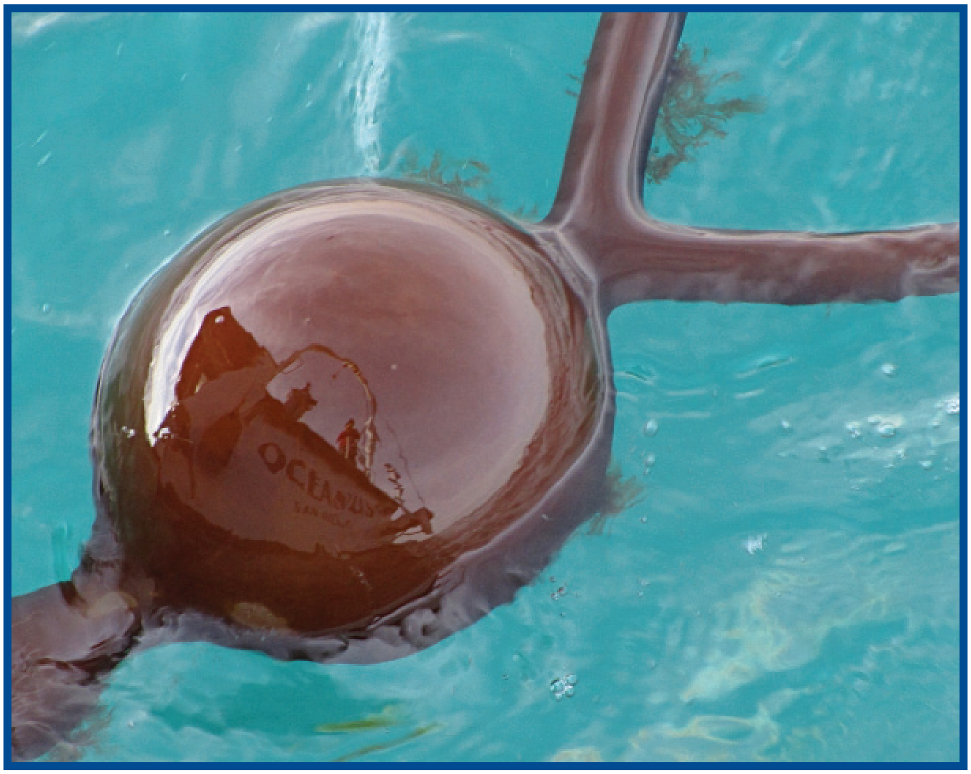
The City of San Diego

Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall 2011



City of San Diego
Ocean Monitoring Program

Public Utilities Department
Environmental Monitoring and Technical Services Division

THE CITY OF SAN DIEGO

June 29, 2012

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

Attention: POTW Compliance Unit

Dear Sir:

Enclosed on CD is the 2011 Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall as required per NPDES Permit No. CA0107409, Order No. R9-2009-0001. This report contains data summaries, analyses and interpretations of the various portions of the ocean monitoring program, including oceanographic conditions, water quality, sediment characteristics, 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,

Steve Meyer
Deputy Public Utilities Director

TDS/akl

Enclosure: CD containing PDF file of this report

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

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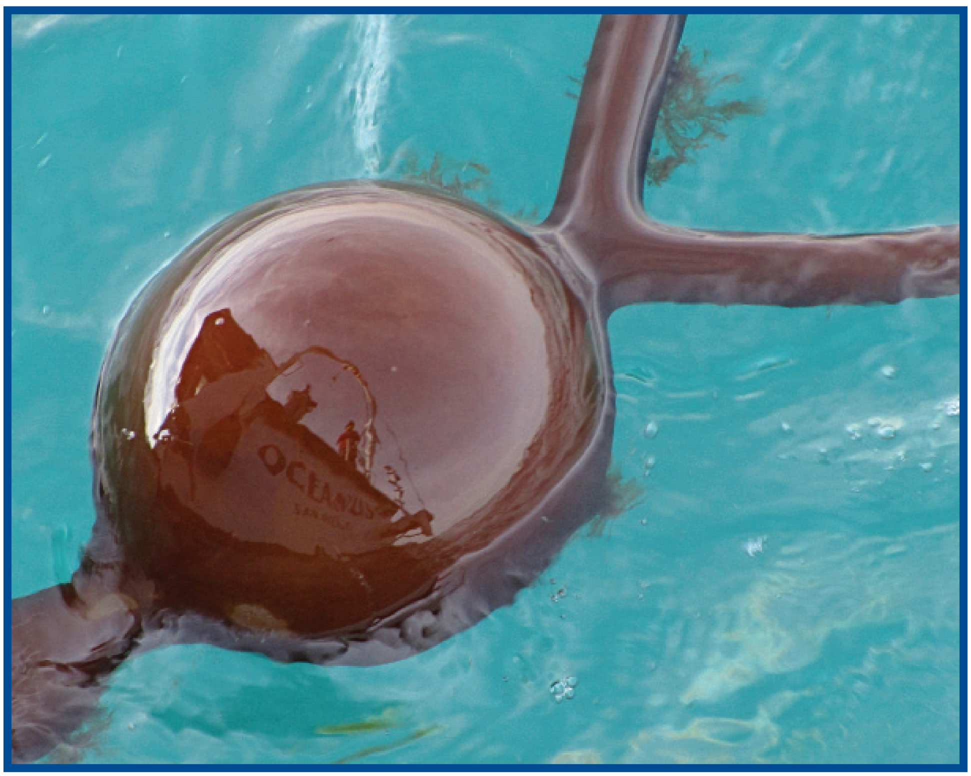
for the
Point Loma Ocean Outfall
2011



Prepared by:

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

June 2012

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Acknowledgments:
We are grateful to the personnel of the City's Marine Biology, Marine Microbiology, and Wastewater Chemistry Services Laboratories for their assistance in the collection and/or processing of all samples, and for discussions of the results. The completion of this report would not have been possible without their continued efforts and contributions. We would especially like to thank G. Daly, A. Davenport, A. Feit, M. Kelly, D. Olson, D. Silvaggio, R. Velarde, and L. Wiborg for their critical reviews of various chapters of this report. We would also like to thank Dr. E. Parnell of the Scripps Institution of Oceanography for his advice and assistance. Complete staff listings for the above labs and additional details concerning relevant QA/QC activities for the receiving waters monitoring data reported herein are available online in the 2011 Annual Receiving Waters Monitoring & Toxicity Testing Quality Assurance Report (www.sandiego.gov/mwwd/environment/reports.shtml).

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

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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
BOD	Biochemical Oxygen Demand
BRI	Benthic Response Index
CalCOFI	California Cooperative Fisheries Investigation
CCS	California Current System
CDIP	Coastal Data Information Program
CDOM	Colored Dissolved Organic Matter
CDPH	California Department of Public Health
CFU	Colony Forming Units
cm	centimeter
CSDMML	City of San Diego Marine Microbiology Laboratory
CTD	Conductivity, Temperature, Depth instrument
DDT	Dichlorodiphenyltrichloroethane
df	degrees of freedom
DO	Dissolved Oxygen
ELAP	Environmental Laboratory Accreditation Program
EMAP	Environmental Monitoring and Assessment Program
EMTS	Environmental Monitoring and Technical Services
ENSO	El Niño Southern Oscillation
ERL	Effects Range Low
ERM	Effects Range Mediam
F:T	Fecal to Total coliform ratio
FET	Fisher's Exact Test
FIB	Fecal Indicator Bacteria
ft	feet
FTR	Fecal to Total coliform Ratio criterion
g	gram
Global R	ANOSIM test value that examines for global differences within a factor
H'	Shannon diversity index
HCB	Hexachlorobenzene
HCH	Hexachlorocylclohexane
IGODS	Interactive Geographical Ocean Data System
in	inches
IR	Infrared
IWTP	International Wastewater Treament Plant
J'	Pielou's evenness index
kg	kilogram
km	kilometer
km^2	square kilometer
L	Liter

Acronyms and Abbreviations (*continued*)

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

Acronyms and Abbreviations (*continued*)

SDRWQCB	San Diego Regional Water Quiality Control Board
SIMPER	Similarity Percentages Routine
SIMPROF	Similarity Profile Analysis
SIO	Scripps Institution of Oceanography
sp	species (singular)
spp	species (plural)
SSL	Sub-surface Low Salinity Layer
SSM	Single Sample Maximum
SWRCB	Califonia State Water Resources Control Board
tDDT	total DDT
TN	Total Nitrogen
TOC	Total Organic Carbon
tPAH	total PAH
tPCB	total PCB
TSS	Total Suspended Solids
TVS	Total Volatile Solids
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
USGS	United States Geological Survey
USIBWC	United States International Boundary and Water Commission
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

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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 Ocean Outfall (PLOO). The data collected are used to determine compliance with receiving water conditions as specified in the NPDES regulatory permit for the City's Point Loma Wastewater Treatment Plant (PLWTP).

The primary objectives of the ocean monitoring efforts for the Point Loma outfall region are to: (a) measure compliance with NPDES permit requirements and 2005 California Ocean Plan (Ocean Plan) water-contact standards, (b) monitor changes in ocean conditions over space and time, and (c) 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. The regular fixed-grid monitoring area encompasses approximately 184 km^2 of coastal waters centered around the PLOO discharge site, which is located approximately 7.2 km offshore of the PLWTP at a depth of nearly 100 m. Shoreline monitoring extends from Mission Beach to the tip of Point Loma, while regular offshore monitoring occurs in adjacent waters overlying the continental shelf at depths of about 9 to 116 m.

Prior to the initiation of wastewater discharge at the present deepwater location in late 1993, the City conducted a 2½-year baseline study at regular fixed stations designed to characterize background conditions in the region. Additionally, a broader regional survey of benthic conditions is conducted each year at randomly selected sites that range from northern San Diego County to the USA/Mexico border 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 additional information for distinguishing reference from impacted areas. Results of the 2011 regional survey off San Diego are included in the annual receiving waters monitoring report for the South Bay outfall region.

The results and conclusions of all ocean monitoring activities conducted for the Point Loma outfall region from January through December 2011 are organized into seven chapters in this report. Chapter 1 presents a general introduction and overview, while chapters 2–7 include results of all fixed site monitoring 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 to determine compliance with Ocean Plan standards. 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 determine contaminant loads present 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 of ocean waters in the region. One such project involves satellite imaging of the San Diego coastal region, the 2011 results of which are incorporated into Chapters 2 and 3 herein. A summary of the main findings for each of the above components is included below.

OCEANOGRAPHIC CONDITIONS

Oceanographic data collected in the PLOO region support reports that describe 2011 as a La Niña year characterized by the early onset of relatively strong upwelling. Conditions indicative of local upwelling off Point Loma were most evident during May.

Additionally, satellite images revealed colder-than-normal surface waters during the summer as would be expected during a La Niña. As is typical for the area, maximum stratification of the water column occurred in mid-summer, while reduced stratification occurred during the winter and fall. The only indication of the wastewater plume based on oceanographic data was relatively low water clarity (transmissivity) and high CDOM (colored dissolved organic matter) values measured near the discharge site. Changes in temperature, salinity, pH, and dissolved oxygen levels relative to the outfall were not discernible. Satellite imagery results also revealed no evidence that the plume surfaced or was transported inshore into recreational waters. Overall, ocean conditions during the year were consistent with well documented patterns for southern California. These findings suggest that natural factors such as the upwelling of cool, deep ocean waters and effects of widespread climatic events such as El Niño-La Niña oscillations explain most of the temporal and spatial variability observed in the coastal waters off Point Loma.

WATER QUALITY

Water quality conditions were excellent in the Point Loma region during 2011. Overall compliance with Ocean Plan water-contact standards was greater than 99%. There was also no evidence from the bacteriological results that the PLOO wastewater plume reached the shoreline or nearshore recreational waters, which is consistent with the satellite imagery observations mentioned above. Elevated fecal indicator bacteria (FIB) counts were detected at only three shoreline and one kelp bed station during the year. FIB densities were also low at all offshore stations during each quarterly sampling event (February, May, August and November), with only six samples having elevated enterococcus levels. Each of these high enterococcus counts was collected from depths $\geq$60 m at stations located beyond State waters boundaries. These results are consistent with other data that indicate the wastewater plume remains restricted to relatively deep, offshore waters throughout the year.

SEDIMENT CONDITIONS

Ocean sediments at stations surrounding the PLOO in 2011 were composed primarily of fine sands and coarse silt, which is similar to patterns seen in previous years. There was no evident relationship between sediment grain size distributions and proximity to the discharge site. Instead, most differences may be due to factors such as the presence of outfall construction materials, offshore disposal of dredged sediments from local bays, multiple geological origins of different sediment types, and recent deposits of detrital materials. Sediment quality in the region was similar in 2011 to previous years with overall contaminant loads remaining within the typical range of variability for San Diego and other coastal areas of southern California. There was no clear evidence of significant contaminant accumulation associated with wastewater discharge. For example, the highest concentrations of several organic indicators and trace metals were found in sediments from the northern-most reference stations, while several pesticides, PCBs and PAHs were detected mostly in sediments from stations located south of the outfall. This latter pattern is consistent with other studies that have suggested that sediment contamination in this area is most likely due to short dumps of dredged materials originally destined for the USEPA designated LA5 disposal site. The only evidence of possible organic enrichment was slightly higher sulfide and BOD levels at a few nearfield stations located within 300 m of the discharge zone. Finally, the potential for environmental degradation by the various contaminants was evaluated using the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines when available. The only exceedances of either threshold during the year were for lead (one ERL and one ERM in January), silver (one ERL in January), and DDT (one ERL in July).

MACROBENTHIC COMMUNITIES

Benthic macrofaunal communities surrounding the PLOO were similar in 2011 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* continued to be the most abundant species even though its overall population abundances were the lowest since monitoring began. The spionid polychaete *Paraprionospio alata* was the most widespread benthic invertebrate, which represented a resurgence of its prominence in the region. There have been some minor changes in assemblages located within ~300 m of the discharge zone that would be expected near large ocean outfalls. For example, some descriptors of benthic community structure (e.g., infaunal abundance, species diversity) or populations of indicator species (e.g., *A. urtica*) have shown changes over time between reference areas and sites located nearest the outfall. Despite these changes, however, results for the benthic response index (BRI) remain characteristic of undisturbed sediments. In addition, documented changes during the year were similar in magnitude to those reported previously for the PLOO region and elsewhere off southern California. Overall, macrofaunal assemblages off Point Loma continue to be characteristic of natural indigenous communities. There was no evidence that wastewater discharge has caused degradation of the marine benthos in the PLOO monitoring region.

DEMERSAL FISHES AND MEGABENTHIC INVERTEBRATES

Comparisons of the 2011 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, suggesting a lack of significant anthropogenic influence. Pacific sanddabs continued to dominate the fish assemblages, occurring at all stations and accounting for 40% of the year's catch. Other common species included California lizardfish, stripetail rockfish, longspine combfish, shortspine combfish, Dover sole, English sole, halfbanded rockfish, pink seaperch, greenstriped rockfish, California tonguefish, plainfin midshipman, and hornyhead turbot. Megabenthic invertebrate assemblages were dominated by the white sea urchin *Lytechinus pictus*, which also occurred in all trawls and accounted for 85% of all invertebrates captured. Other common, but far less abundant invertebrates included the brittle star *Ophiura luetkenii*, the sea stars *Astropecten californicus*, *Luidia asthenosoma* and *L. foliolata*, the sea cucumber *Parastichopus californicus*, the gastropods *Philine auriformis* and *Pleurobranchaea californica*, the octopus *Octopus rubescens*, and the octocoral *Thesea* sp B. Finally, external examinations of all fish captured during trawling activities indicated that fish populations remain healthy, with < 1% of the fish collected having external parasites or evidence of disease (e.g., tumors).

CONTAMINANTS IN FISH TISSUES

The bioaccumulation 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 2011. Although several metals, pesticides, and PCB congeners were detected in both tissue types, these contaminants occurred in fishes from throughout the region with no patterns that could be attributed to wastewater discharge. Only a few samples exceeded any state or federal fish contaminant goals or international standards. Furthermore, concentrations of all contaminants were within ranges reported previously for southern California fishes. The occurrence of some metals and chlorinated hydrocarbons in Point Loma fishes may be due to many factors, including the ubiquitous distribution of many contaminants in southern California coastal sediments. Other factors that can affect the bioaccumulation of contaminants in marine fishes include the different physiologies and life history traits of various species. Additionally, exposure can vary greatly between fish species and even among individuals of the same species depending on migration habits. For example, fish may be exposed to pollutants in a highly polluted area and then migrate to a region that is less contaminated. This is of particular concern for fishes collected in the vicinity of the PLOO, as there are many other point and non-point sources that may contribute to contamination.

CONCLUSIONS

The findings and conclusions for the ocean monitoring efforts conducted for the Point Loma outfall region during calendar year 2011 were consistent with previous years. Overall, there were limited impacts to local receiving waters, benthic sediments, and marine invertebrate and fish communities. Water quality conditions and compliance with Ocean Plan standards were excellent, and there was no evidence that the wastewater plume from the outfall reached surface or nearshore recreational waters during the year. There were also no significant outfall related patterns in sediment contaminant distributions, or in differences between various invertebrate and fish assemblages. The lack of disease symptoms or physical anomalies in local fishes, as well as the low level of contaminants detected in fish tissues, was also indicative of a healthy marine environment. Finally, benthic habitats in the Point Loma region remain in good condition similar to much of the southern California continental shelf.

Chapter 1
General Introduction

Chapter 1. General Introduction

The City of San Diego (City) Point Loma Wastewater Treatment Plant (PLWTP) discharges advanced primary treated effluent to the Pacific Ocean through the Point Loma Ocean Outfall (PLOO) in accordance with requirements set forth in Order No. R9-2009-0001, NPDES Permit No. CA0107409. This Order was adopted by the San Diego Regional Water Quality Control Board (SDRWQCB) on June 10, 2009 and became effective August 1, 2010. The Monitoring and Reporting Program (MRP) in this order specifies the requirements for monitoring ambient receiving waters conditions off Point Loma, San Diego, including field sampling design and frequency, compliance criteria, types of laboratory analyses, and data analysis and reporting guidelines. The main objectives of the monitoring program are to provide data that satisfy permit requirements, demonstrate compliance with California Ocean Plan (Ocean Plan) provisions, detect dispersion and transport of the waste field (plume), and 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 (see below). 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 2011.

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

The average daily flow of effluent through the PLOO in 2011 was 156 million gallons per day (mgd), ranging from a low of 127 mgd in September to a high of about 220 mgd in March. Overall, this represents about a 0.6% decrease from the 157 mgd average flow rate in 2010. TSS removal averaged about 87.5% in 2011, while total mass emissions for the year was approximately 9,088 metric tons (see City of San Diego 2012a).

Receiving Waters Monitoring

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 inshore site are presented in City of San Diego (1995a), while the results of a three-year "recovery study" are summarized in City of San Diego (1998). From 1991 through 1993, the City also conducted a "pre-discharge" study in the new monitoring area 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 2010 are available in previous annual receiving waters monitoring reports (e.g., City of San Diego 2011). 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, 2012b) or as part of larger, multi-agency surveys of the entire Southern California Bight (SCB). The latter include the 1994 Southern California Bight Pilot Project (Allen et al. 1998, Bergen et al. 1998, 2001, Schiff and Gossett 1998) and subsequent Bight'98, Bight'03 and Bight'08 programs in 1998, 2003 and 2008, respectively (Allen et al. 2002, 2007, 2011, Noblet et al. 2002, Ranasinghe et al. 2003, 2007, 2012, Schiff et al. 2006, 2011). Such large-scale surveys are useful for characterizing the ecological health of diverse coastal areas and in distinguishing reference sites from those impacted by wastewater or stormwater discharges, urban runoff, or other sources of contamination.

The current monitoring area off Point Loma extends from the shoreline seaward to a depth of about 116 m and encompasses an area of approximately 184 km^2 (Figure 1.1). Fixed sites are generally arranged in a grid surrounding the outfall and are sampled in accordance with a prescribed schedule as specified in the MRP. A summary of the results for quality assurance procedures performed in 2011 can be found in City of San Diego (2012c). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the SDRWQCB and United States Environmental Protection Agency (USEPA) throughout the year are available

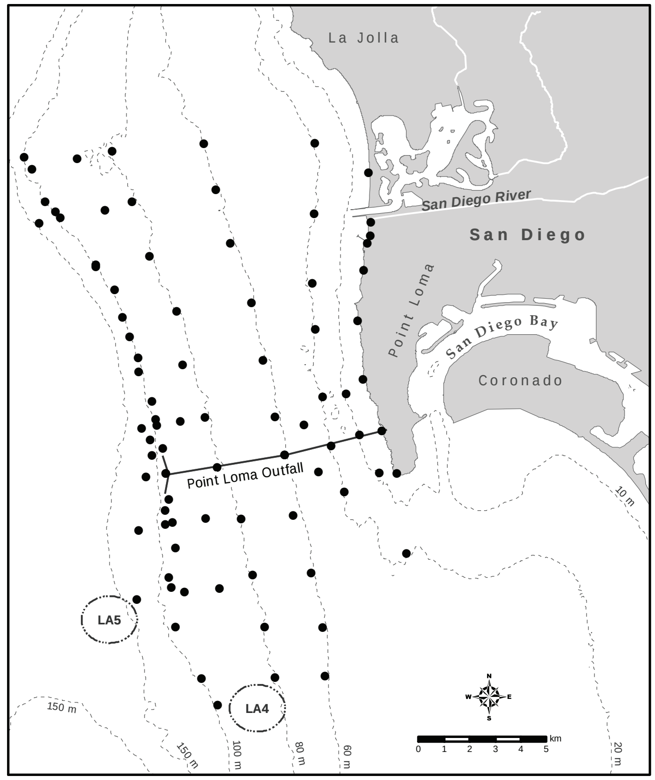

Figure 1.1
Receiving waters monitoring stations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

online at the City's website (www.sandiego.gov/mwwd/environment/oceanmonitor.shtml).

In addition to the above activities, the City provides staffing or funding support for several other projects relevant to assessing ocean quality in the region. One such project involves remote sensing (satellite imaging) of the San Diego/Tijuana coastal region, which is jointly funded by the City and the International Boundary and Water Commission (Svejkovsky 2012). The City also funds a long-term study of the Point Loma and La Jolla kelp forests being conducted by scientists at the Scripps Institution of Oceanography (e.g., Parnell and Riser 2011), and also 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 2011).

The current MRP also includes provisions for adaptive or special strategic process studies as determined by the City in conjunction with the SDRWQCB and USEPA. The first of these studies was a comprehensive review of the Point Loma ocean monitoring program conducted by a team of scientists from the Scripps Institution of Oceanography and several other institutions (SIO 2004). This was followed by a large-scale sediment mapping study of the Point Loma and South Bay coastal regions that began in the summer of 2004 (Stebbins et al. 2004), as well as a pilot study of deeper continental slope benthic habitats off San Diego that occurred in 2005 (Stebbins and Parnell 2005). A second phase of the sediment mapping study focused on just the Point Loma region is scheduled to begin in July 2012. The deep benthic pilot study was subsequently expanded into a multi-year deep benthic habitat assessment project expected to be completed in late 2012 or early 2013. Another active project involves annual sampling at the recovery stations mentioned above and in City of San Diego (1998) as part of a long-term assessment project of benthic conditions near the original outfall discharge site. Finally, a multi-phase project is currently underway to examine water mass dynamics (ocean currents, thermocline) within the Point Loma receiving waters, and to characterize the dispersion behavior of the PLOO wastewater plume (Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010, Rogowski et al. *in press*).

This report presents the results of all regular receiving waters monitoring activities conducted off Point Loma from January through December 2011. The major components of the monitoring program are covered in the following six chapters: Oceanographic Conditions, Water Quality, Sediment Conditions, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, and Bioaccumulation of Contaminants in Fish Tissues.

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Chapter 2
Oceanographic Conditions

Chapter 2. Oceanographic Conditions

Introduction

The City of San Diego collects a comprehensive suite of oceanographic data from offshore ocean waters surrounding both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively) to characterize conditions in the region and to identify possible impacts of wastewater discharge. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen (DO), pH, chlorophyll *a*, and colored dissolved organic matter (CDOM) are important indicators of physical and biological oceanographic processes (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 ocean outfall's diffuser structure and rate of 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). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping. Further, previous studies have shown that wastewater plumes can often be identified by having lower salinity and higher CDOM values than background conditions (Terrill et al. 2009, Todd et al. 2009).

In nearshore coastal waters of the Southern California Bight (SCB) such as the Point Loma outfall region, oceanographic conditions are strongly influenced by several factors, including (1) global and regional climate processes such as El Niño/La Niña, Pacific Decadal and North Pacific Gyre oscillations that can affect long-term (~10–20 years) trends (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, 2011, NOAA/NWS 2011), (2) the California Current System coupled with local gyres that transport distinct water masses throughout the SCB (Lynn and Simpson 1987), and (3) seasonal changes in local weather patterns (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). The seasonality of southern California is responsible for the main stratification patterns of the coastal waters off San Diego. Warmer waters and a more stratified water column are typically present during the dry season (April–September), while cooler waters and weak stratification characterize ocean conditions during the wet season (October–March) (Terrill et al. 2009). For example, storm activity during the winter brings higher winds, rain, and waves that often contribute to the formation of a well-mixed, non-stratified water column (Jackson 1986). The chance of wastewater plumes from sources such as the PLOO reaching surface waters is highest during these times since no barriers (temperature, salinity gradients) exist. These winter conditions often extend into spring until the frequency of storms decreases and the transition from wet to dry conditions begins. In late spring the surface waters begin to warm, which results in increased surface evaporation (Jackson 1986). Once the water column becomes stratified, minimal mixing conditions typically remain throughout the summer and early fall months. In the fall, cooler temperatures, along with increases in stormy weather, begin to cause the return of well-mixed water column conditions.

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

This chapter presents analyses and interpretations of the oceanographic data collected during 2011 at fixed monitoring stations surrounding the PLOO. The primary goals are to: (1) summarize oceanographic conditions in the region, (2) identify potential natural and anthropogenic sources of variability, (3) assess possible influence of the PLOO wastewater plume relative to other inputs, and (4) determine the extent to which water mass movement or water column mixing affects the dispersion/dilution potential for discharged materials. Results of remote sensing observations (e.g., satellite imagery) are combined with measurements of physical oceanographic parameters to provide additional insight on the horizontal transport of surface waters in the region (Pickard and Emery 1990, Svejkovsky 2012). In addition, a multi-phase project is currently underway to examine the dynamics and strength of the thermocline and ocean currents off Point Loma, as well as the dispersion behavior of the PLOO wastewater plume using a combination of current meters, thermistor strings, and automated underwater vehicles (see Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010, Rogowski et al. in press). Finally, the results reported in this chapter are also referred to in subsequent chapters to help explain patterns of indicator bacteria distributions (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 fixed sampling sites arranged in a grid pattern surrounding the PLOO and encompassing an 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 stations occurs quarterly (February, May, August, November) to correspond with similar sampling for the Central Bight Regional Water Quality Monitoring Program conducted off Orange County, Los Angeles County, and Ventura County. For sampling and analysis purposes, the quarterly water quality monitoring sites are grouped by depth contour as follows: (a) “100-m WQ” = stations F26–F36 (n = 11); (b) “80-m WQ” = stations F15–F25 (n = 11); (c) “20 & 60-m WQ” = stations F01–F14 (n = 14). All stations within each of these three groups are sampled on a single day during each quarterly survey. In addition, sampling at the eight kelp bed stations (“Kelp WQ”) is conducted five

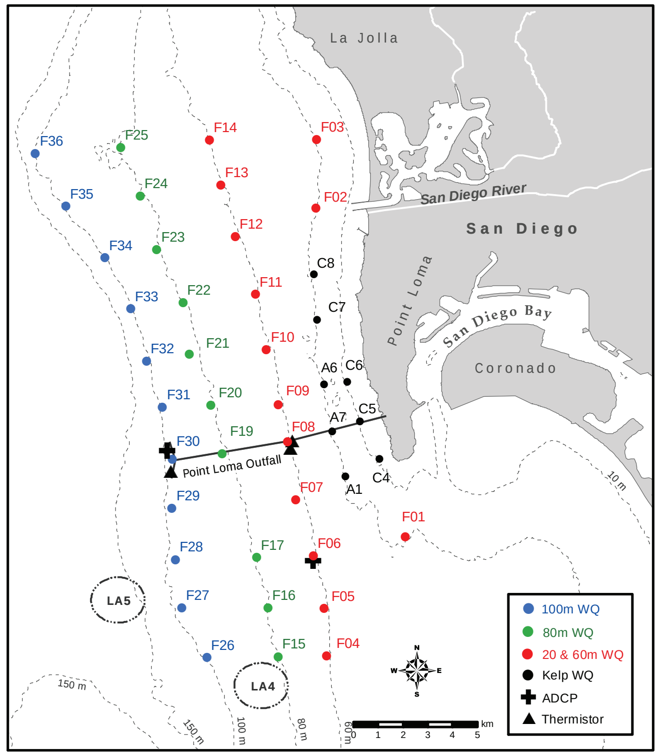

Figure 2.1
Locations of moored instruments (i.e., ADCP, thermistor) and water quality (WQ) monitoring stations where CTD casts are taken around the Point Loma Ocean Outfall as part of the City of San Diego’s Ocean Monitoring Program.

Table 2.1
Sample dates for quarterly oceanographic surveys conducted in the Point Loma outfall region during 2011. Each survey was conducted over four consecutive days with all stations in each station group sampled on a single day (see Figure 2.1 for stations and locations).

	2011 Quarterly Survey Dates			
Station Group	Feb	May	Aug	Nov
20 & 60 m WQ	8	4	16	1
80 m WQ	9	5	17	2
100 m WQ	10	6	18	3
Kelp WQ	11	7	19	4

times per month to meet monitoring requirements for fecal indicator bacteria; however, only Kelp WQ data collected within 1 day of the quarterly stations are analyzed in this chapter, such that all stations were sampled over a 4-day period (see Table 2.1).

Oceanographic data were collected using a SeaBird conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, salinity, density, pH, transmissivity (a proxy for water clarity), chlorophyll *a* (a proxy for the presence of phytoplankton), DO, and CDOM. Water column profiles of each parameter were then constructed for each station by averaging the data values recorded in each 1-m depth interval. This data reduction ensured that physical measurements used in subsequent analyses corresponded to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Moored Instrument Data Collection

Moored instruments, including current meters (ADCPs: Acoustic Doppler Current Profilers) and vertical arrays of temperature sensors (thermistors) were deployed at three primary locations off Point Loma in order to provide nearly continuous measurements of ocean currents and water temperatures for the area. These included one site near the present PLOO discharge zone at a depth of about 100 m, one site located near the outfall pipe at a depth of about 60 m, and one site located south of the outfall along the 60-m depth contour (Figure 2.1).

Ocean current data were collected throughout 2011 using one ADCP moored at two of the above sites (i.e., 100-m site, 60-m site south of the outfall). The ADCP data were collected every five minutes and then averaged into depth bins of 4 m. For the 60-m ADCP, this resulted in 15 bins that ranged in depth from 5 to 53 m; data from this ADCP were unavailable from July 16 through August 3 and from October 19 through December 22 due to battery failure. For the 100-m ADCP, 25 bins were created that ranged in depth from 5 to 93 m. Data from the 100-m ADCP were unavailable from April 22 through August 11 due to a failed deployment. Additional details for processing and analyzing the ADCP data are presented below under 'Data Analysis.'

Temperature data were collected every 10 minutes throughout 2011 from thermistor strings located at the 100-m and 60-m outfall mooring sites. The individual thermistors (Onset Tidbit temperature loggers) were deployed on mooring lines at each site starting at 2 m off the seafloor and extending in series every 4 m to within 6 m of the surface. Occasional gaps exist in the time series where individual thermistors were lost at sea or failed to record data properly. Additional details on specific methodology are available in Storms et al. (2006).

Remote Sensing

Coastal monitoring of the PLOO region during 2011 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite imaging data acquired during the year were made available for review and download from OI's website (Ocean Imaging 2012), while a separate annual report summarizing results for the year was also produced (Svejkovsky 2012). 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. These technologies differ in terms of their capabilities as described in the "Technology Overview" section of Svejkovsky (2012), but are generally useful for revealing patterns in surface waters as deep as 12 m, depending on ocean conditions (e.g., water clarity).

Data Analysis

With the exception of CDOM, the various water column parameters measured in 2011 were summarized as means of surface (top 2 m) and bottom (bottom 2 m) waters for each survey pooled over all stations along each of the 9, 18, 60, 80, and 100-m depth contours. CDOM data were not included in these summaries due to calibration issues with individual CDOM probes that made absolute (measured) values unreliable. For spatial analysis, 3-D graphical views were created for each survey using Interactive Geographical Ocean Data System (IGODS) software, which interpolates data across all depths at each site and between stations along each depth contour. CDOM data were included as part of the IGODS analyses using relative values that were not affected by the calibration issues mentioned above. Additionally, a time series of anomalies for each parameter was created to evaluate significant oceanographic events that have occurred in the region. The anomalies were calculated by subtracting the mean of all 21 survey years to date combined (i.e., 1991–2011) from the monthly means for each year. These mean values were calculated using data from all 100-m depth contour stations, with all water column depths combined.

Because ocean currents typically vary by season, the ADCP data were subset into four seasons prior to conducting subsequent analyses: (a) Winter (December–February); (b) Spring (March–May); Summer (June–August); and Fall (September–November). Although the winter period for 2011 includes non-continuous months (i.e., January–February versus December), preliminary analysis suggested that the current regimes for these three months were similar enough to justify pooling them together for analysis. Since tidal currents are predictable and not likely to result in a net flow of water in a particular direction, tides were filtered prior to any data visualization or analysis using the PL33 filter developed by C. Flagg and R. Beardsley (Alessi et al. 1984). In order to examine modes of currents that were present each season, an empirical orthogonal function (EOF) analysis was completed by singular value decomposition (Anderson et al. 1999) in MATLAB (2012). The first EOF mode for currents was plotted on compass plots for selected depth bins.

Results and Discussion

Oceanographic Conditions in 2011

Water Temperature

Average surface temperatures in 2011 ranged from 14°C in February to 19.6°C in August across the PLOO based on CTD data collected from all of the quarterly water quality stations, while bottom temperatures averaged from 9.7°C in February to 15.7°C in August (Appendix A.1). Although these data were limited to only four surveys, ocean temperatures varied by season as expected, with no discernible patterns relative to wastewater discharge (Figure 2.2). For example, the lowest average temperatures of the year occurred during May at bottom depths, which was likely indicative of spring upwelling. However, relatively cold water (<~11ºC) was also present near the bottom at most of the 60, 80 and 98-m stations during all four surveys, which suggests that upwelling may have occurred at other times as well. Thermal stratification also followed expected seasonal patterns, with the greatest difference between surface and bottom water temperatures (~10°C) occurring during late summer (August). Temperature data from the 60 and 100-m thermistor strings yielded similar results, thus indicating that the general thermal stratification patterns observed during the quarterly CTD surveys actually persisted throughout much of the year (Figure 2.3).

Salinity

Average salinities for the PLOO region in 2011 ranged from 33.30 psu in November to 33.57 psu

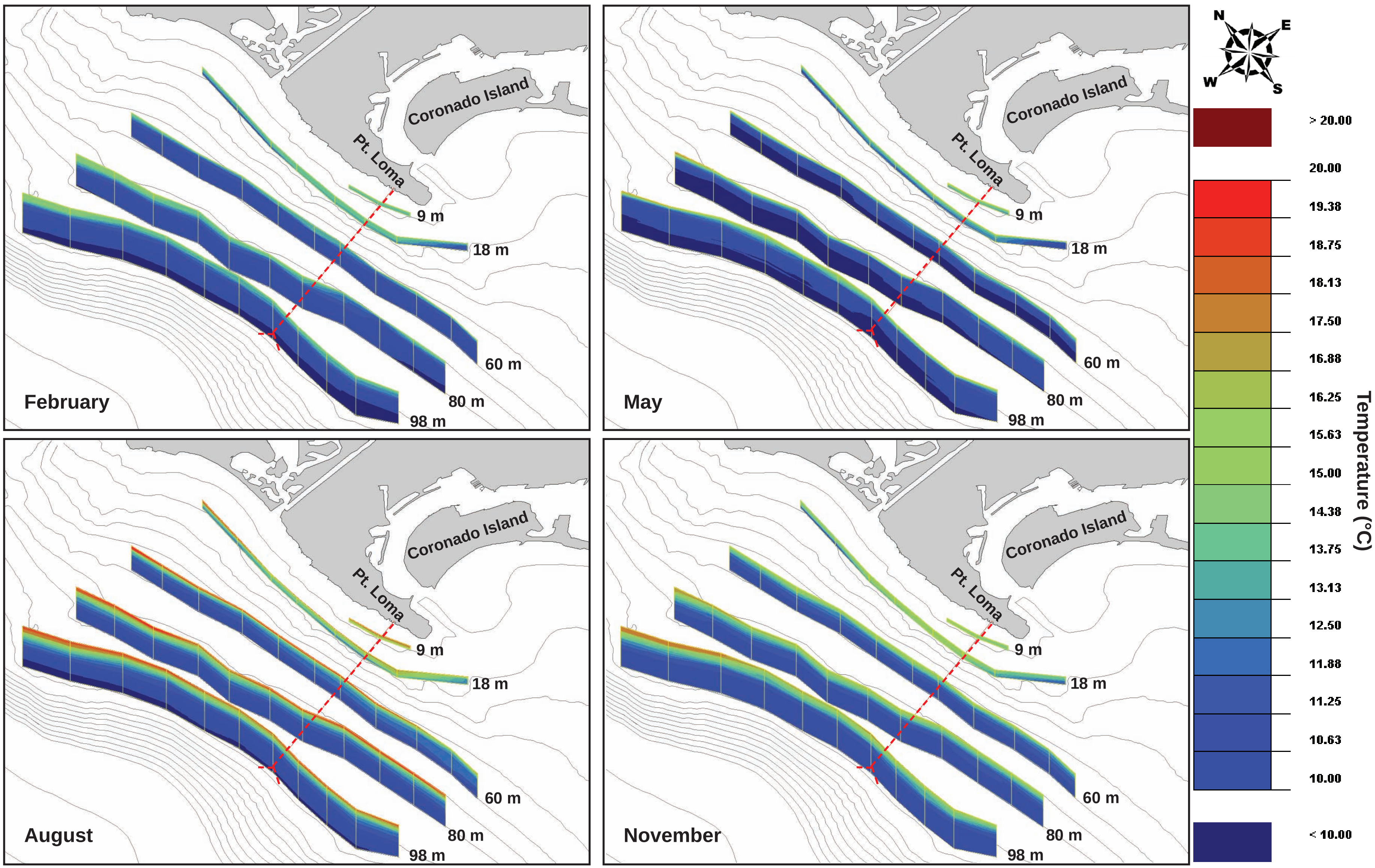

Figure 2.2
Ocean temperatures recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day.

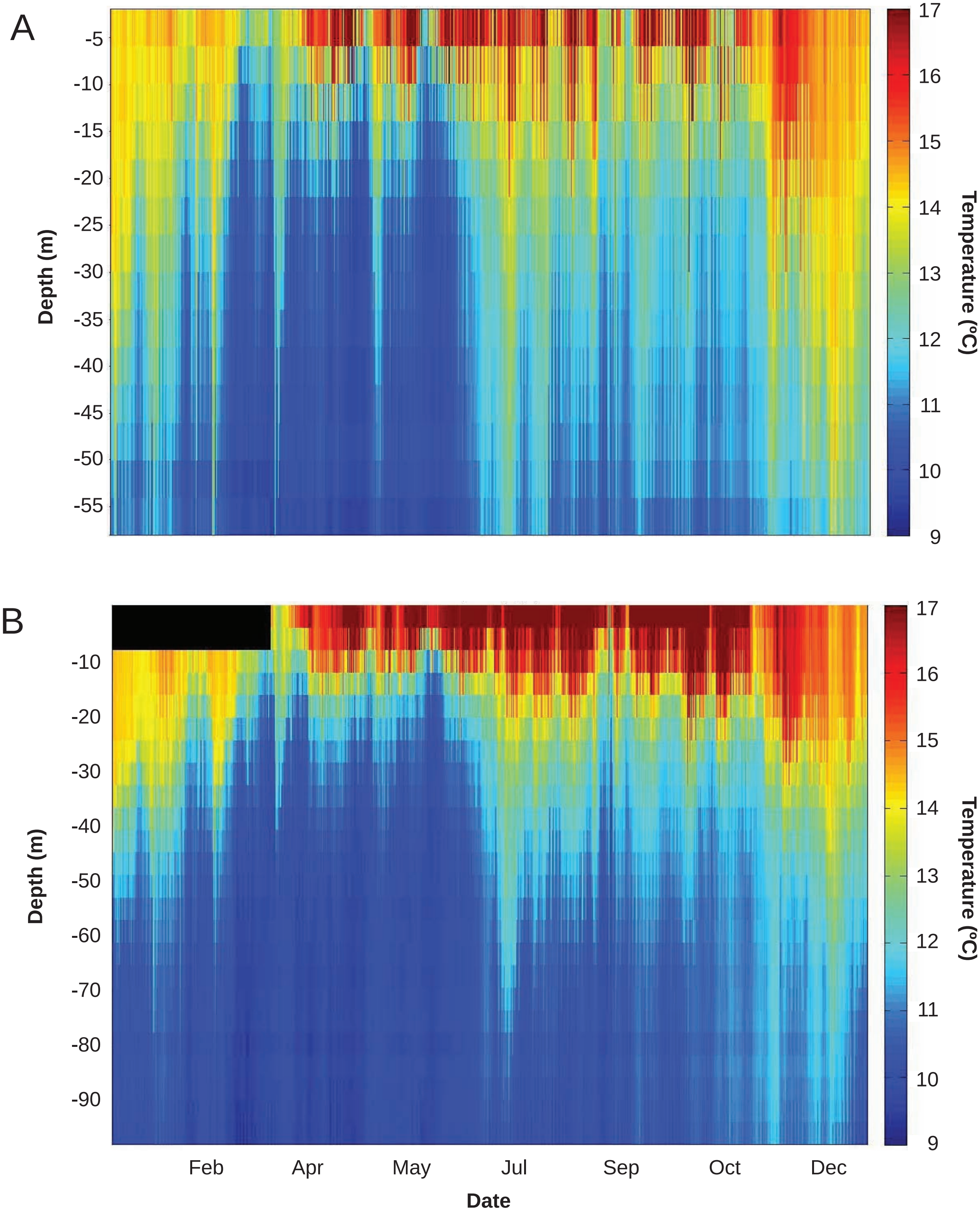

Figure 2.3
Temperature logger data collected at the (A) 60-m and (B) 100-m thermistor sites between January and December 2011. Data were collected every 10 minutes. Missing data (black area) are the result of individual thermistors that were lost at sea.

in May for surface waters, and from 33.32 psu in November to 33.95 psu in May at bottom depths (Appendix A.1). As with ocean temperatures, salinity appeared to vary by season, with no discernible patterns relative to wastewater discharge (Figure 2.4). Relatively high salinity (>~33.6 psu) was present at bottom depths of most 60, 80, and 98-m stations during all four surveys, with the highest values occurring at bottom depths during May. Higher salinity values tended to correspond with lower temperatures found at bottom depths as described above. Taken together, these factors are likely indicative of local coastal upwelling (Jackson 1986).

As in previous years, there was some evidence of another region-wide phenomenon that occurred during May and August, when a layer of relatively low salinity values occurred at mid-water or "sub-surface" depths between about 10–40 m. It seems unlikely that this sub-surface salinity layer (SSL) could be due to wastewater discharge from the PLOO for two reasons. First, seawater samples collected at the same depths and times did not contain levels of indicator bacteria (see Chapter 3). Second, similar SSLs have been reported previously off San Diego and elsewhere in southern California, including Orange and Ventura Counties (e.g., OCSD 1999, 2009, City of San Diego 2011a, b, 2012). Further investigations are required to determine the possible source(s) of this phenomenon.

Dissolved Oxygen and pH

DO concentrations averaged from 7.6 mg/L in August to 10.9 mg/L in May in surface waters, and from 2.7 mg/L in November to 9.7 mg/L in May in bottom waters across the Point Loma outfall region in 2011. Mean pH values ranged from 8.1 in February and November to 8.3 in May in surface waters, and from 7.6 in November to 8.2 in May in bottom waters (Appendix A.1). Changes in pH were closely linked to DO concentrations (e.g., Appendices A.2, A.3) since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975). Similar distributions of both pH and DO values across all stations and along each depth contour indicate that the quarterly surveys were synoptic even though sampling occurred over a 4-day period (Table 2.1, Appendices A.2, A.3).

DO and pH stratification followed normal seasonal patterns, with maximum stratification occurring during the spring (i.e., May) (Appendices A.1, A.2, A.3). Low DO concentrations and pH values at mid- and deeper depths during each survey may have been due to cold, saline and oxygen poor waters moving inshore during periods of local upwelling as described above for temperature and salinity. In contrast, very high DO values just below surface waters were likely associated with phytoplankton blooms that were evident by high chlorophyll values at the same depths and surveys (see below). Changes in DO and pH levels relative to wastewater discharge were not discernible during the year.

Transmissivity

Water clarity varied within typical ranges for the PLOO region during 2011, with average transmissivity values between 70–89% in surface and bottom waters (Appendix A.1). Transmissivity was consistently higher at the offshore sites than in inshore waters, by as much as 18% at the surface and 15% near the bottom. Reduced transmissivity at surface and mid-water depths appeared to co-occur somewhat with peaks in chlorophyll concentrations associated with phytoplankton blooms (Appendices A.4, A.5). Lower transmissivity during February and November may also have been due to wave and storm activity and resultant increases in suspended sediment concentrations. For example, substantial turbidity plumes were evident throughout the region in a satellite image taken February 10, 2011 following a major rain event (Figure 2.5). This plume was massive enough to extend past the end of the PLOO, and corresponded to lower water clarity that reached as far offshore as the 98-m stations at surface depths (Appendix A.4). In contrast, reductions in transmissivity that occurred offshore at depths >60 m were more likely associated with wastewater discharge from the PLOO. During 2011, reduced water clarity was most evident in August at station F30 located nearest the discharge site. This observation was corroborated by relatively

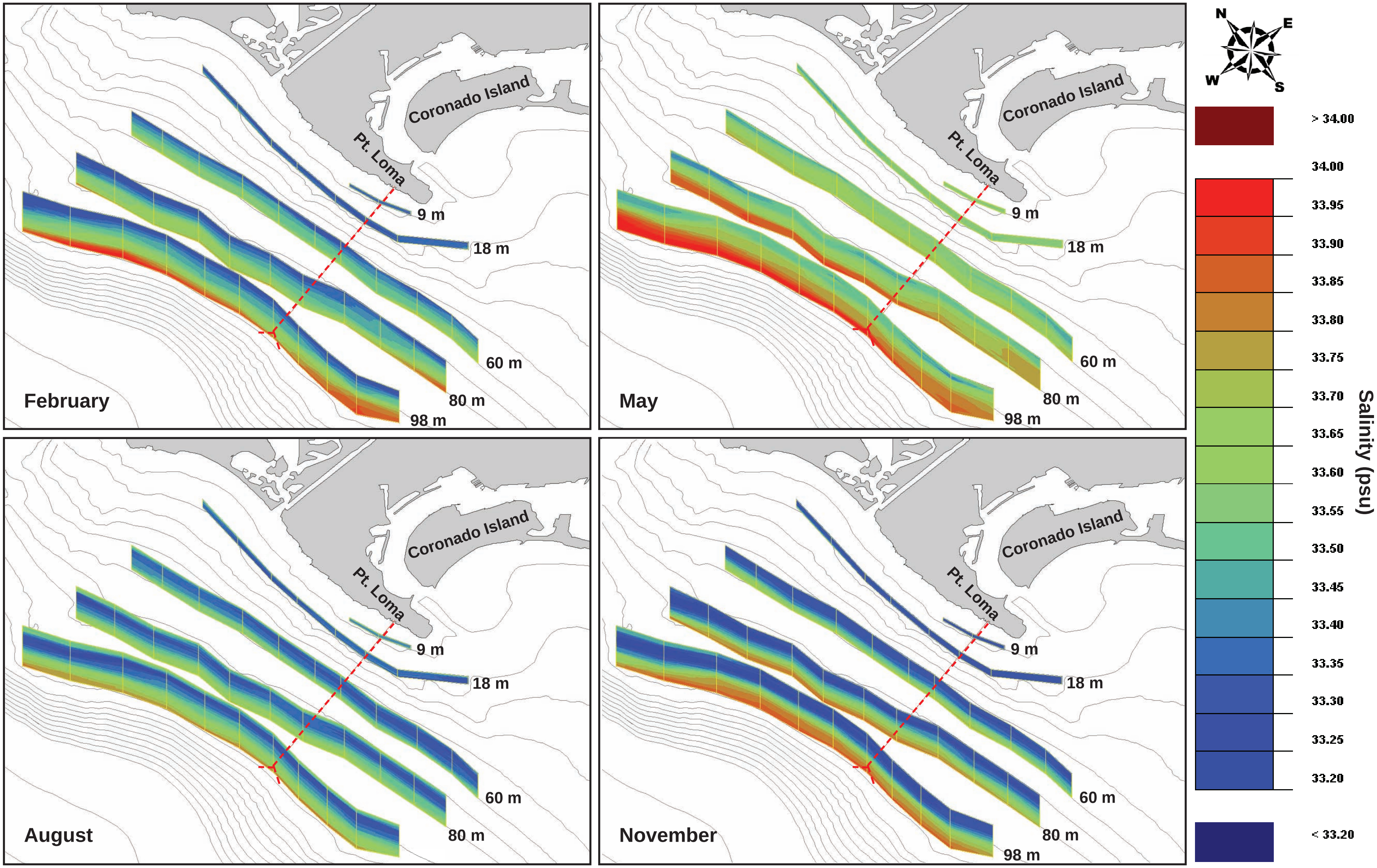

Figure 2.4

Levels of salinity recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day.

Figure 2.5
Rapid Eye satellite image of the Point Loma region acquired February 10, 2011 (Ocean Imaging 2012) showing extensive turbidity plumes originating from Mission Bay, San Diego Bay, and other coastal sources.

high CDOM values at this location during the same survey (e.g., Figure 2.6). However, relatively high CDOM values were also found at station F30 at depths below 60 m during February, May and November as well. These results also corresponded somewhat to occasional elevated enterococcus counts over the past year.

Chlorophyll a

Chlorophyll concentrations averaged from 1.5 mg/L in August to 17.4 mg/L in November in surface waters, and from 0.4 mg/L in February and November to 23.5 mg/L in November in bottom waters (Appendix A.1). However, subsequent analysis clearly showed that the highest chlorophyll concentrations typically occurred at sub-surface depths during all quarters (Appendix A.5), reflecting the fact that phytoplankton often mass at the bottom of the pycnocline (Lalli and Parsons 1993). For example, the highest concentrations of chlorophyll *a* in 2011 were observed 10 to 20 m below the surface during May across much of the region. Remote sensing observations revealed that the Point Loma outfall region was consistently influenced by phytoplankton blooms between early March and October (Svejkovsky 2012). These data showed that the frequency of blooms was considerably higher during 2011 than in most previous years, and that the blooms often extended seaward beyond the end of the PLOO (e.g., Figure 2.7). Samples from the red tide blooms depicted in Figure 2.7 were dominated by the dinoflagellate *Lingulodinium polyedrum*.

Summary of Oceanographic Currents in 2011

In the ocean current data analysis summarized below, the first EOFs for all seasons at the 100-m ADCP site indicated the primary current direction was in the north-south axis for all depth bins, with some deviations slightly northwest-southeast (for example the 11-m depth bin during summer) or slight deviations northeast-southwest (for example, the 11-m depth bin during winter) (Figure 2.8). Overall, currents were strongest in the 11-m depth bin. The strongest of all currents occurred in spring. Trends in direction and magnitude seen in the first EOF were generally the same in the second EOF, with lower magnitude currents overall in the 35-m depth bin and higher magnitude currents in the 63 and 91-m depth bins than in the first EOF. Mean current speeds at the end of the PLOO during quarterly sampling events were very slow, all less than 0.125 m/s.

The first EOF modes for the 60-m currents were slightly different than those at the 100-m ADCP station (Figure 2.9). Most current directions during all seasons were along the northeast-southwest axis. However, during fall the first EOF at all depth bins was oriented along the north-south axis. As in the 100-m ADCP data, the strongest currents were in the 11-m depth bin. However the strongest currents at the 60-m ADCP were recorded in the fall.

Historical Assessment of Oceanographic Conditions

A review of 21 years (1991–2011) of oceanographic data collected at stations along the 98-m depth contour revealed no measurable impacts that could

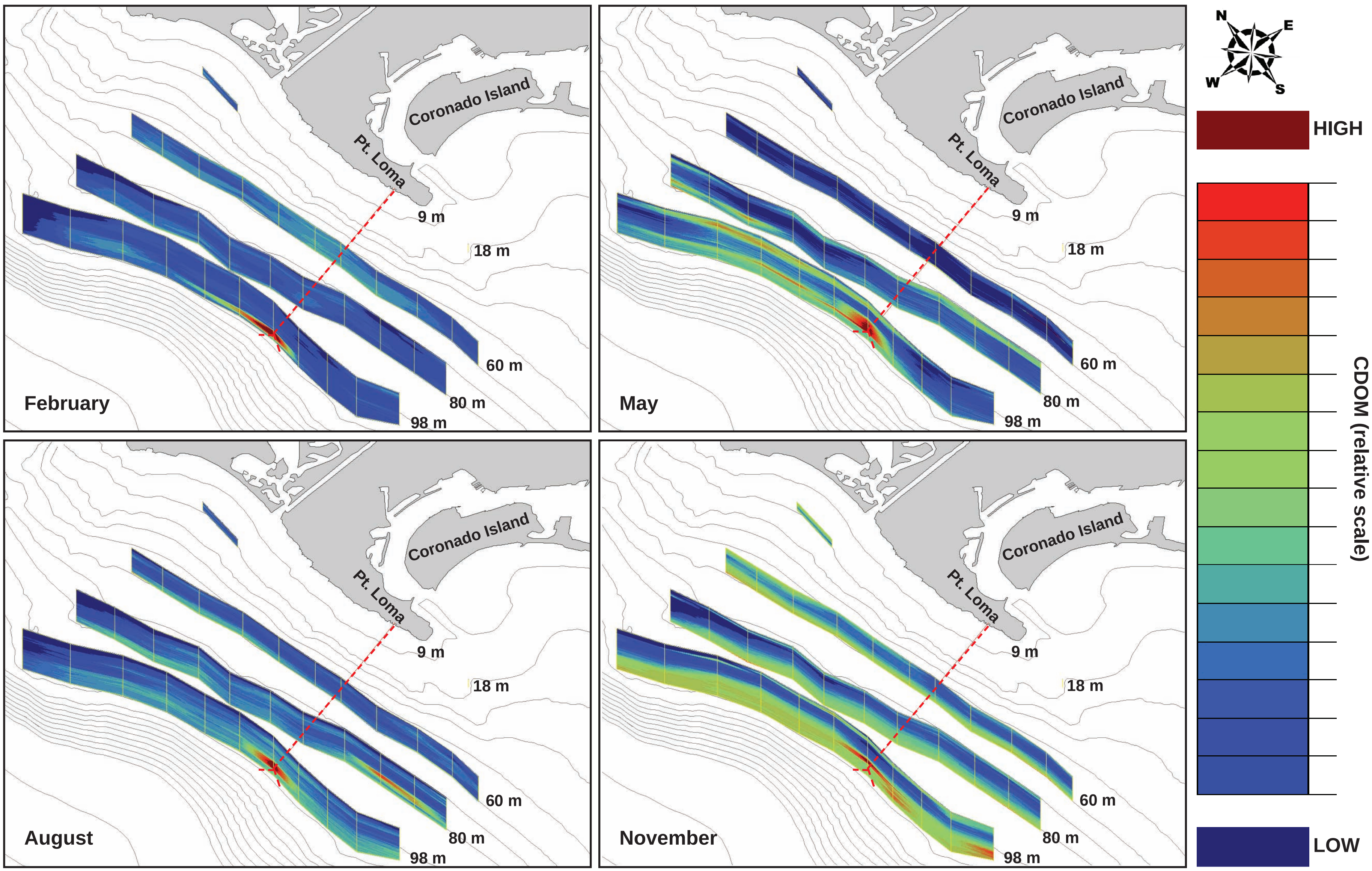

Figure 2.6
Relative CDOM values recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day. For each sampling event, the highest value was set to red and the lowest was set to blue.

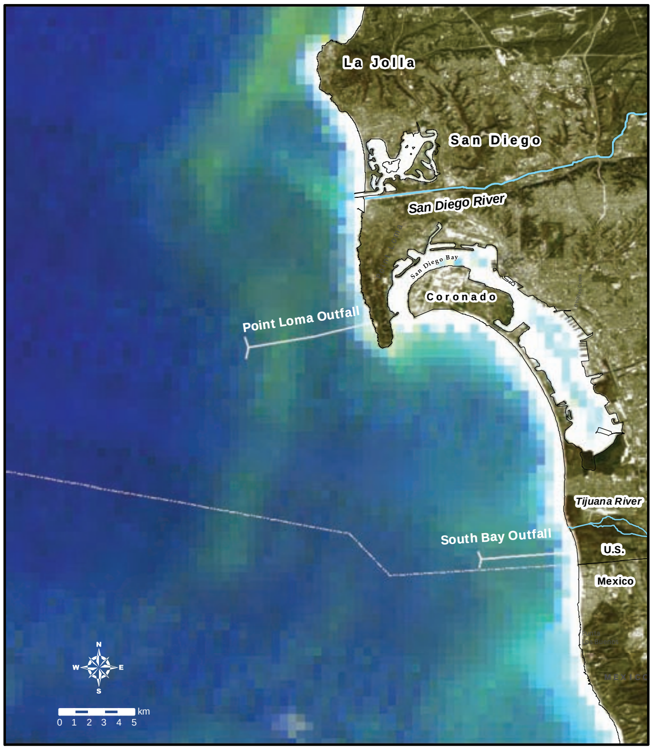

Figure 2.7
Wide-spread phytoplankton blooms in San Diego's nearshore waters acquired on September 8, 2011 with Terra MODIS imagery (from Ocean Imaging 2012).

be attributed to wastewater discharge (Figure 2.10). Although the change from monthly to quarterly sampling in late 2003 reduced the number of data points for interpretation, results are still consistent with described changes in large-scale patterns in the California Current System (CCS) as described in Peterson et al. (2006), McClatchie et al. (2008, 2009), Bjokstedt et al. (2010), and NOAA/NWS (2011). For example six major events have affected the CCS during the last decade: (1) the 1997–1998 El Niño event; (2) a shift to cold ocean conditions between 1999–2002; (3) a subtle but persistent return to warm ocean conditions beginning in October 2002 that lasted through 2006; (4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña event in 2007 that coincided with a cooling of the PDO; (6) development of a second La Niña event starting in May 2010. Ocean temperatures and salinity for the Point Loma outfall 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 2005 and 2006. During these two years ocean conditions off San Diego were more consistent with observations from northern Baja California (Mexico) where temperatures were well below the decadal mean (Peterson et al. 2006). During 2008 and 2009, temperatures remained cool, but closer to the overall average, whereas 2010 saw the return of cold La Niña conditions which remained through the end of 2011.

Water clarity (transmissivity) around the PLOO has tended to be higher than the historical average since about mid-1996 (Figure 2.10). This may be due in part to relatively low values recorded in 1995 and early 1996, perhaps related to factors such as sediment plumes associated with offshore disposal of dredged materials from a large dredging project in San Diego Bay. Particularly low transmissivity occurred in January of 1995 which corresponded with heavy rainfall. Subsequent reductions in transmissivity during some winters (e.g., 1998 and 2000) appear to be the result of increased amounts of suspended solids associated with strong storm activity (e.g., NOAA/NWS 2011). Additionally, there have been no apparent large-scale historical trends in DO concentrations or pH values related to the PLOO discharge.

Summary and Conclusions

Oceanographic data collected in the Point Loma outfall region concur with reports that describe 2011 as a La Niña year characterized by the early onset of relatively strong upwelling (Bjorkstedt et al. 2011). For example, colder-than-normal sea surface temperatures were observed during summer months as would be expected during La Niña conditions; these results were evident in data collected by the City and corroborated by remote sensing observations (Svejkovsky 2012). Conditions indicative of local coastal upwelling, such as relatively cold, dense, saline waters with low DO and pH levels at mid-depths and below, were observed during all surveys, but were most evident during May. Phytoplankton blooms, indicated by high chlorophyll concentrations and confirmed by satellite imagery were present throughout the region during much of the year.

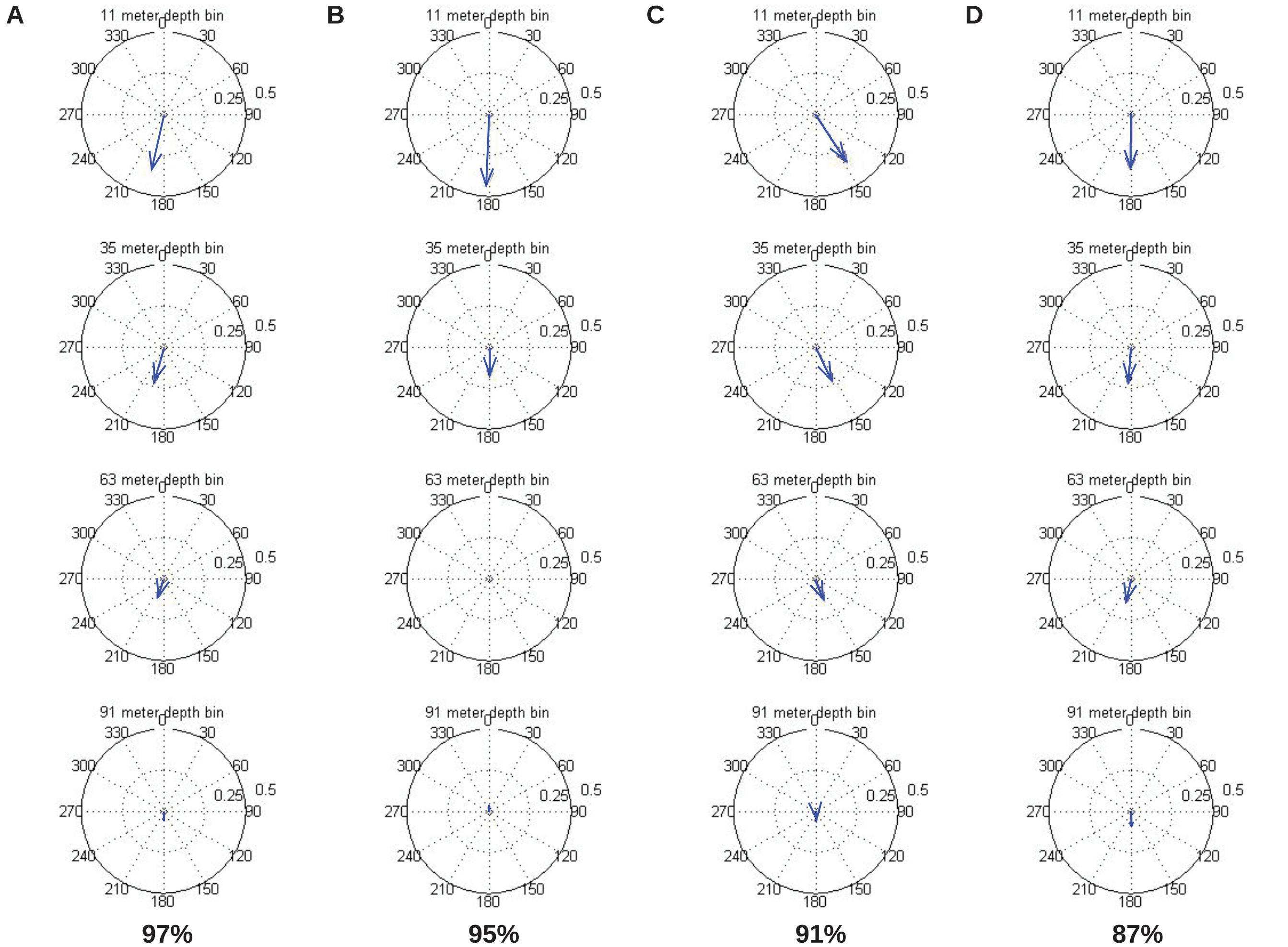

Figure 2.8
Empirical Orthogonal Function 1 (EOF) for (A) winter, (B) spring, (C) summer, and (D) fall in 2011 at the 100-m ADCP. Percentages indicate fraction of the total variance accounted for by the EOF. Arrow length indicates current magnitude in m/s.

Additionally, water column stratification followed patterns typical for San Diego coastal waters, with maximum stratification occurring in mid-summer. Further, oceanographic conditions for the region remained consistent with other well documented large-scale patterns (e.g., Peterson et al. 2006, Goericke et al. 2007, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, NOAA/NWS 2011). These observations suggest that other factors such as upwelling of deep ocean waters and large-scale climatic events such as El Niño and La Niña continue to explain most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego.

Satellite imagery results revealed no evidence of the wastewater plume reaching near-surface waters during 2011, even during the winter and fall months when the water column was only weakly stratified (Svejkovsky 2012). This is consistent with bacteriological sampling results for the same region described herein (see Chapter 3) and results of historical analyses of remote sensing observations made between 2003 and 2009 (Svejkovsky 2010). These findings have been supported by additional satellite imagery in subsequent years (Svejkovsky 2011, 2012), and by the application of IGODS analytical techniques to data collected over the past several years (City of San Diego 2010, 2011a). For example, although small differences in water clarity have been observed at the station closest to the outfall discharge site, and relatively high CDOM concentrations were found near the outfall during all surveys this year, it was clear from

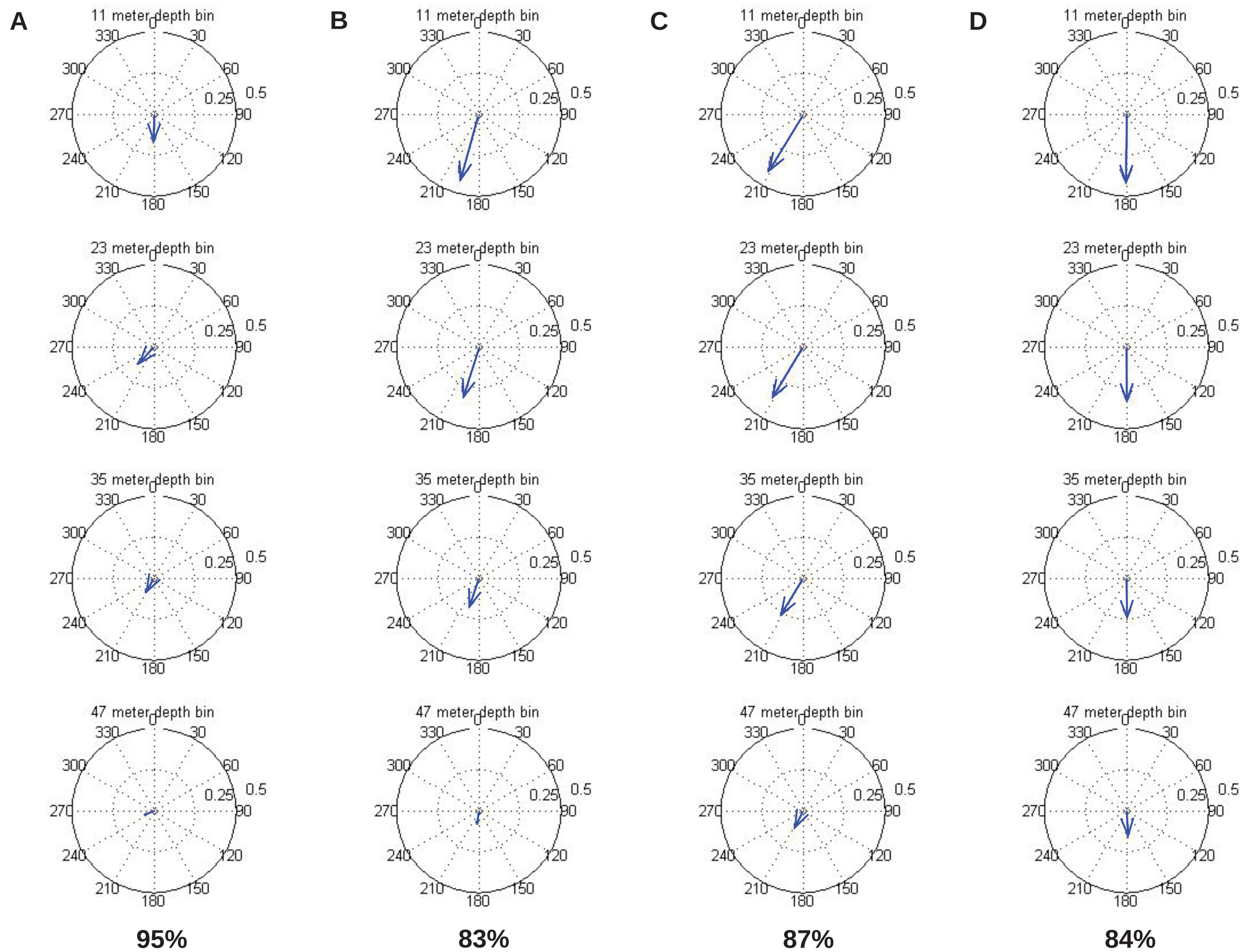

Figure 2.9

Empirical Orthogonal Function 1 (EOF) for (A) winter (B) spring (C) summer and (D) fall in 2011 at the 60-m ADCP. Percentages indicate fraction of the total variance accounted for by the EOF. Arrow length indicates current magnitude in m/s.

all analyses that variations among stations at any particular depth were very slight and highly localized. Current meter data generated in 2011 also suggested that local currents flowed in northerly and southerly directions throughout most of the year, although these measurements excluded the possible effects of tidal currents and internal waves. However, these results still suggest that current conditions off Point Loma are probably not conducive to shoreward transport of the PLOO wastefield.

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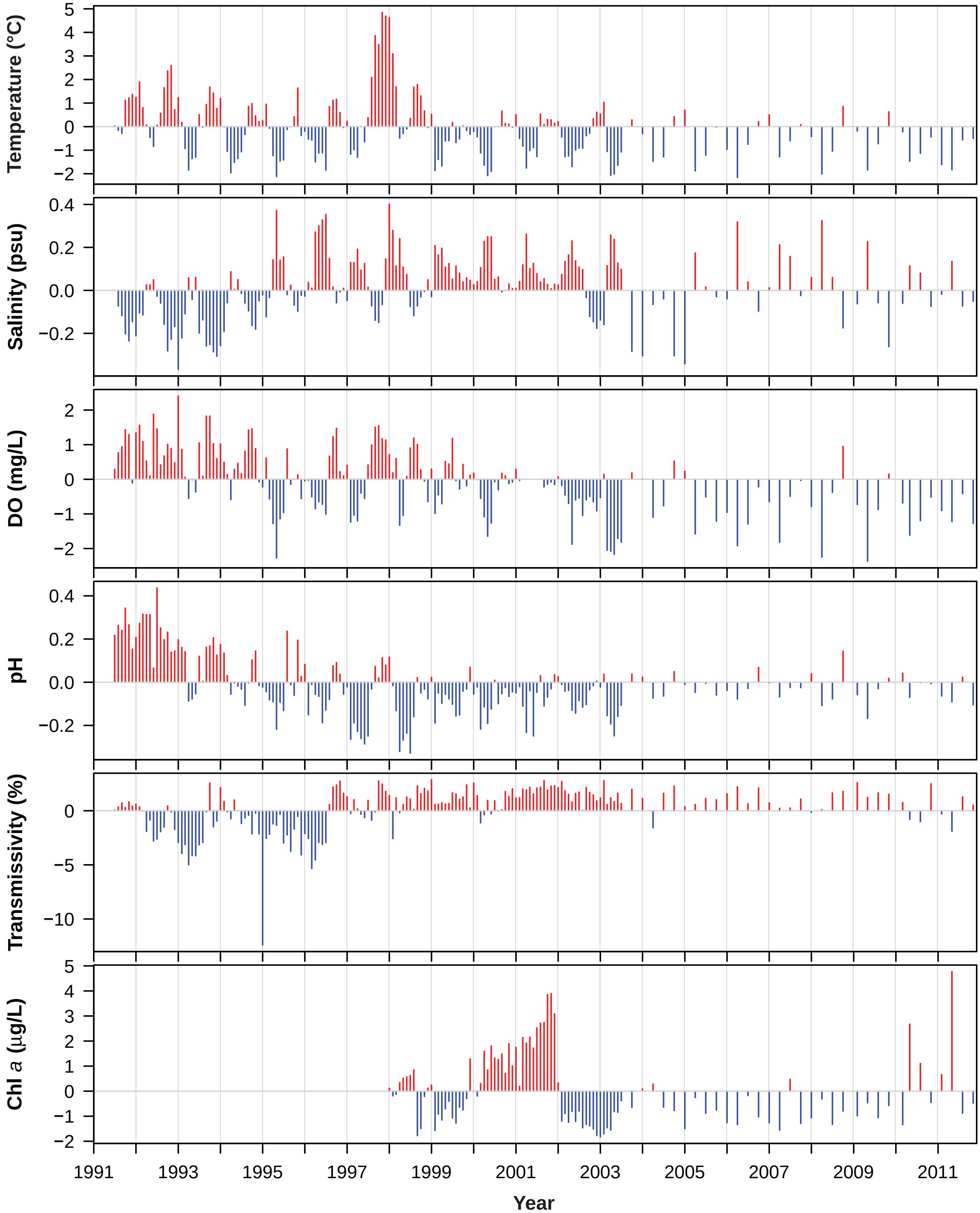

Figure 2.10

Time series of temperature, salinity, dissolved oxygen (DO), pH, transmissivity, and chlorophyll *a* fluorescence (chl *a*) anomalies between 1991 and 2011. Anomalies are calculated by subtracting the mean of all years (1991–2011) combined from monthly or quarterly means of each year; data were limited to all stations located along the 100-m contour, all depths combined.

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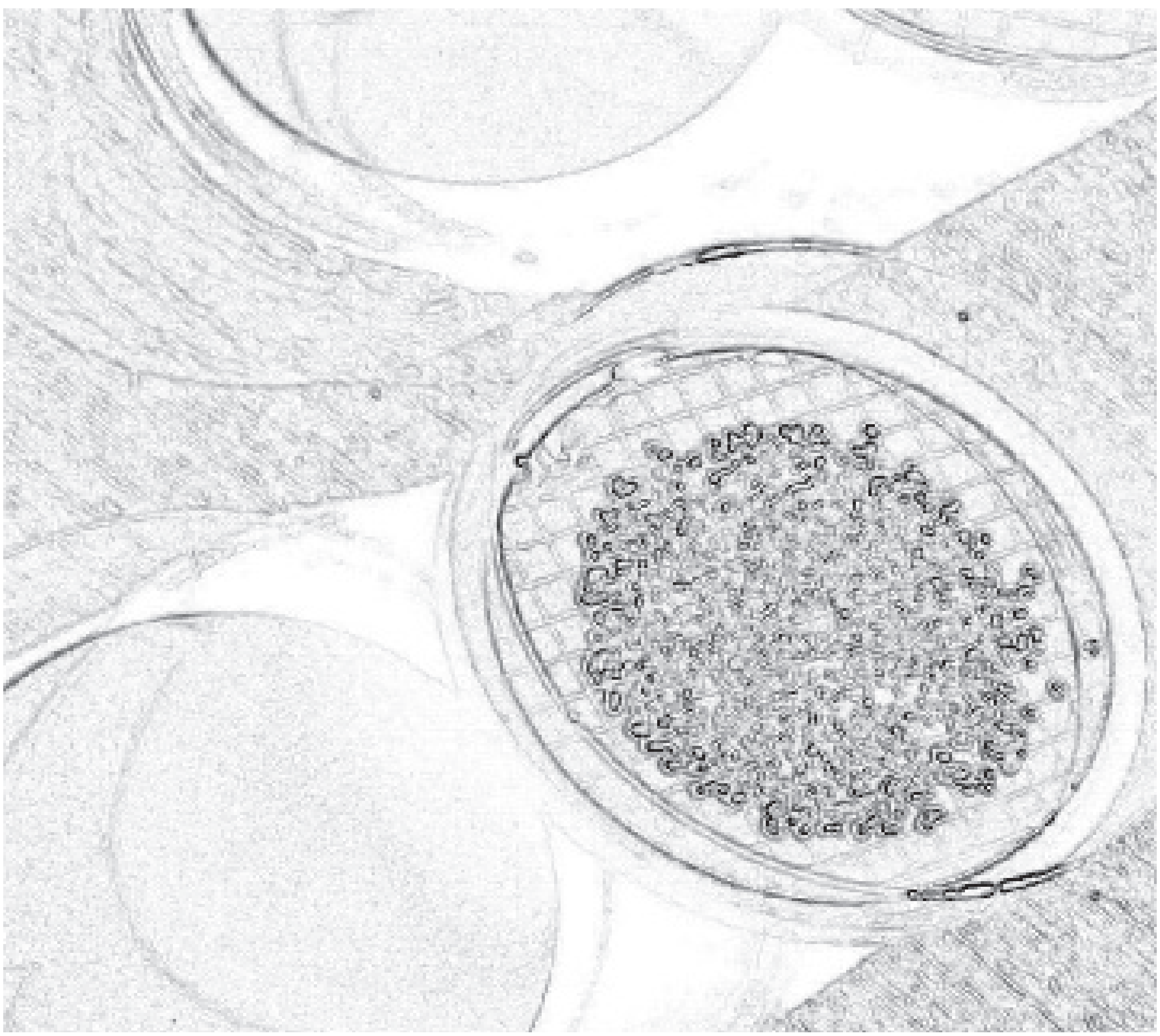
Chapter 3
Water Quality



Chapter 3. Water Quality

Introduction

The City of San Diego (City) analyzes seawater samples collected along the shoreline and in offshore coastal waters surrounding both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively) to characterize water quality conditions in the region and to identify possible impacts of wastewater discharge on the marine environment. Densities of three types of fecal indicator bacteria (FIB), including total coliforms, fecal coliforms and enterococcus are measured and evaluated in context with oceanographic data (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged into the Pacific Ocean through the PLOO and SBOO. Evaluation of these data may also help to identify other sources of bacterial contamination. Further, the City's water quality monitoring efforts are designed to assess compliance with the water contact standards specified in the 2005 California Ocean Plan (Ocean Plan), which defines bacterial water quality objectives and standards with the intent of protecting the beneficial uses of State ocean waters (SWRCB 2005).

In the PLOO region, multiple natural and anthropogenic point and non-point sources of potential bacterial contamination exist in addition to the outfall. Therefore, being able to separate the impacts associated with a wastewater plume from other sources of contamination in ocean waters is often challenging. Examples of other local, but non-outfall sources include tidal exchange from San Diego Bay, and outflows from the Tijuana and San Diego Rivers and coastal lagoons in northern San Diego County (Nezlin et al. 2007, Svejkovsky 2012). Likewise, storm drain discharges and wet-weather runoff from local watersheds can also flush contaminants seaward (Noble et al. 2003, Reeves et al. 2004, Griffith et al. 2010, Sercu et al. 2009). Moreover, beach wrack (e.g., kelp, seagrass), storm drains impacted by tidal flushing, and beach sediments can act as reservoirs, cultivating bacteria until release into nearshore waters by a returning tide, rainfall, and/or other disturbances (Gruber et al. 2005, Martin and Gruber 2005, Noble et al. 2006, Yamahara et al. 2007, Phillips et al. 2011). The presence of birds and their droppings have also been associated with bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2010).

This chapter presents analyses and interpretations of the microbiological and water chemistry data collected during 2011 at fixed water quality monitoring stations surrounding the PLOO. The primary goals are to: (1) document overall water quality conditions in the region during the year, (2) distinguish between the PLOO wastewater plume and other sources of bacterial contamination, (3) evaluate potential movement and dispersal of the plume, and (4) assess compliance with water contact standards defined in the 2005 Ocean Plan.

Materials and Methods

Field Sampling

Shore stations

Seawater samples were collected at eight shore stations (i.e., stations D4, D5, and D7–D12; Figure 3.1) to monitor concentrations of total coliform, fecal coliform and enterococcus bacteria in waters adjacent to public beaches and to evaluate compliance with 2005 Ocean Plan water contact standards (see Box 3.1). These samples were collected from the surf zone in sterile 250-mL bottles at each station five times per month. Visual observations of water color, surf height, human or animal activity, and weather conditions were also recorded at the time of collection. The samples were then transported on blue ice to the City's Marine Microbiology Laboratory for analysis.

Kelp bed and offshore stations

Eight stations located in nearshore waters within the Point Loma kelp forest were sampled weekly

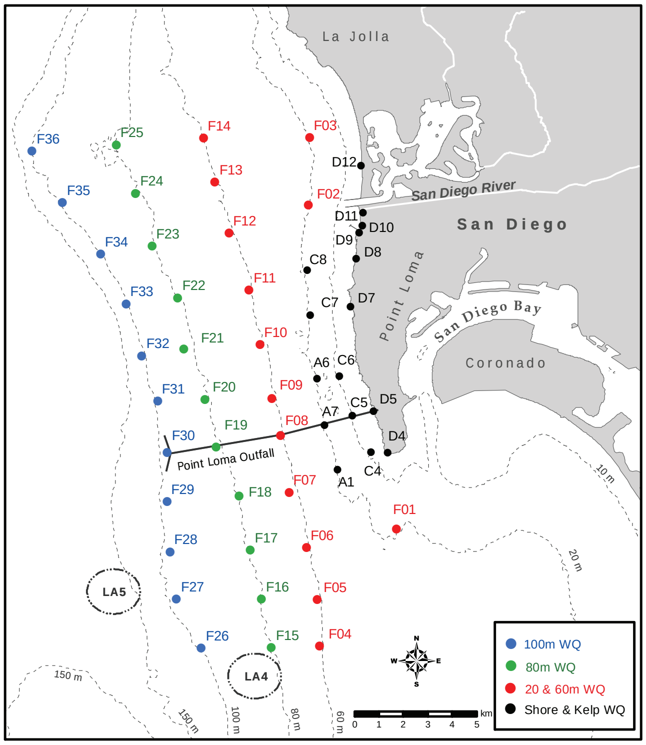


Figure 3.1

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.

to assess water quality conditions and Ocean Plan compliance in areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking. These included stations C4, C5 and C6 located near the inner edge of the kelp bed along the 9-m depth contour and stations A1, A6, A7, C7 and C8 located near the outer edge of the kelp bed along the 18-m depth contour (Figure 3.1). Weekly monitoring at each of the kelp bed sites consisted of collecting seawater samples to determine concentrations of the same fecal indicator bacteria as at the shore stations. Additional samples to assess ammonia levels were collected quarterly at these kelp sites to correspond with offshore water quality sampling schedule described below.

An additional 36 stations located offshore of the kelp bed stations were sampled in order to monitor FIB levels in these deeper waters and to estimate dispersion of the wastewater plume. These offshore "F" stations are arranged in a grid surrounding the discharge site along or adjacent to the 18, 60, 80, and 98-m depth contours (Figure 3.1). In contrast to shore and kelp bed stations, monitoring at the offshore stations was conducted on a quarterly basis during February, May, August and November; each of these quarterly surveys was conducted over a 3-day period (see Table 2.1 for the specific survey dates). Bacterial analyses for these samples were limited to enterococcus. Additional monitoring for ammonia occurred at the same discrete depths where bacterial samples were collected at the 15 offshore stations located within State jurisdictional waters (i.e., within 3 nautical miles of shore).

Seawater samples for the kelp and offshore stations were collected at 3, 4 or 5 discrete depths depending upon station depth (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. Visual observations of weather and sea conditions, and human and/or animal activity were also recorded at the time of sampling.

Laboratory Analyses

The City's Microbiology Lab follows guidelines issued by the United States Environmental Protection Agency (USEPA) Water Quality Office and the California Department of Public Health (CDPH) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1995, CDPH 2000, USEPA 2006). All bacterial analyses were performed within eight hours of sample collection and conformed to standard membrane filtration techniques (APHA 1995).

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

Box 3.1

Bacteriological compliance standards for water contact areas, 2005 California Ocean Plan (SWRCB 2005). 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.

means and in determining compliance with Ocean Plan standards.

Quality assurance tests were performed routinely on seawater samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split bacteriological samples were processed according to method requirements to measure intra-sample and inter-analyst variability, respectively. Results of these procedures were reported under separate cover (City of San Diego 2012a).

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

Data Analyses

FIB densities were summarized as monthly averages for each shore station and by depth contour for each of the kelp bed stations. To evaluate any spatial or temporal trends, the data were summarized as the number of samples in which FIB concentrations exceeded benchmark levels. For this report, the Single Sample Maximum (SSM) values defined in the 2005 Ocean Plan for total coliforms, fecal coliforms, and enterococcus (see Box 3.1 herein, and SWRCB 2005) were used as the benchmarks to distinguish elevated FIB values. Concentrations of each elevated FIB are identified by sample in Table 3.2. Bacterial densities were compared to rain data from Lindbergh Field, San Diego, CA (see NOAA 2012). Fisher's Exact Tests (FET) were used for historical analyses to test for differences in the frequency of samples with elevated FIBs. Finally, compliance with Ocean Plan water-contact standards was summarized as the number of times per month that each of the shore and kelp bed stations exceeded the various standards.

Results

Distribution of Fecal Indicator Bacteria

Shore stations

Concentrations of fecal indicator bacteria (FIB) were generally low along the Point Loma shoreline in 2011, which is similar to conditions seen in previous years. Monthly FIB densities at the individual stations averaged 6–1292 CFU/100 mL for total coliforms, 2–178 CFU/100 mL for fecal coliforms, and 2–49 CFU/100 mL for enterococcus (Appendix B.1). Of the 486 shore samples collected during the year, only three (0.6%) had elevated FIBs (Table 3.2). These included one sample from station D8 in January, one sample from station D5 in April, and one sample from station D9 in June. The total number of elevated FIB samples was much lower in 2011 than has been reported in previous years (Figure 3.2, Appendix B.2). This historical comparison also illustrates that chances of getting FIB hits in the wet season were only slightly

Table 3.1

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

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

more likely than in the dry season (7% versus 2%, respectively; $n = 6686$, $p < 0.0001$, FET).

Kelp bed stations

FIB concentrations were also generally low at the eight kelp bed stations during 2011. Monthly densities averaged 4–37 CFU/100 mL for total coliforms, 2–4 CFU/100 mL for fecal coliforms, and 2–15 CFU/100 mL for enterococcus (Table 3.3). Only a single sample collected in the Point Loma kelp forest during the entire year (~0.07%; $n = 1437$) had elevated FIBs (Table 3.2). The low incidence of elevated FIBs at these sites is consistent with water quality results dating back to 1994 after the outfall was extended offshore to its present deepwater site (Figure 3.3, Appendix B.3). In contrast, bacteria levels were much higher at the kelp bed stations prior to the outfall extension. No relationship between rainfall and elevated bacterial levels was evident at these stations, in that the chances of getting FIB hits was similar between wet and dry seasons (~4% for both).

Offshore stations

The maximum concentration of enterococcus bacteria at the 36 offshore stations was 660 CFU/100 mL in 2011 (Table 3.2). Only 6 of 548 samples (1.1%) had elevated enterococcus levels, all of which were collected at depths ≥60 m from four stations located along the 80 and 98-m depth contours (Figure 3.4). No exceedances occurred within State waters. These results suggest that the wastewater plume remained restricted to relatively deep, offshore waters throughout the year. This conclusion is consistent with remote sensing observations that provided no evidence of the plume reaching surface waters in 2011 (Svejkovsky 2012). These findings are also consistent with historical

Table 3.2

Summary of elevated bacteria densities in samples collected at PLOO shore, kelp bed, and offshore stations during 2011. Bold values exceed benchmarks for total coliform, fecal coliform, enterococcus, and/or the FTR criterion.

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
Shore Stations						
D8	3 Jan 2011	—	1600	160	**200**	0.10
D5	21 Apr 2011	—	1300	**880**	**180**	**0.68**
D9	2 Jun 2011	—	920	**580**	56	0.63
Kelp Bed Stations						
A1	13 Apr 2011	12	10	2	**880**	0.20
Offshore Stations						
F30	10 Feb 2011	80	—	—	**660**	—
F30	10 Feb 2011	98	—	—	**110**	—
F31	10 Feb 2011	80	—	—	**160**	—
F30	6 May 2011	80	—	—	**380**	—
F16	17 Aug 2011	60	—	—	**380**	—
F17	17 Aug 2011	60	—	—	**420**	—

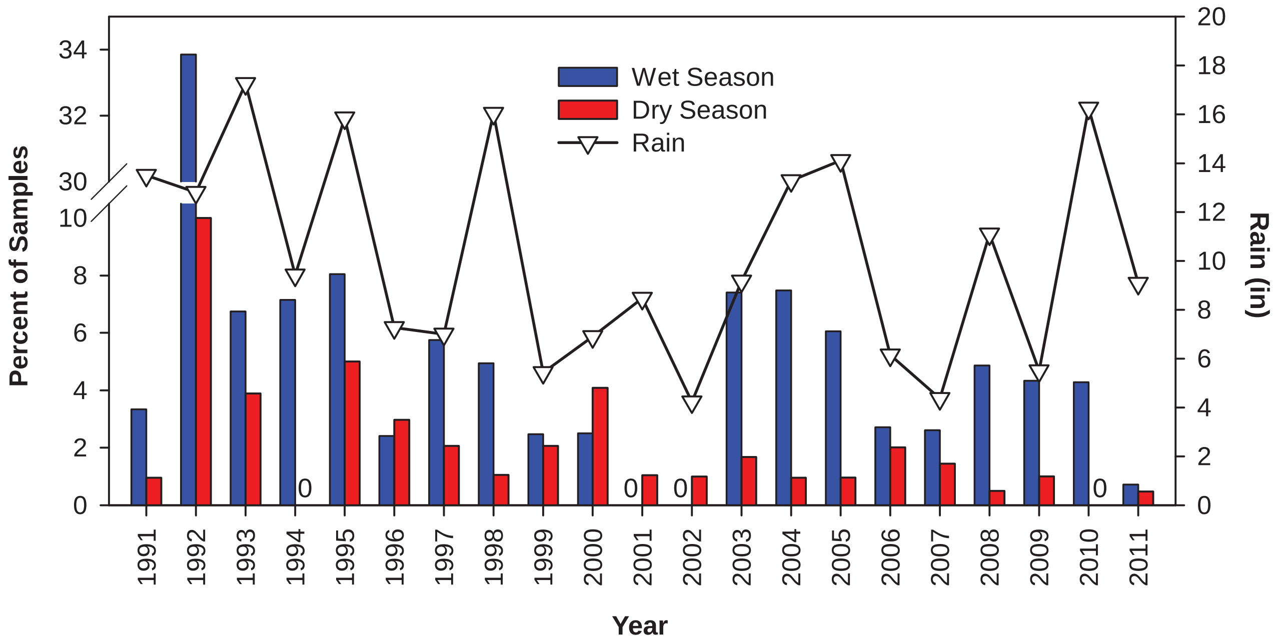


Figure 3.2
Comparison of annual rainfall to the percent of samples with elevated FIB denities in wet versus dry seasons at PLOO shore stations between 1991 and 2011. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA.

analyses, which revealed that less than 1% of the samples collected from ≥25 m at the eleven 98-m PLOO stations between 1993 and 2011 contained elevated levels of enterococcus (Figure 3.5A). Over this time period, collecting a sample with elevated FIBs was significantly more likely at station F30 than at any other 98-m station (23.7% versus 6.6%, respectively; $n = 5133$, $p < 0.0001$, FET; Figure 3.5B). Additionally, the number of samples with elevated enterococcus dropped significantly at most 98-m stations following the initiation of chlorination in August 2008 (7.5% before versus 1.7% after; $n = 4415$, $p < 0.0001$, FET), but not at station F30 (24.0% before versus 20.0% after, $n = 718$, $p < 0.542$, FET).

California Ocean Plan Compliance

Overall compliance with the seven Ocean Plan standards was 99.8% during 2011 (see Appendix B.4). Shoreline compliance with the three 30-day geometric means standards was 100% for total and fecal coliforms, and 95–100% for enterococcus (Appendix B.4). The only exeedances of the enterococcus geometric mean standard occurred during January at stations D8, D10 and D11. Compliance with the four single sample maximum (SSM) standards was also very high (>98%) for each of the shore stations during the year. The SSM for total coliforms was not exceeded, while the SSMs for fecal coliforms and enterococcus were each exceeded twice, and the SSM for the FTR criterion was exceeded only once. Only one of the Ocean Plan standards was exceeded at the kelp stations (i.e., the enterococcus SSM at station A1 in April). Finally, all of the offshore stations located within State waters were 100% compliant during 2011; these stations are not sampled frequently enough for appropriate geometric mean assessments.

Samples were analyzed for ammonia at the eight kelp stations and 15 other offshore stations located within State waters. Ammonia was detected in 12% of the 288 samples collected from 14 of these stations during 2011. No ammonia was detected at any of the 9-m depth sites, while concentrations at the 18-m, 60-m, and 80-m sites ranged up to a maximum of 0.26 mg/L (Table 3.4). These levels are substantially 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;

Table 3.3

Summary of bacteria levels at PLOO water quality stations during 2011. Total coliform, fecal coliform, and enterococcus densities are expressed as mean CFU/100 mL for all stations along each depth contour by month. Rain data are from Lindbergh Field, San Diego, CA. *n* = total number of samples per month.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011 Total Rain (in)	0.30	2.10	1.46	0.26	0.36	0.03	0.00	0.00	0.13	0.46	3.12	0.86
Shore Stations (*n* = 40) [a]												
Total	81	376	102	234	41	59	82	63	74	111	109	56
Fecal	12	20	8	29	4	19	10	9	8	22	10	5
Entero	11	10	6	8	3	6	5	4	4	17	8	3
Kelp Bed Stations (*n* = 45)												
9-m Contour												
Total	8	4	23	6	9	4	7	4	5	5	4	5
Fecal	2	2	3	2	2	2	2	2	2	2	2	2
Entero	2	3	2	2	2	2	2	2	2	2	2	2
18-m Contour												
Total	10	12	37	12	11	4	24	8	8	5	11	4
Fecal	2	2	2	2	2	2	4	2	2	2	3	2
Entero	2	2	2	15	2	3	2	2	2	2	3	2
Offshore Stations [b]												
18-m Contour (*n* = 9)	—	2	—	—	2	—	—	2	—	—	2	—
60-m Contour (*n* = 33)	—	4	—	—	2	—	—	4	—	—	2	—
80-m Contour (*n* = 40)	—	6	—	—	4	—	—	30	—	—	5	—
98-m Contour (*n* = 55)	—	23	—	—	13	—	—	7	—	—	5	—

[a] February and October *n* = 39; July *n* = 48. [b] Enterococcus only

SWRCB 2005). None of the samples where ammonia was detected had elevated concentrations of enterococcus bacteria (see City of San Diego 2012b).

Discussion

Water quality conditions in the Point Loma outfall region were excellent during 2011. Overall compliance with 2005 Ocean Plan water-contact standards was 99.8%, which was only marginally higher than the 99.7% compliance observed during the previous year (City of San Diego 2011). In addition, there was no evidence during the year that wastewater discharged into the ocean via the PLOO reached the shoreline or nearshore recreational waters. Elevated FIBs were detected at only four shoreline or kelp bed stations during the year. Over the years, elevated FIBs detected at shore and kelp bed stations have tended to be associated with rainfall events, heavy recreational use, or the presence of seabirds or decaying kelp and surfgrass (e.g., City of San Diego 2009–2011). The main exception to this pattern occurred during a short period in 1992 following a catastrophic break of the outfall within the Point Loma kelp bed (e.g., Tegner et al. 1995).

Previous reports have indicated that the PLOO wastefield typically remains well offshore and submerged in deep waters ever since the extension of the outfall was completed in late 1993 (e.g., City of San Diego 2007–2011). This pattern remained true for 2011 with evidence that the wastewater plume was restricted to depths of 60 m or below in offshore waters. Moreover, no visual evidence of the plume surfacing was detected in satellite imagery during 2011 (Svejkovsky 2012). The deepwater (98-m) location of the discharge site may be the dominant factor that inhibits the plume from reaching surface

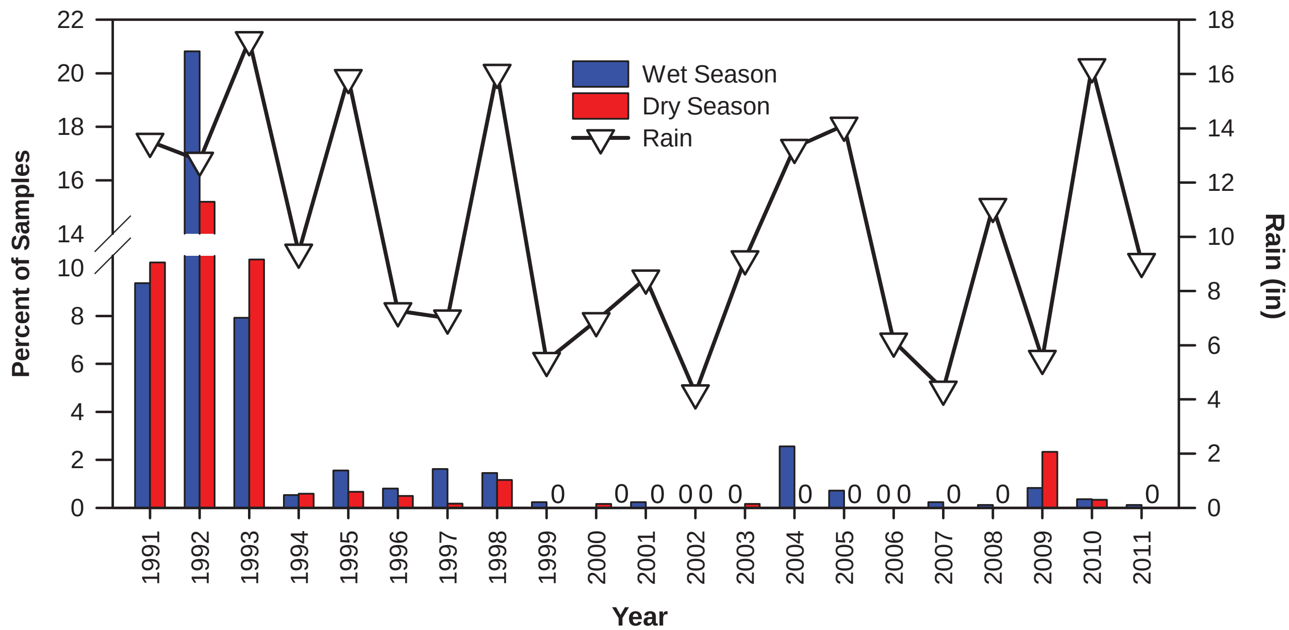


Figure 3.3

Comparison of annual rainfall to the percent of samples with elevated FIB denities in wet versus dry seasons at PLOO kelp bed stations bewteen 1991 and 2011. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA.

waters. For example, wastewater released into these deep, cold and dense waters does not appear to mix with the top 25 m of the water column (see Chapter 2). Finally, it appears that not only is the plume from the PLOO being trapped below the thermocline, but now that effluent is undergoing chlorination prior to discharge, densities of indicator bacteria have dropped significantly at stations more than 1000 m from the outfall.

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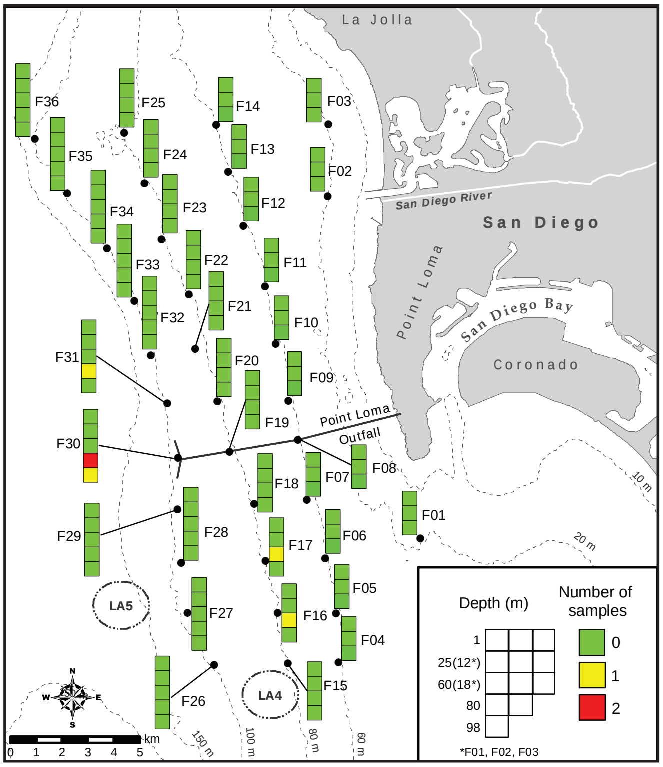

Figure 3.4
Distribution of seawater samples with elevated enterococcus densities at offshore stations during 2011. Data are numbers of samples that exceeded concentrations >104 CFU/100 mL. See text and Table 2.1 for sampling details.

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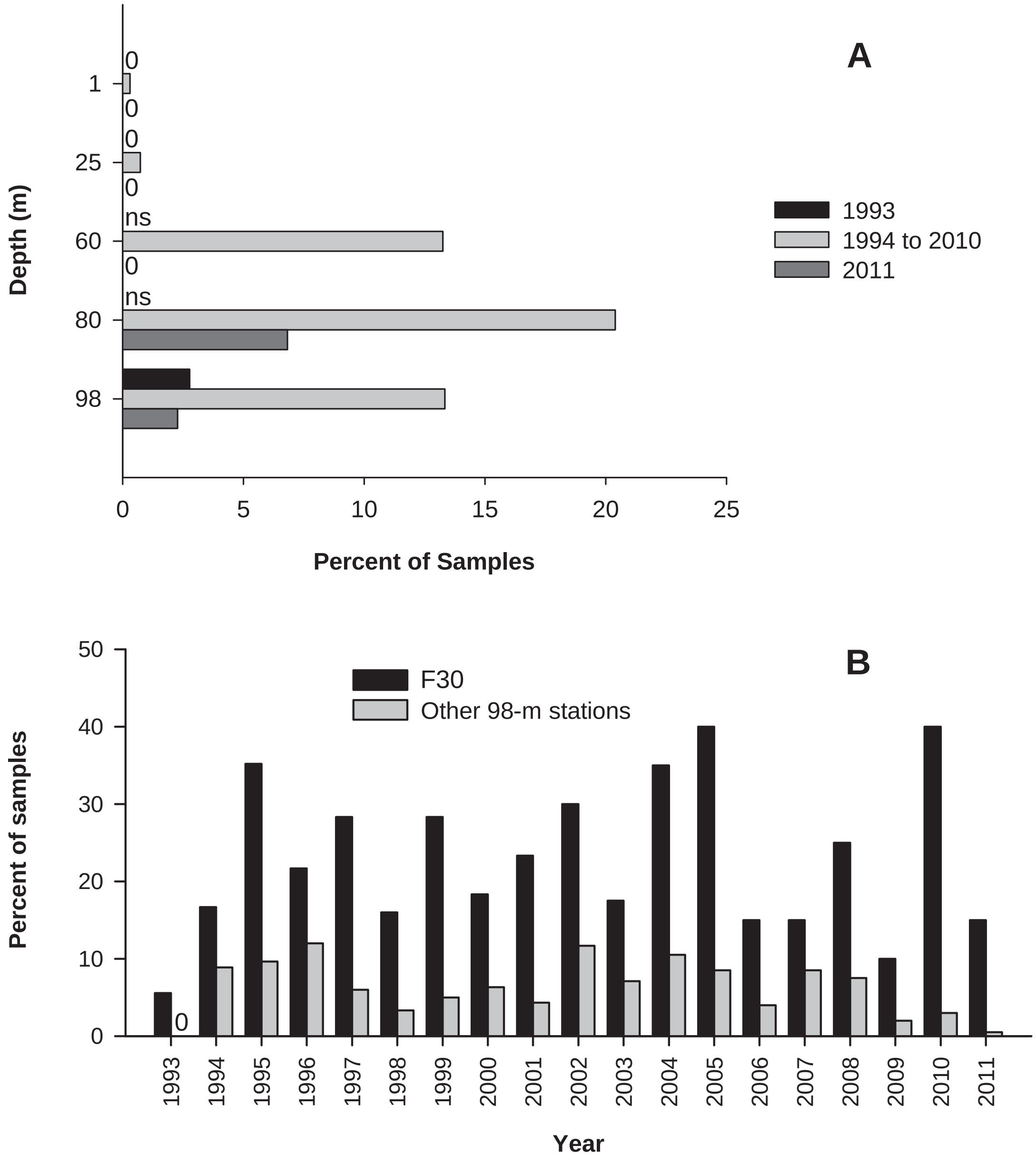

Figure 3.5
Percent of samples collected from PLOO 98-m offshore stations with elevated enterococcus densities. Samples from 2011 are compared to samples taken between 1993–2010 by (A) sampling depth and by (B) outfall (F30) and other non-outfall stations. Depth data are limited to current sample depths. ns = not sampled.

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Table 3.4

Summary of ammonia concentrations in samples collected from the 23 PLOO kelp bed and offshore stations located within State waters during 2011. Data include the number of samples per month (*n*) and detection rate, as well as the minimum, maximum, and mean detected concentrations for each month. The method detection limit for ammonia = 0.01 mg/L.

	Feb	May	Aug	Nov
9-m Depth Contour (n = 9)				
Detection Rate (%)	0	0	0	0
Min	—	—	—	—
Max	—	—	—	—
Mean	—	—	—	—
18-m Depth Contour (n = 24)				
Detection Rate (%)	8.3	12.5	20.8	0
Min	nd	nd	nd	—
Max	0.03	0.06	0.06	—
Mean	0.02	0.04	0.03	—
60-m Depth Contour (n = 27)				
Detection Rate (%)	0	11.1	18.5	37.0
Min	—	nd	nd	nd
Max	—	0.02	0.03	0.13
Mean	—	0.01	0.02	0.04
80-m Depth Contour (n = 12)				
Detection Rate (%)	0	0	0	58.3
Min	—	—	—	nd
Max	—	—	—	0.26
Mean	—	—	—	0.08

nd = not detected

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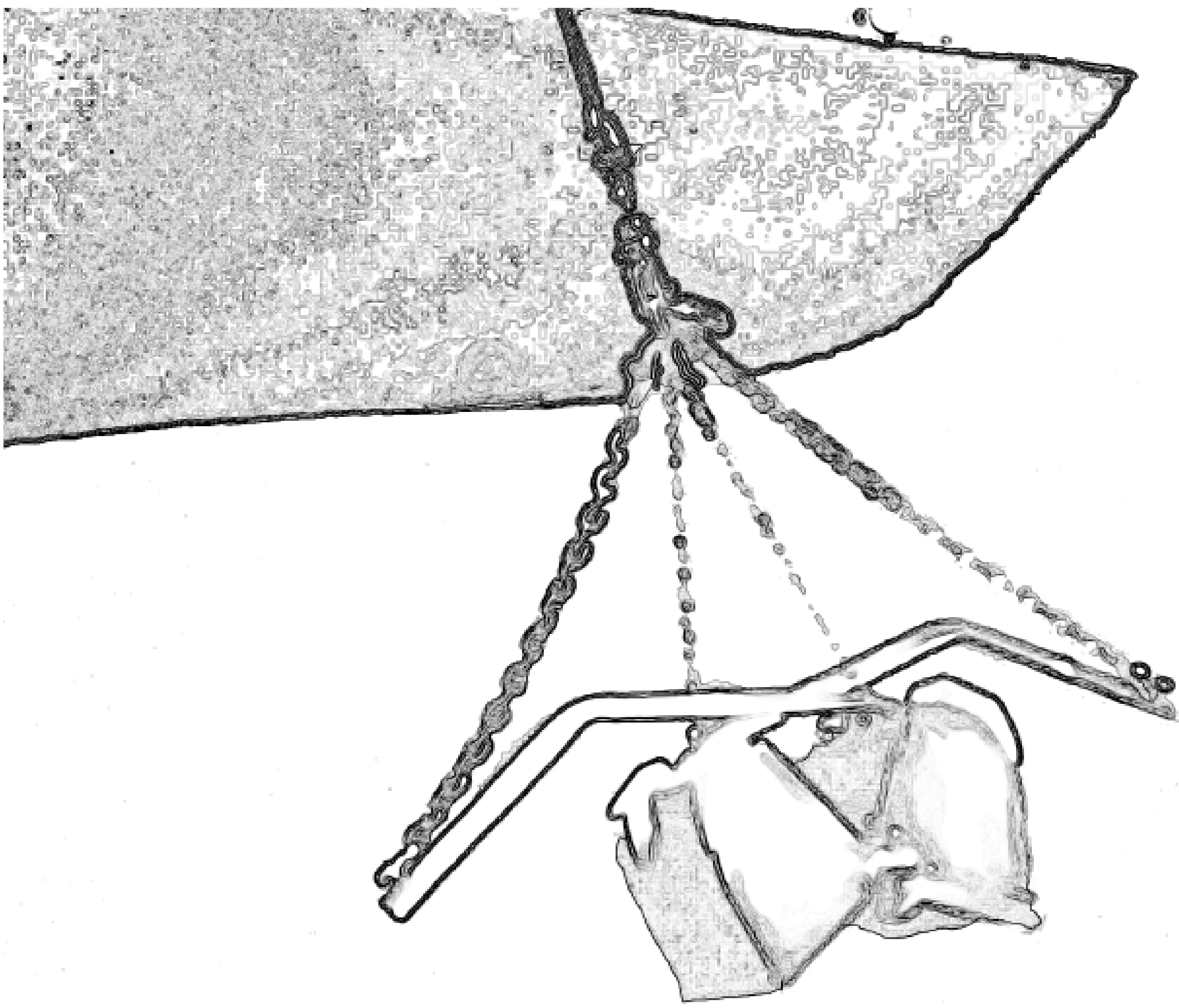
Chapter 4
Sediment Conditions



Chapter 4. Sediment Characteristics

Introduction

Ocean sediment samples are analyzed as part of the City of San Diego's Ocean Monitoring Program to examine potential effects of wastewater discharge on the marine benthos from both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively). Analyses of various contaminants are conducted because anthropogenic inputs to the marine ecosystem, including municipal wastewater outfalls, can lead to increased concentrations of pollutants within the local environment. Sediment grain sizes (e.g., relative percentages of sand, silt, clay) are also determined, because concentrations of some compounds are known to be directly linked to sediment composition (Emery 1960, Eganhouse and Venkatesan 1993) and because they can provide useful information about current velocity, wave action, and overall habitat stability (e.g., Folk 1980). Finally, physical and chemical sediment characteristics are monitored because they define the primary microhabitats for benthic invertebrates that live within or on the seafloor, and subsequently influence the distribution and presence of various species. For example, differences in sediment composition and associated levels of organic loading affect the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Also, many demersal fish species are associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Overall, understanding the differences in sediment conditions and quality over time and space is crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

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

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

This chapter presents analyses and interpretations of sediment grain size and chemistry data collected in 2011 at fixed benthic monitoring stations surrounding the PLOO. The primary goals are to: (1) document sediment conditions during the year, (2) identify possible effects of wastewater discharge on sediment conditions in the region, and (3) identify other potential natural and anthropogenic sources of sediment contaminants to the local marine ecosystem.

Materials and Methods

Field Sampling

Sediment samples were collected at 22 fixed stations in the PLOO region during January and July 2011 (Figure 4.1). These stations range in depth from 88 to 116 m and are distributed along or adjacent to three main depth contours. These sites included 17 'E' stations ranging from approximately 5 km south to 8 km north of the outfall, and five 'B' stations located about 10−12 km north of the tip of the northern diffuser leg (see Chapter 1). The four stations considered to represent "nearfield" conditions (i.e., E11, E14, E15 and E17) are located within 1000 m of the outfall wye or diffuser legs.

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

Laboratory Analyses

All sediment chemistry and grain size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Grain size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of nested sieves. The Horiba measures particles ranging in size from about 0.5 to 2000 µm. Coarser sediments were removed and quantified prior to laser analysis by

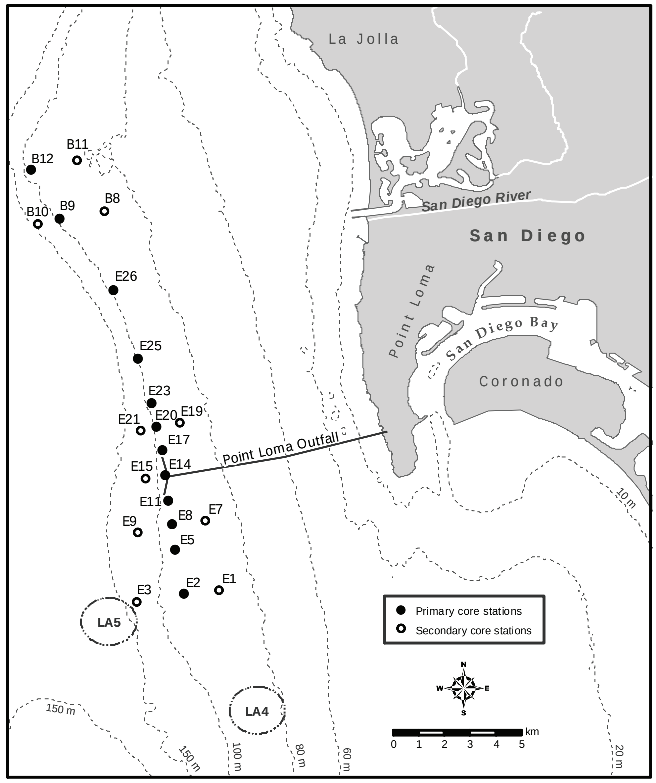


Figure 4.1
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

screening samples through a 2000 µm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%. When a sample contained substantial amounts of coarse sand, gravel, or shell hash that could damage the Horiba analyzer and/or where the general distribution of sediments would be poorly represented by laser analysis, a set of sieves with mesh sizes of 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, and 63 µm was used to divide the samples into seven fractions. Sieve results and output from the Horiba were converted into grain size fractions (e.g., percent sand, silt, clay) based on the Wentworth scale (Appendix C.1). The proportion of fine particles (percent fines) was calculated as the sum of silt and clay fractions for each sample, and each sample was then categorized as a "sediment type" based on relative proportions of percent fines, sand, and coarser particles (Appendix C.2). The distribution of grain sizes within each sample was also summarized as mean particle size in microns, and the median, mean, and standard deviations of phi sizes. The latter values were calculated by converting raw data measured in microns into phi sizes, fitting appropriate distribution curves (e.g., normal probability curve for most Horiba samples), and then determining the descriptive statistics mentioned above.

Each sediment sample was also analyzed to determine concentrations of biochemical oxygen demand, total organic carbon, total nitrogen, total sulfides, total volatile solids, trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis. Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix C.3). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemistry Services Laboratory (City of San Diego 2012a).

Data Analyses

Data summaries for the various sediment parameters measured included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values. Total DDT (tDDT), PCB (tPCB), and PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix C.4 for individual constituent values). Sediment contaminant concentrations were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed, while values above the ERL but below the ERM represent levels at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998).

Results

Sediment Grain Size Distribution

Ocean sediments sampled off Point Loma ranged from 55 to 146 μm in 2011, indicating that they were composed predominantly of coarse silt and fine sands (Table 4.1, Appendix C.1). The fine and sand sediment fractions averaged 38% and 62% of each sample, respectively, while the average coarse fraction was only 1%. Despite the dominance of finer materials in PLOO sediments, visual observations of corresponding macrofaunal samples revealed the presence of coarse sands (including black sands), gravel, and/or shell hash at different stations (see Appendix C.5). Differences in grain size composition between the winter and summer surveys tended to be minimal. For example, the percent of fine and coarse material at any one station differed by ≤4% between the January and July surveys, with only a few exceptions. One such exception occurred at station E2, which had 12% coarse material in July but none in January. Another exception occurred at station E9, which had 40% fines and 2% coarse materials in January, but only 4% fines and 27% coarse materials in July.

During 2011, there were no spatial patterns in the categorization of stations by sediment type relative to the PLOO discharge site (Figure 4.2). Instead, all but four samples contained 27–46% fines. The four exceptions were collected from stations E2 and E9 (July only, see above) and at station B8 (both surveys). The latter station averaged 58% fines for the year (Appendix C.5). There was no evidence that the amount of fine particles has increased at nearfield or farfield 98-m stations since the onset of wastewater discharge at the end of 1993 (Figure 4.3). Instead, sediment composition at these stations have remained fairly consistent over time, composed primarily of sand with high proportions of fine material (Appendix C.6). These results indicate that there is some long-term stability in the region in terms of the overall proportions of the major grain size fractions.

Table 4.1

Summary of sediment grain sizes and sediment chemistry concentrations in sediments from PLOO benthic stations sampled during 2011. Data include the detection rate (DR), areal mean of detected values, and minimum, median, and maximum values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1991–1993) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold; SD = standard deviation.

	2011 Summary[a]					Pre-discharge		
Parameter	**DR (%)**	**Areal Mean**	**Min**	**Median**	**Max**	**Max**	**ERL[b]**	**ERM[b]**
Sediment Grain Size								
Mean (*μm*)	—	93.0	55.0	85.6	146	na	na	na
Mean (*phi*)	—	4.10	1.05	4.16	4.80	na	na	na
SD (*phi*)	—	1.58	1.06	1.53	2.02	na	na	na
Coarse (*%*)	—	1.10	0.00	0.00	27.2	26.4	na	na
Sand (*%*)	—	61.5	40.5	61.9	73.3	79	na	na
Fines(*%*)	—	37.5	3.70	38.1	59.5	74.2	na	na
Organic Indicators								
BOD (*ppm*)[c]	100	374	251	365	541	656	na	na
Sulfides (*ppm*)	100	6.91	1.10	3.65	52.40	20	na	na
TN (*% weight*)	100	0.059	0.038	0.058	0.095	0.074	na	na
TOC (*% weight*)	100	0.79	0.32	0.51	4.18	1.24	na	na
TVS (*% weight*)	100	2.35	1.64	2.25	4.04	4.00	na	na
Trace Metals (*ppm*)								
Aluminum	100	6394	3270	5915	12,900	na	na	na
Antimony	98	0.48	nd	0.47	0.91	6	na	na
Arsenic	100	3.3	1.1	3.6	7.8	5.6	8.2	70
Barium	100	35.26	17.40	32.90	67.90	na	na	na
Beryllium	100	0.15	0.08	0.14	0.25	2.01	na	na
Cadmium	100	0.16	0.08	0.14	0.52	6.1	1.2	9.6
Chromium	100	15.36	9.24	14.65	24.10	43.6	81	370
Copper	100	7.7	4.9	7.0	13.8	34	34	270
Iron	100	10,794	5800	10,550	17,200	26,200	na	na
Lead	100	13.75	3.18	5.89	326.00	18	46.7	218
Manganese	100	79.67	45.30	75.20	140.00	na	na	na
Mercury	100	0.029	0.015	0.027	0.060	0.096	0.15	0.71
Nickel	100	6.87	4.37	6.71	11.60	14	20.9	51.6
Selenium	0	—	—	—	—	0.9	na	na
Silver	7	1.23	nd	nd	2.81	4	1	3.7
Thallium	2	0.99	nd	nd	0.99	113	na	na
Tin	100	1.01	0.54	0.91	2.74	na	na	na
Zinc	100	28.46	17.30	27.35	46.00	67	150	410
Pesticides (*ppt*)								
Total DDT	95	403	nd	330	1620	13,200	1580	46,100
HCB	11	432	nd	nd	680	nd	na	na
Total PCB (*ppt*)	23	10,914	nd	nd	63,890	na	na	na
Total PAH (*ppb*)	18	148	nd	nd	306.1	199	4022	44,792

na = not available; nd = not detected

[a] Minimum, median, and maximum values were calculated based on all samples ($n = 44$), whereas means were calculated on detected values only ($n \leq 44$).

[b] From Long et al. 1995

[c] BOD values are from January only ($n = 22$).

There also appears to be stability within sediment size fractions (e.g., types of sand present) at most stations, including B9, E5, E8, E11, E17, E20, E23, E25 and E26 (Appendix C.6). However, sediments from a few stations such as B12, E14 and E2 show substantial variability within sediment size categories, especially the size ranges indicative of sand and coarse fractions. This variability likely corresponds to patches of coarse sands (e.g., black sands) and other coarse materials (e.g., gravel, shell hash) encountered at various times. For example, coarse black sands were found at station E14 this year (Appendix C.5), but in 2010 sediments at this station also contained gravel and rocks (City of San Diego 2011). These coarse materials may be due in part to the presence of ballast or bedding material around the outfall, and are why the average percent fines are slightly lower at nearfield versus farfield stations over time (Figure 4.3; see also City of San Diego 2007).

The sorting coefficient for sediments is calculated as the standard deviation (SD) in phi size units for each sample, and is considered indicative of the level of disturbance (e.g., variable currents, sediment deposition) in an area. The sediments collected off Point Loma in 2011 (including near the outfall) were poorly to very poorly sorted with sorting coefficients ranging from 1.06 to 2.02 phi (Table 4.1). The sediments most likely exposed to higher levels of disturbance (i.e., SD $\geq$2.0 phi) occurred at stations B11 and E3 in January (Appendix C.5).

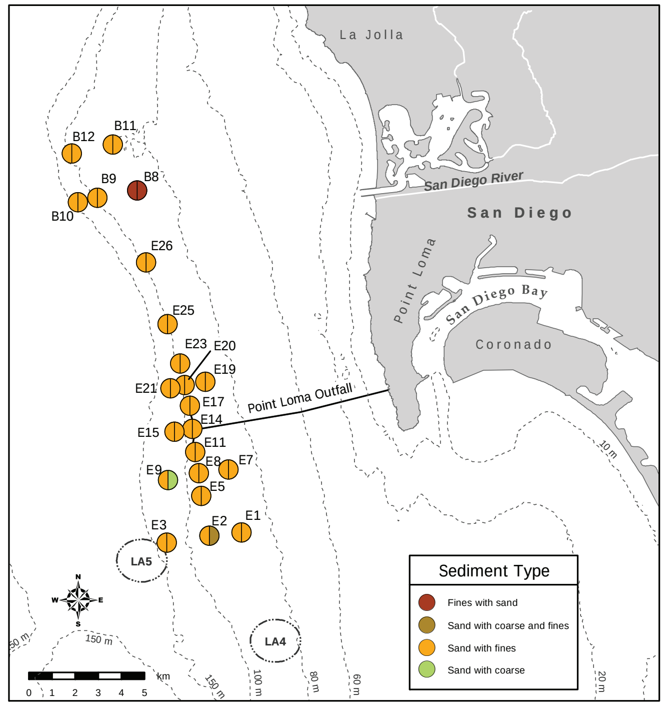


Figure 4.2
Distribution of sediment types at PLOO benthic stations sampled in 2011. Split circles show results of January (left) and July (right) surveys.

Indicators of Organic Loading

Indicators of organic loading, including biochemical oxygen demand (BOD), sulfides, total nitrogen (TN), total organic carbon (TOC) and total volatile solids (TVS), had detection rates of 100% during 2011 (Table 4.1). Concentrations of BOD ranged from 251 to 541 ppm, while sulfides ranged from 1.1 to 52.4 ppm, TN ranged from 0.038 to 0.095% wt, TOC ranged from 0.32 to 4.18% wt and TVS ranged from 1.64 to 4.04% wt. All but BOD were detected at concentrations higher than the maximum values reported prior to wastewater discharge. The highest TN, TOC and TVS concentrations tended to occur at the northern 'B' stations located at least 10 km north of the outfall (Appendix C.7). In contrast, the highest sulfide and BOD concentrations recorded in 2011 were from station E14 located nearest the discharge site. In general, only sulfides, and to a lesser extent BOD, have shown changes near the outfall that appear to be associated with possible organic enrichment (Figure 4.3; see also City of San Diego 2007, 2011).

Trace Metals

Fourteen trace metals occurred in all sediment samples collected during 2011, including aluminum, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, and zinc (Table 4.1). Antimony was also detected in almost all samples (98%), while silver and thallium occurred much less frequently at rates of 2–7%. Selenium was not detected in any sediment sample analyzed during the year. Almost all of the metals occurred at levels below both the ERL and ERM thresholds. The only exceptions were for silver and lead (Appendix C.8), as follows: (a) silver exceeded

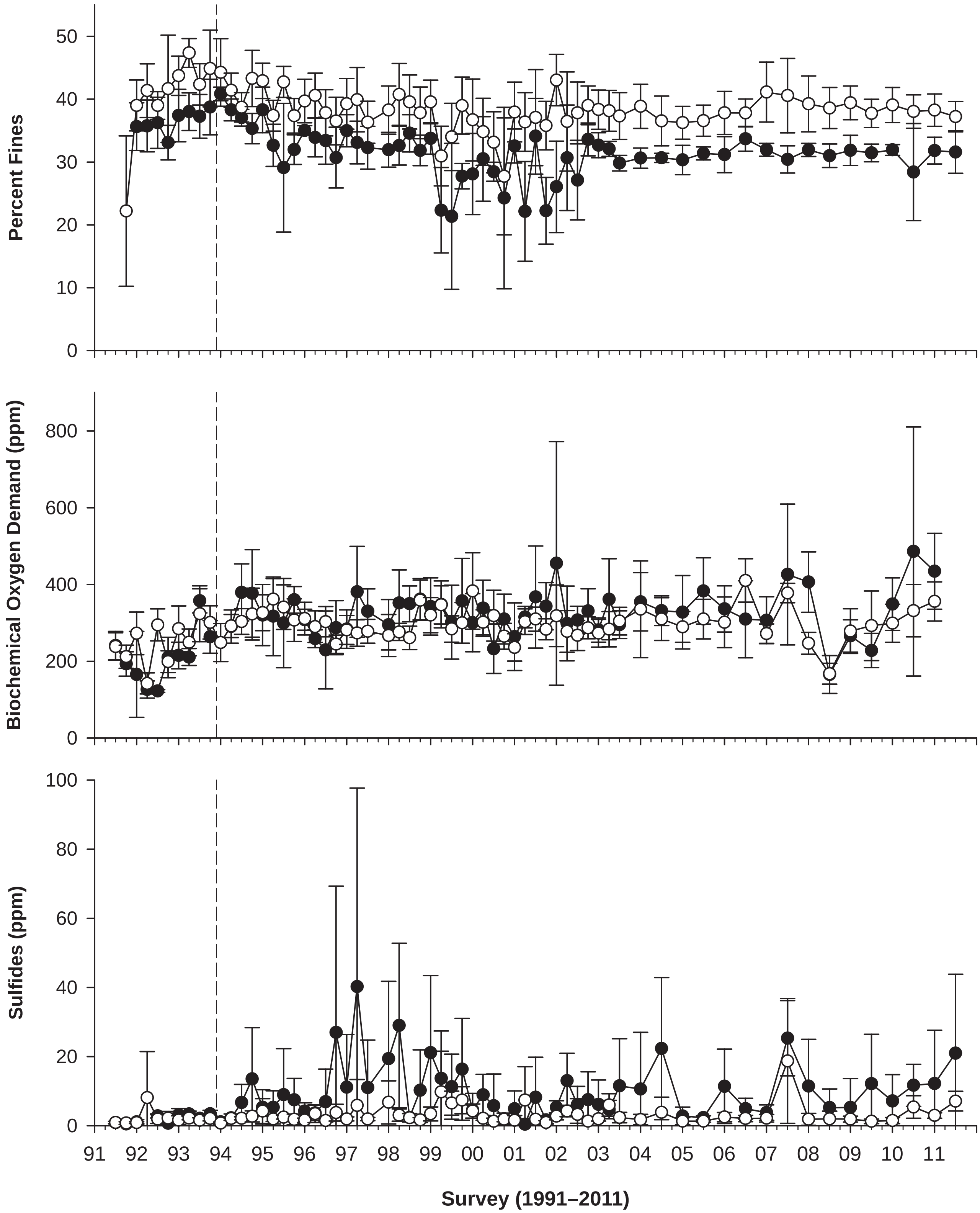


Figure 4.3

Sediment grain size and organic loading indicators at PLOO 98-m benthic stations sampled between 1991–2011. Data are expressed as means of detected values ±95% confidence intervals for samples pooled over nearfield stations (filled circles; $n = 4$) versus farfield stations (open circles; $n = 9$) for each survey. Dashed lines indicate onset of discharge from the PLOO extension.

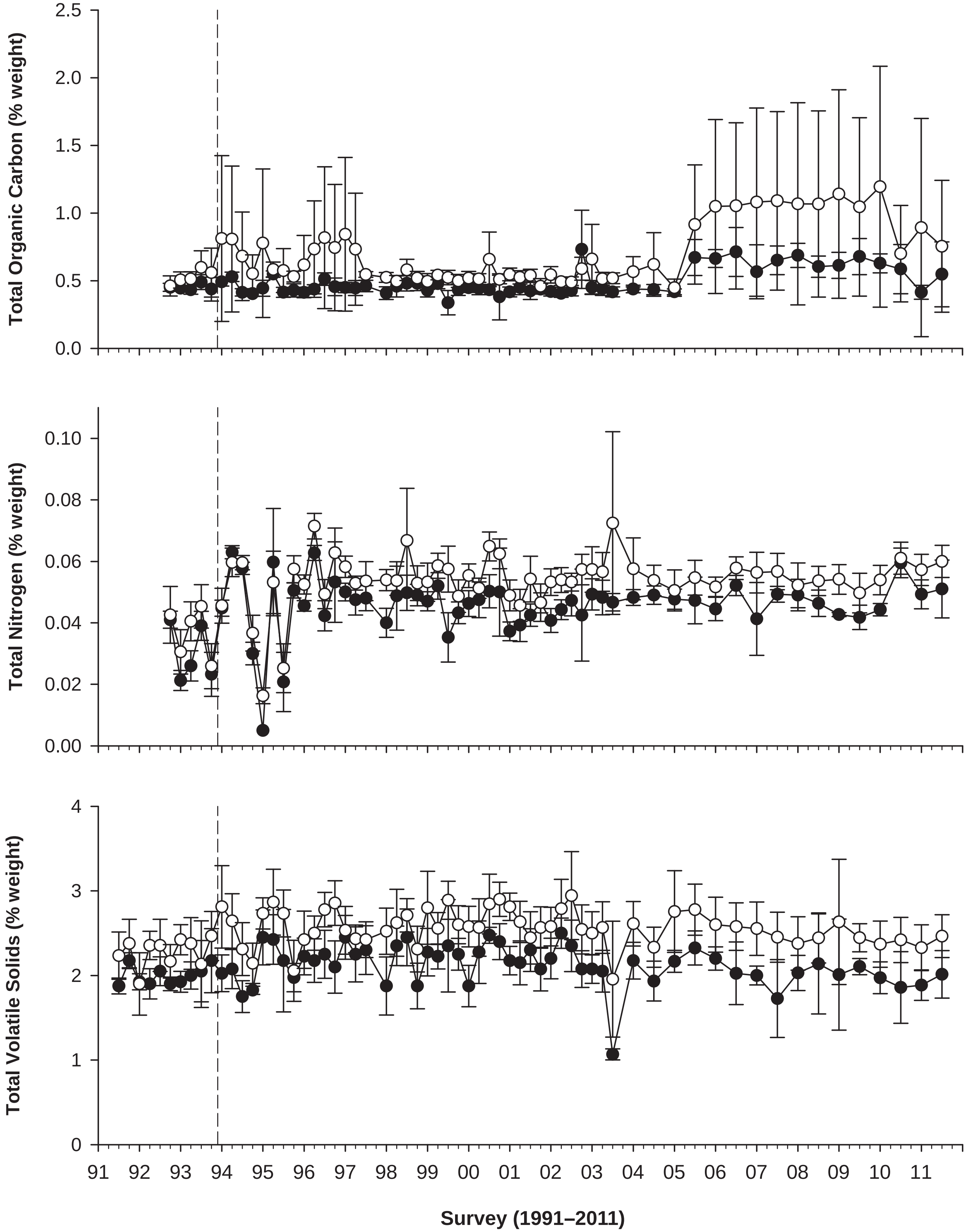


Figure 4.3 *continued*

the ERL (but not the ERM) at station E26 in January; (b) lead exceeded both the ERL and ERM at station E3 in January. Only arsenic and lead occurred at concentrations higher than reported during the pre-discharge period. For example, the concentration of lead in sediments from station E3 in January (326 ppm) is the highest value ever reported at the PLOO stations, and also exceeds average values reported for the SCB regional monitoring surveys conducted in 1994, 1998, 2003 and 2008 (City of San Diego 2007, Schiff et al. 2011).

In addition to overall low concentrations, metal distributions were spatially variable, with no discernible patterns relative to the outfall (Appendix C.8). The highest concentrations of several metals occurred in sediments from one or more of the northern 'B' stations or southern 'E' stations (e.g., E1, E2, E3, E9). Additionally, several metals, including aluminum, antimony, barium, beryllium, chromium, copper, iron, manganese and nickel were detected at relatively high concentrations in sediments from station E21 during January. The second highest concentration of cadmium was recorded at station E14 in January.

Pesticides

DDT and hexachlorobenzene (HCB) were the only two pesticides detected in PLOO sediments during 2011 (Appendix C.9). Total DDT, comprised primarily of p,p-DDE, occurred in 95% of the samples at concentrations up to 1620 ppt (Table 4.1). Although the highest DDT concentration measured during year (i.e., at station E1 in July) exceeded the ERL, all DDT values were below values reported prior to discharge. HCB was found in only five sediment samples at concentrations ≤680 ppt. These samples were all collected during July, and at five different stations (E1, E3, E7, E15, E26). No patterns indicative of an outfall effect were evident in the distribution of pesticides.

PCBs and PAHs

PCBs and PAHs occurred infrequently in PLOO sediments during 2011, with detection rates ≤23% (Table 4.1). Total PCB occurred at concentrations up to 63,890 ppt in samples from just six stations. These values could not be compared to threshold or pre-discharge values, because they were calculated based on PCB arochlors instead of congeners. The most commonly detected PCB congeners were PCB 110, PCB 118, and PCB 149. Total PAH occurred at concentrations up to 306 ppb in samples from just seven stations. While tPAH exceeded pre-discharge levels in one sample, all values were below ERL and ERM thresholds. The most commonly detected PAHs included 3,4-benzo (B) fluoranthene, benzo [A] anthracene, benzo [A] pyrene, benzo [G,H,I] perilyene, dibenzo (A,H) anthracene, fluoranthene, and indeno (1,2,3-CD) pyrene. No patterns indicative of an outfall effect were evident in the distribution of either tPCB or tPAH. Both were primarily found in sediments from stations located south of the outfall (e.g., E1, E2, E3, E9; Appendix C.9).

Discussion

Sediment grain size composition at the PLOO stations was similar in 2011 to that reported during recent years (City of San Diego 2007–2011), with fine sands and coarse silt composing the largest proportion of all samples. Most sediments were poorly sorted, consisting of particles of varied sizes, which suggest that sediments in the region were subject to low wave and current activity and/or variable physical disturbance (see Folk 1980). There was no evident spatial relationship between sediment composition and proximity to the outfall discharge site. Overall, variability in composition of sediments in the PLOO region is likely affected by both anthropogenic and natural influences, including outfall construction materials, offshore disposal of dredged materials, multiple geologic origins of different sediment types, and recent deposition of sediment and detrital materials (Emery 1960, City of San Diego 2007, Parnell et al. 2008). The 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 (Farnsworth and Warrick 2007, Svejkovsky 2012), thus widening the range of potential sediment sources to the region.

Various trace metals, pesticides, PCBs, and organic loading indicators were detected in sediment samples collected throughout the PLOO region in 2011, but in highly variable concentrations. Although some contaminants were detected at levels above pre-discharge maximums, there were very few exceedances of either ERL or ERM thresholds. Additionally, most parameters remained within ranges typical for other areas of the southern California continental shelf (see Schiff and Gossett 1998, City of San Diego 2000, 2012b, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

There were few spatial patterns in sediment contaminants relative to the PLOO discharge site in 2011. The only exceptions were slightly higher sulfide and BOD levels near the outfall as described in previous years (e.g., City of San Diego 2007, 2011). Instead, the highest concentrations of several organic indicators, trace metals, pesticides, PCBs, and PAHs were found in sediments from the southern and/or northern farfield stations. Historically, concentrations of contaminants have been higher in sediments at southern sites such as stations E1–E3, E5, and E7–E9 than elsewhere off San Diego (City of San Diego 2007–2011). This pattern may be due in part to short dumps of dredged materials destined originally for LA5 (Anderson et al. 1993, Steinberger et al. 2003, Parnell et al. 2008).

The frequent and wide-spread occurrences of various contaminants in sediments from the PLOO region are likely derived from several different 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) concluded there are no areas off southern California that are sufficiently free of contaminants to be considered good reference sites. This conclusion has been supported by more recent surveys of SCB continental shelf habitats (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011). The lack of contaminant-free reference areas clearly pertains to the Point Loma outfall region as demonstrated by the presence of many contaminants in sediments prior to wastewater discharge (see City of San Diego 2007). Further, historical assessments of sediments off of Los Angeles have shown that as wastewater treatment improved, sediment conditions were more likely to be affected by other factors (Stein and Cadien 2009). Such factors include bioturbative re-exposure of buried legacy sediments (Niederoda et al. 1996, Stull et al. 1996), large storms that assist redistribution of legacy contaminants (Sherwood et al. 2002), and stormwater discharges (Schiff et al. 2006, Nezlin et al. 2007). Possible non-outfall sources 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 (see Parnell et al. 2008).

Overall, there is little evidence of contaminant loading or organic enrichment in sediments throughout the PLOO region after 18 years of wastewater discharge. For example, concentrations of most indicators continue to occur at low levels below available thresholds and within the range of variability typical for the San Diego region (e.g., see City of San Diego 2007, 2012b). The only sustained effects have been restricted to a few sites located within about 300 m of the outfall (i.e., stations E11, E14 and E17). These effects include measurable increases in sulfide concentrations, and smaller increases in BOD (City of San Diego 2007). However, there is no evidence to suggest that wastewater discharge is affecting the quality of benthic sediments in the region to the point that it will degrade the resident marine biota (e.g., see Chapters 5 and 6).

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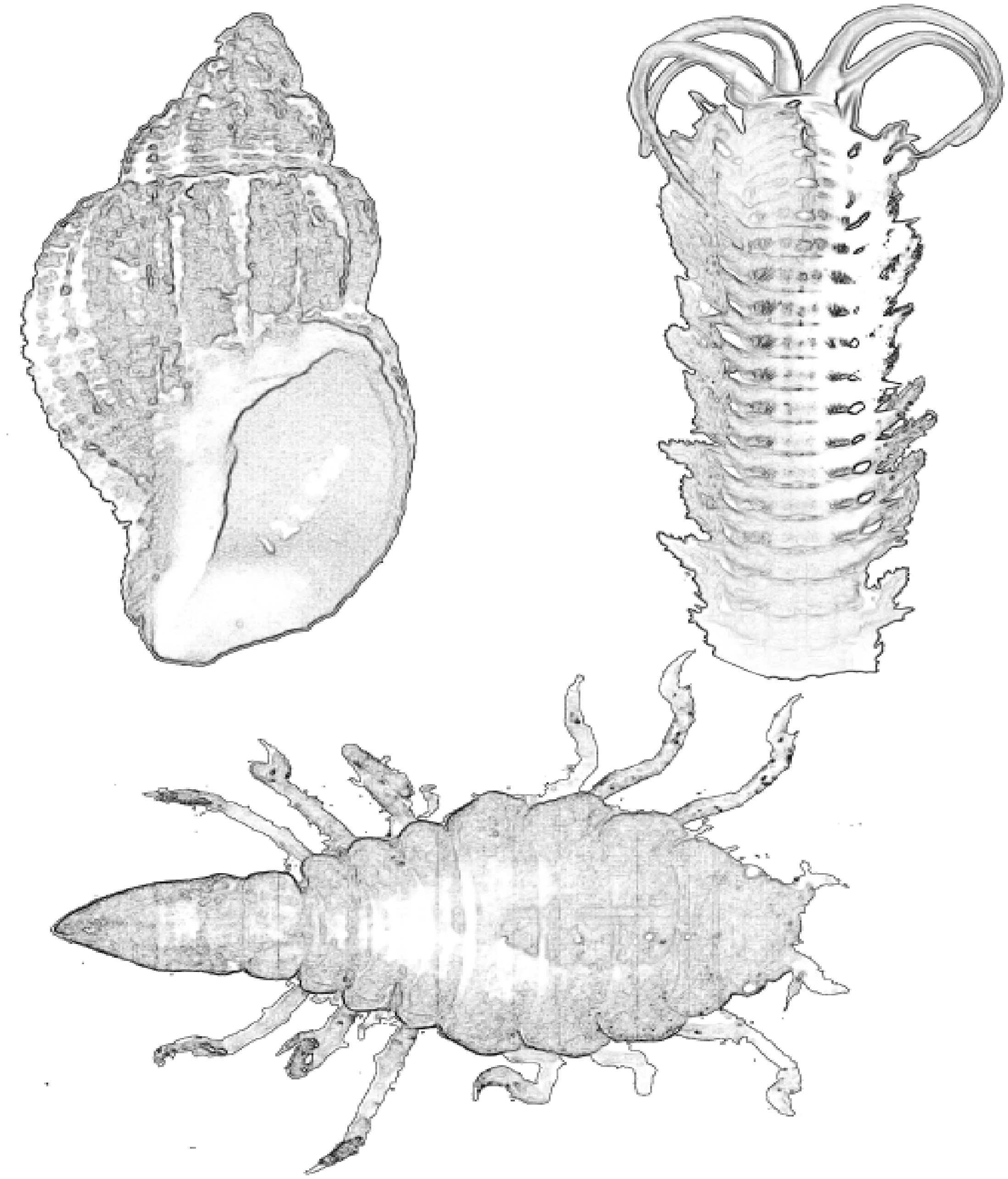
Chapter 5
Macrobenthic Communities



Chapter 5. Macrobenthic Communities

Introduction

Small invertebrates (macrofauna) that live within or on the surface of soft-bottom habitats are monitored by the City of San Diego (City) to examine potential effects of wastewater discharge on the marine benthos from both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively). These benthic macrofauna are targeted for monitoring because they are known to play critical ecological roles in marine environments along the Southern California Bight (SCB) coastal shelf (Fauchald and Jones 1979, Thompson et al. 1993a, Snelgrove et al. 1997). In conjunction with their ecological importance, many benthic species are relatively stationary and long-lived and they integrate the effects of pollution or disturbance over time (Hartley 1982, Bilyard 1987). Various species also respond differently to environmental stressors, and monitoring changes in individual populations or more complex communities can help identify locations susceptible to anthropogenic impacts (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). For example, pollution-tolerant species are often opportunistic and predictably outcompete others in impacted environments. In contrast, pollution-sensitive species decrease in response to toxic contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation (Gray 1979). Consequently, assessment of benthic community structure has become a major component of many ocean monitoring programs.

The structure of marine macrobenthic communities is influenced by natural factors such as ocean depth, sediment composition (e.g., percent of fine versus coarse sediments), sediment quality (e.g., contaminant loads, toxicity), oceanographic conditions (e.g., temperature, dissolved oxygen, nutrient levels, currents), and biological interactions (e.g., competition, predation, bioturbation). For example, assemblages on the SCB coastal shelf typically vary along depth gradients and/or with sediment grain size (Bergen et al. 2001). Therefore, an understanding of background or reference conditions is necessary to determine whether differences in community structure may be related to anthropogenic activities. Such information is available for the monitoring area surrounding the PLOO and the San Diego region in general (e.g., City of San Diego 1999, 2011, 2012, Ranasinghe et al. 2003, 2007, 2010, 2012).

The City relies on a suite of scientifically-accepted indices and statistical analyses to evaluate changes in local marine invertebrate communities. For example, the benthic response index (BRI), Shannon diversity index, and Swartz dominance index are used as metrics of invertebrate community structure, while multivariate analyses are used to detect spatial and temporal differences among communities (e.g., Warwick and Clarke 1993, Smith et al. 2001). The use of multiple analyses provides better resolution than single parameters, and some include established benchmarks for determining anthropogenically-induced environmental impacts. For example, the BRI was developed specifically for use in the SCB with values <25 indicative of reference conditions and values >34 characteristic of degraded habitats. All together, the data are used to determine whether invertebrate assemblages in the San Diego region are similar to those from habitats with similar depth and sediment characteristics, or whether observable impacts from outfalls or other sources occur. Minor organic enrichment caused by wastewater discharge should be evident through an increase in species richness and abundance, whereas major impacts should result in decreases in overall species diversity and richness coupled with dominance by a few pollution-tolerant species (Pearson and Rosenberg 1978).

This chapter presents analyses and interpretations of the macrofaunal data collected during calendar

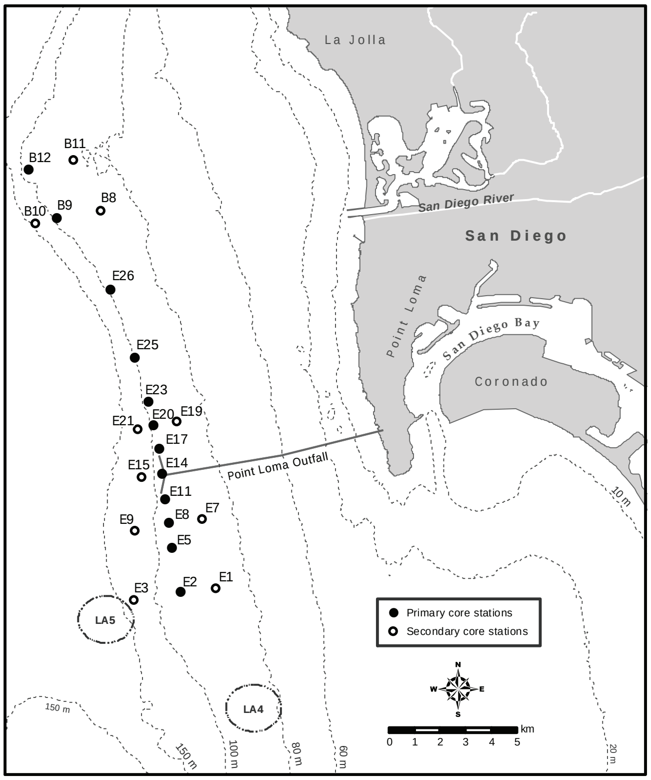


Figure 5.1
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

year 2011 at fixed benthic monitoring stations surrounding the PLOO. Included are descriptions of benthic community structure and comparisons of the different invertebrate communities in the region. The primary goals are to: (1) document the benthic macrofaunal communities present during the year, (2) determine the presence or absence of biological impacts associated with wastewater discharge, and (3) identify other potential natural and anthropogenic sources of variability to the local marine ecosystem.

Materials and Methods

Collection and Processing of Samples

Benthic samples were collected at 22 fixed stations in the PLOO region during January and July 2011 (Figure 5.1). These stations range in depth from 88 to 116 m and are distributed along or adjacent to three main depth contours. These sites included 17 'E' stations ranging from approximately 5 km south to 8 km north of the outfall, and five 'B' stations located about 10–12 km north of the tip of the northern diffuser leg (see Chapter 1). The four stations considered to represent "nearfield" conditions (i.e., E11, E14, E15 and E17) are located within 1000 m of the outfall wye or diffuser legs.

Two replicate samples for benthic community analyses were collected per station during each survey using a double 0.1-m^2 Van Veen grab. The first sample was used for analysis of macrofauna, while the adjacent grab was used for sediment quality analysis (see Chapter 4). A second macrofaunal grab was then collected from a subsequent cast. Criteria established by the USEPA to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen. Macrofaunal organisms retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution and then fixed with buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All macrofauna were sorted from the debris into major taxonomic groups by a subcontractor and then identified to species (or the lowest taxon possible) and enumerated by City marine biologists. All identifications followed nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT 2011).

Data Analyses

Each grab sample was considered an independent replicate for analysis. The following community structure parameters were calculated for each station per 0.1-m^2 grab: species richness (number of species), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (see Swartz et al. 1986, Ferraro et al. 1994), and benthic response index (BRI; see Smith et al. 2001). Additionally, the total or cumulative number of species among all grabs ($n = 4$) was calculated for each station.

Comparisons to historical ranges are based on data collected at the PLOO grid stations from 1991 through 2010, while comparisons to tolerance intervals are based on data from randomly selected regional stations sampled between 1994–2003 (City of San Diego 2007).

To further examine spatial patterns among benthic communities in the PLOO region, multivariate analyses were conducted using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). Macrofaunal abundance data were square-root transformed to lessen the influence of the most abundant species and increase the importance of rare species, and a Bray-Curtis similarity matrix was created using sediment type (see Appendix C.2) as a factor. A 1-way ANOSIM (maximum number of permutations = 9999) was conducted to determine whether communities varied by sediment type across the region. To visually depict the relationship of individual grab samples to each other based on macrofaunal composition, hierarchical agglomerative clustering (cluster analysis) with group-average linking was conducted. Similarity profile (SIMPROF) analysis was used to confirm non-random structure of resultant clades in the dendrogram (Clarke et al. 2008), and major ecologically-relevant clusters supported by SIMPROF were retained at > 42.3% similarly. Similarity percentages (SIMPER) analyses were used to determine which organisms were responsible for the greatest contribution to within-group similarities (i.e., characteristic species), and to identify which species accounted for: (1) significant differences identified through ANOSIM, and (2) differences among clades occurring in the dendrogram.

A BACIP (Before-After-Control-Impact-Paired) statistical model was used to test the null hypothesis that there have been no changes in select 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 sites at times before (July 1991–October 1993) and after (January 1994–July 2011) an impact event (i.e., the onset of discharge). The analyses presented in this report are based on 2.5 years (10 quarterly surveys) of before impact data and 18 years (55 quarterly or semi-annual surveys) of after impact data. The 'E' stations, located between ~0.1 and 8 km of the outfall, are considered most likely to be affected by wastewater discharge (Smith and Riege 1994). Station E14 was selected as the impact site for all analyses; this station is located near the boundary of the Zone of Initial Dilution (ZID) and probably is the site most susceptible to impact. The 'B' stations are located farther from the outfall (> 10 km north) and were originally designed to be reference or control sites. However, benthic communities differed between the 'B' and 'E' stations prior to discharge (Smith and Riege 1994, City of San Diego 1995). Thus, two 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, while previous analyses suggested station B9 was the most appropriate 'B' station for comparison with the 'E' stations (Smith and Riege 1994, City of San Diego 1995). Six dependent variables were analyzed, including number of species (species richness), macrofaunal abundance, the benthic response index (BRI), and abundances of three taxa considered sensitive to organic enrichment. These indicator taxa include ophiuroids in the genus *Amphiodia* (mostly *A. urtica*), and amphipods in the genera *Ampelisca* and *Rhepoxynius*. All BACIP analyses were interpreted using one-tailed paired t-tests with a type I error rate of $\alpha = 0.05$.

Results

Community Parameters

Species richness

A total of 532 taxa were identified during the 2011 PLOO surveys. Of these, 419 taxa (79%) were identified to species, 64 to genus, 21 to family, 14 to order, 11 to class, and 3 to phylum. Most taxa occurred at multiple sites, although about 22% (*n* = 119) represented taxa recorded only once. No new species were found in the region. Average species richness

Table 5.1

Summary of macrofaunal community parameters for PLOO benthic stations sampled during 2011. Tot Spp = cumulative no. of species for the year; SR = species richness (no. species/0.1 m^2); Abun = abundance (no. individuals/0.1 m^2); H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index. Data for each station are expressed as annual means (n = 4 grabs) except Tot Spp (n = 1). Stations are listed north to south from top to bottom.

	Station	Tot Spp	SR	Abun	H'	J'	Dom	BRI
88-m Depth Contour	B11	217	98	242	4.1	0.90	42	12
	B8	132	59	147	3.4	0.83	25	8
	E19	152	70	220	3.6	0.85	26	12
	E7	170	76	241	3.7	0.86	28	12
	E1	156	73	272	3.1	0.72	20	8
98-m Depth Contour	B12	210	116	430	4.2	0.88	40	14
	B9	192	102	311	4.1	0.88	40	10
	E26	151	88	282	3.9	0.87	30	10
	E25	172	102	378	4.0	0.87	34	14
	E23	159	84	301	3.8	0.87	30	14
	E20	145	76	260	3.8	0.89	28	15
	E17[a]	151	76	290	3.8	0.88	26	15
	E14[a]	165	88	333	3.8	0.85	30	22
	E11[a]	156	82	287	3.8	0.87	28	14
	E8	161	84	254	4.0	0.89	33	11
	E5	169	79	232	3.9	0.88	32	10
	E2	182	94	302	3.8	0.85	34	13
116-m Depth Contour	B10	188	98	312	4.0	0.88	36	14
	E21	174	100	352	4.0	0.87	35	14
	E15[a]	195	84	244	4.0	0.90	36	15
	E9	211	112	274	4.4	0.93	52	9
	E3	205	108	304	4.3	0.92	46	12
All Grabs	Mean	173	89	285	3.9	0.87	33	13
	95% CI	11	4	15	0.07	0.01	2	0.8
	Min	132	47	88	2.3	0.58	8	3
	Max	217	129	467	4.5	0.95	58	24

[a] = nearfield station

ranged from 59 taxa per 0.1 m^2 grab at station B8 to 116 taxa per grab at station B12 (Table 5.1). Both of these reference stations are located ≥10 km north of the outfall. Although the number of species per site varied spatially, there were no clear patterns relative to distance from the discharge site. Values recorded during the year were within the historical range of 49–160 taxa/grab reported between 1991–2010. Further, species richness at 91% of the stations was within the tolerance intervals of 72–175 taxa/grab calculated for the region.

Macrofaunal abundance

A total of 25,101 macrofaunal individuals were counted in 2011, with mean abundance ranging from 147 to 430 animals per grab (Table 5.1). The greatest number of animals occurred at station B12 where species richness was also highest. The fewest animals occurred at station B8, the site which also had the lowest species richness. No spatial patterns in abundance related to the outfall were observed. Except for station B8, values recorded during the year were within the historical range of 162–1074 individuals/grab reported between 1991–2010, and 91% of stations were within the tolerance interval bounds for macrofaunal abundance (230–671 individuals/grab) calculated for the region.

Species diversity, evenness, and dominance

Shannon diversity (H'), evenness (J'), and Swartz dominance (Dom) results for the PLOO stations sampled in 2011 are summarized in Table 5.1. H' values averaged from 3.1 to 4.4 at the different stations, while J' averaged from 0.72 to 0.93. These results are similar to historical values reported between 1991–2010 and suggest that local benthic assemblages remained characterized by relatively high numbers of evenly distributed species. There were also no patterns in diversity or evenness relative to the discharge site with both the highest and lowest values occurring south of the outfall at stations E9 and E1, respectively. Except for these two stations, average diversity values in 2011 were within regional tolerance intervals (H' = 3.4–4.3). In contrast, average evenness values were above the upper tolerance interval bound (J' = 0.86) at 16 of 22 stations and below the lower bound (J' = 0.75) at one station.

Swartz dominance values averaged from 20 to 52 species per station. The highest dominance (lowest index value) occurred at station E1 located inshore of the LA5 disposal site, while the lowest dominance (highest index value) occurred at station E9 located southwest of the PLOO. Dominance values in 2011 were generally similar to historical values, and except for stations E3 and E9 were within regional tolerance intervals (Dom = 7–44).

Benthic response index

Benthic response index (BRI) values are an important tool for gauging possible anthropogenic impacts to marine environments throughout the SCB. Values below 25 are considered indicative of reference conditions, values 25–33 represent "a minor deviation from reference conditions," and values ≥34 represent increasing levels of degradation (Smith et al. 2001). All of the benthic

Table 5.2

Percent composition of species and abundance by major taxonomic group (phylum) for PLOO benthic stations sampled during 2011. Data are expressed as annual means (range) for all stations combined; *n* = 22.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	48 (44–83)	60 (28–85)
Arthropoda (Crustacea)	22 (9–33)	20 (8–35)
Mollusca	17 (1–20)	6 (1–18)
Echinodermata	5 (1–13)	12 (1–58)
Other Phyla	8 (1–9)	2 (1–5)

samples collected off Point Loma in 2011 had BRI values < 25 (Table 5.1). The highest average value (BRI = 22) occurred at station E14 located about 120 m from the end of the main outfall pipe (center of the wye), while the lowest values (BRI = 8) occurred at stations B8 and E1 located about 10 km north and 4 km south of the PLOO, respectively. Only BRI values for station E14 were above the upper tolerance interval of 15 for the PLOO region (City of San Diego 2007).

Dominant Species

Polychaete worms were the dominant taxonomic group found in the PLOO region in 2011 and accounted for 48% of all species collected (Table 5.2). Crustaceans accounted for 22% of species reported, while molluscs, echinoderms, and all other taxa combined accounted for the remaining 17%, 5%, and 8%, respectively. Polychaetes were also the most numerous animals, accounting for 60% of the total abundance. Crustaceans accounted for 20% of the animals collected, molluscs 6%, echinoderms 12%, and the remaining phyla 2%. Overall, the percentage of taxa that occurred within each major taxonomic grouping and their relative abundances were similar to those observed in 2010 (City of San Diego 2011).

Table 5.3

The 10 most abundant macroinvertebrates collected at the PLOO benthic stations during 2011. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample. Percent occurrence = percent of total samples where the species was collected.

Species	Taxonomic Classification	Abundance per Sample	Percent Occurrence
Amphiodia urtica	Echinodermata: Ophiuroidea	23.1	93
Chloeia pinnata	Polychaeta: Amphinomidae	9.5	70
Euphilomedes producta	Arthropoda: Ostracoda	8.8	86
Chaetozone hartmanae	Polychaeta: Cirratulidae	8.7	92
Prionospio (*Prionospio*) *jubata*	Polychaeta: Spionidae	8.3	93
Euphilomedes carcharodonta	Arthropoda: Ostracoda	8.2	77
Spiophanes berkeleyorum	Polychaeta: Spionidae	7.0	92
Aricidea (*Acmira*) *catherinae*	Polychaeta: Paraonidae	6.8	82
Lumbrineris cruzensis	Polychaeta: Lumbrineridae	6.6	72
Paraprionospio alata	Polychaeta: Spionidae	6.3	97

The 10 most abundant species included seven polychaetes, two crustaceans, and one echinoderm (Table 5.3). The dominant polychaetes were the amphinomid *Chloeia pinnata*, the cirratulid *Chaetozone hartmanae*, the spionids *Prionospio* (*Prionospio*) *jubata*, *Spiophanes berkeleyorum* and *Paraprionospio alata*, the paraonid *Aricidea* (*Acmira*) *catherinae*, and the lumbrinerid *Lumbrineris cruzensis*. Dominant crustaceans were the ostracods *Euphilomedes producta* and *E. carcharodonta*. The dominant echinoderm was the ophiuroid *Amphiodia urtica*, which was also the most abundant species collected during the year at an average of ~23 individuals per grab. Although this brittle star occurred at every site and accounted for ~11% of all benthic invertebrates collected, its abundances in 2011 were the lowest they have been since monitoring began (Figure 5.2). The most widely distributed species was *Paraprionospio alata*, which occurred in 97% of the samples.

BACIP Analyses

BACIP t-tests indicate that there has been a net change in the mean difference of species richness, BRI values, and *Amphiodia* spp abundance between impact site E14 and both control sites since the onset of wastewater discharge from the PLOO (Table 5.4). There also has been a net change in infaunal abundance between E14 and control site B9, and a net change in *Ampelisca* spp abundance between E14 and E26. The change in species richness is likely driven by increased variability and higher numbers of species at E14 beginning in 1997 (Figure 5.3A). The BACIP results for total infaunal abundances were more ambiguous (Figure 5.3B). While the difference in mean abundances between stations B9 and E14 has changed since discharge began, no significant change is apparent at the second control site (station E26). Changes in BRI differences generally have occurred due to increased index values at station E14 since 1994 (Figure 5.3C). The change in the difference in mean abundance of ampeliscid amphipods (i.e., *Ampelisca*) between E14 and E26 occurred more recently, beginning around 2003 (Figure 5.3D). The variable nature of *Ampelisca* populations at the three stations makes interpretation of this relatively small difference difficult. Significant differences in *Amphiodia* populations reflect both a decrease in the number of ophiuroids collected at E14 and a general increase at the control stations that occurred until about 2006 (Figure 5.3E). *Amphiodia* spp densities at station E14 in 2011 are in range of the low densities reported since about 1999. While populations of this brittle star have also declined in recent years at both control sites, their densities at these sites are more similar to pre-discharge values than to densities near the outfall. Finally, no significant changes in the difference in mean abundances

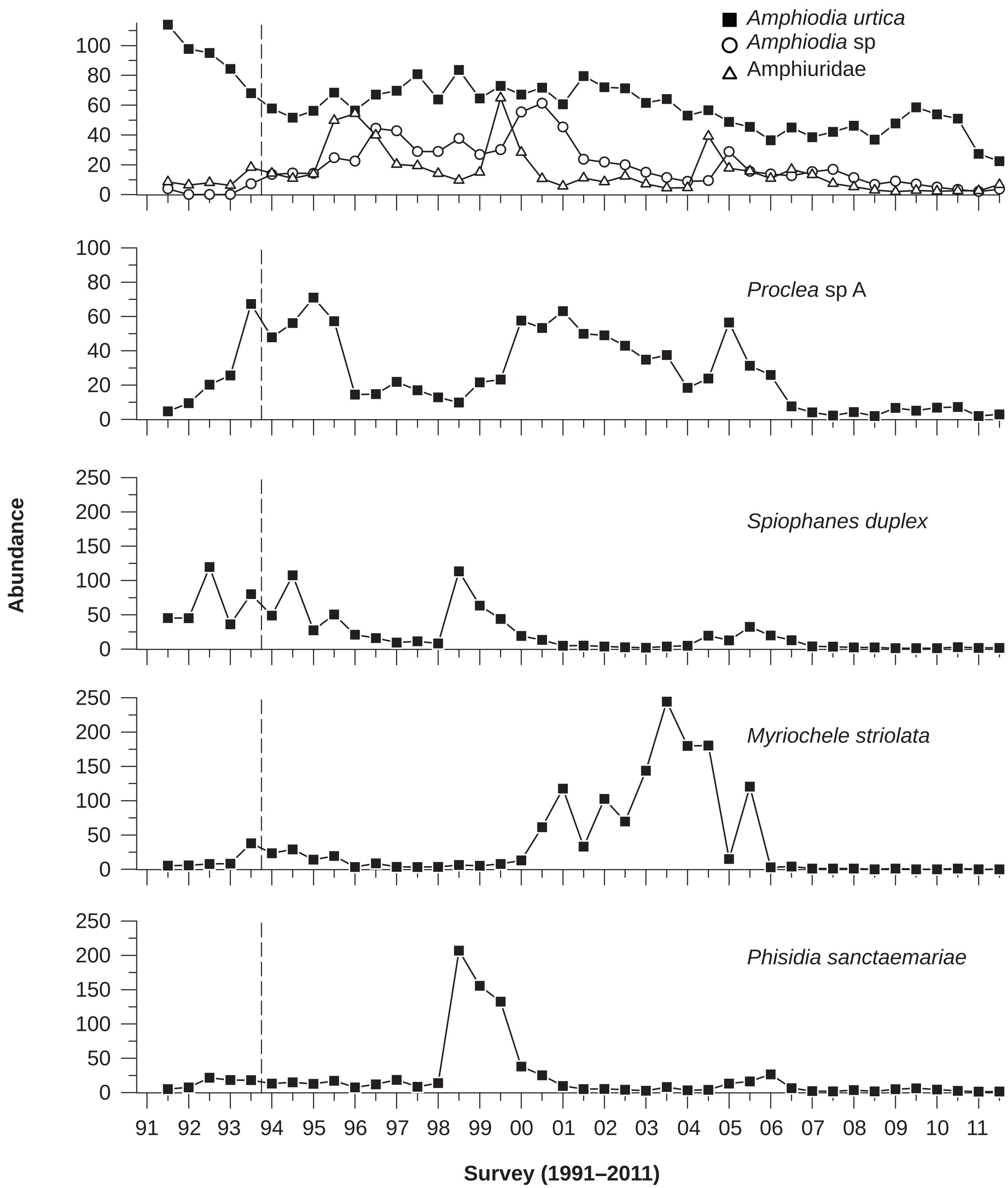


Figure 5.2

Abundance per survey for each of the five most abundant species (taxa) at the PLOO benthic stations sampled between 1995–2011. *Amphiodia urtica* and unidentifiable juveniles (*Amphiodia* sp and Amphiuridea) are graphed together; note expanded scale for *Spiophanes duplex*, *Myriochele striolata*, and *Phisidia sanctaemariae*. Data are expressed as mean values of biannual (i.e., first and third quarters) samples during each survey ($n = 44$); samples were limited to primary core stations ($n = 24$) during the quarters 03-3, 04-3, 05-1, 08-3, and 09-1 due to regulatory relief to accommodate special projects; prior to 2003, $n = 42$. Dashed lines indicate onset of wastewater discharge.

Table 5.4

Results of BACIP t-tests for species richness (SR), infaunal abundance, BRI, and abundance of several representative taxa around the PLOO (1991–2011). Critical t-value = 1.680 for $\alpha = 0.05$ (one-tailed t-tests, df = 63); ns = not significant.

Variable	Control vs. Impact	t	*p*
SR	E26 vs E14	-3.15	0.001
	B9 vs E14	-3.44	0.001
Abundance	E26 vs E14	-1.44	ns
	B9 vs E14	-2.68	0.005
BRI	E26 vs E14	-13.25	< 0.001
	B9 vs E14	-9.82	< 0.001
Ampelisca spp	E26 vs E14	-1.79	0.039
	B9 vs E14	-1.18	ns
Amphiodia spp	E26 vs E14	-6.26	< 0.001
	B9 vs E14	-4.33	< 0.001
Rhepoxynius spp	E26 vs E14	-0.55	ns
	B9 vs E14	-0.37	ns

of phoxocephalid amphipods (i.e., *Rhepoxynius*) at the impact and control sites have occurred over time.

Classification of Macrobenthic Assemblages

The results of a 1-way ANOSIM examining the relationship of invertebrate communities by sediment type revealed significant differences between assemblages occurring in sandy sediments with a high fraction of fines and assemblages occurring in fine sediments with a high fraction of sand (pairwise r = 0.854, Appendix D.1) (see Chapter 4 for sediment type details). Differences in these assemblages were characterized by minor variations in abundances of many common taxa. The five species with the greatest contribution to differences (~2% each) were the polychaetes *Chaetozone hartmanae* and *Chloeia pinnata*, and the ostracod *Euphilomedes carcharodonta* (all three of which were absent in fine sediments with a sand fraction), the ostracod *Euphilomedes producta* (which was more abundant in sandier sediments), and the ophiuroid *Amphiodia urtica* (which was more abundant in finer sediments). No other pairwise tests comparing benthic communities between sediment types were significant.

Discrimination of cluster groups

Classification (cluster) analysis was used to discriminate between invertebrate communities from individual grab samples, resulting in four ecologically-relevant SIMPROF-supported groups (Figure 5.4, Table 5.5). These "assemblages," referred to herein as cluster groups A through D contained between 1–66 grabs each, and exhibited mean species richness values ranging from 64 to 106 taxa per grab and mean abundances of 200 to 315 individuals per grab (Table 5.5). Grabs within each cluster generally were collected from sites with similar depth and sediment characteristics (Appendix D.2). For example, cluster groups A and B were restricted to samples from three 88-m stations that had percent fines of 46–60%, while cluster group C represented samples from one 98-m station and three 116-m stations where percent fines ranged between 28–40%.

Description of cluster groups

Cluster group A consisted of a single July grab collected at station B11, the northernmost 88-m site sampled in the region (Figure 5.4). Species richness and abundance were 94 taxa and 234 individuals/grab, respectively (Table 5.5). Sediments consisted of 53.6% sand and 46.4% fines (Appendix D.2). The five most abundant species encountered were the polychaetes *Chloeia pinnata*, *Prionospio* (*Prionospio*) *jubata*, *Chaetozone hartmanae*, and *Paraprionospio alata*, and the amphipod *Ampelisca pugetica*. Abundance of these species ranged from 7 to 38 individuals/grab.

Cluster group B consisted of all four grabs from station B8, and three grabs from station E1 (Figure 5.4). This group had the lowest average species richness and abundance of any cluster group at 64 taxa and 200 individuals/grab, respectively (Table 5.5). Sediments averaged 52.2% fines with significant fractions of sand (Appendix D.2). Ophiuroids (brittle stars) dominated this group, with approximately 69 *Amphiodia urtica* occurring in each grab. The polychaetes *Lumbrineris cruzensis*,

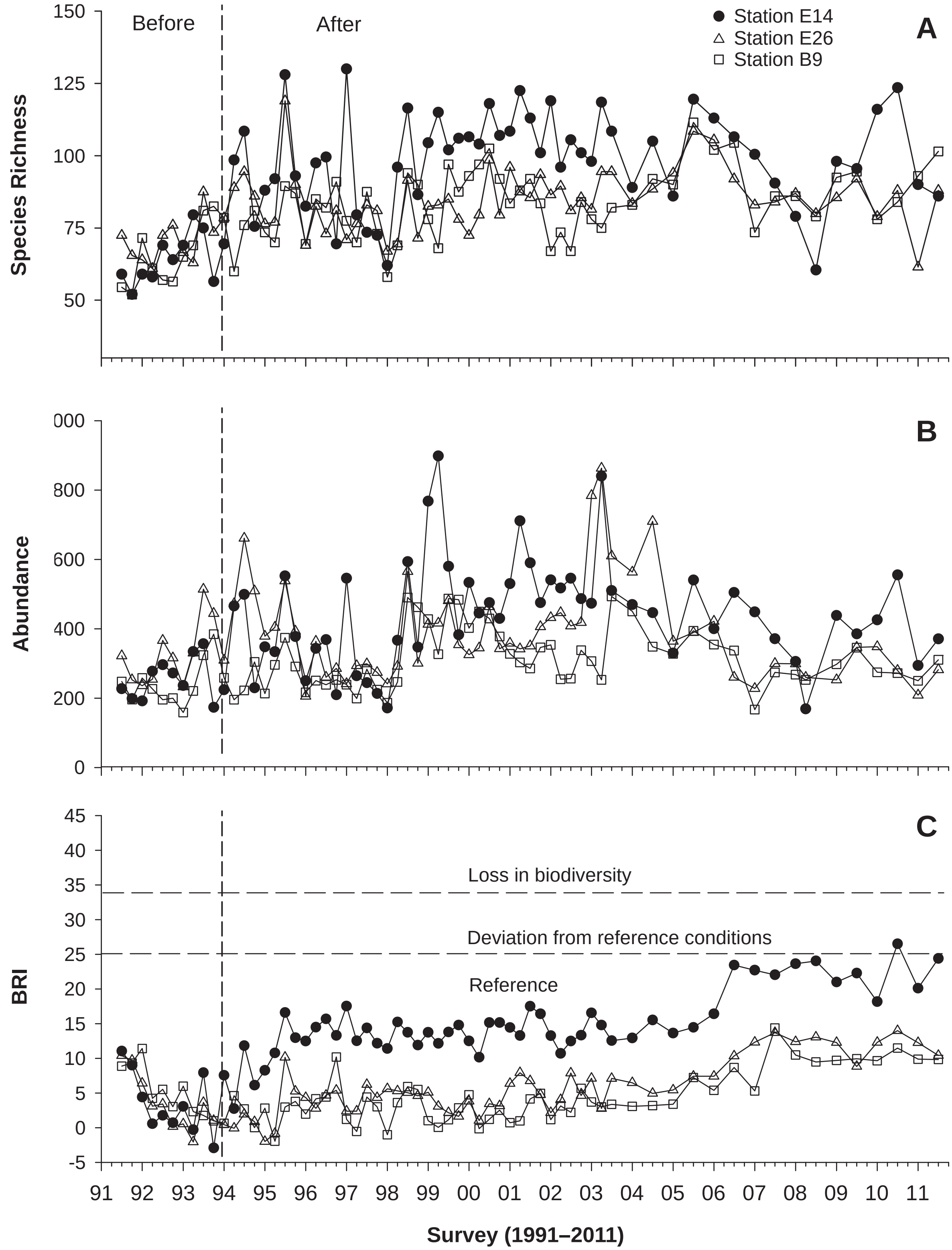


Figure 5.3

Comparison of several parameters at "impact" site (station E14) and "control" sites (stations E26, B9) used in BACIP analyses (see Table 5.4) between 1991–2011. Parameters include: (A) species richness; (B) infaunal abundance; (C) benthic response index (BRI); (D) abundance of *Ampelisca* spp; (E) abundance of *Amphiodia* spp. Data for each station are expressed as means per 0.1 m^2 ($n = 2$ per survey).

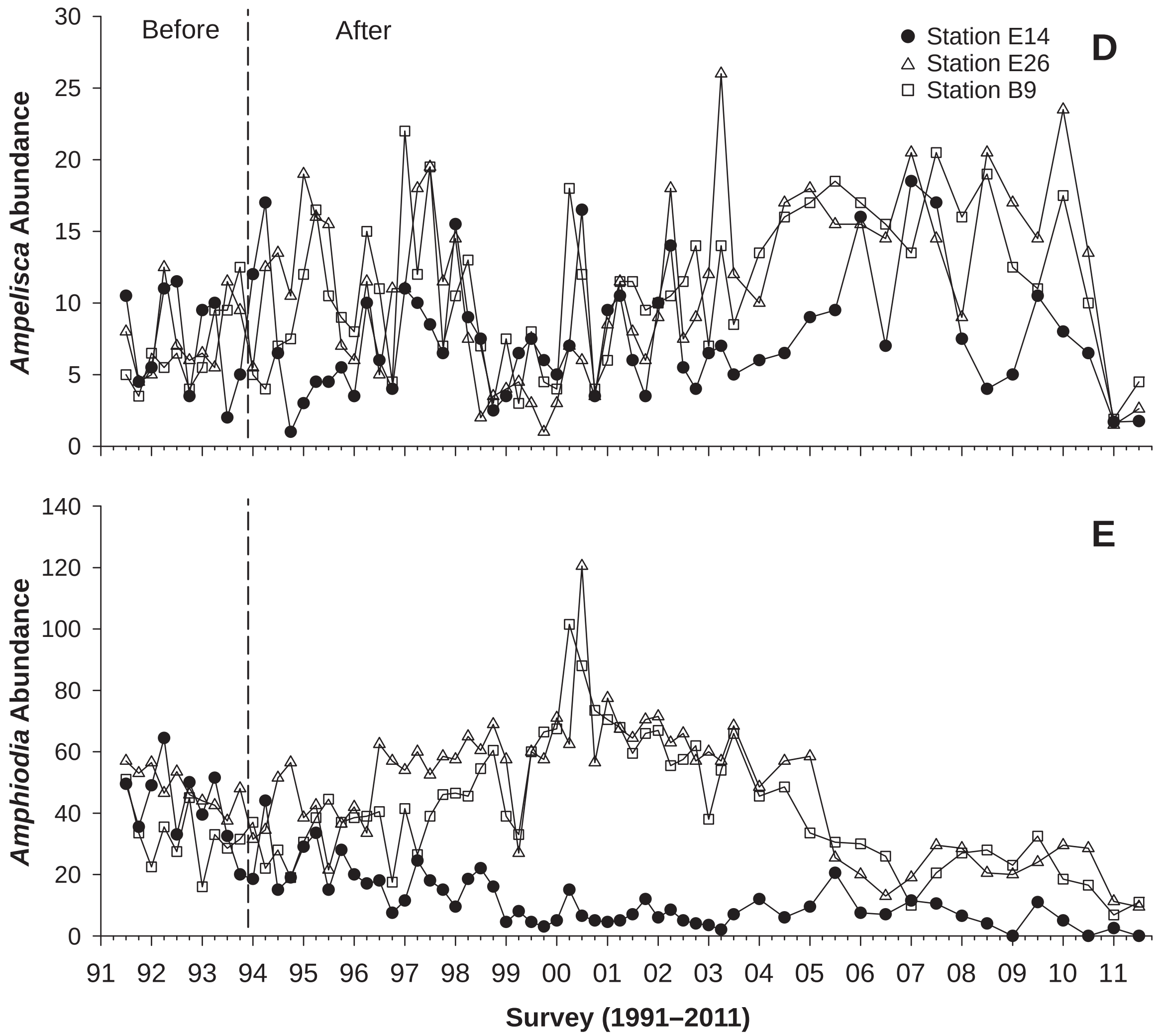


Figure 5.3 *continued*

Travisia brevis and *Sternaspis fossor*, and the bivalve *Ennucula tenuis* were also very common, averaging between 6–7 individuals per grab. No other species had abundances >4/grab. SIMPER revealed *A. urtica*, *E. tenuis*, *S. fossor*, and the polychaete *Paraprionospio alata* and amphipod *Rhepoxynius bicuspidatus* to be the five most characteristic species of the assemblage.

Cluster group C consisted of 14 grabs from four sites located at 98-m and 116-m depths, including all grabs from stations B10, B12 and E3, and the two January grabs from station E9 (Figure 5.4). Average species richness and abundance were the highest of all cluster groups with 106 taxa and 315 individuals/grab, respectively (Table 5.5). The sediments in this group had the lowest percent fines, averaging only 34% (Appendix D.2). The five most abundant species encountered were the polychaetes *Chloeia pinnata*, *Prionospio* (*Prionospio*) *jubata*, *Spiophanes kimballi*, *Aphelochaeta glandaria* Cmplx and *Chaetozone hartmanae*, all of which averaged between 7–14 individuals/grab. SIMPER revealed *A. glandaria* Cmplx, *C. pinnata*, *S. kimballi*, the amphipod *Ampelisca careyi*, and the ophiuroid *Amphiodia digitata* be the five most characteristic species of the assemblage.

Cluster group D consisted of 75% of all grabs sampled during the year (Figure 5.4). The cluster group possessed grabs from all nearfield sites, as well as the majority of sites located both north and south of the outfall (Figure 5.4). Average species richness and abundance were 87 taxa and 289 individuals/grab, respectively (Table 5.5). The five most abundant species were the ophiuroid

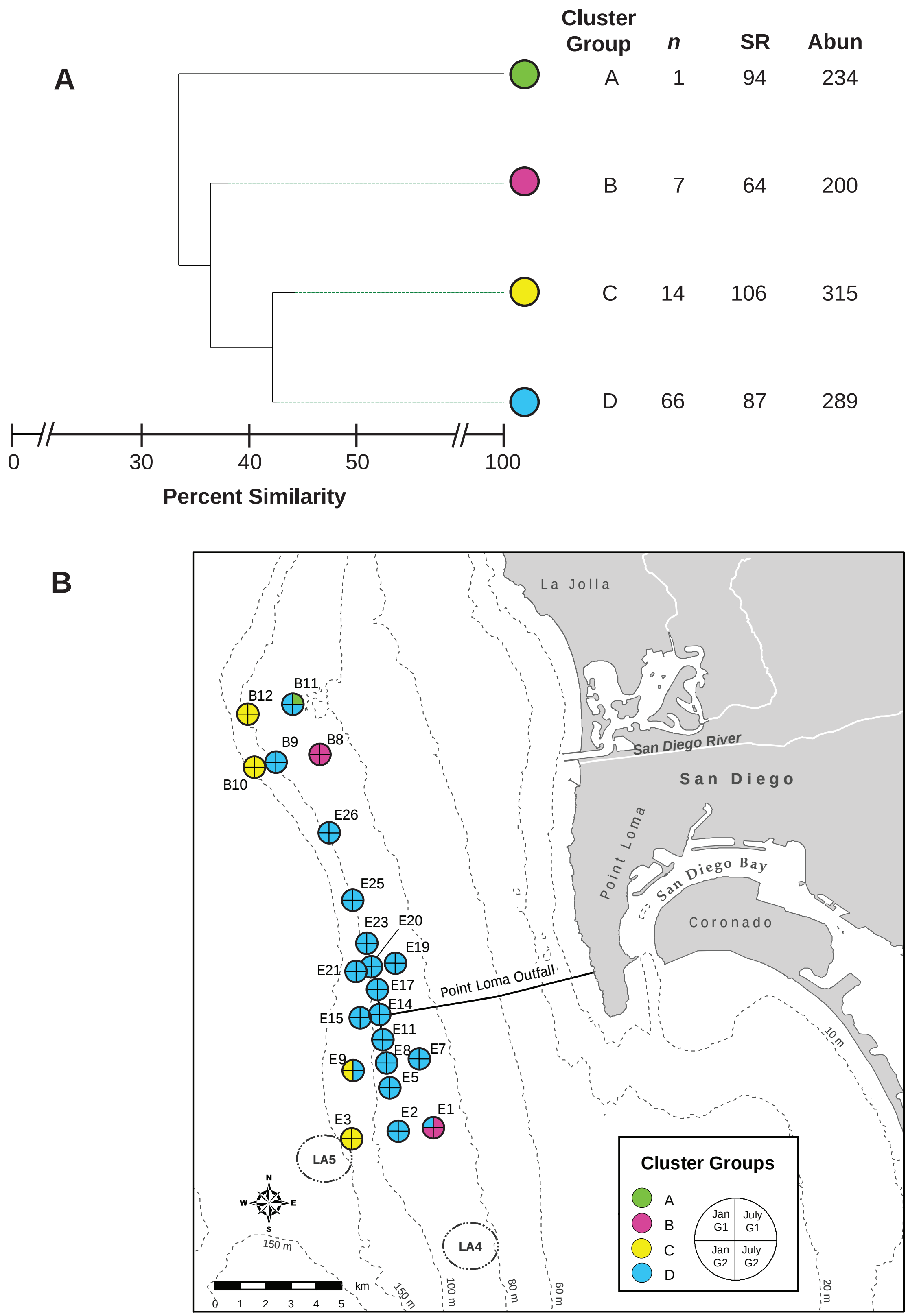


Figure 5.4

(A) Cluster analysis of macrofaunal assemblages at PLOO stations sampled during 2011. Data for species richness (SR) and infaunal abundance (Abun) are expressed as mean values per 0.1-m^2 over all stations in each group (*n*). (B) Spatial distribution of cluster groups in the PLOO region. Colors of each circle correspond to colors in the dendrogram.

Table 5.5

Mean abundance of the most common species found in cluster groups A–D (defined in Figure 5.4). Bold values indicate taxa that were considered among the most characteristic of that group according to SIMPER analysis.

	Cluster Groups			
Taxa	A[a]	B	C	D
Chloeia pinnata	38.0	0.3	**13.6**	9.1
Prionospio (*Prionospio*) *jubata*	13.0	1.7	9.0	**8.8**
Chaetozone hartmanae	12.0	0.1	7.4	**9.8**
Paraprionospio alata	8.0	**3.9**	6.3	6.6
Ampelisca pugetica	7.0	0.4	1.7	1.3
Amphiodia urtica	3.0	**68.7**	2.4	**23.0**
Lumbrineris cruzensis	3.0	6.6	1.2	7.9
Travisia brevis	3.0	6.0	1.9	2.2
Ennucula tenuis	2.0	**5.7**	1.6	3.0
Sternaspis fossor	1.0	**5.6**	4.0	5.4
Spiophanes kimballi	3.0	1.0	**8.8**	5.4
Aphelochaeta glandaria Cmplx	1.0	0.3	**8.1**	4.8
Euphilomedes producta	0.0	0.7	5.4	**10.6**
Euphilomedes carcharodonta	0.0	0.1	2.6	**10.3**

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

Amphiodia urtica, the ostracods *Euphilomedes carcharodonta* and *Euphilomedes producta*, and the polychaetes *Chaetozone hartmanae* and *Chloeia pinnata*, all of which occurred at densities of 9–23 individuals/grab. SIMPER revealed *A. urtica*, *C. hartmanae*, *E. carcharodonta*, *E. producta*, and the polychaete *Prionospio* (*Prionospio*) *jubata* to be the five most characteristic taxa of the assemblage.

Discussion

Benthic communities across the Point Loma outfall region in 2011 were similar to those encountered during previous years, including the period before wastewater discharge (see City of San Diego 1995, 2011). These communities remained dominated by ophiuroid-polychaete based assemblages. Although the brittle star *Amphiodia urtica* remained the most abundant species off Point Loma, its overall population abundances were the lowest since monitoring began about 20 years ago. The spionid polychaete *Paraprionospio alata* was the most widespread benthic invertebrate encountered during the year, which represents a resurgence of its prominence in the region. The overall abundance and dominance of most species typically were within historical ranges (e.g., City of San Diego 1995, 1999, 2007, 2011). One exception is that populations of the spionid polychaete *Spiophanes duplex* have shown a notable decrease over the past few years. As previously reported, most sites along the 98-m isobath spanning the PLOO discharge site had sandy sediments with a high fraction of fines that supported similar types of benthic communities. Most variability in macrofaunal populations occurred at sites located several kilometers to the north and south of the outfall that possessed slightly higher fractions of coarse or fine sediments. Put into a broader regional context, values for diversity, evenness and dominance off Point Loma were within ranges of those described for other areas of the SCB (Thompson et al. 1993b, Bergen et al. 1998, 2000, 2001, Ranasinghe et al. 2003, 2007), and sites surveyed off Point Loma during the year were found to have species assemblages similar to those described for other areas in southern California (e.g., 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. 2010).

Changes in populations of pollution-sensitive or pollution-tolerant species or other indicators of benthic condition have shown 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 populations of *A. urtica* have decreased significantly near the discharge site (i.e., station E14) over the past 15 or more years, there has been a region-wide decrease in this species as well, especially during the past year (see above). Although long-term changes in *A. urtica* populations at station E14 may be related to organic enrichment, factors such as altered sediment composition (e.g., coarser sediments) and increased predation pressure near the outfall may also be important. Regardless of the cause of these changes, abundances of *A. urtica* off Point Loma remain within the range of natural variation in SCB populations. Another important indicator species in the SCB is the opportunistic polychaete *Capitella teleta* (previously considered within the *Capitella capitata* species complex), which can reach densities as high as 5000/m^2 in polluted sediments (e.g., Reish 1957, Swartz et al. 1986). Although populations of *C. teleta* have fluctuated off Point Loma, overall abundances of this species have remained low and characteristic of undisturbed habitats. For example, the highest number *C. teleta* observed over the past decade occurred in 2009 when a total of 206 individuals were recorded, 97% of which occurred at nearfield stations E11, E14 and E17 (City of San Diego 2010). Abundances of *C. teleta* were very low in 2011 with only a total of seven individuals reported. Further, populations of pollution-sensitive phoxocephalid amphipods in the genus *Rhepoxynius* have remained stable at the nearfield sites, suggesting that wastewater discharge has had little to no effect on these species. Finally, although benthic response index (BRI) values have increased at station E14 as well as at two other nearfield stations (E11 and E17) since outfall operations began, overall BRI values in 2011 were indicative of undisturbed areas (Smith et al. 2001, Ranasinghe et al. 2010).

In conclusion, benthic macrofaunal communities appear to be in good condition off Point Loma, with all of the sites surveyed in 2011 being classified in reference condition based on assessments using the BRI. This agrees with findings in Ranasinghe et al. (2010, 2012) who reported that at least 98% of the entire SCB mainland shelf is in good condition based on data from bight-wide surveys. Most communities near the PLOO remain similar to natural indigenous assemblages characteristic of the San Diego region (see Chapter 9 in City of San Diego 2012), 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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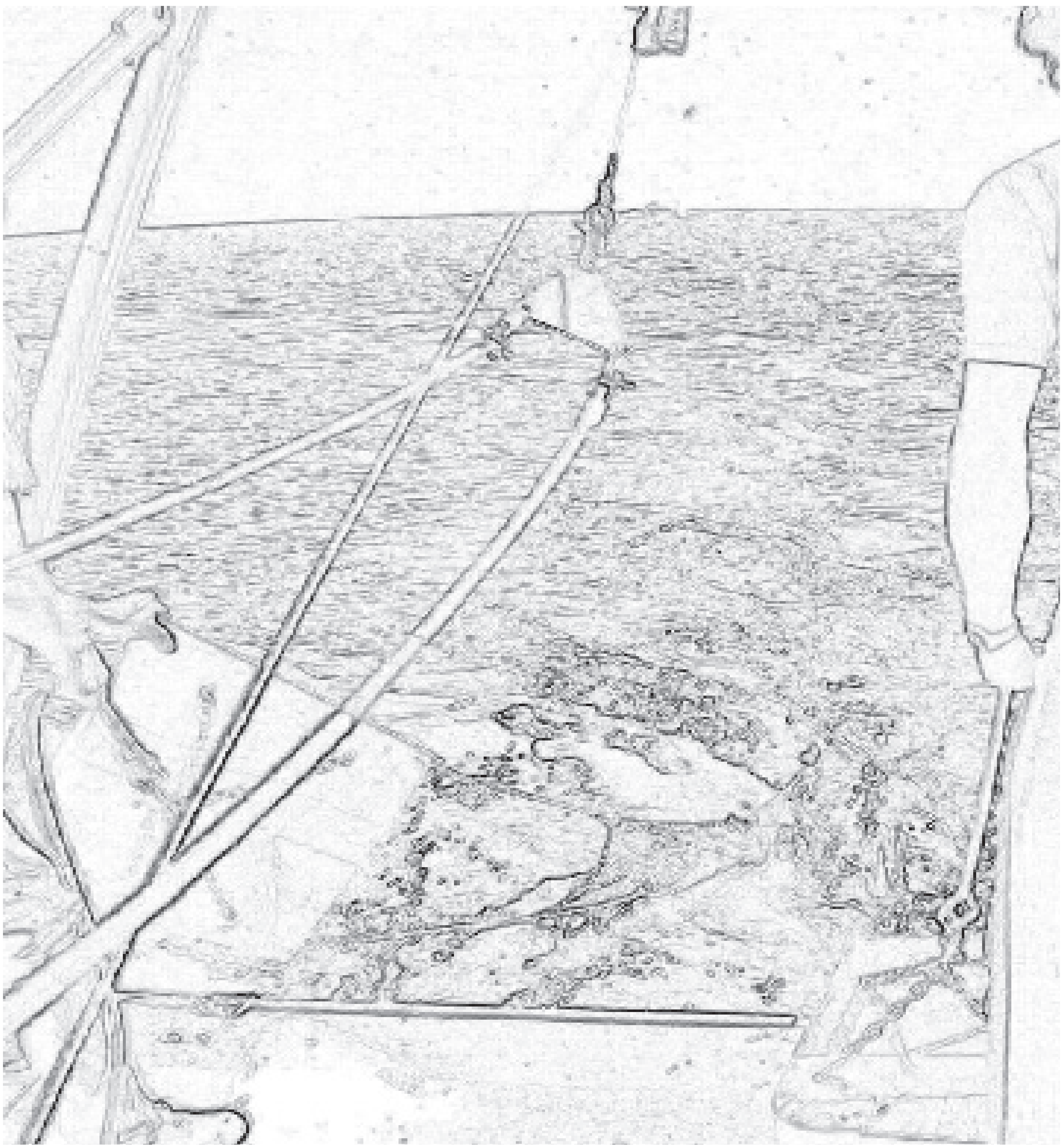
Chapter 6
Demersal Fishes
and Megabenthic Invertebrates



Chapter 6. Demersal Fishes and Megabenthic Invertebrates

Introduction

Bottom dwelling (demersal) fishes and relatively large (megabenthic) mobile invertebrates are monitored by the City of San Diego (City) to examine potential effects of wastewater discharge on marine environments around both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively). These fish and invertebrate communities are conspicuous members of continental shelf habitats and are targeted for monitoring because they are known to play critical ecological roles on the southern California coastal shelf, serving vital functions in wide ranging capacities (Allen et al. 2006, Thompson et al. 1993a, b). Because such organisms live in close proximity to the seafloor, they can be impacted by changes in sediments affected by both point and non-point sources (e.g., discharges from ocean outfalls and storm drains, surface runoff from watersheds, outflows from rivers and bays, disposal of dredge materials; see Chapter 4). For these reasons, their assessment has become an important focus of ocean monitoring programs throughout the world, but especially in the Southern California Bight (SCB) where they have been sampled extensively on the mainland shelf for the past three decades (Stein and Cadien 2009).

In healthy ecosystems, fish and invertebrate communities are known to be inherently variable and influenced by many natural factors. These factors include prey availability (Cross et al. 1985), bottom relief and sediment structure (Helvey and Smith 1985), and changes in water temperatures associated with large scale oceanographic events such as El Niño/La Niña oscillations (Karinen et al. 1985, Stein and Cadien 2009). The mobile nature of many species allows them to migrate toward or away from different habitats, and natural ambient conditions throughout the SCB affect migration patterns of adult fishes and the recruitment of juveniles into different areas (Murawski 1993). Therefore, an understanding of background or reference conditions is necessary before determining whether observed differences in community structure may be related to anthropogenic activities. Such information is available for the monitoring area surrounding the PLOO (e.g., City of San Diego 2007b) and the San Diego region in general (e.g., Allen et al. 1998, 2002, 2007, 2011).

The City relies on a suite of scientifically-accepted indices and statistical analyses to evaluate changes in local fish and invertebrate communities. These include community structure metrics such as species richness, abundance and the Shannon diversity index, while multivariate analyses are used to detect spatial and temporal differences among communities (e.g., Warwick 1993). The use of multiple analyses provides better resolution than single parameters for determining anthropogenically-induced environmental impacts. In addition, trawled organisms are inspected for evidence of fin rot, tumors, skeletal abnormalities, exoskeletal lesions, spine loss, or other anomalies that have been found previously to be indicators of degraded habitats (e.g., Cross and Allen 1993, Stull et al. 2001). All together, the data are used to determine whether fish and invertebrate assemblages near outfalls are similar to those from habitats with similar depth and sediment characteristics, or whether observable impacts from the outfalls or other sources occur.

This chapter presents analyses and interpretations of trawl survey data collected during 2011, as well as a long-term assessment of these communities from 1991 through 2011. The primary goals are to: (1) document the demersal fish and megabenthic invertebrate communities present during the year, (2) determine the presence or absence of biological impacts associated with wastewater discharge, and (3) identify other potential natural

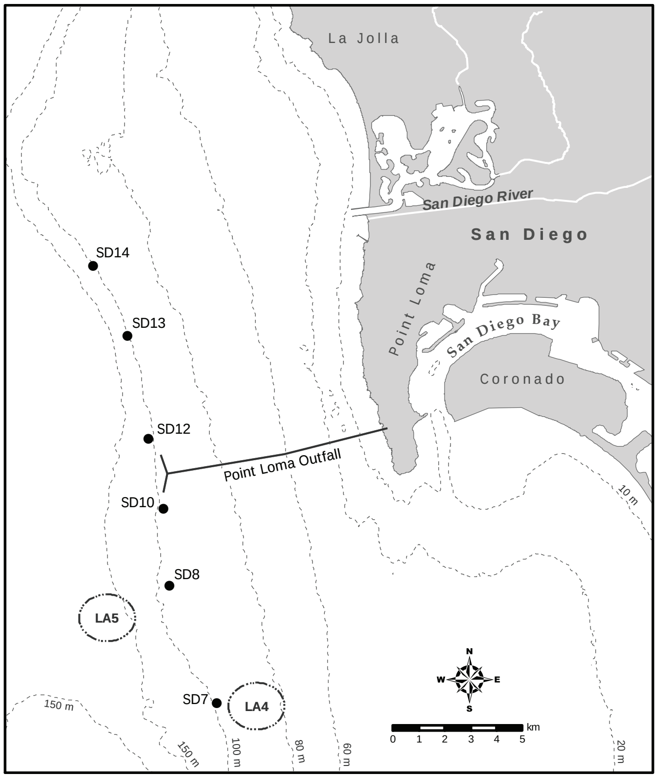


Figure 6.1
Otter trawl station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

and anthropogenic sources of variability to the local marine ecosystem.

Materials and Methods

Field Sampling

Trawl surveys were conducted at six fixed monitoring sites in the PLOO region during January and July 2011 (Figure 6.1). These trawl stations, designated SD7, SD8, SD10, SD12, SD13 and SD14, are located along the 100-m depth contour, and encompass an area ranging from 9 km south to 8 km north of the PLOO. The two stations considered to represent "nearfield" conditions (i.e., SD10, SD12) are located within 1000 m of the outfall wye. A single trawl was performed at each station during each survey using a 7.6-m Marinovich otter trawl fitted with a 1.3-cm cod-end mesh net. The net was towed for 10 minutes of bottom time at a speed of about 2.0 knots along a predetermined heading.

The total catch from each trawl was brought onboard the ship for sorting and inspection. All fishes and invertebrates captured were identified to species or to the lowest taxon possible. If an animal could not be identified in the field, it was returned to the laboratory for further identification. For fishes, the total number of individuals and total biomass (kg, wet weight) were recorded for each species. Additionally, each individual fish was inspected for physical anomalies, indicators of disease (e.g., tumors, fin erosion, discoloration), as well as the presence of external parasites. Lengths of individual fish were measured to centimeter size class on measuring boards; total length (TL) was measured for cartilaginous fishes and standard length (SL) was measured for bony fishes. For invertebrates, the total number of individuals was recorded per species.

Data Analyses

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

Multivariate analyses of demersal fish communities sampled in the region were performed using data collected from 1991 through 2011. In order to reduce statistical noise due to seasonal variation in population abundances, analyses were limited to data from summer (mostly July) surveys only. PRIMER software was used to examine spatio-temporal patterns among fish assemblages

Table 6.1

Demersal fish species collected in 12 trawls conducted in the PLOO region during 2011. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
Pacific sanddab	40	100	153	153	Bigmouth sole	<1	33	<1	2
Stripetail rockfish	15	100	57	57	Greenspotted rockfish	<1	25	<1	3
Halfbanded rockfish	14	92	56	61	Spotfin sculpin	<1	8	<1	7
California lizardfish	12	100	45	45	Slender sole	<1	42	<1	1
Longspine combfish	5	100	18	18	Roughback sculpin	<1	33	<1	2
Dover sole	5	100	18	18	Spotted cusk-eel	<1	17	<1	3
Pink seaperch	3	92	10	11	California skate	<1	8	<1	5
Shortspine combfish	2	100	8	8	Pygmy poacher	<1	25	<1	1
English sole	1	100	4	4	Blackbelly eelpout	<1	17	<1	1
Yellowchin sculpin	<1	42	3	7	Greenblotched rockfish	<1	17	<1	1
Squarespot rockfish	<1	17	2	14	Tiger rockfish	<1	17	<1	1
Greenstriped rockfish	<1	58	2	3	Blacktip poacher	<1	8	<1	1
California tonguefish	<1	58	2	3	Roundel batfish	<1	8	<1	1
Plainfin midshipman	<1	50	2	3	Shortbelly rockfish	<1	8	<1	1
California scorpionfish	<1	42	2	4	Thornback	<1	8	<1	1
Hornyhead turbot	<1	50	1	3					

(Clarke 1993, Warwick 1993, Clarke and Gorley 2006). Abundance data were square-root transformed to lessen the influence of abundant species and increase the importance of rare species, and a Bray-Curtis similarity matrix was created using station and year as factors. Because species composition was sparse at some stations, a "dummy" species with an abundance value of 1 was added to all samples prior to computing similarities (Clarke and Gorley 2006). A 2-way crossed ANOSIM (max. no. of permutations = 9999) was conducted to determine whether communities varied by station or year across the region. To visually depict the relationship of individual trawls to each other based on fish composition, hierarchical agglomerative clustering (cluster analysis) with group-average linking was conducted. Similarity profile (SIMPROF) analyses were used to confirm the non-random structure of the resultant cluster dendrograms (Clarke et al. 2008). Major ecologically-relevant SIMPROF-supported clades with < 61.29% similarity were retained. Similarity percentages (SIMPER) analysis was used to identify which species were responsible for the greatest contribution to within group similarities (i.e., characteristic species).

Results

Demersal Fish Communities

Thirty-one species of fish were collected in the area surrounding the PLOO in 2011 (Table 6.1). A single tiger rockfish (*Sebastes nigroinetus*) collected at SD13 in July represented a new record for the region (Appendix E.1). The total catch for the year was 4646 individuals (Appendix E.2), representing an average of 387 fish per trawl. As in previous years, Pacific sanddabs were dominant. This species occurred in every haul and accounted for 40% of all fishes collected at an average of 153 individuals per trawl. No other species contributed to more than 15% of the total catch during the year. For example, California lizardfish, stripetail rockfish, longspine combfish, shortspine combfish, Dover sole, and English sole also occurred in every trawl, but at much lower numbers (~4–57 individuals per haul). Other species collected frequently (≥50% of the trawls) but in relatively low numbers (≤56 individuals per haul) included halfbanded rockfish, pink seaperch, greenstriped rockfish, California tonguefish, plainfin midshipman, and hornyhead turbot. The

Table 6.2

Summary of demersal fish community parameters for PLOO trawl stations sampled during 2011. Data are included for species richness, abundance, diversity (H'), and biomass (kg, wet weight). SD = standard deviation.

Station	January	July
Species Richness		
SD7	17	14
SD8	14	15
SD10	15	14
SD12	16	13
SD13	14	16
SD14	14	15
Survey Mean	15	15
Survey SD	1	1
Abundance		
SD7	267	337
SD8	294	520
SD10	561	441
SD12	383	190
SD13	532	297
SD14	297	527
Survey Mean	389	385
Survey SD	128	134
Diversity		
SD7	1.9	1.3
SD8	1.9	1.4
SD10	1.7	1.6
SD12	1.7	2.0
SD13	1.9	1.7
SD14	1.5	1.4
Survey Mean	1.8	1.6
Survey SD	0.2	0.3
Biomass		
SD7	5.9	5.4
SD8	4.6	9.9
SD10	8.7	10.6
SD12	11.2	4.9
SD13	14.7	11.8
SD14	16.1	25.8
Survey Mean	10.2	7.2
Survey SD	4.7	2.6

majority of fishes captured in the region tended to be relatively small with an average length ≤21 cm (Appendix E.1). The only exception was the California skate, which averaged 38 cm in length for the five specimens collected.

No more than 17 species of fish occurred in any one haul during 2011, and the corresponding diversity (H') values were all ≤2.0 (Table 6.2). Total abundance for all species combined ranged from 190 to 561 fishes per haul. This high variation in abundance was mostly due to differences in the numbers of Pacific sanddab, halfbanded rockfish, stripetail rockfish, and California lizardfish captured at each station (Appendix E.2). Total fish biomass ranged from 4.6 to 25.8 kg per haul, with higher values coincident with either greater numbers of fishes or the presence of large individuals (Appendix E.3). For example, one roundel batfish accounted for 2.1 kg of the total biomass at station SD12 in January, whereas 225 Pacific sanddab and 213 halfbanded rockfish accounted for about 21.8 kg of the biomass at station SD14 in July. No spatial patterns related to the outfall were observed for species richness, diversity, abundance, or biomass.

Large fluctuations in populations of a few dominant species have been the primary factor contributing to the high variation in fish community structure off Point Loma since 1991 (Figures 6.2, 6.3). Over the years, species richness values for individual trawls have ranged from 7 to 26 species, while total abundance per haul has varied from 44 to 2322 individuals per station per survey. Oscillations of overall abundance primarily reflect changes in Pacific sanddab, longfin sanddab, and Dover sole populations that tend to occur across large portions of the study area (i.e., over multiple stations). In addition, intra-station variability has been due to large hauls of species such as yellowchin sculpin, longspine combish, and halfbanded rockfish that occur infrequently at one or two stations. Overall, none of the observed changes appear to be associated with wastewater discharge.

Classification of Fish Assemblages

Multivariate analyses performed on data collected between 1991 and 2011 (summer surveys only) discriminated between ten main types of fish assemblages in the Point Loma outfall region (Figure 6.4). ANOSIM results revealed that fish

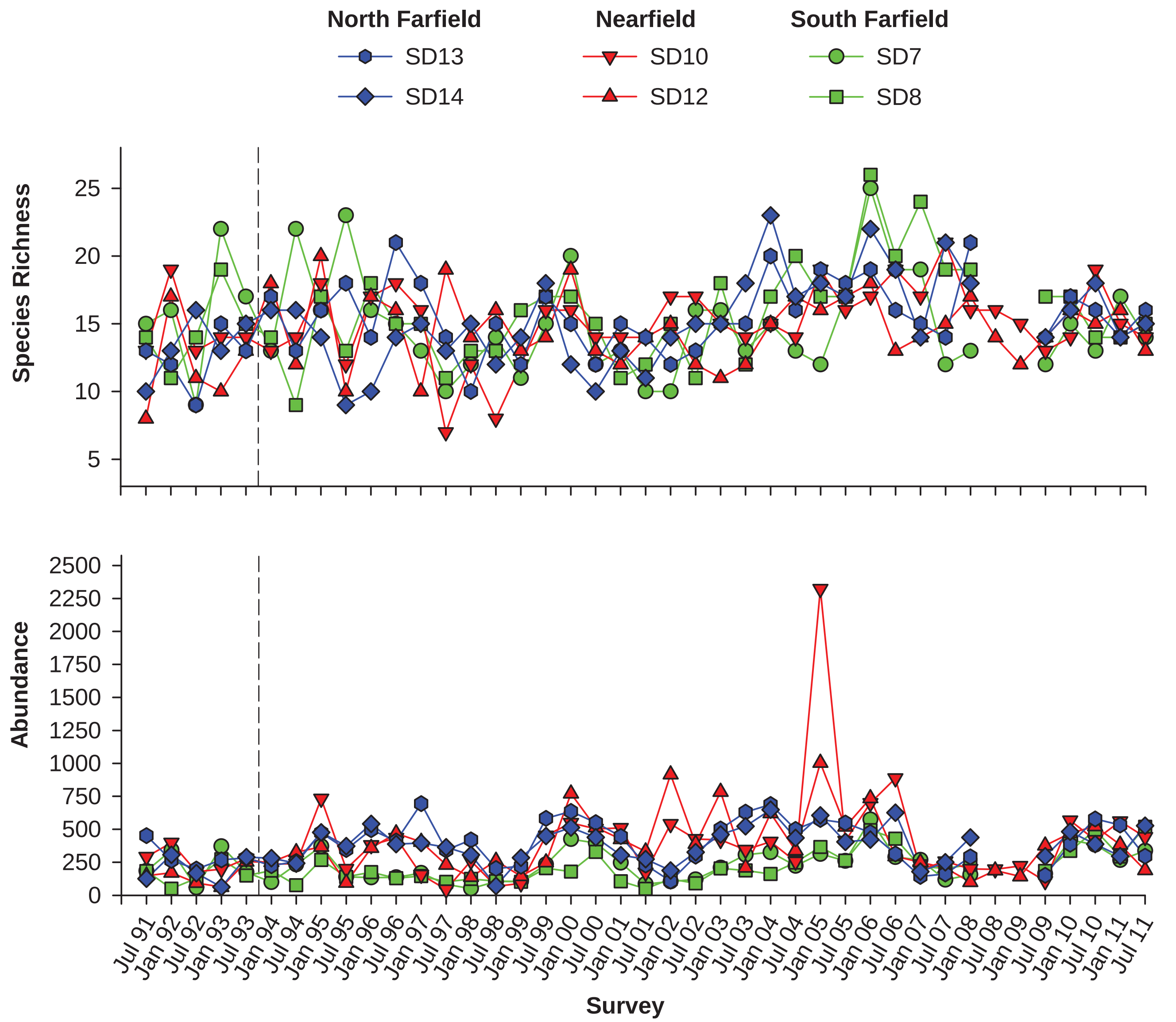


Figure 6.2

Species richness and abundance of demersal fishes collected at each PLOO trawl station between 1991–2011. Data are total number of species and total number of individuals per haul, respectively. Dashed lines indicate onset of wastewater discharge. Only stations SD10 and SD12 were sampled during July 2008 and January 2009 due to a Bight'08 resource exchange.

communities in the region differed significantly by site and by year (Appendix E.4). However, the distribution of assemblages in 2011 was generally similar to that seen in previous years, especially between 2006–2010, and there were no discernible patterns associated with proximity to the outfall. Instead, most differences appear more closely related to large-scale oceanographic events (e.g., El Niño in 1998) or the unique characteristics of a specific station location. For example, stations SD7 and SD8 located south of the outfall often grouped apart from the remaining stations. These assemblages (cluster groups A–J) were distinguished by differences in the relative abundances of the common species present, although most were dominated by Pacific sanddabs. The composition and main characteristics of each cluster group are described below.

Cluster groups A, B and E each comprised a single trawl outlier (Figure 6.4). Together, they accounted for ~3% of all hauls included in the analysis. Although most of these catches were

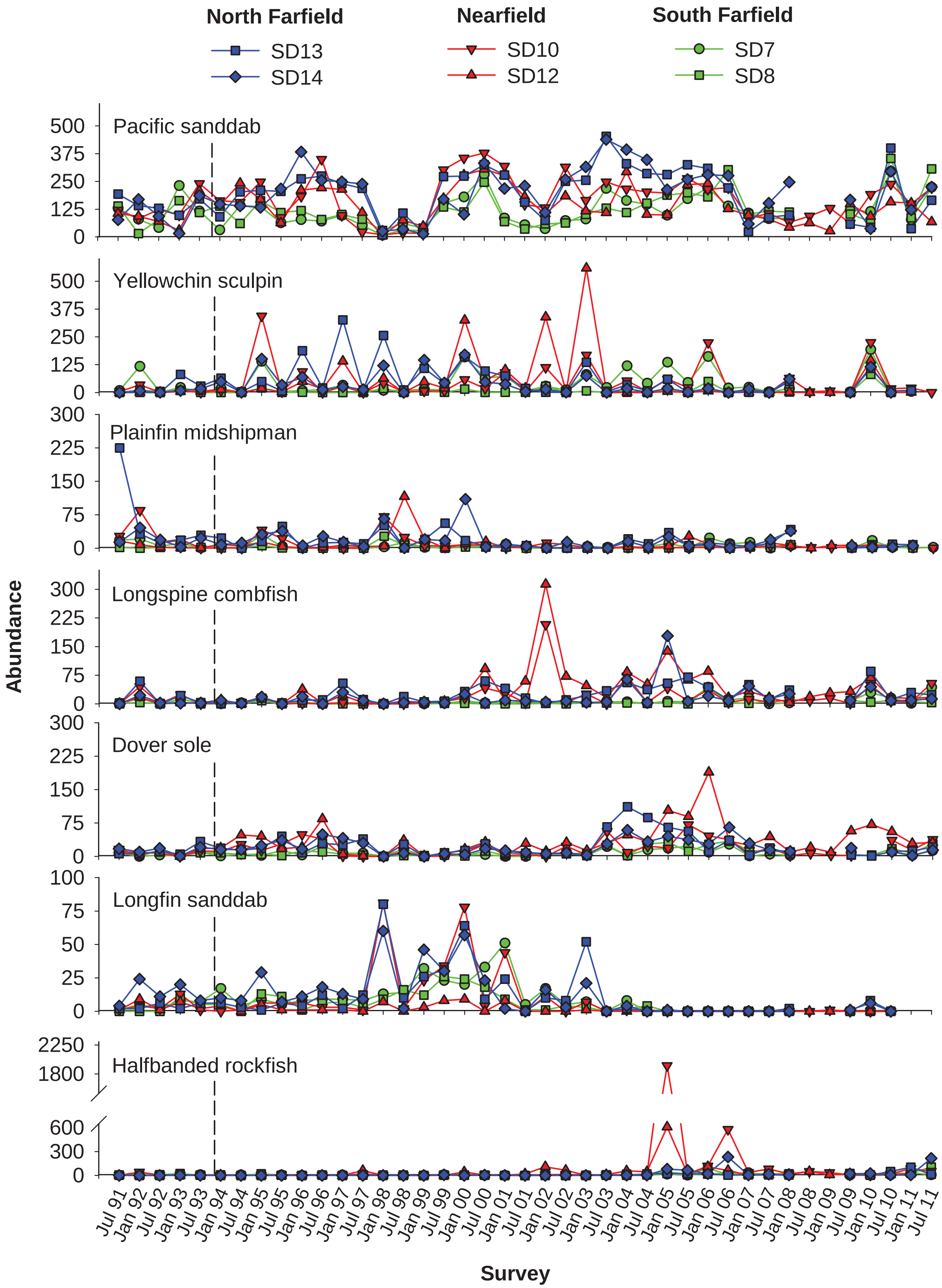


Figure 6.3

The seven most abundant fish species collected in the PLOO region between 1991–2011. Data are total number of individuals per haul. Dashed lines indicate onset of wastewater discharge. Only stations SD10 and SD12 were sampled during July 2008 and January 2009 due to a Bight'08 resource exchange.

dominated by Pacific sanddabs, they were unique compared to the other assemblages in terms of either low mean abundance, fewer species, or relatively high numbers of less common fishes (e.g., midshipman, rockfish) (Table 6.3). The assemblage at station SD10 in 1997 (group A) was characterized by the fewest species and lowest abundance of any cluster group (i.e., 7 species, 44 fishes), as well as the fewest Pacific sanddabs. The assemblage at SD12 in 1998 (group B) was unique because it contained high numbers of plainfin midshipman (116 individuals). The assemblage at SD12 in 1997 (group E) had the highest species richness of any cluster group, and relatively high numbers of halfbanded rockfish (60 individuals) and squarespot rockfish (23 individuals).

Cluster groups C, G and H comprised 4, 3 and 6 outlier trawls, respectively (Figure 6.4). Combined, these groups accounted for ~11% of all hauls included in the analysis. Group C occurred at the following stations: (a) station SD8 in 1994, (b) station SD14 in 1998, and (c) stations SD7 and SD8 in 2001. This group had the second lowest mean abundance (~71 fishes per haul) and species richness (~11 species per haul) of any cluster group (Table 6.3). SIMPER revealed that relative abundances of Pacific sanddabs (~47 individuals per haul), longfin sanddab (~2 individuals per haul), Dover sole (~3 individuals per haul), and greenblotched rockfish (~1 individual per haul) were characteristic of the assemblages represented by this group. Group G occurred during 1999 at stations SD10, SD13, and SD14. This group had the most species on average (~17 species per haul), the highest mean abundance (~495 fishes per haul), and was characterized by relative abundances of Pacific sanddabs (~248 individuals per haul), stripetail rockfish (~102 individuals per haul), longfin sanddab (~32 individuals per haul), yellowchin sculpin (~31 individuals per haul), and plainfin midshipman (~26 individuals per haul). Group H occurred at stations SD7 in 2003–05, SD8 in 1991–92, and SD10 in 2001, and was characterized by relative abundances of Pacific sanddab (~150 individuals per haul), yellowchin sculpin (~20 individuals per haul), Dover sole (~15 individuals per haul), shortspine combfish (~5 individuals per haul), and plainfin midshipman (~2 individuals per haul).

Cluster group D comprised 30 trawls, including 18 of 24 hauls from stations SD7 and SD8 sampled between 1991–2002, as well as hauls from: (a) every station sampled during 1991–1992 except SD8, (b) stations SD10 and SD12 sampled in 1995, (c) station SD10 sampled in 1998, and (d) station SD7 sampled in 2007 (Figure 6.4). Overall, this group averaged 13 species per haul and ~162 fishes per haul (Table 6.3). SIMPER revealed that relative abundances of Pacific sanddab (~97 individuals per haul), plainfin midshipman (~15 individuals per haul), Dover sole (~10 individuals per haul), longfin sanddab (~7 individuals per haul), and California tonguefish were characteristic of the assemblages represented by this group.

Cluster group F included 97% of the trawls conducted in the PLOO region over the past six years (Figure 6.4). It also included two hauls from SD12 sampled in 2003 and 2004 and three from SD8 sampled between 2003 and 2005. Assemblages represented by group F were characterized by ~16 species per haul, ~332 fishes per haul, and the relative abundances of Pacific sanddabs (~175 individuals per haul), halfbanded rockfish (~49 individuals per haul), Dover sole (~24 individuals per haul), longspine combfish (~13 individuals per haul), and shortspine combfish (~10 individuals per haul) (Table 6.3).

Cluster groups I and J represented most assemblages sampled at stations around or north of the PLOO between 1993 and 2005 (i.e., stations SD10-SD14). Exceptions included some of the outliers described above (i.e., all or parts of groups A, B, C, E, G) that occurred around the time of the 1998 El Niño. Group I averaged 14 species and 307 fishes per haul, and was characterized by relative abundances of Pacific sanddab (~215 individuals per haul), Dover sole (~23 individuals per haul), yellowchin sculpin (~15 individuals per haul), stripetail rockfish (~10 individuals per haul), and longfin

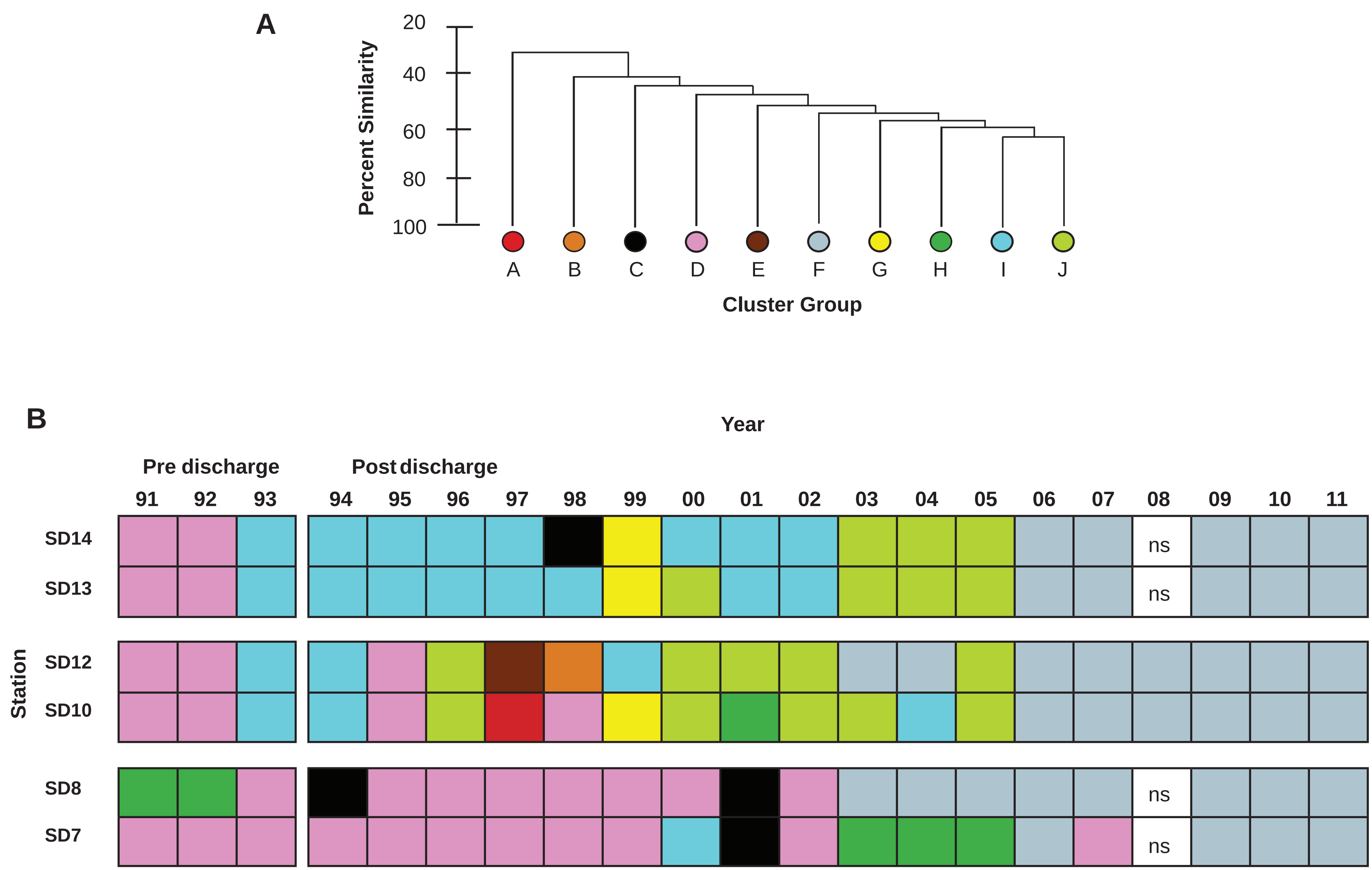


Figure 6.4
Results of cluster analysis of demersal fish assemblages at PLOO trawl stations between 1991 and 2011 (summer surveys only). Data are presented as (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time.

Table 6.3

Description of demersal fish cluster groups A–J defined in Figure 6.4. Data include number of hauls, mean species richness, mean total abundance, and mean abundance of the top five most abundant species. Bold values indicate species that were considered most characteristic of that group according to SIMPER analysis.

	Cluster Groups									
	A[a]	B[a]	C	D	E[a]	F	G	H	I	J
Number of Hauls	1	1	4	30	1	36	3	6	23	17
Mean Species Richness	7	16	11	13	19	16	17	14	14	16
Mean Abundance	44	261	71	162	231	332	495	213	307	467
Species	**Mean Abundance**									
Pacific sanddab	23	75	**47**	**97**	110	**175**	**248**	**150**	**215**	**301**
Halfbanded rockfish	16			2	60	**49**	7	3	1	**16**
Longfin sanddab	1		**2**	**7**		<1	**32**		**8**	1
Pink seaperch	1	4	1	1	1	4	4	2	6	4
Spotfin sculpin	1		1	2		1				1
Gulf sanddab	1	5	1	<1			10	<1	<1	<1
Greenspotted rockfish	1			<1	1	<1	<1		1	<1
Stripetail rockfish		1	4	8	5	7	**102**	<1	**10**	6
Dover sole		36	**3**	**10**	1	**24**	5	**15**	**23**	**48**
Yellowchin sculpin			3	4		2	**31**	**20**	**15**	**16**
Longspine combfish		7	**2**	1	2	**13**	5	3	5	**33**
Greenblotched rockfish			**1**	1	8	<1	1	2	1	1
Plainfin midshipman		116	1	**15**	4	4	**26**	**2**	11	6
California lizardfish			1	<1		21	6			
California tonguefish			1	**3**	1	1	3	2	<1	1
Greenstriped rockfish			1	<1		3	<1	1	<1	1
Squarespot rockfish			<1	<1	23	1				
Slender sole		2	<1	1		5	6	1	2	12
Shortspine combfish				2	3	**10**		**5**	<1	4
Vermilion rockfish					6					

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

sanddab (~8 individuals per haul). Group J averaged 16 species and 467 fishes per haul, and was characterized by relative abundances of Pacific sanddab (~301 individuals per haul), Dover sole (~48 individuals per haul), longspine combfish (~33 individuals per haul), yellowchin sculpin and halfbanded rockfish (both ~16 individuals per haul).

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the PLOO region during 2011. There were no incidences of fin rot, discoloration, or skin lesions among fishes collected during the year; however, tumors were observed on 4.1% of Dover sole (6 individuals) collected in July. Five of these individuals were taken at station SD8. Evidence of parasitism was also very low for trawl-caught fishes off Point Loma. The copepod *Phrixocephalus cincinnatus* infected <1.0% of the Pacific sanddabs collected during the year; this eye parasite was found on fish from all stations sampled except for SD8. Additionally, four individuals of the cymothoid isopod, *Elthusa vulgaris*, were identified as part of the trawl catch during the year (see Appendix E.5). Since cymothoids often become detached from

Table 6.4

Species of megabenthic invertebrates collected in 12 trawls conducted in the PLOO region during 2011. PA=percent abundance; FO=frequency of occurrence; MAH=mean abundance per haul; MAO=mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
Lytechinus pictus	85	100	949	949	*Ophiopholis bakeri*	< 1	17	< 1	3
Strongylocentrotus fragilis	6	42	65	155	*Arctonoe pulchra*	<1	8	<1	4
Ophiura luetkenii	5	100	54	54	*Elthusa vulgaris*	<1	25	<1	1
Luidia foliolata	1	100	13	13	*Calliostoma tricolor*	<1	8	<1	3
Acanthoptilum sp	<1	42	6	14	*Cancellaria crawfordiana*	<1	25	<1	1
Pleurobranchaea californica	<1	100	5	5	*Calliostoma turbinum*	<1	25	<1	1
Luidia asthenosoma	<1	83	3	4	*Antiplanes catalinae*	<1	8	<1	3
Astropecten californicus	<1	92	3	3	*Paguristes bakeri*	<1	17	<1	1
Parastichopus californicus	<1	75	2	3	*Rossia pacifica*	<1	17	<1	1
Thesea sp B	<1	50	2	4	*Metridium farcimen*	<1	17	<1	1
Philine auriformis	<1	58	1	2	*Cancellaria cooperii*	<1	8	<1	1
Neosimnia barbarensis	<1	25	1	5	*Tritonia diomedea*	<1	8	<1	1
Nymphon pixellae	<1	17	1	7	*Amphiodia* sp	<1	8	<1	1
Octopus rubescens	<1	50	<1	2	*Amphichondrius granulatus*	<1	8	<1	1
Acanthodoris brunnea	<1	25	<1	3	*Parapagurodes laurentae*	<1	8	<1	1
Florometra serratissima	<1	17	<1	5	*Podochela lobifrons*	<1	8	<1	1
Sicyonia ingentis	<1	42	<1	2	*Barbarofusus barbarensis*	<1	8	<1	1
Philine alba	<1	17	<1	4	*Leptogorgia chilensis*	<1	8	<1	1
Hinea insculpta	<1	33	<1	2	*Dendronotus frondosus*	<1	8	<1	1
Crangon alaskensis	<1	25	<1	2	*Telesto californica*	<1	8	<1	1
Megasurcula carpenteriana	<1	17	<1	3	*Suberites latus*	<1	8	<1	1
Armina californica	<1	17	<1	3					

their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these isopods. However, *E. vulgaris* is known to be especially common on sanddabs and California lizardfish in southern California waters, where it may reach infestation rates of 3% and 80%, respectively (see Brusca 1978, 1981).

Megabenthic Invertebrate Communities

A total of 13,378 megabenthic invertebrates (~1115 per trawl) representing 43 taxa were collected in 2011, with no new species recorded (Table 6.4, Appendix E.5). The sea urchin *Lytechinus pictus* was the most abundant and most frequently captured species (~949 individuals per haul), accounting for 85% of the total invertebrate abundance and occurring in 100% of the trawls. The brittle star *Ophiura luetkenii*, the sea star *Luidia foliolata*, and the nudibranch *Pleurobranchaea californica* were also collected in every haul, but in much lower numbers (≤54 individuals per haul). Other species collected frequently (≥50% of the trawls) but in relatively low numbers (≤3 per haul) included the sea stars *Astropecten californicus* and *Luidia asthenosoma*, the octocoral *Thesea* sp. B, the sea cucumber *Parastichopus californicus,* the gastropod *Philine auriformis*, and the octopus *Octopus rubescens*.

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.5). For each haul, species richness ranged from 10 to 22 species, diversity (H') ranged from 0.2 to 1.3 units, and total abundance ranged from 279 to 2107 individuals. Patterns in total invertebrate abundance mirrored variation in populations of *Lytechinus pictus* because of its overwhelming dominance at all but

Table 6.5
Summary of megabenthic invertebrate community parameters for PLOO trawl stations sampled during 2011. Data are included for species richness, abundance, and diversity (H'). SD = standard deviation.

Station	January	July
Species Richness		
SD7	15	22
SD8	14	14
SD10	13	12
SD12	18	13
SD13	12	12
SD14	11	10
Survey Mean	14	14
Survey SD	2	4
Abundance		
SD7	1494	2107
SD8	1250	1858
SD10	1307	1878
SD12	1006	279
SD13	447	538
SD14	572	642
Survey Mean	1013	1217
Survey SD	422	814
Diversity		
SD7	0.2	0.4
SD8	0.3	0.3
SD10	0.3	0.2
SD12	0.6	1.1
SD13	1.2	1.3
SD14	1.3	1.2
Survey Mean	0.6	0.7
Survey SD	0.5	0.5

one station (Appendix E.6). For example, in July, stations SD7, SD8 and SD10 had much higher invertebrate abundances than the other three stations due to relatively large catches of *L. pictus* (i.e., ≥1700 per haul versus ≤300 per haul). Similarly, low diversity values (≤1.3) for the region were caused by the numerical dominance of this single species.

Variations in megabenthic invertebrate community structure in the Point Loma outfall region generally reflect changes in species abundance (Figures 6.5, 6.6). Both species richness and total abundance have varied over the years (e.g., 3–29 species per trawl, 16–11,177 individuals per haul). These large differences typically have been due to fluctuations in populations of several dominant species, including the sea urchins *Lytechinus pictus* and *Strongylocentrotus fragilis*, the sea pen *Acanthoptilum* sp, the shrimp *Sicyonia ingentis*, and the sea star *Astropectin californicus*. For example, stations SD8 and SD10 have among the highest average abundances of invertebrates since 1991 due to relatively large hauls of *L. pictus*. Additionally, abundances of *L. pictus* and *A. californicus* are typically much lower at the two northern sites, which likely reflects differences in sediment composition (e.g., fine sands versus mixed coarse per fine sediments, see Chapter 4). None of the observed variability in the trawl-caught invertebrate communities appears to be related to the Point Loma outfall.

Discussion

Pacific sanddabs dominated fish assemblages surrounding the PLOO in 2011 as they have since monitoring began in 1991. This species occurred at all stations and accounted for 40% of the total catch. Other commonly captured, but less abundant species, included California lizardfish, stripetail rockfish, longspine combfish, shortspine combfish, Dover sole, English sole, halfbanded rockfish, pink seaperch, greenstriped rockfish, California tonguefish, plainfin midshipman, and hornyhead turbot. The majority these fishes tended to be relatively small with an average length ≤20 cm. Although the composition and structure of the fish assemblages varied among stations, these differences were mostly due to natural fluctuations of common fish populations.

Assemblages of megabenthic, trawl-caught invertebrates in the region were dominated by the sea urchin *Lytechinus pictus*, which occurred in all trawls and accounted for 85% of the total invertebrate abundance. Other species collected frequently included the brittle star *Ophiura luetkenii*, the sea stars *Luidia foliolata*, *L. asthenosoma*

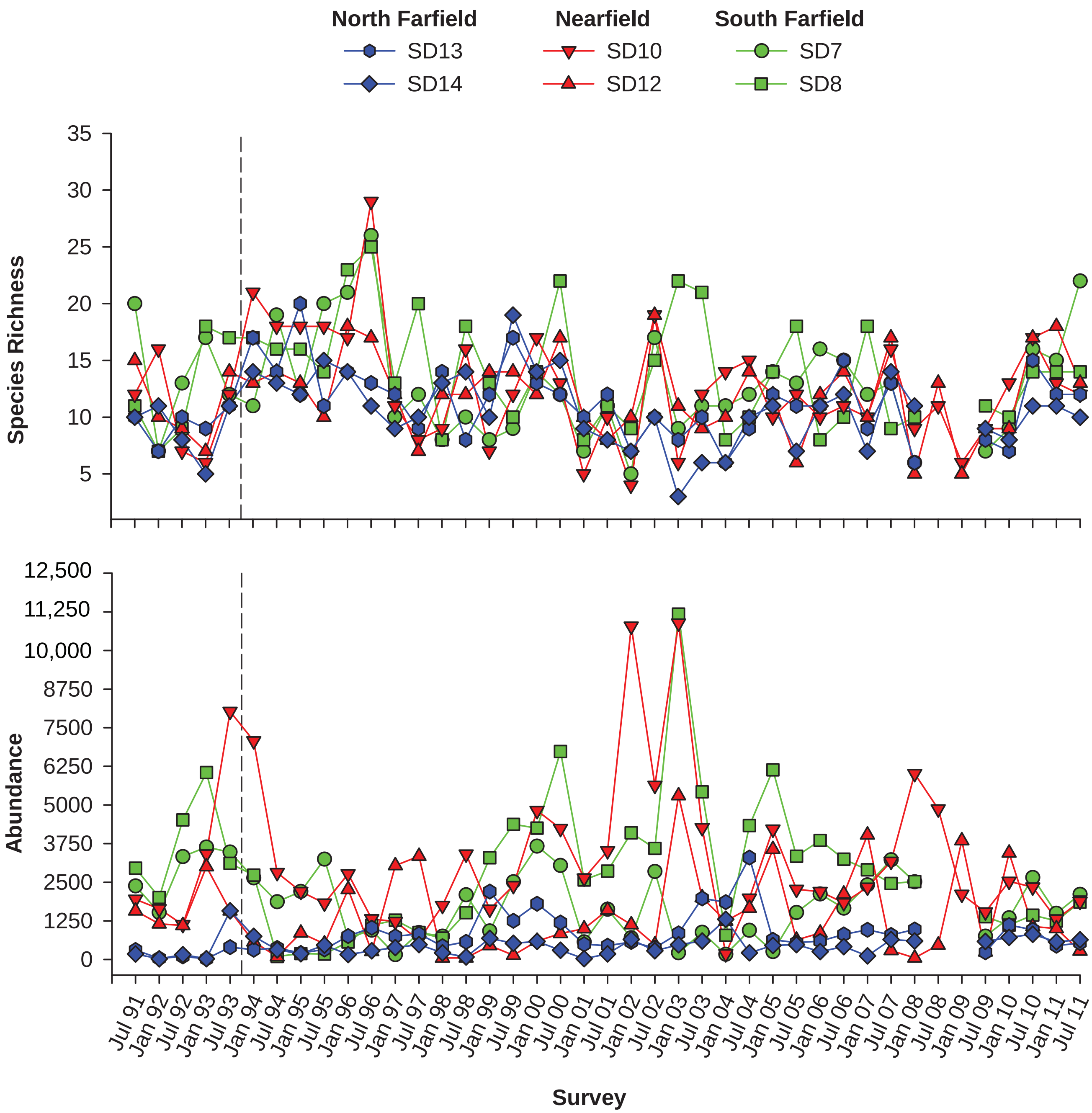


Figure 6.5

Species richness and abundance of megabenthic invertebrates collected at each trawl station between 1991–2011. Data are total number of species and total number of individuals per haul, respectively. Dashed lines indicate onset of wastewater discharge. Only stations SD10 and SD12 were sampled during July 2008 and January 2009 due to a Bight'08 resource exchange.

and *Astropecten californicus*, the nudibranch *Pleurobranchaea californica*, the octocoral *Thesea* sp. B, the sea cucumber *Parastichopus californicus*, the gastropod *Philine auriformis*, and the octopus *Octopus rubescens*. As with demersal fishes in the PLOO region, the composition and structure of megabenthic assemblages varied among stations, reflecting population fluctuations in the species mentioned above.

Overall, results of the 2011 trawl surveys provide no evidence that wastewater discharged through

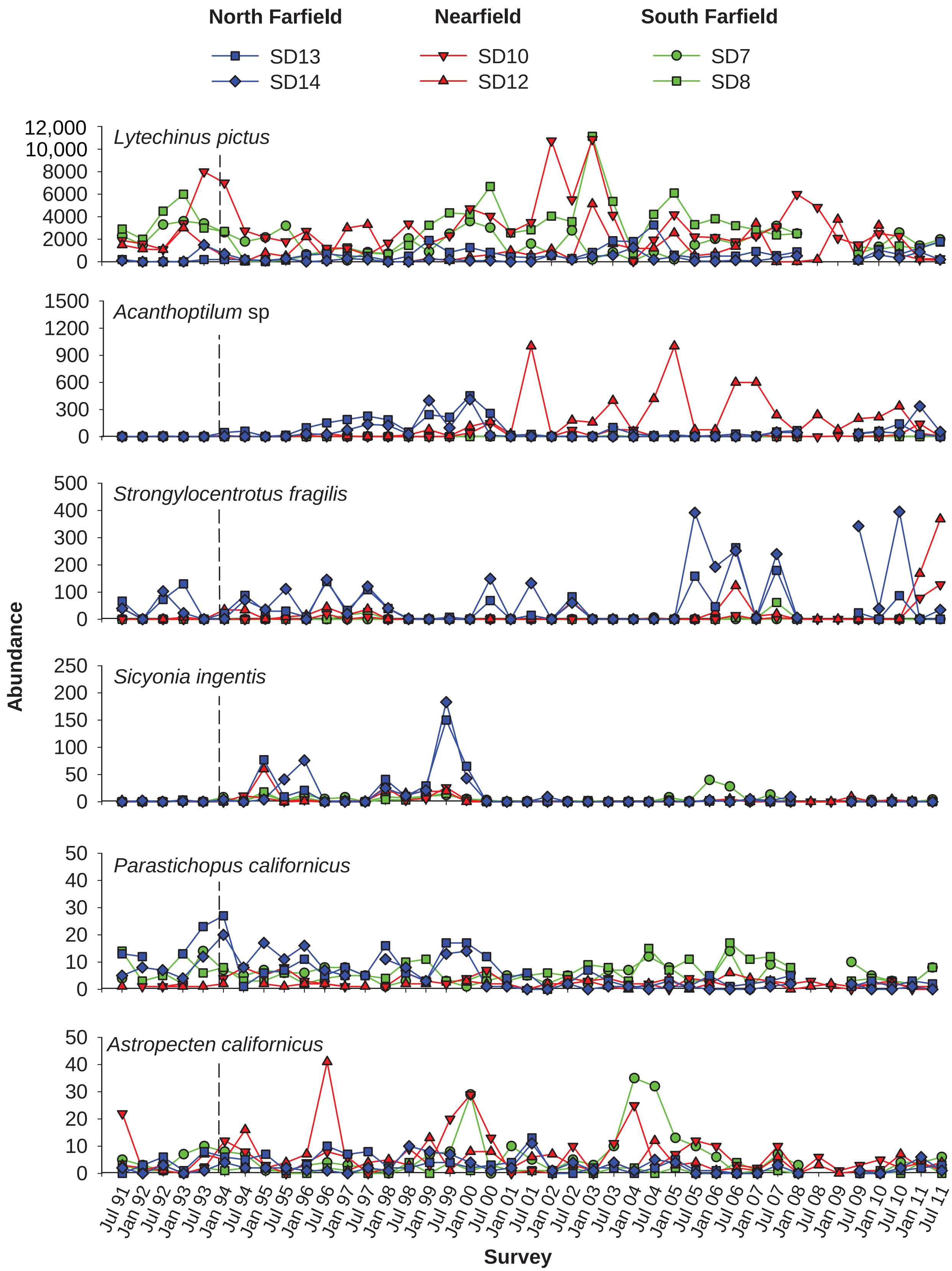


Figure 6.6

The six most abundant megabenthic invertebrate species collected in the PLOO region between 1991–2011. Data are total number of individuals per haul. Dashed lines indicate onset of wastewater discharge. Only stations SD10 and SD12 were sampled during July 2008 and January 2009 due to a Bight'08 resource exchange.

the PLOO has affected either demersal fish or megabenthic invertebrate communities in the region. Although highly variable, patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away, with no discernible changes in the region following the onset of wastewater discharge through the PLOO in 1994. Instead, the high degree of variability present during the year was similar to that observed in previous years (e.g., City of San Diego 2005–2011), including the period before initiation of wastewater discharge (City of San Diego 2007b). Changes in these communities appear to be more likely due to natural factors such as changes in ocean water temperatures associated with large-scale oceanographic events (e.g., El Niño or La Niña) or to the mobile nature of many of the resident species collected. Finally, the absence of disease or other physical abnormalities in local fishes suggests that populations in the area continue to be healthy.

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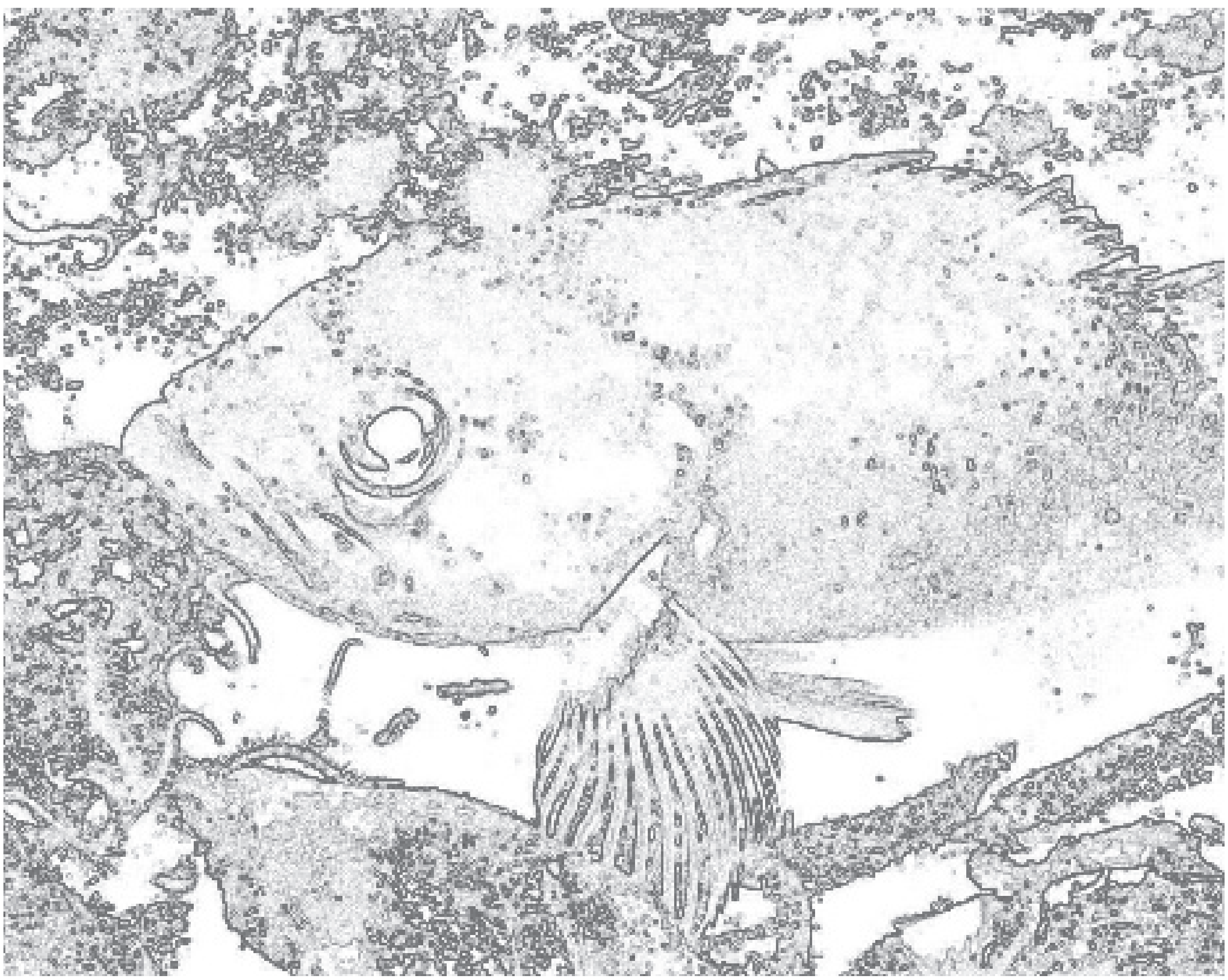
Chapter 7
Bioaccumulation of Contaminants in Fish Tissues



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 and South Bay Ocean Outfalls (PLOO and SBOO, respectively) 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) liver tissues are analyzed for trawl-caught fishes; (2) muscle tissues are analyzed for fishes collected by hook and line (rig fishing). Species collected by trawling activities (see Chapter 6) are representative of the general demersal fish community, and are targeted based on their overall prevalence and ecological significance. The chemical analysis of liver tissues in these fish is especially important for assessing population effects because this is the organ where contaminants typically concentrate (i.e., bioaccumulate). In contrast, fishes targeted for capture by rig fishing represent species that are 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 tissues are analyzed from these fishes because it is the tissue most often consumed by humans. All liver and muscle samples collected during the year are analyzed for contaminants as specified in the NPDES permit that governs the PLOO monitoring program (see Chapter 1). Most of these contaminants are also sampled for NOAA's 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 summaries and interpretations of all chemical analyses that were performed on the tissues of fishes collected in the PLOO region during 2011. The primary goals are to: (1) document levels of contaminant loading in local demersal fishes, (2) identify possible effects of wastewater discharge on contaminant bioaccumulation in fishes from the PLOO region, and (3) identify other potential natural and anthropogenic sources of pollutants to the local marine ecosystem.

Materials and Methods

Field Collection

Fishes were collected during October 2011 from four trawl zones and two rig fishing stations (Figure 7.1). Each trawl zone represents an area centered around one or two specific trawl stations as specified in Chapter 6. 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. Zone 2 includes the area within a 1-km radius surrounding northern farfield stations SD13 and SD14. Zone 3 represents the area within a 1-km radius surrounding farfield

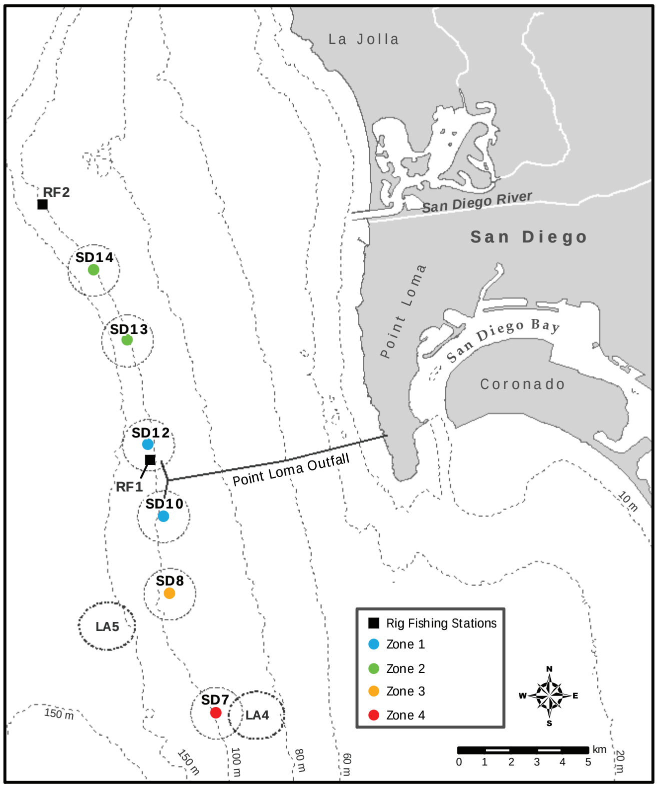


Figure 7.1
Otter trawl and rig fishing station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

station SD8, which is located south of the outfall near the LA5 dredged material disposal site. 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 LA4 disposal site. All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for collection methods). Efforts to collect targeted fish species at the trawl stations were limited to five 10-minute (bottom time) trawls per zone. Fishes collected at the two rig fishing stations were caught within 1 km of the station coordinates using standard rod and reel procedures. Station RF1 is located within 1 km of the outfall and is considered the nearfield site. In contrast, station RF2 is located about 11 km northwest of the outfall and is considered farfield for the analyses herein. Fishing effort was limited to 5 hours at each station.

Pacific sanddabs (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawling zones, while three species of rockfish were collected for analysis of muscle tissues at the rig fishing stations, including chilipepper rockfish (*Sebastes goodei*), flag rockfish (*Sebastes rubrivinctus*), and vermilion rockfish (*Sebastes miniatus*) (Table 7.1).

In order to facilitate collection of sufficient tissue for chemical analysis, only fish ≥13 cm in standard length were retained. These fish were sorted into three composite samples per station, with a minimum of three individuals in each composite. All fish were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were stored at -80°C until 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 and cleaned with a paper towel to remove loose scales and excess mucus. The standard length (cm) and weight (g) of each fish 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 then placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City's Wastewater Chemistry Services Laboratory for analysis within 10 days of dissection.

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

Table 7.1
Species of fish collected from each PLOO trawl zone and rig fishing station during October 2011. Comp = composite; PS = Pacific sanddab; CRF = chilipepper rockfish; VRF = vermilion rockfish; FRF = flag rockfish.

Station/Zone	Comp 1	Comp 2	Comp3
Zone 1	PS	PS	PS
Zone 2	PS	PS	PS
Zone 3	PS	PS	PS
Zone 4	PS	PS	PS
RF1	VRF	VRF	VRF
RF2	CRF	CRF	FRF

Wastewater Chemistry Services Laboratory (City of San Diego 2012a).

Data Analyses

Data summaries for each contaminant include detection rates, minimum, maximum, and mean detected values of each parameter by species. Total chlordane, total DDT (tDDT), and total PCB (tPCB) were calculated for each sample as the sum of all constituents with reported values (see Appendix F.3 for individual constituent values). In addition, the distribution of contaminants with detection rates ≥20% was assessed by comparing concentrations in fishes collected from "nearfield" zone/stations (zone 1, station RF1) to those from "farfield" stations located farther away to the north (zone 2, station RF2) and south (zones 3–4).

Contaminant levels in muscle tissue samples collected in 2011 were compared to state, national, and international limits and standards in order to address seafood safety and public health issues, including: (1) the California Office of Environmental Health Hazard Assessment (OEHHA), which has developed fish contaminant goals for chlordane, DDT, methylmercury, selenium, and PCBs (Klasing and Brodberg 2008); (2) the United States Food and Drug Administration (USFDA), which has set limits on the amount of mercury, total DDT, and chlordane in seafood that is to be sold for human consumption (Mearns et al. 1991); (3) international standards for acceptable concentrations of various metals and DDT (Mearns et al. 1991).

In order to examine spatial and temporal patterns in contaminant loading of fishes collected from the PLOO region, multivariate analyses were performed using a 3-year data matrix composed of the main chemical parameters analyzed for each tissue sample (i.e., trace metals, pesticides, total PCBs). This analysis was conducted for all data collected between 2009 and 2011 using PRIMER software (see Clarke and Warwick 2001, Clarke and Gorley 2006). Data were limited to these three years to limit the influence of differing MDLs (Appendix F.2). Any non-detects (i.e., analyte concentrations < MDL) were first converted to "0" values to avoid data deletion issues with the clustering program, after which the data were normalized and two Euclidean distance matrices created: one for liver tissue and one for muscle tissue. For liver tissue analyses, a two-way crossed ANOSIM was conducted to determine if significant differences occurred among survey period or lipid content. For muscle tissue analyses, a two-way crossed ANOSIM was conducted to determine if significant differences occurred among survey period or species (lipids not tested since all values fell within same lipid bin; see Appendix F.4 for species list). Similarity percentages (SIMPER) analyses were used to determine which parameters accounted for significant differences identified through ANOSIM.

Results

Contaminants in Trawl-Caught Fishes

Trace Metals

Eleven trace metals occurred in 100% of the liver tissue samples analyzed from trawl-caught Pacific sanddabs during 2011, including arsenic, cadmium, chromium, copper, iron, manganese, mercury, selenium, thallium, tin and zinc (Table 7.2). Another five metals (Al, Ba, Pb, Ni, Ag) were also detected, but less frequently, at rates between 8–92%. Neither antimony nor beryllium was detected in any of liver sample collected during the year. Most metals occurred at concentrations ≤19.2 ppm. Exceptions included higher levels up to ~29 ppm for aluminum, ~37 ppm for zinc and 101 ppm for iron. Comparisons of metals in sanddab livers from the nearfield zone (zone 1) to those from zones 2–4 revealed no clear relationship between contaminant loads and proximity to the outfall (Figure 7.2).

Pesticides

Only three chlorinated pesticides were detected in fish liver tissues during 2011 (Table 7.2). Hexachlorobenzene (HCB) and DDT were detected in all tissue samples at concentrations up to about 6 and 299 ppb, respectively. The DDT derivative p,p-DDE was found in 100% of these samples, while p,pDDMU, p,p-DDD, o,p-DDE, and p,p-DDT occurred in at least 60% (Appendix F.3). Chlordane occurred in 92% of the liver samples, at concentrations up to about 17 ppb. This pesticide consisted of one or more of the following constituents: alpha (cis) chlordane, cis-nonachlor, gamma (trans) chlordane, and trans-nonachlor. Overall, there were no clear relationships between pesticide concentrations in fish livers and proximity to the outfall (Figure 7.3).

PCBs

PCBs occurred in all liver tissue samples analyzed during 2011 at concentrations up to 317 ppb (Table 7.2). Eleven of the 31 detected congeners occurred in 100% of the samples, including PCB 99, PCB 101, PCB 110, PCB 118, PCB 138, PCB 149, PCB 151, PCB 153/168, PCB 180, PCB 183, and PCB 187 (Appendix F.3). All other congeners were found in anywhere from 8 to 92% of the samples. Overall, there was no clear relationship between total PCB and proximity to the outfall (Figure 7.3).

Table 7.2

Summary of metals, pesticides, total PCBs, and lipids in liver tissues of Pacific sanddabs collected from PLOO trawl zones during 2011. Data include detection rate (DR), minimum, maximum, and mean[a] detected concentrations (*n* = 12). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT, total chlordane and total PCB.

Parameter	DR (%)	Min	Max	Mean
Metals (*ppm*)				
Aluminum	92	nd	29.1	9.4
Antimony	0	—	—	—
Arsenic	100	3.1	4.5	3.7
Barium	83	nd	0.150	0.068
Beryllium	0	—	—	—
Cadmium	100	3.96	19.20	9.82
Chromium	100	0.16	0.33	0.23
Copper	100	2.7	10.5	4.7
Iron	100	35.3	101.0	67.2
Lead	8	nd	0.362	0.362
Mangenese	100	0.68	1.3	1.0
Mercury	100	0.037	0.473	0.110
Nickel	8	nd	0.206	0.206
Selenium	100	0.56	1.19	0.87
Silver	33	nd	0.107	0.077
Thallium	100	0.45	1.17	0.78
Tin	100	0.222	0.762	0.421
Zinc	100	19.1	36.7	24.8
Pesticides (*ppb*)				
HCB	100	1.7	5.7	3.7
Total chlordane	92	nd	16.7	8.8
Total DDT	100	44.8	298.6	212.0
Total PCB (*ppb*)	100	35.2	317.4	189.2
Lipids (*% weight*)	100	19.4	51.8	35.2

nd = not detected

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

Contaminants in Fishes Collected by Rig Fishing in 2011

Arsenic, mercury, selenium and zinc occurred in 100% of the muscle tissue samples from rockfish collected at the two rig fishing stations in 2011 (Table 7.3). Another five metals (aluminum, copper, iron, thallium, tin) were also detected, but less frequently at rates between 33–83%. Antimony, barium, beryllium, cadmium, chromium, lead, manganese, nickel and silver went undetected during the year. The metals present in the highest concentrations were zinc (≤4.4 ppm), aluminum (≤4.2 ppm), iron (≤2.5 ppm), and arsenic (≤1.5 ppm). Concentrations of the remaining metals in muscle tissues were all less than 1 ppm.

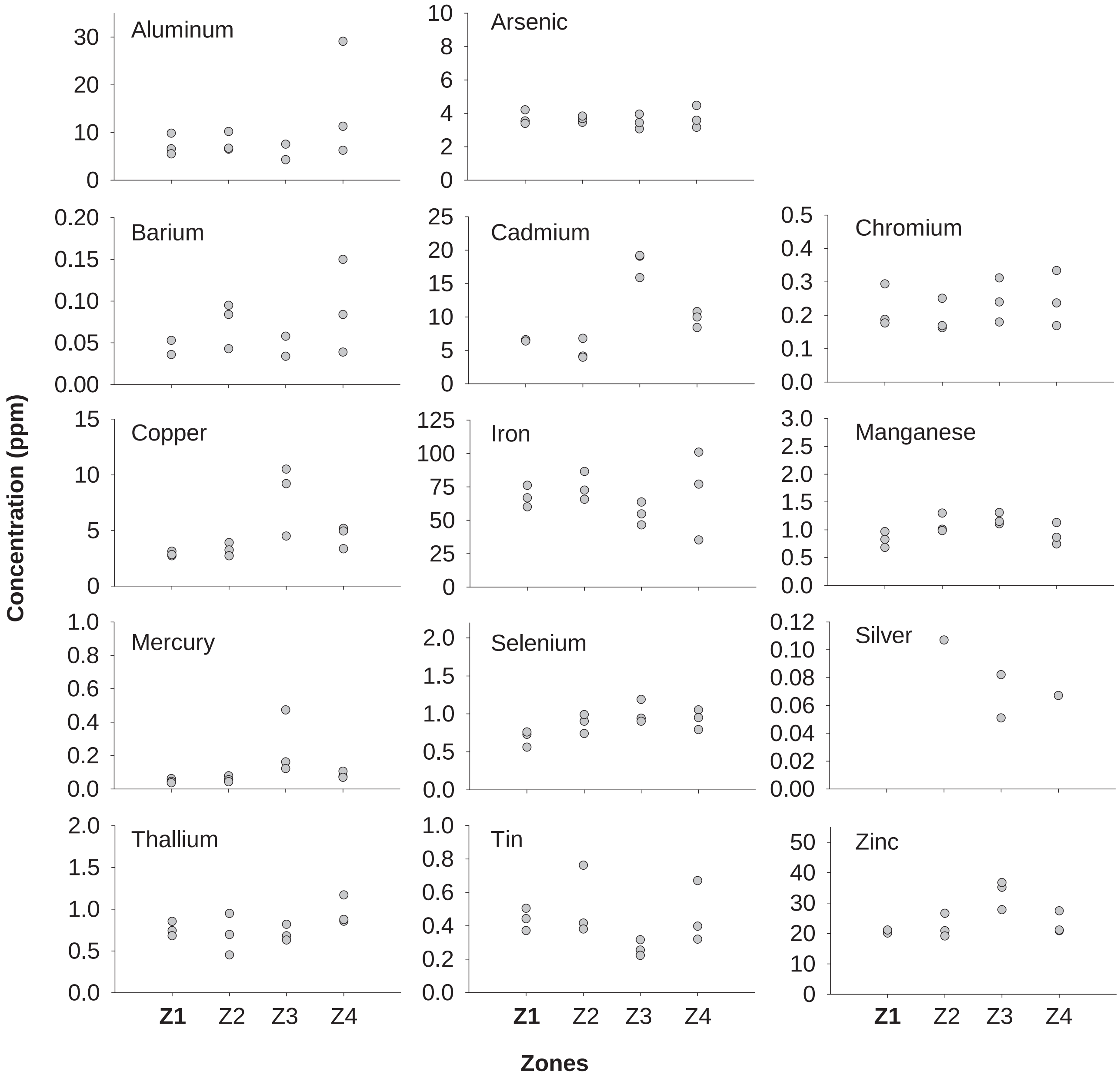


Figure 7.2

Concentrations of metals detection rates ≥20% of liver tissue of Pacific sanddabs collected from each trawl zone (Z1–Z4) off Point Loma during 2011. Missing values = non-detects. Zone 1 is considered "nearfield" (bold; see text).

Overall, metal values were fairly similar between fish collected at each rig fishing station (Figure 7.4).

Two pesticides (DDT and HCB) and PCBs were detected in every muscle tissue sample collected at the two rig fishing stations in 2011 (Table 7.4). Concentrations of all three contaminants were ≤7 ppb and none demonstrated a clear relationship with proximity to the outfall (Figure 7.4). The DDT derivative p,p-DDE and the PCB congener PCB 187 were found in all samples (Appendix F.3). An additional eight PCB congeners were detected at least 50% of the time.

Most of the contaminants detected in fish muscle tissues occurred at concentrations below state, national, and international limits or standards (Tables 7.3, 7.4). Only arsenic and selenium occurred at levels higher than median international standards, while total PCB exceeded state OEHHA fish contaminant goals. Neither mercury nor total DDT exceeded USFDA action limits, OEHHA fish contaminant goals, or international standards. All three rockfish species had elevated concentrations (i.e., higher than threshold values) of selenium, whereas elevated arsenic levels occurred solely in vermilion rockfish, and elevated values of PCB occurred only in chilipepper rockfish.

Historical Assessment of Contaminants in Fish Tissues

ANOSIM results revealed significantly different contaminant levels in fish liver tissues based on survey period, but not by lipid content (Appendix F.5). Of the three pairwise comparisons possible for survey period, all were significant. SIMPER demonstrated that although concentrations of contaminants varied significantly among Pacific sanddabs collected during different periods, temporal trends of decreasing or increasing concentrations were not evident for any of the parameters tested (Table 7.5, Figure 7.5). Instead, concentrations of select metals, pesticides or PCBs appeared to spike randomly (e.g., aluminum in October 2009) and drove observed differences among contaminant levels in fishes collected at various times.

ANOSIM results revealed significantly different contaminant levels in fish muscle tissues based on survey period, but not among species (Appendix F.6). Pairwise comparisons revealed 2009 samples to be significantly different from 2011 samples, whereas 2010 samples were *almost* significantly different from 2011 samples, and 2010 and 2011 samples did not differ. As with liver tissues, no temporal trend of decreasing or increasing concentration was evident for any contaminant tested (Table 7.6, Figure 7.6). It is interesting to note that when high aluminum concentrations were reported from liver tissues in October 2009, concentrations were also high in muscle tissue.

Discussion

Several trace metals, pesticides (e.g., DDT, HCB, chlordane) and PCB congeners were detected in liver tissue samples from Pacific sanddab liver

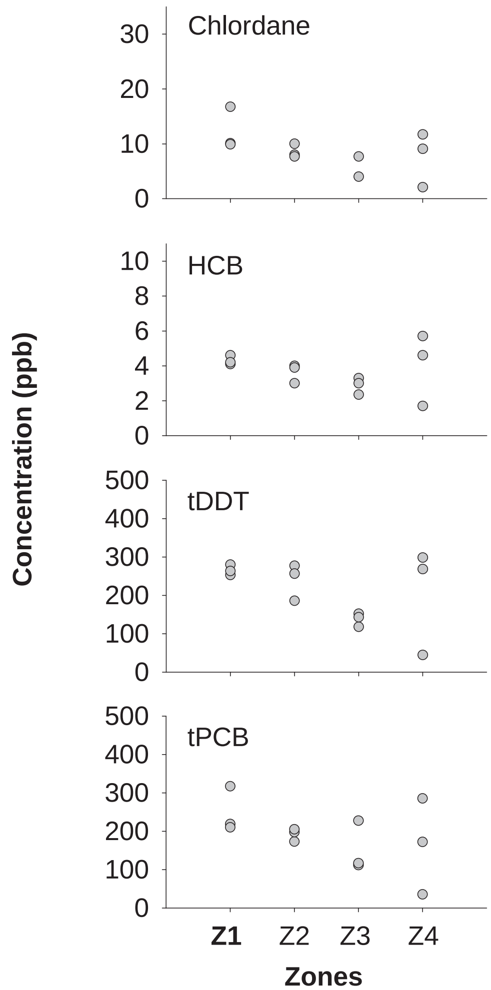


Figure 7.3
Concentrations of total chlordane, HCB, tDDT, and tPCB in liver tissues of Pacific sanddabs collected from each PLOO trawl zone (Z1–Z4) during 2011. All missing values = non-detects. Zone 1 is considered "nearfield" (bold; see text).

tissues collected in the PLOO region during 2011. Many of the same metals, DDT, HCB 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 between the four different species and stations, all values were within ranges reported previously for Southern California Bight (SCB) fishes (see Mearns et al. 1991, Allen et al. 1998, City of San Diego 2000, City of San Diego 2007). Additionally, all muscle tissue samples from rockfish collected in the area had mercury and DDT concentrations below USFDA action limits, OEHHA fish contaminant goals, and

Table 7.3

Summary of metals in muscle tissues of fishes collected from PLOO rig fishing stations during 2011. Data include the number of detected values (*n*), minimum, maximum, and mean[a] detected concentrations per species, and the detection rate and maximum value for all species. Concentrations are expressed as parts per million (ppm). The number of samples per species is indicated in parentheses. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits (AL), or median international standards (IS). See Appendix F.2 for names of each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Chilipepper rockfish																		
n (out of 2)	0	0	2	0	0	0	0	2	2	0	0	2	0	2	0	1	1	2
Min	—	—	0.7	—	—	—	—	0.3	2.1	—	—	0.061	—	**0.43**	—	nd	0.241	3.67
Max	—	—	0.9	—	—	—	—	0.4	2.5	—	—	0.093	—	**0.53**	—	0.53	0.241	3.72
Mean	—	—	0.8	—	—	—	—	0.3	2.3	—	—	0.077	—	**0.48**	—	0.53	0.241	3.69
Flag rockfish																		
n (out of 1)	1	0	1	0	0	0	0	1	0	0	0	1	0	1	0	1	1	1
Min	3.4	—	0.7	—	—	—	—	0.3	—	—	—	0.125	—	**0.54**	—	0.40	0.284	4.38
Max	3.4	—	0.7	—	—	—	—	0.3	—	—	—	0.125	—	**0.54**	—	0.40	0.284	4.38
Mean	3.4	—	0.7	—	—	—	—	0.3	—	—	—	0.125	—	**0.54**	—	0.40	0.284	4.38
Vermilion rockfish																		
n (out of 3)	1	0	3	0	0	0	0	2	0	0	0	3	0	3	0	1	2	3
Min	nd	—	1.0	—	—	—	—	nd	—	—	—	0.039	—	**0.33**	—	nd	0.212	3.56
Max	4.2	—	**1.5**	—	—	—	—	0.5	—	—	—	0.052	—	**0.38**	—	0.49	0.234	4.04
Mean	4.2	—	1.3	—	—	—	—	0.4	—	—	—	0.045	—	**0.36**	—	0.49	0.223	3.74
All Species:																		
Detection Rate (%)	33	0	100	0	0	0	0	83	33	0	0	100	0	100	0	50	67	100
Max	4.2	—	**1.5**	—	—	—	—	0.5	2.5	—	—	0.125	—	**0.54**	—	0.53	0.284	4.38
OEHHA[b]	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
AL[c]	na	na	na	na	na	na	na	na	na	na	na	1.00	na	na	na	na	na	na
IS[c]	na	na	1.4	na	na	na	1	20	na	na	na	0.50	na	0.3	na	na	na	70

na = not available; nd = not detected

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

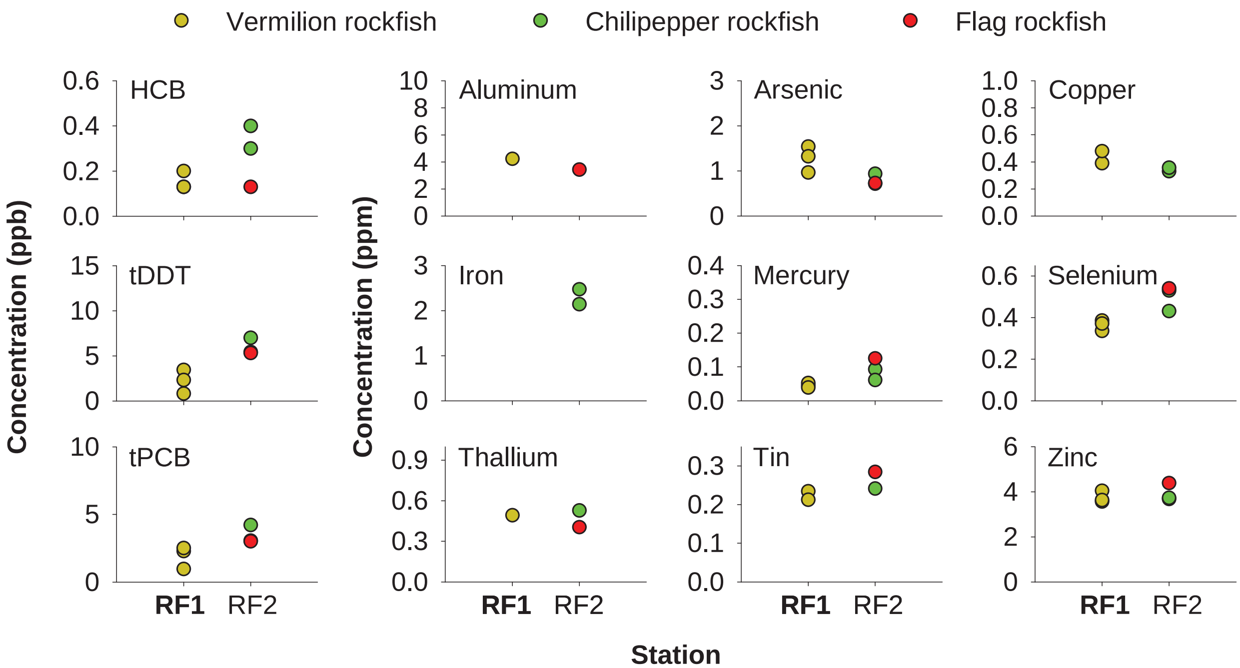


Figure 7.4
Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each PLOO rig fishing station during 2011. Missing values = non-detects. Station RF1 is considered "nearfield" (bold; see text).

international standards. However, some muscle tissues had concentrations of arsenic and selenium above the median international standards for human consumption, and some had PCB concentrations that exceeded OEHHA fish contaminant goals. Elevated levels of these contaminants are not uncommon in sportfish from the PLOO survey area (City of San Diego 2007–2011) or from the rest of the San Diego region (see City of San Diego 2012b and references therein). For example, muscle tissue samples from fishes collected over the years in the South Bay outfall survey area, including the Coronado Islands, have also had concentrations of metals such as arsenic, selenium and mercury that exceeded consumption limits.

The frequent occurrence of metals and chlorinated hydrocarbons in PLOO fish tissues may be due to multiple factors. Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT and PCBs as being ubiquitous in the SCB. In fact, many metals occur naturally in the environment, although little information is available on background levels in fish tissues. Brown et al. (1986) determined that no areas of the SCB are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent work regarding PCBs and DDTs (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 PLOO region, as there are many point and non-point sources that may contribute to local contamination such as the San Diego River, San Diego Bay, and dredged materials disposal sites (see Chapters 2–4; Parnell et al. 2008). In contrast, assessments of contaminant loading in sediments surrounding the PLOO reveal no evidence that the outfall is a major source of pollutants to the area (Chapter 4; Parnell et al. 2008).

Table 7.4

Summary of pesticides, tPCB, and lipids in muscle tissues of fishes collected from PLOO rig fishing stations during 2011. Data include number of detected values (*n*), minimum, maximum, and mean[a] detected concentrations per species, and the detection rate (DR) and maximum value for all species. The number of samples per species is indicated in parentheses. Bold values meet or exceed OEHHA fish contaminant goals, USFDA action limits (AL), or median international standards (IS). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for tDDT and tPCB.

	Pesticides			
	HCB (ppb)	**tDDT (ppb)**	**tPCB (ppb)**	**Lipids (% weight)**
Chilipepper rockfish				
n (out of 2)	2	2	2	2
Min	0.3	5.4	3.0	1.6
Max	0.4	7.0	**4.2**	2.9
Mean	0.3	6.2	**3.6**	2.2
Flag rockfish				
n (out of 1)	1	1	1	1
Min	0.1	5.3	3.0	0.5
Max	0.1	5.3	3.0	0.5
Mean	0.1	5.3	3.0	0.5
Vermilion rockfish				
n (out of 3)	3	3	3	3
Min	0.1	0.8	1.0	0.3
Max	0.2	3.4	2.5	0.7
Mean	0.2	2.2	1.9	0.4
All Species:				
DR%	100	100	100	100
Max	0.4	7.0	**4.2**	2.9
OEHHA[b]	na	21	3.6	na
AL[c]	na	5000	na	na
IS[c]	na	5000	na	na

na = not available; nd = not detected

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

There was no evidence of contaminant bioaccumulation in Point Loma fishes during 2011 that could be associated with wastewater discharge from the outfall. Concentrations of most contaminants were similar across zones or stations, and no relationship relevant to the PLOO was evident. These results are consistent with findings of two recent assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007, Parnell et al. 2008). Additionally, the results of multivariate analyses confirmed that although there have been significant fluctuations in fish tissue contaminant levels over time, no relevant spatial or temporal trends are apparent. Instead, occasional spikes in tissue contaminants appear random and may be due to original exposure in other areas. Finally, there were no other indications of poor fish health in the region, such as the presence of fin rot, other indicators of disease, or any physical anomalies (see Chapter 6).

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Table 7.5

Summary of contaminant loads in liver tissues of Pacific sanddabs collected from the PLOO region between 2009 and 2011. Data are expressed as mean values overall samples collected during each survey. Bold indicates parameters that were considered most defining for each group according to SIMPER analysis.

Parameter	Year 2009	2010	2011
Trace Metals (*ppm*)			
Aluminum	12.20	4.60	8.65
Antimony	**0.02**	0.00	0.00
Arsenic	3.24	2.95	3.66
Barium	0.09	0.04	0.06
Beryllium	**0.002**	0.000	0.000
Cadmium	6.07	7.05	**9.82**
Chromium	**0.113**	0.164	0.226
Copper	5.580	3.150	4.690
Iron	**62.20**	63.20	67.20
Lead	0.00	0.00	**0.03**
Manganese	0.869	**1.350**	1.010
Mercury	0.106	0.062	**0.110**
Nickel	0.02	**0.04**	0.02
Selenium	1.040	0.808	0.875
Silver	0.01	**0.05**	0.03
Thallium	0.299	0.452	0.783
Tin	0.145	0.128	0.421
Zinc	23.30	24.70	**24.80**
Chlorinated Pesticides (*ppb*)			
HCB	6.280	**5.310**	3.700
Total chlordane	0.00	**2.08**	8.09
Total DDT	**406**	128	212
Total PCB (*ppb*)	209	195	**189**

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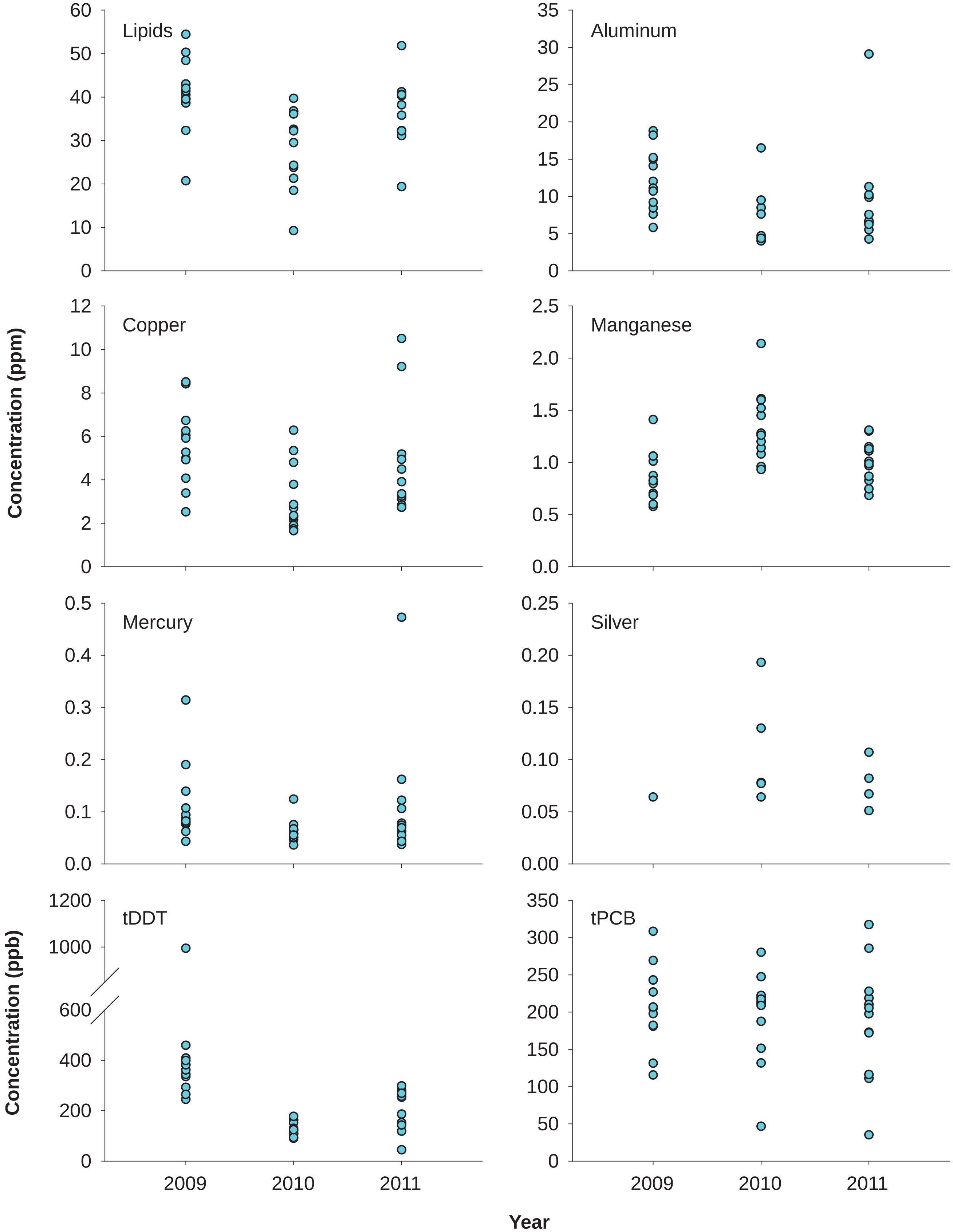

Figure 7.5
Concentrations of select parameters in liver tissues of Pacific sanddabs collected in the PLOO region between 2009 and 2011.

Table 7.6

Summary of contaminant loads in muscle tissues of fishes collected from the PLOO region between 2009 and 2011. Data are expressed as mean values overall samples collected during each survey. Bold indicates parameters that were considered most defining for each group according to SIMPER analysis.

	Year		
Parameter	**2009**	**2010**	**2011**
Trace Metals (*ppm*)			
Aluminum	5.45	0.52	1.27
Arsenic	**1.68**	1.38	1.03
Barium	0.04	0.00	0.00
Chromium	0.13	0.02	0.00
Copper	0.428	0.344	**0.316**
Iron	**1.81**	**1.40**	**0.77**
Mercury	0.191	**0.164**	0.069
Selenium	**0.456**	0.314	0.432
Silver	**0.04**	0.00	0.00
Thallium	0.000	**0.179**	**0.237**
Tin	0.000	0.000	**0.162**
Zinc	3.19	3.50	3.83
Chlorinated Pesticides (*ppb*)			
HCB	0.000	**0.158**	0.215
Total chlordane	0.00	0.00	**0.08**
Total DDT	6.50	**4.33**	4.04
Total PCB (*ppb*)	**4.02**	3.21	2.67

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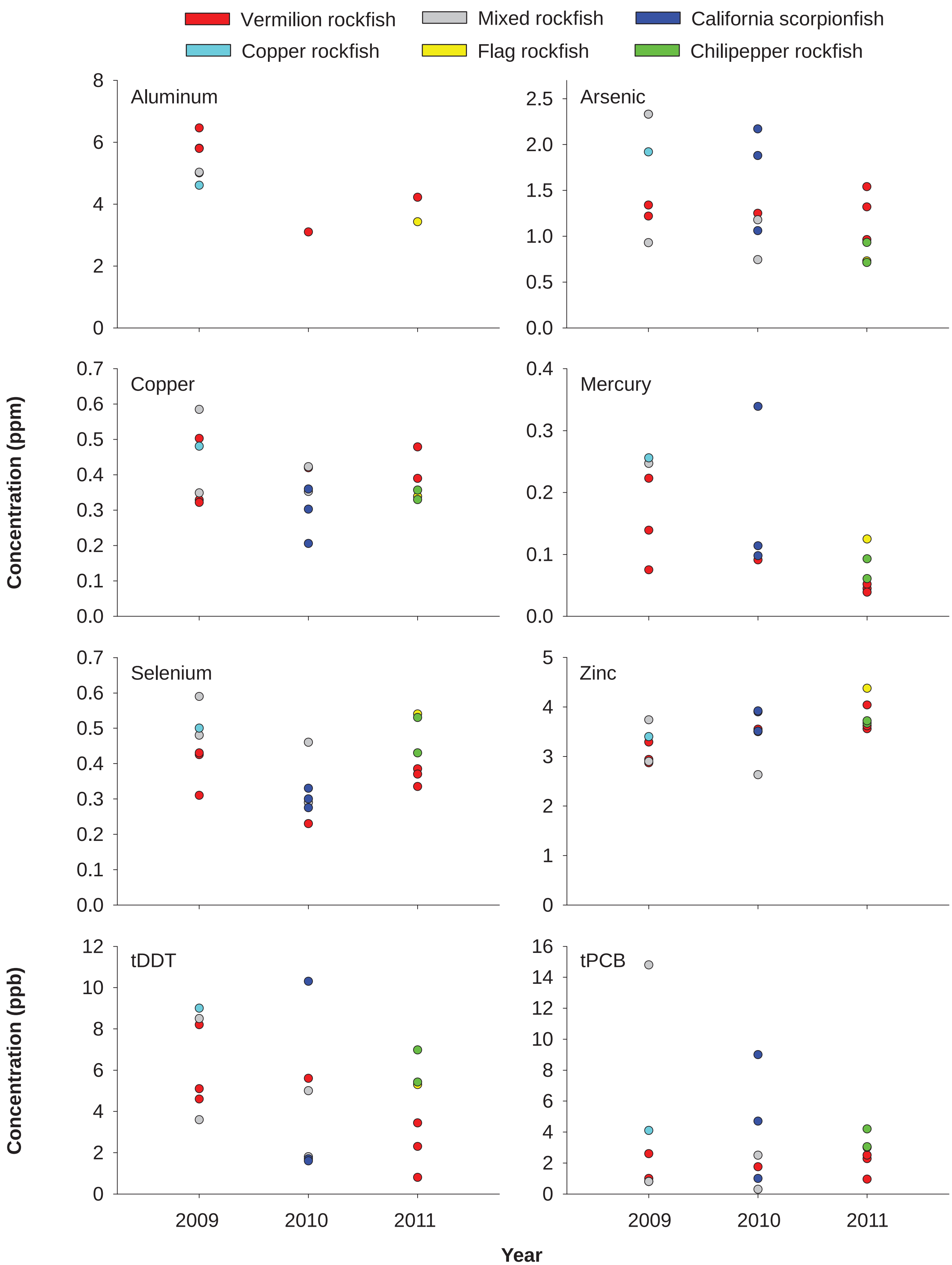

Figure 7.6
Concentrations of select parameters in muscle tissues of fishes collected in the PLOO region between 2009 and 2011.

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Glossary

Glossary

Absorption
The movement of dissolved substances (e.g., pollution) into cells by diffusion.

Adsorption
The adhesion of dissolved substances to the surface of sediment or on the surface of an organism (e.g., a flatfish).

Anthropogenic
Made and introduced into the environment by humans, especially pertaining to pollutants.

Assemblage
An association of interacting populations in a given habitat (e.g., an assemblage of benthic invertebrates on the ocean floor).

Before-After-Control-Impact-Paired (BACIP) analysis
An analytical tool used to assess environmental changes caused by the effects of pollution. A statistical test is applied to data from matching pairs of control and impacted sites before and after an event (i.e., initiation of wastewater discharge) to test for significant change. Significant differences are generally interpreted as being the result of the environmental change attributed to the event. Variation that is not significant reflects natural variation.

Benthic zone
Pertaining to the ecological zone inhabited by organisms living on or in the ocean bottom.

Benthos
Living organisms (e.g., algae and animals) associated with the sea bottom.

Bioaccumulation
The process by which a chemical becomes accumulated in tissue over time through direct intake of contaminated water, the consumption of contaminated prey, or absorption through the skin or gills.

Biota
The living organisms within a habitat or region.

Biochemical Oxygen Demand (BOD)
BOD is the amount of oxygen consumed (through biological or biochemical processes) during the decomposition of organic material contained in a water or sediment sample. It is a measure for certain types of organic pollution, such that high BOD levels suggest elevated levels of organic pollution.

Benthic Response Index (BRI)
The BRI measures levels of environmental disturbance by assessing the condition of a benthic assemblage. The index was based on historic distributions of organisms found in the soft sediments of the Southern California Bight.

Colony-Forming Unit (CFU)
The CFU is the bacterial cell or group of cells which reproduce on a plate and result in a visible colony that can be quantified as a measurement of density; it is often used to estimate bacteria concentrations in ocean water.

Control site
A geographic location that is far enough from a known pollution source (e.g., ocean outfall) to be considered representative of an undisturbed environment. Data collected from control sites are used as a reference and compared to impacted sites.

California Ocean Plan (Ocean Plan)
The COP is California's ocean water quality control plan. It limits wastewater discharge and implements ocean monitoring. Federal law requires the plan to be reviewed every three years.

Crustacea
A group (subphylum) of marine invertebrates characterized by jointed legs and an exoskeleton (e.g., crabs, shrimp, and lobsters).

Conductivity, Temperature, Depth (CTD)
A profiling instrument that when deployed continually measures a variety of physical and chemical parameters throughout the water column, all as a function of depth.

Demersal
Organisms living on or near the bottom of the ocean and capable of active swimming.

Dendrogram
A tree-like diagram used to represent hierarchal relationships from a multivariate analysis where results from several monitoring parameters are compared among sites.

Detritus
Particles of organic material originating from decomposing organisms. Used as an important source of nutrients in a food web.

Diversity
A measurement of community structure which describes the abundances of different species within a community, taking into account their relative rarity or commonness.

Dominance
A measurement of community structure that describes the minimum number of species accounting for 75% of the abundance in each grab.

Echinodermata
A taxonomic phylum of marine invertebrates characterized by the presence of spines, a radially symmetrical body, and tube feet (e.g., sea stars, sea urchins, and sea cucumbers).

Effluent
Wastewater that flows out of a sewer, treatment plant outfall, or other point source and is discharged into a water body (e.g., ocean, river).

Epifauna
Animals living upon the surface of marine sediments.

Fecal Indicator Bacteria (FIB)
FIB are the bacteria (total coliform, fecal coliform, and enterococcus) measured and evaluated to provide information about the movement and dispersion of wastewater discharged to the Pacific Ocean through the outfall.

Halocline
A vertical zone of water in which the salinity changes rapidly with depth.

Impact site
A geographic location that has been altered by the effects of a pollution source, such as a wastewater outfall.

Indicator species
Marine invertebrates whose presence in the community reflects the state of the environment. The loss of pollution-sensitive species or the introduction of pollution-tolerant species can indicate anthropogenic impact.

Infauna
Animals living in the soft bottom sediments, usually burrowing or building tubes within.

Invertebrate
An animal without a backbone (e.g., sea star, crab, or worm).

Macrobenthic invertebrate
Epifaunal or infaunal benthic invertebrates that are visible with the naked eye. This group typically includes those animals larger than meiofauna and smaller than megafauna. These animals are collected in grab samples from soft-bottom marine habitats and retained on a 1-mm mesh screen.

Method Detection Limit (MDL)
Defined by the USEPA as "the minimum concentration that can be determined with 99% confidence that the true concentration is greater than zero."

Megabenthic invertebrate
A larger, usually epibenthic and often motile,

bottom-dwelling animal such as a sea urchin, crab, or snail. These animals are typically collected by otter trawl nets with a minimum mesh size of 1 cm.

Mollusca
A taxonomic phylum of invertebrates characterized as having a muscular foot, visceral mass, and a shell. Examples include snails, clams, and octopuses.

Motile
Self-propelled or actively moving.

Niskin bottle
A device used to collect discrete water samples that is composed of a long plastic tube that allows seawater to pass through until the caps at both ends are triggered to close from the surface. They often are arrayed with several others in a rosette sampler to collect water at various depths.

Non-point source
Pollution sources from numerous points, not a specific outlet.

National Pollutant Discharge Elimination System (NPDES)
The NPDES is a federal permit program that controls water pollution by regulating point sources that discharge pollutants into waters of the United States.

Ophiuroidea
A taxonomic class of echinoderms that comprises brittle stars. Brittle stars usually have five long, flexible arms and a central disk-shaped body.

Polycyclic Aromatic Hydrocarbons (PAHs)
The USGS defines PAHs as, "hydrocarbon compounds with multiple benzene rings. PAHs are typical components of asphalts, fuels, oils, and greases."

Polychlorinated Biphenyls (PCBs)
The USEPA defines PCBs as, "a category, or family, of chemical compounds formed by the addition of chlorine (C_{l2}) to biphenyl ($C_{12}H_{10}$), which is a dual-ring structure comprising two 6-carbon benzene rings linked by a single carbon-carbon bond."

PCB congener
The USEPA defines a PCB congener as "one of the 209 different PCB compounds. A congener may have between one and 10 chlorine atoms, which may be located at various positions on the PCB molecule."

Phi
The conventional unit of sediment size based on the log of sediment grain diameter. The larger the phi number, the smaller the grain size.

Plankton
Minute animal and plant-like organisms that are that are passively carried by ocean currents.

Point Loma Ocean Outfall (PLOO)
The PLOO is the 7.2 km (4.5 mi) underwater pipe that originates at the Point Loma Wastewater Treatment Plant and discharges treated wastewater at a depth of 96 m (320 ft).

Point source
Pollution discharged from a single source (e.g., municipal wastewater treatment plant, storm drain) to a specific location through a pipe or outfall.

Polychaeta
A taxonomic class of invertebrates characterized as having worm-like features, segments, and bristles or tiny hairs. Examples include bristle worms and tube worms.

Pycnocline
A zone in the ocean where sea water density changes rapidly with depth.

Recruitment
The retention (passive or self-recruiting) of larvae and juveniles into the adult population in an open ocean environment.

Relict sand
Coarse reddish-brown sand that is a remnant of a pre-existing formation after other parts have disappeared. Typically originating from land and transported to the ocean bottom through erosional processes.

Rosette sampler
A device consisting of a round metal frame housing a CTD in the center and multiple Niskin bottles arrayed about the perimeter. As the instrument is lowered through the water column, continuous measurements of various physical and chemical parameters are recorded by the CTD. Discrete water samples are captured at desired depths by the bottles.

South Bay Ocean Outfall (SBOO)
The SBOO is the underwater pipe originating at the International Wastewater Treatment Plant and used to discharge treated wastewater. It extends 5.6 km (3.5 miles) offshore and discharges into about 27 m (90 ft) of water.

South Bay Water Reclamation Plant (SBWRP)
The SBWRP provides local wastewater treatment services and reclaimed water to the South Bay. The plant began operation in 2002 and has a wastewater treatment capacity of 15 million gallons a day.

Southern California Bight (SCB)
The SCB is the geographic region that stretches from Point Conception, USA to Cabo Colnett, Mexico and encompasses nearly 80,000 km^2 of coastal land and sea.

Shell hash
Sediments composed of a large fraction of shell fragments.

Skewness
A measure of the lack of symmetry in a distribution or data set. Skewness can indicate where most of the data lies within a distribution. It can be used to describe the distribution of particle sizes within sediment grain size samples.

Sorting
The range of grain sizes that composes marine sediments. Also refers to the process by which sediments of similar size are naturally segregated during transport and deposition according to the velocity and transporting medium. Well sorted sediments are of similar size (such as desert sand), while poorly sorted sediments have a wide range of grain sizes (as in a glacial till).

Species richness
The number of species per sample or unit area. A metric used to evaluate the health of macrobenthic communities.

Standard length
The measurement of a fish from the most forward tip of the body to the base of the tail (excluding the tail fin rays). Fin rays can sometimes be eroded by pollution or preservation so measurement that includes them (i.e., total length) is considered less reliable.

Thermocline
A thermally stratified zone of water that separates warmer surface water from colder deep water and within which temperature changes rapidly over a short depth.

Tissue burden
The total concentration of measured chemicals that is present in a tissue (e.g., fish muscle).

Transmissivity
A measure of water clarity based upon the ability of water to transmit light along a straight path. Light that is scattered or absorbed by particulates (e.g., plankton, suspended solid materials) decreases the transmissivity (or clarity) of the water.

Upwelling
The movement of nutrient-rich and typically cold water from the depths of the ocean to the surface waters.

Van Dorn bottle
Another form of water collection devise, similar to a Niskin bottle, that is composed of a long plastic tube that allows seawater to pass through until the caps at both ends are triggered to close from the surface. They are often used in an array with several others along a suspended line in the water column.

Van Veen grab
A mechanical device designed to collect ocean sediment samples. The device consists of a pair of

hinged jaws and a release mechanism that allows the opened jaws to close and entrap a 0.1 m^2 sediment sample once the grab touches bottom.

Wastewater
A mixture of water and waste materials originating from homes, businesses, industries, and sewage treatment plants.

Zone of Initial Dilution (ZID)
This is the region of initial mixing of the surrounding receiving waters with wastewater from the diffuser ports of an outfall. The area includes the underlying seabed. In the ZID, the environment may be chronically exposed to pollutants and often is the most impacted part of an ecosystem.

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Appendices

Appendix A

Supporting Data

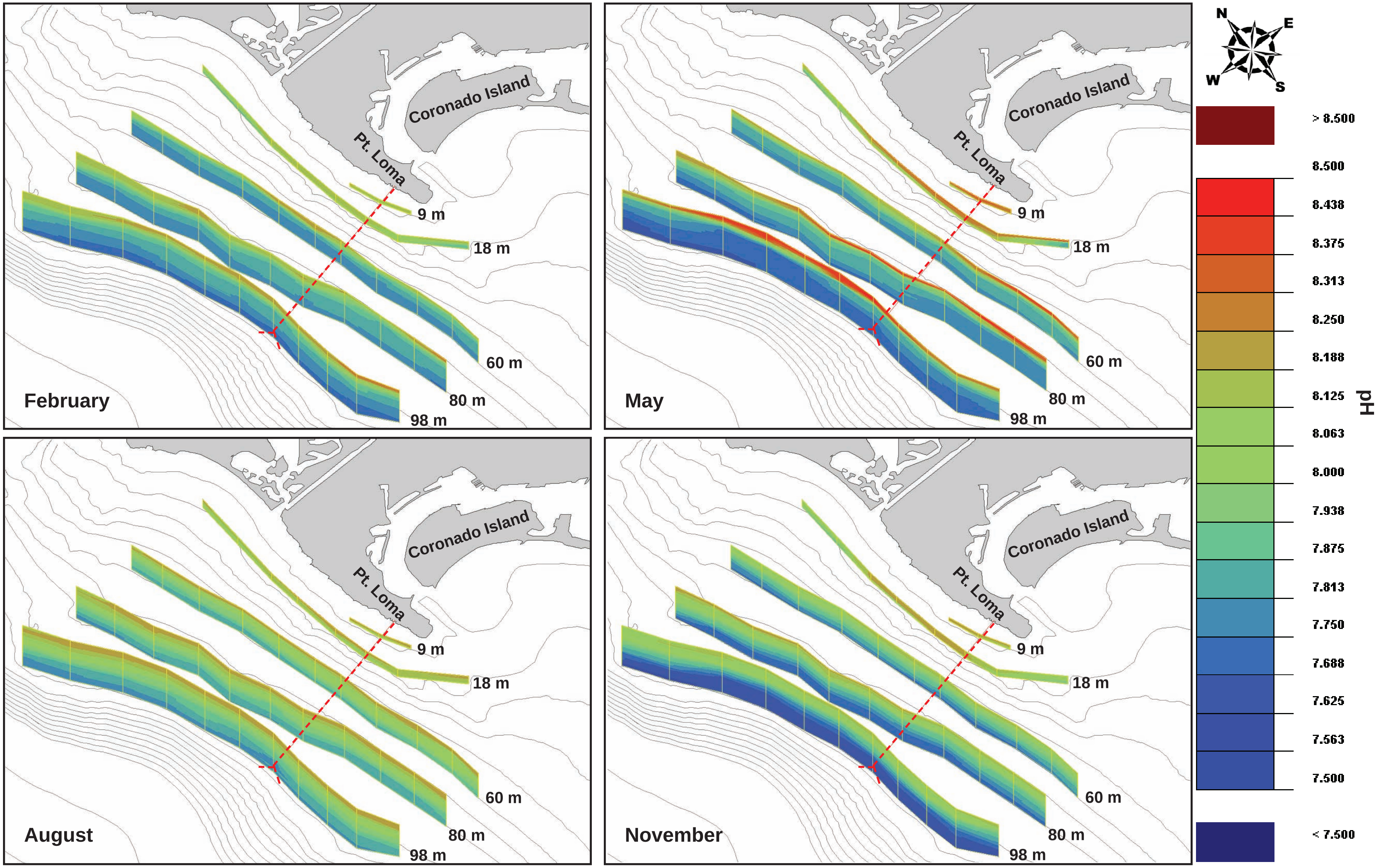
2011 PLOO Stations

Oceanographic Conditions

Appendix A.1

Summary of temperature, salinity, transmissivity, dissolved oxygen, pH, and chlorophyll *a* for surface (1–2 m) and bottom (within 2 m of bottom) waters in the PLOO region during 2011. Values are expressed as means for each survey pooled over all stations along each depth contour.

Depth	Contour	Feb	May	Aug	Nov	Depth	Contour	Feb	May	Aug	Nov
Temperature (°C)						**pH**					
9-m	Surface	14.3	15.8	18.5	15.1	9-m	Surface	8.2	8.3	8.2	8.2
	Bottom	13.6	13.5	15.7	14.7		Bottom	8.1	8.2	8.1	8.1
18-m	Surface	14.0	15.1	18.2	15.2	18-m	Surface	8.1	8.3	8.2	8.1
	Bottom	12.3	11.5	13.1	12.9		Bottom	8.0	8.0	8.1	8.0
60-m	Surface	14.0	15.1	19.0	15.6	60-m	Surface	8.2	8.3	8.2	8.1
	Bottom	10.3	9.8	10.5	10.9		Bottom	7.8	7.8	7.9	7.7
80-m	Surface	14.3	15.7	19.4	16.6	80-m	Surface	8.2	8.3	8.2	8.2
	Bottom	10.0	9.8	10.2	10.8		Bottom	7.8	7.8	7.8	7.7
98-m	Surface	14.3	16.3	19.6	17.1	98-m	Surface	8.2	8.3	8.2	8.1
	Bottom	9.7	9.9	9.9	10.6		Bottom	7.7	7.7	7.8	7.6
Salinity (psu)						**Transmissivity (%)**					
9-m	Surface	33.37	33.57	33.44	33.30	9-m	Surface	78	75	80	69
	Bottom	33.36	33.57	33.42	33.32		Bottom	74	79	81	70
18-m	Surface	33.34	33.54	33.44	33.32	18-m	Surface	79	70	82	75
	Bottom	33.39	33.59	33.36	33.36		Bottom	78	80	85	80
60-m	Surface	33.32	33.52	33.49	33.34	60-m	Surface	74	72	85	79
	Bottom	33.62	33.72	33.57	33.68		Bottom	86	84	81	83
80-m	Surface	33.33	33.50	33.52	33.34	80-m	Surface	81	77	87	85
	Bottom	33.75	33.86	33.64	33.81		Bottom	87	87	84	86
98-m	Surface	33.34	33.49	33.53	33.38	98-m	Surface	81	82	88	87
	Bottom	33.92	33.95	33.80	33.88		Bottom	89	88	88	88
Dissolved Oxygen (mg/L)						**Chlorophyll *a* (µg/L)**					
9-m	Surface	8.4	10.8	9.1	9.5	9-m	Surface	1.9	8.7	5.1	17.4
	Bottom	7.8	9.7	8.6	8.8		Bottom	3.7	12.3	5.8	23.5
18-m	Surface	8.6	10.5	9.2	8.7	18-m	Surface	9.0	16.6	5.7	17.1
	Bottom	6.7	7.0	8.0	6.9		Bottom	7.5	16.8	6.6	13.6
60-m	Surface	9.2	9.8	8.4	8.4	60-m	Surface	12.4	11.0	3.4	11.3
	Bottom	4.5	4.1	4.9	3.4		Bottom	0.8	2.1	1.5	0.9
80-m	Surface	9.0	10.9	7.6	8.2	80-m	Surface	5.4	8.7	2.3	3.2
	Bottom	4.2	3.5	4.4	2.8		Bottom	0.6	1.2	0.8	0.6
98-m	Surface	9.3	10.7	7.7	8.1	98-m	Surface	4.8	5.5	1.5	2.0
	Bottom	3.6	3.0	3.9	2.7		Bottom	0.4	0.9	0.7	0.4



Appendix A.2

Measurements of pH recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day.

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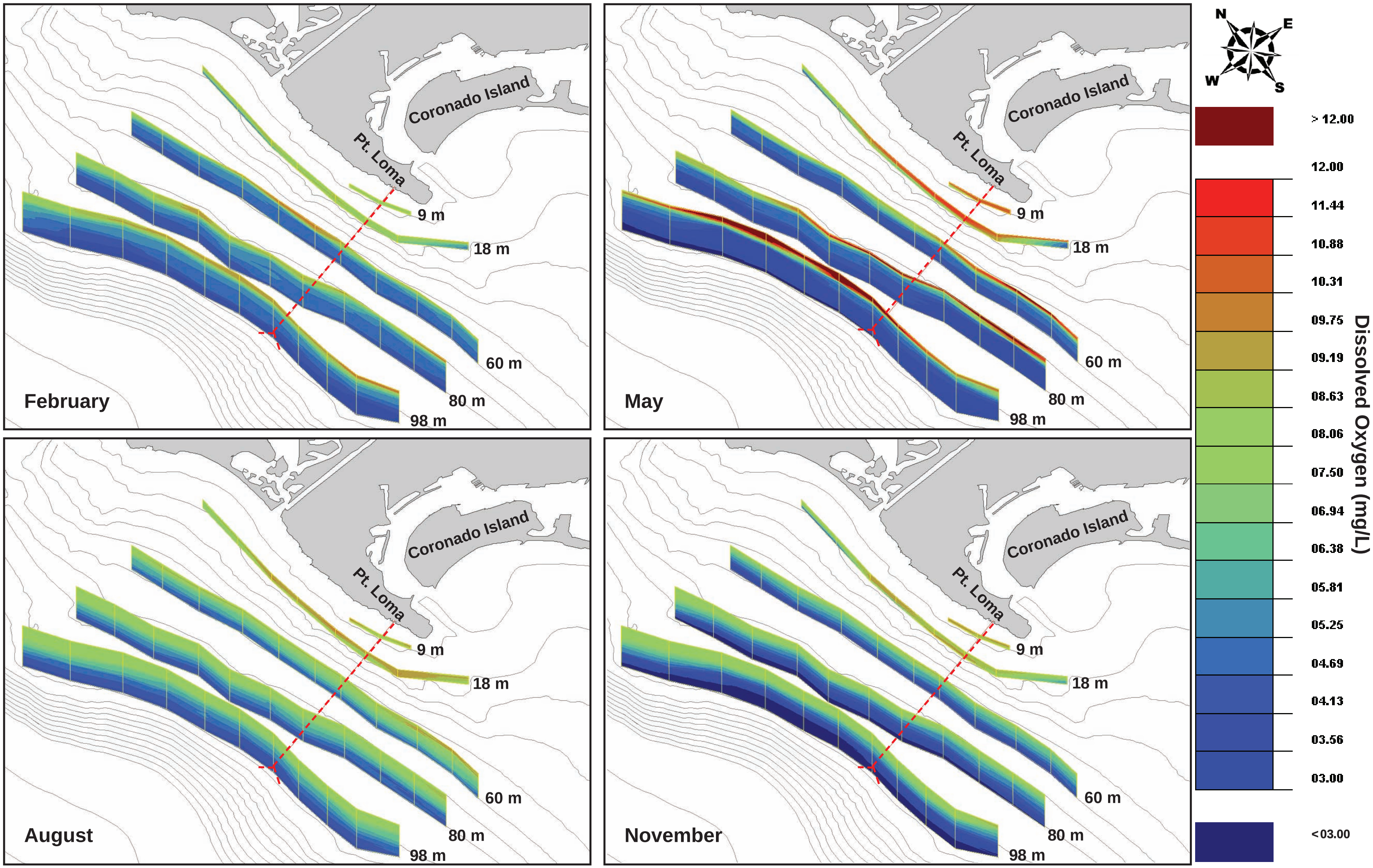
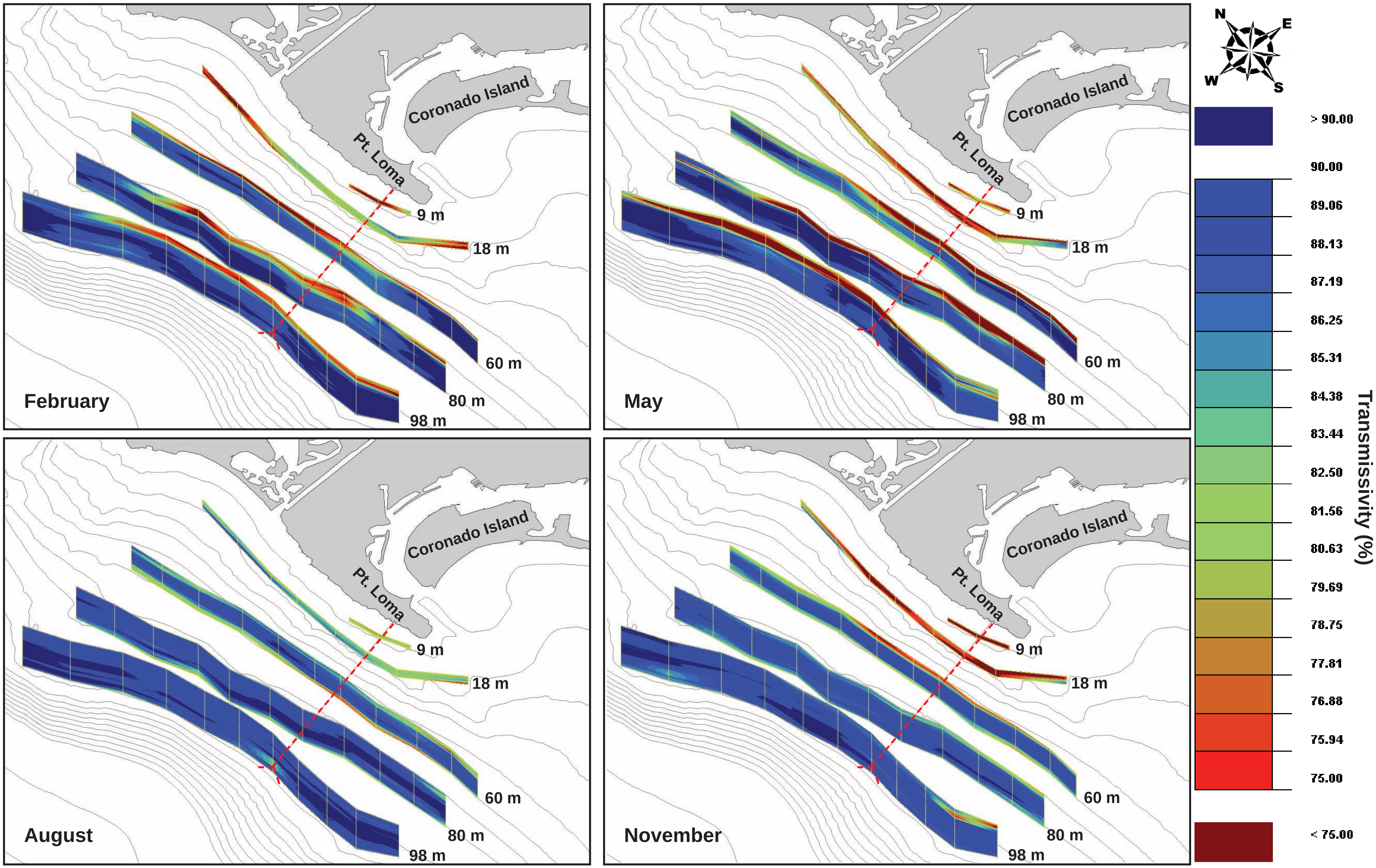


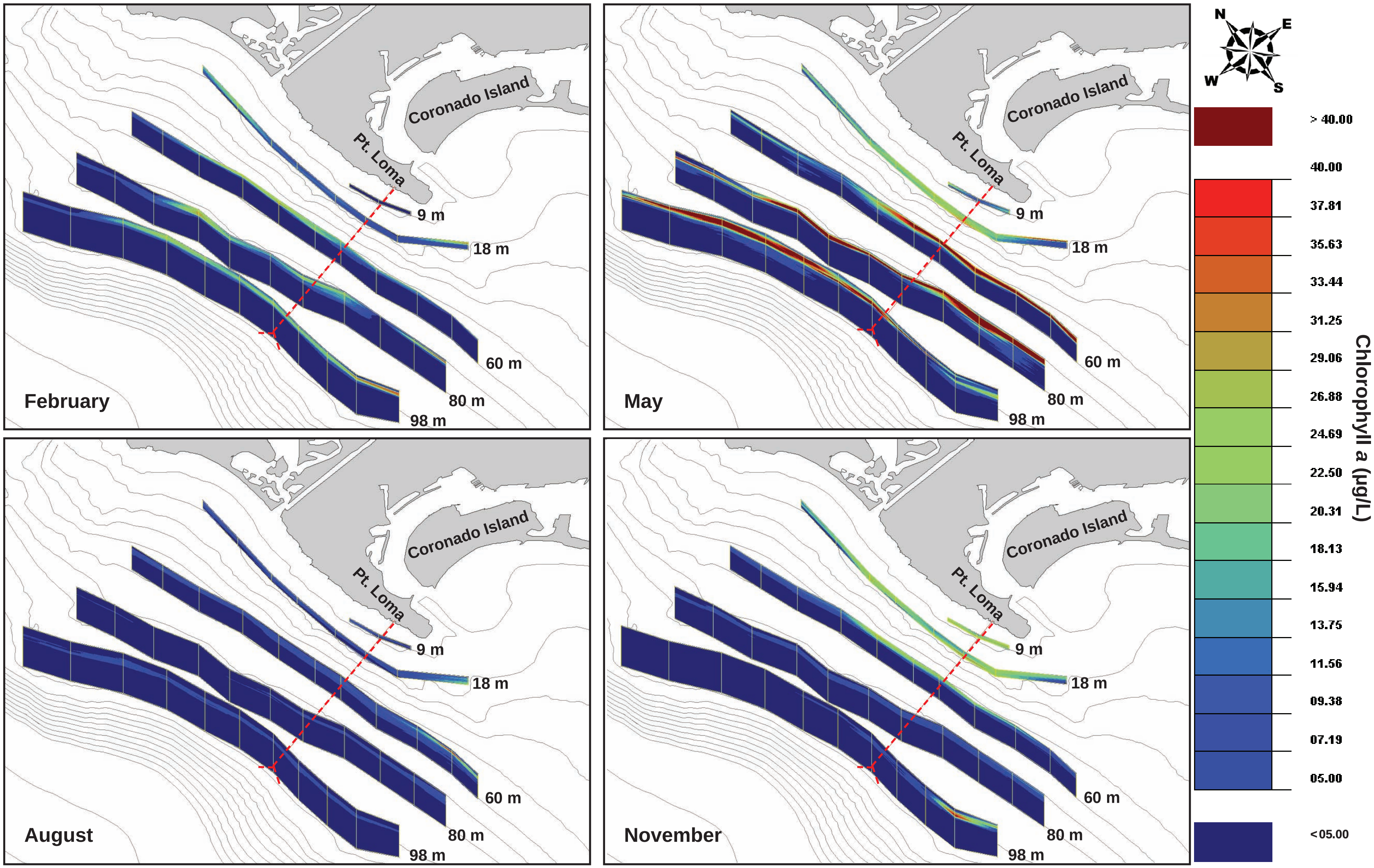
Appendix A.3

Dissolved oxygen recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day.



Appendix A.4

Transmissivity recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day.



Appendix A.5

Chlorophyll *a* fluorescence recorded in 2011 for the PLOO region. Data are collected over four consecutive days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day.

Appendix B

Supporting Data

2011 PLOO Stations

Water Quality

Appendix B.1

Summary of rainfall and bacteria levels at PLOO shore stations during 2011. Total coliform, fecal coliform, and enterococcus densities are expressed as mean CFU/100 mL per month and for the entire year. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom; *n* = total number of samples.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011 Total Rain (in):		**0.30**	**2.10**	**1.46**	**0.26**	**0.36**	**0.03**	**0.00**	**0.00**	**0.13**	**0.46**	**3.12**	**0.86**
D12	*Total*	20	25	17	49	49	16	132	24	13	90	21	16
	Fecal	3	2	4	2	3	2	4	3	2	16	11	6
	Entero	4	3	3	2	3	2	12	2	2	31	5	4
D11	*Total*	36	1032	448	1292	108	92	124	37	19	108	52	34
	Fecal	8	50	19	35	10	10	41	14	4	25	10	3
	Entero	7	18	17	9	4	20	9	11	4	18	17	2
D10	*Total*	80	724	184	108	24	66	28	173	32	116	52	53
	Fecal	14	13	8	10	4	6	9	9	4	29	14	4
	Entero	14	18	3	2	2	2	3	6	2	15	8	4
D9	*Total*	17	381	14	57	16	221	56	27	20	52	44	89
	Fecal	6	12	2	2	2	118	2	3	2	16	7	7
	Entero	5	12	3	2	2	13	2	2	2	14	4	2
D8	*Total*	432	596	88	48	64	20	64	110	180	405	532	189
	Fecal	54	59	11	3	3	5	4	36	8	72	18	11
	Entero	49	16	13	2	3	3	3	2	2	39	19	4
D7	*Total*	20	88	36	20	28	21	100	50	208	64	60	6
	Fecal	4	8	17	4	3	5	12	5	32	8	10	7
	Entero	2	3	2	3	2	2	4	3	9	13	6	2
D5	*Total*	24	30	16	276	16	21	96	20	56	92	92	52
	Fecal	2	6	2	178	2	2	4	3	10	6	4	2
	Entero	2	2	2	38	2	2	2	3	6	3	5	3
D4	*Total*	18	60	9	24	22	16	56	67	64	16	17	9
	Fecal	2	3	2	3	3	2	5	2	4	6	2	2
	Entero	2	2	3	2	2	2	3	2	3	2	2	2
	n	40	39	40	40	40	40	40	48	40	39	40	40
Annual	*Total*	81	376	102	234	41	59	82	63	74	111	109	56
Means	*Fecal*	12	20	8	29	4	19	10	9	8	22	10	5
	Entero	11	10	6	8	3	6	5	4	4	17	8	3

Appendix B.2

Summary of samples with elevated FIB densities at PLOO shore stations during wet and dry seasons between 1991–2011. Wet = January–April and October–December; Dry = May–September; *n* = total number of samples. Rain was measured at Lindbergh Field, San Diego, CA. Stations are listed north to south from left to right.

Year	Season	D12	D11	D10	D9	D8	D7	D5	D4	Rain (in)	Total	*n*
1991	Wet	ns	ns	ns	0	2	0	1	0	12.97	3	90
	Dry	ns	ns	ns	0	1	0	0	0	0.54	1	105
1992	Wet	ns	ns	ns	6	11	18	53	42	12.62	130	384
	Dry	ns	ns	ns	0	1	1	7	2	0.19	11	110
1993	Wet	ns	ns	ns	0	2	2	2	0	16.81	6	89
	Dry	ns	ns	ns	0	1	2	1	0	0.45	4	103
1994	Wet	ns	ns	ns	3	2	0	0	1	9.32	6	84
	Dry	ns	ns	ns	0	0	0	0	0	0.11	0	95
1995	Wet	ns	ns	ns	2	3	0	1	1	14.76	7	87
	Dry	ns	ns	ns	0	2	3	0	0	1.10	5	100
1996	Wet	ns	ns	ns	0	2	0	0	0	7.13	2	83
	Dry	ns	ns	ns	0	3	0	0	0	0.14	3	101
1997	Wet	ns	ns	ns	1	4	0	0	0	6.15	5	87
	Dry	ns	ns	ns	0	0	1	0	1	0.85	2	97
1998	Wet	ns	ns	ns	1	2	1	0	0	15.08	4	81
	Dry	ns	ns	ns	0	1	0	0	0	0.97	1	95
1999	Wet	ns	ns	ns	1	1	0	0	0	5.31	2	81
	Dry	ns	ns	ns	0	2	0	0	0	0.12	2	97
2000	Wet	ns	ns	ns	0	1	1	0	0	6.89	2	80
	Dry	ns	ns	ns	1	1	1	0	1	0.01	4	98
2001	Wet	ns	ns	ns	0	0	0	0	0	8.46	0	80
	Dry	ns	ns	ns	0	1	0	0	0	0.01	1	96
2002	Wet	ns	ns	ns	0	0	0	0	0	3.92	0	79
	Dry	ns	ns	ns	0	0	1	0	0	0.31	1	100
2003	Wet	0	1	2	2	4	2	1	0	8.88	12	162
	Dry	0	0	0	0	0	1	1	0	0.30	2	119
2004	Wet	2	5	4	2	3	2	2	1	13.29	21	281
	Dry	0	0	0	0	1	0	1	0	0.00	2	210
2005	Wet	0	3	0	3	6	1	2	2	13.86	17	281
	Dry	0	1	0	0	1	0	0	0	0.25	2	208
2006	Wet	1	1	1	0	4	0	1	0	5.33	8	295
	Dry	0	3	0	0	1	0	0	0	0.82	4	199
2007	Wet	2	2	2	0	2	0	0	0	4.32	8	306
	Dry	1	1	0	0	0	1	0	0	0.05	3	208
2008	Wet	1	2	3	3	4	1	0	0	10.86	14	288
	Dry	0	0	0	1	0	0	0	0	0.25	1	200
2009	Wet	0	2	1	0	7	1	0	1	5.43	12	277
	Dry	1	0	0	0	1	0	0	0	0.07	2	199
2010	Wet	2	2	2	0	1	2	1	1	16.20	11	257
	Dry	0	0	0	0	0	0	0	0	0.08	0	208
2011	Wet	0	0	0	0	1	0	1	0	8.56	2	278
	Dry	0	0	0	1	0	0	0	0	0.52	1	208
Total	**Wet**	**8**	**18**	**15**	**24**	**62**	**31**	**65**	**49**	**162.97**	**272**	**3730**
	Dry	**2**	**5**	**0**	**3**	**17**	**11**	**10**	**4**	**5.27**	**52**	**2956**

ns = not sampled

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Appendix B.3

Summary of samples with elevated FIB densities at PLOO kelp bed stations during wet and dry seasons between 1991–2011. Wet = January–April and October–December; Dry = May–September; *n* = total number of samples. Rain was measured at Lindbergh Field, San Diego, CA. Stations are listed north to south from left to right.

		9-m Stations			18-m Stations							
Year	**Season**	**C6**	**C5**	**C4**	**A6**	**A7**	**A1**	**C8**	**C7**	**Rain (in)**	**Total**	***n***
1991	Wet	2	5	1	45	47	42	24	30	12.97	196	2093
	Dry	2	1	4	30	38	29	22	27	0.54	153	1496
1992	Wet	48	77	52	116	87	68	34	55	12.62	537	2579
	Dry	3	8	1	64	67	58	24	39	0.19	264	1737
1993	Wet	4	3	4	36	50	45	18	25	16.81	185	2336
	Dry	3	2	0	38	51	37	23	23	0.45	177	1711
1994	Wet	1	1	1	0	0	1	1	5	9.32	10	1868
	Dry	1	0	0	4	0	1	1	0	0.11	7	1189
1995	Wet	1	4	2	2	1	2	2	2	14.76	16	1028
	Dry	1	0	1	0	2	0	0	0	1.10	4	596
1996	Wet	0	2	1	1	1	1	0	1	7.13	7	870
	Dry	0	2	0	0	0	1	0	0	0.14	3	599
1997	Wet	1	0	2	4	3	3	0	0	6.15	13	806
	Dry	0	0	0	0	0	0	0	1	0.85	1	576
1998	Wet	0	2	2	1	3	1	3	0	15.08	12	824
	Dry	1	0	1	1	2	2	0	0	0.97	7	600
1999	Wet	0	0	0	1	0	1	0	0	5.31	2	840
	Dry	0	0	0	0	0	0	0	0	0.12	0	600
2000	Wet	0	0	0	0	0	0	0	0	6.89	0	831
	Dry	0	0	0	0	0	0	1	0	0.01	1	599
2001	Wet	0	0	0	0	0	0	0	2	8.46	2	840
	Dry	0	0	0	0	0	0	0	0	0.01	0	600
2002	Wet	0	0	0	0	0	0	0	0	3.92	0	802
	Dry	0	0	0	0	0	0	0	0	0.31	0	599
2003	Wet	0	0	0	0	0	0	0	0	8.88	0	823
	Dry	0	0	0	0	0	1	0	0	0.30	1	600
2004	Wet	0	5	5	0	5	4	2	0	13.29	21	820
	Dry	0	0	0	0	0	0	0	0	0.00	0	599
2005	Wet	2	1	0	1	0	0	1	1	13.86	6	831
	Dry	0	0	0	0	0	0	0	0	0.25	0	597
2006	Wet	0	0	0	0	0	0	0	0	5.33	0	837
	Dry	0	0	0	0	0	0	0	0	0.82	0	600
2007	Wet	0	0	0	0	0	2	0	0	4.32	2	831
	Dry	0	0	0	0	0	0	0	0	0.05	0	600
2008	Wet	0	1	0	0	0	0	0	0	10.86	1	837
	Dry	0	0	0	0	0	0	0	0	0.25	0	598
2009	Wet	0	0	2	1	1	2	1	0	5.43	7	839
	Dry	0	0	0	4	4	2	3	1	0.07	14	600
2010	Wet	0	0	1	0	1	1	0	0	16.20	3	831
	Dry	0	0	0	1	1	0	0	0	0.08	2	598
2011	Wet	0	0	0	0	0	0	0	0	8.56	0	837
	Dry	0	0	0	0	0	1	0	0	0.52	1	600
Total	**Wet**	**59**	**101**	**73**	**208**	**199**	**174**	**86**	**121**	**162.97**	**1021**	**23,203**
	Dry	**11**	**13**	**7**	**142**	**165**	**131**	**74**	**91**	**5.27**	**634**	**16,294**

Appendix B.4

Summary of compliance with the 2005 California Ocean Plan water contact standards for PLOO shore, kelp bed, and offshore stations during 2011. The values reflect the number of times per month that each station exceeded various total coliform, fecal coliform, and enterococcus bacterial standards (see Chapter 3; Box 3.1).

	30-day Geometric Mean Standards Shore Stations							
Month	**D4**	**D5**	**D7**	**D8**	**D9**	**D10**	**D11**	**D12**
Total Coliform								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Fecal Coliform								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Enterococcus								
January	0	0	0	13	0	18	20	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**96%**	**100%**	**95%**	**95%**	**100%**

Appendix B.4 *continued*

Month	Single Sample Maximum Standards Shore Stations							
	D4	D5	D7	D8	D9	D10	D11	D12
Total Coliform								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Fecal Coliform								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	1	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	1	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**98.4%**	**100%**	**100%**	**98.4%**	**100%**	**100%**	**100%**

Appendix B.4 *continued*

Month	Single Sample Maximum Standards Shore Stations							
	D4	D5	D7	D8	D9	D10	D11	D12
Enterococcus								
January	0	0	0	1	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	1	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**98.4%**	**100%**	**98.4%**	**100%**	**100%**	**100%**	**100%**
***Fecal/Total Coliform Ratio* (*FTR*)**								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	1	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**98.4%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

30-day Geometric Mean Standards
Kelp Bed Stations

	9-m Stations			18-m Stations				
Month	**C4**	**C5**	**C6**	**A1**	**A7**	**A6**	**C7**	**C8**
Total Coliform								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Fecal Coliform								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Enterococcus								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix B.4 *continued*

	Single Sample Maximum Standards							
	Kelp Bed Stations							
	9-m Stations			18-m Stations				
Month	**C4**	**C5**	**C6**	**A1**	**A7**	**A6**	**C7**	**C8**
Total Coliform								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Fecal Coliform								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Enterococcus								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	1	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**99.4%**	**100%**	**100%**	**100%**	**100%**

Appendix B.4 *continued*

Single Sample Maximum Standards

Kelp Bed Stations

	9-m Stations			18-m Stations				
Month	**C4**	**C5**	**C6**	**A1**	**A7**	**A6**	**C7**	**C8**
Fecal/Total Coliform Ratio (FTR)								
January	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Offshore Stations within 3 nautical miles of State waters

	F02	**F03**	**F11**	**F12**	**F13**	**F14**	**F01**	**F06**	**F18**	**F07**	**F08**	**F09**	**F10**	**F19**	**F20**
Enterococcus															
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compliance Rate	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix C

Supporting Data

2011 PLOO Stations

Sediment Conditions

Appendix C.1

A subset of the Wentworth scale and sorting coefficients (both based on Folk 1980) used in the analysis of sediments collected from the PLOO region in 2011. Sediment grain size is presented in phi size and microns along with descriptions of each size range and how they are classified within size fractions. The sorting coefficients are the standard deviation (SD) of sediment grain sizes in a sample measured as phi.

Wentworth Scale

Phi size	Microns	Description	Fraction
≤-1	≥ 2000	Granules–Pebbles	Coarse
0	1000 - 1999	Very coarse sand	
1	500 - 999	Coarse sand	Sand
2	250 - 499	Medium sand	
3	125 - 249	Fine sand	
4	62.5 - 124	Very fine sand	
5	31 – 62.4	Coarse silt	Silt
6	15.6 – 30.9	Medium silt	
7	7.8 – 15.5	Fine silt	
8	3.9 – 7.7	Very fine silt	
9	2.0 – 3.8	Clay	Clay
10	0.98 – 1.9	Clay	
11	≤ 0.97	Clay	

Sorting Coefficient

SD, phi	Sorting Category
< 0.35	very well sorted
0.35 – 0.50	well sorted
0.50 – 0.71	moderately well sorted
0.71 – 1.00	moderately sorted
1.00 – 2.00	poorly sorted
2.00 – 4.00	very poorly sorted
> 4.00	extremely poorly sorted

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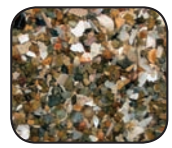
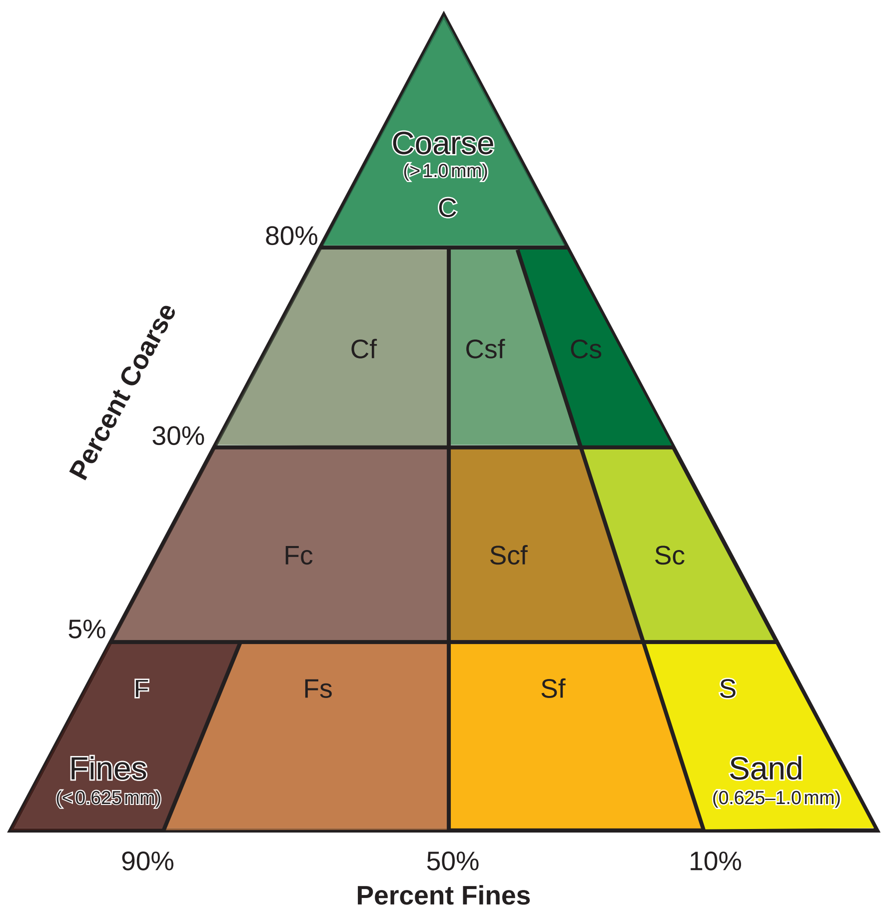
Appendix C.2

Classification of sediment types defined by relative proportions of percent fines, sand, and coarse particles (based on Folk 1980). Data include the amount of fine and coarse material that determine the sediment type.

Abbr.	Sediment Type	% Fines	% Coarse	Example
F	Fines	90 – 100	0 – 5	
Fs	Fines with sand	50 – 90	0 – 5	
Fc	Fines with coarse	50 – 95	5 – 30	
S	Sand	0 – 10	0 – 5	
Sf	Sand with fines	10 – 50	0 – 5	
Scf	Sand with coarse and fines	10 – 50	5 – 30	
Sc	Sand with coarse	0 – 10	5 – 30	
C	Coarse	0 – 20	80 – 100	
Cf	Coarse with fines	50 – 70	30 – 80	
Csf	Coarse with sand and fines	10 – 50	30 – 80	
Cs	Coarse with sand	0 – 10	30 – 80	



Appendix C.3

Constituents and method detection limits (MDL) used for the analysis of sediments collected from the PLOO region during 2011.

Parameter	MDL	Parameter	MDL
Organic Indicators			
BOD (ppm)	2	Total Sulfides (ppm)	0.14
Total Nitrogen (TN, % wt.)	0.005	Total Volatile Solids (TVS, % wt.)	0.11
Total Organic Carbon (TOC, % wt.)	0.01		
Metals (ppm)			
Aluminum (Al)	2	Lead (Pb)	0.8
Antimony (Sb)	0.3	Manganese (Mn)	0.08
Arsenic (As)	0.33	Mercury (Hg)	0.003, 0.004[a]
Barium (Ba)	0.02	Nickel (Ni)	0.1
Beryllium (Be)	0.01	Selenium (Se)	0.24
Cadmium (Cd)	0.06	Silver (Ag)	0.04
Chromium (Cr)	0.1	Thallium (Ti)	0.5
Copper (Cu)	0.2	Tin (Sn)	0.3
Iron (Fe)	9	Zinc (Zn)	0.25
Chlorinated Pesticides (ppt)			
Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	150	HCH, Delta isomer	700
HCH, Beta isomer	310	HCH, Gamma isomer	260
Total Chlordane			
Alpha (cis) Chlordane	240	Heptachlor epoxide	120
Cis Nonachlor	240	Methoxychlor	1100
Gamma (trans) Chlordane	350	Oxychlordane	240
Heptachlor	1200	Trans Nonachlor	250
Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	830	p,p-DDE	260
o,p-DDE	720	p,-p-DDMU	[b]
o,p-DDT	800	p,p-DDT	800
p,p-DDD	470		
Miscellaneous Pesticides			
Aldrin	430	Endrin	830
Alpha Endosulfan	240	Endrin aldehyde	830
Beta Endosulfan	350	Hexachlorobenzene	470
Dieldrin	310	Mirex	500
Endosulfan Sulfate	260		

[a] Methods changed between January and July.; [b] No MDL available for this parameter.

Appendix C.3 *continued*

Parameter	MDL		MDL
Polychlorinated Biphenyl Congeners (PCBs) (ppt)			
PCB 18	540	PCB 126	720
PCB 28	700	PCB 128	570
PCB 37	700	PCB 138	590
PCB 44	700	PCB 149	500
PCB 49	700	PCB 151	640
PCB 52	700	PCB 153/168	600
PCB 66	700	PCB 156	620
PCB 70	700	PCB 157	700
PCB 74	700	PCB 158	510
PCB 77	700	PCB 167	620
PCB 81	700	PCB 169	610
PCB 87	700	PCB 170	570
PCB 99	700	PCB 177	650
PCB 101	430	PCB 180	530
PCB 105	720	PCB 183	530
PCB 110	640	PCB 187	470
PCB 114	700	PCB 189	620
PCB 118	830	PCB 194	420
PCB 119	560	PCB 201	530
PCB 123	660	PCB 206	510
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)			
1-methylnaphthalene	20	Benzo[G,H,I]perylene	20
1-methylphenanthrene	20	Benzo[K]fluoranthene	20
2,3,5-trimethylnaphthalene	20	Biphenyl	30
2,6-dimethylnaphthalene	20	Chrysene	40
2-methylnaphthalene	20	Dibenzo(A,H)anthracene	20
3,4-benzo(B)fluoranthene	20	Fluoranthene	20
Acenaphthene	20	Fluorene	20
Acenaphthylene	30	Indeno(1,2,3-CD)pyrene	20
Anthracene	20	Naphthalene	30
Benzo[A]anthracene	20	Perylene	30
Benzo[A]pyrene	20	Phenanthrene	30
Benzo[e]pyrene	20	Pyrene	20

e=values estimated regardless of MDL

Appendix C.4

Summary of the constituents that make up total DDT, total PCB, and total PAH in sediments from the PLOO region during 2011.

Station	Class	Constituent	January	July	Units
B8	DDT	p,p-DDE	670	620	ppt
B9	DDT	p,p-DDE	390	570	ppt
B10	DDT	p,p-DDE	340	360	ppt
B11	DDT	p,p-DDE	430	530	ppt
B12	DDT	p,p-DDE	nd	220	ppt
E1	DDT	p,p-DDE	580	920	ppt
E1	DDT	p,p-DDT	nd	700	ppt
E1	PAH	3,4-benzo(B)fluoranthene	nd	41.3	ppb
E1	PAH	Benzo[A]pyrene	nd	40.1	ppb
E1	PAH	Fluoranthene	nd	31.8	ppb
E1	PAH	Pyrene	nd	41.5	ppb
E1	PCB	PCB 101	nd	890	ppt
E1	PCB	PCB 110	260	640	ppt
E1	PCB	PCB 118	230	830	ppt
E1	PCB	PCB 138	nd	590	ppt
E1	PCB	PCB 149	270	500	ppt
E1	PCB	PCB 187	140	470	ppt
E1	PCB	PCB 206	nd	510	ppt
E1	PCB	PCB 28	nd	660	ppt
E1	PCB	PCB 52	140	nd	ppt
E1	PCB	PCB 66	52	nd	ppt
E1	PCB	PCB 70	77	nd	ppt
E1	PCB	PCB 99	nd	660	ppt
E2	DDT	p,p-DDE	290	710	ppt
E2	PAH	3,4-benzo(B)fluoranthene	nd	31.5	ppb
E2	PAH	Benzo[A]anthracene	nd	22.0	ppb
E2	PAH	Benzo[A]pyrene	nd	29.6	ppb
E2	PAH	Fluoranthene	nd	23.2	ppb
E2	PAH	Pyrene	nd	21.8	ppb
E2	PCB	PCB 101	nd	680	ppt
E2	PCB	PCB 105	nd	720	ppt
E2	PCB	PCB 110	150	640	ppt
E2	PCB	PCB 118	nd	830	ppt
E2	PCB	PCB 138	68	590	ppt
E2	PCB	PCB 149	120	500	ppt
E2	PCB	PCB 153/168	nd	600	ppt
E2	PCB	PCB 49	nd	850	ppt
E2	PCB	PCB 52	nd	1000	ppt
E2	PCB	PCB 70	nd	1100	ppt
E2	PCB	PCB 87	nd	600	ppt
E3	DDT	p,p-DDE	330	330	ppt
E3	PAH	3,4-benzo(B)fluoranthene	33.1	57.2	ppb
E3	PAH	Benzo[A]anthracene	28.5	27.1	ppb

nd = not detected

Appendix C.4 *continued*

Station	Class	Constituent	January	July	Units
E3	PAH	Benzo[A]pyrene	34.5	51.2	ppb
E3	PAH	Benzo[e]pyrene	21.4	30.1	ppb
E3	PAH	Benzo[G,H,I]perylene	21.1	27.8	ppb
E3	PAH	Benzo[K]fluoranthene	nd	24.1	ppb
E3	PAH	Fluoranthene	22	37.1	ppb
E3	PAH	Indeno(1,2,3-CD)pyrene	nd	22.7	ppb
E3	PAH	Pyrene	35.8	28.8	ppb
E3	PCB	PCB 101	1500	840	ppt
E3	PCB	PCB 105	410	nd	ppt
E3	PCB	PCB 110	1300	640	ppt
E3	PCB	PCB 118	1100	830	ppt
E3	PCB	PCB 128	300	nd	ppt
E3	PCB	PCB 138	410	590	ppt
E3	PCB	PCB 149	790	500	ppt
E3	PCB	PCB 151	350	nd	ppt
E3	PCB	PCB 153/168	420	600	ppt
E3	PCB	PCB 170	150	nd	ppt
E3	PCB	PCB 180	280	530	ppt
E3	PCB	PCB 187	210	nd	ppt
E3	PCB	PCB 44	330	nd	ppt
E3	PCB	PCB 49	320	nd	ppt
E3	PCB	PCB 52	1000	nd	ppt
E3	PCB	PCB 66	360	920	ppt
E3	PCB	PCB 70	1500	1100	ppt
E3	PCB	PCB 74	160	nd	ppt
E3	PCB	PCB 87	670	nd	ppt
E3	PCB	PCB 99	530	660	ppt
E5	DDT	p,p-DDE	300	320	ppt
E7	DDT	p,p-DDE	380	460	ppt
E8	DDT	p,p-DDE	250	260	ppt
E9	DDT	p,p-DDE	260	580	ppt
E9	PAH	Benzo[A]anthracene	nd	22.5	ppb
E9	PCB	PCB 101	770	8200	ppt
E9	PCB	PCB 105	240	2000	ppt
E9	PCB	PCB 110	560	6700	ppt
E9	PCB	PCB 118	530	5200	ppt
E9	PCB	PCB 123	nd	660	ppt
E9	PCB	PCB 128	nd	1400	ppt
E9	PCB	PCB 138	nd	2000	ppt
E9	PCB	PCB 149	550	3700	ppt
E9	PCB	PCB 151	290	1700	ppt
E9	PCB	PCB 153/168	nd	3600	ppt
E9	PCB	PCB 156	nd	800	ppt
E9	PCB	PCB 157	nd	700	ppt
E9	PCB	PCB 158	nd	980	ppt
E9	PCB	PCB 167	nd	620	ppt

nd = not detected

Appendix C.4 *continued*

Station	Class	Constituent	January	July	Units
E9	PCB	PCB 170	310	700	ppt
E9	PCB	PCB 177	400	650	ppt
E9	PCB	PCB 18	nd	560	ppt
E9	PCB	PCB 180	710	980	ppt
E9	PCB	PCB 183	210	530	ppt
E9	PCB	PCB 187	420	510	ppt
E9	PCB	PCB 194	310	nd	ppt
E9	PCB	PCB 201	230	nd	ppt
E9	PCB	PCB 206	190	nd	ppt
E9	PCB	PCB 28	150	700	ppt
E9	PCB	PCB 44	420	1800	ppt
E9	PCB	PCB 49	nd	1400	ppt
E9	PCB	PCB 52	630	5400	ppt
E9	PCB	PCB 66	340	1900	ppt
E9	PCB	PCB 70	690	3200	ppt
E9	PCB	PCB 74	270	1200	ppt
E9	PCB	PCB 87	nd	3600	ppt
E9	PCB	PCB 99	230	2500	ppt
E11	DDT	p,p-DDE	200	300	ppt
E14	DDT	p,p-DDE	210	250	ppt
E15	DDT	p,p-DDE	190	580	ppt
E15	PCB	PCB 110	nd	640	ppt
E15	PCB	PCB 118	nd	830	ppt
E15	PCB	PCB 149	nd	500	ppt
E17	DDT	p,p-DDE	210	nd	ppt
E19	DDT	p,p-DDE	360	360	ppt
E20	DDT	p,p-DDE	280	nd	ppt
E21	DDT	p,p-DDE	220	520	ppt
E21	PCB	PCB 206	160	nd	ppt
E23	DDT	p,p-DDE	290	450	ppt
E23	PAH	Benzo[G,H,I]perylene	nd	57.8	ppb
E23	PAH	Dibenzo(A,H)anthracene	nd	41.3	ppb
E23	PAH	Indeno(1,2,3-CD)pyrene	nd	47.6	ppb
E25	DDT	p,p-DDE	280	690	ppt
E25	PAH	Benzo[G,H,I]perylene	nd	47.5	ppb
E25	PAH	Dibenzo(A,H)anthracene	nd	38.5	ppb
E25	PAH	Indeno(1,2,3-CD)pyrene	nd	35.1	ppb
E26	DDT	p,p-DDE	330	390	ppt
E26	PAH	Benzo[G,H,I]perylene	nd	44.9	ppb
E26	PAH	Dibenzo(A,H)anthracene	nd	31.3	ppb
E26	PAH	Indeno(1,2,3-CD)pyrene	nd	34.7	ppb

nd = not detected

Appendix C.5

Summary of sediment grain size parameters for each PLOO station sampled during January 2011. SD = standard deviation. Silt and clay fractions are indistinguishable for samples analyzed by sieve. Visual observations are from sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis).

	Mean (µm)	Mean (phi)	SD (phi)	Median (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Sediment Type	Visual Observations
88-m Depth Contour											
B11[a]	134	4.4	2.0	4.0	1.8	51.0	43.5	3.7	47.2	Sand with fines	pea gravel/gravel/shell hash
B8	55	4.8	1.6	4.5	0.0	40.5	55.6	3.9	59.5	Fines with sand	
E19	68	4.4	1.5	4.0	0.0	54.3	43.1	2.7	45.7	Sand with fines	worm tubes/organic debris/shell hash
E7	72	4.4	1.5	4.0	0.0	56.4	41.0	2.6	43.6	Sand with fines	worm tubes/shell hash
E1	90	4.2	1.7	3.8	0.0	57.5	39.3	3.2	42.5	Sand with fines	coarse sand/pea gravel/gravel/shell hash
98-m Depth Contour											
B12	110	3.9	1.8	3.5	0.0	66.8	30.4	2.9	33.2	Sand with fines	pea gravel/gravel/shell hash
B9	74	4.4	1.6	4.0	0.0	56.5	40.5	3.0	43.5	Sand with fines	pea gravel/gravel
E26	72	4.4	1.5	4.0	0.0	57.3	39.9	2.9	42.7	Sand with fines	worm tubes/organic debris/shell hash
E25	78	4.2	1.5	3.8	0.0	60.9	36.7	2.5	39.1	Sand with fines	worm tubes/organic debris/shell hash
E23	73	4.3	1.5	4.0	0.0	58.4	38.9	2.8	41.7	Sand with fines	worm tubes/organic debris/shell hash
E20	77	4.2	1.5	3.8	0.0	62.2	35.4	2.4	37.8	Sand with fines	worm tubes/organic debris/shell hash
E17[a,b]	135	4.0	1.7	3.8	1.9	63.9	32.0	2.2	34.2	Sand with fines	worm tubes/organic debris/shell hash
E14[b]	88	4.0	1.4	3.7	0.0	70.9	27.3	1.9	29.2	Sand with fines	coarse black sand/shell hash
E11[b]	85	4.1	1.5	3.7	0.0	67.2	30.7	2.1	32.8	Sand with fines	worm tubes/organic debris/shell hash
E8	85	4.1	1.5	3.8	0.0	66.1	31.9	2.1	34.0	Sand with fines	coarse black sand/worm tubes/shell hash
E5[a]	124	4.0	1.6	3.7	1.2	65.0	31.8	1.9	33.8	Sand with fines	coarse black sand/shell hash
E2	88	4.2	1.6	3.8	0.0	61.7	35.6	2.8	38.3	Sand with fines	coarse sand/pea gravel/gravel/shell hash
116-m Depth Contour											
B10	92	4.1	1.7	3.5	0.0	68.4	28.8	2.8	31.6	Sand with fines	shell hash
E21	82	4.1	1.5	3.7	0.0	66.4	31.5	2.2	33.7	Sand with fines	worm tubes/organic debris/shell hash
E15[b]	86	4.0	1.4	3.7	0.0	68.9	29.0	2.0	31.0	Sand with fines	coarse black sand/shell hash
E9[a]	133	4.2	1.8	3.8	1.8	58.4	36.7	3.1	39.7	Sand with fines	coarse black sand/shell hash
E3[a]	146	4.0	2.0	3.5	1.3	60.0	35.2	3.4	38.6	Sand with fines	coarse sand/pea gravel/gravel/shell hash

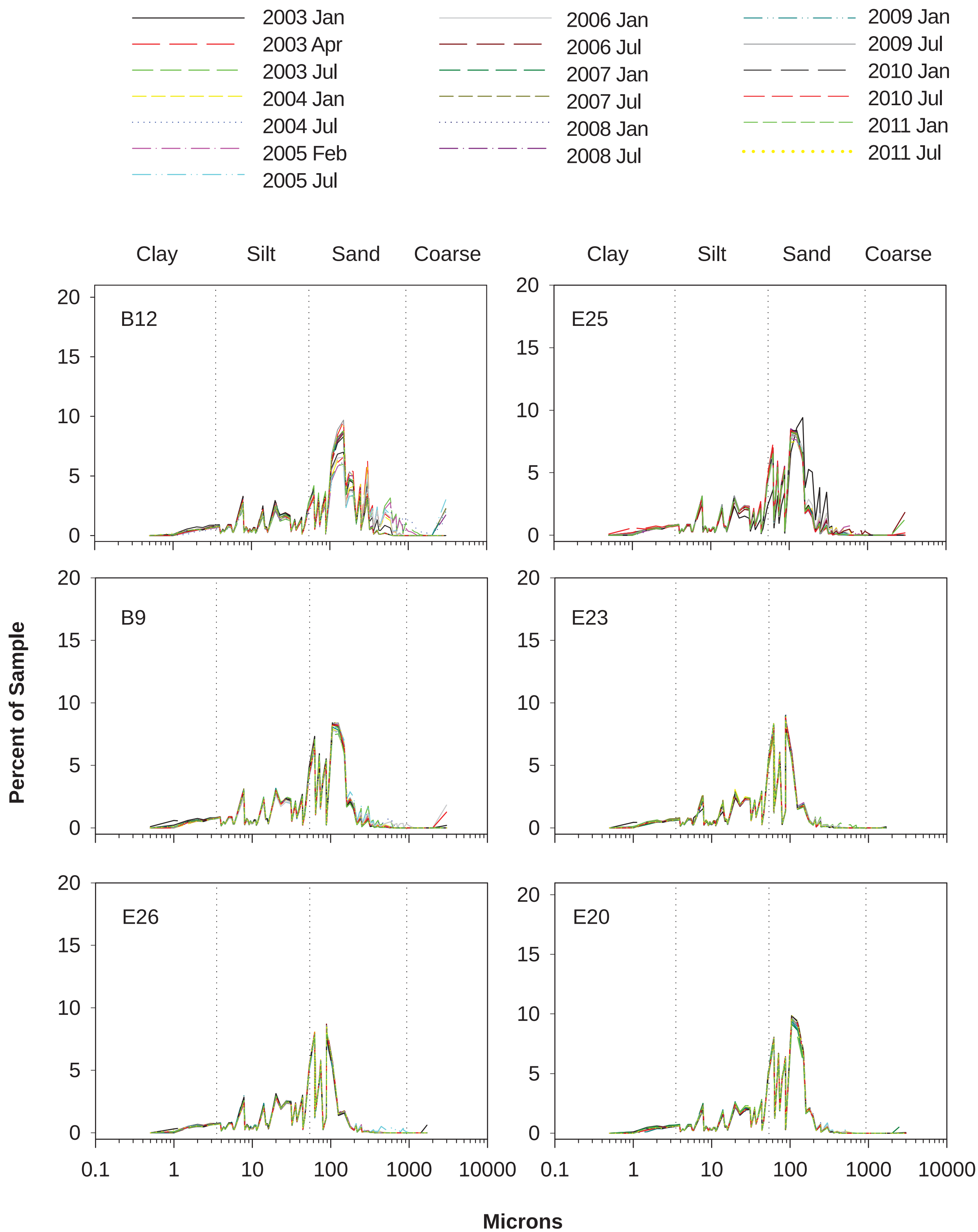
[a] Contains fraction > 2000 microns measured by sieve (not Horiba); [b] nearfield station

Appendix C.5 *continued*

Summary of sediment grain size parameters for each PLOO station sampled during July 2011. SD = standard deviation. Silt and clay fractions are indistinguishable for samples analyzed by sieve. Visual observations are from sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis).

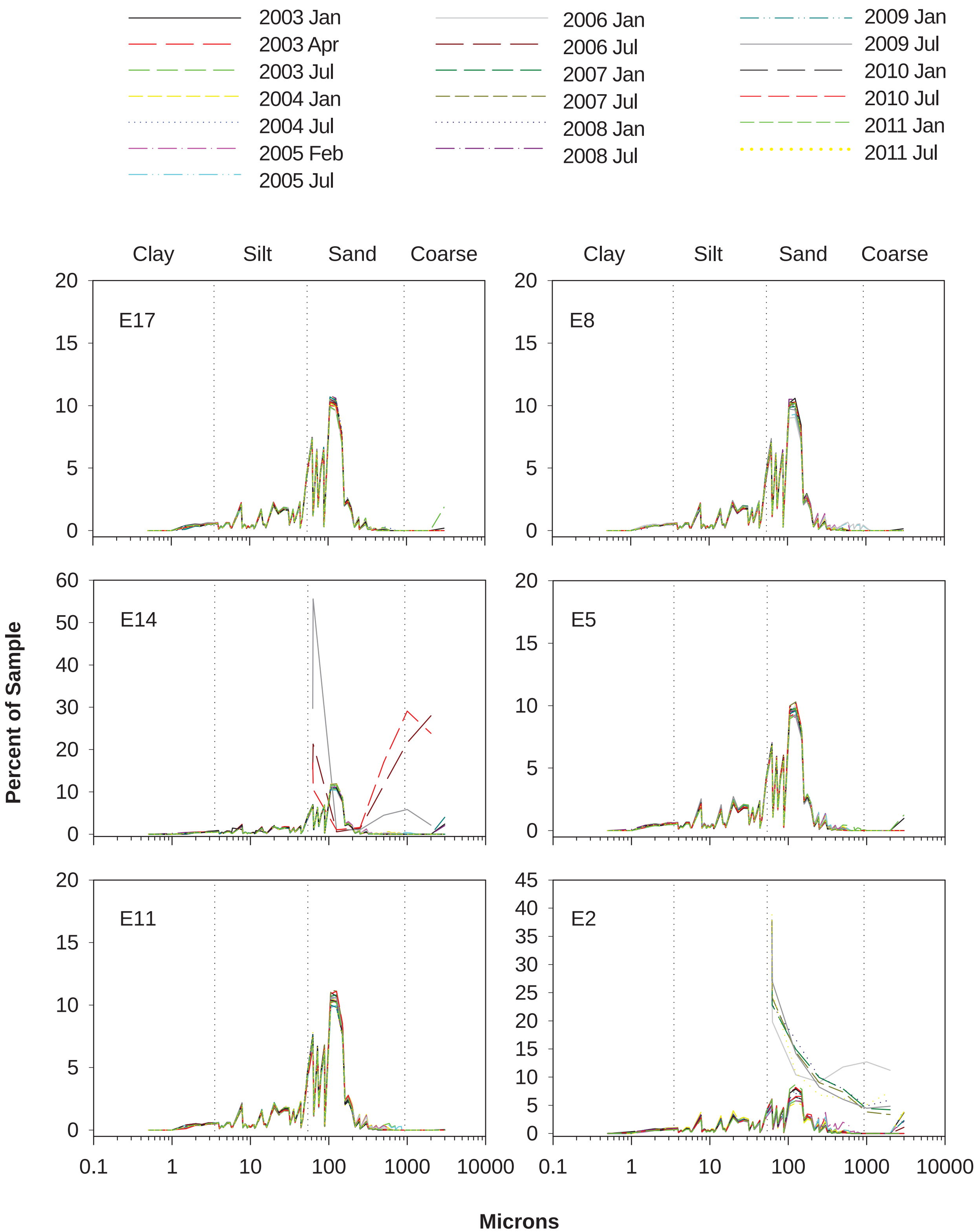
	Mean (µm)	Mean (phi)	SD (phi)	Median (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Sediment Type	Visual Observations
88-m Depth Contour											
B11	84	4.4	1.8	4.0	0.0	53.6	42.8	3.6	46.4	Sand with fines	pea gravel/gravel/shell hash
B8	58	4.7	1.6	4.2	0.0	44.2	51.7	4.1	55.8	Fines with sand	
E19	67	4.5	1.5	4.0	0.0	53.8	42.9	3.4	46.3	Sand with fines	shell hash
E7	71	4.4	1.5	4.0	0.0	55.7	41.6	2.8	44.3	Sand with fines	
E1	90	4.2	1.7	3.8	0.0	58.8	38.3	3.0	41.2	Sand with fines	coarse sand/pea gravel/shell hash
98-m Depth Contour											
B12	113	3.9	1.8	3.3	0.0	68.0	29.0	3.1	32.0	Sand with fines	coarse sand/pea gravel/shell hash
B9	80	4.3	1.7	3.8	0.0	59.4	37.7	3.0	40.6	Sand with fines	pea gravel/gravel
E26	73	4.3	1.5	4.0	0.0	58.3	38.7	3.0	41.7	Sand with fines	shell hash
E25	77	4.3	1.5	3.8	0.0	60.2	37.3	2.5	39.8	Sand with fines	shell hash
E23	75	4.3	1.5	3.8	0.0	60.2	37.2	2.5	39.8	Sand with fines	shell hash
E20	80	4.2	1.5	3.8	0.0	64.2	33.5	2.3	35.8	Sand with fines	shell hash
E17[b]	86	4.0	1.5	3.7	0.0	68.4	29.6	2.0	31.6	Sand with fines	shell hash
E14[b]	92	3.9	1.4	3.5	0.0	73.3	24.9	1.8	26.7	Sand with fines	coarse black sand/shell hash
E11[b]	83	4.1	1.4	3.8	0.0	66.3	31.8	1.9	33.7	Sand with fines	shell hash
E8	86	4.1	1.5	3.7	0.0	67.2	30.5	2.2	32.7	Sand with fines	
E5	86	4.1	1.5	3.7	0.0	66.3	31.5	2.3	33.8	Sand with fines	
E2[a]	300	3.0	1.6	4.0	12.5	48.8	—	—	38.8	Sand with coarse and fines	coarse sand/pea gravel/shell hash
116-m Depth Contour											
B10	96	3.9	1.6	3.5	0.0	71.9	25.7	2.3	28.0	Sand with fines	shell hash
E21	83	4.1	1.5	3.7	0.0	66.5	31.1	2.4	33.5	Sand with fines	shell hash
E15[b]	83	4.2	1.6	3.7	0.0	65.6	31.3	3.0	34.3	Sand with fines	coarse black sand/shell hash
E9[a]	617	1.1	1.1	1.0	27.2	69.1	—	—	3.7	Sand with coarse	coarse sand/shell hash
E3	117	3.9	1.9	3.3	0.0	65.6	31.5	3.0	34.4	Sand with fines	coarse sand/pea gravel/shell hash

[a] Contains fraction > 2000 microns measured by sieve (not Horiba); [b] nearfield station



Appendix C.6

Plots illustrating historical sediment grain size distributions in sediments from PLOO Primary Core stations sampled between 2003–2011.



Appendix C.6 *continued*

Appendix C.7

Summary of organic loading indicators in sediments from PLOO stations sampled during January and July 2011. Bold values indicate concentrations that exceed the 95th percentile calculated for entire year.

	January					July				
	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	365	2.46	0.079	**3.10**	**3.64**	nr	8.66	0.06	1.09	**4.04**
B8	439	2.51	**0.095**	0.81	**3.25**	nr	13.10	0.06	0.49	3.07
E19	430	1.70	0.067	0.57	2.50	nr	3.00	0.04	0.37	2.42
E7	357	2.75	0.070	0.61	2.09	nr	3.31	0.05	1.06	2.29
E1	303	2.84	0.052	0.48	2.24	nr	3.97	0.05	0.36	2.18
98-m Depth Contour										
B12	**524**	3.80	0.059	**4.18**	3.17	nr	3.63	0.07	2.73	3.21
B9	301	2.95	0.071	0.62	2.70	nr	10.90	0.07	0.67	2.82
E26	398	4.50	0.065	0.56	2.38	nr	9.30	0.07	0.56	2.54
E25	344	1.88	0.057	0.48	2.28	nr	3.67	0.06	0.50	2.63
E23	311	1.10	0.061	0.52	2.26	nr	2.11	0.06	0.48	2.21
E20	251	2.01	0.053	0.43	1.78	nr	1.75	0.07	0.57	2.07
E17[a]	406	3.97	0.051	0.41	2.09	nr	**24.80**	0.06	0.54	1.99
E14[a]	**541**	**35.70**	0.047	0.39	1.65	nr	**52.40**	0.05	0.43	1.64
E11[a]	483	3.26	0.055	0.49	1.94	nr	2.16	0.05	0.89	2.09
E8	383	2.68	0.051	0.43	1.98	nr	11.80	0.05	0.39	2.06
E5	321	4.67	0.045	0.38	2.03	nr	7.58	0.05	0.42	2.16
E2	371	2.90	0.053	0.45	2.37	nr	12.90	0.05	0.47	2.48
116-m Depth Contour										
B10	365	1.86	0.060	1.09	2.49	nr	8.97	0.06	0.86	2.72
E21	350	3.84	0.059	0.49	1.81	nr	3.20	0.06	0.46	2.18
E15[a]	308	5.86	0.044	0.37	1.86	nr	4.45	0.04	0.33	2.33
E9	388	2.81	0.051	1.06	1.84	nr	5.66	0.07	0.99	2.42
E3	282	3.28	0.046	0.36	1.78	nr	7.57	0.04	0.32	1.90
Detection Rate (%)	100	100	100	100	100	—	100	100	100	100
95th Percentile	523	23.05	0.08	2.79	3.24	—	23.05	0.08	2.79	3.24

[a] nearfield station; nr = not reportable

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Appendix C.8

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during January 2011. See Appendix C.3 for MDLs and translation of periodic table symbols. Bold values indicate concentrations that exceed the 95th percentile calculated for entire year; values that exceed thresholds are highlighted (see Table 4.1).

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	6710	0.49	3.6	34.3	0.223	0.18	20.3	8.7	15,800	8.60	108.0	0.022	8.25	nd	nd	nd	1.04	38.4
B8	**11,100**	**0.91**	2.9	**61.9**	**0.224**	**0.52**	**24.1**	**13.2**	16,100	**10.30**	**140.0**	0.038	**11.60**	nd	nd	0.99	**2.74**	**42.6**
E19	10,400	0.57	2.6	48.6	0.188	0.19	20.4	8.9	14,300	8.78	115.0	0.027	**9.51**	nd	nd	nd	1.10	37.3
E7	6260	0.42	2.5	41.9	0.144	0.14	15.0	8.8	9580	7.81	86.2	0.026	7.53	nd	nd	nd	1.00	28.8
E1	5150	0.30	2.1	22.9	**0.252**	0.18	**21.8**	5.0	**17,200**	6.48	53.1	0.040	6.07	nd	nd	nd	0.69	34.4
98-m Depth Contour																		
B12	6840	0.47	4.0	**67.9**	0.195	0.11	14.5	13.1	14,600	9.86	120.0	0.015	6.77	nd	nd	nd	0.94	31.9
B9	5730	0.41	2.8	37.4	0.183	0.10	17.3	6.4	12,000	6.58	82.3	0.020	7.01	nd	nd	nd	0.80	30.9
E26	8360	0.43	1.5	39.9	0.168	0.13	15.6	7.7	11,600	7.91	85.0	0.027	7.35	nd	2.81	nd	0.87	28.2
E25	7660	0.51	2.1	35.0	0.139	0.13	15.6	6.9	10,600	6.39	87.1	0.028	7.11	nd	nd	nd	0.82	27.5
E23	8330	0.43	1.8	37.2	0.169	0.13	17.2	7.0	11,900	7.25	92.9	0.029	7.84	nd	nd	nd	0.90	31.1
E20	6460	0.44	2.2	32.2	0.123	0.12	14.3	6.5	9700	5.86	76.8	0.015	6.52	nd	nd	nd	0.72	26.4
E17[a]	6400	0.49	1.8	31.3	0.143	0.17	14.9	6.4	10,200	5.61	75.3	0.021	6.91	nd	0.73	nd	0.86	26.4
E14[a]	5460	0.48	2.0	26.1	0.140	**0.35**	12.4	5.9	8420	4.53	62.3	0.022	5.81	nd	0.16	nd	0.83	22.4
E11[a]	5670	nd	2.2	26.2	0.135	0.13	13.2	5.6	9470	5.03	64.7	0.016	5.97	nd	nd	nd	0.78	23.6
E8	4880	0.31	1.8	28.6	0.119	0.10	12.4	6.4	7500	5.62	62.2	0.020	5.72	nd	nd	nd	0.74	22.8
E5	5180	0.47	1.3	35.5	0.121	0.11	12.0	7.5	7660	6.40	66.9	0.030	5.68	nd	nd	nd	0.86	23.9
E2	5600	0.50	1.8	45.6	0.139	0.08	12.8	9.3	9100	7.37	78.7	0.034	5.87	nd	nd	nd	0.73	27.6
116-m Depth Contour																		
B10	4480	0.34	2.1	21.0	0.150	0.12	14.7	5.0	9790	5.26	53.9	0.016	5.16	nd	nd	nd	0.58	25.2
E21	**12,900**	**0.80**	1.9	**57.1**	**0.238**	0.23	**23.8**	**13.3**	**17,000**	9.67	**129.0**	0.017	**10.70**	nd	nd	nd	1.28	40.9
E15[a]	7240	0.34	1.1	32.3	0.156	0.13	13.6	6.5	10,500	5.31	65.7	0.016	6.09	nd	nd	nd	0.92	23.2
E9	6100	0.63	2.2	26.2	0.159	0.14	17.2	**13.8**	12,300	7.56	67.9	0.023	5.99	nd	nd	nd	0.91	**46.0**
E3	4110	0.46	1.6	44.0	0.099	0.08	9.2	10.1	6900	**326.00**	69.0	**0.051**	4.37	nd	nd	nd	1.09	25.0
Detection Rate (%)	100	95	100	100	100	100	100	100	100	100	100	100	100	0	14	5	100	100
95th Percentile[b]	10,995	0.64	4.9	56.2	0.224	0.29	21.8	13.2	16,610	10.23	126.8	0.051	9.40	—	—	—	1.63	42.3

[a] nearfield stations; [b] 95th Percentile not calculated if detection rate <50%.

nd = not detected; na = not available

Appendix C.8 *continued*

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during July 2011. See Appendix C.3 for MDLs and translation of periodic table symbols. Bold values indicate concentrations that exceed the 95th percentile calculated for entire year; values that exceed thresholds are highlighted (see Table 4.1).

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour																		
B11	5270	0.59	**6.1**	31.5	0.184	0.14	16.1	7.9	13,900	6.85	**128.0**	0.042	7.78	nd	nd	nd	0.97	31.7
B8	6270	0.43	4.6	44.1	0.164	0.12	16.4	8.6	11,700	7.14	95.4	0.040	8.75	nd	nd	nd	1.22	31.1
E19	5230	0.59	4.8	37.9	0.132	0.15	13.8	7.0	8770	5.53	75.1	0.039	7.35	nd	nd	nd	1.01	24.5
E7	4490	0.46	4.7	33.2	0.119	0.14	12.0	7.0	7860	5.38	66.4	0.037	6.58	nd	nd	nd	0.92	22.0
E1	7570	0.44	4.3	42.9	0.127	0.11	14.6	9.5	11,300	7.97	89.1	**0.058**	6.68	nd	nd	nd	**1.78**	33.0
98-m Depth Contour																		
B12	4200	0.50	**7.8**	17.4	0.215	0.14	21.5	4.9	**16,700**	5.22	49.8	0.018	6.11	nd	nd	nd	0.63	32.3
B9	4710	0.53	4.8	33.8	0.184	**0.30**	15.8	5.9	11,100	5.41	71.1	0.031	6.57	nd	nd	nd	0.92	28.5
E26	4670	0.39	4.1	32.3	0.126	0.14	13.1	6.3	7950	5.14	67.6	0.032	7.01	nd	nd	nd	0.88	22.1
E25	4360	0.48	4.3	31.3	0.122	0.15	13.7	6.3	7450	5.35	69.0	0.031	6.75	nd	nd	nd	0.84	22.4
E23	4920	0.48	4.2	33.7	0.132	0.22	13.4	6.6	8090	4.77	68.2	0.028	7.18	nd	nd	nd	1.04	22.8
E20	4590	0.46	3.8	31.0	0.114	0.17	13.7	6.1	7570	4.98	68.6	0.025	7.04	nd	nd	nd	0.70	22.7
E17[a]	8830	0.58	4.2	32.3	0.143	0.18	15.5	7.5	10,700	5.69	86.4	0.024	7.23	nd	nd	nd	1.32	27.2
E14[a]	3310	0.31	4.4	21.2	0.085	0.17	10.0	5.2	5880	3.18	45.3	0.019	5.20	nd	nd	nd	0.55	17.6
E11[a]	8300	0.44	3.5	29.8	0.140	0.15	14.1	6.1	9760	4.89	80.7	0.020	6.56	nd	nd	nd	1.16	24.0
E8	9560	0.50	3.8	32.6	0.157	0.14	16.6	7.3	11,700	6.37	92.4	0.024	7.27	nd	nd	nd	1.39	28.5
E5	8210	0.45	3.7	33.5	0.144	0.12	15.3	7.0	10,900	5.92	82.0	0.028	6.67	nd	nd	nd	1.52	26.3
E2	**11,100**	**0.64**	4.1	50.8	0.187	0.14	19.1	12.2	15,400	8.93	114.0	**0.060**	8.47	nd	nd	nd	**1.65**	36.9
116-m Depth Contour																		
B10	3900	0.42	3.9	21.0	0.144	0.13	14.5	4.9	9690	4.65	52.4	0.023	5.41	nd	nd	nd	0.54	24.6
E21	3270	0.34	3.9	22.8	0.096	0.14	10.5	5.1	5800	3.83	46.7	0.025	5.77	nd	nd	nd	0.64	17.3
E15[a]	3700	0.41	4.4	24.7	0.107	0.14	11.6	6.0	6610	4.41	51.3	0.030	5.84	nd	nd	nd	0.88	19.4
E9	6560	0.62	4.7	30.4	0.152	0.15	18.4	8.7	12,400	5.72	68.9	0.029	6.86	nd	nd	nd	1.23	29.6
E3	7300	0.53	4.2	50.0	0.126	0.10	13.8	11.0	11,500	**13.30**	94.9	0.048	5.16	nd	nd	nd	1.47	**43.3**
Detection Rate (%)	100	100	100	100	100	100	100	100	100	100	100	100	100	0	0	0	100	100
95th Percentile	10,995	0.64	4.9	56.2	0.224	0.29	21.8	13.2	16,610	10.23	126.8	0.051	9.40	—	—	—	1.63	42.3

[a] nearfield stations; [b] 95th Percentile not calculated if detection rate <50%.

nd = not detected; na = not available

Appendix C.9

Concentrations of HCB, total DDT, total PCB, and total PAH detected in sediments from PLOO stations sampled during January and July 2011. Bold values indicate concentrations that exceed the 95th percentile calculated for entire year; values that exceed thresholds are highlighted (see Table 4.1).

	January				July			
	HCB (ppt)	**tDDT (ppt)**	**tPCB (ppt)**	**tPAH (ppb)**	**HCB (ppt)**	**tDDT (ppt)**	**tPCB (ppt)**	**tPAH (ppb)**
88-m Stations								
B11	nd	430	nd	nd	nd	530	nd	nd
B8	nd	670	nd	nd	nd	620	nd	nd
E19	nd	360	nd	nd	nd	360	nd	nd
E7	nd	380	nd	nd	**680**	460	nd	nd
E1	nd	580	1169	nd	300	**1620**	5750	155
98-m Stations								
B12	nd	nd	nd	nd	nd	220	nd	nd
B9	nd	390	nd	nd	nd	570	nd	nd
E26	nd	330	nd	nd	390	390	nd	111
E25	nd	280	nd	nd	nd	**690**	nd	121
E23	nd	290	nd	nd	nd	450	nd	147
E20	nd	280	nd	nd	nd	nd	nd	nd
E17[a]	nd	210	nd	nd	nd	nd	nd	nd
E14[a]	nd	210	nd	nd	nd	250	nd	nd
E11[a]	nd	200	nd	nd	nd	300	nd	nd
E8	nd	250	nd	nd	nd	260	nd	nd
E5	nd	300	nd	nd	nd	320	nd	nd
E2	nd	290	338	nd	nd	**710**	8110	128
116-m Stations								
B10	nd	340	nd	nd	nd	360	nd	nd
E21	nd	220	160	nd	nd	520	nd	nd
E15[a]	nd	190	nd	nd	600	580	1970	nd
E9	nd	260	8450	nd	nd	580	**63,890**	23
E3	nd	330	12,090	196	190	330	7210	**306**
Detection Rate (%)	0	95	23	5	23	91	23	32
95th Percentile[b]	—	689	—	—	—	689	—	—

[a] nearfield stations; [b] 95th Percentile not calculated if detection rate <50%.
nd = not detected; na = not available

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Appendix D

Supporting Data

2011 PLOO Stations

Macrobenthic Communities

Appendix D.1

PLOO one-way ANOSIM results for benthic infauna.

Global Test

Tests for differences between sediment types

Sample statistic (Global R):	0.47
Significance level of sample statistic:	1.2%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	116

Pairwise tests

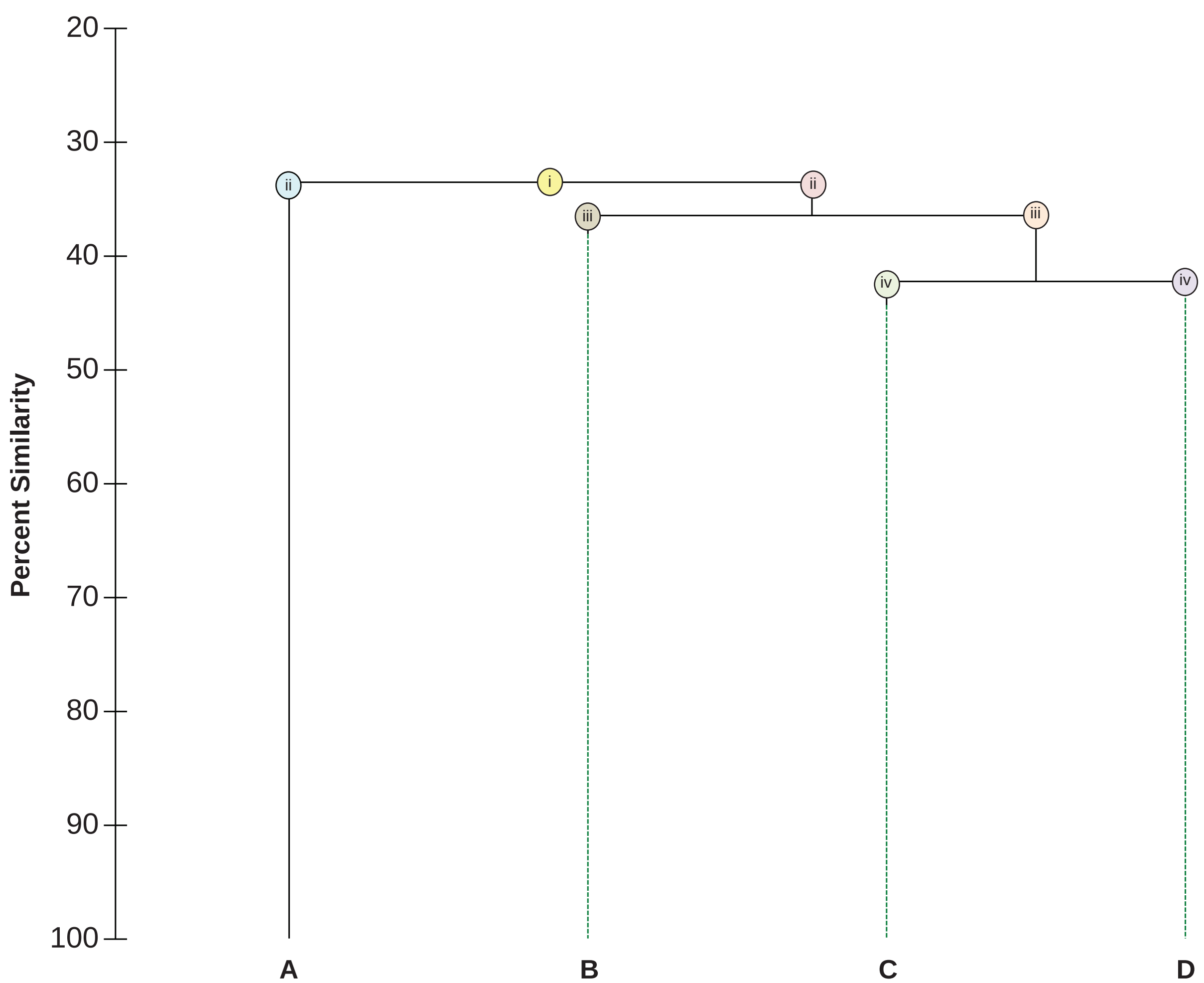
Tests for pairwise differences between individual sediment types: r values (p values)

	Fines with sand	Sand with coarse and fines	Sand with coarse
Sand with fines	0.854 (0.002)	0.256 (0.268)	-0.09 (0.585)
Fines with sand		0 (0.667)	1 (0.333)
Sand with coarse and fines			no test

Appendix D.2

Delineation of cluster groups (see Figure 5.4) by species exclusivity (i.e., species that occur solely in each supported clade versus species that occur in multiple non-related clades). Roman numerals and colored circles in dendrogram (below) correspond to numbers and colors delineating each SIMPROF-supported split featured in the appendix (following pages). Mid = mid-shelf (30−120 m). Sc = sand with coarse, Sf = sand with fines, Fs = fines with sand, Scf = sand with coarse and fines.

	n				**Depth**				**Fines**			
CG	**invert**	**sed.**	**nearfield**	**Stratum**	**mean**	**min**	**max**	**Sed.**	**mean**	**min**	**max**	**Depth/sed. exceptions**
A	1	1	0	mid	88	88	88	Sf	46.4	46.4	46.4	
B	7	3	0	mid	88	88	88	varied	52.2	41.2	59.5	Fs = 2, Sf = 1
C	14	7	0	mid	110.9	98	116	Sf	34.0	28.0	39.8	
D	66	33	16	mid	98.9	87	118	varied	36.6	3.7	47.2	Sf = 31, Sc = 1, Scf = 1



Appendix D.2 *continued*

(i.) Species occurring in all cluster groups

Cluster groups	**A**	**B**	**C**	**D**
Aphelochaeta tigrina	1	0.14	1.29	0.5
Kurtzina beta	1	0.43	0.43	0.29
Nemocardium centifilosum	1	0.14	0.43	0.44
Rhachotropis sp A	1	0.14	0.07	0.09

(ii.) Species delineating the separation of cluster group A from cluster groups D through K (33.52% similarity)

	A	**B**	**C**	**D**
Calocarides spinulicauda	1	0	0	0
Eusyllis blomstrandi	1	0	0	0
Hiatella arctica	1	0	0	0
Listriella melanica	1	0	0	0
Maera jerrica	2	0	0	0
Malmgreniella macginitiei	1	0	0	0
Philine auriformis	0	0.29	0.29	0.26
additional 28 taxa (≤0.29)	0	x	x	x

(iii.) Species delineating the separation of cluster group B from cluster groups C and D (36.45% similarity)

	A	**B**	**C**	**D**
Chaetoderma pacificum	0	0.29	0	0
Megalomma sp	0	0.29	0	0
Aricidea (Acmira) sp	0	0.14	0	0
Brissopsis pacifica	0	0.14	0	0
Phyllochaetopterus limicolus	0	0.14	0	0
Typosyllis heterochaeta	0	0	0.36	0.18
Aphelochaeta williamsae	0	0	0.36	0.05
additional 41 taxa (≤0.29)	0	0	x	x

(iv.) Species delineating the separation of cluster group C from cluster group D (42.25% similarity)

	A	**B**	**C**	**D**
Chaetozone sp SD3	0	0	1.07	0
Mooreonuphis exigua	0	0	0.5	0
additional 36 taxa (≤0.21)	0	0	x	0
Rhepoxynius menziesi	0	0	0	1.91
Lumbrineris latreilli	0	0	0	0.5
Solemya pervernicosa	0	0	0	0.5
Terebellides sp	0	0	0	0.45
Euclymeninae sp A	0	0	0	0.24
additional 158 taxa (≤0.18)	0	0	0	x

Appendix E

Supporting Data

2011 PLOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Summary of demersal fish species captured during 2011 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 Allen (2005).

				Length		
Taxon/Species	**Common name**	***n***	**BM**	**Min**	**Max**	**Mean**
RAJIFORMES[a]						
Rajidae						
Raja inornata	California skate	5	2.1	27	42	38
Platyrhynidae						
Platyrhinodidis triseriata	thornback	1	0.1	17	17	17
AULOPIFORMES						
Synodontidae						
Synodus lucioceps	California lizardfish	541	7.4	8	29	12
OPHIDIIFORMES						
Ophidiidae						
Chilara taylori	spotted cusk-eel	5	0.2	12	19	15
BATRACHOIDIFORMES						
Batrachoididae						
Porichthys notatus	plainfin midshipman	19	0.8	11	16	12
LOPHIIFORMES						
Ogcocephalidae						
Zalieutes elater	roundel batfish	1	2.1	15	15	15
SCORPAENIFORMES						
Scorpaenidae						
Scorpaena guttata	California scorpionfish	18	6.7	16	25	21
Sebastes chlorostictus	greenspotted rockfish	8	0.7	6	23	14
Sebastes elongatus	greenstriped rockfish	24	0.8	6	13	10
Sebastes hopkinsi	squarespot rockfish	27	0.9	8	18	12
Sebastes jordani	shortbelly rockfish	1	0.1	16	16	16
Sebastes nigrocinetus	tiger rockfish	2	0.2	6	19	13
Sebastes rosenblatti	greenblotched rockfish	2	0.2	8	9	9
Sebastes saxicola	stripetail rockfish	689	9.2	4	13	8
Sebastes semicinctus	halfbanded rockfish	667	16.6	5	17	10
Hexagrammidae						
Zaniolepis frenata	shortspine combfish	93	2.8	8	18	13
Zaniolepis latipinnis	longspine combfish	216	1.8	6	15	8
Cottidae						
Chitonotus pugetensis	roughback sculpin	6	0.4	7	12	9
Icelinus quadriseriatus	yellowchin sculpin	37	0.5	6	9	7
Icelinus tenuis	spotfin sculpin	7	0.1	8	11	9
Agonidae						
Odontopyxis trisponosa	pygmy poacher	3	0.3	6	15	10
PERCIFORMES						
Embiotocidae						
Zalembius rosaceus	pink seaperch	120	3.3	4	15	10
Zoarcidae						
Lycodes pacificus	blackbelly eelpout	2	0.2	19	20	20
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 Min	Length Max	Length Mean
PLEURONECTIFORMES						
Paralichthyidae						
Citharichthys sordidus	Pacific sanddab	1837	54.6	3	26	10
Hippoglossina stomata	bigmouth sole	8	1.8	17	31	21
Pleuronectidae						
Eopsetta exilis	slender sole	6	0.5	14	18	16
Microstomus pacificus	Dover sole	211	7.2	6	20	13
Parophrys vetulus	English sole	52	5.4	7	25	18
Pleuronichthys verticalis	hornyhead turbot	16	1.8	12	29	17
Cynoglossidae						
Symphurus atricauda	California tonguefish	21	0.7	10	18	14

Appendix E.2

Summary of total abundance by species and station for demersal fish at the PLOO trawl stations during 2011.

	January 2011						
Name	**SD7**	**SD8**	**SD10**	**SD12**	**SD13**	**SD14**	**Species Abundance by Survey**
Pacific sanddab	78	86	149	153	38	122	626
Stripetail rockfish	59	75	213	121	74	10	552
California lizardfish	53	56	51	3	184	113	460
Halfbanded rockfish	36	27	85	23	101	4	276
Pink seaperch	4	7	1		55	15	82
Dover sole	2	7	14	29	12	2	66
Longspine combfish	1	5	5	14	29	9	63
Shortspine combfish	12	17	5	14	4	1	53
Yellowchin sculpin	5		21	1	9		36
English sole	5	1	3	4	11	6	30
California scorpionfish	1		3	8	4	2	18
Plainfin midshipman	1	1			8	6	16
California tonguefish	4	4	4	2			14
Greenstriped rockfish	1	6	2	3			12
Hornyhead turbot	1		2	4	2		9
Bigmouth sole	3				1	1	5
California skate						5	5
Roughback sculpin	1	1	3				5
Greenspotted rockfish				2			2
Pygmy poacher		1		1			2
Roundel batfish				1			1
Thornback						1	1
Total	267	294	561	383	532	297	2334

Appendix E.2 *continued*

Name	July 2011 SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
Pacific sanddab	224	307	222	68	165	225	1211
Halfbanded rockfish	7	103	53		15	213	391
Longspine combfish	43	3	54	17	23	13	153
Dover sole	13	28	38	31	21	14	145
Stripetail rockfish	4	32	36	20	25	20	137
California lizardfish	19	15	13	18	15	1	81
Shortspine combfish	8	7	7	7	4	7	40
Pink seaperch	6	1	7	1	16	7	38
Squarespot rockfish				11		16	27
English sole	3	5	4	4	3	3	22
Greenstriped rockfish		5	3	4			12
California tonguefish	2	4	1				7
Hornyhead turbot	1			6			7
Spotfin sculpin		7					7
Greenspotted rockfish					2	4	6
Slender sole		1	1	2	1	1	6
Spotted cusk-eel	4				1		5
Bigmouth sole					3		3
Plainfin midshipman	2		1				3
Blackbelly eelpout					1	1	2
Greenblotched rockfish				1		1	2
Tiger rockfish					1	1	2
Blacktip poacher					1		1
Pygmy poacher		1					1
Roughback sculpin	1						1
Shortbelly rockfish		1					1
Yellowchin sculpin			1				1
Total	337	520	441	190	297	527	2312

Appendix E.3

Summary of biomass (kg) by species and station for demersal fish at the PLOO trawl stations during 2011.

	January 2011						
Name	SD7	SD8	SD10	SD12	SD13	SD14	Biomass by Survey
Pacific sanddab	0.8	0.8	3.3	3.2	2.1	8.6	18.8
Stripetail rockfish	0.5	0.8	1.5	1.0	2.7	0.2	6.7
California scorpionfish	0.5		1.1	2.1	1.5	1.5	6.7
California lizardfish	0.8	0.7	0.6	0.1	2.4	1.4	6.0
Halfbanded rockfish	0.4	0.5	0.8	0.4	1.4	0.1	3.6
English sole	0.4	0.1	0.4	0.5	1.2	0.8	3.4
Pink seaperch	0.2	0.4	0.1		1.2	0.4	2.3
California skate						2.1	2.1
Roundel batfish				2.1			2.1
Dover sole	0.1	0.2	0.2	0.6	0.6	0.1	1.8
Shortspine combfish	0.8	0.4	0.1	0.2	0.2	0.1	1.8
Bigmouth sole	0.7				0.2	0.5	1.4
Hornyhead turbot	0.1		0.1	0.4	0.5		1.1
Longspine combfish	0.1	0.1	0.1	0.1	0.3	0.1	0.8
Plainfin midshipman	0.1	0.1			0.3	0.1	0.6
Greenstriped rockfish	0.1	0.2	0.1	0.1			0.5
California tonguefish	0.1	0.1	0.1	0.1			0.4
Yellowchin sculpin	0.1		0.1	0.1	0.1		0.4
Roughback sculpin	0.1	0.1	0.1				0.3
Pygmy poacher		0.1		0.1			0.2
Greenspotted rockfish				0.1			0.1
Thornback						0.1	0.1
Total	5.9	4.6	8.7	11.2	14.7	16.1	61.2

Appendix E.3 *continued*

Name	July 2011						Biomass by Survey
	SD7	SD8	SD10	SD12	SD13	SD14	
Pacific sanddab	3.5	4.8	6.4	1.5	7.5	12.1	35.8
Halfbanded rockfish	0.1	1.9	1.0		0.3	9.7	13.0
Dover sole	0.2	0.7	1.2	1.0	1.3	1.0	5.4
Stripetail rockfish	0.1	0.6	0.6	0.3	0.5	0.4	2.5
English sole	0.2	0.4	0.4	0.6	0.3	0.1	2.0
California lizardfish	0.3	0.5	0.1	0.1	0.3	0.1	1.4
Longspine combfish	0.2	0.1	0.2	0.1	0.1	0.3	1.0
Shortspine combfish	0.2	0.2	0.1	0.1	0.1	0.3	1.0
Pink seaperch	0.1	0.1	0.1	0.1	0.4	0.2	1.0
Squarespot rockfish				0.2		0.7	0.9
Hornyhead turbot	0.1			0.6			0.7
Greenspotted rockfish					0.1	0.5	0.6
Slender sole		0.1	0.1	0.1	0.1	0.1	0.5
Bigmouth sole					0.4		0.4
California tonguefish	0.1	0.1	0.1				0.3
Greenstriped rockfish		0.1	0.1	0.1			0.3
Blackbelly eelpout					0.1	0.1	0.2
Greenblotched rockfish				0.1		0.1	0.2
Plainfin midshipman	0.1		0.1				0.2
Spotted cusk-eel	0.1				0.1		0.2
Tiger rockfish					0.1	0.1	0.2
Blacktip poacher					0.1		0.1
Pygmy poacher		0.1					0.1
Roughback sculpin	0.1						0.1
Shortbelly rockfish		0.1					0.1
Spotfin sculpin		0.1					0.1
Yellowchin sculpin			0.1				0.1
Total	5.4	9.9	10.6	4.9	11.8	25.8	68.4

Appendix E.4

PLOO two-way crossed ANOSIM (no replicates) results for fish (A = stations, B = years).

Global Test: Factor A	
Tests for differences between stations (across all years)	
Sample statistic (Rho):	0.279
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Rho:	0
Global Test: Factor B	
Tests for differences between years (across all stations)	
Sample statistic (Rho):	0.315
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Rho:	0

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Appendix E.5

List of megabenthic invertebrate taxa captured during 2011 at PLOO trawl stations. Data are number of individuals (*n*). Taxonomic arrangement from SCAMIT (2011).

Taxon/Species					*n*
SILICEA					
	DEMOSPONGIAE				
		Hadromerida			
			Suberitidae		
				Suberites latus	1
CNIDARIA					
	ANTHOZOA				
		Stolonifera			
			Telestidae		
				Telesto californica	1
		Alcyonacea			
			Gorgoniidae		
				Leptogorgia chilensis	1
			Plexauridae		
				Thesea sp B	21
		Pennatulacea			
			Virgulariidae		
				Acanthoptilum sp	70
		Actiniaria			
			Metridiidae		
				Metridium farcimen	2
MOLLUSCA					
	GASTROPODA				
			Calliostomatidae		
				Calliostoma tricolor	3
				Calliostoma turbinum	3
		Hypsogastropoda			
			Ovulidae		
				Neosimnia barbarensis	14
			Fasciolariidae		
				Barbarofusus barbarensis	1
			Nassriidae		
				Hinea insculpta	6
			Turridae		
				Megasurcula carpenteriana	5
				Antiplanes catalinae	3

Appendix E.5 *continued*

Taxon/Species					*n*
			Cancellariidae		
				Cancellaria cooperii	1
				Cancellaria crawfordiana	3
		Opisthobranchia			
			Philinidae		
				Philine alba	8
				Philine auriformis	16
			Pleurobranchidae		
				Pleurobranchaea californica	64
			Onchidorididae		
				Acanthodoris brunnea	10
			Arminidae		
				Armina californica	5
			Tritoniidae		
				Tritonia diomedea	1
			Dendronotidae		
				Dendronotus venustus	1
	CEPHALOPODA				
		Sepiolida			
			Sepiolidae		
				Rossia pacifica	2
		Octopoda			
			Octopodidae		
				Octopus rubescens	11
ANNELIDA					
	POLYCHAETA				
		Aciculata			
			Polynoidae		
				Arctonoe pulchra	4
ARTHROPODA					
	PYCNOGONIDA				
		Pegmata			
			Nymphonidae		
				Nymphon pixellae	13
	MALACOSTRACA				
		Isopoda			
			Cymothoidae		
				Elthusa vulgaris	4

Appendix E.5 *continued*

Taxon/Species					*n*
		Decapoda			
			Sicyoniidae		
				Sicyonia ingentis	8
			Crangonidae		
				Crangon alaskensis	5
			Diogenidae		
				Paguristes bakeri	2
			Paguridae		
				Parapagurodes laurentae	1
			Inachidae		
				Podochela lobifrons	1
ECHINODERMATA					
	CRINOIDEA				
		Comatulida			
			Antedonidae		
				Florometra serratissima	9
	ASTEROIDEA				
		Paxillosida			
			Luidiidae		
				Luidia asthenosoma	38
				Luidia foliolata	159
			Astropectinidae		
				Astropecten californicus	37
	OPHIUROIDEA				
		Ophiurida			
			Ophiactidae		
				Ophiopholis bakeri	5
			Amphiuridae		
				Amphichondrius granulatus	1
				Amphiodia sp	1
			Ophiuridae		
				Ophiura luetkenii	648
	ECHINOIDEA				
		Camarodonta			
			Toxopneustidae		
				Lytechinus pictus	11,384
			Strongylocentrotidae		
				Strongylocentrotus fragilis	777

Appendix E.5 *continued*

Taxon/Species	*n*
HOLOTHUROIDEA	
Aspidochirotida	
Stichopodidae	
Parastichopus californicus	28

Appendix E.6

Summary of total abundance by species and station for megabenthic invertebrates at the PLOO trawl stations during 2011.

Species	January 2011						Species Abundance by Survey
	SD7	SD8	SD10	SD12	SD13	SD14	
Lytechinus pictus	1435	1188	1238	878	256	234	5229
Ophiura luetkenii	35	16	36	20	96	148	351
Strongylocentrotus fragilis					78	168	246
Acanthoptilum sp		2	4	55	1	8	70
Luidia foliolata	3	7	8	6	1	4	29
Astropecten californicus	4	4	2	6	4	2	22
Pleurobranchaea californica	3	9	3	4	2	1	22
Luidia asthenosoma	1	8	4		4	2	19
Thesea sp B	1	2		12			15
Neosimnia barbarensis				8	2		10
Parastichopus californicus	2	2	3	1		1	9
Philine auriformis	3		3	1			7
Acanthodoris brunnea				6			6
Octopus rubescens		2			1	3	6
Philine alba		6					6
Crangon alaskensis	1		3	1			5
Armina californica				3			3
Calliostoma turbinum	1				1		2
Cancellaria crawfordiana		1	1				2
Florometra serratissima	2						2
Hinea insculpta	1			1			2
Nymphon pixellae		2					2
Sicyonia ingentis			1			1	2
Amphichondrius granulatus		1					1
Amphiodia sp				1			1
Barbarofusus barbarensis	1						1
Dendronotus venustus				1			1
Elthusa vulgaris					1		1
Leptogorgia chilensis				1			1
Paguristes bakeri	1						1
Rossia pacifica			1				1
Tritonia diomedea				1			1
Total	1494	1250	1307	1006	447	572	6076

Appendix E.6 *continued*

Species	July 2011 SD7	SD8	SD10	SD12	SD13	SD14	Species Abundance by Survey
Lytechinus pictus	1976	1750	1796	203	300	130	6155
Strongylocentrotus fragilis				35	128	368	531
Ophiura luetkenii	46	38	49	17	48	99	297
Luidia foliolata	22	25	10	6	34	33	130
Pleurobranchaea californica	7	10	10	2	12	1	42
Luidia asthenosoma	5	4		1	5	4	19
Parastichopus californicus	8	8	2			1	19
Astropecten californicus	6		3	1	1	4	15
Nymphon pixellae		11					11
Philine auriformis	5	1	1		2		9
Florometra serratissima	7						7
Sicyonia ingentis	4	1			1		6
Thesea sp B	1	4		1			6
Megasurcula carpenteriana			2	3			5
Octopus rubescens	3	1				1	5
Ophiopholis bakeri	3	2					5
Acanthodoris brunnea			2	2			4
Arctonoe pulchra					4		4
Hinea insculpta	2			2			4
Neosimnia barbarensis				4			4
Antiplanes catalinae	3						3
Calliostoma tricolor	3						3
Elthusa vulgaris	1				2		3
Armina californica				2			2
Metridium farcimen			1		1		2
Philine alba		2					2
Calliostoma turbinum			1				1
Cancellaria cooperii	1						1
Cancellaria crawfordiana			1				1
Paguristes bakeri	1						1
Parapagurodes laurentae	1						1
Podochela lobifrons						1	1
Rossia pacifica	1						1
Suberites latus	1						1
Telesto californica		1					1
Total	2107	1858	1878	279	538	642	7302

Appendix F

Supporting Data

2011 PLOO Stations

Bioaccumulation of Contaminants in Fish Tissues

Appendix F.1

Lengths and weights of fishes used for each composite (Comp) tissue sample from PLOO trawl zones and rig fishing stations during October 2011. Data are summarized as number of individuals (*n*), minimum, maximum, and mean values.

				Length (cm, size class)			Weight (g)		
Station	**Comp**	**Species**	***n***	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
RF1	1	Vermilion rockfish	3	23	27	25	320	517	403
RF1	2	Vermilion rockfish	3	23	25	24	291	485	399
RF1	3	Vermilion rockfish	3	22	25	23	339	468	383
RF2	1	Chilipepper rockfish	3	26	32	28	499	970	664
RF2	2	Chilipepper rockfish	3	24	28	26	357	501	451
RF2	3	Flag rockfish	3	22	25	23	267	447	344
Zone 1	1	Pacific sanddab	8	15	18	17	55	105	69
Zone 1	2	Pacific sanddab	6	17	18	18	69	85	75
Zone 1	3	Pacific sanddab	6	16	18	17	62	87	73
Zone 2	1	Pacific sanddab	7	14	19	16	40	108	76
Zone 2	2	Pacific sanddab	8	15	18	17	44	86	65
Zone 2	3	Pacific sanddab	12	13	15	14	35	59	47
Zone 3	1	Pacific sanddab	3	20	22	21	126	225	179
Zone 3	2	Pacific sanddab	3	21	21	21	151	204	177
Zone 3	3	Pacific Sanddab	5	20	22	21	112	171	133
Zone 4	1	Pacific sanddab	7	16	17	16	51	84	70
Zone 4	2	Pacific sanddab	3	18	23	20	87	245	144
Zone 4	3	Pacific sanddab	7	15	18	17	57	97	75

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 between 2009 and 2011.

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Metals (ppm)					
Aluminum (Al)	3	3	Lead (Pb)	0.2	0.2
Antimony (Sb)	0.2	0.2	Manganese (Mn)	0.1	0.1
Arsenic (As)	0.24	0.24	Mercury (Hg)	0.002	0.002
Barium (Ba)	0.03	0.03	Nickel (Ni)	0.2	0.2
Beryllium (Be)	0.006	0.006	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.06	0.06	Silver (Ag)	0.05	0.05
Chromium (Cr)	0.1	0.1	Thallium (Ti)	0.4	0.4
Copper (Cu)	0.3	0.3	Tin (Sn)	0.2	0.2
Iron (Fe)	2	2	Zinc (Zn)	0.15	0.15
Chlorinated Pesticides (ppb)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	24.70	2.47	HCH, Delta isomer	4.53	0.45
HCH, Beta isomer	4.68	0.47	HCH, Gamma isomer	63.4	6.34
Total Chlordane					
Alpha (cis) chlordane	4.56	0.46	Heptachlor epoxide	3.89	0.39
Cis nonachlor	4.70	0.47	Oxychlordane	7.77	0.78
Gamma (trans) chlordane	2.59	0.26	Trans nonachlor	2.58	0.26
Heptachlor	3.82	0.38			
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	2.02	0.20	p,p-DDD	3.36	0.34
o,p-DDE	2.79	0.28	p,p-DDE	2.08	0.21
o,p-DDT	1.62	0.16	p,p-DDT	2.69	0.27
p,-p-DDMU	3.29	0.33			
Miscellaneous Pesticides					
Aldrin	88.10	8.81	Hexachlorobenzene (HCB)	1.32	0.13
Alpha endosulfan	118.00	11.80	Mirex	1.49	0.15
Dieldrin	17.10	1.71	Toxaphene	342.00	34.20
Endrin	14.20	1.42			

Appendix F.2 *continued*

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Polychlorinated Biphenyl Congeners (PCBs) (ppb)					
PCB 18	2.86	0.29	PCB 126	1.52	0.15
PCB 28	2.47	0.28	PCB 128	1.23	0.12
PCB 37	2.77	0.25	PCB 138	1.73	0.17
PCB 44	3.65	0.36	PCB 149	2.34	0.23
PCB 49	5.02	0.50	PCB 151	1.86	0.19
PCB 52	5.32	0.53	PCB 153/168	2.54	0.25
PCB 66	2.81	0.28	PCB 156	0.64	0.06
PCB 70	2.49	0.25	PCB 157	2.88	0.29
PCB 74	3.10	0.31	PCB 158	2.72	0.27
PCB 77	2.01	0.20	PCB 167	1.63	0.16
PCB 81	3.56	0.36	PCB 169	2.76	0.28
PCB 87	3.01	0.30	PCB 170	1.23	0.12
PCB 99	3.05	0.30	PCB 177	1.91	0.19
PCB 101	4.34	0.43	PCB 180	2.58	0.26
PCB 105	2.29	0.23	PCB 183	1.55	0.15
PCB 110	2.50	0.25	PCB 187	2.50	0.25
PCB 114	3.15	0.31	PCB 189	1.78	0.18
PCB 118	2.06	0.21	PCB 194	1.14	0.11
PCB 119	2.39	0.24	PCB 201	2.88	0.29
PCB 123	2.64	0.26	PCB 206	1.28	0.13

Appendix F.3

Summary of constituents that make up total DDT, total chlordane (tCHLOR) and total PCB in composite (Comp) tissue samples from the PLOO region during October 2011.

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	RF1	1	Vermilion rockfish	Muscle	PCB	PCB 101	0.4	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	PCB	PCB 118	0.2	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	PCB	PCB 138	0.2	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	PCB	PCB 149	0.2	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	PCB	PCB 153/168	0.4	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	PCB	PCB 180	0.3	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	PCB	PCB 187	0.3	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	PCB	PCB 99	0.3	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	DDT	o,p-DDE	0.3	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	DDT	p,p-DDD	0.3	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	DDT	p,p-DDE	2.5	ppb
2011-4	RF1	1	Vermilion rockfish	Muscle	DDT	p,p-DDT	0.3	ppb
2011-4	RF1	2	Vermilion rockfish	Muscle	PCB	PCB 118	0.2	ppb
2011-4	RF1	2	Vermilion rockfish	Muscle	PCB	PCB 138	0.2	ppb
2011-4	RF1	2	Vermilion rockfish	Muscle	PCB	PCB 153/168	0.3	ppb
2011-4	RF1	2	Vermilion rockfish	Muscle	PCB	PCB 187	0.3	ppb
2011-4	RF1	2	Vermilion rockfish	Muscle	DDT	o,p-DDD	0.3	ppb
2011-4	RF1	2	Vermilion rockfish	Muscle	DDT	p,p-DDE	1.5	ppb
2011-4	RF1	2	Vermilion rockfish	Muscle	DDT	p,p-DDT	0.5	ppb
2011-4	RF1	3	Vermilion rockfish	Muscle	PCB	PCB 101	0.4	ppb
2011-4	RF1	3	Vermilion rockfish	Muscle	PCB	PCB 118	0.2	ppb
2011-4	RF1	3	Vermilion rockfish	Muscle	PCB	PCB 180	0.3	ppb
2011-4	RF1	3	Vermilion rockfish	Muscle	PCB	PCB 187	0.3	ppb
2011-4	RF1	3	Vermilion rockfish	Muscle	PCB	PCB 28	0.3	ppb
2011-4	RF1	3	Vermilion rockfish	Muscle	PCB	PCB 49	0.5	ppb
2011-4	RF1	3	Vermilion rockfish	Muscle	PCB	PCB 66	0.3	ppb
2011-4	RF1	3	Vermilion rockfish	Muscle	PCB	PCB 99	0.3	ppb
2011-4	RF1	3	Vermilion rockfish	Muscle	DDT	p,p-DDE	0.8	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 101	0.4	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 110	0.3	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 118	0.4	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 138	0.5	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 149	0.2	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 153/168	0.7	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 180	0.3	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 187	0.3	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 66	0.3	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 70	0.3	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 74	0.3	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	PCB	PCB 99	0.3	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	DDT	o,p-DDE	0.3	ppb
2011-4	RF2	1	Chilipepper rockfish	Muscle	DDT	p,p-DDE	6.7	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 101	0.4	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 110	0.3	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 138	0.3	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 149	0.2	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 153/168	0.5	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 180	0.3	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 187	0.3	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 66	0.3	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 70	0.3	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	PCB	PCB 99	0.3	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	DDT	o,p-DDE	0.3	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	DDT	p,p-DDD	0.3	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	DDT	p,p-DDE	4.5	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	DDT	p,p-DDT	0.3	ppb
2011-4	RF2	2	Chilipepper rockfish	Muscle	tCHLOR	Alpha (cis) Chlordane	0.5	ppb
2011-4	RF2	3	Flag rockfish	Muscle	PCB	PCB 101	0.4	ppb
2011-4	RF2	3	Flag rockfish	Muscle	PCB	PCB 118	0.3	ppb
2011-4	RF2	3	Flag rockfish	Muscle	PCB	PCB 138	0.4	ppb
2011-4	RF2	3	Flag rockfish	Muscle	PCB	PCB 153/168	0.8	ppb
2011-4	RF2	3	Flag rockfish	Muscle	PCB	PCB 170	0.1	ppb
2011-4	RF2	3	Flag rockfish	Muscle	PCB	PCB 180	0.3	ppb
2011-4	RF2	3	Flag rockfish	Muscle	PCB	PCB 187	0.3	ppb
2011-4	RF2	3	Flag rockfish	Muscle	PCB	PCB 99	0.3	ppb
2011-4	RF2	3	Flag rockfish	Muscle	DDT	p,p-DDE	5.3	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 101	7.4	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 105	5.5	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 110	8.6	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 118	17.0	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 119	0.7	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 123	2.1	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 128	9.7	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 138	25.0	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 149	7.5	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 151	4.4	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 153/168	45.0	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 156	5.8	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 158	2.6	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 167	2.9	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 170	4.6	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 177	2.8	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 180	15.0	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 183	3.8	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 187	14.0	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 194	3.7	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 201	2.2	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 206	2.6	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 44	1.1	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 49	2.3	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 52	3.4	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 66	2.4	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 70	2.5	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 74	1.7	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 87	2.4	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	PCB	PCB 99	10.0	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	DDT	o,p-DDE	1.9	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	DDT	o,p-DDT	0.7	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	22.0	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,p-DDD	4.4	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,p-DDE	220.0	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	DDT	p,p-DDT	4.3	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	3.2	ppb
2011-4	Zone 1	1	Pacific sanddab	Liver	tCHLOR	Cis Nonachlor	1.9	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 101	11.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 105	7.9	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 110	13.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 118	25.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 119	1.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 123	3.4	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 128	14.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 138	34.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 149	12.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 151	7.5	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 153/168	67.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 156	10.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 158	3.9	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 167	4.5	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 170	5.1	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 177	3.9	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 180	19.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 183	5.9	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 187	20.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 194	5.2	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 201	2.7	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 206	3.5	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 44	1.3	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 49	3.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 52	5.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 66	3.8	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 70	3.5	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 74	1.9	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 87	3.4	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	PCB	PCB 99	16.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	DDT	o,p-DDE	2.6	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	28.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,p-DDD	5.1	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,p-DDE	240.0	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	DDT	p,p-DDT	4.8	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	3.7	ppb
2011-4	Zone 1	2	Pacific sanddab	Liver	tCHLOR	Cis Nonachlor	2.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 101	7.2	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 105	5.7	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 110	8.6	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 118	18.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 119	0.6	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 123	2.3	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 128	11.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 138	25.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 149	6.3	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 151	4.9	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 153/168	41.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 156	6.9	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 158	2.4	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 167	3.1	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 170	3.8	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 177	2.3	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 180	13.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 183	3.2	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 187	12.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 194	2.9	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 201	2.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 206	2.1	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 44	1.1	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 49	2.4	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 52	4.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 66	2.3	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 70	2.8	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 74	1.6	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 87	2.2	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	PCB	PCB 99	9.6	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	DDT	o,p-DDE	3.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	22.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,p-DDD	4.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,p-DDE	230.0	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	DDT	p,p-DDT	4.6	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	4.6	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	tCHLOR	Cis Nonachlor	4.7	ppb
2011-4	Zone 1	3	Pacific sanddab	Liver	tCHLOR	Gamma (trans) Chlordane	2.6	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 101	4.6	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 105	4.5	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 110	5.7	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 118	13.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 119	0.6	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 123	2.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 128	10.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 138	21.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 149	5.2	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 151	3.4	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 153/168	36.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 156	5.1	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 158	2.7	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 167	2.7	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 170	4.2	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 177	2.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 180	11.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 183	3.3	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 187	11.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 194	3.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 201	2.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 206	1.9	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 44	0.7	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 49	1.5	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 52	2.3	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 66	2.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 70	1.8	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 74	1.4	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 87	1.3	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	PCB	PCB 99	7.2	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	DDT	o,p-DDE	2.1	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	17.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,p-DDD	3.6	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,p-DDE	160.0	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	DDT	p,p-DDT	3.7	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	2.3	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	tCHLOR	Cis Nonachlor	1.7	ppb
2011-4	Zone 2	1	Pacific sanddab	Liver	tCHLOR	Gamma (trans) Chlordane	0.5	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 101	5.8	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 105	4.5	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 110	6.9	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 118	13.0	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 119	0.7	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 123	2.2	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 128	8.5	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 138	21.0	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 149	5.2	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 151	3.7	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 153/168	40.0	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 156	6.3	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 158	1.9	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 167	2.9	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 170	4.3	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 177	2.7	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 180	14.0	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 183	4.0	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 187	13.0	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 194	4.1	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 201	2.4	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 206	2.7	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 44	0.8	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 49	1.9	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 52	3.1	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 66	2.5	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 70	2.6	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 74	1.6	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 87	6.9	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	PCB	PCB 99	8.5	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	DDT	o,p-DDE	2.6	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	26.0	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,p-DDD	4.8	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,p-DDE	240.0	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	DDT	p,p-DDT	4.0	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	3.2	ppb
2011-4	Zone 2	2	Pacific sanddab	Liver	tCHLOR	Cis Nonachlor	2.3	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 101	6.4	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 105	4.7	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 110	10.6	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 118	16.0	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 128	12.5	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 138	25.0	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 149	6.8	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 151	5.0	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 153/168	45.5	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 156	6.4	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 167	3.1	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 170	5.5	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 177	2.8	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 180	16.5	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 183	4.6	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 187	14.0	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 194	4.7	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 206	3.1	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 70	2.6	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	PCB	PCB 99	9.5	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	23.5	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,p-DDD	4.9	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,p-DDE	225.0	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	DDT	p,p-DDT	3.5	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	2.9	ppb
2011-4	Zone 2	3	Pacific sanddab	Liver	tCHLOR	Gamma (trans) Chlordane	0.6	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 101	4.9	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 105	3.2	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 110	5.7	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 118	9.5	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 123	1.3	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 128	5.3	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 138	12.0	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 149	4.7	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 151	2.5	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 153/168	23.0	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 156	3.0	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 158	1.2	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 177	1.2	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 18	0.2	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 180	6.5	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 183	2.3	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 187	6.9	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 194	1.7	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 201	1.2	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 44	0.7	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 49	1.5	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 52	2.5	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 66	1.6	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 70	2.3	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 74	1.2	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	PCB	PCB 99	5.0	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	DDT	o,p-DDE	1.2	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	13.0	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,p-DDD	2.1	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,p-DDE	100.0	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	DDT	p,p-DDT	2.1	ppb
2011-4	Zone 3	1	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	1.9	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 101	6.0	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 105	2.9	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 110	5.7	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 118	11.0	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 123	1.4	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 128	4.9	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 138	12.0	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 149	4.4	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 151	2.9	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 153/168	24.0	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 158	1.2	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 177	1.4	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 180	8.0	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 183	2.1	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 187	7.1	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 194	2.5	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 201	1.4	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 206	1.9	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 44	0.9	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 49	1.8	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 52	2.5	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 66	1.4	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 70	2.2	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 74	1.3	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	PCB	PCB 99	5.3	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	DDT	o,p-DDD	0.6	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	15.0	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,p-DDD	3.0	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,p-DDE	130.0	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	DDT	p,p-DDT	3.5	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	Zone 3	2	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	3.4	ppb
2011-4	Zone 3	2	Pacific sanddab	Liver	tCHLOR	Cis Nonachlor	1.3	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 101	12.5	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 105	6.3	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 110	15.0	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 118	21.0	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 128	8.2	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 138	19.5	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 149	6.7	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 151	3.7	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 153/168	36.0	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 156	5.2	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 167	2.8	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 170	3.3	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 177	2.0	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 180	9.5	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 183	2.7	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 187	9.3	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 194	3.1	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 206	2.0	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 44	2.5	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 49	10.5	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 52	17.5	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 66	5.0	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 70	7.6	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 87	4.8	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	PCB	PCB 99	11.0	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	13.0	ppb
2011-4	Zone 3	3	Pacific sanddab	Liver	DDT	p,p-DDE	130.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 101	9.3	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 105	7.2	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 110	13.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 118	23.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 119	1.1	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 123	3.3	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 128	13.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 138	33.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 149	8.8	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 151	6.3	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 153/168	62.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 156	8.2	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 158	2.8	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 167	3.7	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 170	5.8	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 177	3.2	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 180	20.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 183	5.3	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 187	17.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 194	4.7	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 201	2.6	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 206	3.2	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 44	1.4	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 49	2.9	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 52	4.2	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 66	3.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 74	2.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 87	2.7	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	PCB	PCB 99	13.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	DDT	o,p-DDE	2.5	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,-p-DDMU	26.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,p-DDD	5.1	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,p-DDE	260.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	DDT	p,p-DDT	5.0	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	3.4	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	tCHLOR	Cis Nonachlor	2.9	ppb
2011-4	Zone 4	1	Pacific sanddab	Liver	tCHLOR	Gamma (trans) Chlordane	0.6	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 101	2.7	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 110	2.1	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 118	3.4	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 138	3.7	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 149	2.4	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 151	1.0	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 153/168	7.9	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 180	2.5	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 183	0.6	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 187	2.6	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 44	0.4	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 49	0.8	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 52	1.2	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 66	0.6	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 70	1.1	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 74	0.4	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	PCB	PCB 99	1.8	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	DDT	o,p-DDD	0.9	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	DDT	o,p-DDE	1.1	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	DDT	o,p-DDT	0.6	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,-p-DDMU	5.6	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,p-DDD	1.6	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	DDT	p,p-DDE	35.0	ppb
2011-4	Zone 4	2	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	1.3	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 101	7.6	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 105	4.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 110	7.6	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 118	13.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 123	2.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 128	8.7	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 138	18.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 149	7.0	ppb

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 151	4.4	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 153/168	34.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 156	5.5	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 158	1.5	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 167	2.1	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 170	3.1	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 177	2.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 180	10.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 183	2.9	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 187	10.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 194	2.1	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 201	1.4	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 206	1.9	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 44	0.9	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 49	2.3	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 52	3.3	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 66	2.2	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 70	2.7	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 74	1.5	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 87	2.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	PCB	PCB 99	8.4	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	DDT	o,p-DDE	2.9	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,-p-DDMU	27.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,p-DDD	5.1	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,p-DDE	230.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	DDT	p,p-DDT	4.0	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	tCHLOR	Alpha (cis) Chlordane	3.2	ppb
2011-4	Zone 4	3	Pacific sanddab	Liver	tCHLOR	Cis Nonachlor	1.7	ppb

Appendix F.4

Species of fish collected from each PLOO trawl and rig fishing station between 2009 and 2011.

Station	Comp	2009	2010	2011
RF1	1	Copper rockfish	Ca. scorpionfish	Vermilion Rockfish
RF1	2	Vermilion rockfish	Ca. scorpionfish	Vermilion Rockfish
RF1	3	Sebastes spp.	Ca. scorpionfish	Vermilion Rockfish
RF2	1	Vermilion rockfish	Vermilion rockfish	Chilipepper
RF2	2	Vermilion rockfish	Mixed rockfish	Chilipepper
RF2	3	Sebastes spp.	Mixed rockfish	Flag rockfish
Zone 1	1	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 1	2	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 1	3	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 2	1	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 2	2	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 2	3	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 3	1	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 3	2	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 3	3	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 4	1	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 4	2	Pacific sanddab	Pacific sanddab	Pacific Sanddab
Zone 4	3	Pacific sanddab	Pacific sanddab	Pacific Sanddab

Appendix F.5

PLOO two-way crossed ANOSIM results for liver tissue (A = survey, B = lipid content). Lipid content bins: 1 = 0–10%, 2 = 10.1%–20%, 3 = 20.1%–30%, 4 = 30.1%–40%, 5 = 40.1%–50%, 6 = > 50.1%.

Global Test: Factor A

Tests for differences between survey (across all across all lipid groups)

Sample statistic (Global R):	0.352
Significance level of sample statistic:	0.01%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	0

Pairwise Tests: Factor A

Tests for pairwise differences between individual surveys across all lipid groups: r values (p values)

	2010	2011
2009	0.437 (0.005)	0.327 (0.002)
2010		0.268 (0.009)

Global Test: Factor B

Tests for differences between across all lipid groups (across all surveys)

Sample statistic (Global R):	0.077
Significance level of sample statistic:	22.2%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	2217

Pairwise Tests: Factor B

Tests for pairwise differences between lipid groups across all surveys: r values (p values)

	2	3	4	5	6
1	no test	1 (0.200)	0.822 (0.143)	no test	no test
2		-0.167 (0.600)	-0.346 (0.952)	1 (0.067)	1 (0.333)
3			-0.124 (0.766)	-0.24 (0.833)	1 (0.333)
4				0.091 (0.146)	0.216 (0.233)
5					0.228 (0.19)

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Appendix F.6

PLOO two-way crossed ANOSIM results for muscle tissue (A = survey, B = species).

Global Test: Factor A

Tests for differences between surveys (across all species)

Sample statistic (Global R):	0.727
Significance level of sample statistic:	3.3%
Number of permutations:	210
Number of permuted statistics greater than or equal to Global R:	7

Pairwise Tests: Factor A

Tests for pairwise differences between individual surveys across all species: r values (p values)

	2010	2011
2009	0.721 (0.167)	1 (0.100)
2010		-0.333 (1.00)

Global Test: Factor B

Tests for differences between species (across all surveys)

Sample statistic (Global R):	0.076
Significance level of sample statistic:	34.6%
Number of permutations:	9999
Number of permuted statistics greater than or equal to Global R:	3455

Pairwise Tests: Factor B

Tests for pairwise differences between individual species across all surveys: r values (p values)

	Chilipepper rockfish	Flag rockfish	California scorpionfish	Mixed rockfish	Copper rockfish
Vermilion rockfish	0.333 (0.200)	0.111 (0.750)	-0.556 (1.00)	0.21 (0.200)	1 (0.25)
Chilipepper rockfish		-1 (1.00)	no test	no test	no test
Flag rockfish				no test	no test
California scorpionfish				-0.25 (0.90)	no test
Mixed rockfish					-1 (1.00)