall, none of the observed changes appear to be associated with wastewater discharge.

Multivariate Analysis of Invertebrate Assemblages

A long-term analysis of trawl-caught invertebrate assemblages from a total of 142 trawls conducted at six monitoring stations during summer surveys from 1991 through 2014 showed significant differences among the nearfield, north farfield, and south farfield station groups and by year (Table 6.7). Pairwise comparisons showed that assemblages at the north farfield stations differed from those at the nearfield and south farfield stations (Table 6.7), while 2014 assemblages differed from those present during 1992–1994, 1996, 1997, and 2001 (Appendix E.7). Species that contributed to these spatial and temporal differences included the urchins *Lytechinus pictus* and *Strongylocentrotus fragilis*, the sea stars *Astropecten californicus* and *Luidia foliolata*, the brittle star *Ophiura luetkenii*, the sea pen *Acanthoptilum* sp, and the sea cucumber *Parastichopus californicus* (Figure 6.9).

Classification (cluster) analysis discriminated between four main types of invertebrate assemblages in the outfall region over the past 24 years (cluster groups A–D; Figure 6.10, Table 6.8). These included two small groups representative of four and one hauls each (Groups A and B, respectively), and two larger groups representing ~96% of all trawls (groups C and D). The distribution of assemblages in 2014 was generally similar to that seen in previous years and there continued to be no discernible patterns associated with proximity to the outfall. Instead, assemblages

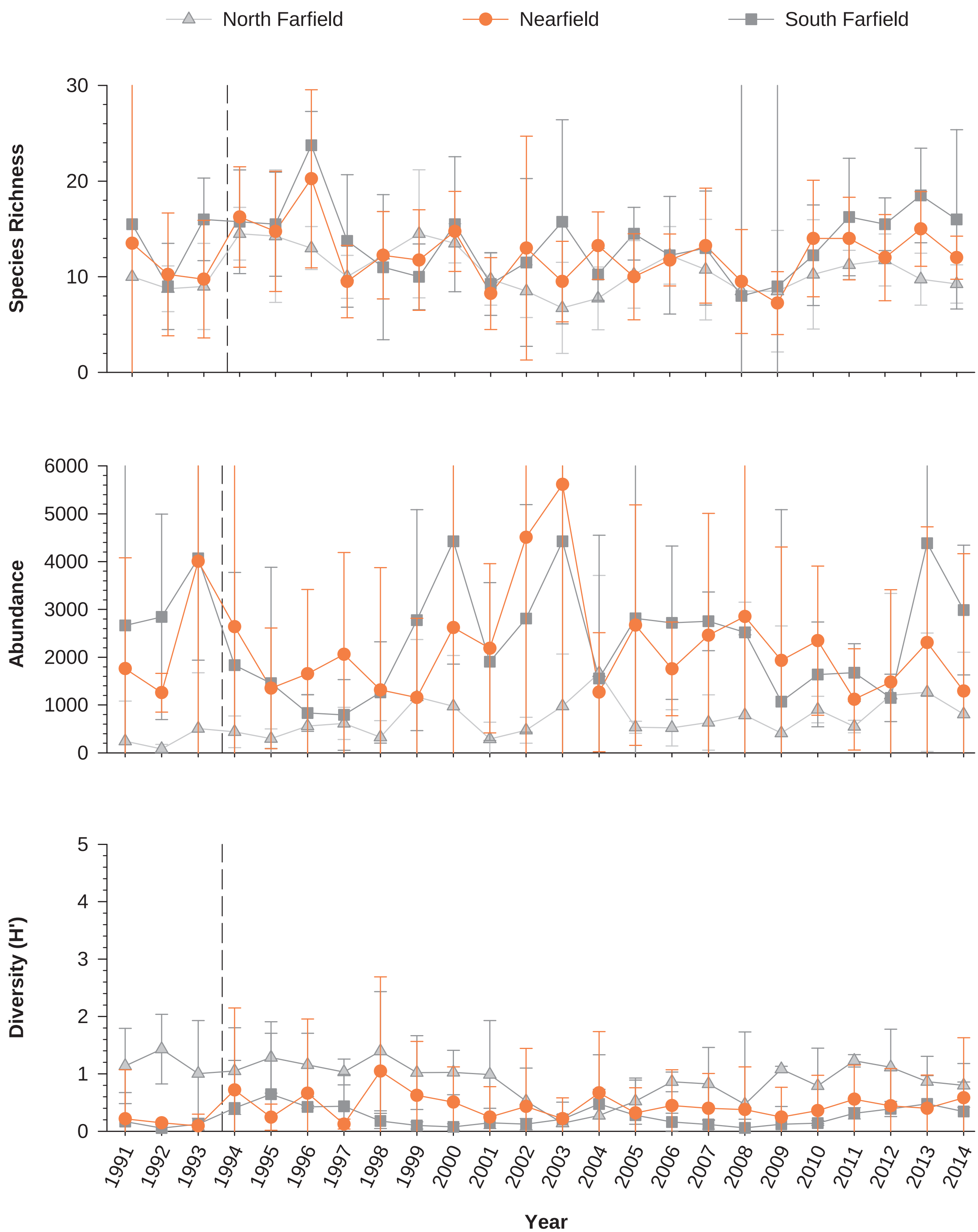

Figure 6.7
Species richness, abundance, and diversity of megabenthic invertebrates collected from PLOO trawl stations from 1991 through 2014. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤4), and south farfield stations (n≤4). Dashed lines indicate onset of wastewater discharge.

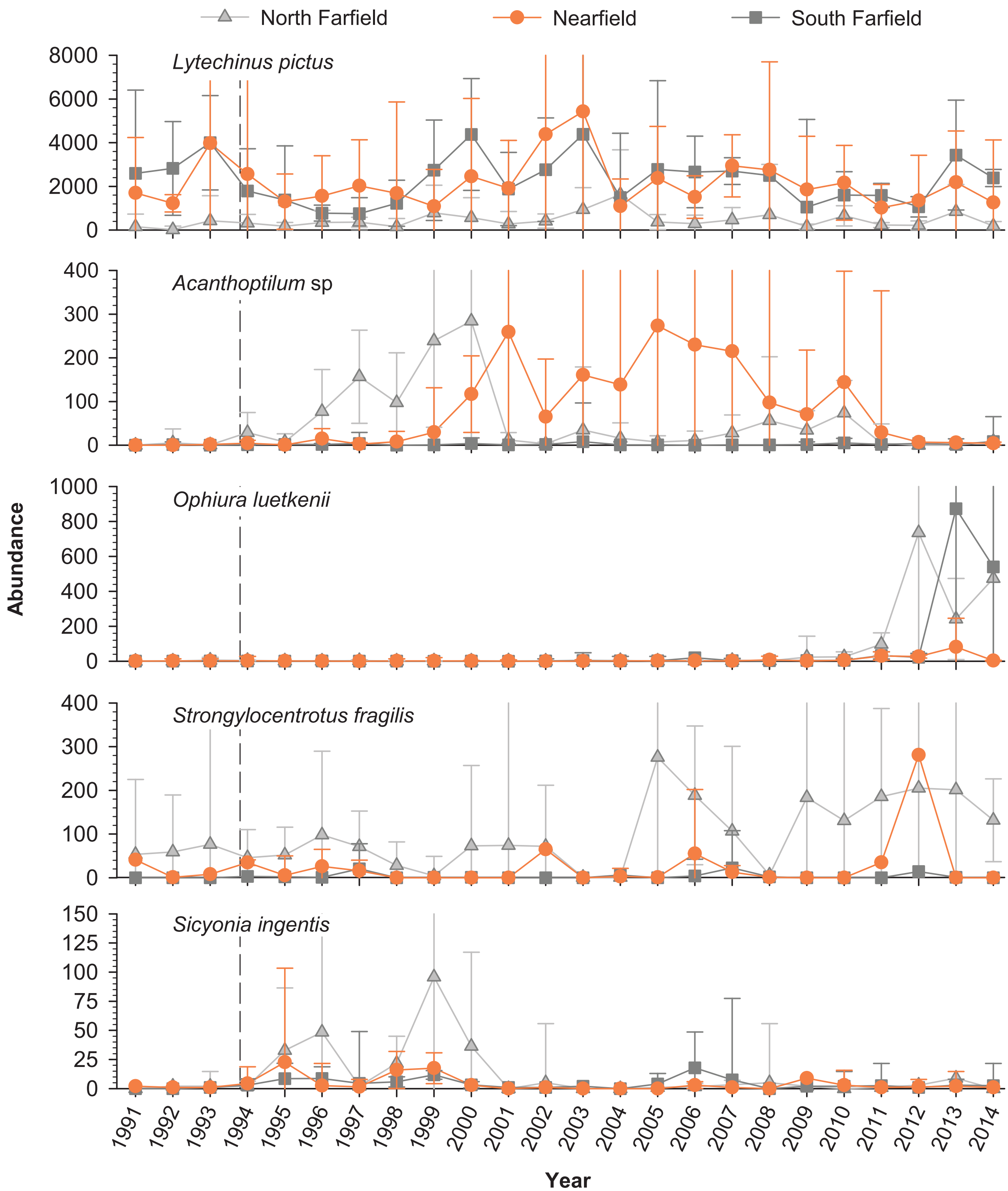

Figure 6.8
The ten most abundant invertebrate species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2014. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤4), and south farfield stations (n≤4). Dashed lines indicate onset of wastewater discharge.

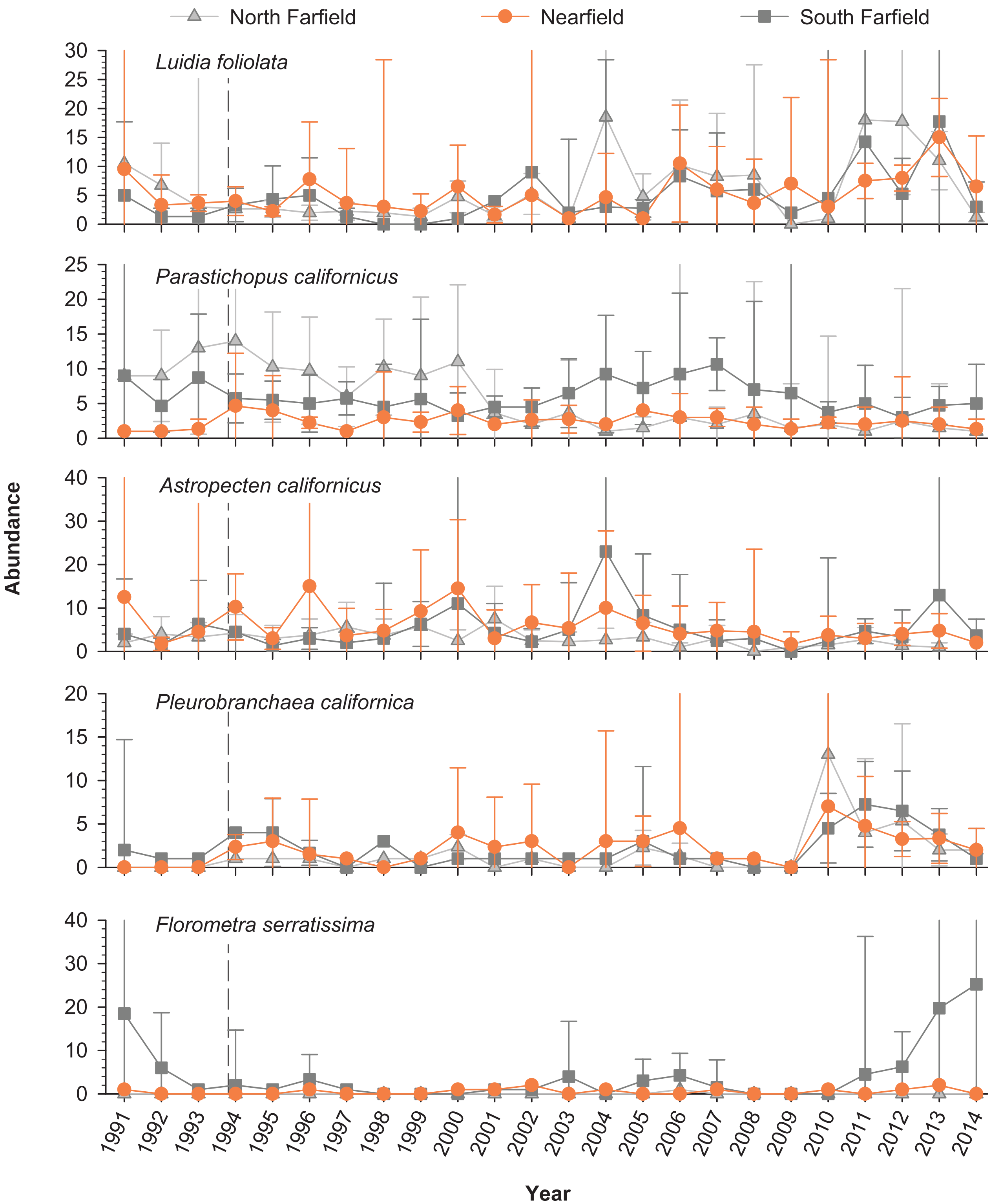

Figure 6.8 *continued*

appear influenced by the distribution of the more abundant species or the unique characteristics of a specific station location. For example, stations SD13 and SD14 located north of the outfall often grouped apart from the remaining stations. The species composition and main descriptive characteristics of each cluster group are described below.

Cluster group A comprised four hauls, including those from station SD12 in 1998, 2007, and 2009,

Table 6.7

Results of 2-way crossed ANOSIM (with replicates) for megabenthic invertebrate assemblages sampled around the PLOO from 1991 through 2014. Data were limited to summer surveys.

Global Test: Factor A (station groups)

Tests for differences between station group (across all years)

Sample statistic (Global R):	0.411 [a]
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0

Pairwise Tests: Factor A

Tests for pairwise differences between individual station groups across all years: r values (p values)

	Nearfield	South Farfield
North Farfield	0.359 (0.01)	0.760 (0.01)
South farfield	0.087 (15.2)	

Global Test: Factor B (years)

Tests for differences between years (across all station groups, see Appendix E.7)

Sample statistic (Global R):	0.270 [a]
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0

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

and from station SD14 in 1998 (Figure 6.10). Assemblages represented by this group had the second highest species richness (13 species per haul), the lowest total abundance (171 individuals per haul), the highest number of *Acanthoptilum* sp (121 per haul) and lowest number of *Lytechinus pictus* (10 per haul) (Table 6.8). SIMPER results indicated that *Sicyonia ingentis*, *Astropecten californicus*, *Parastichopus california*, *Ophiura luetkenii*, and *Octopus rubescens*, which averaged 1–9 individuals per haul, were also characteristic of group A.

Cluster group B represented a unique megabenthic invertebrate assemblage that occurred at station SD14 in 2012 (Figure 6.10). This assemblage had the lowest species richness (n = 10 species), the highest abundance (n = 3205 individuals), the highest numbers of *Ophiura luetkenii* (n = 2640 individuals) and *Strongylocentrotus fragilis* (n = 442 individuals), and the second lowest number of *Lytechinus pictus* (n = 102 individuals) of any cluster group (Table 6.8).

Cluster group C was the largest group, representing assemblages from a total of 89 hauls that included 87% (n = 82) of the trawls conducted at stations SD7–SD12 over the past 24 years, as well as the trawls from station SD13 in 1998–1999 and 2003–2004, and the trawls from station SD14 in 1993, 1999 and 2003 (Figure 6.10). These assemblages had the highest species richness (14 species per haul), the second highest total abundance (2327 individuals per haul), and the highest number of *Lytechinus pictus* (2188 per haul) (Table 6.8). Other characteristic species were *Astropecten californicus* (5 per haul) and *Parastichopus californicus* (5 per haul).

Cluster group D was the second largest group, representing assemblages from a total of 46 hauls that included 80% (n = 37) of the trawls conducted at north farfield stations SD13 and SD14 over the past 24 years, as well as the trawls from station SD8 in 1994 and 1995 and from station SD12 in 1994, 1996, 1999, and 2011–2014 (Figure 6.10). These assemblages averaged 12 species and

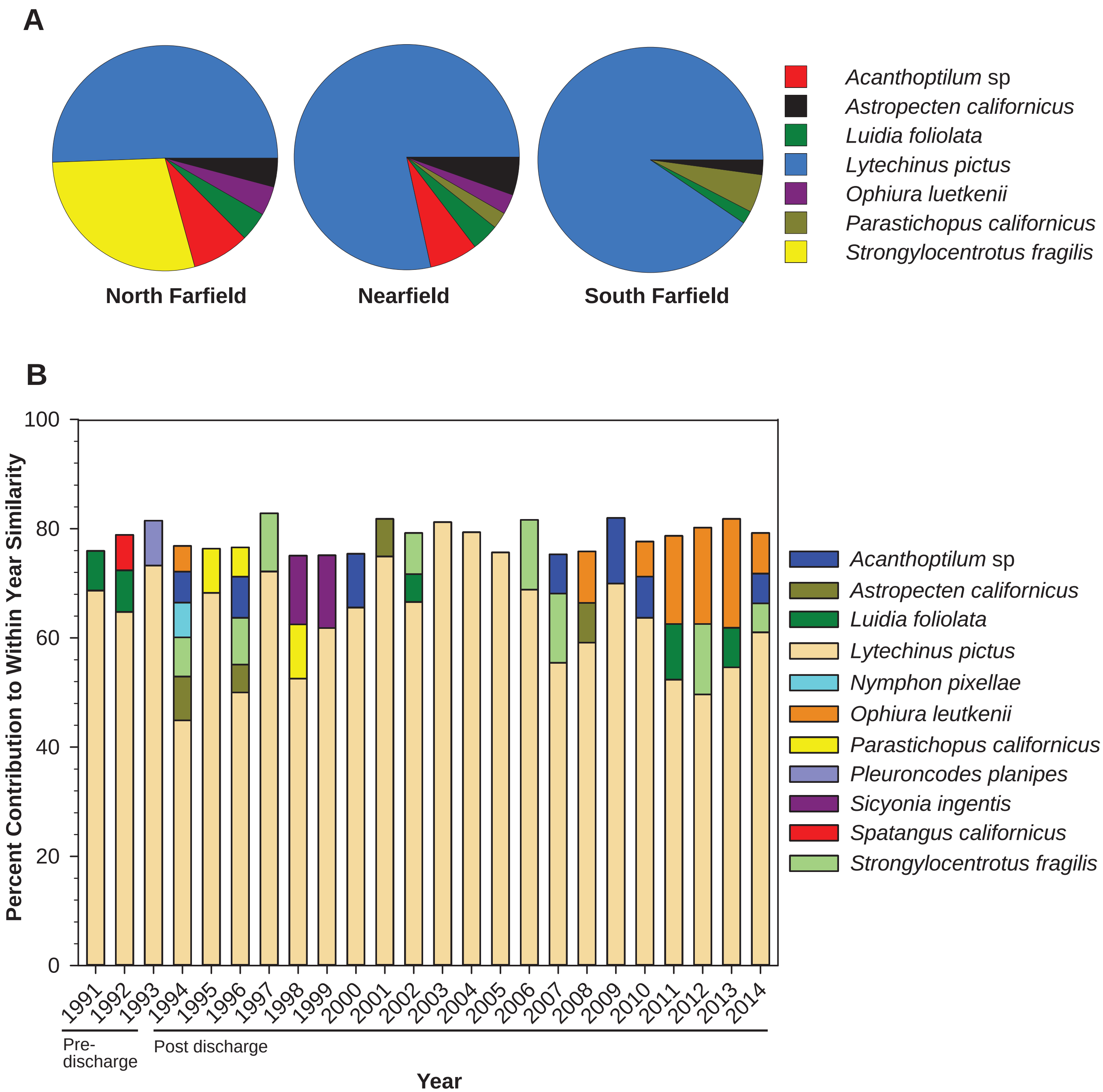

Figure 6.9
Characteristic megabenthic invertebrate species collected from PLOO trawl stations sampled during summer surveys from 1991 through 2014 that contribute up to 93% of within group similarity for (A) each station group (Factor A), and (B) each year group (Factor B) according to SIMPER analysis (see Table 6.7).

450 individuals per haul, and had the second highest number of *Lytechinus pictus* (239 per haul) (Table 6.8). SIMPER results indicated that *Strongylocentrotus fragilis*, *Acanthoptilum* sp, *Ophiura luetkenii*, and *Luidia foliolata*, which averaged 6–135 individuals per haul, were also characteristic of this group.

Summary

Pacific Sanddab and California Lizardfish dominated Point Loma fish assemblages during 2014, with both species occurring at all stations and each accounting for about 34% of the year's catch.

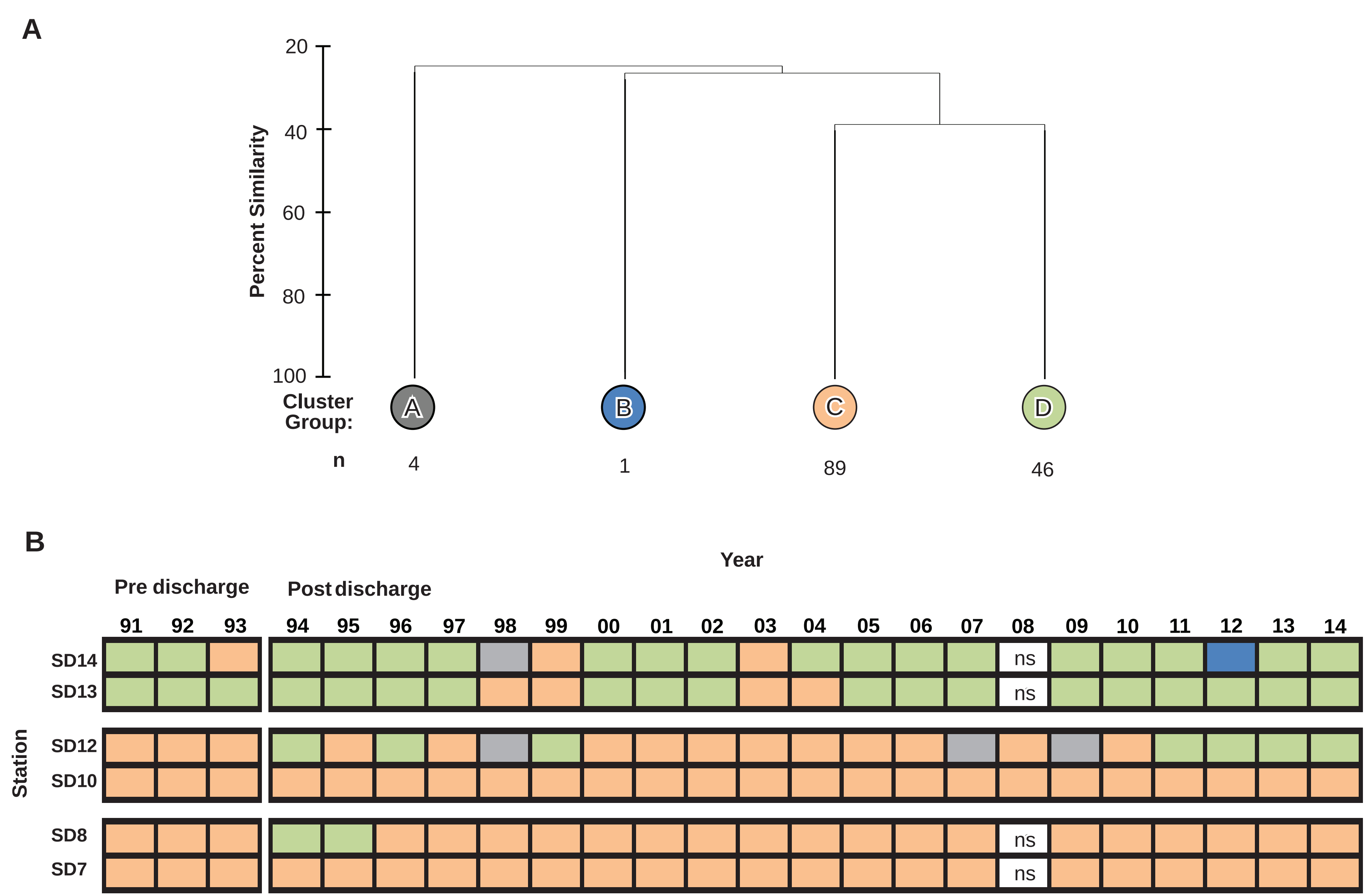

Figure 6.10
Results of cluster analysis of megabenthic invertebrate assemblages from PLOO trawl stations sampled from 1991 through 2014. Data are limited to summer surveys and presented as (A) a dendrogram of main cluster groups and (B) a matrix showing distribution of cluster groups over time; n=number of hauls; ns=not sampled.

Table 6.8

Description of megabenthic invertebrate cluster groups A–D defined in Figure 6.10. Bold values indicate species that were considered most characteristic of that group contributing up to 89% within-group similarity according to SIMPER analysis.

	Cluster Group			
	A	B[a]	C	D
Number of Hauls	4	1	89	46
Mean Species Richness	13	10	14	12
Mean Abundance	171	3205	2327	450
Species	**Mean Abundance**			
Acanthoptilum sp	**121**	0	49	**31**
Lytechinus pictus	10	102	**2188**	**239**
Strongylocentrotus fragilis	6	442	6	**135**
Ophiura luetkenii	**2**	2640	41	**18**
Sicyonia ingentis	**9**	0	6	2
Astropecten californicus	**5**	1	**5**	4
Parastichopus californicus	**4**	0	**5**	3
Octopus rubescens	**1**	0	1	1
Luidia foliolata	0	11	4	**6**

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

Other common species off Point Loma included Bigmouth Sole, California Skate, California Tonguefish, Dover Sole, English Sole, Halfbanded Rockfish, Hornyhead Turbot, Longspine Combfish, Pink Seaperch, Plainfin Midshipman, Shortspine Combfish, Stripetail Rockfish, and Yellowchin Sculpin. Almost all fishes collected were <20 cm in length. Although the composition and structure of the fish assemblages varied among stations and surveys in 2014, these differences appear to be due to natural fluctuations of common species.

Assemblages of trawl-caught invertebrates in 2014 were dominated by the sea urchin *Lytechinus pictus*, which occurred in all trawls and accounted for 76% of all invertebrates captured. The sea star *Luidia foliolata* and the brittle star *Ophiura luetkenii* were also collected at all stations, although usually in fairly low numbers at most sites. Other common, but far less abundant invertebrates included the sea urchin *Strongylocentrotus fragilis*, the sea stars *Astropecten californicus* and *Luidia asthenosoma*, the sea cucumber *Parastichopus californicus*, the opisthobranch *Pleurobranchaea californica*, the cephalopod *Octopus rubescens*, the sea pen *Acanthoptilum* sp, and the cymothoid isopod *Elthusa vulgaris*. As with demersal fishes, the composition of the trawl-caught invertebrate assemblages in the PLOO region varied among stations and surveys, generally reflecting population fluctuations in the species mentioned above.

Overall, there is no evidence that wastewater discharged through the PLOO affected demersal fish or megabenthic invertebrate communities in 2014. Although highly variable, patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away. Instead, the high degree of variability in these assemblages during the year was similar to that observed in previous years including before wastewater discharge began (City of San Diego 2005, 2006, 2007a, b, 2008–2015). Further, this sort of variability has also been observed in similar benthic habitats elsewhere in the Southern California Bight (Allen et al. 1998, 2002, 2007, 2011). Consequently, changes in local community structure of these organisms are more likely due to natural factors such as changes in ocean temperatures associated with El Niño or other large-scale oceanographic events, and to the mobile nature of many resident species. Finally, the absence of disease indicators or other physical abnormalities in local fishes suggests that populations in the Point Loma outfall region continue to be healthy.

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Chapter 7
Bioaccumulation of Contaminants in Fish Tissues

Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

Introduction

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

The bioaccumulation portion of the City's monitoring program consists of two components: (1) analyzing liver tissues from trawl-caught fishes; (2) analyzing muscle tissues from fishes collected by hook and line (rig fishing). Species targeted by trawling activities (see Chapter 6) are considered representative of the general demersal fish community off San Diego due to their numerical dominance. The chemical analysis of liver tissues in these trawl-caught fishes is important for assessing population effects because this is the organ where contaminants typically bioaccumulate. In contrast, species targeted for capture by rig fishing represent fish that are more characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance and more directly relevant to human health concerns. Consequently, muscle samples are analyzed from these fishes because this is the tissue most often consumed by humans. All liver and muscle tissue samples collected during the year are analyzed for contaminants as specified in the NPDES discharge permit that governs monitoring requirements for the PLOO (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 Point Loma outfall region during 2014. The primary goals are to: (1) document levels of contaminant loading in local demersal fishes; (2) identify whether any contaminant bioaccumulation detected in fishes collected around the PLOO may be due to the outfall discharge; (3) identify other potential natural and anthropogenic sources of pollutants to the local marine environment.

Materials and Methods

Field Collection

Fishes were collected during October 2014 from four trawl zones (TZ1–TZ4) and two rig fishing stations (RF1–RF2) (Figure 7.1). Each trawl zone represents an area centered on one or two specific trawl stations as specified in Chapter 6. Trawl Zone 1 includes the "nearfield" area within a 1-km radius of stations SD10 and SD12 located just south and north of the PLOO, respectively. Trawl Zone 2

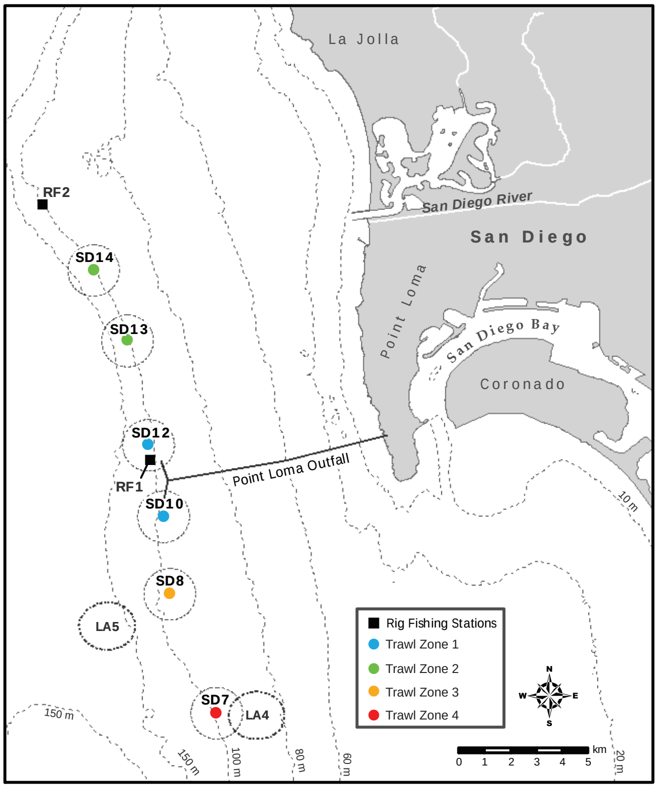

Figure 7.1
Trawl and rig fishing station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

includes the area within a 1-km radius surrounding northern "farfield" stations SD13 and SD14. Trawl Zone 3 represents the area within a 1-km radius surrounding "farfield" station SD8, which is located south of the outfall near the LA-5 dredged material disposal site. Trawl Zone 4 is the area within a 1-km radius surrounding "farfield" station SD7 located several kilometers south of the outfall near the non-active LA-4 disposal site. All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for collection methods). Fishes collected at the two rig fishing stations were caught within 1 km of the nominal station coordinates using standard rod and reel procedures. Station RF1 is located within 1 km of the outfall and is considered the "nearfield" rig fishing site. In contrast, station RF2 is located about 11 km northwest of the outfall and is considered "farfield" for the analyses herein.

Pacific Sanddab (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawl zones, while three different species of rockfish were collected for analysis of muscle tissues at the rig fishing stations, including Copper Rockfish (*Sebastes caurinus*), Speckled Rockfish (*Sebastes ovalis*) and Vermilion Rockfish (*Sebastes miniatus*) (Table 7.1). Only fishes with a standard length ≥13 cm were retained in order to facilitate collection of sufficient tissue for analysis. These fishes were sorted into three composite samples per station, with a minimum of three individuals in each composite. All fishes were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were stored at -20°C prior to dissection and tissue processing.

Tissue Processing and Chemical Analyses

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

All tissue analyses were performed at the City of San Diego's Environmental Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2015a). Briefly, fish tissue samples were analyzed on a wet weight basis to determine the concentrations of 18 trace metals, 9 chlorinated pesticides, and 40 polychlorinated biphenyl compound congeners (PCBs). Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix F.2). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry.

Table 7.1
Species of fish collected from each PLOO trawl zone and rig fishing station during 2014.

Station/Zone	Composite 1	Composite 2	Composite 3
Trawl Zone 1 (TZ1)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
Trawl Zone 2 (TZ2)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
Trawl Zone 3 (TZ3)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
Trawl Zone 4 (TZ4)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
Rig Fishing Station 1 (RF1)	Vermilion Rockfish	Vermilion Rockfish	Copper Rockfish
Rig Fishing Station 2 (RF2)	Speckled Rockfish	Speckled Rockfish	Speckled Rockfish

Data Analyses

Data summaries for the various parameters included detection rate, minimum, maximum, and mean values by species. All means were calculated using detected values only; no substitutions were made for non-detects in the data (i.e., analyte concentrations <MDL). Total DDT (tDDT), total hexachlorocyclohexane (tHCH), total chlordane, and total PCB (tPCB) were calculated for each sample as the sum of all constituents with reported values (see Appendix F.3 for individual constituent values). In addition, the distribution of contaminants with detection rates ≥20% was assessed by comparing values in fishes collected from "nearfield" stations located within 1000 m of the outfall diffuser structure (TZ1, RF1) to those from "farfield" stations located >3.6 km away to the north (TZ2, RF2) and south (TZ3, TZ4). Because contaminant levels can vary drastically among different species of fish, only intra-species comparisons were used for these assessments.

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

Results

Contaminants in Trawl-Caught Fishes

Trace Metals

Eight trace metals were detected in all liver tissue samples from trawl-caught Pacific Sanddab collected in the Point Loma outfall region during 2014 (Table 7.2). These included aluminum, arsenic, cadmium, copper, iron, manganese, mercury, and zinc. Antimony, barium, beryllium, chromium, lead, selenium, and silver were also detected, but in fewer samples (17–92%). Nickel, thallium, and tin were not detected in any liver samples collected in the PLOO region during the year. Most metals occurred at concentrations ≤8.13 ppm, although higher concentrations up to ~34 ppm for zinc and 139 ppm for iron were recorded. Comparisons between nearfield and farfield zones suggest that there was no clear relationship between metal concentrations in Pacific Sanddab liver tissues and proximity to the outfall (Figure 7.2). Most metals were present in samples from all stations, although at variable concentrations. Fishes from TZ1 had the highest concentrations of arsenic and zinc in their liver tissues; TZ2 fishes had the highest concentrations of aluminum, manganese and selenium; TZ3 fishes had the highest concentrations of cadmium and mercury; TZ4 fishes had the highest concentrations of copper, iron, lead, and silver. These results are consistent with the findings of long term analyses reported previously (City of San Diego 2015b).

Pesticides

DDT and hexachlorobenzene (HCB) were the only two chlorinated pesticides detected in Pacific Sanddab liver tissue samples from the Point Loma Outfall region during 2014 (Table 7.2). DDT was present in every liver tissue sample at concentrations up to 330.3 ppb (Table 7.2), with no patterns evident relative to proximity to the outfall (Figure 7.3). The DDT metabolites p,p-DDE, and p,p-DDMU were found in 100% of the samples, whereas o,p-DDE, p,p-DDD, and p,p-DDT were detected in ≤67% of the samples (Appendix F.3). HCB was also found in all liver samples, with concentrations up to 8.0 ppb. Although HCB was detected in samples from all stations, the highest value was recorded from nearfield zone TZ1 (Figure 7.3). The pesticides HCH, chlordane, aldrin, endosulfan, dieldrin, endrin, and mirex were not detected in any sanddab liver tissues during 2014. With the exception of DDT, chlorinated pesticides have historically been detected infrequently at low concentrations in the liver tissues of fishes from the PLOO region (City of San Diego 2015b). In contrast, DDT has been detected in all species of fish at a rate of 99% over the past 21 years, but with no evident patterns indicative of an outfall discharge effect.

PCBs

PCBs were detected in every Pacific sanddab liver tissue sample collected from the Point Loma outfall region during 2014 (Table 7.2). Total PCB concentrations were variable, ranging from 80.8 to 1224.5 ppb. Fourteen of the 31 detected congeners occurred in all samples, including PCB 49, PCB 66, PCB 70, PCB 74, PCB 99, PCB 101, PCB 110, PCB 118, PCB 138, PCB 149, PCB 153/168, PCB180, PCB 183, and PCB 187 (Appendix F.3). The remaining congeners were found in 8 to 92% of the samples. PCB was detected in samples from all stations; however, the highest values were recorded from nearfield zone TZ1 (Figure 7.3). Historically, PCBs have been detected frequently in liver tissues of fishes from the PLOO region, but with no patterns indicative of an outfall discharge effect evident since sampling for PCB congeners began (City of San Diego 2015b). Instead, PCBs have been detected most frequently at TZ3 located near the LA-5 dredged materials disposal site.

Table 7.2

Summary of metals, pesticides, total PCB, and lipids in liver tissues of Pacific sanddabs collected from PLOO trawl zones during 2014. Data include detection rate (DR), minimum, maximum, and mean[a] detected concentrations (n = 12). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT and total PCB; nd = not detected.

Parameter	DR (%)	Min	Max	Mean
Metals (*ppm*)				
Aluminum	100	2.5	6.5	4.3
Antimony	25	nd	0.2	0.2
Arsenic	100	1.82	3.80	2.66
Barium	17	nd	0.03	0.02
Beryllium	83	nd	0.006	0.005
Cadmium	100	3.42	8.13	5.79
Chromium	17	nd	0.1	0.1
Copper	100	3.9	6.7	5.1
Iron	100	49.4	139.0	77.3
Lead	83	nd	0.2	0.2
Manganese	100	0.5	0.8	0.6
Mercury	100	0.096	0.210	0.151
Nickel	0	—	—	—
Selenium	92	nd	1.49	1.09
Silver	83	nd	0.14	0.07
Thallium	0	—	—	—
Tin	0	—	—	—
Zinc	100	24.80	34.30	29.53
Pesticides (*ppb*)				
HCB	100	4.5	8.0	5.6
Total DDT	100	133.8	330.3	217.8
Total PCB (*ppb*)	100	80.8	1224.5	238.0
Lipids (*% weight*)	100	39.7	69.6	48.3

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

Contaminants in Fishes Collected by Rig Fishing in 2014

Seven trace metals occurred in all rockfish muscle tissue samples collected at the PLOO rig fishing stations during 2014, including arsenic, cadmium, copper, manganese, mercury, selenium, and zinc

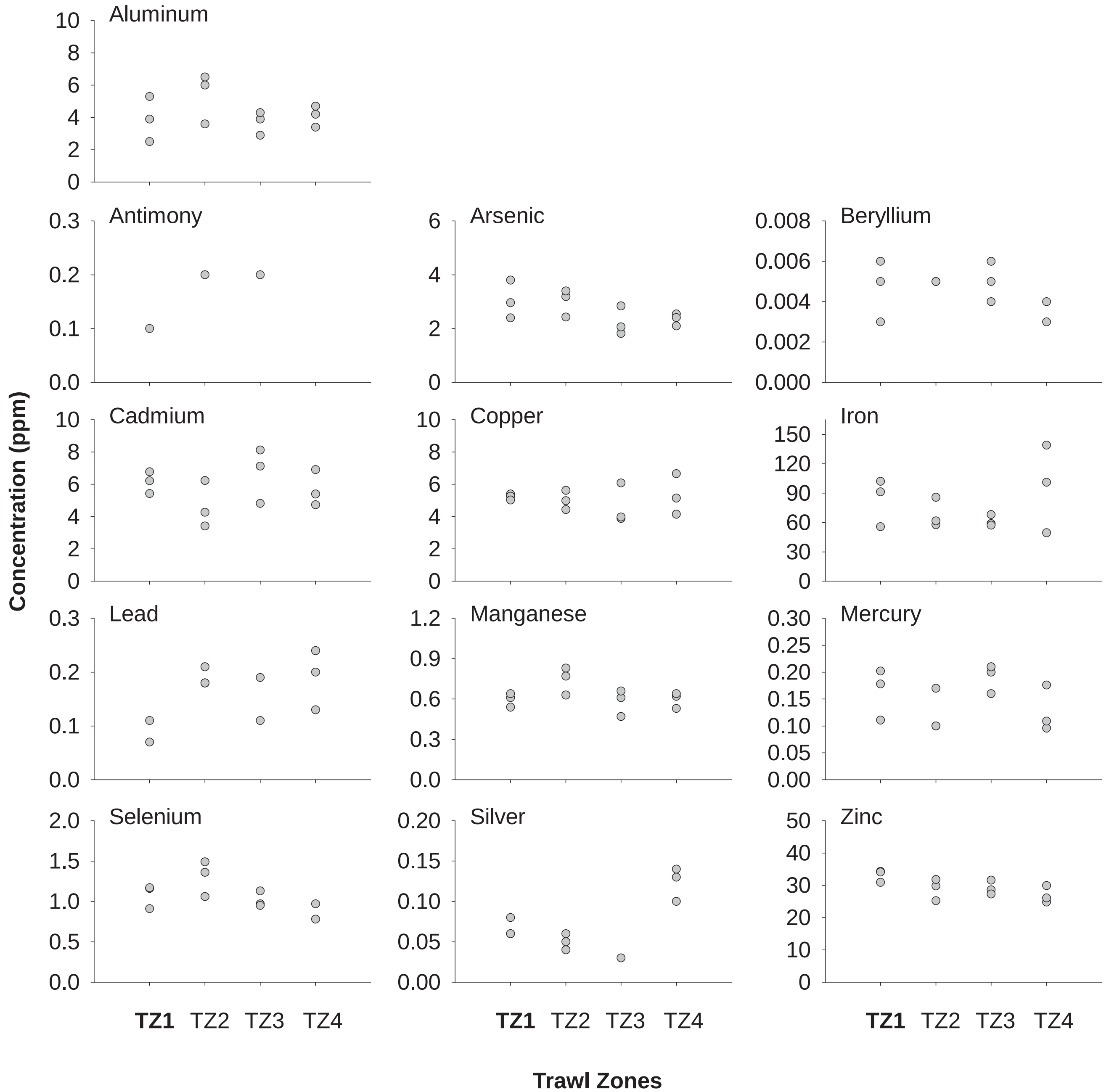

Figure 7.2
Concentrations of metals with detection rates ≥20% in liver tissues of Pacific Sanddab collected from each PLOO trawl zone during 2014. Zone TZ1 is considered nearfield (bold; see text). All missing values are non-detects.

(Table 7.3). Aluminum, beryllium, iron, and lead were also detected, but at rates ≤83%. In contrast, antimony, barium, chromium, nickel, silver, thallium, and tin were not detected in any muscle tissue samples. The metals present in the highest concentrations were aluminum, arsenic, iron, and zinc, however all were ≤3.1 ppm. The highest concentrations of arsenic, cadmium, copper, iron, manganese, selenium, and zinc were found in one to three samples from station RF1, while the highest concentration of mercury was found in a sample collected from station RF2 (Figure 7.4). Overall, variations in the concentrations of these metals were minor and may have been due to weight, length, and/or life history differences between the three different species (or individual specimens of each species). Historically, arsenic, copper, mercury, selenium, and zinc have been detected frequently in the muscle tissues of fishes collected from both of the PLOO rig fishing stations (City of San Diego 2015b).

DDT and HCB were also the only pesticides detected in rockfish muscle tissues collected in the Point Loma outfall region during 2014, whereas PCBs were not detected (Table 7.4). Total DDT (composed solely of p,p-DDE) was detected in a total of four of the samples (detection rate = 67%) at relatively low concentrations ≤ 1.3 ppb. HCB was detected in three samples (detection rate = 50%), all with concentrations of 0.2 ppb. As with metal concentrations, variations in the concentrations of DDT were minor and may have been due to weight, length, and/or life history differences between the three different species (or individual specimens of each species) (Figure 7.4). These results are consistent with the findings of long term analyses reported previously (City of San Diego 2015b).

Most contaminants detected in rockfish muscle tissues during 2014 occurred at concentrations below state, national, and international limits or standards (Figure 7.4, Tables 7.3, 7.4). Exceptions included: (1) arsenic, which occurred at levels higher than the median international standard in one sample of Copper Rockfish and two samples of Vermilion Rockfish from station RF1; (2) selenium, which exceeded the median international standard in all muscle tissue samples from both stations; (3) mercury, which exceeded OEHHA fish contaminant goals in one sample of Copper Rockfish from station RF1 and three samples of Speckled Rockfish from station RF4.

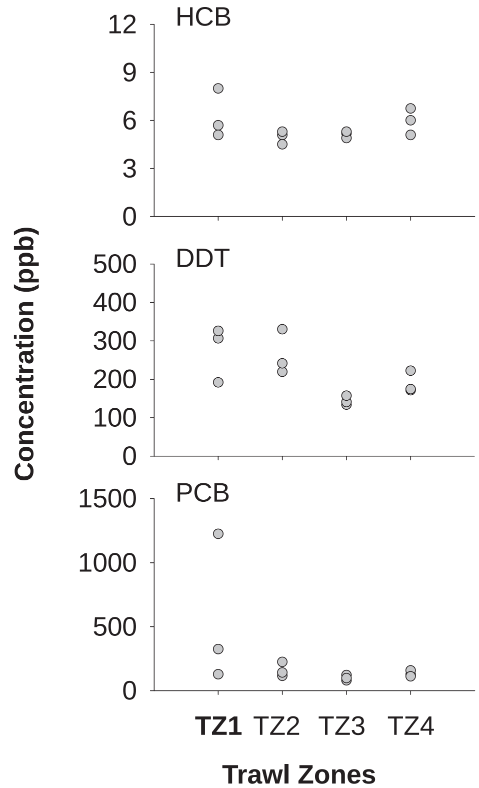

Figure 7.3
Concentrations of HCB, total DDT, and total PCB in liver tissues of Pacific Sanddab collected from each PLOO trawl zone during 2014. Zone TZ1 is considered nearfield (bold; see text). All missing values are non-detects.

Discussion

Several trace metals, PCB congeners, and the chlorinated pesticides DDT and HCB were detected in liver tissues from Pacific Sanddabs collected in the Point Loma outfall region during 2014. Many of the same metals, DDT and HCB were also detected in rockfish 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 2000, City of San Diego 2007, City of San Diego 2015b). Additionally, all muscle tissue samples from sport fish collected in the region had concentrations of mercury and total DDT below USFDA action limits and international standards. However, some composite tissue samples had arsenic and selenium concentrations above median international standards for human consumption, and some had concentrations of mercury that exceeded OEHHA fish contaminant goals. Elevated levels of these contaminants are not uncommon in sport fish from the PLOO survey area (City of San Diego 2007–2014) or from other parts of the San Diego region (see City of San Diego 2015c and references therein). For example, muscle tissue samples from fishes collected since 1995 in the South Bay outfall survey area, including the Coronado Islands, have occasionally had concentrations of arsenic, mercury, selenium, and total PCB in excess of different consumption limits.

Table 7.3

Summary of metals in muscle tissues of fishes collected from PLOO rig fishing stations during 2014. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the detection rate and maximum value for all species. The number of samples per species is indicated in parentheses. Concentrations are expressed as parts per million (ppm); na = not available; nd = not detected. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits (AL), or median international standards (IS). See Appendix F.2 for names of each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Speckled Rockfish																		
n (out of 3)	0	0	3	0	2	3	0	3	3	0	3	3	0	3	0	0	0	3
Min	—	—	0.40	—	nd	0.01	—	0.2	0.8	—	0.0	**0.260**	—	**0.36**	—	—	—	2.40
Max	—	—	0.53	—	0.003	0.02	—	0.2	1.1	—	0.1	**0.390**	—	**0.41**	—	—	—	2.70
Mean	—	—	0.47	—	0.003	0.01	—	0.2	0.9	—	0.1	**0.311**	—	**0.38**	—	—	—	2.53
Copper Rockfish																		
n (out of 1)	0	0	1	0	0	1	0	1	0	0	1	1	0	1	0	0	0	1
Value	—	—	**2.0**	—	—	0.04	—	0.2	—	—	0.04	**0.313**	—	**0.71**	—	—	—	3.10
Vermilion Rockfish																		
n (out of 2)	1	0	2	0	0	2	0	2	2	1	2	2	0	2	0	0	0	2
Min	nd	—	**1.56**	—	—	0.03	—	0.2	1.2	nd	0.08	0.110	—	**0.34**	—	—	—	2.80
Max	1.3	—	**2.40**	—	—	0.05	—	0.2	1.3	0.1	0.10	0.200	—	**0.45**	—	—	—	3.00
Mean	1.3	—	**1.98**	—	—	0.04	—	0.2	1.2	0.1	0.09	0.155	—	**0.40**	—	—	—	2.90
All Species:																		
Detection Rate (%)	17	0	100	0	33	100	0	100	83	17	100	100	0	100	0	0	0	100
Max	1.3	—	**2.4**	—	0.003	0.05	—	0.2	1.3	0.1	0.10	**0.390**	—	**0.71**	—	—	—	3.10
OEHHA[b]	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
AL[c]	na	na	na	na	na	na	na	na	na	na	na	1.00	na	na	na	na	na	na
IS[c]	na	na	1.4	na	na	1.0	1.0	20	na	2.0	na	0.50	na	0.3	na	na	175	70

[a] Minimum and maximum values were based on all samples, whereas means were calculated from detected values only
[b] From the California OEHHA (Klasing and Brodberg 2008)
[c] From Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish

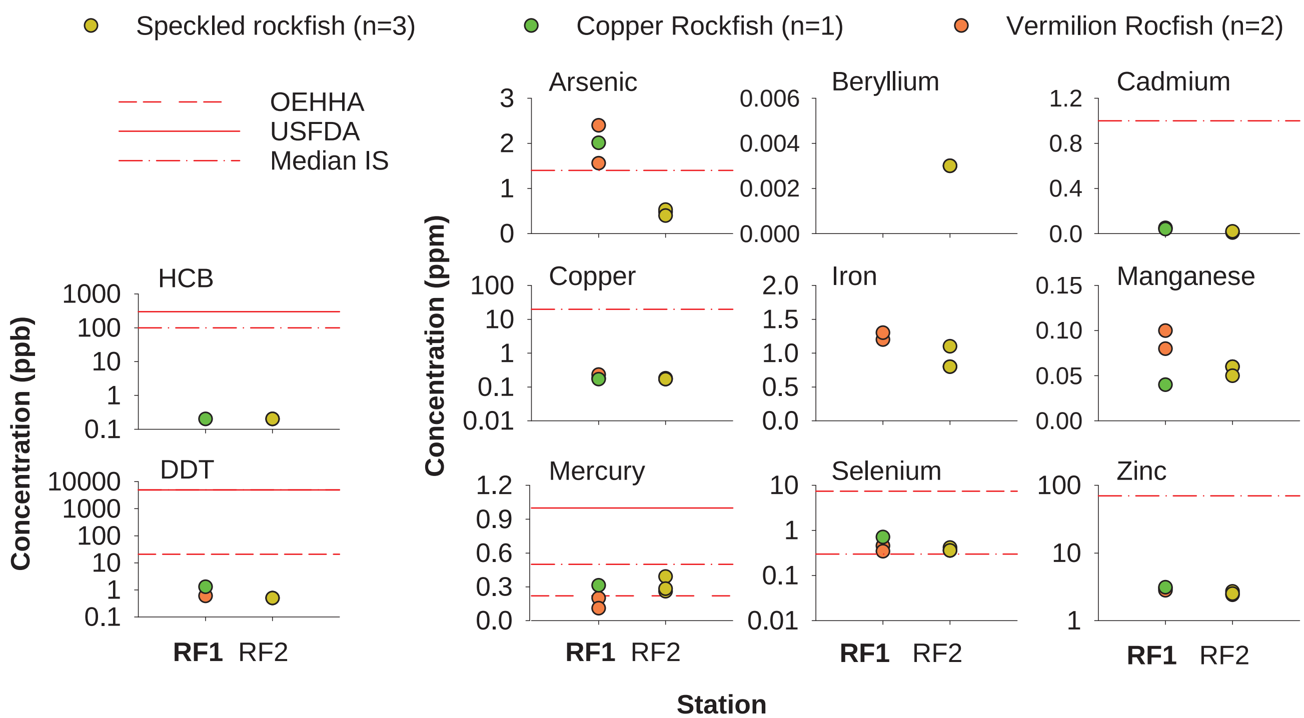

Figure 7.4

Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each PLOO rig fishing station during 2014. See Tables 7.3 and 7.4 for thresholds. Missing data are non-detects. Station RF1 is considered nearfield (bold; see text).

The occurrence of metals and chlorinated hydrocarbons in the tissues of fish captured off Point Loma may be due to multiple factors. Many metals occur naturally in the environment, although little information is available on background levels in fish tissues. Brown et al. (1986) determined that there may be no area in the SCB sufficiently free of chemical contaminants to be considered a reference site, while Mearns et al. (1991) described the distribution of several contaminants such as arsenic, mercury, DDT, and PCBs as being ubiquitous. The wide-spread distribution of contaminants in SCB fishes has been supported by more recent work regarding PCBs and DDT (e.g., Allen et al. 1998, 2002).

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 of fish and among individuals of the same species depending on migration habits (Otway 1991). Fishes may be exposed to contaminants in a highly polluted area 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 PLOO, as there are many point and non-point sources that may contribute to local contamination in the region, including the San Diego River, San Diego Bay, and offshore dredged material disposal sites (see Chapters 2–4 and Parnell et al. 2008). In contrast, assessments of contaminant loading in sediments surrounding the outfall have revealed no evidence to indicate that the PLOO is a major source of pollutants to the area (see Chapter 4 and Parnell et al. 2008).

Overall, there was no evidence of contaminant bioaccumulation in PLOO fishes during 2014 that could be associated with wastewater discharge from the outfall. Concentrations of most contaminants were generally similar across zones or stations, and no relationship relevant to the PLOO was evident. These results are consistent with findings of other assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007, 2015b,

Table 7.4

Summary of pesticides, total PCB, and lipids in muscle tissues of fishes collected from PLOO rig fishing stations during 2014. Data include number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the detection rate (DR) and maximum value for all species. The number of samples per species is indicated in parentheses; na = not available; nd = not detected. See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT.

	Pesticides			
	HCB (ppb)	tDDT (ppb)	tPCB (ppb)	Lipids (% weight)
Speckled Rockfish				
n (out of 3)	2	2	0	3
Min	nd	nd	—	0.1
Max	0.2	0.5	—	0.4
Mean	0.2	0.5	—	0.2
Copper Rockfish				
n (out of 1)	1	1	0	1
Value	0.2	1.3	—	1.2
Vermilion Rockfish				
n (out of 2)	0	1	0	2
Min	—	nd	—	0.7
Max	—	0.6	—	0.7
Mean	—	0.6	—	0.7
All Species:				
DR(%)	50	67	0	100
Max	0.2	1.3	—	1.2
OEHHA[b]	na	21	3.6	na
AL[c]	300	5000	na	na
IS[c]	100	5000	na	na

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

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

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

Parnell et al. 2008). Finally, there were no other indications of poor fish health in the region, such as the presence of fin rot or other indicators of disease (see Chapter 6).

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Appendices

Appendix A

Supporting Data

2014 PLOO Stations

Coastal 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 PLOO stations during 2014. For each quarter n = 804 (1–20 m), n = 1320 (21–60 m), n ≥ 439 (61–80 m), n ≥ 194 (81–100 m). Sample sizes differed due to variations in bottom depth at individual stations.

		Depth (m)				
Temperature (°C)		**1–20**	**21–60**	**61–80**	**81–100**	**1–100**
February	min	11.2	10.3	10.1	10.0	10.0
	max	15.5	15.0	11.7	10.8	15.5
	mean	14.2	11.5	10.5	10.3	12.1
May	min	12.4	10.5	10.2	9.9	9.9
	max	19.3	15.0	11.2	10.7	19.3
	mean	16.1	12.0	10.6	10.2	12.9
August	min	13.3	11.4	11.0	10.7	10.7
	max	23.4	17.5	12.3	11.6	23.4
	mean	18.3	13.0	11.5	11.1	14.2
November	min	15.1	12.1	11.2	10.4	10.4
	max	20.9	19.9	14.1	12.4	20.9
	mean	19.4	14.8	12.5	11.4	15.6
Annual	min	11.2	10.3	10.1	9.9	9.9
	max	23.4	19.9	14.1	12.4	23.4
	mean	17.0	12.9	11.3	10.8	13.7
Salinity (psu)						
February	min	33.35	33.31	33.43	33.69	33.31
	max	33.62	33.87	33.93	33.96	33.96
	mean	33.49	33.57	33.76	33.83	33.60
May	min	33.32	33.31	33.44	33.59	33.31
	max	33.65	33.61	33.68	33.78	33.78
	mean	33.49	33.47	33.60	33.68	33.51
August	min	33.32	33.33	33.37	33.42	33.32
	max	33.68	33.50	33.58	33.67	33.68
	mean	33.47	33.38	33.46	33.54	33.43
November	min	33.24	33.17	33.31	33.42	33.17
	max	33.67	33.57	33.53	33.78	33.78
	mean	33.54	33.34	33.42	33.52	33.42
Annual	min	33.24	33.17	33.31	33.42	33.17
	max	33.68	33.87	33.93	33.96	33.96
	mean	33.50	33.44	33.56	33.64	33.49

Appendix A.1 *continued*

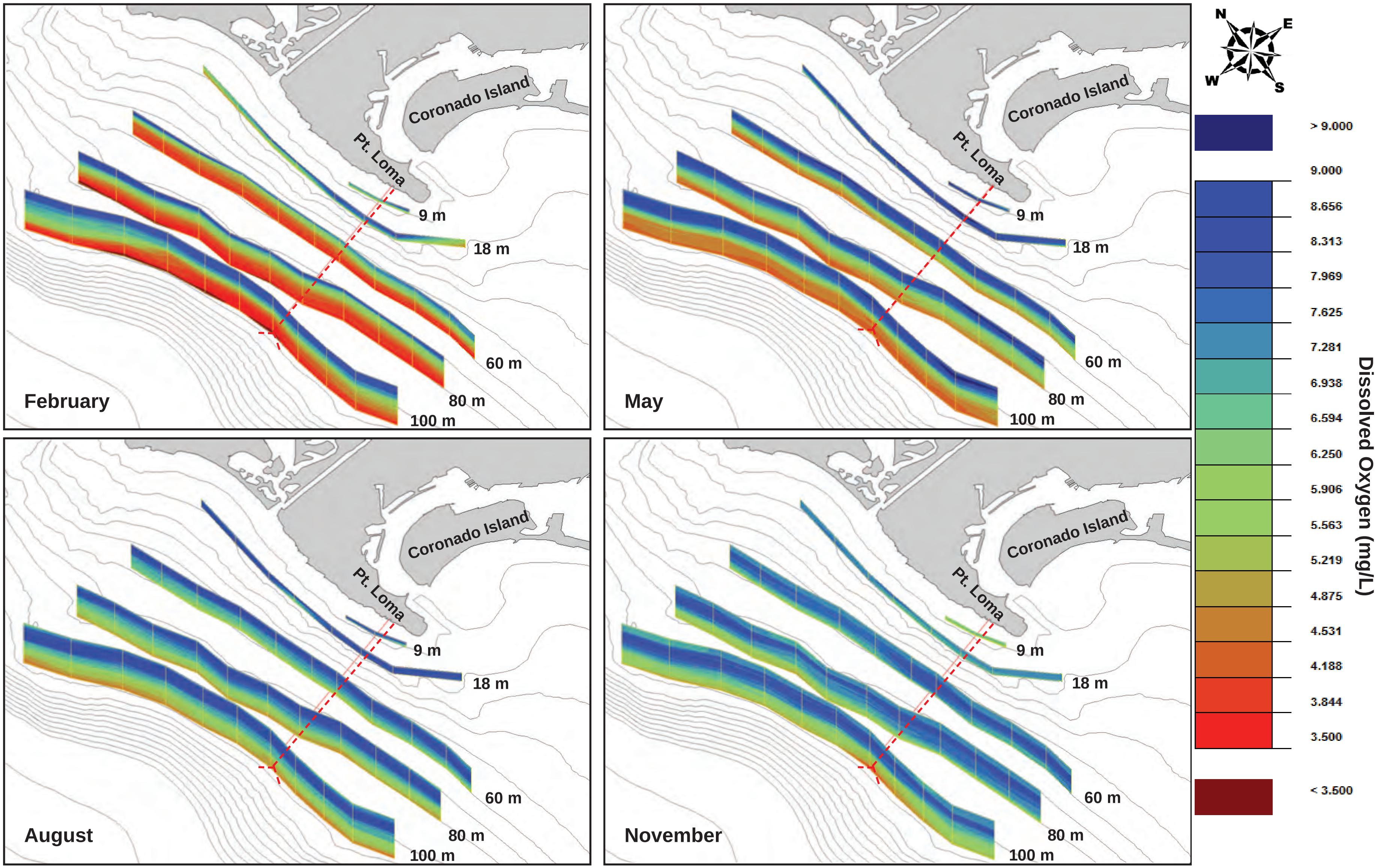
DO (mg/L)		Depth (m) 1–20	21–60	61–80	81–100	1–100
February	min	4.8	3.5	3.3	3.2	3.2
	max	8.9	8.3	6.3	4.6	8.9
	mean	7.5	5.4	4.2	3.8	5.7
May	min	6.6	4.4	4.2	4.2	4.2
	max	9.5	8.9	6.1	5.0	9.5
	mean	8.4	6.6	4.8	4.4	6.7
August	min	6.6	5.4	4.8	4.4	4.4
	max	9.1	8.7	6.9	5.9	9.1
	mean	8.1	7.4	5.7	5.1	7.2
November	min	5.7	6.0	5.2	4.0	4.0
	max	8.3	8.5	7.7	6.3	8.5
	mean	7.4	7.8	6.3	5.4	7.3
Annual	min	4.8	3.5	3.3	3.2	3.2
	max	9.5	8.9	7.7	6.3	9.5
	mean	7.9	6.8	5.3	4.7	6.7

pH		1–20	21–60	61–80	81–100	1–100
February	min	7.8	7.7	7.6	7.7	7.6
	max	8.2	8.1	7.9	7.8	8.2
	mean	8.0	7.8	7.7	7.7	7.9
May	min	8.0	7.8	7.8	7.8	7.8
	max	8.2	8.2	7.9	7.8	8.2
	mean	8.2	8.0	7.8	7.8	8.0
August	min	8.1	7.9	7.9	7.8	7.8
	max	8.3	8.2	8.0	7.9	8.3
	mean	8.2	8.1	7.9	7.9	8.1
November	min	8.1	8.0	7.9	7.8	7.8
	max	8.2	8.2	8.1	8.0	8.2
	mean	8.2	8.1	8.0	7.9	8.1
Annual	min	7.8	7.7	7.6	7.7	7.6
	max	8.3	8.2	8.1	8.0	8.3
	mean	8.1	8.0	7.9	7.8	8.0

Appendix A.1 *continued*

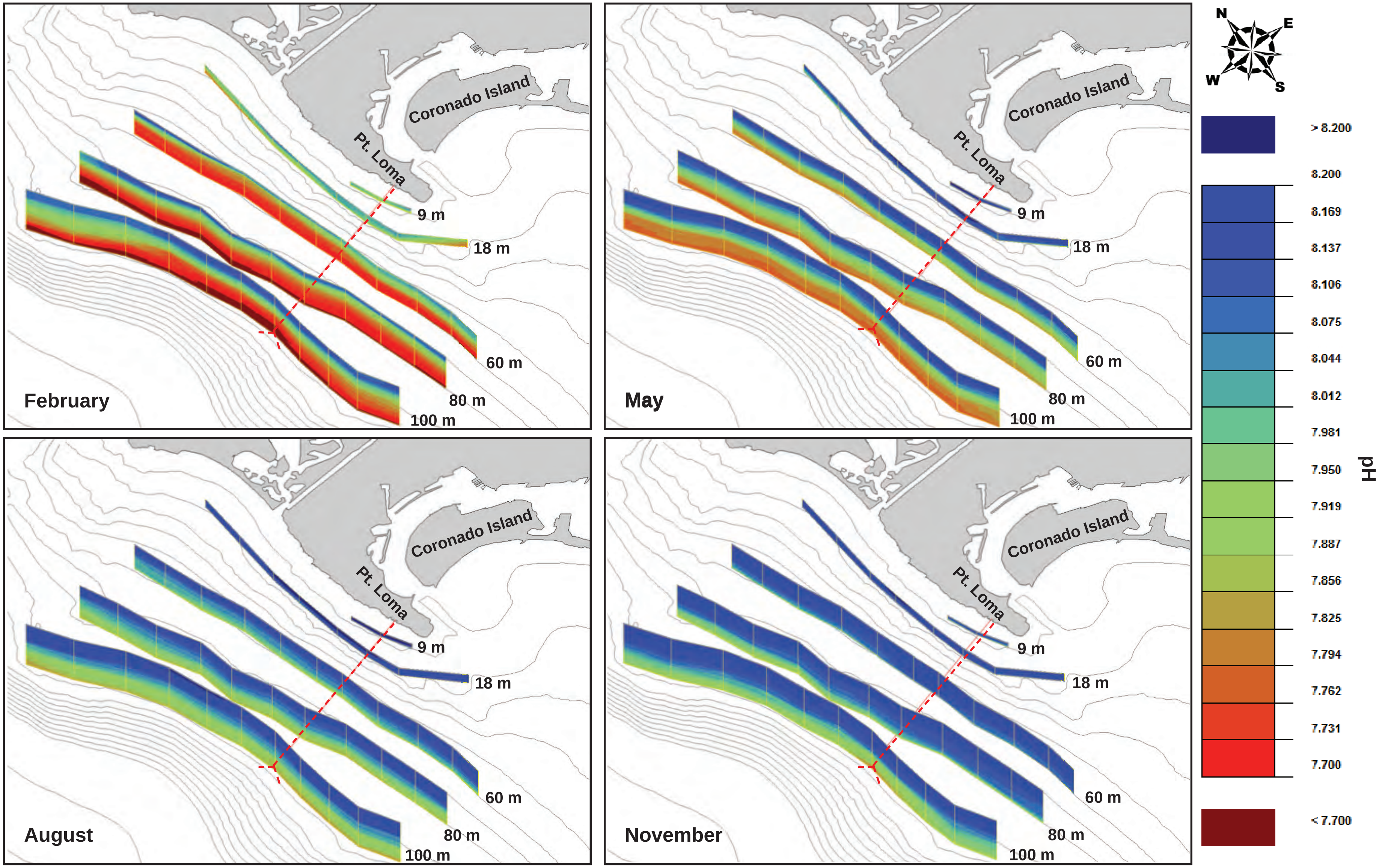
Transmissivity (%)		Depth (m) 1–20	21–60	61–80	81–100	1–100
February	min	17	85	84	83	17
	max	89	90	91	90	91
	mean	84	89	89	89	87
May	min	52	77	78	79	52
	max	90	89	89	89	90
	mean	85	87	87	87	87
August	min	79	75	73	79	73
	max	90	90	90	89	90
	mean	87	87	87	87	87
November	min	73	80	80	81	73
	max	91	91	90	90	91
	mean	88	88	88	88	88
Annual	min	17	75	73	79	17
	max	91	91	91	90	91
	mean	86	88	88	88	87

Chlorophyll *a* (μg/L)		1–20	21–60	61–80	81–100	1–100
February	min	0.2	0.2	0.1	0.2	0.1
	max	11.5	2.6	0.5	1.3	11.5
	mean	1.6	0.5	0.2	0.2	0.8
May	min	0.1	0.4	0.4	0.4	0.1
	max	3.5	4.5	1.8	2.6	4.5
	mean	0.9	1.3	0.6	0.6	1.0
August	min	0.2	0.2	0.2	0.2	0.2
	max	4.1	4.2	1.1	0.9	4.2
	mean	0.9	1.4	0.5	0.3	1.0
November	min	0.1	0.2	0.2	0.1	0.1
	max	2.6	2.0	1.0	0.5	2.6
	mean	0.5	0.9	0.5	0.3	0.7
Annual	min	0.1	0.2	0.1	0.1	0.1
	max	11.5	4.5	1.8	2.6	11.5
	mean	1.0	1.0	0.5	0.3	0.9



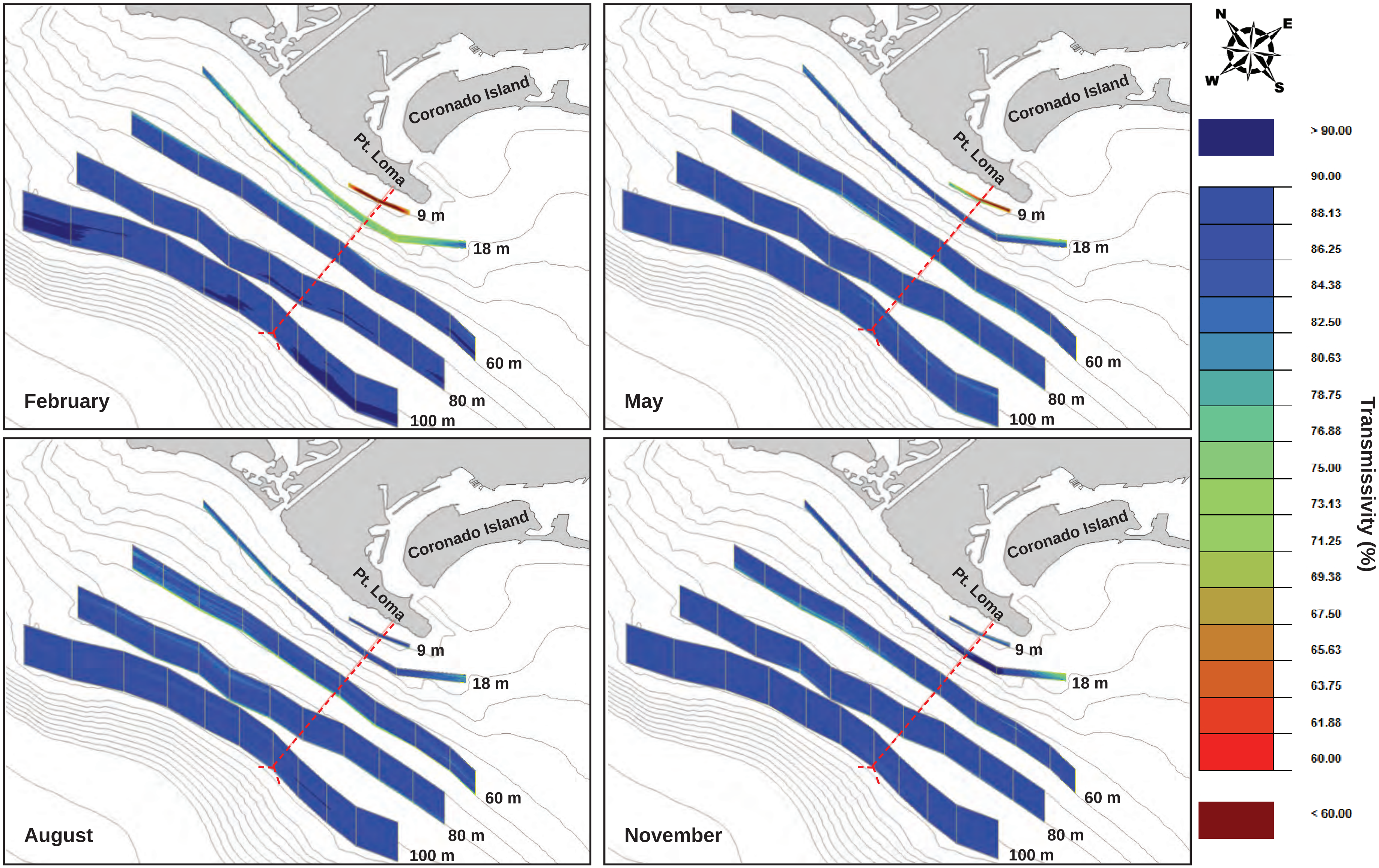
Appendix A.2

Dissolved oxygen recorded in the PLOO region during 2014. Data were collected over 4–9 days during each quarterly survey.

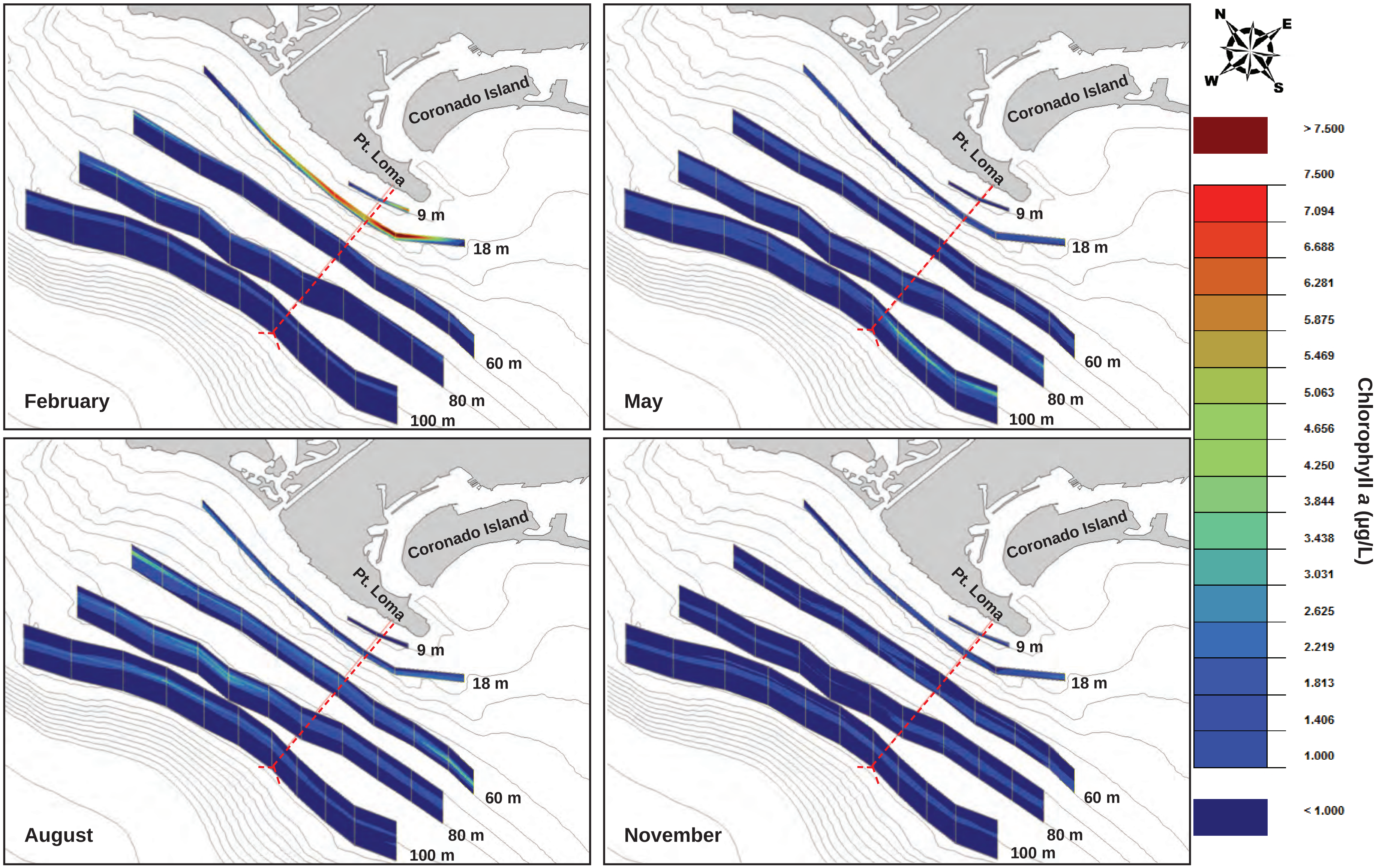


Appendix A.3

Measurements of pH recorded in the PLOO region during 2014. Data were collected over 4–9 days during each quarterly survey.



Appendix A.4
Transmissivity recorded in the PLOO region during 2014. Data were collected over 4–9 days during each quarterly survey.



Appendix A.5
Concentrations of chlorophyll *a* recorded in the PLOO region during 2014. Data were collected over 4–9 days during each quarterly survey.

Appendix A.6

Summary of current velocity magnitude and direction from the 100-m ADCP off Point Loma in 2014. Data are presented as seasonal means with 95% confidence intervals. Minimum and maximum angles of velocity are not shown due to the circular nature of the measurement. Fall data are not shown due to instrumentation issues.

100-m ADCP		Magnitude (mm/s)				Angle (°)	
	Depth (m)	Min	Max	Mean	95% CI	Mean	95% CI
Winter	11	2	345	101	5	173	34
	15	4	336	102	5	183	36
	19	2	312	97	4	181	37
	23	1	286	92	4	180	39
	27	2	263	87	4	177	40
	31	5	245	84	3	170	40
	35	3	227	81	3	157	41
	39	1	207	78	3	354	41
	43	4	189	76	3	349	42
	47	3	171	73	2	352	43
	51	2	155	69	2	352	43
	55	2	139	65	2	351	43
	59	4	124	60	2	349	43
	63	4	113	56	1	346	42
	67	1	100	51	1	346	42
	71	1	91	46	1	357	43
	75	4	86	42	1	20	45
	79	5	79	39	1	58	45
	83	6	68	37	1	101	42
	87	9	57	35	1	134	37
	91	4	55	33	1	161	37
	95	0	54	35	1	188	52

Appendix A.6 *continued*

100-m ADCP

		Magnitude (mm/s)				Angle (°)	
	Depth (m)	**Min**	**Max**	**Mean**	**95% CI**	**Mean**	**95% CI**
Spring	11	4	377	184	4	161	26
	15	3	349	143	4	168	35
	19	2	316	129	4	168	36
	23	0	308	112	4	166	36
	27	1	292	98	3	164	36
	31	4	279	87	3	162	37
	35	0	268	77	3	159	38
	39	4	257	71	3	156	40
	43	3	241	64	2	153	41
	47	3	221	60	2	147	41
	51	3	197	57	2	131	41
	55	1	169	54	2	85	43
	59	0	142	50	2	34	46
	63	1	118	46	1	14	48
	67	2	112	44	1	8	49
	71	2	108	42	1	8	49
	75	4	103	41	1	11	50
	79	4	98	39	1	18	48
	83	6	94	35	1	26	41
	87	8	86	32	1	37	32
	91	1	72	27	1	53	27
	95	1	54	23	1	101	29

Appendix A.6 *continued*

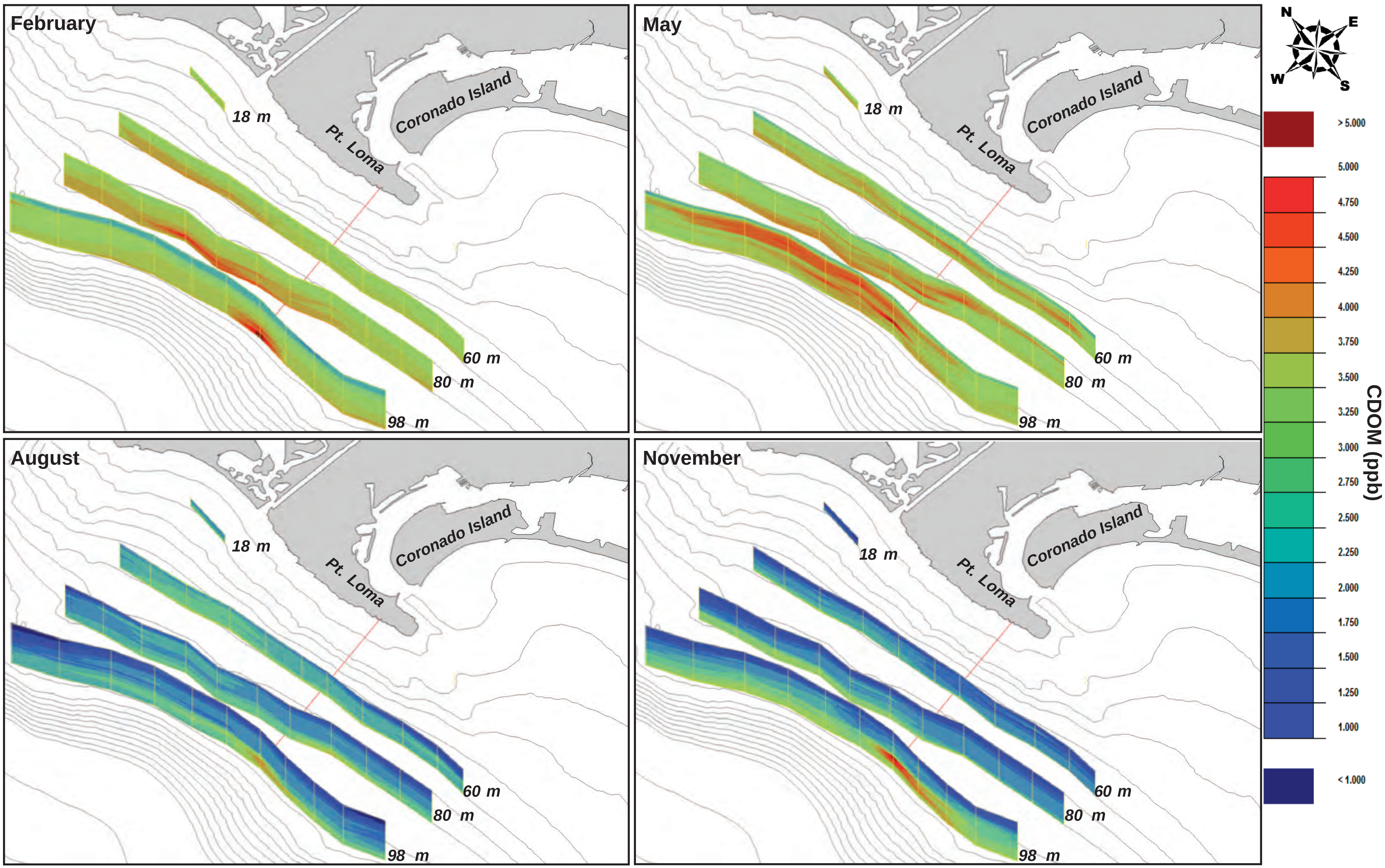
100-m ADCP		Magnitude (mm/s)				Angle (°)	
	Depth (m)	Min	Max	Mean	95% CI	Mean	95% CI
Summer	11	23	380	168	4	127	31
	15	1	248	87	3	131	66
	19	6	252	84	3	145	55
	23	1	191	69	2	133	52
	27	5	148	65	2	91	48
	31	8	143	62	1	44	46
	35	8	142	60	1	23	45
	39	8	154	57	2	14	43
	43	6	166	54	2	8	41
	47	7	181	54	2	5	41
	51	3	188	55	2	2	40
	55	3	192	57	2	358	39
	59	1	190	59	2	352	39
	63	2	185	59	2	348	38
	67	5	183	57	2	345	38
	71	4	180	54	2	344	41
	75	1	177	49	2	345	42
	79	1	173	45	2	350	42
	83	4	168	42	2	358	40
	87	3	160	42	2	11	39
	91	1	146	43	1	27	39
	95	2	127	40	1	39	39

Appendix B

Supporting Data

2014 PLOO Stations

Water Quality Compliance and Plume Dispersion



Appendix B.1
CDOM values recorded in the PLOO region during 2014. Data were collected over three consecutive days during each of these surveys.

Appendix B.2

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

Month	Stations
February	F01, F02, F03, F04, F05, F06, F07, F08, F09, F16, F17, F28, F29, F31, F32, F33, F35
May	F02, F03, F04, F06, F12, F13, F14, F15, F17, F24, F26, F27, F36
August	F02, F14, F24, F25, F35, F36
November	F01, F02, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F15, F16, F17

Appendix B.3

Summary of rainfall and bacteria levels from PLOO shore stations during 2014. Total coliform, fecal coliform, and *Enterococcus* densities are expressed as mean CFU/100 mL per month. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom; n = total number of samples.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Rain (in):		0.01	1.00	1.28	0.53	0.00	0.00	0.00	0.08	0.00	0.00	0.37	4.50
	n	40	40	40	40	40	40	40	40	40	40	40	48
D12	*Total*	14	22	92	16	10	9	13	21	50	21	9	50
	Fecal	7	10	13	2	2	2	2	6	18	6	2	5
	Entero	9	19	20	3	2	3	2	58	12	8	6	7
D11	*Total*	26	77	104	176	20	32	2424	28	52	26	135	223
	Fecal	7	34	29	14	4	6	166	11	7	3	22	28
	Entero	22	16	13	16	4	20	40	19	12	5	32	44
D10	*Total*	18	59	30	60	64	30	1100	68	76	40	32	61
	Fecal	9	58	8	8	40	2	26	17	6	5	6	11
	Entero	16	80	3	6	3	5	10	14	18	21	14	15
D9	*Total*	25	87	19	48	24	30	224	24	66	17	31	46
	Fecal	2	53	6	3	6	2	14	2	3	2	14	12
	Entero	7	32	2	2	2	4	13	7	4	2	4	12
D8	*Total*	36	212	128	60	200	56	100	136	128	3810	340	197
	Fecal	16	60	6	3	9	3	18	5	5	2825	127	16
	Entero	14	127	11	2	4	6	46	6	5	158	79	23
D7	*Total*	16	61	16	16	16	92	56	100	120	24	70	30
	Fecal	3	6	8	3	2	8	3	15	8	18	19	11
	Entero	5	10	3	2	2	7	8	32	2	8	6	2
D5	*Total*	52	56	32	16	16	16	72	24	128	192	48	55
	Fecal	2	17	4	2	3	2	2	3	3	16	8	2
	Entero	122	10	2	3	2	2	2	2	4	34	19	2
D4	*Total*	13	19	17	6	6	10	20	20	56	32	64	13
	Fecal	7	8	7	2	2	2	2	6	3	4	3	3
	Entero	2	2	2	2	2	2	2	3	2	4	2	2

Appendix B.4

Summary of elevated bacteria densities in samples collected from PLOO shore, kelp bed, and offshore stations during 2014. Bold values exceed benchmarks for total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), *Enterococcus* (>104 CFU/100 mL), and/or the FTR criterion (total coliforms > 1000 CFU/100 mL and F:T > 0.10).

Station Group	Date	Depth (m)	Total	Fecal	Entero	F:T
Shore Stations						
D5	29 Jan 14	—	20	2	**600**	0.1
D8	28 Feb 14	—	800	240	**620**	0.3
D10	28 Feb 14	—	240	260	**380**	1.08
D8	28 Jul 14	—	400	80	**220**	0.2
D11	28-Jul-14	—	**12,000**	**800**	**160**	0.07
D7	9 Aug 14	—	60	48	**140**	0.8
D12	27 Aug 14	—	40	20	**280**	0.5
D8	14 Oct 14	—	**15,000**	**14,000**	**720**	**0.93**
D5	26 Oct 14	—	320	58	**160**	0.18
D8	1 Nov 14	—	640	80	**340**	0.12
D11	1 Nov 14	—	600	100	**140**	0.17
Kelp Bed Stations						
A6	8 Dec 14	18	3400	400	**120**	**0.12**
Offshore Stations						
F30	10 Feb 14	98	—	—	**180**	—
F30	11 Aug 14	98	—	—	**620**	—
F18	5 Nov 14	80	—	—	**340**	—
F19	5 Nov 14	80	—	—	**280**	—
F23	5 Nov 14	60	—	—	**160**	—
F18[a]	7 Nov 14	80	—	—	**300**	—
F19[a]	7 Nov 14	80	—	—	**260**	—
F28	6 Nov 14	80	—	—	**240**	—
F28	6 Nov 14	98	—	—	**130**	—
F29	6 Nov 14	60	—	—	**340**	—
F29	6 Nov 14	80	—	—	**620**	—
F30	6 Nov 14	80	—	—	**640**	—
F32	6 Nov 14	80	—	—	**140**	—

[a]Resample

Appendix B.5

Summary of bacteria levels from PLOO kelp bed and offshore stations during 2014. Total coliform, fecal coliform, and *Enterococcus* densities are expressed as mean CFU/100 mL for all stations along each depth contour by month or quarter; n = total number of samples per sampling period.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kelp Bed Stations												
9-m Contour (n = 45)												
Total	3	4	5	4	16	2	46	5	13	12	10	5
Fecal	2	2	2	2	2	2	2	2	2	2	2	2
Entero	2	2	2	3	2	2	4	2	2	4	2	2
18-m Contour (n = 75)												
Total	6	4	6	2	3	2	15	25	3	20	4	110
Fecal	3	2	3	2	2	2	2	2	2	2	2	13
Entero	3	2	2	2	2	2	4	5	2	3	2	6
Offshore Stations[a]												
18-m Contour (n = 9)	—	2	—	—	2	—	—	2	—	—	2	—
60-m Contour (n = 33)	—	8	—	—	2	—	—	3	—	—	6	—
80-m Contour (n = 44)	—	5	—	—	2	—	—	4	—	—	42	—
100-m Contour (n = 55)	—	8	—	—	2	—	—	18	—	—	46	—

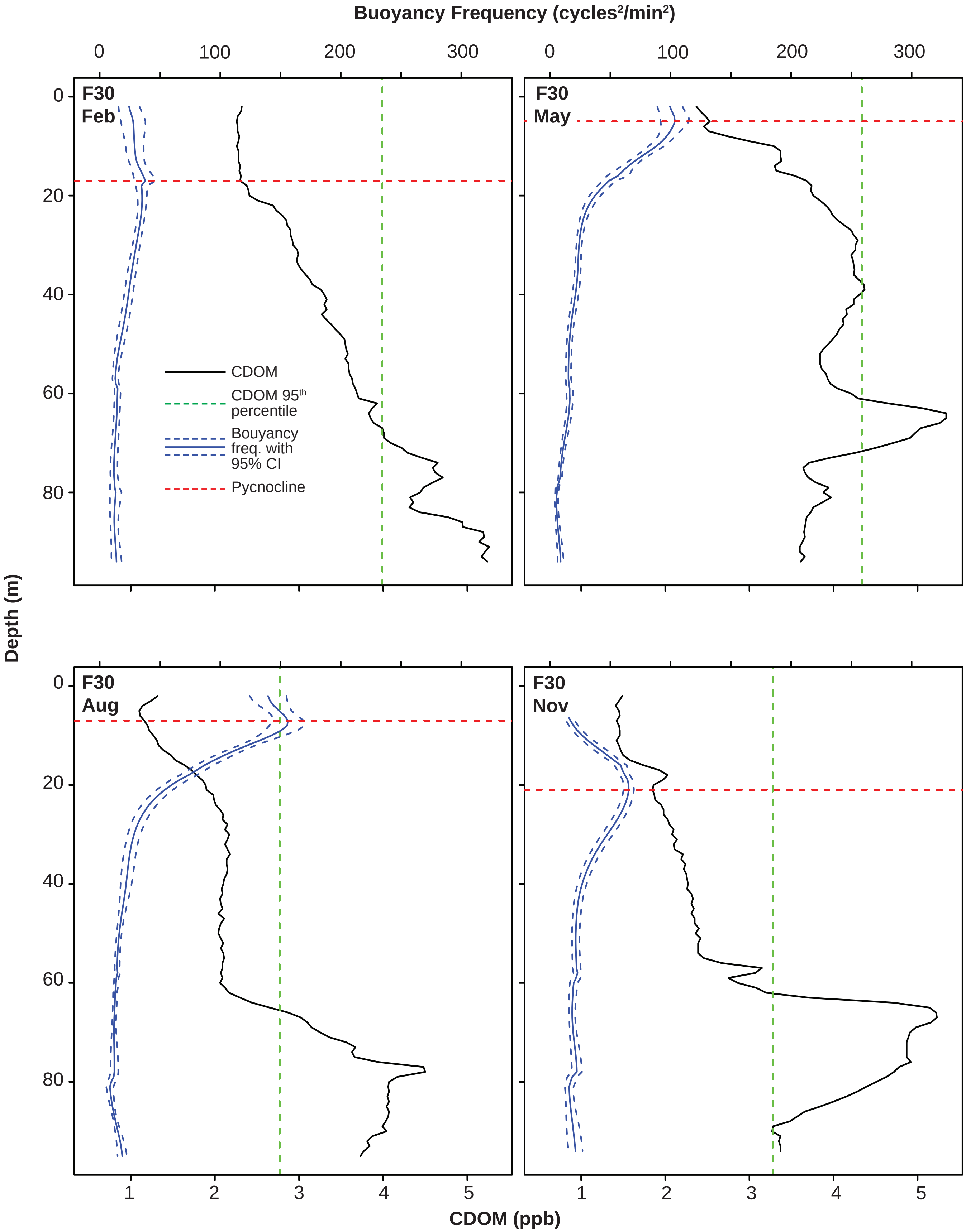
[a] *Enterococcus* only

Appendix B.6

Summary of oceanographic data within potential detected plume at PLOO offshore stations and corresponding reference values during 2014. Plume depth is the minimum depth at which CDOM exceeds the 95th percentile while plume width is the number of depth meters across which that exceedance occurs. Highlighted and bold values indicate out-of-range values. DO = dissolved oxygen; XMS = transmissivity; SD = standard deviation; CI = confidence interval.

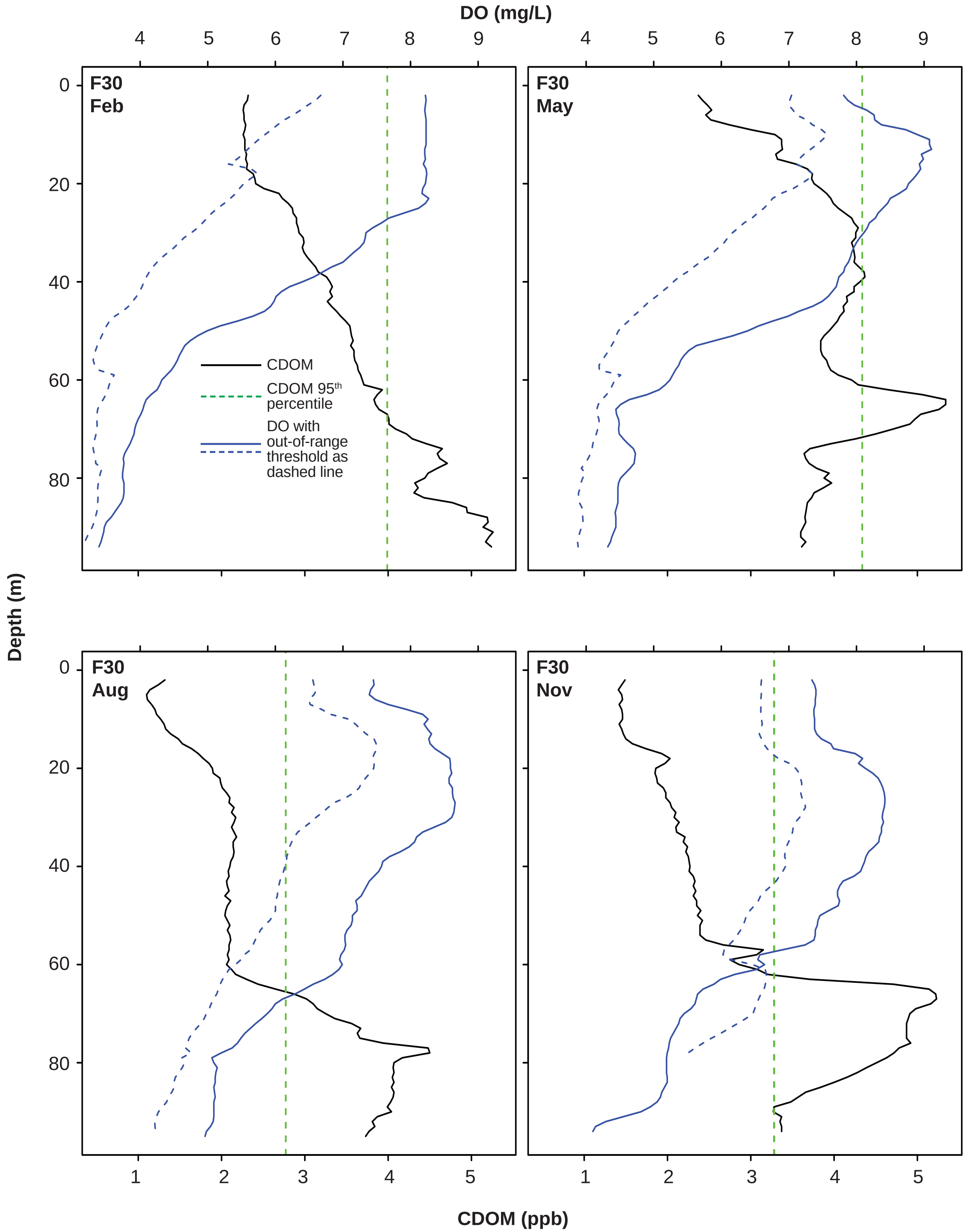
		Potential Plume					Reference		
Station	**Date**	**Depth (m)**	**Width (m)**	**Mean DO**	**Mean pH**	**Mean XMS**	**DO (Mean - SD)**	**pH (Mean)**	**XMS (Mean - 95% CI)**
F30	10 Feb 14	68	27	3.7	7.7	**88**	3.7	7.7	89
F20[a]	11 Feb 14	50	11	4.0	7.7	**88**	3.8	7.8	89
F21	11 Feb 14	53	27	3.9	7.7	**88**	3.8	7.8	89
F22	11 Feb 14	59	19	3.9	7.7	**88**	3.8	7.8	89
F23	11 Feb 14	64	2	4.0	7.7	89	3.8	7.8	89
F11[a]	12 Feb 14	47	4	4.0	7.7	**87**	3.9	7.8	89
F30	21 May 14	64	8	5.1	7.9	**87**	5.0	7.9	88
F31	21 May 14	59	2	7.4	8.0	88	6.9	8.1	86
F32	21 May 14	67	7	6.8	8.0	88	6.2	8.0	87
F19[a]	22 May 14	54	6	5.0	7.9	88	4.8	7.9	86
F26	11 Aug 14	91	2	5.1	7.9	89	4.7	7.9	88
F27	11 Aug 14	92	2	5.1	7.9	89	4.7	7.9	88
F28	11 Aug 14	85	12	4.9	7.9	**88**	4.8	7.9	88
F29	11 Aug 14	83	14	5.0	7.9	**87**	4.8	7.9	88
F30	11 Aug 14	66	30	5.4	7.9	**86**	5.2	7.9	88
F31	11 Aug 14	67	11	5.7	7.9	87	5.4	7.9	87
F32	11 Aug 14	66	11	5.8	7.9	89	5.3	7.9	87
F16	12 Aug 14	71	3	5.6	7.9	88	5.4	7.9	87
F17	12 Aug 14	75	5	5.4	7.9	**85**	5.2	7.9	86
F18[a]	12 Aug 14	68	11	5.2	7.9	**86**	5.4	7.9	87
F12[a]	13 Aug 14	54	5	5.9	8.0	**82**	6.3	8.0	86
F28	06 Nov 14	57	36	**5.6**	7.9	88	6.9	8.1	86
F29	06 Nov 14	64	29	**5.3**	7.9	**86**	6.9	8.1	87
F30	06 Nov 14	63	30	**5.2**	7.9	**86**	6.9	8.1	87

[a]Stations located within State jurisdictional waters



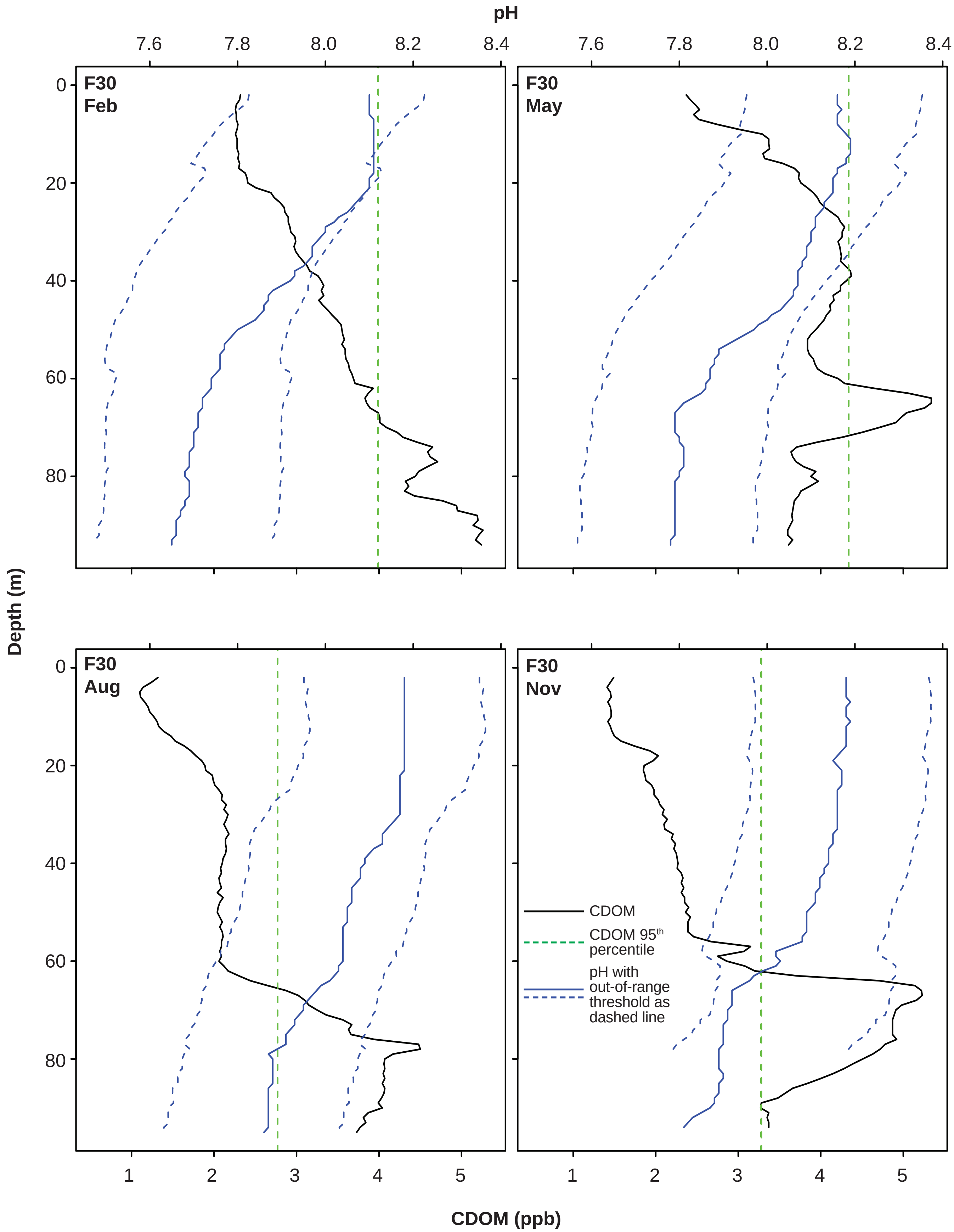
Appendix B.7

Representative vertical profiles of CDOM and buoyancy frequency from PLOO near-ZID station F30 during 2014.



Appendix B.8

Representative vertical profiles of CDOM and dissolved oxygen (DO) from PLOO near-ZID station F30 during 2014.



Appendix B.9

Representative vertical profiles of CDOM and pH from PLOO near-ZID station F30 during 2014.

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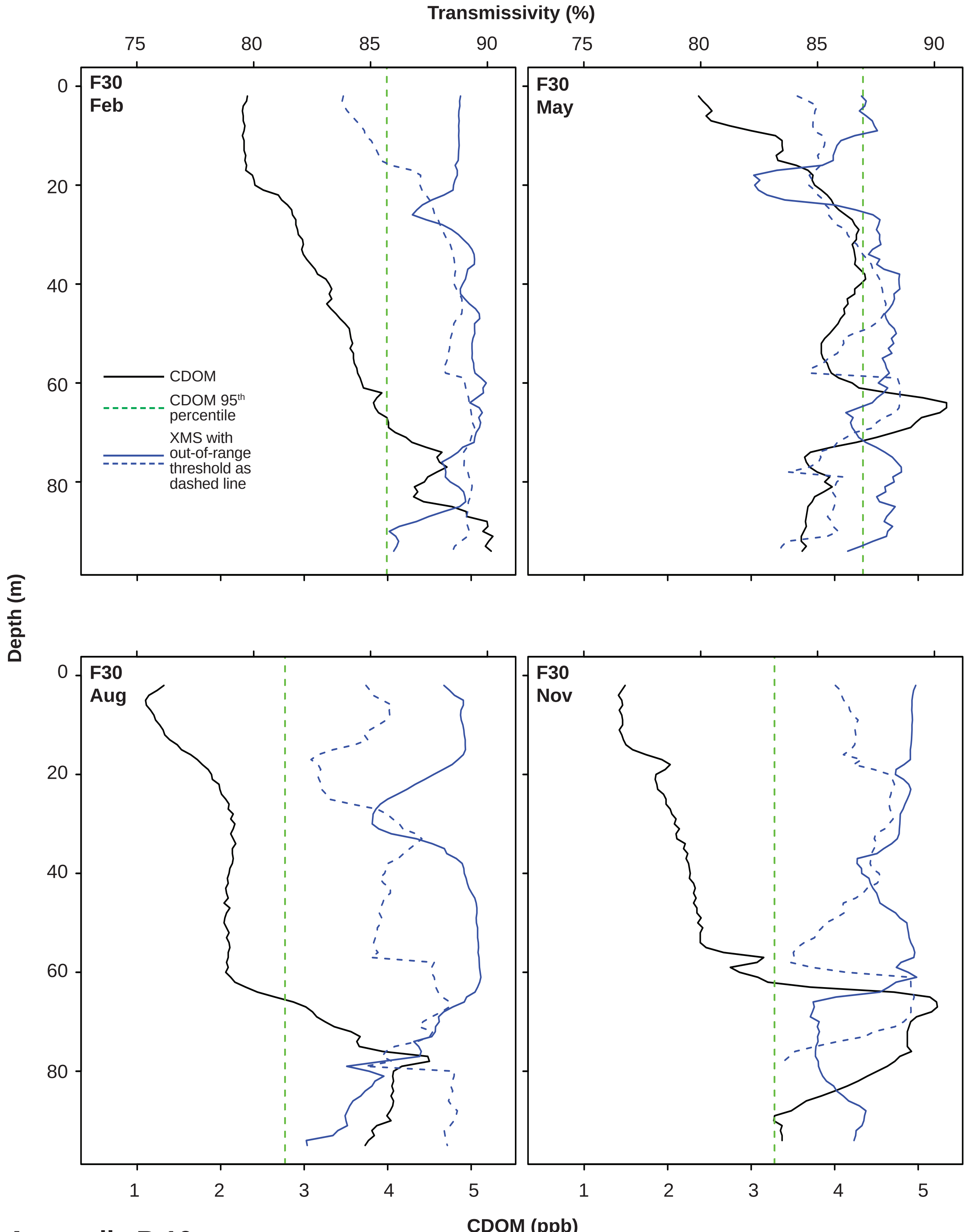

Appendix B.10

Representative vertical profiles of CDOM and transmissivity from PLOO near-ZID station F30 during 2014. XMS = transmissivity.

Appendix C

Supporting Data

2014 PLOO Stations

Sediment Conditions

Appendix C.1

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

Parameter	MDL	Parameter	MDL
Organic Indicators			
Biological Oxygen Demand (BOD, ppm)	2	Total Sulfides (ppm)	0.14
Total Nitrogen (TN, % wt.)	0.005	Total Volatile Solids (TVS, % wt.)	0.11
Total Organic Carbon (TOC, % wt.)	0.01		
Metals (ppm)			
Aluminum (Al)	2	Lead (Pb)	0.8
Antimony (Sb)	0.3	Manganese (Mn)	0.08
Arsenic (As)	0.33	Mercury (Hg)	0.004
Barium (Ba)	0.02	Nickel (Ni)	0.1
Beryllium (Be)	0.01	Selenium (Se)	0.24
Cadmium (Cd)	0.06	Silver (Ag)	0.04
Chromium (Cr)	0.1	Thallium (Tl)	0.5
Copper (Cu)	0.2	Tin (Sn)	0.3
Iron (Fe)	9	Zinc (Zn)	0.25
Chlorinated Pesticides (ppt)			
Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	100	HCH, Delta isomer	220
HCH, Beta isomer	50	HCH, Gamma isomer	190
Total Chlordane			
Alpha (cis) Chlordane	160	Heptachlor epoxide	300
Cis Nonachlor	380	Methoxychlor	90
Gamma (trans) Chlordane	190	Oxychlordane	1200
Heptachlor	120	Trans Nonachlor	240
Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	100	p,p-DDE	90
o,p-DDE	60	p,p-DDMU [a]	—
o,p-DDT	110	p,p-DDT	70
p,p-DDD	160		
Miscellaneous Pesticides			
Aldrin	70	Endrin	510
Alpha Endosulfan	720	Endrin aldehyde	2400
Beta Endosulfan	780	Hexachlorobenzene (HCB)	70
Dieldrin	340	Mirex	60
Endosulfan Sulfate	1100		

[a] No MDL available for this parameter

Appendix C.1 *continued*

Parameter	MDL	Parameter	MDL
Polychlorinated Biphenyl Congeners (PCBs) (ppt)			
PCB 18	90	PCB 126	70
PCB 28	60	PCB 128	80
PCB 37	90	PCB 138	80
PCB 44	100	PCB 149	110
PCB 49	70	PCB 151	80
PCB 52	90	PCB 153/168	150
PCB 66	100	PCB 156	90
PCB 70	60	PCB 157	100
PCB 74	100	PCB 158	70
PCB 77	110	PCB 167	30
PCB 81	130	PCB 169	90
PCB 87	200	PCB 170	80
PCB 99	120	PCB 177	70
PCB 101	100	PCB 180	80
PCB 105	50	PCB 183	60
PCB 110	110	PCB 187	110
PCB 114	130	PCB 189	60
PCB 118	90	PCB 194	80
PCB 119	80	PCB 201	70
PCB 123	130	PCB 206	50
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)			
1-methylnaphthalene	20	Benzo[G,H,I]perylene	20
1-methylphenanthrene	20	Benzo[K]fluoranthene	20
2,3,5-trimethylnaphthalene	20	Biphenyl	30
2,6-dimethylnaphthalene	20	Chrysene	40
2-methylnaphthalene	20	Dibenzo(A,H)anthracene	20
3,4-benzo(B)fluoranthene	20	Fluoranthene	20
Acenaphthene	20	Fluorene	20
Acenaphthylene	30	Indeno(1,2,3-CD)pyrene	20
Anthracene	20	Naphthalene	30
Benzo[A]anthracene	20	Perylene	30
Benzo[A]pyrene	20	Phenanthrene	30
Benzo[e]pyrene	20	Pyrene	20

Appendix C.2

Particle size classification schemes (based on Folk 1980) used in the analysis of sediments from the PLOO region during 2014. Included is a subset of the Wentworth scale presented as “phi” categories with corresponding Horiba channels, sieve sizes, and size fractions.

Wentworth Scale

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

[a] values correspond to Horiba channels; particles > 2000 µm measured by sieve
[b] SIEVE_0 = sum of all silt and clay, which cannot be distinguished for samples processed by nested sieves
[c] Fine particles also referred to as percent fines

Appendix C.3

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

Station	Class	Constituent	Winter	Summer	Units
B-8	DDT	p,p-DDE	420	500	ppt
B-8	DDT	p,p-DDT	nd	90	ppt
B-8	PAH	2,6-dimethylnaphthalene	14	14	ppb
B-8	PAH	3,4-benzo(B)fluoranthene	9	40	ppb
B-8	PAH	Acenaphthylene	nd	7	ppb
B-8	PAH	Benzo[A]anthracene	nd	30	ppb
B-8	PAH	Benzo[A]pyrene	nd	30	ppb
B-8	PAH	Benzo[G,H,I]perylene	nd	20	ppb
B-8	PAH	Biphenyl	nd	13	ppb
B-8	PAH	Chrysene	nd	21	ppb
B-8	PAH	Dibenzo(A,H)anthracene	nd	16	ppb
B-8	PAH	Fluoranthene	8	30	ppb
B-8	PAH	Fluorene	nd	11	ppb
B-8	PAH	Indeno(1,2,3-CD)pyrene	nd	30	ppb
B-8	PAH	Phenanthrene	nd	20	ppb
B-8	PAH	Dibenzo(A,H)anthracene	nd	16	ppb
B-8	PAH	Fluoranthene	8	30	ppb
B-8	PAH	Fluorene	nd	11	ppb
B-8	PAH	Indeno(1,2,3-CD)pyrene	nd	30	ppb
B-8	PAH	Phenanthrene	nd	20	ppb
B-8	PAH	Pyrene	10	30	ppb
B-9	DDT	p,p-DDD	nd	260	ppt
B-9	DDT	p,p-DDE	340	570	ppt
B-9	DDT	p,p-DDT	nd	17,000	ppt
B-9	PAH	2,6-dimethylnaphthalene	12	9	ppb
B-9	PAH	Biphenyl	nd	9	ppb
B-10	DDT	p,p-DDD	nd	190	ppt
B-10	DDT	p,p-DDE	410	530	ppt
B-10	DDT	p,p-DDT	nd	5400	ppt
B-10	PAH	1-methylnaphthalene	nd	8	ppb
B-10	PAH	2,6-dimethylnaphthalene	10	13	ppb
B-10	PAH	2-methylnaphthalene	nd	8	ppb
B-10	PAH	Acenaphthene	nd	9	ppb
B-10	PAH	Biphenyl	nd	13	ppb
B-11	DDT	p,p-DDE	310	420	ppt
B-11	PAH	2,6-dimethylnaphthalene	13	nd	ppb
B-12	DDT	p,p-DDE	285	390	ppt
B-12	PAH	2,6-dimethylnaphthalene	8	nd	ppb
B-12	PCB	PCB 66	180	nd	ppt
E-1	DDT	p,p-DDD	nd	195	ppt
E-1	DDT	p,p-DDE	540	790	ppt
E-1	DDT	p,p-DDT	nd	185	ppt
E-1	PAH	2,6-dimethylnaphthalene	12	7	ppb
E-1	PAH	3,4-benzo(B)fluoranthene	40	24	ppb
E-1	PAH	Anthracene	10	nd	ppb
E-1	PAH	Benzo[A]anthracene	24	nd	ppb
E-1	PAH	Benzo[A]pyrene	31	21	ppb

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
E-1	PAH	Benzo[e]pyrene	23	15	ppb
E-1	PAH	Benzo[G,H,I]perylene	17	15	ppb
E-1	PAH	Benzo[K]fluoranthene	16	nd	ppb
E-1	PAH	Chrysene	39	14	ppb
E-1	PAH	Fluoranthene	9	21	ppb
E-1	PAH	Indeno(1,2,3-CD)pyrene	15	13	ppb
E-1	PAH	Phenanthrene	15	nd	ppb
E-1	PAH	Pyrene	11	20	ppb
E-1	PCB	PCB 28	ns	49	ppt
E-1	PCB	PCB 49	ns	120	ppt
E-1	PCB	PCB 52	ns	190	ppt
E-1	PCB	PCB 66	73	75	ppt
E-1	PCB	PCB 70	110	ns	ppt
E-1	PCB	PCB 87	ns	150	ppt
E-1	PCB	PCB 99	ns	170	ppt
E-1	PCB	PCB 101	nd	420	ppt
E-1	PCB	PCB 105	nd	120	ppt
E-1	PCB	PCB 110	320	520	ppt
E-1	PCB	PCB 118	290	330	ppt
E-1	PCB	PCB 128	nd	120	ppt
E-1	PCB	PCB 138	320	430	ppt
E-1	PCB	PCB 149	250	350	ppt
E-1	PCB	PCB 153/168	430	990	ppt
E-1	PCB	PCB 170	nd	110	ppt
E-1	PCB	PCB 177	nd	130	ppt
E-1	PCB	PCB 180	160	340	ppt
E-1	PCB	PCB 183	nd	130	ppt
E-1	PCB	PCB 187	nd	260	ppt
E-1	PCB	PCB 201	nd	380	ppt
E-1	PCB	PCB 206	nd	270	ppt
E-2	DDT	p,p-DDE	460	680	ppt
E-2	DDT	p,p-DDT	nd	120	ppt
E-2	PAH	2,6-dimethylnaphthalene	11	10	ppb
E-2	PAH	3,4-benzo(B)fluoranthene	nd	19	ppb
E-2	PAH	Anthracene	8	nd	ppb
E-2	PAH	Benzo[A]anthracene	13	nd	ppb
E-2	PAH	Benzo[A]pyrene	20	15	ppb
E-2	PAH	Benzo[e]pyrene	12	12	ppb
E-2	PAH	Benzo[G,H,I]perylene	nd	12	ppb
E-2	PAH	Benzo[K]fluoranthene	8	nd	ppb
E-2	PAH	Chrysene	23	9	ppb
E-2	PAH	Dibenzo(A,H)anthracene	12	nd	ppb
E-2	PAH	Fluoranthene	13	10	ppb
E-2	PAH	Indeno(1,2,3-CD)pyrene	12	9	ppb
E-2	PAH	Pyrene	14	14	ppb
E-2	PCB	PCB 28	nd	83	ppt
E-2	PCB	PCB 44	640	nd	ppt
E-2	PCB	PCB 49	330	150	ppt
E-2	PCB	PCB 52	1600	410	ppt
E-2	PCB	PCB 66	280	150	ppt
E-2	PCB	PCB 70	890	nd	ppt
E-2	PCB	PCB 74	200	nd	ppt
E-2	PCB	PCB 87	1400	410	ppt
E-2	PCB	PCB 99	900	nd	ppt

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
E-2	PCB	PCB 101	2400	570	ppt
E-2	PCB	PCB 105	880	nd	ppt
E-2	PCB	PCB 110	2600	730	ppt
E-2	PCB	PCB 118	2100	660	ppt
E-2	PCB	PCB 128	580	190	ppt
E-2	PCB	PCB 138	1900	620	ppt
E-2	PCB	PCB 149	1400	400	ppt
E-2	PCB	PCB 151	nd	220	ppt
E-2	PCB	PCB 153/168	2600	nd	ppt
E-2	PCB	PCB 156	320	120	ppt
E-2	PCB	PCB 158	270	120	ppt
E-2	PCB	PCB 167	nd	71	ppt
E-2	PCB	PCB 170	310	160	ppt
E-2	PCB	PCB 177	nd	110	ppt
E-2	PCB	PCB 180	640	280	ppt
E-2	PCB	PCB 183	180	nd	ppt
E-2	PCB	PCB 187	270	160	ppt
E-2	PCB	PCB 201	nd	84	ppt
E-3	DDT	o,p-DDD	nd	170	ppt
E-3	DDT	p,p-DDD	nd	420	ppt
E-3	DDT	p,p-DDE	270	420	ppt
E-3	DDT	p,p-DDT	nd	56	ppt
E-3	PAH	2,6-dimethylnaphthalene	9	nd	ppb
E-3	PAH	3,4-benzo(B)fluoranthene	298	30	ppb
E-3	PAH	Acenaphthylene	8	nd	ppb
E-3	PAH	Anthracene	12	10	ppb
E-3	PAH	Benzo[A]anthracene	51	nd	ppb
E-3	PAH	Benzo[A]pyrene	227	20	ppb
E-3	PAH	Benzo[e]pyrene	136	15	ppb
E-3	PAH	Benzo[G,H,I]perylene	63	14	ppb
E-3	PAH	Benzo[K]fluoranthene	96	nd	ppb
E-3	PAH	Chrysene	105	10	ppb
E-3	PAH	Fluoranthene	16	9	ppb
E-3	PAH	Indeno(1,2,3-CD)pyrene	72	13	ppb
E-3	PAH	Perylene	50	nd	ppb
E-3	PAH	Phenanthrene	6	nd	ppb
E-3	PAH	Pyrene	23	13	ppb
E-3	PCB	PCB 28	250	87	ppt
E-3	PCB	PCB 49	230	97	ppt
E-3	PCB	PCB 52	370	nd	ppt
E-3	PCB	PCB 66	190	nd	ppt
E-3	PCB	PCB 70	190	nd	ppt
E-3	PCB	PCB 74	84	nd	ppt
E-3	PCB	PCB 101	nd	170	ppt
E-3	PCB	PCB 105	nd	71	ppt
E-3	PCB	PCB 110	370	230	ppt
E-3	PCB	PCB 118	nd	170	ppt
E-3	PCB	PCB 138	270	220	ppt
E-3	PCB	PCB 149	230	160	ppt
E-3	PCB	PCB 153/168	480	510	ppt
E-3	PCB	PCB 180	240	170	ppt
E-3	PCB	PCB 187	130	140	ppt
E-5	DDT	p,p-DDE	290	nd	ppt

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
E-5	PAH	2,6-dimethylnaphthalene	8.5	nd	ppb
E-7	DDT	p,p-DDE	140	350	ppt
E-7	DDT	p,p-DDT	nd	400	ppt
E-7	PAH	2,6-dimethylnaphthalene	13	14	ppb
E-7	PAH	Benzo[A]pyrene	nd	9	ppb
E-7	PCB	PCB 101	nd	140	ppt
E-7	PCB	PCB 110	nd	130	ppt
E-7	PCB	PCB 118	nd	110	ppt
E-7	PCB	PCB 138	nd	140	ppt
E-7	PCB	PCB 149	nd	120	ppt
E-7	PCB	PCB 153/168	nd	290	ppt
E-7	PCB	PCB 206	77	81	ppt
E-8	DDT	p,p-DDE	92	340	ppt
E-8	DDT	p,p-DDT	nd	110	ppt
E-8	PAH	2,6-dimethylnaphthalene	12	nd	ppb
E-8	PCB	PCB 118	nd	100	ppt
E-9	Chlordane	Heptachlor	nd	250	ppt
E-9	Chlordane	Trans Nonachlor	nd	360	ppt
E-9	DDT	o,p-DDE	nd	190	ppt
E-9	DDT	o,p-DDT	nd	110	ppt
E-9	DDT	p,p-DDE	220	340	ppt
E-9	DDT	p,p-DDMU	nd	130	ppt
E-9	DDT	p,p-DDT	240	130	ppt
E-9	PAH	2,6-dimethylnaphthalene	11	9	ppb
E-9	PAH	3,4-benzo(B)fluoranthene	66	nd	ppb
E-9	PAH	Anthracene	9	nd	ppb
E-9	PAH	Benzo[A]anthracene	25	nd	ppb
E-9	PAH	Benzo[A]pyrene	45	12	ppb
E-9	PAH	Benzo[e]pyrene	30	10	ppb
E-9	PAH	Benzo[G,H,I]perylene	19	9	ppb
E-9	PAH	Benzo[K]fluoranthene	21	nd	ppb
E-9	PAH	Chrysene	25	11	ppb
E-9	PAH	Fluoranthene	9	8	ppb
E-9	PAH	Indeno(1,2,3-CD)pyrene	17	nd	ppb
E-9	PAH	Perylene	11	nd	ppb
E-9	PAH	Pyrene	16	8	ppb
E-9	PCB	PCB 18	nd	100	ppt
E-9	PCB	PCB 28	nd	130	ppt
E-9	PCB	PCB 37	nd	140	ppt
E-9	PCB	PCB 49	nd	160	ppt
E-9	PCB	PCB 66	nd	160	ppt
E-9	PCB	PCB 74	nd	140	ppt
E-9	PCB	PCB 77	nd	140	ppt
E-9	PCB	PCB 81	nd	160	ppt
E-9	PCB	PCB 99	nd	120	ppt
E-9	PCB	PCB 101	100	150	ppt
E-9	PCB	PCB 105	nd	85	ppt
E-9	PCB	PCB 110	nd	130	ppt
E-9	PCB	PCB 118	nd	160	ppt
E-9	PCB	PCB 119	nd	110	ppt

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
E-9	PCB	PCB 138	nd	90	ppt
E-9	PCB	PCB 151	nd	140	ppt
E-9	PCB	PCB 153/168	nd	210	ppt
E-9	PCB	PCB 180	nd	90	ppt
E-11	DDT	p,p-DDE	240	385	ppt
E-11	DDT	p,p-DDT	nd	190	ppt
E-11	PAH	2,6-dimethylnaphthalene	13	11	ppb
E-11	PAH	Chrysene	nd	11	ppb
E-11	PCB	PCB 101	nd	150	ppt
E-11	PCB	PCB 110	nd	120	ppt
E-11	PCB	PCB 118	nd	200	ppt
E-11	PCB	PCB 138	nd	230	ppt
E-11	PCB	PCB 153/168	nd	470	ppt
E-11	PCB	PCB 158	nd	80	ppt
E-11	PCB	PCB 201	nd	140	ppt
E-11	PCB	PCB 206	nd	200	ppt
E-14	DDT	p,p-DDE	190	290	ppt
E-14	PAH	2,6-dimethylnaphthalene	14	13	ppb
E-15	DDT	p,p-DDE	320	880	ppt
E-15	PAH	2,6-dimethylnaphthalene	14	nd	ppb
E-17	DDT	p,p-DDE	160	110	ppt
E-17	DDT	p,p-DDT	nd	140	ppt
E-17	PAH	2,6-dimethylnaphthalene	14	11	ppb
E-19	DDT	p,p-DDE	220	480	ppt
E-19	DDT	p,p-DDT	nd	120	ppt
E-19	PAH	2,6-dimethylnaphthalene	20	12	ppb
E-19	PAH	Pyrene	8	nd	ppb
E-20	DDT	p,p-DDE	120	170	ppt
E-20	DDT	p,p-DDT	nd	110	ppt
E-20	PAH	2,6-dimethylnaphthalene	16	10	ppb
E-21	DDT	p,p-DDE	130	340	ppt
E-21	DDT	p,p-DDT	nd	80	ppt
E-21	PAH	2,6-dimethylnaphthalene	15	11	ppb
E-23	DDT	p,p-DDE	130	190	ppt
E-23	PAH	2,6-dimethylnaphthalene	16	11	ppb
E-25	DDT	p,p-DDE	155	760	ppt
E-25	PAH	2,6-dimethylnaphthalene	13	8	ppb
E-26	DDT	p,p-DDE	340	650	ppt
E-26	PAH	2,6-dimethylnaphthalene	13	10	ppb
E-26	PAH	Fluoranthene	6.13	nd	ppb
E-26	PAH	Pyrene	7.89	nd	ppb

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Appendix C.4

Summary of particle size parameters (%) for each PLOO station sampled during winter 2014. Visual observations are from sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VCSand=Very Coarse Sand; CSand=Coarse Sand; MSand=Medium Sand; FSand=Fine Sand; VFSand=Very Fine Sand; CSilt=Coarse Silt; MSilt=Medium Silt; FSilt=Fine Silt; VFSilt=Very Fine Silt.

		Coarse Particles		Med-Coarse Sands		Fine Sands		Fine Particles					Visual Observations
		Granules	VCSand	CSand	MSand	FSand	VFSand	CSilt	MSilt	FSilt	VFSilt	Clay	
88-m Stations	B11	5.6	0.0	0.1	7.6	15.9	25.9	15.6	9.0	14.4	5.5	0.3	shell hash, gravel
	B8	0.0	0.0	0.0	0.1	5.7	31.1	28.5	13.8	16.2	4.6	0.1	
	E19	0.0	0.0	0.0	0.2	8.6	38.9	26.5	9.6	12.0	4.1	0.1	
	E7	0.0	0.0	0.0	0.7	12.1	40.6	23.7	8.6	10.5	3.6	0.1	
	E1	0.0	0.0	0.0	6.7	24.5	30.5	16.9	7.8	9.6	3.9	0.1	gravel, shell hash, rock
98-m Stations	B12	0.0	0.0	4.3	27.2	24.8	17.0	10.3	5.0	7.3	4.0	0.2	shell hash, gravel, rock
	B9	0.0	0.0	0.0	1.6	14.5	36.4	19.1	9.6	14.3	4.5	0.1	gravel, shell hash
	E26	0.0	0.0	0.0	0.2	10.5	40.7	23.7	9.0	11.4	4.3	0.2	shell hash
	E25	0.0	0.0	0.0	1.2	15.9	43.8	20.5	6.7	8.5	3.2	0.1	shell hash
	E23	0.0	0.0	0.0	0.5	12.6	44.0	21.3	7.6	10.3	3.5	0.1	shell hash, organic debris
	E20	0.0	0.0	0.0	0.6	13.5	45.3	20.2	6.9	9.8	3.6	0.1	shell hash, organic debris
	E17 [a]	0.0	0.0	0.0	0.7	15.7	48.0	18.2	5.6	8.3	3.4	0.1	shell hash, organic debris
	E14 [a]	0.0	0.0	0.0	0.9	17.7	50.5	15.2	4.1	7.3	3.9	0.3	black sand, shell hash
	E11 [a]	0.0	0.0	0.0	1.6	17.4	45.0	18.4	5.9	8.3	3.3	0.1	shell hash
	E8	0.0	0.0	0.0	1.4	17.6	43.8	17.5	6.5	9.7	3.5	0.1	
	E5	0.0	0.0	0.0	2.0	19.9	42.7	16.9	6.3	8.8	3.3	0.1	shell hash
	E2	0.0	1.3	3.4	7.1	17.1	29.0	15.7	8.5	13.1	4.6	0.1	shell hash, rock
116-m Stations	B10	0.0	0.0	0.0	2.4	22.2	40.5	12.3	4.0	7.7	5.5	0.4	shell hash, gravel
	E21	0.0	0.0	0.0	0.6	14.9	47.5	17.5	6.0	9.4	3.8	0.1	
	E15	0.0	0.0	0.0	0.9	16.9	45.5	16.1	6.1	10.3	4.2	0.1	black sand, shell hash
	E9	0.0	6.6	5.7	5.4	13.5	30.2	14.4	6.9	12.2	4.9	0.2	black sand
	E3	1.2	0.0	5.0	21.3	27.5	14.1	9.7	6.7	9.7	4.8	0.2	gravel, shell hash

[a] near-ZID stations

Appendix C.4 *continued*

Summary of particle size parameters (%) for each PLOO station sampled during summer 2014. Visual observations are from sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VCSand=Very Coarse Sand; CSand=Coarse Sand; MSand=Medium Sand; FSand=Fine Sand; VFSand=Very Fine Sand; CSilt=Coarse Silt; MSilt=Medium Silt; FSilt=Fine Silt; VFSilt=Very Fine Silt.

		Coarse Particles		Med-Coarse Sands		Fine Sands		Fine Particles					Visual Observations
		Granules	VCSand	CSand	MSand	FSand	VFSand	CSilt	MSilt	FSilt	VFSilt	Clay	
88-m Stations	B11[s]	2.7	4.3	7.4	12.0	11.7	28.0	33.9	—	—	—	—	shell hash, pea gravel, rocks
	B8	0.0	0.0	0.0	0.1	5.6	31.1	28.9	13.7	15.6	4.8	0.2	
	E19	0.0	0.0	0.0	0.2	8.3	38.8	27.7	9.6	11.2	4.1	0.2	
	E7	0.0	0.0	0.0	0.5	11.0	40.6	24.2	8.9	10.9	3.8	0.1	shell hash
	E1	0.0	0.0	0.0	5.9	22.5	31.1	16.7	8.6	11.4	3.8	0.1	shell hash
98-m Stations	B12	0.0	0.0	6.4	25.2	24.2	18.2	10.3	4.6	6.6	4.3	0.4	shell hash, pea gravel
	B9	0.0	0.0	0.0	1.7	15.6	38.2	18.4	8.3	12.9	4.8	0.2	mud, pea gravel
	E26	0.0	0.0	0.0	0.2	10.6	40.4	23.8	9.2	11.6	4.2	0.2	shell hash
	E25	0.0	0.0	0.0	0.7	13.3	41.4	22.2	8.0	10.3	3.9	0.2	shell hash
	E23	0.0	0.0	0.0	0.5	11.7	43.2	22.7	7.8	10.1	3.7	0.1	shell hash
	E20	0.0	0.0	0.0	0.5	12.8	45.2	21.0	7.3	9.7	3.4	0.1	shell hash
	E17[a]	0.0	0.0	0.0	0.6	14.1	44.8	19.2	7.3	10.6	3.5	0.0	
	E14[a]	0.0	0.0	0.0	1.2	16.0	49.4	17.2	4.6	7.4	3.9	0.3	black sand
	E11[a]	0.0	0.0	0.0	1.4	17.3	46.1	17.6	5.7	8.4	3.4	0.1	shell hash
	E8	0.0	0.0	0.0	1.8	19.0	46.3	18.1	5.1	6.7	3.0	0.1	
	E5	0.0	0.0	0.0	2.0	19.3	43.0	17.3	6.1	8.7	3.5	0.1	shell hash
	E2	0.0	0.1	3.3	8.9	19.0	29.2	15.7	8.2	11.7	3.9	0.1	shell hash, pea gravel
116-m Stations	B10[s]	1.0	0.6	0.5	1.2	12.4	70.4	13.9	—	—	—	—	shell hash, pea gravel, rocks
	E21	0.0	0.0	0.0	0.6	15.2	47.8	17.5	6.1	9.2	3.5	0.1	shell hash
	E15	0.0	0.0	0.0	1.2	16.6	45.0	16.4	6.2	10.0	4.3	0.3	shell hash
	E9	0.0	7.3	9.6	5.1	11.8	28.4	15.6	5.9	9.8	5.5	0.6	black sand
	E3	0.0	0.5	10.1	17.7	22.4	14.8	10.7	7.5	10.9	5.2	0.2	pea gravel, shell hash

[a] near-ZID stations; [s] measured by sieve (not Horiba; silt and clay fractions are indistinguishable)

Appendix C.5

Summary of organic loading indicators in sediments from PLOO stations sampled during winter and summer 2014.

	Winter					Summer				
	BOD (ppm)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)	BOD (ppm)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
88-m Depth Contour										
B11	285	3.83	0.075	0.85	3.55	463	4.86	0.038	0.25	3.47
B8	253	2.12	0.085	0.74	2.93	378	9.51	0.061	0.74	3.17
E19	357	3.90	0.063	0.54	2.41	221	3.62	0.056	0.61	2.34
E7	305	3.41	0.059	0.49	2.09	206	3.99	0.029	0.51	2.29
E1	173	3.26	0.046	0.37	1.97	217	3.09	0.039	0.50	1.80
98-m Depth Contour										
B12	266	1.15	0.050	1.39	2.90	426	4.18	0.022	0.33	3.13
B9	224	2.19	0.066	0.56	2.59	302	12.80	0.005	0.63	2.66
E26	192	1.40	0.058	0.48	2.28	331	16.20	0.017	0.63	2.09
E25	222	3.70	0.055	0.44	1.91	340	4.43	0.022	0.47	2.08
E23	314	4.72	0.040	0.37	2.09	220	3.20	0.046	0.67	2.02
E20	322	3.49	0.050	0.43	2.01	194	3.31	0.043	0.48	1.80
E17[a]	326	15.60	0.046	0.38	1.67	306	3.57	0.050	0.47	1.91
E14[a]	471	58.80	0.047	0.37	1.74	610	68.20	0.019	0.40	1.78
E11[a]	264	11.40	0.049	0.38	1.95	258	3.41	0.021	0.57	2.04
E8	362	12.70	0.061	0.51	1.99	140	3.27	0.021	0.43	1.60
E5	176	2.68	0.047	0.39	1.97	174	3.36	0.024	0.34	1.86
E2	202	6.70	0.050	0.40	2.48	281	4.58	0.050	0.69	2.52
116-m Depth Contour										
B10	258	4.07	0.053	0.45	2.23	580	7.20	0.032	0.87	2.35
E21	312	4.24	0.040	0.28	1.96	192	2.98	0.042	0.54	1.81
E15	217	31.20	0.055	0.47	2.09	517	17.70	0.016	0.51	1.98
E9	223	6.58	0.056	0.47	2.17	279	3.84	0.029	0.16	2.63
E3	172	5.71	0.043	0.35	2.11	261	4.72	0.038	0.48	1.81
Detection Rate (%)	100	100	100	100	100	100	100	100	100	100

[a] near-ZID stations

Appendix C.6

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during winter 2014. See Appendix C.1 for MDLs and translation of periodic table symbols; nd = not detected.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	9130	0.8	3.99	38.50	nd	nd	21.6	5.9	17,400	6.6	137.0	0.035	9.7	nd	nd	nd	1.3	42.5
B8	11,000	0.5	3.41	49.80	nd	nd	21.3	6.7	15,300	6.7	119.0	0.053	10.2	0.11	nd	nd	1.1	38.4
E19	14,500	1.2	3.34	48.40	nd	0.07	19.6	5.0	14,100	4.3	162.0	0.039	10.0	0.13	nd	nd	1.2	36.5
E7	7990	0.5	4.38	40.50	nd	nd	15.0	5.2	11,400	4.6	91.4	0.034	7.4	nd	nd	nd	1.3	30.6
E1	7060	0.7	3.71	41.20	nd	nd	14.1	5.8	11,000	5.3	87.9	0.039	6.4	nd	nd	nd	1.3	27.3
98-m Depth Contour																		
B12	7080	1.2	6.41	30.40	0.06	nd	26.9	2.1	24,900	6.1	66.3	0.018	7.6	0.26	nd	nd	1.3	41.7
B9	8120	0.8	3.10	50.60	nd	nd	19.5	4.0	15,500	4.7	96.8	0.032	8.0	nd	nd	nd	1.2	35.0
E26	12,400	0.6	2.09	39.20	0.21	nd	18.0	3.9	13,100	4.1	143.0	0.032	9.3	0.16	nd	nd	0.8	33.0
E25	12,300	1.1	1.94	37.70	nd	nd	16.2	3.4	12,500	3.7	145.0	0.027	8.6	nd	nd	nd	0.6	31.1
E23	13,300	1.1	2.50	41.10	nd	0.07	17.7	3.8	13,300	3.7	153.0	0.036	9.3	nd	nd	nd	1.0	33.6
E20	12,000	0.8	2.97	35.90	nd	0.07	16.2	3.2	12,200	3.3	141.0	0.030	8.6	0.22	nd	nd	1.2	30.3
E17[a]	9650	0.7	2.47	27.90	nd	0.09	13.7	2.9	10,000	2.4	118.0	0.027	7.5	0.07	nd	nd	1.0	25.8
E14[a]	9160	0.8	2.17	27.60	nd	0.11	13.1	3.5	9100	2.2	113.0	0.027	7.6	0.18	nd	nd	0.8	25.7
E11[a]	9570	0.7	2.56	30.20	0.17	0.07	14.7	2.8	10,800	2.7	124.0	0.022	7.1	nd	nd	nd	0.7	27.5
E8	6710	0.6	4.10	27.90	nd	nd	13.3	4.9	10,200	3.9	75.2	0.024	6.3	nd	nd	nd	1.1	25.3
E5	6920	0.6	3.45	38.30	nd	nd	13.4	4.1	10,500	3.5	77.8	0.027	6.3	nd	nd	nd	0.9	43.4
E2	8490	0.9	2.76	50.90	nd	nd	16.5	10.0	13,200	6.3	103.0	0.057	7.6	nd	nd	nd	1.6	34.1
116-m Depth Contour																		
B10	5780	0.7	2.93	25.00	nd	0.08	16.2	2.8	11,800	3.7	67.1	0.019	5.9	nd	nd	nd	1.0	27.2
E21	10,200	0.8	2.61	29.20	nd	0.07	14.5	3.1	10,500	2.9	118.0	0.028	7.8	0.42	nd	nd	1.1	26.3
E15	11,000	1.0	2.33	31.80	nd	0.08	16.0	3.9	11,400	3.4	126.0	0.027	8.1	nd	nd	nd	1.1	30.1
E9	7560	0.9	3.72	36.40	nd	0.10	18.8	9.5	13,000	5.4	80.7	0.032	7.0	nd	nd	nd	1.5	38.5
E3	7740	0.7	3.42	49.40	nd	nd	14.0	11.8	12,700	8.1	96.0	0.062	5.8	nd	nd	nd	1.4	35.4
Detection Rate (%)	100	100	100	100	14	45	100	100	100	100	100	100	100	36	0	0	100	100

[a] near-ZID stations

Appendix C.6 *continued*

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during summer 2014. See Appendix C.1 for MDLs and translation of periodic table symbols; nd = not detected.

.	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	10,600	0.7	3.12	80.40	nd	0.11	19.3	6.0	16,800	6.4	108.0	0.008	9.1	nd	nd	0.7	1.5	38.9
B8	10,400	0.4	2.97	48.80	nd	nd	18.9	7.3	14,800	6.5	113.0	0.009	9.7	nd	nd	nd	1.3	37.5
E19	8550	1.1	2.13	46.40	0.22	0.12	16.7	5.8	12,300	5.7	99.3	0.009	8.3	nd	nd	nd	0.8	32.1
E7	7720	0.3	2.71	37.20	nd	nd	13.8	5.6	10,400	4.5	84.0	0.009	7.3	nd	nd	0.9	1.2	29.9
E1	6510	0.5	2.77	33.80	nd	nd	11.8	5.2	9480	5.5	71.5	0.013	5.6	0.15	nd	nd	1.1	24.3
98-m Depth Contour																		
B12	7500	0.7	4.62	28.50	0.01	nd	23.1	2.7	20,900	5.8	62.4	0.004	7.0	nd	nd	nd	0.8	37.6
B9	7380	0.6	3.65	37.70	nd	nd	17.6	4.0	14,500	4.8	80.9	0.005	7.1	nd	nd	0.8	1.0	31.5
E26	7630	1.0	1.53	36.90	0.14	nd	15.2	4.8	11,000	4.1	86.4	0.007	7.6	nd	nd	nd	1.1	28.2
E25	7320	0.9	2.01	34.90	0.14	nd	14.7	4.7	10,800	4.4	83.5	0.006	7.1	nd	nd	nd	1.3	27.6
E23	7380	0.4	3.26	35.40	0.13	nd	14.7	4.8	11,000	4.4	83.6	0.007	7.2	nd	nd	0.6	1.2	27.4
E20	6000	0.7	2.18	27.70	0.10	nd	12.3	3.6	8800	3.5	67.4	0.005	5.9	nd	nd	0.6	1.0	21.9
E17 [a]	6140	1.0	2.98	27.70	0.11	nd	12.6	4.2	9310	3.7	68.2	0.014	6.1	nd	nd	1.1	1.1	23.4
E14 [a]	5030	0.6	1.41	24.70	0.09	0.10	11.3	4.6	7580	2.3	58.2	0.005	5.6	nd	nd	0.6	0.9	21.5
E11 [a]	5250	0.3	2.53	21.60	nd	0.06	10.3	3.6	7770	3.3	55.2	0.005	5.1	nd	nd	0.7	0.9	19.6
E8	5200	0.4	1.68	20.00	nd	nd	10.1	2.7	7560	2.8	54.8	0.007	4.7	nd	nd	1.1	0.9	18.5
E5	6190	0.6	1.81	26.50	nd	nd	11.6	4.0	8800	3.8	65.6	0.007	5.6	nd	nd	0.7	0.9	22.1
E2	7790	0.9	2.83	42.70	0.14	nd	14.5	7.2	12,500	5.3	86.9	0.016	6.6	nd	nd	nd	0.8	30.6
116-m Depth Contour																		
B10	5640	0.5	2.31	21.60	nd	nd	14.1	3.1	10,800	3.8	57.6	0.004	5.3	nd	nd	0.8	1.15	24.7
E21	6070	0.7	1.82	26.90	0.11	nd	12.9	3.9	8990	3.6	66.5	0.005	6.1	nd	nd	nd	1.0	22.8
E15	5790	0.5	1.81	25.10	0.11	nd	12.6	4.1	8880	3.5	61.6	0.005	5.9	nd	nd	1.0	1.0	23.0
E9	6630	0.7	2.78	28.60	nd	nd	15.9	7.0	11,900	5.0	67.2	0.007	6.6	0.10	nd	1.8	1.1	34.8
E3	9990	1.0	2.19	61.50	nd	0.07	15.7	9.9	15,100	8.3	117.0	0.014	7.1	nd	nd	nd	1.3	37.7
Detection Rate (%)	100	100	100	100	50	23	100	100	100	100	100	100	100	9	0	59	100	100

[a] near-ZID stations

Appendix C.7

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

	Winter					Summer				
	HCB (ppt)	tDDT (ppt)	tCHLOR (ppb)	tPCB (ppt)	tPAH (ppb)	HCB (ppt)	tDDT (ppt)	tCHLOR (ppb)	tPCB (ppt)	tPAH (ppb)
88-m Stations										
B11	nd	310	nd	nd	13	150	420	nd	nd	nd
B8	nd	420	nd	nd	42	nd	590	nd	nd	312
E19	nd	220	nd	nd	28	nd	600	nd	nd	12
E7	nd	140	nd	77	13	nd	750	nd	1011	23
E1	nd	540	nd	1953	263	nd	1170	nd	5380	150
98-m Stations										
B12	nd	285	nd	180	8	nd	390	nd	nd	nd
B9	nd	340	nd	nd	12	nd	17,830	nd	nd	18
E26	nd	340	nd	nd	27	nd	650	nd	nd	10
E25	nd	155	nd	nd	13	nd	760	nd	nd	8
E23	nd	130	nd	nd	16	555	190	nd	nd	11
E20	nd	120	nd	nd	16	91	280	nd	nd	10
E17 [a]	nd	160	nd	nd	14	nd	250	nd	nd	11
E14 [a]	nd	190	nd	nd	14	nd	290	nd	nd	13
E11 [a]	nd	240	nd	nd	13	nd	575	nd	1590	22
E8	nd	92	nd	nd	12	nd	450	nd	100	nd
E5	nd	290	nd	nd	9	nd	nd	nd	nd	nd
E2	nd	460	nd	22,690	148	nd	800	nd	5698	110
116-m Stations										
B10	nd	410	nd	nd	10	nd	6120	nd	nd	51
E21	nd	130	nd	nd	15	nd	420	nd	nd	11
E15	nd	320	nd	nd	15	1600	880	nd	nd	nd
E9	nd	460	nd	100	303	nd	770	610	2415	67
E3	nd	270	nd	3034	1173	nd	1066	nd	2025	134
Detection Rate (%)	0	100	0	27	100	18	95	5	32	77

[a] near-ZID stations

Appendix D

Supporting Data

2014 PLOO Stations

Macrobenthic Communities

Appendix D.1

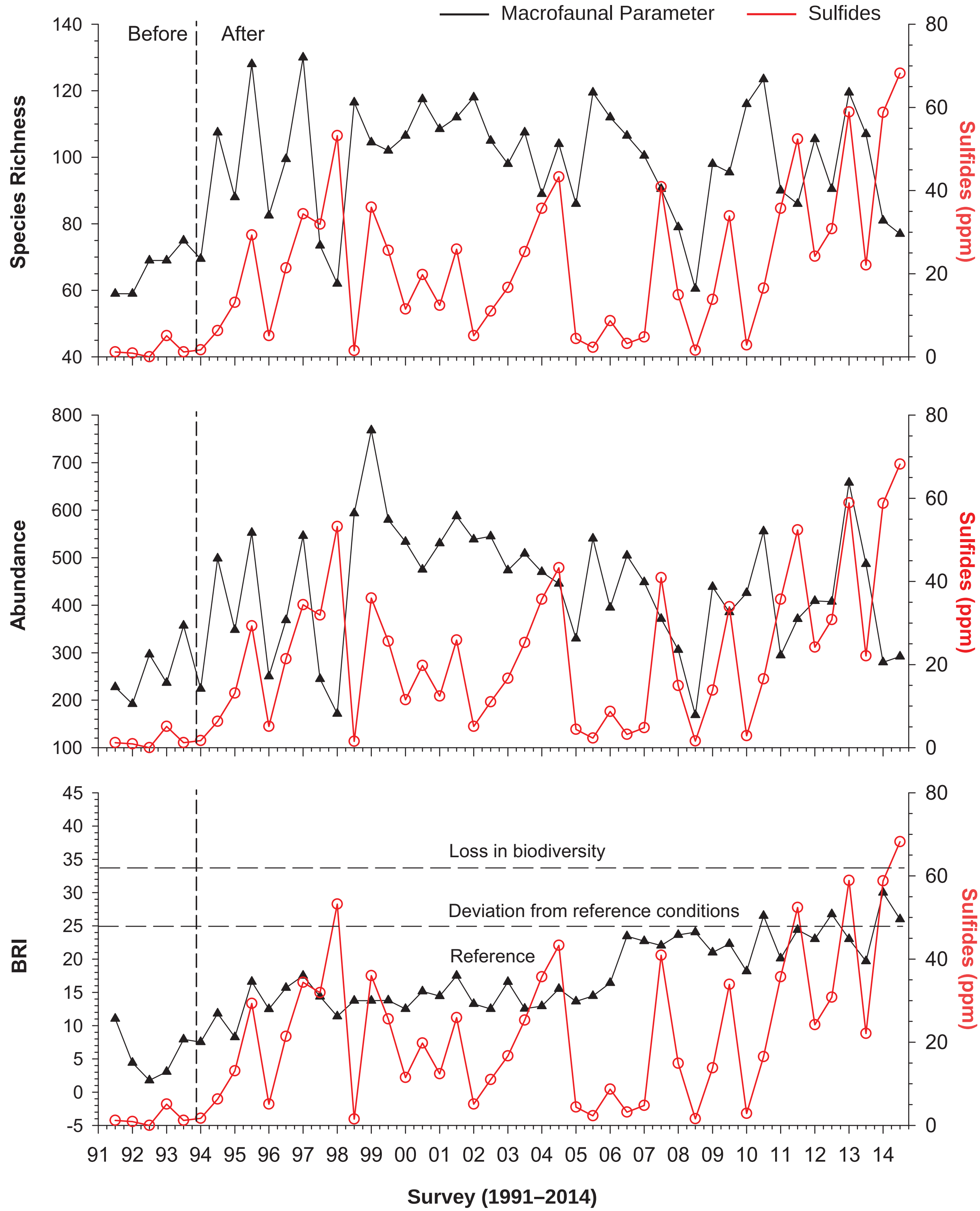
Macrofaunal community parameters by grab for PLOO benthic stations sampled during 2014. SR=species richness; Abun=abundance; H'=Shannon diversity index; J'=evenness; Dom=Swartz dominance; BRI=benthic response index. Stations are listed north to south from top to bottom for each depth contour.

Depth Contour	Station	Survey	SR	Abun	H'	J'	Dom	BRI
88-m	B11	winter	91	230	4.0	0.89	37	11
		summer	122	278	4.4	0.91	53	12
	B8	winter	72	215	3.5	0.83	28	9
		summer	59	179	3.1	0.77	20	11
	E19	winter	98	386	3.8	0.82	30	12
		summer	70	294	3.3	0.78	19	12
	E7	winter	79	364	3.6	0.81	23	12
		summer	91	253	4.0	0.88	37	16
	E1	winter	81	346	3.4	0.78	24	14
		summer	81	326	3.4	0.78	23	10
98-m	B12	winter	92	250	4.0	0.90	39	15
		summer	98	280	4.1	0.90	40	16
	B9	winter	84	232	3.9	0.87	33	10
		summer	82	221	3.9	0.88	32	13
	E26	winter	71	202	3.6	0.84	26	11
		summer	67	186	3.6	0.85	30	10
	E25	winter	74	256	3.6	0.83	24	14
		summer	80	300	3.7	0.85	28	11
	E23	winter	81	308	3.6	0.83	25	17
		summer	86	263	3.7	0.84	30	13
	E20	winter	81	407	3.7	0.84	22	17
		summer	73	258	3.5	0.83	22	12
	E17[a]	winter	83	399	3.7	0.83	23	18
		summer	75	251	3.6	0.83	24	17
	E14[a]	winter	81	280	3.7	0.85	25	30
		summer	77	292	3.5	0.82	22	26
	E11[a]	winter	95	410	3.8	0.84	28	17
		summer	92	404	3.8	0.84	26	16
	E8	winter	86	309	3.8	0.86	31	13
		summer	92	316	3.9	0.86	32	16
	E5	winter	93	366	3.8	0.84	27	15
		summer	72	228	3.6	0.85	26	13
	E2	winter	105	330	4.1	0.89	41	15
		summer	77	210	3.7	0.86	29	11
116-m	B10	winter	111	377	4.0	0.86	37	14
		summer	99	288	4.1	0.90	40	14
	E21	winter	76	294	3.5	0.82	20	13
		summer	74	246	3.7	0.86	25	13

[a] near-ZID stations

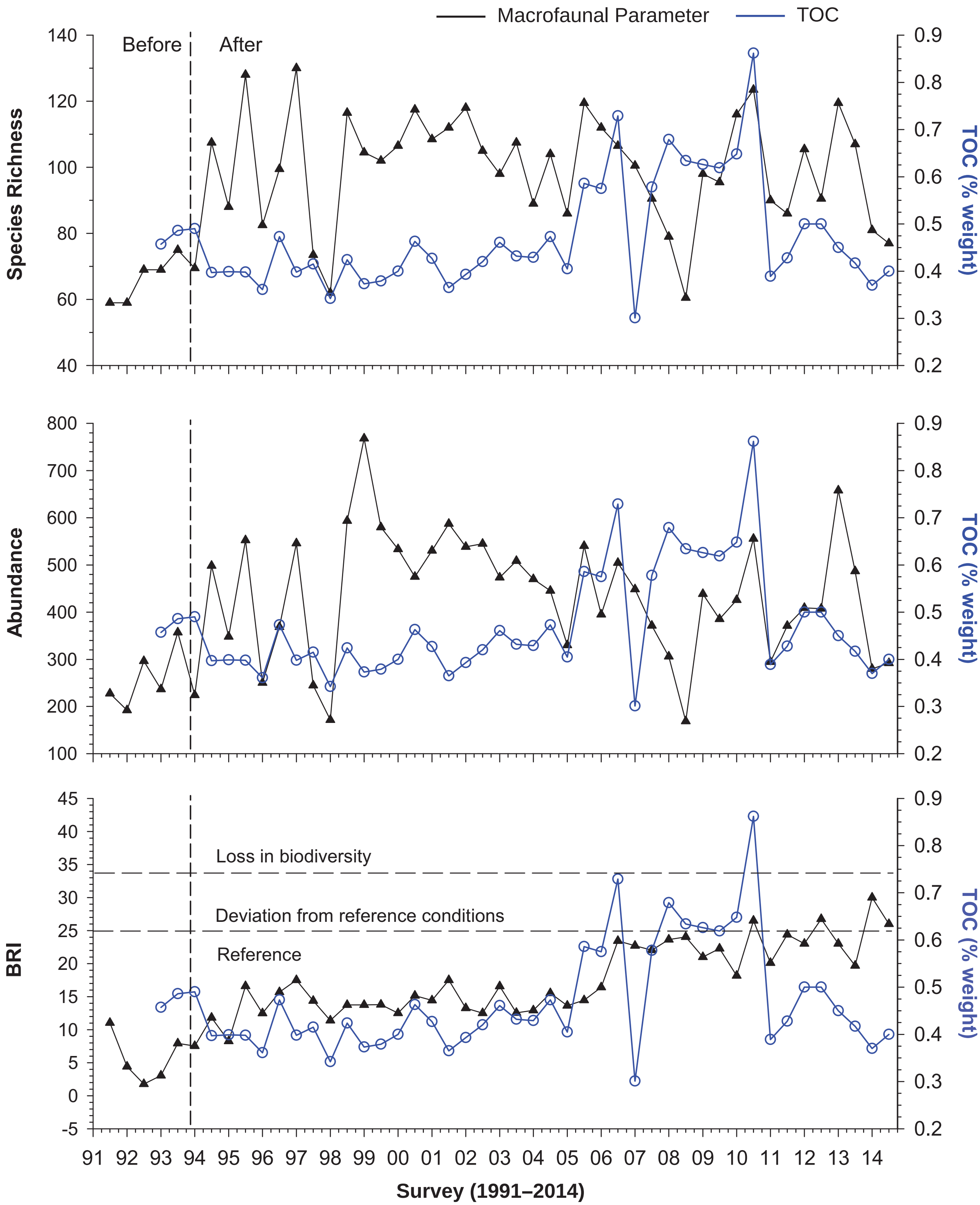
Appendix D.1 *continued*

Depth Contour	Station	Survey	SR	Abun	H'	J'	Dom	BRI
116-m	E15	winter	84	253	3.8	0.85	32	10
		summer	90	373	3.8	0.84	29	10
	E9	winter	88	221	4.1	0.91	37	16
		summer	98	287	4.2	0.91	39	11
	E3	winter	131	398	4.3	0.87	47	10
		summer	91	214	4.2	0.92	40	6

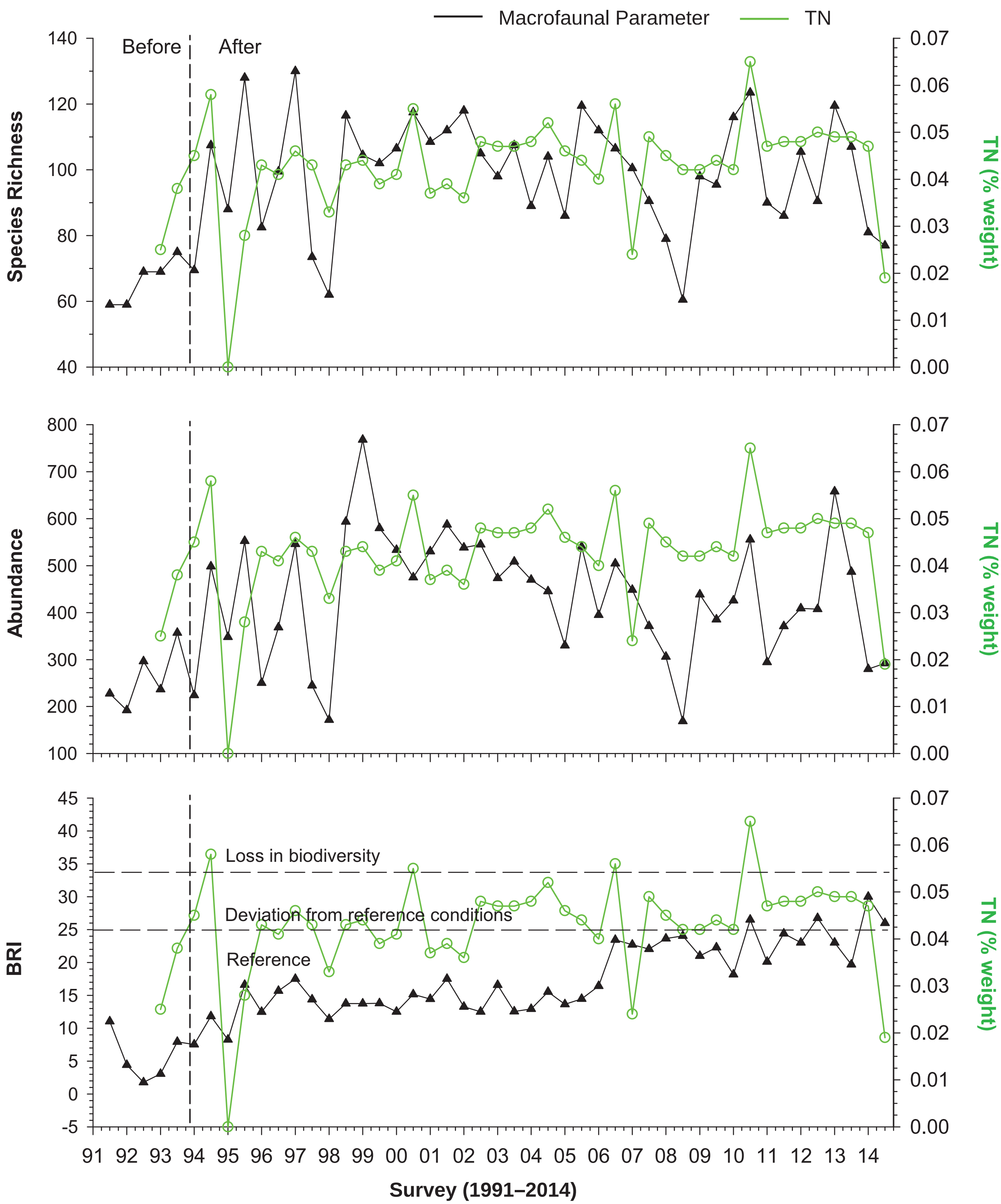


Appendix D.2

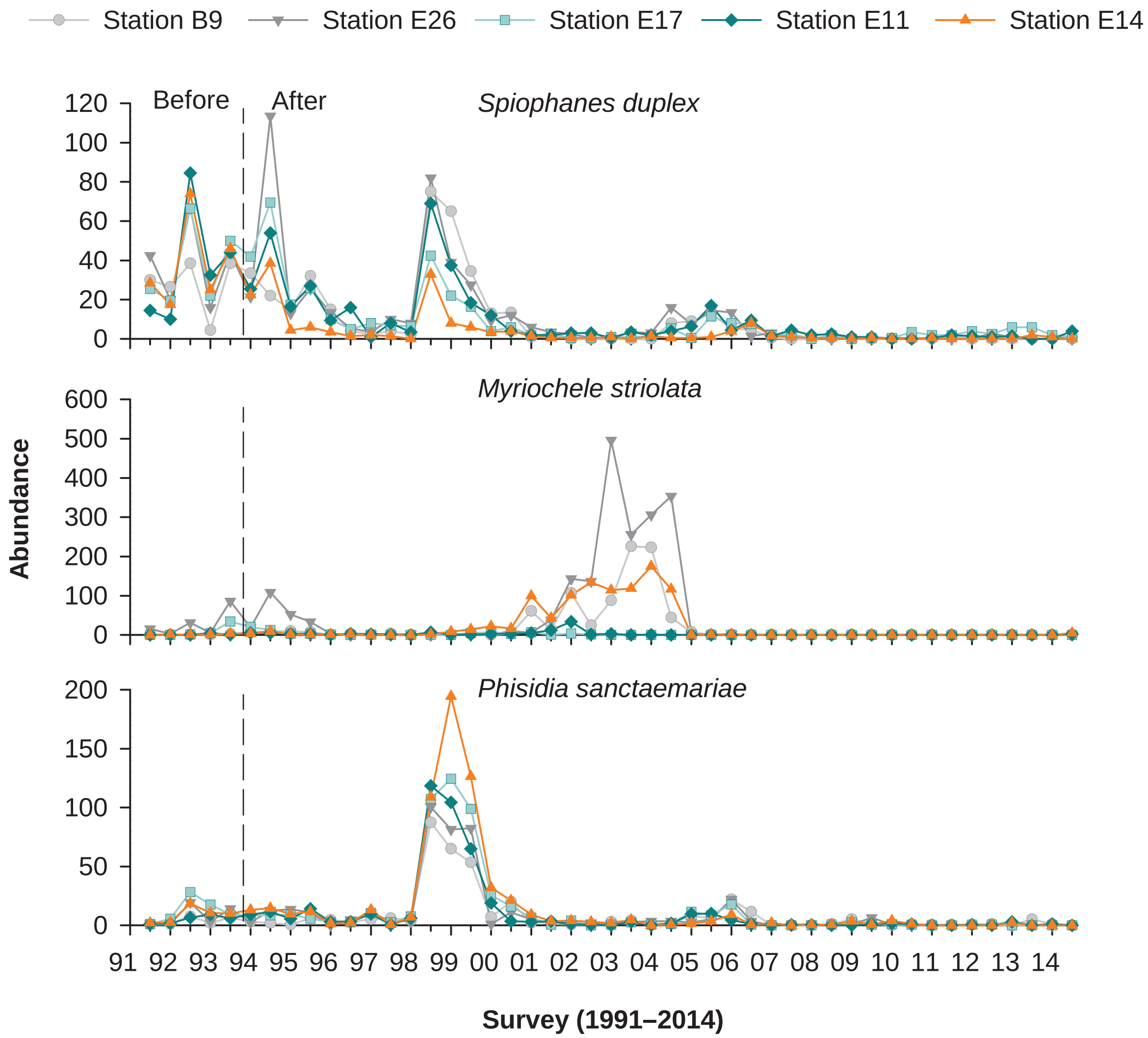
Comparison of community parameters and various organic indicators at near-ZID station E14 from 1991 through 2014. Organic indicators include: sulfides, total nitrogen (TN), and total organic carbon (TOC). Parameters include: species richness, infaunal abundance and benthic response index (BRI). Data for community parameters are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.



Appendix D.2 *continued*



Appendix D.2 *continued*



Appendix D.3

Three of the five historically most abundant species recorded from 1991 through 2014 at PLOO near-ZID stations E11, E14, and E17 and farfield stations E26 and B9. *Amphiodia urtica* and *Proclea* sp A are shown in Figures 5.3 and 5.4. Data for each station are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.

Appendix D.4

Mean abundance of the characteristic species found in each cluster group A–F (defined in Figure 5.5). Highlighted/bold values indicate taxa that account for up to 45% of intra-group similarity according to SIMPER analysis; the top five most characteristic species are boxed.

Taxa	Cluster Group A	B	C	D	E	F[a]
Amphiodia urtica	<1	**2**	1	**20**	**36**	**56**
Euphilomedes producta	**7**	**5**	**8**	0	**23**	4
Euphilomedes carcharodonta	3	**4**	**40**	<1	**21**	2
Chloeia pinnata	**21**	**22**	**11**	**4**	**12**	0
Prionospio (Prionospio) jubata	**23**	**7**	**15**	7	**10**	0
Nuculana sp A	<1	**8**	**17**	**6**	**9**	2
Chaetozone hartmanae	4	**18**	6	**10**	**9**	0
Amphiodia sp	1	2	0	**11**	**7**	**13**
Rhepoxynius bicuspidatus	0	1	1	0	**6**	5
Tellina carpenteri	**8**	**8**	**10**	3	**6**	0
Prionospio (Prionospio) dubia	4	**3**	1	**10**	**5**	2
Ennucula tenuis	**2**	**3**	6	**6**	**4**	1
Amphiodia digitata	**10**	**7**	0	<1	<1	0
Ampelisca brevisimulata	**9**	0	<1	<1	2	1
Ampelisca careyi	**7**	5	<1	2	3	4
Ampelisca pugetica	**7**	1	<1	**3**	2	0
Notomastus sp A	**7**	**3**	**22**	3	1	1
Leptosynapta sp	**6**	2	0	2	2	0
Clymenura gracilis	**5**	3	<1	**4**	2	2
Amphichondrius granulatus	**4**	<1	1	0	1	0
Exogone lourei	**4**	<1	0	2	0	0
Ampelisca hancocki	**3**	<1	0	4	1	0
Haliophasma geminatum	**2**	<1	0	1	<1	0
Axinopsida serricata	1	**4**	8	<1	4	2
Fauveliopsis sp SD1	0	**4**	0	0	0	0
Compressidens stearnsii	2	**3**	0	2	1	0
Pholoe glabra	2	**2**	1	2	2	2
Spiophanes berkeleyorum	<1	**2**	1	1	2	1
Kurtzina beta	0	**2**	2	1	4	1
Caecognathia crenulatifrons	1	**2**	2	1	2	2
Lumbrineris cruzensis	<1	<1	**14**	3	2	0
Solemya pervernicosa	0	0	**13**	0	<1	0
Aphelochaeta glandaria Cmplx	4	5	2	**2**	2	0
Leptochelia dubia Cmplx	2	2	1	**5**	2	0
Heterophoxus oculatus	0	<1	1	**3**	3	6
Amphiuridae	2	1	<1	**8**	4	**16**
Spiophanes duplex	0	<1	<1	**3**	<1	0
Adontorhina cyclia	0	3	0	**10**	1	1
Sthenelanella uniformis	<1	1	0	**2**	<1	1
Sternaspis affinis	2	4	<1	3	**3**	1

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

Appendix E

Supporting Data

2014 PLOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Taxonomic listing of demersal fish species captured during 2014 at PLOO trawl stations. Data are number of fish (n), biomass (BM, wet weight, kg), minimum (Min), maximum (Max), and mean length (standard length, cm). Taxonomic arrangement and scientific names are of Eschmeyer and Herald (1998) and Lawrence et al. (2013).

						Length	
Taxon/Species			Common name	n	BM	Min	Max	Mean
CARCHARHINIFORMES								
	Scyliorhinidae							
		Cephaloscyllium ventriosum	Swell Shark[a]	1	0.1	27	27	27
RAJIFORMES								
	Rajidae							
		Raja inornata	California Skate[a]	17	4.5	13	55	32
		Raja stellulata	Starry Skate[a]	1	0.3	38	38	38
ARGENTINIFORMES								
	Argentinidae							
		Argentina sialis	Pacific Argentine	4	0.1	5	7	6
AULOPIFORMES								
	Synodontidae							
		Synodus lucioceps	California Lizardfish	1756	20.9	7	30	12
OPHIDIIFORMES								
	Ophidiidae							
		Chilara taylori	Spotted Cusk-eel	5	0.5	10	17	14
BATRACHOIDIFORMES								
	Batrachoididae							
		Porichthys notatus	Plainfin Midshipman	53	1.6	9	19	14
GASTEROSTEIFORMES								
	Syngnathidae							
		Syngnathus californiensis	Kelp Pipefish	1	0.1	13	13	13
SCORPAENIFORMES								
	Scorpaenidae							
		Scorpaena guttata	California Scorpionfish	13	3.5	16	27	21
		Sebastes sp	Unidentified Rockfish	3	0.2	3	4	3
		Sebastes elongatus	Greenstriped Rockfish	3	0.2	5	6	6
		Sebastes goodei	Chilipepper	10	0.3	14	15	15
		Sebastes helvomaculatus	Rosethorn Rockfish	2	0.2	7	11	9
		Sebastes levis	Cowcod	2	0.1	7	8	8
		Sebastes rubrivinctus	Flag Rockfish	7	0.1	3	4	3
		Sebastes saxicola	Stripetail Rockfish	167	2.8	6	16	9
		Sebastes semicinctus	Halfbanded Rockfish	398	8.6	6	15	11
	Hexagrammidae							
		Zaniolepis frenata	Shortspine Combfish	102	2	9	18	13
		Zaniolepis latipinnis	Longspine Combfish	560	5.1	6	15	10
	Cottidae							
		Chitonotus pugetensis	Roughback Sculpin	3	0.2	10	12	11
		Icelinus fimbriatus	Fringed Sculpin	2	0.1	14	18	16
		Icelinus quadriseriatus	Yellowchin Sculpin	16	0.6	7	8	8
		Icelinus tenuis	Spotfin Sculpin	7	0.2	9	11	10
	Agonidae							
		Xeneretmus latifrons	Blacktip Poacher	1	0.1	13	13	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
PERCIFORMES								
	Embiotocidae							
		Zalembius rosaceus	Pink Seaperch	100	1.9	4	16	8
	Bathymasteridae							
		Rathbunella hypoplecta	Bluebanded Ronquil	1	0.1	10	10	10
	Zoarcidae							
		Lycodes pacificus	Blackbelly Eelpout	2	0.2	22	24	23
PLEURONECTIFORMES								
	Paralichthyidae							
		Citharichthys sordidus	Pacific Sanddab	1722	25.8	3	24	9
		Hippoglossina stomata	Bigmouth Sole	14	1.2	14	25	18
	Pleuronectidae							
		Lyopsetta exilis	Slender Sole	2	0.1	16	16	16
		Microstomus pacificus	Dover Sole	54	2	6	22	15
		Parophrys vetulus	English Sole	40	3.3	14	26	18
		Pleuronichthys decurrens	Curlfin Sole	1	0.1	13	13	13
		Pleuronichthys verticalis	Hornyhead Turbot	18	1.8	12	23	16
	Cynoglossidae							
		Symphurus atricaudus	California Tonguefish	21	0.7	13	20	16

Appendix E.2

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

	Winter 2014						
Species	SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
Pacific Sanddab	187	255	109	186	87	174	998
California Lizardfish	50	37	40	62	115	259	563
Longspine Combfish	16	5	69	61	101	207	459
Halfbanded Rockfish	300	12	9	12			333
Stripetail Rockfish	27		35	13	3	28	106
Pink Seaperch	72		2	5	2	1	82
Shortspine Combfish	15	18	8	8		5	54
Plainfin Midshipman	5	3	6	1	7	24	46
English Sole	8	2	10	3	8	6	37
California Tonguefish	9	5	2	1	1	1	19
Dover Sole		5	1	8	2	3	19
Yellowchin Sculpin	6	1	5		2	1	15
California Scorpionfish	2	1	8	2			13
Bigmouth Sole	4	1		3	2	2	12
Chilipepper	10						10
California Skate	3	1	1			2	7
Flag Rockfish					7		7
Hornyhead Turbot		2		1		4	7
Pacific Argentine	4						4
Greenstriped Rockfish	1	2					3
Roughback Sculpin	1	2					3
Slender Sole				2			2
Spotfin Sculpin	2						2
Kelp Pipefish		1					1
Rosethorn Rockfish	1						1
Starry Skate				1			1
Survey Total	723	353	305	369	337	717	2804

Appendix E.2 *continued*

Species	Summer 2014 SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
California Lizardfish	95	58	149	237	320	334	1193
Pacific Sanddab	126	89	211	85	82	131	724
Longspine Combfish	4	4	59	18	8	8	101
Halfbanded Rockfish		42	18		2	3	65
Stripetail Rockfish	1		41	1	2	16	61
Shortspine Combfish	12	17	7	6	2	4	48
Dover Sole	4	3	3	5	11	9	35
Pink Seaperch	7	1	4	4		2	18
Hornyhead Turbot	1		3	1	3	3	11
California Skate	2		2	5		1	10
Plainfin Midshipman	1	1	3	2			7
Spotfin Sculpin		5					5
Spotted Cusk-eel	1	1	1	1	1		5
English Sole			1	2			3
Unidentified Rockfish	2		1				3
Bigmouth Sole	1		1				2
Blackbelly Eelpout				1		1	2
California Tonguefish		2					2
Cowcod			2				2
Fringed Sculpin		2					2
Blacktip Poacher		1					1
Bluebanded Ronquil		1					1
Curlfin Sole	1						1
Rosethorn Rockfish						1	1
Swell Shark	1						1
Yellowchin Sculpin			1				1
Survey Total	259	227	507	368	431	513	2305
Annual Total	**982**	**580**	**812**	**737**	**768**	**1230**	**5109**

Appendix E.3

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

	Winter 2014						
Species	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Species Biomass by Survey**
Pacific Sanddab	2.0	3.0	2.3	1.8	1.2	1.5	11.8
California Lizardfish	0.7	0.8	0.7	0.8	1.6	3.8	8.4
Halfbanded Rockfish	6.7	0.1	0.1	0.2			7.1
Longspine Combfish	0.1	0.1	0.6	0.3	0.8	2.1	4.0
California Scorpionfish	0.6	0.1	2.3	0.5			3.5
English Sole	0.5	0.1	1.2	0.3	0.5	0.5	3.1
Stripetail Rockfish	0.8		0.3	0.2	0.1	0.4	1.8
Pink Seaperch	1.0		0.1	0.1	0.1	0.1	1.4
California Skate	0.2	0.1	0.4			0.6	1.3
Plainfin Midshipman	0.1	0.1	0.1	0.1	0.1	0.7	1.2
Bigmouth Sole	0.3	0.2		0.2	0.2	0.1	1.0
Shortspine Combfish	0.2	0.3	0.1	0.2		0.1	0.9
Hornyhead Turbot		0.1		0.1		0.5	0.7
California Tonguefish	0.1	0.1	0.1	0.1	0.1	0.1	0.6
Dover Sole		0.1	0.1	0.1	0.1	0.1	0.5
Yellowchin Sculpin	0.1	0.1	0.1		0.1	0.1	0.5
Chilipepper	0.3						0.3
Starry Skate				0.3			0.3
Greenstriped Rockfish	0.1	0.1					0.2
Roughback Sculpin	0.1	0.1					0.2
Flag Rockfish					0.1		0.1
Kelp Pipefish		0.1					0.1
Pacific Argentine	0.1						0.1
Rosethorn Rockfish	0.1						0.1
Slender Sole				0.1			0.1
Spotfin Sculpin	0.1						0.1
Survey Total	14.2	5.6	8.5	5.4	5.0	10.7	49.4

Appendix E.3 *continued*

Species	Summer 2014						Species Biomass by Survey
	SD7	SD8	SD10	SD12	SD13	SD14	
Pacific Sanddab	2.6	2.3	3.0	1.3	1.6	3.2	14.0
California Lizardfish	1.0	0.5	1.7	2.2	3.0	4.1	12.5
California Skate	0.2		1.0	1.9		0.1	3.2
Dover Sole	0.2	0.1	0.2	0.2	0.3	0.5	1.5
Halfbanded Rockfish		1.2	0.1		0.1	0.1	1.5
Hornyhead Turbot	0.1		0.1	0.1	0.4	0.4	1.1
Longspine Combfish	0.1	0.1	0.6	0.1	0.1	0.1	1.1
Shortspine Combfish	0.3	0.4	0.1	0.1	0.1	0.1	1.1
Stripetail Rockfish	0.1		0.5	0.1	0.1	0.2	1.0
Pink Seaperch	0.1	0.1	0.1	0.1		0.1	0.5
Spotted Cusk-eel	0.1	0.1	0.1	0.1	0.1		0.5
Plainfin Midshipman	0.1	0.1	0.1	0.1			0.4
Bigmouth Sole	0.1		0.1				0.2
Blackbelly Eelpout				0.1		0.1	0.2
English Sole			0.1	0.1			0.2
Unidentified Rockfish	0.1		0.1				0.2
Blacktip Poacher		0.1					0.1
Bluebanded Ronquil		0.1					0.1
California Tonguefish		0.1					0.1
Cowcod			0.1				0.1
Curlfin Sole	0.1						0.1
Fringed Sculpin		0.1					0.1
Rosethorn Rockfish						0.1	0.1
Spotfin Sculpin		0.1					0.1
Swell Shark	0.1						0.1
Yellowchin Sculpin			0.1				0.1
Survey Total	5.3	5.4	8.1	6.5	5.8	9.1	40.2
Annual Total	**19.5**	**11.0**	**16.6**	**11.9**	**10.8**	**19.8**	**89.6**

Appendix E.4

Pairwise r- and significance values for all year comparisons (Factor B) from the PLOO two-way crossed ANOSIM for demersal fish assemblages sampled from 1991 through 2014. Data are limited to summer surveys. Shading indicates significant difference (See Table 6.3).

		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1992	r-value	0.080																						
	sig-value	55.6																						
1993	r-value	0.833	0.750																					
	sig-value	3.7	3.7																					
1994	r-value	0.583	0.583	0.250																				
	sig-value	11.1	11.1	22.2																				
1995	r-value	0.167	0.083	0.250	0.417																			
	sig-value	44.4	55.6	14.8	14.8																			
1996	r-value	0.667	0.750	0.417	0.417	0.167																		
	sig-value	3.7	3.7	22.2	14.8	29.6																		
1997	r-value	0.667	0.167	0.500	0.417	0.167	0.167																	
	sig-value	7.4	37	3.7	14.8	29.6	25.9																	
1998	r-value	0.583	0.167	0.667	0.583	0.000	0.667	0.333																
	sig-value	7.4	22.2	3.7	3.7	59.3	3.7	25.9																
1999	r-value	0.833	0.833	1.000	0.833	0.667	0.917	0.500	1.000															
	sig-value	3.7	3.7	3.7	3.7	11.1	3.7	7.4	3.7															
2000	r-value	1.000	0.917	0.833	0.750	0.583	0.667	0.750	0.500	0.667														
	sig-value	3.7	3.7	3.7	3.7	11.1	3.7	3.7	7.4	7.4														
2001	r-value	1.000	0.750	0.917	1.000	0.667	1.000	0.500	0.500	1.000	0.667													
	sig-value	3.7	3.7	3.7	3.7	7.4	3.7	7.4	7.4	3.7	7.4													
2002	r-value	0.917	0.583	0.833	0.667	0.583	0.500	0.500	0.500	0.917	0.750	0.417												
	sig-value	3.7	7.4	3.7	3.7	7.4	11.1	11.1	3.7	3.7	7.4	14.8												
2003	r-value	0.917	0.833	0.833	0.667	0.750	0.500	0.667	0.750	1.000	0.583	0.750	0.583											
	sig-value	3.7	3.7	3.7	3.7	7.4	11.1	3.7	3.7	3.7	7.4	3.7	11.1											
2004	r-value	0.420	0.500	0.500	0.420	0.330	0.167	0.500	0.250	0.580	0.170	0.750	0.420	-0.250										
	sig-value	11.1	3.7	11.1	14.8	22.2	33.3	14.8	18.5	7.4	37	7.4	25.9	77.8										
2005	r-value	0.670	0.750	0.920	0.830	0.830	0.667	0.667	0.750	1.000	0.583	0.750	0.500	0.250	0.083									
	sig-value	11.1	7.4	3.7	3.7	3.7	7.4	7.4	3.7	3.7	14.8	3.7	11.1	22.2	44.4									
2006	r-value	0.917	0.917	1.000	0.833	0.917	1.000	0.833	0.750	1.000	0.833	0.917	0.750	0.417	0.167	0.250								
	sig-value	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	7.4	3.7	7.4	18.5	29.6	25.9								
2007	r-value	1.000	0.750	0.917	0.833	0.667	0.833	0.500	0.750	1.000	0.917	1.000	0.917	0.583	0.083	0.500	0.250							
	sig-value	3.7	3.7	3.7	3.7	7.4	7.4	11.1	3.7	3.7	3.7	3.7	3.7	11.1	55.6	14.8	29.6							
2008	r-value	1.000	1.000	1.000	1.000	1.000	1.000	0.500	0.500	1.000	1.000	1.000	0.750	0.500	0.000	1.000	0.000	0.500						
	sig-value	33.3	33.3	33.3	33.3	33.3	33.3	33.3	33.3	33.3	33.3	33.3	33.3	33.3	66.7	33.3	66.7	33.3						
2009	r-value	0.833	0.833	1.000	0.750	0.667	1.000	0.583	0.750	1.000	1.000	0.917	0.917	0.667	0.583	0.583	0.667	0.417	0.250					
	sig-value	3.7	3.7	3.7	3.7	7.4	3.7	7.4	3.7	3.7	3.7	3.7	3.7	11.1	14.8	7.4	3.7	7.4	66.7					
2010	r-value	1.000	0.833	1.000	0.833	0.917	0.833	0.833	0.833	1.000	0.917	0.917	0.917	0.833	0.417	0.583	0.583	0.833	1.000	0.583				
	sig-value	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	7.4	14.8	7.4	7.4	3.7	33.3	7.4				
2011	r-value	1.000	0.917	1.000	0.833	0.917	1.000	0.833	0.750	1.000	1.000	0.833	0.750	0.833	0.417	0.417	0.083	0.917	1.000	0.417	0.333			
	sig-value	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	7.4	3.7	22.2	11.1	44.4	3.7	33.3	7.4	25.9			
2012	r-value	1.000	0.917	1.000	0.833	1.000	1.000	0.833	0.750	1.000	1.000	0.833	0.917	0.917	0.583	1.000	0.583	0.833	1.000	0.167	0.500	0.083		
	sig-value	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	7.4	3.7	11.1	3.7	33.3	33.3	7.4	44.4		
2013	r-value	1.000	1.000	1.000	0.833	0.917	1.000	0.833	0.917	1.000	1.000	1.000	0.917	1.000	0.583	0.917	0.667	0.833	1.000	0.583	0.667	0.250	0.167	
	sig-value	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	11.1	3.7	7.4	3.7	33.3	3.7	7.4	25.9	37	
2014	r-value	1.000	0.917	1.000	0.833	1.000	1.000	0.833	0.917	1.000	1.000	0.917	1.000	1.000	0.833	1.000	1.000	0.917	1.000	0.500	0.583	0.833	0.583	0.833
	sig-value	3.7	3.7	3.7	7.4	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	33.3	11.1	11.1	7.4	11.1	7.4

Appendix E.5

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

Taxon/Species				n
SILICEA				
	Demospongiae			
		Suberitidae	*Suberites latus*	4
CNIDARIA				
	Anthozoa			
		Plexauridae	*Thesea* sp B	13
		Virgulariidae	*Acanthoptilum* sp	39
		Metridiidae	*Metridium farcimen*	2
MOLLUSCA				
	Polyplacophora			
		Ischnochitonidae	*Lepidozona* sp	1
	Gastropoda			
		Calliostomatidae	*Calliostoma turbinum*	1
		Naticidae	*Calinaticina oldroydii*	2
			Euspira draconis	1
		Fasciolariidae	*Barbarofusus barbarensis*	1
		Nassariidae	*Hinea insculpta*	2
		Muricidae	*Pteropurpura macroptera*	1
		Pseudomelatomidae	*Antiplanes catalinae*	1
			Megasurcula carpenteriana	1
		Cancellariidae	*Cancellaria crawfordiana*	1
		Philinidae	*Philine alba*	2
			Philine auriformis	1
		Pleurobranchidae	*Pleurobranchaea californica*	14
		Onchidorididae	*Acanthodoris brunnea*	12
		Tritoniidae	*Tritonia tetraquetra*	1
	Cephalopoda			
		Octopodidae	*Octopus rubescens*	17
ANNELIDA				
	Polychaeta			
		Polynoidae	*Arctonoe pulchra*	2
ARTHROPODA				
	Malocostraca			
		Squillidae	*Schmittius politus*	2
		Cymothoidae	*Elthusa vulgaris*	15
		Sicyoniidae	*Sicyonia ingentis*	6
		Pandalidae	*Pandalus danae*	2
		Diogenidae	*Paguristes bakeri*	1
			Paguristes turgidus	4
		Paguridae	*Enallopaguropsis guatemoci*	1
		Calappidae	*Platymera gaudichaudii*	1
		Inachidae	*Ericerodes hemphillii*	1
			Podochela lobifrons	2

Appendix E.5 *continued*

Taxon/Species				n
ECHINODERMATA				
	Crinoidea			
		Antedonidae	*Florometra serratissima*	101
	Asteroidea			
		Luidiidae	*Luidia asthenosoma*	10
			Luidia foliolata	43
		Astropectinidae	*Astropecten californicus*	19
		Asteriidae	Asteriidae	1
	Ophiuroidea			
		Ophiuridae	*Ophiura luetkenii*	4071
		Ophiactidae	*Ophiopholis bakeri*	2
		Ophiotricidae	*Ophiothrix spiculata*	18
	Echinoidea			
		Toxopneustidae	*Lytechinus pictus*	15362
		Strongylocentrotidae	*Strongylocentrotus fragilis*	526
		Spatangidae	*Spatangus californicus*	4
	Holothuroidea			
		Stichopodidae	*Parastichopus californicus*	27

Appendix E.6

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

	Winter 2014						
Species	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Species Abundance by Survey**
Lytechinus pictus	2315	2501	3913	31	370	123	9253
Ophiura luetkenii	50	36	3	3	95	1794	1981
Strongylocentrotus fragilis					66	96	162
Florometra serratissima	30	9					39
Luidia foliolata	2	7	13	9	1	1	33
Ophiothrix spiculata		17					17
Elthusa vulgaris	2	2		3	2	2	11
Parastichopus californicus	3	2	2	1	1	1	10
Astropecten californicus	4		2	2		1	9
Octopus rubescens	1	1		1	2	1	6
Acanthodoris brunnea			1	4			5
Luidia asthenosoma	2		3				5
Pleurobranchaea californica	1		2			2	5
Thesea sp B			4				4
Acanthoptilum sp			3				3
Arctonoe pulchra			2				2
Hinea insculpta	1			1			2
Pandalus danae	1	1					2
Sicyonia ingentis	1			1			2
Asteriidae					1		1
Cancellaria crawfordiana			1				1
Spatangus californicus		1					1
Tritonia tetraquetra	1						1
Survey Total	2414	2577	3949	56	538	2021	11,555

Appendix E.6 *continued*

Species	Summer 2014 SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
Lytechinus pictus	2081	2655	858	243	186	86	6109
Ophiura luetkenii	2070	4	4	5	5	2	2090
Strongylocentrotus fragilis					184	180	364
Florometra serratissima	60	2					62
Acanthoptilum sp	13	4	5	5	9		36
Parastichopus californicus	5	10	1		1		17
Octopus rubescens		3	2	1	3	2	11
Astropecten californicus	5	2	2		1		10
Luidia foliolata	1	2	3	1	1	2	10
Pleurobranchaea californica	1		3	1	1	3	9
Thesea sp B	4	2	3				9
Acanthodoris brunnea			1	6			7
Luidia asthenosoma	1	1	1	1	1		5
Elthusa vulgaris			3			1	4
Paguristes turgidus	2	1		1			4
Sicyonia ingentis	4						4
Suberites latus	2	1		1			4
Spatangus californicus		3					3
Calinaticina oldroydii				1		1	2
Metridium farcimen		1				1	2
Ophiopholis bakeri	2						2
Philine alba		2					2
Podochela lobifrons		2					2
Schmittius politus					2		2
Antiplanes catalinae				1			1
Barbarofusus barbarensis		1					1
Calliostoma turbinum	1						1
Enallopaguropsis guatemoci		1					1
Ericerodes hemphillii	1						1
Euspira draconis			1				1
Lepidozona sp		1					1
Megasurcula carpenteriana		1					1
Ophiothrix spiculata		1					1
Paguristes bakeri		1					1
Philine auriformis		1					1
Platymera gaudichaudii				1			1
Pteropurpura macroptera		1					1
Survey Total	4253	2703	887	268	394	278	8783
Annual Total	**6667**	**5280**	**4836**	**324**	**932**	**2299**	**20,338**

Appendix E.7

Pairwise r- and significance values for all year comparisons (Factor B) from the PLOO two-way crossed ANOSIM for megabenthic invertebrate assemblages sampled from 1991 through 2014. Data are limited to summer surveys. Shading indicates significant difference (See Table 6.7).

		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1992	r-value	0.333																						
	sig-value	3.7																						
1993	r-value	0.250	0.583																					
	sig-value	22.2	3.7																					
1994	r-value	0.667	0.583	0.333																				
	sig-value	3.7	3.7	11.1																				
1995	r-value	0.083	0.5	0.167	0.250																			
	sig-value	40.7	7.4	29.6	33.3																			
1996	r-value	0.667	0.667	0.667	-0.083	0.083																		
	sig-value	3.7	3.7	3.7	55.6	44.4																		
1997	r-value	0.667	0.667	0.333	0.417	0.000	0.167																	
	sig-value	11.1	7.4	22.2	11.1	51.9	29.6																	
1998	r-value	0.75	0.833	0.500	0.083	0.083	0.333	0.500																
	sig-value	7.4	3.7	14.8	48.1	40.7	18.5	3.7																
1999	r-value	0.667	0.667	0.583	0.500	0.417	0.667	0.750	0.083															
	sig-value	7.4	7.4	11.1	14.8	14.8	7.4	7.4	40.7															
2000	r-value	0.667	0.500	0.250	0.417	0.083	0.417	0.667	0.250	0.250														
	sig-value	11.1	7.4	33.3	7.4	66.7	14.8	7.4	22.2	22.2														
2001	r-value	0.333	0.167	0.083	0.250	-0.167	0.333	0.250	0.167	0.167	-0.333													
	sig-value	7.4	14.8	40.7	7.4	70.4	25.9	25.9	44.4	22.2	85.2													
2002	r-value	0.583	0.583	0.500	0.500	0.250	0.417	0.667	0.333	0.750	-0.083	-0.167												
	sig-value	7.4	3.7	7.4	14.8	22.2	18.5	7.4	18.5	7.4	55.6	77.8												
2003	r-value	0.667	0.667	0.083	0.333	0.333	0.250	0.250	0.083	0.333	0.000	-0.083	0.250											
	sig-value	7.4	7.4	44.4	22.2	18.5	22.2	25.9	40.7	14.8	55.6	63.0	25.9											
2004	r-value	0.167	0.417	0.000	0.167	-0.083	0.167	0.250	-0.083	0.250	-0.250	-0.250	0.000	-0.417										
	sig-value	22.2	18.5	66.7	40.7	77.8	44.4	22.2	70.4	22.2	81.5	77.8	44.4	92.6										
2005	r-value	0.333	0.25	0.167	0.417	0.000	0.417	0.583	0.083	0.5	-0.167	-0.25	-0.167	0.083	-0.167									
	sig-value	18.5	33.3	11.1	22.2	55.6	3.7	11.1	44.4	14.8	74.1	85.2	88.9	55.6	70.4									
2006	r-value	0.417	0.667	0.333	0.583	0.333	0.500	0.583	0.250	0.500	0.083	0.083	0.500	0.333	-0.083	-0.250								
	sig-value	14.8	3.7	11.1	7.4	22.2	7.4	11.1	25.9	3.7	44.4	48.1	11.1	18.5	63	85.2								
2007	r-value	0.25	0.667	0.250	0.500	0.417	0.333	0.667	0.250	0.333	-0.083	0.000	0.333	0.167	0.000	0.083	0.083							
	sig-value	25.9	3.7	11.1	11.1	11.1	18.5	3.7	33.3	22.2	77.8	59.3	14.8	33.3	59.3	44.4	44.4							
2008	r-value	0.500	0.000	-0.250	0.000	-0.250	0.000	0.000	0.000	-0.250	-0.500	-0.250	-0.500	-0.250	-0.250	-0.500	-0.250	-0.500						
	sig-value	33.3	100.0	100.0	66.7	66.7	66.7	66.7	66.7	66.7	100.0	66.7	100.0	66.7	66.7	100.0	66.7	100.0						
2009	r-value	0.667	0.833	0.583	0.250	0.167	0.417	0.333	0.333	0.583	0.417	-0.083	0.500	0.333	0.000	0.167	0.333	0.417	-0.500					
	sig-value	11.1	3.7	11.1	25.9	37.0	14.8	11.1	22.2	7.4	11.1	77.8	22.2	22.2	59.3	29.6	14.8	14.8	100.0					
2010	r-value	0.500	0.667	0.667	0.417	0.333	0.583	0.750	0.333	0.583	0.083	-0.250	0.417	0.167	0.000	-0.083	0.250	0.083	-0.500	0.250				
	sig-value	7.4	3.7	3.7	14.8	25.9	7.4	7.4	18.5	7.4	44.4	70.4	14.8	37.0	51.9	63.0	37.0	44.4	100.0	25.9				
2011	r-value	0.667	0.833	0.50	0.50	0.17	0.75	0.67	0.75	0.75	0.42	0.50	0.67	0.50	0.25	0.25	0.75	0.67	-0.25	0.42	0.42			
	sig-value	7.4	3.7	11.1	14.8	55.6	7.4	7.4	7.4	7.4	7.4	14.8	11.1	7.4	22.2	29.6	3.7	7.4	66.7	11.1	11.1			
2012	r-value	0.75	0.833	0.583	0.500	0.250	0.667	0.583	0.667	0.833	0.667	0.583	0.500	0.583	0.417	0.250	0.500	0.583	-0.250	0.417	0.667	0.167		
	sig-value	3.7	3.7	3.7	14.8	25.9	11.1	7.4	11.1	7.4	11.1	7.4	11.1	3.7	7.4	14.8	7.4	7.4	100	11.1	3.7	55.6		
2013	r-value	0.5	0.667	0.417	0.417	0.25	0.583	0.833	0.500	0.583	0.500	0.417	0.500	0.417	0.250	0.250	0.583	0.417	-0.250	0.417	0.333	-0.250	0.000	
	sig-value	11.1	3.7	11.1	22.2	29.6	7.4	7.4	11.1	7.4	14.8	22.2	14.8	22.2	22.2	37.0	7.4	14.8	66.7	11.1	18.5	77.8	55.6	
2014	r-value	0.500	0.667	0.500	0.583	0.417	0.417	0.667	0.333	0.500	0.333	0.333	0.583	0.667	0.250	-0.250	0.333	0.250	0.000	0.333	0.417	0.333	0.583	0.000
	sig-value	11.1	3.7	3.7	3.7	11.1	3.7	3.7	33.3	14.8	11.1	3.7	7.4	11.1	11.1	92.6	11.1	18.5	66.7	14.8	11.1	22.2	7.4	55.6

Appendix F

Supporting Data

2014 PLOO Stations

Bioaccumulation of Contaminants in Fish Tissues

Appendix F.1

Lengths and weights of fishes used for each composite (Comp) tissue sample from PLOO trawl zones and rig fishing stations during 2014. Data are summarized as number of individuals (n), minimum, maximum, and mean values.

				Length (cm, size class)			Weight (g)		
Station	Comp	Species	n	Min	Max	Mean	Min	Max	Mean
Rig Fishing 1	1	Vermilion Rockfish	3	20	26	24	182	458	364
Rig Fishing 1	2	Vermilion Rockfish	3	18	19	19	157	175	166
Rig Fishing 1	3	Copper Rockfish	3	32	36	34	1010	1384	1138
Rig Fishing 2	1	Speckled Rockfish	3	23	28	26	251	564	442
Rig Fishing 2	2	Speckled Rockfish	3	24	31	28	272	633	478
Rig Fishing 2	3	Speckled Rockfish	3	23	28	26	280	541	420
Trawl Zone 1	1	Pacific sanddab	5	17	19	18	64	85	74
Trawl Zone 1	2	Pacific sanddab	3	17	20	19	68	118	100
Trawl Zone 1	3	Pacific sanddab	3	17	20	19	69	119	95
Trawl Zone 2	1	Pacific sanddab	7	13	21	16	36	148	63
Trawl Zone 2	2	Pacific sanddab	4	17	19	18	60	90	76
Trawl Zone 2	3	Pacific sanddab	5	16	18	17	54	81	68
Trawl Zone 3	1	Pacific sanddab	3	19	24	22	101	213	163
Trawl Zone 3	2	Pacific sanddab	3	20	21	20	123	160	135
Trawl Zone 3	3	Pacific sanddab	3	19	20	20	96	123	111
Trawl Zone 4	1	Pacific sanddab	8	13	17	15	31	71	51
Trawl Zone 4	2	Pacific sanddab	6	14	19	17	42	106	67
Trawl Zone 4	3	Pacific sanddab	4	16	21	19	57	153	104

Appendix F.2

Constituents and method detection limits (MDL) used for the analysis of liver and muscle tissues of fishes collected from the PLOO region during 2014.

Parameter	MDL Liver	MDL Muscle	Constituent	MDL Liver	MDL Muscle
Metals (ppm)					
Aluminum (Al)	1.2	1.2	Lead (Pb)	0.2	0.2
Antimony (Sb)	0.1	0.1	Manganese (Mn)	0.1	0.1
Arsenic (As)	0.12	0.12	Mercury (Hg)	0.002	0.002
Barium (Ba)	0.02	0.02	Nickel (Ni)	0.2	0.2
Beryllium (Be)	0.002	0.002	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.06	0.06	Silver (Ag)	0.05	0.05
Chromium (Cr)	0.1	0.1	Thallium (Tl)	0.1	0.1
Copper (Cu)	0.3	0.3	Tin (Sn)	0.2	0.2
Iron (Fe)	2.0	2.0	Zinc (Zn)	0.15	0.15
Chlorinated Pesticides (ppb)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	17.4	1.74	HCH, Delta isomer	6.32	0.63
HCH, Beta isomer	10.3	1.03	HCH, Gamma isomer	50.40	5.04
Total Chlordane					
Alpha (cis) chlordane	2.02	0.2	Heptachlor epoxide	3.79	0.38
Cis nonachlor	1.91	0.19	Methoxychlor	12.1	1.21
Gamma (trans) chlordane	3.07	0.31	Oxychlordane	2.92	0.29
Heptachlor	2.1	0.21	Trans nonachlor	1.44	0.14
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	1.98	0.2	p,p-DDD	2.86	0.29
o,p-DDE	2.52	0.25	p,p-DDE	4.94	0.49
o,p-DDT	2.05	0.2	p,p-DDT	2.76	0.28
p,p-DDMU	1.82	0.18			
Miscellaneous Pesticides					
Aldrin	25.3	2.53	Endrin	30.3	3.03
Alpha endosulfan	24.7	2.47	Endrin aldehyde	10.20	1.02
Beta endosulfan	43.8	4.38	Hexachlorobenzene (HCB)	2.29	0.23
Dieldrin	12.6	1.26	Mirex	1.77	0.18
Endosulfan sulfate	58.3	5.83			

Appendix F.2 *continued*

Parameter	MDL Liver	MDL Muscle	Constituent	MDL Liver	MDL Muscle
Polychlorinated Biphenyl Congeners (PCBs) (ppb)					
PCB 18	1.49	0.15	PCB 126	1.93	0.19
PCB 28	1.47	0.15	PCB 128	2.28	0.23
PCB 37	2.03	0.20	PCB 138	1.93	0.19
PCB 44	1.88	0.19	PCB 149	1.92	0.19
PCB 49	1.67	0.17	PCB 151	1.52	0.15
PCB 52	1.66	0.17	PCB 153/168	3.76	0.38
PCB 66	1.86	0.19	PCB 156	2.33	0.23
PCB 70	2.05	0.20	PCB 157	2.77	0.28
PCB 74	2.11	0.21	PCB 158	2.55	0.26
PCB 77	3.32	0.33	PCB 167	2.05	0.21
PCB 81	1.91	0.19	PCB 169	1.41	0.14
PCB 87	1.95	0.19	PCB 170	2.16	0.22
PCB 99	1.54	0.15	PCB 177	1.96	0.20
PCB 101	1.70	0.17	PCB 180	2.89	0.29
PCB 105	2.28	0.23	PCB 183	2.06	0.21
PCB 110	2.13	0.21	PCB 187	2.25	0.23
PCB 114	2.77	0.28	PCB 189	1.78	0.18
PCB 118	2.56	0.26	PCB 194	3.41	0.34
PCB 119	2.72	0.27	PCB 201	2.76	0.28
PCB 123	3.04	0.30	PCB 206	1.84	0.18

Appendix F.3

Summary of constituents that make up total DDT and total PCB in composite (Comp) tissue samples from the PLOO region during 2014. RF = rig fishing; TZ = trawl zone.

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
RF1	1	Vermilion Rockfish	Muscle	DDT	p,p-DDE	0.6	ppb
RF1	3	Copper Rockfish	Muscle	DDT	p,p-DDE	1.3	ppb
RF2	1	Speckled Rockfish	Muscle	DDT	p,p-DDE	0.5	ppb
RF2	3	Speckled Rockfish	Muscle	DDT	p,p-DDE	0.5	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 101	13.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 105	7.4	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 110	12.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 118	28.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 128	7.4	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 138	37.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 149	7.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 151	6.2	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 153/168	64.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 156	3.7	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 158	3.4	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 167	2.2	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 170	12.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 180	27.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 183	7.9	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 187	25.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 194	6.8	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 201	7.5	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 206	5.2	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 49	3.3	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 52	4.1	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 66	3.5	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 70	3.1	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 74	2.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 99	26.0	ppb
TZ1	1	Pacific Sanddab	Liver	DDT	o,p-DDE	4.5	ppb
TZ1	1	Pacific Sanddab	Liver	DDT	p,p-DDMU	16.0	ppb
TZ1	1	Pacific Sanddab	Liver	DDT	p,p-DDE	280.0	ppb
TZ1	1	Pacific Sanddab	Liver	DDT	p,p-DDT	5.9	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 101	6.4	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 110	5.4	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 118	13.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 128	2.9	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 138	17.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 149	4.6	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 151	4.3	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 153/168	28.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 158	1.3	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 170	3.5	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 180	9.3	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 183	3.1	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 187	10.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 194	2.4	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 49	2.1	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 66	2.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 70	1.8	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 74	1.2	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 99	9.9	ppb
TZ1	2	Pacific Sanddab	Liver	DDT	o,p-DDE	2.3	ppb
TZ1	2	Pacific Sanddab	Liver	DDT	p,p-DDMU	9.3	ppb
TZ1	2	Pacific Sanddab	Liver	DDT	p,p-DDE	180.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 101	92.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 105	21.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 110	57.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 118	130.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 119	7.1	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 123	9.5	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 128	24.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 138	110.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 149	29.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 151	14.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 153/168	210.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 156	11.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 157	2.7	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 158	14.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 167	7.6	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 170	17.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 18	8.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 180	38.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 183	11.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 187	30.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 194	7.2	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 201	6.9	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 28	4.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 49	64.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 52	98.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 66	20.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 70	13.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 74	7.5	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 87	11.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 99	150.0	ppb
TZ1	3	Pacific Sanddab	Liver	DDT	o,p-DDE	3.5	ppb
TZ1	3	Pacific Sanddab	Liver	DDT	p,p-DDMU	12.0	ppb
TZ1	3	Pacific Sanddab	Liver	DDT	p,p-DDE	310.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 101	6.9	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 105	2.2	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 110	4.5	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 118	9.9	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 128	2.8	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 138	12.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 149	3.7	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 151	2.3	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 153/168	25.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 156	1.6	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 170	3.5	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 180	9.2	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 183	3.3	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 187	8.9	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 194	2.9	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 201	3.2	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 49	1.9	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 66	2.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 70	1.7	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 74	1.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 99	7.8	ppb
TZ2	1	Pacific Sanddab	Liver	DDT	o,p-DDE	3.3	ppb
TZ2	1	Pacific Sanddab	Liver	DDT	p,p-DDMU	13.0	ppb
TZ2	1	Pacific Sanddab	Liver	DDT	p,p-DDD	3.0	ppb
TZ2	1	Pacific Sanddab	Liver	DDT	p,p-DDE	200.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 101	7.1	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 105	2.8	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 110	5.4	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 118	11.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 128	3.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 138	16.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 149	4.1	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 151	2.7	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 153/168	28.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 158	1.4	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 170	3.9	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 180	13.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 183	3.5	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 187	12.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 194	3.8	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 201	4.5	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 206	3.5	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 28	1.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 49	2.3	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 66	2.1	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 70	1.8	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 74	1.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 99	8.5	ppb
TZ2	2	Pacific Sanddab	Liver	DDT	o,p-DDE	5.7	ppb
TZ2	2	Pacific Sanddab	Liver	DDT	p,p-DDMU	13.0	ppb
TZ2	2	Pacific Sanddab	Liver	DDT	p,p-DDD	2.8	ppb
TZ2	2	Pacific Sanddab	Liver	DDT	p,p-DDE	220.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 101	12.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 105	5.5	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 110	9.2	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 118	22.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 128	5.8	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 138	27.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 149	6.7	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 151	4.4	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 153/168	44.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 156	3.2	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 158	2.5	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 167	1.8	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 170	5.6	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 180	14.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 183	3.9	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 187	15.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 194	4.2	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 201	4.3	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 28	1.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 49	3.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 52	4.0	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 66	2.9	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 70	2.4	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 74	1.6	ppb
TZ2	3	Pacific Sanddab	Liver	PCB	PCB 99	18.0	ppb
TZ2	3	Pacific Sanddab	Liver	DDT	o,p-DDE	6.9	ppb
TZ2	3	Pacific Sanddab	Liver	DDT	p,p-DDMU	16.0	ppb
TZ2	3	Pacific Sanddab	Liver	DDT	p,p-DDD	3.9	ppb
TZ2	3	Pacific Sanddab	Liver	DDT	p,p-DDE	300.0	ppb
TZ2	3	Pacific Sanddab	Liver	DDT	p,p-DDT	3.5	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 101	6.3	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 110	4.2	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 118	9.0	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 138	9.5	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 149	3.6	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 153/168	19.0	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 180	6.2	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 183	1.8	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 187	8.1	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 49	2.4	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 66	1.9	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 70	1.6	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 74	1.0	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 99	6.0	ppb
TZ3	1	Pacific Sanddab	Liver	DDT	p,p-DDMU	8.8	ppb
TZ3	1	Pacific Sanddab	Liver	DDT	p,p-DDE	125.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 101	6.9	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 110	4.5	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 118	13.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 128	3.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 138	16.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 149	3.6	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 153/168	32.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 156	1.9	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 170	4.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 180	11.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 183	3.1	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 187	8.3	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 49	2.1	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 66	1.7	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 70	1.3	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 74	1.1	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 99	9.3	ppb
TZ3	2	Pacific Sanddab	Liver	DDT	p,p-DDMU	7.6	ppb
TZ3	2	Pacific Sanddab	Liver	DDT	p,p-DDD	3.1	ppb
TZ3	2	Pacific Sanddab	Liver	DDT	p,p-DDE	130.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 101	7.5	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 110	4.8	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 118	9.6	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 138	12.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 149	5.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 153/168	24.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 170	2.9	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 180	6.6	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 183	2.4	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 187	8.9	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 49	2.5	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 66	1.9	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 70	1.6	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 74	0.9	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 99	8.4	ppb
TZ3	3	Pacific Sanddab	Liver	DDT	p,p-DDMU	7.2	ppb
TZ3	3	Pacific Sanddab	Liver	DDT	p,p-DDE	150.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 101	9.3	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 110	5.9	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 118	13.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 138	15.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 149	4.9	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 153/168	32.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 170	4.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 180	8.3	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 183	2.8	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 187	9.5	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 49	3.2	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 66	2.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 70	1.6	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 74	1.1	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 99	12.0	ppb
TZ4	1	Pacific Sanddab	Liver	DDT	p,p-DDMU	11.0	ppb
TZ4	1	Pacific Sanddab	Liver	DDT	p,p-DDE	160.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 101	8.1	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 110	6.4	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 118	13.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 128	4.3	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 138	20.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 149	4.1	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 151	3.6	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 153/168	38.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 156	1.8	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 158	2.2	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 170	5.2	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 180	12.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 183	3.2	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 187	12.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 201	4.3	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 49	2.7	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 66	2.1	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 70	2.1	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 74	1.5	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 99	11.0	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	o,p-DDE	2.6	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	p,p-DDMU	12.0	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	p,p-DDD	3.7	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	p,p-DDE	200.0	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	p,p-DDT	3.8	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 101	7.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 110	6.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 118	8.6	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 138	11.5	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 149	4.3	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 151	3.3	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 153/168	21.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 158	1.8	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 170	3.4	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 180	8.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 183	2.8	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 187	8.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 28	2.1	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 49	2.9	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 52	3.6	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 66	3.2	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 70	3.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 74	2.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 99	8.3	ppb
TZ4	3	Pacific Sanddab	Liver	DDT	o,p-DDE	2.8	ppb
TZ4	3	Pacific Sanddab	Liver	DDT	p,p-DDMU	9.4	ppb
TZ4	3	Pacific Sanddab	Liver	DDT	p,p-DDD	5.2	ppb
TZ4	3	Pacific Sanddab	Liver	DDT	p,p-DDE	150.0	ppb
TZ4	3	Pacific Sanddab	Liver	DDT	p,p-DDT	6.8	ppb