SD Public Utilities

Point Loma Ocean Outfall Annual Receiving Waters Monitoring & Assessment Report

2015

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

THE CITY OF SAN DIEGO

June 30, 2016

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 2015 Annual Receiving Waters Monitoring and Assessment Report for the Point Loma Ocean Outfall as required per Order No. R9-2009-0001, NPDES No. CA0107409. This assessment report contains data summaries, analyses and interpretations of all portions of the ocean monitoring program conducted during calendar year 2015, including oceanographic conditions, water quality, sediment conditions, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues.

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

Sincerely,

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

TDS/akl

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

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Point Loma Ocean Outfall

Annual Receiving Waters Monitoring & Assessment Report, 2015

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

Prepared by:

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

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June 2016

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Collage highlighting examples of trawl-caught invertebrates found in the Point Loma Ocean Outfall monitoring region (clockwise from top left): the feather star *Florometra serratissima*; the red crab *Pleuroncodes planipes*; the sea anemone *Metridium farcimen*; the crab *Paralithodes californiensis;* the urchin *Stronglylocentrotus fragilis*. Photos are from the Bight'13 regional survey voucher collection and were taken by various Marine Biologists.

Acknowledgments:
We are grateful to the personnel of the City's Marine Biology, Marine Microbiology, and Environmental Chemistry Services Laboratories for their assistance in the collection and/or processing of all samples, and for discussions of the results. The completion of this report would not have been possible without their continued efforts and contributions. Complete staff listings for the above labs and additional details concerning relevant QA/QC activities for the receiving waters monitoring data reported herein are available online in the 2015 Annual Receiving Waters Monitoring & Toxicity Testing Quality Assurance Report (www.sandiego.gov/mwwd/environment/reports.shtml).

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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
FIB	Fecal Indicator Bacteria
ft	feet
FTR	Fecal to Total coliform Ratio criterion
g	gram
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
L	Liter
m	meter

Acronyms and Abbreviations

m^2	square meter
MDL	Method Detection Limit
mg	milligram
mgd	millions of gallons per day
ml	maximum length
mL	milliliter
mm	millimeter
MODIS	Moderate Resolution Imaging Spectroradiometer
MRP	Monitoring and Reporting Program
mt	metric ton
n	sample size
N	number of observations used in a Chi-square analysis
ng	nanograms
no.	number
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPGO	North Pacific Gyre Oscillation
NWS	National Weather Service
O&G	Oil and Grease
OCSD	Orange County Sanitation District
OEHHA	California Office of Environmental Health Hazard Assessment
OI	Ocean Imaging
OOR	Out-of-range
p	probability
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PDO	Pacific Decadal Oscillation
pH	Acidity/Alkalinity value
PLOO	Point Loma Ocean Outfall
PLWTP	Point Loma Wastewater Treatment Plant
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PRIMER	Plymouth Routines in Multivariate Ecological Research
psu	practical salinity units
r_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
SCBPP	Southern California Bight Pilot Project
SCCWRP	Southern California Coastal Water Research Project
SD	Standard Deviation
SDRWQCB	San Diego Regional Water Quiality Control Board
SIMPER	Similarity Percentages Routine

Acronyms and Abbreviations

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

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Executive Summary

Executive Summary

The City of San Diego (City) conducts an extensive ocean monitoring program to evaluate potential environmental effects from the discharge of treated wastewater to the Pacific Ocean via the Point Loma Ocean Outfall (PLOO). The data collected are used to determine compliance with receiving water conditions as specified in the National Pollutant Discharge Elimination System (NPDES) regulatory permit for the City's Point Loma Wastewater Treatment Plant (PLWTP).

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

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

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

Regular (core) monitoring sites that are sampled on a weekly, quarterly or semiannual basis are arranged in a grid surrounding the PLOO, which terminates approximately 7.2 km offshore of the PLWTP at a discharge depth of about 100 m. Monitoring at the shoreline stations extends from Mission Beach southward to the tip of Point Loma, while regular monitoring in the Point Loma Kelp Forest and further offshore occurs in waters overlying the continental shelf at depths of about 9 to 116 m. In addition to the above core monitoring, a broader geographic survey of benthic conditions is typically conducted each year at randomly selected sites that range from the USA/Mexico border region to northern San Diego County and that extend further offshore to waters as deep as 500 m. These regional surveys are useful for evaluating patterns and trends over a larger geographic area, and thus provide important information for distinguishing reference from impact areas. Additional information on background environmental conditions for the Point Loma region is also available from a baseline study conducted by the City over a 2½ year period prior to wastewater discharge.

Details of the results and conclusions of all receiving waters monitoring activities conducted from January through December 2015 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 other projects relevant to assessing the quality and movement of ocean waters in the region. One such project involves satellite imaging of the San Diego/

Tijuana coastal region, of which the 2015 results are incorporated into Chapters 2 and 3. A summary of the main findings for each of the above components is included below.

Coastal Oceanographic Conditions

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

Water Quality Compliance & Plume Dispersion

Water quality conditions were excellent in the Point Loma region during 2015. Overall compliance with the Ocean Plan's single sample maximum and geometric mean standards for fecal indicator bacteria (FIB) was >99% for the shore, kelp bed and other offshore stations located within State waters. Compliance was also very high with Ocean Plan objectives for natural light (i.e., water clarity or transmissivity), pH, and dissolved oxygen in Point Loma coastal waters where the plume is likely to occur (see below).

There was no evidence that wastewater discharged to the ocean via the PLOO reached the shore or nearshore kelp forests in 2015. These results are consistent with satellite imagery observations, as well as findings from a recent plume behavior study that showed the PLOO waste field is unlikely to surface and that plume dispersion is typically directed away from the Point Loma kelp beds. During the year, elevated FIB densities were detected in just 18 seawater samples from six of the eight shore stations, whereas none of the samples collected from the kelp stations were found to have elevated FIB counts. FIB densities were also generally low at all offshore stations during each quarterly survey, with only 3% of the samples having elevated *Enterococcus* levels. All of the samples with elevated *Enterococcus* were collected from depths of 60 m or deeper, and the majority (94%) were from stations located along the 80 or 100-m depth contours. The low rate of bacterial contamination near the outfall discharge site 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 22% of the time off Point Loma, with most detections occurring beyond State waters and at depths below 40 m. Overall, the results from 2015 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 2015 were composed primarily of fine sands and finer particles, which is similar to patterns seen in previous years. There were no changes in the amount of fine sediments that could be attributed to wastewater discharge, nor was there any other apparent relationship between particle size distributions and proximity to the outfall. Instead, most differences between monitoring sites are probably due to factors such as offshore disposal of dredged sediments, deposition of detrital materials, presence of residual construction materials near the outfall, and the geological history and origins of different sediment types.

As in previous years, sediment quality was very high in 2015, with overall contaminant loads remaining relatively low compared to available thresholds and other southern California coastal areas. The potential for environmental degradation by various contaminants was evaluated using the effects-range low (ERL) and effects-range median (ERM) sediment quality guidelines when available. The only exceedances of these thresholds in 2015 were for total DDT, which was found in excess of its ERL at two stations during the year. Additionally, there was no evidence of contaminant accumulation associated with wastewater discharge. Concentrations of the various organic loading indicators, trace metals, pesticides, PCBs and PAHs varied widely throughout the region, and there were no patterns that could be attributed to the outfall or other point sources. Instead, the highest concentrations of several contaminants occurred in sediments collected from the northern-most or southern-most stations. The occurrence of elevated levels of pesticides, PCBs and PAHs south of the outfall is consistent with other studies that have suggested that sediment contamination in the area is probably related to short dumps of dredged materials destined originally for the USEPA designated LA-5 disposal site. The only evidence of possible organic enrichment in Point Loma sediments was slightly higher sulfide and BOD levels at a few stations located within 200 m of the zone of initial dilution (ZID).

MACROBENTHIC COMMUNITIES

Benthic macrofaunal communities surrounding the PLOO were similar in 2015 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 25 years ago. The cirratulid polychaete *Chaetozone hartmanae* was the most widespread benthic invertebrate. There have been some minor changes in macrofaunal assemblages located within ~200 m of the discharge zone that would be expected near large ocean outfalls. For example, some descriptors of benthic community structure (e.g., infaunal abundance, species richness) or populations of indicator species (e.g., *A. urtica*) have shown changes over time between reference areas and sites located nearest the outfall. Despite these changes, however, benthic response index (BRI) results for 97% of the samples remained characteristic of undisturbed habitats. Only the BRI values for four grab samples collected at near-ZID station E14 indicated a possible minor deviation from reference condition. In addition, changes documented during the year were similar in magnitude to those reported previously for the region and elsewhere off southern California. Overall, macrofaunal assemblages off Point Loma remain similar to natural indigenous communities that are characteristic of similar habitats on the southern California continental shelf. There was no evidence that wastewater discharge has caused degradation of the marine benthos at any of the monitoring stations.

DEMERSAL FISHES AND MEGABENTHIC INVERTEBRATES

Comparisons of the 2015 trawl survey results with previous surveys indicate that demersal fish and megabenthic invertebrate communities in the region remain unaffected by wastewater discharge. Although highly variable, patterns in the abundance and distribution of individual species were similar at stations located near the outfall and farther away. Pacific Sanddab and Halfbanded Rockfish dominated Point Loma fish assemblages during 2015, with both species occurring at all stations and together accounting for about 73% of the year's catch. Other common species off Point Loma included Longspine Combfish, Stripetail Rockfish, California Scorpionfish, California Lizardfish, Yellowchin Sculpin, English Sole, Pink Seaperch, Shortspine Combfish, Plainfin Midshipman, Greenstriped Rockfish, Dover Sole, Hornyhead Turbot, California Tonguefish, California Skate, and Bigmouth Sole. Trawl-caught invertebrate assemblages were dominated by the sea urchin *Lytechinus pictus*, which also occurred in all trawls and accounted for 87% of all invertebrates captured. The shrimp *Sicyonia ingentis* was also collected at all stations, although usually in fairly low numbers at most sites. Other common, but far less abundant invertebrates included the sea stars *Astropecten californicus*, *Luidia asthenosoma* and *Luidia foliolata*, the sea cucumber *Parastichopus californicus*, the cephalopod *Octopus rubescens*, and the cymothoid isopod *Elthusa vulgaris*. Finally, external examinations of the fish captured during the year indicated that local fish populations remain healthy, with <1% of all fish having external parasites or any evidence of disease.

Contaminants in Fish Tissues

The accumulation of chemical contaminants in local fishes was assessed by analyzing liver tissues from trawl-caught flatfish and muscle tissues from rockfish captured by hook and line. Results from both analyses indicated no evidence that contaminant loads in Point Loma fishes were affected by wastewater discharge in 2015. Although several metals, pesticides, and PCB congeners were detected in both tissue types, these contaminants occurred in fishes distributed throughout the region with no patterns that could be attributed to wastewater discharge. While several rockfish muscle samples exceeded state or international standards for a few contaminants, all samples were within federal (USFDA) action limits. Furthermore, concentrations of all contaminants were within ranges reported previously for southern California fishes. The occurrence of some metals and chlorinated hydrocarbons in local fishes may be due to many factors, including the ubiquitous distribution of many contaminants in southern California coastal sediments. Other factors that affect bioaccumulation in marine fishes include differences in physiology and life history traits of various species. In addition, exposure can vary greatly between different species of fish and even among individuals of the same species depending on their migration habits. For example, an individual fish may be exposed to contaminants at a polluted site and then migrate to an area that is less contaminated. This is of particular concern for fishes collected in the vicinity of the PLOO, as there are many other potential point and non-point sources of contamination.

Conclusions

The findings and conclusions for the ocean monitoring efforts conducted for the Point Loma outfall region during calendar year 2015 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 on June 10, 2009, became effective August 1, 2010, and expired July 31, 2015. The Monitoring and Reporting Program (MRP) in this order specifies the requirements for monitoring ambient receiving waters conditions off Point Loma, San Diego, including field sampling design and frequency, compliance criteria, types of laboratory analyses, and data analysis and reporting guidelines.

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

BACKGROUND

The City began operation of the PLWTP and original ocean outfall off Point Loma in 1963, at which time treated effluent (wastewater) was discharged approximately 3.9 km offshore at a depth of about 60 m. From 1963 to 1985, the plant operated as a primary treatment facility, removing approximately 60% of the total suspended solids (TSS) by gravity separation. The City began upgrading the process to advanced primary treatment (APT) in mid-1985, with full APT status being achieved by July 1986. This improvement involved the addition of chemical coagulation to the treatment process which increased the removal of TSS to about 75%. Since 1986, treatment has been further enhanced with the addition of several more sedimentation basins, expanded aerated grit removal, and refinements in chemical treatment. These enhancements have further reduced mass emissions from the plant. TSS removals are now consistently greater than the 80% required by the permit. Finally, the City began testing disinfection of PLWTP effluent using a sodium hypochlorite solution in September 2008 following adoption of Addendum No. 2 to previous Order No. R9-2002-0025. Partial chlorination continued throughout 2015.

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

The average daily flow of effluent through the PLOO in 2015 was 131.6 million gallons per day (mgd), ranging from a low of about 110 mgd on August 3, 2015 to a high of about 163 mgd on March 1, 2015. Overall, this represents about a 5.5% decrease from the average flow rate in 2014. TSS removal averaged about 92% in 2015, while total mass emissions for the year were approximately 5451 metric tons (see City of San Diego 2016a).

RECEIVING WATERS MONITORING

The core monitoring area off Point Loma extends from stations along the shore seaward to a depth of about 116 m, encompassing an area of approximately 184 km^2 (Figure 1.1). A total of 82 core monitoring sites surrounding the outfall are sampled for various parameters in accordance with a prescribed schedule as specified in the MRP. A summary of the results for quality assurance procedures performed in 2015 in support of these requirements can be found in City of San Diego (2016b). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the Regional Water Board and U.S. Environmental Protection Agency (USEPA) throughout the year are available online at the City's website (www.sandiego.gov/mwwd/environment/oceanmonitor.shtml).

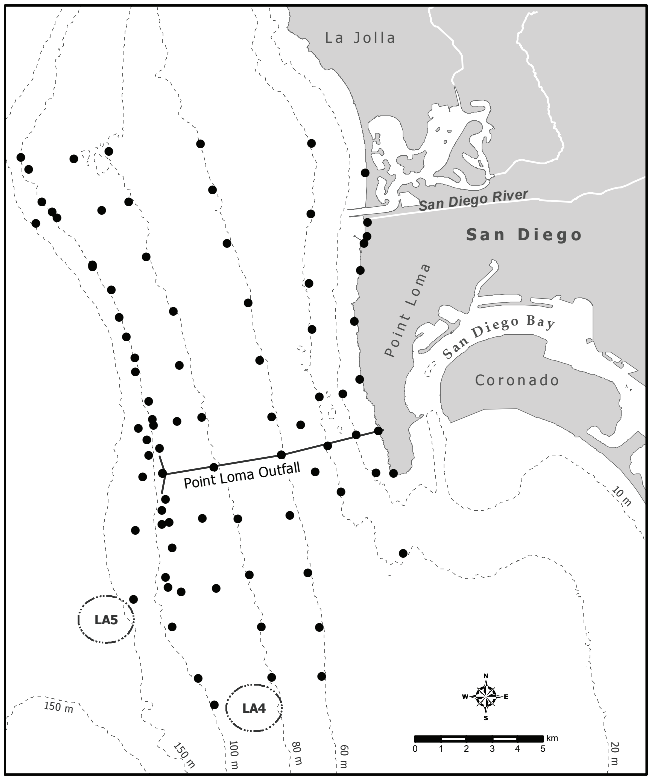

Figure 1.1
Receiving waters monitoring stations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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 "pre-discharge" monitoring 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 2014 are available in previous annual receiving waters monitoring reports (e.g., City of San Diego 2015b). 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, 2016c) or as part of larger, multi-agency surveys of the entire Southern California Bight (SCB). The latter include the 1994 Southern California Bight Pilot Project (Allen et al. 1998, Bergen et al. 1998, 2001, Schiff and Gossett 1998) and subsequent Bight'98, Bight'03, Bight'08, and Bight'13 programs in 1998, 2003, 2008, and 2013 respectively (Allen et al. 2002, 2007, 2011, Noblet et al. 2002, Ranasinghe et al. 2003, 2007, 2012, Schiff et al. 2006, 2011, Bight'13 CIA 2013, Dodder et al. 2016). These large-scale surveys are useful for characterizing the ecological health of diverse coastal areas and in distinguishing reference sites from those impacted by wastewater or storm water discharges, urban runoff, or other sources of contamination. In addition to the above activities, the City participates as a member of the Region Nine Kelp Survey Consortium to fund aerial surveys of all the major kelp beds in San Diego and Orange Counties (e.g., MBC Applied Environmental Sciences 2015).

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

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

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

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

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

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

- San Diego Kelp Forest Ecosystem Monitoring Project: This project represents continuation of a long-term commitment by the City to support this important research conducted by the Scripps Intuition of Oceanography. Overall, this work is essential to assessing the health of San Diego's kelp forests and to monitoring the effects of wastewater discharge on the local coastal ecosystem relative to other factors. The final project report for the most recent 4-year agreement (2010–2014) with SIO is available in Parnell et al. (2014), while work on a new 5-year agreement through June 2019 is currently underway.

This report presents the results of all regular core receiving waters monitoring activities conducted off Point Loma from January through December 2015. 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 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 2016); (2) the California Current System coupled with local gyres that transport distinct water masses into and out of the SCB (Lynn and Simpson 1987, Leising et al. 2014); (3) seasonal changes in local weather patterns (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Seasonality is responsible for the main stratification patterns observed in the coastal waters off San Diego and the rest of southern California (Terrill et al. 2009, Rogowski et al. 2012a, b, 2013). Relatively warm waters and a more stratified water column are typically present during the dry season from May to September, while cooler waters coupled with greater mixing and weaker stratification characterize ocean conditions during the wet season from October through April (e.g., City of San Diego 2015a). For example, winter storms bring higher winds, rain, and waves that typically result in a well-mixed, non-stratified water column (Jackson 1986). Surface waters begin to warm by late spring and are then subjected to increased surface evaporation. Once the water column becomes stratified, minimal mixing conditions typically remain throughout the summer and into early fall. Toward the end of the year, surface water cooling along with increased storm frequency returns the water column to well-mixed conditions.

Understanding changes in oceanographic conditions due to natural processes such as seasonal patterns is important since they can affect the transport and distribution of wastewater, storm water, and other types of plumes. In the Point Loma outfall region these include sediment or turbidity plumes associated with outflows from local bays, major rivers, lagoons and estuaries, discharges from storm drains or other point sources, surface runoff from local watersheds, seasonal upwelling, and variable ocean currents or eddies. For example, outflows from the San Diego River, San Diego Bay, and the Tijuana River, which are fed by 1140 km^2, 1165 km^2, and 4483 km^2 of watersheds, respectively (Project Clean Water 2012), can contribute significantly to patterns of nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009, Svejkovsky 2010, 2016).

This chapter presents analysis and interpretation of the oceanographic monitoring data collected during calendar year 2015 for the coastal waters surrounding the PLOO. The primary goals are to:

(1) summarize coastal oceanographic conditions in the region; (2) identify natural and anthropogenic sources of variability; (3) evaluate local conditions off Point Loma within the context of regional climate processes. Additionally, results of remote sensing observations (e.g., satellite imagery) are combined with measurements of physical oceanographic parameters to provide further insight on the horizontal transport of surface waters in the region (Pickard and Emery 1990, Svejkovsky 2010, 2016). 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).

MATERIALS AND METHODS

Field Sampling

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

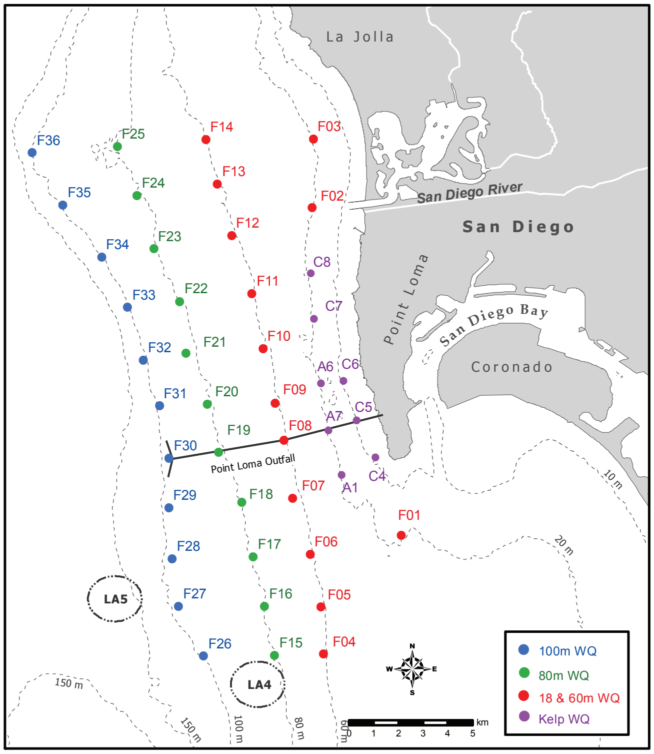

Figure 2.1
Locations of water quality (WQ) monitoring stations where CTD casts are taken around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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

Table 2.1

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

	2015 Sampling Dates			
Station Group	Feb	May	Aug	Nov
Kelp WQ	12	15	13	7
18 & 60-m WQ	9	12	10	2
80-m WQ	10	13	11	5
100-m WQ	11	14	12	6

Remote Sensing

Coastal monitoring of the Point Loma outfall region during 2015 included remote imaging analyses performed by Ocean Imaging of Solana Beach, CA. All satellite imaging data acquired during the year were made available for review and download from Ocean Imaging's website (Ocean Imaging 2016), while a separate report summarizing results for the year was also produced (Svejkovsky 2016). Several different types of satellite imagery were analyzed, including Moderate Resolution Imaging Spectroradiometer (MODIS), Thematic Mapper TM7 color/thermal, and high resolution Rapid Eye images. While these technologies differ in terms of 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 2015 were summarized as quarterly means pooled over all stations by the following depth layers: 1–20 m, 21–60 m, 61–80 m, 81–100 m. The top layer is herein referred to as surface water while the subsurface layers account for mid and bottom waters. Unless otherwise noted, analyses were performed using R (R Core Team, 2015) and various functions within the Hmisc, oce, reshape2, Rmisc, and RODBC packages (Wickham 2007, Hope 2013, Harrell et al. 2015, Kelley and Richards 2015, Ripley and Lapsley 2015). For spatial analysis of all parameters, 3-dimensional graphical views were created for each survey using Interactive Geographical Ocean Data System (IGODS) software, which interpolates data between stations along each depth contour (Ocean Software 2009).

Vertical density profiles were constructed to depict the pycnocline (i.e., depth layer where the density gradient was greatest) for each survey and to illustrate seasonal changes in water column stratification. Data for these density profiles were limited to the 100-m 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 dρ/dz is the density gradient (Mann and Lazier 1991). The depth of maximum BF was used as a proxy for the depth at which stratification was the greatest.

Additionally, time series of anomalies for temperature, salinity, and DO were calculated to evaluate regional oceanographic events in context with larger scale processes (i.e., ENSO events). These analyses were also limited to data from the 11 outfall depth stations, with all water column depths combined. Anomalies were then calculated by subtracting the average of all 25 years combined (i.e., 1991–2015) from the monthly means for each year.

RESULTS AND DISCUSSION

Oceanographic Conditions in 2015

Water Temperature and Density

Surface water temperatures (1–20 m) across the PLOO region ranged from 10.6 to 22.1°C during 2015. Subsurface water temperatures ranged from 10.2 to 20.5°C at 21–60 m, 10.2 to 16.8°C

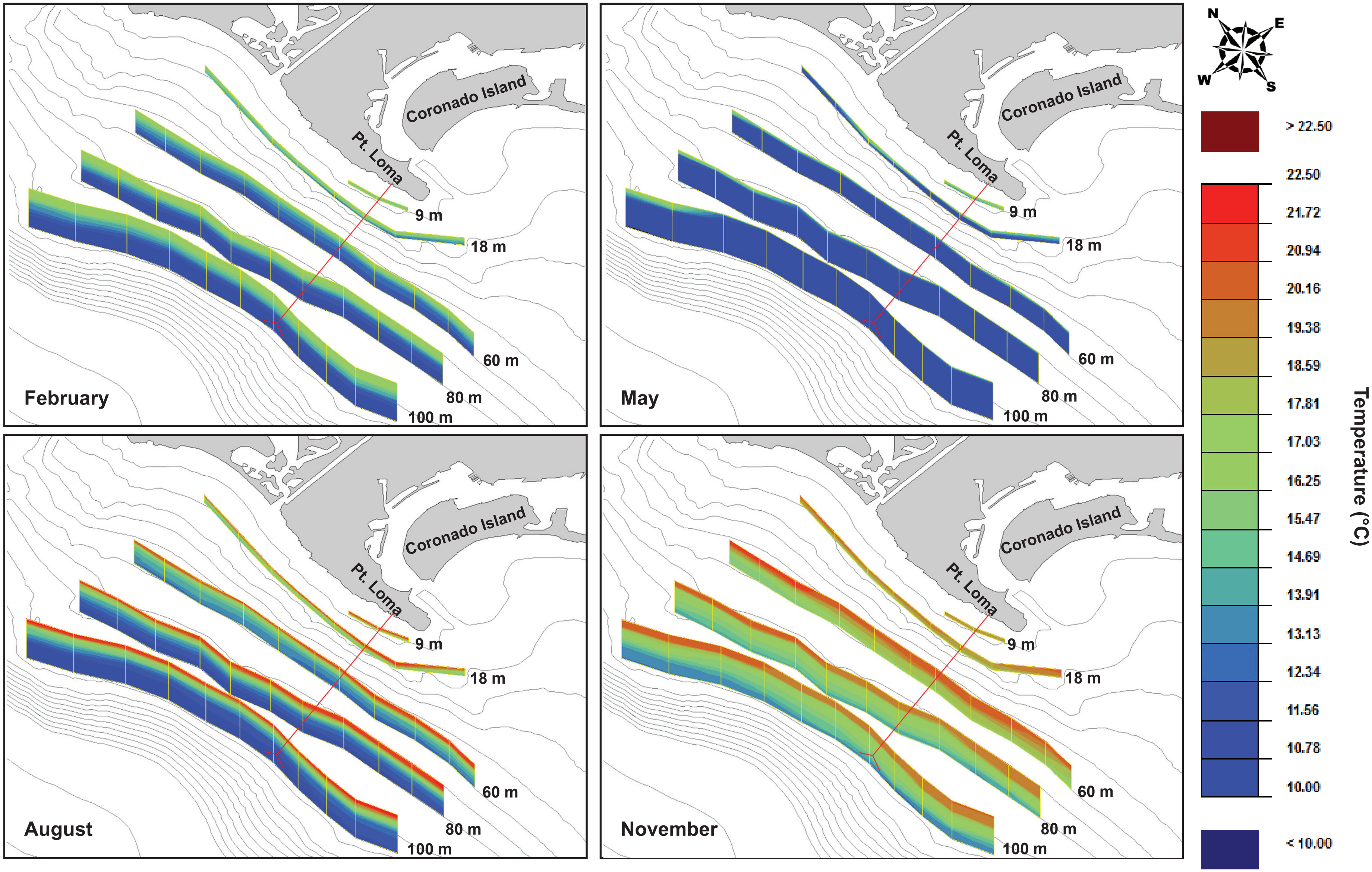

Figure 2.2
Ocean temperatures recorded in the PLOO region during 2015. Data were collected over 4–6 days during each quarterly survey.

at 61–80 m, and 10.0 to 15.2°C at 81–100 m (Appendix A.1). Ocean temperatures varied seasonally as expected throughout the year, with the maximum surface temperature occurring in August. However, warm waters persisted later into 2015, indicated by November's mean surface temperature (19.8ºC) which was ~0.4ºC higher than November 2014 (Appendix A.1, City of San Diego 2015b). Additionally, all maximum subsurface temperatures occurred in November and were several degrees warmer than during the same time frame in 2014. The warm subsurface temperatures in November were consistent with El Niño conditions (Leising et al. 2015). Thermal stratification also followed typical seasonal patterns, with the greatest difference between surface and bottom waters (11.2ºC) occurring during August (Figure 2.2, Appendix A.1).

In shallow coastal waters of southern California and elsewhere, density is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, seasonal changes in thermal stratification were mirrored by the density stratification of the water column during each survey (Figure 2.3). These vertical density profiles further demonstrated how the water column ranged from minimally stratified during February (max BF = 39 cycles^2/min^2), to stratified in May (max BF = 107 cycles^2/min^2) and August (max BF = 97 cycles^2/min^2), to moderately stratified again in November (max BF = 51 cycles^2/min^2). The values observed in February and May were greater than observed during the same months in 2014 (City of San Diego 2015b). As expected, the depth of the pycnocline also varied by season, with shallower pycnocline depths (≤12 m) in May and August corresponding to greater stratification (Figure 2.3).

Salinity

Salinities recorded in 2015 were similar to those reported previously in the PLOO region (e.g., City of San Diego 2014a, 2015b). Surface salinities ranged from 33.19 to 33.53 psu at 1–20 m. Subsurface salinities ranged from 33.09 to 33.73 psu at 21–60 m, 33.21 to 33.88 psu at 61–80 m, and 33.25 to 34.00 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 May at depths that corresponded with the lowest water temperatures for that survey (Figures 2.2, 2.4). Taken together, low temperatures and high salinity may indicate local coastal upwelling (Jackson 1986).

As in previous years, a layer of relatively low salinity water was evident at subsurface depths across the PLOO region in February, August, and November (Figure 2.4). This subsurface salinity minimum layer (SSML) was most apparent at offshore stations in November along the 80 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 related to larger-scale oceanographic processes (e.g., City of San Diego 2011–2014a, b, 2015b, c, OCSD 2015). Finally, other potential indicators of wastewater, such as elevated levels of fecal indicator bacteria or colored dissolved organic matter (CDOM), did not correspond to the SSML (see Chapter 3). Further investigation is required to determine the 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 2014a, 2015b). Surface DO ranged from 5.0 to 9.6 mg/L at 1–20 m. Subsurface DO ranged from 3.8 to 8.8 mg/L at 21–60 m, 3.2 to 7.5 mg/L at 61–80 m, and 2.8 to 6.7 mg/L at 81–100 m. Surface pH ranged from 7.8 to 8.3 at 1–20 m. Subsurface pH ranged from 7.8 to 8.3 at 21–60 m, 7.7 to 8.2 at 61–80 m, and 7.7 to 8.1 at 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).

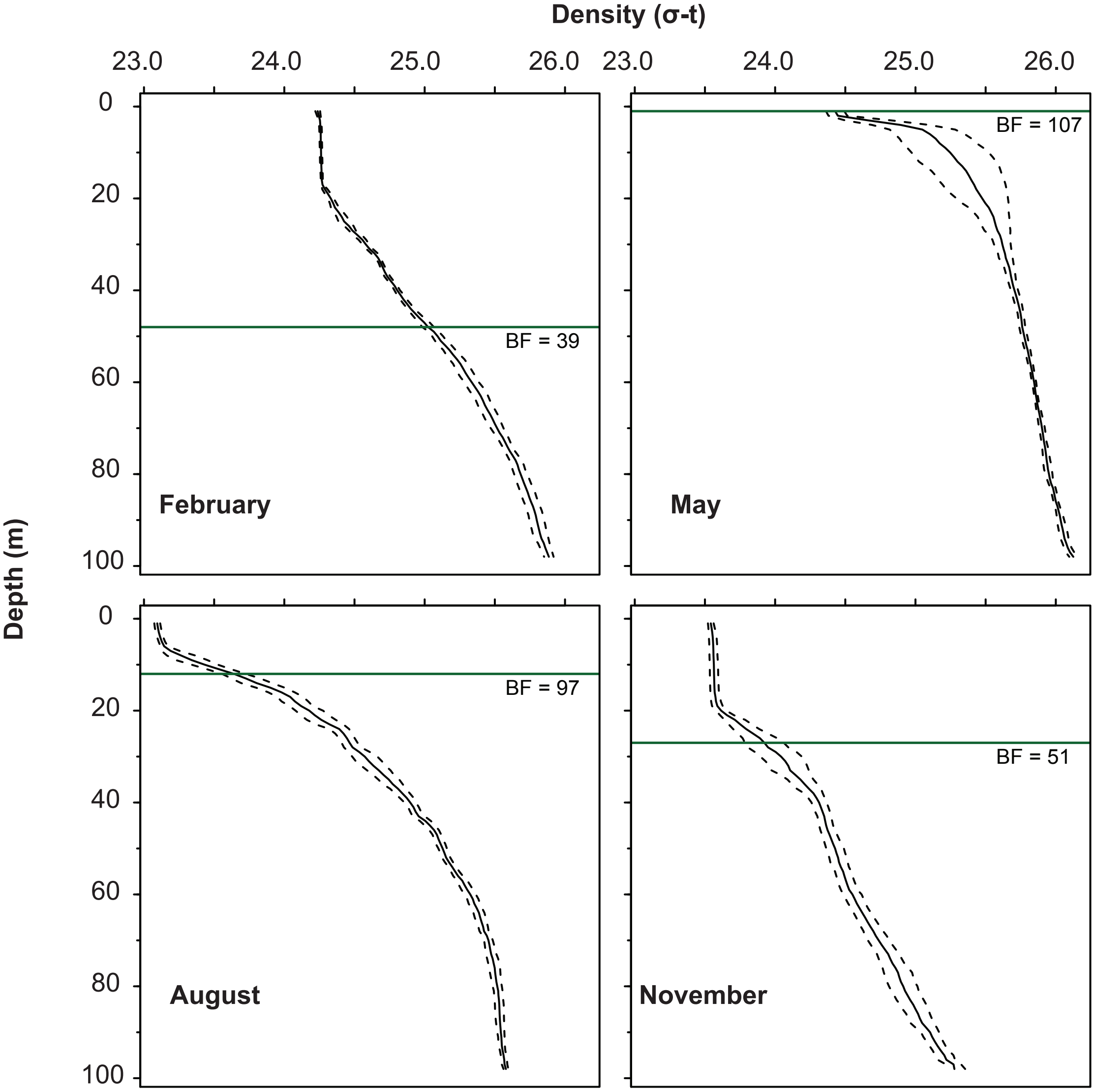

Figure 2.3

Density profiles and maximum buoyancy frequency (BF) for each quarter at outfall depth stations sampled in the PLOO region during 2015. 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.

Changes in DO and pH followed expected patterns that corresponded to seasonal fluctuations in water column stratification and phytoplankton productivity. The greatest cross-shelf variation and maximum stratification occurred during May (Appendices A.2, A.3). Low values for DO and pH that occurred at depths deeper than 20 m during May were likely due to upwelling of cold, saline, oxygen poor water moving inshore as described above for temperature and salinity. Conversely, higher DO and pH concentrations during the year were often associated with phytoplankton, evident from relatively high chlorophyll *a* concentrations.

Transmissivity

Overall, water clarity during 2015 was within historical ranges throughout the year for the Point Loma region (e.g., City of San Diego 2014a, 2015b). Surface transmissivity ranged from 42 to 93% at 1–20 m. Subsurface transmissivity ranged from 58 to 91% at 21–60 m, 55 to 91% at 61–80 m, and 62 to 91% at 81–100 m. (Appendix A.1). Water clarity at the 9-m depth contour stations tended to be lower than other stations in the region throughout the year, most likely due to coastal runoff and sediment resuspension from wave activity (see Figure 2.5,

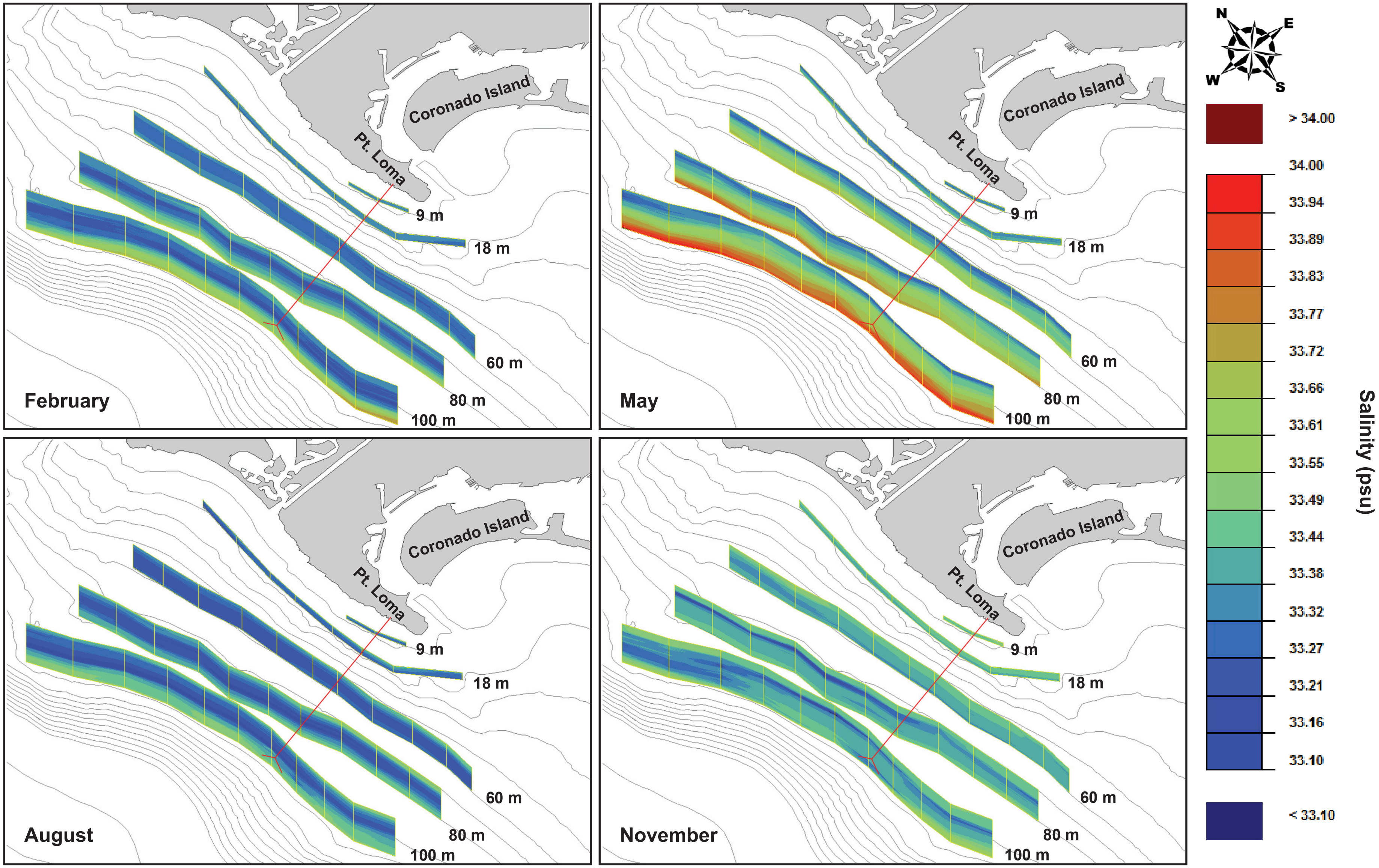

Figure 2.4
Ocean salinity recorded in the PLOO region during 2015. Data were collected over 4–6 days during each quarterly survey.

Figure 2.5
Rapid Eye image of the Point Loma region acquired February 11, 2015 (Ocean Imaging 2015) depicting increased turbidity along the coast. Bright white areas along the Point Loma coast are breaking waves.

Appendix A.4, CDIP 2016). In May, reduced transmissivity at the surface and subsurface of the 60, 80, and 100 m stations tended to co-occur with peaks in chlorophyll *a* concentrations associated with phytoplankton blooms (see following section and Appendices A.1, A.4, A.5).

Chlorophyll a

Concentrations of chlorophyll *a* off Point Loma ranged from 0.1 to 16.0 µg/L during 2015 (Appendix A.1). The highest chlorophyll *a* concentrations coincided with the upwelling events during May described in previous sections. These elevated values (>8 µg/L) of chlorophyll *a* were observed in surface waters along the 60, 80, and 100-m depth contours (Appendix A.5). Thin, patchy layers of slightly elevated chlorophyll *a* concentrations (i.e., 3–4 µg/L) also occurred at subsurface depths during February and August along the 60, 80, and 100-m depth contours. These results reflect the tendency for phytoplankton to accumulate along isopycnals where nutrients are available and light is not limiting (Lalli and Parsons 1993).

Historical Assessment of Oceanographic Conditions

A review of temperature, salinity, and DO data from all outfall depth stations sampled from 1991 through 2015 indicates how the PLOO coastal region has responded to long-term climate-related changes in the SCB (Figure 2.6). Overall, these results are consistent with large-scale temporal patterns in the California Current System (CCS) associated with ENSO, PDO and NPGO events (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, Leising et al. 2014, 2015, NOAA/NWS 2016). For example, seven major events have affected SCB coastal waters during the last two decades: (1) the 1997–98 El Niño; (2) a shift to cold ocean conditions reflected in ENSO and PDO indices between 1999 and 2002; (3) a subtle but persistent return to warm ocean conditions in the CCS that began in October 2002 and lasted through 2006; (4) the intrusion of subarctic waters into the CCS that resulted in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña in 2007 that coincided with a PDO cooling event and a return to positive NPGO values indicating an increased flow of cold, nutrient-rich water from the north; (6) development of another La Niña starting in May 2010; (7) a region-wide warming beginning in the winter of 2013/2014 when the PDO, NPGO and MEI (Multivariate ENSO Index) all changed phase preceding a strong El Niño in 2015. Temperature and salinity data for the 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). During 2015, temperatures were warmer than the long-term average in February, August and November; while temperatures were cooler in May, likely due to upwelling. The increased positive temperature anomalies in the latter half of the year are consistent with the ENSO event that developed to

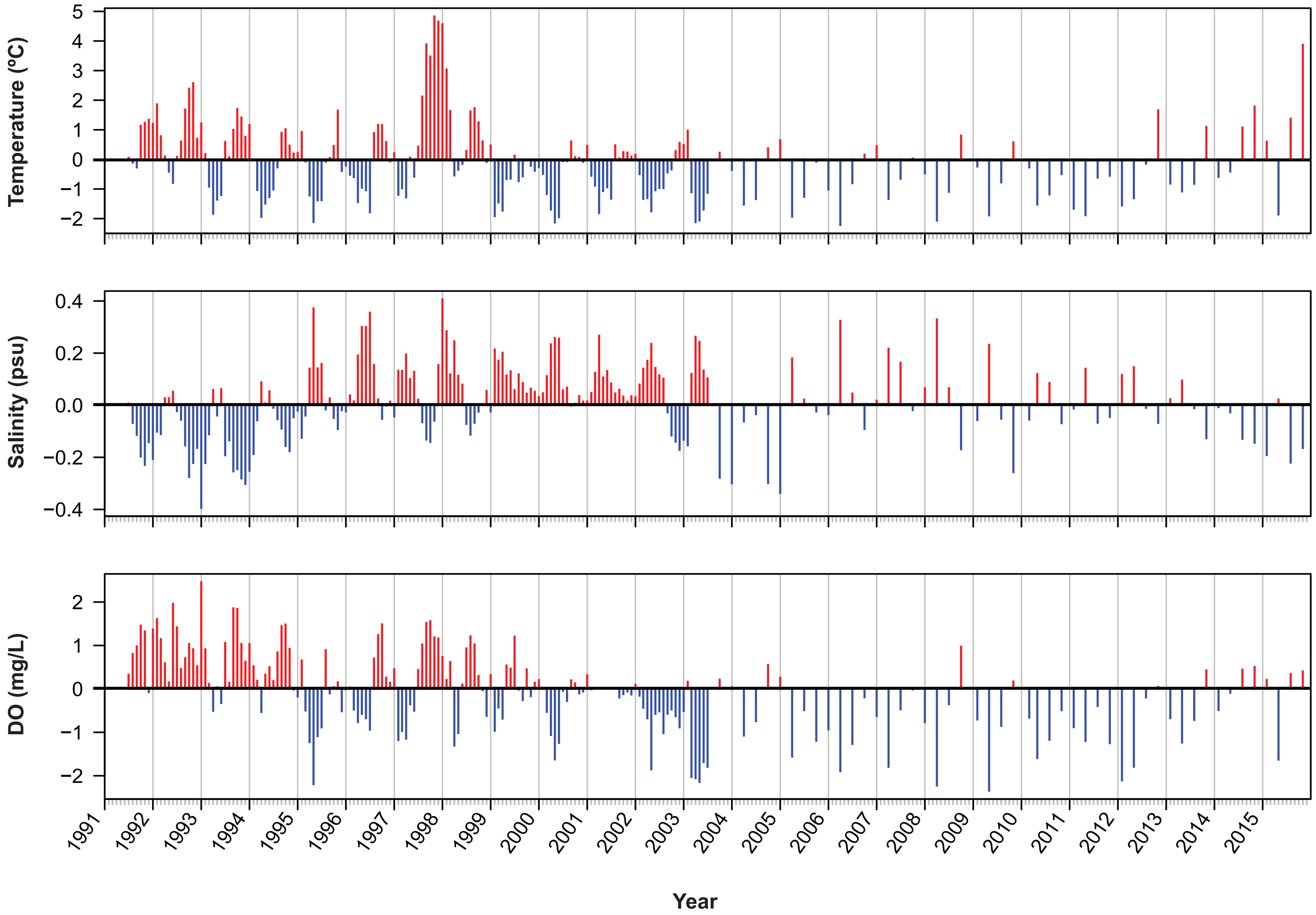

Figure 2.6
Time series of temperature, salinity, and dissolved oxygen (DO) anomalies from 1991 through 2015 at the 11 outfall depth stations sampled in the PLOO region with all depths combined.

near record level in 2015 (NOAA/NWS 2016). 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). Except for the upwelling observed in May 2015, these large negative anomalies have been mostly absent since late-2013, and conditions remained generally positive for most of 2014 and 2015.

SUMMARY

Oceanographic data collected in the Point Loma outfall region were consistent with reports from NOAA that the ENSO-positive conditions that began in 2013 persisted and strengthened through the end of 2015 (Leising et al. 2015, NOAA/NWS 2016). Conditions indicative of local coastal upwelling, such as relatively cold, dense, saline waters with low DO and pH at mid-depths and below, were most evident during May. Phytoplankton blooms, indicated by relatively high chlorophyll *a* concentrations, were also most evident during May.

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

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Chapter 3

Water Quality Compliance & Plume Dispersion

Chapter 3. Water Quality Compliance & Plume Dispersion

INTRODUCTION

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

Multiple sources of potential bacterial contamination exist in the Point Loma outfall monitoring region. Therefore, being able to separate any impacts associated with the discharge of wastewater from the PLOO or other sources of contamination is often challenging. Examples of other sources of contamination include outflows from San Diego Bay and the Tijuana and San Diego Rivers (Nezlin et al. 2007, Svejkovsky 2016). Likewise, storm water discharges and runoff from local watersheds during wet weather can also flush contaminants seaward (Noble et al. 2003, Reeves et al. 2004, Sercu et al. 2009, Griffith et al. 2010). Moreover, beach wrack (e.g., kelp, seagrass), storm drains, and beach sediments can act as reservoirs for bacteria until release into nearshore waters by returning tides, rainfall, or other disturbances (Gruber et al. 2005, Martin and Gruber 2005, Noble et al. 2006, Yamahara et al. 2007, Phillips et al. 2011). Further, the presence of birds and their droppings has been associated with bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2010).

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

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

MATERIALS AND METHODS

Field Sampling

Shore stations

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

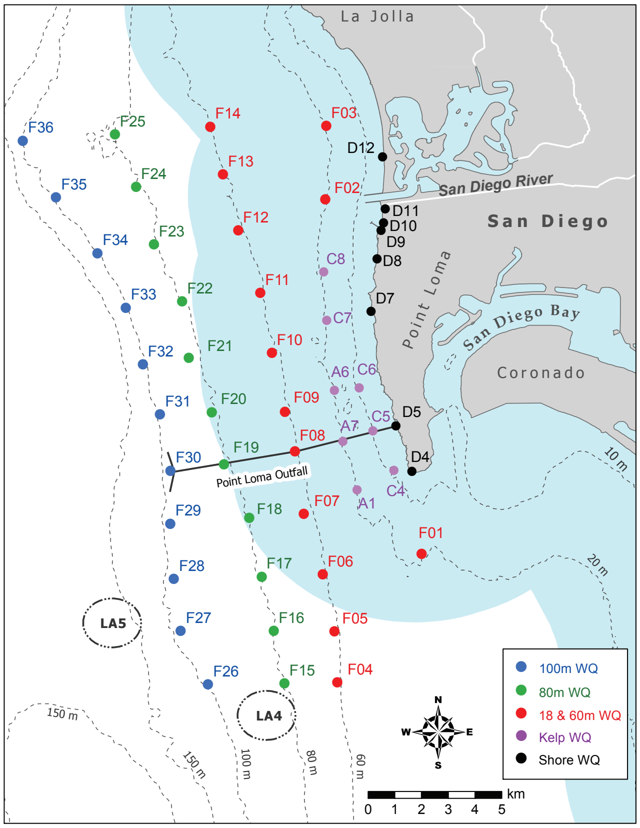

Figure 3.1
Water quality (WQ) monitoring station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program. Light blue shading represents State jurisdictional waters.

D5, D7– D12) located from Mission Beach southward to the tip of Point Loma to monitor fecal indicator bacteria (FIB) concentrations in waters adjacent to public beaches (Figure 3.1) and to evaluate compliance with Ocean Plan water contact standards (see Box 3.1). Seawater samples were collected from the surf zone at each shore station in sterile 250-mL bottles, transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML), and analyzed to determine concentrations of total coliform, fecal coliform, and *Enterococcus* bacteria. In addition, water temperature and visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. These observations were previously reported in monthly receiving waters monitoring reports submitted to the San Diego Regional Water Quality Control Board (SDRWQCB) (see City of San Diego 2015-2016).

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 stations consisted of collecting seawater samples to determine concentrations of the same three types of fecal indicator bacteria as at the shore stations. Samples were also collected to assess ammonia levels at these kelp stations according to the offshore water quality sampling schedule described below.

An additional 36 offshore stations were sampled quarterly in order to monitor *Enterococcus* levels and to estimate dispersion of the wastewater plume. These offshore "F" stations are arranged in a grid surrounding the discharge zone along or adjacent to the 18, 60, 80, and 100-m depth contours (Figure 3.1). These quarterly offshore stations were monitored during February, May, August and November in 2015 over a 3-5 day period (see Table 2.1 in Chapter 2). Monitoring for ammonia occurred at the same discrete depths where bacteria samples were collected at the 15 "F" stations located within State jurisdictional waters.

Seawater samples for bacterial analyses were collected from 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 either an array of Van Dorn bottles or a rosette sampler fitted with Niskin bottles. 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. Oceanographic data were collected from these stations using a CTD

Box 3.1

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

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

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

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

(b) *Single Sample Maximum*:

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

B. Physical Characteristics

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

C. Chemical Characteristics

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

to measure temperature, conductivity (salinity), pressure (depth), chlorophyll *a*, CDOM, dissolved oxygen (DO), pH, and light transmissivity (see Chapter 2). Measurements of CDOM were only taken at offshore "F" stations; therefore subsequent plume detection analyses were limited to these stations. Visual observations of weather, sea conditions, and human and/or animal activity were also recorded at the time of sampling. These observations were also previously reported in monthly receiving waters monitoring reports submitted to the SDRWQCB (see City of San Diego 2015-2016).

Laboratory Analyses

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

Enumeration of FIB density was performed and validated in accordance with USEPA (Bordner et al. 1978, USEPA 2006) and APHA (2005) guidelines. Plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values when calculating means and in determining compliance with Ocean Plan standards. Quality assurance tests were performed routinely on seawater samples to ensure that analyses and sampling variability did not exceed acceptable

Table 3.1

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

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

limits. Bacteriological laboratory and field duplicate samples were processed according to method requirements to measure analyst precision and variability between samples, respectively. Results of these procedures were reported under separate cover (City of San Diego 2016).

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

Data Analyses

Bacteriology

FIB densities (total coliforms, fecal coliforms, *Enterococcus*) were summarized as monthly means for each shore station and by depth contour and month for the kelp bed stations. Bacterial and ammonia concentrations were summarized by quarter for the offshore stations. In order to assess temporal and spatial trends, the data were summarized as the number of samples in which FIB concentrations exceeded benchmark levels. For this report, the single sample maximum standards defined in the Ocean Plan for total coliforms, fecal coliforms, and *Enterococcus* were used as benchmarks to distinguish elevated FIB values (see Box 3.1 and SWRCB 2012). Bacterial densities were compared to rainfall data from Lindbergh Field, San Diego, CA (see NOAA 2016). Chi-squared Tests (χ^2) were conducted to determine if the frequency of samples with elevated FIB counts at the shore stations differed between wet (October–April) and dry (May–September) seasons and to determine if elevated FIB counts at kelp bed stations differed before and after the completion of the outfall extension over 20 years ago. Additional χ^2 tests were conducted to determine whether elevated FIB counts differed at outfall stations (i.e., F29, F30, F31) compared to other stations along the 100-m contour as well as whether elevated counts differed at these stations before and after the initiation of effluent chlorination in 2008. Satellite images of the San Diego coastal region were provided by Ocean Imaging of Solana Beach, California (Svejkovsky 2016) and used to aid in the analysis and interpretation of water quality data (see Chapter 2 for remote sensing details). Finally, compliance with Ocean Plan water contact standards was summarized as the number of times per sampling period that each shore, kelp, and offshore station within State jurisdictional waters exceeded the various standards. These analyses were performed using R (R Core Team, 2015) and various functions within the Hmisc, psych, quantreg, reshape2, R.oo and RODBC packages (Bengtsson 2003, Wickham 2007, Harrell et al. 2015, Revelle 2015, Ripley and Lapsley 2015, Koenker 2016).

Wastewater Plume Detection and Out-of-Range Calculations

The potential presence or absence of the wastewater plume was determined at each station using a combination of oceanographic parameters (i.e., detection criteria). If present, a strong alongshore CDOM signal due to coastal runoff could interfere with plume detection. However, pre-screening of CDOM data revealed only minimal interference along the 18-m and 60-m depth contours within the PLOO region during November (Appendix B.1), and therefore all 36 offshore "F" stations were 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 2010–2015b, Rogowski et al. 2012a, b, 2013). Water column stratification and pycnocline depth were quantified using calculations of buoyancy frequency (BF, cycles^2/min^2) for each quarterly survey (see Chapter 2). For the purposes of the plume dispersion analysis, BF calculations included data from those stations that would be most likely to demonstrate the potential plume trapping depth (i.e., all stations located along the 18, 60, 80, and 100-m depth contours). If the water column was stratified (i.e., maximum BF > 32 cycles^2/min^2), subsequent analyses were limited to depths below the pycnocline. Identification of a potential plume signal at a station was based on: (1) high CDOM; (2) low chlorophyll *a*; (3) visual interpretation of the water column profile. Detection thresholds were adaptively set for each quarterly survey according to the following criteria: CDOM exceeding the 95th percentile and chlorophyll *a* below the 40th percentile. The threshold for chlorophyll *a* was incorporated to exclude CDOM derived from marine phytoplankton (Nelson et al. 1998, Rochelle-Newall and Fisher 2002, Romera-Castillo et al. 2010). These analyses were performed using R (R Core Team, 2015) and various functions within the oce, reshape2, Rmisc, and RODBC packages (Wickham 2007, Hope 2013, Kelley and Richards 2015, Ripley and Lapsley 2015). It should be noted that these thresholds are based on regional observations of ocean properties off Point Loma and are thus constrained to use within the region. Finally, water column profiles were visually interpreted to remove stations with spurious signals (e.g., CDOM signals near the sea floor that were likely caused by resuspension of sediments). Exclusion of stations using the chlorophyll *a* criterion was confirmed as part of the visual interpretation of the profiles.

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

RESULTS AND DISCUSSION

Bacteriological Compliance and Distribution

Shore stations

During 2015, compliance at the eight shore stations in the PLOO region was 100% for the 30-day total coliform and fecal coliform geometric mean standards, while compliance with the 30-day *Enterococcus* geometric mean standard was 98–100%. Compliance with the single sample maximum (SSM) standards was 98–100% for total coliforms, fecal coliforms, and the fecal:total coliform (FTR) criterion, and 83–100% for *Enterococcus* (Figure 3.2). Sewage-like odors were rarely observed along the shore during the year (City of San Diego 2015-2016). Monthly mean FIB densities ranged from 2 to 3052 CFU/100 mL for total coliforms, 2 to 522 CFU/100 mL for fecal coliforms, and 2 to 569 CFU/100 mL for *Enterococcus* (Appendix B.3). The highest mean values for total and fecal coliforms occurred at station D11 in October, while the highest mean value for *Enterococcus* also occurred in October at station D8. Of the 495 shore samples collected during the year (not including resamples), only 18 (~3.6%) had elevated FIB (Table 3.2, Appendix B.4). This represents a slight increase

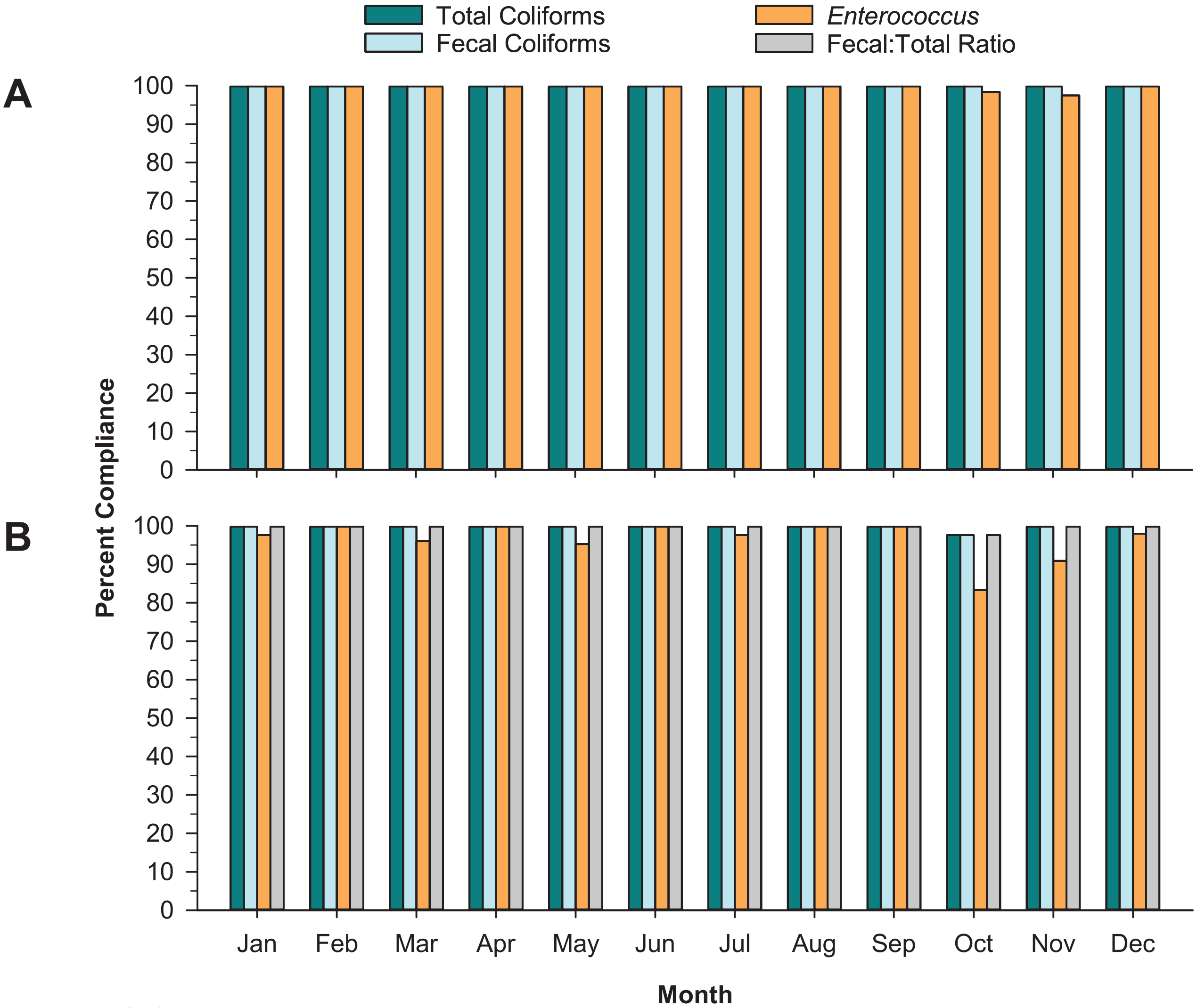

Figure 3.2
Compliance rates for (A) the three geometric mean and (B) the four single sample maximum water contact standards from PLOO shore stations during 2015.

from the 11 samples with elevated FIB in 2014 and likely reflects higher rainfall, which totaled 9.92 inches in 2015 in contrast to 7.78 inches in 2014 (City of San Diego 2015b). Despite the unusually high amount of rain that fell during the dry season in 2015 (5.40 inches), a majority (85%) of the shore samples with elevated FIB were collected in the wet season when rainfall totaled 4.5 inches (Table 3.2). This general relationship between rainfall and elevated bacterial levels at the shore stations has been evident from water quality monitoring in the Point Loma outfall region since 1991 (Figure 3.3). Historical analysis indicates that the occurrence of a sample with elevated FIB is significantly more likely to occur during the wet season than during the dry season (6% versus 2%, respectively; n = 8661, $\chi^2 = 103.53$, $p < 0.0001$).

Kelp bed stations

During 2015, compliance at the eight kelp bed stations was 100% for all 30-day geometric mean and single sample maximum (SSM) water contact standards. These results are slightly higher than last year for the *Enterococcus* and FTR criterion standards, and are the same as 2013 when compliance rates were also 100% for all standards (City of San Diego 2014, 2015b). Monthly mean FIB densities at the kelp stations were lower than those along the shore, ranging from 2 to 28 CFU/100 mL for total coliforms, and 2 to 3 CFU/100 mL for

Table 3.2

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

	Seasons		
Station	**Wet**	**Dry**	**% Wet**
D12	4	0	100
D11	2	2	50
D10	3	0	100
D9	1	0	100
D8	3	0	100
D7	0	0	—
D5	2	1	67
D4	0	0	—
Rain (in)	4.52	5.40	46
Total eFIB	15	3	83
Total Samples	295	200	60

both fecal coliforms and *Enterococcus* throughout the year (Appendix B.5). This low incidence of elevated FIB is consistent with water quality results dating back to 1994 after the outfall was extended to its present discharge site (Figure 3.4). In contrast, the likelihood of encountering elevated FIB concentrations was significantly higher at the kelp bed stations prior to the outfall extension (13% versus 4%; n = 42,438, $\chi^2 = 3491.7$, $p < 0.0001$). No relationship between rainfall and elevated FIB levels has been evident at these stations over the years, as the proportion of samples with high FIBs is similar between wet and dry seasons (~4% for both, n = 42,438, $\chi^2 = 4.93$, $p = 0.026$). No signs of wastewater such as sewage-like odors were observed at any of the kelp stations in 2015 (City of San Diego 2015-2016). Satellite imagery showed that rain runoff was typically restricted to the areas inside and just outside of the kelp forest during the year (Svejkovsky 2016).

Offshore stations

The maximum concentration of *Enterococcus* at the offshore stations was 580 CFU/100 mL in 2015 (Appendix B.4). Eighteen of 564 offshore samples (~3%) had elevated *Enterococcus* densities >104 CFU/100 mL. However, all of these elevated samples were from 60 m or deeper and the majority (94%) were from stations located along the 80 or 100-m depth contours (Figure 3.5). Only six of the exceedances occurred in State jurisdictional waters (i.e., stations F11, F18, F19, and F20) resulting in

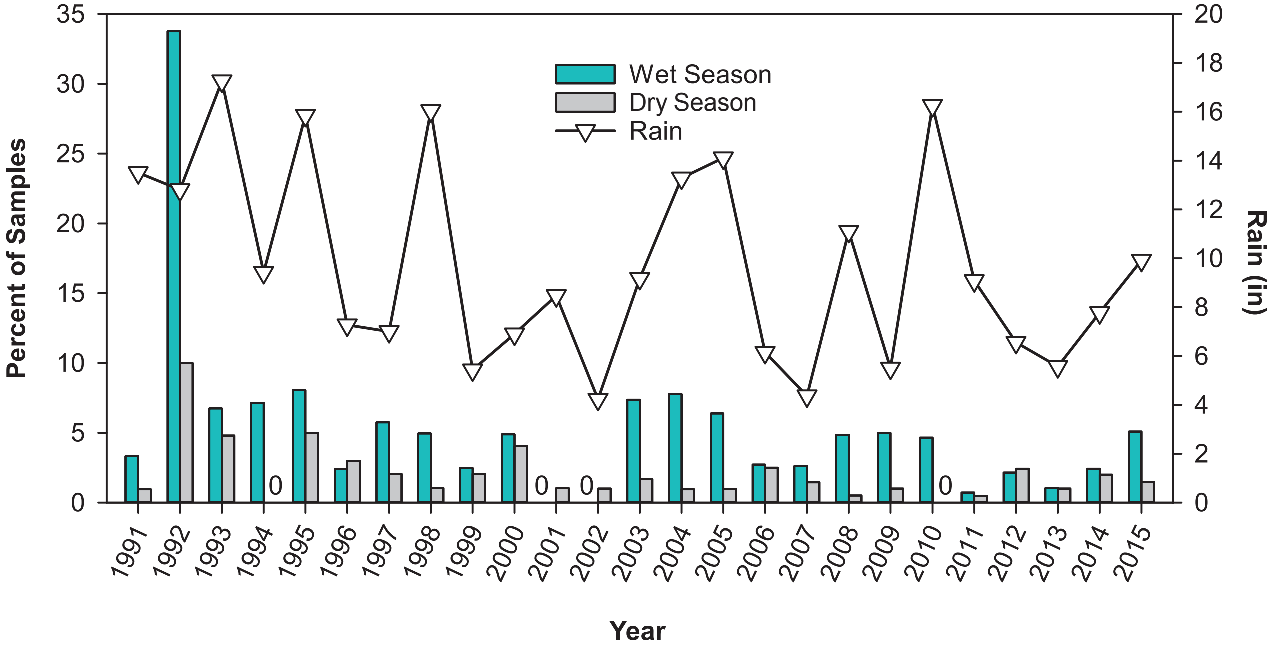

Figure 3.3

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 2015. Rain data are from Lindbergh Field, San Diego, CA.

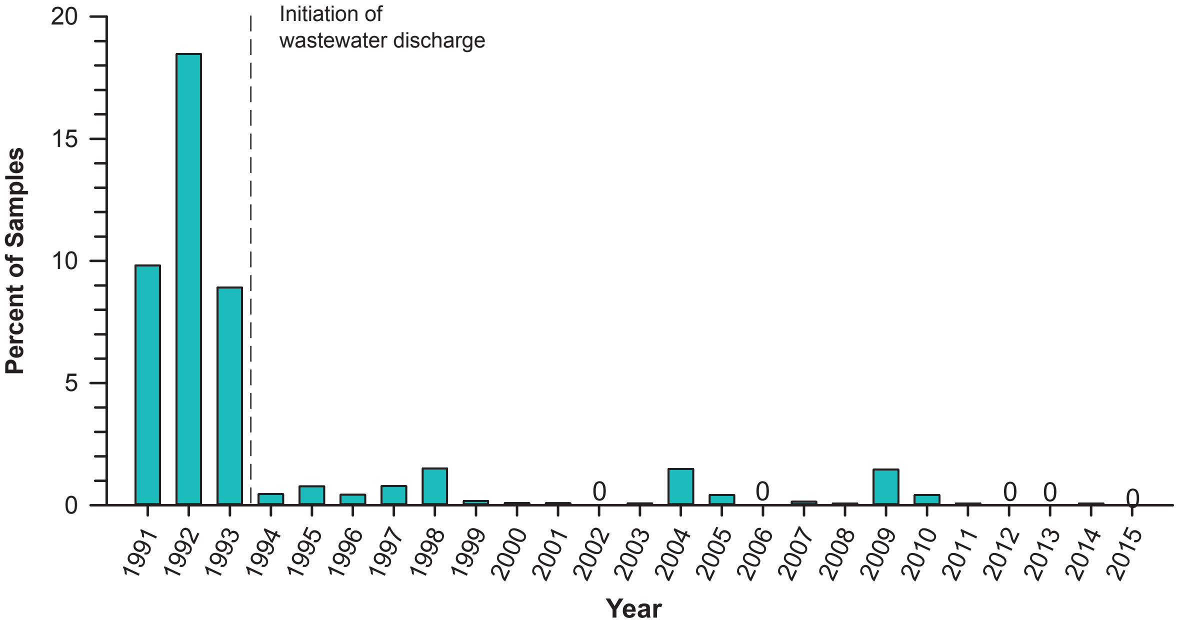

Figure 3.4
Percent of samples with elevated FIB densities at PLOO kelp bed stations from 1991 through 2015.

~97% compliance with the *Enterococcus* SSM standard for these stations in 2015. These results suggest that the wastewater plume from the PLOO was restricted to relatively deep, offshore waters throughout the year. Additionally, there were no signs of wastewater at any of these 36 stations based on visual observations of the surface (City of San Diego 2015-2016). This conclusion is consistent with remote sensing observations that provided no evidence of the plume reaching surface waters in 2015 (Svejkovsky 2016). These findings are also consistent with historical results, which revealed that < 1% of the samples collected from 1991 through 2015 from depths ≤ 25 m at the stations located along the 100-m discharge depth contour had elevated levels of *Enterococcus* (Figure 3.6A). Over this time period, detection of elevated FIB was significantly more likely at the three stations located near the discharge zone (i.e., F29, F30, F31) than at any other 100-m site (15% versus 5%, respectively; n = 5460, $\chi^2 = 171.37$, $p < 0.0001$) (Figure 3.6B). Following the initiation of partial chlorination in 2008 (City of San Diego 2009), the number of samples with elevated *Enterococcus* also dropped significantly at these three stations (17% before versus 8% after, n = 1841, $\chi^2 = 18.35$, $p < 0.0001$), as well as at the other 100-m stations (6% before versus < 1% after; n = 3619, $\chi^2 = 46.05$, $p < 0.0001$) (Figure 3.6C).

Ammonia

Ammonia was detected in ~13% of the 288 samples collected during 2015. This parameter was found at 15 of the 23 stations sampled and was recorded during each of the quarterly surveys with no concentration greater than 0.02 mg/L (Table 3.3, Figure 3.7). These levels are an order of magnitude lower than the water quality objectives for ammonia defined in the Ocean Plan (i.e., instant maximum of 6.0 mg/L, daily maximum of 2.4 mg/L; SWRCB 2012). Ammonia is considered a possible wastewater plume indicator (e.g., LACSD 2014), however only one sample collected from station F19 at a depth of 80 m during May had a detectable level of ammonia that coincided with an elevated density of *Enterococcus*. Due to high levels of CDOM, there was evidence of a potential plume signature at the time this sample was collected, however there were no physical parameters (transmissivity, DO, and pH) with out-of-range values (see following section).

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 2015.

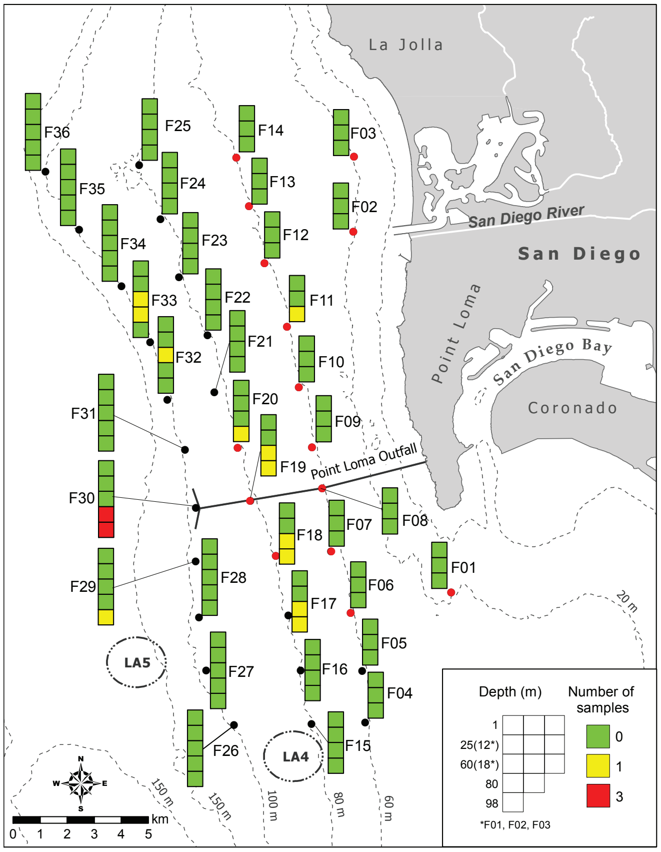

Figure 3.5

Distribution of samples with elevated *Enterococcus* collected at PLOO offshore stations during 2015. Data are number of samples that exceeded 104 CFU/100 mL. Red circles indicate stations sampled within State jurisdictional waters.

Based on the criteria described in the Materials and Methods section, potential evidence of a plume signal was detected a total of 31 times during the year from 23 different stations, while 12–25 stations were identified as reference sites during each quarterly survey (Table 3.4, Figure 3.8, Appendix B.2). About 26% of possible plume detections (n=8) occurred at the three stations located closest to the outfall (F29, F30, F31), equating to a detection rate of 67% at these nearfield sites over the year. Another 34% of the possible detections (n=12) occurred at stations located up to 8 km south of the outfall along the 80 and/or 100-m depth contours in February and May, and at stations located up to 12.5 km north of the outfall along the 100-m depth contour in August. The remaining potential plume signals may be spurious due to their distance from the outfall and/or proximity to other known sources of organic matter. For example, stations F4 and F6 are located within the possible influence of San Diego Bay tidal pumping, while stations F11–F14 are located within the possible influence of San Diego River outflows. Overall, the variation in plume dispersion observed off Point Loma in 2015 was similar to flow-mediated dispersal patterns reported previously for the region (Rogowski et al. 2012a, b, 2013).

The width and rise height of the PLOO wastewater plume varied between stations throughout the year (Appendix B.6). Despite fluctuations in the depth of the pycnocline, the plume remained below 43 m even during periods of weak water column stratification (Appendix B.7). This finding is in agreement with satellite imagery observations that showed no visual evidence of the plume surfacing during 2015 (Svejkovsky 2016). Eleven of the potential plume detections corresponded with elevated *Enterococcus* densities. These samples were all collected from ≥60 m depth (see Appendix B.4).

The effects of the PLOO wastewater plume on the three physical water quality indicators mentioned above were calculated for each station and depth where a plume signal was indicated. For each of these detections, mean values for natural light (% transmissivity), DO, and pH within the estimated plume were compared to thresholds within similar depths from non-plume reference stations (Appendix B.6). Of the 31 potential plume signals that occurred during 2015, a total of 14 out-of-range (OOR) events were identified, which consisted of 13 OOR events for natural light at various stations throughout the year, and 1 OOR event for DO (Table 3.4, Appendices B.7, B.8, B.9, and B.10). There were no OOR events for pH. Seven of the 14 OOR events, all for natural light, occurred at stations located within State jurisdictional waters where Ocean Plan compliance standards apply (i.e., stations F06, F08-F11, F13, F18).

SUMMARY

Water quality conditions in the Point Loma outfall region were excellent during 2015. Overall compliance with Ocean Plan water contact standards was >99%,

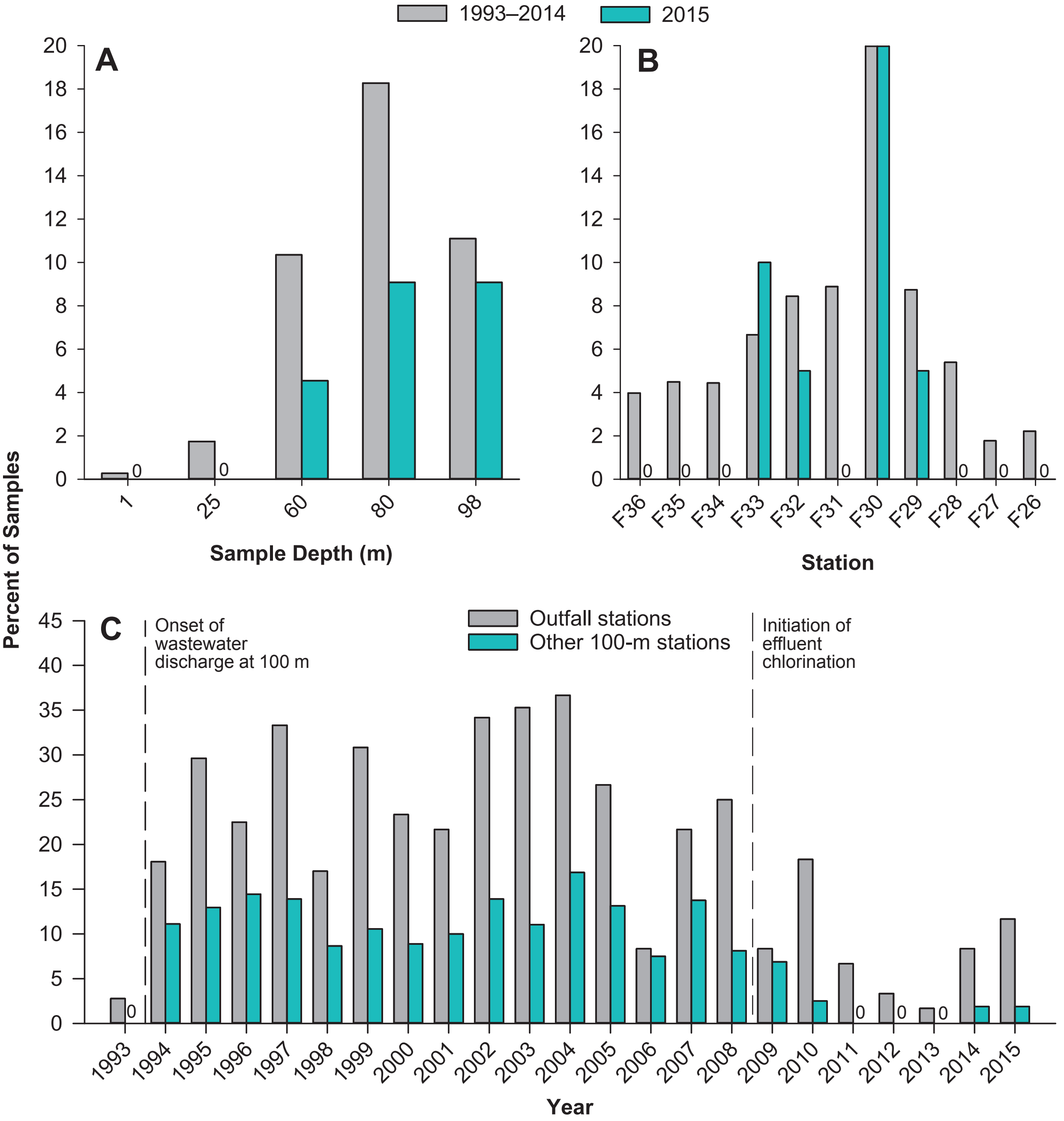

Figure 3.6
Percent of samples collected from PLOO 100-m offshore stations with elevated *Enterococcus* densities. Samples from 2015 are compared to those collected from 1993 through 2014 by (A) sampling depth, (B) stations listed north to south from left to right, and (C) year.

which was similar to that observed during the past several years (City of San Diego 2010–2015b). In addition, there was no evidence that wastewater discharged into the ocean via the PLOO reached inshore of the 60-m depth contour stations located at least 3.2 km offshore. Elevated FIB densities were detected in just 18 samples collected from 6 of the 8 shoreline stations sampled during the year, while no elevated bacterial counts were detected from 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 2009–2015b). 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).

Table 3.3

Summary of ammonia concentrations in samples collected from the 23 PLOO kelp bed and offshore stations located within State jurisdictional waters during 2015. Data include the number of samples per month (n) and detection rate, as well as the minimum, maximum, and mean[a] detected concentrations for each month. The method detection limit for ammonia = 0.01 mg/L; nd = not detected.

	Feb	May	Aug	Nov
9-m Depth Contour (n = 9)				
Detection Rate (%)	0	33	22	0
Min	—	nd	nd	—
Max	—	0.01	0.01	—
Mean	—	0.01	0.01	—
18-m Depth Contour (n = 24)				
Detection Rate (%)	8	21	13	21
Min	nd	nd	nd	nd
Max	0.01	0.02	0.02	0.01
Mean	0.01	0.02	0.01	0.01
60-m Depth Contour (n = 27)				
Detection Rate (%)	0	15	0	11
Min	—	nd	—	nd
Max	—	0.01	—	0.02
Mean	—	0.01	—	0.01
80-m Depth Contour (n = 12)				
Detection Rate (%)	25	25	33	8
Min	nd	nd	nd	nd
Max	0.02	0.02	0.02	0.01
Mean	0.01	0.01	0.01	0.01

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

There were few instances of elevated FIB concentrations at the 36 offshore water quality stations sampled in the PLOO region during 2015. Sixty-one percent of the samples with elevated levels of *Enterococcus* were collected from a depth of 60 m or greater from stations located along the 100-m depth contour. Only 3% of the samples collected from stations located within State jurisdictional waters had elevated *Enterococcus* densities. Additionally, detection of the PLOO wastewater plume and its effects on physical water quality indicators was low during the year.

These results are consistent with previous studies that have indicated the PLOO wastefield typically remains offshore and submerged in deep waters ever since the extension of the outfall was completed in late 1993 (e.g., City of San Diego 2007–2015a, 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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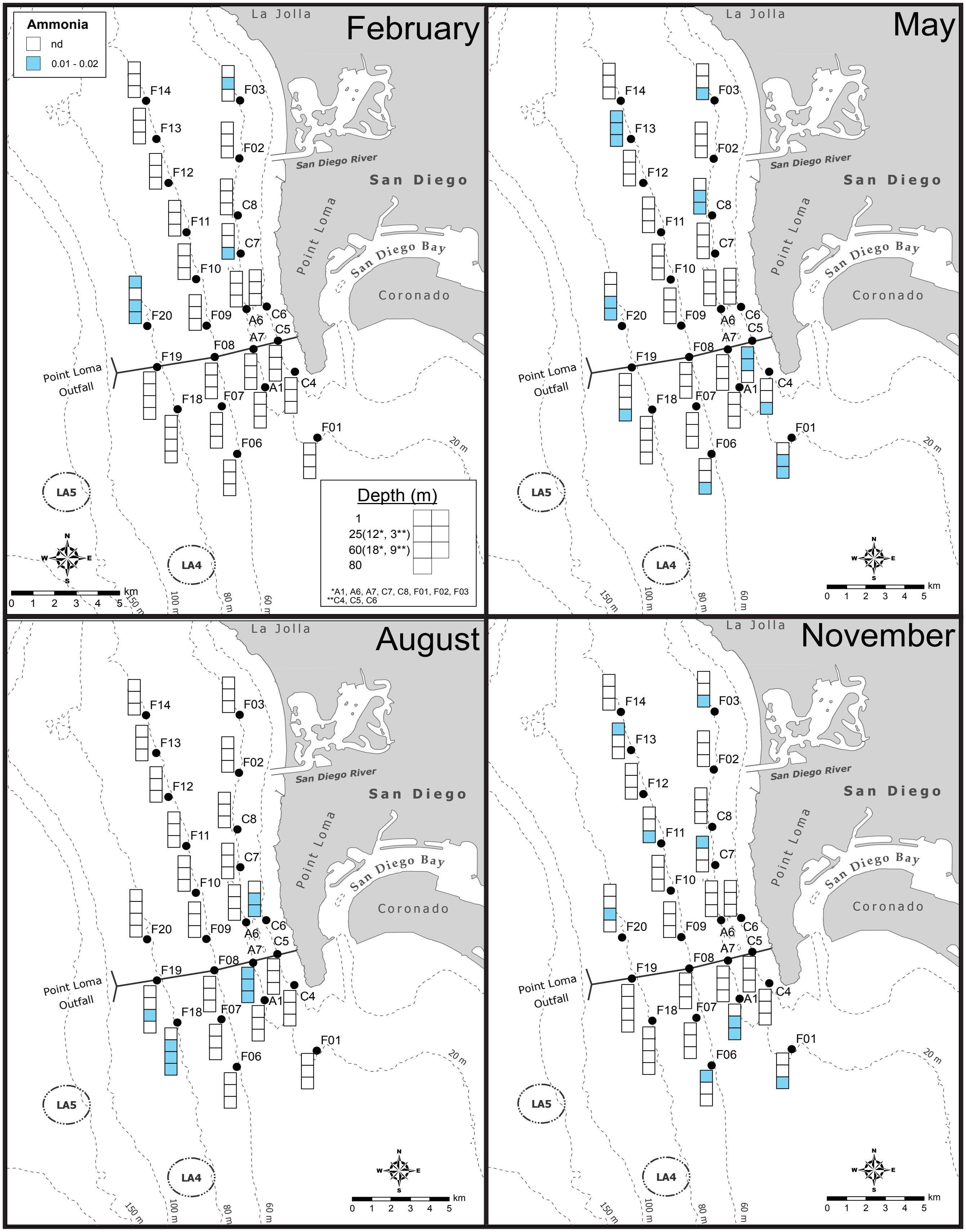

Figure 3.7
Distribution of ammonia (as nitrogen, mg/L) in seawater samples collected during the PLOO quarterly surveys in 2015; nd = not detected.

Table 3.4

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

Month	Potential Plume Detections	Out of Range DO	Out of Range pH	Out of Range XMS	Stations
Feb	11	0	0	6	**F08** [b], **F09** [b], **F10** [b], **F11** [b], **F13** [b], **F20**, F26, F27 F28, F29, F30 [b]
May	7	1	0	3	F17 [b], **F18** [b], **F19**, F27, F28, F29, F30 [a,b]
Aug	6	0	0	0	F30, F31, F32, F33, F34, F36
Nov	7	0	0	4	F04 [b], **F06** [b], **F12**, **F13**, **F14**, F29 [b], F30 [b]
Detection Rate (%)	22.2	0.6	0.0	9.0	
Total Count	31	1	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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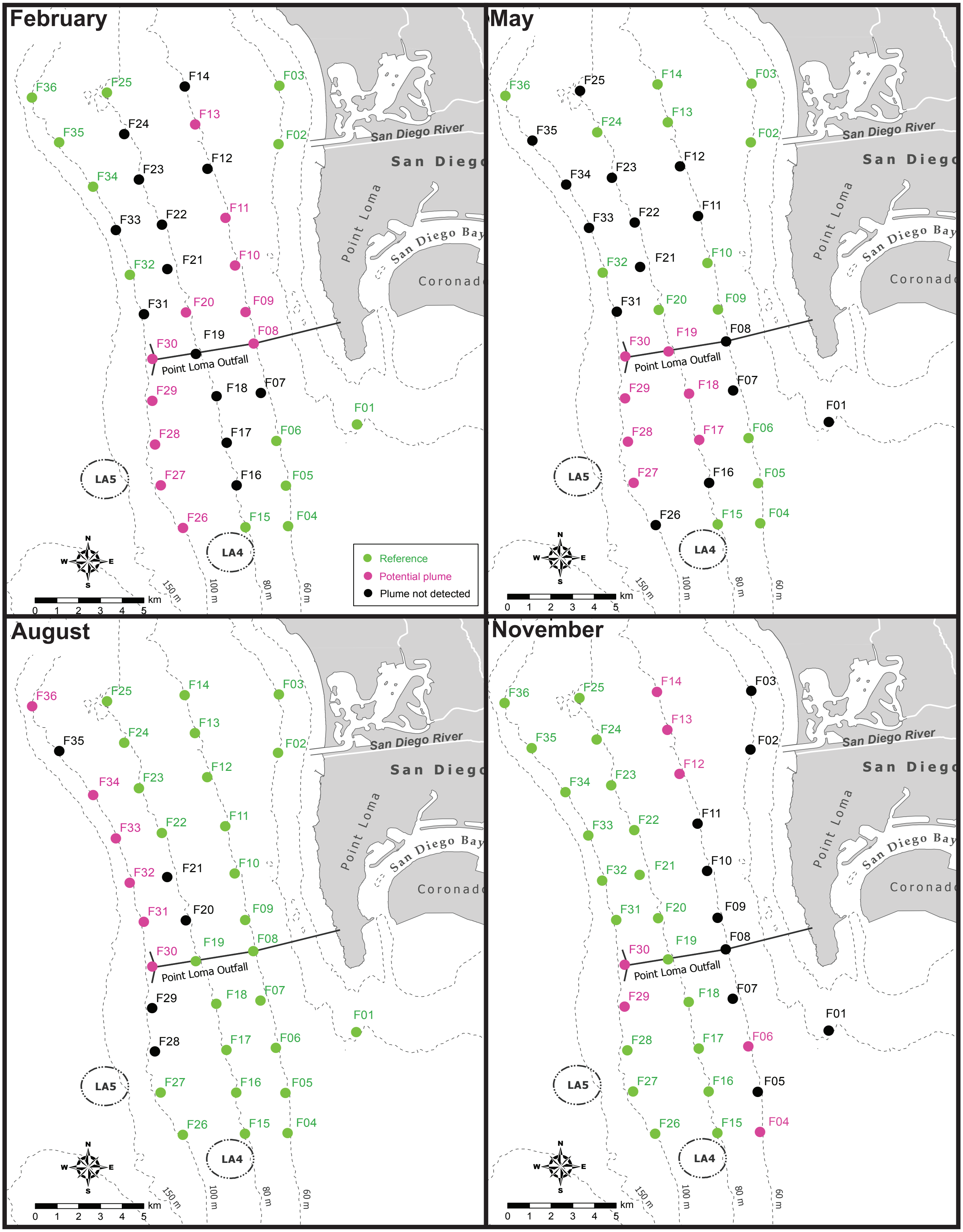

Figure 3.8
Distribution of stations where potential wastewater plume was detected and those used as reference stations for water quality compliance calculations during the PLOO quarterly surveys in 2015.

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Chapter 4
Sedimentation Conditions

Chapter 4. Sediment Conditions

Introduction

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

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

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

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

Materials and Methods

Field Sampling

Sediment samples were collected at 22 monitoring stations in the PLOO region during winter (January) and summer (July) of 2015 (Figure 4.1). These stations are distributed along or adjacent to three main depth contours, with the primary core stations located along the 98-m contour (i.e., outfall discharge depth), and the secondary core stations located along the 88-m or 116-m contours. These 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 three stations located closest (i.e., within 200 m) to the boundary of the zone of initial dilution (ZID) are considered to represent near-ZID conditions (i.e., stations E11, E14, E17).

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

Laboratory Analyses

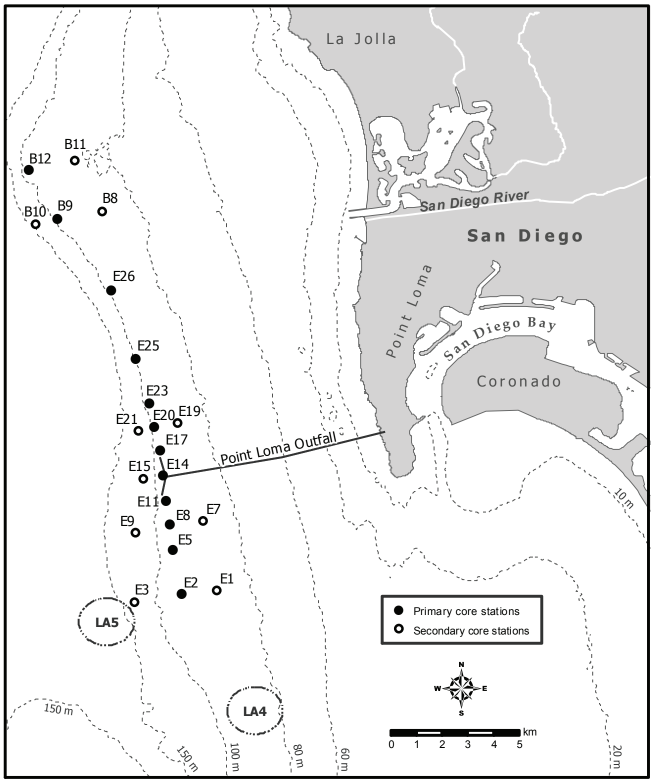


Figure 4.1
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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

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

Data Analyses

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

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

Results

Particle Size Distribution

Ocean sediments sampled off Point Loma were composed primarily of fine particles (i.e., silt and clay; also referred to as percent fines) and fine sands during 2015. Percent fines ranged from 12 to 64% per sample, while fine sands ranged from 30 to 85%, medium-coarse sands ranged from <1 to 32%, and coarse particles ranged from 0 to 17% per sample (Table 4.1, Figure 4.2). Coarser particles often included shell hash, rock, black sand, and/or gravel (Appendix C.4). Particle size composition varied within sites between the winter and summer surveys by as much as 14% per size fraction, with the greatest intra-station differences occurring at southern stations E1, E2, E3, and E9, and northern stations B10 and B11. Overall, there were no spatial patterns in sediment composition relative to the PLOO discharge site (Figure 4.2). Sediments collected from near-ZID stations ranged from 32 to 38% fines and 61 to 68% fine sands per sample, while sediments >200 m from the outfall ranged from 12 to 64% fines and 30 to 85% fine sands per sample (Appendix C.4). These results are consistent with the findings from long term analyses reported previously (City of San Diego 2014, 2015a, b).

Classification (cluster) analysis of the 2015 particle size sub-fraction data discriminated seven main cluster groups (cluster groups 1–7) (Figure 4.3). According to SIMPER results, these seven groups were primarily distinguished by proportions of fines, very fine sand, and fine sand. The main cluster group (group 6) included 64% of the sediment samples collected during 2015, including all of the samples from near-ZID stations E11, E14, and E17. These sediments had the third largest proportion of percent fines

Table 4.1

Summary of particle sizes and chemistry concentrations in sediments from PLOO benthic stations sampled during 2015. Data include the detection rate (DR), mean, minimum, and maximum values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1991–1993) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold; na = not available; nd = not detected.

	2015 Summary[a]				Pre-discharge		
Parameter	**DR (%)**	**Mean**	**Min**	**Max**	**Max**	**ERL[b]**	**ERM[b]**
Particle Size							
Coarse Particles(%)	25	1.4	0	17.4	26.4	na	na
Med-Coarse Sands (%)	100	5.1	0.1	32.3	41.6	na	na
Fine sands (%)	100	53.1	29.5	85.1	72.6	na	na
Fines (%)	100	40.4	12.0	64.0	74.4	na	na
Organic Indicators							
BOD (ppm)	100	261	100	456	656	na	na
Sulfides (ppm)	100	7.23	1.16	76.50	20.0	na	na
TN (% weight)	100	0.049	0.009	0.089	0.074	na	na
TOC (% weight)	100	0.69	0.39	3.36	1.24	na	na
TVS (% weight)	100	2.34	1.70	4.20	4.0	na	na
Trace Metals (*ppm*)							
Aluminum	100	9241	6200	12,600	na	na	na
Antimony	89	0.7	nd	1.7	6.0	na	na
Arsenic	100	2.73	1.89	5.77	5.6	8.2	70
Barium	100	40.11	22.80	67.90	na	na	na
Beryllium	50	0.20	nd	0.33	2.01	na	na
Cadmium	30	0.08	nd	0.12	6.10	1.2	9.6
Chromium	100	18.1	11.5	31.0	43.6	81	370
Copper	100	7.0	3.0	17.3	34.0	34	270
Iron	100	13,050	8240	23,400	26,200	na	na
Lead	100	5.2	2.5	30.8	18.0	46.7	218
Manganese	100	102.3	66.9	153.0	na	na	na
Mercury	100	0.024	0.008	0.071	0.096	0.15	0.71
Nickel	100	7.9	5.4	11.4	14.0	20.9	51.6
Selenium	23	0.24	nd	0.35	0.90	na	na
Silver	0	nd	nd	nd	4.00	1.0	3.7
Thallium	45	2.3	nd	3.3	113.0	na	na
Tin	89	0.8	nd	3.2	na	na	na
Zinc	100	31.7	21.7	45.5	67.0	150	410
Pesticides (*ppt*)							
Total DDT	98	1136	nd		13,200	1580	46,100
HCB	30	809	nd	3300	nd	na	na
Total PCB (*ppt*)	23	1472	nd	6394	na	na	na
Total PAH (*ppb*)	80	46	nd	536	199	4022	44,792

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

[b] From Long et al. 1995

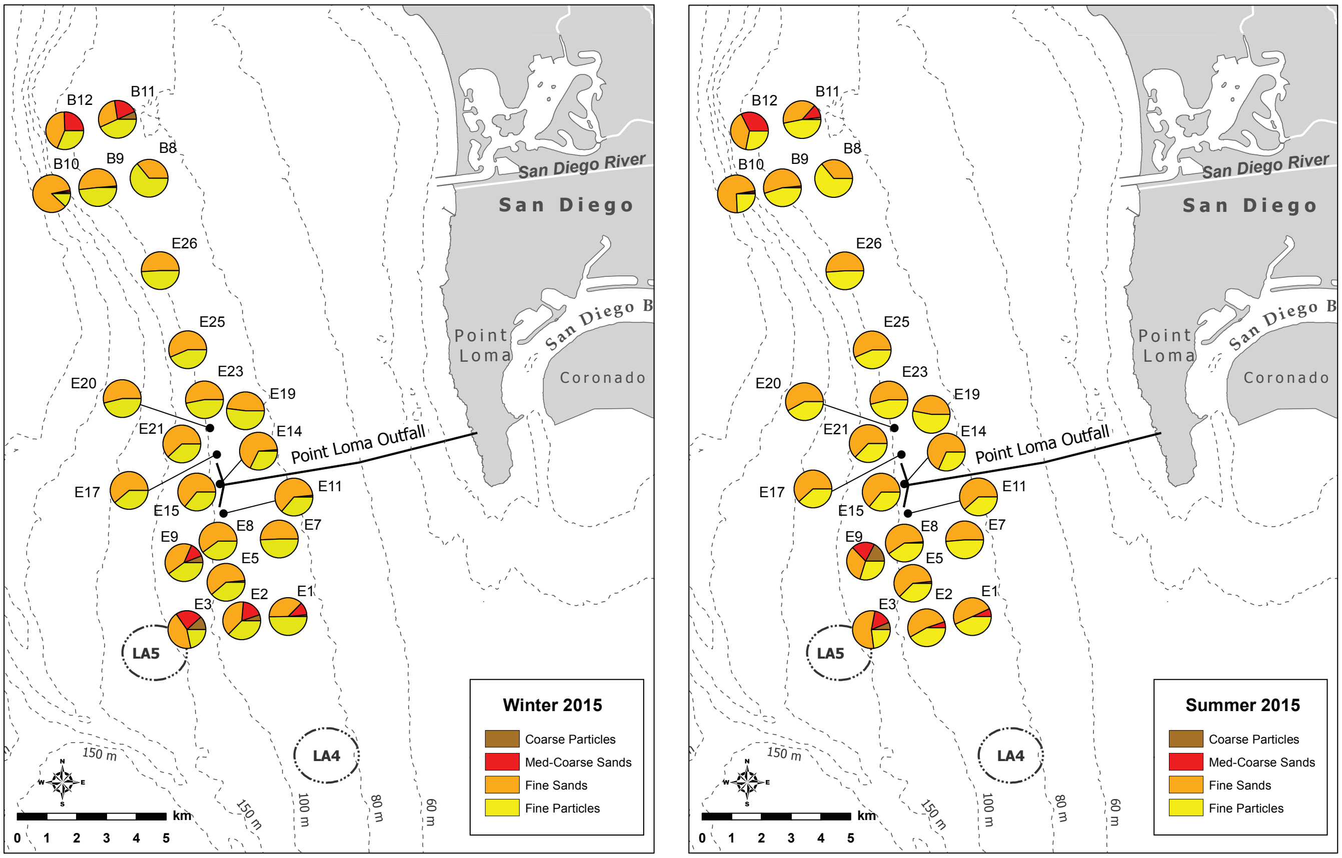
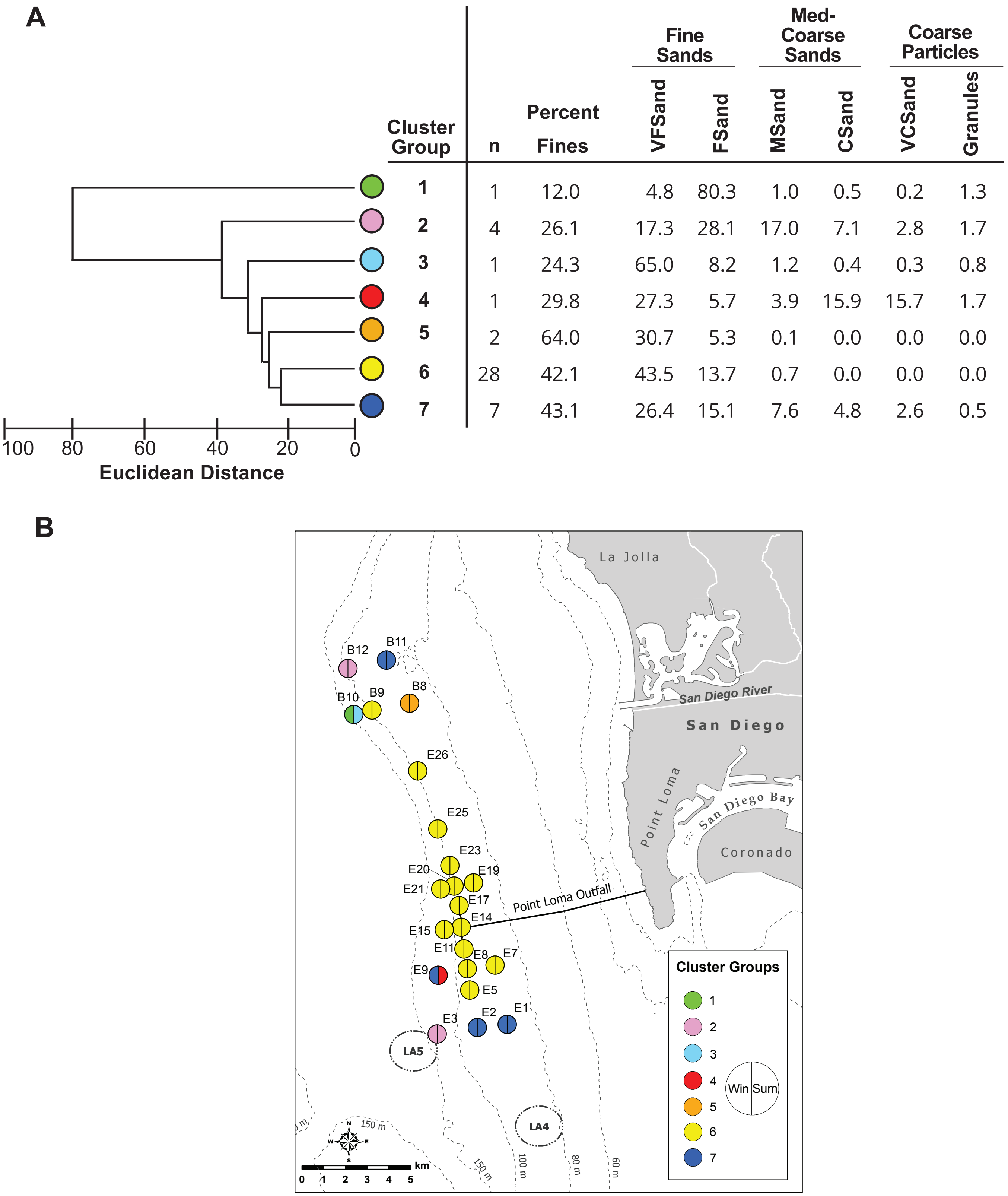


Figure 4.2

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

(42% per sample), the second largest proportion of very fine sand (44% per sample), and also averaged 14% fine sand and <1% medium sand. Coarse sand, very coarse sand, and granules were absent from group 6 sediments. Cluster group 7 was the second largest group and comprised seven samples, including the winter and summer samples from northern station B11 and southern stations E1 and E2, as well as the winter sample from southern station E9. Sediments in these seven samples averaged 43% fines, 26% very fine sand, 15% fine sand, 8% medium sand, 5% coarse sand, 3% very coarse sand, and <1% granules per sample. Cluster group 2, the third largest group, comprised the four samples collected during the winter and summer from northern station B12 and southern station E3. These sediments had the largest proportion of medium sand (17% per sample), the second largest proportions of fine sand (28% per sample) and coarse sand (7% per sample), and also averaged 26% fines, 17% very fine sand, 3% very coarse sand, and 2% granules. The four remaining cluster groups each comprised 1–2 samples. Cluster group 1 included the winter sample from northern station B10. Sediments in this sample had the largest proportion of fine sand (80%) and the smallest proportions of percent fines (12%) and very fine sand (5%). Cluster group 3 included the summer sample from station B10, which had sediments with the largest proportion of very fine sand (65%) and the second smallest proportion of percent fines (24%). Cluster group 4 included the summer sample from station E9. Sediments in this sample had the largest proportions of coarse sand (16%) and very coarse sand (16%). Cluster group 5 comprised the winter and summer samples from northern station B8. These sediments had the highest proportion of percent fines (64% per sample) and the smallest proportion of fine sand (5% per sample). As with cluster group 6, coarse sand, very coarse sand, and granules were absent from group 5 sediments.



Cluster Group	n	Percent Fines	Fine Sands		Med-Coarse Sands		Coarse Particles	
			VFSand	FSand	MSand	CSand	VCSand	Granules
1	1	12.0	4.8	80.3	1.0	0.5	0.2	1.3
2	4	26.1	17.3	28.1	17.0	7.1	2.8	1.7
3	1	24.3	65.0	8.2	1.2	0.4	0.3	0.8
4	1	29.8	27.3	5.7	3.9	15.9	15.7	1.7
5	2	64.0	30.7	5.3	0.1	0.0	0.0	0.0
6	28	42.1	43.5	13.7	0.7	0.0	0.0	0.0
7	7	43.1	26.4	15.1	7.6	4.8	2.6	0.5

Figure 4.3

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

Indicators of Organic Loading

Indicators of organic loading in benthic sediments, including biochemical oxygen demand (BOD), sulfides, total nitrogen (TN), total organic carbon (TOC), and total volatile solids (TVS), were detected in all sediment samples collected from the Point Loma outfall region during 2015 (Table 4.1). BOD concentrations ranged from 100 to 456 ppm, while sulfides ranged from 1.16 to 76.50 ppm, TN ranged from 0.009 to 0.089% weight, TOC ranged from 0.39 to 3.36% weight, and TVS ranged from 1.70 to 4.20% weight. Of these five indicators, only BOD was detected at concentrations lower than observed before wastewater discharge began. The highest TN (≥0.085% weight), TOC (≥0.74% weight), and TVS (≥2.80% weight) concentrations occurred primarily at the northern 'B' stations located at least 10 km north of the outfall (Figure 4.4, Appendix C.5). In contrast, the highest sulfide and BOD concentrations occurred at near-ZID station E14 located nearest the discharge zone. In general, only sulfide and BOD concentrations have shown changes near the outfall that appear consistent with possible organic enrichment (City of San Diego 2014, 2015a, b).

Trace Metals

Eleven trace metals were detected in all sediment samples collected in the PLOO region during 2015, including aluminum, arsenic, barium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc (Table 4.1, Appendix C.6). Antimony and tin were detected slightly less frequently, each at a rate of 89%, while beryllium, cadmium, selenium, and thallium were detected in ≤50% of the samples. Silver was not detected in any PLOO sediment samples collected during the year. Each of the nine metals with published ERLs and ERMs (see Long et al. 1995) were reported at levels below these thresholds. Additionally, most of the metals were detected at levels within ranges reported prior to wastewater discharge off Point Loma (City of San Diego 2015a), and/or elsewhere in the Southern California Bight (SCB) (e.g., Dodder et al 2016). Only arsenic and lead were reported at levels higher than pre-discharge values. In addition to being low overall, metal concentrations varied between stations with no discernible patterns relative to the outfall. Instead, the highest levels of several metals occurred in sediments from one or more of the northern 'B' stations (e.g., arsenic, beryllium, chromium, iron, manganese, zinc) or southern 'E' stations (e.g., barium, copper, lead, mercury) (Figure 4.4, Appendix C.6). These results are consistent with the findings from long term analyses reported previously (City of San Diego 2014, 2015a, b).

Pesticides

Two chlorinated pesticides were detected in PLOO sediments during 2015, including DDT and hexachlorobenzene (HCB) (Table 4.1, Appendix C.3, C.7). Total DDT, composed primarily of p,p-DDE, was detected in 98% of the sediment samples at concentrations up to 16,040 ppt. Two samples, including the winter sample from station E3 and the summer sample from station E20, had total DDT values in excess of the ERL threshold of 1580 ppt (Figure 4.4, Appendix C.7). However, neither of these samples exceeded the ERM threshold. HCB was detected in 30% of the sediment samples at concentrations up to 3300 ppt. The highest HCB values (≥470 ppt) were found in sediments from stations B8, B12, E1, E7, and E8 (Figure 4.4, Appendix C.7). The pesticides chlordane, HCH, aldrin, endosulfan, dieldrin, endrin, and mirex were not detected at any of the PLOO stations during 2015. These results are consistent with the findings from long term analyses reported previously (City of San Diego 2014, 2015a, b).

PCBs

PCBs were detected in only 23% of the sediment samples collected around the PLOO in 2015 at concentrations up to 6394 ppt (Table 4.1, Appendix C.7). Although no ERL or ERM thresholds exist for PCBs measured as congeners, all PCB values recorded during the year were well within ranges reported elsewhere in the SCB (e.g., Dodder et al. 2016). The most

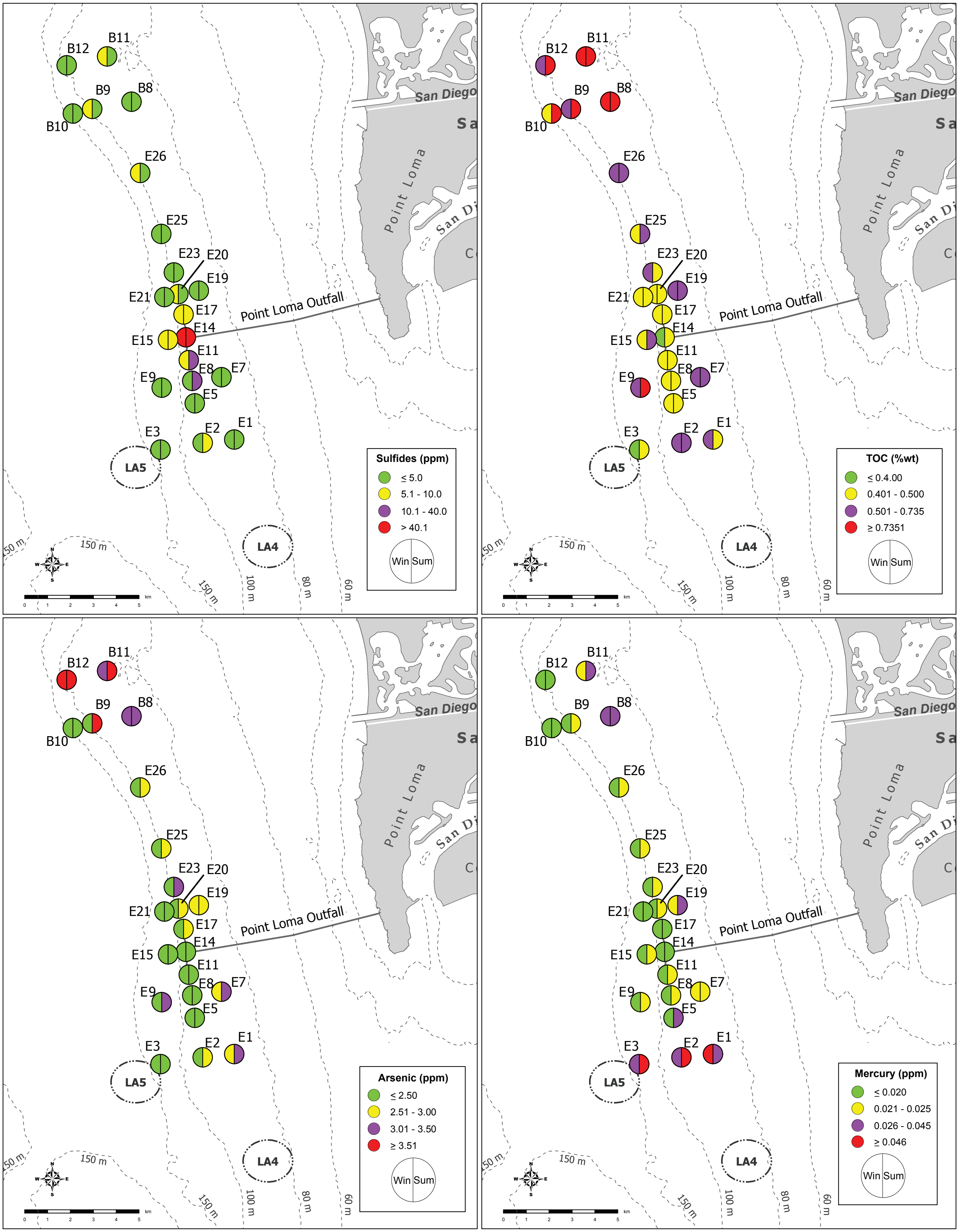


Figure 4.4

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

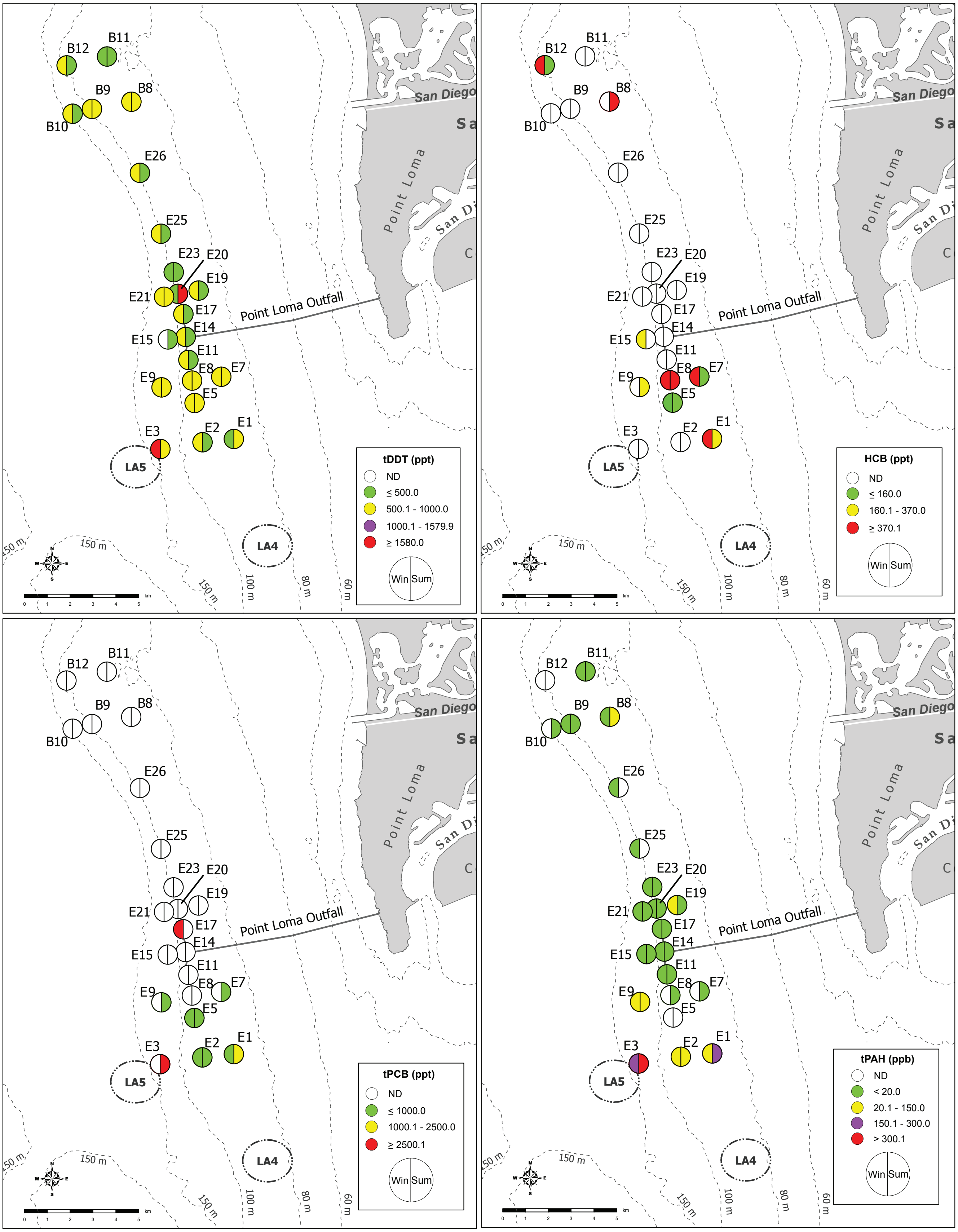


Figure 4.4 *continued*

commonly detected PCB congeners that occurred in ≥11% of the samples were PCB 49, PCB 52, PCB 66, PCB 70, PCB 149, and PCB 153/168 (Appendix C.3). Historically, PCBs have been detected infrequently at low concentrations in the PLOO region with no patterns relative to the outfall evident (City of San Diego 2014, 2015a, b). Instead, PCBs have been detected most frequently at the southern 'E' stations. For example, 90% of the samples with detectable levels of PCB collected during 2015 were from stations E1, E2, E3, E5, E7 and E9 (Figure 4.4).

PAHs

PAHs were detected in 80% of the sediment samples collected from the Point Loma outfall region in 2015 (Table 4.1, Appendix C.7). Concentrations of total PAH reached 536 ppb during the past year, above the pre-discharge maximum of 199 ppb but well below the ERL threshold of 4022 ppb and the Bight'13 maximum of 2900 ppb (Dodder et al. 2016). The most frequently recorded compound was 2,6-dimethylnaphthalene, which occurred in 89% of the samples with detectable levels of PAHs. Other individual PAHs found during the year included 3,4-benzo(B)fluoranthene, acenaphthylene, anthracene, benzo[A]anthracene, benzo[A]pyrene, benzo[e]pyrene, benzo[G,H,I]perylene, benzo[K]fluoranthene, biphenyl, chrysene, fluoranthene, indeno(1,2,3-CD)pyrene, perylene, phenanthrene, and pyrene (Appendix C.3). Over the past 25 years, PAHs have been detected infrequently in PLOO sediments, with all reported values below the ERL, and there have been no patterns indicative of a wastewater impact at the primary core stations (City of San Diego 2014, 2015a, b). Historically, the highest concentrations of PAHs have been found at the southern 'E' stations. During 2015, PAHs levels were highest at stations E1 and E3 (Figure 4.4).

DISCUSSION

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

Various organic indicators, trace metals, pesticides, PCBs, and PAHs were detected in sediment samples collected throughout the PLOO region in 2015, though concentrations were all below ERM thresholds, mostly below ERL thresholds, and/or within historical ranges (City of San Diego 2014, 2015a, b). 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, 2015c, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009, Dodder et al. 2016).

There have been few spatial patterns consistent with an outfall effect on sediment chemistry over the past several years, with concentrations of most contaminants at the three near-ZID sites falling within the range of values at the farfield stations. The only exceptions were slightly higher sulfide and BOD levels near the outfall (City of San Diego 2014, 2015a, b). 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 2014, 2015a, b). This pattern may be due in part to the dumping of dredged materials destined originally for the LA-5 dumpsite (Anderson et al. 1993, Steinberger et al. 2003, Parnell et al. 2008).

The broad distribution of various contaminants in sediments throughout the PLOO region is likely derived from several sources. Mearns et al. (1991) described the distribution of contaminants such as arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB, while Brown et al. (1986) determined that there may be no coastal areas in southern California that are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent surveys of SCB continental shelf habitats (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Dodder et al. 2016). The lack of contaminant-free reference areas clearly pertains to the Point Loma outfall region as demonstrated by the presence of many contaminants in sediments prior to wastewater discharge (see City of San Diego 2015a). Further, historical assessments of sediments off the coast of Los Angeles have shown that as wastewater treatment has improved, sediment conditions are more likely affected by other factors (Stein and Cadien 2009). These factors may include bioturbative re-exposure of buried legacy sediments (Niedoroda et al. 1996, Stull et al. 1996), large storms that assist redistribution of legacy contaminants (Sherwood et al. 2002), and stormwater discharges (Schiff et al. 2006, Nezlin et al. 2007). Possible non-outfall sources and pathways of contaminant dispersal off San Diego include transport of contaminated sediments from San Diego Bay via tidal exchange, offshore disposal of sediments dredged from the Bay, and surface runoff from local watersheds (Parnell et al. 2008).

Overall, there is little evidence of contaminant loading or organic enrichment in sediments throughout the PLOO region after 22 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 2014, 2015a, b). The only sustained effects have been restricted to a few sites located within about 200 m of the outfall (i.e., near-ZID stations E11, E14, E17). These effects include measurable increases in sulfide and BOD concentrations (City of San Diego 2015a). 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).

LITERATURE CITED

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Chapter 5
Macrobenthic Communities

Chapter 5. Macrobenthic Communities

INTRODUCTION

The City of San Diego (City) monitors communities of small benthic invertebrates (macrofauna) that live within or on the surface of soft-bottom seafloor habitats to examine potential effects of wastewater discharge on the marine benthos around the Point Loma Ocean Outfall (PLOO). Benthic macrofauna are targeted for monitoring because these organisms play important ecological roles in coastal marine ecosystems off southern California and throughout the world (e.g., Fauchald and Jones 1979, Thompson et al. 1993a, Snelgrove et al. 1997). Additionally, because many benthic species live long and relatively stationary lives, they may integrate the effects of pollution or other disturbances over time through pathways such as physical contact with or ingestion of the sediments (Gray 1974, Hartley 1982, Bilyard 1987). The response of many of these species to environmental stressors is well documented, and monitoring changes in discrete populations or more complex communities can help identify locations impacted by anthropogenic inputs (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). For example, pollution-tolerant species are often opportunistic and can therefore displace more sensitive species in impacted areas as their populations increase. In contrast, populations of pollution-sensitive species will typically decrease in numbers in response to contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation (Gray 1979). For these reasons, the assessment of benthic community structure has become a major component of many ocean monitoring programs.

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

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

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

MATERIALS AND METHODS

Collection and Processing of Samples

Benthic samples were collected at 22 monitoring stations in the PLOO region during winter (January) and summer (July) of 2015 (Figure 5.1). These stations are distributed along or adjacent to three main depth contours, with the primary core stations located along the 98-m contour (i.e., outfall discharge depth), and the secondary core stations located along the 88-m or 116-m contours. These 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 three stations located closest (i.e., within 200 m) to the boundary of the zone of initial dilution (ZID) are considered to represent near-ZID conditions (i.e., stations E11, E14, E17).

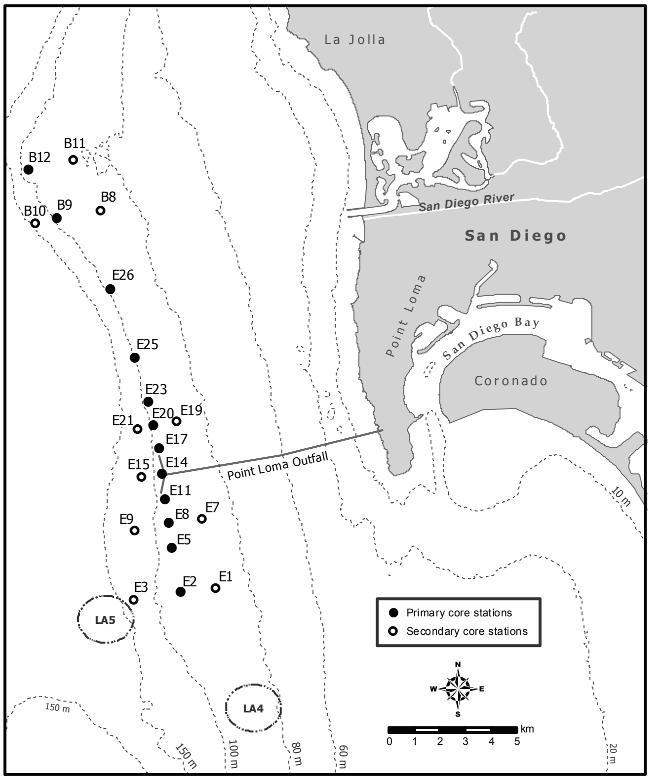


Figure 5.1
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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). A second replicate sample for community analysis only was taken on a subsequent cast. Criteria established by the U.S. Environmental Protection Agency (USEPA) to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were brought aboard ship, washed with seawater, and sieved through a 1.0-mm mesh screen. The organisms retained on the screen were then collected, transferred to sample jars, and relaxed for 30 minutes in a magnesium sulfate solution before being fixed with buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol for final preservation. All macrofaunal organisms were separated from the raw material and sorted into five higher taxonomic groups (i.e., Annelida, Arthropoda, Mollusca, Echinodermata, miscellaneous phyla) by a subcontract lab, after which they were identified to species (or the lowest taxon possible) and enumerated by City marine biologists. All identifications followed nomenclatural standards established by the Southern

California Association of Marine Invertebrate Taxonomists (SCAMIT 2014).

Data Analyses

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

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

A Before-After-Control-Impact-Paired (BACIP) statistical model was used to test the null hypothesis that there have been no changes in community parameters due to operation of the PLOO (Bernstein and Zalinski 1983, Stewart-Oaten et al. 1986, 1992, Osenberg et al. 1994). The BACIP model compares differences between control (reference) and impact stations at times before and after an impact event. The analyses presented in this report are based on 2.5 years (10 quarterly surveys) of before-impact data from July 1991–October 1993 and 22 years (63 quarterly or semi-annual surveys) of after-impact data from January 1994 through July 2015. The 'E' stations, located ~0.1–8 km from the outfall, are considered most likely to be affected by wastewater discharge (Smith and Riege 1994), whereas the 'B' stations, located >10 km north of the outfall were originally designed to be control sites. However, benthic communities differed between the 'B' and 'E' stations prior to discharge (Smith and Riege 1994, City of San Diego 1995). Station E14 was selected as the impact site for all analyses due to its proximity to the boundary of the ZID making it most susceptible to impact. Stations E26 and B9 were selected to represent separate control sites in the BACIP tests. Station E26 is located 8 km north of the outfall and is considered the 'E' station least likely to be impacted, and previous analyses have suggested that station B9 was the most appropriate 'B' station for comparison with the 'E' stations (Smith and Riege 1994, City of San Diego 1995). Six dependent variables were analyzed, including number of species (species richness), macrofaunal abundance, the benthic response index (BRI), and abundances of three taxa considered sensitive to organic enrichment. These indicator taxa include ophiuroids in the genus *Amphiodia* (mostly *A. urtica*), and amphipods in the genera *Ampelisca* and *Rhepoxynius*. All BACIP analyses were interpreted using one-tailed paired t-tests with a type I error rate of α=0.05.

RESULTS AND DISCUSSION

Community Parameters

Species richness

A total of 535 taxa were identified during the 2015 PLOO surveys. Of these, 429 (80%) were

Table 5.1

Summary of macrofaunal community parameters for PLOO benthic stations sampled during 2015. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = Pielou's evenness; Dom = Swartz dominance; BRI = benthic response index. Data for each station are expressed as annual means (n = 4). 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	104	248	4.3	0.93	48	13
	B8	64	196	3.2	0.78	22	10
	E19	64	242	3.2	0.77	20	13
	E7	69	272	3.4	0.81	22	13
	E1	76	259	3.4	0.78	25	10
98-m Depth Contour	B12	98	292	4.2	0.91	39	14
	B9	80	218	3.8	0.88	32	10
	E26	65	189	3.6	0.86	26	8
	E25	78	272	3.7	0.85	28	10
	E23	66	227	3.5	0.84	24	9
	E20	72	252	3.6	0.86	24	12
	E17[a]	77	288	3.7	0.86	26	16
	E14[a]	91	426	3.7	0.82	24	27
	E11[a]	81	392	3.7	0.83	23	15
	E8	82	288	3.8	0.86	28	11
	E5	79	256	3.7	0.85	28	10
	E2	87	218	4.0	0.89	37	13
116-m Depth Contour	B10	104	364	4.1	0.88	38	16
	E21	64	234	3.5	0.85	21	11
	E15	84	340	3.7	0.84	24	11
	E9	96	291	4.1	0.91	40	11
	E3	103	239	4.3	0.93	47	11
All Grabs	Mean	81	273	3.7	0.85	29	12
	95% CI	3	16	0.1	0.01	2	1
	Min	52	160	3.0	0.73	15	4
	Max	127	497	4.5	0.95	56	28

[a] near-ZID stations

identified to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although 30% (n = 163) were recorded only once. Three species not previously reported by the City's Ocean Monitoring Program were encountered, including the polychaete worm *Nephtys* cf *punctata* (Phylum Annelida), an unidentified anthozoan (Phylum Cnidaria, Order Zoanthidea), and an unidentified sponge (Phylum Silicea, Class Demospongiae).

Species richness averaged from 64 taxa per grab at stations B8, E19, and E21 to 104 taxa per grab at stations B11 and B10 (Table 5.1), and there were no clear patterns relative to the discharge site, depth, or sediment particle size (see Chapter 4). Additionally, species richness values at the different monitoring sites in 2015 (Appendix D.1) were within the range of 33–174 taxa per grab reported at these sites from 1991 through 2014 (City of San Diego 2015a), while 91% of samples were within the tolerance

Table 5.2

Results of BACIP t-tests for species richness (SR), infaunal abundance, BRI, and abundance of several indicator taxa around the PLOO (1991–2015). Critical t-value = 1.67 for $\alpha = 0.05$ (one-tailed t-tests, df = 68); ns = not significant.

Variable	Control vs. Impact	t	*p*
SR	E26 vs E14	-3.45	0.001
	B9 vs E14	-3.27	0.001
Abundance	E26 vs E14	-1.87	0.033
	B9 vs E14	-2.93	0.002
BRI	E26 vs E14	-13.28	< 0.001
	B9 vs E14	-10.04	< 0.001
Amphiodia spp	E26 vs E14	-6.44	< 0.001
	B9 vs E14	-4.20	< 0.001
Ampelisca spp	E26 vs E14	-2.33	0.011
	B9 vs E14	-1.55	ns
Rhepoxynius spp	E26 vs E14	-0.64	ns
	B9 vs E14	-0.71	ns

interval range of 60–145 taxa per grab calculated for the region (see City of San Diego 2015b).

BACIP t-test results indicated a net change in the mean difference of species richness between impact station E14 and both control stations following the onset of wastewater discharge (Table 5.2). This change appears driven by increased variability and higher numbers of species at E14 during most surveys beginning in 1994 (Figure 5.2A); however, the cause of increased species richness near the discharge site remains unclear. For example, species richness has not co-varied with the concentrations of sulfides, total organic carbon, or total nitrogen present in the sediments at station E14 over the years (Appendix D.2), and sediment composition has remained somewhat consistent at this station, with no evidence that the proportion of fine particles has increased since wastewater discharge began (City of San Diego 2015a, c).

Macrofaunal abundance

A total of 24,008 macrofaunal individuals were recorded in 2015. Mean abundance ranged from 189 animals per grab at farfield station E26 to 426 per grab at nearfield station E14 (Table 5.1). Except for the relatively higher numbers at near-ZID stations E14 and E11, there were no clear spatial patterns in abundance related to the discharge site, depth, or sediment particle size (see Chapter 4). During the past year, macrofaunal abundance at all stations was within the range of 70–1509 individuals per grab reported from 1991 through 2014 (see Appendix D.1, City of San Diego 2015a). Additionally, 73% of grabs were within the tolerance interval range of 223–603 individuals per grab calculated for the region (City of San Diego 2015b). A total of 24 samples collected from 11 of the farfield monitoring sites (stations B8, B9, B11, E19, E2, E3, E5, E20, E21, E23, E26) had abundance values below the lower tolerance interval bound, while no samples exceeded the upper bound (Appendix D.1).

BACIP t-test results indicated a net change in macrofaunal abundance between impact station E14 and both control stations following the onset of wastewater discharge (Table 5.2). All three stations have been highly variable since monitoring began (Figure 5.2B). As with species richness, the cause of the general increase in total numbers of macrobenthic invertebrates nearest the discharge site remains unclear, but does not appear to be linked to changes in organics or sediment particle size (see Appendix D.2 and City of San Diego 2015a).

Species diversity, evenness, and dominance

Shannon diversity index (H') values averaged from 3.2 to 4.3 per grab for each station while Pielou's evenness (J') averaged from 0.77 to 0.93 per grab, indicating that local benthic communities remain characterized by relatively diverse assemblages of evenly distributed species (Table 5.1). No clear patterns relative to the discharge site, depth, or sediment particle size (see Chapter 4) were evident. For example, the highest mean H' and J' values of 4.3 and 0.93, respectively, were reported for both the northernmost farfield site along the 88-m contour (station B11) and the southernmost farfield site along the 116-m contour (station E3), while the lowest mean H' occurred at two farfield sites along the 88-m contour (stations B8 and E19) and the lowest mean J' also occurred at station E19. During the past year, diversity and evenness values were generally similar to historical values (Figures 5.2C, D). Additionally, one individual grab

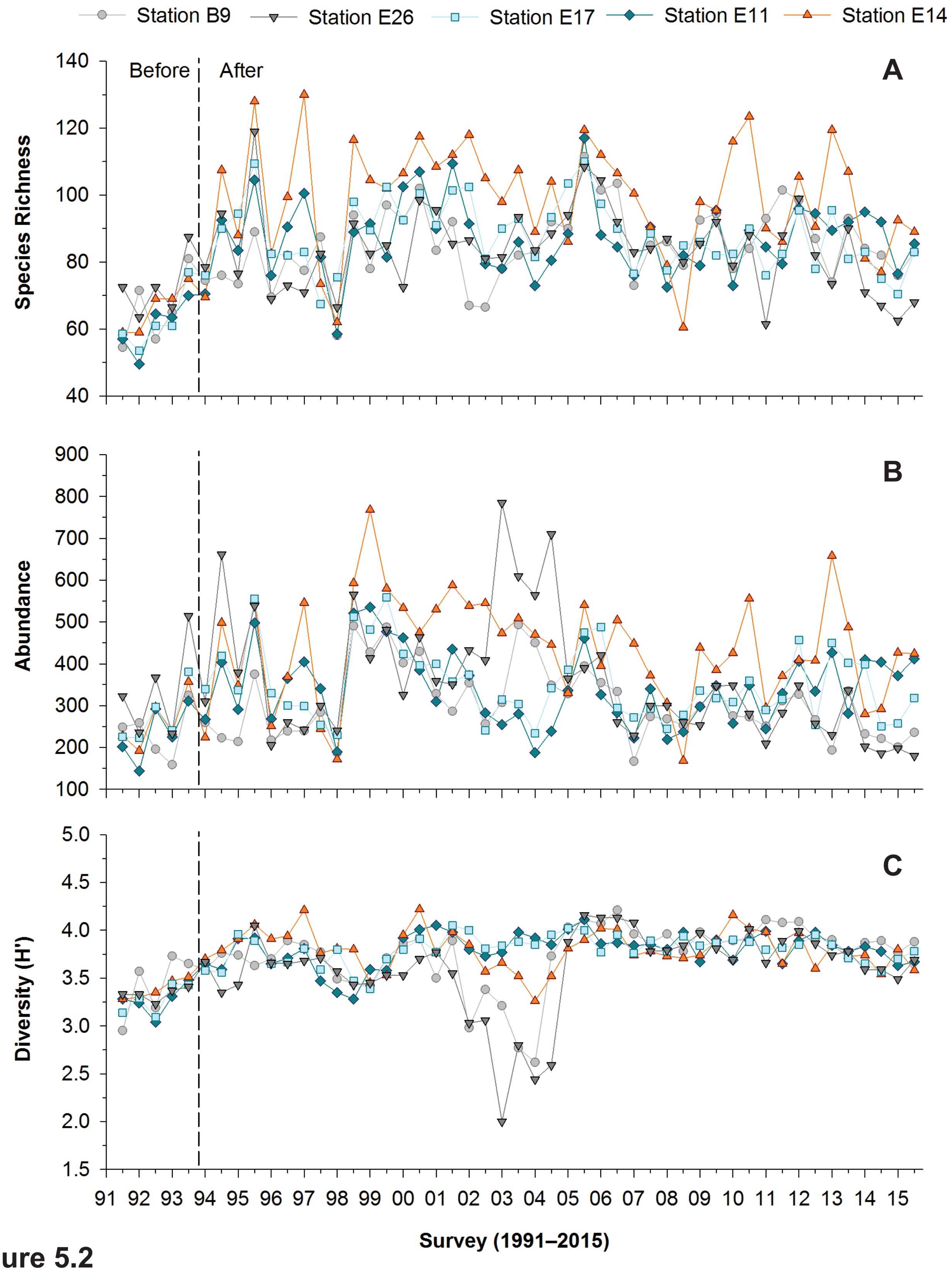


Figure 5.2

Comparison of community parameters at PLOO near-ZID stations E11, E14, and E17, and farfield stations E26 and B9 sampled from 1991 through 2015. Parameters include: (A) species richness; (B) infaunal abundance; (C) Shannon diversity index (H'); (D) Pielou's evenness (J'); (E) Swartz dominance; (F) benthic response index (BRI). Data for each station are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.

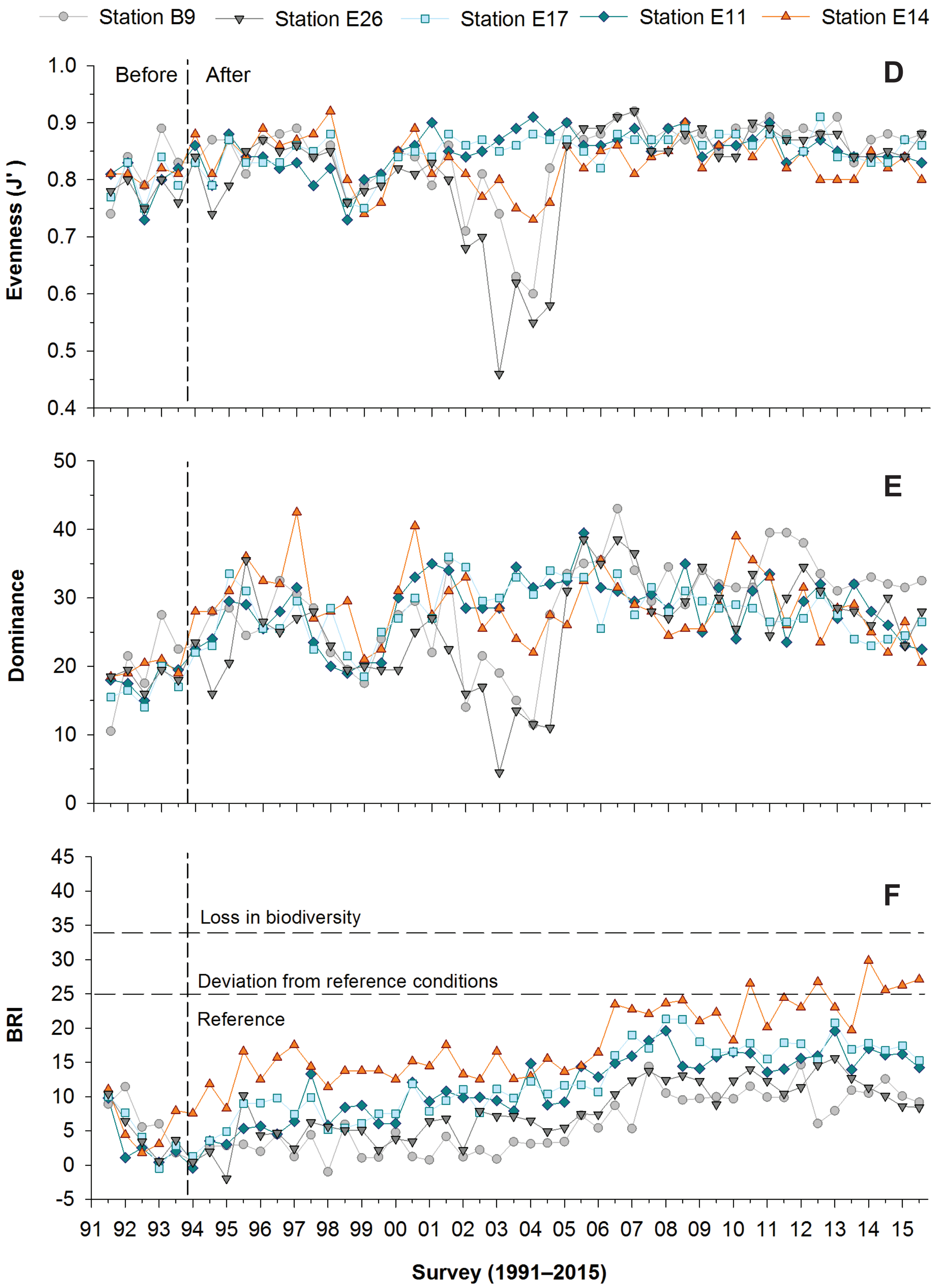


Figure 5.2 *continued*

sample from the summer survey at station E3 had a diversity value exceeding the regional tolerance intervals of 2.5–4.4 for H' while eight samples from four stations (B11, B12, E3, E9) exceeded the tolerance interval of 0.58–0.92 for evenness (see Appendix D.1 and City of San Diego 2015b).

Swartz dominance averaged from 20 to 48 species per grab, with the lowest dominance (highest index value) occurring at northern farfield station B11 and the highest dominance (lowest index value) occurring at farfield station E19 (Table 5.1). No patterns relative to the outfall, depth, or sediment particle size were evident (see Chapter 4, Figure 5.2E). During the past year, all but four grab samples were within the regional tolerance interval range of 7–49 per grab (City of San Diego 2015b). The only exceptions occurred at northern farfield station B11 in winter and southern farfield station E3 in summer with dominance index values ≥51 (Appendix D.1).

Benthic response index

The benthic response index (BRI) is an important tool for gauging anthropogenic impacts to coastal seafloor habitats throughout the SCB. BRI values below 25 are considered indicative of reference conditions, while values above 34 represent increasing levels of disturbance or environmental degradation (Smith et al. 2001). In 2015, 97% of the individual benthic samples collected off Point Loma were characteristic of reference conditions (Appendix D.1). Only the four samples collected at near-ZID station E14 had BRI scores indicative of a possible minor deviation in benthic condition (BRI = 25−28). Although the three primary core stations closest to the discharge zone (i.e., stations E11, E14, E17) had slightly higher BRI values than most sites located farther away, no other spatial patterns relative to depth or sediments were observed.

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

Species of Interest

Dominant taxa

Polychaete worms were the dominant taxonomic group found in the PLOO region in 2015 and accounted for 46% of all taxa collected (Table 5.3). Crustaceans accounted for 22% of the taxa reported, while the remainder comprised 16% molluscs, 5% echinoderms, and about 10% all other taxa combined. Polychaetes were also the most numerous organisms, accounting for 46% of the total macrofaunal abundance. Crustaceans accounted for 21% of the organisms collected, while molluscs, echinoderms, and all other taxa combined each contributed to ≤16% of the total abundance. Overall, the percentage of taxa that occurred within each of the above major taxonomic groupings and their relative abundances has remained relatively consistent since monitoring began in 1991 and is similar to other areas within the SCB (see City of San Diego 1995, 2015a, Bergen et al 2000, Ranasinghe et al 2012).

The 10 most abundant species in 2015 included four polychaetes, two crustaceans, one echinoderm, and three molluscs (Table 5.4). Together these species accounted for about 40% of all invertebrates identified during the year. The numerically dominant polychaetes included the cirratulid *Chaetozone hartmanae*, the amphinomid *Chloeia pinnata*, the capitellid *Mediomastus* sp, and the maldanid *Praxillella pacifica*. The dominant crustaceans included the ostracods *Euphilomedes carcharodonta* and *Euphilomedes producta*, while the ophiuroid *Amphiodia urtica* was the dominant echinoderm. The dominant molluscs were the bivalves *Nuculana* sp A, *Tellina carpenteri*, and *Axinopsida serricata*. *Amphiodia urtica* was the most abundant species during the year, accounting for ~11% of all invertebrates collected, and occurring in 93% of grabs with a mean abundance of ~31 individuals per grab. *Chaetozone hartmanae* was ubiquitous, occurring in all samples from all sites; however, this polychaete accounted for only

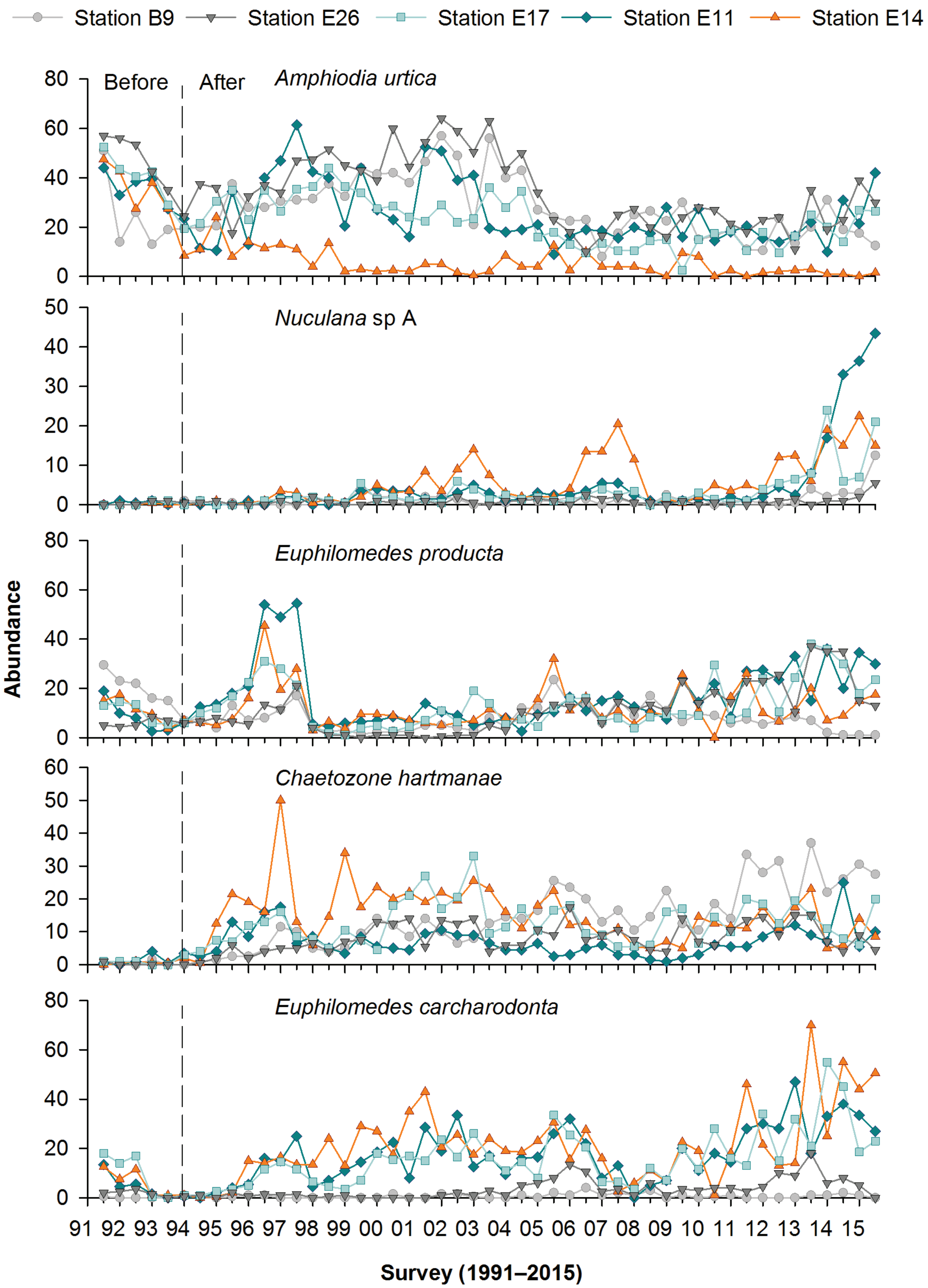


Figure 5.3

Abundances of the five most numerically dominant species recorded during 2015 (presented in order) at PLOO near-ZID stations E11, E14, and E17 and farfield stations E26 and B9. Data for each station are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.

4% of all macrobenthic invertebrates collected during the year with an average abundance of ~10 worms per grab. The remaining eight species occurred in 72–95% of the grabs collected during 2015 and averaged ≤12 individuals per grab.

With the exceptions of *Amphiodia urtica* and *Euphilomedes producta*, the top five species have occurred sporadically or have become more abundant in the region during recent years (Figure 5.3). *Amphiodia urtica* remains the most abundant invertebrate in the Point Loma outfall region after 22 years of outfall operation (Figure 5.3), although it comprised at least 75% of all organisms sampled during the pre-discharge period compared to only about 53% during the post-discharge period (City of San Diego 2015a). The other top three historically dominant species are all polychaetes, including the terebellid *Proclea* sp A, the spionid *Spiophanes duplex*, and the oweniid *Myriochele striolata* (Figure 5.4, Appendix D.3).

Indicator species

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

In 2015, indicator species with similar abundances at nearfield and farfield stations included *Proclea* sp A and *Rhepoxynius* spp (Figure 5.4). Since 2007, *Proclea* sp A populations have been low throughout the region. Patterns of abundance for *Rhepoxynius* spp have shown increased variability between targeted stations off Point Loma since monitoring began, but have remained within tolerance intervals calculated for the region (City of San Diego 2015b), which suggests little to no impact associated with the outfall discharge. Further, the results of BACIP analyses examining mean differences in abundances of *Rhepoxynius* spp demonstrated that no net change has occurred between "impact" station E14 and "control" stations E26 and B9 (Table 5.2). In contrast, abundances of *Ampelisca* spp were slightly lower at near-ZID station E14 than at northern station E26 during both surveys in 2015 (Figure 5.4), and BACIP results did indicate a net change in *Ampelisca* spp abundance between these stations although there was no significant change between E14 and B9 (Table 5.2). However, caution should be exercised in interpreting these results given the relatively low abundances and natural population fluctuations of *Ampelisca* spp, and that the average number of *Ampelisca* spp per station (including near-ZID site E14) has remained within regional tolerance intervals of 2–31 amphipods per grab (City of San Diego 2015b).

The abundance of *Amphiodia urtica* was lower at nearfield station E14 than other stations in 2015 (Figure 5.3), and is one of the factors driving the moderately higher BRI values for station E14 (Table 5.1, Appendix D.1). Results of BACIP t-tests indicated a significant change in the difference in abundances between "impact" station E14 and both of the "control" stations E26 and B9 between the 2.5 year pre-discharge and 22 year post-discharge periods (Table 5.2). For example, average *Amphiodia* spp abundances have decreased about 78% at E14 compared to much smaller decreases at E26 and B9. Although this pattern is consistent with the predicted effects of organic enrichment, predation by fish predators (e.g., sea basses and surfperch) attracted to the outfall pipe may also contribute to reduced brittle star numbers in nearby areas such as station E14 (see Davis et al. 1982, Ambrose and Anderson 1990, Posey and Ambrose 1994). For example, Amphiodia abundances at near-ZID stations E11 and E17 appear much less affected. Whether or not these population changes are due to wastewater discharge, increased predation pressure, or some

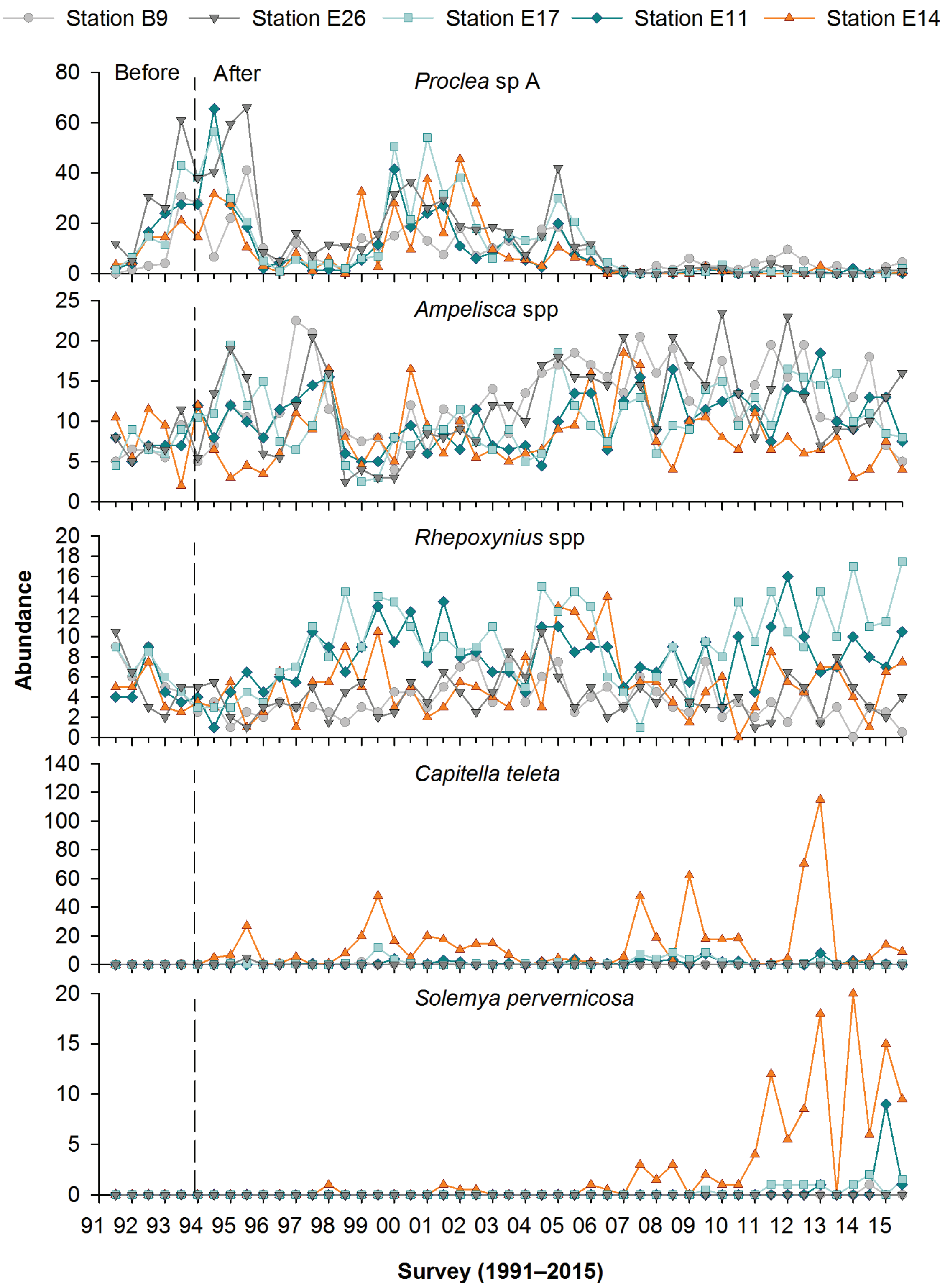


Figure 5.4
Abundances of representative ecologically important indicator taxa at PLOO near-ZID stations E11, E14, and E17 and farfield stations E26 and B9 sampled from 1991 through 2015. Data for each station are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.

other factor, abundances of *Amphiodia* spp near the outfall and elsewhere are still within the range of natural variability seen at similar depths throughout the SCB (e.g., Bergen et al. 1998, 2001, Ranasinghe et al. 2003, 2007, 2012).

Opportunistic species such as *Capitella teleta* and *Solemya pervernicosa* typically increase in abundance in areas having high organic content (Linton and Taghon 2000, McLeod and Wing 2009). From 2013 to 2015, populations of *C. teleta* decreased from the highest ever recorded at the PLOO stations (i.e., 140 individuals in a grab from E14 in winter 2013) to ≤22 worms per grab at stations B9, E3, E11, E17, E20, and E14 for a total of 51 animals during the entire year. *Solemya pervernicosa* reached a maximum of 18 individuals per grab during 2015 at station E14. Additionally, low numbers (≤9 per grab) were observed at stations B10, E11, and E15 during both winter and summer, at station E3 in the winter, and station E17 during the summer. Despite occasionally exceeding regional tolerance intervals of 0–1 individuals per grab (City of San Diego 2015b), abundances of these two species remained characteristic of relatively undisturbed habitats. For example, *C. teleta* commonly reaches densities as high as 500 individuals per 0.1-m^2 grab in polluted sediments (Reish 1957; Swartz et al. 1986).

Classification of Macrobenthic Assemblages

Classification (cluster) analysis was used to discriminate between macrofaunal assemblages from a total of 44 grab samples collected at 22 PLOO monitoring stations in 2015, resulting in seven ecologically relevant SIMPROF-supported groups (Figures 5.5, 5.6, Appendices D.4, D.5). These assemblages (referred to herein as cluster groups A–G) represented 1–28 grabs each and varied in terms of the specific taxa present, as well as their relative abundances, and occurred at sites distinguished by different sediment microhabitats. For example, similar patterns of variation occurred in the benthic macrofaunal similarity matrix and sediment dissimilarity matrix (see Chapter 4) used to generate their respective cluster dendrograms, thus confirming that the local PLOO assemblages were correlated to sediment composition (RELATE ρ=0.728, p=0.001). The sediment sub-fractions that were most highly correlated to the macrofaunal assemblages included granules, medium sand, very fine sand, and fines (BEST ρ=0.747, p=0.001). The main characteristics of each of these seven assemblages and their associated sediments are described below.

Table 5.3
Percent composition and abundance of major taxonomic groups in PLOO benthic grabs sampled during 2015.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	46	46
Arthropoda (Crustacea)	22	21
Mollusca	16	15
Echinodermata	5	16
Other Phyla	10	2

Cluster group A represented a unique macrofaunal assemblage from the winter sample at southern farfield station E3 (Figure 5.5). This assemblage had the third lowest species richness (77 taxa) and lowest abundance (160 animals) of the seven cluster groups (Appendix D.5). SIMPER results cannot be calculated for a single sample, however the most abundant taxa for group A included the ophiuroids *Amphiodia digitata* (n=14) and *Amphichondrius granulatus* (n=6), as well as the ostracod *Euphilomedes producta* (n=7) and the onuphid polychaete *Diopatra tridentata* (n=7) (Appendix D.4). This assemblage was also distinguished from those in the other six cluster groups by the absence of species such as the polychaetes *Mediomastus* sp and *Chloeia pinnata* as well as the ophiuroid *Amphiodia urtica* (Figure 5.6). Compared to the other cluster groups, the sediments associated with the group A assemblage had the highest proportions of medium sand (~12%), coarse sand (~11%), and granules (~5%) as well as the lowest proportions of fines (~22%) and very fine sand (~13%) (Appendix D.5). Pea gravel, rock, and shell hash were observed in this sample (see Appendix C.4).

Table 5.4

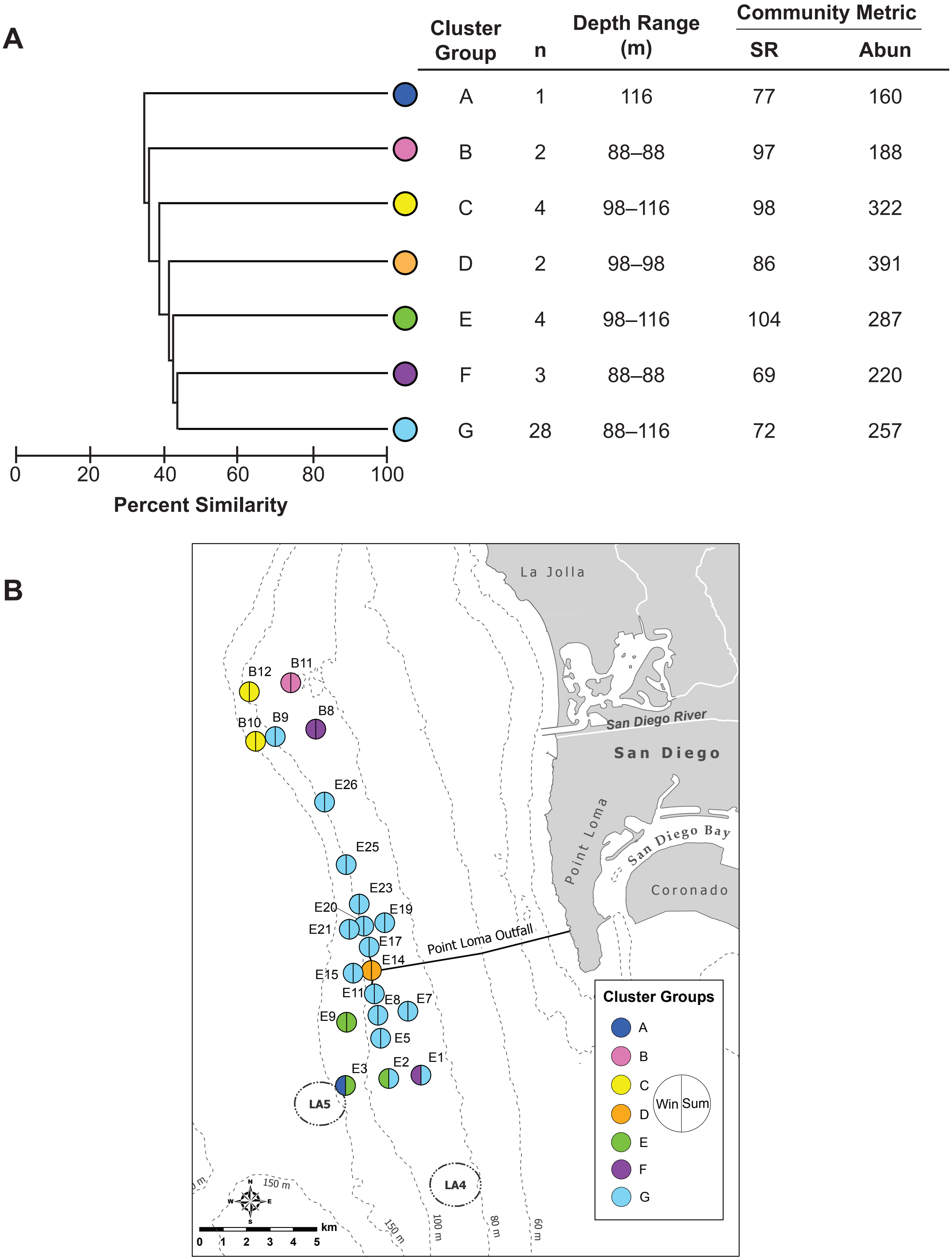
The 10 most abundant macroinvertebrate taxa collected from PLOO benthic stations during 2015. Data are expressed as percent abundance (number of individuals per species/total abundance of all species), frequency of occurrence (percentage of grabs in which a species occurred) and abundance per grab (mean number of individuals per grab, n = 88).

Species	Taxonomic Classification	Percent Abundance	Frequency of Occurrence	Abundance per Grab
Amphiodia urtica	Echinodermata: Ophiuroidea	11	93	31
Nuculana sp A	Mollusca: Bivalvia	5	95	12
Euphilomedes producta	Arthropoda: Ostracoda	4	91	12
Chaetozone hartmanae	Polychaeta: Cirratulidae	4	100	10
Euphilomedes carcharodonta	Arthropoda: Ostracoda	3	81	9
Chloeia pinnata	Polychaeta: Amphinomidae	3	72	8
Tellina carpenteri	Mollusca: Bivalvia	3	93	7
Mediomastus sp	Polychaeta: Capitellidae	3	84	7
Axinopsida serricata	Mollusca: Bivalvia	2	89	6
Praxillella pacifica	Polychaeta: Maldanidae	2	90	5

Cluster group B represented macrofaunal assemblages from both the winter and summer grabs collected in 2015 at northern farfield station B11 located on the 88-m depth contour (Figure 5.5). Mean species richness was 97 taxa per grab while mean abundance was 188 individuals per grab (Appendix D.5). The five most characteristic species of group B according to SIMPER results included the spionid polychaete *Prionospio (Prionospio) dubia* (8 per grab), the bivalve *Adontorhina cyclia* (7 per grab), the cirratulid polychaete *Chaetozone hartmanae* (5 per grab), the lumbrinerid polychaete complex *Lumbrineris* sp Group I (5 per grab), and the ampeliscid amphipod *Ampelisca pugetica* (4 per grab) (Appendix D.4). This assemblage was distinguished from other groups by the absence of the ostracods *Euphilomedes carcharodonta* and *Euphilomedes producta* (Figure 5.6). The sediments associated with these two samples averaged the second highest proportion of fines (45%) and the second lowest proportions of very fine sand (21%) and fine sand (13%) (Appendix D.5).

Cluster group C represented assemblages from the four samples collected at northern farfield stations B10 and B12 during the winter and summer of 2015 (Figure 5.5). Species richness for this assemblage averaged 98 taxa per grab, while macrofaunal abundance averaged 322 individuals per grab (Appendix D.5). The five most characteristic species in group C according to SIMPER results included three polychaetes: *Chaetozone hartmanae* (23 per grab), the capitellid *Mediomastus* sp (11 per grab), and the cirratulid *Monticellina siblina* (8 per grab). The remaining two species were both bivalves: *Tellina carpenteri* (13 per grab) and *Nuculana* sp A (12 per grab) (Appendix D.4). This assemblage was distinguished from groups A, B, and F by relatively large populations of the polychaetes mentioned above (Figure 5.6). The sediments associated with this cluster group averaged the highest proportion of fine sand (33%) and the second lowest proportion of fines (24%) (Appendix D.5).

Cluster group D represented the macrofaunal assemblages from the winter and summer grabs collected at near-ZID station E14 in 2015 (Figure 5.5). Assemblages at this site are the most likely to be impacted by wastewater discharge or other factors associated with the outfall structure. Species richness averaged 86 taxa per grab, while macrofaunal abundance averaged 391 individuals per grab, the highest number of individuals of all groups (Appendix D.5). The assemblages at this station were the only ones where BRI values were slightly higher than those characteristic of reference condition (i.e., 25−28; see Appendix D.1). The five most characteristic species of group D according to



Cluster Group	n	Depth Range (m)	Community Metric SR	Community Metric Abun
A	1	116	77	160
B	2	88–88	97	188
C	4	98–116	98	322
D	2	98–98	86	391
E	4	98–116	104	287
F	3	88–88	69	220
G	28	88–116	72	257

Figure 5.5

Results of cluster analysis macrofaunal assemblages at PLOO benthic stations sampled during 2015. Data are presented as: (A) dendrogram of main cluster groups with community metrics presented as means across all stations within a cluster group (n) and (B) distribution of cluster groups in the PLOO region. SR = species richness; Abun = abundance.

SIMPER results were the ostracods *Euphilomedes carcharodonta* (55 per grab) and *Euphilomedes producta* (23 per grab), the capitellid polychaetes *Notomastus* sp A (33 per grab) and *Mediomastus* sp (21 per grab), and the bivalve *Solemya pervernicosa* (14 per grab) (Appendix D.4). In addition to the species listed above, the presence of at least six individuals of the pollution-tolerant capitellid *Capitella teleta* in each of these two samples distinguished these assemblages from those in the other cluster groups (Figure 5.6). Cluster group D was also separated from groups E, F, and G by low numbers of the brittle star *Amphiodia urtica* (~1 per grab). The sediments associated with these two samples averaged the highest proportion of very fine sand (~50%) and had no coarse sand, very coarse sand or granules (Appendix D.5).

Cluster group E represented the macrofaunal assemblages from the winter and summer grabs collected at station E9 during 2015 as well as the winter grab from station E2 and the summer grab from station E3 (Figure 5.5). Species richness for these assemblages averaged 104 taxa per grab, which was the highest of the seven cluster groups (Appendix D.5), while the mean abundance of 287 individuals per grab was the third largest. The five most characteristic species of group E according to SIMPER results included the polychaetes *Mediomastus* sp (14 per grab), *Notomastus* sp A (11 per grab), and *Chaetozone hartmanae* (10 per grab), as well as juvenile or damaged ophiuroids identified as *Amphiodia* sp (5 per grab) and the bivalve *Ennucula tenuis* (5 per grab) (Appendix D.4). This group was also distinguished from groups A, B, and F by its relatively large population of *Euphilomedes producta* (Figure 5.6). Sediments associated with these four samples averaged the highest proportion of very coarse sand (~7%) and the second highest proportions of coarse sand (~10%) and granules (~1%) (Appendix D.5). Shell hash, black sand and gravel were also observed at these stations (see Appendix C.4).

Cluster group F represented the macrofaunal assemblages present at northern farfield station B8 during the winter and summer surveys as well as the winter sample from southern farfield station E1 (Figure 5.5). These samples averaged the lowest species richness (69 taxa per grab) and third lowest abundance (220 animals per grab) of the seven cluster groups (Appendix D.5). The top five most characteristic species for this group included the ophiuroids *Amphiodia urtica* (75 per grab) and *Amphiodia* sp (12 per grab), the maldanid *Praxillella pacifica* (6 per grab), the phoxocephalid amphipod *Rhepoxynius bicuspidatus* (5 per grab), and the spionid *Prionospio (Prionospio) dubia* (4 per grab). This assemblage was also distinguished from those in the other six cluster groups by the absence of the polychaetes *Chloeia pinnata* and *Monticellina siblina* (Figure 5.6). Compared to the other cluster groups, the sediments associated with the group F assemblage had the highest proportion of fines (59%), the lowest proportion of fine sand (~8%) and no granules (Appendix D.5).

Cluster group G represented the main group of macrofaunal assemblages present in the PLOO region during 2015, comprising about 64% of the samples analyzed during the year from 15 different monitoring stations (Figure 5.5). These included both the winter and summer samples from most primary core stations located along the 98-m discharge depth contour (i.e., stations B9, E5, E8, E11, E17, E20, E23, E25, E26), as well as stations E21 and E15 along the 116-m depth contour and stations E7 and E19 located along the 88-m contour. Additionally, the summer grabs from southern stations E2 and E1 were included in this group. Compared to the other cluster groups, the group G assemblages averaged the second lowest species richness of 72 taxa per grab and the fourth highest abundance of 257 animals per grab (Appendix D.5). The five most characteristic species according to SIMPER results were *Amphiodia urtica* (40 per grab), *Euphilomedes producta* (16 per grab), *Nuculana* sp A (14 per grab), *Chaetozone hartmanae* (10 per grab), and *Rhepoxynius bicuspidatus* (8 per grab) (Appendix D.4). Overall, the characteristics of the assemblages in cluster group G are comparable to background conditions for the PLOO monitoring region that have been described over many years (City of San Diego 2015a, b) and are generally

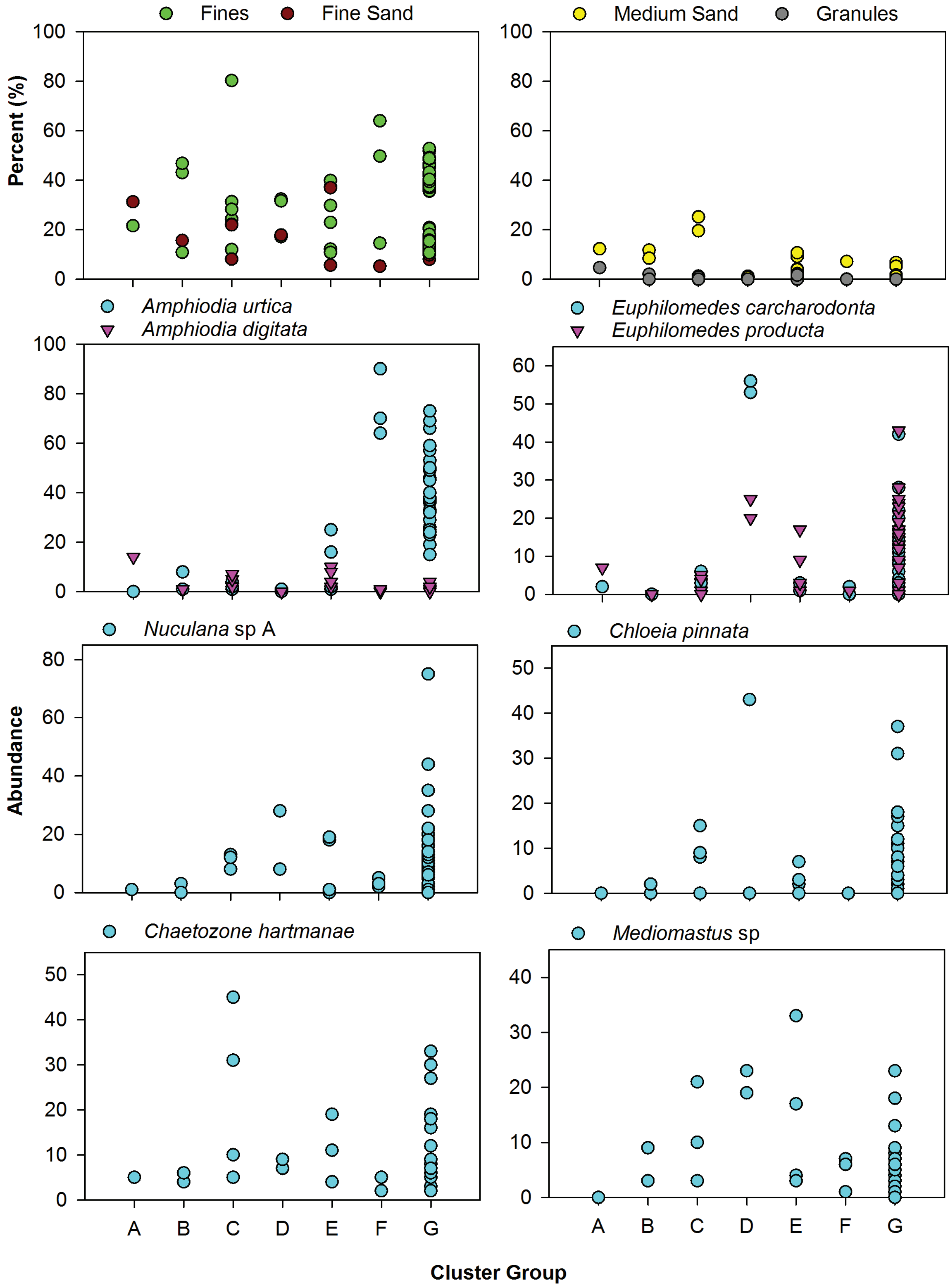


Figure 5.6
Sediment composition and abundances of select species that contributed to cluster group dissimilarities in the PLOO region during 2015 (see Figure 5.5). Each data point represents a single sediment or grab sample.

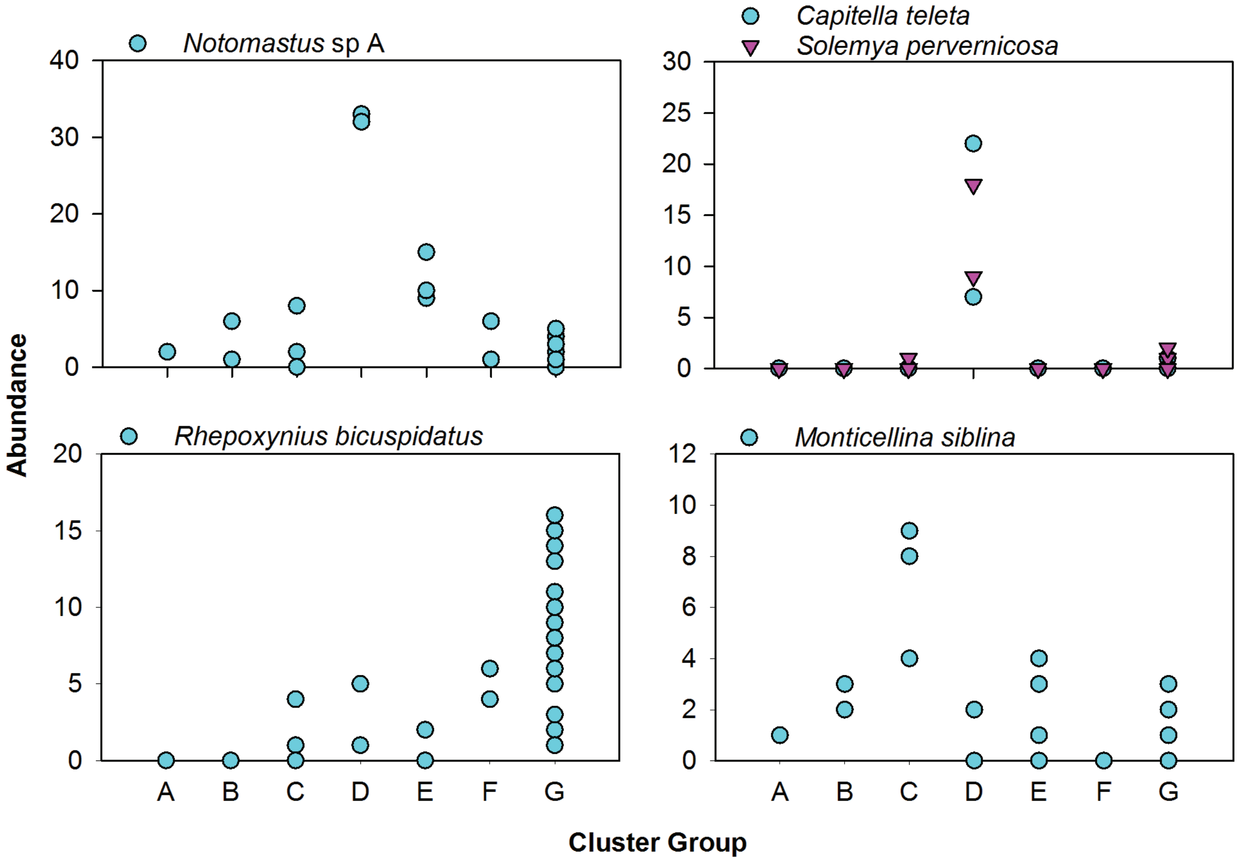


Figure 5.6 *continued*

characteristic of similar mid-shelf soft-bottom habitats in the SCB. The sediments associated with this cluster group averaged the second highest proportion of very fine sand (42%) and contained no very coarse sand or granules (Appendix D.5).

SUMMARY

Analysis of the 2015 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 2015 were similar to those encountered previously, including the 2.5 year pre-discharge monitoring period (City of San Diego 1995, 2015a). Overall, these communities remain dominated by ophiuroid-polychaete based assemblages. As in past years, the brittle star *Amphiodia urtica* was the most abundant species off Point Loma, although its population has generally decreased since monitoring began in 1991. Of the 10 most abundant species recorded during 2015, the cirratulid polychaete *Chaetozone hartmanae* was the most widespread and occurred at every station. Additionally, abundance and dominance of most species were typically within historical ranges (City of San Diego 2015a). As previously reported, most of the primary core stations along the 98-m contour had sandy sediments with a high fraction of fines that supported similar types of benthic communities. Most of the variability in individual species populations occurred at stations located several kilometers to the north and south of the outfall that had slightly higher fractions of coarse sediments. Put into a broader biogeographical context, most values for species richness, macrofaunal abundance, diversity, evenness, and dominance off Point Loma were indicative of natural ranges reported for the San Diego region (City of San Diego 2015b) and the entire SCB (Barnard and Ziesenhenne 1961, Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993b, Zmarzly et al. 1994, Diener and Fuller 1995, Bergen et al. 1998, 2000, 2001, Ranasinghe et al. 2003, 2007, 2010, 2012).

Changes in populations of pollution-sensitive or pollution-tolerant species or other indicators of benthic condition provide little to no evidence of significant environmental degradation off Point Loma. For instance, the brittle star *Amphiodia urtica* is a well-known dominant of mid-shelf, mostly fine sediment habitats in the SCB that is sensitive to changes near wastewater outfalls. Although BACIP tests reveal that populations of *A. urtica* have decreased significantly over time near the discharge site (i.e., station E14), there has also been a concomitant decrease in this species region-wide. Although long-term changes in *A. urtica* populations at near-ZID station E14 may be related to organic enrichment, factors such as increased predation pressure near the outfall may also be important. Regardless of the cause of these changes, abundances of *A. urtica* off Point Loma remain within the range of natural variation in SCB populations. Other important indicator species in the SCB are the opportunistic polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa*. During 2015, total abundances of these two species were ≤22 individuals per grab. Historically, abundances of *C. teleta* and *S. pervernicosa* have been ephemeral and remained relatively low at the nearfield stations when compared to other SCB dischargers (e.g., LACSD 2014, OCSD 2015). For example, *C. teleta* is known to reach densities as high as 500 per 0.1 m^2 in polluted sediments (e.g., Reish 1957, Swartz et al. 1986). Further, no difference in variability in populations of pollution-sensitive phoxocephalid amphipods in the genus *Rhepoxynius* have occurred at the nearfield sites compared to farfield sites, suggesting that wastewater discharge has had little to no effect on these species.

Benthic macrofaunal communities appear to be healthy and in good condition off Point Loma, with about 97% of the assemblages surveyed in 2015 classified in reference condition based on assessments using the BRI. This agrees with findings in Ranasinghe et al. (2010, 2012) who reported that at least 98% of the entire SCB mainland shelf was in good condition based on data from bight-wide surveys. Most communities near the PLOO remain similar to natural indigenous assemblages characteristic of the San Diego region (City of San Diego 2015b), although some minor changes in component species or community structure have appeared near the outfall. However, it is not currently possible to definitively determine whether these observed changes are due to habitat alteration related to organic enrichment, physical structure of the outfall, or a combination of factors. In addition, abundances of soft bottom marine invertebrates exhibit substantial natural spatial and temporal variability that may mask the effects of disturbance events (Morrisey et al. 1992a, 1992b, Otway 1995), and the effects associated with the discharge of advanced primary treated sewage may be difficult to detect in areas subjected to strong currents that facilitate rapid dispersion of the wastewater plume (Diener and Fuller 1995).

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Chapter 6

Demersal Fishes and Megabenthic Invertebrates

Chapter 6. Demersal Fishes and Megabenthic Invertebrates

Introduction

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

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

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

This chapter presents analysis and interpretation of demersal fish and megabenthic invertebrate data collected during calendar year 2015, as well as long-term assessments of these communities from 1991 through 2015. The primary goals are to: (1) document assemblages present during the year; (2) determine the presence or absence of biological impacts associated with wastewater discharge; (3) identify other potential natural and anthropogenic sources of variability to the local marine ecosystem.

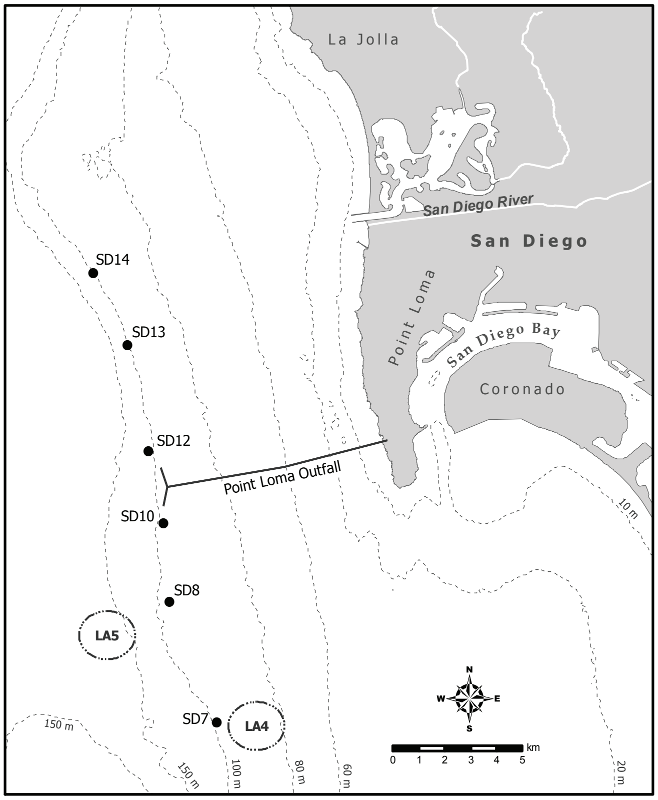


Figure 6.1
Trawl station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

MATERIALS AND METHODS

Field Sampling

Trawl surveys were conducted at six monitoring stations in the PLOO region sampled during winter (January) and summer (August) 2015 (Figure 6.1). These stations, designated SD7–SD14, are all located along the 100-m depth contour ranging from 9 km south to 8 km north of the PLOO. Stations SD10 and SD12 are located within 1000 m of the outfall wye, and represent the "nearfield" station group. Stations SD7 and SD8 are located > 3.6 km south of the outfall and represent the "south farfield" station group, while SD13 and SD14 are located > 4.7 km north of the outfall and represent the "north farfield" station group.

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

Data Analyses

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

Multivariate analyses were performed in PRIMER v7 software using demersal fish

Table 6.1

Demersal fish species collected from 12 trawls conducted in the PLOO region during 2015. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO
Pacific Sanddab	53	100	234	234
Halfbanded Rockfish	20	100	88	88
Longspine Combfish	7	100	33	33
California Lizardfish	3	83	13	16
Yellowchin Sculpin	2	75	10	14
Stripetail Rockfish	2	100	10	10
Squarespot Rockfish	2	8	10	117
English Sole	1	92	6	7
Shortbelly Rockfish	1	25	4	15
Pink Seaperch	1	75	3	5
Shortspine Combfish	1	92	3	4
Plainfin Midshipman	1	58	3	5
Greenstriped Rockfish	1	50	3	6
California Scorpionfish	1	100	3	3
Vermilion Rockfish	1	17	2	14
Dover Sole	1	67	2	4
Hornyhead Turbot	<1	67	2	2
Unidentifed Rockfish	<1	33	1	4
California Tonguefish	<1	58	1	2
California Skate	<1	67	1	1
Pacific Argentine	<1	17	1	6
Bigmouth Sole	<1	50	1	1
Blackbelly Eelpout	<1	25	1	2
Slender Sole	<1	17	<1	3
Bluebanded Ronquil	<1	8	<1	3
Longfin Sanddab	<1	17	<1	2
Roughback Sculpin	<1	17	<1	2
Blackeye Goby	<1	17	<1	1
Greenspotted Rockfish	<1	17	<1	1
Spotfin Sculpin	<1	8	<1	2
Basketweave Cusk-eel	<1	8	<1	1
Blacktip Poacher	<1	8	<1	1
Chilipepper	<1	8	<1	1
Specklefin Midshipman	<1	8	<1	1
Threadfin Sculpin	<1	8	<1	1

and megabenthic invertebrate data collected from 1991 through 2015 (see Clarke 1993, Warwick 1993, Clarke et al. 2014). Prior to these analyses, all data were limited to summer surveys only to reduce statistical noise from natural seasonal variations evident in previous studies (e.g., City of San Diego 1997, 2013). Analyses included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). The Bray-Curtis measure of similarity was used as the basis for the cluster analysis, and abundance data were square-root transformed to lessen the influence of the most abundant species and increase the importance of rare species. Major ecologically-relevant clusters receiving SIMPROF support were retained, and similarity percentages analysis (SIMPER) was used to determine which species were responsible for the greatest contributions to within-group similarity (i.e., characteristic species).

Results and Discussion

Demersal Fishes

Community Parameters

At least 35 species of fish were collected in the PLOO monitoring region in 2015, representing 17 different families (Table 6.1, Appendices E.1, E.2). A total of 5243 individual fish were collected during the winter and summer trawls combined, which represents an average of ~437 fish per trawl. This total catch for 2015 was about 3% larger than the catch for 2014 (City of San Diego 2015b). The two most abundant species encountered during 2015 included Pacific Sanddabs within the family Paralichthyidae and Halfbanded Rockfish within the family Sebastidae (Table 6.1, Appendix E.1). Together these two species accounted for 73% of all fish captured during the year. Pacific Sanddabs continued to dominate PLOO fish assemblages, occurring in every haul and accounting for 53% of all fish collected (mean = 234 fish per haul). This average catch of Pacific Sanddabs represents about a 39% increase compared to 2014. Halfbanded Rockfish was the second most abundant and common species present in 2015, occurring in 100% of the trawls and accounting for 20% of the fish collected (mean = 88 fish per haul). This represents about a 62% increase in Halfbanded Rockfish abundances reported for 2014. Other species collected in all of the trawls, but in relatively low numbers (≤33 fish per haul), included Longspine Combfish, Stripetail Rockfish, and California Scorpionfish. Additionally, California Lizardfish, Yellowchin Sculpin, English Sole, Pink Seaperch, Shortspine Combfish, Plainfin Midshipman, Greenstriped Rockfish, Dover Sole, Hornyhead Turbot, California Tonguefish, California Skate, and Bigmouth Sole all occurred in at least 50% of the trawls in numbers ≤ 13 fish per haul. No new species of fish were reported during the 2015 surveys.

More than 99% of the fishes collected in 2015 were ≤25 cm in length (Appendix E.1). Larger fishes included one Bigmouth Sole (26 cm), four Vermillion Rockfish (28–32 cm), and seven California Skate (32–54 cm). Median lengths per haul of the four most abundant species collected in 2015 ranged from 6 to 14 cm for Pacific Sanddab, 7 to 14 cm for Halfbanded Rockfish, 7 to 13 cm for Longspine Combfish, and 12 to 21 cm for California Lizardfish (Figure 6.2). Several seasonal and site differences were observed during the past year. For example, the largest Pacific Sanddabs with median lengths ≥10 cm per haul were collected from all stations during the winter, but were limited to station SD14 during the summer. In contrast, Pacific Sanddabs collected from stations SD7–SD13 during the summer had median lengths 6–7 cm per haul. Median lengths for Halfbanded Rockfish were consistent across all stations over the summer (9–10 cm per haul), but ranged widely during the winter from 7 cm per haul at stations SD7, SD10, and SD13 to 14 cm per haul at station D14. The largest Longspine Combfish with median lengths ≥12 cm per haul were collected from stations SD7 and SD8 during the winter, and from stations SD8 and SD14 during the summer. The largest California Lizardfish with median lengths ≥16 cm per haul were collected from station SD8 during the winter, and from stations SD8, SD10, SD13, and SD14 during the summer. No California Lizardfish were collected from stations SD7 and SD12 in the summer.

Species richness and diversity were consistently low for demersal fish communities sampled during 2015, as is typical for the region (e.g., Allen et al. 1998, 2002, 2007, 2011, City of San Diego 1995, 1998). Species richness ranged from 12 species per haul at station SD12 (both surveys) to 20 species per haul at station SD8 during the summer (Table 6.2). Diversity (H') ranged from 0.9 to 1.8 per haul, with the lowest values recorded at stations SD7, SD12, and SD13 during the summer, and the highest value recorded at station SD10 during the winter. In contrast, abundance and biomass were much more variable among stations and between surveys during the year. For example, total abundance ranged from 180 to 1060 individuals per haul, and total biomass ranged from 5.7 to 57.5 kg. The smallest hauls with ≤296 individuals were from stations SD8, SD10, SD12, and SD13 in the winter. The largest hauls with ≥536 individuals were from station SD14 in the winter, and stations SD10, SD13, and SD14 in the summer. The largest winter catch included 689 Halfbanded Rockfish, while the largest summer catches included ≥396 Pacific Sanddabs (Appendix E.2). Hauls from station SD14 in the winter and stations SD13 and SD14 in the summer were also the heaviest, weighing ≥12.2 kg per haul (Table 6.2). The total weight of 57.5 kg for the trawl from station SD14 reflected the 32.5 kg of sizable Halfbanded Rockfish collected at that station during the winter (see above, and Appendix E.3).

Over the past 25 years, mean species richness and diversity values for demersal fishes have remained below 23 and 1.9 per haul, respectively, whereas there has been considerably greater variability in mean abundance (i.e., 97–1065 fishes per haul) (Figure 6.3). The latter has largely been due to population fluctuations of a few numerically dominant species (Figure 6.4). For example, differences in overall fish abundance primarily track changes in Pacific Sanddab populations, since this species has been numerically dominant in the PLOO

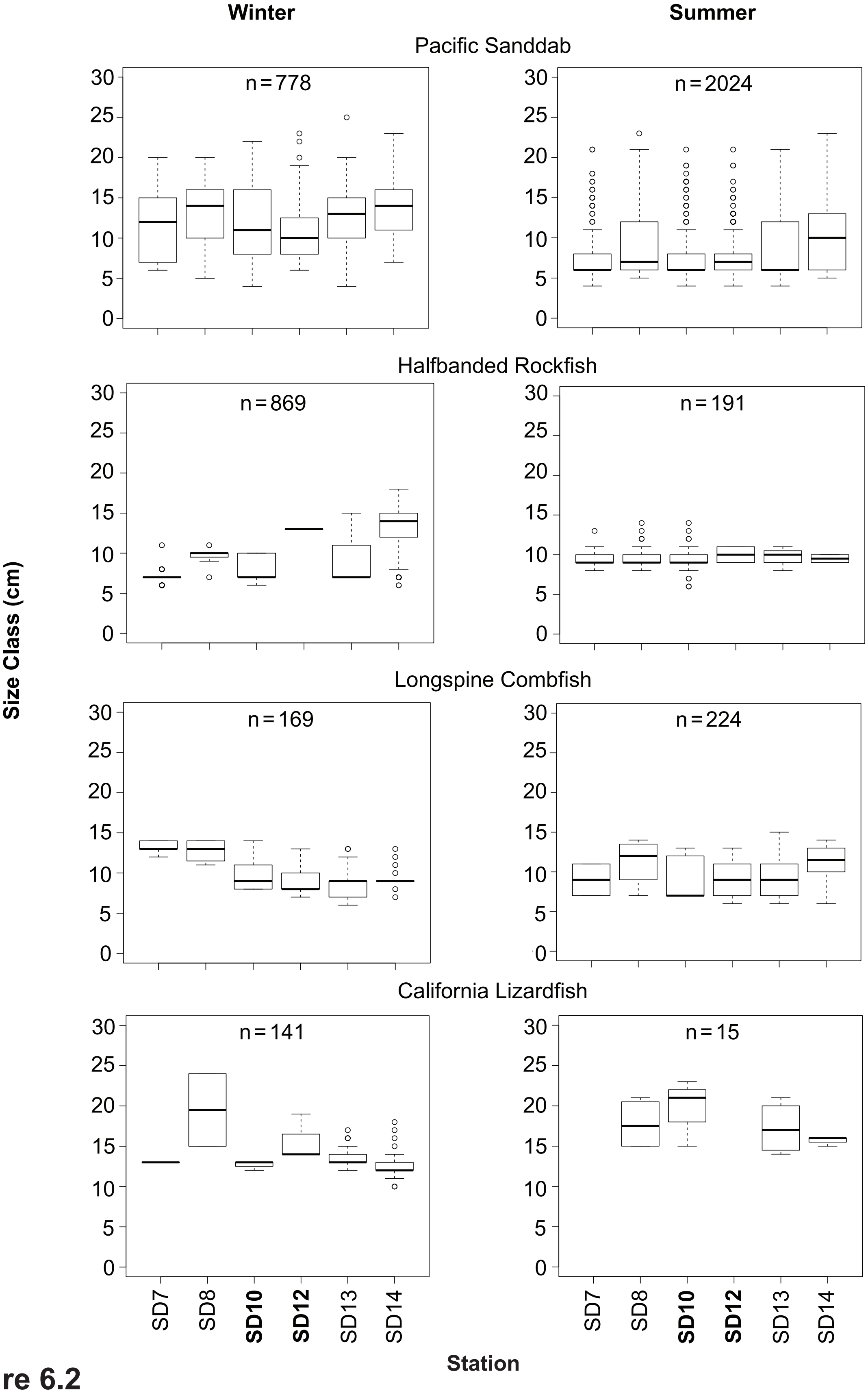


Figure 6.2

Summary of fish lengths by survey and station for each of the four most abundant species collected in the PLOO region during 2015. 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.

Table 6.2

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

Station	Winter	Summer
Species Richness		
SD7	16	13
SD8	18	20
SD10	16	18
SD12	12	12
SD13	15	18
SD14	15	19
Survey Mean	15	17
Survey SD	2	3
Abundance		
SD7	362	311
SD8	237	421
SD10	296	541
SD12	180	363
SD13	282	654
SD14	1060	536
Survey Mean	403	471
Survey SD	328	128
Diversity		
SD7	1.5	0.9
SD8	1.0	1.6
SD10	1.8	1.2
SD12	1.3	0.9
SD13	1.7	0.9
SD14	1.3	1.1
Survey Mean	1.4	1.1
Survey SD	0.3	0.3
Biomass		
SD7	7.5	8.1
SD8	9.4	12.0
SD10	8.7	7.5
SD12	5.7	9.2
SD13	6.5	12.2
SD14	57.5	11.2
Survey Mean	15.9	10.0
Survey SD	20.4	2.0

region since sampling began (see following section and City of San Diego 2015a). In addition, occasional spikes in abundance have been due to large hauls of other common species such as Yellowchin Sculpin, Halfbanded Rockfish, Longspine Combfish, California Lizardfish, Stripetail Rockfish, Plainfin Midshipman, and Longfin Sanddab. Overall, none of the observed changes appear to be associated with wastewater discharge.

Classification of Demersal Fish Assemblages

Classification (cluster) analysis discriminated between 11 main types of fish assemblages in the Point Loma outfall region over the past 25 years (cluster groups A–K; Figure 6.5, Table 6.3). These included seven small groups representative of one to nine hauls each (groups A–E, H, I), and four larger groups ranging from 15 to 40 hauls each and representing ~84% of all trawls (groups F, G, J, K). The distribution of assemblages in 2015 (see description of groups G and H below) was generally similar to those observed from 2010 through 2013, 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, there was a shift in assemblages after 2008 that reflected increased numbers of California Lizardfish in the region. Additionally, assemblages from stations SD7 and SD8 located south of the outfall often grouped apart from the remaining stations between 1993 and 2007. The species composition and main descriptive characteristics of each cluster group are described below.

Cluster groups A, B, C and E each represented a unique demersal fish assemblage sampled at one of the nearfield stations (Figure 6.5). The assemblage represented by group A occurred at station SD10 in 1997 and had the lowest species richness (n=7), lowest total abundance (n=44), and the lowest number of Pacific Sanddab of any cluster group (n=23) (Table 6.3). The assemblage represented by group B occurred at station SD12 in 1998 and had 16 species and 261 individuals, and the highest numbers of Plainfin Midshipman (n=116), Dover Sole (n=36), and Bigfin Eelpout (n=4) of any group. The assemblage represented by group C occurred at station SD12 in 1997 and had the highest species richness (n=19), 231 individuals, and the highest numbers of Halfbanded Rockfish (n=60), Squarespot Rockfish (n=23), Greenblotched Rockfish (n=8), and Vermilion Rockfish (n=6). The assemblage represented by group E occurred at station SD12 in

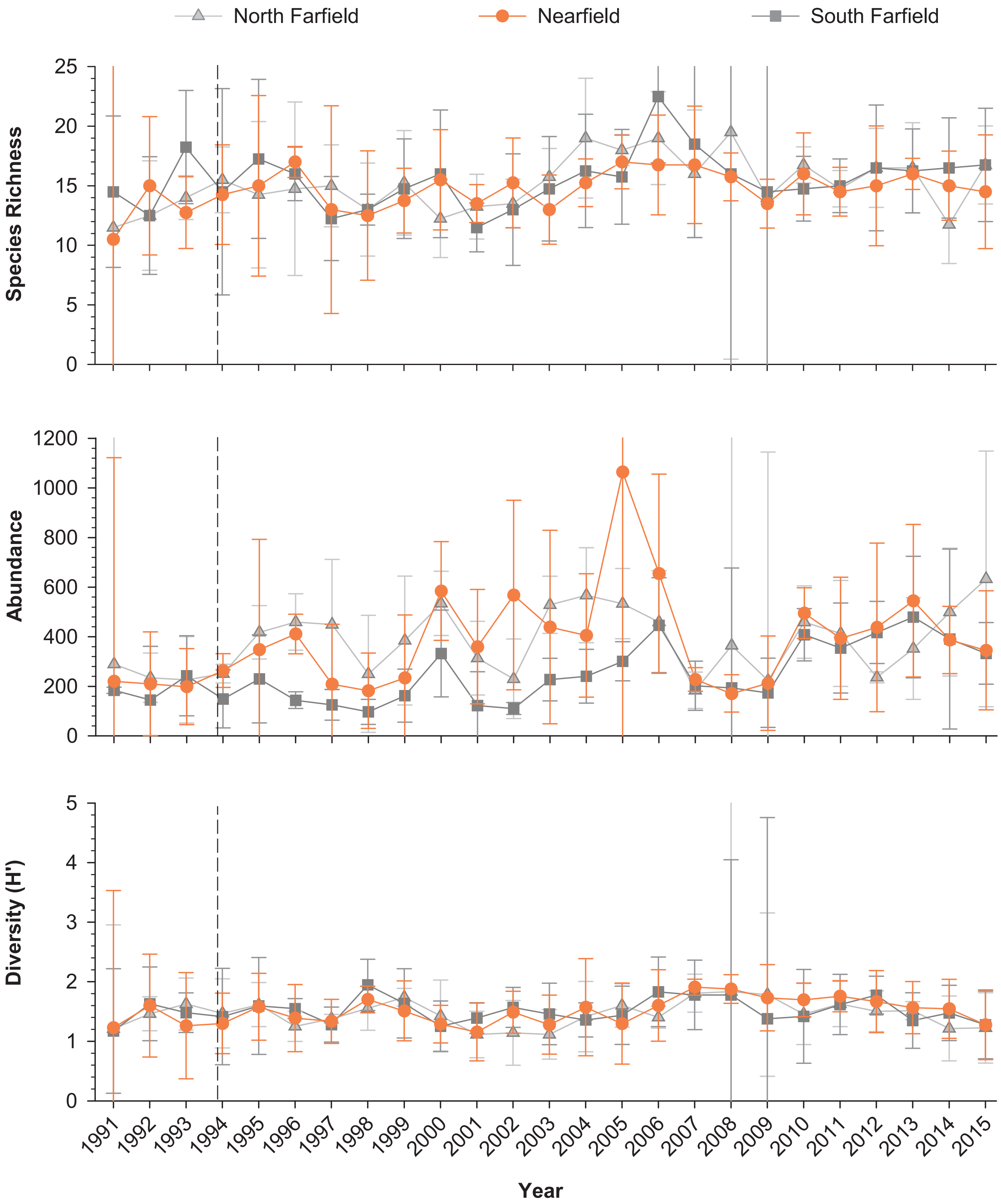


Figure 6.3

Species richness, abundance, and diversity of demersal fishes collected from PLOO trawl stations sampled from 1991 through 2015. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤4), and south farfield stations (n≤4). Dashed lines indicate onset of wastewater discharge in November 1993.

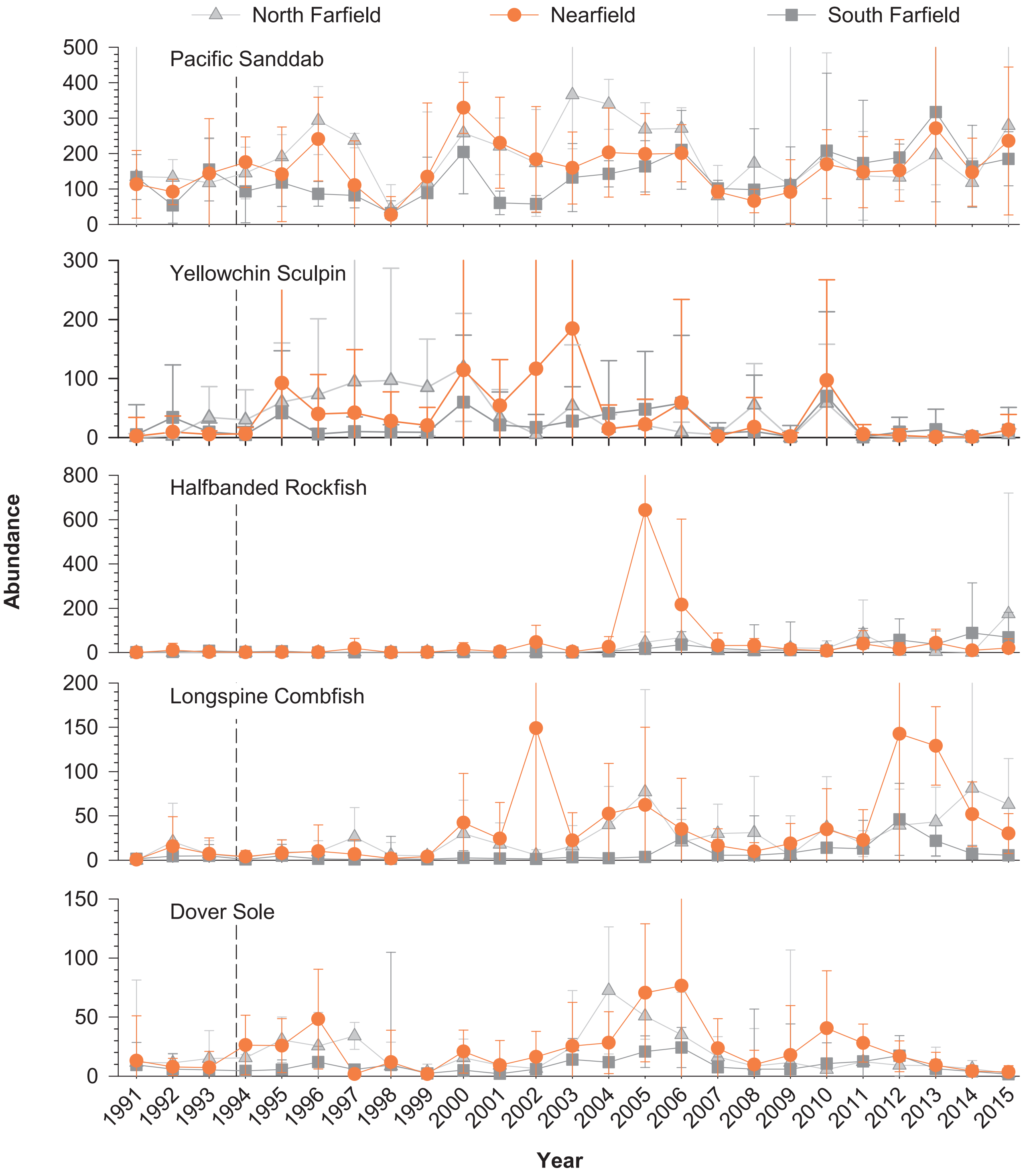


Figure 6.4

The ten most abundant fish species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2015. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤4), and south farfield stations (n≤4). Dashed lines indicate onset of wastewater discharge in November 1993.

2011 and had 13 species, 190 individuals, the second lowest number of Pacific Sanddab (n=68), the highest number of Hornyhead Turbot (n=6), and the second highest number of Stripetail Rockfish (n=20).

Cluster group D represented assemblages from a total of nine hauls collected in either 2009 or 2014 (Figure 6.5). This group averaged 13 species and 267 individuals per haul (Table 6.3).

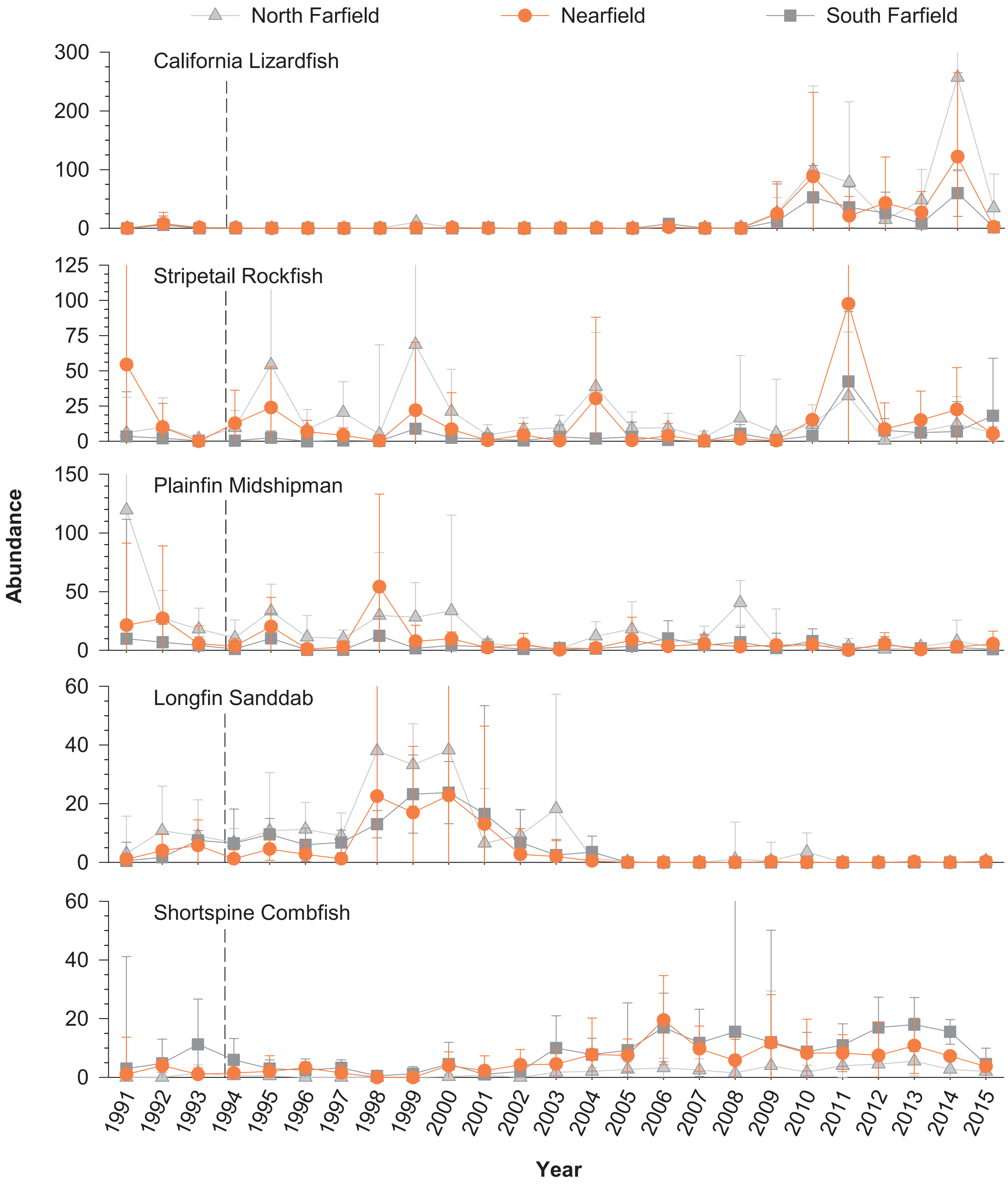


Figure 6.4 *continued*

Group D had the highest number of California Lizardfish per haul (n = 125) relative to the other cluster groups. This species, along with Pacific Sanddab (95 per haul), Shortspine Combfish (8 per haul), Longspine Combfish (7 per haul), and Dover Sole (6 per haul), were the most characteristic species of group D according to SIMPER results.

Cluster group F comprised 15 of the 27 trawls conducted at stations SD8, SD10, SD12, SD13 and SD14 between 2003 and 2008, 67% of which

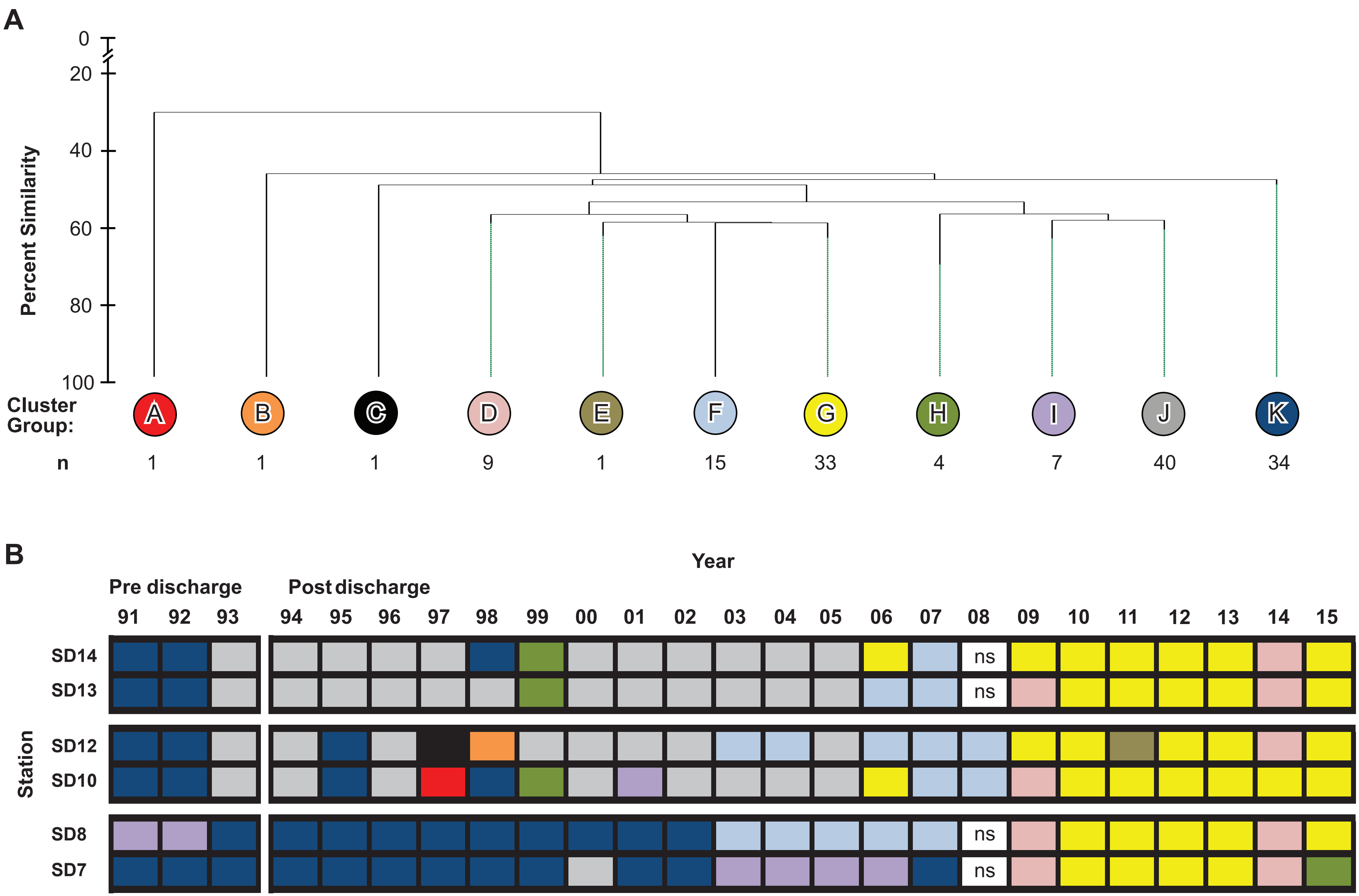


Figure 6.5
Results of cluster analysis of demersal fish assemblages from PLOO trawl stations sampled from 1991 through 2015. Data are limited to summer surveys and are presented as (A) a dendrogram of main cluster groups and (B) a matrix showing distribution of cluster groups over time; n = number of hauls; ns = not sampled.

Table 6.3

Description of demersal fish cluster groups A–K defined in Figure 6.6. Values highlighted in gray indicate species that account for up to 95% of intra-group similarity according to SIMPER analysis; the top five most characteristic species for each group are highlighted in yellow.

	Cluster Group										
	A[a]	B[a]	C[a]	D	E[a]	F	G	H	I	J	K
Number of Hauls	1	1	1	9	1	15	33	4	7	40	34
Mean Species Richness	7	16	19	13	13	16	16	16	15	15	13
Mean Abundance	44	261	231	267	190	250	465	449	223	375	151
Species	Mean Abundance										
Pacific Sanddab	23	75	110	**95**	68	**136**	**268**	**243**	**149**	**252**	**91**
California Lizardfish	0	0	0	**125**	18	<1	**35**	5	<1	0	<1
Dover Sole	0	36	1	**6**	31	**24**	**19**	4	**16**	**34**	**9**
Longspine Combfish	0	7	2	**7**	17	**12**	**39**	4	4	**17**	<1
Shortspine Combfish	0	0	3	**8**	7	**12**	9	<1	**7**	2	2
Yellowchin Sculpin	0	0	0	<1	0	<1	2	**24**	**20**	**15**	3
Stripetail Rockfish	0	1	5	3	20	2	10	**91**	<1	**9**	8
Plainfin Midshipman	0	116	4	1	0	4	3	20	**3**	9	**13**
Halfbanded Rockfish	16	0	60	11	0	**25**	**54**	**9**	6	7	2
Longfin Sanddab	1	0	0	0	0	<1	<1	**24**	0	5	**6**
California Tonguefish	0	0	1	<1	0	2	<1	2	1	<1	**3**
Slender Sole	0	2	0	1	2	8	2	5	2	6	1
Pink Seaperch	1	4	1	3	1	3	5	3	3	5	<1
Bay Goby	0	0	0	0	0	<1	0	<1	<1	3	1
English Sole	0	3	1	1	4	3	5	2	<1	2	1
Greenblotched Rockfish	0	0	8	0	1	<1	<1	1	2	1	<1
Bigmouth Sole	0	0	1	<1	0	<1	1	<1	<1	<1	<1
Roughback Sculpin	0	2	0	<1	0	<1	<1	0	3	<1	<1
Greenstriped Rockfish	0	0	0	<1	4	4	2	<1	1	<1	<1
Hornyhead Turbot	0	1	1	1	6	2	<1	0	<1	<1	<1
Gulf Sanddab	1	5	0	0	0	0	0	7	<1	<1	<1
Bigfin Eelpout	0	4	0	0	0	<1	<1	0	0	<1	0
Vermilion Rockfish	0	0	6	0	0	0	0	<1	0	0	0
Squarespot Rockfish	0	0	23	0	11	<1	<1	0	0	0	<1

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

were from stations SD8 and SD12 (Figure 6.5). Assemblages represented by this group averaged 16 species and 250 individuals per haul (Table 6.3). SIMPER results indicated that the most characteristic species of group F included Pacific Sanddab (136 per haul), Halfbanded Rockfish (25 per haul), Dover Sole (24 per haul), Longspine Combfish (12 per haul), and Shortspine Combfish (12 per haul).

Cluster group G was the third largest cluster group, representing assemblages from a total of 33 hauls that included all but one of the trawls (i.e., station SD7) conducted during 2015 (Figure 6.5). This group also represented assemblages from 96% (n=23) of the trawls conducted at all stations sampled from 2010 through 2013, as well as the trawls from station SD10 and station SD14 in 2006, the trawls from station SD12 and station SD14 in 2009, and the trawl from station SD10 in 2014. These assemblages averaged 16 species and 465 individuals per haul (Table 6.3). Group G had the highest number of Pacific Sanddabs at 268 fish per haul. Pacific Sanddabs, along with Halfbanded Rockfish (54 per haul), California Lizardfish (35 per haul), Longspine Combfish (39 per haul), and Dover Sole (19 per haul), were the most characteristic species of group G according to SIMPER results.

Cluster group H comprised the assemblages from four hauls, including the trawl from station SD7 in 2015, as well as the trawls from stations SD10, SD13 and SD14 during 1999 (Figure 6.5). This group averaged 16 species and 449 fish per haul (Table 6.3). Group H had the third highest number of Pacific Sanddab (243 per haul) and the highest numbers of Stripetail Rockfish (91 per haul), Longfin Sanddab (24 per haul), and Yellowchin Sculpin (24 per haul) of any cluster group. Halfbanded Rockfish, with 9 individuals per haul, rounded out the top five most characteristic species of this group according to SIMPER results.

Cluster group I represented assemblages from seven hauls that included station SD7 sampled in 2003–2006, station SD8 sampled in 1991–1992, and station SD10 sampled in 2001 (Figure 6.5). These assemblages averaged 15 species of fish, 223 individuals, and 149 Pacific Sanddab per haul (Table 6.3). In addition to Pacific Sanddab, SIMPER results indicated that the most characteristic species of group I were Yellowchin Sculpin (20 per haul), Dover Sole (16 per haul), Shortspine Combfish (7 per haul), and Plainfin Midshipman (3 per haul).

Cluster group J was the largest group, representing assemblages from a total of 40 hauls that included 75% (n=39) of the trawls conducted at stations SD10, SD12, SD13 and SD14 from 1993 through 2005, as well as the trawl conducted at station SD7 in 2000 (Figure 6.5). Group J averaged 15 species and 375 individuals per haul (Table 6.3). This group the second highest number of Pacific Sanddab (252 per haul). According to SIMPER results, the most characteristic species of these assemblages also included Dover Sole (34 per haul), Longspine Combfish (17 per haul), Yellowchin Sculpin (15 per haul) and Stripetail Rockfish (9 per haul).

Cluster group K was the second largest group, representing assemblages from a total of 34 hauls that included 88% (n=21) of the trawls conducted at south farfield stations SD7 and SD8 from 1991 through 2002 (Figure 6.5). This group also included all of the trawls from stations SD10, SD12, SD13, and SD14 sampled in 1991 and 1992, the trawls from stations SD10 and SD12 sampled in 1995, the trawls from stations SD10 and SD14 sampled in 1998, and the trawl from station SD7 sampled in 2007. These assemblages averaged 13 species, 151 individuals, and 91 Pacific Sanddab per haul (Table 6.3). Along with Pacific Sanddabs, Plainfin Midshipman (13 per haul), Dover Sole (9 per haul), Longfin Sanddab (6 per haul), and California Tonguefish (3 per haul) were the most characteristic species of these assemblages according to SIMPER results.

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the PLOO region during 2015. There were no incidences of fin rot, skin lesions, or tumors on any fish sampled during the year. Evidence of parasitism was very low (0.8%) for trawl-caught fishes in the region. The copepod *Phrixocephalus cincinnatus* infected 1.5% of the Pacific Sanddabs (42 individuals) collected during the year. This eye parasite was found on fish from all stations. Additionally, 36 individuals of the cymothoid isopod gill parasite *Elthusa vulgaris* were identified as part of the trawl invertebrate catches during the year (see Appendices E.4, E.5). Since *E. vulgaris* often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these 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 15,935 megabenthic invertebrates (~1328 per trawl) representing 39 taxa from six phyla were collected in 2015 (Table 6.4, Appendices E.4, E.5). Overall, the total catch in 2015 was 22% smaller than in 2014 (City of San Diego 2015b), and continued to be dominated by echinoderms. The sea urchin *Lytechinus pictus* occurred in every haul

Table 6.4

Megabenthic invertebrates collected from 12 trawls conducted in the PLOO region during 2015. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO
Lytechinus pictus	87	100	1159	1159
Ophiura luetkenii	6	75	78	104
Strongylocentrotus fragilis	3	25	36	142
Ophiothrix spiculata	1	25	14	55
Sicyonia ingentis	1	100	11	11
Acanthoptilum sp	<1	42	6	15
Florometra serratissima	<1	17	6	36
Pleuroncodes planipes	<1	25	3	14
Elthusa vulgaris	<1	83	3	4
Astropecten californicus	<1	58	2	3
Parastichopus californicus	<1	92	2	2
Luidia asthenosoma	<1	58	2	3
Luidia foliolata	<1	67	1	2
Octopus rubescens	<1	58	1	2
Thesea sp B	<1	42	1	3
Armina californica	<1	25	1	3
Ophiopteris papillosa	<1	8	<1	5
Metridium farcimen	<1	8	<1	4
Pleurobranchaea californica	<1	33	<1	1
Platymera gaudichaudii	<1	25	<1	1
Barbarofusus barbarensis	<1	17	<1	1
Cancellaria cooperii	<1	17	<1	1
Orthopagurus minimus	<1	8	<1	2
Paguristes turgidus	<1	17	<1	1
Pyromaia tuberculata	<1	17	<1	1
Acanthascininae	<1	8	<1	1
Aphrodita refulgida	<1	8	<1	1
Calinaticina oldroydii	<1	8	<1	1
Calliostoma turbinum	<1	8	<1	1
Luidia armata	<1	8	<1	1
Metacarcinus anthonyi	<1	8	<1	1
Moloha faxoni	<1	8	<1	1
Neocrangon zacae	<1	8	<1	1
Paguristes bakeri	<1	8	<1	1
Pagurus armatus	<1	8	<1	1
Platydoris macfarlandi	<1	8	<1	1
Podochela lobifrons	<1	8	<1	1
Simnia barbarensis	<1	8	<1	1
Suberites latus	<1	8	<1	1

and was the most abundant invertebrate overall, averaging 1159 individuals per haul and accounting for ~87% of the total abundance. No other species contributed to more than 6% of the total catch. For example, the shrimp *Sicyonia ingentis* also occurred in every trawl, but averaged just 11 individuals per haul. Other species collected during the year that occurred in at least 50% of the trawls but in low numbers (i.e., ≤78 per haul) included the brittle star *Ophiura luetkenii*, the sea stars *Astropecten californicus, Luidia asthenosoma* and *Luidia foliolata*, the sea cucumber *Parastichopus californicus*, the cephalopod *Octopus rubescens*, and the cymothoid isopod *Elthusa vulgaris*. One species not previously reported for the region by the City's monitoring program was encountered during the 2015 PLOO surveys: a sponge in the subfamily Acanthasciniae was collected in January at station SD14 (Appendices E.1, E.2).

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.5). For each haul, species richness ranged from 8 to 15 species, and total abundance ranged from 61 to 3420 individuals. The lowest species richness values (≤10) during 2015 were recorded at station SD7 (winter only) and at station SD14 (both surveys), while the highest value was recorded at station SD7 in the summer. Patterns of total invertebrate abundance mirrored variation in populations of *Lytechinus pictus* because of the overwhelming dominance of this sea urchin (Appendix E.5). For example, high invertebrate abundances with ≥ 1124 individuals per haul reflected large hauls of *L. pictus* (i.e., 1002–3370 per haul) recorded at station SD12 in the winter and stations SD7, SD8, and SD10 during the both winter and summer surveys. In addition, large numbers of the brittle star *Ophiura luetkenii* at station SD7 (i.e., 808 per haul) and the urchin *Strongylocentrotus fragilis* at station SD14 (i.e., 328 per haul) contributed to high total abundances during the summer survey. The low diversity values (≤ 1.5) observed throughout the PLOO region during

Table 6.5

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

Station	Winter	Summer
Species Richness		
SD7	10	15
SD8	12	11
SD10	13	14
SD12	12	11
SD13	13	11
SD14	8	9
Survey Mean	11	12
Survey SD	2	2
Abundance		
SD7	1124	2139
SD8	3420	2493
SD10	1125	2387
SD12	1191	400
SD13	785	302
SD14	61	508
Survey Mean	1284	1372
Survey SD	1128	1069
Diversity		
SD7	0.5	1.1
SD8	0.1	0.2
SD10	0.3	0.2
SD12	0.2	0.2
SD13	0.4	1.1
SD14	1.5	0.8
Survey Mean	0.5	0.6
Survey SD	0.5	0.5

2015 were caused by the numerical dominance of *L. pictus*, *O. luetkenii* and *S. fragilis*.

As described for demersal fishes, large fluctuations in the abundances of a few numerically dominant species have contributed to the high variation in trawl-caught invertebrate community structure in the Point Loma outfall region since 1991 (Figure 6.6, 6.7). Over the years, mean species richness has remained below 24 per haul and mean diversity has remained below 1.4 per haul, whereas there has been considerably greater variability in mean abundance (i.e., 79–5613 individuals per haul). Differences in overall invertebrate abundance, especially at the 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 2015a). Other influential species include the sea pen *Acanthoptilum* sp, the sea urchin *Strongylocentrotus fragilis,* and more recently the brittle star *Ophiura luetkenii*. For example, fluctuations of *S. fragilis* populations have contributed greatly to changes in total abundance at the north farfield stations and occasionally at the nearfield 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.

Classification Analysis of Invertebrate Assemblages

Classification (cluster) analysis discriminated between four main types of invertebrate assemblages in the outfall region over the past 25 years (cluster groups A–D; Figure 6.8, Table 6.6). These included one small group representing four hauls (group A), one small group representing a single haul (group B), and two larger groups that together represented ~96% of all trawls (groups C and D). The distribution of assemblages in 2015 (see group C and D descriptions below) was generally similar to that seen in previous years, and there continued to be no discernible patterns associated with proximity to the outfall. Instead, the PLOO trawl-caught invertebrate 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.

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

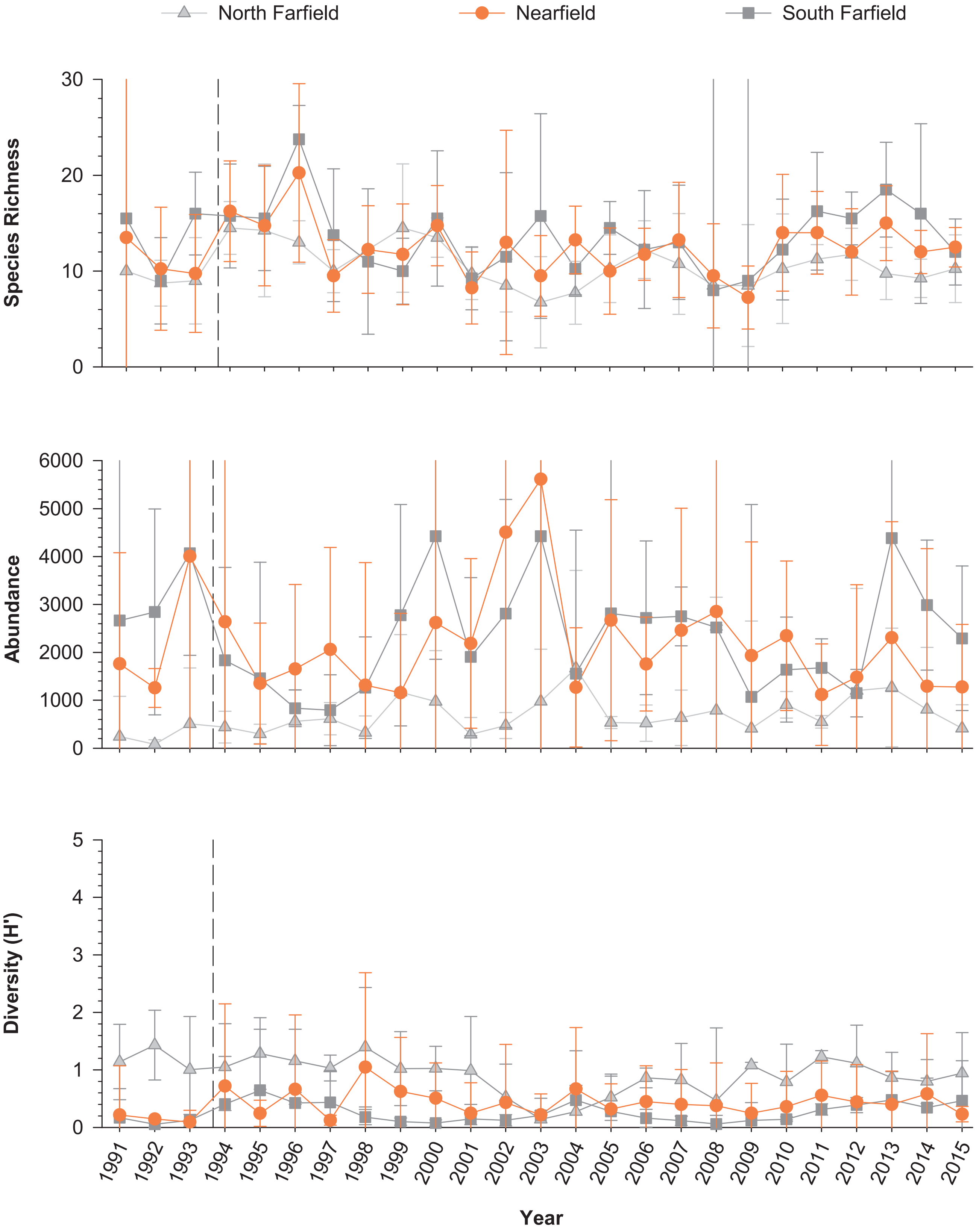


Figure 6.6

Species richness, abundance, and diversity of megabenthic invertebrates collected from PLOO trawl stations from 1991 through 2015. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤4), and south farfield stations (n≤4). Dashed lines indicate onset of wastewater discharge in November 1993.

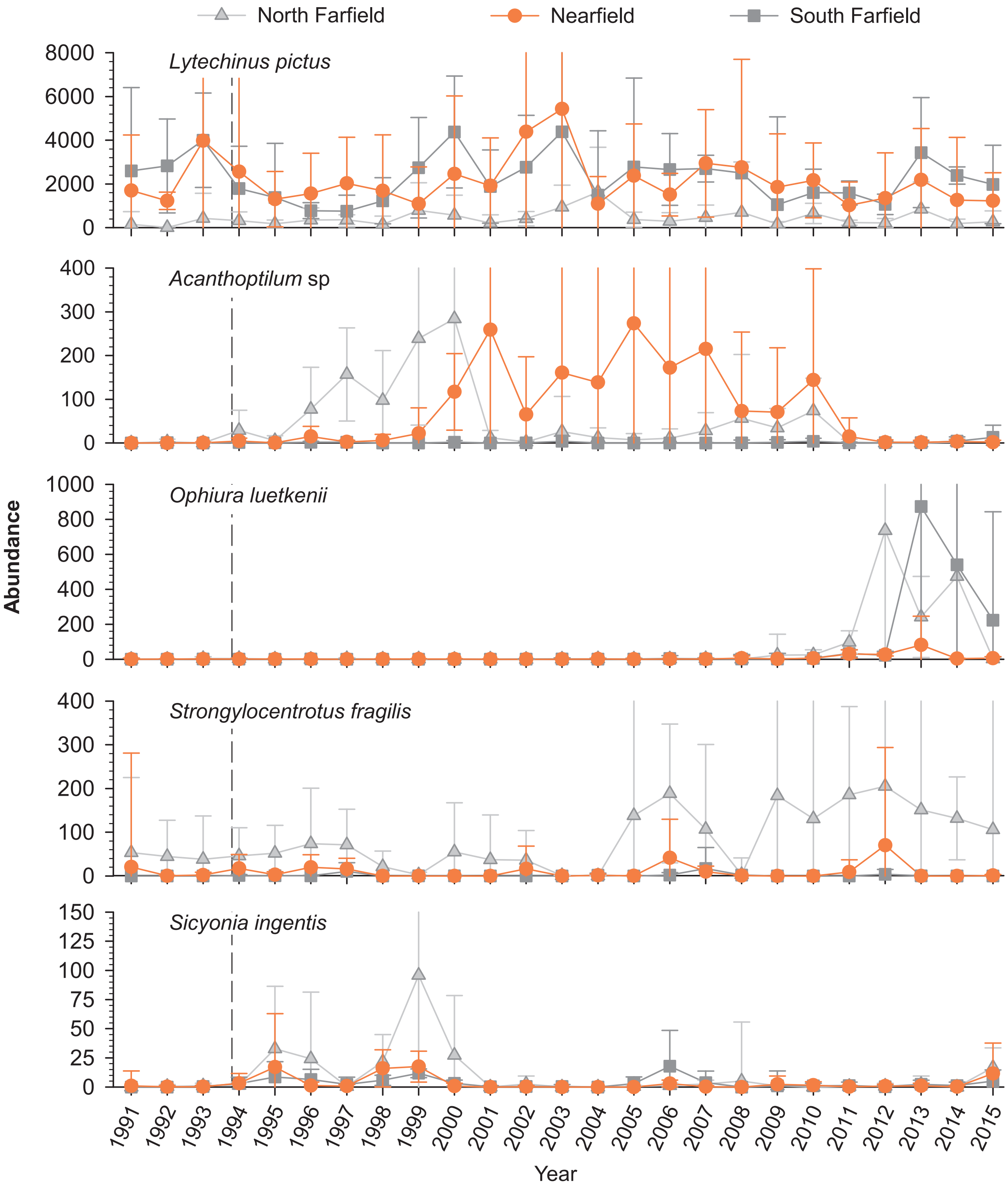


Figure 6.7

The ten most abundant invertebrate species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2015. Data are annual means with 95% confidence intervals for nearfield (n≤4), north farfield (n≤4), and south farfield stations (n≤4). Dashed lines indicate onset of wastewater discharge in November 1993.

from station SD14 in 1998 (Figure 6.8). Assemblages represented by this group averaged the second highest species richness (13 species per haul), the lowest total abundance (171 individuals per haul), the highest number of *Acanthoptilum* sp (121 per haul), and lowest number of *Lytechinus pictus* (10 per haul) (Table 6.6). These two species, along with *Sicyonia ingentis* (9 per haul), *Ophiura luetkenii*

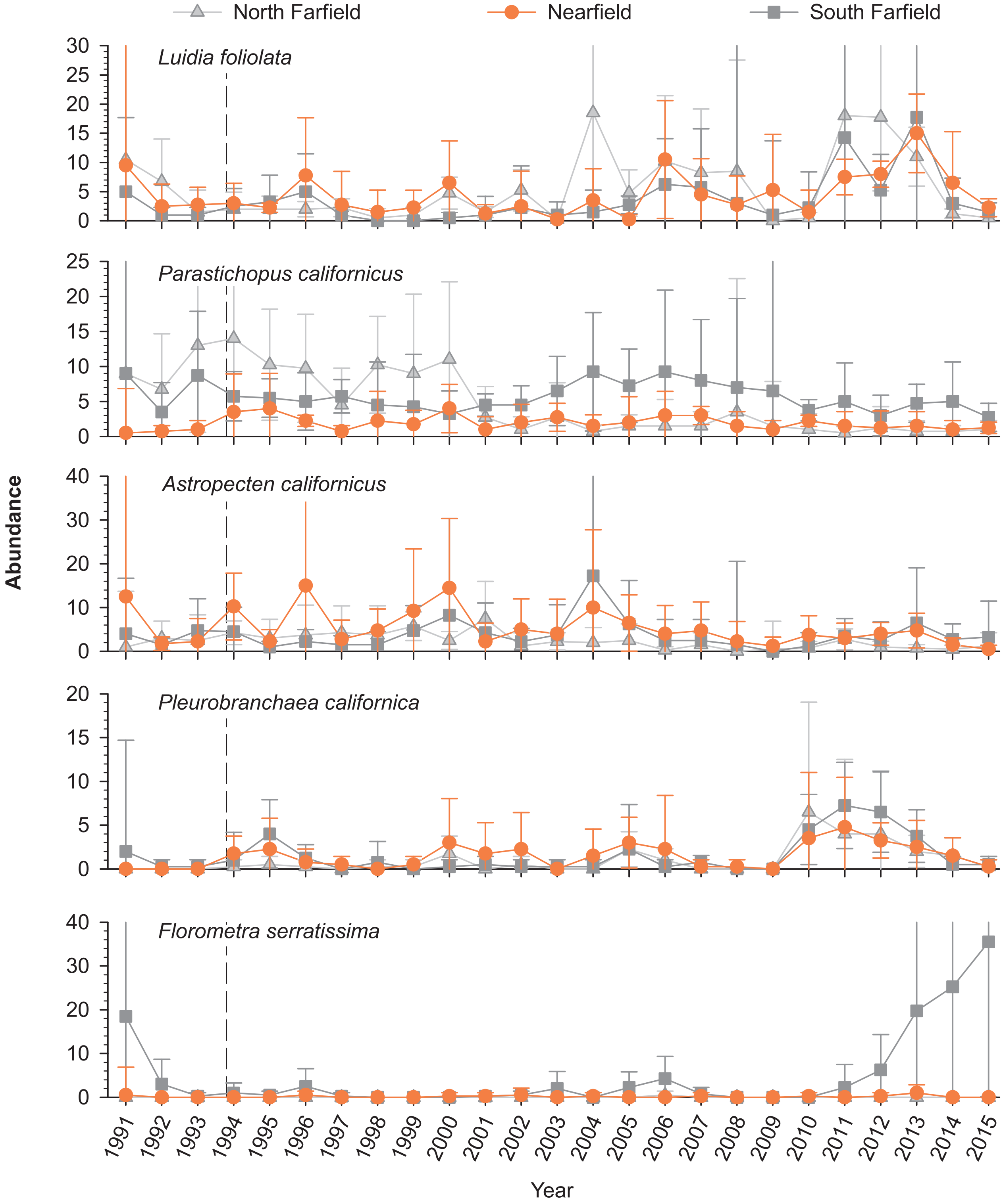
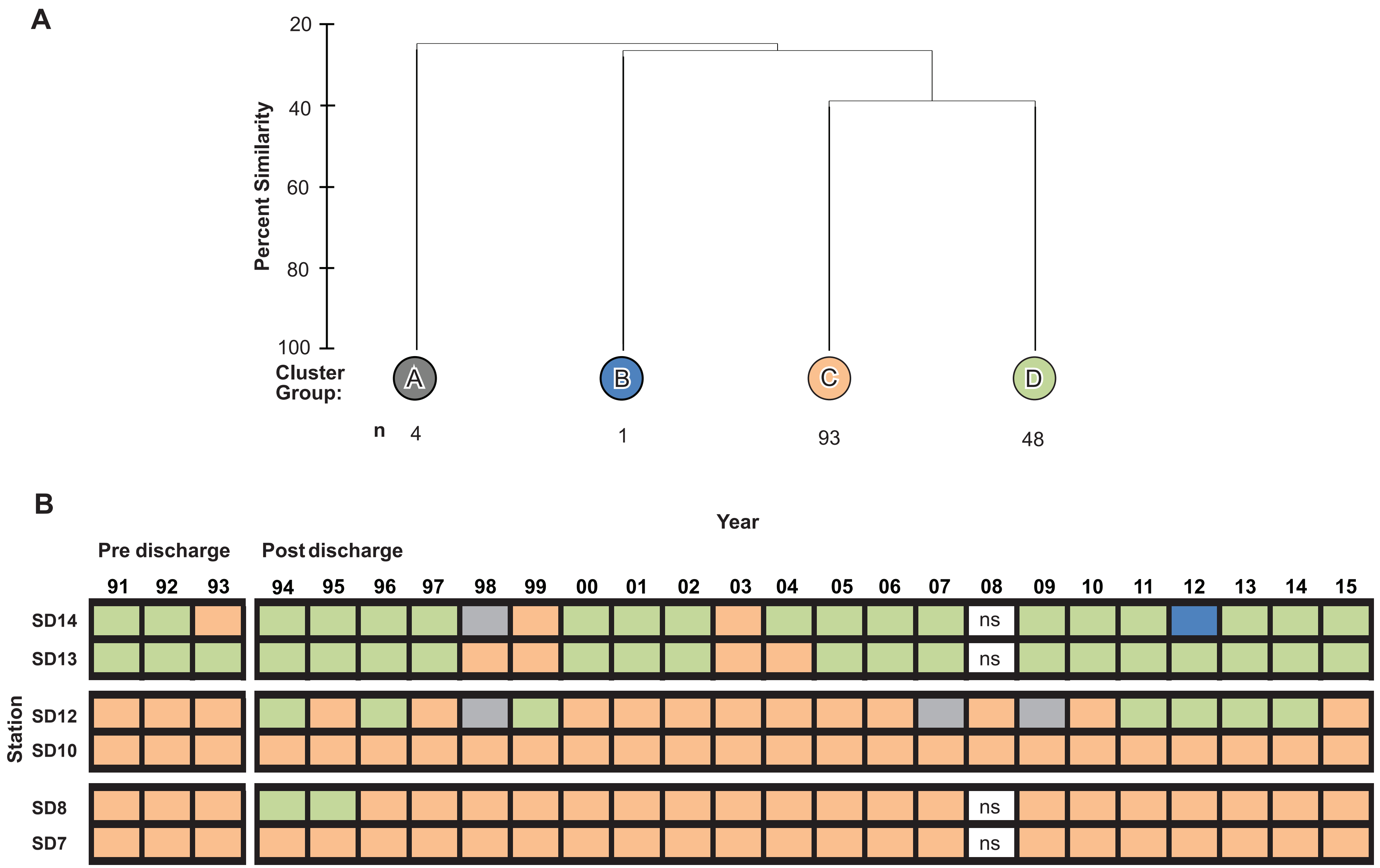


Figure 6.7 *continued*

(2 per haul), *Astropecten californicus* (5 per haul), and *Parastichopus california* (4 per haul), were the most characteristic species of these assemblages according to SIMPER results.

Cluster group B represented a unique megabenthic invertebrate assemblage that occurred at station SD14 in 2012 (Figure 6.8). This assemblage had the lowest species richness (n=10 species),



Station	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
SD14	🟩	🟩	🟧	🟩	🟩	🟩	🟩	▨	🟧	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟩	ns	🟩	🟩	🟩	🟦	🟩	🟩	🟩
SD13	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟩	🟩	🟩	🟧	🟧	🟩	🟩	🟩	ns	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SD12	🟧	🟧	🟧	🟩	🟧	🟩	🟧	▨	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	▨	🟧	▨	🟧	🟩	🟩	🟩	🟩	🟧
SD10	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
SD8	🟧	🟧	🟧	🟩	🟩	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	ns	🟧	🟧	🟧	🟧	🟧	🟧	🟧
SD7	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	ns	🟧	🟧	🟧	🟧	🟧	🟧	🟧

Figure 6.8
Results of cluster analysis of megabenthic invertebrate assemblages from PLOO trawl stations sampled from 1991 through 2015. Data are limited to summer surveys and presented as (A) a dendrogram of main cluster groups and (B) a matrix showing distribution of cluster groups over time; n = number of hauls; ns = not sampled.

Table 6.6

Description of megabenthic invertebrate cluster groups A–D defined in Figure 6.8. Values highlighted in gray indicate species that account for up to 96% intra-group similarity according to SIMPER analysis; the top five most characteristic species for each group are highlighted in yellow.

	Cluster Group			
	A	B[a]	C	D
Number of Hauls	4	1	93	48
Mean Species Richness	13	10	14	12
Mean Abundance	171	3205	2306	448
Species	**Mean Abundance**			
Lytechinus pictus	10	102	**2161**	**236**
Acanthoptilum sp	**121**	0	**47**	**29**
Ophiura luetkenii	**2**	2640	49	**17**
Strongylocentrotus fragilis	6	442	5	**138**
Sicyonia ingentis	**9**	0	6	2
Astropecten californicus	**5**	1	**5**	4
Parastichopus californicus	**4**	0	**5**	3
Luidia foliolata	0	11	**4**	**6**
Luidia armata	3	0	<1	<1
Octopus rubescens	<1	0	1	1
Thesea sp B	<1	0	2	1
Pleurobranchaea californica	1	1	2	2

[a] SIMPER analysis only conducted on cluster groups that contained more than one trawl. Highlighted values for single sample cluster groups cummulatively account for about 96% of the total abundance.

the highest abundance (n = 3205 individuals), the highest numbers of *Ophiura luetkenii* (n = 2640 individuals) and *Strongylocentrotus fragilis* (n = 442 individuals), and the second lowest number of *Lytechinus pictus* (n = 102 individuals) of any cluster group (Table 6.6).

Cluster group C was the largest group, representing assemblages from a total of 93 hauls that included all but two of the trawls conducted during 2015 (Figure 6.8). This group also represented assemblages from 87% (n = 82) of the trawls conducted at the nearfield and south farfield stations (i.e., stations SD7, SD8, SD10, SD12) from 1991 through 2014. These assemblages averaged the highest species richness (14 species per haul), the second highest total abundance (2306 individuals per haul), and the highest number of *Lytechinus pictus* (2161 per haul) (Table 6.6). This species, along with *Acanthoptilum* sp (47 per haul), *Astropecten californicus* (5 per haul), *Parastichopus californicus* (5 per haul), and *Luidia foliolata* (4 per haul) were the most characteristic species of group C assemblages according to SIMPER results.

Cluster group D was the second largest group, representing assemblages from a total of 46 hauls that included trawls 81% (n=39) of the trawls conducted at north farfield stations SD13 and SD14 over the past 25 years, as well as the trawls from south farfield station SD8 in 1994 and 1995 and from nearfield station SD12 in 1994, 1996, 1999, and 2011–2014 (Figure 6.8). These assemblages averaged 12 species and 450 individuals per haul (Table 6.6). SIMPER results indicated that the most characteristic species of group D were *Lytechinus pictus* (236 per haul), *Strongylocentrotus fragilis* (138 per haul), *Acanthoptilum* sp (29 per haul), *Ophiura luetkenii* (17 per haul), and *Luidia foliolata* (5 per haul).

Summary

Pacific Sanddab dominated fish assemblages surrounding the PLOO during 2015, occurring at all stations and accounting for about 53% of the year's catch. Other common species of fish off Point Loma included Halfbanded Rockfish, Longspine Combfish, Stripetail Rockfish, California Scorpionfish, California Lizardfish, Yellowchin Sculpin, English Sole, Pink Seaperch, Shortspine Combfish, Plainfin Midshipman, Greenstriped Rockfish, Dover Sole, Hornyhead Turbot, California Tonguefish, California Skate, and Bigmouth Sole. Almost all fishes collected were < 25 cm in length. Although the composition and structure of the fish assemblages varied among stations and surveys in 2015, these differences appear to be due to natural population fluctuations of common species.

Assemblages of trawl-caught invertebrates in 2015 were dominated by the sea urchin *Lytechinus pictus*, which occurred in all trawls and accounted for 87% of all invertebrates captured. The shrimp *Sicyonia ingentis* was also collected at all stations, although usually in fairly low numbers. Other common, but far less abundant invertebrates included the sea stars *Astropecten californicus, Luidia asthenosoma* and *Luidia foliolata*, the sea cucumber *Parastichopus californicus*, the cephalopod *Octopus rubescens*, and the cymothoid isopod *Elthusa vulgaris*. As with demersal fishes, the composition of the trawl-caught invertebrate assemblages in the PLOO region varied among stations and surveys, generally reflecting population fluctuations of the species mentioned above.

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

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Chapter 7
Bioaccumulation of Contaminants in Fish Tissues

Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

Introduction

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

The bioaccumulation portion of the City's monitoring program consists of two components: (1) analyzing liver tissues from trawl-caught fishes; (2) analyzing muscle tissues from fishes collected by hook and line (rig fishing). Species targeted by trawling activities (see Chapter 6) are considered representative of the general demersal fish community off San Diego. 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 2015. The primary goals are to: (1) document levels of contaminant loading in local demersal fishes; (2) identify whether any contaminant bioaccumulation detected in fishes collected around the PLOO may be due to the outfall discharge; (3) identify other potential natural and anthropogenic sources of pollutants to the local marine environment.

Materials and Methods

Field Collection

Fishes were collected during October 2015 from four trawl zones (TZ1–TZ4) and two rig fishing stations (RF1–RF2) (Figure 7.1). Each trawl zone represents an area centered on one or two 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

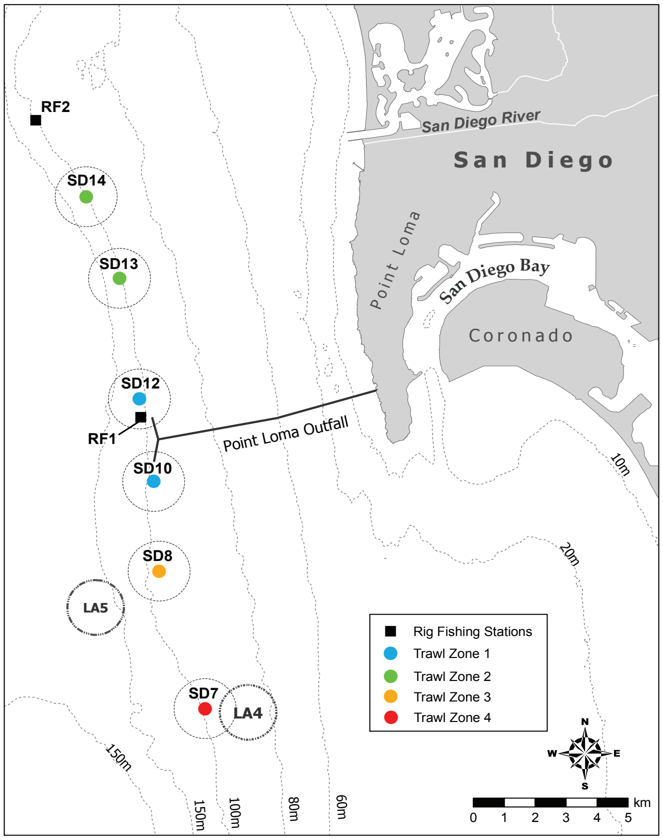

Figure 7.1
Trawl and rig fishing station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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

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

Tissue Processing and Chemical Analyses

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

All tissue analyses were performed at the City of San Diego's Environmental Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2016a). Briefly, fish tissue samples were analyzed on a wet weight basis to determine the concentrations of 18 trace metals, 9 chlorinated pesticides, and 40 polychlorinated biphenyl compound congeners (PCBs). Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix F.2). However, concentrations below MDLs were included as

Table 7.1

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

Station/Zone	Composite 1	Composite 2	Composite 3
Trawl Zone 1 (TZ1)	Pacific Sanddab [a]	Pacific Sanddab [a]	Pacific Sanddab [a]
Trawl Zone 2 (TZ2)	Pacific Sanddab [a]	Pacific Sanddab [a]	English Sole [a]
Trawl Zone 3 (TZ3)	Pacific Sanddab [a]	Pacific Sanddab [a]	Pacific Sanddab [a]
Trawl Zone 4 (TZ4)	Pacific Sanddab [a]	Pacific Sanddab [a]	Pacific Ssanddab [a]
Rig Fishing station 1 (RF1)	Vermilion Rockfish [a]	Copper Rockfish [a]	Mixed Rockfish [a, b]
Rig Fishing station 2 (RF2)	Speckled Rockfish [a]	Speckled Rockfish [a]	Speckled Rockfish [a]

[a] No methoxychlor, aldrin, alpha endosulfan, beta endosulfan,dieldrin, endrin, or endrin aldehyde; [b] includes Vermilion and Copper Rockfish

estimated values if the presence of the specific constituent was verified by mass-spectrometry.

Data Analyses

Data summaries for the various parameters included detection rate, minimum, maximum, and mean values by species. All means were calculated using detected values only; no substitutions were made for non-detects in the data (i.e., analyte concentrations <MDL). Total DDT (tDDT), total chlordane, total hexachlorocyclohexane (tHCH), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix F.3 for individual constituent values). In addition, the distribution of contaminants with detection rates ≥20% was assessed by comparing values in fishes collected from "nearfield" stations located within 1000 m of the outfall diffuser structure (TZ1, RF1) to those from "farfield" stations located >3.6 km away to the north (TZ2, RF2) and south (TZ3, TZ4). Because contaminant levels can vary drastically among different species of fish, only intra-species comparisons were used for these assessments. Analyses were performed using SAS software v9.3.

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

RESULTS

Contaminants in Trawl-Caught Fishes

Trace Metals

Nine trace metals were detected in all liver tissue samples from Pacific Sanddabs and English Sole collected in the Point Loma outfall region during 2015 (Table 7.2). These included arsenic, cadmium, copper, iron, manganese, mercury, selenium, tin and zinc. Aluminum, antimony, barium, beryllium, chromium, lead, silver, and thallium were also detected, but in fewer samples (8–92%). Nickel was not detected in any liver tissue samples collected in the PLOO region during the year. Most metals occurred at concentrations ≤9.8 ppm, although higher concentrations up to 15.4 ppm for arsenic, 69.3 ppm for zinc, and 175 ppm for iron were recorded. Most metals were present in samples from all zones, although at variable concentrations (Figure 7.2). Pacific Sanddabs from TZ1 had the highest concentrations of arsenic, chromium,

Table 7.2

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

	English Sole (n out of 1)		Pacific Sanddab (n out of 11)				All Species	
Parameter	**n**	**Value**	**n**	**Min**	**Max**	**Mean**	**DR(%)**	**Max**
Metals (ppm)								
Aluminum	0	—	6	nd	7.0	4.3	50	7.0
Antimony	0	—	1	nd	0.3	0.3	8	0.3
Arsenic	1	10	11	4.00	15.40	6.04	100	15.40
Barium	1	0.05	5	nd	0.07	0.05	50	0.07
Beryllium	1	0.007	5	nd	0.020	0.011	50	0.020
Cadmium	1	0.90	11	0.59	9.84	4.22	100	9.84
Chromium	1	0.1	6	nd	0.4	0.2	58	0.4
Copper	1	1.3	11	0.9	8.8	3.7	100	8.8
Iron	1	175.0	11	65.0	122.0	91.5	100	175.0
Lead	1	0.7	1	nd	0.6	0.6	17	0.7
Manganese	1	0.8	11	0.5	1.0	0.6	100	1.0
Nickel	0	—	0	—	—	—	0	—
Mercury	1	0.064	11	0.036	0.108	0.074	100	0.108
Selenium	1	3.24	11	0.82	3.20	1.26	100	3.24
Silver	1	0.05	1	nd	0.05	0.05	17	0.05
Thallium	0	—	11	0.40	0.80	0.61	92	0.80
Tin	1	0.600	11	0.700	1.500	0.891	100	1.500
Zinc	1	49.90	11	22.60	69.30	35.08	100	69.30
Pesticides (ppb)								
HCB	1	3.4	11	3.4	67.0	12.3	100	67.0
Total chlordane	0	—	11	1.4	14.5	7.1	92	14.5
Total DDT	1	78.9	11	109.1	720.0	360.3	100	720.0
Total PCB *(ppb)*	1	96.1	11	119.4	596.0	261.5	100	596.0
Lipids *(% weight)*	1	9.5	11	12.7	56.7	47.6	100	56.7

^{a}Minimum and maximum values were based on all samples, whereas means were calculated from detected values only

copper, iron, mercury, selenium tin, and zinc in their liver tissues; Sanddabs collected from TZ2 had the highest concentrations of manganese and thallium; Sanddabs collected from TZ3 had the highest concentrations of aluminum; Sanddabs collected from TZ4 had the highest concentrations of barium, and cadmium. These results are consistent with the findings of long term analyses reported previously (City of San Diego 2015a).

Pesticides

Only three chlorinated pesticides were detected in Pacific Sanddabs and English Sole collected from the Point Loma outfall region during 2015. DDT was present in every liver tissue sample at concentrations up to 720 ppb (Table 7.2), with no patterns relative to proximity to the outfall evident (Figure 7.3). The highest DDT values were recorded for Pacific Sanddab samples from farfield zones TZ3 and TZ4. The DDT metabolites p,p-DDE and p,p-DDMU were found in 100% of the samples, while p,p-DDD, o,p-DDE and p,p-DDT were found in ≤83% of the samples (Appendix F.3). Hexachlorobenzene (HCB) was also present in every liver tissue sample; it occurred at concentrations up to 67 ppb (Table 7.2). The highest HCB value was recorded

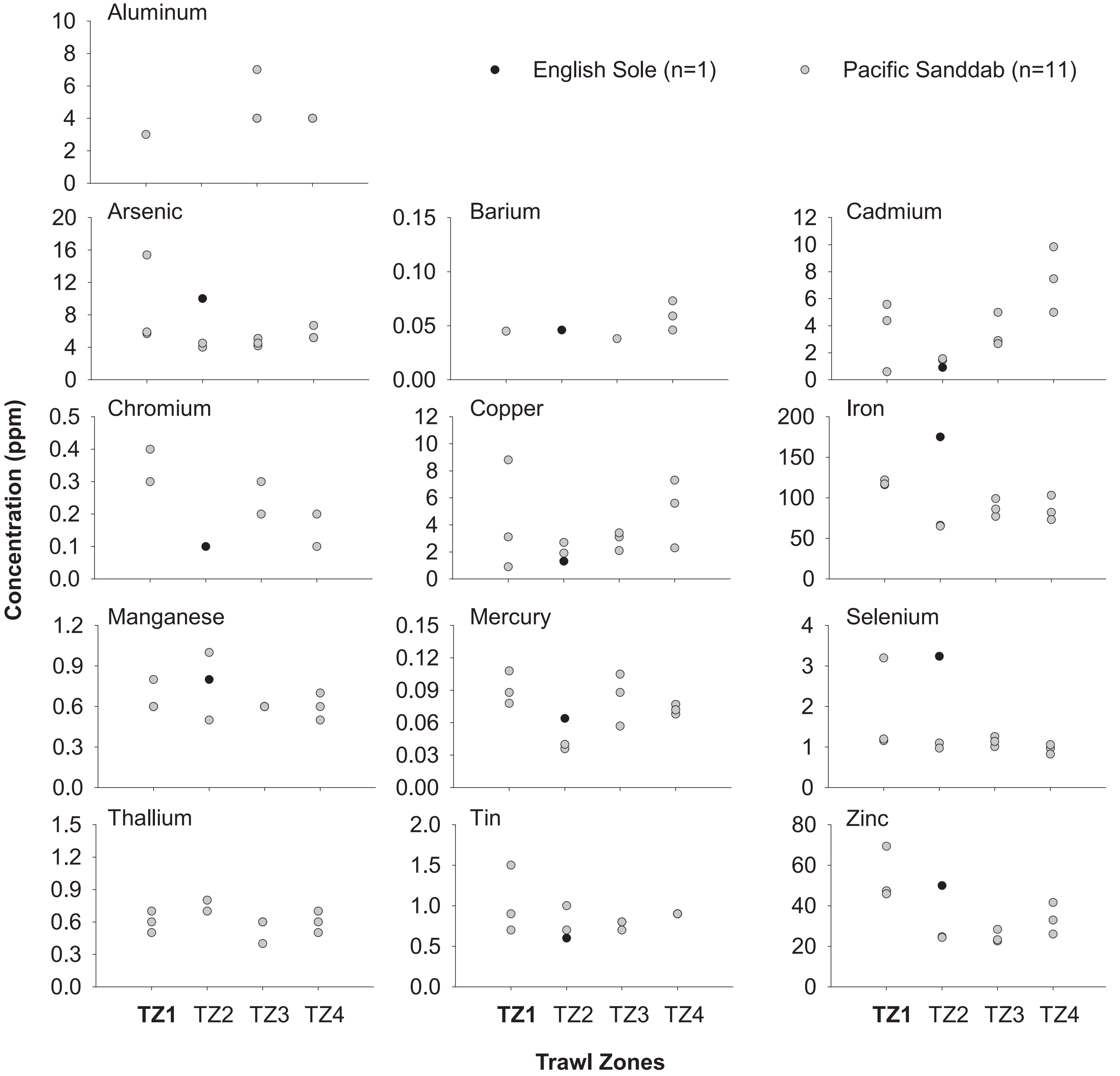

Figure 7.2
Concentrations of metals with detection rates ≥20% in liver tissues of fishes collected from each PLOO trawl zone during 2015. Zone TZ1 is considered nearfield. All missing values are non-detects.

in a Pacific Sanddab sample collected from farfield zone TZ4 (Figure 7.3). Chlordane was found in 92% of the PLOO fish liver samples at concentrations up to 14.5 ppb (Table 7.2). The highest chlordane values were recorded in Pacific Sanddab samples collected from zone TZ3. Total chlordane included alpha(cis)chlordane in 67% of the samples and trans nonachlor in 92% of the samples (Appendix F.3). With the exception of DDT, chlorinated pesticides have historically been detected infrequently at low concentrations in the liver tissues of fishes from the PLOO region (City of San Diego 2015a). In contrast, DDT has been detected in all species of fish at a rate of about 99% over the past 22 years, but with no patterns indicative of an outfall discharge effect evident.

PCBs

PCBs were detected in every Pacific Sanddab and English Sole liver tissue sample collected from the Point Loma outfall region during 2015 (Table 7.2). Total PCB concentrations were variable, ranging from 96.1 to 596 ppb. Only 17 of the 31 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 138, PCB 149, PCB 151, PCB 153/168, PCB 177, PCB 180, and PCB 187 (Appendix F.3). The remaining congeners were found in 17 to 92% of the samples. PCB was detected in samples from all stations; however, the highest values were recorded from farfield zone TZ3 (Figure 7.3). Historically, PCBs have been detected frequently in liver tissues of fishes from the PLOO region, but with no patterns indicative of an outfall discharge effect evident since sampling for PCB congeners began (City of San Diego 2015a). Instead, PCBs have been detected most frequently at TZ3 located near the LA-5 dredged materials disposal site.

Contaminants in Fishes Collected by Rig Fishing

Only five trace metals occurred in all rockfish muscle tissue samples collected at the two PLOO rig fishing stations during 2015, including arsenic, mercury, selenium, tin and zinc (Table 7.3). Detection rates for three other metals (chromium, copper, iron) were ≤83%, while aluminum, antimony, barium, beryllium, cadmium, lead, manganese, nickel, silver, and thallium were not detected in any of the samples. The metals present in the highest concentrations were arsenic and zinc, although all were ≤13.5 ppm. The highest values of arsenic, copper, mercury, selenium, tin, and zinc were found in samples from station RF1 (Figure 7.4). Overall, variations in the concentrations of these metals were minor and may have been due to weight, length, and/or life history differences between the different species of fish (Appendix F.1). Historically, arsenic, copper, mercury, selenium, tin, and zinc have been detected frequently in the muscle tissues of fishes collected from both of the PLOO rig fishing stations (City of San Diego 2015a).

DDT (composed primarily of p,p-DDE) and HCB were the only pesticides detected in rockfish muscle tissues collected in the Point Loma outfall region during 2015 (Table 7.4, Appendix F.3). DDT was detected in 83% of the samples at concentrations up to 7.2 ppb, while HCB was detected in 50% of the samples at concentrations up to 1.3 ppb. During 2015, PCBs (composed primarily of PCB 153/168) were detected in 50% of the PLOO muscle tissue samples, at concentrations up to 2.3 ppb. The highest values of both pesticides and PCBs were found in a Mixed Rockfish sample from station RF1 (Figure 7.4). As with metal concentrations, variations in the concentrations of these contaminants were minor and may have been due to weight, length, and/or life history differences between the three different fish species (Appendix F.1). These results are

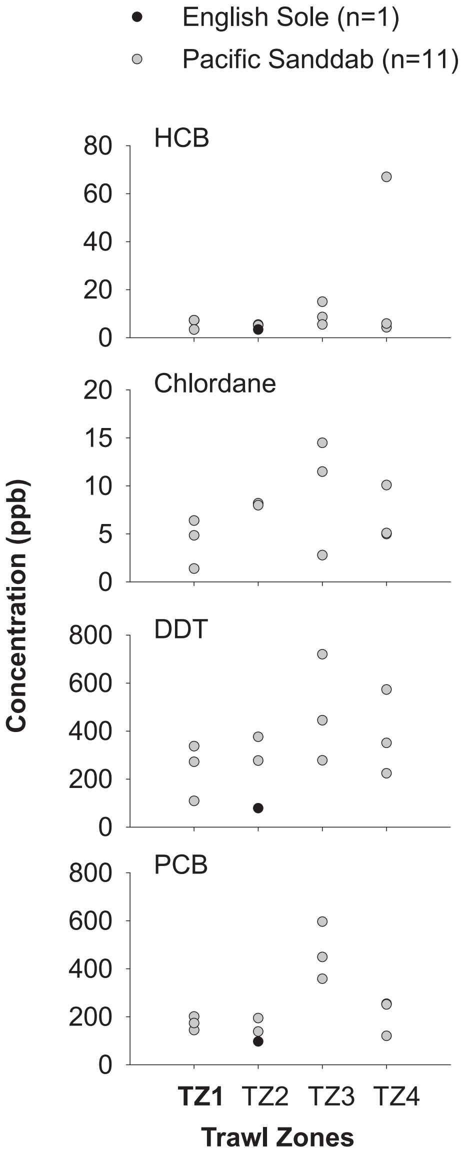

Figure 7.3

Concentrations of HCB, total chlordane, total DDT, and total PCB in liver tissues of fishes collected from each PLOO trawl zone during 2015. Zone TZ1 is considered nearfield. All missing values are non-detects.

Table 7.3

Summary of metals in muscle tissues of fishes collected from PLOO rig fishing stations during 2015. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the detection rate and maximum value for all species. The number of samples per species is indicated in parentheses. Concentrations are expressed as parts per million (ppm); na = not available; nd = not detected. Highlighted/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
Copper Rockfish																		
n (out of 1)	0	0	1	0	0	0	1	1	0	0	0	1	0	1	0	0	1	1
Value	—	—	**2.5**	—	—	—	0.2	0.1	—	—	—	0.196	—	**0.60**	—	—	0.6	5.9
Mixed Rockfish																		
n (out of 1)	0	0	**1**	0	0	0	0	0	0	0	0	1	0	**1**	0	0	1	1
Value	—	—	**5.6**	—	—	—	—	—	—	—	—	0.065	—	**0.38**	—	—	0.5	4.5
Speckled Rockfish																		
n (out of 3)	0	0	**3**	0	0	0	3	0	2	0	0	3	0	**3**	0	0	3	3
Min	—	—	**1.4**	—	—	—	0.1	—	nd	—	—	0.063	—	**0.39**	—	—	0.5	4.3
Max	—	—	**3.1**	—	—	—	0.2	—	3	—	—	0.109	—	**0.43**	—	—	0.5	4.5
Mean	—	—	**2.43**	—	—	—	0.1	—	3	—	—	0.079	—	**0.41**	—	—	0.5	4.4
Vermilion Rockfish																		
n (out of 1)	0	0	1	0	0	0	1	1	0	0	0	1	0	1	0	0	1	1
Value	—	—	**13.5**	—	—	—	0.2	0.1	—	—	—	0.052	—	**0.41**	—	—	0.5	5.8
All Species:																		
Detection Rate (%)	0	0	100	0	0	0	83	33	33	0	0	100	0	100	0	0	100	100
Max	—	—	**13.5**	—	—	—	0.2	0.1	3	—	—	0.196	—	**0.60**	—	—	0.6	5.9
OEHHA[b]	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
USFDA Action Limit[c]	na	na	na	na	na	na	na	na	na	na	na	1	na	na	na	na	na	na
Median IS[c]	na	na	1.4	na	na	1.0	1.0	20	na	2	na	0.50	na	0.3	na	na	175	70

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

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

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

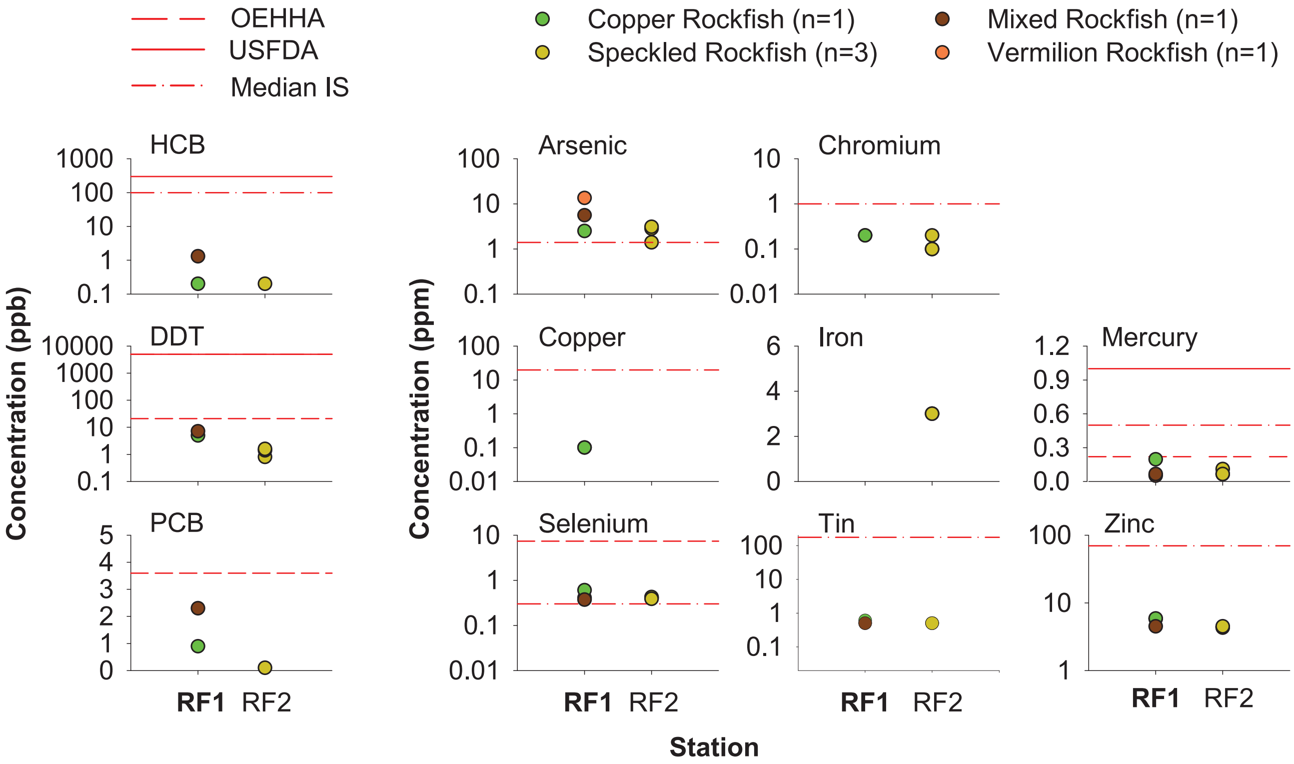

Figure 7.4
Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each PLOO rig fishing station during 2015. See Tables 7.3 and 7.4 for thresholds. Missing data are non-detects. Station RF1 is considered nearfield.

consistent with the findings of long term analyses reported previously (City of San Diego 2015a).

Most contaminants detected in rockfish muscle tissues during 2015 occurred at concentrations below state, national, and international limits or standards (Tables 7.3, 7.4, Figure 7.4). Exceptions included arsenic and selenium, both of which exceeded the median international standard in all muscle tissue samples from both RF stations.

DISCUSSION

Several trace metals, PCB congeners, and the chlorinated pesticides DDT, HCB, and chlordane were detected in liver tissues from Pacific Sanddabs and English Sole collected in the Point Loma outfall region during 2015. Many of the same metals, pesticides, and PCBs were also detected in rockfish muscle tissues during the year, although often less frequently and/or in lower concentrations. Although tissue contaminant concentrations varied among different species of fish and between stations, all values were within ranges reported previously for Southern California Bight (SCB) fishes (see Mearns et al. 1991, Allen et al. 1998, City of San Diego 2000, City of San Diego 2007, City of San Diego 2015a). Additionally, all muscle tissue samples from sport fish collected in the region had concentrations of mercury, HCB and total DDT below USFDA action limits and international standards. However, all muscle tissue samples had arsenic and selenium concentrations above median international standards for human consumption. Elevated levels of these contaminants are not uncommon in sport fish from the PLOO region (City of San Diego 2007–2015b) or from other parts of the San Diego region (see City of San Diego 2016b and references therein). For example, muscle tissue samples from fishes collected since 1995 in the South Bay outfall survey area, including the Coronado Islands, have occasionally had concentrations of arsenic, mercury, selenium, and total PCB in excess of different consumption limits.

Table 7.4

Summary of pesticides, total PCB, and lipids in muscle tissues of fishes collected from PLOO rig fishing stations during 2015. Data include number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the detection rate (DR) and maximum value for all species. The number of samples per species is indicated in parentheses; na = not available; nd = not detected. See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT and tPCB.

	Pesticides			
	HCB (ppb)	tDDT (ppb)	tPCB (ppb)	Lipids (% wt)
Copper Rockfish				
n (out of 1)	1	1	1	1
Value	0.2	5	0.9	0.7
Mixed Rockfish				
n (out of 1)	1	1	1	1
Min	1.3	7.2	2.3	0.8
Speckled Rockfish				
n (out of 3)	1	3	1	3
Min	nd	0.8	nd	0.4
Max	0.2	1.6	0.1	0.7
Mean	0.2	1.3	0.1	0.5
Vermilion Rockfish				
n (out of 1)	0	0	0	1
Value	—	—	—	0.4
All Species:				
DR(%)	50	83	50	100
Max	1.3	7.2	2.3	0.8
OEHHA[b]	na	21	3.6	na
USFDA Action Limit[c]	300	5000	na	na
Median IS[c]	100	5000	na	na

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

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

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

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).

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

Overall, there was no evidence of contaminant bioaccumulation in PLOO fishes during 2015 that could be associated with wastewater discharge from the outfall. Concentrations of most contaminants were generally similar across zones or stations, and no relationship relevant to the PLOO was evident. These results are consistent with findings of other assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007, 2015a, Parnell et al. 2008). Finally, there were no other indications of poor fish health in the region, such as the presence of fin rot or other indicators of disease (see Chapter 6).

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Appendices

Appendix A

Supporting Data

2015 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 2015. For each quarter: n = 804 (1–20 m), n = 1320 (21–60 m), n ≥ 439 (61–80 m), n ≥ 194 (81–100 m). Sample sizes differed due to variations in bottom depth at individual stations.

		Depth (m)				
Temperature (°C)		**1–20**	**21–60**	**61–80**	**81–100**	**1–100**
February	min	12.9	11.2	10.6	10.1	10.1
	max	17.3	16.9	12.3	11.0	17.3
	mean	16.4	13.4	11.1	10.5	13.7
May	min	10.6	10.2	10.2	10.0	10.0
	max	16.8	13.3	10.6	10.4	16.8
	mean	12.9	10.6	10.4	10.2	11.2
August	min	14.9	11.5	10.9	11.1	10.9
	max	22.1	18.9	12.9	11.7	22.1
	mean	19.5	13.9	11.5	11.3	15.1
November	min	16.6	14.7	13.3	12.7	12.7
	max	21.4	20.5	16.8	15.2	21.4
	mean	19.8	17.3	15.0	13.7	17.5
Annual	min	10.6	10.2	10.2	10.0	10.0
	max	22.1	20.5	16.8	15.2	22.1
	mean	17.3	13.8	12.0	11.4	14.4

Salinity (psu)						
February	min	33.24	33.16	33.26	33.39	33.16
	max	33.42	33.46	33.59	33.75	33.75
	mean	33.35	33.30	33.46	33.62	33.36
May	min	33.22	33.26	33.60	33.74	33.22
	max	33.53	33.73	33.88	34.00	34.00
	mean	33.35	33.53	33.73	33.86	33.53
August	min	33.23	33.14	33.21	33.44	33.14
	max	33.52	33.42	33.52	33.53	33.53
	mean	33.38	33.26	33.41	33.49	33.33
November	min	33.19	33.09	33.28	33.25	33.09
	max	33.52	33.48	33.55	33.62	33.62
	mean	33.46	33.38	33.42	33.49	33.42
Annual	min	33.19	33.09	33.21	33.25	33.09
	max	33.53	33.73	33.88	34.00	34.00
	mean	33.39	33.37	33.51	33.61	33.41

Appendix A.1 *continued*

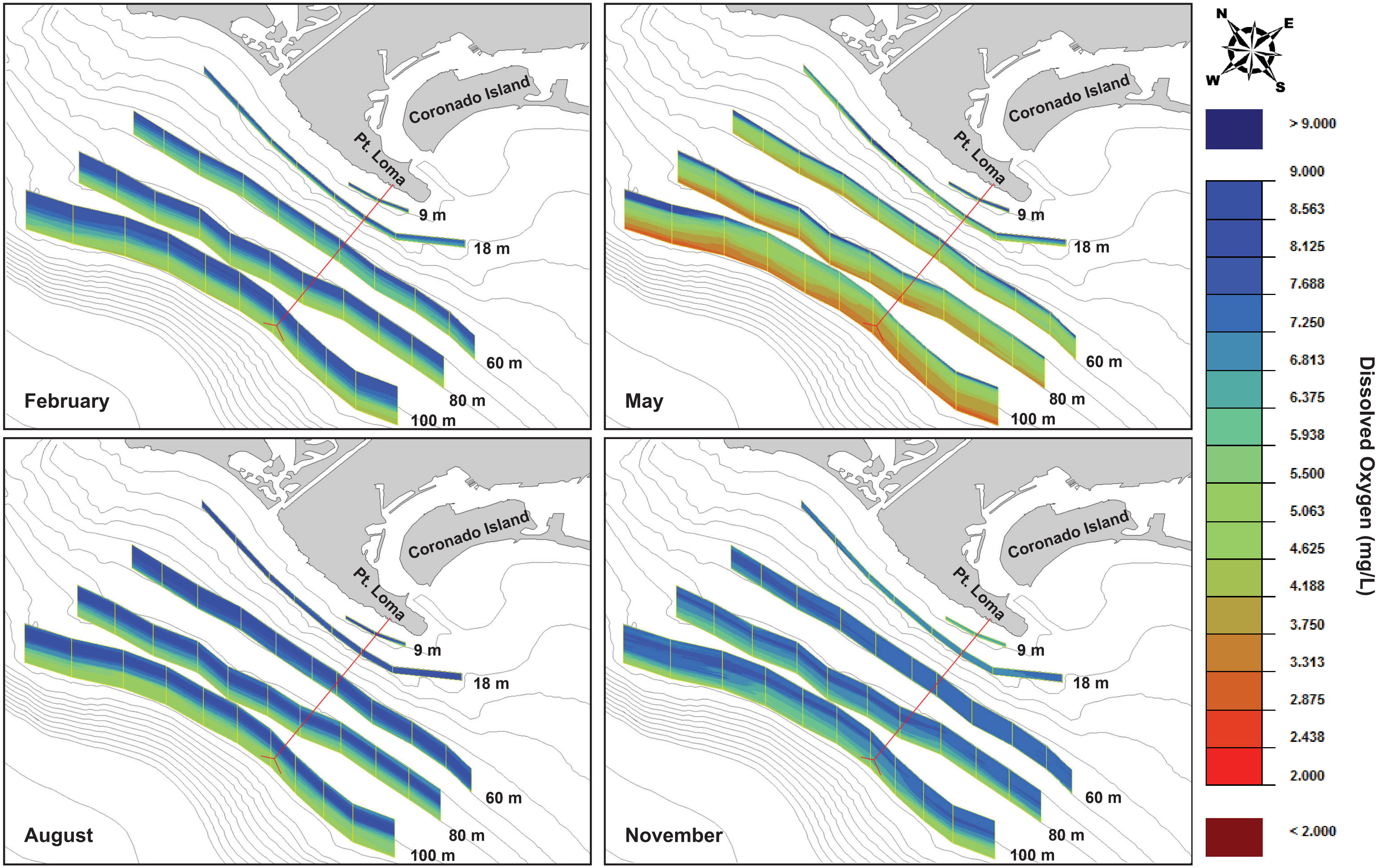
		Depth (m)				
DO (mg/L)		**1–20**	**21–60**	**61–80**	**81–100**	**1–100**
February	min	5.9	5.5	4.8	4.2	4.2
	max	8.4	8.3	6.8	6.1	8.4
	mean	7.7	6.9	5.5	4.8	6.8
May	min	5.0	3.8	3.2	2.8	2.8
	max	9.6	7.9	4.7	4.0	9.6
	mean	6.9	5.0	3.9	3.5	5.3
August	min	6.0	5.8	5.2	5.0	5.0
	max	9.2	8.8	6.9	5.6	9.2
	mean	7.8	7.6	5.7	5.3	7.2
November	min	5.9	6.5	5.2	4.6	4.6
	max	8.2	8.2	7.5	6.7	8.2
	mean	7.3	7.4	6.3	5.5	7.1
Annual	min	5.0	3.8	3.2	2.8	2.8
	max	9.6	8.8	7.5	6.7	9.6
	mean	7.4	6.7	5.4	4.8	6.6

pH						
February	min	8.0	7.9	7.8	7.8	7.8
	max	8.2	8.2	8.0	7.9	8.2
	mean	8.2	8.1	7.9	7.9	8.1
May	min	7.8	7.8	7.7	7.7	7.7
	max	8.3	8.1	7.8	7.8	8.3
	mean	8.0	7.9	7.8	7.7	7.9
August	min	8.1	8.0	8.0	8.0	8.0
	max	8.3	8.3	8.1	8.1	8.3
	mean	8.2	8.2	8.0	8.0	8.2
November	min	8.0	8.1	8.0	7.9	7.9
	max	8.2	8.2	8.2	8.1	8.2
	mean	8.2	8.2	8.1	8.0	8.1
Annual	min	7.8	7.8	7.7	7.7	7.7
	max	8.3	8.3	8.2	8.1	8.3
	mean	8.2	8.1	7.9	7.9	8.1

Appendix A.1 *continued*

Transmissivity (%)		**Depth (m)** **1–20**	**21–60**	**61–80**	**81–100**	**1–100**
February	min	42	58	55	62	42
	max	90	91	91	91	91
	mean	86	88	87	88	87
May	min	56	67	79	83	56
	max	90	91	91	91	91
	mean	81	89	89	89	87
August	min	80	82	84	85	80
	max	91	91	91	91	91
	mean	88	88	89	89	89
November	min	60	79	82	84	60
	max	93	91	91	91	93
	mean	88	88	89	89	88
Annual	min	42	58	55	62	42
	max	93	91	91	91	93
	mean	86	88	89	89	88

Chlorophyll *a* (µg/L)						
February	min	0.2	0.3	0.2	0.2	0.2
	max	3.4	3.9	0.7	1.0	3.9
	mean	1.0	1.1	0.3	0.2	0.9
May	min	0.5	0.3	0.2	0.2	0.2
	max	16.0	9.1	0.6	0.6	16.0
	mean	2.8	0.8	0.3	0.2	1.3
August	min	0.1	0.2	0.4	0.4	0.1
	max	4.2	5.0	1.8	0.8	5.0
	mean	0.6	1.8	0.8	0.5	1.2
November	min	0.2	0.4	0.2	0.2	0.2
	max	1.6	2.7	2.3	2.2	2.7
	mean	0.6	1.2	0.5	0.3	0.9
Annual	min	0.1	0.2	0.2	0.2	0.1
	max	16.0	9.1	2.3	2.2	16.0
	mean	1.2	1.2	0.5	0.3	1.1



Appendix A.2

Dissolved oxygen recorded in the PLOO region during 2015. Data were collected over 4–6 days during each quarterly survey.

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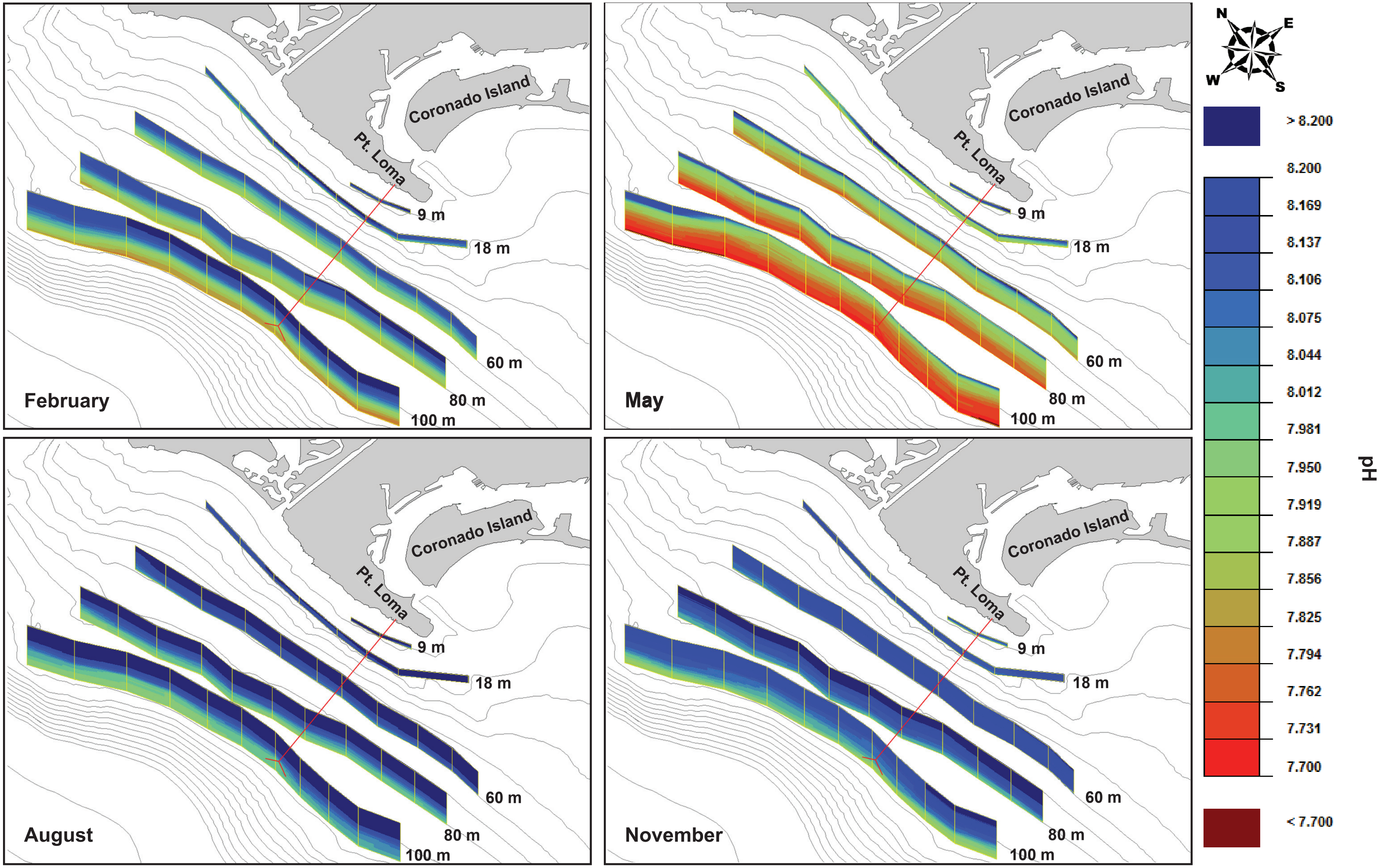

Appendix A.3
Measurements of pH recorded in the PLOO region during 2015. Data were collected over 4–6 days during each quarterly survey.

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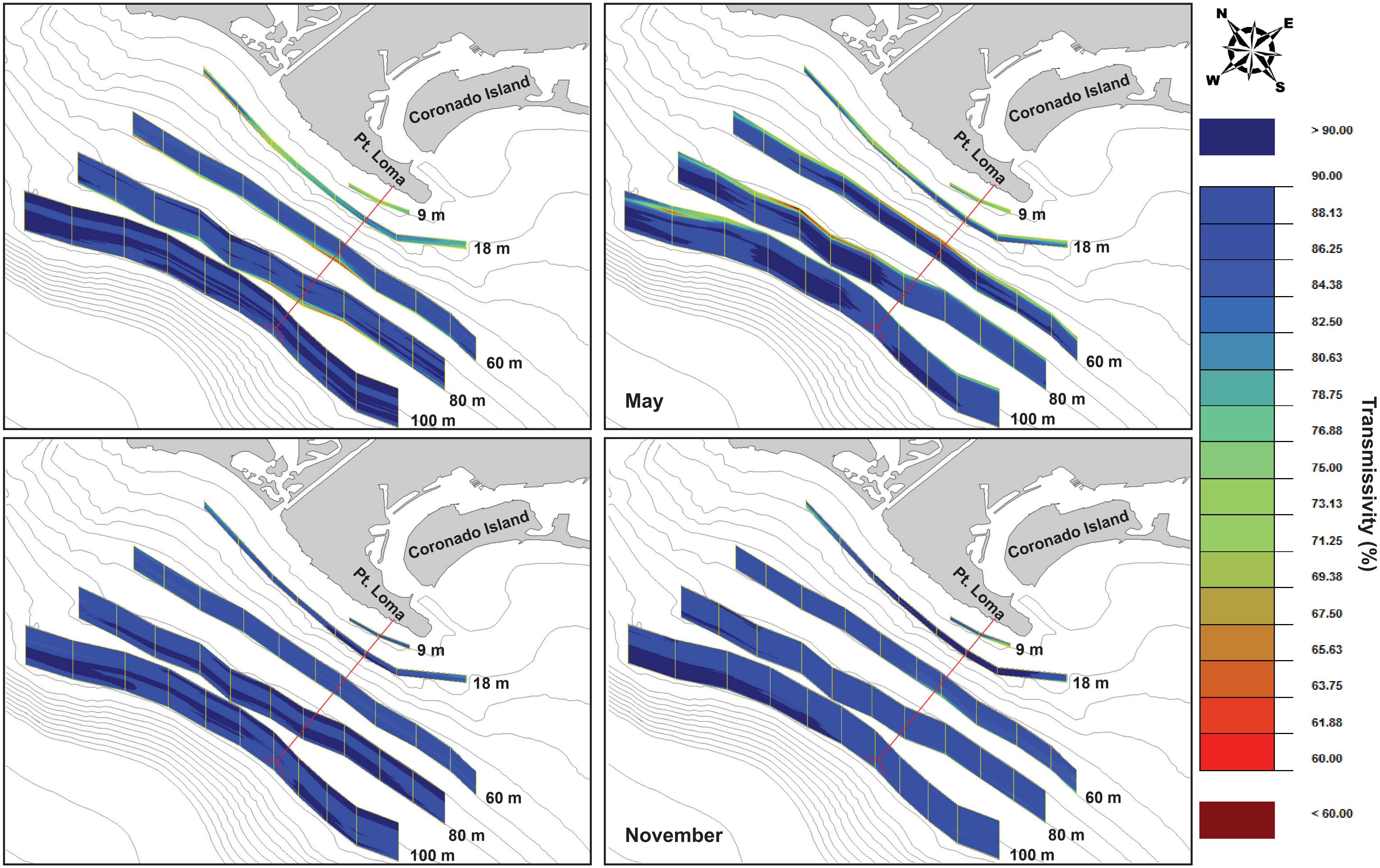
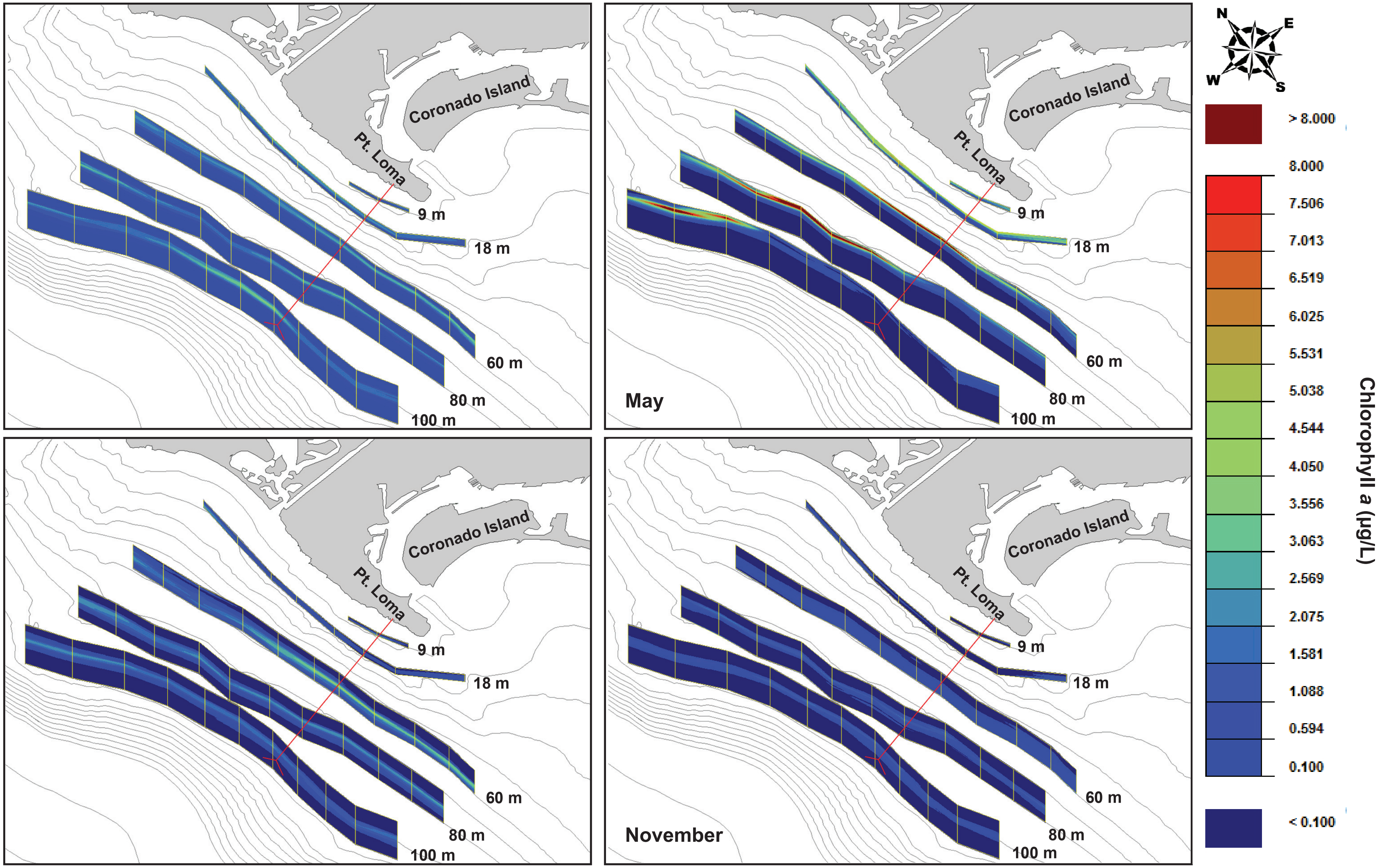


Appendix A.4

Transmissivity recorded in the PLOO region during 2015. Data were collected over 4–6 days during each quarterly survey.



Appendix A.5

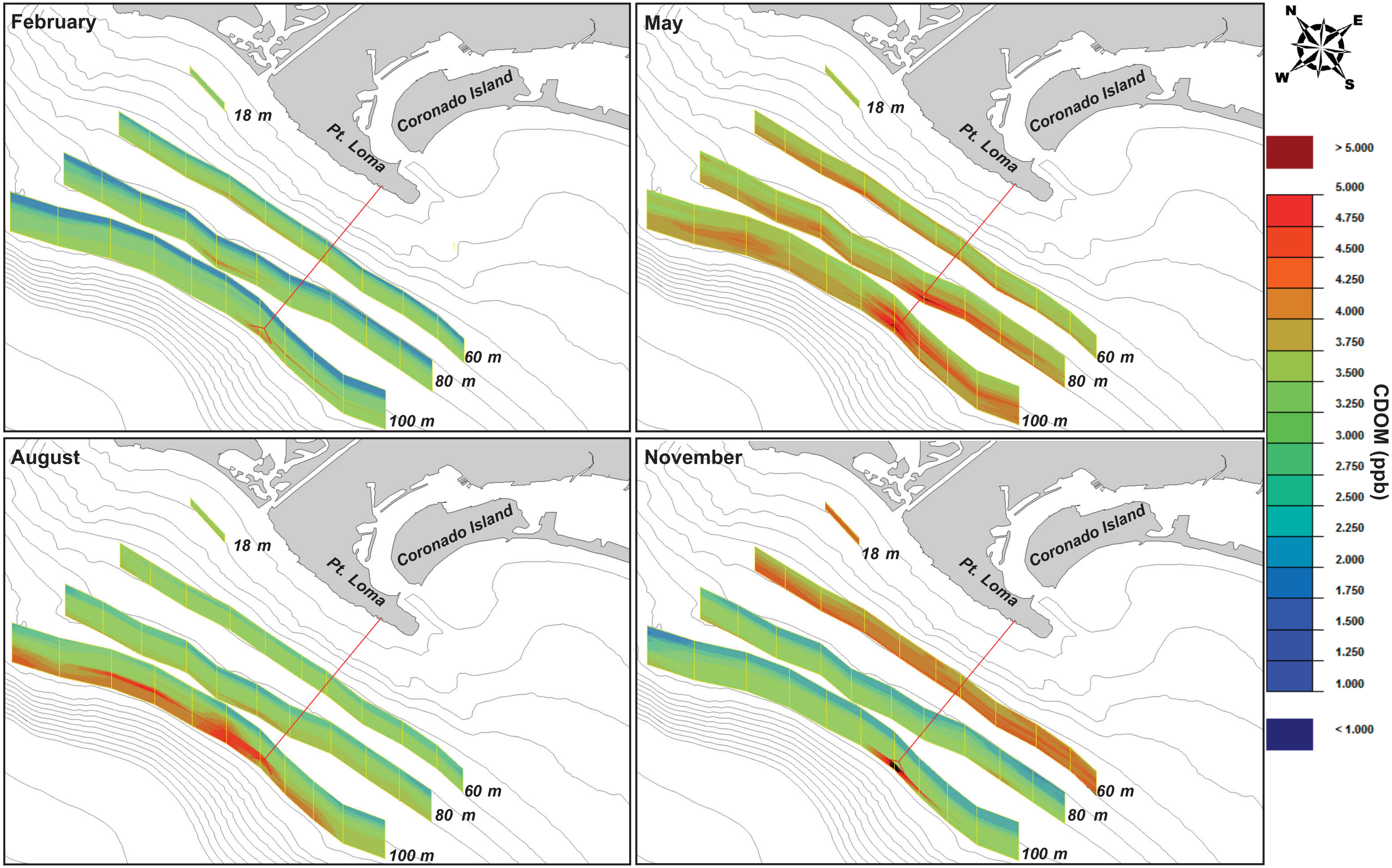
Concentrations of chlorophyll *a* recorded in the PLOO region during 2015. Data were collected over 4–6 days during each quarterly survey.

Appendix B

Supporting Data

2015 PLOO Stations

Water Quality Compliance and Plume Dispersion



Appendix B.1
CDOM values recorded in the PLOO region during 2015. Data were collected over 3–5 days during each of these surveys.

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Appendix B.2

Summary of PLOO reference stations used during 2015 to calculate out-of-range thresholds (see text for details).

Month	Stations
February	F01, F02, F03, F04, F05, F06, F15, F25, F32, F34, F35, F36
May	F02, F03, F04, F05, F06, F09, F10, F13, F14, F15, F20, F24, F32, F36
August	F01, F02, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F15, F16, F17, F18, F19, F22, F23, F24, F25, F26, F27
November	F15, F16, F17, F18, F19, F20, F21, F22, F23, F24, F25, F26, F27, F28, F31, F32, F33, F34, F35, F36

Appendix B.3

Summary of rainfall and bacteria levels from PLOO shore stations during 2015. Total coliform, fecal coliform, and *Enterococcus* densities are expressed as mean CFU/100 mL per month. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom; n = total number of samples.

		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Total Rain (in):		0.42	0.28	0.93	0.02	2.39	0.04	1.72	0.01	1.24	0.43	1.55	0.89
	n	40	40	48	40	40	40	40	40	40	40	40	48
D12	*Total*	9	50	25	13	3	16	17	16	20	324	57	20
	Fecal	2	4	19	2	2	2	2	6	3	15	21	7
	Entero	4	12	18	3	3	2	5	3	4	173	36	30
D11	*Total*	452	92	158	36	114	24	352	40	84	3052	36	60
	Fecal	42	9	21	9	18	8	15	11	6	522	14	8
	Entero	129	13	31	8	29	6	95	10	9	30	18	29
D10	*Total*	134	12	20	29	38	36	64	34	132	152	76	34
	Fecal	7	6	8	14	4	12	11	7	6	28	15	13
	Entero	19	5	13	8	8	4	4	20	6	116	33	20
D9	*Total*	15	20	48	17	19	24	53	18	56	33	53	19
	Fecal	2	3	19	6	2	3	4	3	2	4	7	3
	Entero	3	8	24	2	6	3	4	2	4	14	8	5
D8	*Total*	137	89	84	56	58	20	32	20	212	164	296	80
	Fecal	13	20	18	10	4	4	3	4	7	32	81	15
	Entero	24	19	46	23	6	4	4	3	8	569	121	28
D7	*Total*	42	10	23	19	10	20	16	20	172	92	71	16
	Fecal	3	4	38	8	2	2	2	4	11	14	50	3
	Entero	2	2	14	11	2	2	4	4	9	7	20	3
D5	*Total*	20	10	22	40	49	16	16	20	92	48	65[a]	27
	Fecal	3	2	2	14	6	2	2	2	3	11	4	7
	Entero	4	2	3	8	24	19	2	2	2	57	342	5
D4	*Total*	2	9	6	10	86	21	13	13	24	25	53	54
	Fecal	2	2	2	4	46	2	2	2	2	2	2	6
	Entero	2	5	2	2	2	3	2	2	3	3	9	5

[a] n = 39

Appendix B.4

Summary of elevated bacteria densities in samples collected from PLOO shore and offshore stations during 2015. Bold values exceed benchmarks for total coliform (>10,000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), *Enterococcus* (>104 CFU/100 mL), and/or the FTR criterion (total coliforms > 1000 CFU/100 mL and F:T > 0.10).

Station Group	Date	Depth (m)	Total	Fecal	Entero	F:T
Shore Stations						
D11	12 Jan 15	—	2200	200	**600**	0.09
D8	01 Mar 15	—	360	60	**200**	0.17
D9	18 Mar 15	—	200	100	**120**	0.50
D5	05 May 15	—	200	20	**110**	0.10
D11	17 May 15	—	400	60	**130**	0.15
D11	22 Jul 15	—	1400	40	**420**	0.03
D8	08 Oct 15	—	200	60	**2800**	0.30
D5	14 Oct 15	—	120	24	**240**	0.20
D10	14 Oct 15	—	200	44	**240**	0.22
D11	14 Oct 15	—	**15,000**	**2600**	46	**0.17**
D12	14 Oct 15	—	600	18	**300**	0.03
D10	26 Oct 15	—	200	80	**320**	0.40
D12	26 Oct 15	—	400	20	**460**	0.05
D12[a]	28 Oct 15	—	—	—	**200**	—
D12[a]	29 Oct 15	—	—	—	**820**	—
D5	25 Nov 15	—	—	6	**1700**	—
D8	25 Nov 15	—	1000	260	**520**	0.26
D10	25 Nov 15	—	200	28	**140**	0.14
D12	25 Nov 15	—	200	84	**160**	0.42
D12	23 Dec 15	—	80	30	**140**	0.38
Offshore Stations						
F11	09 Feb 15	60	—	—	**140**	—
F11[a]	11 Feb 15	60	—	—	**120**	—
F30	11 Feb 15	80	—	—	**540**	—
F30	11 Feb 15	98	—	—	**140**	—
F17	13 May 15	60	—	—	**120**	—
F18	13 May 15	60	—	—	**190**	—
F18	13 May 15	80	—	—	**130**	—

Appendix B.4 *continued*

Station Group	Date	Depth (m)	Total	Fecal	Entero	F:T
F19	13 May 15	60	—	—	**460**	—
F19	13 May 15	80	—	—	**160**	—
F29	14 May 15	98	—	—	**160**	—
F30	14 May 15	98	—	—	**520**	—
F19[a]	15 May 15	80	—	—	**140**	—
F20	11 Aug 15	80	—	—	**160**	—
F30	12 Aug 15	80	—	—	**340**	—
F32	12 Aug 15	60	—	—	**130**	—
F33	12 Aug 15	60	—	—	**420**	—
F33	12 Aug 15	80	—	—	**120**	—
F17	05 Nov 15	80	—	—	**400**	—
F30	06 Nov 15	80	—	—	**340**	—
F30	06 Nov 15	98	—	—	**580**	—

[a] Resample

Appendix B.5

Summary of bacteria levels from PLOO kelp bed and offshore stations during 2015. Total coliform, fecal coliform, and *Enterococcus* densities are expressed as mean CFU/100 mL for all stations along each depth contour by month or quarter; n = total number of samples per sampling period.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kelp Bed Stations												
9-m Contour												
n	45	45	45	45	45	36	45	45	45	45	45	45
Total	2	2	2	2	3	4	3	2	6	9	16	15
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	75	75	75	75	60	75	75	75	75	75	75
Total	4	4	12	4	8	16	7	3	28	9	22[a]	26[b]
Fecal	2	2	3	2	2	2	2	2	3	2	2	2
Entero	2	2	2	2	2	2	2	2	3	3	2	3
Offshore Stations[c]												
18-m Contour (n = 9)	—	2	—	—	2	—	—	2	—	—	2	—
60-m Contour (n = 33)	—	10	—	—	5	—	—	2	—	—	3	—
80-m Contour (n = 44)	—	11	—	—	30	—	—	10	—	—	16	—
100-m Contour (n = 55)	—	16	—	—	24	—	—	23	—	—	22	—

[a] n = 73

[b] n = 74

[c] *Enterococcus* only

Appendix B.6

Summary of oceanographic data within potential detected plume at PLOO offshore stations and corresponding reference values during 2015. Plume depth is the minimum depth at which CDOM exceeds the 95th percentile while plume width is the number of meters across which that exceedance occurs. Highlighted/bold values indicate out-of-range values. DO = dissolved oxygen; XMS = transmissivity; SD = standard deviation; CI = confidence interval.

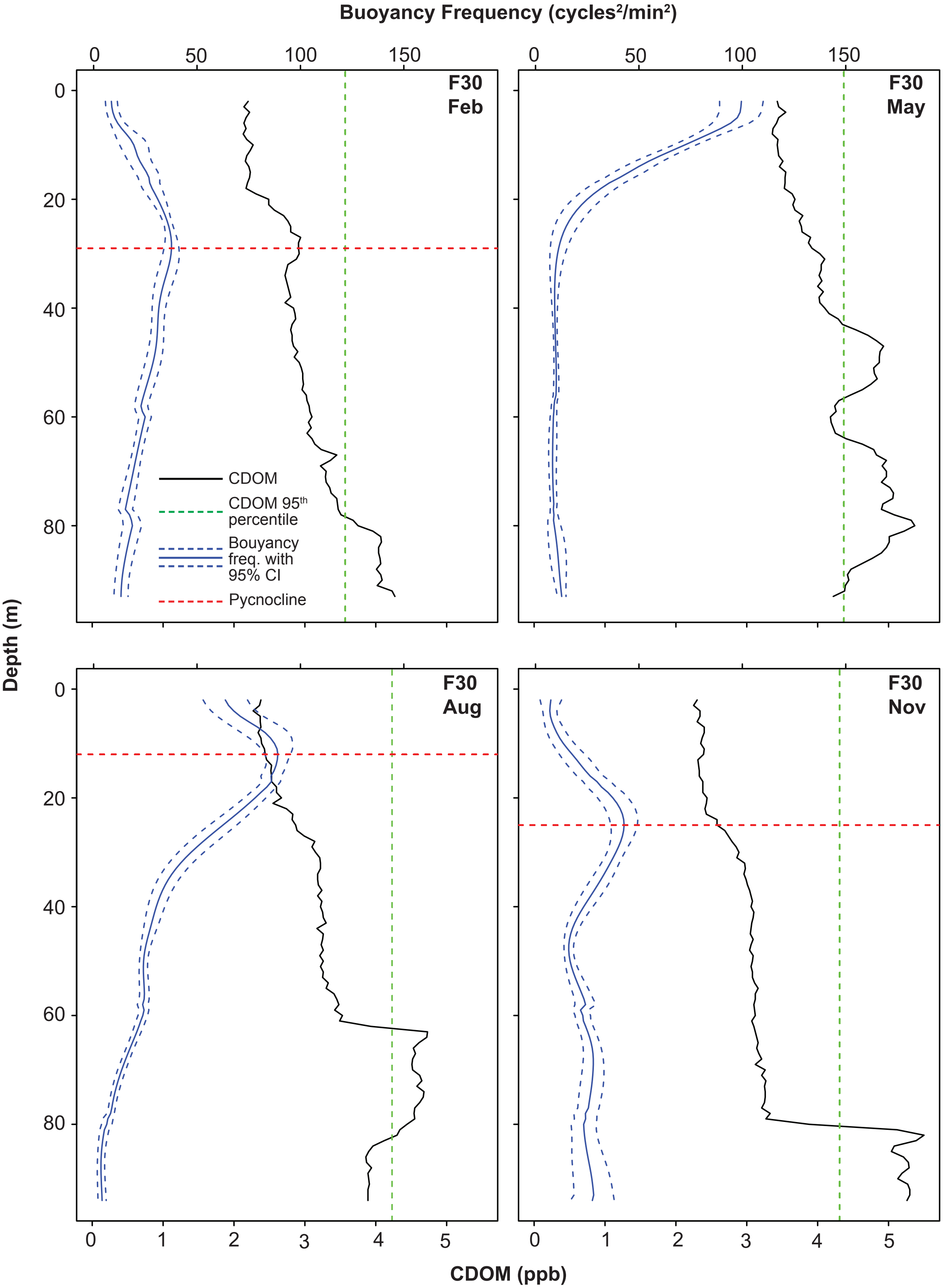
		Potential Plume					Reference		
Station	**Date**	**Depth (m)**	**Width (m)**	**Mean DO**	**Mean pH**	**Mean XMS**	**DO (Mean - SD)**	**pH (Mean)**	**XMS (Mean - 95% CI)**
F08[a]	09 Feb 15	49	2	6.0	8.0	**80**	6.3	8.0	90
F09[a]	09 Feb 15	54	3	5.8	7.9	**79**	5.9	8.0	87
F10[a]	09 Feb 15	53	7	5.8	7.9	**83**	5.8	8.0	87
F11[a]	09 Feb 15	50	9	5.7	7.9	**85**	5.9	8.0	87
F13[a]	09 Feb 15	56	3	5.8	7.9	**83**	5.8	8.0	86
F20[a]	10 Feb 15	52	8	5.7	7.9	88	5.8	8.0	88
F26	11 Feb 15	68	2	5.6	8.0	90	5.4	7.9	88
F27	11 Feb 15	70	3	5.4	7.9	90	5.4	7.9	88
F28	11 Feb 15	70	5	5.3	7.9	89	5.3	7.9	86
F29	11 Feb 15	72	5	5.1	7.9	88	5.2	7.9	85
F30	11 Feb 15	79	15	4.9	7.9	**86**	4.8	7.9	88
F17	13 May 15	57	6	4.0	7.8	**88**	4.1	7.8	90
F18[a]	13 May 15	59	16	3.9	7.8	**89**	3.9	7.8	90
F19	13 May 15	53	25	3.8	7.8	89	4.0	7.8	89
F27	14 May 15	54	3	3.9	7.8	89	4.3	7.8	88
F28	14 May 15	49	13	4.0	7.8	89	4.3	7.8	88
F29	14 May 15	49	13	3.9	7.8	89	4.3	7.8	89
F30	14 May 15	44	42	**3.7**	7.7	**88**	4.2	7.8	89
F30	12 Aug 15	63	20	5.4	8.0	88	5.6	8.0	88
F31	12 Aug 15	52	42	5.7	8.0	90	5.9	8.1	88
F32	12 Aug 15	67	2	5.7	8.0	90	5.6	8.0	89
F33	12 Aug 15	61	13	5.4	8.0	89	5.7	8.0	89
F34	12 Aug 15	61	9	5.4	8.0	89	5.8	8.0	89
F36	12 Aug 15	78	18	5.3	8.0	89	5.4	8.0	89
F04	02 Nov 15	28	15	7.2	8.1	**84**	7.0	8.1	89
F06[a]	02 Nov 15	32	9	7.5	8.2	**86**	7.3	8.2	88
F12[a]	02 Nov 15	55	2	7.0	8.1	89	6.7	8.1	89

[a] Stations located within State jurisdictional waters

Appendix B.6 *continued*

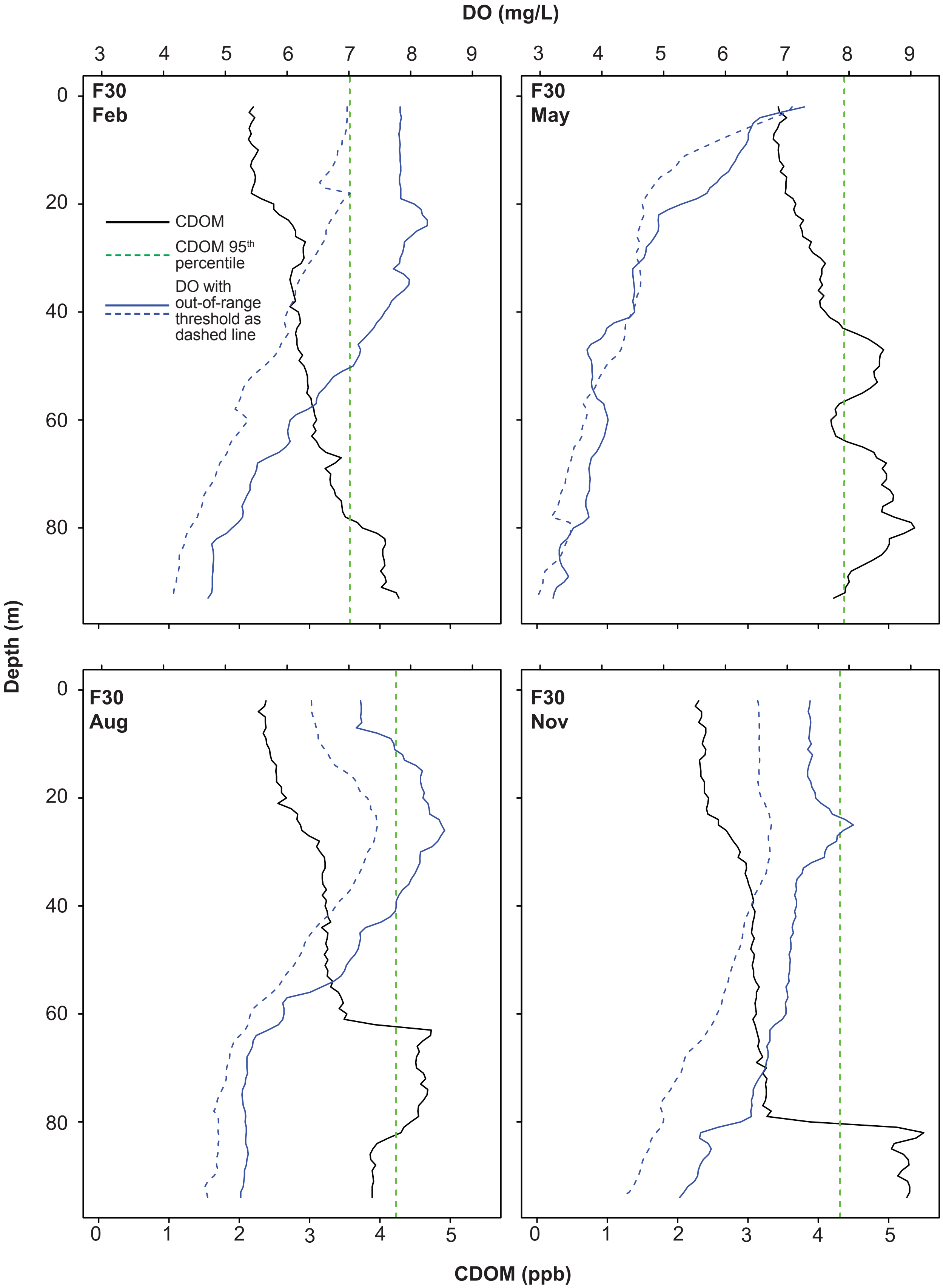
		Potential Plume					Reference		
Station	**Date**	**Depth (m)**	**Width (m)**	**Mean DO**	**Mean pH**	**Mean XMS**	**DO (Mean - SD)**	**pH (Mean)**	**XMS (Mean - 95% CI)**
F13[a]	02 Nov 15	45	12	6.9	8.1	89	6.8	8.1	89
F14[a]	02 Nov 15	42	13	7.0	8.1	89	6.9	8.1	89
F29	06 Nov 15	83	4	5.8	8.0	**86**	5.3	8.0	89
F30	06 Nov 15	81	14	5.6	8.0	**86**	5.2	8.0	89

[a] Stations located within State jurisdictional waters



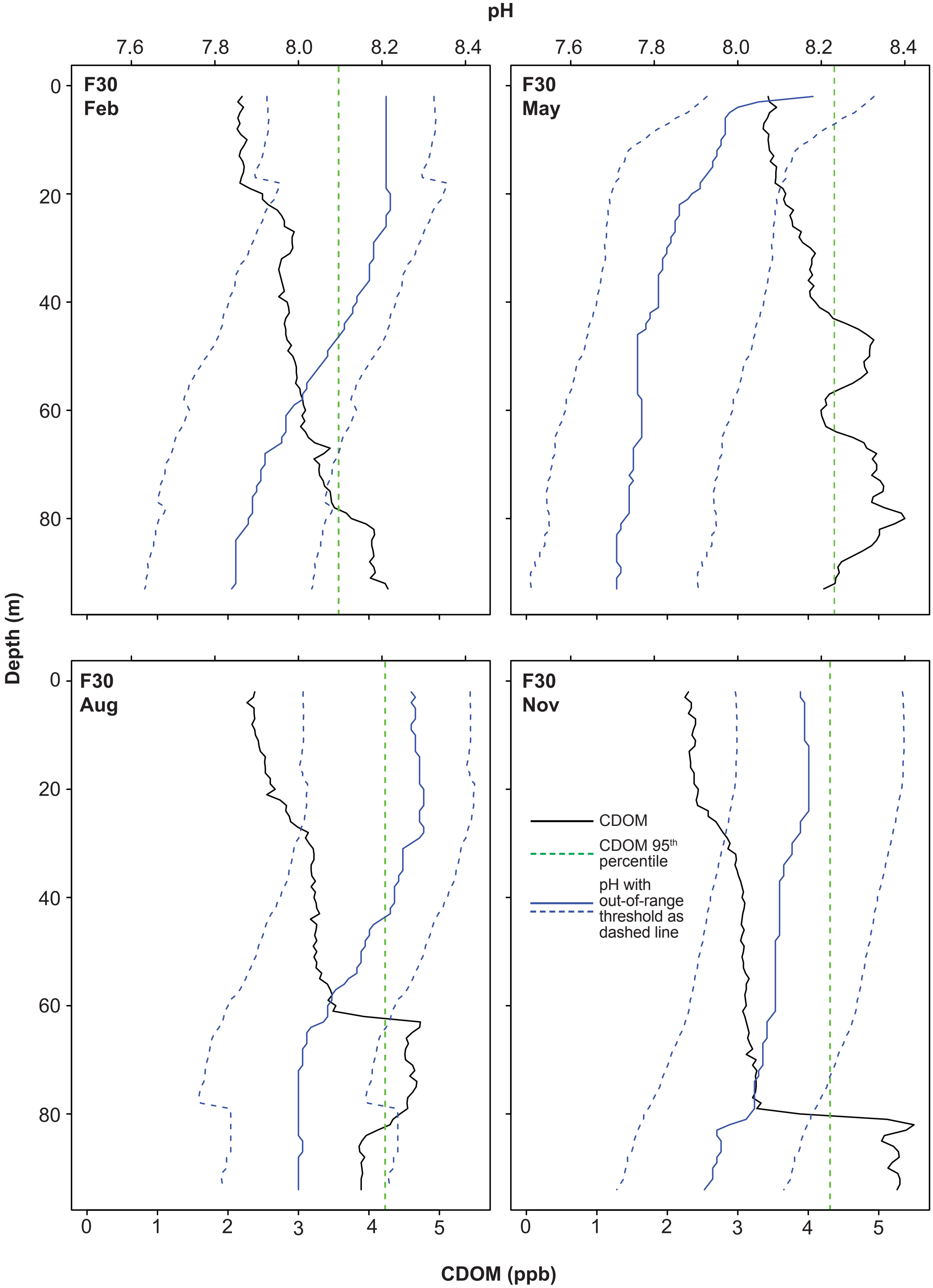
Appendix B.7

Representative vertical profiles of CDOM and buoyancy frequency from PLOO near-ZID station F30 during 2015.



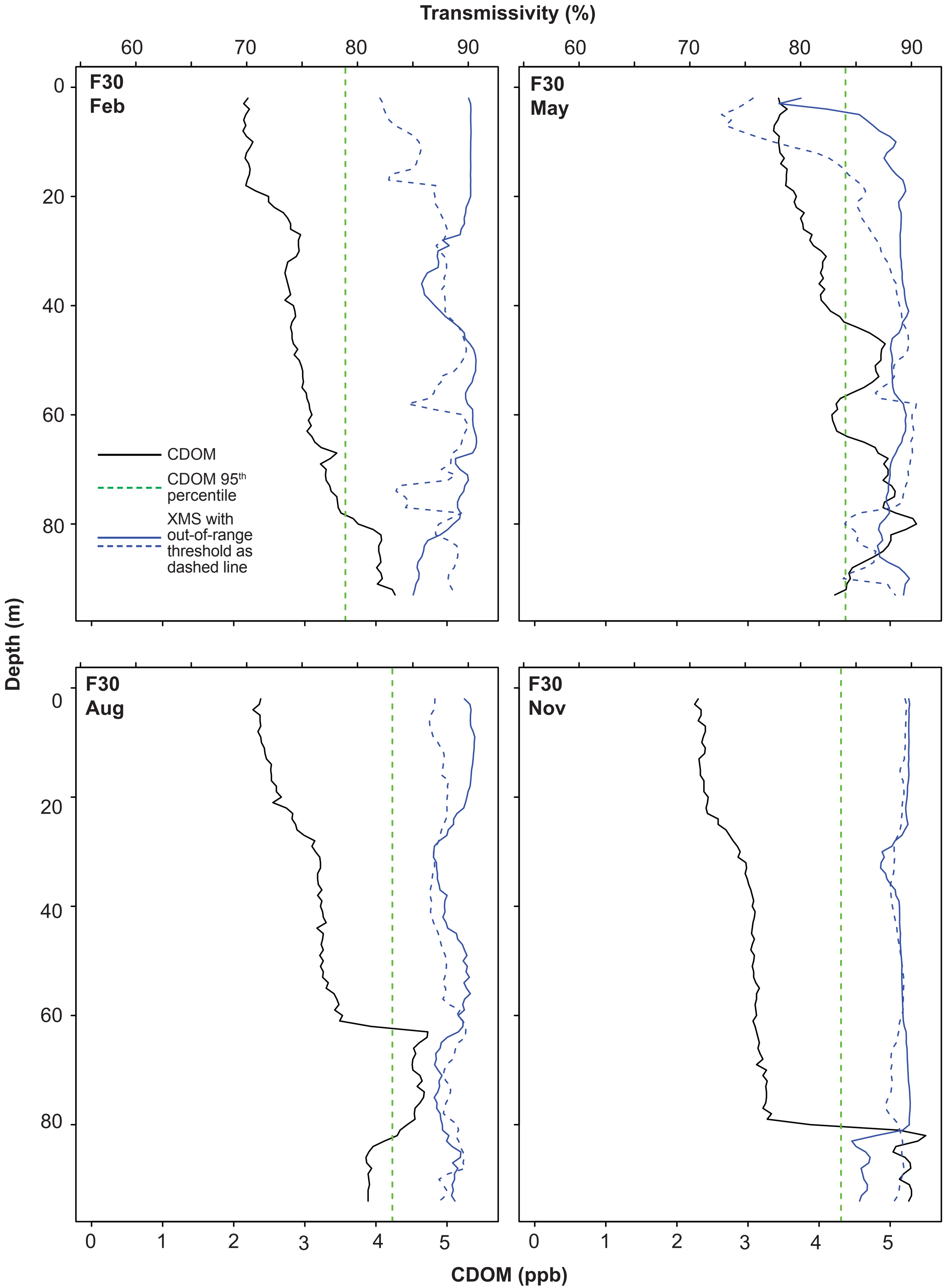
Appendix B.8

Representative vertical profiles of CDOM and dissolved oxygen (DO) from PLOO near-ZID station F30 during 2015.



Appendix B.9

Representative vertical profiles of CDOM and pH from PLOO near-ZID station F30 during 2015.



Appendix B.10

Representative vertical profiles of CDOM and transmissivity from PLOO near-ZID station F30 during 2015. XMS = transmissivity.

Appendix C

Supporting Data

2015 PLOO Stations

Sediment Conditions

Appendix C.1

Constituents and method detection limits (MDL) used for the analysis of sediments from the PLOO region during 2015.

Parameter	MDL	Parameter	MDL
Organic Indicators			
Biological Oxygen Demand (BOD, ppm)	2	Total Sulfides (ppm)	0.14
Total Nitrogen (TN, % wt.)	0.01, 0.004 [a]	Total Volatile Solids (TVS, % wt.)	0.11
Total Organic Carbon (TOC, % wt.)	0.04		
Metals (ppm)			
Aluminum (Al)	2	Lead (Pb)	0.8
Antimony (Sb)	0.3	Manganese (Mn)	0.08
Arsenic (As)	0.33	Mercury (Hg)	0.004
Barium (Ba)	0.02	Nickel (Ni)	0.1
Beryllium (Be)	0.01	Selenium (Se)	0.24
Cadmium (Cd)	0.06	Silver (Ag)	0.04
Chromium (Cr)	0.1	Thallium (Tl)	0.5
Copper (Cu)	0.2	Tin (Sn)	0.3
Iron (Fe)	9	Zinc (Zn)	0.25
Chlorinated Pesticides (ppt)			
Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	100	HCH, Delta isomer	220
HCH, Beta isomer	50	HCH, Gamma isomer	190
Total Chlordane			
Alpha (cis) Chlordane	160	Heptachlor epoxide	300
Cis Nonachlor	380	Methoxychlor	90
Gamma (trans) Chlordane	190	Oxychlordane	1200
Heptachlor	120	Trans Nonachlor	240
Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	100	p,p-DDE	90, 260 [a]
o,p-DDE	60	p,p-DDMU [b]	—
o,p-DDT	110	p,p-DDT	70
p,p-DDD	160		
Miscellaneous Pesticides			
Aldrin	70	Endrin	510
Alpha Endosulfan	720	Endrin aldehyde	2400
Beta Endosulfan	780	Hexachlorobenzene (HCB)	70
Dieldrin	340	Mirex	60
Endosulfan Sulfate	1100		

[a] MDL differed from Q1 to Q3 for this parameter

[b] No MDL available for this parameter

Appendix C.1 *continued*

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

Appendix C.2

Particle size classification schemes (based on Folk 1980) used in the analysis of sediments from the PLOO region during 2015. Included is a subset of the Wentworth scale presented as "phi" categories with corresponding Horiba channels, sieve sizes, and size fractions.

Wentworth Scale

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

[a] Values correspond to Horiba channels; particles > 2000 µm measured by sieve

[b] SIEVE_0 = sum of all silt and clay, which cannot be distinguished for samples processed by nested sieves

[c] Fine particles also referred to as percent fines

Appendix C.3

Summary of the constituents that make up total DDT, total PCB, and total PAH in sediments from the PLOO region during 2015; nd = not detected.

Station	Class	Constituent	Winter	Summer	Units
B-8	DDT	p,p-DDE	980	620	ppt
B-8	PAH	Benzo[G,H,I]perylene	nd	4	ppb
B-8	PAH	Biphenyl	nd	4	ppb
B-8	PAH	Fluoranthene	nd	8	ppb
B-8	PAH	Pyrene	7	8	ppb
B-9	DDT	p,p-DDD	nd	100	ppt
B-9	DDT	p,p-DDE	520	660	ppt
B-9	PAH	2,6-dimethylnaphthalene	6	7	ppb
B-10	DDT	p,p-DDE	750	380	ppt
B-10	PAH	2,6-dimethylnaphthalene	nd	9	ppb
B-11	DDT	p,p-DDD	nd	68	ppt
B-11	DDT	p,p-DDE	400	300	ppt
B-11	PAH	2,6-dimethylnaphthalene	7	8	ppb
B-12	DDT	p,p-DDE	600	340	ppt
E-1	DDT	p,p-DDD	nd	130	ppt
E-1	DDT	p,p-DDE	470	510	ppt
E-1	PAH	2,6-dimethylnaphthalene	nd	7	ppb
E-1	PAH	3,4-benzo(B)fluoranthene	17	37	ppb
E-1	PAH	Acenaphthylene	nd	4	ppb
E-1	PAH	Anthracene	nd	5	ppb
E-1	PAH	Benzo[A]anthracene	nd	26	ppb
E-1	PAH	Benzo[A]pyrene	15	31	ppb
E-1	PAH	Benzo[e]pyrene	12	19	ppb
E-1	PAH	Benzo[G,H,I]perylene	14	23	ppb
E-1	PAH	Benzo[K]fluoranthene	nd	21	ppb
E-1	PAH	Biphenyl	nd	5	ppb
E-1	PAH	Chrysene	5	22	ppb
E-1	PAH	Fluoranthene	12	19	ppb
E-1	PAH	Indeno(1,2,3-CD)pyrene	10	18	ppb
E-1	PAH	Perylene	nd	8	ppb
E-1	PAH	Pyrene	16	13	ppb
E-1	PCB	PCB 44	nd	74	ppt
E-1	PCB	PCB 49	nd	86	ppt
E-1	PCB	PCB 52	nd	72	ppt
E-1	PCB	PCB 99	nd	95	ppt
E-1	PCB	PCB 101	nd	150	ppt
E-1	PCB	PCB 149	nd	210	ppt
E-1	PCB	PCB 153/168	400	280	ppt
E-1	PCB	PCB 180	nd	160	ppt
E-2	DDT	p,p-DDE	640	410	ppt
E-2	PAH	2,6-dimethylnaphthalene	nd	8	ppb
E-2	PAH	3,4-benzo(B)fluoranthene	14	nd	ppb
E-2	PAH	Benzo[A]anthracene	12	nd	ppb
E-2	PAH	Benzo[A]pyrene	11	16	ppb
E-2	PAH	Benzo[e]pyrene	8	12	ppb
E-2	PAH	Benzo[G,H,I]perylene	9	14	ppb

Station	Class	Constituent	Winter	Summer	Units
E-2	PAH	Benzo[K]fluoranthene	nd	10	ppb
E-2	PAH	Biphenyl	nd	8	ppb
E-2	PAH	Chrysene	nd	8	ppb
E-2	PAH	Fluoranthene	nd	11	ppb
E-2	PAH	Indeno(1,2,3-CD)pyrene	nd	11	ppb
E-2	PAH	Pyrene	nd	14	ppb
E-2	PCB	PCB 49	nd	43	ppt
E-2	PCB	PCB 52	nd	44	ppt
E-2	PCB	PCB 66	nd	65	ppt
E-2	PCB	PCB 70	nd	55	ppt
E-2	PCB	PCB 110	300	nd	ppt
E-2	PCB	PCB 153/168	400	200	ppt
E-3	DDT	p,p-DDD	560	200	ppt
E-3	DDT	p,p-DDE	480	460	ppt
E-3	DDT	p,p-DDT	15,000	nd	ppt
E-3	PAH	2,6-dimethylnaphthalene	nd	7	ppb
E-3	PAH	3,4-benzo(B)fluoranthene	40	62	ppb
E-3	PAH	Acenaphthylene	nd	8	ppb
E-3	PAH	Anthracene	nd	13	ppb
E-3	PAH	Benzo[A]anthracene	20	30	ppb
E-3	PAH	Benzo[A]pyrene	30	51	ppb
E-3	PAH	Benzo[e]pyrene	19	34	ppb
E-3	PAH	Benzo[G,H,I]perylene	20	44	ppb
E-3	PAH	Benzo[K]fluoranthene	nd	29	ppb
E-3	PAH	Biphenyl	nd	9	ppb
E-3	PAH	Chrysene	19	44	ppb
E-3	PAH	Fluoranthene	19	57	ppb
E-3	PAH	Indeno(1,2,3-CD)pyrene	18	33	ppb
E-3	PAH	Perylene	nd	13	ppb
E-3	PAH	Phenanthrene	nd	37	ppb
E-3	PAH	Pyrene	20	65	ppb
E-3	PCB	PCB 18	nd	160	ppt
E-3	PCB	PCB 28	nd	290	ppt
E-3	PCB	PCB 37	nd	46	ppt
E-3	PCB	PCB 44	nd	360	ppt
E-3	PCB	PCB 49	nd	250	ppt
E-3	PCB	PCB 52	nd	420	ppt
E-3	PCB	PCB 66	nd	400	ppt
E-3	PCB	PCB 70	nd	390	ppt
E-3	PCB	PCB 74	nd	150	ppt
E-3	PCB	PCB 87	nd	150	ppt
E-3	PCB	PCB 99	nd	280	ppt
E-3	PCB	PCB 101	nd	440	ppt
E-3	PCB	PCB 105	nd	170	ppt
E-3	PCB	PCB 110	nd	460	ppt
E-3	PCB	PCB 118	nd	470	ppt
E-3	PCB	PCB 128	nd	160	ppt
E-3	PCB	PCB 138	nd	460	ppt
E-3	PCB	PCB 149	nd	310	ppt
E-3	PCB	PCB 153/168	nd	560	ppt
E-3	PCB	PCB 156	nd	78	ppt
E-3	PCB	PCB 180	nd	240	ppt
E-3	PCB	PCB 187	nd	150	ppt

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
E-5	DDT	p,p-DDE	550	610	ppt
E-5	PCB	PCB 66	160	67	ppt
E-5	PCB	PCB 70	170	nd	ppt
E-5	PCB	PCB 74	100	nd	ppt
E-5	PCB	PCB 153/168	nd	210	ppt
E-7	DDT	p,p-DDD	nd	150	ppt
E-7	DDT	p,p-DDE	990	790	ppt
E-7	PAH	2,6-dimethylnaphthalene	nd	7	ppb
E-7	PCB	PCB 149	nd	91	ppt
E-8	DDT	p,p-DDE	740	540	ppt
E-8	PAH	2,6-dimethylnaphthalene	nd	7	ppb
E-9	DDT	p,p-DDE	650	520	ppt
E-9	PAH	3,4-benzo(B)fluoranthene	8	10	ppb
E-9	PAH	Benzo[A]pyrene	6	8	ppb
E-9	PAH	Chrysene	nd	7	ppb
E-9	PAH	Pyrene	8	11	ppb
E-9	PCB	PCB 153/168	nd	240	ppt
E-11	DDT	p,p-DDE	720	400	ppt
E-11	PAH	2,6-dimethylnaphthalene	4	11	ppb
E-14	DDT	p,p-DDE	620	320	ppt
E-14	PAH	2,6-dimethylnaphthalene	7	8	ppb
E-14	PAH	Biphenyl	5	nd	ppb
E-15	DDT	p,p-DDD	nd	88	ppt
E-15	DDT	p,p-DDE	nd	390	ppt
E-15	PAH	2,6-dimethylnaphthalene	8	7	ppb
E-17	DDT	p,p-DDE	600	410	ppt
E-17	PAH	2,6-dimethylnaphthalene	9	7	ppb
E-17	PAH	Biphenyl	6	nd	ppb
E-17	PCB	PCB 70	230	nd	ppt
E-17	PCB	PCB 101	440	nd	ppt
E-17	PCB	PCB 105	450	nd	ppt
E-17	PCB	PCB 110	580	nd	ppt
E-17	PCB	PCB 118	520	nd	ppt
E-17	PCB	PCB 138	900	nd	ppt
E-17	PCB	PCB 149	420	nd	ppt
E-17	PCB	PCB 153/168	920	nd	ppt
E-17	PCB	PCB 187	190	nd	ppt
E-19	DDT	p,p-DDD	nd	94	ppt
E-19	DDT	p,p-DDE	685	280	ppt
E-19	PAH	2,6-dimethylnaphthalene	8	nd	ppb
E-19	PAH	3,4-benzo(B)fluoranthene	7	6	ppb
E-19	PAH	Biphenyl	7	7	ppb
E-19	PAH	Fluoranthene	9	nd	ppb
E-19	PAH	Pyrene	nd	7	ppb

Appendix C.3 *continued*

Station	Class	Constituent	Winter	Summer	Units
E-20	DDT	p,p-DDD	nd	420	ppt
E-20	DDT	p,p-DDE	480	330	ppt
E-20	DDT	p,p-DDT	nd	8800	ppt
E-20	PAH	2,6-dimethylnaphthalene	7	7	ppb
E-20	PAH	Biphenyl	nd	7	ppb
E-21	DDT	p,p-DDE	570	550	ppt
E-21	PAH	2,6-dimethylnaphthalene	7	9	ppb
E-21	PAH	Biphenyl	nd	9	ppb
E-23	DDT	p,p-DDE	380	360	ppt
E-23	PAH	2,6-dimethylnaphthalene	9	7	ppb
E-23	PAH	Biphenyl	nd	8	ppb
E-25	DDT	p,p-DDE	660	460	ppt
E-25	PAH	2,6-dimethylnaphthalene	8	nd	ppb
E-26	DDT	p,p-DDE	620	495	ppt
E-26	PAH	2,6-dimethylnaphthalene	10	nd	ppb

Appendix C.4

Summary of particle size parameters (%) for each PLOO station sampled during winter 2015. Visual observations are from sieved “grunge” (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VCSand = Very Coarse Sand; CSand = Coarse Sand; MSand = Medium Sand; FSand = Fine Sand; VFSand = Very Fine Sand; CSilt = Coarse Silt; MSilt = Medium Silt; FSilt = Fine Silt; VFSilt = Very Fine Silt.

		Coarse Particles		Med-Coarse Sands		Fine Sands		Fine Particles					Visual Observations
		Granules	VCSand	CSand	MSand	FSand	VFSand	CSilt	MSilt	FSilt	VFSilt	Clay	
88-m Stations	B11[s]	2.1	4.7	8.8	11.8	10.9	18.6	43.1	—	—	—	—	shell hash
	B8	0.0	0.0	0.0	0.1	5.3	30.7	29.2	14.3	15.9	4.4	0.1	
	E19	0.0	0.0	0.0	0.1	8.1	40.0	27.3	9.2	11.3	3.9	0.1	shell hash
	E7	0.0	0.0	0.0	0.2	9.9	40.7	25.5	9.2	11.0	3.5	0.0	
	E1	0.0	1.5	3.9	7.2	14.6	23.0	15.6	9.8	15.1	7.6	1.6	pea gravel, rock, shell hash
98-m Stations	B12	0.0	0.0	5.9	19.6	22.2	20.9	12.5	5.7	8.0	4.8	0.4	pea gravel, shell hash
	B9	0.0	0.0	0.0	1.2	13.1	37.5	19.5	9.5	14.3	4.6	0.1	pea gravel, mud balls, shell hash
	E26	0.0	0.0	0.0	0.2	10.0	41.0	23.3	9.0	12.1	4.3	0.1	shell hash
	E25	0.0	0.0	0.0	0.7	13.7	42.3	21.7	7.7	10.0	3.7	0.1	shell hash
	E23	0.0	0.0	0.0	0.5	10.8	41.9	24.0	8.5	10.5	3.7	0.1	shell hash
	E20	0.0	0.0	0.0	0.2	11.6	42.1	21.0	8.4	12.1	4.4	0.2	shell hash
	E17[a]	0.0	0.0	0.0	0.6	14.5	46.4	19.0	6.5	9.4	3.4	0.1	shell hash
	E14[a]	0.0	0.0	0.0	1.2	17.2	49.2	16.3	4.9	7.7	3.3	0.1	black sand, pea gravel, shell hash
	E11[a]	0.0	0.0	0.0	1.5	17.3	45.0	17.9	5.8	8.8	3.6	0.1	black sand, shell hash
	E8	0.0	0.0	0.0	0.8	15.8	43.9	18.5	7.1	10.2	3.6	0.1	black sand, shell hash
	E5	0.0	0.0	0.0	1.7	17.6	41.9	18.5	7.0	9.6	3.6	0.1	pea gravel, shell hash
	E2[s]	1.5	3.9	9.2	9.2	12.2	26.6	37.4	—	—	—	—	
116-m Stations	B10[s]	1.3	0.2	0.5	1.0	80.3	4.8	12.0	—	—	—	—	shell hash
	E21	0.0	0.0	0.0	0.6	14.9	46.7	17.6	6.2	9.5	4.2	0.3	
	E15	0.0	0.0	0.0	0.8	16.7	46.9	15.9	5.7	9.8	4.0	0.2	black sand
	E9	0.0	6.0	8.5	4.1	10.8	30.9	16.2	7.0	11.6	4.8	0.3	black sand
	E3[s]	4.7	7.0	10.5	12.3	31.3	12.6	21.6	—	—	—	—	pea gravel, rock, shell hash

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

Appendix C.4 *continued*

Summary of particle size parameters (%) for each PLOO station sampled during summer 2015. Visual observations are from sieved “grunge” (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis). VCSand = Very Coarse Sand; CSand = Coarse Sand; MSand = Medium Sand; FSand = Fine Sand; VFSand = Very Fine Sand; CSilt = Coarse Silt; MSilt = Medium Silt; FSilt = Fine Silt; VFSilt = Very Fine Silt.

		Coarse Particles		Med-Coarse Sands		Fine Sands		Fine Particles					Visual Observations
		Granules	VCSand	CSand	MSand	FSand	VFSand	CSilt	MSilt	FSilt	VFSilt	Clay	
88-m Stations	B11	0.0	2.0	3.1	8.5	15.7	23.9	14.7	10.0	16.3	5.7	0.2	shell hash
	B8	0.0	0.0	0.0	0.1	5.2	30.7	29.5	14.1	15.7	4.6	0.1	
	E19	0.0	0.0	0.0	0.2	8.1	38.9	27.4	9.8	11.5	4.0	0.1	
	E7	0.0	0.0	0.0	0.2	10.7	40.4	24.9	9.3	10.8	3.7	0.1	shell hash, worm tubes
	E1	0.0	0.0	0.0	6.8	20.9	29.0	17.1	9.0	12.1	4.7	0.3	shell hash, gravel, cobble
98-m Stations	B12	0.0	0.0	7.1	25.2	22.0	17.4	10.7	5.1	7.5	4.6	0.4	shell hash, gravel
	B9	0.0	0.0	0.0	1.5	14.6	38.8	19.0	8.7	13.0	4.3	0.1	pea gravel, mud balls
	E26	0.0	0.0	0.0	0.2	10.2	40.9	22.6	9.0	12.5	4.4	0.1	shell hash
	E25	0.0	0.0	0.0	0.7	13.7	42.3	21.4	7.8	10.3	3.7	0.1	shell hash
	E23	0.0	0.0	0.0	0.2	10.9	42.8	24.2	8.1	10.0	3.7	0.1	shell hash, worm tubes
	E20	0.0	0.0	0.0	0.2	12.3	45.3	21.4	7.3	9.8	3.6	0.1	shell hash
	E17[a]	0.0	0.0	0.0	0.6	14.3	47.0	19.5	6.2	8.7	3.5	0.1	shell hash, worm tubes
	E14[a]	0.0	0.0	0.0	0.8	17.9	49.7	14.2	4.6	8.6	4.1	0.2	black sand, shell hash
	E11[a]	0.0	0.0	0.0	0.7	14.8	46.4	19.6	6.3	8.7	3.4	0.1	shell hash, worm tubes
	E8	0.0	0.0	0.0	1.2	15.4	43.0	19.7	7.0	9.5	3.9	0.3	shell hash, worm tubes
	E5	0.0	0.0	0.0	1.8	18.1	42.6	18.1	6.5	9.2	3.6	0.1	shell hash, worm tubes
	E2	0.0	0.0	0.0	5.2	20.4	32.8	17.1	8.5	11.9	4.0	0.1	shell hash, gravel, cobble
116-m Stations	B10[s]	0.8	0.3	0.4	1.2	8.2	65.0	24.3	—	—	—	—	shell hash
	E21	0.0	0.0	0.0	0.6	14.7	47.6	17.8	6.1	9.2	3.8	0.2	
	E15	0.0	0.0	0.0	0.8	16.6	47.0	16.9	5.7	9.0	3.8	0.2	black sand, shell hash, worm tubes
	E9[s]	1.7	15.7	15.9	3.9	5.7	27.3	29.8	—	—	—	—	black sand, shell hash
	E3[s]	2.3	4.1	4.9	10.7	37.0	18.1	23.0	—	—	—	—	shell hash, gravel

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

Appendix C.5

Summary of organic loading indicators in sediments from PLOO stations sampled during winter and summer 2015; nr = not reportable.

	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	nr	5.90	0.085	0.80	3.50	419	1.34	0.050	3.36	4.20
B8	nr	3.50	0.089	0.78	3.10	nr	3.01	0.063	0.74	3.00
E19	nr	4.88	0.068	0.59	2.60	419	4.39	0.026	0.58	2.50
E7	227	4.38	0.065	0.58	2.40	nr	3.01	0.044	0.57	2.20
E1	183	4.50	0.063	0.54	2.40	260	2.63	0.031	0.40	1.80
98-m Depth Contour										
B12	nr	2.20	0.059	0.70	2.90	327	1.16	0.027	3.11	2.90
B9	nr	7.00	0.069	0.60	2.80	nr	2.50	0.057	0.78	2.90
E26	nr	5.60	0.062	0.54	1.90	nr	3.64	0.037	0.62	2.60
E25	nr	3.80	0.053	0.47	2.40	nr	2.62	0.021	0.50	2.10
E23	nr	5.00	0.059	0.52	2.20	349	3.74	0.020	0.46	2.30
E20	nr	5.59	0.057	0.49	2.00	235	3.05	0.021	0.47	1.80
E17[a]	nr	9.09	0.055	0.47	2.00	265	5.14	0.076	0.49	2.10
E14[a]	nr	49.20	0.044	0.39	1.80	456	76.50	0.020	0.42	1.70
E11[a]	nr	5.56	0.050	0.42	2.05	300	12.70	0.043	0.42	2.20
E8	194	4.06	0.053	0.43	1.90	nr	10.60	0.030	0.50	2.30
E5	188	4.66	0.053	0.42	2.10	nr	2.92	0.033	0.48	2.00
E2	161	3.72	0.065	0.55	2.50	230	6.18	0.026	0.58	2.50
116-m Depth Contour										
B10	nr	4.70	0.059	0.50	2.40	nr	4.10	0.024	1.26	2.20
E21	nr	4.10	0.052	0.45	2.00	242	3.23	0.031	0.45	2.10
E15	nr	8.43	0.053	0.44	2.10	267	7.26	0.047	0.68	2.20
E9	215	3.33	0.076	0.66	2.50	nr	2.13	0.063	1.29	2.30
E3	100	3.52	0.049	0.40	1.70	185	3.47	0.009	0.49	2.00
Detection Rate (%)	100	100	100	100	100	100	100	100	100	100

[a] Near-ZID stations

Appendix C.6

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during winter 2015. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted (see Table 4.1); nd = not detected.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	11,100	0.6	3.41	58.20	0.29	nd	22.2	6.0	19,200	6.5	153.0	0.021	10.4	nd	nd	2.2	0.4	45.5
B8	12,500	0.6	3.01	54.60	0.25	nd	21.8	7.6	15,800	6.4	131.0	0.032	11.4	nd	nd	2.4	0.9	41.8
E19	10,700	0.5	2.77	48.70	0.21	nd	18.5	6.8	13,300	5.3	114.0	0.024	9.6	nd	nd	2.3	0.9	35.4
E7	9890	0.3	2.78	45.30	0.20	nd	17.0	6.4	12,400	5.0	106.0	0.025	8.5	nd	nd	2.0	0.8	33.2
E1	11,300	nd	2.76	67.90	0.23	nd	16.5	7.7	14,000	6.8	102.0	0.055	8.5	nd	nd	3.3	0.6	35.2
98-m Depth Contour																		
B12	8840	0.9	4.81	25.50	0.33	nd	27.0	3.0	23,400	5.5	75.5	0.011	8.6	nd	nd	1.3	nd	44.2
B9	9470	0.6	2.50	54.10	0.26	nd	21.2	7.5	16,000	5.4	104.0	0.019	8.7	nd	nd	2.1	nd	38.8
E26	11,100	0.6	2.33	40.50	0.18	0.06	18.2	6.7	12,800	4.0	109.0	0.017	10.6	nd	nd	nd	1.4	29.1
E25	11,000	0.7	2.10	36.60	0.17	0.07	16.8	7.6	11,900	3.8	109.0	0.013	10.3	nd	nd	nd	1.4	29.9
E23	10,500	0.6	2.35	44.60	0.20	nd	18.3	5.7	13,200	4.4	111.0	0.014	9.8	nd	nd	2.0	0.6	34.1
E20	8190	0.4	2.23	32.20	0.17	nd	14.7	4.4	10,500	3.6	88.2	0.018	7.2	nd	nd	1.7	nd	26.6
E17[a]	8030	nd	2.29	32.60	0.16	nd	14.7	5.3	10,400	3.6	87.9	0.013	7.2	nd	nd	2.6	0.5	28.2
E14[a]	6210	0.4	1.95	23.70	0.14	nd	11.9	4.3	8260	3.0	69.4	0.008	5.9	nd	nd	2.1	0.5	22.5
E11[a]	6200	nd	2.35	22.80	0.15	nd	11.5	3.6	8240	2.5	66.9	0.011	5.5	nd	nd	2.1	nd	21.7
E8	7400	0.6	1.95	29.80	0.16	nd	13.3	4.2	9490	3.8	79.4	0.017	6.8	nd	nd	2.2	nd	24.3
E5	8310	0.4	2.04	34.80	0.17	nd	14.4	5.0	10,900	3.4	87.0	0.018	7.1	nd	nd	2.5	0.7	27.4
E2	11,100	0.6	2.48	56.60	0.21	nd	17.1	8.8	15,400	5.5	114.0	0.043	8.3	nd	nd	0.9	0.7	36.0
116-m Depth Contour																		
B10	6920	nd	2.03	26.50	0.18	nd	15.9	3.6	11,300	3.8	74.6	0.013	6.5	nd	nd	3.0	0.4	27.0
E21	7450	nd	2.02	28.80	0.16	nd	13.8	4.3	9650	3.6	78.6	0.014	6.8	nd	nd	2.8	nd	24.8
E15	7500	0.4	1.89	27.60	0.17	nd	14.6	4.9	10,100	4.1	78.4	0.013	6.6	nd	nd	3.3	0.3	26.5
E9	7460	0.5	2.26	27.30	0.19	nd	16.6	6.7	12,100	4.2	80.8	0.013	7.3	nd	nd	2.5	nd	30.7
E3	9520	0.7	2.19	56.80	0.17	nd	14.2	17.3	13,000	6.3	105.0	0.032	6.8	nd	nd	3.1	0.5	35.6
Detection Rate (%)	100	77	100	100	100	9	100	100	100	100	100	100	100	0	0	91	68	100

[a] Near-ZID stations

Appendix C.6 *continued*

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during summer 2015. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted (see Table 4.1); nd = not detected.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	10,900	0.9	4.71	42.40	nd	nd	26.4	9.3	20,600	5.1	145.0	0.029	8.5	0.35	nd	nd	1.0	39.7
B8	12,200	0.9	3.06	54.00	nd	nd	22.6	10.3	15,700	5.7	135.0	0.036	9.5	0.25	nd	nd	1.1	39.4
E19	12,600	1.0	2.90	58.40	nd	0.09	21.9	9.8	14,600	5.0	140.0	0.031	10.8	0.24	nd	nd	1.0	37.5
E7	9420	0.8	3.02	43.00	nd	nd	16.7	7.5	11,800	3.9	108.0	0.024	7.5	nd	nd	nd	0.7	29.3
E1	9670	1.0	3.12	46.50	nd	nd	18.7	9.8	12,000	7.1	110.0	0.044	7.2	nd	nd	nd	1.0	33.9
98-m Depth Contour																		
B12	7300	0.9	5.77	23.40	nd	nd	31.0	4.1	23,100	4.4	86.3	0.015	6.4	nd	nd	nd	0.7	35.5
B9	9690	0.9	4.80	40.90	nd	nd	24.9	6.3	19,300	4.9	114.0	0.025	8.0	0.19	nd	nd	0.8	38.5
E26	11,000	0.9	2.77	49.10	nd	nd	19.6	8.0	13,300	4.3	126.0	0.024	10.0	0.24	nd	nd	0.7	32.8
E25	10,400	0.9	2.65	45.40	nd	0.07	19.0	7.5	12,500	4.2	118.0	0.022	9.3	0.24	nd	nd	0.7	31.4
E23	10,800	1.0	3.03	47.00	nd	0.08	19.2	7.8	13,100	4.3	121.0	0.022	9.7	nd	nd	nd	0.7	32.1
E20	9790	0.8	2.69	41.10	nd	0.07	17.6	7.0	11,700	3.9	112.0	0.021	9.0	nd	nd	nd	0.6	29.2
E17[a]	9580	0.9	2.62	40.20	nd	0.09	18.2	7.1	11,900	4.0	113.0	0.020	9.2	nd	nd	nd	0.8	29.8
E14[a]	6500	0.7	2.25	27.30	nd	0.12	13.7	6.9	8520	3.0	81.9	0.017	5.9	nd	nd	nd	0.6	24.0
E11[a]	7760	0.7	2.22	31.80	nd	0.08	14.9	6.5	9880	3.3	93.8	0.023	6.2	nd	nd	nd	3.2	27.1
E8	8760	0.9	2.14	37.50	nd	0.06	16.3	7.3	11,400	3.7	102.0	0.021	6.7	nd	nd	nd	0.8	29.4
E5	8410	0.7	2.48	35.90	nd	nd	15.9	7.0	11,000	3.9	96.4	0.026	6.3	nd	nd	nd	0.7	28.0
E2	10,700	1.0	2.80	54.10	nd	nd	18.6	10.7	14,500	6.2	119.0	0.048	7.1	nd	nd	nd	0.7	35.2
116-m Depth Contour																		
B10	6740	0.6	2.45	23.40	nd	nd	17.2	4.6	11,900	3.4	78.3	0.016	5.4	0.10	nd	nd	0.5	25.4
E21	8250	0.7	2.26	31.40	nd	0.07	15.6	5.9	10,300	3.9	93.4	0.020	8.0	0.19	nd	nd	0.6	25.2
E15	7460	0.6	2.31	28.40	nd	0.06	15.2	6.2	9970	3.5	85.7	0.021	6.0	0.28	nd	nd	0.6	24.7
E9	7500	0.7	3.23	29.50	nd	nd	18.0	7.3	11,900	8.0	79.6	0.022	5.9	0.32	nd	nd	0.6	27.8
E3	10,500	1.7	2.23	58.70	nd	0.07	23.7	14.9	13,900	30.8	116.0	0.071	6.2	nd	nd	nd	1.0	38.3
Detection Rate (%)	100	100	100	100	0	50	100	100	100	100	100	100	100	41	0	0	100	100

[a] Near-ZID stations

Appendix C.7

Concentrations of hexachlorobenzene (HCB), total DDT, total chlordane (tChlor), total PCB, and total PAH detected in sediments from PLOO stations sampled during winter and summer 2015. Values that exceed thresholds are highlighted (see Table 4.1); nd = not detected.

	Winter					Summer				
	HCB (ppt)	tDDT (ppt)	tChlor (ppb)	tPCB (ppt)	tPAH (ppb)	HCB (ppt)	tDDT (ppt)	tChlor (ppb)	tPCB (ppt)	tPAH (ppb)
88-m Stations										
B11	nd	400	nd	nd	7	nd	368	nd	nd	8
B8	nd	980	nd	nd	7	470	620	nd	nd	24
E19	nd	685	nd	nd	31	nd	374	nd	nd	20
E7	600	990	nd	nd	nd	160	940	nd	91	7
E1	590	470	nd	400	99	370	640	nd	1127	255
98-m Stations										
B12	3300	600	nd	nd	nd	120	340	nd	nd	nd
B9	nd	520	nd	nd	6	nd	760	nd	nd	7
E26	nd	620	nd	nd	10	nd	495	nd	nd	nd
E25	nd	660	nd	nd	8	nd	460	nd	nd	nd
E23	nd	380	nd	nd	9	nd	360	nd	nd	15
E20	nd	480	nd	nd	7	nd	9550	nd	nd	14
E17[a]	nd	600	nd	4650	15	nd	410	nd	nd	7
E14[a]	nd	620	nd	nd	12	nd	320	nd	nd	8
E11[a]	nd	720	nd	nd	4	nd	400	nd	nd	11
E8	2800	740	nd	nd	nd	1300	540	nd	nd	7
E5	150	550	nd	430	nd	130	610	nd	277	nd
E2	nd	640	nd	700	54	nd	410	nd	407	112
116-m Stations										
B10	nd	750	nd	nd	nd	nd	380	nd	nd	9
E21	nd	570	nd	nd	7	nd	550	nd	nd	18
E15	360	nd	nd	nd	8	nd	478	nd	nd	7
E9	nd	650	nd	nd	22	170	520	nd	240	35
E3	nd	16,040	nd	nd	205	nd	660	nd	6394	536
Detection Rate (%)	27	95	0	18	77	32	100	0	27	82

[a] Near-ZID stations

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Appendix D

Supporting Data

2015 PLOO Stations

Macrobenthic Communities

Appendix D.1

Macrofaunal community parameters by grab for PLOO benthic stations sampled during 2015. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = Pielou's evenness; Dom = Swartz dominance; BRI = benthic response index. Stations are listed north to south from top to bottom for each depth contour.

Depth Contour	Station	Quarter	Grab	SR	Abun	H'	J'	Dom	BRI
88-m	B11	winter	1	104	194	4.4	0.94	56	18
			2	124	339	4.4	0.91	51	11
		summer	1	90	181	4.3	0.95	45	13
			2	98	276	4.2	0.91	40	11
	B8	winter	1	69	217	3.2	0.76	20	9
			2	57	196	3.3	0.81	22	13
		summer	1	61	175	3.1	0.75	20	11
			2	70	194	3.4	0.80	26	5
	E19	winter	1	67	266	3.4	0.81	22	19
			2	75	284	3.4	0.80	25	18
		summer	1	53	167	3.0	0.76	15	6
			2	59	252	3.0	0.73	18	10
	E7	winter	1	60	269	3.2	0.79	17	14
			2	62	272	3.2	0.77	19	12
		summer	1	71	243	3.6	0.85	24	11
			2	82	305	3.7	0.84	26	14
	E1	winter	1	78	269	3.3	0.76	23	12
			2	75	306	3.1	0.73	22	6
		summer	1	72	234	3.4	0.79	22	13
			2	79	227	3.7	0.84	32	10
98-m	B12	winter	1	113	327	4.4	0.93	47	17
			2	93	267	4.1	0.91	38	18
		summer	1	86	282	4.0	0.90	33	7
			2	101	292	4.2	0.90	39	14
	B9	winter	1	68	194	3.7	0.87	30	7
			2	84	207	3.9	0.87	33	13
		summer	1	94	263	4.0	0.88	35	12
			2	72	208	3.8	0.88	30	6
	E26	winter	1	55	180	3.3	0.81	19	6
			2	70	216	3.7	0.88	27	11
		summer	1	67	200	3.7	0.87	26	7
			2	69	160	3.7	0.88	30	10
	E25	winter	1	82	281	3.6	0.83	27	14
			2	87	293	3.9	0.87	33	11
		summer	1	67	251	3.7	0.87	24	10
			2	75	265	3.6	0.85	26	4

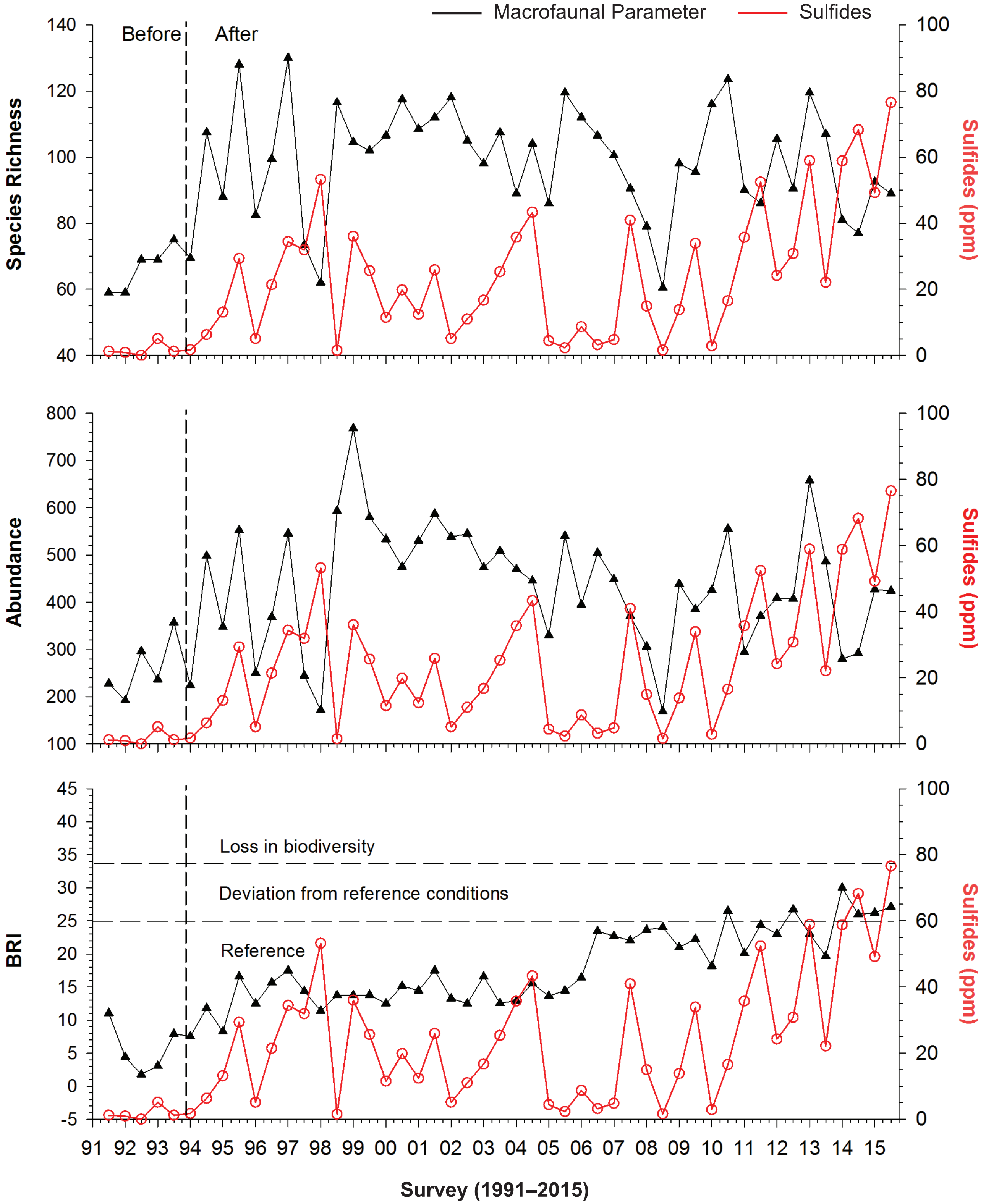
Appendix D.1 *continued*

Depth Contour	Station	Quarter	Grab	SR	Abun	H'	J'	Dom	BRI
98-m	E23	winter	1	72	275	3.6	0.83	23	11
			2	71	247	3.6	0.85	27	12
		summer	1	68	217	3.5	0.83	23	10
			2	55	169	3.4	0.86	22	4
	E20	winter	1	97	316	4.0	0.87	33	14
			2	73	263	3.6	0.85	24	14
		summer	1	64	226	3.6	0.87	23	13
			2	52	202	3.3	0.84	18	7
	E17[a]	winter	1	67	264	3.6	0.85	20	17
			2	74	251	3.8	0.89	29	18
		summer	1	79	307	3.7	0.85	24	15
			2	87	330	3.9	0.86	29	16
	E14[a]	winter	1	89	430	3.7	0.82	22	25
			2	96	424	3.9	0.86	31	28
		summer	1	82	351	3.4	0.78	18	27
			2	96	497	3.7	0.81	23	27
	E11[a]	winter	1	75	358	3.5	0.81	20	15
			2	78	384	3.8	0.86	26	17
		summer	1	86	383	3.6	0.82	23	11
			2	85	441	3.7	0.83	22	17
	E8	winter	1	73	252	3.6	0.84	23	12
			2	89	306	3.9	0.88	31	13
		summer	1	76	263	3.7	0.86	26	9
			2	88	331	3.9	0.87	30	10
	E5	winter	1	71	191	3.5	0.83	29	12
			2	75	225	3.8	0.88	29	14
		summer	1	78	274	3.6	0.83	25	5
			2	93	334	3.9	0.86	31	8
	E2	winter	1	99	241	4.1	0.90	43	14
			2	88	242	3.9	0.88	36	12
		summer	1	74	189	3.8	0.88	32	13
			2	86	202	4.1	0.91	38	13
116-m	B10	winter	1	94	324	4.0	0.87	34	14
			2	96	333	4.2	0.91	39	18
		summer	1	99	353	4.0	0.87	34	17
			2	127	445	4.2	0.87	43	16
	E21	winter	1	76	264	3.7	0.85	26	11
			2	68	299	3.6	0.86	22	12
		summer	1	58	195	3.6	0.87	20	11
			2	56	179	3.3	0.83	17	9

[a] Near-ZID station

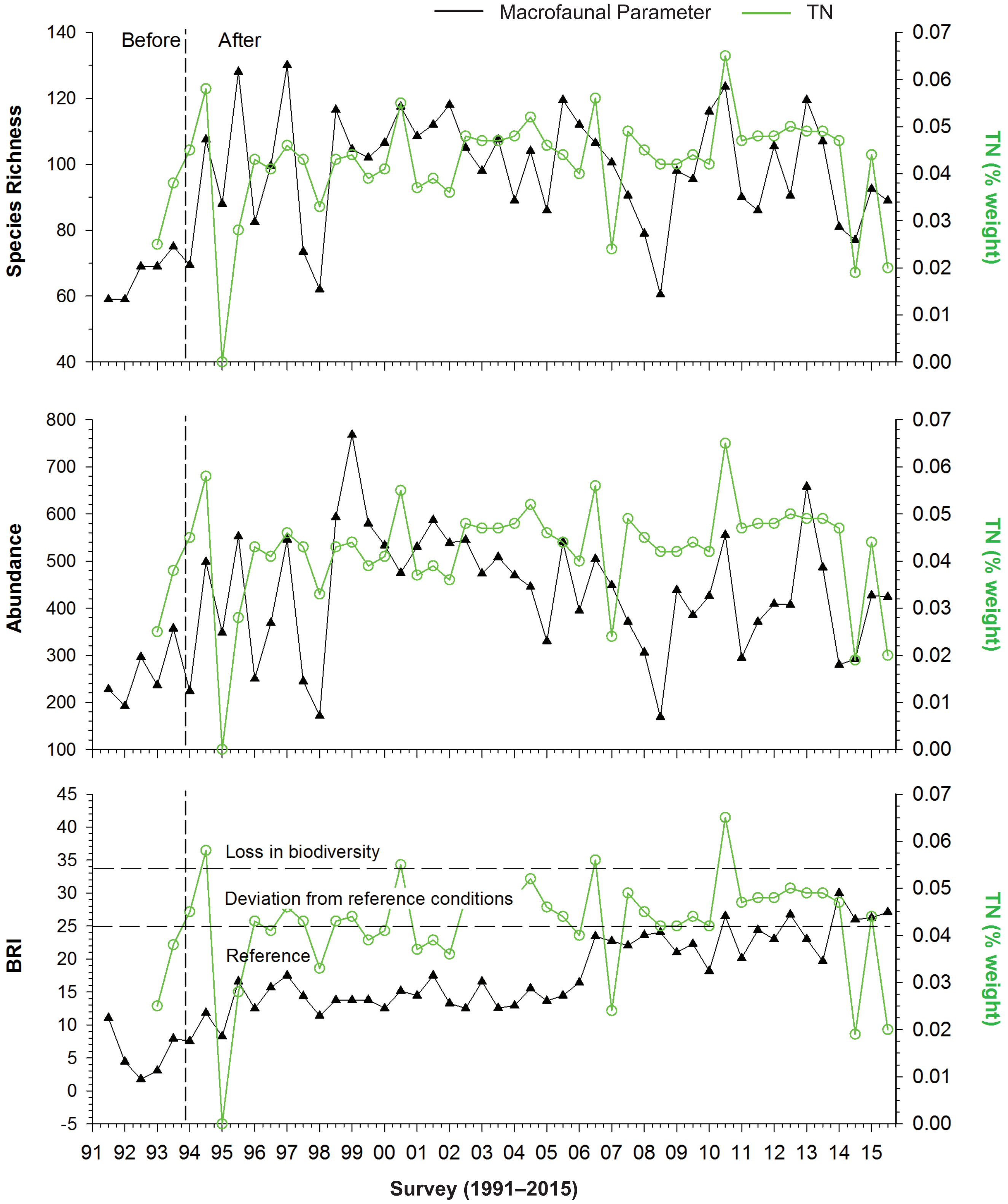
Appendix D.1 *continued*

Depth Contour	Station	Quarter	Grab	SR	Abun	H'	J'	Dom	BRI
116-m	E15	winter	1	76	273	3.7	0.85	25	10
			2	81	352	3.7	0.85	23	11
		summer	1	97	463	3.7	0.80	23	11
			2	81	271	3.7	0.85	27	12
	E9	winter	1	93	237	4.1	0.90	38	11
			2	88	229	4.2	0.94	42	9
		summer	1	109	391	4.2	0.89	41	13
			2	94	306	4.1	0.91	38	10
	E3	winter	1	77	160	4.0	0.93	38	12
			2	99	221	4.3	0.93	46	14
		summer	1	116	280	4.4	0.93	51	8
			2	119	296	4.5	0.93	54	9

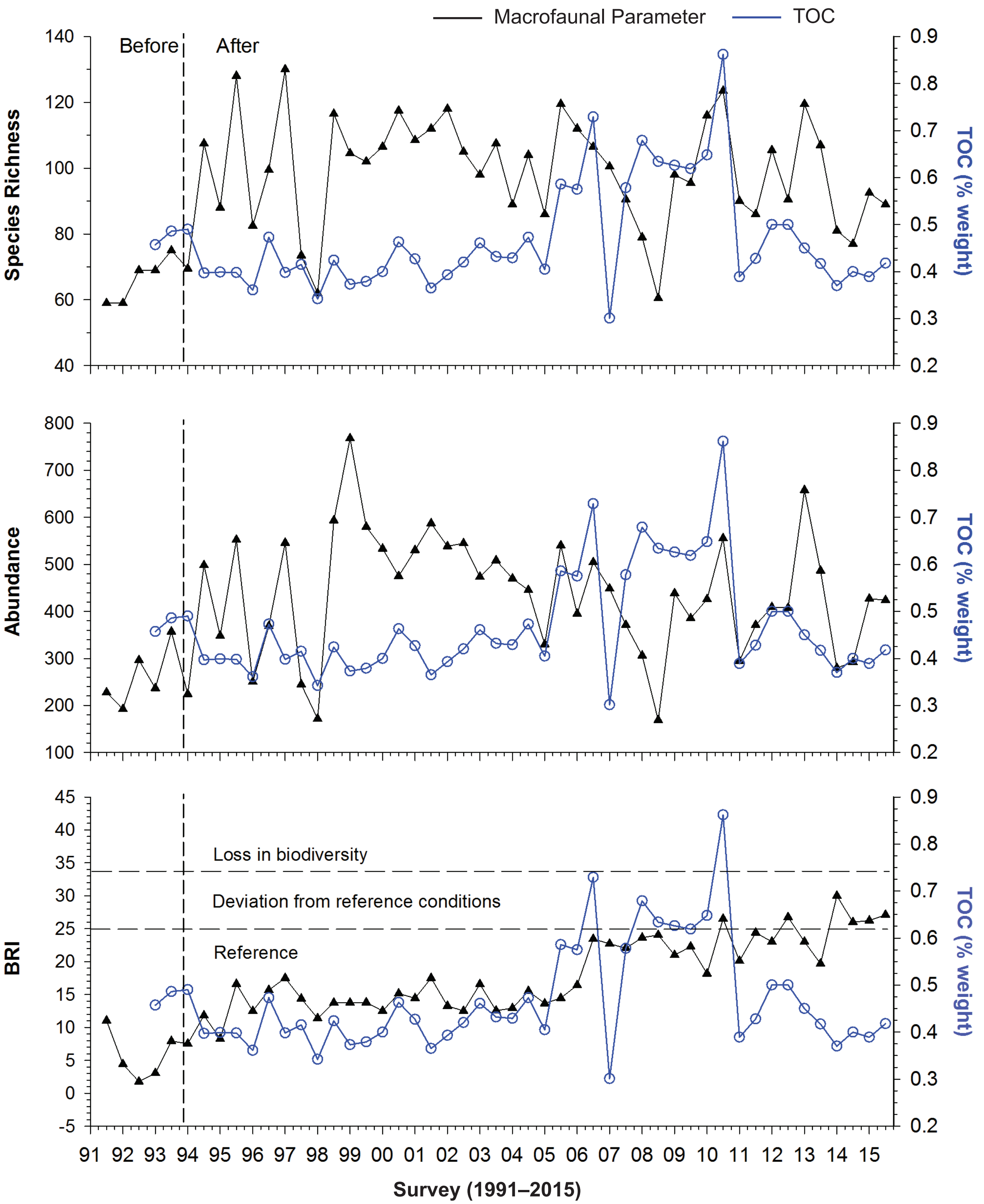


Appendix D.2

Comparison of macrofaunal community parameters and various organic indicators at near-ZID station E14 from 1991 through 2015. Organic indicators include: sulfides, total nitrogen (TN), and total organic carbon (TOC). Community parameters include: species richness, infaunal abundance and benthic response index (BRI). Data for community parameters are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.



Appendix D.2 *continued*



Appendix D.2 *continued*

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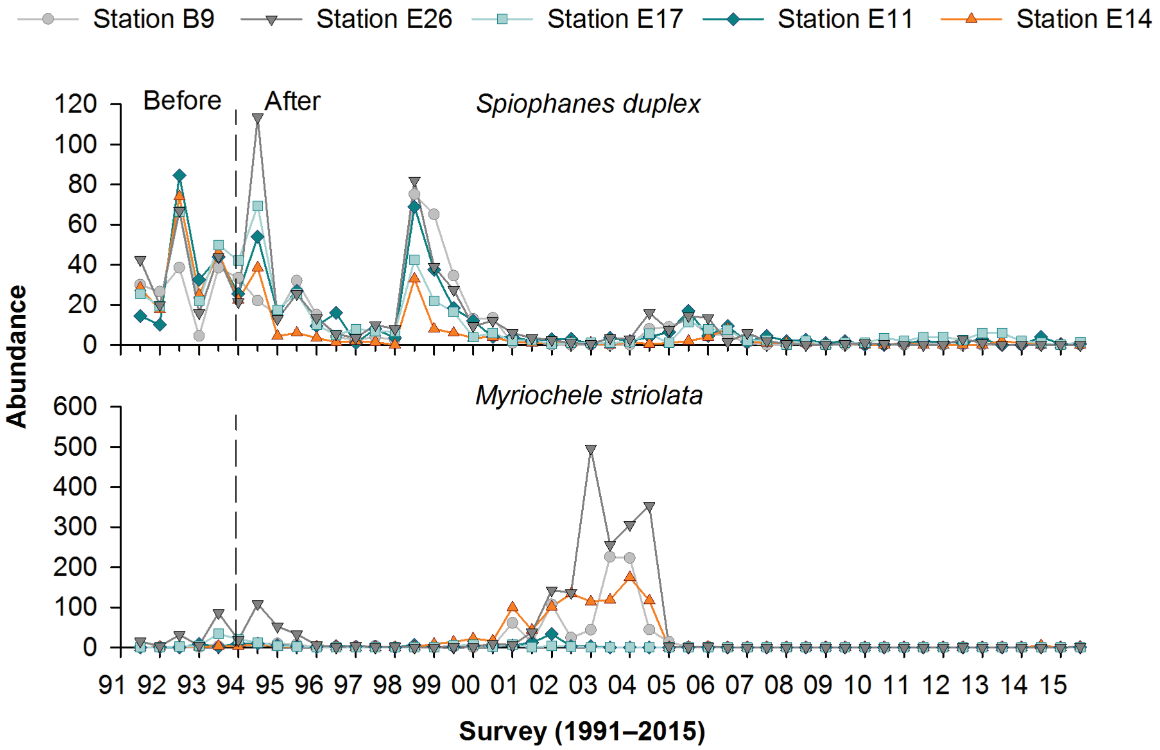

Appendix D.3

Two of the five historically most abundant species recorded from 1991 through 2015 at PLOO near-ZID stations E11, E14, and E17 and farfield stations E26 and B9. *Amphiodia urtica, Euphilomedes producta,* and *Proclea* sp A are shown in Figures 5.3 and 5.4. Data for each station are expressed as means per grab (n = 2 except for summer 2013 and all of 2014 when n = 1). Dashed lines indicate onset of wastewater discharge.

Appendix D.4

Mean abundance of the characteristic species found in each cluster group A–G (defined in Figure 5.5). Values highlighted in gray indicate taxa that account for up to 45% of intra-group similarity according to SIMPER analysis; the top five most characteristic species for each group are highlighted in yellow.

	Cluster Group						
Taxa	**A[a]**	**B**	**C**	**D**	**E**	**F**	**G**
Amphiodia digitata	14	1	4	0	6	<1	1
Diopatra tridentata	7	0	0	0	0	0	0
Amphichondrius granulatus	6	0	0	1	4	0	1
Ampelisca brevisimulata	5	0	<1	3	2	1	2
Maldanidae	5	2	1	1	3	2	2
Glycera nana	5	1	2	3	3	3	1
Amphiuridae	5	2	2	1	3	3	1
Euphilomedes producta	7	0	3	**23**	8	1	**16**
Ennucula tenuis	5	3	4	8	**5**	1	4
Chaetozone hartmanae	5	**5**	**23**	8	**10**	**4**	**10**
Prionospio (Prionospio) dubia	4	**8**	7	1	6	**4**	4
Adontorhina cyclia	0	**7**	2	1	0	1	1
Lumbrineris sp Group I	1	**5**	0	7	3	1	1
Ampelisca pugetica	0	**4**	1	2	1	<1	1
Aricidea (Acmira) simplex	1	4	2	0	1	<1	1
Maldane sarsi	1	4	2	1	2	3	2
Aphelochaeta sp LA1	0	3	1	0	0	0	<1
Lysippe sp B	1	2	2	1	3	<1	1
Petaloclymene pacifica	0	2	2	0	1	0	1
Magelona berkeleyi	0	2	1	0	0	0	<1
Mediomastus sp	0	6	**11**	**21**	**14**	5	5
Tellina carpenteri	3	3	**13**	17	8	0	7
Nuculana sp A	1	2	**12**	18	10	3	**14**
Monticellina siblina	1	3	**8**	1	2	0	1
Chloeia pinnata	0	1	8	22	3	0	8
Prionospio (Prionospio) jubata	1	3	6	3	2	2	3
Paradiopatra parva	3	0	4	1	<1	1	0
Parvilucina tenuisculpta	0	0	3	2	<1	0	1
Dougaloplus amphacanthus	1	1	2	0	<1	0	<1
Eclysippe trilobata	2	1	9	1	4	1	3
Sternaspis affinis	1	4	5	3	3	3	3
Lysippe sp A	1	2	3	2	5	<1	1
Euphilomedes carcharodonta	2	0	4	**55**	3	1	9
Notomastus sp A	2	4	3	**33**	**11**	3	1
Solemya pervernicosa	0	0	<1	**14**	0	0	<1
Capitella teleta	0	0	0	15	0	0	0
Leptochelia dubia Cmplx	0	2	1	3	5	<1	2
Leptosynapta sp	2	1	1	0	4	1	2
Ampelisca careyi	0	1	2	1	3	3	2
Pholoe glabra	1	1	1	0	3	2	2

Appendix D.4 *continued*

Taxa	Cluster Group						
	A[a]	B	C	D	E	F	G
Terebellides californica	0	1	<1	0	3	1	2
Amphiodia urtica	0	5	2	1	11	**75**	**40**
Amphiodia sp	0	3	2	1	**5**	**12**	4
Praxillella pacifica	1	0	1	4	2	**6**	8
Rhepoxynius bicuspidatus	0	0	1	3	1	**5**	**8**
Heterophoxus oculatus	0	2	<1	4	1	3	2
Axinopsida serricata	0	2	9	13	3	2	6

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

Appendix D.5

Sediment particle size summary for each cluster group A–G (defined in Figure 5.5). Data are presented as means (ranges) calculated over all stations within a cluster group. VF = very fine, Med = medium, VC = very coarse.

	Sediments (%)						
Cluster Group	**Fines**	**VF Sand**	**Fine Sand**	**Med Sand**	**Coarse Sand**	**VC Sand**	**Granules**
A	21.6	12.6	31.3	12.3	10.5	7.0	4.7
B	45.0	21.3	13.3	10.1	6.0	3.4	1.0
	(43.1–46.8)	(18.6–23.9)	(10.9–15.7)	(8.5–11.8)	(3.1–8.8)	(2.0–4.7)	(0.0–2.1)
C	24.0	27.0	33.2	11.7	3.5	0.1	0.5
	(12.0–31.4)	(4.8–65.0)	(8.2–80.3)	(1.0–25.2)	(0.4–7.1)	(0.0–0.3)	(0.0–1.3)
D	32.0	49.5	17.6	1.0	0.0	0.0	0.0
	(31.6–32.4)	(49.2–49.7)	(17.2–17.9)	(0.8–1.2)	—	—	—
E	32.5	25.7	16.4	7.0	9.6	7.4	1.4
	(23.0–39.9)	(18.1–30.9)	(5.7–37.0)	(3.9–10.7)	(4.9–15.9)	(3.9–15.7)	(0.0–2.3)
F	59.2	28.1	8.4	2.5	1.3	0.5	0.0
	(49.8–64.0)	(23.0–30.7)	(5.2–14.6)	(0.1–7.2)	(0.0–3.9)	(0.0–1.5)	—
G	42.8	42.2	13.9	1.1	< 0.1	0.0	0.0
	(35.6–52.8)	(29.0–47.6)	(8.1–20.9)	(0.1–6.8)	(0.0–0.04)	—	—

Appendix E

Supporting Data

2015 PLOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Taxonomic listing of demersal fish species captured during 2015 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 (cm)		
Taxon/Species			Common name	n	BM	Min	Max	Mean
RAJIFORMES								
	Rajidae							
		Raja inornata	California Skate[a]	11	6.7	13	54	36
ARGENTINIFORMES								
	Argentinidae							
		Argentina sialis	Pacific Argentine	11	0.2	5	8	7
AULOPIFORMES								
	Synodontidae							
		Synodus lucioceps	California Lizardfish	156	2.3	10	24	14
OPHIDIIFORMES								
	Ophidiidae							
		Ophidion scrippsae	Basketweave Cusk-eel	1	0.1	17	17	17
BATRACHOIDIFORMES								
	Batrachoididae							
		Porichthys myriaster	Specklefin midshipman	1	0.1	22	22	22
		Porichthys notatus	Plainfin Midshipman	37	0.7	7	19	11
SCORPAENIFORMES								
	Scorpaenidae							
		Scorpaena guttata	California Scorpionfish	34	12.0	12	25	19
	Sebastidae							
		Sebastes spp	Unidentified Rockfish	15	0.4	3	5	4
		Sebastes chlorostictus	Greenspotted Rockfish	2	0.2	12	15	14
		Sebastes elongatus	Greenstriped Rockfish	35	0.6	5	9	6
		Sebastes goodei	Chilipepper	1	0.1	10	10	10
		Sebastes hopkinsi	Squaerspot Rockfish	117	8.3	9	21	15
		Sebastes jordani	Shortbelly Rockfish	44	1.3	9	16	10
		Sebastes miniatus	Vermillion Rockfish	29	8.3	9	32	22
		Sebastes saxicola	Stripetail Rockfish	118	2.0	6	12	7
		Sebastes semicinctus	Halfbanded Rockfish	1060	37.9	6	18	12
	Hexagrammidae							
		Zaniolepis frenata	Shortspine Combfish	41	1.1	8	17	12
		Zaniolepis latipinnis	Longspine Combfish	393	3.4	6	15	10
	Cottidae							
		Chitonotus pugetensis	Roughback Sculpin	3	0.2	10	10	10
		Icelinus filamentosus	Threadfin Sculpin	1	0.1	8	8	8
		Icelinus quadriseriatus	Yellowchin Sculpin	125	1.3	4	10	7
		Icelinus tenuis	Spotfin Sculpin	2	0.1	10	10	10
	Agonidae							
		Xeneretmus latifrons	Blacktip Poacher	1	0.1	14	14	14

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

Appendix E.1 *continued*

Taxon/Species			Common name	n	BM	Length (cm) Min	Max	Mean
PERCIFORMES								
	Embiotocidae							
		Zalembius rosaceus	Pink Seaperch	41	0.9	5	12	8
	Bathymasteridae							
		Rathbunella hypoplecta	Bluebanded Ronquil	3	0.1	13	20	18
	Zoarcidae							
		Lycodes pacificus	Blackbelly Eelpout	7	0.3	17	19	18
	Gobiidae							
		Rhinogobips nicholsii	Blackeye Goby	2	0.2	7	7	7
PLEURONECTIFORMES								
	Paralichthyidae							
		Citharichthys sordidus	Pacific Sanddab	2802	56.1	4	25	10
		Citharichthys xanthostig	Longfin Sanddab	3	0.2	5	14	8
		Hippoglossina stomata	Bigmouth Sole	8	1.0	18	26	21
	Pleuronectidae							
		Lyopsetta exilis	Slender Sole	6	0.2	16	18	17
		Microstomus pacificus	Dover Sole	28	0.8	6	17	11
		Parophrys vetulus	English Sole	73	5.9	8	24	17
		Pleuronichthys verticalis	Hornyhead Turbot	18	1.6	10	20	15
	Cynoglossidae							
		Symphurus atricaudus	California Tonguefish	14	0.7	10	17	14

Appendix E.2

Total abundance by species and station for demersal fish at the PLOO trawl stations during 2015.

	Winter 2015						
Species	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Species Abundance by Survey**
Halfbanded Rockfish	151	7	18	1	3	689	869
Pacific Sanddab	117	190	147	112	107	105	778
Longspine Combfish	8	4	39	37	60	21	169
California Lizardfish	1	2	3	3	62	70	141
Squarespot Rockfish						117	117
Yellowchin Sculpin	49	1	36		14	4	104
English Sole	11	6	9	9	11	5	51
Vermilion Rockfish						28	28
Pink Seaperch	2		4	1	11	9	27
Stripetail Rockfish	3	2	7	5	4	3	24
Shortspine Combfish	3	9	4	2	1		19
Plainfin Midshipman	1	3	14		1		19
Hornyhead Turbot	4	2	5		1	1	13
California Tonguefish		2	5	1	3	1	12
California Scorpionfish	1	1	2	2	2	3	11
California Skate	1	1	1	4	1		8
Pacific Argentine	7						7
Dover Sole		1		3			4
Bigmouth Sole	2	1				1	4
Shortbelly Rockfish						3	3
Spotfin Sculpin		2					2
Greenstriped Rockfish		2					2
Specklefin Midshipman			1				1
Roughback Sculpin					1		1
Unidentifed Rockfish			1				1
Greenspotted Rockfish	1						1
Blacktip Poacher		1					1
Total Survey	362	237	296	180	282	1060	2417

Appendix E.2 *continued*

	Summer 2015						
Species	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Species Abundance by Survey**
Pacific Sanddab	226	209	396	288	506	399	2024
Longspine Combfish	2	8	9	35	100	70	224
Halfbanded Rockfish	14	106	58	4	3	6	191
Stripetail Rockfish	56	12	8	1	2	15	94
Shortbelly Rockfish		35	6				41
Greenstriped Rockfish		11	14	6	1	1	33
Dover Sole	1	3	3	8	8	1	24
California Scorpionfish	2	3	2	4	5	7	23
Shortspine Combfish	1	5	5	4	1	6	22
English Sole	3	8		3	4	4	22
Yellowchin Sculpin	2		14	3	2		21
Plainfin Midshipman			8		9	1	18
California Lizardfish		4	4		4	3	15
Unidentified Rockfish			6	5		3	14
Pink Seaperch	1	3			1	9	14
Blackbelly Eelpout				2	3	2	7
Slender Sole					1	5	6
Hornyhead Turbot		1	3			1	5
Pacific Argentine		4					4
Bigmouth Sole			2		1	1	4
Longfin Sanddab			1		2		3
California Skate	1	1				1	3
Bluebanded Ronquil		3					3
Roughback Sculpin		2					2
California Tonguefish		1	1				2
Blackeye Goby		1			1		2
Vermilion Rockfish	1						1
Threadfin Sculpin			1				1
Greenspotted Rockfish		1					1
Chilipepper	1						1
Basketweave Cusk-eel						1	1
Survey Total	311	421	541	363	654	536	2826
Annual Total	**673**	**658**	**837**	**543**	**936**	**1596**	**5243**

Appendix E.3

Biomass (kg) by species and station for demersal fish at the PLOO trawl stations during 2015.

	Winter 2015						
Species	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Species Biomass by Survey**
Halfbanded Rockfish	0.8	0.1	0.2	0.1	0.1	32.5	33.8
Pacific Sanddab	3.5	6.6	4.6	3.0	3.6	4.2	25.5
Squarespot Rockfish						8.3	8.3
Vermilion Rockfish						8.2	8.2
English Sole	0.8	0.5	0.7	0.5	0.6	1.0	4.1
California Skate	0.5	0.3	0.9	0.8	0.2		2.7
California Scorpionfish	0.1	0.2	0.4	0.4	0.5	0.6	2.2
California Lizardfish	0.1	0.2	0.1	0.1	0.4	1.0	1.9
Hornyhead Turbot	0.5	0.2	0.4		0.1	0.1	1.3
Longspine Combfish	0.1	0.1	0.3	0.3	0.3	0.1	1.2
Shortbelly Rockfish						1.0	1.0
Yellowchin Sculpin	0.3	0.1	0.3		0.1	0.1	0.9
Stripetail Rockfish	0.1	0.1	0.2	0.1	0.1	0.1	0.7
Bigmouth Sole	0.2	0.3				0.1	0.6
Shortspine Combfish	0.1	0.1	0.1	0.1	0.1		0.5
Pink Seaperch	0.1		0.1	0.1	0.1	0.1	0.5
California Tonguefish		0.1	0.1	0.1	0.1	0.1	0.5
Plainfin Midshipman	0.1	0.1	0.1		0.1		0.4
Dover Sole		0.1		0.1			0.2
Spotfin Sculpin		0.1					0.1
Specklefin Midshipman			0.1				0.1
Roughback Sculpin					0.1		0.1
Unidentified Rockfish			0.1				0.1
Pacific Argentine	0.1						0.1
Greenstriped Rockfish		0.1					0.1
Greenspotted Rockfish	0.1						0.1
Blacktip Poacher		0.1					0.1
Total Survey	7.5	9.4	8.7	5.7	6.5	57.5	95.3

Appendix E.3 *continued*

	Summer 2015						
Species	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Species Biomass by Survey**
Pacific Sanddab	2.5	4.8	4.0	4.7	7.3	7.3	30.6
California Scorpionfish	1.4	1.0	0.6	3.5	2.0	1.3	9.8
Halfbanded Rockfish	0.1	2.4	1.3	0.1	0.1	0.1	4.1
California Skate	2.5	1.4				0.1	4.0
Longspine Combfish	0.1	0.1	0.1	0.1	1.1	0.7	2.2
English Sole	0.1	0.8		0.1	0.4	0.4	1.8
Stripetail Rockfish	0.8	0.1	0.1	0.1	0.1	0.1	1.3
Shortspine Combfish	0.1	0.1	0.1	0.1	0.1	0.1	0.6
Dover Sole	0.1	0.1	0.1	0.1	0.1	0.1	0.6
Greenstriped Rockfish		0.1	0.1	0.1	0.1	0.1	0.5
Yellowchin Sculpin	0.1		0.1	0.1	0.1		0.4
Pink Seaperch	0.1	0.1			0.1	0.1	0.4
California Lizardfish		0.1	0.1		0.1	0.1	0.4
Bigmouth Sole			0.2		0.1	0.1	0.4
Shortbelly Rockfish		0.2	0.1				0.3
Unidentifed Rockfish			0.1	0.1		0.1	0.3
Plainfin Midshipman			0.1		0.1	0.1	0.3
Hornyhead Turbot		0.1	0.1			0.1	0.3
Blackbelly Eelpout				0.1	0.1	0.1	0.3
Slender Sole					0.1	0.1	0.2
Longfin Sanddab			0.1		0.1		0.2
California Tonguefish		0.1	0.1				0.2
Blackeye Goby		0.1			0.1		0.2
Vermilion Rockfish	0.1						0.1
Threadfin Sculpin			0.1				0.1
Roughback Sculpin		0.1					0.1
Pacific Argentine		0.1					0.1
Greenspotted Rockfish		0.1					0.1
Chilipepper	0.1						0.1
Bluebanded Ronquil		0.1					0.1
Basketweave Cusk-eel						0.1	0.1
Survey Total	8.1	12.0	7.5	9.2	12.2	11.2	60.2
Annual Total	**15.6**	**21.4**	**16.2**	**14.9**	**18.7**	**68.7**	**155.5**

Appendix E.4

Taxonomic listing of megabenthic invertebrate taxa captured during 2015 at PLOO trawl stations. Data are number of individuals (n). Taxonomic arrangement from SCAMIT (2014).

Taxon/Species				n
SILICEA				
	Hexactinellida			
		Rossellidae	Acanthascininae	1
	Demospongiae			
		Suberitidae	*Suberites latus*	1
CNIDARIA				
	Anthozoa			
		Plexauridae	*Thesea* sp B	13
		Virgulariidae	*Acanthoptilum* sp	73
		Metridiidae	*Metridium farcimen*	4
MOLLUSCA				
	Gastropoda			
		Calliostomatidae	*Calliostoma turbinum*	1
		Ovulidae	*Simnia barbarensis*	1
		Naticidae	*Calinaticina oldroydii*	1
		Fasciolariidae	*Barbarofusus barbarensis*	2
		Cancellariidae	*Cancellaria cooperii*	2
		Pleurobranchidae	*Pleurobranchaea californica*	4
		Discodorididae	*Platydoris macfarlandi*	1
		Arminidae	*Armina californica*	10
	Cephalopoda			
		Octopodidae	*Octopus rubescens*	14
ANNELIDA				
	Polychaeta			
		Aphroditidae	*Aphrodita refulgida*	1
ARTHROPODA				
	Malocostraca			
		Cymothoidae	*Elthusa vulgaris*	36
		Sicyoniidae	*Sicyonia ingentis*	133
		Crangonidae	*Neocrangon zacae*	1
		Diogenidae	*Paguristes bakeri*	1
			Paguristes turgidus	2
		Paguridae	*Orthopagurus minimus*	2
			Pagurus armatus	1
		Munididae	*Pleuroncodes planipes*	41
		Homolidae	*Moloha faxoni*	1
		Calappidae	*Platymera gaudichaudii*	3
		Inachidae	*Podochela lobifrons*	1
		Inachoididae	*Pyromaia tuberculata*	2
		Cancridae	*Metacarcinus anthonyi*	1

Appendix E.4 *continued*

Taxon/Species				n
ECHINODERMATA				
	Crinoidea			
		Antedonidae	*Florometra serratissima*	71
	Asteroidea			
		Luidiidae	*Luidia armata*	1
			Luidia asthenosoma	19
			Luidia foliolata	17
		Astropectinidae	*Astropecten californicus*	20
	Ophiuroidea			
		Ophiuridae	*Ophiura luetkenii*	934
		Ophiotricidae	*Ophiothrix spiculata*	164
		Ophiocomidae	*Ophiopteris papillosa*	5
	Echinoidea			
		Toxopneustidae	*Lytechinus pictus*	13,903
		Strongylocentrotidae	*Strongylocentrotus fragilis*	427
	Holothuroidea			
		Stichopodidae	*Parastichopus californicus*	20

Appendix E.5

Total abundance by species and station for megabenthic invertebrates at the PLOO trawl stations during 2015.

	Winter 2015						
Species	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Species Abundance by Survey**
Lytechinus pictus	1002	3370	1051	1154	729	10	7316
Ophiura luetkenii	34	21	13	6	9		83
Sicyonia ingentis	3	1	2	6	12	32	56
Florometra serratissima	46						46
Pleuroncodes planipes	32			6	3		41
Ophiothrix spiculata			39				39
Acanthoptilum sp		15	2	6	13		36
Elthusa vulgaris	3	2	2	2	6	8	23
Luidia asthenosoma		2	1	1	6		10
Armina californica			7		2		9
Parastichopus californicus	1	3	2	1	1		8
Luidia foliolata		2	3	3			8
Astropecten californicus		1		1	1	4	7
Octopus rubescens				4	1	1	6
Metridium farcimen						4	4
Platymera gaudichaudii		1		1			2
Paguristes turgidus	1		1				2
Barbarofusus barbarensis		1	1				2
Suberites latus		1					1
Podochela lobifrons	1						1
Pleurobranchaea californica			1				1
Paguristes bakeri						1	1
Neocrangon zacae					1		1
Moloha faxoni					1		1
Calliostoma turbinum	1						1
Acanthascininae						1	1
Survey Total	1124	3420	1125	1191	785	61	7706

Appendix E.5 *continued*

	Summer 2015						
Species	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Species Abundance by Survey**
Lytechinus pictus	1120	2415	2329	387	175	161	6587
Ophiura luetkenii	808	34	7		2		851
Strongylocentrotus fragilis				3	96	328	427
Ophiothrix spiculata	124	1					125
Sicyonia ingentis	2	14	36	2	15	8	77
Acanthoptilum sp	37						37
Florometra serratissima	25						25
Thesea sp B	7	3	1	1	1		13
Elthusa vulgaris			4	1	4	4	13
Astropecten californicus	1	11	1				13
Parastichopus californicus	3	4	1	1	1	2	12
Luidia foliolata	2	2	2	1		2	9
Luidia asthenosoma	1	7		1			9
Octopus rubescens	1		1		5	1	8
Ophiopteris papillosa	5						5
Pleurobranchaea californica	1	1				1	3
Pyromaia tuberculata			1	1			2
Orthopagurus minimus	2						2
Cancellaria cooperii			1	1			2
Simnia barbarensis			1				1
Platymera gaudichaudii					1		1
Platydoris macfarlandi		1					1
Pagurus armatus			1				1
Metacarcinus anthonyi						1	1
Luidia armata					1		1
Calinaticina oldroydii			1				1
Armina californica					1		1
Aphrodita refulgida				1			1
Survey Total	2139	2493	2387	400	302	508	8229
Annual Total	**3263**	**5913**	**3512**	**1591**	**1087**	**569**	**15,935**

Appendix F

Supporting Data

2015 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 2015. Data are summarized as number of individuals (n), minimum, maximum, and mean values.

				Length (cm, size class)			Weight (g)		
Station/Zone	Comp	Species	n	Min	Max	Mean	Min	Max	Mean
Rig Fishing 1	1	Vermillion Rockfish	3	25	26	26	362	490	424
Rig Fishing 1	2	Copper Rockfish	3	28	36	32	622	1510	1031
Rig Fishing 1	3	Mixed Rockfish	3	28	36	33	568	1106	923
Rig Fishing 2	1	Speckled Rockfish	3	22	24	23	239	275	262
Rig Fishing 2	2	Speckled Rockfish	3	23	25	24	261	331	296
Rig Fishing 2	3	Speckled Rockfish	3	25	27	26	337	437	394
Trawl Zone 1	1	Pacific Sanddab	6	15	20	16	42	133	64
Trawl Zone 1	2	Pacific Sanddab	4	16	21	18	56	147	96
Trawl Zone 1	3	English Sole	6	14	22	18	37	197	100
Trawl Zone 2	1	Pacific Sanddab	13	13	15	14	31	42	36
Trawl Zone 2	2	Pacific Sanddab	9	14	16	15	38	60	45
Trawl Zone 2	3	English Sole	9	16	23	18	52	166	80
Trawl Zone 3	1	Pacific Sanddab	11	13	18	15	30	94	51
Trawl Zone 3	2	Pacific Sanddab	10	13	17	15	29	87	45
Trawl Zone 3	3	Pacific Sanddab	5	15	19	17	46	130	77
Trawl Zone 4	1	Pacific Sanddab	6	16	20	18	59	116	85
Trawl Zone 4	2	Pacific Sanddab	6	16	17	17	66	85	76
Trawl Zone 4	3	Pacific Sanddab	4	19	21	20	92	143	111

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 2015; na = not analyzed.

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Metals (ppm)					
Aluminum (Al)	1.2	1.2	Lead (Pb)	0.07	0.07
Antimony (Sb)	0.1	0.1	Manganese (Mn)	0.02	0.02
Arsenic (As)	0.12	0.12	Mercury (Hg)	0.002	0.002
Barium (Ba)	0.02	0.02	Nickel (Ni)	0.06	0.06
Beryllium (Be)	0.002	0.002	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.01	0.01	Silver (Ag)	0.03	0.03
Chromium (Cr)	0.07	0.07	Thallium (Tl)	0.1	0.1
Copper (Cu)	0.043	0.043	Tin (Sn)	0.05	0.05
Iron (Fe)	0.7	0.7	Zinc (Zn)	0.1	0.1
Chlorinated Pesticides (ppb)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	13.2	0.95	HCH, Delta isomer	2.63	0.56
HCH, Beta isomer	6.00	0.51	HCH, Gamma isomer	13.00	0.78
Total Chlordane					
Alpha (cis) chlordane	1.79	0.21	Heptachlor epoxide	4.11	0.28
Cis nonachlor	2.60	0.19	Methoxychlor	na	na
Gamma (trans) chlordane	2.41	0.24	Oxychlordane	5.24	0.48
Heptachlor	1.23	0.25	Trans nonachlor	2.24	0.20
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	1.04	0.23	p,p-DDD	2.10	0.35
o,p-DDE	1.58	0.21	p,p-DDE	2.07	0.29
o,p-DDT	2.37	0.23	p,p-DDT	1.48	0.33
p,p-DDMU	0.87	0.25			
Miscellaneous Pesticides					
Aldrin	na	na	Endrin	na	na
Alpha endosulfan	na	na	Endrin aldehyde	na	na
Beta endosulfan	na	na	Hexachlorobenzene (HCB)	2.35	0.42
Dieldrin	na	na	Mirex	1.79	0.32
Endosulfan sulfate	28.50	2.84			

Appendix F.2 *continued*

Parameter	MDL		Parameter	MDL	
	Liver	Muscle		Liver	Muscle
Polychlorinated Biphenyl Congeners (PCBs) (ppb)					
PCB 18	0.89	0.22	PCB 126	1.48	0.36
PCB 28	1.12	0.18	PCB 128	1.81	0.29
PCB 37	0.29	0.15	PCB 138	2.18	0.30
PCB 44	0.77	0.09	PCB 149	1.60	0.30
PCB 49	0.45	0.16	PCB 151	2.33	0.12
PCB 52	0.77	0.15	PCB 153/168	3.49	0.56
PCB 66	0.87	0.18	PCB 156	1.24	0.23
PCB 70	0.76	0.19	PCB 157	1.00	0.14
PCB 74	0.72	0.17	PCB 158	1.24	0.13
PCB 77	1.20	0.31	PCB 167	0.74	0.17
PCB 81	1.01	0.31	PCB 169	1.15	0.23
PCB 87	1.02	0.23	PCB 170	2.12	0.41
PCB 99	1.71	0.14	PCB 177	1.75	0.49
PCB 101	2.31	0.25	PCB 180	2.49	0.42
PCB 105	2.63	0.19	PCB 183	1.56	0.46
PCB 110	2.18	0.38	PCB 187	1.25	0.47
PCB 114	2.10	0.21	PCB 189	2.04	0.36
PCB 118	2.29	0.31	PCB 194	11.40	0.61
PCB 119	1.04	0.05	PCB 201	1.69	0.21
PCB 123	1.49	0.25	PCB 206	0.67	0.14

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 2015. RF = rig fishing; TZ = trawl zone.

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
RF1	2	Copper Rockfish	Muscle	DDT	p,p-DDE	5.0	ppb
RF1	2	Copper Rockfish	Muscle	PCB	PCB 153/168	0.9	ppb
RF1	3	Mixed Rockfish	Muscle	DDT	p,p-DDE	7.1	ppb
RF1	3	Mixed Rockfish	Muscle	DDT	p,p-DDD	0.1	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 44	0.1	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 49	0.1	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 52	0.1	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 99	0.2	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 101	0.3	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 118	0.3	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 149	0.2	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 153/168	0.6	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 180	0.2	ppb
RF1	3	Mixed Rockfish	Muscle	PCB	PCB 187	0.2	ppb
RF2	1	Speckled Rockfish	Muscle	DDT	p,p-DDE	0.8	ppb
RF2	2	Speckled Rockfish	Muscle	DDT	p,p-DDE	1.4	ppb
RF2	3	Speckled Rockfish	Muscle	DDT	p,p-DDE	1.6	ppb
RF2	3	Speckled Rockfish	Muscle	PCB	PCB 153/168	0.1	ppb
TZ1	1	Pacific Sanddab	Liver	DDT	p,p-DDD	2.9	ppb
TZ1	1	Pacific Sanddab	Liver	DDT	p,p-DDE	250.0	ppb
TZ1	1	Pacific Sanddab	Liver	DDT	p,-p-DDMU	19.5	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 49	1.8	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 52	1.9	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 66	2.1	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 70	1.8	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 74	1.1	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 99	9.3	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 101	6.8	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 105	3.5	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 110	5.4	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 118	14.5	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 138	21.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 149	4.3	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 151	2.9	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 153/168	30.0	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 158	1.5	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 170	4.6	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 177	1.8	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 180	14.5	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 183	3.4	ppb
TZ1	1	Pacific Sanddab	Liver	PCB	PCB 187	11.5	ppb
TZ1	1	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	4.0	ppb
TZ1	1	Pacific Sanddab	Liver	Chlordane	Alpha (cis) chlordane	2.3	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ1	2	Pacific Sanddab	Liver	DDT	p,p-DDD	4.1	ppb
TZ1	2	Pacific Sanddab	Liver	DDT	p,p-DDE	305.0	ppb
TZ1	2	Pacific Sanddab	Liver	DDT	p,-p-DDMU	28.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 44	0.9	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 49	2.9	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 52	3.9	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 66	3.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 70	3.1	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 74	1.8	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 99	13.5	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 101	11.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 105	5.8	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 110	9.7	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 118	21.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 138	25.5	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 149	6.9	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 151	4.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 153/168	39.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 158	1.9	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 167	1.6	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 170	5.1	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 177	2.6	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 180	15.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 183	3.9	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 187	14.0	ppb
TZ1	2	Pacific Sanddab	Liver	PCB	PCB 206	4.2	ppb
TZ1	2	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	4.8	ppb
TZ1	3	Pacific Sanddab	Liver	DDT	p,p-DDD	3.7	ppb
TZ1	3	Pacific Sanddab	Liver	DDT	p,p-DDE	100.0	ppb
TZ1	3	Pacific Sanddab	Liver	DDT	p,-p-DDMU	5.4	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 28	0.9	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 44	0.8	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 49	2.9	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 52	2.7	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 66	2.6	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 70	2.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 74	1.2	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 87	2.2	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 99	9.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 101	10.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 105	4.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 110	7.9	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 118	14.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 123	1.8	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 138	17.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 149	13.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 151	2.9	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 153/168	31.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 158	2.6	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 167	1.4	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 170	4.7	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 177	3.3	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 180	14.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 183	4.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 187	11.0	ppb
TZ1	3	Pacific Sanddab	Liver	PCB	PCB 206	6.0	ppb
TZ1	3	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	1.4	ppb
TZ2	1	Pacific Sanddab	Liver	DDT	p,p-DDD	4.1	ppb
TZ2	1	Pacific Sanddab	Liver	DDT	o,p-DDE	3.9	ppb
TZ2	1	Pacific Sanddab	Liver	DDT	p,p-DDE	240.0	ppb
TZ2	1	Pacific Sanddab	Liver	DDT	p,p-DDT	5.0	ppb
TZ2	1	Pacific Sanddab	Liver	DDT	p,-p-DDMU	24.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 44	0.6	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 49	2.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 52	2.4	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 66	2.3	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 70	2.1	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 74	1.4	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 99	9.2	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 101	7.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 105	4.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 110	5.1	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 118	13.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 123	1.8	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 138	18.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 149	4.8	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 151	3.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 153/168	29.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 177	2.6	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 180	12.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 183	3.2	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 187	11.0	ppb
TZ2	1	Pacific Sanddab	Liver	PCB	PCB 206	3.4	ppb
TZ2	1	Pacific Sanddab	Liver	Chlordane	Alpha (cis) chlordane	3.3	ppb
TZ2	1	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	4.9	ppb
TZ2	2	Pacific Sanddab	Liver	DDT	p,p-DDD	3.9	ppb
TZ2	2	Pacific Sanddab	Liver	DDT	o,p-DDE	4.4	ppb
TZ2	2	Pacific Sanddab	Liver	DDT	p,p-DDE	330.0	ppb
TZ2	2	Pacific Sanddab	Liver	DDT	p,p-DDT	4.9	ppb
TZ2	2	Pacific Sanddab	Liver	DDT	p,-p-DDMU	33.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 44	0.8	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 49	2.2	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 52	2.6	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 66	2.7	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 70	2.3	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 74	1.6	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 87	2.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 99	11.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 101	7.8	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 105	4.3	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 110	6.7	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 118	15.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 123	2.1	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 138	23.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 149	6.3	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 151	3.1	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 153/168	37.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 158	1.7	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 167	1.6	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 170	6.1	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 177	3.1	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 180	17.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 183	4.2	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 187	15.0	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 194	4.8	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 201	5.3	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 206	3.7	ppb
TZ2	2	Pacific Sanddab	Liver	PCB	PCB 28	1.0	ppb
TZ2	2	Pacific Sanddab	Liver	Chlordane	Alpha (cis) chlordane	2.6	ppb
TZ2	2	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	5.4	ppb
TZ2	3	English Sole	Liver	DDT	o,p-DDE	2.9	ppb
TZ2	3	English Sole	Liver	DDT	p,p-DDE	73.0	ppb
TZ2	3	English Sole	Liver	DDT	p,-p-DDMU	3.0	ppb
TZ2	3	English Sole	Liver	PCB	PCB 49	1.6	ppb
TZ2	3	English Sole	Liver	PCB	PCB 52	1.0	ppb
TZ2	3	English Sole	Liver	PCB	PCB 66	1.8	ppb
TZ2	3	English Sole	Liver	PCB	PCB 70	1.0	ppb
TZ2	3	English Sole	Liver	PCB	PCB 74	0.6	ppb
TZ2	3	English Sole	Liver	PCB	PCB 99	4.8	ppb
TZ2	3	English Sole	Liver	PCB	PCB 101	4.7	ppb
TZ2	3	English Sole	Liver	PCB	PCB 105	1.8	ppb
TZ2	3	English Sole	Liver	PCB	PCB 110	3.0	ppb
TZ2	3	English Sole	Liver	PCB	PCB 118	5.4	ppb
TZ2	3	English Sole	Liver	PCB	PCB 123	1.0	ppb
TZ2	3	English Sole	Liver	PCB	PCB 138	10.0	ppb
TZ2	3	English Sole	Liver	PCB	PCB 149	6.2	ppb
TZ2	3	English Sole	Liver	PCB	PCB 151	1.8	ppb
TZ2	3	English Sole	Liver	PCB	PCB 153/168	16.0	ppb
TZ2	3	English Sole	Liver	PCB	PCB 158	0.8	ppb
TZ2	3	English Sole	Liver	PCB	PCB 170	3.6	ppb
TZ2	3	English Sole	Liver	PCB	PCB 177	2.9	ppb
TZ2	3	English Sole	Liver	PCB	PCB 180	10.0	ppb
TZ2	3	English Sole	Liver	PCB	PCB 183	2.7	ppb
TZ2	3	English Sole	Liver	PCB	PCB 187	9.9	ppb
TZ2	3	English Sole	Liver	PCB	PCB 206	5.5	ppb
TZ3	1	Pacific Sanddab	Liver	DDT	p,p-DDE	685.0	ppb
TZ3	1	Pacific Sanddab	Liver	DDT	p,-p-DDMU	35.0	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 44	2.0	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 49	6.1	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 52	8.9	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 66	6.1	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 70	5.6	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 74	3.2	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 99	32.0	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 101	20.5	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 105	12.5	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 110	23.5	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 118	45.0	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 123	5.1	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 138	64.0	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 149	14.5	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 151	8.9	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 153/168	94.0	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 156	4.8	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 170	11.5	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 177	7.1	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 180	38.0	ppb
TZ3	1	Pacific Sanddab	Liver	PCB	PCB 187	35.0	ppb
TZ3	1	Pacific Sanddab	Liver	Chlordane	Alpha (cis) chlordane	4.4	ppb
TZ3	1	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	10.1	ppb
TZ3	2	Pacific Sanddab	Liver	DDT	p,p-DDD	5.1	ppb
TZ3	2	Pacific Sanddab	Liver	DDT	o,p-DDE	5.3	ppb
TZ3	2	Pacific Sanddab	Liver	DDT	p,p-DDE	400.0	ppb
TZ3	2	Pacific Sanddab	Liver	DDT	p,-p-DDMU	35.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 44	1.9	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 49	6.7	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 52	9.6	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 66	6.8	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 70	6.1	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 74	3.8	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 87	6.5	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 99	35.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 101	24.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 105	15.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 110	29.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 118	56.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 119	2.2	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 123	5.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 128	15.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 138	79.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 149	16.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 151	11.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 153/168	120.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 156	5.2	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 158	6.9	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 167	5.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 170	14.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 177	6.5	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 180	42.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 183	11.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 187	37.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 194	10.0	ppb
TZ3	2	Pacific Sanddab	Liver	PCB	PCB 206	9.8	ppb
TZ3	2	Pacific Sanddab	Liver	Chlordane	Alpha (cis) chlordane	4.4	ppb
TZ3	2	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	7.1	ppb
TZ3	3	Pacific Sanddab	Liver	DDT	p,p-DDD	3.8	ppb
TZ3	3	Pacific Sanddab	Liver	DDT	o,p-DDE	2.5	ppb
TZ3	3	Pacific Sanddab	Liver	DDT	p,p-DDE	250.0	ppb
TZ3	3	Pacific Sanddab	Liver	DDT	p,-p-DDMU	22.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 44	1.6	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 49	4.7	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 52	6.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 66	4.7	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 70	3.9	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 74	2.4	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 87	3.5	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 99	23.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 101	15.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 105	8.1	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 110	14.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 118	29.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 119	1.6	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 123	3.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 128	9.1	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 138	42.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 149	11.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 151	6.7	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 153/168	65.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 156	3.8	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 158	4.1	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 167	3.4	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 170	10.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 177	3.9	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 180	25.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 183	7.5	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 187	25.0	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 194	8.4	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 201	7.1	ppb
TZ3	3	Pacific Sanddab	Liver	PCB	PCB 206	5.7	ppb
TZ3	3	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	2.8	ppb
TZ4	1	Pacific Sanddab	Liver	DDT	p,p-DDD	3.8	ppb
TZ4	1	Pacific Sanddab	Liver	DDT	p,p-DDE	320.0	ppb
TZ4	1	Pacific Sanddab	Liver	DDT	p,-p-DDMU	27.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 44	0.8	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 49	2.5	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 52	3.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 66	2.9	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 70	2.4	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 74	1.6	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 87	2.4	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 99	14.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 101	9.8	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 105	5.5	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 110	8.5	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 118	20.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 123	2.2	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 138	25.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 149	7.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 151	5.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 153/168	52.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 158	2.8	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 167	2.1	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 170	7.5	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 177	3.3	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 180	26.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 183	7.4	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 187	20.0	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 194	7.5	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 201	6.8	ppb
TZ4	1	Pacific Sanddab	Liver	PCB	PCB 206	5.7	ppb
TZ4	1	Pacific Sanddab	Liver	Chlordane	Alpha (cis) chlordane	2.1	ppb
TZ4	1	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	2.9	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	o,p-DDE	3.2	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	p,p-DDE	520.0	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	p,p-DDD	4.0	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	p,p-DDT	5.9	ppb
TZ4	2	Pacific Sanddab	Liver	DDT	p,-p-DDMU	40.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 101	14.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 105	7.3	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 110	8.7	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 118	25.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 123	2.9	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 138	29.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 149	7.1	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 151	4.8	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 153/168	51.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 156	2.2	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 158	2.9	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 167	2.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 170	6.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 177	2.9	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 180	19.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 183	4.7	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 187	17.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 194	4.3	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 206	4.1	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 44	0.9	ppb

Appendix F.3 *continued*

Station	Comp	Species	Tissue	Class	Constituent	Value	Units
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 49	2.8	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 52	4.1	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 66	4.0	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 70	3.7	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 74	2.2	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 87	2.2	ppb
TZ4	2	Pacific Sanddab	Liver	PCB	PCB 99	16.0	ppb
TZ4	2	Pacific Sanddab	Liver	Chlordane	Alpha (cis) chlordane	4.3	ppb
TZ4	2	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	5.8	ppb
TZ4	3	Pacific Sanddab	Liver	DDT	p,p-DDD	2.2	ppb
TZ4	3	Pacific Sanddab	Liver	DDT	p,p-DDE	200.0	ppb
TZ4	3	Pacific Sanddab	Liver	DDT	p,-p-DDMU	22.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 44	0.7	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 49	1.8	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 52	2.2	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 66	2.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 70	1.9	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 74	0.9	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 99	7.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 101	5.5	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 105	3.5	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 110	4.9	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 118	12.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 138	15.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 149	3.9	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 151	2.4	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 153/168	26.0	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 158	1.4	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 167	1.1	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 170	2.4	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 177	1.8	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 180	8.7	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 183	2.2	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 187	8.7	ppb
TZ4	3	Pacific Sanddab	Liver	PCB	PCB 206	3.4	ppb
TZ4	3	Pacific Sanddab	Liver	Chlordane	Alpha (cis) chlordane	2.3	ppb
TZ4	3	Pacific Sanddab	Liver	Chlordane	Trans nonachlor	2.8	ppb