THE CITY OF SAN DIEGO

Point Loma Ocean Outfall

Annual Receiving Waters Monitoring & Assessment Report

2013

City of San Diego Ocean Monitoring Program

Environmental Monitoring & Technical Services Division

Public Utilities Department

THE CITY OF SAN DIEGO

June 30, 2014

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 2013 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 2013, 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

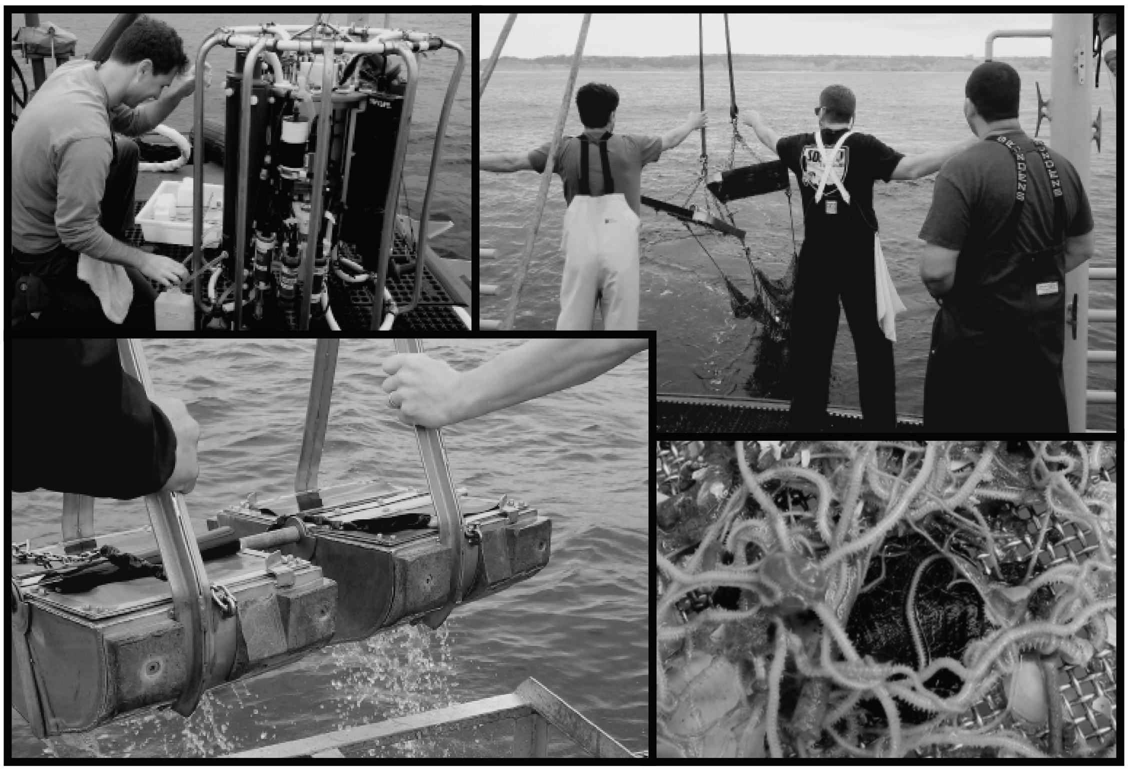
TDS/akl

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

Point Loma Ocean Outfall

Annual Receiving Waters Monitoring & Assessment Report, 2013

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



Prepared by:

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June 2014

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Examples of ocean sampling activities conducted for the Point Loma Ocean Outfall monitoring region. Activities are (clockwise from upper left): marine biologist collecting seawater samples from a Sea-Bird rosette sampler; marine biologists retrieving otter trawl net; retrieval of a double Van Veen benthic grab; benthic infauna (e.g., brittle stars) being sieved out on a mesh screen. Photos by P. Matson and N. Haring (top), and M. Nelson (bottom).

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Acronyms and Abbreviations

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

Acronyms and Abbreviations

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

Acronyms and Abbreviations

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

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Executive Summary

Executive Summary

The City of San Diego (City) conducts an extensive ocean monitoring program to evaluate potential environmental effects from the discharge of treated wastewater to the Pacific Ocean via the Point Loma Ocean Outfall (PLOO). The data collected are used to determine compliance with receiving water conditions as specified in the 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 southern San Diego's coastal waters in 2013 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 region-wide 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. These regional stations extend further offshore to waters as deep as 500 m and are used to evaluate patterns and trends over a broader geographic area. However, no such regional survey was conducted in 2013 due to a resource exchange agreement approved by the Regional Water Board and USEPA that allowed the City to devote these resources towards participation in the 2013 Southern California Bight Regional Monitoring Program (Bight'13). Data from Bight'13 are not yet available and are therefore not included herein. 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 2013 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 supports or conducts 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 coastal region, of which the 2013 results are incorporated into Chapters 2 and 3. A summary of the main findings for each of the above chapters is included below.

Coastal Oceanographic Conditions

Sea surface temperatures off Point Loma in 2013 were cooler than the long-term average during the winter (February), spring (May) and summer (August), while waters were warmer than normal during the fall (November). Ocean conditions indicative of local coastal upwelling were observed during February and May. As is typical for the Point Loma outfall region, maximum stratification (layering) of the water column occurred during mid-summer, while waters were more mixed during winter and fall. Water clarity (% transmissivity) during the year was within historical ranges for the region, with low values predominantly associated with turbid waters near the shore or kelp beds, re-suspension of bottom sediments due to waves or storm activity, or plankton blooms that occurred during May and August. Ocean currents 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 2013. Overall compliance with the Ocean Plan's single sample maximum and geometric mean standards for fecal indicator bacteria (FIB) was 99.9% for the shore, kelp bed and other offshore stations located within State waters in 2013. 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 2013. These results are consistent with satellite imagery observations, as well as findings from a recently completed 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 counts were detected at only three shore stations (5 samples) and at no kelp stations during the year. FIB densities were also low at all offshore stations during each quarterly survey, with only a single sample having an elevated *Enterococcus* count. This sample was collected at a depth of 80 m at station F30 located nearest the outfall discharge site. 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 CDOM (colored dissolved organic matter) values may be more useful detecting and tracking the plume. For example, waters with a CDOM-characteristic plume signature were detected about 21% of the time off Point Loma, with most detections occurring beyond State waters at depths below 40 m. Overall, the results from 2013 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 2013 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.

Sediment quality was similar in 2013 to previous years with overall contaminant loads off Point Loma being relatively low compared to other southern California coastal areas. Additionally, only a few contaminants (e.g., cadmium, silver, DDT) have ever exceeded their effects-range low (ERL) or effects-range median (ERM) sediment quality guidelines since monitoring began, and such exceedences have been rare. Although concentrations of the various organic loading indicators, trace metals, pesticides, PCBs and PAHs varied widely during 2013, there were no patterns that could be attributed to wastewater discharge or proximity to the outfall. 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 300 m of the discharge zone.

Macrobenthic Communities

Benthic macrofaunal communities surrounding the PLOO were similar in 2013 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 23 years ago. The polychaetes *Prionospio (Prionospio) jubata* and *Chaetozone hartmanae* were the most widespread benthic invertebrates. There have been some minor changes in macrofaunal assemblages located within ~300 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 diversity) 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 98% of the samples remained characteristic of undisturbed habitats. Only BRI values for a single grab collected at near-ZID station E14 indicated a possible minor deviation from reference conditions. 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 2013 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 sanddabs continued to dominate Point Loma fish assemblages, occurring at all stations and accounting for 57% of the year's catch. Other common species included bigmouth sole, California lizardfish, California skate, Dover sole, English sole, halfbanded rockfish, hornyhead turbot, longspine combfish, Pacific argentine, pink seaperch, plainfin midshipman, shortspine combfish, and stripetail rockfish. Trawl-caught invertebrate assemblages were dominated by the white sea urchin *Lytechinus pictus*, which also occurred in all trawls and accounted for 81% of all invertebrates captured. The brittle star *Ophiura luetkenii* was also collected in every haul, although in fairly low numbers at most sites. However, an unusually large number of *O. luetkenii* was collected at the southernmost trawl station during both winter and summer surveys. Other common, but far less abundant invertebrates included the crinoid *Florometra seserratissima*, the sea stars *Astropecten californicus* and *Luidia foliolata*, the sea cucumber *Parastichopus californicus*, the opisthobranch *Pleurobranchaea californica*, the cephalopod *Octopus rubescens*, and the shrimp *Sicyonia ingentis*. 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 2013. 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 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 2013 were consistent with previous years. Overall, there were few changes to local receiving waters, benthic sediments, and 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, NPDES Permit No. CA0107409. This Order was adopted by the San Diego Regional Water Quality Control Board (SDRWQCB) on June 10, 2009 and became effective August 1, 2010. 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. The main objectives of the monitoring program are to: 1) provide data that satisfy permit requirements, 2) demonstrate compliance with California Ocean Plan (Ocean Plan) provisions, 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 2013.

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 outfall presently 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 2013 was 144 million gallons per day (mgd), ranging from a low of 126 mgd in December to a high of about 187 mgd in January. Overall, this represents about a 3% decrease from the average flow rate in 2012. TSS removal averaged about 91% in 2013, while total mass emissions for the year were approximately 6770 metric tons (see City of San Diego 2014a).

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 are generally arranged in a grid surrounding the outfall and 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 2013 in support of these requirements can be found in City of San Diego (2014b). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the SDRWQCB and United States Environmental Protection Agency (USEPA) throughout the year are available 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 2012 are available in previous annual receiving waters monitoring reports (e.g., City of San Diego 2013a). 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, 2013b) 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, and Bight'08 programs in 1998, 2003, and 2008 respectively (Allen et al. 2002, 2007, 2011, Noblet et al. 2002, Ranasinghe et al. 2003, 2007, 2012, Schiff et al. 2006, 2011). During 2013, the City participated in the fifth SCB-wide survey (Bight'13 CIA 2013). These large-scale surveys are useful for characterizing the ecological health of diverse coastal areas and in distinguishing reference sites from those impacted by wastewater or stormwater discharges, urban runoff, or other sources of contamination.

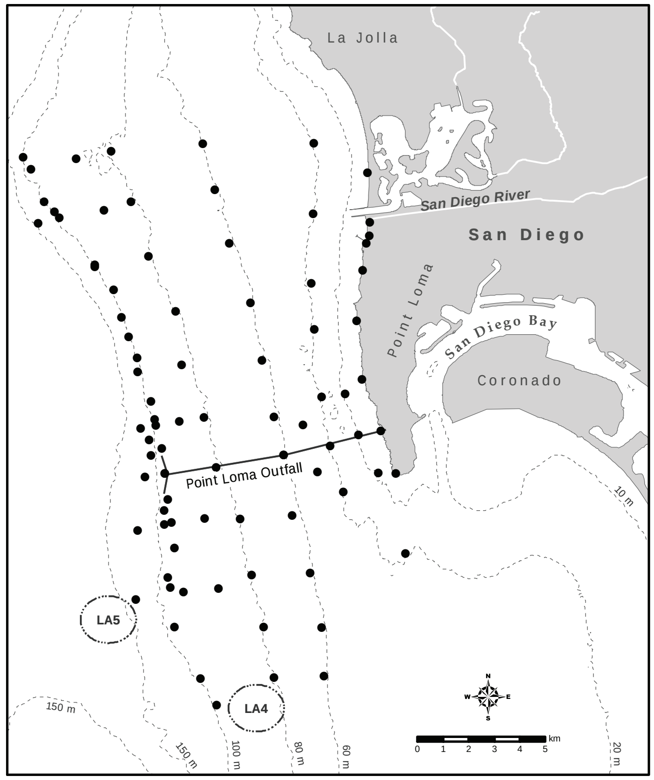

Figure 1.1
Receiving waters monitoring stations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

In addition to the above activities, the City provides staffing or funding support for several other projects relevant to assessing ocean quality in the region. One such project involves remote sensing (satellite imaging) of the San Diego/Tijuana coastal region, which is jointly funded by the City and the International Boundary and Water Commission, U.S. Section (Svejkovsky 2014). The City also funds a long-term study of the Point Loma and La Jolla kelp forests being conducted by scientists at the Scripps Institution of Oceanography (e.g., Parnell and Riser 2012), and 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 2013).

The current MRP also includes provisions for adaptive or special strategic process studies as determined by the City in conjunction with the SDRWQCB and USEPA. The first of these studies was a comprehensive review of the Point Loma ocean monitoring program conducted by a team of scientists from the Scripps Institution of Oceanography and several other institutions (Scripps Institution of Oceanography 2004). This was followed by the first phase of a large-scale sediment mapping study of the Point Loma and South Bay coastal regions that began in the summer of 2004 (Stebbins et al. 2004), as well as a pilot study of deeper continental slope benthic habitats off San Diego that occurred in 2005 (Stebbins and Parnell 2005). Sampling for a second phase of the sediment mapping study was conducted during the summer of 2012 (Stebbins et al. 2012), and a final project report is expected to be completed by late 2014. The deep benthic pilot study was subsequently expanded into a multi-year deep benthic habitat assessment project for the San Diego region; significant additional sampling for this project was conducted during July–August 2013 as part of the Bight'13 regional monitoring program. Another ongoing project involves annual sampling at the recovery stations mentioned above and in City of San Diego (1998) as part of a long-term assessment project of benthic conditions near the original outfall discharge site. Finally, a major project completed during 2012 was a special study designed to determine the characteristic fates of the PLOO wastewater plume in the coastal waters off Point Loma. This study involved a combination of observational and modeling approaches. The observational component involved using moored oceanographic instrumentation (e.g., current meters, temperature loggers) in order to characterize the current and temperature structure of the marine receiving waters on the Point Loma shelf and to support the use of an autonomous underwater vehicle (AUV) equipped with sensors capable of detecting the wastewater plume. The modeling component consisted of predicting plume rise height in the near field and post-hoc validation with AUV based records of plume dilution. The results of this plume behavior study are incorporated into discussions of plume detection and dispersion in Chapters 2 and 3 of this report, while full details of the study's conclusions and recommendations are available in Rogowski et al. (2012a, b, 2013).

This report presents the results of all regular core receiving waters monitoring activities conducted off Point Loma from January through December 2013. 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 2014), (2) the California Current System coupled with local gyres that transport distinct water masses into and out of the SCB (Lynn and Simpson 1987), and (3) seasonal changes in local weather patterns (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Seasonality is responsible for the main stratification patterns observed in the coastal waters off San Diego and the rest of southern California (Terrill et al. 2009, 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 with greater mixing and weaker stratification characterize ocean conditions during the wet season from October to April (City of San Diego 2011a, 2012a, 2013a). 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 changing 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 nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009, Svejkovsky 2010, 2011).

This chapter presents analyses and interpretations of the oceanographic monitoring data collected during

2013 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, and (3) evaluate local conditions off Point Loma in context with regional climate processes. Data from current meters and thermistor strings that were part of a multi-phase project to examine the dynamics and strength of the thermocline and ocean currents off Point Loma are included (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 2014). 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).

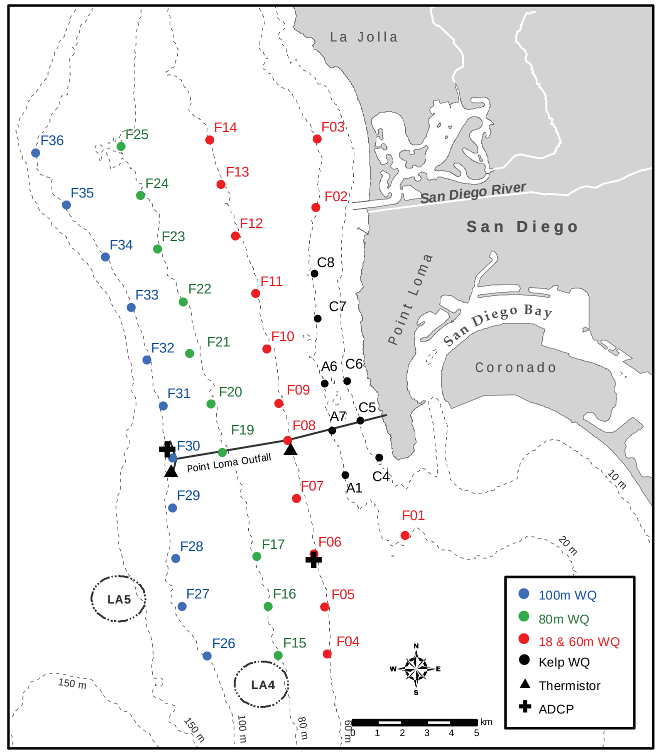

Figure 2.1

Locations of water quality (WQ) monitoring stations where CTD casts are taken and moored instruments are placed (i.e., ADCP, thermistor) 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 and 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) to correspond with similar sampling for the Central Bight Regional Water Quality Monitoring Program conducted off Orange County, Los Angeles County, and Ventura County (e.g., OCSD 2009). 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 1 day of the quarterly stations are analyzed in this chapter, such that all stations were sampled over a 4-day period (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

Table 2.1
Sample dates for quarterly oceanographic surveys conducted in the Point Loma outfall region during 2013. Each survey was conducted over four consecutive days with all stations in each station group sampled on a single day (see Figure 2.1 for stations and locations).

	2013 Sampling Dates			
Station Group	Feb	May	Aug	Nov
18 & 60 m WQ	13	15	27	13
80 m WQ	12	14	28	14
100 m WQ	11	13	29	15
Kelp WQ	10	16	26	12

chlorophyll *a* (a proxy for phytoplankton). Water column profiles of each parameter were constructed for each station by averaging the data values recorded within each 1-m depth bin. This data reduction ensured that physical measurements used in subsequent analyses would correspond to the discrete sampling depths required for fecal indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Moored Instrument Data Collection

Moored oceanographic instruments were deployed at three primary locations off Point Loma in order to provide nearly continuous measurements of ocean currents and water temperature for the area. These included one site near the present PLOO discharge zone at 100 m depth, one site located near the original outfall diffuser structure at 60 m depth, and one site located ~4.7 km south of the PLOO along the 60-m depth contour (Figure 2.1).

Ocean current data were collected during 2013 from seafloor mounted Teledyne RDI Acoustic Doppler Current Profilers (ADCP), including one ADCP placed at the 100-m site and one ADCP at the southern 60-m site. Deployment at the 60-m site in 2013 was only from January through November when the ADCP was retrieved prior to the end of the year. The ADCP data were recorded every five minutes and then averaged into depth bins of 4 m. For the 60-m ADCP, this resulted in 15 bins with midpoints ranging in depth from just below the surface to 55 m. For the 100-m ADCP, 25 bins were created with midpoints ranging in depth from just below the surface to 95 m. However, the top three bins from each instrument were excluded from all analyses due to surface backscatter interference. Additional details regarding ADCP data processing and analyses are presented below under 'Data Analysis.'

Temperature data were collected from a vertical series of temperature sensors (thermistors) every 10 minutes during 2013 from duplicate arrays located at the 100-m and 60-m sites. The thermistors (Onset Tidbit temperature loggers) were deployed on mooring lines at each site starting at 2 m above the seafloor and extending through the water column every 4 m to within 6 m of the surface. Additional details on the specific methodology for both thermistor and ADCP instrumentation are available in Storms et al. (2006).

Remote Sensing

Coastal monitoring of the Point Loma outfall region during 2013 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite imaging data acquired during the year were made available for review and download from OI's website (Ocean Imaging 2014), while a separate report summarizing results for the year was also produced (Svejkovsky 2014). 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 2013 were summarized as means for each quarter pooled over all stations by the following depth layers: 1–20 m, 21–60 m, 61–80 m, 81–100 m. 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.

Vertical density profiles were constructed to depict the pycnocline for each survey and to illustrate seasonal changes in water column stratification. Data 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 created to evaluate regional oceanographic events in context with larger scale processes (i.e., ENSO events). These analyses were 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 23 years combined (i.e., 1991–2013) from the monthly means for each year.

Summary statistics for seasonal ocean current data were generated for each depth bin and prevailing current modes were examined by empirical orthogonal function (EOF) analysis using singular value decomposition (Anderson et al. 1999). Since ocean currents in southern California typically vary seasonally (Winant and Bratkovich 1981), ADCP data were subset by season prior to subsequent analyses: winter (December–February); spring (March–May); summer (June–August); and fall (September–November). Although the winter season for 2013 included non-continuous months (i.e., January–February and December), preliminary analysis suggested that the current regimes for these three months were similar enough to justify pooling them together. In addition, since tidal currents are not likely to result in net transport, tides were removed prior to analyses using the PL33 filter (Alessi et al. 1984).

Results and Discussion

Oceanographic Conditions in 2013

Water Temperature and Density

Surface water temperature (1–20 m) across the Point Loma outfall region ranged from 10.7°C–20.3°C during 2013. Subsurface water temperatures ranged from 10.0 to 16.0°C at 21–60 m, 9.8 to 13.2°C at 61–80 m, and 9.5 to 12.7°C at 81–100 m (Appendix A.1). The maximum surface temperature recorded in August was ~2.1ºC lower than in 2012 (City of San Diego 2013a). Although these data were limited to only four surveys, ocean temperatures varied by season as expected (Figure 2.2). For example, some of the lowest average temperatures (<11ºC) occurred during May at depths below 20 m along the 60, 80, and 100-m depth contour; these cold waters may be indicative of spring upwelling. Thermal stratification also followed expected seasonal patterns, with the greatest differences between surface and bottom water temperatures occurring during May and August (9.9 and 9.8ºC, respectively). Continuous temperature data from the 60-m and 100-m thermistor arrays yielded similar results, indicating potential upwelling events from late February through August and confirming that the general thermal stratification patterns observed during the quarterly CTD surveys were representative of the overall spatial and temporal temperature patterns throughout the year (Figure 2.3). These data also demonstrated that seasonal patterns of water column mixing, as well as surface warming and cooling, were consistent between the 60-m and 100-m moorings.

In shallow coastal waters of southern California and elsewhere, density is influenced primarily by

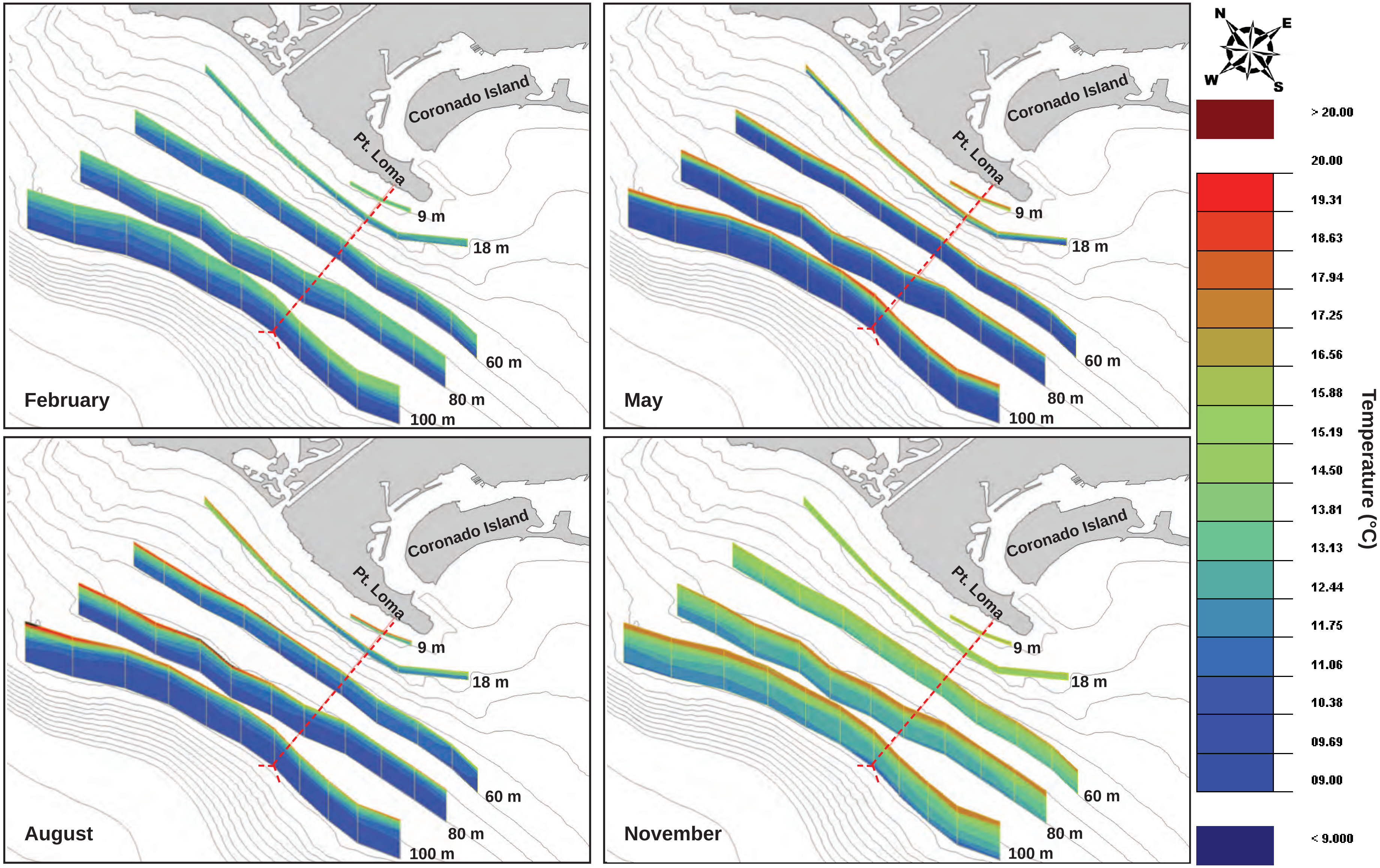

Figure 2.2
Ocean temperatures recorded in the PLOO region during 2013. Data were collected over four consecutive days during each survey.

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 highly stratified in May and August with a maximum BF of 101 and 121 cycles^2/min^2, repectively, to weakly stratified again in November with a maximum BF of 48 cycles^2/min^2. These results also illustrated how the depth of the pycnocline (i.e., depth layer where the density gradient was greatest) varied by season, with shallower pycnocline depths tending to correspond with greater stratification.

Salinity

Salinities recorded in 2013 were similar to those reported previously in the PLOO region (e.g., City of San Diego 2012a, 2013a). Surface salinities ranged from 33.35 to 33.73 psu at 1–20 m. Subsurface salinities ranged from 33.35 to 33.81 psu at 21–60 m, 33.38 to 33.92 psu at 61–80 m, and 33.38 to 34.03 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 and May at depths that corresponded with the lowest water temperatures for those surveys (Figures 2.2, 2.5). Taken together, low temperatures and high salinity may indicate local coastal upwelling that typically occurs during spring months (Jackson 1986) or may be due to divergent southerly flow in the lee of Point Loma (Roughan et al. 2005).

As in previous years, a layer of relatively low salinity water was evident at sub-surface depths at various stations in the PLOO region during the May, August, and November surveys in 2013 (Figure 2.5). This sub-surface 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 1999, 2009, City of San Diego 2011a, b, 2012a, b, 2013a, b, 2014). Finally, other potential indicators of wastewater, such as elevated levels of fecal indicator bacteria or colored dissolved organic matter (CDOM), do not correspond to the SSML (see Chapter 3). Further investigation is required to determine the possible source or sources of this phenomenon.

Dissolved Oxygen and pH

Overall, DO and pH levels were within historical ranges throughout the year for the Point Loma region (e.g., City of San Diego 2012a, 2013a). Surface DO ranged from 3.9 to 10.9 mg/L at 1–20 m. Subsurface DO ranged from 3.2 to 10.4 mg/L at 21–60 m, 3.1 to 7.1 mg/L at 61–80 m, and 2.8 to 6.4 mg/L at 81–100 m. Surface pH ranged from 7.7 to 8.4 at 1–20 m. Subsurface pH ranged from 7.7 to 8.3 at 21–60 m, and 7.7 to 8.0 at 61–80 m and 81–100 m. (Appendix A.1). Changes in pH and DO were closely linked since both parameters reflect fluctuations in dissolved carbon dioxide associated with biological activity in coastal waters (Skirrow 1975). Additionally, because these parameters varied similarly across all stations, there was no evidence to indicate that the monthly surveys were not synoptic even though sampling occurred over a 4-day period (e.g., Appendices A.2, A.3).

Changes in DO and pH followed expected patterns that corresponded to seasonal fluctuations in water column stratification and phytoplankton productivity. The greatest variation and maximum stratification occurred during May and August (Appendices A.2, A.3). Low values for DO and pH that occurred at depths below 20 m were likely due to upwelling of cold, saline, oxygen

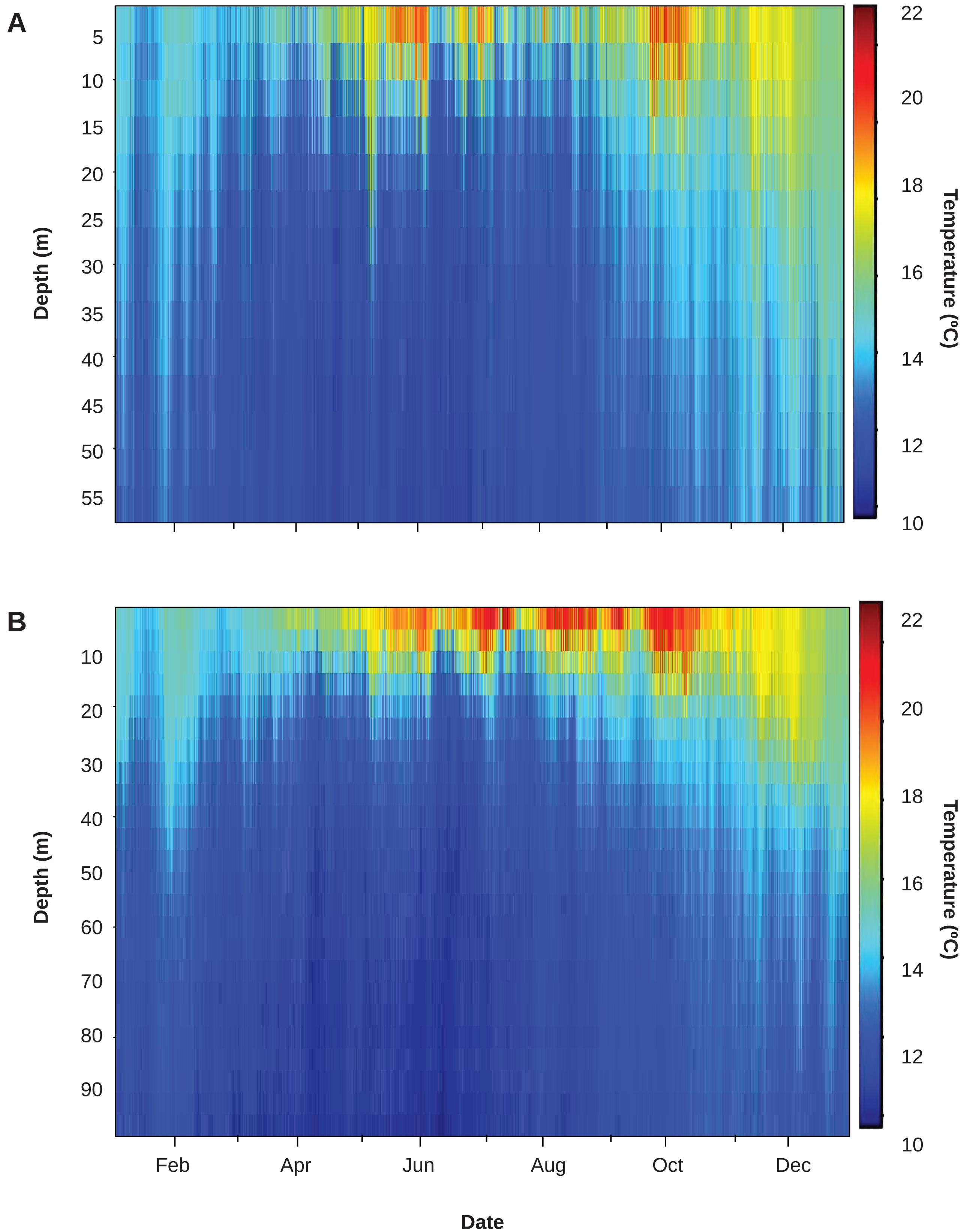

Figure 2.3

Temperature logger data collected at the (A) 60-m and (B) 100-m thermistor sites from January through December 2013. Data were collected every 10 minutes.

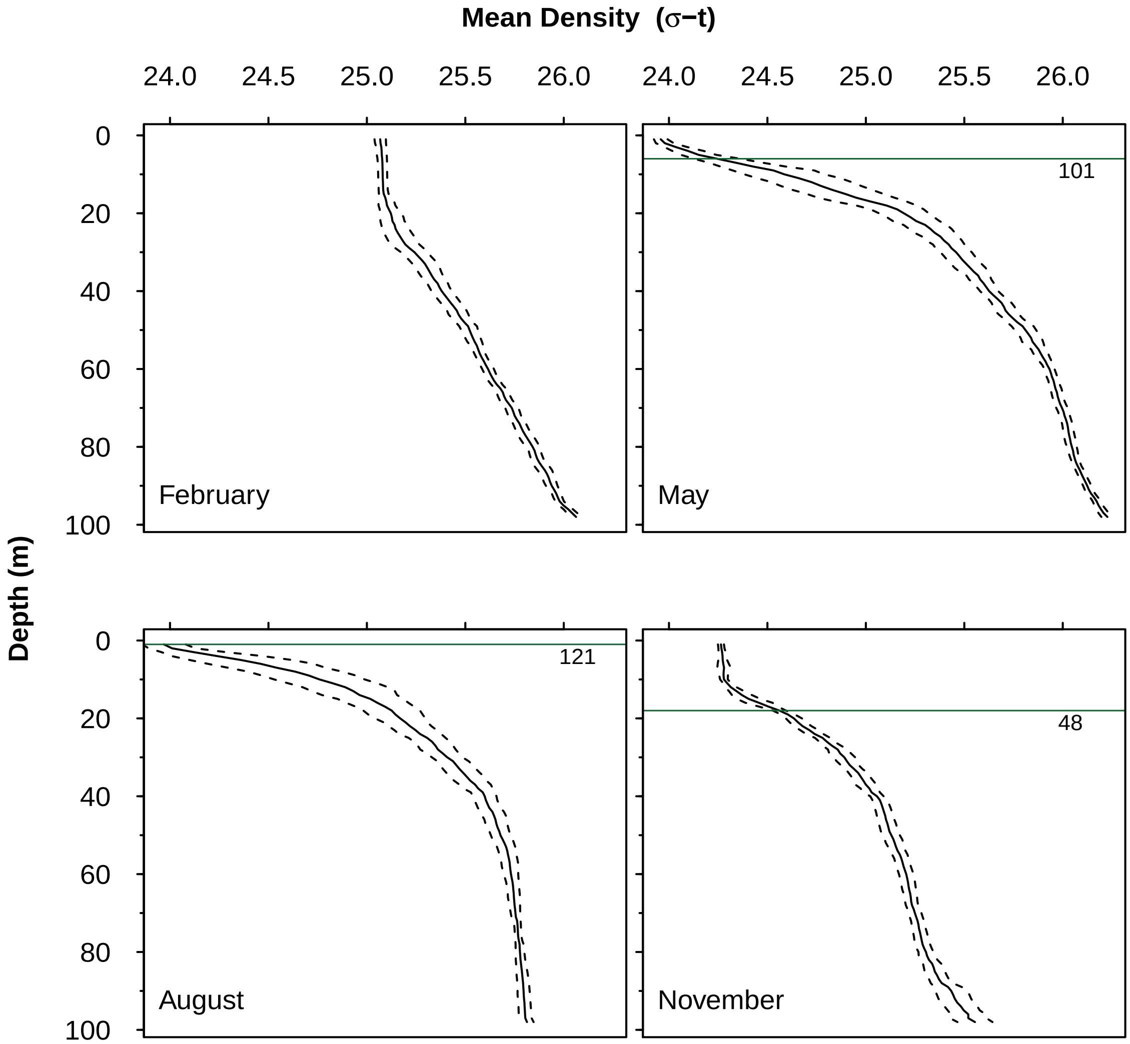

Figure 2.4
Density and maximum buoyancy frequency (BF) for each quarter at outfall depth stations sampled in the PLOO region during 2013. Solid lines are means, dotted lines are 95% confidence intervals (n=11). Horizontal lines indicate depth of maximum BF with the number indicating the value in cycles^2/min^2. BF values less than 32 cycles^2/min^2 indicate a well-mixed water column and are not shown.

poor water moving inshore as described above for temperature and salinity. Conversely, high DO concentrations in May and August were associated with phytoplankton blooms as evident by high chlorophyll *a* concentrations.

Transmissivity

Overall, maximum water clarity was ~6% lower in 2013 than in 2012 (City of San Diego 2013a). Surface transmissivity ranged from 48 to 90% at 1–20 m. Subsurface transmissivity ranged from 62 to 91% at 21–60 m, 76 to 91% at 61–80 m, and 69 to 91% at 81–100 m. (Appendix A.1). Transmissivity was low inside the kelp bed at 9-m stations during February, May, and November (Appendix A.4). Offshore from the kelp bed, reduced transmissivity at depths <30 m coincided with peaks in chlorophyll *a* concentrations associated with phytoplankton blooms during May and August (see following section and Appendices A.1, A.4, A.5). Low transmissivity recorded during winter months may also have been due to wave and storm activity and resultant increases in suspended sediments. For example, turbidity plumes originating from Mission Bay and San Diego Bay (Figure 2.6) coincided with reduced transmissivity (<80%) throughout the water column at the 18-m stations during November (Appendix A.4).

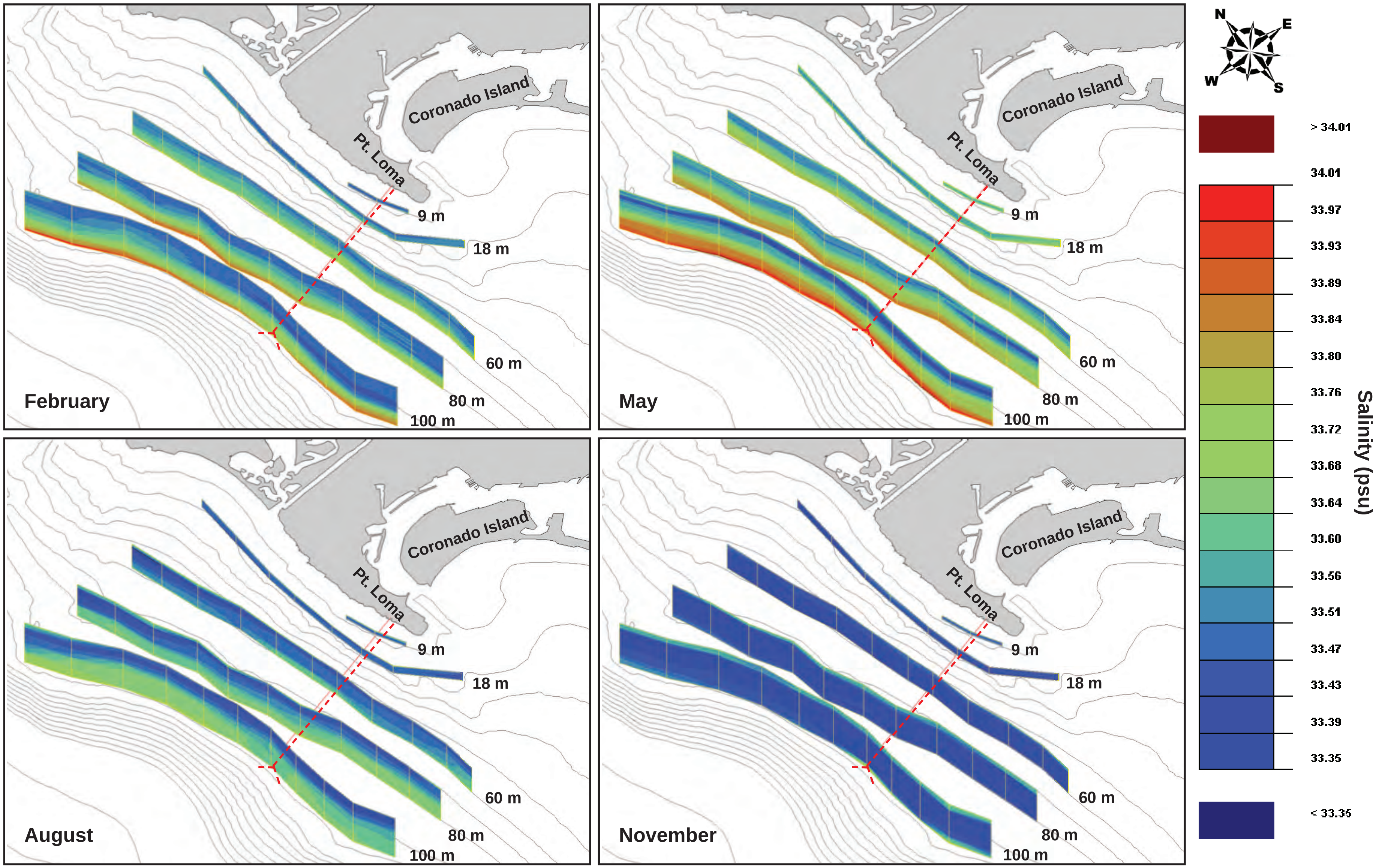

Figure 2.5
Ocean salinity recorded in the PLOO region during 2013. Data were collected over four consecutive days during each survey.

Figure 2.6
Rapid Eye image of the Point Loma region acquired November 13, 2013 (Ocean Imaging 2014) depicting turbidity plumes originating from Mission Bay, San Diego Bay, and other coastal sources.

***Chlorophyll* a**
Concentrations of chlorophyll *a* off Point Loma ranged from 0.2 µg/L to 41.5 µg/L during 2013 (Appendix A.1). Thin, patchy layers of high chlorophyll concentrations typically occurred at sub-surface depths during May and August (Appendix A.5). These results reflect the tendency for phytoplankton to accumulate along isopycnals where nutrient levels are high and light is not limiting (Lalli and Parsons 1993).

Summary of Ocean Currents in 2013

Current patterns varied by season, depth, and mooring location in the PLOO region during 2013 (Appendix A.6). The general axis of current flow across the water column at both the 60-m and 100-m ADCP sites, as indicated by the dominant current mode (EOF 1), was predominantly along a north-south axis with occasional flow along a northwest-southeast axis (Figure 2.7). This differs slightly from patterns observed in 2012 that alternated between northeast-southwest and north-south currents during the year but is generally comparable to those obtained during previous studies (e.g., Parnell and Rasmussen 2010, Rogowski et al. 2012a, b, 2013). Current direction differed by both depth and time (Figure 2.8A). At shallow depths (< 60 m), current flow oscillated between north and south throughout the year with southward flow being more common in May and August. At deeper depths (60–80 m), flow was predominantly to the north with much less oscillation, except during October when flow at this depth range went south. Current velocities at the 100-m ADCP site generally decreased with increasing depth (Figure 2.8B). In the upper 10–20 m depths, velocities varied seasonally, with higher velocities during the spring and late summer before decreasing during fall. At depths below 60 m, current velocities were generally slower, except for periods in late January and from late August through early September.

Historical Assessment of Oceanographic Conditions

A review of temperature, salinity, and DO data from all outfall depth stations sampled from 1991 through 2013 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, NOAA/NWS 2014). For example, six major events have affected SCB coastal waters during the last two decades: (1) the 1997–98 El Niño; (2) a shift to cold ocean conditions reflected in ENSO and PDO indices between 1999 and 2002; (3) a subtle but persistent return to warm ocean conditions in the 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

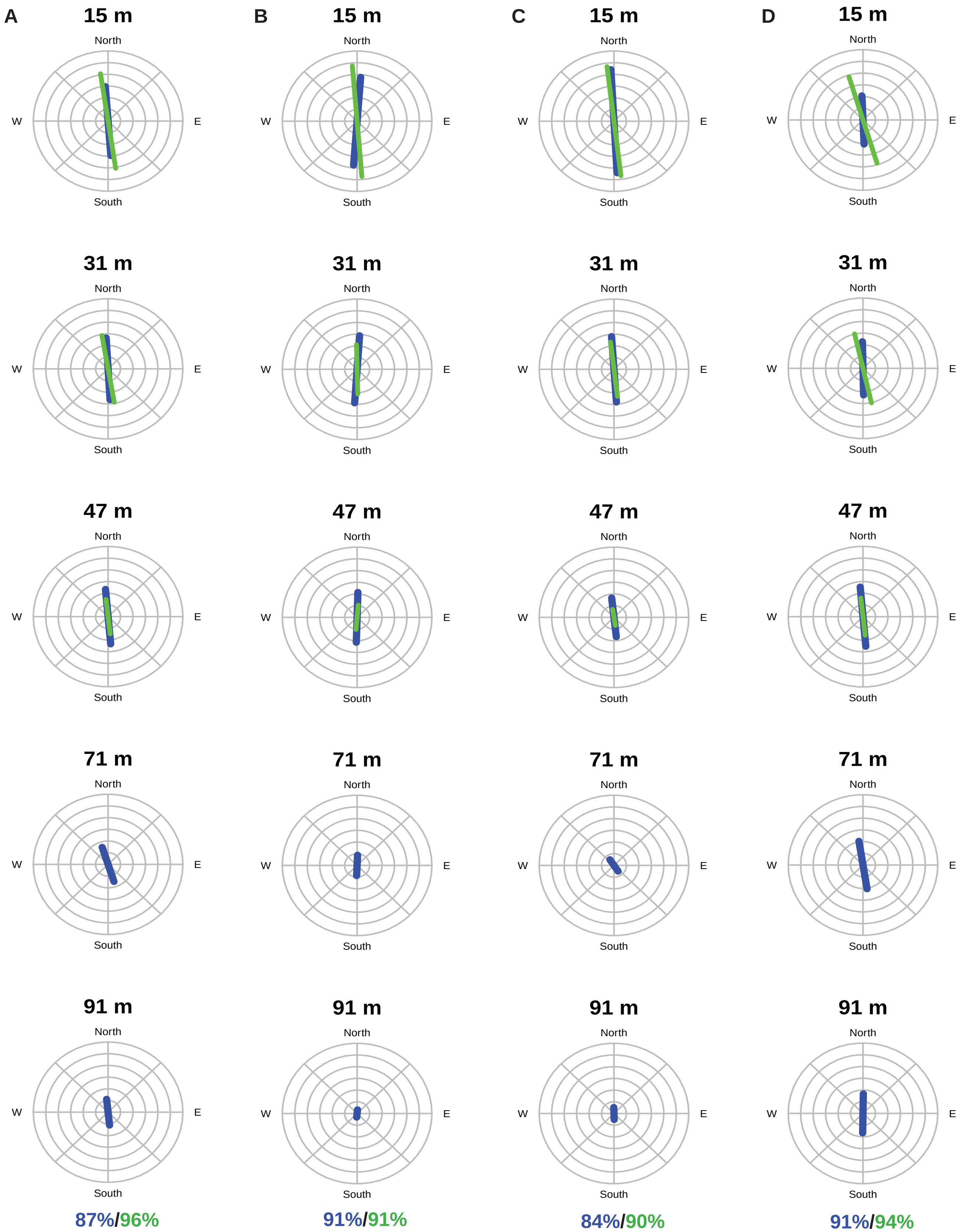

Figure 2.7

Dominant current modes (EOF 1) for (A) winter, (B) spring, (C) summer, and (D) fall in 2013 at the 100-m (blue) and 60-m (green) ADCP sites for selected depth bins. Percentages indicate fraction of the total variance accounted for by the EOF for each location. Line length indicates magnitude. Each concentric ring is 0.1 mm/s.

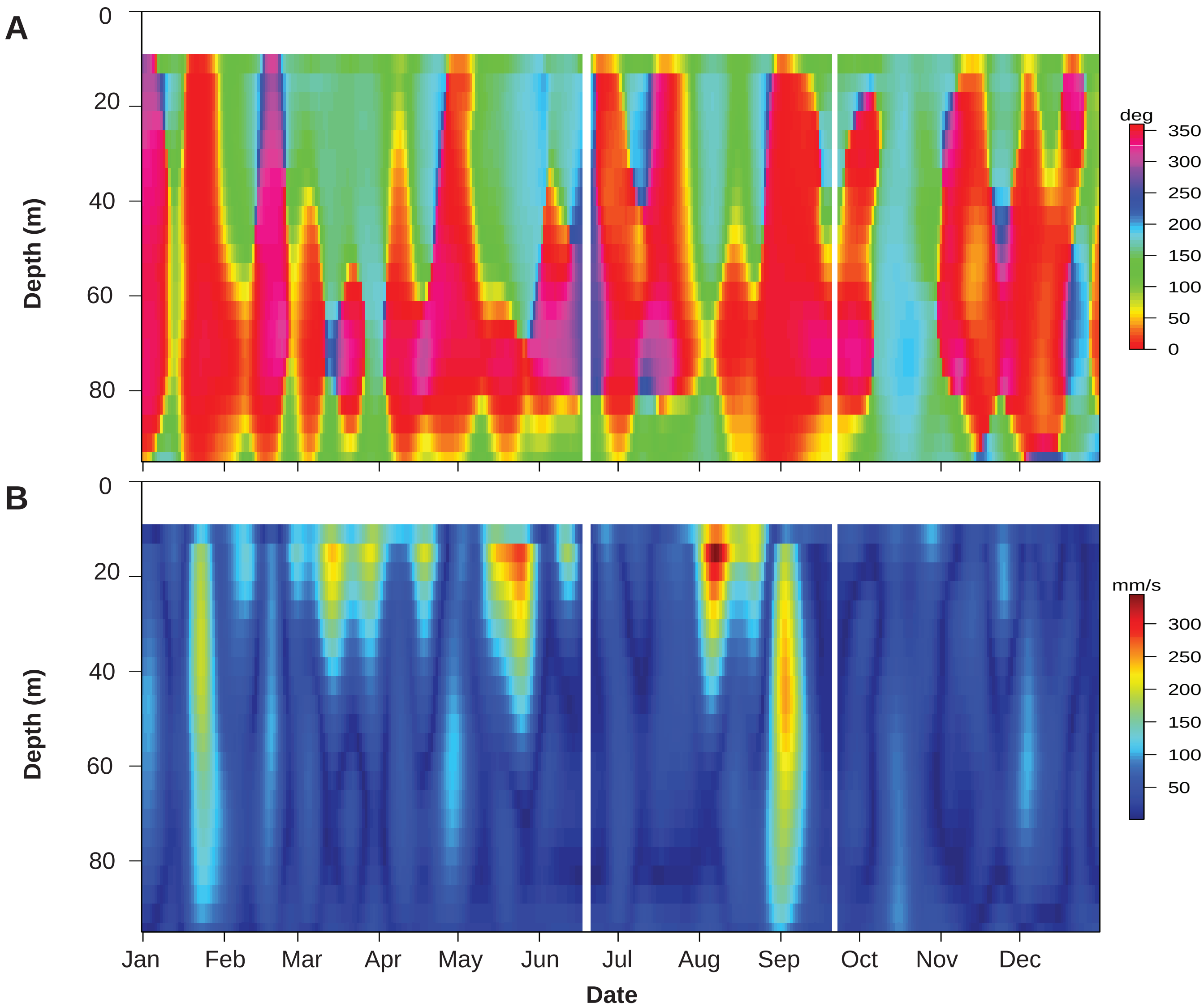

Figure 2.8
ADCP data collected at the 100 m site showing daily average (A) direction, and (B) horizontal velocity of currents from January through December 2013. Missing data (white area) are the result of interference with the doppler signal near the surface or instrument maintenance.

cooling event and a return to positive NPGO values indicating an increased flow of cold, nutrient-rich water from the north; (6) development of another La Niña starting in May 2010. Temperature and salinity data for the 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 2013, temperatures remained cooler than the long-term average in February, May, and August before warming again in November. The low magnitude of the temperature, salinity and DO anomalies are consistent with the ENSO-neutral conditions that have persisted since mid 2012 (NOAA/NWS 2014). 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).

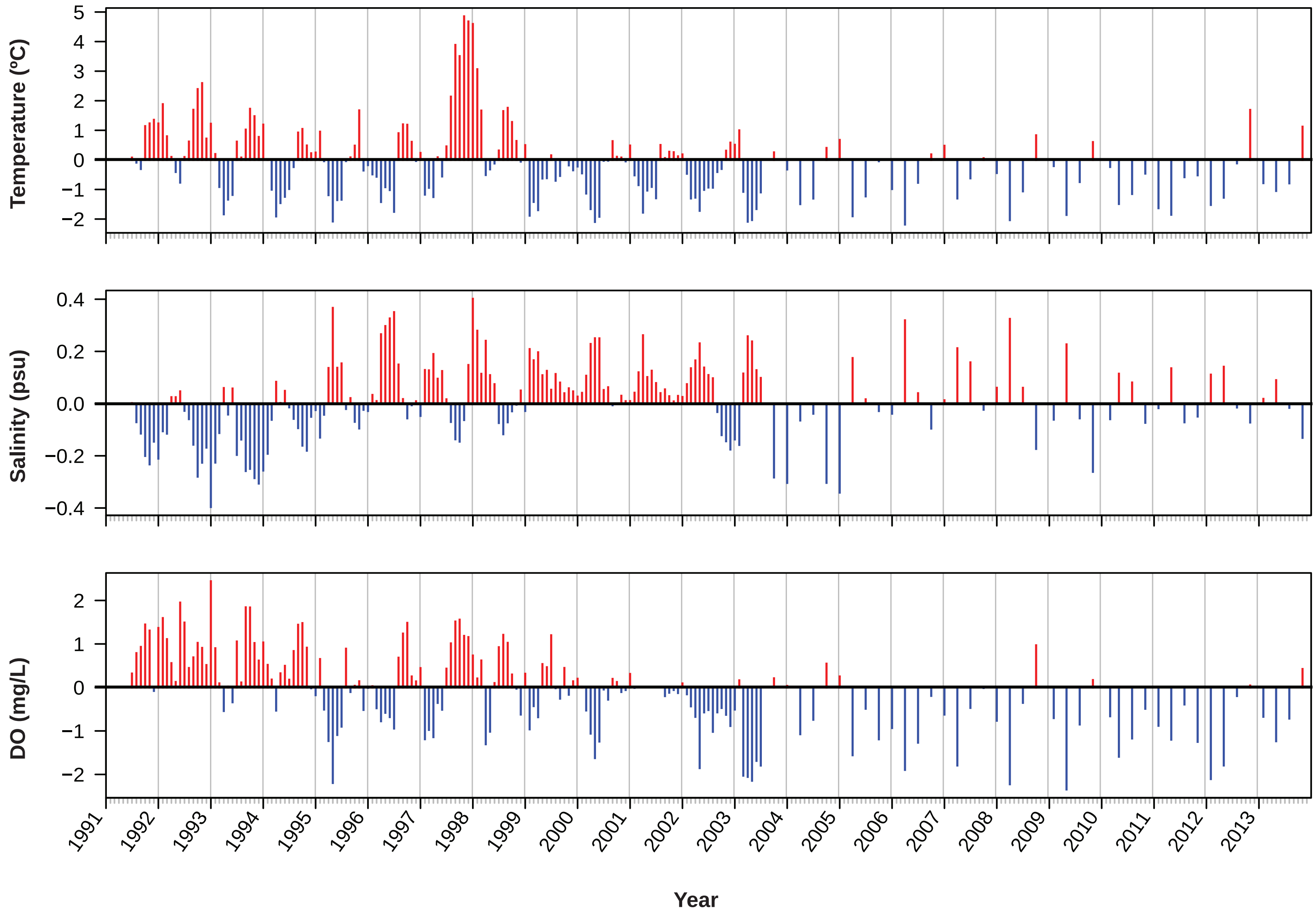

Figure 2.9
Time series of temperature, salinity, and dissolved oxygen (DO) anomalies from 1991 through 2013 at the 11 outfall depth stations sampled in the PLOO region with all depths combined.

Summary

Oceanographic data collected in the Point Loma outfall region were consistent with reports from NOAA that the mild ENSO-neutral conditions of 2012 persisted throughout 2013 (NOAA/NWS 2014). Conditions indicative of local coastal upwelling, such as relatively cold, dense, saline waters with low DO and pH at mid-depths and below, were observed during February and May.

Overall, water column stratification in 2013 followed seasonal patterns typical for the San Diego region. Maximum stratification occurred in May and August, while well-mixed and weakly-stratified waters were present during February and November. Ocean currents flowed predominantly along a north-south axis during most of the year, although these measurements excluded the influence of tidal currents and internal waves. 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, NOAA/NWS 2014) 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 explained by a combination of local (e.g., coastal upwelling, rain-related runoff) and large-scale oceanographic processes (e.g., ENSO, PDO, NPGO).

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Chapter 3
Water Quality Compliance & Plume Dispersion

Chapter 3. Water Quality Compliance & 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 2009 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 2009).

Multiple sources of potential bacterial contamination exist in the Point Loma monitoring region in addition to the outfall. Therefore, being able to separate any effects or impacts associated with the discharge of wastewater from the outfall from other sources of contamination is often challenging. Examples of other such non-outfall sources of contamination include outflows from San Diego Bay and the Tijuana and San Diego Rivers (Nezlin et al. 2007, Svejkovsky 2014). Likewise, storm water discharges and wet-weather runoff from local watersheds 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, cultivating 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 also 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 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 analyses and interpretations of the microbiological, water chemistry, and oceanographic data collected during 2013 at water quality monitoring stations surrounding the PLOO. The primary goals are to: (1) document overall water quality conditions in the region during the year, (2) distinguish between the PLOO wastewater plume and other sources of bacterial contamination, (3) evaluate potential movement and dispersal of the plume, and (4) assess compliance with water-contact standards defined in the Ocean Plan. Results of remote sensing data are also evaluated to provide insight into wastewater transport and the extent of significant events in surface waters during the year (e.g., turbidity plumes).

Materials and Methods

Field Sampling

Shore stations

Seawater samples were collected five times per month at eight shore stations (i.e., D4, D5, and

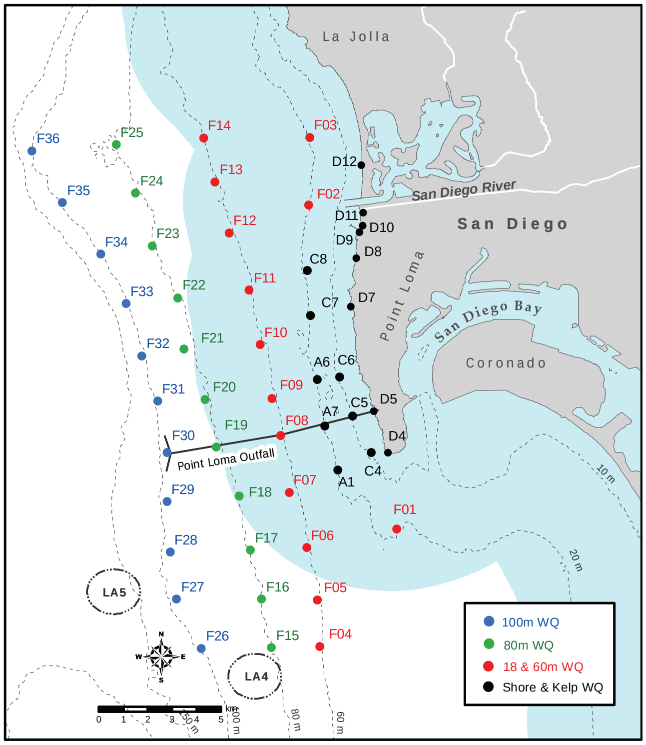

Figure 3.1

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.

D7–D12) 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. The samples were then transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML) and analyzed to determine concentrations of total coliform, fecal coliform, and *Enterococcus* bacteria. In addition, visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. These observations were reported in monthly receiving waters monitoring reports (e.g., City of San Diego 2014b).

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 fecal indicator bacteria as at the shore stations. Additional samples were collected to assess ammonia levels at these kelp sites following the quarterly offshore water quality sampling schedule described below.

An additional 36 offshore stations were sampled in order to monitor *Enterococcus* levels in these deeper waters and to estimate dispersion of the wastewater plume. These offshore "F" stations are arranged in a grid surrounding the discharge site along or adjacent to the 18, 60, 80, and 100-m depth contours (Figure 3.1). In contrast to shore and kelp bed stations, offshore stations were monitored on a quarterly basis during February, May, August and November; each of these quarterly surveys was generally completed over a 3-day period (see Table 2.1 for specific survey dates). Additional monitoring for ammonia occurred at the same discrete depths where bacterial 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

Box 3.1

Water quality objectives for water contact areas, 2009 California Ocean Plan (SWRCB 2009).

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.

to measure temperature, conductivity (salinity), pressure (depth), chlorophyll *a*, colored dissolved organic matter (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 City's Marine Microbiology Laboratory follows guidelines issued by the United States Environmental Protection Agency (USEPA) Water Quality Office and the California Department of Public Health (CDPH) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1995, CDPH 2000, USEPA 2006). All bacterial analyses were performed within eight hours of sample collection and conformed to standard membrane filtration techniques (APHA 1995).

Enumeration of FIB density was performed and validated in accordance with USEPA (Bordner et al. 1978, USEPA 2006) and APHA (1995) guidelines. Plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values when calculating means and 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

Table 3.1
Depths at which seawater samples are collected for bacteriological analysis at 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

variability between samples, respectively. Results of these procedures were reported under separate cover (City of San Diego 2014a).

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 blanks.

Data Analyses

Bacteriology

FIB densities were summarized as monthly means for each shore station and by depth contour for the kelp bed and offshore stations. To assess temporal and spatial trends, the data were summarized as the number of samples in which FIB concentrations exceeded benchmark levels. For this report, the single sample maximum standards defined in the 2009 Ocean Plan for total coliforms, fecal coliforms, and *Enterococcus* were used as benchmarks to distinguish elevated FIB values (see Box 3.1 and SWRCB 2009). Bacterial densities were compared to rainfall data from Lindbergh Field, San Diego, CA (see NOAA 2014). Chi-squared Tests (χ^2) were conducted to determine if the frequency of samples with elevated FIB counts differed at the shore and kelp bed stations between wet (October–April) and dry (May–September) seasons. Satellite images of the San Diego coastal region were provided by Ocean Imaging of Solana Beach, California (Svejkovsky 2014) and used to aid in the analysis and interpretation of water quality data (see Chapter 2 for remote sensing details). Finally, compliance with Ocean Plan water-contact standards was summarized as the number of times per month that each shore, kelp, and offshore station within State jurisdiction waters exceeded the various standards.

Plume Detection and Out-of-Range Calculations

The potential presence or absence of wastewater plume was determined at each station using a combination of oceanographic parameters (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 2010–2013, Rogowski et al. 2012a, b, 2013). Water column stratification and pycnocline depth were quantified using calculations of buoyancy frequency (cycles2/min2) for each quarter (Chapter 2). If the water column was stratified, subsequent analyses were limited to depths below the pycnocline. Identification of potential plume signal at each station relied on multiple criteria, including (1) high CDOM, (2) low chlorophyll a, and (3) visual interpretation of the water column profile. Detection thresholds were adaptively set for each quarterly sampling period according to the following criteria: CDOM exceeding the 90th 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

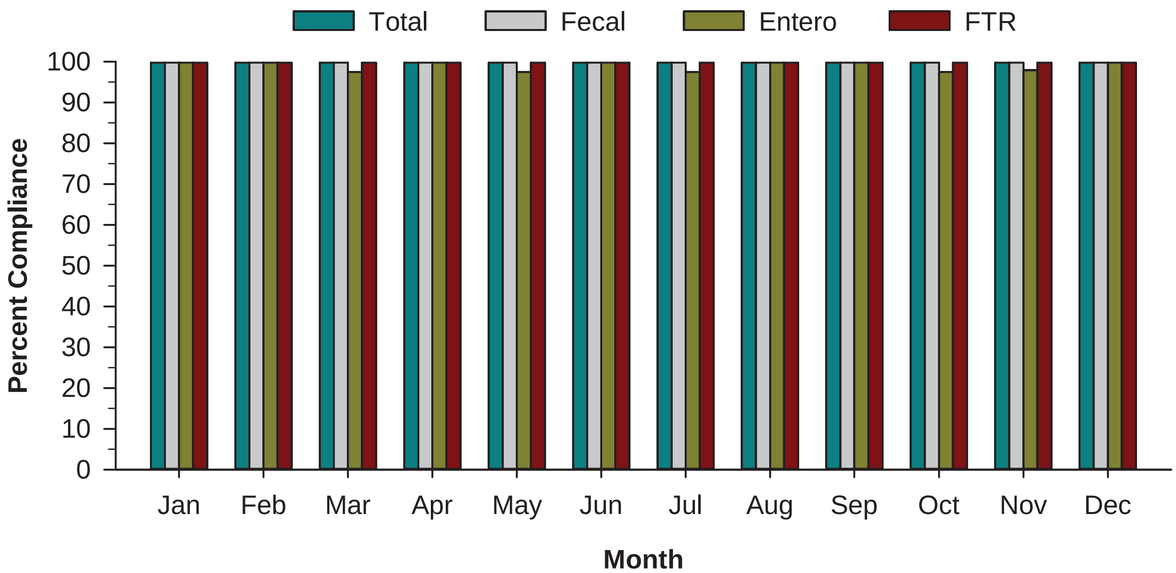

Figure 3.2
Compliance rates for the four single sample maximum standards at PLOO shore stations during 2013.

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).

After identifying the monitoring stations and depth-ranges where the above criteria suggested the PLOO wastewater plume may be present, the potential impact of the plume on water quality was assessed by comparing mean values of DO, pH and transmissivity within the plume to thresholds calculated for similar depths from reference stations. Any station with a CDOM value below the 90th percentile was considered non-plume and used as a reference station for that survey (Appendix B.5). Individual stations were determined to be out-of-range (OOR) compared to the reference stations if values exceeded the narrative water quality standards for above natural water quality indicators as defined by the Ocean Plan (see Box 3.1). For example, the OOR threshold was calculated as a 10% reduction from that which occurs naturally for DO, as a 0.2 unit reduction for pH, and as dropping below the 95% confidence interval for transmissivity. For the purposes of this report, "natural" was defined for DO and pH as the mean minus one standard deviation.

Results and Discussion

Bacteriological Compliance and Distribution

Shore stations

During 2013, compliance at the eight shore stations in the PLOO region was 100% for the 30-day total coliforms, fecal coliforms, and *Enterococcus* geometric mean standards. Compliance with the single sample maximum (SSM) standards was 100% for total coliforms, fecal coliforms, and the fecal:total coliform (FTR) criterion, and 98-100% for *Enterococcus* (Figure 3.2). In addition, a sewage-like odor and surface scum on the water were observed at several shore stations at various times during the year, while observations of foam were only reported following rain events. Monthly mean FIB densities ranged from 2 to 556 CFU/100 mL for total coliforms, 2 to 43 CFU/100 mL for fecal coliforms, and 2 to 1442 CFU/100 mL for *Enterococcus* (Appendix B.2). Of the 488 shore samples collected during the year, only five (~1.0%) had elevated FIB, occurring at stations D7, D8, and D11 (Table 3.2, Appendix B.3). This represents a slight decrease from the eleven samples with elevated FIB counts in 2012. A general relationship between rainfall and elevated bacterial levels at shore stations has been evident since water quality monitoring began in the Point Loma

Table 3.2

The number of samples with elevated FIB densities collected at PLOO shore stations during the wet and dry seasons in 2013. 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	0	—
D11	1	1	50
D10	0	0	—
D9	0	0	—
D8	0	1	0
D7	2	0	100
D5	0	0	—
D4	0	0	—
Rain (in)	5.26	0.31	94
Total Counts	3	2	60
n	288	200	59

region (Figure 3.3). Historical data indicate that the occurrence of a sample with elevated FIB was significantly more likely during the wet season than during the dry season (7% versus 2%, respectively; n = 7678, $\chi^2 = 102.171$, $p < 0.0001$). Contrary to this historical trend, no seasonal effect was observed for FIB exceedances in 2013.

Kelp bed stations

Compliance at the eight kelp bed stations was 100% with all bacteriological standards during 2013. These results are consistent with those from 2012, when the water contact standard compliance rates were also at 100% (City of San Diego 2013). Further, no signs of wastewater (e.g., foam, sewage-like odor) were observed at any of the kelp stations during the year. Satellite imagery showed that runoff from the San Diego River in 2013 was typically restricted to the area between the shore and inside of the kelp forest (Svejkovsky 2014). Monthly mean FIB densities at the kelp stations were lower than those along the shore, ranging from 2 to 31 CFU/100 mL for total coliforms, 2 to 3 CFU/100 mL for fecal coliforms, and only 2 CFU/100 mL for *Enterococcus* throughout the year (Appendix B.4). This low incidence of elevated FIBs 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, FIB levels were much higher at the kelp bed stations prior to the outfall extension. 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).

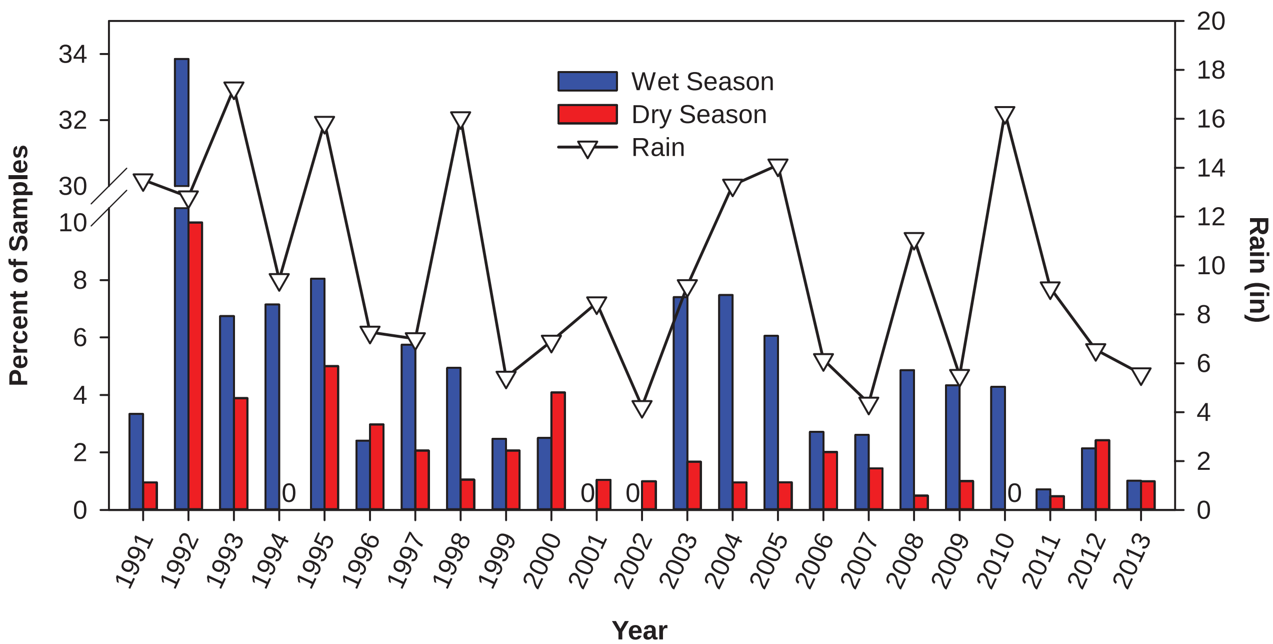

Figure 3.3

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 2013. Rain data are from Lindbergh Field, San Diego, CA.

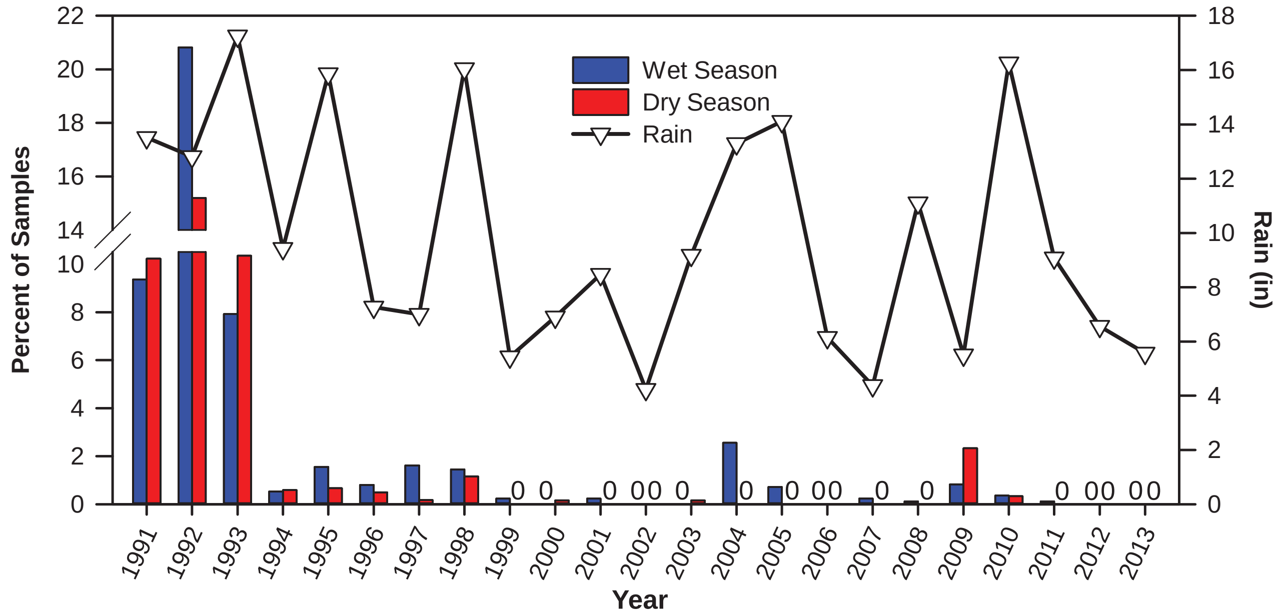

Figure 3.4
Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet versus dry seasons at PLOO kelp bed stations from 1991 through 2013. Rain data are from Lindbergh Field, San Diego, CA.

Offshore stations

The maximum concentration of *Enterococcus* at the offshore stations was 400 CFU/100 mL in 2013 (Appendix B.3). There were also no signs of wastewater at any of these 36 stations based on visual observations (City of San Diego 2014b). Only one of 564 offshore samples (0.2%) had elevated *Enterococcus* levels >104 CFU/100 mL. It was collected at station F30 located nearest the discharge site at a sample depth of 80 m (Figure 3.5). These results suggest that the wastewater plume was restricted to relatively deep, offshore waters throughout the year. This conclusion is consistent with remote sensing observations that provided no evidence of the plume reaching surface waters in 2013 (Svejkovsky 2014). These findings are also consistent with historical results, which revealed that <1% of the samples collected from 1991 through 2013 from depths ≤25 m at the eleven stations located along the 100-m discharge depth contour contained 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 = 5020, $\chi^2 = 154.97$, $p < 0.0001$) (Figure 3.6B). Following the initiation of chlorination in August 2008, the number of samples with elevated *Enterococcus* also dropped significantly at these three stations (17% before versus 7% after, n = 1721, $\chi^2 = 18.85$, $p < 0.0001$), as well as at the other 100-m stations (6% before versus 0.6% after; n = 3299, $\chi^2 = 42.25$, $p < 0.0001$) (Figure 3.6C).

Ammonia

Ammonia concentrations at stations along the 9, 18, 60, and 80-m contours reached a maximum of 0.36 mg/L (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 2009). Ammonia was detected at 19 of the 23 stations sampled and in 15.6% of the 288 samples collected during 2013. No ammonia was detected at any station during February (Figure 3.7). None of the samples with detectable levels of ammonia corresponded to samples containing elevated concentrations of *Enterococcus* (see City of San Diego 2014b).

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 2013. Based on

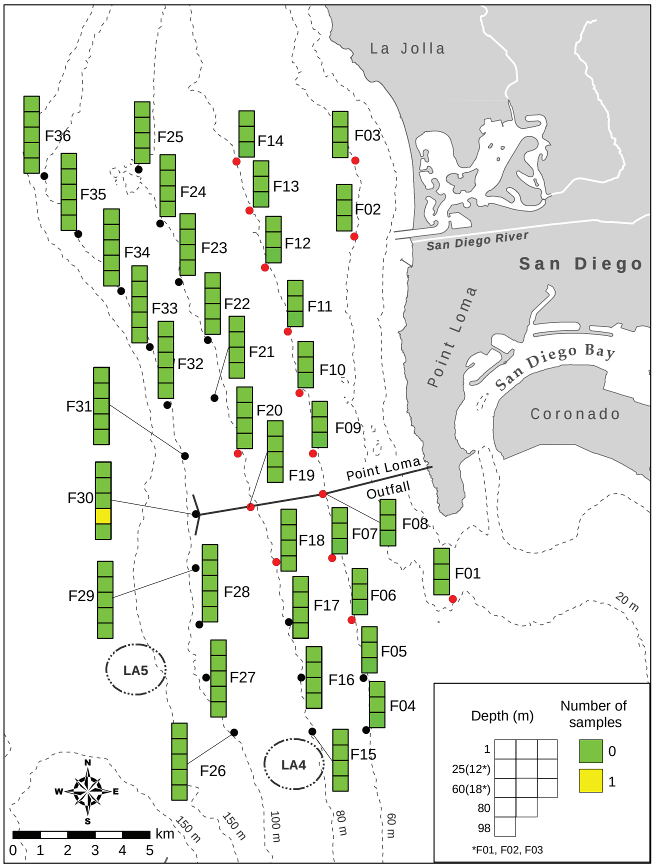

Figure 3.5

Distribution of elevated *Enterococcus* samples collected at offshore stations during 2013. 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 2.1 for sampling details.

the criteria described in the Materials and Methods section, evidence of potential plume was detected a total of 30 times during the year from 21 different stations (Table 3.4), while 10-15 stations were identified as reference sites during each quarterly survey (Appendix B.5). Although the plume was consistently detected at station F30 located near the center of the zone of initial diltion (ZID; Figure 3.8), dispersion away from the outfall appeared to vary primarily in accordance with prevailing current directions (see Chapter 2). Thirty percent of the possible detections (n=9) occurred during February when presence of the plume was mostly restricted to five sites (i.e., stations F29, F30, F31, F32, F33) located about 1.2 km south to 5.5 km north of the outfall along the discharge depth contour, and two stations located slightly inshore along the 80-m depth contour either directly over the outfall pipe (i.e., station F19) or about 2 km to the north (i.e., station F20). Results for two other sites (stations F15 and F16) located relatively far southeast of the discharge area were considered unlikely to be related to wastewater dispersion due to the lack of reliable detection events at adjacent sites closer to the outfall. About 47% of the detections (n=14) occurred during May when the plume was detected near or over the outfall at stations F30 and F19, and at all but one of the stations located south of the outfall along the 60, 80 and 100-m depth contours. The possible detection of plume water at station F11 located about 6.5 km north of the outfall along the 60-m depth contour was considered unlikely to be plume related for reasons similar to those described above for stations F15 and F16 in February. Reliable detection of the plume was rare during the last two surveys of the year, with presence of the plume restricted to stations F30 and F31 in August and to station F30 in November. Additional possible detections at stations F24 and F25 located >9.8 km north of the outfall during both August and November were also considered to be non-plume related events. Overall, the variation in plume dispersion observed off Point Loma in 2013 is similar to flow-mediated dispersal patterns reported previously for the region (Rogowski et al. 2012a, b, 2013).

Variation in the breadth and vertical dispersion of the PLOO wastewater plume could only be evaluated for station F30 since this was the only site where the plume was detected during each quarterly survey. Although plume depth did vary over the year, it remained below 40 m even during periods of weak water column stratification (Appendix B.6). This finding is in agreement with satellite imagery observations that showed no visual evidence of the plume surfacing during 2013 (Svejkovsky 2014). Presence of the plume at station F30 was corroborated by a seawater sample collected February 11 at a depth of 80 m that had an elevated concentration of *Enterococcus* bacteria (see Figure 3.5, Appendices B.1, B.6).

The effects of the PLOO wastewater plume on the three natural water quality indicators mentioned above were calculated for each station and depth where it was detected. For each of these, mean values for natural light (% transmissivity), DO, and

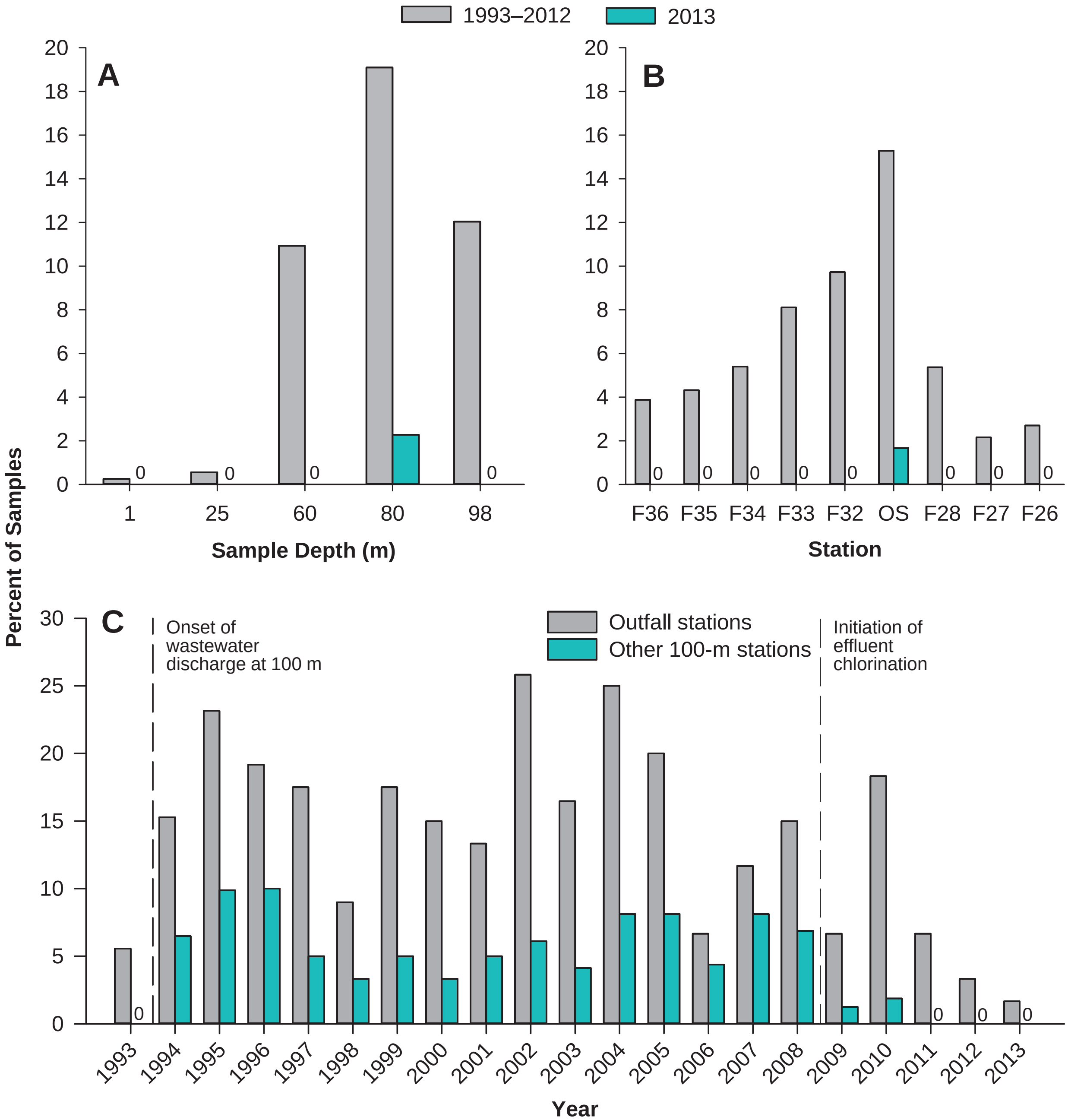

Figure 3.6
Percent of samples collected from PLOO 100-m offshore stations with elevated *Enterococcus* densities. Samples from 2013 are compared to those collected from 1993 through 2012 by (A) sampling depth, (B) stations listed north to south from left to right, and (C) year. OS = outfall stations (F29, F30, F31).

pH within the plume was compared to thresholds within similar depths from non-plume reference stations (Appendix B.7). Of the 30 potential plume detections that occurred during 2013, a total of 19 out-of-range (OOR) events were identified, which consisted of 13 OORs for natural light at various stations throughout the year, six OORs for DO, and no OOR events for pH (Table 3.4, Appendices B.8, B.9, and B.10). A total of eight of the OOR events (5 natural light, 3 DO), all during May, occurred at stations located within State waters where Ocean Plan compliance standards apply.

Summary

Water quality conditions in the Point Loma outfall region were excellent during 2013. Overall

Table 3.3
Summary of ammonia concentrations in samples collected from the 23 PLOO kelp bed and offshore stations located within State waters during 2013. Data include the number of samples per month (n) and detection rate, as well as the minimum, maximum, and mean detected concentrations for each month. The method detection limit for ammonia = 0.01 mg/L.

	Feb	May	Aug	Nov
9-m Depth Contour (n = 9)				
Detection Rate (%)	0	89	44	0
Min	—	nd	nd	—
Max	—	0.36	0.01	—
Mean	—	0.23	0.01	—
18-m Depth Contour (n = 24)				
Detection Rate (%)	0	42	12	4
Min	—	nd	nd	nd
Max	—	0.35	0.02	0.03
Mean	—	0.20	0.01	0.03
60-m Depth Contour (n = 27)				
Detection Rate (%)	0	30	19	15
Min	—	nd	nd	nd
Max	—	0.02	0.04	0.02
Mean	—	0.01	0.02	0.01
80-m Depth Contour (n = 12)				
Detection Rate (%)	0	0	0	17
Min	—	—	—	nd
Max	—	—	—	0.01
Mean	—	—	—	0.01

nd = not detected

compliance with Ocean Plan water-contact standards was >99.9%, which was similar to that observed during the previous year (City of San Diego 2013). In addition, there was no evidence that wastewater discharged into the ocean via the PLOO reached inshore of the 60-m stations. Elevated FIB densities were detected in just five samples collected from three of the eight shoreline stations sampled during the year, while elevated bacterial counts were not detected at any of 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 2009–2013). 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 was little indication of bacterial contamination at the 36 offshore water quality stations sampled in the PLOO region during 2013. The only sample with elevated levels of *Enterococcus* was collected from a depth of 80 m at the station located nearest the center of the ZID. No samples with elevated *Enterococcus* were collected from stations located within State waters. Further, detection of the PLOO wastewater plume and its effects on natural 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 2007–2013, 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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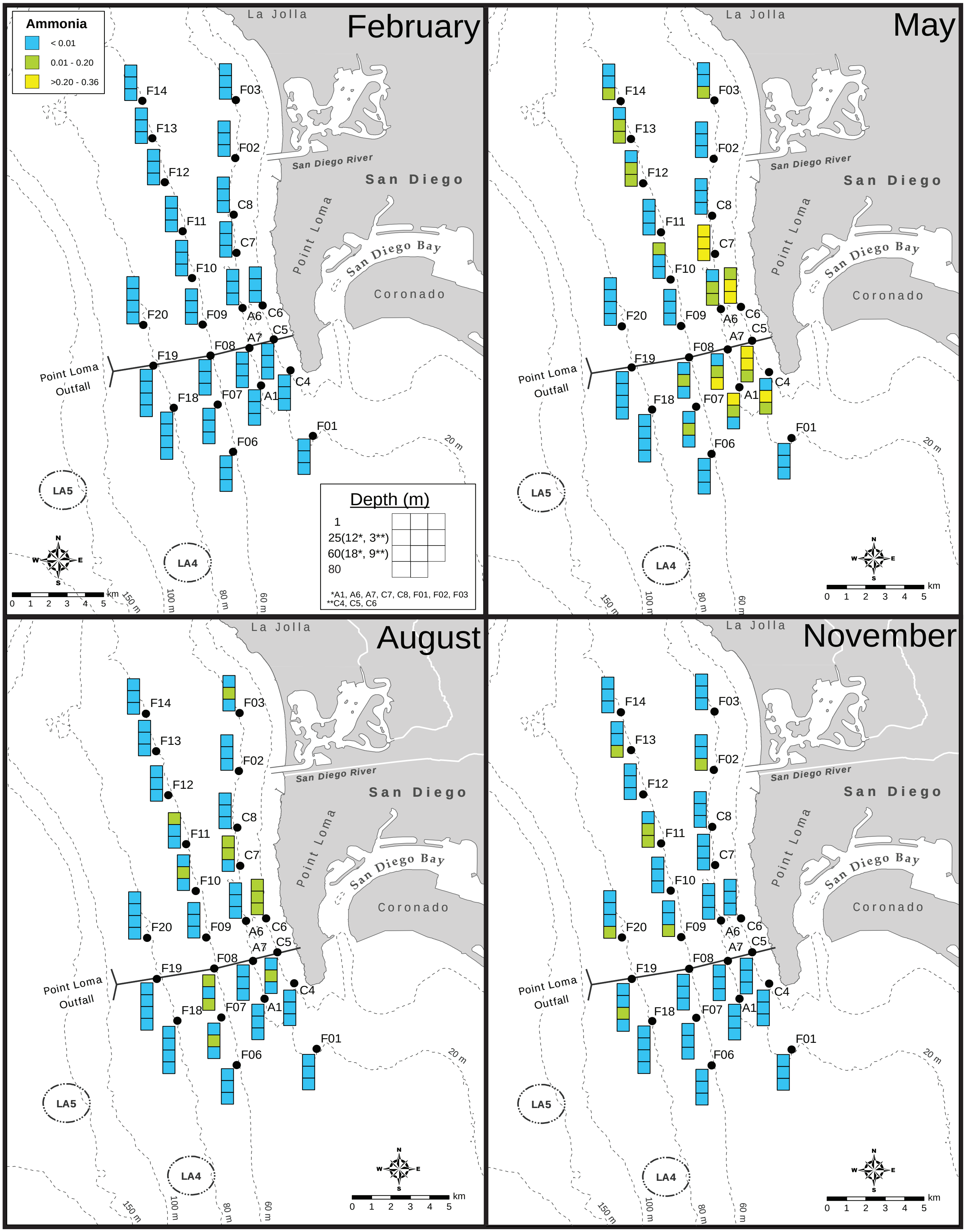

Figure 3.7

Distribution of ammonia (as nitrogen, mg/L) in seawater samples collected during the PLOO quarterly surveys in 2013. See text and Table 3.1 for sampling details.

Table 3.4
Summary of possible plume detections and calculated out-of-range values at PLOO offshore stations during 2013. Stations within State jurisdictional waters are in bold. DO = dissolved oxygen; XMS = transmissivity.

		Out of Range			
Month	**Plume Detections**	**DO**	**pH**	**XMS**	**Stations**
Feb	9	0	0	0	F15, F16, **F19**, **F20**, F29, F30, F31, F32, F33
May	14	4	0	8	F04[ab], F05[b], **F06[ab]**, **F07[ab]**, **F11[b]**, F15, F16, F17[b], **F18[ab]**, **F19[b]**, F26, F27, F28, F30
Aug	4	0	0	2	F24[b], F25[b], F30, F31
Nov	3	2	0	3	F24[ab], F25[ab], F30[b]
Detection Rate (%)	20.8	4.2	0.0	9.0	
Total Count	30	6	0	13	
n	144	144	144	144	

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

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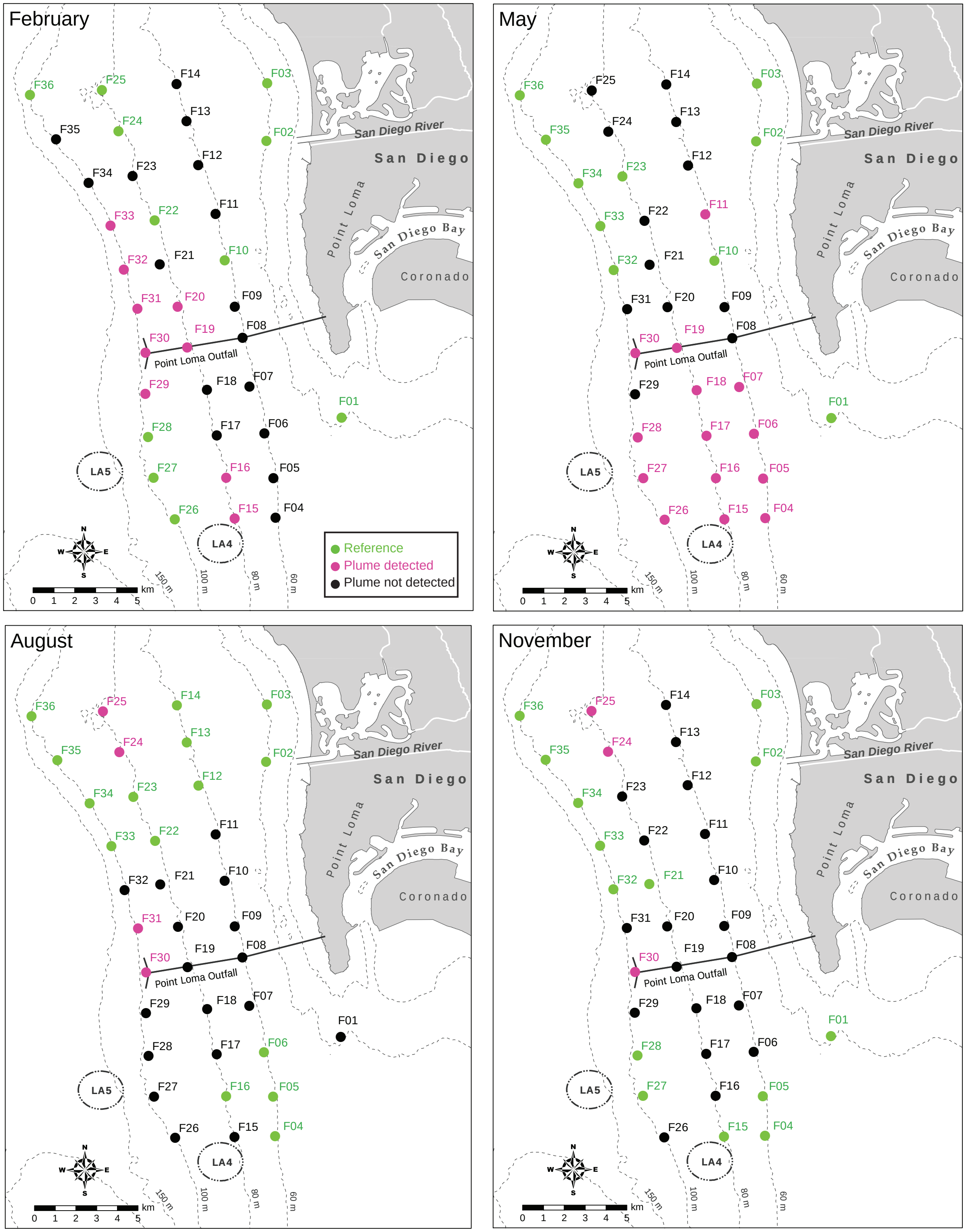

Figure 3.8
Distribution of stations where potential wastewater plume was detected and those used as reference stations for water quality compliance calculations during the PLOO quarterly surveys in 2013.

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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, and 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 analyses and interpretations of sediment particle size and chemistry data collected at monitoring stations surrounding the PLOO during 2013, as well as a long-term assessment of sediment conditions in the region from 1991 through 2013. The primary goals are to: (1) document sediment conditions during the year, (2) identify possible effects of wastewater discharge on sediment quality in the region, and (3) identify other potential natural and anthropogenic sources of sediment contaminants to the local marine ecosystem.

Materials and Methods

Field Sampling

Sediment samples were collected at 12 primary core stations in the PLOO region during winter (January) and summer (July) 2013, and at an additional 10 secondary stations during the summer survey (Figure 4.1). These latter 10 stations were not sampled during the winter as part of a resource exchange agreement for the 2012 sediment mapping project (see Chapter 1). All 22 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 sites include 17 '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 four stations considered to represent "nearfield" conditions (i.e., E11, E14, E15 and E17) are located within 1000 m of the outfall diffuser structure.

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

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. A

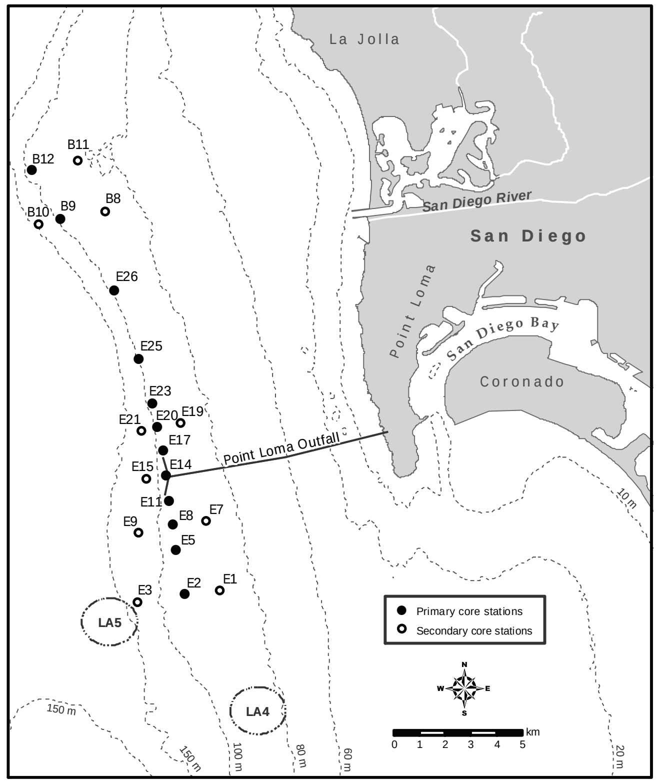

Figure 4.1
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

detailed description of the analytical protocols can be found in City of San Diego (2014a). Briefly, sediment sub-samples were analyzed 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 (e.g., DDT), 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis. Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix C.1). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry.

Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of nested sieves. The Horiba measures particles ranging in size from 0.5 to 2000 μm. Coarser sediments were removed and quantified prior to laser analysis by screening samples through a 2000 μm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%, and then classified into 4 main size fractions and 11 sub-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, median, maximum and mean values for all samples combined. All means were calculated using detected values only; no substitutions were made for non-detects in the data (i.e., analyte concentrations < MDL). Total DDT (tDDT), total hexachlorocyclohexane (tHCH), total chlordane, 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 software to examine spatio-temporal patterns in the overall particle size composition in the Point Loma outfall region (Clarke and Warwick 2001, Clarke and Gorley 2006). These included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008).

Results

Particle Size Distribution

Ocean sediments sampled off Point Loma were composed predominantly of fine particles (i.e., silt and clay; also referred to as percent fines) and fine sands during 2013. Percent fines ranged from 19 to 71% per sample, while fine sands ranged from 29 to 62%, medium-coarse sands ranged from < 1 to 22%, and coarse particles ranged from 0 to 6% (Table 4.1, Figure 4.2). Coarse particles may have comprised black sand, gravel, pea gravel, rock and/or shell hash (Appendix C.4). For the primary core stations sampled during the winter and summer, particle size composition varied by as much as 10% per size fraction, with the greatest intra-station differences occurring at station E8 (Figure 4.2, Appendix C.4). For example, sediments from this station sampled during the winter consisted of 38% fines, 61% fine sands, and 1% medium-coarse sands, while the summer sample consisted of 48% fines, 51% fine sands, and 1% medium-coarse sands. Overall, there were no spatial patterns in sediment composition relative to the PLOO discharge site. For example, sediments collected from nearfield stations ranged from 37 to 46% fines and 53 to 62% fine sands, while sediments > 1000 m from the outfall ranged from 19 to 71% fines and 29 to 61% fine sands.

Classification (cluster) analysis of the 2013 particle size sub-fraction data for the primary core stations discriminated three main cluster groups (cluster groups 1–3; Figure 4.3). Cluster group 1 represented three samples, including one collected during the winter at southern station E2 and both the winter and summer samples from northern station B12. Sediments in these samples averaged the largest proportion of fine sand (24% per sample) and medium sand (6% per sample), and the smallest proportion of coarse silt (14% per sample). Cluster group 2 comprised 8 samples, including both winter and summer samples from

Table 4.1

Summary of particle sizes and chemistry concentrations in sediments from PLOO benthic stations sampled during 2013. Data include the detection rate (DR), mean, minimum, median, and maximum values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1991–1993) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold.

	2013 Summary[a]					Pre-discharge		
Parameter	**DR (%)**	**Mean**	**Min**	**Median**	**Max**	**Max**	**ERL[b]**	**ERM[b]**
Particle Size								
Coarse Particles(%)	—	0.5	0.0	0.0	5.8	26.4	na	na
Med-Coarse Sands (%)	—	2.4	0.2	1.0	21.8	41.6	na	na
Fine sands (%)	—	50.1	29.0	51.1	62.2	72.6	na	na
Fines (%)	—	47.1	19.4	46.6	70.9	74.4	na	na
Organic Indicators								
BOD (ppm)	100	306	160	275	508	656	na	na
Sulfides (ppm)	100	7.3	1.4	4.0	58.9	20.0	na	na
TN (% weight)	100	0.056	0.039	0.053	0.089	0.074	na	na
TOC (% weight)	100	0.59	0.30	0.45	3.26	1.24	na	na
TVS (% weight)	100	2.29	1.70	2.10	4.00	4.0	na	na
Trace Metals (*ppm*)								
Aluminum	100	14,232	10,300	14,400	20,700	na	na	na
Antimony	82	0.56	nd	0.54	0.94	6.00	na	na
Arsenic	100	2.7	1.9	2.6	4.9	5.6	8.2	70
Barium	100	39.0	22.8	34.8	108.0	na	na	na
Beryllium	100	0.238	0.173	0.230	0.360	2.010	na	na
Cadmium	97	0.15	nd	0.15	0.22	6.10	1.2	9.6
Chromium	100	18.5	14.1	17.6	28.2	43.6	81	370
Copper	100	9.2	5.1	8.6	20.0	34.0	34	270
Iron	100	14,309	9610	13,400	23,300	26,200	na	na
Lead	100	7.01	4.74	6.55	11.90	18.00	46.7	218
Manganese	100	172.7	94.6	178.5	225.0	na	na	na
Mercury	100	0.029	0.017	0.027	0.052	0.096	0.15	0.71
Nickel	100	9.98	6.35	10.30	14.60	14.00	20.9	51.6
Selenium	85	0.49	nd	0.48	0.66	0.90	na	na
Silver	50	1.95	nd	0.13	3.77	4.00	1	3.7
Thallium	0	—	—	—	—	113.00	na	na
Tin	100	1.21	0.61	1.27	1.88	na	na	na
Zinc	100	33.7	23.9	33.5	43.8	67.0	150	410
Pesticides (*ppt*)								
HCB	3	26	nd	nd	26	nd	na	na
Total DDT	100	554	100	290	8820	13,200	1580	46,100
Total PCB (*ppt*)	35	1022	nd	nd	5210	na	na	na
Total PAH (*ppb*)	53	34.1	nd	9.5	222.6	199	4022	44,792

na = not available; nd = not detected

[a] Minimum, median, and maximum values were calculated based on all samples (n = 34), whereas means were calculated on detected values only (n ≤ 34)

[b] From Long et al. 1995

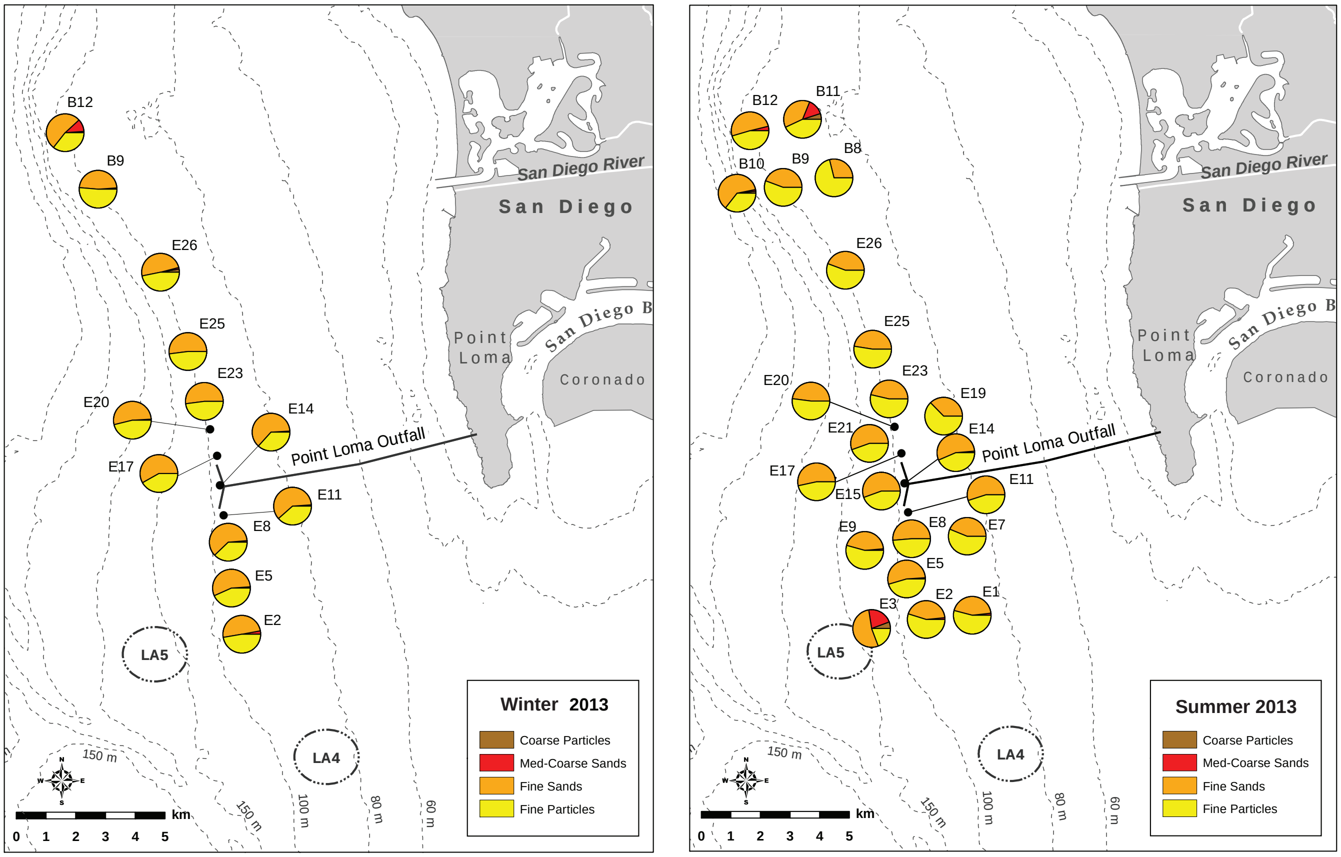

Figure 4.2

Sediment composition at PLOO benthic stations sampled in 2013 during winter and summer surveys.

stations B9 and E26, and the summer samples from stations E2, E20, E23, and E25. These sediments averaged 11% fine sand, 35% very fine sand, 22% coarse silt, and ≤11% medium silt, fine silt, and very fine silt. Cluster group 3 represented the remaining 13 samples collected during the year, including all samples from the three primary core nearfield stations. These sediments were only slightly different than those that characterized group 2, and had the largest proportion of very fine sand (41% per sample) and the smallest proportions of very fine silt, fine silt, and medium silt (5%, 8%, and 8% per sample, respectively).

There is no evidence that the percent fines component has increased at any of the PLOO primary core stations since wastewater discharge began in late 1993 (Figure 4.4). Instead, sediment composition has remained fairly consistent over time (Figure 4.5). These results are indicative of long-term stability in the region in terms of the overall proportions of the major particle size fractions. However, sediments at a few sites such as northern reference station B12, near-zid station E14, and southern station E2 show substantial temporal variability within the size ranges indicative of sand and coarser fractions. This variability often corresponds to occasional patches of coarse sands (e.g., black sand) or larger particles (e.g., gravel, shell hash). For example, coarse black sands were observed at station E14 this year (Appendix C.4), whereas gravel and larger rocks were observed at this station in 2010 (City of San Diego 2011), possibly due in part to the presence of ballast or bedding material around the outfall (City of San Diego 2007).

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 in the Point Loma outfall region during 2013

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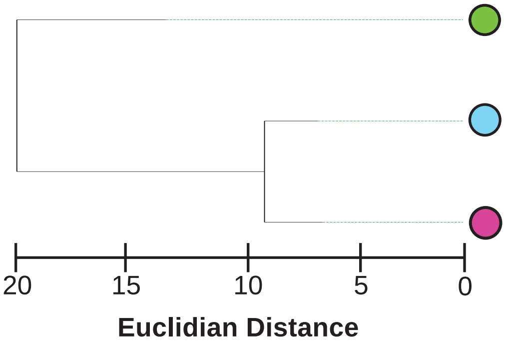


		Percent Fines					Fine Sands		Med-Coarse Sands		Coarse Particles	
Cluster Group	n	CLAY	VFSILT	FSILT	MSILT	CSILT	VFSAND	FSAND	MSAND	CSAND	VCSAND	GRANULES
1	3	4	7	10	9	14	27	24	6	0	0	0
2	8	3	7	11	10	22	35	11	1	0	0	0
3	13	3	5	8	8	21	41	14	1	0	0	0

B

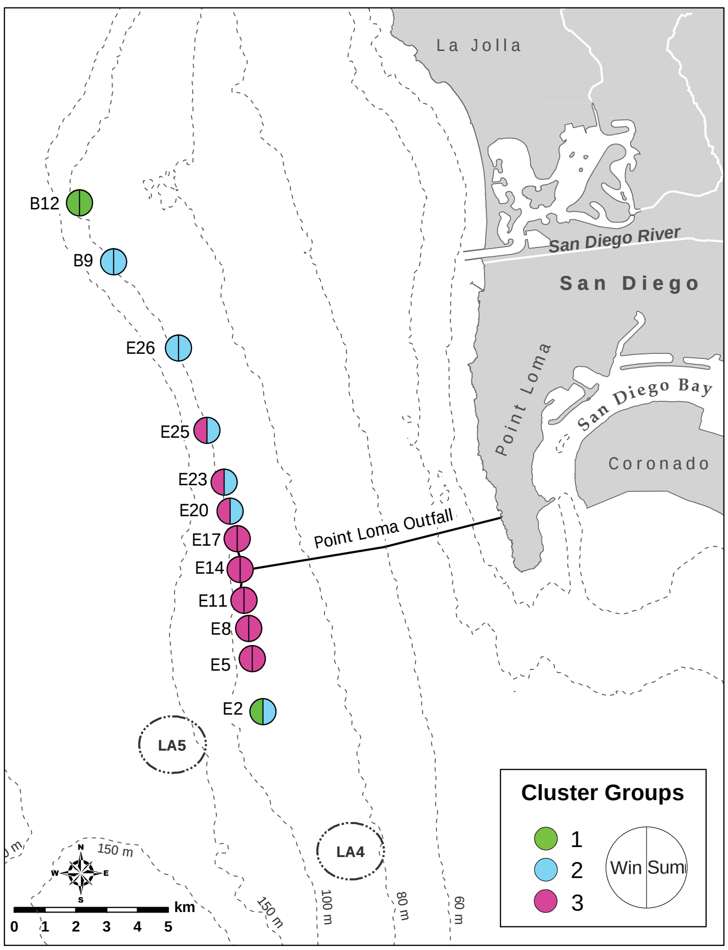


Figure 4.3

Cluster analysis of particle size sub-fraction data from PLOO primary core stations sampled during 2013. Data are presented as: (A) cluster results and (B) spatial distribution of sediment samples as delineated by cluster analysis. Data for particle size sub-fractions are mean percentages calculated over all stations within a cluster group (n). VFSILT=Very Fine Silt; FSILT=Fine Silt; MSILT=Medium Silt; CSILT=Coarse Silt; VFSAND=Very Fine Sand; FSAND=Fine Sand; MSAND=Medium Sand; CSAND=Coarse Sand; VCSAND=Very Coarse Sand.

(Table 4.1). BOD concentrations ranged from 160 to 508 ppm, while sulfides ranged from 1.4 to 58.9 ppm, TN ranged from 0.039 to 0.089% weight, TOC ranged from 0.30 to 3.26% weight, and TVS ranged from 1.7 to 4.0% weight. Of these five indicators only sulfides, TN and TOC were detected at concentrations higher than observed before wastewater discharge began. The highest TN, TOC, and TVS concentrations occurred at the northern 'B' stations located at least 10 km north of the outfall (Appendix C.5). In contrast, the highest sulfide and BOD concentrations occurred at station E14 located nearest the discharge site. In general, only sulfide and BOD concentrations have shown changes near the outfall that appear consistent with possible organic enrichment (Figure 4.4; see also City of San Diego 2007).

Trace Metals

Thirteen trace metals were detected in all sediment samples collected in the PLOO region during 2013, including aluminum, arsenic, barium, beryllium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, and zinc (Table 4.1, Appendix C.6). Antimony, cadmium, selenium, and silver were also detected, but in fewer samples (50–97%). Thallium was not detected in any sediment sample collected during the year. Only one of the nine metals that have published ERLs and ERMs (see Long et al. 1995) were reported at levels above these thresholds. Silver exceeded its ERL throughout the survey area during the summer at stations B11, E3, E7, E8, E11, E14, E17, E19, E20, E21, E23, and E25; it also exceeded its ERM at station E26 during the summer. The remaining 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). 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, station B8 sediments had the highest zinc value, station B9 sediments had the highest barium and nickel values, station B12 sediments had the highest arsenic, beryllium, chromium, and iron values, station E1 sediments had the highest lead and mercury values, station E3 sediments had the highest copper values, station E5 sediments had the highest antimony values, and station E7 sediments had the highest manganese value.

Detection rates for several metals have been high ever since monitoring began in 1991 (Table 4.2). For example, aluminum, arsenic, barium, chromium, copper, iron, manganese, nickel, and zinc have been detected in ≥96% of the samples collected over the past 23 years. During this time period, arsenic, chromium, copper, lead, mercury, nickel, and zinc never exceeded their ERL or ERM thresholds, while exceedances for cadmium and silver were rare (i.e., ≤9% of the samples collected). Concentrations of the remaining metals were extremely variable and most were detected at levels within ranges reported elsewhere in the SCB (e.g., Schiff et al. 2011). While high values of various metals have been occasionally recorded at the nearfield stations, there were no discernible long-term patterns that could be associated with proximity to the outfall or the onset of wastewater discharge (Figure 4.6, Appendix C.7).

Pesticides

Only two chlorinated pesticides were detected in PLOO sediments during 2013, including DDT and hexachlorobenzene (HCB) (Table 4.1, Appendix C.8). Total DDT, composed primarily of p,p-DDE, was detected in all sediment samples at concentrations up to 8820 ppt. Although the highest DDT concentration exceeded its ERL threshold at station B9 during the winter, all DDT values were below those reported prior to wastewater discharge and within ranges reported elsewhere in the SCB (e.g., Schiff et al. 2011). HCB was found in a single sediment sample from station E1 during the summer at a concentration of 26 ppt.

Except for DDT, chlorinated pesticides have rarely been detected in the PLOO region since sampling began (Table 4.2). Over the past 23 years, detection rates were 53% for tDDT, 4% for

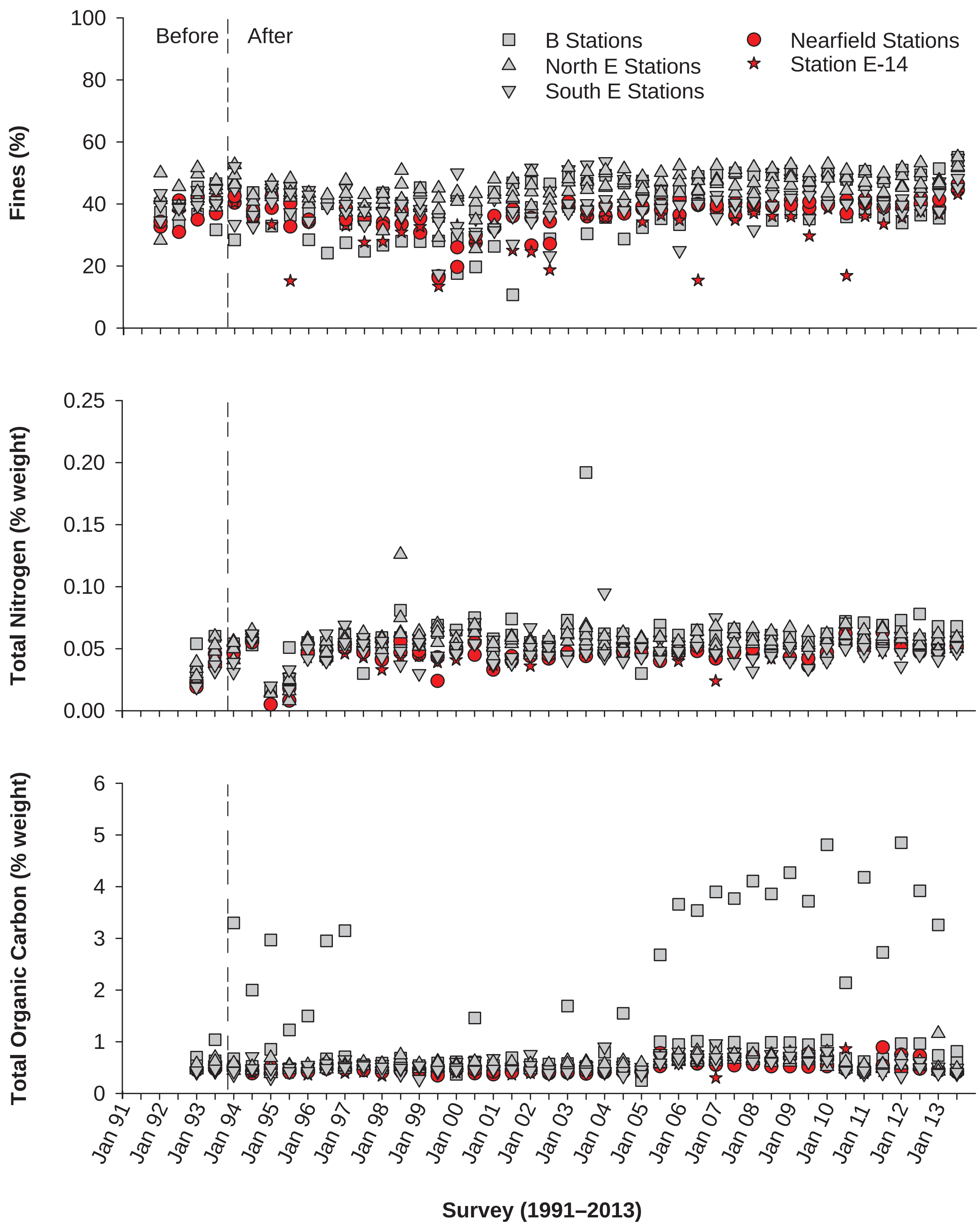
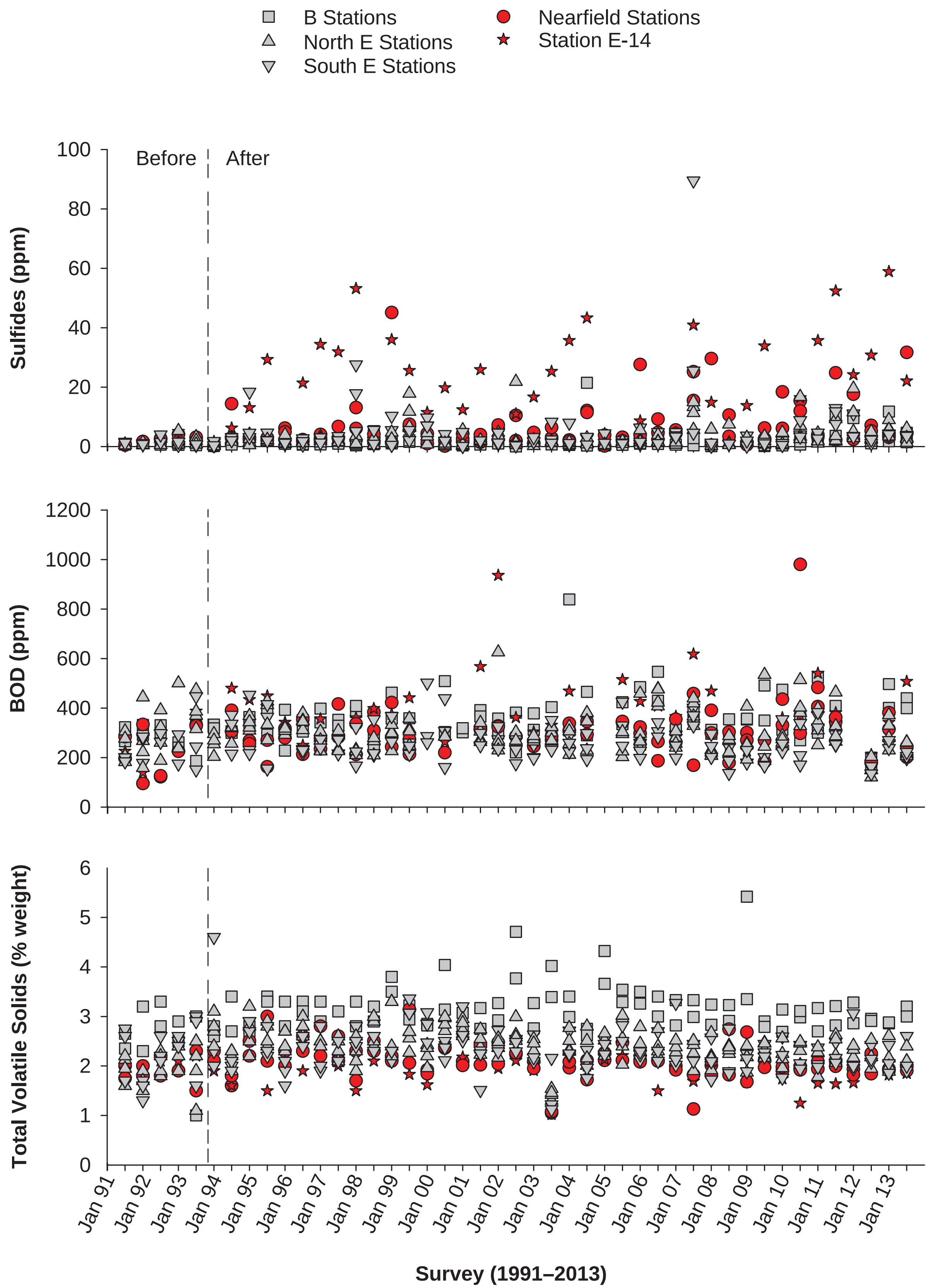


Figure 4.4

Percent fines and concentrations of organic indicators in sediments from PLOO primary core stations sampled from 1991 through 2013. Data represent detected values from each station, n≤12 samples per survey. Dashed lines indicate onset of discharge from the PLOO.



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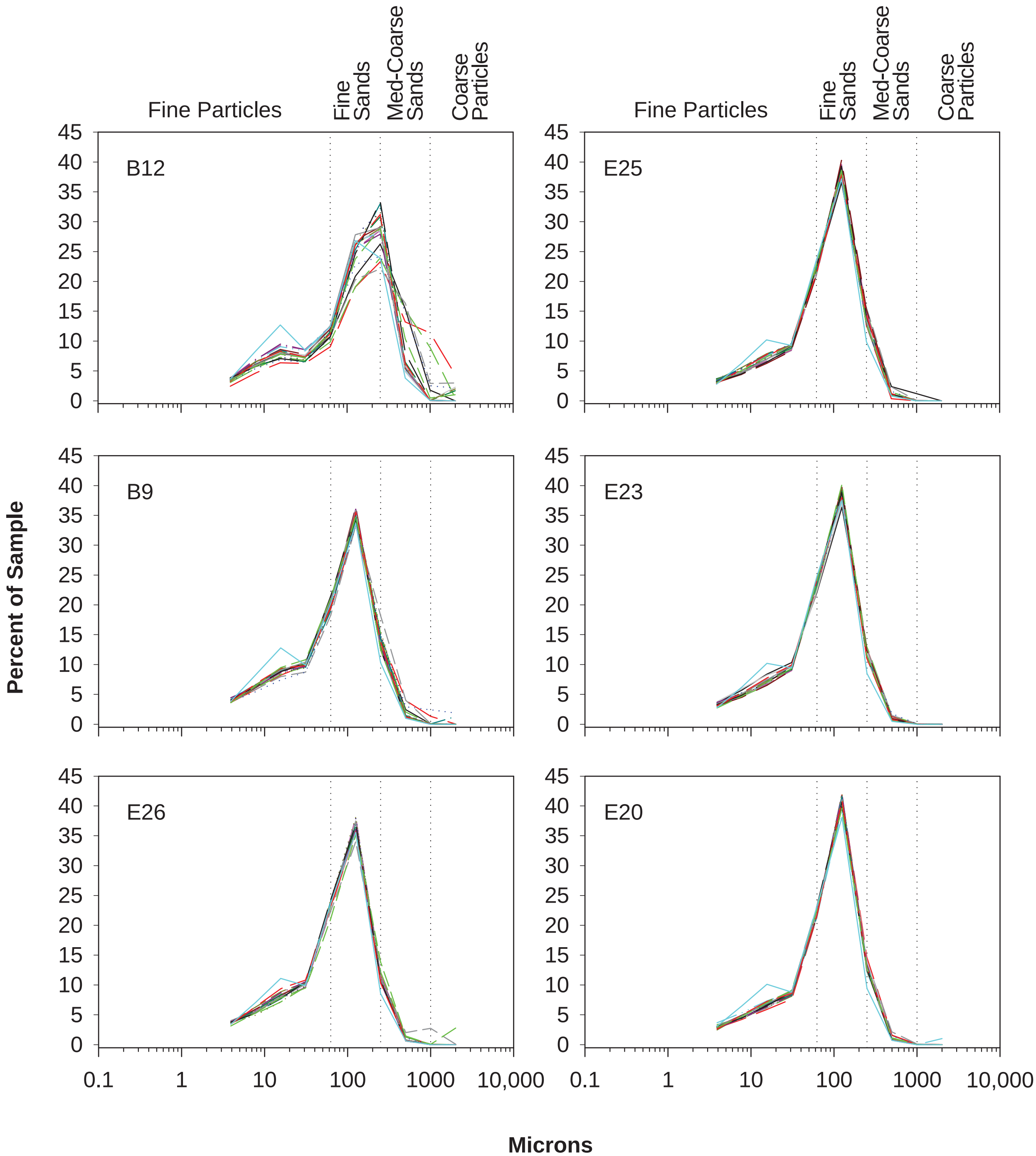

Figure 4.5

Historical particle size distributions in sediments collected from PLOO primary core stations sampled from 2004 through 2013. Each line represents an individual survey.

HCB, and <1% for dieldrin, endrin, chlordane, and tHCH. Aldrin, endosulphan, and mirex have never been found in sediments around the PLOO. Additionally, pesticide concentrations have been consistently low, with tDDT exceeding its ERL in just 12% of the samples collected. Total DDT and total chlordane concentrations have also been below values reported previously for the SCB (e.g., Schiff et al. 2011). Finally, DDT demonstrated no discernible long-term patterns that could be associated with proximity to the outfall or the onset of wastewater discharge

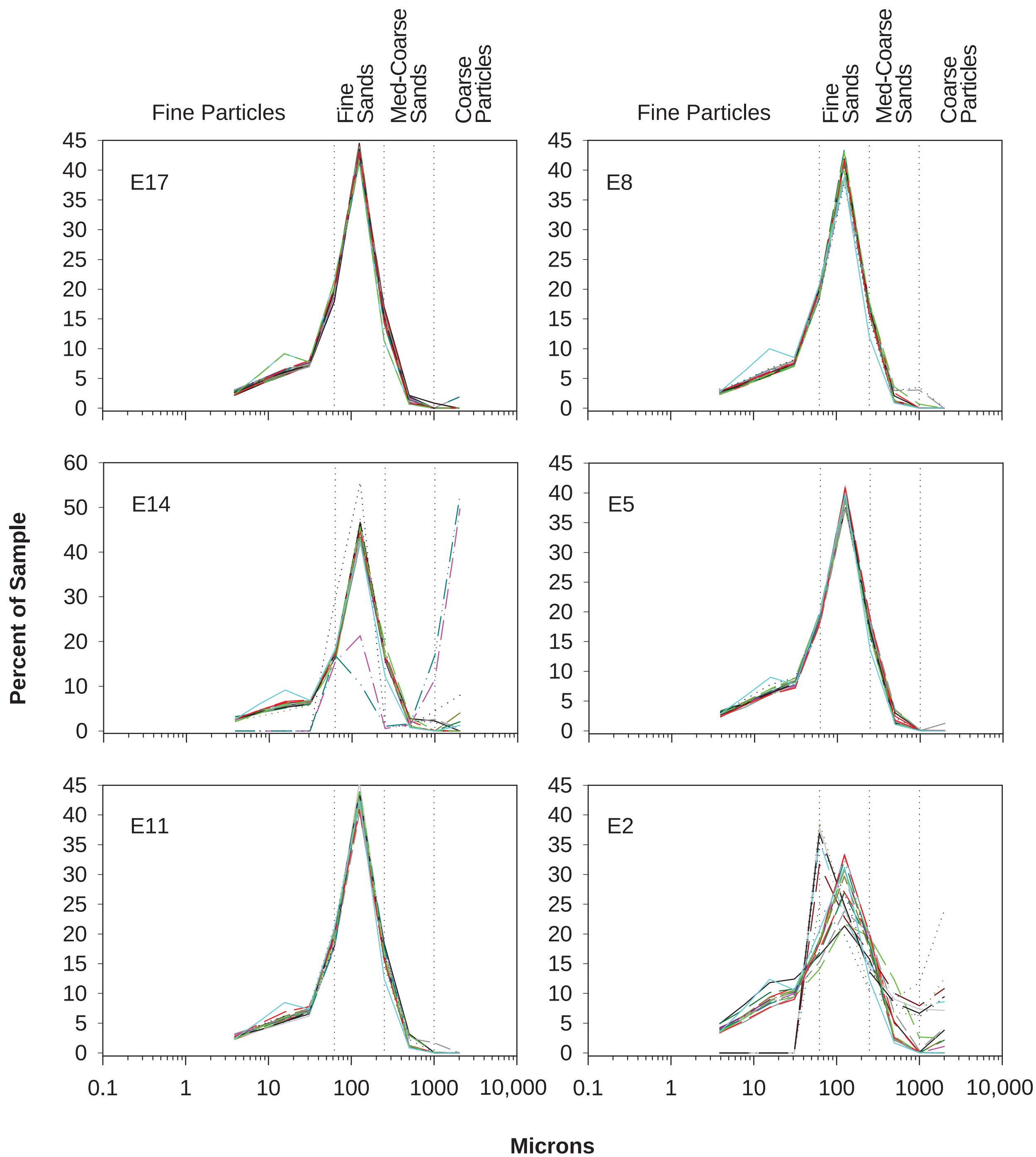

Figure 4.5 *continued*

(e.g., Figure 4.7). Instead, relatively high concentrations of tDDT occurred most frequently at outfall depth stations B9, E2, and E8.

PCBs

PCBs were detected in 35% of the sediment samples collected around the PLOO in 2013 (Table 4.1). Total PCB had a maximum concentration of 5210 ppt, reported from station E3 during the summer (Appendix C.8). The most commonly detected PCB congeners that occurred in 12–26% of the samples were PCB 70, PCB 110, PCB 138, PCB 149, and PCB 153/168 (Appendix C.3). Although no ERL or ERM thresholds exist for PCBs measured as congeners, all PCB values

Table 4.2

Summary of particle sizes and chemistry concentrations in sediments from PLOO primary core stations sampled from 1991 through 2013. Data include detection rates (DR), minimum, median, maximum, and mean values for all samples collected (n ≤ 998 samples). Detection rates are also provided for samples collected from 2004 through 2013 (n ≤ 240) to show how they have changed over the past 10 years. See Table 4.1 for ERL and ERM details.

	Detection Rate		Concentrations (all years)[a]				% Exceedances	
Parameter	**All years**	**2004–2013**	**Mean**	**Min**	**Median**	**Max**	**ERL**	**ERM**
Particle Size								
Coarse Particles (%)	26	15	1.3	0	0.0	64.2	na	na
Med-Coarse Sands (%)	93	100	3.4	0	1.1	90.6	na	na
Fine Sands (%)	99	100	55.7	0	56.6	87.1	na	na
Fines (%)	99	100	39.0	0	39.9	74.4	na	na
Organic Indicators								
BOD (ppm)	100	100	301	nd	292	980	na	na
Sulfides (ppm)	93	97	5.4	nd	2.0	127.0	na	na
TN (% weight)	98	100	0.051	nd	0.052	0.192	na	na
TOC (% weight)	100	100	0.64	0.13	0.52	4.85	na	na
TVS (% weight)	100	100	2.39	1.00	2.31	5.42	na	na
Trace Metals (ppm)								
Aluminum	100	100	9833	3130	9545	23,200	na	na
Antimony	25	57	2.68	nd	nd	16.40	na	na
Arsenic	100	100	3.1	1.0	3.0	7.9	0	0
Barium	100	100	38.1	10.3	34.3	155.0	na	na
Beryllium	38	65	0.510	nd	nd	3.060	na	na
Cadmium	39	92	0.85	nd	nd	6.10	9	0
Chromium	100	100	17.1	7.0	16.4	43.6	0	0
Copper	100	100	8.1	1.3	7.3	82.4	0	0
Iron	100	100	13,163	4840	12,100	27,200	na	na
Lead	45	100	5.91	nd	nd	67.60	0	0
Manganese	100	100	104.0	31.5	93.1	317.0	na	na
Mercury	49	100	0.030	nd	nd	0.093	0	0
Nickel	96	100	7.44	nd	7.23	29.00	0	0
Selenium	60	19	0.25	nd	0.18	0.90	na	na
Silver	12	39	1.30	nd	nd	7.60	5	1
Thallium	6	13	14.63	nd	nd	113.00	na	na
Tin	43	99	1.96	nd	nd	42.00	na	na
Zinc	100	100	28.8	12.4	27.7	176.0	0	0

na = not available; nd = not detected; [a]Minimum, median, and maximum values were calculated based on all samples, whereas means were calculated on detected values only

recorded during the year were within ranges reported previously for the SCB (e.g., Schiff et al. 2011). Historically, PCBs have been detected in just 11% of the sediment samples collected in the PLOO region since the City started reporting the data as congeners in July 1998 (Table 4.2). Concentrations of tPCB in sediments from outfall depth stations have been highly variable over these past 17 years, with no patterns indicative of an outfall impact evident (Figure 4.7). Instead, PCBs have been detected most frequently at the southern 'E' stations (see Discussion below).

Table 4.2 *continued*

Parameter	Detection Rate All years	Detection Rate 2004–2013	Concentrations (all years)[a] Mean	Min	Median	Max	% Exceedances ERL	ERM
Pesticides (ppt)								
Dieldrin	<1	<1	270	nd	nd	270	na	na
Endrin aldehyde	<1	<1	970	nd	nd	970	na	na
HCB	4	13	406	nd	nd	1900	na	na
Total DDT	53	65	1417	nd	190	44,830	12	0
Total Chlordane	<1	1	767	nd	nd	2000	na	na
Total HCH	<1	<1	370	nd	nd	370	na	na
Total PCB (ppt)	11	18	2196	nd	nd	35,690	na	na
Total PAH (ppb)	17	48	146.2	nd	nd	3062.6	0	0

na = not available; nd = not detected; [a] Minimum, median, and maximum values were calculated based on all samples, whereas means were calculated on detected values only

PAHs

PAHs were detected in 53% of the sediment samples collected from the Point Loma outfall region in 2013 (Table 4.1). These samples were all collected during July, from all but four stations (Appendix C.8). Concentrations of total PAH reached 222.6 ppb during the past year, slightly 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). Individual PAHs detected during the year included 2,6-dimethylnaphthalene, 3,4-benzo(B)fluoranthene, anthracene, benzo[A]pyrene, benzo[e]pyrene, benzo[G,H,I]perylene, benzo[K]fluoranthene, chrysene, fluoranthene, indeno(1,2,3-CD)pyrene, perylene, phenanthrene, and pyrene (Appendix C.3). Over the past 23 years, the detection rate for tPAH was just 17% with all reported values below the ERL (Table 4.2), and there have been no patterns indicative of a wastewater impact at the outfall depth stations (Figure 4.7). As with PCBs, PAHs have been detected most frequently at the southern 'E' stations (see Discussion below).

Discussion

Particle size composition at the PLOO stations was similar in 2013 to that reported during recent years (City of San Diego 2007–2013), 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 nearfield 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, City of San Diego 2007, Parnell et al. 2008). 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 trace metals, pesticides, PCBs, PAHs, and organic loading indicators were detected in sediment samples collected throughout the PLOO region in 2013, with highly variable concentrations. Although some contaminants were detected at higher concentrations than during the pre-discharge

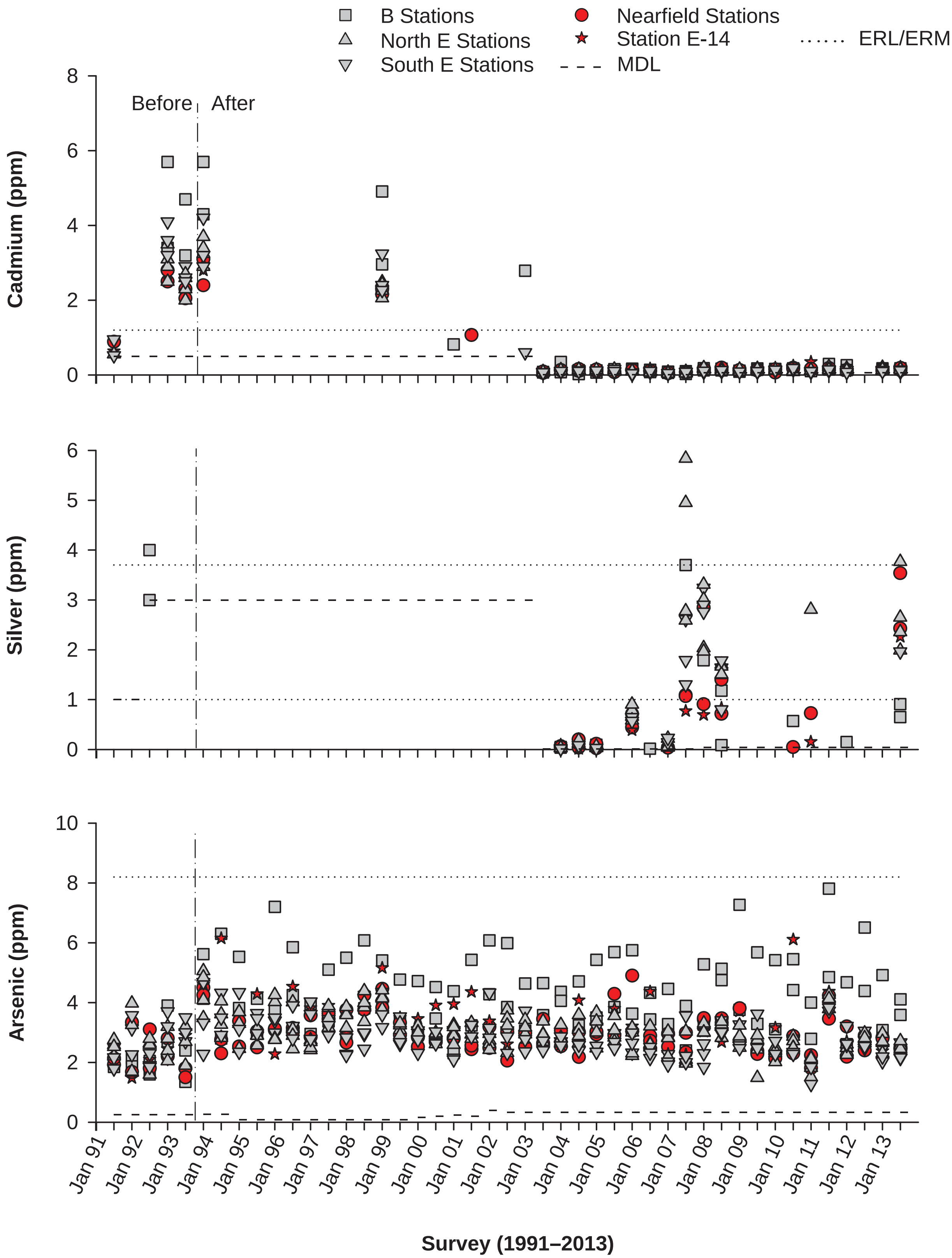

Figure 4.6

Concentrations of select metals in sediments from PLOO primary core stations sampled from 1991 through 2013. Data represent detected values from each station, n≤12 samples per survey. Dashed lines indicate onset of discharge from the PLOO. See Table 4.1 for values of ERLs and ERMs.

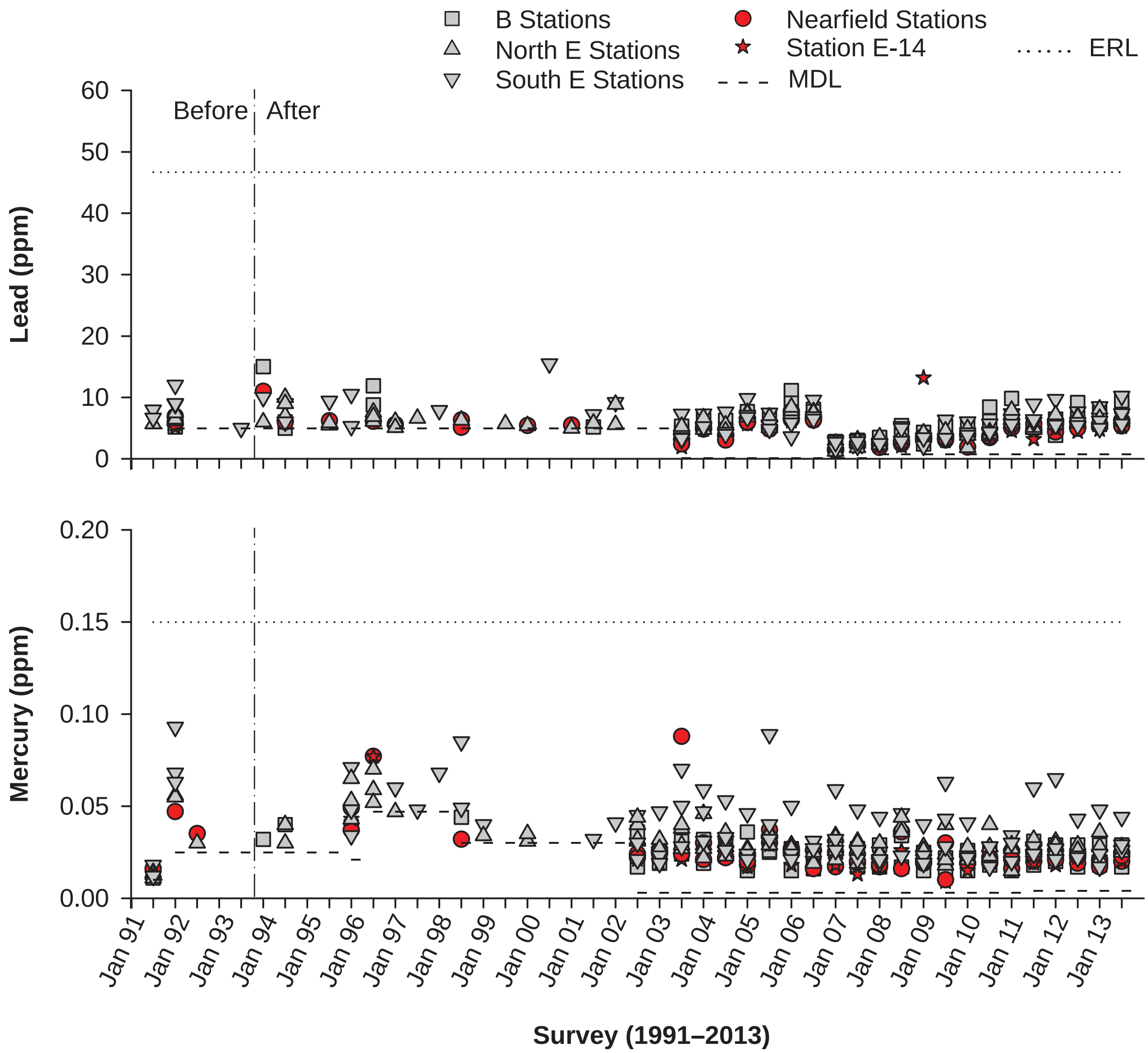

Figure 4.6 *continued*

period, there were very few exceedances of either ERL or ERM thresholds. 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 four nearfield 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 2007–2013). 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 2007–2013). 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

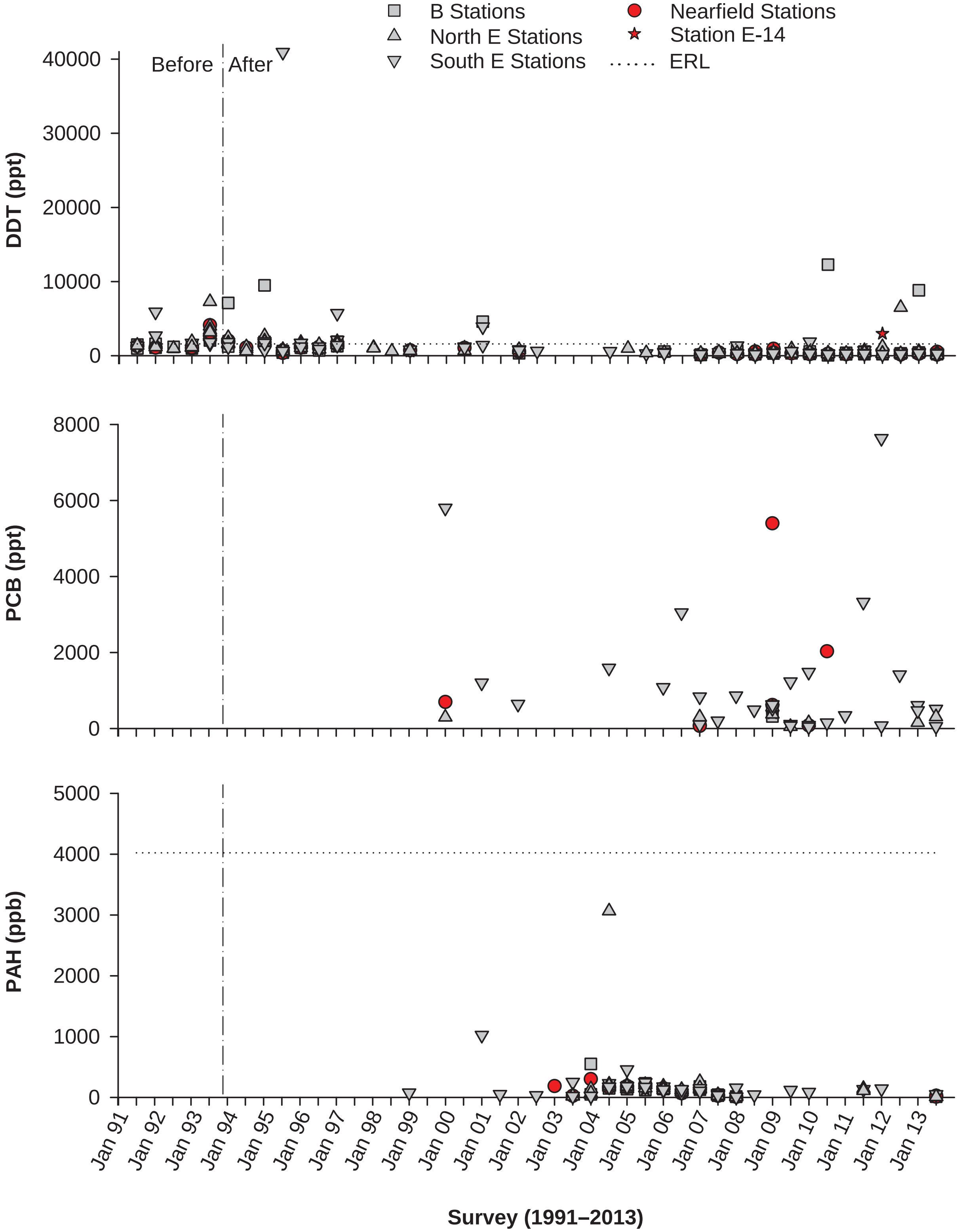

Figure 4.7

Concentrations of total DDT, total PCB, and total PAH in sediments from PLOO primary core stations sampled from 1991 through 2013. Data represent detected values from each station, n≤12 samples per survey. Dashed lines indicate onset of discharge from the PLOO. See Table 4.1 for values of ERLs.

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). Further, historical assessments of sediments off of Los Angeles have shown that as wastewater treatment has improved, sediment conditions are more likely affected by other factors (Stein and Cadien 2009). 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 20 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 2007, City of San Diego 2013). 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 and E17). These effects include measurable increases in sulfide and BOD concentrations (City of San Diego 2007). 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) collects small invertebrates (macrofauna) that live within or on the surface of soft-bottom habitats to examine potential effects of wastewater discharge on the marine benthos around the Point Loma Ocean Outfall (PLOO). These benthic macrofauna are targeted for monitoring because they are known to play critical ecological roles in marine environments along the Southern California Bight (SCB) coastal shelf (Fauchald and Jones 1979, Thompson et al. 1993a, Snelgrove et al. 1997). Additionally, because many benthic species are relatively stationary and long-lived, they integrate the effects of pollution or disturbance over time (Hartley 1982, Bilyard 1987). The response of many species to environmental stressors is well documented, and monitoring changes in discrete populations or more complex communities can help identify locations experiencing anthropogenic impacts (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). For example, pollution-tolerant species are often opportunistic and can displace others in impacted environments. In contrast, populations of pollution-sensitive species decrease in response to toxic contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation (Gray 1979). For these reasons, the assessment of benthic community structure has become a major component of many ocean monitoring programs.

The structure of marine macrobenthic communities is naturally influenced by factors such as ocean depth, sediment composition (e.g., percent of fine versus coarse sediments), sediment quality (e.g., contaminant loads, toxicity), oceanographic conditions (e.g., temperature, dissolved oxygen, nutrient levels, currents) and biological interactions (e.g., competition, predation, bioturbation). On the SCB coastal shelf, assemblages typically vary along depth gradients and/or with sediment particle size (Bergen et al. 2001); therefore, an understanding of natural background or reference conditions provides the context necessary to identify whether spatial differences in community structure are likely attributable to anthropogenic activities. Off the coast of San Diego, past monitoring efforts for both shelf and upper slope habitats have led to considerable understanding of regional environmental variability (City of San Diego 1999, 2013a, b, Ranasinghe et al. 2003, 2007, 2010, 2012). These efforts allow for spatial and temporal comparison of the current year's monitoring data with past surveys to determine if and where changes due to wastewater discharge have occurred.

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

This chapter presents analyses and interpretations of macrofaunal data collected at designated benthic

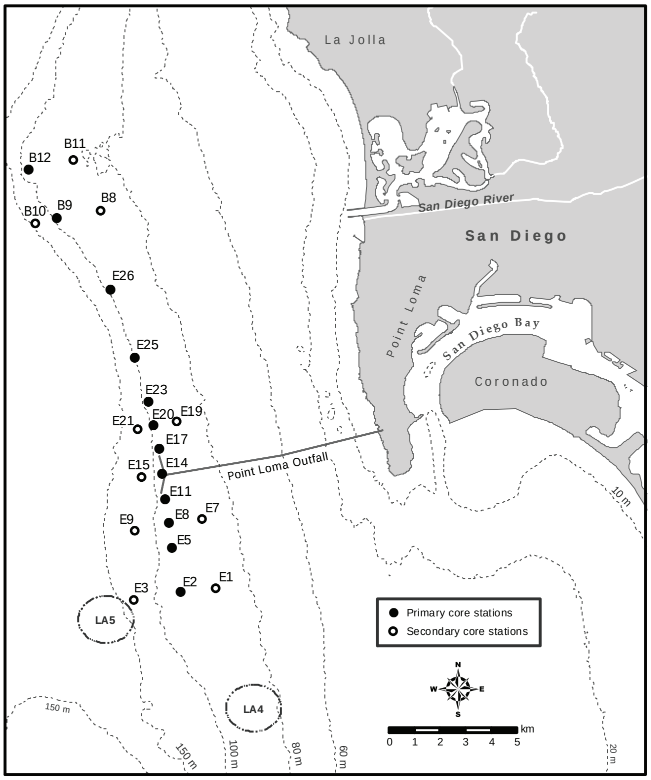


Figure 5.1
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

monitoring stations surrounding the PLOO during 2013, and includes descriptions and comparisons of the different invertebrate communities in the region. The primary goals are to: (1) document the benthic assemblages present during the year, (2) determine the presence or absence of biological impacts associated with wastewater discharge, and (3) identify other potential natural and anthropogenic sources of variability in the local marine ecosystem.

Materials and Methods

Collection and Processing of Samples

Benthic samples were collected at 12 primary core stations in the PLOO region during winter (January) and summer (July) 2013, and at an additional 10 secondary stations during the summer survey (Figure 5.1). These latter 10 stations were not sampled during the winter as part of a resource exchange agreement for the 2012 sediment mapping project (see Chapter 1). All 22 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 sites include 17 ‘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 four stations considered to represent “nearfield” conditions (i.e., E11, E14, E15 and E17) are located within 1000 m of the outfall diffuser structure.

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 the winter survey of the primary core stations, a second macrofaunal grab was collected from a subsequent cast; the second replicate was not collected during the summer as part of the Bight’13 resource exchange agreement (see Chapter 1). Criteria established by the USEPA to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen. Macrofaunal organisms retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution and then fixed with buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All macrofauna were sorted from the raw material into major taxonomic groups by a subcontractor and then identified to species (or the lowest taxon possible) and enumerated by City marine biologists. All identifications followed nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT 2013).

Data Analyses

Each grab sample was considered an independent replicate for analysis. 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). Comparisons to tolerance intervals were based on data from the randomized regional stations sampled from 1994 through 2003 (City of San Diego 2007).

To further examine spatial and temporal patterns among benthic communities in the PLOO region, multivariate analyses were conducted on macrofaunal grabs that had a corresponding sediment sample. These analyses were performed using PRIMER and 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 and Warwick 2001, Clarke and Gorley 2006, Clarke et al. 2008). Only data from the primary core stations were included in this year's analysis since no secondary core stations were sampled during the winter survey. 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 organisms were responsible for the greatest contributions to within-group similarity (i.e., characteristic species) and between-group dissimilarity for retained clusters. To determine whether macrofaunal communities varied by sediment particle size fractions, a RELATE test was used to compare patterns of rank abundance in the macrofauna Bray-Curtis similarity matrix with rank abundance in the sediment Euclidean distance matrix (see Chapter 4). When significant similarity was found, a BEST test using the BIO-ENV procedure was conducted to determine which subset of sediment subfractions 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 20 years (59 quarterly or semi-annual surveys) of after-impact data from January 1994–July 2013. 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 Zone of Initial Dilution (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 446 taxa were identified during the 2013 PLOO surveys. Of these, 363 (81%) were identified

Table 5.1

Summary of macrofaunal community parameters for PLOO benthic stations sampled during 2013. 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 = 3 grabs for 98-m stations, n = 1 for 88-m and 116-m stations). 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	111	394	3.8	0.80	35	11
	B8	66	213	3.3	0.80	22	11
	E19	80	330	3.5	0.79	21	14
	E7	70	310	3.2	0.76	17	12
	E1	83	366	3.4	0.78	20	13
98-m Depth Contour	B12	101	302	3.9	0.86	40	14
	B9	80	241	3.9	0.88	31	9
	E26	79	265	3.8	0.87	28	15
	E25	91	313	3.8	0.84	29	16
	E23	81	320	3.6	0.82	24	13
	E20	85	355	3.6	0.81	21	18
	E17[a]	91	434	3.8	0.84	26	19
	E14[a]	115	601	3.8	0.80	29	22
	E11[a]	90	378	3.8	0.85	29	18
	E8	87	349	3.8	0.85	29	14
	E5	99	431	3.9	0.85	31	14
	E2	102	380	3.9	0.86	36	13
116-m Depth Contour	B10	106	377	3.9	0.84	36	21
	E21	76	368	3.3	0.77	18	13
	E15[a]	101	421	3.8	0.82	29	11
	E9	138	558	4.3	0.87	46	12
	E3	143	518	4.5	0.90	53	11
All Grabs	Mean	93	369	3.8	0.84	29	15
	95% CI	6	34	0.1	0.01	2	1
	Min	54	124	3.2	0.76	15	3
	Max	143	701	4.5	0.92	53	25

[a] nearfield station

to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although 21% (n = 109) were recorded only once. One likely new species not previously reported by the City's Ocean Monitoring Program was encountered, the nemertean Hoplonemertea sp C.

Mean species richness ranged from 66 taxa per grab at station B8 located 9.8 km north of the outfall wye to 143 taxa per grab at station E3 located 4.2 km south of the wye (Table 5.1). No clear patterns relative to the discharge site, depth, or sediment particle size were observed. Species richness was within the range of 33–174 taxa per grab reported from 1991 through 2012 (Appendix D.1), and 89% of grabs were within the tolerance interval range of 72–175 taxa per grab calculated for the region (City of San Diego 2007). Five grabs with values below tolerance interval bounds occurred

Table 5.2
Results of BACIP t-tests for species richness (SR), infaunal abundance, BRI, and abundance of several indicator taxa around the PLOO (1991–2013). Critical t-value = 1.680 for $\alpha = 0.05$ (one-tailed t-tests, df = 67); ns = not significant.

Variable	Control vs. Impact	t	*p*
SR	E26 vs E14	-3.31	< 0.001
	B9 vs E14	-3.31	< 0.001
Abundance	E26 vs E14	-1.74	0.043
	B9 vs E14	-2.81	0.003
BRI	E26 vs E14	-13.53	< 0.001
	B9 vs E14	-9.84	< 0.001
Amphiodia spp	E26 vs E14	-6.35	< 0.001
	B9 vs E14	-4.24	< 0.001
Ampelisca spp	E26 vs E14	-2.22	0.015
	B9 vs E14	-1.7	0.047
Rhepoxynius spp	E26 vs E14	-0.59	ns
	B9 vs E14	-0.56	ns

at farfield stations located 1.2–9.8 km away from the outfall.

BACIP t-test results indicated a net change in the mean difference of species richness between impact station E14 and both control stations since the onset of wastewater discharge (Table 5.2). This change is driven by increased variability and higher numbers of species at E14 beginning in 1997 (Figure 5.2A); however, the cause of increased species richness near the discharge site remains unclear. For example, although minor organic enrichment occurs at station E14 (see Appendix C.4), no similarity in pattern between concentration of organics and species richness was apparent (Appendix D.2). Additionally, sediment particle size fractions at station E14 are similar to those from stations located 2–4 km away from the outfall wye (see Figure 4.2 in Chapter 4), and not likely the cause of species richness differences.

Macrofaunal abundance

A total of 16,961 macrofaunal individuals were identified in 2013. Mean abundance ranged from 213 animals per grab at station B8 (the same farfield station where mean species richness was also lowest) to 601 per grab at nearfield station E14 (Table 5.1). The high value reflects a relatively large population of the indicator polychaete *Capitella teleta* (considered within the *Capitella capitata* species complex) that occurred in both grabs from E14 during the winter survey. However, the 90–140 individuals of *C. teleta* present in these two samples are not, by themselves, indicative of a highly disturbed habitat (see discussion in Indicator Species, below). Overall, no other spatial patterns in abundance related to discharge site, depth or sediment particle size were observed. During the past year, abundance at all stations was within the range of 70–1509 individuals per grab reported from 1991 through 2012 (Appendix D.1). Eighty-seven percent of grabs were within the tolerance interval range of 230–671 individuals per grab calculated for the region (City of San Diego 2007). Five grabs with values below tolerance interval bounds occurred at farfield stations located 3.9–12.0 km away from the outfall, while one value above occurred in a grab at nearfield station E14.

BACIP t-test results indicated a net change in macrofaunal abundance between impact station E14 and both control stations since the onset of wastewater discharge (Table 5.2). Historical trends in abundance differ among all three stations, particularly from 1999 onward; however, differences typically appear less between stations E14 and E26 than between E14 and B9 (Figure 5.2B). As with species richness, the cause of increased abundance near the discharge site remains unclear but with no apparent link to organics or sediment particle size (Appendices C.4, D.2).

Species diversity, evenness, and dominance

Shannon diversity (H') index values averaged from 3.2 to 4.5 per grab for each station while mean evenness (J') ranged from 0.76 to 0.90 per grab, indicating that local benthic communities remain characterized by relatively diverse assemblages of evenly distributed species (Table 5.1). No patterns relative to wastewater discharge, depth, or sediment particle size were evident. The lowest values for both parameters co-occurred at farfield station E7, while the highest values co-occurred at farfield station E3. These stations were located 1.6 km and

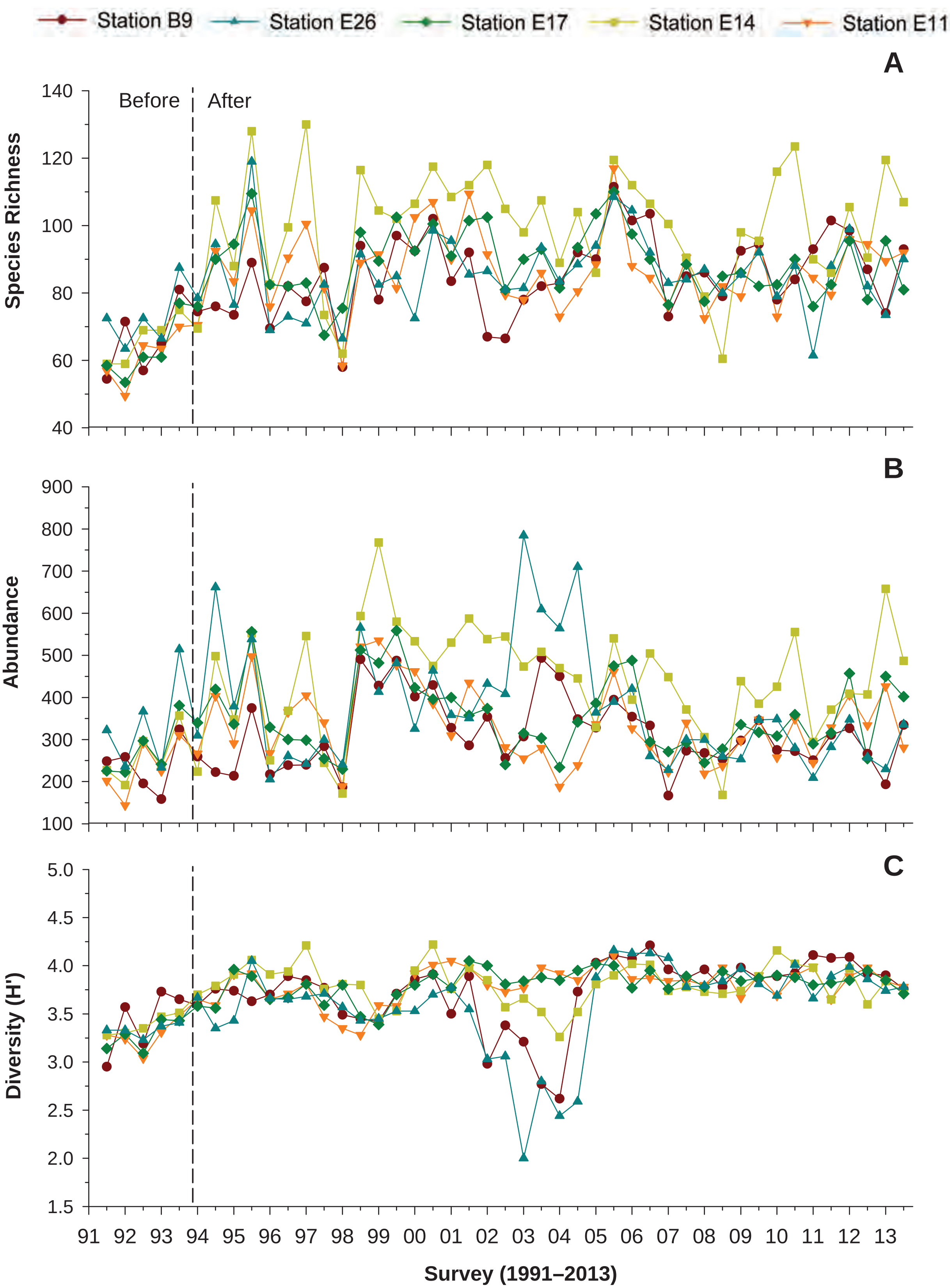


Figure 5.2

Comparison of community parameters at PLOO nearfield stations E11, E14 and E17, and farfield stations E26 and B9 sampled from 1991 through 2013. 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 when n=1). Dashed lines indicate onset of wastewater discharge.

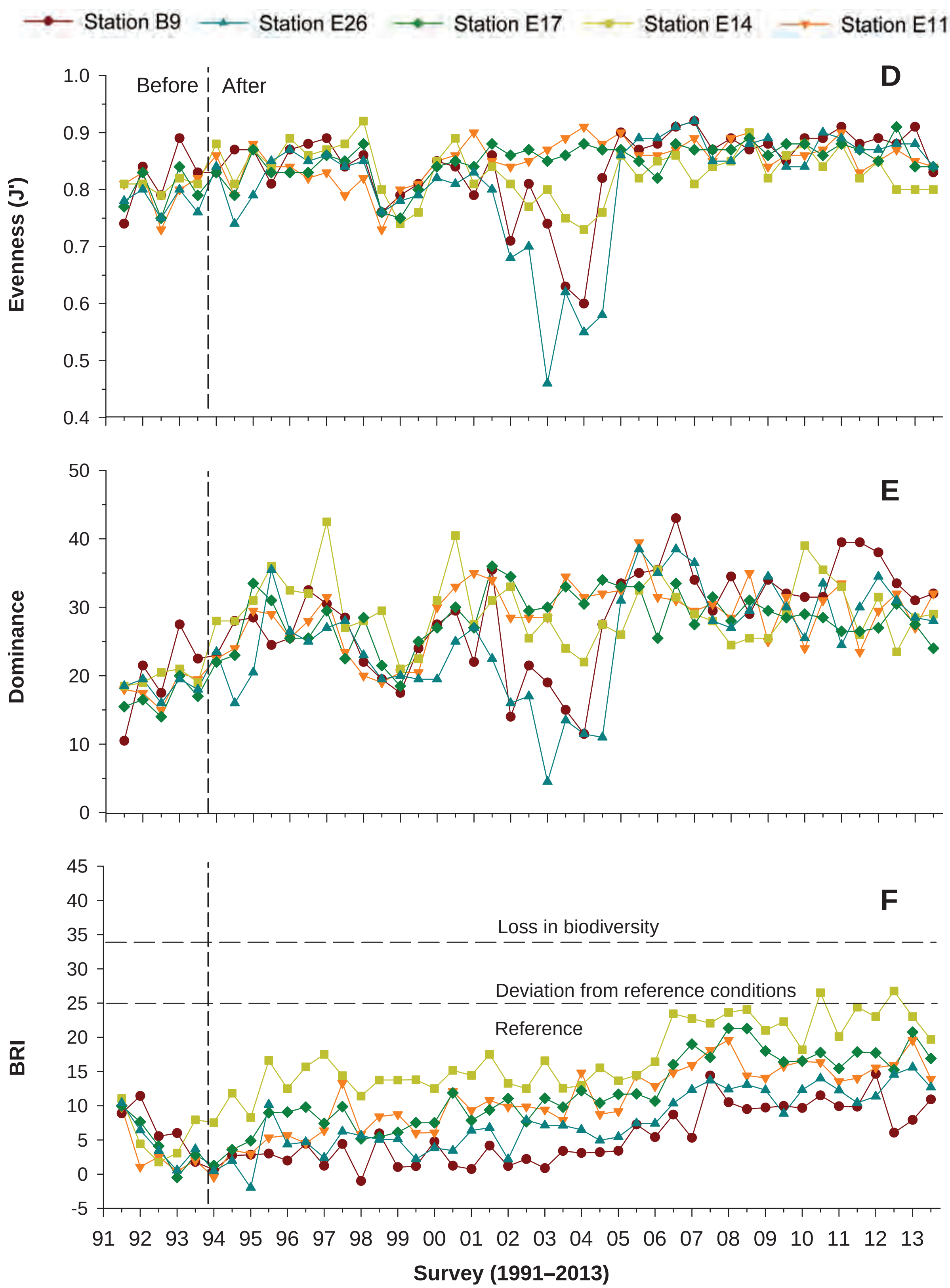


Figure 5.2 *continued*

4.2 km south of the outfall, respectively. During the past year, diversity and evenness were similar to historical values with the exception of relatively low values associated with high densities of the ophiuroid *Amphiodia urtica* at stations B9 and E26 from 2002 through 2005 (Figures 5.2C, D, 5.3). Ninety-one percent of grabs were within the tolerance interval range of 3.4–4.3 for diversity, and 76% of grabs were within the tolerance interval range of 0.75–0.86 for evenness (Appendix D.1) (City of San Diego 2007). Four farfield grabs located 1.2–9.8 km away from the outfall had diversity below tolerance interval bounds, while one farfield grab located 4.2 km away from the outfall had diversity above (Appendix D.1) (City of San Diego 2007). Eleven grabs located 1.1–12.0 km away from the outfall had evenness above 0.86.

Swartz dominance averaged from 17 to 53 taxa per grab for each station with the lowest dominance (highest index value) occurring at farfield station E3 and the highest dominance (lowest index value) occurring at farfield station E7, the same southern stations that had lowest and highest diversity and evenness (Table 5.1). No patterns relative to wastewater discharge, depth, or sediment particle size were evident. During the past year, index values at all stations were within the range of 1–69 taxa per grab reported from 1991 through 2012 (Appendix D.1). In addition, 96% of grabs were within the tolerance interval range of 7–44 per grab calculated for the region (Appendix D.1) (City of San Diego 2007). The two grabs with values above tolerance interval bounds occurred at farfield stations located 1.7–4.2 km away from the outfall.

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 2013, 98% of the individual benthic samples collected off Point Loma were characteristic of reference conditions (Appendix D.1). Only a single grab collected at near-ZID station E14 during the winter had a BRI score indicative of perhaps a minor deviation in benthic condition (BRI = 25), and this value was due primarily to slightly higher numbers of *Capitella teleta* present during this survey (Figure 5.4). Additionally, no stations sampled during the year had mean BRI values >22 per grab (Table 5.1), further indicating that benthic conditions at stations across the region remain relatively undisturbed. Although most primary core stations within about 1 km of the discharge zone (i.e., E11, E14, E17, and E20) 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 since 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 (*Amphiodia urtica*) populations as well as temporary increases in populations of opportunistic species such as *Capitella teleta*. Although these data suggest an outfall related pattern, the effect appears minor and restricted to the ZID boundary sampling site.

Species of Interest

Dominant taxa

Polychaete worms were the dominant taxonomic group found in the PLOO region in 2013 and accounted for 54% of all taxa collected (Table 5.3). Crustaceans accounted for 23% of taxa reported, while molluscs, echinoderms, and all other taxa combined each contributed to ≤13% of mean total invertebrate composition. Polychaetes were also the most numerous animals, accounting for 52% of the total abundance. Crustaceans accounted for 25% of the animals collected, while molluscs, echinoderms, and all other taxa combined each contributed to ≤12% of mean total abundance. Overall, the percentage of taxa that occurred within each of the above major taxonomic groupings and their relative abundances were similar to those observed in 2012 and have remained consistent since monitoring began in 1991 (City of San Diego 1995, 2013a).

The 10 most abundant species in 2013 included five polychaetes, two arthropods, two echinoderms, and one mollusc (Table 5.4). The numerically dominant polychaetes included the amphinomid *Chloeia pinnata*, the spionid *Prionospio* (*Prionospio*) *jubata*, the cirratulid *Chaetozone hartmanae*, the capitellid *Mediomastus* sp, and the lumbrinerid *Lumbrineris* sp GROUP I[1]. The dominant crustaceans included the ostracods *Euphilomedes carcharodonta* and *E. producta*, while the ophiuroids *Amphiodia urtica* and *Amphiodia* sp[2] were the dominant echinoderms. The dominant mollusc was the bivalve *Tellina carpenteri*. *Amphioida urtica* was the most abundant species overall, accounting for ~7% of all invertebrates collected, and occurring in 98% of grabs with a mean abundance of ~24 individuals per grab. Of the 10 most abundant species, the most widely distributed were *Prionospio* (*Prionospio*) *jubata* and *Chaetozone hartmanae,* both of which occurred in 100% of samples.

With the exceptions of *Tellina carpenteri* and *Amphiodia* sp, the most abundant species in 2013 were also among the most abundant collected in 2012 (City of San Diego 2013a). Populations of these species typically were within historical ranges reported since 1991 (Figure 5.3); however, unprecedentedly high numbers of *Chloeia pinnata* were recorded from stations B11, B12, E2, and E14 where abundances ranged from 71–104 individuals per grab. Populations of *C. pinnata* equivalent to about 480 individuals per 0.1 m^2 grab have been reported previously in healthy environments of the SCB (Jones and Thompson 1987), and the high abundances of this species during 2013 probably represent a natural population cycle not related to wastewater discharge. Abundances of *Prionospio* (*Prionospio*) *jubata* have also been higher during the past two years compared to most previous years (with the exception of 2005–2007), suggesting a possible resurgence of this species.

[1]*Lumbrineris* sp GROUP I likely represents unidentifiable juvenile specimens or anterior fragments of adult *L. cruzensis* that are missing necessary diagnostic characters.

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

Historically abundant species that did not occur in high densities during 2013 include the oweniid polychaete *Myriochele striolata*, the terebellid polychaetes *Phisidia sanctaemariae* and *Proclea* sp A, and the spionid polychaete *Spiophanes duplex*. *Myriochele striolata* had a population spike from 2001 through 2005 (Appendix D.3), while *P. sanctaemariae* and *P.* sp A spiked from 1998–2000 or exhibited variable population densities over time, respectively (Appendix D.3, Figure 5.4). Populations of *S. duplex* have varied since monitoring began in 1991. Although untested, it is hypothesized that population fluctuations of these species may either follow cyclical “boom and bust” patterns that take years or decades to complete, or may be linked to undetermined natural environmental parameters such as ocean warming and cooling cycles (e.g., *P. sanctaemariae* and *S. duplex* populations were possibly influenced by the strong El Niño in 1998; see Chapter 2).

Indicator species

Several species known to be useful indicators of environmental change that occur in the PLOO region include the polychaetes *Capitella teleta* and *Proclea* sp A, amphipods in the genera *Ampelisca* and *Rhepoxynius*, the bivalve *Solemya pervernicosa*, and the ophiuroid *Amphiodia urtica.* 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 2013, indicator species with similar abundances at nearfield and farfield stations included *Proclea* sp A, *Ampelisca* spp and *Rhepoxynius* spp (Figure 5.4). Abundances of these species have followed similar patterns across the region since monitoring began, which suggests little to no impact associated with the outfall discharge. The results of the BACIP analysis examining mean differences of

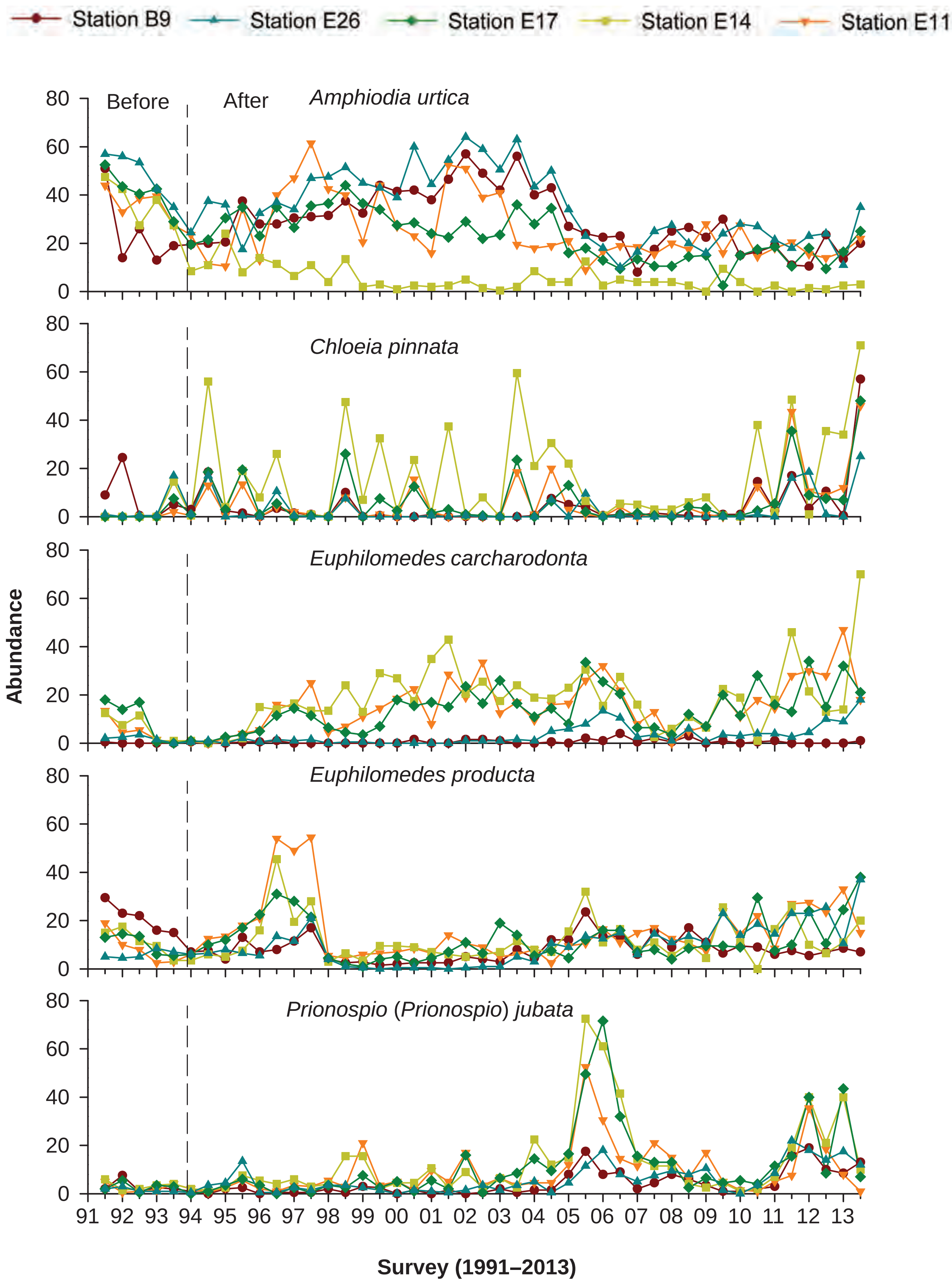


Figure 5.3
Historical abundances of the five most numerically dominant taxa (presented in order) recorded during 2013 at PLOO nearfield stations E11, E14, and E17 and farfield stations E26 and B9. Data for each station are expressed as means per grab (n = 2 except for summer 2013 when n = 1). Dashed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

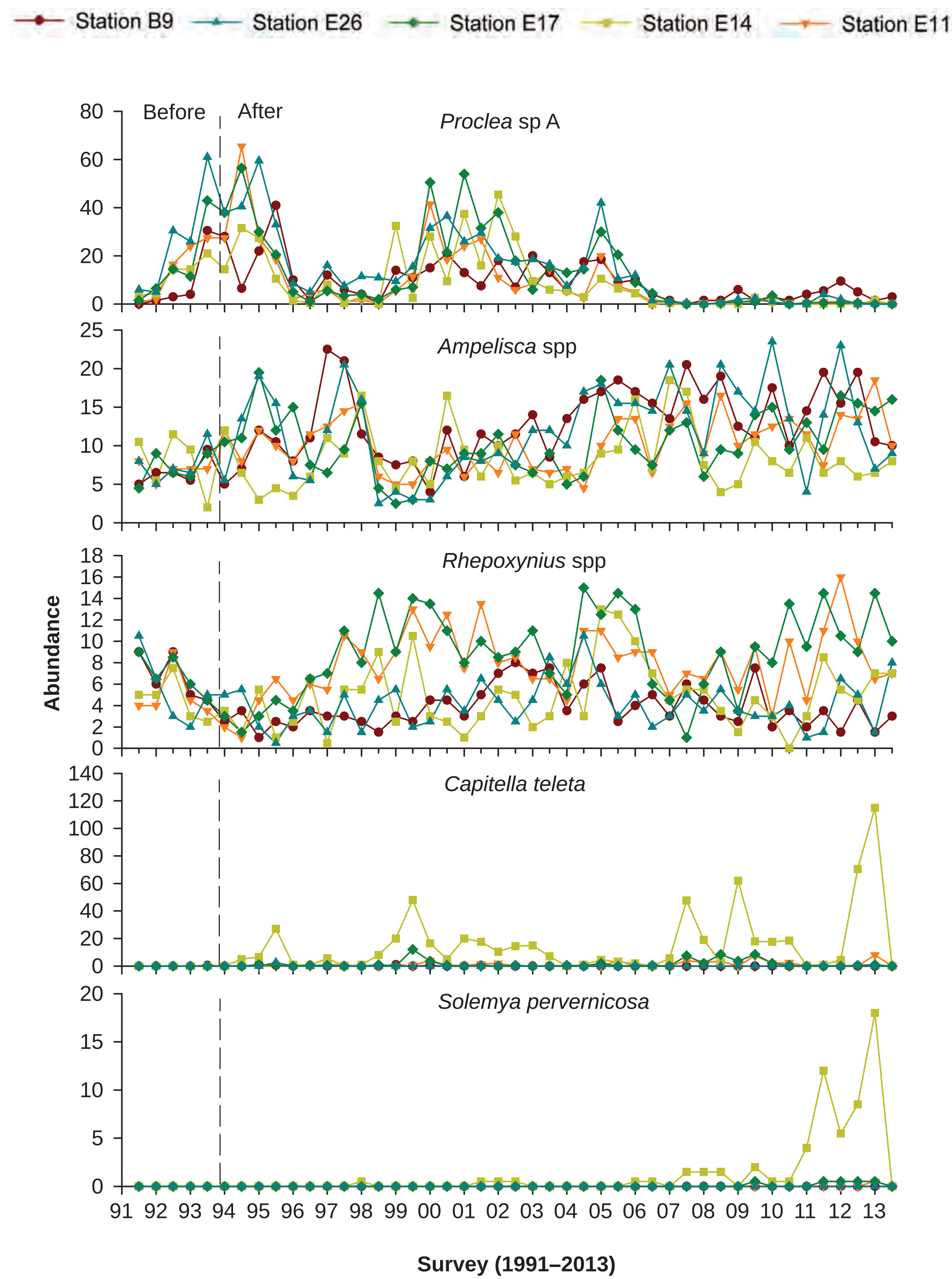


Figure 5.4

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

Rhepoxynius spp abundance support this premise, and show that no net change has occurred between "impact" station E14 and "control" stations E26 and B9 (Table 5.2). However, BACIP results do indicate a net change in *Ampelisca* spp abundance between E14 and both farfield stations. The change between stations E14 and E26 first began around 2003, but the significant difference between E14 and B9 only began this year. The variable nature of *Ampelisca* populations among stations makes interpretation of these relatively small differences difficult.

The abundance of *Amphiodia urtica* was lower at nearfield station E14 than other stations in 2013 (Figure 5.3), and is one of the factors driving the relatively higher BRI values for station E14 (Table 5.1, Appendix D.1). Abundances of this species at nearfield stations E11 and E17 have historically been similar to farfield stations. However, nearfield station E14 has experienced low abundances of *A. urtica* since 1994, possibly due to altered sediment composition (e.g., coarser sediments due to outfall construction) or increased predation pressure near the outfall. Accordingly, BACIP t-test results show a net change in the mean difference of *Amphiodia* spp abundance between station E14 and both control sites since the onset of wastewater discharge (Table 5.2), which is due to both a decrease in the number of *Amphiodia* at E14 and a general increase in abundances at the control stations that occurred until about 2005. In 2013, *A. urtica* densities at station E14 were similar to those reported since about 1999. Overall, the abundance of *A. urtica* has decreased across the entire PLOO region since 2005, but remains within the range of natural variation for SCB populations at similar depths (Thompson et al. 1993a).

Opportunistic species such as *Capitella teleta* and *Solemya pervernicosa* increase in abundance in areas having high organic content (Linton and Taghon 2000, McLeod and Wing 2009). The highest number of individuals recorded since 1991 for both species occurred at station E14 during the winter survey of 2013 (Figure 5.4). *Capitella teleta* had abundances of up to 140 individuals and *Solemya pervernicosa* had abundances of up to 21 individuals per grab. However, despite these record highs, abundances of these 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 2013; n = 46.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	54 (42–65)	52 (31–75)
Arthropoda (Crustacea)	23 (14–32)	25 (10–45)
Mollusca	13 (6–23)	8 (1–16)
Echinodermata	6 (2–10)	12 (1–31)
Other Phyla	4 (1–8)	2 (<1–4)

Classification of Macrobenthic Assemblages

Similarity of Assemblages

Classification (cluster) analysis was used to discriminate between macrofaunal assemblages from 24 individual grab samples collected at the 12 primary core stations in 2013 (12/survey), resulting in five ecologically-relevant SIMPROF-supported groups (Figure 5.5, Appendix D.4). These assemblages (referred to herein as cluster groups A–E) represented from 1 to 19 grabs each, and exhibited mean species richness ranging from 63 to 116 taxa per grab and mean abundances of 143 to 701 individuals per grab. The assemblages appear to be primarily influenced by sediment particle size and proximity to the outfall as described below.

Cluster group A represented the macrofaunal assemblages from the two samples collected at station B12, the northernmost of the primary core stations (Figure 5.5). Mean species richness of 102 taxa and mean abundance of 310 individuals per grab were within the range of all cluster

Table 5.4

The 10 most abundant macroinvertebrate taxa collected at the PLOO benthic stations during 2013. Abundance values are expressed as mean number of individuals per grab. Percent occurrence = percentage of grabs in which a species occurred.

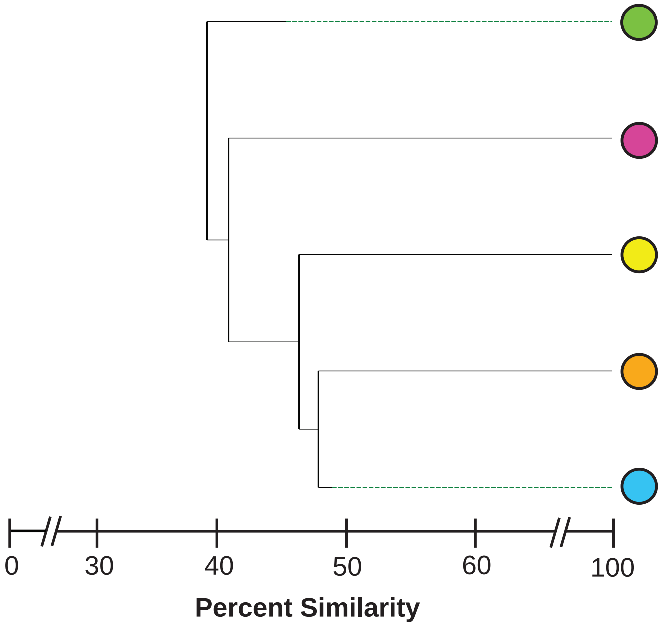
Species	Taxonomic Classification	Abundance per Grab	Percent Occurrence
Amphiodia urtica	Echinodermata: Ophiuroidea	24.4	98
Euphilomedes carcharodonta	Arthropoda: Ostracoda	23.6	93
Chloeia pinnata	Polychaeta: Amphinomidae	23.3	80
Euphilomedes producta	Arthropoda: Ostracoda	22.1	98
Prionospio (*Prionospio*) *jubata*	Polychaeta: Spionidae	18.7	100
Chaetozone hartmanae	Polychaeta: Cirratulidae	13	100
Mediomastus sp	Polychaeta: Capitellidae	10.3	93
Lumbrineris sp GROUP I	Polychaeta: Lumbrineridae	7.9	80
Tellina carpenteri	Mollusca: Bivalvia	7.9	96
Amphiodia sp	Echinodermata: Ophiuroidea	7.7	91

groups. The most abundant species included the polychaetes *Chloeia pinnata*, *Prionospio* (*Prionospio*) *jubata*, and *Chaetozone hartmanae* and the bivalve *Tellina carpenteri*, all of which averaged 10 to 51 individuals per grab (Appendix D.4). No other taxon had abundances >8 individuals per grab. Species contributing to ≥25% of within group similarity included *Tellina carpenteri*, the polychaetes *Chaetozone hartmanae* and *Fauveliopsis* sp SD1, the ostracods *Euphilomedes producta* and *E. carcharodonta*, the ophiuroid *Amphiodia digitata*, and the gastropod *Lirobittium larum*. Compared to most other cluster groups, these assemblages had high abundances of *Chloeia pinnata* (Figure 5.6), *Amphiodia digitata*, *Fauveliopsis* sp SD1, and *Lirobittium larum*, and were the only assemblages to include the polychaete *Mooreonuphis exigua* and the gastropod *Micranellum crebricinctum*. Sediments from station B12 were typically coarser than those found for other cluster groups, with 4–11% medium-coarse sands and only 35–45% fines. Gravel and shell hash were observed in these two grabs (Appendix C.4).

Cluster group B represented the assemblage present in the single winter grab collected at station B9, the second northernmost primary core station (Figure 5.5). This assemblage was characterized by the lowest species richness and abundance of any cluster group: 63 taxa and 143 individuals. The most abundant species in group B were the ophiuroid *Amphiodia urtica*, the polychaetes *Prionospio* (*Prionospio*) *jubata*, *Chaetozone hartmanae*, *Sternaspis affinis*, and *Malmgreniella* sp A, the bivalve *Tellina carpenteri*, and the ostracod *Euphilomedes producta*, all of which had abundances ranging from 6 to 15 individuals (Appendix D.4). No other taxon had abundances >5 individuals. Compared to most other cluster groups, this assemblage had low abundances of the ostracod *Euphilomedes carcharodonta*, the capitellid polychaetes *Notomastus* sp A and *Mediomastus* sp, and the amphinomid polychaete *Chloeia pinnata* (Figure 5.6). Sediments from station B9 during winter were 51% fines and 48% fine sands. Similar to cluster group A, gravel and shell hash were observed in this grab (Appendix C.4).

Cluster group C represented the macrofaunal assemblage at southernmost station E2 during the winter survey (Figure 5.5). This group had the second lowest species richness of 90 taxa, and an abundance of 352 individuals. The most abundant taxa were the polychaetes *Prionospio* (*Prionospio*) *jubata*, *P.* (*P.*) *dubia*, *Lumbrineris* sp GROUP I, *Lumbrineris cruzensis*, *Clymenura gracilis*, and *Chaetozone hartmanae*, the ophiuroid *Amphiodia urtica*, and the ostracod *Euphilomedes*

A



Cluster Group	n	SR	Abun
A	2	102	310
B	1	63	143
C	1	90	352
D	1	116	701
E	19	93	374

B

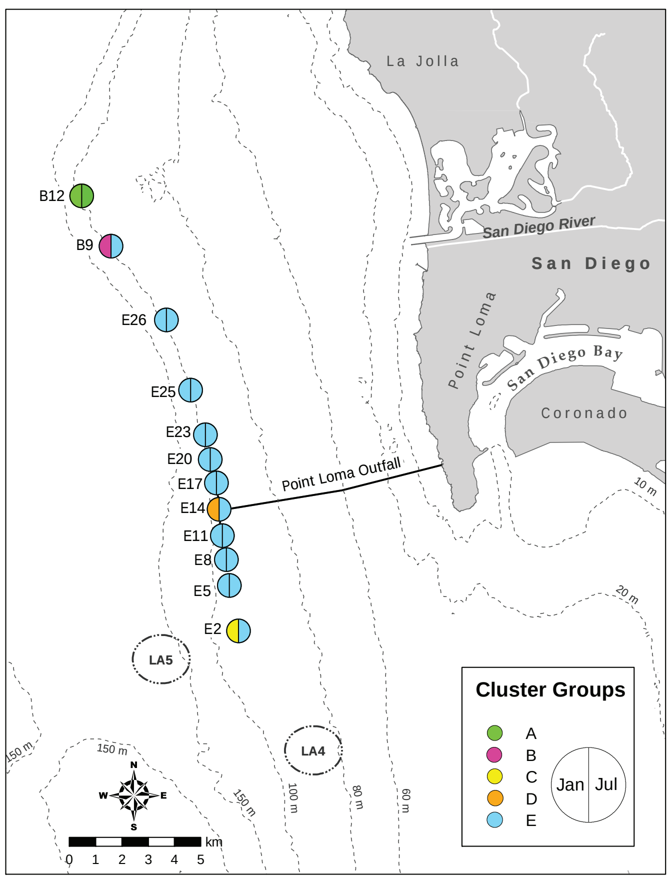


Figure 5.5
(A) Cluster analysis of macrofaunal assemblages at PLOO primary core stations sampled during 2013. SIMPROF-supported clades were retained at <48.5% similarly. Data for species richness (SR) and infaunal abundance (Abun) are expressed as mean values per grab over all stations in each group (n). (B) Distribution of cluster groups in the PLOO region during winter (January) and summer (July) 2013. Colors of each circle correspond to colors in the dendrogram.

carcharodonta, all of which ranged in abundance from 12 to 52 individuals (Appendix D.4). No other taxon had abundances >10 individuals. Group C had the highest abundances of *Prionospio* (*Prionospio*) *jubata* (Figure 5.6) and *Amphiodia urtica* of any cluster, but low abundances of the polychaetes *Chloeia pinnata* and *Pholoe glabra*, the tanaid *Leptochelia dubia* Cmplx, and the bivalve *Tellina carpenteri*. Similar to group B, sediments associated with this assemblage had 47% fines and 50% fine sands. Coarse sand, gravel, rock and shell hash were observed in this grab (Appendix C.4).

Cluster group D represented the macrofaunal assemblage at nearfield station E14 during the winter survey (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 and abundance were the highest of any cluster group, with 116 taxa and 701 individuals, respectively. The assemblage was dominated by the polychaete *Capitella teleta* with an abundance of 140 individuals, and was the only assemblage to contain the bivalve *Solemya pervernicosa* (Figure 5.6). Other abundant taxa included the polychaetes *Prionospio* (*Prionospio*) *jubata*, *Mediomastus* sp, *Chloeia pinnata*, *Lumbrineris* sp GROUP I, and *Aricidea* (*Acmira*) *catherinae*, all of which had abundances ranging from 23 to 50 individuals (Appendix D.4). No other taxon had abundances >20 individuals. Sediments associated with group D contained 62% fine sands and 37% fines. Shell hash and organic debris were observed in this grab (Appendix C.4).

Cluster group E represented the macrofaunal assemblages present in the remaining 19 samples collected during the year (Figure 5.5). These assemblages had average species richness of 93 taxa per grab, and the second highest mean abundance of 374 individuals per grab. The most abundant taxa were the same as those contributing to ≥25% of within group similarity and included the ostracods *Euphilomedes producta* and *E. carcharodonta*, the polychaetes *Chloeia pinnata*, *Prionospio* (*Prionospio*) *jubata*, and *Chaetozone hartmanae*, and the ophiuroid *Amphiodia urtica* (Appendix D.4). Mean abundances of these species ranged from 13 to 30 individuals per grab. No other taxon had abundances >10 individuals per grab. Characteristics of cluster group E are comparable to background conditions for the PLOO monitoring region described over the past four years (City of San Diego 2010–2013a) and are characteristic of 100 meter mid-shelf depths in the SCB. Sediments at these stations were composed of 38–55% fines, 43–61% fine sands, and shell hash was recorded in most grabs (Appendix C.4).

Comparison of Macrobenthic and Sediment Assemblages

Similar patterns of variation occurred in the benthic macrofaunal and sediment similarity/dissimilarity matrices (see Chapter 4) used to generate the cluster dendrograms, confirming that macrofaunal assemblages in the PLOO region are correlated to sediment composition (RELATE $\rho = 0.645$, $p = 0.0001$). The sediment subfractions that were most highly correlated to macrofaunal communities included medium silt, coarse silt, very fine sand, medium sand, and granules (BEST $\rho = 0.675$, $p = 0.001$) (Appendix C.2). The macrofaunal and sediment dendrograms presented in this chapter (Figure 5.5) and Chapter 4 (Figure 4.4), respectively, both show the January grab from station E2 and the January/July grabs from station B12 forming distinct cluster groups (i.e., macrofaunal cluster groups A + C = sediment cluster group 1). This suggests that the macrofaunal assemblages found in these grabs probably form because of higher fractions of coarse and medium sand present in these locations. However, because macrofaunal cluster groups B, D, and E co-mingle within sediment cluster groups 2 and 3, additional factors likely act synergistically with sediments to influence benthic assemblages in these groups. These factors may include: (1) differences in concentrations of organic material, (e.g., sulfide concentrations at station E14, see Appendix C.5), (2) differences in oceanographic parameters, or (3) differences in biological factors (e.g., predation pressure, differential recruitment).

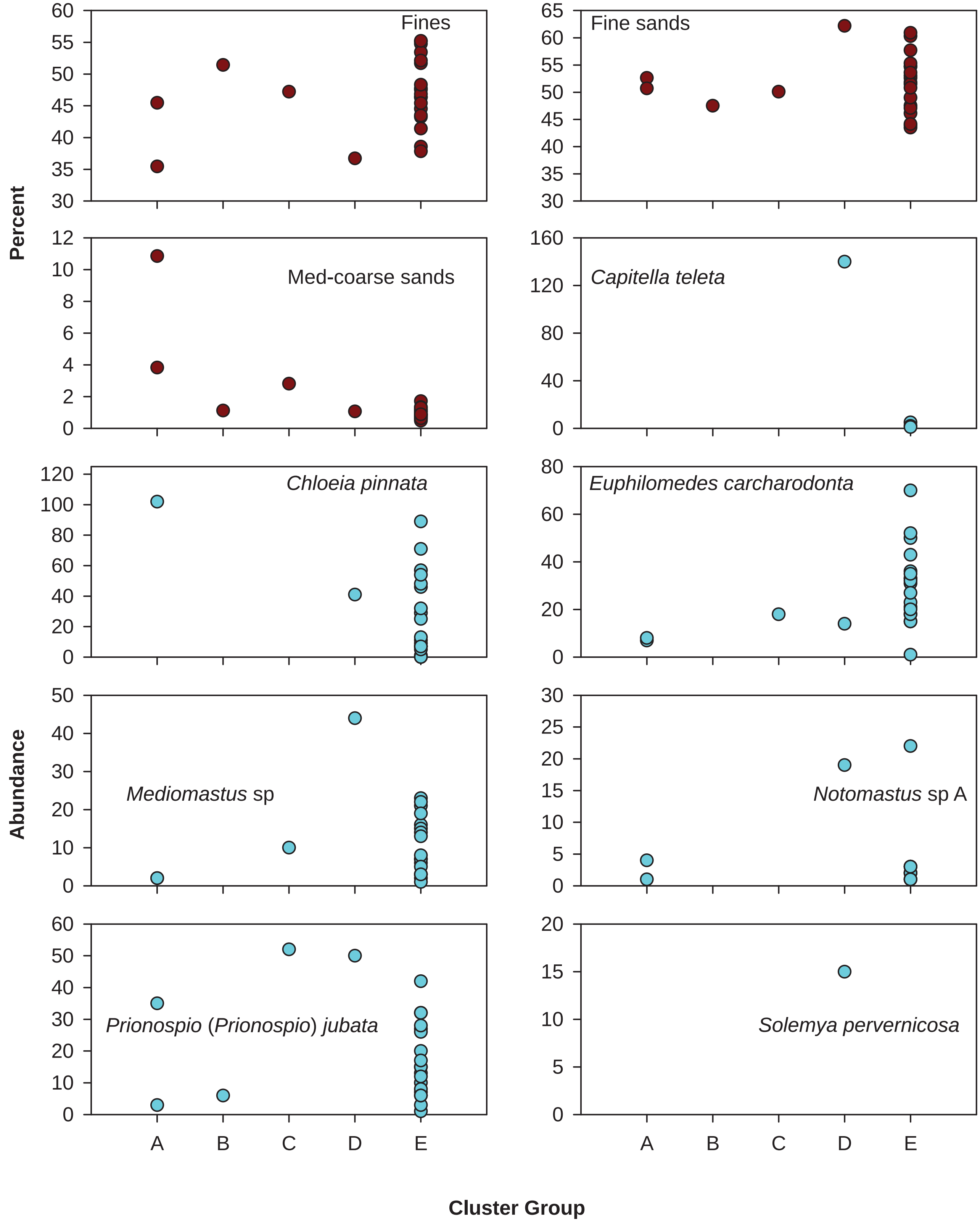


Figure 5.6
Sediment composition and abundances of select species that contributed to cluster group dissimilarities in the PLOO region during 2013 (see Figure 5.5). Each data point represents a single sediment or grab sample.

Summary

Analysis of the 2013 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 2013 were similar to those encountered during previous years, including the period before wastewater discharge (City of San Diego 1995, 2013a). 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 overall population abundances have decreased since monitoring began in 1991. Of the 10 most abundant species recorded during the year, the spionid polychaete *Prionospio* (*Prionospio*) *jubata* and the cirratulid polychaete *Chaetozone hartmanae* were the most widespread and occurred at every station. The overall abundance and dominance of most species were typically within historical ranges (see City of San Diego 1995, 1999, 2007, 2013a). As previously reported, most 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 macrofaunal 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, abundance, diversity, evenness and dominance off Point Loma were indicative of natural ranges reported for the San Diego region (see Chapter 9 in City of San Diego 2013b) 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 near the discharge site (i.e., station E14) over the past 16 or more years, 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 altered sediment composition (e.g., coarser sediments due to construction of the outfall) and 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*. *Capitella 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). Although total abundances of *C. teleta* (n = 250) and *S. pervernicosa* (n = 38) were higher than normal, these abundances were ephemeral and remained relatively low at the nearfield stations when compared to other SCB dischargers (e.g., LACSD 2012, OCSD 2012) and no other characteristics of unhealthy habitats were evident. 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 in good condition off Point Loma, with about 98% of the assemblages surveyed in 2013 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 is 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 (see Chapter 9 in City of San Diego 2013b), 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 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 the 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 analyses and interpretations of demersal fish and megabenthic invertebrate data collected during 2013, as well as a long-term assessment of these communities from 1991 through 2013. The primary goals are to: (1) document assemblages present during the year, (2) determine the presence or absence of biological impacts associated with wastewater discharge, and (3) identify other potential natural and anthropogenic sources of variability to the local marine ecosystem.

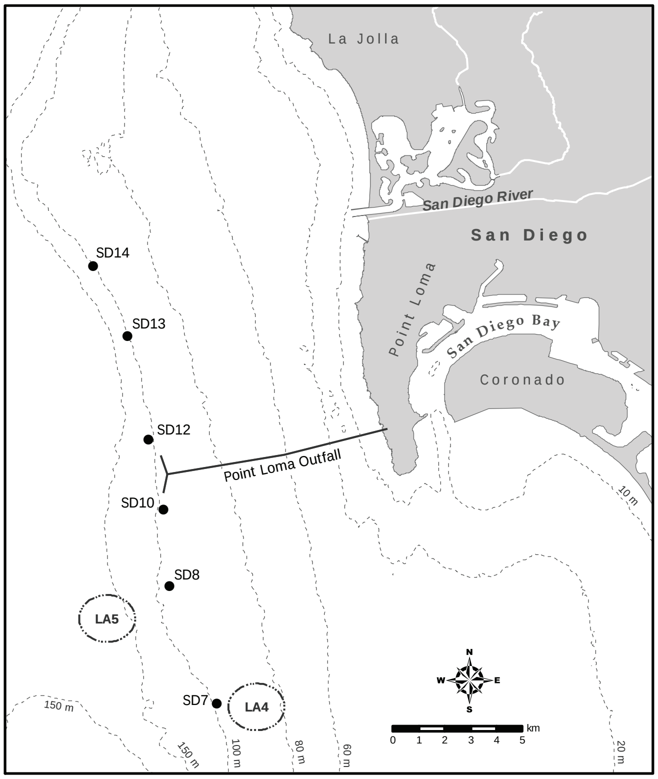

Figure 6.1
Trawl station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

Materials and Methods

Field Sampling

Trawl surveys were conducted at six monitoring stations in the PLOO region during winter and summer 2013 (i.e., January and July, respectively). 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 (Figure 6.1). 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). 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 using demersal fish and megabenthic invertebrate data collected from 1991 through 2013 (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 variation (e.g., City of San Diego

Table 6.1

Demersal fish species collected from 12 trawls conducted in the PLOO region during 2013. 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
Pacific sanddab	57	100	262	262	Slender sole	<1	17	1	4
Longspine combfish	14	100	65	65	Blacktip poacher	<1	25	<1	2
Halfbanded rockfish	6	92	29	31	Bluespotted poacher	<1	25	<1	2
California lizardfish	6	83	28	33	Pink rockfish	<1	17	<1	2
Shortspine combfish	2	100	11	11	Greenspotted rockfish	<1	17	<1	2
Pacific argentine	2	67	11	16	Spotted cusk-eel	<1	25	<1	1
English sole	2	100	10	10	Flag rockfish	<1	17	<1	2
Stripetail rockfish	2	83	9	11	Fringed sculpin	<1	17	<1	1
Dover sole	2	92	8	9	Kelp pipefish	<1	17	<1	1
Pink seaperch	2	100	8	8	Roughback sculpin	<1	17	<1	1
Yellowchin sculpin	1	42	5	12	Unidentified rockfish	<1	8	1	7
Plainfin midshipman	<1	75	2	3	Bigfin eelpout	<1	8	<1	1
California tonguefish	<1	42	1	3	California scorpionfish	<1	8	<1	1
Bigmouth sole	<1	92	1	1	Copper rockfish	<1	8	<1	1
Hornyhead turbot	<1	58	1	2	Curlfin sole	<1	8	<1	1
California skate	<1	67	1	2	Lingcod	<1	8	<1	1
Spotfin sculpin	<1	25	1	3	Longfin sanddab	<1	8	<1	1
Blackbelly eelpout	<1	17	1	4	Red brotula	<1	8	<1	1
Pygmy poacher	<1	33	1	2					

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. The major ecologically-relevant clusters supported by SIMPROF were retained, and similarity percentages analysis (SIMPER) was used to determine which organisms were responsible for at least 75% of 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-seven species of fish were collected in the area surrounding the PLOO during 2013 (Table 6.1, Appendix E.1). The total catch for the year was 5509 individuals (Appendix E.2), representing an average of ~459 fish per trawl. Of 16 families represented, six accounted for 93% of the total abundance (i.e., Argentinidae, Hexagrammidae, Paralichthyidae, Pleuronectidae, Scorpaenidae, Synodontidae). Overall, the total catch for 2013 was 21% larger than in 2012, and continued to be dominated by Pacific sanddab. This species occurred in every haul and accounted for 57% of all fishes collected at an average of 262 individuals per trawl. No other species contributed to more than 14% of the total catch. For example, longspine combfish, shortspine combfish, English sole, and pink seaperch also occurred in every trawl, but averaged only 8–65 individuals per occurrence.

Other species collected in at least 50% of trawls, but in relatively low numbers (≤29/haul) included halfbanded rockfish, Dover sole, bigmouth sole, California lizardfish, stripetail rockfish, plainfin midshipman, Pacific argentine, California skate, and hornyhead turbot.

More than 99% of the fishes collected during 2013 were <21 cm in length (Appendix E.1). Larger fishes included eight California skate (25–37 cm), one California lizardfish (29 cm), one spotted cusk-eel (24 cm), one copper rockfish (28 cm), one greenspotted rockfish (26 cm), three blackbelly eelpout (23–25 cm), four Pacific sanddab (22–23 cm), four bigmouth sole (22–25 cm), and three English sole (22 cm). Median lengths per haul for the four most abundant species ranged from 5 to 13 cm for Pacific sanddab, 7 to 13 cm for longspine combfish, 11 to 13 cm for California lizardfish, and 8 to 11 cm for halfbanded rockfish (Figure 6.2). Several seasonal and site differences were observed during the past year. For example, the smallest Pacific sanddab with median lengths ≤7 cm were found at stations SD7, SD10, SD12, and SD14 during the summer survey, and at station SD8 during both surveys. In contrast, Pacific sanddab with median lengths ≥10 cm were found at stations SD7, SD10, SD12, and SD14 during the winter and from station SD13 during the summer. The smallest longspine combfish with median lengths ≤9 cm occurred at SD13 during the winter, SD7 during the summer, and stations SD10 and SD12 during both surveys, whereas this species consistently had median lengths ≥11 cm at stations SD8 and SD14. Median lengths of halfbanded rockfish were ≤9 cm at stations SD7 and SD14 and ≥10 at stations SD8, SD10, and SD12 during both winter and summer.

Fish community structure varied among stations and between surveys during the year (Table 6.2, Appendices E.2, E.3). For each haul, species richness ranged from 13 to 19 species, diversity (H') ranged from 1.0 to 1.8, total abundance ranged from 184 to 810 fish, and total biomass ranged from 3.4 to 14.8 kg. The lowest species richness (≤14 species/haul) was recorded at SD7 during winter and at station SD13 during summer, while the lowest diversity values ≤1.2 were recorded at stations SD7, SD8, and SD10 during summer. Abundances >500 individuals were captured at stations SD7, SD8, SD10, and SD12 during summer. These large hauls reflected considerable numbers of Pacific sanddab (277–534 fish/haul) collected at these sites during that survey. High biomass values ≥10.4 kg/haul recorded at stations SD8 and SD10 during winter and at stations SD10, SD12 and SD14 during summer also reflected large hauls of Pacific sanddab. For example, Pacific sanddab accounted for more than 5 kg of the biomass recorded at stations SD12 and SD14 during the summer survey and at station SD10 during both surveys. Halfbanded rockfish also contributed more than 2 kg of the biomass recorded at stations SD8 and SD10 during winter, while California lizardfish made up 2.9 kg of the 14.8 kg total weight for the haul from station SD14 during summer.

Mean demersal fish species richness and diversity have remained within narrow ranges (i.e., SR = 10–22 species/haul, H' = 1.1–1.9) off Point Loma since 1991 (Figure 6.3). In contrast, there has been considerable variability in abundance (i.e., 97–1065 fishes/haul) over the years, largely 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 2007b). In addition, occasional spikes in abundance have been due to large hauls of other individual species such as yellowchin sculpin, halfbanded rockfish, and longspine combfish. 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 sampled during the summer surveys from 1991 through 2013 showed significant differences among the nearfield, north farfield, and south farfield station groups and by year (Table 6.3).

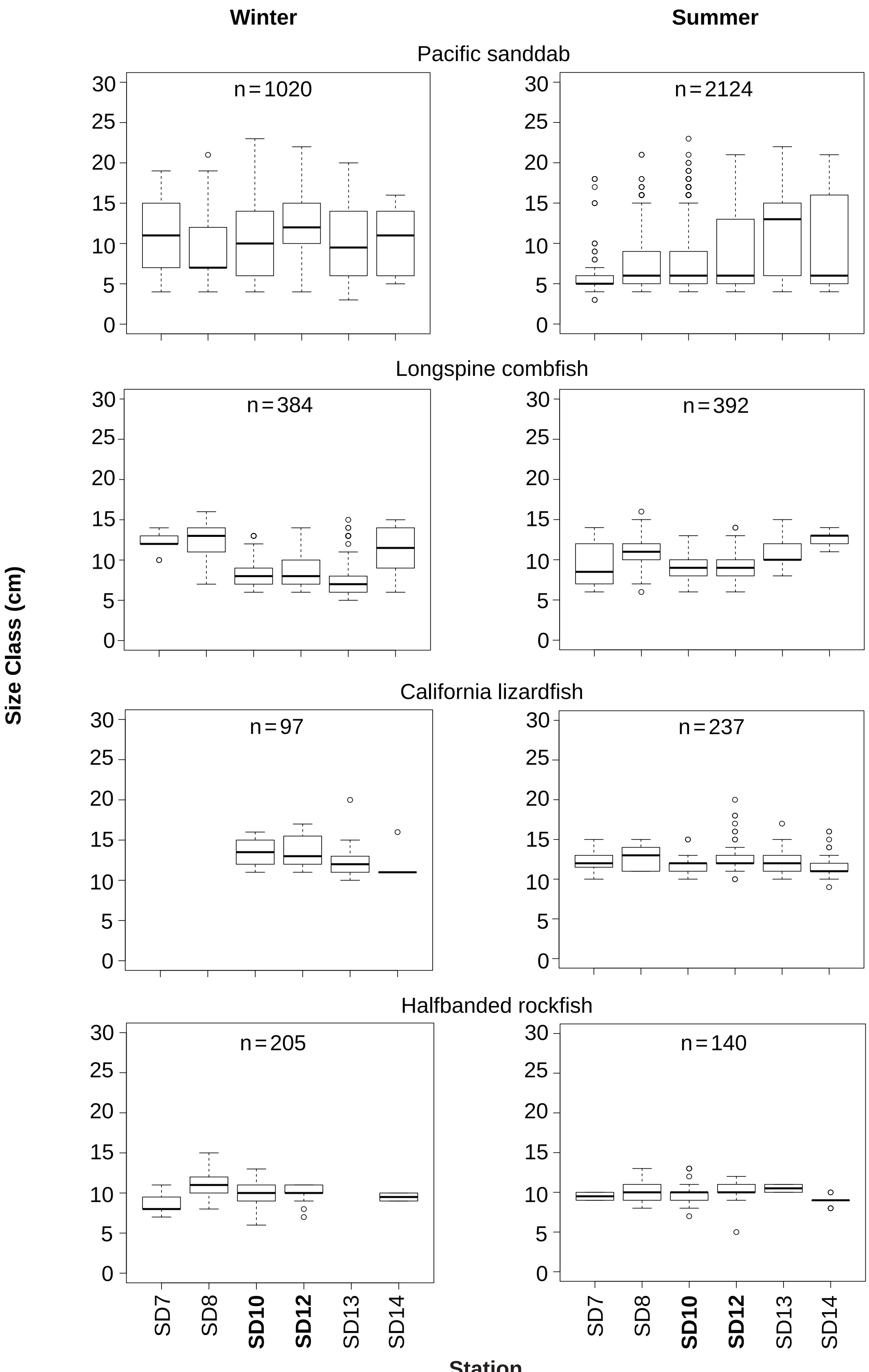

Figure 6.2

Summary of fish lengths by survey and station for each of the four most abundant species collected in the PLOO region during 2013. 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 2013. Data are included for species richness, abundance, diversity (H'), and biomass (kg, wet weight). SD = standard deviation.

Station	Winter	Summer
Species Richness		
SD7	13	17
SD8	17	18
SD10	17	16
SD12	15	16
SD13	15	14
SD14	19	18
Survey Mean	16	16
Survey SD	2	2
Abundance		
SD7	346	678
SD8	370	524
SD10	498	810
SD12	347	526
SD13	458	319
SD14	184	449
Survey Mean	367	551
Survey SD	109	173
Diversity		
SD7	1.7	1.0
SD8	1.5	1.2
SD10	1.7	1.2
SD12	1.8	1.6
SD13	1.6	1.5
SD14	1.4	1.6
Survey Mean	1.6	1.4
Survey SD	0.1	0.3
Biomass		
SD7	8.8	3.4
SD8	11.2	7.8
SD10	10.8	12.3
SD12	6.8	10.4
SD13	9.6	7.6
SD14	4.3	14.8
Survey Mean	8.6	9.4
Survey SD	2.6	4.0

Pairwise comparisons showed that assemblages at the south farfield stations differed from those at the north farfield stations (Table 6.3), while 2013 assemblages differed from those present in all other years except for 2004, 2006, and 2010–2012 (Appendix E.4). Species that contributed to these spatial and temporal differences included bay goby, California lizardfish, California tonguefish, greenblotched rockfish, halfbanded rockfish, longfin sanddab, longspine combfish, Pacific argentine, pink seaperch, plainfin midshipman, shortspine combfish, slender sole, stripetail rockfish, and yellowchin sculpin (Figure 6.5).

Classification (cluster) analysis discriminated between 11 main types of fish assemblages in the Point Loma outfall region over the past 23 years (cluster groups A–K; Figure 6.6). These included six small groups representative of one to six hauls each (groups A–E, H), and five larger groups ranging from 17 to 34 hauls each and representing ~89% of all trawls (groups F, G, I–K). The distribution of assemblages in 2013 was generally similar to the past three years, 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. The species composition and main descriptive characteristics of each cluster group are described below and summarized in Table 6.4.

Cluster group A represented a single trawl from station SD10 sampled in 1997. This assemblage had the lowest species richness (7 species), lowest abundance (44 individuals), and fewest Pacific sanddab (23 fish) of any cluster group. This haul also contained 16 halfbanded rockfish, and single individuals of longfin sanddab, spotfin sculpin, pink seaperch, gulf sanddab, and greenspotted rockfish.

Cluster group B represented a single trawl from station SD12 sampled in 1998. This assemblage contained 16 species and 261 individuals, and relatively few Pacific sanddab (75 fish) compared to most other cluster groups. It also had the highest number of plainfin midshipman (116 fish) and the second highest number of Dover sole (36 fish) of any group.

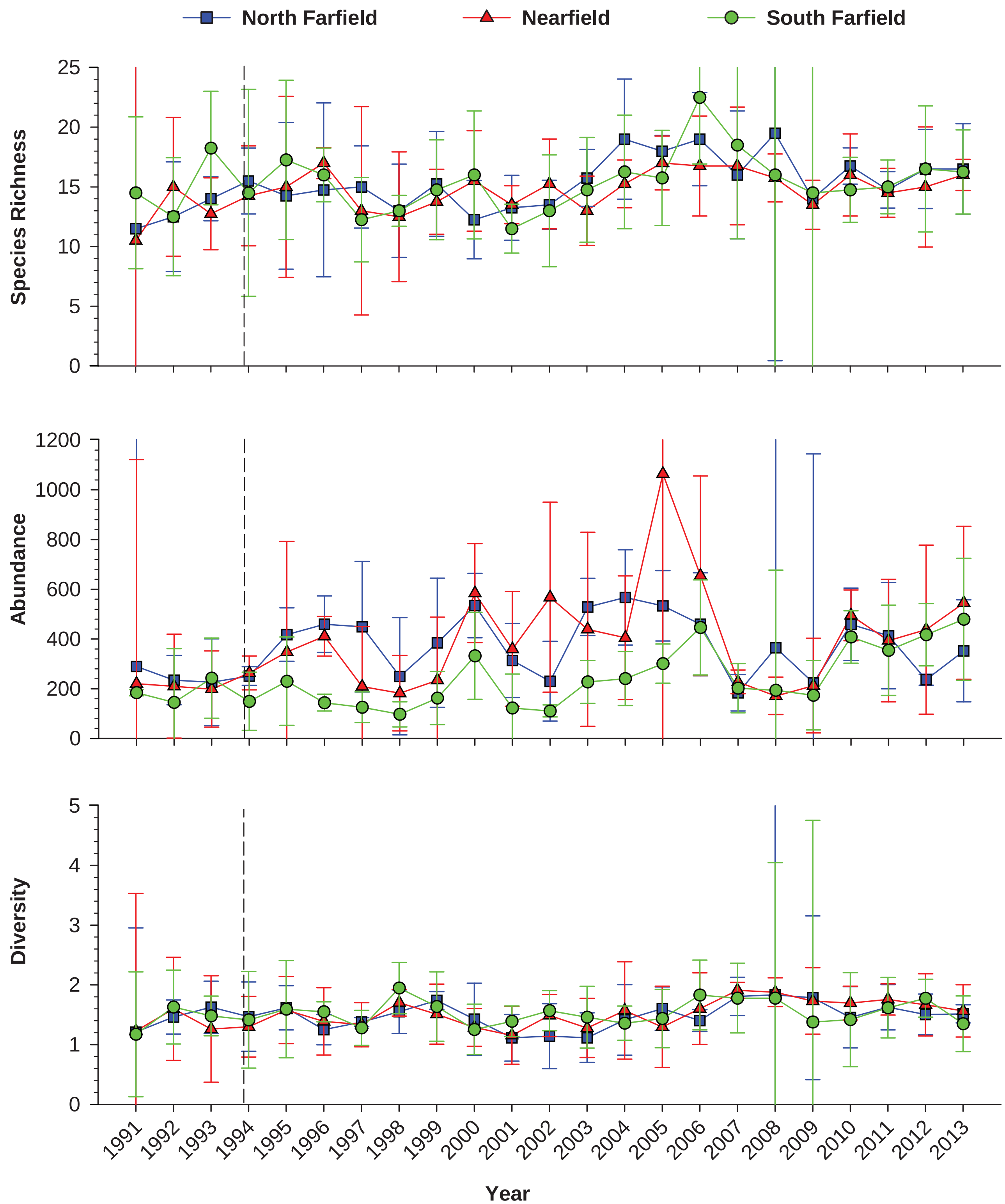

Figure 6.3
Species richness, abundance, and diversity of demersal fishes collected from PLOO trawl stations sampled from 1991 through 2013. Data are annual means with 95% confidence intervals for nearfield stations (n ≤ 4), north farfield stations (n ≤ 4), and south farfield stations (n ≤ 4). Dashed lines indicate onset of wastewater discharge.

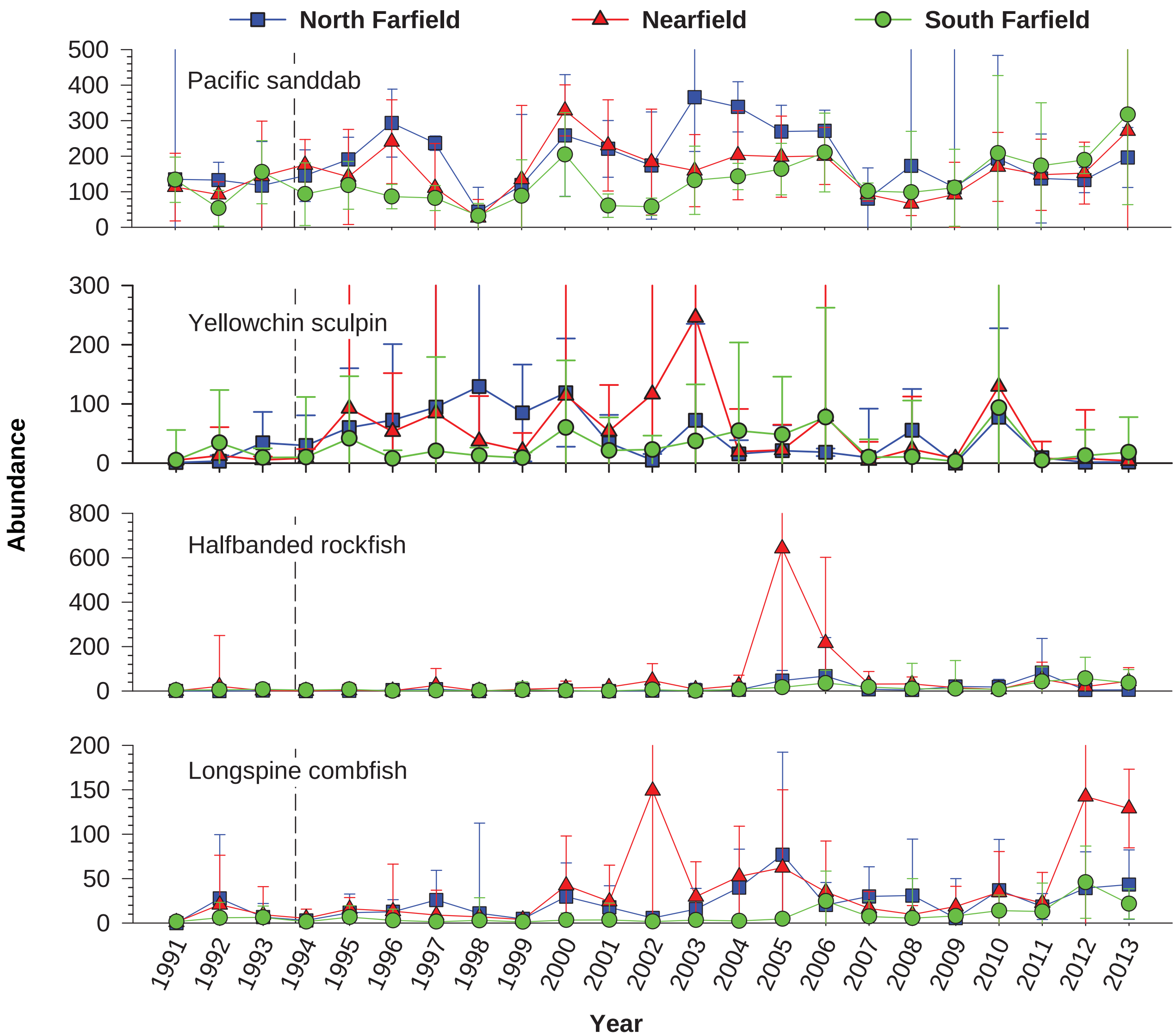

Figure 6.4

The eight most abundant fish species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2013. Data are annual means with 95% confidence intervals for nearfield stations (n ≤ 4), north farfield stations (n ≤ 4), and south farfield stations (n ≤ 4). Dashed lines indicate onset of wastewater discharge.

Cluster group C represented a single trawl from station SD12 sampled in 1997. This assemblage had the highest number of species (19 species), moderate abundance (231 individuals), and relatively few Pacific sanddab (110 fish) compared to most other groups. It also had the highest number of halfbanded rockfish (60 fish), squarespot rockfish (23 fish), greenblotch rockfish (8 fish), and the only vermilion rockfish (6 fish).

Cluster group D comprised the assemblages from three hauls collected at stations SD10, SD13, and SD14 during 1999. This group had the second highest species richness (17 species/haul), the highest total abundance (495 individuals/haul), and the second highest number of Pacific sanddab (248/haul). Group D also had the highest numbers of stripetail rockfish (102/haul), longfin sanddab (32/haul), and yellowchin sculpin (31/haul) of any cluster group. Other characteristic species that contributed to ≥75% within-group similarity (see Methods) for group D included plainfin midshipman and halfbanded rockfish.

Cluster group E comprised six hauls, including those from station SD7 sampled in 2003–2005,

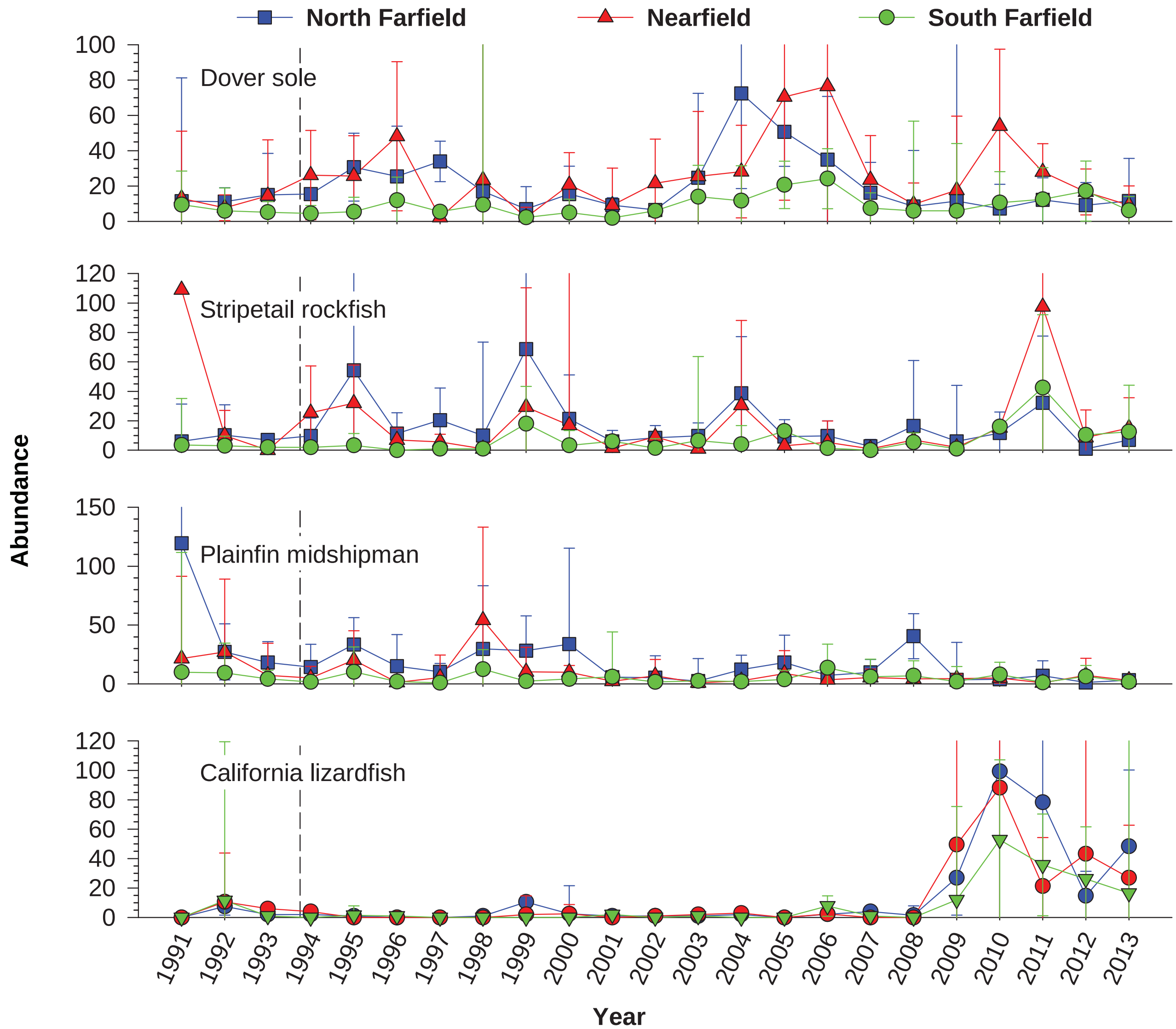

Figure 6.4 *continued*

station SD8 sampled in 1991–1992, and station D10 sampled in 2001. Assemblages represented by this group averaged 14 species of fish, 213 individuals, and 150 Pacific sanddab per haul. Other characteristic species included plainfin midshipman, Dover sole, shortspine combfish, and yellowchin sculpin.

Cluster group F comprised 23 hauls, including those from station SD7 sampled in 2000, station SD10 sampled in 1993–1994 and 2004, station SD12 sampled in 1993–1994 and 1999, station SD13 sampled in 1993–1998 and 2001–2002, and station SD14 sampled in 1993–1997 and 2000–2002. Assemblages represented by this group averaged 14 species, 307 individuals, and 215 Pacific sanddab per haul. Other characteristic species included Dover sole, stripetail rockfish, longfin sanddab, and yellowchin sculpin.

Cluster group G comprised 17 hauls, including those from station SD10 sampled in 1996, 2000, 2002–2003 and 2005, station SD12 sampled in 1996, 2000–2002 and 2005, station SD13 sampled in 2000 and 2003–2005, and station SD14 sampled in 2003–2005. This group averaged 16 species per haul and had the second highest abundance (467 individuals/haul), the highest numbers of Pacific sanddab (301/haul), the highest numbers of Dover sole (48/haul), and the second highest numbers of longspine combfish (33/haul) of any cluster group. Other characteristic species for group G included yellowchin sculpin and halfbanded rockfish.

Table 6.3

Results of 2-way crossed ANOSIM (with replicates) for demersal fish assemblages sampled around the PLOO from 1991 through 2013. 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):	0.354 [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	0.193 (1.5)	0.682 (0.01)
South farfield	0.239 (0.3)	

Global Test: Factor B (years)

Tests for differences between years (across all station groups)

Sample statistic (Global R):	0.649 [a]
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0

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

Cluster group H comprised three hauls, including those from stations SD10 and SD13 sampled during 2009, and from station SD12 sampled during 2011. Assemblages represented by this group averaged 13 species, 150 individuals, and just 63 Pacific sanddab per haul. Other characteristic species for Group H included California lizardfish and Dover sole.

Cluster group I was the second largest group, representing assemblages from a total of 27 hauls that included 95% (n = 23) of the trawls conducted at all stations sampled from 2010 through 2013, as well as the trawls from stations SD10 and SD14 in 2006, and the trawls from stations SD12 and SD14 in 2009. These assemblages averaged 15 species and 457 individuals per haul. Group I had the highest numbers of longspine combfish (37/haul) and California lizardfish (36/haul), and the second highest numbers of Pacific sanddab (254/haul) and halfbanded rockfish (59/haul) of any cluster group. Other characteristic species included Dover sole and shortspine combfish.

Cluster group J comprised 18 hauls, including those from stations SD8 and SD12 sampled in 2003–2004, station SD8 sampled in 2005, stations SD7–SD8 and SD12–SD13 sampled in 2006, stations SD8–SD14 sampled in 2007, stations SD10–SD12 sampled in 2008, and stations SD7–SD8 sampled in 2009. Assemblages represented by group J averaged 16 species, 244 individuals, and 134 Pacific sanddab per haul. This group had the highest abundance of shortspine combfish (12/haul) of any cluster group. Other characteristic species included Dover sole, halfbanded rockfish, and longspine combfish.

Cluster group K was the largest group, representing assemblages from a total of 34 hauls that included 87% (n = 21) of the trawls conducted at stations SD7 and SD8 from 1991 through 2002, as well as all of the trawls from stations SD10–SD14 in 1991 and 1992, the trawls from stations SD10 and SD12 in 1995, the trawls from stations SD10 and SD14 in 1998, and the trawl from SD7 in 2007. These assemblages averaged 13 species,

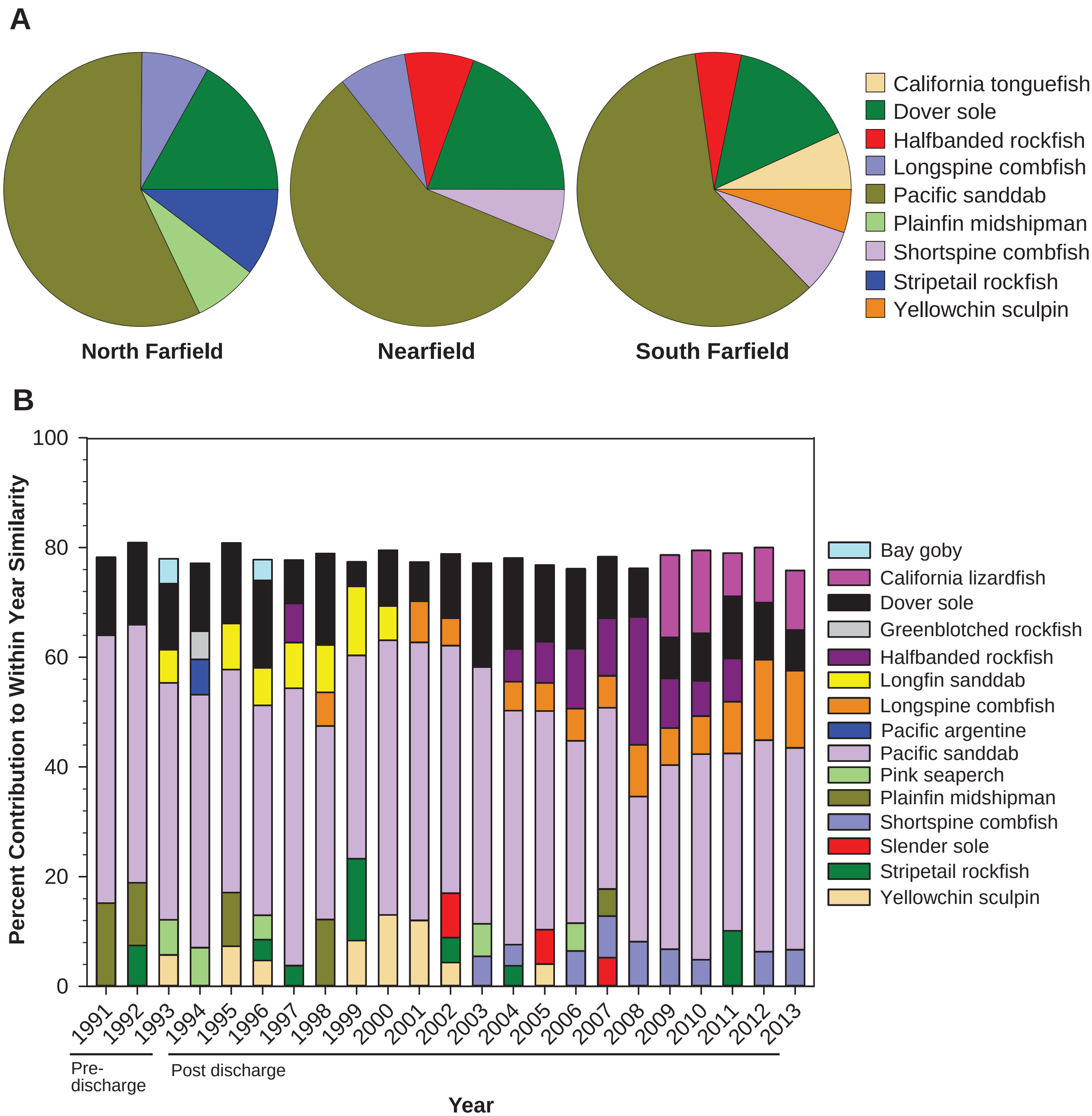

Figure 6.5

Characteristic demersal fish species collected from PLOO trawl stations sampled from 1991 through 2013 that contribute to ≥75% 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).

151 individuals, and 91 Pacific sanddab per haul. Other characteristic species included plainfin midshipman, Dover sole, and longfin sanddab.

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the PLOO region during 2013. There were no incidences of fin rot, tumors, discoloration, or skin lesions among fishes collected during the year. Evidence of parasitism was also very low (0.3%) for trawl-caught fishes off Point Loma. The copepod *Phrixocephalus cincinnatus* infected <1.0% of the Pacific sanddab (13 individuals) collected during the year; this eye parasite was

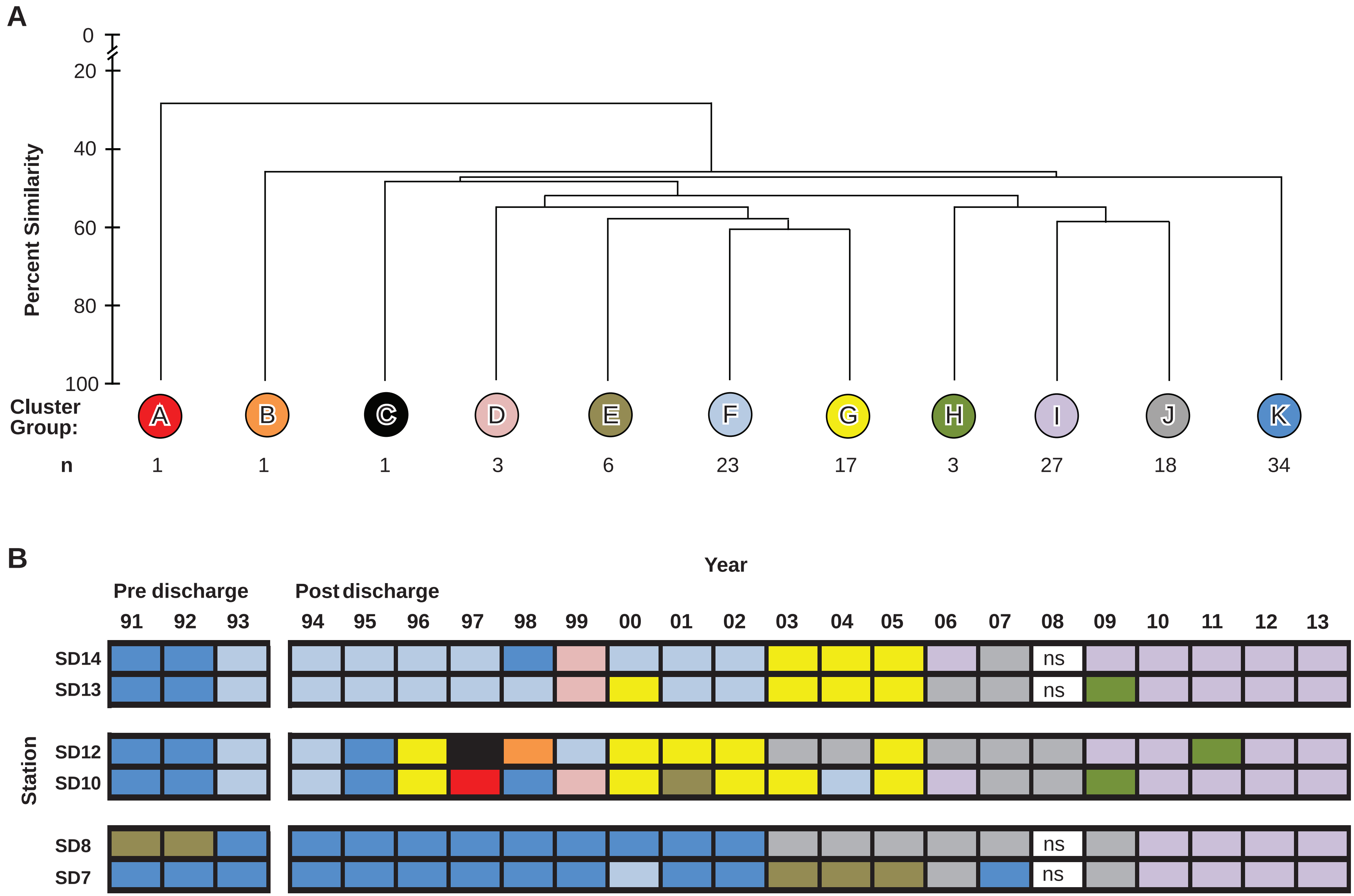

Figure 6.6
Results of cluster analysis of demersal fish assemblages from PLOO trawl stations sampled from 1991 through 2013. Data are limited to summer surveys and are presented as (A) a dendrogram of main cluster groups and (B) a matrix showing distribution of cluster groups over time. Major ecologically relevant SIMPROF supported clades with <55% similarity were retained; n=number of hauls; ns=not sampled.

Table 6.4

Description of demersal fish cluster groups A–K defined in Figure 6.6. Species included represent the five most abundant taxa recorded for each cluster group. Bold values indicate species that were considered most characteristic of that group (i.e., contributing to ≥75% within-group similarity) according to SIMPER analysis.

	Cluster Group										
	A[a]	B[a]	C[a]	D	E	F	G	H	I	J	K
Number of Hauls	1	1	1	3	6	23	17	3	27	18	34
Mean Species Richness	7	16	19	17	14	14	16	13	15	16	13
Mean Abundance	44	261	231	495	213	307	467	150	457	244	151
Species	**Mean Abundance**										
Pacific sanddab	23	75	110	**248**	**150**	**215**	**301**	**63**	**254**	**134**	**91**
Plainfin midshipman		116	4	**26**	**2**	2	6	1	2	4	**13**
Dover sole		36	1	5	**15**	**23**	**48**	**12**	**22**	**22**	**9**
Stripetail rockfish		1	5	**102**	<1	**10**	6	10	9	2	8
Longfin sanddab	1			**32**		**8**	1		1	<1	**6**
Yellowchin sculpin				**31**	**20**	**15**	**16**		2	2	3
Spotfin sculpin	1						1		1	2	2
Shortspine combfish			3		**5**	<1	4	3	**10**	**12**	2
Halfbanded rockfish	16		60	**7**	3	1	**16**	9	**59**	**23**	2
Pink seaperch	1	4	1	4	2	6	4	4	6	3	1
Bigmouth sole			1	1	<1	1	1		1	1	1
Squarespot rockfish			23					4	1	<1	1
Longspine combfish		7	2	5	3	5	**33**	7	**37**	**11**	1
Greenblotched rockfish			8	1	2	1	1	<1	<1	<1	1
Gulf sanddab	1	5		10	<1	<1	<1				<1
Greenspotted rockfish	1		1	<1		1	<1		<1		<1
California lizardfish				6				**24**	**36**	2	<1
Vermilion rockfish			6								

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

found on fish from all stations. In addition, there was one Pacific sanddab that had a damaged eye, one spotted cusk-eel reported with lumpy skin, and three Pacific sanddab observed with attached specimens of the cymothoid isopod gill parasite *Elthusa vulgaris*. Finally, five individuals of *E. vulgaris* were identified as part of invertebrate trawl catches during the year (see Appendix E.5). Since these isopods often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these isopods. However, *E. vulgaris* is known to be especially common on 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 31,844 megabenthic invertebrates (~2654 per trawl) representing 51 taxa from 6 phyla were collected in 2013 (Table 6.5, Appendices E.5, E.6). Overall, the total catch for the year was 52% larger than in 2012, and continued to be dominated by echinoderms. The sea urchin *Lytechinus pictus* was the most abundant and most frequently captured trawl-caught invertebrate, averaging 2157 individuals per haul (=81% of total abundance) and occurring in 100% of the trawls. The brittle star *Ophiura luetkenii* was also collected in every haul; this species only accounted for 15%

Table 6.5

Megabenthic invertebrates collected from 12 trawls conducted in the PLOO region during 2013. 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	81	100	2157	2157	*Hinea insculpta*	<1	17	<1	2
Ophiura luetkenii	15	100	399	399	*Megasurcula carpenteriana*	<1	25	<1	1
Strongylocentrotus fragilis	2	33	50	151	*Paguristes turgidus*	<1	25	<1	1
Luidia foliolata	1	100	15	15	*Suberites latus*	<1	17	<1	2
Florometra serratissima	<1	50	7	14	*Adelogorgia phyllosclera*	<1	17	<1	1
Astropecten californicus	<1	75	4	5	*Cancellaria crawfordiana*	<1	17	<1	1
Octopus rubescens	<1	83	3	3	*Hololepida magna*	<1	17	<1	1
Pleurobranchaea californica	<1	92	3	3	*Amphichondrius granulatus*	<1	8	<1	1
Parastichopus californicus	<1	75	2	3	*Doryteuthis opalescens*	<1	8	<1	1
Sicyonia ingentis	<1	50	2	4	*Enallopaguropsis guatemoci*	<1	8	<1	1
Arctonoe pulchra	<1	33	1	3	*Lamellaria diegoensis*	<1	8	<1	1
Acanthoptilum sp	<1	25	1	3	*Loxorhynchus crispatus*	<1	8	<1	1
Calliostoma turbinum	<1	25	1	3	*Luidia armata*	<1	8	<1	1
Luidia asthenosoma	<1	33	1	2	*Moloha faxoni*	<1	8	<1	1
Ophiopholis bakeri	<1	33	1	2	*Neocrangon zacae*	<1	8	<1	1
Metridium farcimen	<1	8	1	7	*Nymphon pixellae*	<1	8	<1	1
Spatangus californicus	<1	42	1	1	*Pagurus armatus*	<1	8	<1	1
Philine alba	<1	25	<1	2	*Paralithodes rathbuni*	<1	8	<1	1
Thesea sp B	<1	17	<1	3	*Parapagurodes makarovi*	<1	8	<1	1
Acanthodoris brunnea	<1	17	<1	2	*Philine auriformis*	<1	8	<1	1
Barbarofusus barbarensis	<1	17	<1	2	*Platymera gaudichaudii*	<1	8	<1	1
Elthusa vulgaris	<1	33	<1	1	*Podochela lobifrons*	<1	8	<1	1
Paguristes bakeri	<1	25	<1	2	*Pteropurpura vokesae*	<1	8	<1	1
Ophiothrix spiculata	<1	17	<1	2	*Pyromaia tuberculata*	<1	8	<1	1
Rossia pacifica	<1	33	<1	1	Stolonifera (unidentified)	<1	8	<1	1
Crangon alaskensis	<1	17	<1	2					

of the total catch, but occurred in exceptionally high numbers (≥962/haul) at station SD7 during both surveys. No other species contributed to more than 2% of the total catch. Other species collected during the year in at least 50% of the trawls but in low numbers (i.e., ≤7/haul) included the crinoid *Florometra seserratisima*, the sea stars *Astropecten californicus* and *Luidia foliolata*, the sea cucumber *Parastichopus californicus*, the opisthobranch *Pleurobranchaea californica*, the cephalopod *Octopus rubescens*, and the shrimp *Sicyonia ingentis*.

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 23 species and total abundance ranged from 370 to 6305 individuals. During 2013, the lowest species richness values ≤10 species were recorded at station SD14 during winter and at stations SD13 and SD14 during 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 (1260–6305 individuals/haul) recorded at all stations during the winter and at stations SD7, SD8, and SD10 during the summer reflected large hauls of *L. pictus* (i.e., 876–5443/haul) and *Ophiura*

Table 6.6

Summary of megabenthic invertebrate community parameters for PLOO trawl stations sampled during 2013. Data are included for species richness, abundance, and diversity (H'). SD = standard deviation.

Station	Winter	Summer
Species Richness		
SD7	16	18
SD8	23	17
SD10	12	18
SD12	15	15
SD13	12	8
SD14	9	10
Survey Mean	14	14
Survey SD	5	4
Abundance		
SD7	6305	3810
SD8	5616	1809
SD10	3699	3324
SD12	1842	370
SD13	2360	597
SD14	1260	852
Survey Mean	3514	1794
Survey SD	2071	1467
Diversity		
SD7	0.8	0.7
SD8	0.2	0.2
SD10	0.1	0.4
SD12	0.2	0.9
SD13	0.6	1.1
SD14	0.7	1.1
Survey Mean	0.4	0.7
Survey SD	0.3	0.4

luetkenii (962–2417/haul). The low diversity values (≤1.1) observed throughout the PLOO region during 2013 were caused by the numerical dominance of one or both of these two species.

As described above for demersal fishes, mean trawl-caught invertebrate species richness and diversity have remained within narrow ranges (i.e., SR = 7–24 species per haul, H' = 0.1–1.4) 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 2007b). Other influential species include the sea pen *Acanthoptilum* sp, *Ophiura luetkenii*, and the urchin *Strongylocentrotus fragilis*. 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 the trawl-caught invertebrate assemblages sampled during the summer surveys from 1991 through 2013 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 2013 assemblages differed from those present during 1992 and 1997 (Appendix E.4). Species that contributed to these spatial and temporal differences included the sea urchins *Lytechinus pictus* and *Strongylocentrotus fragilis*, the heart urchin *Spatangus californicus*, the sea stars *Astropecten californicus* and *Luidia foliolata*, the brittle star *Ophiura luetkenii*, the sea pen *Acanthoptilum* sp, the sea cucumber *Parastichopus californicus*, the crab *Pleuroncodes planipes*, the shrimp *Sicyonia ingentis*, and the sea spider *Nymphon pixella* (Figure 6.9).

Classification (cluster) analysis discriminated between four main types of invertebrate assemblages in the outfall region over the past 23 years (cluster

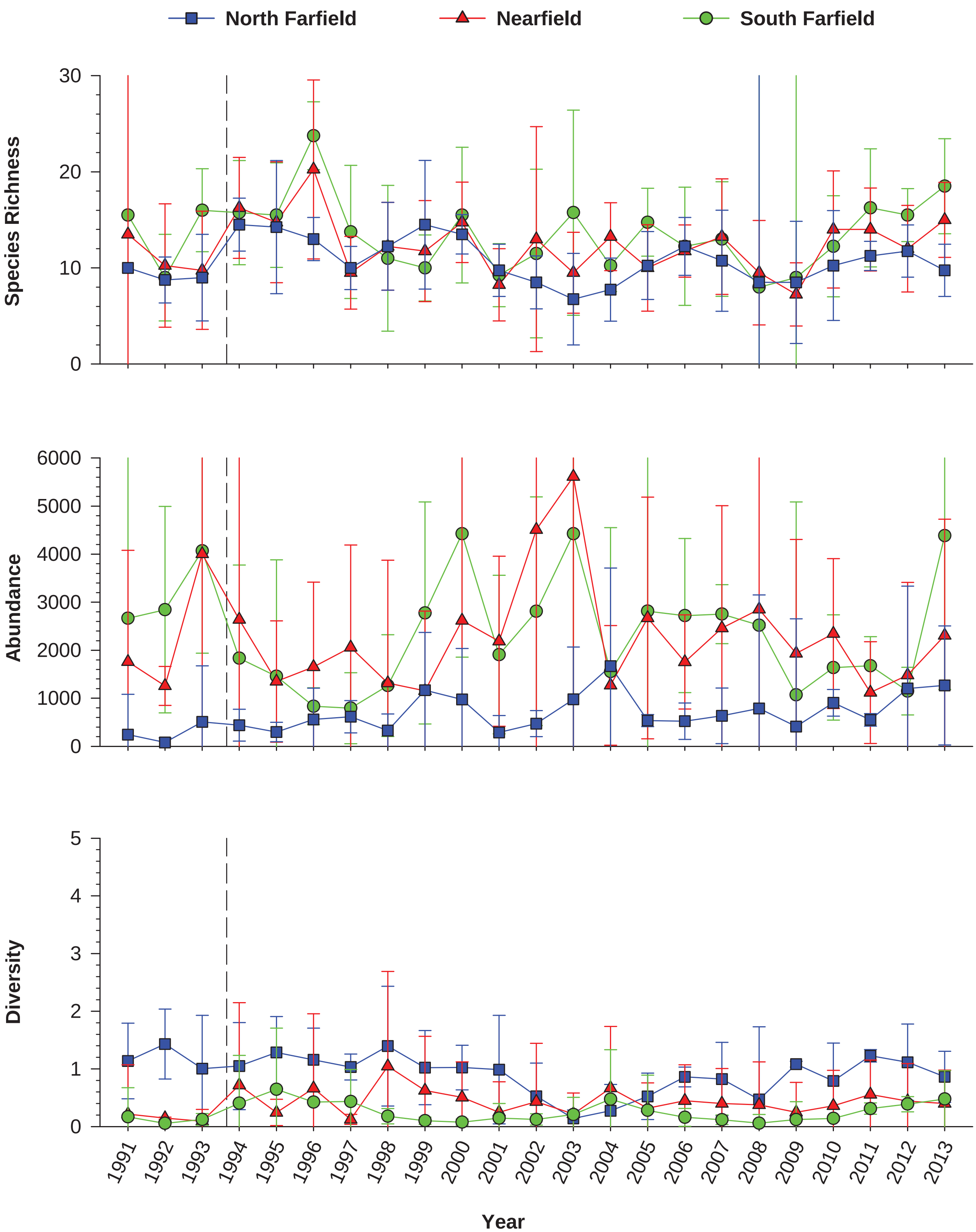

Figure 6.7

Species richness, abundance, and diversity of megabenthic invertebrates collected from PLOO trawl stations from 1991 through 2013. Data are annual means with 95% confidence intervals for nearfield stations (n ≤ 4), north farfield stations (n ≤ 4), and south farfield stations (n ≤ 4). Dashed lines indicate onset of wastewater discharge.

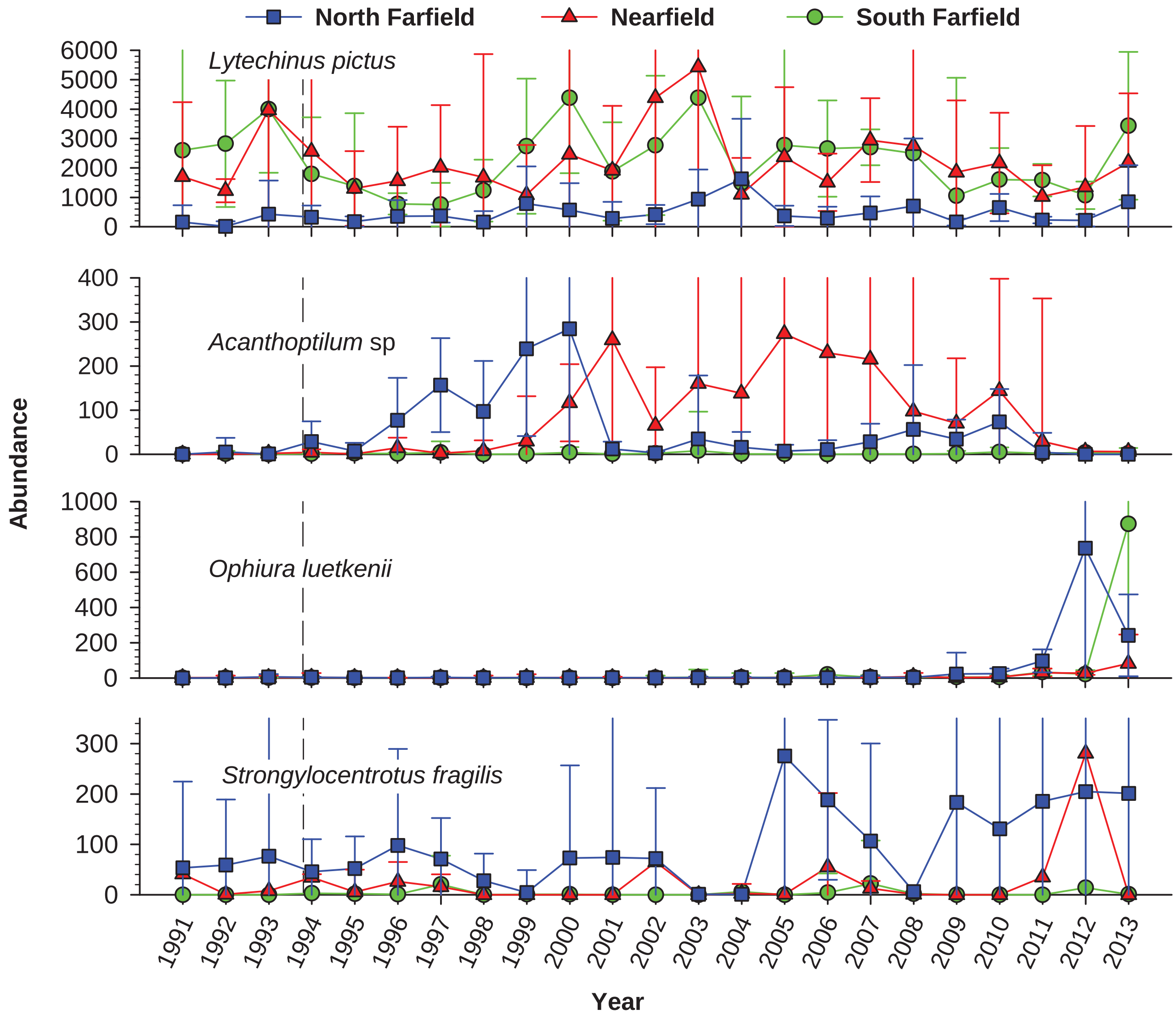

Figure 6.8
The eight most abundant invertebrate species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2013. Data are annual means with 95% confidence intervals for nearfield stations (n ≤ 4), north farfield stations (n ≤ 4), and south farfield stations (n ≤ 4). Dashed lines indicate onset of wastewater discharge.

groups A–D; Figure 6.10). These included two small groups representative of six and one hauls each (groups A and B, respectively), and two larger groups representing ~95% of all trawls (groups C and D). The distribution of assemblages in 2013 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 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 and summarized in Table 6.8.

Cluster group A comprised six hauls, including those from station SD12 in 1994, 1998, 2007, and 2008, station SD13 in 1992, and SD14 in 1998. This group averaged 13 species per haul and had the lowest total abundance (147 individuals/haul), the highest number of *Acanthoptilum* sp (83/haul) and lowest number of *Lytechinus pictus* (10/haul) of any cluster group. Other characteristic species that contributed to ≥ 75% within-group similarity (see Methods) for group A included *Strongylocentrotus fragilis*,

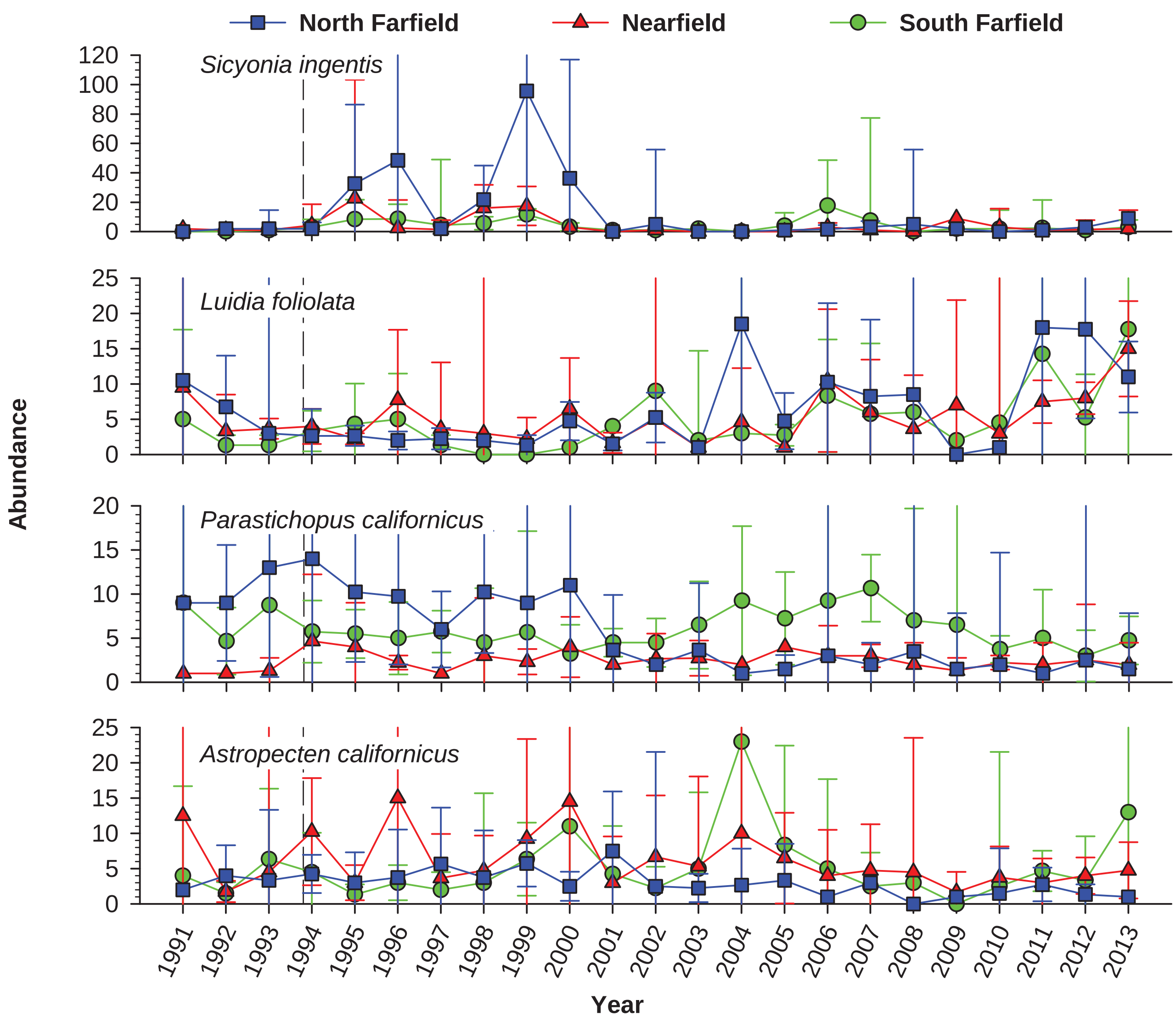

Figure 6.8 *continued*

Astropecten californicus, *Sicyonia ingentis*, and *Ophiura luetkenii*.

Cluster group B represented a single haul from station SD14 sampled in 2012. This assemblage had the lowest species richness (10 species), the highest abundance (3205 individuals), the highest numbers of *Ophiura luetkenii* (2640 individuals) and *Strongylocentrotus fragilis* (442 individuals), and the second lowest number of *Lytechinus pictus* (102 individuals) of any cluster group. It also included ≤11 of each of the following species: *Luidia foliolata*, the sea star *Astropecten ornatissimus*, and *Astropecten californicus*.

Cluster group C was the largest group, representing assemblages from a total of 84 hauls that included 86% (n=77) of the trawls conducted at stations SD7–SD12 over the past 23 years, as well as the trawls from station SD13 in 1998–1999 and 2003–2004, and station SD14 in 1993, 1999 and 2003. These assemblages averaged 14 species per haul, and had the second highest total abundance (2381 individuals/haul) and the highest number of *Lytechinus pictus* (2247/haul) of any cluster group.

Cluster group D was the second largest group, representing assemblages from a total of 43 hauls that included 77% (n=34) of the trawls conducted at stations SD13 and SD14 over the past 23 years, as well as the trawls from station SD8 in 1994–1995 and station SD12 in 1996, 1999, 2002, 2008, and 2011–2013. These assemblages averaged 12 species and 447 individuals per

Table 6.7

Results of 2-way crossed ANOSIM (with replicates) for megabenthic invertebrate assemblages sampled around the PLOO from 1991 through 2013. 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):	0.391 [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	0.330 (0.03)	0.750 (0.01)
South farfield	0.068 (21.60)	

Global Test: Factor B (years)

Tests for differences between years (across all station groups)

Sample statistic (Global R):	0.272 [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)

haul. Species characteristic of group D included *Lytechinus pictus*, *Strongylocentrotus fragilis* and *Acanthoptilum* sp.

Summary

Pacific sanddab dominated fish assemblages surrounding the PLOO in 2013 as they have since monitoring began in 1991. This species occurred in all trawls and accounted for 57% of the total catch. Other commonly captured, but less abundant species, included bigmouth sole, California lizardfish, California skate, Dover sole, English sole, halfbanded rockfish, hornyhead turbot, longspine combfish, Pacific argentine, pink seaperch, plainfin midshipman, shortspine combfish, and stripetail rockfish. Almost all fishes collected were < 21 cm in length. Although the composition and structure of the fish assemblages varied among stations and surveys in 2013 as in previous years, these differences appear to be due to natural fluctuations of common species.

Assemblages of trawl-caught invertebrates in 2013 were dominated by the sea urchin *Lytechinus pictus*, which occurred in all trawls and accounted for 81% of the total invertebrate abundance. The brittle star *Ophiura luetkenii* was also collected at all stations, and occurred in exceptional numbers at station SD7 during both surveys. Other frequently collected megabenthic invertebrates included the crinoid *Florometra seserratisima*, the sea stars *Astropecten californicus* and *Luidia foliolata,* the sea cucumber *Parastichopus californicus*, the opisthobranch *Pleurobranchaea californica*, the cephalopod *Octopus rubescens*, and the shrimp *Sicyonia ingentis*. 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 2013. Although highly variable, patterns in the abundance

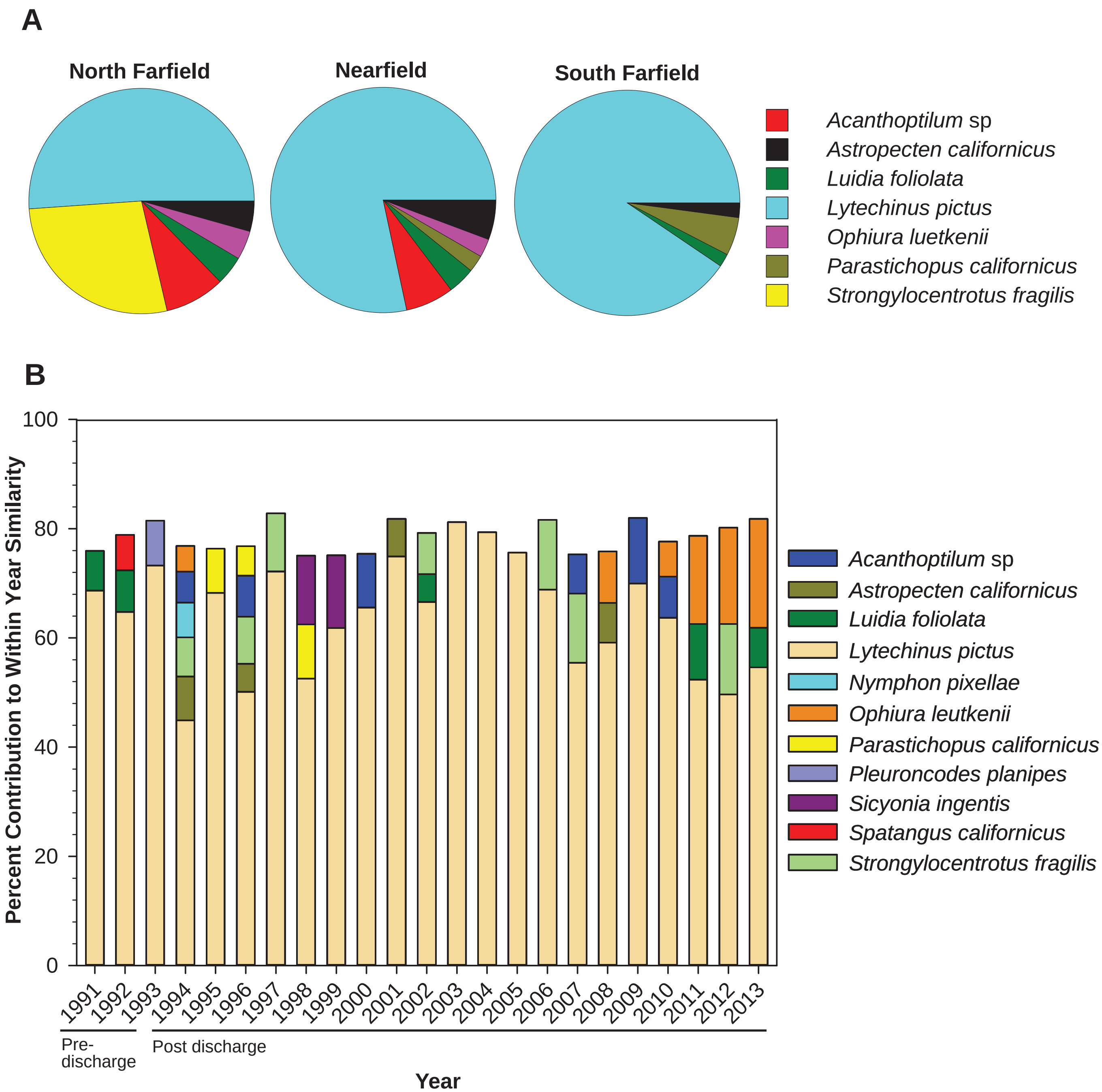

Figure 6.9

Characteristic megabenthic invertebrate species collected from PLOO trawl stations sampled during summary surveys from 1991 through 2013 that contribute to ≥75% 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).

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, 2008–2013). 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

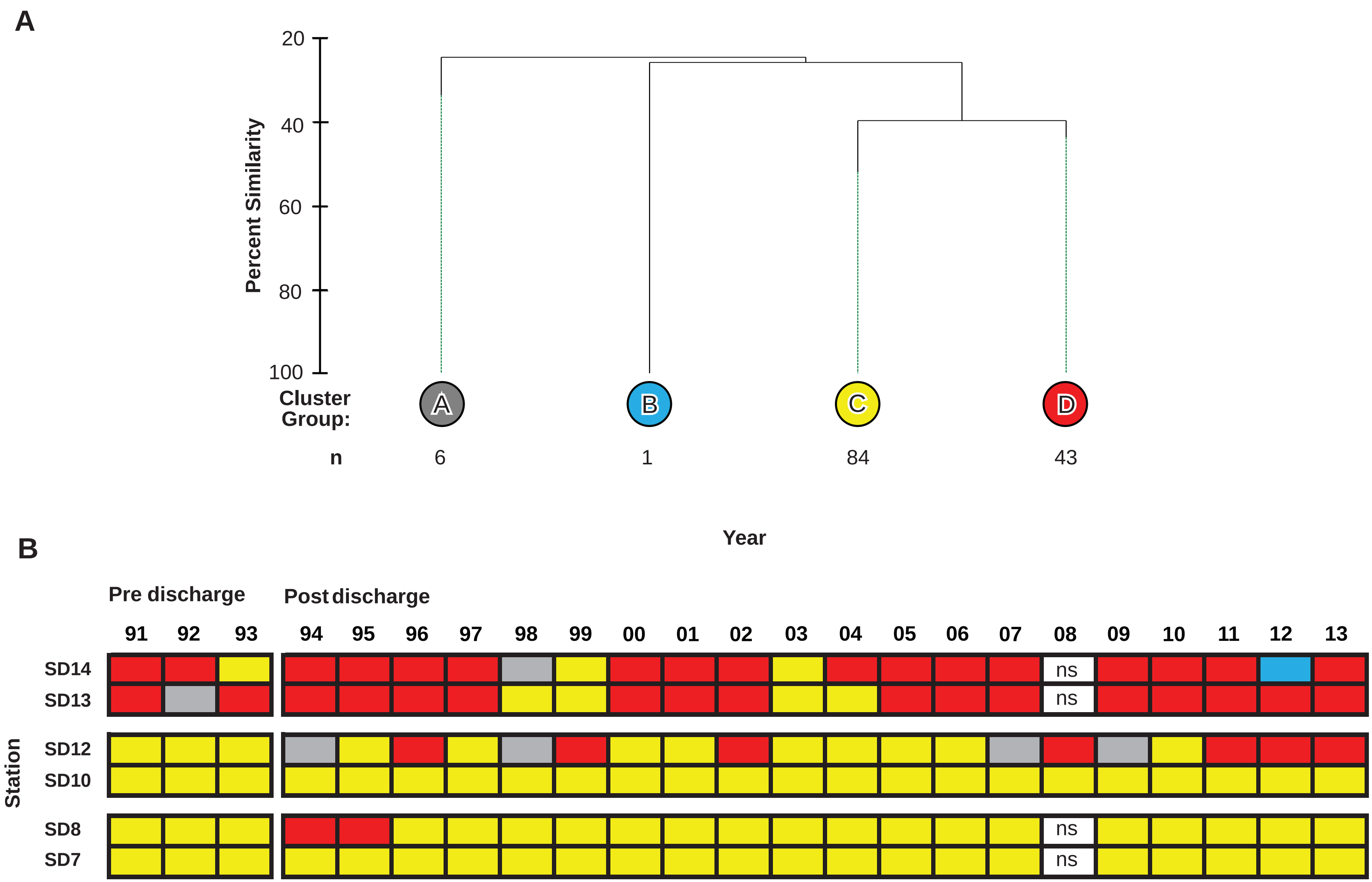

Figure 6.10
Results of cluster analysis of megabenthic invertebrate assemblages from PLOO trawl stations sampled from 1991 through 2013. Data are limited to summer surveys and presented as (A) a dendrogram of main cluster groups and (B) a matrix showing distribution of cluster groups over time. Major ecologically relevant SIMPROF supported clades with <40% similarity were retained; n = number of hauls; ns = not sampled.

Table 6.8

Description of megabenthic invertebrate cluster groups A–D defined in Figure 6.10. Species included represent the five most abundant taxa recorded for each cluster group. Bold values indicate species that were considered most characteristic of that group (i.e., contributing to ≥ 75% within-group similarity) according to SIMPER analysis.

	Cluster Group			
	A	B[a]	C	D
Number of Hauls	6	1	84	43
Mean Species Richness	13	10	14	12
Mean Abundance	147	3205	2361	447
Species	Mean Abundance			
Acanthoptilum sp	**83**		47	**42**
Strongylocentrotus fragilis	**22**	442	5	**135**
Lytechinus pictus	10	102	**2247**	**253**
Astropecten californicus	**7**	1	5	4
Sicyonia ingentis	**6**		6	2
Parastichopus californicus	2		5	3
Ophiura luetkenii	**2**	2640	19	20
Luidia foliolata	< 1	11	4	6
Astropecten ornatissimus	< 1	5	< 1	< 1

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

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 2013. 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, and (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 2013 from four trawl zones and two rig fishing stations (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 includes the area within a 1-km radius surrounding northern "farfield" stations SD13 and SD14. Trawl Zone 3 represents the area within a

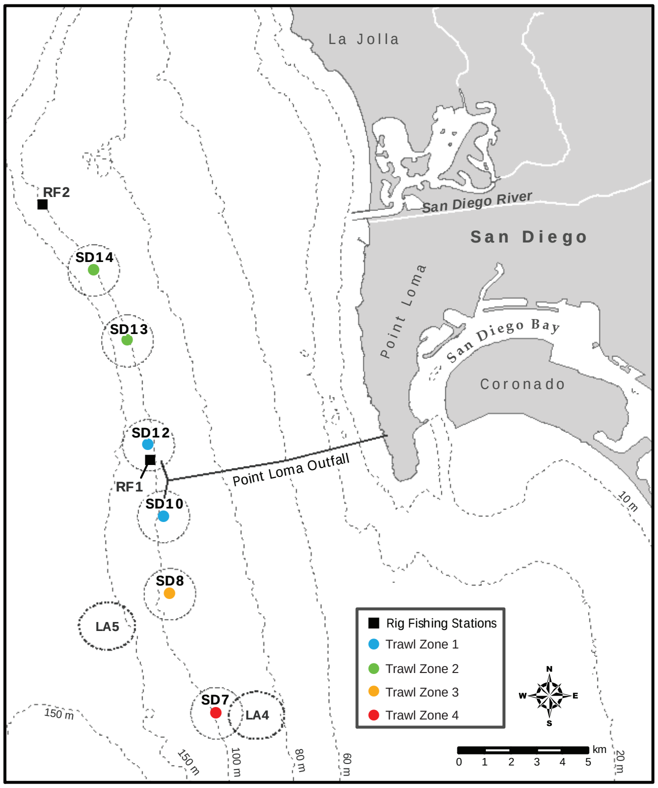

Figure 7.1
Trawl and rig fishing station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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 sanddabs (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawl zones, while six different species of rockfish were collected for analysis of muscle tissues at the rig fishing stations, including copper rockfish (*Sebastes caurinus*), greenblotched rockfish (*Sebastes rosenblatti*), rosy rockfish (*Sebastes rosaceus*), speckled rockfish (*Sebastes ovalis*), starry rockfish (*Sebastes constellatus*), 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 samples were subsequently delivered to the City's Wastewater Chemistry Services Laboratory within 10 days of dissection.

Chemical constituents were measured on a wet weight basis, and included 18 trace metals, 9 chlorinated pesticides (e.g., DDT), and 40 polychlorinated biphenyl compound congeners (PCBs) (see Appendix F.2). Data were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemistry Services Laboratory (City of San Diego 2014a).

Table 7.1
Species of fish collected from each PLOO trawl zone and rig fishing station during October 2013.

Station/Zone	Composite 1	Composite 2	Composite 3
Trawl Zone 1	Pacific sanddab	Pacific sanddab	Pacific sanddab
Trawl Zone 2	Pacific sanddab	Pacific sanddab	Pacific sanddab
Trawl Zone 3	Pacific sanddab	Pacific sanddab	Pacific sanddab
Trawl Zone 4	Pacific sanddab	Pacific sanddab	Pacific sanddab
Rig Fishing 1	Mixed rockfish [a]	Mixed rockfish [b]	Starry rockfish
Rig Fishing 2	Speckled rockfish	Speckled rockfish	Speckled rockfish

[a] Includes rosy and vermilion rockfish; [b] includes copper, greenblotched, speckled and starry rockfish

Data Analyses

Data summaries for each contaminant include detection rate, minimum, maximum, and mean detected values of each parameter by species. All means were calculated using detected values only; no substitutions were made for non-detects (i.e., analyte concentrations <MDL) in the data. Total DDT (tDDT), 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 (Trawl Zone 1, Rig Fishing Station RF1) to those from "farfield" stations (Trawl Zones 2–4, Rig Fishing Station RF2). Because contaminant levels can vary drastically among different species of fish, only intra-species comparisons were used for these assessments.

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

Results

Contaminants in Trawl-Caught Fishes

Trace Metals

Nine trace metals occurred in 100% of the liver tissue samples from trawl-caught Pacific sanddabs collected in the Point Loma outfall region during 2013 (Table 7.2). These included arsenic, cadmium, copper, iron, manganese, mercury, selenium, tin and zinc. Antimony, barium, chromium, lead, silver and thallium were also detected, but at rates between 8–92%. Aluminum, beryllium and nickel were not detected in any liver samples collected during the year. Most metals occurred at concentrations ≤14.3 ppm, though higher concentrations up to 31 ppm for zinc and 152 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 at variable concentrations. Trawl Zone 1 fishes had the highest values of arsenic, cadmium, iron, mercury, and silver, Trawl Zone 2 fishes had the highest values of antimony, manganese and lead, Trawl Zone 3 fishes had the highest values of selenium, tin, and zinc, and Trawl Zone 4 fishes had the highest values of barium, copper, and thallium.

Pesticides

Only three chlorinated pesticides were detected in Pacific sanddab liver tissues during 2013 (Table 7.2). DDT was found in every tissue sample collected in the PLOO region, with tDDT concentrations ranging from 163 to 461 ppb. The DDT metabolites p,p-DDD, p,p-DDE, and p,p-DDMU were found in 100% of the samples, whereas o,p-DDE and p,p-DDT were detected in 92% of the samples (Appendix F.3). Hexachlorobenzene (HCB) and chlordane also occurred frequently at rates of 100% and 92%, respectively, but at much lower concentrations than tDDT (≤15 ppb). Total chlordane consisted of alpha (cis) chlordane (detection rate = 17%) and trans nonachlor (detection rate = 83%). Total DDT, HCB and chlordane were present in samples from all stations at variable concentrations, with the highest values occurring in tissues from Trawl Zone 1 or Trawl Zone 4 (Figure 7.3).

PCBs

PCBs were detected in every Pacific sanddab liver tissue sample collected from the Point Loma outfall region during 2013 (Table 7.2). Total PCB concentrations were somewhat variable, ranging from 116 to 520 ppb. Twenty of the 29 detected congeners occurred in all samples, including PCB 49, PCB 52, PCB 66, PCB 70, PCB 74, PCB 99, PCB 101, PCB 105, PCB 110, PCB 118, PCB 128, PCB 138, PCB 149, PCB 153/168, PCB 158, PCB 70, PCB 170, PCB 180, PCB 183, and PCB 187 (Appendix F.3). The remaining congeners were found in 17–92% of the samples. Overall, there was no clear relationship between total PCB and proximity to the outfall with the highest value occurring in a sample from Trawl Zone 3 (Figure 7.3).

Table 7.2

Summary of metals, pesticides, total PCB, and lipids in liver tissues of Pacific sanddabs collected from PLOO trawl zones during 2013. 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, total chlordane and total PCB.

Parameter	DR (%)	Min	Max	Mean
Metals (*ppm*)				
Aluminum	0	—	—	—
Antimony	25	nd	0.31	0.25
Arsenic	100	2.4	4.5	3.3
Barium	17	nd	0.075	0.061
Beryllium	0	—	—	—
Cadmium	100	3.63	14.30	7.38
Chromium	92	nd	0.28	0.21
Copper	100	1.5	6.4	2.9
Iron	100	53.9	152.0	95.8
Lead	17	nd	0.33	0.27
Manganese	100	0.7	1.5	1.0
Mercury	100	0.040	0.172	0.090
Nickel	0	—	—	—
Selenium	100	0.18	1.43	1.02
Silver	25	nd	0.140	0.095
Thallium	8	nd	0.75	0.75
Tin	100	1.63	2.61	2.01
Zinc	100	20.1	30.9	25.1
Pesticides (*ppb*)				
HCB	100	2.7	15.0	5.0
Total chlordane	92	nd	12.0	6.7
Total DDT	100	163.1	460.9	299.7
Total PCB (*ppb*)	100	116.1	520.3	280.7
Lipids (*% weight*)	100	32.0	50.7	39.2

nd = detected

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

Contaminants in Fishes
Collected by Rig Fishing in 2013

Only four trace metals occurred in all rockfish muscle tissue samples collected at the PLOO rig fishing stations during 2013, including arsenic, mercury, selenium and tin (Table 7.3). Chromium, copper, iron, and zinc were also detected, but at rates ≤83%. In contrast, aluminum, antimony, barium, beryllium, cadmium, lead, manganese, nickel, silver, and thallium were not detected in any muscle tissue samples. The metals present in the highest concentrations were arsenic (≤2.1 ppm), iron (≤2.6 ppm), and zinc (≤4.8 ppm). Concentrations of all remaining metals were ≤1.1 ppm. Overall, the six frequently

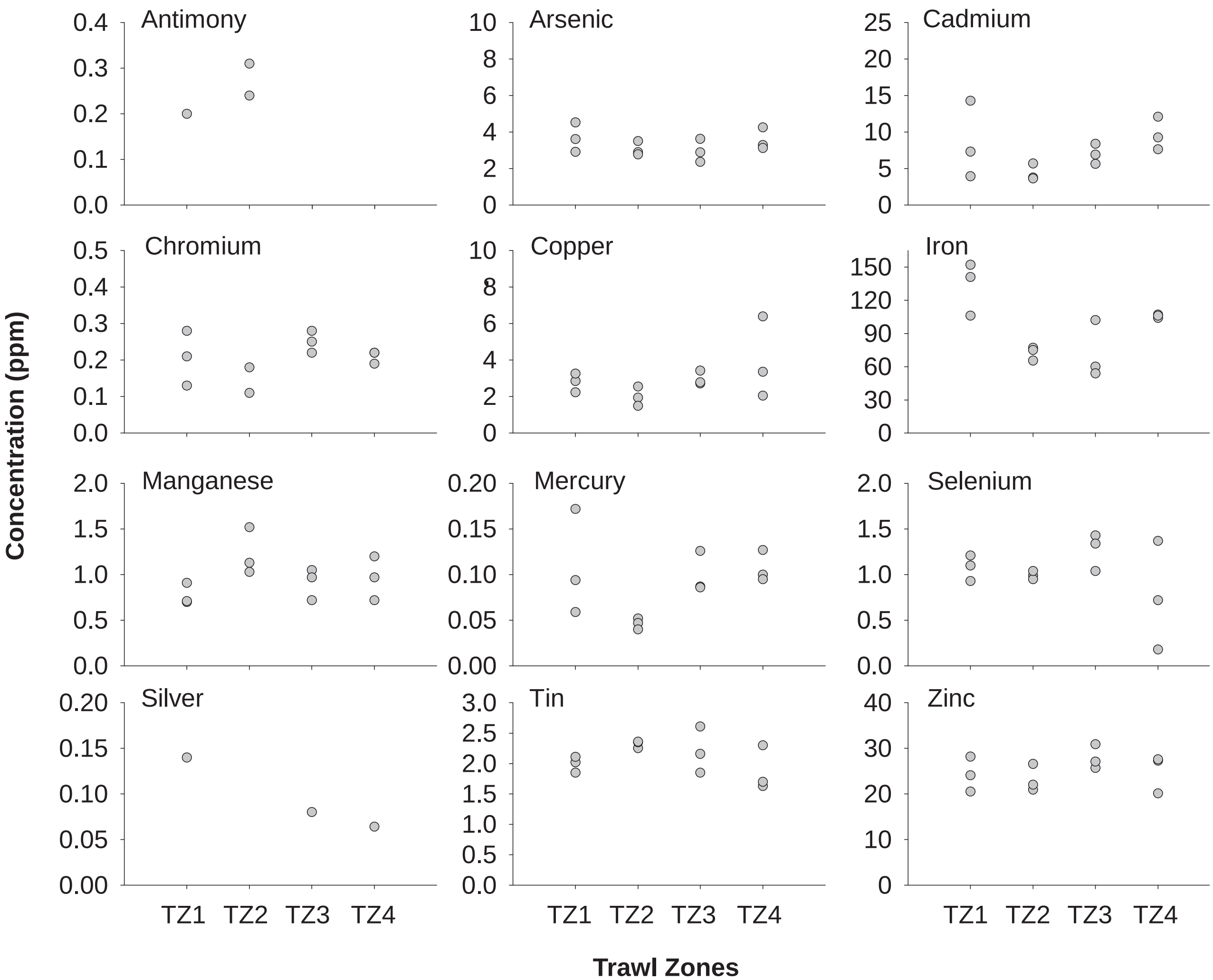

Figure 7.2
Concentrations of metals with detection rates ≥20% in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (TZ) during 2013. Trawl Zone 1 is considered nearfield (see text). All missing values are non-detects.

detected metals had variable concentrations and occurred at both rig fishing stations (Figure 7.4). The highest concentrations of arsenic, mercury, selenium and zinc were found in one or two samples from station RF1; however the fishes that comprised these samples were different species, and larger on average, than those collected at station RF2 (see Appendix F.1 and Discussion below).

Every rockfish muscle tissue sample collected during 2013 contained detectable levels of tDDT, HCB, and tPCB (Table 7.4), while chlordane was found in 33% of the samples. All four of these contaminants had concentrations ≤46.9 ppb, with the highest values reported from one or two samples from station RF1 (Figure 7.4). As noted above for metals, the fishes that comprised these samples differed in terms of weight, length, and species than those collected at station RF2 (see Appendix F.1 and Discussion below). The DDT metabolite p,p-DDE and the PCB congeners PCB 138 and PCB 153/168 were found in all samples (Appendix F.3). Another 23 PCB congeners were detected ≤83% of the time.

Most contaminants detected in rockfish muscle tissues during 2013 occurred at concentrations below state, national, and international limits or standards (Tables 7.3, 7.4). Exceptions included: (1) arsenic, which occurred at levels higher than median international standards in a single sample of mixed rockfish from station RF1; (2) selenium, which exceeded international standards in all samples; (3) mercury, which exceeded OEHHA fish contaminant goals in two samples of mixed rockfish from station RF1; (4) total DDT and total PCB, both of which exceeded OEHHA goals in a single sample of mixed rockfish and a single sample of starry rockfish from station RF1.

Discussion

Several trace metals, PCB congeners, and the chlorinated pesticides DDT, HCB, and chlordane were detected in liver tissues from Pacific sanddabs collected in the Point Loma outfall region during 2013. Many of the same metals, PCBs, chlordane, 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). 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 tissue samples composed of speckled rockfish, starry rockfish and/or mixed species of rockfish had arsenic and selenium concentrations above median international standards for human consumption, and concentrations of mercury, total DDT and total PCB above OEHHA limits. Elevated levels of these contaminants are not uncommon in sport fish from the PLOO survey area (City of San Diego 2007–2013) or from the rest of the San Diego region (see City of San Diego 2014b 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 that exceeded different consumption limits.

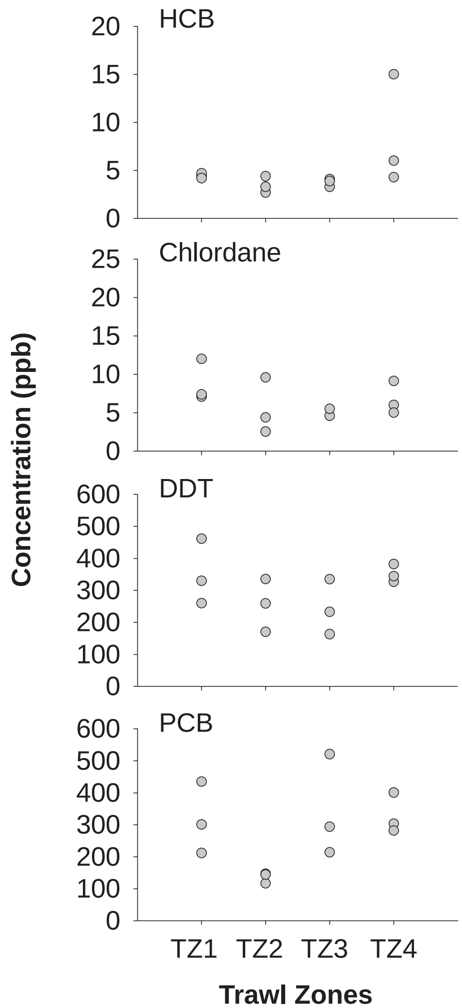

Figure 7.3
Concentrations of HCB, total chlordane, total DDT and total PCB in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (TZ) during 2013. Trawl Zone 1 is considered nearfield (see text). All missing values are non-detects.

The frequent 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).

Table 7.3

Summary of metals in muscle tissues of fishes collected from PLOO rig fishing stations during 2013. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the detection rate and maximum value for all species. Concentrations are expressed as parts per million (ppm). The number of samples per species is indicated in parentheses. 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	0	0	2	0	0	0	0	3	0	3	0	0	3	2
Min	—	—	0.4	—	—	—	nd	—	—	—	—	0.066	—	**0.34**	—	—	0.880	nd
Max	—	—	0.5	—	—	—	0.25	—	—	—	—	0.091	—	**0.40**	—	—	1.080	3.4
Mean	—	—	0.5	—	—	—	0.20	—	—	—	—	0.080	—	**0.38**	—	—	0.993	3.3
Starry rockfish																		
n (out of 1)	0	0	1	0	0	0	1	0	1	0	0	1	0	1	0	0	1	1
Value	—	—	0.5	—	—	—	0.16	—	2.6	—	—	0.160	—	**0.69**	—	—	0.975	4.0
Mixed rockfish																		
n (out of 2)	0	0	2	0	0	0	2	1	0	0	0	2	0	2	0	0	2	2
Min	—	—	0.4	—	—	—	0.15	nd	—	—	—	**0.249**	—	**0.46**	—	—	0.600	3.0
Max	—	—	**2.1**	—	—	—	0.19	0.1	—	—	—	**0.447**	—	**0.47**	—	—	0.610	4.8
Mean	—	—	1.2	—	—	—	0.17	0.1	—	—	—	**0.348**	—	**0.46**	—	—	0.605	3.9
All Species:																		
Detection Rate (%)	0	0	100	0	0	0	83	17	17	0	0	100	0	100	0	0	100	83
Max	—	—	**2.1**	—	—	—	0.25	0.1	2.6	—	—	**0.447**	—	**0.69**	—	—	1.080	4.8
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	na	na	na	na	na	na
IS[c]	na	na	1.4	na	na	1.0	1.0	20	na	2.0	na	0.5	na	0.3	na	na	175	70

na = not available; nd=not detected

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

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

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

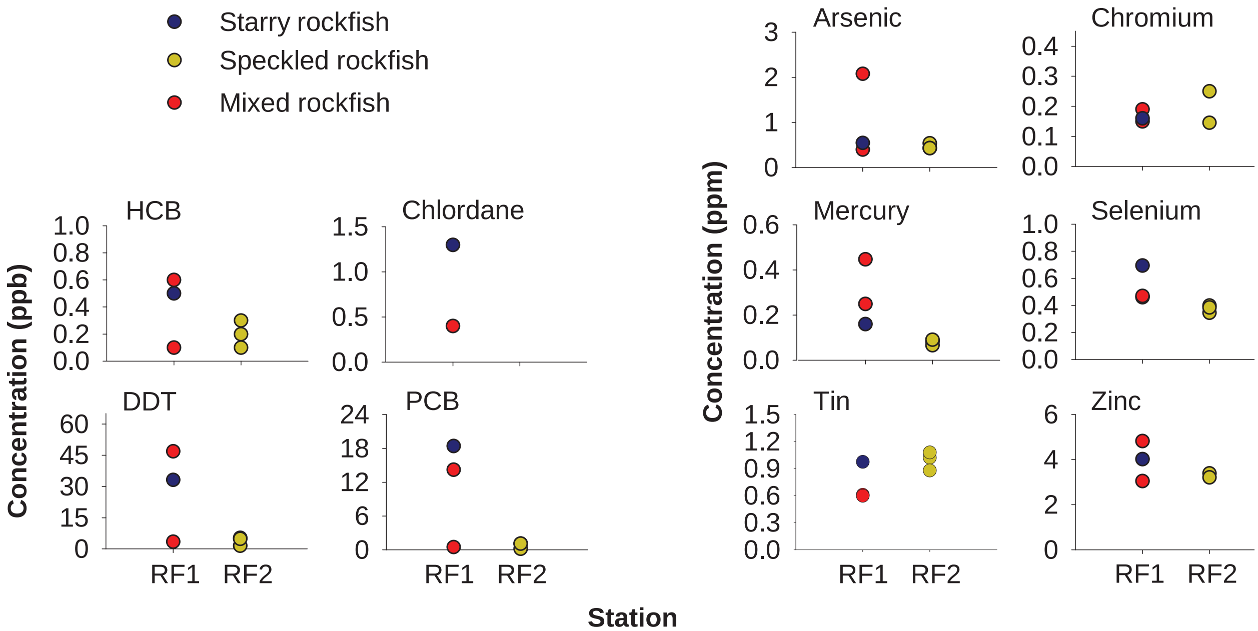

Figure 7.4
Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each PLOO rig fishing station during 2013. Station RF1 is considered nearfield (see text). All missing data are non-detects.

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; 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 (Chapter 4; Parnell et al. 2008).

Overall, there was no evidence of contaminant bioaccumulation in PLOO fishes during 2013 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 two other assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007, 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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Table 7.4

Summary of pesticides, total PCB, and lipids in muscle tissues of fishes collected from PLOO rig fishing stations during 2013. 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. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits (AL), or median international standards (IS). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT, chlordane (tChlor) and tPCB.

	Pesticides				
	HCB (ppb)	tDDT (ppb)	tChlor (ppb)	tPCB (ppb)	Lipids (% weight)
Speckled rockfish					
n (out of 3)	3	3	0	3	3
Min	0.1	1.5	—	0.2	1.0
Max	0.3	5.3	—	1.1	1.9
Mean	0.2	3.9	—	0.8	1.4
Starry rockfish					
n (out of 1)	1	1	1	1	1
Value	0.5	**33.1**	1.3	**18.4**	4.4
Mixed rockfish					
n (out of 2)	2	2	1	2	2
Min	0.1	3.5	nd	0.5	0.5
Max	0.6	**46.9**	0.4	**14.2**	1.9
Mean	0.3	**25.2**	0.4	**7.3**	1.2
All Species:					
DR(%)	100	100	33	100	100
Max	0.6	**46.9**	1.3	**18.4**	4.4
OEHHA[b]	na	21	5.6	3.6	na
AL[c]	300	5000	na	na	na
IS[c]	100	5000	100	na	na

na = not available; nd=not detected
[a] Minimum and maximum values were calculated based on all samples, whereas means were calculated from detected values only
[b] From the California OEHHA (Klasing and Brodberg 2008)
[c] From Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish

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Appendices

Appendix A

Supporting Data

2013 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 2013. For each quarter n = 714–804 (1–20 m), n = 1320 (21–60 m), n =439– 440 (61–80 m), n = 193–197 (81–100 m). Sample sizes differed due to sensor issues at individual stations.

		Depth (m)				
Temperature (°C)		**1–20**	**21–60**	**61–80**	**81–100**	**1–100**
February	min	11.7	10.6	10.1	10.0	10.0
	max	14.1	13.9	11.6	11.0	14.1
	mean	13.4	11.9	10.9	10.4	12.1
May	min	10.7	10.0	9.8	9.5	9.5
	max	19.4	13.9	10.5	10.1	19.4
	mean	15.1	10.8	10.1	9.8	11.9
August	min	11.4	10.6	10.5	10.5	10.5
	max	20.3	14.7	11.2	10.8	20.3
	mean	14.9	11.5	10.7	10.7	12.3
November	min	14.2	12.3	11.8	11.1	11.1
	max	17.9	16.0	13.2	12.7	17.9
	mean	16.4	13.7	12.5	12.0	14.1
Annual	min	10.7	10.0	9.8	9.5	9.5
	max	20.3	16.0	13.2	12.7	20.3
	mean	14.9	12.0	11.0	10.7	12.6

Appendix A.1 *continued*

Salinity (psu)		Depth (m) 1–20	21–60	61–80	81–100	1–100
February	min	33.41	33.44	33.51	33.70	33.41
	max	33.61	33.76	33.92	33.99	33.99
	mean	33.52	33.57	33.70	33.80	33.59
May	min	33.38	33.37	33.70	33.78	33.37
	max	33.73	33.81	33.89	34.03	34.03
	mean	33.54	33.64	33.81	33.90	33.66
August	min	33.35	33.41	33.55	33.60	33.35
	max	33.70	33.66	33.69	33.73	33.73
	mean	33.48	33.53	33.64	33.66	33.54
November	min	33.37	33.35	33.38	33.38	33.35
	max	33.60	33.45	33.50	33.78	33.78
	mean	33.49	33.40	33.43	33.50	33.44
Annual	min	33.35	33.35	33.38	33.38	33.35
	max	33.73	33.81	33.92	34.03	34.03
	mean	33.51	33.54	33.65	33.72	33.56

Appendix A.1 *continued*

DO (mg/L)		Depth (m)				
		1–20	21–60	61–80	81–100	1–100
February	min	5.2	3.6	3.2	2.8	2.8
	max	8.5	8.4	5.5	4.3	8.5
	mean	7.8	5.6	4.2	3.7	5.9
May	min	3.9	3.2	3.1	2.8	2.8
	max	10.9	8.6	4.6	3.6	10.9
	mean	7.8	4.8	3.6	3.3	5.4
August	min	5.7	4.0	3.9	3.7	3.7
	max	10.7	10.4	5.7	4.3	10.7
	mean	8.3	5.8	4.2	4.0	6.1
November	min	7.1	5.8	4.8	3.9	3.9
	max	8.4	8.3	7.1	6.4	8.4
	mean	8.0	7.1	6.2	5.6	7.1
Annual	min	3.9	3.2	3.1	2.8	2.8
	max	10.9	10.4	7.1	6.4	10.9
	mean	7.9	5.9	4.6	4.2	6.1

Appendix A.1 *continued*

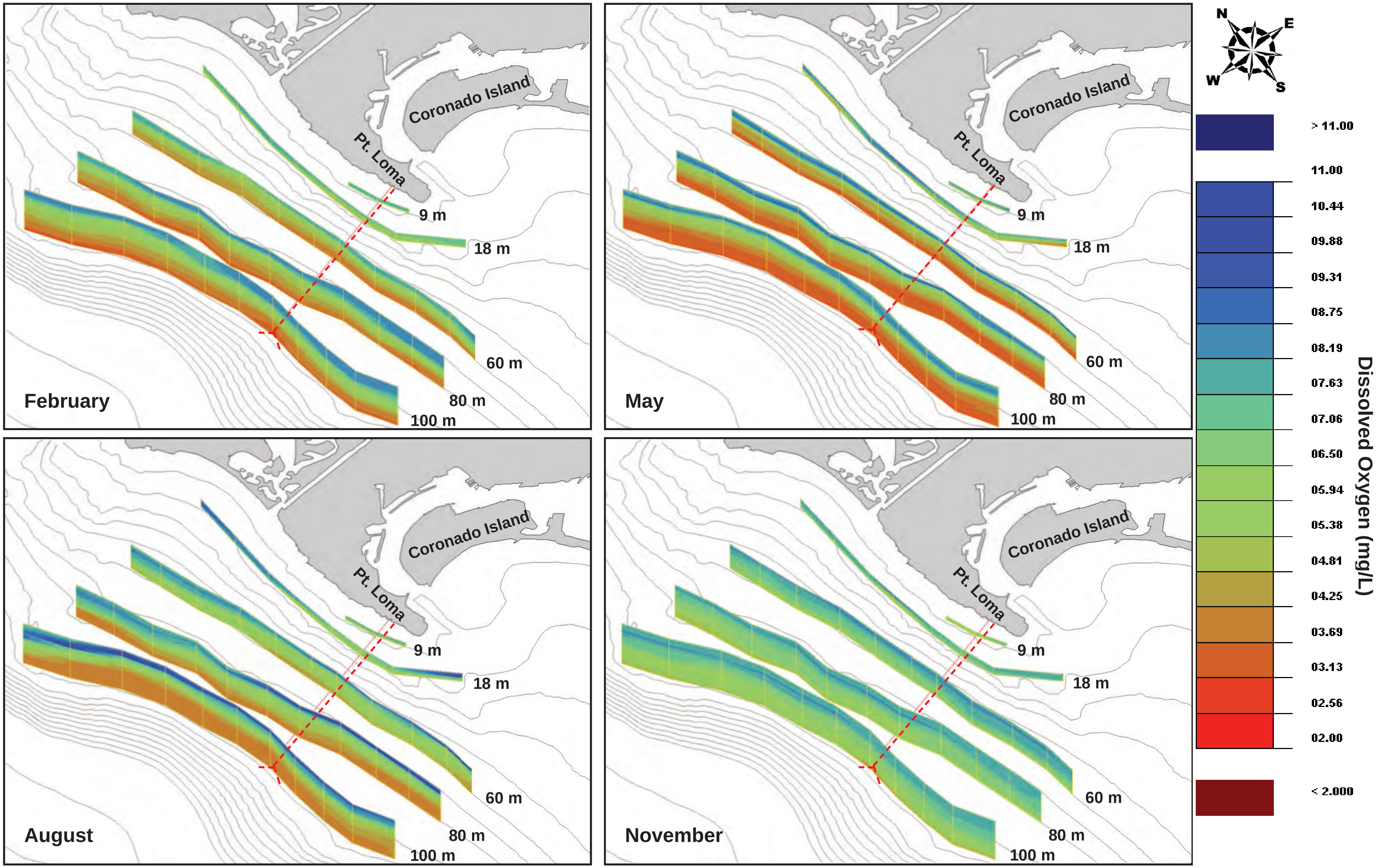
pH		Depth (m)				
		1–20	21–60	61–80	81–100	1–100
February	min	8.0	7.8	7.8	7.8	7.8
	max	8.2	8.2	8.0	7.9	8.2
	mean	8.1	8.0	7.9	7.8	8.0
May	min	7.7	7.7	7.7	7.7	7.7
	max	8.4	8.2	7.8	7.8	8.4
	mean	8.1	7.8	7.7	7.7	7.9
August	min	7.9	7.8	7.7	7.8	7.7
	max	8.3	8.3	7.9	7.8	8.3
	mean	8.1	7.9	7.8	7.8	8.0
November	min	8.0	7.9	7.8	7.7	7.7
	max	8.2	8.1	8.0	8.0	8.2
	mean	8.1	8.0	7.9	7.9	8.0
Annual	min	7.7	7.7	7.7	7.7	7.7
	max	8.4	8.3	8.0	8.0	8.4
	mean	8.1	7.9	7.8	7.8	8.0

Appendix A.1 *continued*

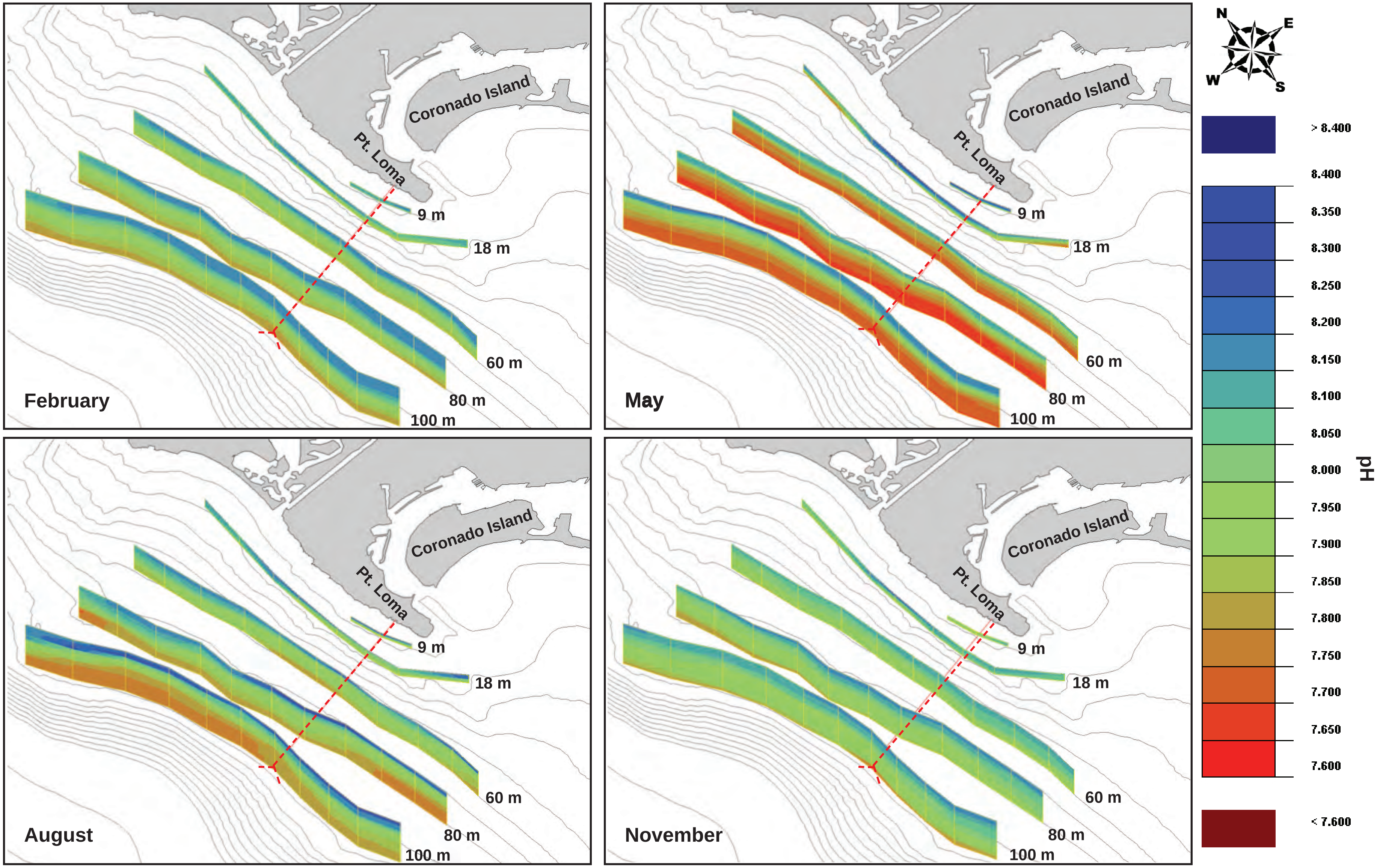
Transmissivity (%)		Depth (m)				
		1–20	**21–60**	**61–80**	**81–100**	**1–100**
February	min	74	62	79	85	62
	max	89	91	91	91	91
	mean	84	87	88	89	86
May	min	54	76	77	69	54
	max	89	90	90	89	90
	mean	84	89	88	87	87
August	min	48	67	76	86	48
	max	90	90	89	88	90
	mean	84	87	87	87	86
November	min	81	78	81	82	78
	max	89	89	89	89	89
	mean	87	87	88	87	87
Annual	min	48	62	76	69	48
	max	90	91	91	91	91
	mean	85	88	88	88	87

Appendix A.1 *continued*

Chlorophyll *a* (μg/L)		Depth (m) 1–20	21–60	61–80	81–100	1–100
February	min	0.6	1.8	1.7	1.7	0.6
	max	4.5	4.4	2.0	1.8	4.5
	mean	2.9	2.3	1.9	1.8	2.4
May	min	0.4	0.3	0.3	0.2	0.2
	max	23.5	8.7	0.7	0.4	23.5
	mean	2.4	1.1	0.4	0.3	1.3
August	min	0.2	0.4	0.4	0.3	0.2
	max	41.5	22.9	0.9	0.8	41.5
	mean	3.2	1.6	0.5	0.4	1.8
November	min	0.4	0.5	0.3	0.3	0.3
	max	3.3	2.9	1.2	0.8	3.3
	mean	1.2	1.3	0.7	0.5	1.1
Annual	min	0.2	0.3	0.3	0.2	0.2
	max	41.5	22.9	2.0	1.8	41.5
	mean	2.5	1.6	0.9	0.7	1.6

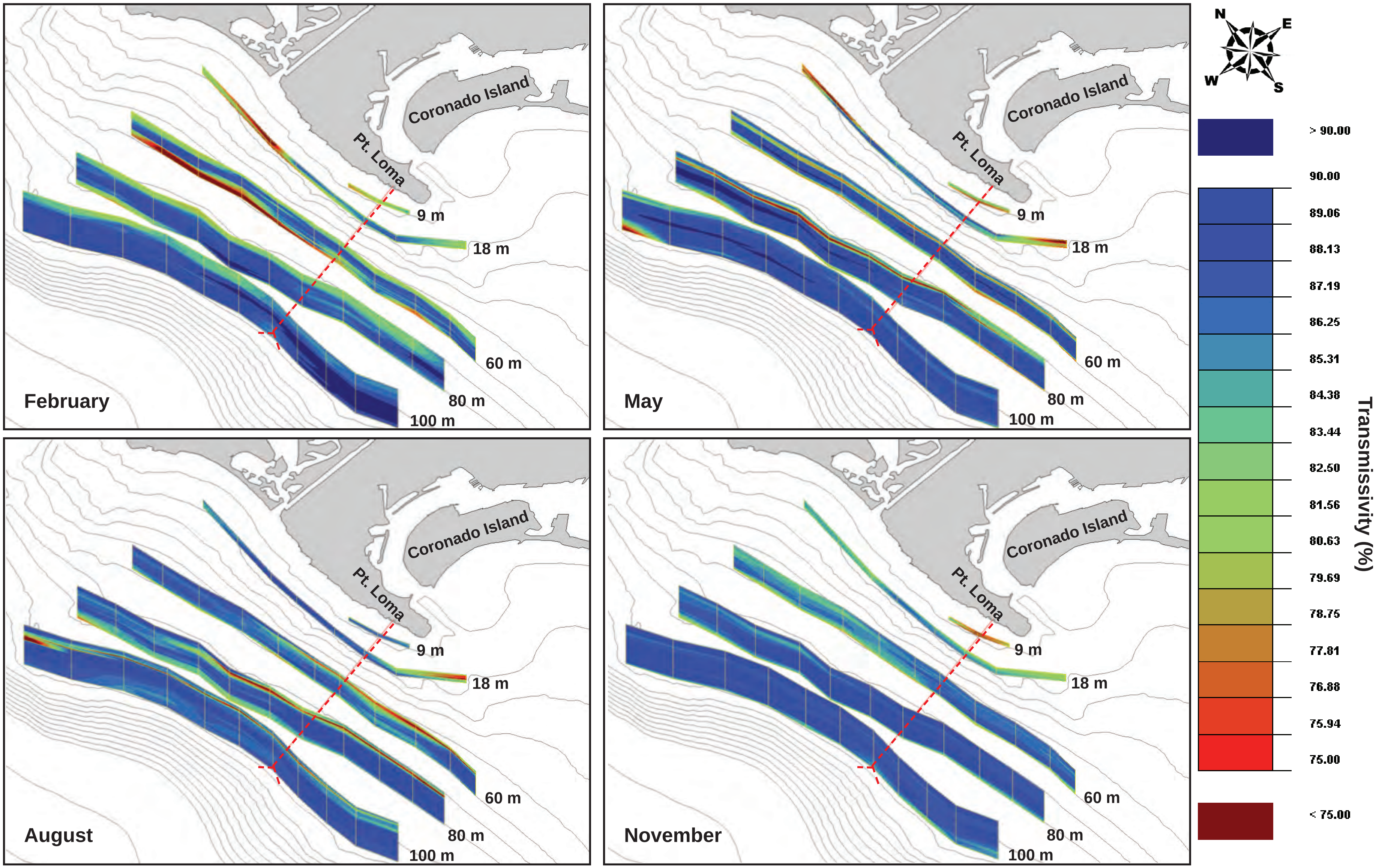


Appendix A.2
Dissolved oxygen recorded in the PLOO region during 2013. Data were collected over four consecutive days during each survey.



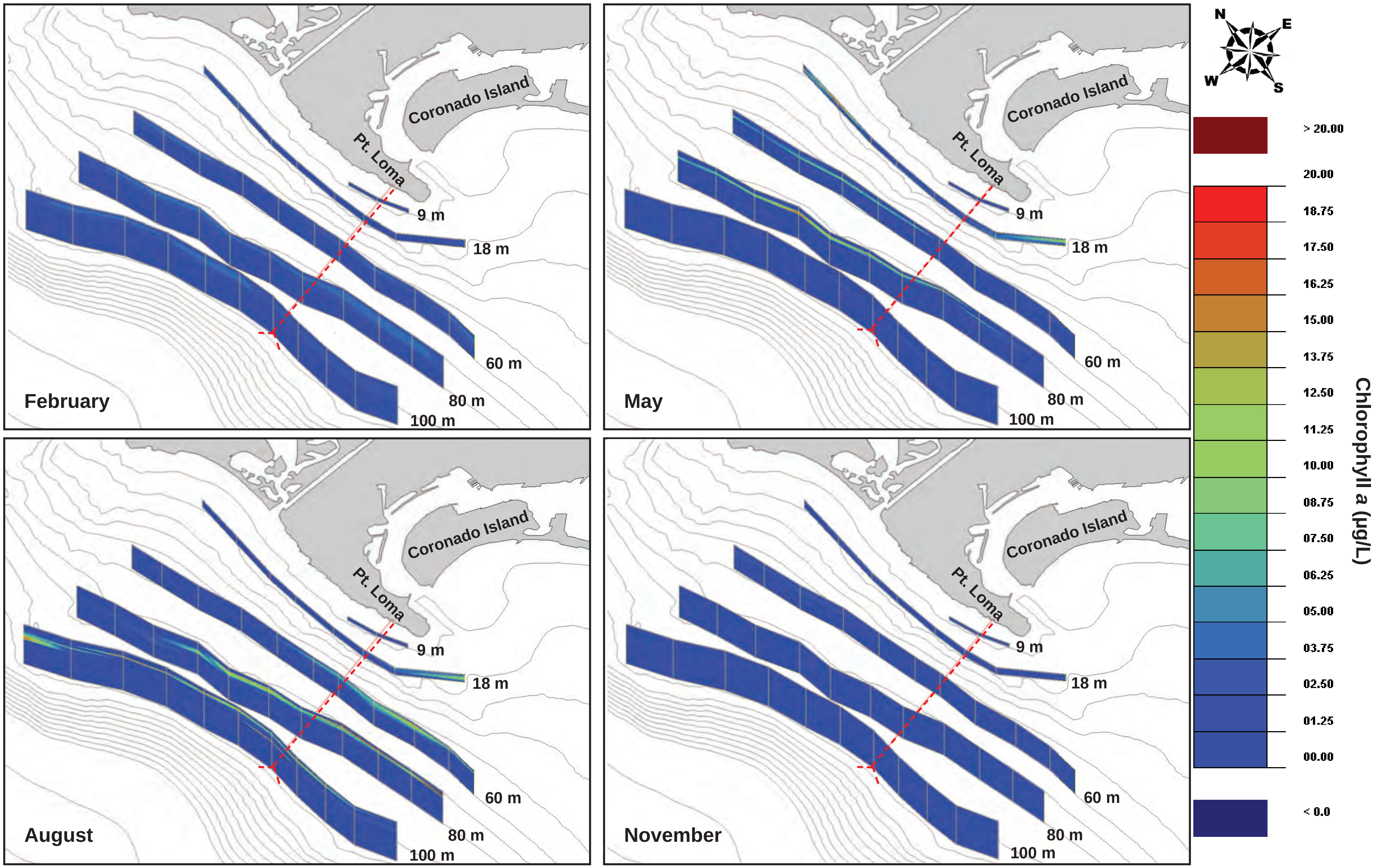
Appendix A.3

Measurements of pH recorded in the PLOO region during 2013. Data were collected over four consecutive days during each survey.



Appendix A.4

Transmissivity recorded in the PLOO region during 2013. Data were collected over four consecutive days during each survey.



Appendix A.5

Concentrations of chlorophyll *a* recorded in the PLOO region during 2013. Data were collected over four consecutive days during each survey.

Appendix A.6

Summary of current velocity magnitude and direction from the 60- and 100-m ADCP instruments in 2013. 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.

60-m ADCP

		Magnitude (cm/s)				Angle (°)	
	Depth (m)	**Min**	**Max**	**Mean**	**95% CI**	**Mean**	**95% CI**
Winter	11	3	212	95	3	228	6
	15	1	200	92	3	221	6
	19	14	179	88	3	213	6
	23	21	154	85	2	210	7
	27	20	152	82	2	208	7
	31	19	154	78	2	206	7
	35	16	155	74	2	203	7
	39	14	152	69	2	198	8
	43	10	142	62	2	178	8
	47	7	127	54	2	221	8
	51	0	109	46	2	296	5
	55	2	84	42	1	313	1
Spring	11	26	314	144	3	191	2
	15	20	257	114	3	192	2
	19	15	202	88	2	193	3
	23	9	156	67	2	194	3
	27	4	114	49	1	182	3
	31	1	81	36	1	183	4
	35	2	66	30	1	182	5
	39	1	56	29	1	177	5
	43	1	63	29	1	178	6
	47	1	70	28	1	196	6
	51	1	68	25	1	251	6
	55	3	58	22	1	294	3

Appendix A.6 *continued*

60-m ADCP

		Magnitude (cm/s)				Angle (°)	
	Depth (m)	**Min**	**Max**	**Mean**	**95% CI**	**Mean**	**95% CI**
Summer	11	0	243	93	3	222	4
	15	8	197	84	2	232	4
	19	8	201	74	2	233	4
	23	6	204	65	2	234	4
	27	5	193	59	1	237	5
	31	0	175	53	1	251	5
	35	1	158	49	1	265	5
	39	0	144	46	1	272	5
	43	2	128	43	1	278	5
	47	1	109	38	1	307	4
	51	0	88	32	1	318	3
	55	6	62	26	1	317	1
Fall	11	0	175	47	2	196	5
	15	6	177	50	2	247	5
	19	2	201	60	2	280	5
	23	2	203	65	2	286	5
	27	4	191	64	2	284	5
	31	6	174	60	2	278	5
	35	8	157	54	1	270	6
	39	10	143	48	1	259	6
	43	9	128	42	1	223	7
	47	3	109	35	1	237	7
	51	2	89	28	1	295	4
	55	4	62	24	1	302	2

Appendix A.6 *continued*

100-m ADCP

	Depth (m)	Magnitude (cm/s) Min	Max	Mean	95% CI	Angle (°) Mean	95% CI
Winter	11	5	120	50	1	127	4
	15	0	177	61	2	181	4
	19	1	184	60	2	180	5
	23	3	189	58	2	177	5
	27	3	192	57	2	169	5
	31	6	195	58	2	146	5
	35	1	197	59	2	146	5
	39	5	197	59	2	140	5
	43	4	193	60	2	142	6
	47	1	187	61	2	149	6
	51	2	180	61	2	151	6
	55	6	171	63	2	159	6
	59	5	163	63	2	164	6
	63	3	155	62	2	173	6
	67	1	147	60	2	190	6
	71	2	142	57	1	199	6
	75	5	137	54	1	198	6
	79	5	131	50	1	177	6
	83	3	124	45	1	132	6
	87	8	114	39	1	81	4
	91	2	99	34	1	99	4
	95	5	75	29	1	121	4

Appendix A.6 *continued*

100-m ADCP

	Depth (m)	Magnitude (cm/s) Min	Max	Mean	95% CI	Angle (°) Mean	95% CI
Spring	11	14	178	119	2	132	2
	15	2	284	155	3	143	2
	19	5	267	140	3	142	2
	23	10	245	123	2	144	2
	27	11	225	109	2	145	2
	31	11	209	94	2	145	3
	35	11	189	82	2	144	3
	39	8	169	71	2	139	3
	43	6	149	62	1	139	3
	47	6	128	54	1	145	4
	51	3	107	49	1	144	4
	55	3	110	43	1	136	4
	59	0	110	39	1	147	5
	63	0	109	37	1	199	6
	67	1	106	37	1	238	6
	71	1	101	37	1	286	4
	75	1	95	36	1	271	5
	79	2	87	32	1	231	6
	83	6	77	30	1	97	5
	87	12	65	29	1	52	2
	91	17	51	30	0	70	2
	95	14	39	27	0	87	1

Appendix A.6 *continued*

100-m ADCP

	Depth (m)	Magnitude (cm/s) Min	Max	Mean	95% CI	Angle (°) Mean	95% CI
Summer	11	17	263	110	3	120	2
	15	9	346	120	4	175	4
	19	8	300	100	3	173	4
	23	5	262	87	3	168	4
	27	3	229	75	2	167	4
	31	1	207	65	2	166	4
	35	1	213	56	2	163	5
	39	0	219	50	2	157	5
	43	1	222	44	2	146	5
	47	1	220	40	1	136	5
	51	3	215	38	1	144	6
	55	6	207	38	1	177	6
	59	11	198	38	1	184	6
	63	14	189	39	1	214	6
	67	12	183	39	1	221	6
	71	10	178	37	1	222	6
	75	9	173	34	1	223	6
	79	4	167	29	1	223	6
	83	1	160	27	1	84	4
	87	14	150	33	1	83	2
	91	23	134	39	1	94	2
	95	23	108	38	1	104	2

Appendix A.6 *continued*

100-m ADCP

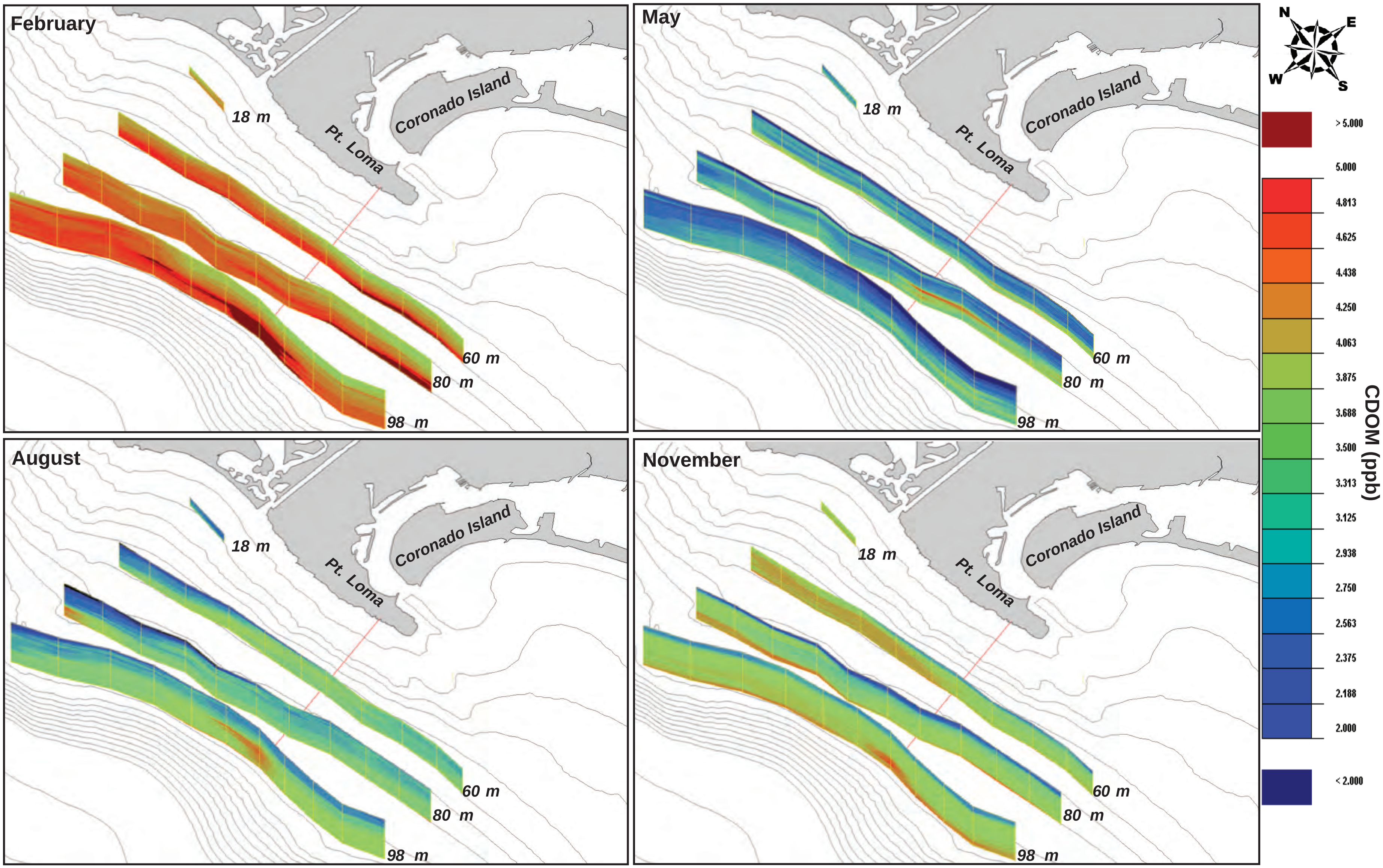
	Depth (m)	Magnitude (cm/s)				Angle (°)	
		Min	Max	Mean	95% CI	Mean	95% CI
Fall	11	15	127	58	1	127	2
	15	4	135	53	2	135	3
	19	3	147	47	2	147	4
	23	0	155	48	2	155	5
	27	1	161	50	2	161	5
	31	1	170	49	2	170	5
	35	0	121	48	2	121	5
	39	1	119	48	2	119	5
	43	5	137	50	2	137	5
	47	7	152	51	2	152	5
	51	8	163	52	2	163	6
	55	6	167	52	2	167	6
	59	1	179	50	2	179	6
	63	1	239	50	2	239	6
	67	0	247	49	2	247	5
	71	1	252	48	2	252	5
	75	0	253	45	2	253	5
	79	2	244	42	2	244	5
	83	0	107	40	2	107	4
	87	1	103	42	2	103	3
	91	2	115	44	1	115	3
	95	5	129	43	1	129	2

Appendix B

Supporting Data

2013 PLOO Stations

Water Quality Compliance & Plume Dispersion



Appendix B.1

CDOM values recorded in 2013 for the PLOO region. Data were collected over 3–4 days during each quarterly survey.

Appendix B.2

Summary of rainfall and bacteria levels at PLOO shore stations during 2013. 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):		1.21	0.63	1.22	0.01	0.26	0.00	0.05	0.00	0.00	0.25	1.48	0.46
D12	*Total*	15	14	8	49	13	52	9	13	93	32	10	21
	Fecal	4	7	4	2	2	2	2	2	9	13	8	5
	Entero	11	4	2	2	2	2	3	2	21	7	3	8
D11	*Total*	60	100	35	100	80	44	112	53	60	21	28	46
	Fecal	5	20	18	20	15	6	15	10	4	5	6	7
	Entero	5	9	8	7	85	7	7	4	5	9	45	4
D10	*Total*	74	29	28	13	56	108	104	38	32	35	81	64
	Fecal	6	5	17	4	7	2	14	12	4	8	12	6
	Entero	4	4	5	2	4	4	10	5	8	10	12	5
D9	*Total*	33	16	18	14	16	56	556	22	20	20	29	84
	Fecal	3	5	2	3	2	2	4	2	2	2	5	2
	Entero	3	4	2	2	2	5	8	2	2	2	3	2
D8	*Total*	24	24	28	56	92	68	100	28	56	132	88	432
	Fecal	4	5	6	6	2	7	8	5	3	22	21	17
	Entero	4	4	2	2	2	2	1442	3	4	21	6	10
D7	*Total*	23	25	448	52	56	92	168	28	56	92	18	24
	Fecal	14	8	42	3	6	9	10	14	6	18	12	6
	Entero	4	2	166	5	3	2	4	6	2	25	4	3
D5	*Total*	11	29	9	14	53	128	32	20	20	80	24	401
	Fecal	3	2	2	2	4	8	7	2	3	2	6	43
	Entero	2	2	2	2	2	2	2	2	2	2	3	12
D4	*Total*	2	6	14	13	98	16	64	16	80	50	16	23
	Fecal	2	2	6	2	10	2	2	2	21	2	2	2
	Entero	2	2	5	2	3	2	2	2	6	2	2	2
	n	40	40	40	40	40	40	40	40	40	48	40	40
Monthly	*Total*	30	30	74	39	58	71	143	27	52	55	37	137
Means	*Fecal*	5	7	12	5	6	5	8	6	6	9	9	11
	Entero	4	4	24	3	13	3	185	3	6	10	10	6

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Appendix B.3

Summary of elevated bacteria densities in samples collected at PLOO shore, kelp bed, and offshore stations during 2013. Bold values exceed benchmarks for total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), *Enterococcus* (>104 CFU/100 mL), and/or the FTR criterion (total coliforms >1000 CFU/100 mL and F:T>0.10).

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
Shore Stations						
D7	11 Mar 13	—	2200	200	**820**	0.09
D11	16 May 13	—	40	10	**400**	0.25
D8	27 Jul 13	—	20	14	**7200**	0.7
D7	31 Oct 13	—	200	40	**120**	0.2
D11	18 Nov 13	—	20	3	**200**	0.15
Kelp Bed Stations						
no exceedances						
Offshore Stations						
F30	11 Feb 13	80	—	—	**400**	—

Appendix B.4

Summary of bacteria levels at PLOO kelp bed and offshore stations during 2013. Total coliform, fecal coliform, and *Enterococcus* densities are expressed as mean CFU/100 mL for all stations along each depth contour by month; n = total number of samples per month.

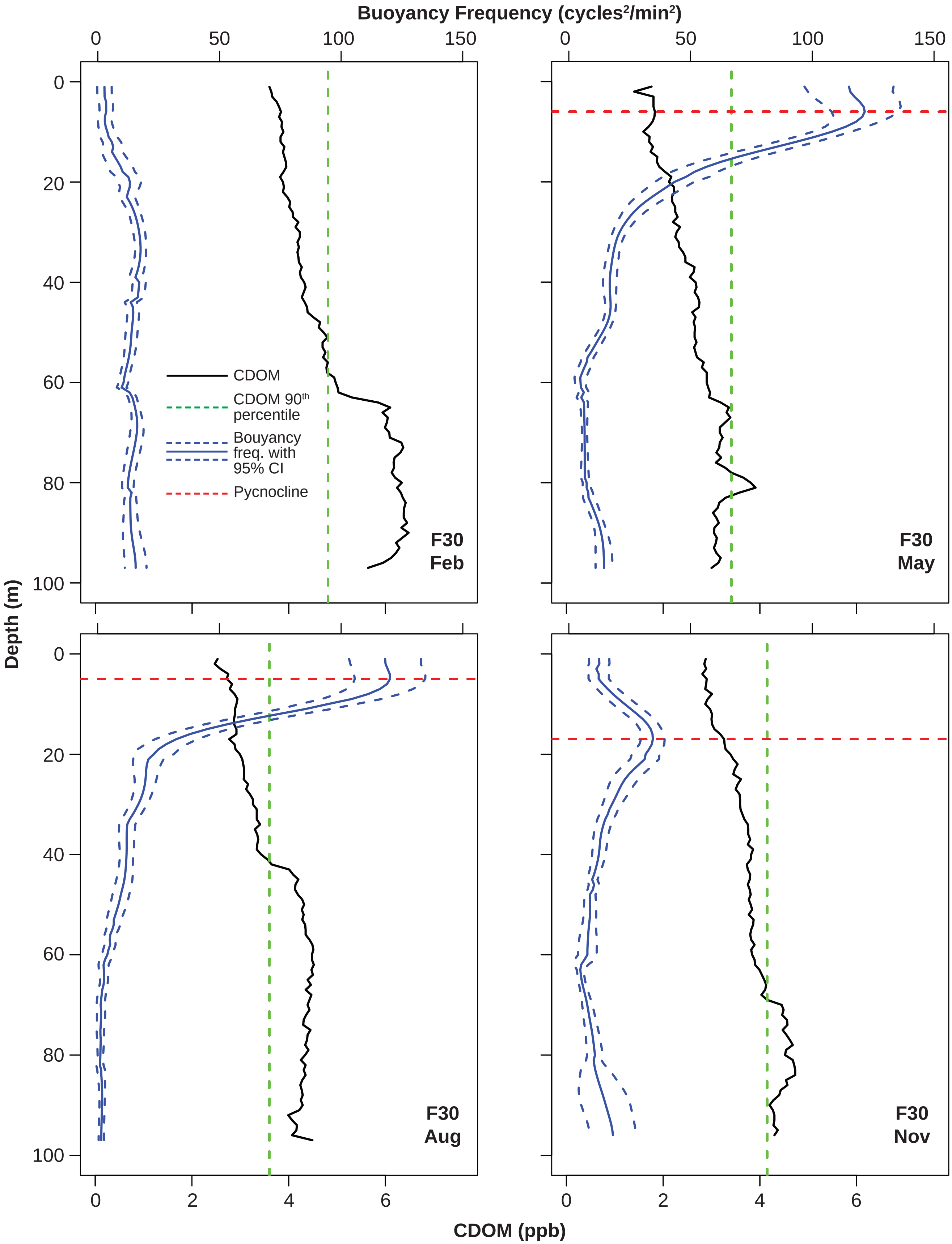
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Rain (in):	1.21	0.63	1.22	0.01	0.26	0.00	0.05	0.00	0.00	0.25	1.48	0.46
Kelp Bed Stations												
9-m Contour (n = 45)												
Total	2	3	4	4	7	31	4	3	8	5	4	5
Fecal	2	2	2	2	2	2	2	2	2	2	2	2
Entero	2	2	2	2	2	2	2	2	2	2	2	2
18-m Contour (n = 75)												
Total	5	23	30	4	3	3	5	3	4	3	3	4
Fecal	2	3	2	2	2	2	2	2	2	2	2	2
Entero	2	2	2	2	2	2	2	2	2	2	2	2
Offshore Stations[a]												
18-m Contour (n = 9)	—	2	—	—	2	—	—	2	—	—	2	—
60-m Contour (n = 33)	—	8	—	—	3	—	—	2	—	—	2	—
80-m Contour (n = 44)	—	10	—	—	6	—	—	2	—	—	8	—
100-m Contour (n = 55)	—	14	—	—	3	—	—	2	—	—	3	—

[a] *Enterococcus* only

Appendix B.5

Summary of PLOO reference stations used during 2013 to calculate out-of-range thresholds (see text for details).

Month	Stations
February	F01, F02, F03, F10, F22, F24, F25, F26, F27, F28, F36
May	F01, F02, F03, F10, F23, F32, F33, F34, F35, F36
August	F02, F03, F04, F05, F06, F12, F13, F14, F16, F22, F23, F33, F34, F35, F36
November	F01, F02, F03, F04, F05, F15, F21, F27, F28, F32, F33, F34, F35, F36



Appendix B.6

Representative vertical profiles of CDOM and buoyancy frequency from outfall station F30 during 2013.

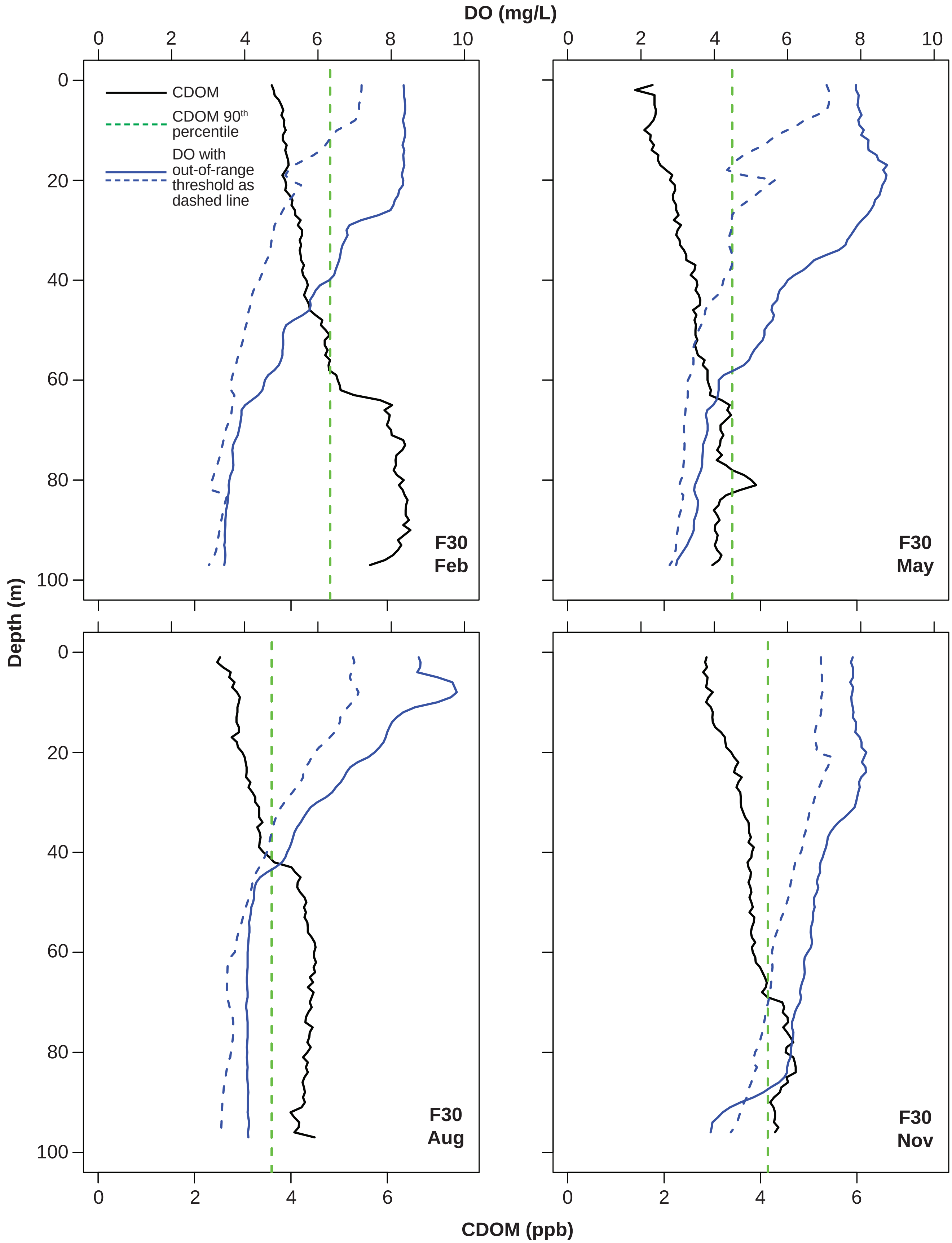
Appendix B.7

Summary of oceanographic data within potential detected plume at PLOO offshore stations and corresponding reference stations during 2013. Bold values indicate out-of-range values. DO = dissolved oxygen; XMS = transmissivity; SD = standard deviation; CI = confidence interval.

			Plume			Reference		
Station	Date	Plume Width (m)	Mean DO	Mean pH	Mean XMS	DO (Mean - SD)	pH (Mean - SD)	XMS (Mean - 95% CI)
F15	12 Feb 13	21	3.98	7.87	88.0	3.82	7.85	84.7
F16	12 Feb 13	20	3.82	7.87	87.1	3.81	7.84	85.4
F19	12 Feb 13	1	4.29	7.88	88.3	4.05	7.86	87.9
F20	12 Feb 13	9	4.42	7.89	89.1	4.20	7.88	84.0
F29	11 Feb 13	24	4.03	7.86	89.3	3.82	7.84	86.7
F30	11 Feb 13	39	3.74	7.85	86.8	3.82	7.84	86.3
F31	11 Feb 13	17	4.35	7.90	89.2	3.83	7.84	86.1
F32	11 Feb 13	15	4.36	7.91	88.6	3.88	7.85	86.2
F33	11 Feb 13	21	4.52	7.91	88.2	3.88	7.85	85.6
F04	15 May 13	8	**3.48**	7.71	**88.0**	3.93	7.75	88.3
F05	15 May 13	9	3.49	7.71	**86.4**	3.82	7.74	87.1
F06	15 May 13	11	**3.43**	7.71	**85.1**	3.84	7.74	87.4
F07	15 May 13	7	**3.41**	7.71	**86.3**	3.96	7.75	88.9
F11	15 May 13	10	3.57	7.72	**84.3**	3.86	7.75	87.6
F15	14 May 13	19	3.50	7.68	87.9	3.64	7.72	87.3
F16	14 May 13	14	3.45	7.68	87.1	3.54	7.71	86.6
F17	14 May 13	21	3.39	7.68	86.0	3.73	7.73	86.8
F18	14 May 13	19	**3.45**	7.68	**87.5**	3.84	7.74	87.8
F19	14 May 13	28	3.40	7.68	**87.0**	3.73	7.73	87.5
F26	13 May 13	10	3.51	7.72	88.1	3.45	7.72	83.5
F27	13 May 13	12	3.56	7.73	88.0	3.65	7.73	86.9
F28	13 May 13	12	3.52	7.72	87.9	3.50	7.71	85.6
F30	13 May 13	4	3.51	7.73	88.6	3.42	7.70	83.8
F24	28 Aug 13	14	4.24	7.83	**84.9**	4.12	7.79	85.9
F25	28 Aug 13	26	4.05	7.76	**83.4**	4.11	7.79	85.7
F30	29 Aug 13	54	4.12	7.81	87.3	4.13	7.80	86.1
F31	29 Aug 13	31	4.16	7.80	87.3	4.04	7.79	86.1

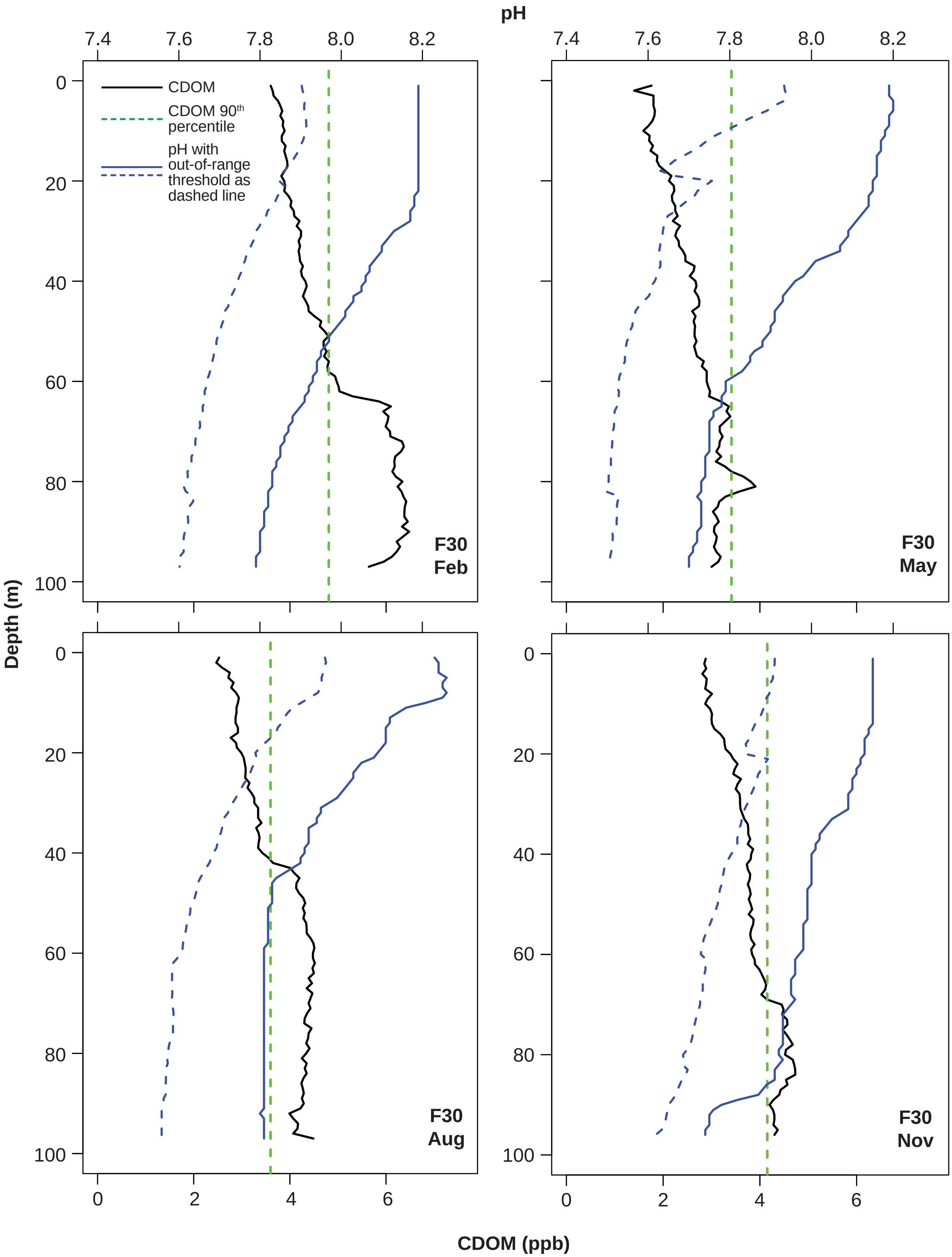
Appendix B.7 *continued*

			Plume			Reference		
Station	**Date**	**Plume Width (m)**	**Mean DO**	**Mean pH**	**Mean XMS**	**DO (Mean - SD)**	**pH (Mean - SD)**	**XMS (Mean - 95% CI)**
F24	14 Nov 13	12	**5.22**	7.85	**84.9**	5.95	7.91	87.5
F25	14 Nov 13	15	**5.12**	7.82	**84.4**	6.02	7.92	87.6
F30	15 Nov 13	27	5.44	7.87	**86.3**	5.61	7.88	86.7



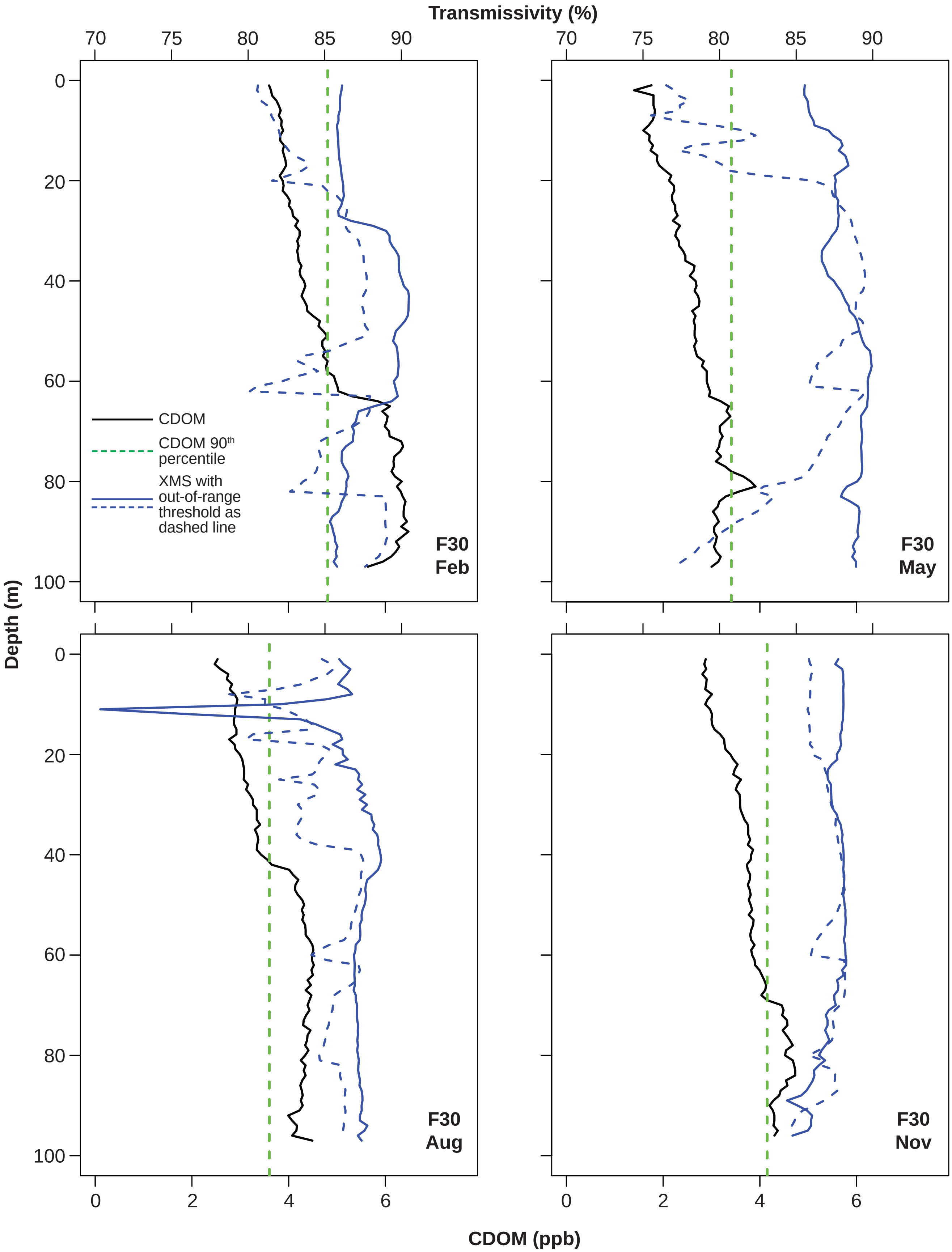
Appendix B.8

Representative vertical profiles of CDOM and dissolved oxygen (DO) from outfall station F30 during 2013.



Appendix B.9

Representative vertical profiles of CDOM and pH from outfall station F30 during 2013.



Appendix B.10

Representative vertical profiles of CDOM and transmissivity from outfall station F30 during 2013. XMS=transmissivity.

Appendix C

Supporting Data

2013 PLOO Stations

Sediment Conditions

Appendix C.1

Constituents and method detection limits (MDL) used for the analysis of sediments collected from the PLOO region during 2013.

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 (Ti)	0.5
Copper (Cu)	0.2	Tin (Sn)	0.3
Iron (Fe)	9	Zinc (Zn)	0.25
Chlorinated Pesticides (ppt)[a]			
Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	150, 100	HCH, Delta isomer	700, 220
HCH, Beta isomer	310, 50	HCH, Gamma isomer	260, 190
Total Chlordane			
Alpha (cis) Chlordane	240, 160	Heptachlor epoxide	120, 300
Cis Nonachlor	240, 380	Methoxychlor	1100, 90
Gamma (trans) Chlordane	350, 190	Oxychlordane	240, 1200
Heptachlor	1200, 120	Trans Nonachlor	250, 240
Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	830, 100	p,p-DDE	260, 90
o,p-DDE	720, 60	p,p-DDMU[b]	—
o,p-DDT	800, 110	p,p-DDT	800, 70
p,p-DDD	470, 160		
Miscellaneous Pesticides			
Aldrin	430, 70	Endrin	830, 510
Alpha Endosulfan	240, 720	Endrin aldehyde	830, 2400
Beta Endosulfan	350, 780	Hexachlorobenzene (HCB)	470, 70
Dieldrin	310, 340	Mirex	500, 60
Endosulfan Sulfate	260, 1100		

[a]MDL values reported separately for winter and summer 2013
[b]No MDL available for this parameter

Appendix C.1 *continued*

Parameter	MDL	Parameter	MDL
Polychlorinated Biphenyl Congeners (PCBs) (ppt)[a]			
PCB 18	540, 90	PCB 126	720, 70
PCB 28	660, 60	PCB 128	570, 80
PCB 37	340, 90	PCB 138	590, 80
PCB 44	890, 100	PCB 149	500, 110
PCB 49	850, 70	PCB 151	640, 80
PCB 52	1000, 90	PCB 153/168	600, 150
PCB 66	920, 100	PCB 156	620, 90
PCB 70	1100, 60	PCB 157	700, 100
PCB 74	900, 100	PCB 158	510, 70
PCB 77	790, 110	PCB 167	620, 30
PCB 81	590, 130	PCB 169	610, 90
PCB 87	600, 200	PCB 170	570, 80
PCB 99	660, 120	PCB 177	650, 70
PCB 101	430, 100	PCB 180	530, 80
PCB 105	720, 50	PCB 183	530, 60
PCB 110	640, 110	PCB 187	470, 110
PCB 114	700, 130	PCB 189	620, 60
PCB 118	830, 90	PCB 194	420, 80
PCB 119	560, 80	PCB 201	530, 70
PCB 123	660, 130	PCB 206	510, 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

[a] MDL values reported separately for winter and summer 2013

Appendix C.2

Particle size classification schemes (based on Folk 1980) used in the analysis of sediments collected from the PLOO region in 2013. 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[c]**
-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
6	16	31	—	Medium silt	Fine Particles
7	8	15.6	—	Fine silt	Fine Particles
8	4	7.8	—	Very fine silt	Fine Particles
9	≤	3.9	—	Clay	Fine Particles

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

Appendix C.3

Summary of the constituents that make up total DDT, total PCB, and total PAH in sediments from the PLOO region during 2013.

Station	Class	Constituent	Winter	Summer	Units
B10	DDT	p,p-DDE	ns	180	ppt
B10	PAH	2,6-dimethylnaphthalene	ns	17.1	ppb
B11	DDT	p,p-DDE	ns	140	ppt
B11	PAH	2,6-dimethylnaphthalene	ns	14	ppb
B11	PCB	PCB 18	ns	110	ppt
B11	PCB	PCB 28	ns	110	ppt
B11	PCB	PCB 70	ns	62	ppt
B12	DDT	p,p-DDE	435	220	ppt
B12	PAH	2,6-dimethylnaphthalene	nd	11.7	ppb
B8	DDT	p,p-DDE	ns	170	ppt
B8	PAH	2,6-dimethylnaphthalene	ns	12.6	ppb
B9	DDT	p,p-DDE	620	290	ppt
B9	DDT	p,p-DDT	8200	nd	ppt
B9	PAH	2,6-dimethylnaphthalene	ns	10.7	ppb
E1	DDT	p,p-DDE	ns	435	ppt
E1	PAH	2,6-dimethylnaphthalene	ns	11.4	ppb
E1	PAH	3,4-benzo(B)fluoranthene	ns	36.2	ppb
E1	PAH	Anthracene	ns	4.8	ppb
E1	PAH	Benzo[A]pyrene	ns	24	ppb
E1	PAH	Benzo[e]pyrene	ns	20.9	ppb
E1	PAH	Benzo[G,H,I]perylene	ns	20.9	ppb
E1	PAH	Benzo[K]fluoranthene	ns	9.25	ppb
E1	PAH	Chrysene	ns	17.7	ppb
E1	PAH	Fluoranthene	ns	23.3	ppb
E1	PAH	Indeno(1,2,3-CD)pyrene	ns	16.4	ppb
E1	PAH	Perylene	ns	4.41	ppb
E1	PAH	Phenanthrene	ns	4.85	ppb
E1	PAH	Pyrene	ns	28.5	ppb
E1	PCB	PCB 70	ns	63	ppt
E1	PCB	PCB 101	ns	260	ppt
E1	PCB	PCB 110	ns	270	ppt
E1	PCB	PCB 118	ns	320	ppt
E1	PCB	PCB 138	ns	540	ppt
E1	PCB	PCB 149	ns	420	ppt
E1	PCB	PCB 153/168	ns	720	ppt
E1	PCB	PCB 180	ns	310	ppt
E1	PCB	PCB 183	ns	94	ppt
E1	PCB	PCB 187	ns	150	ppt
E2	DDT	p,p-DDE	460	380	ppt
E2	PAH	2,6-dimethylnaphthalene	nd	8.92	ppb
E2	PAH	Benzo[e]pyrene	nd	10.7	ppb
E2	PAH	Fluoranthene	nd	11.6	ppb
E2	PAH	Pyrene	nd	15.2	ppb
E2	PCB	PCB 66	120	nd	ppt
E2	PCB	PCB 70	86	nd	ppt

nd = not detected; ns = not sampled

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
E2	PCB	PCB 138	200	150	ppt
E2	PCB	PCB 149	200	150	ppt
E2	PCB	PCB 153/168	nd	210	ppt
E3	DDT	p,p-DDE	ns	265	ppt
E3	PAH	2,6-dimethylnaphthalene	ns	10	ppb
E3	PAH	Anthracene	ns	9.17	ppb
E3	PAH	Benzo[A]pyrene	ns	21.7	ppb
E3	PAH	Benzo[e]pyrene	ns	15.9	ppb
E3	PAH	Chrysene	ns	14.2	ppb
E3	PAH	Fluoranthene	ns	21.8	ppb
E3	PAH	Indeno(1,2,3-CD)pyrene	ns	12.5	ppb
E3	PAH	Phenanthrene	ns	10	ppb
E3	PAH	Pyrene	ns	21.2	ppb
E3	PCB	PCB 18	ns	110	ppt
E3	PCB	PCB 28	ns	81	ppt
E3	PCB	PCB 49	ns	110	ppt
E3	PCB	PCB 52	ns	250	ppt
E3	PCB	PCB 66	ns	120	ppt
E3	PCB	PCB 70	ns	160	ppt
E3	PCB	PCB 74	ns	59	ppt
E3	PCB	PCB 99	ns	220	ppt
E3	PCB	PCB 101	ns	540	ppt
E3	PCB	PCB 110	ns	510	ppt
E3	PCB	PCB 118	ns	490	ppt
E3	PCB	PCB 138	ns	530	ppt
E3	PCB	PCB 149	ns	420	ppt
E3	PCB	PCB 153/168	ns	660	ppt
E3	PCB	PCB 170	ns	170	ppt
E3	PCB	PCB 180	ns	320	ppt
E3	PCB	PCB 187	ns	220	ppt
E3	PCB	PCB 206	ns	240	ppt
E5	DDT	p,p-DDE	310	190	ppt
E5	PCB	PCB 66	nd	54	ppt
E7	DDT	p,p-DDE	ns	280	ppt
E7	PAH	2,6-dimethylnaphthalene	ns	17.1	ppb
E7	PAH	3,4-benzo(B)fluoranthene	ns	9.9	ppb
E8	DDT	p,p-DDE	310	250	ppt
E8	PCB	PCB 138	130	nd	ppt
E8	PCB	PCB 149	99	nd	ppt
E8	PCB	PCB 153/168	240	nd	ppt
E9	DDT	p,p-DDE	ns	290	ppt
E9	PCB	PCB 110	ns	130	ppt
E9	PCB	PCB 138	ns	140	ppt
E9	PCB	PCB 149	ns	130	ppt
E9	PCB	PCB 153/168	ns	160	ppt
E11	DDT	p,p-DDE	280	220	ppt
E11	DDT	p,p-DDT	nd	310	ppt

nd = not detected; ns = not sampled

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
E11	PAH	2,6-dimethylnaphthalene	nd	13.4	ppb
E11	PAH	3,4-benzo(B)fluoranthene	nd	13.4	ppb
E14	DDT	p,p-DDE	250	160	ppt
E14	PAH	2,6-dimethylnaphthalene	nd	10.6	ppb
E15	DDT	p,p-DDE	ns	100	ppt
E15	PAH	2,6-dimethylnaphthalene	ns	9.41	ppb
E17	DDT	p,p-DDE	310	150	ppt
E17	PAH	2,6-dimethylnaphthalene	nd	9.57	ppb
E19	DDT	p,p-DDE	ns	340	ppt
E19	PAH	2,6-dimethylnaphthalene	ns	14.8	ppb
E19	PCB	PCB 153/168	ns	96	ppt
E20	DDT	p,p-DDE	530	400	ppt
E20	PAH	2,6-dimethylnaphthalene	nd	11.2	ppb
E20	PCB	PCB 153/168	160	nd	ppt
E21	DDT	p,p-DDE	ns	340	ppt
E21	PAH	2,6-dimethylnaphthalene	ns	11.1	ppb
E21	PCB	PCB 153/168	ns	120	ppt
E21	PCB	PCB 170	ns	180	ppt
E21	PCB	PCB 180	ns	390	ppt
E21	PCB	PCB 187	ns	170	ppt
E23	DDT	p,p-DDE	580	250	ppt
E23	PAH	2,6-dimethylnaphthalene	nd	10.8	ppb
E25	DDT	p,p-DDE	380	260	ppt
E25	PAH	2,6-dimethylnaphthalene	nd	10.5	ppb
E25	PCB	PCB 110	nd	140	ppt
E25	PCB	PCB 149	nd	72	ppt
E25	PCB	PCB 153/168	nd	100	ppt
E26	DDT	p,p-DDE	410	140	ppt

nd = not detected; ns = not sampled

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Appendix C.4

Summary of particle size parameters with sub-fractions (%) for each PLOO station sampled during winter 2013. 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	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—
	B8	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—
	E19	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—
	E7	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—
	E1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—
98-m Stations	B12	1.0	0.0	0.5	10.4	28.9	23.7	11.3	7.3	7.8	5.7	3.4	gravel/shell hash
	B9	0.0	0.0	0.0	1.1	12.5	35.0	21.1	10.8	9.5	6.4	3.6	pea gravel/shell hash
	E26	2.8	0.0	0.0	1.3	13.8	35.2	21.1	9.5	7.8	5.3	3.1	shell hash/organic debris
	E25	0.0	0.0	0.0	0.9	12.9	38.6	22.7	9.3	7.4	5.1	3.1	shell hash/organic debris
	E23	0.0	0.0	0.0	0.6	11.6	40.2	23.9	9.4	7.0	4.7	2.7	shell hash
	E20	0.0	0.0	0.0	1.1	13.0	39.6	22.6	9.1	7.0	4.7	2.9	shell hash/organic debris
	E17[a]	0.0	0.0	0.0	0.9	14.6	43.1	20.4	8.0	6.5	4.3	2.2	shell hash/organic debris
	E14[a]	0.0	0.0	0.0	1.1	16.6	45.6	17.9	6.8	5.9	4.0	2.1	shell hash/organic debris
	E11[a]	0.0	0.0	0.0	1.2	16.4	43.9	19.1	7.0	6.0	4.3	2.3	shell hash/organic debris
	E8	0.0	0.0	0.0	1.3	17.9	43.0	18.8	7.2	5.7	3.9	2.3	black sand/shell hash
	E5	0.0	0.0	0.0	1.2	15.9	39.4	20.0	8.8	7.1	4.7	2.9	pea gravel/shell hash
	E2	0.0	0.0	0.0	2.8	19.4	30.7	18.8	10.4	8.7	5.9	3.5	gravel/rock/shell hash
116-m Stations	B10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—
	E21	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—
	E15[a]	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—
	E9	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—
	E3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	—

[a] nearfield stations; ns = not sampled

Appendix C.4 *continued*

Summary of particle size parameters with sub-fractions (%) for each PLOO station sampled during summer 2013. 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 Sand		Fine Sands		Fine Particles					Visual Observations
		Granules	VCSand	CSand	MSand	FSand	VFSand	CSilt	MSilt	FSilt	VFSilt	Clay	
88-m Stations	B11[s]	2.5	2.5	5.0	8.8	11.4	26.7	43.1	—	—	—	—	pea gravel/shell hash/organic debris[b]
	B8	0.0	0.0	0.0	0.2	4.0	25.0	28.7	14.6	14.8	8.7	4.1	
	E19	0.0	0.0	0.0	0.4	5.6	31.6	28.8	11.4	11.7	7.1	3.4	shell hash/organic debris[b]
	E7	0.0	0.0	0.0	0.7	8.8	34.8	25.3	10.1	10.5	6.5	3.2	shell hash
	E1	0.0	0.0	0.0	1.8	14.5	29.5	19.7	11.0	12.4	7.4	3.6	pea gravel/shell hash
98-m Stations	B12	0.0	0.0	0.0	3.8	23.9	26.8	12.4	8.5	12.7	8.3	3.6	pea gravel/shell hash/organic debris[b]
	B9	0.0	0.0	0.0	1.0	10.3	33.6	20.3	9.9	12.8	8.3	3.8	pea gravel
	E26	0.0	0.0	0.0	0.6	8.5	35.6	23.7	9.9	11.1	7.1	3.4	shell hash/organic debris
	E25	0.0	0.0	0.0	0.8	9.9	37.2	23.6	9.3	10.2	6.3	2.8	shell hash/organic debris[b]
	E23	0.0	0.0	0.0	0.5	8.5	37.6	24.8	9.4	10.2	6.2	2.8	shell hash
	E20	0.0	0.0	0.0	0.7	9.4	38.1	23.2	8.8	10.1	6.5	3.1	shell hash/organic debris[b]
	E17[a]	0.0	0.0	0.0	0.7	11.4	41.6	21.4	7.8	9.2	5.6	2.4	shell hash/organic debris[b]
	E14[a]	1.3	0.0	0.0	0.8	12.2	42.5	18.4	6.9	9.2	6.2	2.7	black sand/shell hash/organic debris[b]
	E11[a]	0.0	0.0	0.0	0.8	12.4	42.3	20.9	7.3	8.5	5.3	2.4	shell hash
	E8	0.0	0.0	0.0	0.9	12.0	38.8	20.8	8.5	10.0	6.2	2.8	shell hash
	E5	0.0	0.0	0.0	1.1	13.6	40.0	19.9	7.8	9.0	5.8	2.9	shell hash/organic debris[b]
	E2	0.0	0.0	0.0	1.7	12.3	31.2	20.6	10.6	12.4	7.6	3.5	shell hash/organic debris[b]
116-m Stations	B10	1.9	0.0	0.0	1.4	18.1	42.9	13.6	5.2	8.1	6.1	2.8	shell hash/organic debris[b]
	E21	0.0	0.0	0.0	0.7	11.8	43.2	19.5	7.1	9.0	6.0	2.6	organic debris[b]
	E15[a]	0.0	0.0	0.0	0.8	12.6	42.6	18.7	7.1	9.1	6.2	2.9	black sand/shell hash/organic debris[b]
	E9	0.0	0.0	0.0	1.2	10.9	33.8	20.6	8.9	11.9	8.6	4.2	black sand/shell hash
	E3[s]	2.2	3.5	7.6	14.2	36.7	16.4	19.4	—	—	—	—	rock/pea gravel/shell hash/org. debris[b]

[a] nearfield stations; [b] contained worm tubes; [s] measured by sieve (not Horiba; silt and clay fractions are indistinguishable)

Appendix C.5

Summary of organic loading indicators in sediments from PLOO stations sampled during winter and summer 2013.

	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	ns	ns	ns	ns	ns	458	2.9	0.080	0.64	4.00
B8	ns	ns	ns	ns	ns	345	1.9	0.089	0.76	3.20
E19	ns	ns	ns	ns	ns	357	4.1	0.071	0.60	2.40
E7	ns	ns	ns	ns	ns	352	4.2	0.061	0.51	2.40
E1	ns	ns	ns	ns	ns	227	1.6	0.057	0.47	2.00
98-m Depth Contour										
B12	497	1.8	0.060	3.26	2.86	440	1.5	0.061	0.82	3.20
B9	401	11.8	0.068	0.74	2.88	400	4.7	0.068	0.59	3.00
E26	372	5.7	0.062	1.16	2.61	262	1.4	0.059	0.49	2.40
E25	230	9.0	0.049	0.43	1.99	207	2.6	0.059	0.46	2.10
E23	330	6.0	0.057	0.50	2.16	263	3.0	0.050	0.43	2.10
E20	280	3.5	0.050	0.44	1.89	261	6.2	0.056	0.45	2.10
E17[a]	314	3.8	0.053	0.45	1.90	201	31.7	0.052	0.43	1.90
E14[a]	342	58.9	0.049	0.45	1.82	508	22.1	0.049	0.42	1.85
E11[a]	381	3.1	0.048	0.43	1.94	244	4.5	0.052	0.41	2.00
E8	270	4.1	0.041	0.39	1.86	222	3.5	0.052	0.41	2.00
E5	238	4.3	0.046	0.41	2.05	206	3.9	0.047	0.38	1.90
E2	257	3.4	0.050	0.52	2.42	197	3.1	0.057	0.49	2.60
116-m Depth Contour										
B10	ns	ns	ns	ns	ns	446	11.6	0.055	0.44	2.50
E21	ns	ns	ns	ns	ns	226	3.5	0.051	0.42	1.80
E15[a]	ns	ns	ns	ns	ns	293	7.4	0.048	0.41	2.00
E9	ns	ns	ns	ns	ns	207	4.0	0.054	0.44	2.30
E3	ns	ns	ns	ns	ns	160	2.4	0.039	0.30	1.70
Detection Rate (%)	100	100	100	100	100	100	100	100	100	100

[a] nearfield station; ns = not sampled

Appendix C.6

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during winter 2013. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted (see Table 4.1).

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
B8	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E19	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E7	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
98-m Depth Contour																		
B12	10,900	nd	4.9	27.2	0.360	0.18	28.2	6.7	23,300	5.62	94.6	0.018	7.43	0.56	nd	nd	1.62	38.8
B9	14,700	0.51	3.1	108.0	0.330	0.16	24.0	8.7	17,600	7.53	146.0	0.029	9.55	0.56	nd	nd	1.54	38.8
E26	11,900	0.41	2.3	33.5	0.210	0.15	16.0	7.2	10,900	6.59	116.0	0.036	7.52	0.49	nd	nd	1.88	27.5
E25	12,000	0.39	2.7	33.4	0.210	0.11	15.6	6.5	11,100	5.62	122.0	0.021	7.40	0.35	nd	nd	1.36	26.3
E23	16,000	0.80	2.7	45.6	0.290	0.20	21.3	9.8	14,600	8.12	176.0	0.028	9.99	0.66	nd	nd	1.75	36.2
E20	12,300	0.59	3.0	34.9	0.210	0.13	16.1	6.9	11,400	5.96	142.0	0.023	7.50	0.58	nd	nd	1.33	27.0
E17 [a]	11,400	0.56	2.8	31.3	0.200	0.14	15.3	6.8	10,900	5.48	137.0	0.021	7.06	0.33	nd	nd	1.43	25.9
E14 [a]	10,300	0.47	2.4	29.2	0.190	0.17	14.1	7.1	9610	4.74	116.0	0.022	6.68	0.58	nd	nd	1.51	25.4
E11 [a]	11,400	0.49	2.8	29.2	0.210	0.15	15.3	6.5	11,000	5.56	124.0	0.017	6.87	0.37	nd	nd	1.52	25.8
E8	10,800	0.52	2.2	27.4	0.200	0.10	14.1	5.7	10,200	4.95	119.0	0.017	6.35	0.58	nd	nd	1.39	23.9
E5	12,500	0.56	2.0	34.7	0.230	0.13	15.6	7.8	11,800	6.17	147.0	0.024	7.24	0.45	nd	nd	1.29	27.5
E2	15,500	0.65	2.5	48.3	0.270	0.13	18.7	11.8	15,300	8.49	157.0	0.048	8.42	0.42	nd	nd	1.74	35.3
116-m Depth Contour																		
B10	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E21	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E15 [a]	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E9	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
E3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Detection Rate (%)	100	92	100	100	100	100	100	100	100	100	100	100	100	100	0	0	100	100

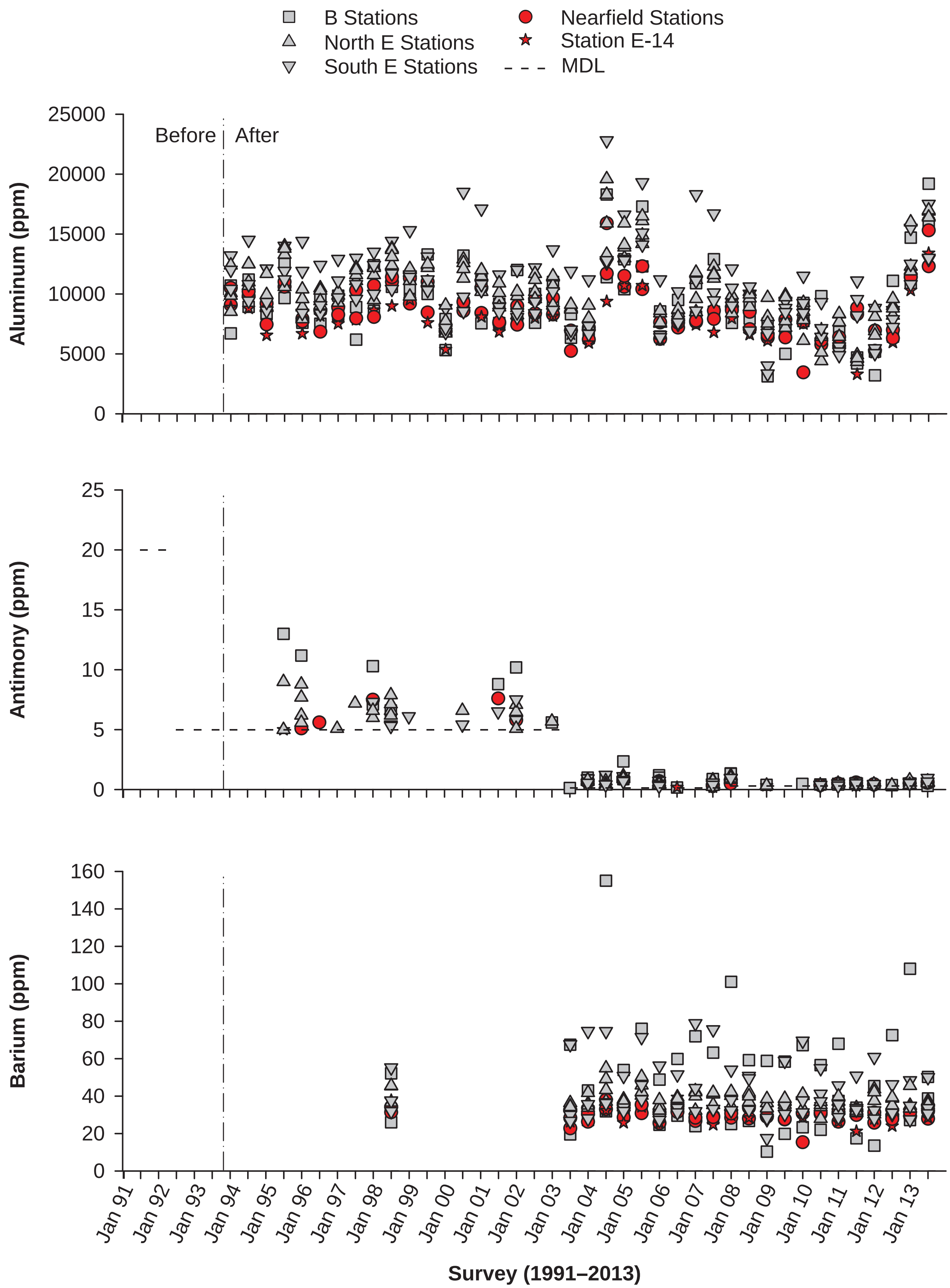
[a] nearfield stations; nd = not detected

Appendix C.6 *continued*

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during summer 2013. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted (see Table 4.1).

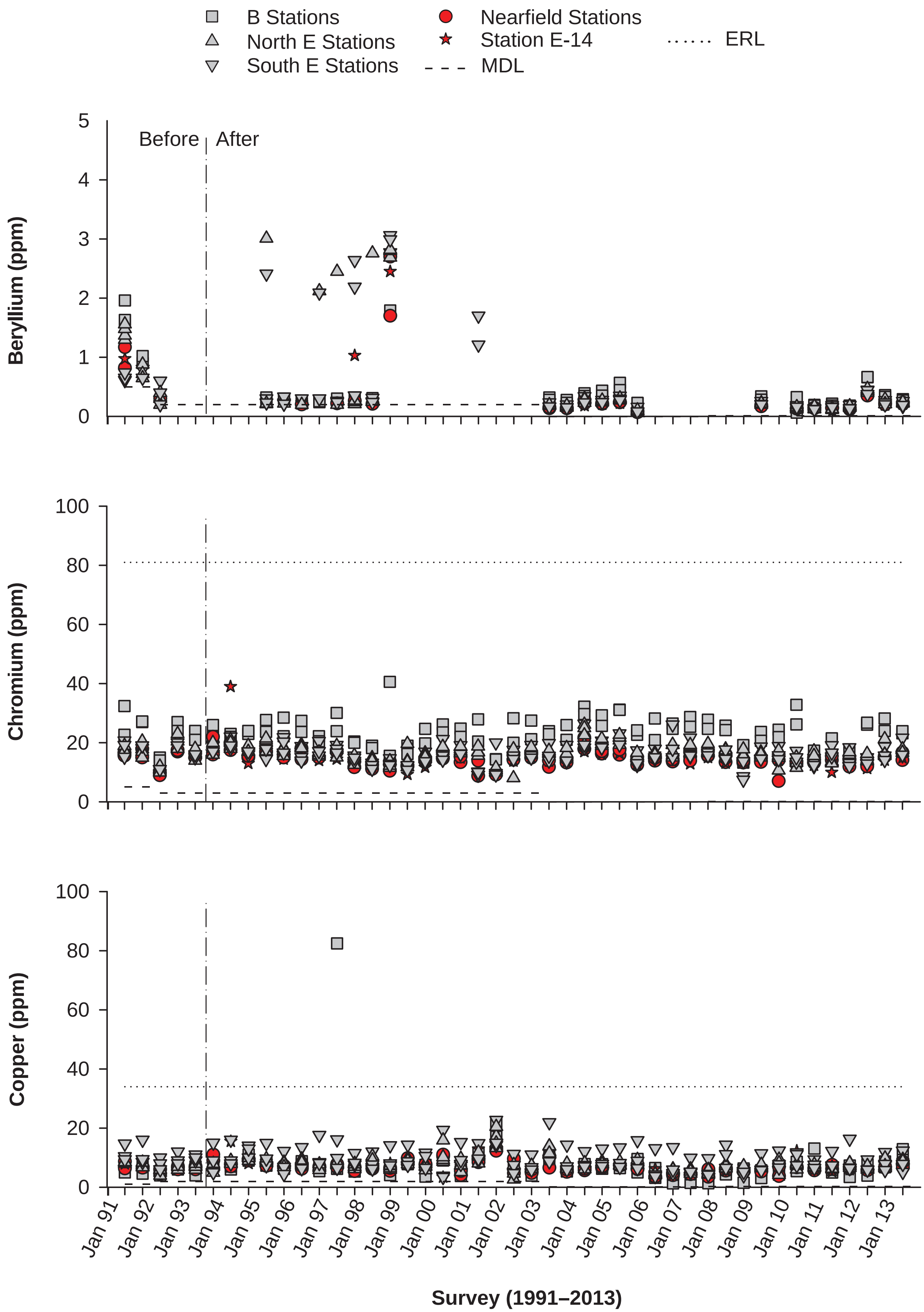
	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	12,000	0.47	3.8	26.6	0.220	0.16	18.9	6.9	15,600	5.60	205.0	0.037	9.72	nd	1.50	nd	0.86	33.6
B8	13,000	0.54	3.2	30.8	0.210	0.14	19.3	18.2	15,100	7.67	165.0	0.046	11.10	nd	0.92	nd	1.45	43.8
E19	20,700	0.57	2.8	49.9	0.260	0.20	21.2	12.2	15,400	8.55	219.0	0.039	14.00	0.49	2.51	nd	1.12	40.8
E7	16,500	0.72	2.5	42.9	0.230	0.16	19.9	10.7	15,600	7.67	225.0	0.036	12.40	0.57	2.30	nd	1.26	36.7
E1	14,700	nd	2.8	46.2	0.240	nd	18.9	10.8	14,100	11.90	219.0	0.052	10.40	0.47	nd	nd	0.69	37.3
98-m Depth Contour																		
B12	15,900	nd	4.1	38.7	0.290	0.18	23.2	10.9	20,400	8.52	212.0	0.017	12.90	nd	0.65	nd	1.45	43.4
B9	19,200	0.31	3.6	50.2	0.270	0.15	23.9	12.9	17,800	9.46	181.0	0.029	14.60	nd	0.91	nd	1.71	42.8
E26	16,400	0.54	2.7	35.5	0.240	0.15	16.7	8.8	14,900	6.50	204.0	0.027	11.20	0.48	3.77	nd	0.62	32.9
E25	17,000	0.70	2.5	36.5	0.240	0.17	17.8	9.1	13,500	6.91	214.0	0.028	11.90	0.43	2.65	nd	0.84	34.3
E23	16,500	0.60	2.6	36.9	0.220	0.17	17.6	9.1	13,300	6.53	197.0	0.027	11.30	0.51	1.99	nd	1.15	33.3
E20	16,900	0.68	2.6	37.5	0.230	0.17	17.5	9.3	13,200	6.58	205.0	0.025	11.50	0.46	2.36	nd	0.91	33.7
E17[a]	15,300	0.64	2.5	31.8	0.230	0.19	16.7	8.6	12,300	6.25	199.0	0.023	11.10	0.49	2.43	nd	0.87	31.6
E14[a]	13,400	0.53	2.4	28.4	0.205	0.22	14.9	9.1	10,900	5.19	179.0	0.020	10.50	0.43	2.26	nd	0.93	30.7
E11[a]	12,300	0.55	2.4	27.8	0.210	0.13	14.1	6.7	11,400	5.35	205.0	0.020	9.53	0.43	3.54	nd	0.61	28.8
E8	13,000	0.64	2.2	30.6	0.190	0.12	15.9	7.8	13,200	5.66	208.0	0.029	10.30	0.43	1.96	nd	0.85	30.2
E5	12,900	0.94	2.1	33.4	0.173	0.14	15.7	5.1	11,600	7.35	186.0	0.026	10.30	0.49	nd	nd	1.33	28.7
E2	17,500	nd	2.7	50.0	0.255	0.08	21.6	12.3	16,700	10.20	209.0	0.044	9.30	0.48	nd	nd	0.70	42.4
116-m Depth Contour																		
B10	15,400	nd	1.9	52.0	0.340	0.13	26.4	9.4	22,100	7.47	157.0	0.019	12.80	nd	0.26	nd	1.53	43.3
E21	14,100	0.54	2.4	29.6	0.200	0.15	15.9	8.3	11,200	5.62	178.0	0.027	10.90	0.48	1.82	nd	0.94	28.6
E15[a]	15,300	0.46	2.3	38.6	0.240	0.16	18.0	7.8	12,800	7.19	198.0	0.023	10.80	0.48	nd	nd	0.62	31.4
E9	11,300	nd	3.1	22.8	0.280	0.18	26.5	7.4	22,600	5.61	135.0	0.030	10.40	0.56	nd	nd	1.12	39.3
E3	14,900	0.35	2.0	68.2	0.205	0.10	15.3	20.0	15,100	11.60	174.0	0.047	10.30	0.58	1.35	nd	1.22	39.9
Detection Rate (%)	100	77	100	100	100	95	100	100	100	100	100	100	100	77	77	0	100	100

[a] nearfield stations; nd = not detected; ns = not sampled

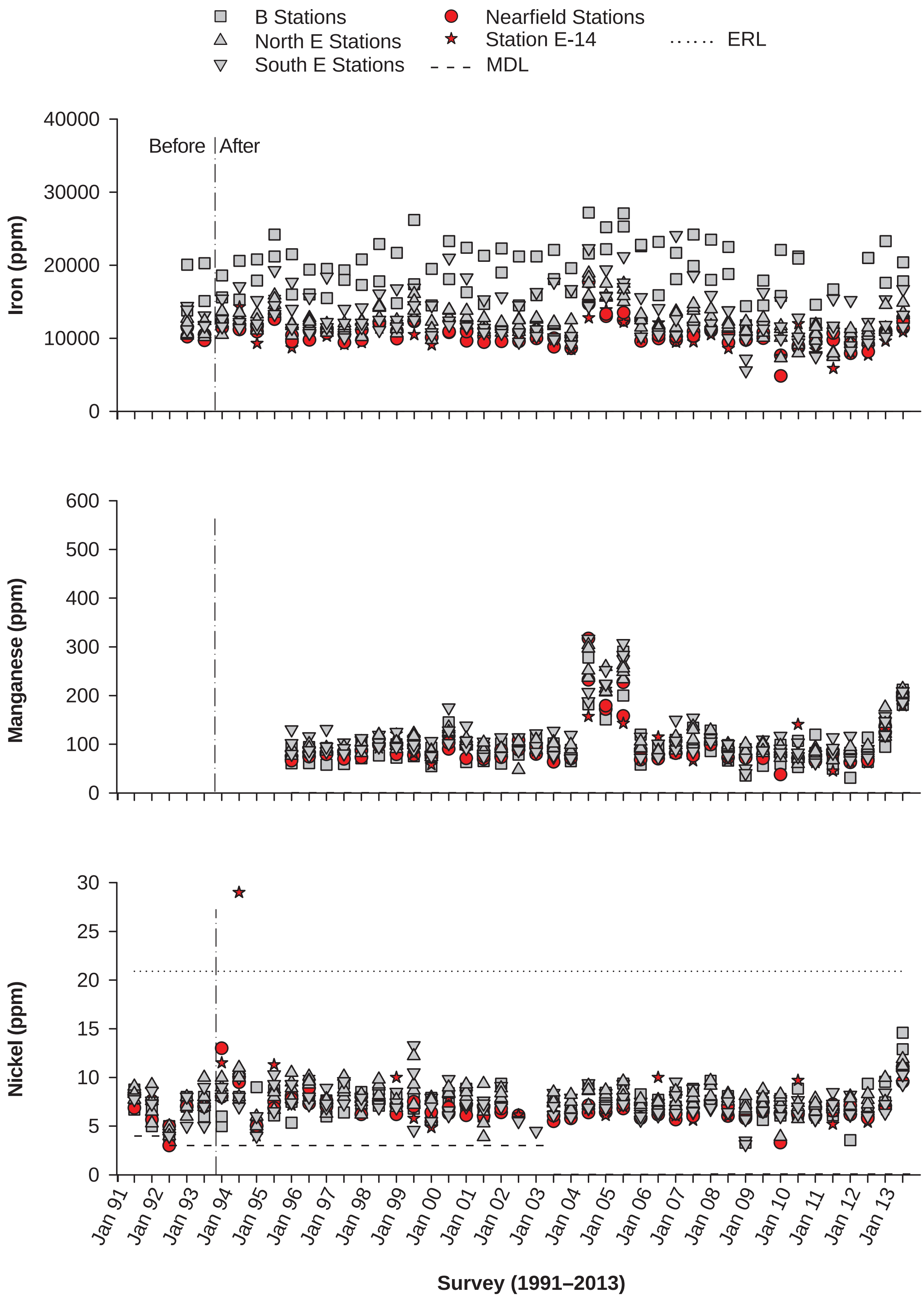


Appendix C.7

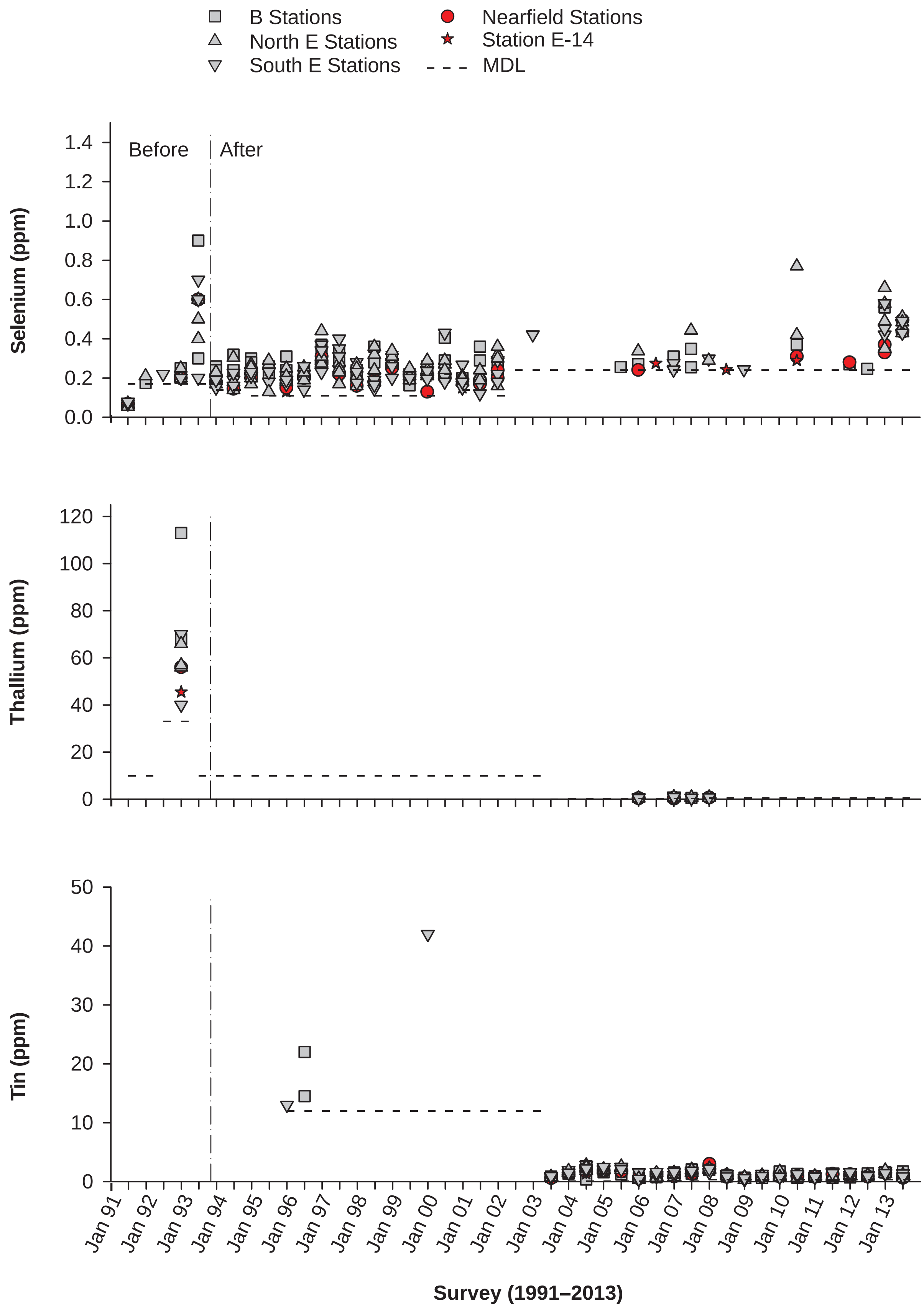
Concentrations of select metals in sediments from PLOO primary core stations sampled from 1991 through 2013. Data represent detected values from each station, n≤12 samples per survey. Dashed lines indicate onset of discharge from the PLOO. See Table 4.1 for values of ERLs and ERMs.



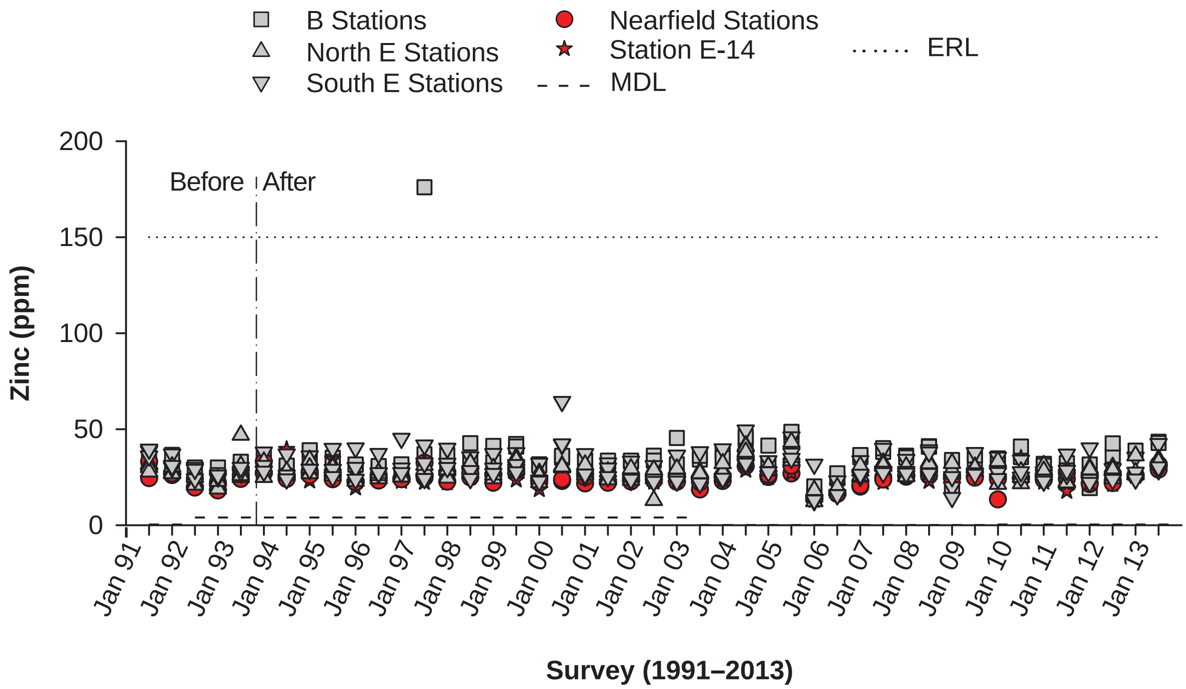
Appendix C.7 *continued*



Appendix C.7 *continued*



Appendix C.7 *continued*



Appendix C.7 *continued*

Appendix C.8

Concentrations of hexachlorobenzene (HCB), total DDT, total PCB, and total PAH detected in sediments from PLOO stations sampled during winter and summer 2013. Values that exceed thresholds are highlighted (see Table 4.1).

	Winter				Summer			
	HCB (ppt)	tDDT (ppt)	tPCB (ppt)	tPAH (ppb)	HCB (ppt)	tDDT (ppt)	tPCB (ppt)	tPAH (ppb)
88-m Stations								
B11	ns	ns	ns	ns	nd	140	282	14.0
B8	ns	ns	ns	ns	nd	170	nd	12.6
E19	ns	ns	ns	ns	nd	340	96	14.8
E7	ns	ns	ns	ns	nd	280	nd	27.0
E1	ns	ns	ns	ns	26	435	3147	222.6
98-m Stations								
B12	nd	435	nd	nd	nd	220	nd	11.7
B9	nd	8820	nd	nd	nd	290	nd	10.7
E26	nd	410	nd	nd	nd	140	nd	nd
E25	nd	380	nd	nd	nd	260	312	10.5
E23	nd	580	nd	nd	nd	250	nd	10.8
E20	nd	530	160	nd	nd	400	nd	11.2
E17[a]	nd	310	nd	nd	nd	150	nd	9.6
E14[a]	nd	250	nd	nd	nd	160	nd	10.6
E11[a]	nd	280	nd	nd	nd	530	nd	26.8
E8	nd	310	469	nd	nd	250	nd	nd
E5	nd	310	nd	nd	nd	190	54	nd
E2	nd	460	606	nd	nd	380	510	46.4
116-m Stations								
B10	ns	ns	ns	ns	nd	180	nd	17.1
E21	ns	ns	ns	ns	nd	340	860	11.1
E15[a]	ns	ns	ns	ns	nd	100	nd	9.4
E9	ns	ns	ns	ns	nd	290	560	nd
E3	ns	ns	ns	ns	nd	265	5210	136.5
Detection Rate (%)	0	100	25	0	5	100	41	82

[a] nearfield stations; nd = not detected; ns = not sampled

Appendix D

Supporting Data

2013 PLOO Stations

Macrobenthic Communities

Appendix D.1

Macrofaunal community parameters by grab for PLOO benthic stations sampled during 2013. 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.

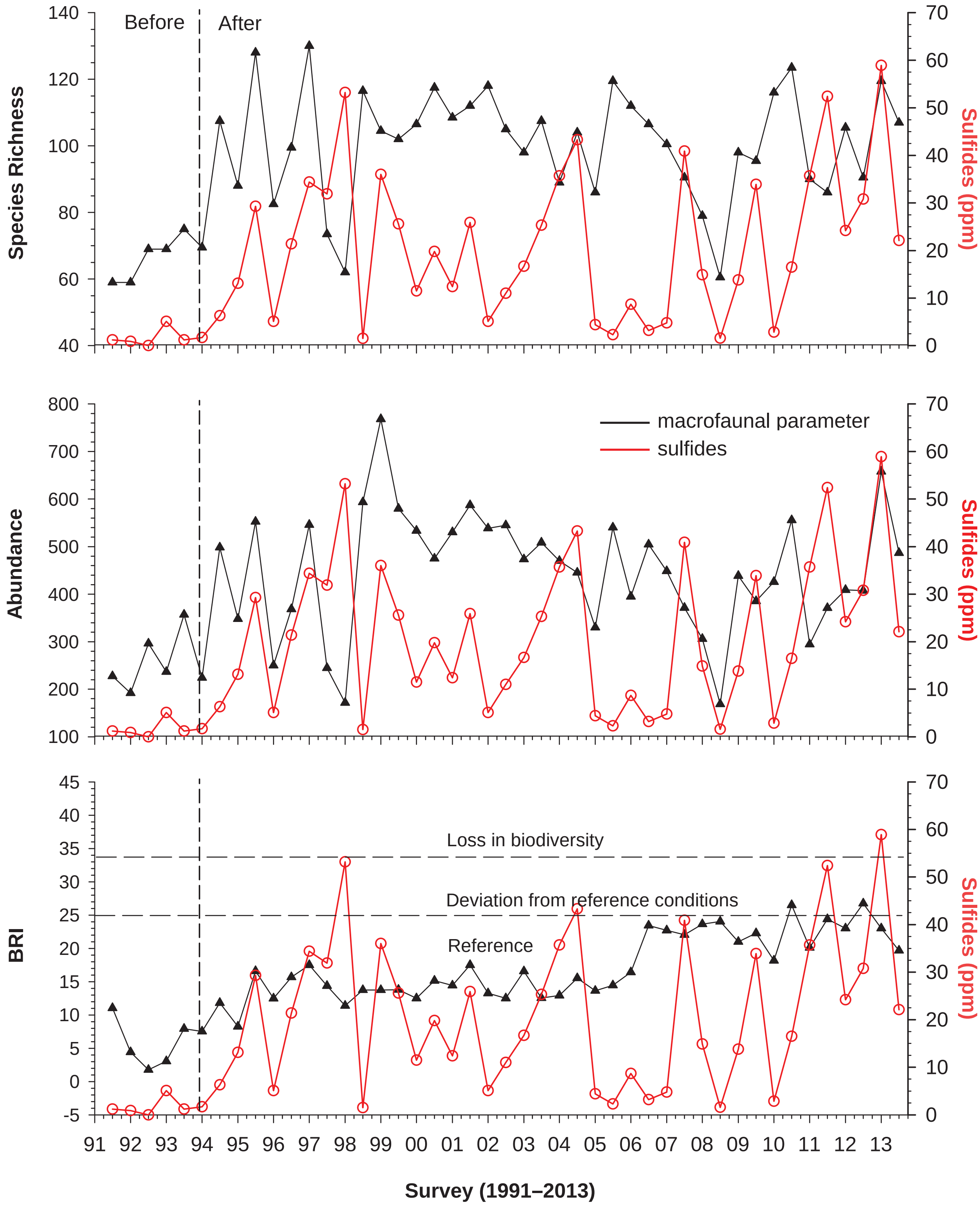
Depth Contour	Station	Survey	Grab	SR	Abun	H'	J'	Dom	BRI
88-m	B11	summer	1	111	394	3.8	0.80	35	11
	B8	summer	1	66	213	3.3	0.80	22	11
	E19	summer	1	80	330	3.5	0.79	21	14
	E7	summer	1	70	310	3.2	0.76	17	12
	E1	summer	1	83	366	3.4	0.78	20	13
98-m	B12	winter	1	85	222	3.9	0.88	36	13
			2	98	287	4.0	0.88	42	17
		summer	1	119	397	3.9	0.81	41	12
	B9	winter	1	63	143	3.8	0.92	29	3
			2	85	244	4.0	0.90	33	13
		summer	1	93	335	3.8	0.83	32	11
	E26	winter	1	93	335	4.0	0.88	33	18
			2	54	124	3.5	0.88	24	13
		summer	1	90	336	3.8	0.84	28	13
	E25	winter	1	91	309	3.7	0.83	27	18
			2	85	293	3.8	0.86	29	12
		summer	1	97	337	3.8	0.83	31	16
	E23	winter	1	77	292	3.7	0.86	26	16
			2	81	362	3.6	0.83	23	10
		summer	1	84	305	3.5	0.79	23	13
	E20	winter	1	101	427	3.7	0.81	23	18
			2	90	358	3.7	0.82	25	17
		summer	1	63	281	3.3	0.79	15	17
	E17[a]	winter	1	102	478	3.9	0.85	28	19
			2	89	422	3.8	0.84	27	22
		summer	1	81	402	3.7	0.84	24	17
	E14[a]	winter	1	116	701	3.7	0.78	26	25
			2	123	615	4.0	0.82	31	21
		summer	1	107	487	3.7	0.80	29	20
	E11[a]	winter	1	98	476	3.9	0.86	30	18
			2	81	377	3.7	0.85	24	21
		summer	1	92	281	3.8	0.84	32	14
	E8	winter	1	77	294	3.7	0.86	27	15
			2	98	386	4.0	0.87	34	13
		summer	1	85	367	3.7	0.83	25	13
	E5	winter	1	91	373	3.9	0.86	29	14
			2	99	493	4.0	0.87	34	15
		summer	1	107	428	3.9	0.83	29	15

[a] nearfield station

Appendix D.1 *continued*

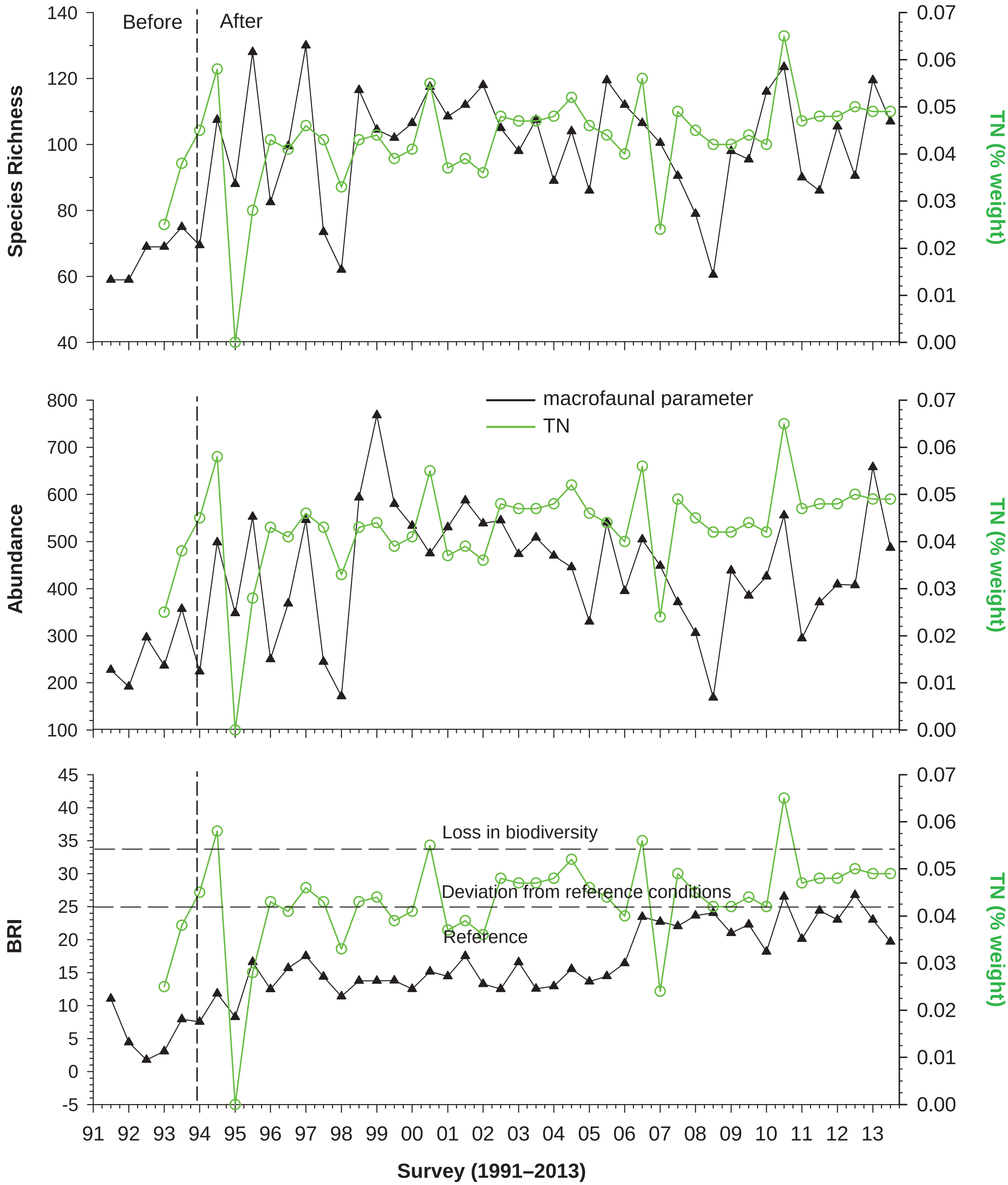
Depth Contour	Station	Survey	Grab	SR	Abun	H'	J'	Dom	BRI
98-m	E2	winter	1	90	352	3.8	0.84	28	14
			2	86	227	4.0	0.90	39	12
		summer	1	130	560	4.1	0.83	42	14
116-m	B10	summer	1	106	377	3.9	0.84	36	21
	E21	summer	1	76	368	3.3	0.77	18	13
	E15[a]	summer	1	101	421	3.8	0.82	29	11
	E9	summer	1	138	558	4.3	0.87	46	12
	E3	summer	1	143	518	4.5	0.90	53	11

[a]nearfield station

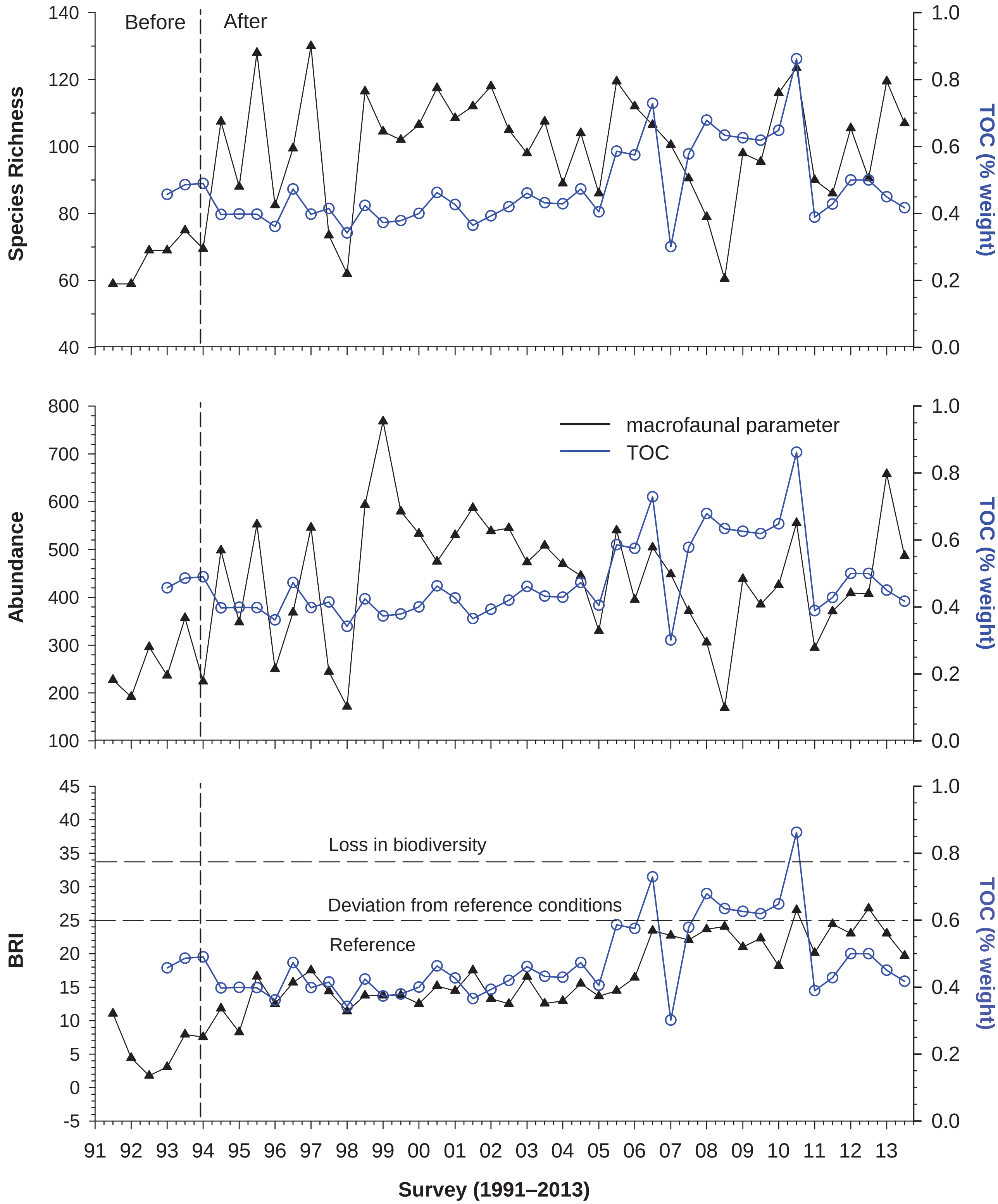


Appendix D.2

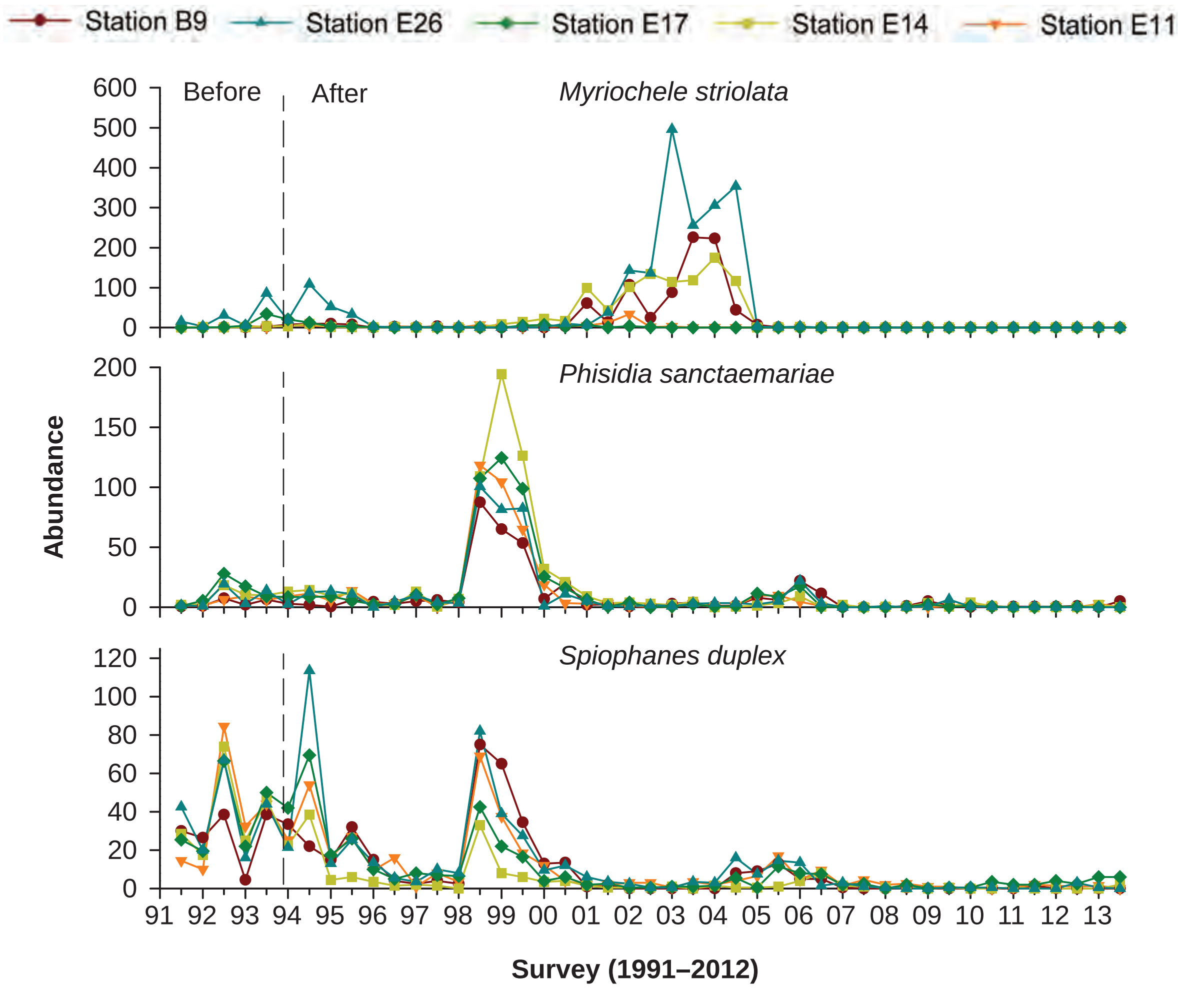
Comparison of community parameters and various organic indicators at nearfield station E14 from 1991 through 2013. Organic indicators include: sulfides, total nitrogen (TN) and total organic carbon (TOC). Parameters include: species richness, infaunal abundance and benthic response index (BRI). Data for community parameters are expressed as means per 0.1 m^2 (n = 2 except for summer 2013 when n = 1). Data for organic indicators are expressed as a single value (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 2013 at PLOO nearfield 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 when n = 1). Dashed lines indicate onset of wastewater discharge.

Appendix D.4

Mean abundance of the 15 most abundant species found in each cluster group A–E (defined in Figure 5.5). Bold values indicate taxa that account for 25% of intra-group similarity according to SIMPER analysis.

Taxa	Cluster Groups				
	A	B[a]	C[a]	D[a]	E
Chloeia pinnata	51.0	0.0	0.0	41.0	**26.9**
Prionospio (*Prionospio*) *jubata*	19.0	6.0	52.0	50.0	**16.8**
Tellina carpenteri	**10.5**	6.0	0.0	20.0	7.7
Chaetozone hartmanae	**9.5**	6.0	12.0	14.0	**13.3**
Mooreonuphis exigua	8.0	0.0	0.0	0.0	0.0
Euphilomedes producta	**7.5**	6.0	6.0	12.0	**27.0**
Euphilomedes carcharodonta	**7.5**	0.0	18.0	14.0	**30.2**
Amphiodia digitata	**7.0**	0.0	0.0	1.0	0.0
Fauveliopsis sp SD1	**6.5**	0.0	0.0	0.0	0.1
Aphelochaeta glandaria Cmplx	6.0	0.0	0.0	11.0	4.3
Lirobittium larum	**6.0**	0.0	0.0	2.0	0.0
Leptochelia dubia Cmplx	5.5	1.0	0.0	3.0	2.4
Pholoe glabra	4.5	1.0	0.0	2.0	2.1
Photis lacia	4.5	0.0	2.0	0.0	0.3
Nuculana sp A	4.0	0.0	0.0	7.0	4.1
Chaetozone sp	3.5	4.0	2.0	0.0	0.4
Amphissa undata	3.5	0.0	0.0	1.0	0.1
Ampelisca careyi	3.0	2.0	3.0	2.0	4.0
Micranellum crebricinctum	3.0	0.0	0.0	0.0	0.0
Amphiodia urtica	2.5	15.0	31.0	4.0	**26.8**
Prionospio (*Prionospio*) *dubia*	2.5	5.0	15.0	5.0	6.5
Aricidea (*Acmira*) *catherinae*	2.5	4.0	9.0	23.0	5.0
Notomastus sp A	2.5	0.0	0.0	19.0	2.1
Clymenura gracilis	2.0	4.0	13.0	1.0	1.5
Mediomastus sp	2.0	0.0	10.0	44.0	9.9
Caecognathia crenulatifrons	2.0	0.0	6.0	2.0	2.0
Glycera nana	1.5	1.0	3.0	15.0	2.1
Sternaspis affinis	1.0	6.0	5.0	5.0	3.7
Malmgreniella sp A	1.0	6.0	1.0	0.0	1.6
Monticellina siblina	1.0	3.0	0.0	0.0	1.3
Chiridota sp	1.0	3.0	0.0	0.0	0.7
Amphiodia sp	1.0	2.0	10.0	5.0	8.9
Rhepoxynius bicuspidatus	0.5	2.0	2.0	8.0	5.5
Lumbrineris cruzensis	0.5	0.0	14.0	11.0	5.7
Monticellina cryptica	0.5	0.0	6.0	4.0	0.7
Spiophanes berkeleyorum	0.5	0.0	1.0	2.0	5.1
Lumbrineris sp GROUP I	0.0	3.0	14.0	24.0	7.1
Goniada brunnea	0.0	3.0	0.0	0.0	0.3
Praxillella pacifica	0.0	2.0	0.0	8.0	5.7
Capitella teleta	0.0	0.0	0.0	140.0	0.4
Solemya pervernicosa	0.0	0.0	0.0	15.0	0.0

[a] SIMPER analysis only conducted on cluster groups that contain more than one benthic grab

Appendix E

Supporting Data

2013 PLOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Taxonomic listing of demersal fish species captured during 2013 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
RAJIFORMES								
	Rajidae							
		Raja inornata	California skate[a]	12	1.6	20	37	25
ARGENTINIFORMES								
	Argentinidae							
		Argentina sialis	Pacific argentine	130	1.1	3	11	7
AULOPIFORMES								
	Synodontidae							
		Synodus lucioceps	California lizardfish	334	6.7	9	29	12
OPHIDIIFORMES								
	Ophidiidae							
		Chilara taylori	Spotted cusk-eel	4	0.3	15	24	19
	Bythitidae							
		Brosmophycis marginata	Red brotula	1	0.1	14	14	14
BATRACHOIDIFORMES								
	Batrachoididae							
		Porichthys notatus	Plainfin midshipman	23	1.3	8	18	14
GASTEROSTEIFORMES								
	Syngnathidae							
		Syngnathus californiensis	Kelp pipefish	2	0.2	13	17	15
SCORPAENIFORMES								
	Scorpaenidae							
		Scorpaena guttata	California scorpionfish	1	0.4	20	20	20
		Sebastes sp	Unidentified rockfish	7	0.1	4	4	4
		Sebastes caurinus	Copper rockfish	1	0.6	28	28	28
		Sebastes chlorostictus	Greenspotted rockfish	4	0.6	9	26	16
		Sebastes eos	Pink rockfish	5	0.2	8	15	12
		Sebastes rubrivinctus	Flag rockfish	3	0.2	7	8	8
		Sebastes saxicola	Stripetail rockfish	113	1.3	5	14	8
		Sebastes semicinctus	Halfbanded rockfish	345	8.0	5	15	10
	Hexagrammidae							
		Ophiodon elongatus	Lingcod	1	0.1	15	15	15
		Zaniolepis frenata	Shortspine combfish	137	2.7	6	17	12
		Zaniolepis latipinnis	Longspine combfish	776	6.9	5	16	9
	Cottidae							
		Chitonotus pugetensis	Roughback sculpin	2	0.2	7	10	8
		Icelinus fimbriatus	Fringed sculpin	2	0.2	14	16	15
		Icelinus quadriseriatus	Yellowchin sculpin	61	1.0	6	10	7
		Icelinus tenuis	Spotfin sculpin	9	0.4	9	15	10
	Agonidae							
		Odontopyxis trispinosa	Pygmy poacher	7	0.4	8	13	10
		Xeneretmus latifrons	Blacktip poacher	5	0.3	13	14	14
		Xeneretmus triacanthus	Bluespotted poacher	5	0.3	10	16	13

[a] Length measured as total length, not standard length (see text)

Appendix E.1 *continued*

Taxon/Species			Common name	n	BM	Length Min	Length Max	Length Mean
PERCIFORMES								
	Embiotocidae							
		Zalembius rosaceus	Pink seaperch	95	2.2	4	13	9
	Zoarcidae							
		Lycodes cortezianus	Bigfin eelpout	1	0.1	19	19	19
		Lycodes pacificus	Blackbelly eelpout	8	0.2	16	25	20
PLEURONECTIFORMES								
	Paralichthyidae							
		Citharichthys sordidus	Pacific sanddab	3144	51.3	3	23	9
		Citharichthys xanthostigma	Longfin sanddab	1	0.1	14	14	14
		Hippoglossina stomata	Bigmouth sole	16	1.5	13	25	18
	Pleuronectidae							
		Lyopsetta exilis	Slender sole	7	0.2	13	17	15
		Microstomus pacificus	Dover sole	97	4.7	6	20	14
		Parophrys vetulus	English sole	118	10.3	13	22	17
		Pleuronichthys decurrens	Curlfin sole	1	0.1	13	13	13
		Pleuronichthys verticalis	Hornyhead turbot	14	1.1	13	17	15
	Cynoglossidae							
		Symphurus atricaudus	California tonguefish	17	0.8	11	16	14

Appendix E.2

Total abundance by species and station for demersal fish at the PLOO trawl stations during 2013.

	Winter 2013						
Name	SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
Pacific sanddab	175	208	189	86	234	128	1020
Longspine combfish	9	17	133	137	74	14	384
Halfbanded rockfish	8	73	102	20		2	205
California lizardfish			6	12	73	6	97
Pacific argentine	50	1	7	2	26	3	89
Stripetail rockfish	15		14	33	8	3	73
English sole	5	7	8	29	17	4	70
Shortspine combfish	11	25	9	10	4	2	61
Pink seaperch	14	13	14	3	9	3	56
Yellowchin sculpin	46	4	4		2		56
Dover sole	1	6	4	3	1		15
Plainfin midshipman	2	3	3		3	4	15
California tonguefish	9	2			1	1	13
Hornyhead turbot		2		3	2	3	10
Bigmouth sole	1		1	2	2	3	9
California skate		1	1	1	2		5
Pink rockfish			1	4			5
Pygmy poacher		1				3	4
Greenspotted rockfish		3					3
Spotfin sculpin		3					3
Flag rockfish				2			2
Blacktip poacher						1	1
Bluespotted poacher		1					1
California scorpionfish			1				1
Curlfin sole			1				1
Kelp pipefish						1	1
Red brotula						1	1
Roughback sculpin						1	1
Spotted cusk-eel						1	1
Survey Total	346	370	498	347	458	184	2203

Appendix E.2 *continued*

Name	Summer 2013 SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
Pacific sanddab	521	367	534	277	182	243	2124
Longspine combfish	32	29	156	90	45	40	392
California lizardfish	27	6	35	55	39	75	237
Halfbanded rockfish	2	67	30	25	2	14	140
Dover sole	5	13	13	17	14	20	82
Shortspine combfish	17	19	5	19	7	9	76
English sole	1	3	8	11	5	20	48
Pacific argentine	39	2					41
Stripetail rockfish	10		11	2	13	4	40
Pink seaperch	6	1	10	12	3	7	39
Blackbelly eelpout				4	4		8
Plainfin midshipman	1	1			1	5	8
Bigmouth sole	1	2	1	1	1	1	7
California skate	1			2	2	2	7
Unidentified rockfish	7						7
Slender sole			1	6			7
Spotfin sculpin		5	1				6
Yellowchin sculpin	5						5
Blacktip poacher				3		1	4
Bluespotted poacher		1				3	4
California tonguefish		4					4
Hornyhead turbot		1			1	2	4
Pygmy poacher	2	1					3
Spotted cusk-eel		1	2				3
Fringed sculpin		1	1				2
Bigfin eelpout						1	1
Copper rockfish						1	1
Flag rockfish			1				1
Greenspotted rockfish	1						1
Kelp pipefish				1			1
Lingcod			1				1
Longfin sanddab				1			1
Roughback sculpin						1	1
Survey Total	678	524	810	526	319	449	3306
Annual Total	**1024**	**894**	**1308**	**873**	**777**	**633**	**5509**

Appendix E.3

Biomass (kg) by species and station for demersal fish at the PLOO trawl stations during 2013.

	Winter 2013						
Name	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Biomass by Survey**
Pacific sanddab	4.5	3.5	5.0	2.5	5.1	2.2	22.8
English sole	0.7	0.9	0.8	2.0	1.5	0.3	6.2
Halfbanded rockfish	0.4	2.2	2.4	0.2		0.1	5.3
Longspine combfish	0.3	0.5	1.0	1.0	0.5	0.1	3.4
California lizardfish			0.1	0.1	1.4	0.1	1.7
Shortspine combfish	0.5	0.7	0.1	0.1	0.1	0.1	1.6
Pink seaperch	0.4	0.7	0.1	0.1	0.1	0.1	1.5
Pacific argentine	0.4	0.1	0.1	0.1	0.1	0.1	0.9
Yellowchin sculpin	0.5	0.2	0.1		0.1		0.9
Hornyhead turbot		0.4		0.1	0.1	0.2	0.8
Plainfin midshipman	0.2	0.3	0.1		0.1	0.1	0.8
California tonguefish	0.3	0.2			0.1	0.1	0.7
Dover sole	0.1	0.3	0.1	0.1	0.1		0.7
Stripetail rockfish	0.3		0.1	0.1	0.1	0.1	0.7
Bigmouth sole	0.2		0.1	0.1	0.1	0.1	0.6
California skate		0.3	0.1	0.1	0.1		0.6
Greenspotted rockfish		0.5					0.5
California scorpionfish			0.4				0.4
Pink rockfish			0.1	0.1			0.2
Pygmy poacher		0.1				0.1	0.2
Spotfin sculpin		0.2					0.2
Blacktip poacher						0.1	0.1
Bluespotted poacher		0.1					0.1
Curlfin sole			0.1				0.1
Flag rockfish				0.1			0.1
Kelp pipefish						0.1	0.1
Red brotula						0.1	0.1
Roughback sculpin						0.1	0.1
Spotted cusk-eel						0.1	0.1
Survey Total	8.8	11.2	10.8	6.8	9.6	4.3	51.5

Appendix E.3 *continued*

Name	SD7	SD8	SD10	SD12	SD13	SD14	Biomass by Survey
	Summer 2013						
Pacific sanddab	1.2	3.8	7.7	5.3	4.3	6.2	28.5
California lizardfish	0.3	0.1	0.3	0.8	0.6	2.9	5.0
English sole	0.1	0.3	0.8	0.9	0.4	1.6	4.1
Dover sole	0.2	0.6	0.5	0.8	0.7	1.2	4.0
Longspine combfish	0.2	0.3	1.1	0.7	0.4	0.8	3.5
Halfbanded rockfish	0.1	1.3	0.6	0.4	0.1	0.2	2.7
Shortspine combfish	0.3	0.3	0.1	0.2	0.1	0.1	1.1
California skate	0.1			0.5	0.3	0.1	1.0
Bigmouth sole	0.1	0.1	0.3	0.1	0.2	0.1	0.9
Pink seaperch	0.1	0.1	0.1	0.1	0.1	0.2	0.7
Stripetail rockfish	0.1		0.2	0.1	0.1	0.1	0.6
Copper rockfish						0.6	0.6
Plainfin midshipman	0.1	0.1			0.1	0.2	0.5
Hornyhead turbot		0.1			0.1	0.1	0.3
Blackbelly eelpout				0.1	0.1		0.2
Blacktip poacher				0.1		0.1	0.2
Bluespotted poacher		0.1				0.1	0.2
Fringed sculpin		0.1	0.1				0.2
Pacific argentine	0.1	0.1					0.2
Pygmy poacher	0.1	0.1					0.2
Slender sole			0.1	0.1			0.2
Spotfin sculpin		0.1	0.1				0.2
Spotted cusk-eel		0.1	0.1				0.2
Bigfin eelpout						0.1	0.1
California tonguefish		0.1					0.1
Flag rockfish			0.1				0.1
Greenspotted rockfish	0.1						0.1
Kelp pipefish				0.1			0.1
Lingcod			0.1				0.1
Longfin sanddab				0.1			0.1
Unidentified rockfish	0.1						0.1
Roughback sculpin						0.1	0.1
Yellowchin sculpin	0.1						0.1
Survey Total	3.4	7.8	12.3	10.4	7.6	14.8	56.3
Annual Total	**12.2**	**19.0**	**23.1**	**17.2**	**17.2**	**19.1**	**107.8**

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 2013. 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
1992	r-value	0.083																					
	sig value	55.6																					
1993	r-value	0.833	0.75																				
	sig value	3.7	3.7																				
1994	r-value	0.583	0.583	0.25																			
	sig value	11.1	11.1	22.2																			
1995	r-value	0.167	0.083	0.25	0.417																		
	sig value	44.4	55.6	14.8	14.8																		
1996	r-value	0.667	0.75	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	0.5	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	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	0.833	0.667	0.917	0.5	1														
	sig value	3.7	3.7	3.7	3.7	11.1	3.7	7.4	3.7														
2000	r-value	1	0.917	0.833	0.75	0.583	0.667	0.75	0.5	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	0.75	0.917	1	0.667	1	0.5	0.5	1	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	0.5	0.5	0.5	0.917	0.75	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	0.75	0.5	0.667	0.75	1	0.583	0.75	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	0.417	0.5	0.5	0.417	0.333	0.167	0.5	0.25	0.583	0.167	0.75	0.417	-0.25									
	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	0.667	0.75	0.917	0.833	0.833	0.667	0.667	0.75	1	0.583	0.75	0.5	0.25	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	0.833	0.917	1	0.833	0.75	1	0.833	0.917	0.75	0.417	0.167	0.25							
	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	0.75	0.917	0.833	0.667	0.833	0.5	0.75	1	0.917	1	0.917	0.583	0.083	0.5	0.25						
	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	1	1	1	1	1	0.5	0.5	1	1	1	0.75	0.5	0	1	0	0.5					
	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	0.75	0.667	1	0.583	0.75	1	1	0.917	0.917	0.667	0.583	0.583	0.667	0.417	0.25				
	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	0.833	1	0.833	0.917	0.833	0.833	0.833	1	0.917	0.917	0.917	0.833	0.417	0.583	0.583	0.833	1	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	0.917	1	0.833	0.917	1	0.833	0.75	1	1	0.833	0.75	0.833	0.417	0.417	0.083	0.917	1	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	0.917	1	0.833	1	1	0.833	0.75	1	1	0.833	0.917	0.917	0.583	1	0.583	0.833	1	0.167	0.5	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	1	1	0.833	0.917	1	0.833	0.917	1	1	1	0.917	1	0.583	0.917	0.667	0.833	1	0.583	0.667	0.25	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

Appendix E.5

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

Taxon/Species				n
SILICEA				
	DEMOSPONGIAE			
		Suberitidae	*Suberites latus*	3
CNIDARIA				
	ANTHOZOA			
			Stolonifera (unidentified)	1
		Gorgoniidae	*Adelogorgia phyllosclera*	2
		Plexauridae	*Thesea* sp B	6
		Virgulariidae	*Acanthoptilum* sp	10
		Metridiidae	*Metridium farcimen*	7
MOLLUSCA				
	GASTROPODA			
		Calliostomatidae	*Calliostoma turbinum*	10
		Velutinidae	*Lamellaria diegoensis*	1
		Fasciolariidae	*Barbarofusus barbarensis*	5
		Nassariidae	*Hinea insculpta*	3
		Muricidae	*Pteropurpura vokesae*	1
		Pseudomelatomidae	*Megasurcula carpenteriana*	3
		Cancellariidae	*Cancellaria crawfordiana*	2
		Philinidae	*Philine alba*	6
			Philine auriformis	1
		Pleurobranchidae	*Pleurobranchaea californica*	33
		Onchidorididae	*Acanthodoris brunnea*	5
	CEPHALOPODA			
		Sepiolidae	*Rossia pacifica*	4
		Loliginidae	*Doryteuthis opalescens*	1
		Octopodidae	*Octopus rubescens*	33
ANNELIDA				
	POLYCHAETA			
		Polynoidae	*Arctonoe pulchra*	11
			Hololepida magna	2
ARTHROPODA				
	PYCNOGONIDA			
		Nymphonidae	*Nymphon pixellae*	1
	MALACOSTRACA			
		Cymothoidae	*Elthusa vulgaris*	5
		Sicyoniidae	*Sicyonia ingentis*	22
		Crangonidae	*Crangon alaskensis*	3
			Neocrangon zacae	1
		Diogenidae	*Paguristes bakeri*	5
			Paguristes turgidus	3
		Paguridae	*Enallopaguropsis guatemoci*	1
			Pagurus armatus	1
			Parapagurodes makarovi	1

Appendix E.5 *continued*

Taxon/Species				n
		Lithodidae	*Paralithodes rathbuni*	1
		Homolidae	*Moloha faxoni*	1
		Calappidae	*Platymera gaudichaudii*	1
		Epialtidae	*Loxorhynchus crispatus*	1
		Inachidae	*Podochela lobifrons*	1
		Inachoididae	*Pyromaia tuberculata*	1
ECHINODERMATA				
	CRINOIDEA			
		Antedonidae	*Florometra serratissima*	83
	ASTEROIDEA			
		Luidiidae	*Luidia armata*	1
			Luidia asthenosoma	9
			Luidia foliolata	175
		Astropectinidae	*Astropecten californicus*	48
	OPHIUROIDEA			
		Ophiuridae	*Ophiura luetkenii*	4792
		Amphiuridae	*Amphichondrius granulatus*	1
		Ophiotricidae	*Ophiothrix spiculata*	4
		Ophiactidae	*Ophiopholis bakeri*	9
	ECHINOIDEA			
		Toxopneustidae	*Lytechinus pictus*	25,883
		Strongylocentrotidae	*Strongylocentrotus fragilis*	605
		Spatangidae	*Spatangus californicus*	7
	HOLOTHUROIDEA			
		Stichopodidae	*Parastichopus californicus*	28

Appendix E.6
Total abundance by species and station for megabenthic invertebrates at the PLOO trawl stations during 2013.

Species	Winter 2013						Species Abundance by Survey
	SD7	SD8	SD10	SD12	SD13	SD14	
Lytechinus pictus	3802	5443	3626	1791	1945	876	17,483
Ophiura luetkenii	2417	91	38	13	377	360	3296
Luidia foliolata	19	38	20	11	15	12	115
Florometra serratissima	31	5	2				38
Octopus rubescens	1	6		1	5	5	18
Astropecten californicus	10		2	4	1		17
Sicyonia ingentis	1	3	1	3	9		17
Pleurobranchaea californica	1	5	4		1	3	14
Parastichopus californicus	7	3		1	2		13
Arctonoe pulchra		5	2				7
Calliostoma turbinum	6	1					7
Metridium farcimen				7			7
Barbarofusus barbarensis		4	1				5
Paguristes bakeri	2	1		2			5
Crangon alaskensis	2				1		3
Hinea insculpta	2		1				3
Philine alba	2	1					3
Suberites latus	1			2			3
Cancellaria crawfordiana		1	1				2
Hololepida magna		1		1			2
Ophiopholis bakeri				2			2
Ophiothrix spiculata				2			2
Rossia pacifica					1	1	2
Strongylocentrotus fragilis					2		2
Acanthoptilum sp		1					1
Adelogorgia phyllosclera			1				1
Amphichondrius granulatus		1					1
Elthusa vulgaris					1		1
Enallopaguropsis guatemoci		1					1
Loxorhynchus crispatus				1			1
Luidia armata						1	1
Luidia asthenosoma	1						1
Neocrangon zacae						1	1
Nymphon pixellae		1					1
Parapagurodes makarovi		1					1
Philine auriformis				1			1
Podochela lobifrons		1					1
Pteropurpura vokesae		1					1
Spatangus californicus						1	1
Stolonifera (unidentified)		1					1
Survey Total	6305	5616	3699	1842	2360	1260	21,082

Appendix E.6 *continued*

Species	Summer 2013 SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
Lytechinus pictus	2750	1746	3038	288	324	254	8400
Ophiura luetkenii	962	24	236	41	127	106	1496
Strongylocentrotus fragilis	1				130	472	603
Luidia foliolata	8	6	17	12	9	8	60
Florometra serratissima	39	4	2				45
Astropecten californicus	16		5	8	1	1	31
Pleurobranchaea californica	4	5	4	2	3	1	19
Parastichopus californicus	5	4	3	2		1	15
Octopus rubescens	3	3		1	1	7	15
Acanthoptilum sp		3	6				9
Luidia asthenosoma	5		1	2			8
Ophiopholis bakeri	4	2	1				7
Spatangus californicus	1	2	2	1			6
Thesea sp B		2		4			6
Acanthodoris brunnea			1	4			5
Sicyonia ingentis	5						5
Arctonoe pulchra			2		2		4
Elthusa vulgaris			1	2		1	4
Calliostoma turbinum	3						3
Megasurcula carpenteriana	1		1	1			3
Paguristes turgidus	1	1	1				3
Philine alba		3					3
Ophiothrix spiculata			2				2
Rossia pacifica	1					1	2
Adelogorgia phyllosclera		1					1
Doryteuthis opalescens				1			1
Lamellaria diegoensis		1					1
Moloha faxoni		1					1
Pagurus armatus			1				1
Paralithodes rathbuni		1					1
Platymera gaudichaudii				1			1
Pyromaia tuberculata	1						1
Survey Total	3810	1809	3324	370	597	852	10762
Annual Total	**10,115**	**7425**	**7023**	**2212**	**2957**	**2112**	**31,844**

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 2013. 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
1992	r-value	0.667																					
	sig value	3.7																					
1993	r-value	0.25	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	0.25																		
	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	0.167																
	sig value	11.1	7.4	22.2	11.1	51.9	29.6																
1998	r-value	0.75	0.833	0.5	0.083	0.083	0.333	0.5															
	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	0.5	0.417	0.667	0.75	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	0.5	0.25	0.417	0.083	0.417	0.667	0.25	0.25													
	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	0.25	-0.167	0.333	0.25	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	0.5	0.5	0.25	0.417	0.667	0.333	0.75	-0.083	-0.167											
	sig value	7.4	3.7	7.4	14.8	22.2	18.5	7.4	22.2	7.4	55.6	100											
2003	r-value	0.667	0.667	0.083	0.333	0.333	0.25	0.25	0.083	0.333	0	-0.083	0.25										
	sig value	7.4	7.4	44.4	22.2	18.5	22.2	25.9	40.7	14.8	55.6	63	25.9										
2004	r-value	0.167	0.417	0	0.167	-0.083	0.167	0.25	-0.083	0.25	-0.25	-0.25	0	-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	0.333	0.167	0.417	0	0.417	0.5	0.083	0.5	-0.167	-0.25	-0.167	0.083	-0.167								
	sig value	18.5	11.1	11.1	22.2	55.6	3.7	14.8	44.4	14.8	74.1	85.2	77.8	55.6	70.4								
2006	r-value	0.417	0.667	0.333	0.583	0.333	0.5	0.583	0.25	0.5	0.083	0.083	0.5	0.333	-0.083	-0.25							
	sig value	14.8	3.7	11.1	7.4	22.2	14.8	11.1	25.9	3.7	44.4	48.1	11.1	18.5	63	85.2							
2007	r-value	0.417	0.667	0.25	0.5	0.417	0.333	0.667	0.25	0.333	-0.083	0	0.333	0.167	0	0.083	0.083						
	sig value	14.8	3.7	11.1	11.1	11.1	22.2	3.7	33.3	22.2	77.8	59.3	14.8	33.3	59.3	44.4	44.4						
2008	r-value	0.5	0	-0.25	0	-0.25	0	0	0	-0.25	-0.5	-0.25	-0.5	-0.25	-0.25	-0.5	-0.25	-0.5					
	sig value	33.3	100	100	66.7	66.7	66.7	66.7	66.7	66.7	100	66.7	100	66.7	66.7	100	66.7	100					
2009	r-value	0.667	0.833	0.583	0.25	0.167	0.417	0.333	0.333	0.583	0.417	-0.083	0.5	0.333	0	0.167	0.333	0.417	-0.5				
	sig value	11.1	3.7	11.1	25.9	37	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				
2010	r-value	0.5	0.667	0.667	0.417	0.333	0.583	0.75	0.333	0.583	0.083	-0.25	0.417	0.167	0	-0.083	0.25	0.083	-0.5	0.25			
	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	51.9	63	37	44.4	100	25.9			
2011	r-value	0.667	0.833	0.5	0.5	0.167	0.75	0.667	0.75	0.75	0.417	0.5	0.667	0.5	0.25	0.25	0.75	0.667	-0.25	0.417	0.417		
	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	0.833	0.833	0.583	0.5	0.25	0.667	0.583	0.667	0.833	0.667	0.583	0.5	0.583	0.417	0.25	0.5	0.583	-0.25	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	0.5	0.583	0.5	0.417	0.5	0.417	0.25	0.25	0.583	0.417	-0.25	0.417	0.333	-0.25	0
	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	7.4	14.8	66.7	11.1	18.5	77.8	55.6

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Appendix F

Supporting Data

2013 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 October 2013. 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	Mixed rockfish	3	22	32	28	253	927	602
Rig Fishing 1	2	Mixed rockfish	3	36	37	36	1343	1781	1577
Rig Fishing 1	3	Starry rockfish	3	24	30	27	312	857	542
Rig Fishing 2	1	Speckled rockfish	3	27	28	27	441	567	514
Rig Fishing 2	2	Speckled rockfish	3	25	28	27	312	643	479
Rig Fishing 2	3	Speckled rockfish	3	27	30	28	571	666	609
Trawl Zone 1	1	Pacific sanddab	8	16	18	17	55	77	67
Trawl Zone 1	2	Pacific sanddab	11	14	17	15	38	58	46
Trawl Zone 1	3	Pacific sanddab	10	15	18	17	46	75	58
Trawl Zone 2	1	Pacific sanddab	8	15	18	16	46	89	59
Trawl Zone 2	2	Pacific sanddab	10	14	16	15	38	64	49
Trawl Zone 2	3	Pacific sanddab	13	12	16	14	32	60	39
Trawl Zone 3	1	Pacific sanddab	8	16	17	17	51	88	67
Trawl Zone 3	2	Pacific sanddab	3	16	23	19	68	195	115
Trawl Zone 3	3	Pacific sanddab	5	16	19	17	63	127	86
Trawl Zone 4	1	Pacific sanddab	6	16	21	17	57	168	82
Trawl Zone 4	2	Pacific sanddab	6	16	20	18	51	131	81
Trawl Zone 4	3	Pacific sanddab	7	16	18	17	49	80	61

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 October 2013.

Parameter	MDL Liver	MDL Muscle	Constituent	MDL Liver	MDL Muscle
Metals (ppm)					
Aluminum (Al)	3.0	3.0	Lead (Pb)	0.2	0.2
Antimony (Sb)	0.2	0.2	Manganese (Mn)	0.1	0.1
Arsenic (As)	0.24	0.24	Mercury (Hg)	0.002	0.002
Barium (Ba)	0.03	0.03	Nickel (Ni)	0.2	0.2
Beryllium (Be)	0.006	0.006	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.06	0.06	Silver (Ag)	0.05	0.05
Chromium (Cr)	0.1	0.1	Thallium (Tl)	0.4	0.4
Copper (Cu)	0.3	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	0.20	Heptachlor epoxide	3.79	0.38
Cis nonachlor	1.91	0.19	Oxychlordane	2.92	0.29
Gamma (trans) chlordane	3.07	0.31	Trans nonachlor	1.44	0.14
Heptachlor	2.10	0.21			
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	1.98	0.20	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	0.20	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	Hexachlorobenzene (HCB)	2.29	0.23
Dieldrin	12.6	1.26	Mirex	1.77	0.18

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, total chlordane and total PCB in composite (Comp) tissue samples from the PLOO region during October 2013. RF = rig fishing; TZ = trawl zone.

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	RF1	1	Mixed rockfish	Muscle	PCB	PCB 138	0.1	ppb
2013-4	RF1	1	Mixed rockfish	Muscle	PCB	PCB 149	0.1	ppb
2013-4	RF1	1	Mixed rockfish	Muscle	PCB	PCB 153/168	0.2	ppb
2013-4	RF1	1	Mixed rockfish	Muscle	PCB	PCB 180	0.1	ppb
2013-4	RF1	1	Mixed rockfish	Muscle	DDT	p,-p-DDMU	0.3	ppb
2013-4	RF1	1	Mixed rockfish	Muscle	DDT	p,p-DDE	3.2	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 28	0.1	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 49	0.2	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 52	0.3	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 66	0.3	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 70	0.2	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 74	0.2	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 99	1.0	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 101	1.2	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 105	0.4	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 110	0.6	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 118	1.5	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 128	0.3	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 138	1.5	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 149	0.6	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 151	0.2	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 153/168	2.5	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 158	0.1	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 170	0.4	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 180	1.0	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 183	0.2	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 187	0.8	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 194	0.3	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	PCB	PCB 201	0.3	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	CHLORDANE	Trans Nonachlor	0.4	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	DDT	o,p-DDE	0.7	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	DDT	p,-p-DDMU	1.6	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	DDT	p,p-DDD	0.6	ppb
2013-4	RF1	2	Mixed rockfish	Muscle	DDT	p,p-DDE	44.0	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 28	0.1	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 49	0.4	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 52	0.5	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 66	0.2	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 70	0.3	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 74	0.2	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 87	0.4	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 99	1.2	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 101	1.8	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 105	0.5	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 110	1.0	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 118	1.9	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 128	0.3	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 138	1.7	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 149	1.0	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 151	0.2	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 153/168	3.1	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 158	0.2	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 170	0.4	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 177	0.2	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 180	1.2	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 183	0.3	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 187	1.0	ppb
2013-4	RF1	3	Starry rockfish	Muscle	PCB	PCB 201	0.3	ppb
2013-4	RF1	3	Starry rockfish	Muscle	CHLORDANE	Alpha (cis) Chlordane	0.6	ppb
2013-4	RF1	3	Starry rockfish	Muscle	CHLORDANE	Trans Nonachlor	0.7	ppb
2013-4	RF1	3	Starry rockfish	Muscle	DDT	o,p-DDE	0.4	ppb
2013-4	RF1	3	Starry rockfish	Muscle	DDT	p,-p-DDMU	1.0	ppb
2013-4	RF1	3	Starry rockfish	Muscle	DDT	p,p-DDD	1.0	ppb
2013-4	RF1	3	Starry rockfish	Muscle	DDT	p,p-DDE	30.0	ppb
2013-4	RF1	3	Starry rockfish	Muscle	DDT	p,p-DDT	0.7	ppb
2013-4	RF2	1	Speckled rockfish	Muscle	PCB	PCB 118	0.3	ppb
2013-4	RF2	1	Speckled rockfish	Muscle	PCB	PCB 138	0.2	ppb
2013-4	RF2	1	Speckled rockfish	Muscle	PCB	PCB 149	0.1	ppb
2013-4	RF2	1	Speckled rockfish	Muscle	PCB	PCB 153/168	0.4	ppb
2013-4	RF2	1	Speckled rockfish	Muscle	PCB	PCB 187	0.1	ppb
2013-4	RF2	1	Speckled rockfish	Muscle	DDT	o,p-DDE	0.1	ppb
2013-4	RF2	1	Speckled rockfish	Muscle	DDT	p,p-DDE	5.2	ppb
2013-4	RF2	2	Speckled rockfish	Muscle	PCB	PCB 138	0.1	ppb
2013-4	RF2	2	Speckled rockfish	Muscle	PCB	PCB 153/168	0.1	ppb
2013-4	RF2	2	Speckled rockfish	Muscle	DDT	p,p-DDE	1.5	ppb
2013-4	RF2	3	Speckled rockfish	Muscle	PCB	PCB 66	0.1	ppb
2013-4	RF2	3	Speckled rockfish	Muscle	PCB	PCB 118	0.2	ppb
2013-4	RF2	3	Speckled rockfish	Muscle	PCB	PCB 138	0.2	ppb
2013-4	RF2	3	Speckled rockfish	Muscle	PCB	PCB 149	0.1	ppb
2013-4	RF2	3	Speckled rockfish	Muscle	PCB	PCB 153/168	0.3	ppb
2013-4	RF2	3	Speckled rockfish	Muscle	PCB	PCB 180	0.1	ppb
2013-4	RF2	3	Speckled rockfish	Muscle	PCB	PCB 187	0.1	ppb
2013-4	RF2	3	Speckled rockfish	Muscle	DDT	o,p-DDE	0.1	ppb
2013-4	RF2	3	Speckled rockfish	Muscle	DDT	p,p-DDE	4.7	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 28	1.2	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 49	3.4	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 52	5.1	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 66	4.2	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 70	4.1	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 74	2.9	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 99	28.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 101	14.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 105	10.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 110	16.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 118	39.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 123	4.1	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 128	9.9	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 138	53.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 149	7.5	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 151	7.9	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 153/168	85.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 156	4.6	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 158	4.2	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 167	2.8	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 170	13.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 177	6.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 180	37.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 183	10.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 187	34.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 194	9.7	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 201	11.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	PCB	PCB 206	7.3	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	12.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	DDT	o,p-DDE	4.1	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	24.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	DDT	p,p-DDD	5.2	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	DDT	p,p-DDE	420.0	ppb
2013-4	TZ1	1	Pacific sanddab	Liver	DDT	p,p-DDT	7.6	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 28	0.9	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 49	2.7	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 52	3.7	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 66	2.7	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 70	2.7	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 74	1.7	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 99	14.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 101	9.4	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 105	4.6	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 110	8.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 118	18.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 128	5.1	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 138	24.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 149	6.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 151	4.5	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 153/168	41.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 158	2.1	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 167	1.2	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 170	5.5	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 177	3.5	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 180	18.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 183	4.9	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 187	17.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 201	6.2	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	PCB	PCB 206	4.2	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	7.1	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	DDT	o,p-DDE	3.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	TZ1	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	16.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	DDT	p,p-DDD	5.7	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	DDT	p,p-DDE	230.0	ppb
2013-4	TZ1	2	Pacific sanddab	Liver	DDT	p,p-DDT	4.6	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 28	0.7	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 49	2.4	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 52	3.6	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 66	2.6	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 70	2.8	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 74	1.9	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 99	18.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 101	9.8	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 105	6.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 110	9.5	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 118	24.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 128	6.8	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 138	38.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 149	7.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 151	5.6	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 153/168	65.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 158	3.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 167	2.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 170	8.4	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 177	4.3	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 180	26.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 183	7.1	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 187	25.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 194	7.1	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 201	8.8	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	PCB	PCB 206	5.7	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	7.4	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	DDT	o,p-DDE	2.5	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	18.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	DDT	p,p-DDD	4.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	DDT	p,p-DDE	300.0	ppb
2013-4	TZ1	3	Pacific sanddab	Liver	DDT	p,p-DDT	5.4	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 49	1.1	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 52	1.7	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 66	1.3	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 70	1.4	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 74	1.0	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 99	6.8	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 101	4.1	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 105	2.4	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 110	4.0	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 118	9.5	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 128	2.9	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 138	13.5	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 149	2.5	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 151	2.1	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 153/168	23.5	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 158	1.1	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 170	3.2	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 177	1.8	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 180	9.5	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 183	2.6	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 187	9.5	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 194	3.3	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 201	4.1	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	PCB	PCB 206	2.9	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	2.5	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	DDT	o,p-DDE	1.0	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	8.3	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	DDT	p,p-DDD	2.8	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	DDT	p,p-DDE	155.0	ppb
2013-4	TZ2	1	Pacific sanddab	Liver	DDT	p,p-DDT	2.8	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 49	1.4	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 52	2.2	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 66	1.5	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 70	1.7	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 74	1.1	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 99	8.8	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 101	6.1	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 105	3.0	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 110	4.5	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 118	12.0	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 123	1.5	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 128	3.8	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 138	17.0	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 149	4.4	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 151	2.5	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 153/168	30.0	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 156	1.4	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 158	1.1	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 167	0.9	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 170	4.3	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 177	2.4	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 180	12.0	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 183	3.5	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 187	12.0	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 194	3.6	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	PCB	PCB 201	4.2	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	4.4	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	DDT	o,p-DDE	2.7	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	9.7	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	DDT	p,p-DDD	3.7	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	DDT	p,p-DDE	240.0	ppb
2013-4	TZ2	2	Pacific sanddab	Liver	DDT	p,p-DDT	3.1	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 28	0.7	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 49	1.5	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 52	2.6	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 66	2.0	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 70	1.8	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 74	1.2	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 99	9.9	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 101	6.2	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 105	3.3	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 110	4.6	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 118	13.0	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 128	3.5	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 138	17.0	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 149	4.1	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 151	2.7	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 153/168	29.0	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 158	1.4	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 167	0.8	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 170	4.4	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 177	2.6	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 180	13.0	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 183	3.9	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 187	12.0	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	PCB	PCB 206	3.1	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	CHLORDANE	Alpha (cis) Chlordane	3.4	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	6.2	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	DDT	o,p-DDE	3.4	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	13.0	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	DDT	p,p-DDD	4.6	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	DDT	p,p-DDE	310.0	ppb
2013-4	TZ2	3	Pacific sanddab	Liver	DDT	p,p-DDT	3.9	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 28	1.1	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 49	6.1	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 52	8.5	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 66	5.3	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 70	5.9	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 74	3.3	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 87	6.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 99	32.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 101	22.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 105	11.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 110	23.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 118	48.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 123	4.2	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 128	13.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 138	63.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 149	14.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 151	11.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 153/168	100.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 156	5.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 158	5.1	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 167	3.1	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 170	12.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 177	6.3	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 180	38.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 183	10.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 187	36.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 194	10.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 201	10.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	PCB	PCB 206	7.4	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	CHLORDANE	Alpha (cis) Chlordane	4.6	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	DDT	o,p-DDE	4.3	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	20.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	DDT	p,p-DDD	5.2	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	DDT	p,p-DDE	300.0	ppb
2013-4	TZ3	1	Pacific sanddab	Liver	DDT	p,p-DDT	4.8	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 28	0.9	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 49	3.5	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 52	5.3	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 66	3.3	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 70	3.6	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 74	2.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 99	18.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 101	15.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 105	6.2	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 110	14.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 118	27.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 128	5.9	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 138	30.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 149	8.5	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 151	5.3	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 153/168	52.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 158	2.5	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 167	16.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 170	6.5	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 177	3.6	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 180	21.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 183	5.9	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 187	20.0	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 194	6.2	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 201	6.7	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	PCB	PCB 206	4.7	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	9.8	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	DDT	p,p-DDD	3.3	ppb
2013-4	TZ3	2	Pacific sanddab	Liver	DDT	p,p-DDE	150.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 28	0.7	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 49	2.3	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 52	3.3	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 66	2.1	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 70	2.5	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 74	1.7	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 99	13.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 101	8.3	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 105	4.7	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 110	7.6	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 118	18.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 123	2.2	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 128	5.2	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 138	25.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 149	5.3	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 151	3.5	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 153/168	47.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 156	2.5	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 158	2.3	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 167	1.2	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 170	5.2	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 177	2.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 180	17.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 183	4.3	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 187	15.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 194	4.3	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 201	4.2	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	PCB	PCB 206	3.5	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	5.5	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	DDT	o,p-DDE	2.6	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	13.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	DDT	p,p-DDD	3.3	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	DDT	p,p-DDE	210.0	ppb
2013-4	TZ3	3	Pacific sanddab	Liver	DDT	p,p-DDT	3.8	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 28	0.9	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 49	3.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 52	4.2	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 66	2.8	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 70	3.1	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 74	2.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 99	20.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 101	15.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 105	6.9	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 110	12.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 118	30.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 123	2.6	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 128	7.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 138	36.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 149	8.5	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 151	5.9	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 153/168	59.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 156	3.1	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 158	3.3	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 167	1.8	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 170	7.1	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 177	4.6	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 180	23.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 183	6.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 187	23.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 201	7.4	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	PCB	PCB 206	5.3	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	6.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	DDT	o,p-DDE	2.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	16.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	DDT	p,p-DDD	4.6	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	DDT	p,p-DDE	300.0	ppb
2013-4	TZ4	1	Pacific sanddab	Liver	DDT	p,p-DDT	3.9	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 28	1.1	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 49	5.4	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 52	6.7	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 66	4.4	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 70	4.3	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 74	2.5	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 87	4.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 99	25.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 101	19.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 105	8.3	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 110	16.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 118	32.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 123	4.1	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 128	8.7	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 138	45.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 149	12.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 151	6.2	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 153/168	78.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 156	4.1	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 158	3.5	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 167	2.6	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 170	10.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 177	5.2	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 180	31.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 183	8.3	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 187	27.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 194	9.3	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 201	10.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	PCB	PCB 206	6.8	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	5.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	DDT	o,p-DDE	3.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	17.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	DDT	p,p-DDD	6.6	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	DDT	p,p-DDE	350.0	ppb
2013-4	TZ4	2	Pacific sanddab	Liver	DDT	p,p-DDT	5.1	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Constituent	Value	Units
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 28	0.9	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 49	5.6	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 52	11.0	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 66	3.8	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 70	4.5	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 74	2.3	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 99	20.5	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 101	16.0	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 105	6.0	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 110	11.5	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 118	25.5	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 123	2.7	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 128	6.3	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 138	30.0	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 149	8.3	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 153/168	54.0	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 156	2.5	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 158	2.4	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 167	1.6	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 170	6.4	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 177	4.0	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 180	20.5	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 183	5.4	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 187	19.5	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 201	6.1	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	PCB	PCB 206	4.3	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	CHLORDANE	Trans Nonachlor	9.1	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	DDT	o,p-DDE	4.5	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	19.0	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	DDT	p,p-DDD	5.5	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	DDT	p,p-DDE	310.0	ppb
2013-4	TZ4	3	Pacific sanddab	Liver	DDT	p,p-DDT	4.8	ppb