THE CITY OF SAN DIEGO

# Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall 2012

## City of San Diego
## Ocean Monitoring Program


**Public Utilities Department**
**Environmental Monitoring and Technical Services Division**

THE CITY OF SAN DIEGO

June 28, 2013

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

Attention: POTW Compliance Unit

Dear Sir:

Enclosed is the 2012 Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall as required per Order No. R9-2009-0001, NPDES Permit No. CA0107409. This assessment report contains data summaries, analyses and interpretations of all portions of the ocean monitoring program conducted during calendar year 2012, including oceanographic conditions, water quality, sediment conditions, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues.

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

Sincerely,

Steve Meyer
Deputy Public Utilities Director

TDS/akl

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



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

## 2012

Prepared by:

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

June 2013

Timothy D. Stebbins, Editor
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High-dynamic-range (HDR) image of Sunset Cliffs Natural Park on the western coast of Point Loma. Photo by Paul Matson.

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# Acronyms and Abbreviations

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

# Acronyms and Abbreviations

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

# Acronyms and Abbreviations

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

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# Executive Summary

# Executive Summary

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

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

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

Overall, the state of southern San Diego's coastal waters in 2012 was in good condition based on the comprehensive scientific assessment of the Point Loma outfall region. This report details the methods, scope, results and evaluation of the ocean monitoring program.

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

Details of the results and conclusions of all receiving waters monitoring activities conducted from January through December 2012 are presented and discussed in the following seven chapters in this report. Chapter 1 represents a general introduction and overview of the City's ocean monitoring program, while Chapters 2–7 include results of all monitoring at the regular core stations conducted during the year. In Chapter 2, data characterizing oceanographic conditions and water mass transport for the region are evaluated. Chapter 3 presents the results of shoreline and offshore water quality monitoring, including measurements of fecal indicator bacteria and oceanographic data to evaluate potential movement and dispersal of the wastewater plume and assess compliance with water contact standards defined in the Ocean Plan. Assessments of benthic sediment quality and the status of macrobenthic invertebrate communities are presented in Chapters 4 and 5, respectively. Chapter 6 presents the results of trawling activities designed to monitor communities of bottom dwelling (demersal) fishes and megabenthic invertebrates. Bioaccumulation assessments to measure contaminant loads in the tissues of local fishes are presented in Chapter 7. Results of the summer 2012 San Diego regional survey of sediment conditions and benthic macrofaunal communities are available in a separate assessment report.[1] In addition to the above activities, the City supports or conducts other projects relevant to assessing the quality and movement of ocean waters in the region. One such long-term project involves satellite imaging of the San Diego coastal region, the results for 2012 which are incorporated into Chapters 2 and 3 herein. Another major project completed during 2012 was a special study designed to determine the characteristic fates of PLOO wastewater plume in the coastal waters off Point Loma. The results of this plume behavior study are incorporated into the discussions of plume dispersal in Chapter 3, while the complete final project report is available separately.[2] A summary of the main findings for each of the above chapters is included below.

## Coastal Oceanographic Conditions

Sea surface temperatures were colder than normal throughout the Point Loma outfall region during the February, May and August quarterly surveys and above average during November. This pattern was consistent with other reports that relatively cool water La Niña conditions persisted throughout the first half of 2012 before beginning to warm. Conditions indicative of local coastal upwelling were observed during February and May. Additionally, satellite images revealed colder-than-normal surface waters during the summer months as would be expected during a La Niña. As is typical for the region, maximum stratification (layering) of the water column occurred in mid-summer, while reduced stratification occurred during winter and fall. Water clarity (transmissivity) was slightly higher in 2012 than during the previous year due to reduced rainfall. The occurrence of phytoplankton blooms often corresponded to upwelling as described above, including a large bloom in February that was verified by satellite imagery to extend seaward beyond the end of the PLOO. Ocean currents flowed along a predominantly north-south to northeast-southwest axis during most of the year, although these measurements excluded the influence of tidal currents and internal waves. Overall, ocean conditions off Point Loma in 2012 were consistent with well documented patterns for southern California and northern Baja California. These findings suggest that natural factors such as upwelling of deep ocean waters and changes due to large-scale climatic events such as El Niño/La Niña oscillations continue to explain most of the temporal and spatial variability observed in the coastal waters off southern San Diego.

## Water Quality Compliance & Plume Dispersion

Water quality conditions were excellent in the Point Loma region during 2012. Overall compliance with 2005 Ocean Plan water-contact standards for fecal indicator bacteria (FIB) was greater than 99%. Compliance at the shore stations was 100% for the three geometric mean standards and at least 92% for each of the four single sample maximum standards, while compliance was 100% for all seven standards at the kelp bed stations. Compliance was also very high with Ocean Plan objectives for natural light (i.e. water clarity or transmissivity), pH, and dissolved oxygen in Point Loma coastal waters. For example, only a single out-of-range (OOR) event for transmissivity occurred within State waters where these objectives apply, while no OOR events were detected for pH or dissolved oxygen.

There was no evidence that wastewater discharged to the ocean via the PLOO reached the shore or Point Loma Kelp Forest during 2012. These results are consistent with satellite imagery observations, as well as findings from a recently completed plume

[1] City of San Diego. (2013). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2012. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

[2] Rogowski, P., E. Terrill, M. Otero, L. Hazard, S.Y. Kim, P.E. Parnell, and P. Dayton. (2012). Final Report: Point Loma Ocean Outfall Plume Behavior Study. Prepared for City of San Diego Public Utilities Department by Scripps Institution of Oceanography, University of California, San Diego, CA.

behavior study that showed the PLOO waste field is highly unlikely to surface and that plume dispersion is typically directed away from Point Loma and the kelp forest. Elevated FIB counts were detected at only four shore stations (11 samples) and at no kelp stations during the year. FIBs were also low at all offshore stations during each quarterly sampling event, with only two samples having elevated *Enterococcus* levels. Both of these high counts were collected from a sample depth of 80 m at station F30 located nearest the outfall discharge site. The low rate of bacterial contamination near the outfall may be due to the partial chlorination of PLWTP effluent that has occurred since about September 2008. Because bacteriological data may no longer be a good indicator of plume presence in the region, other oceanographic measurements such as reduced water clarity and high CDOM (colored dissolved organic matter) values may be more useful detecting and tracking the plume. For example, CDOM signatures were able to detect the plume about 23% of the time off Point Loma, with most detections occurring at depths below 50 m near the discharge zone or at other stations located north of the outfall along the 98-m depth contour. Overall, the results from 2012 are consistent with other data that indicate the PLOO plume remains restricted to relatively deep, offshore waters throughout the year.

## Sediment Conditions

Ocean sediments surrounding the PLOO in 2012 were composed primarily of fine sands and finer particles, which is similar to patterns seen in previous years. There were no changes in the amount of fine sediments that could be attributed to wastewater discharge, nor was there any other apparent relationship between particle size distributions and proximity to the outfall. Instead, most differences between monitoring sites are probably due to factors such as offshore disposal of dredged sediments, deposition of detrital materials, presence of residual construction materials near the outfall pipe, and the geological history and origins of different sediment types.

Sediment quality in the region was similar in 2012 to previous years with overall contaminant loads remaining within the range of variability for San Diego and other coastal areas of southern California. There was no evidence of contaminant accumulation in local sediments that could be attributed to wastewater discharge. For example, the highest concentrations of several trace metals and organic indicators 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 the area is probably due to short dumps of dredged materials originally destined for the USEPA designated LA-5 disposal site. The only evidence of possible organic enrichment off Point Loma was slightly higher sulfide and BOD levels at a few nearfield stations located within 300 m of the discharge zone.

## Macrobenthic Communities

Benthic macrofaunal communities surrounding the PLOO were similar in 2012 to previous years. These communities remained dominated by polychaete worm and ophiuroid (brittle star) assemblages that occur in similar habitats throughout the Southern California Bight. Specifically, the brittle star *Amphiodia urtica* was the most abundant species off Point Loma, although its populations have shown a region-wide decrease since monitoring began 22 years ago. The spionid polychaete *Prionospio (Prionospio) jubata* was the most widespread benthic invertebrate. There have been some minor changes in macrofaunal assemblages located within ~300 m of the discharge zone that would be expected near large ocean outfalls. For example, some descriptors of benthic community structure (e.g., infaunal abundance, species diversity) or populations of indicator species (e.g., *A. urtica*) have shown changes over time between reference areas and sites located nearest the outfall. Despite these changes, however, benthic response index (BRI) results for 97% of the samples (95% of sites) remained characteristic of undisturbed habitats. Only BRI values for the two samples collected at near-ZID station E14 in July indicated a possible minor deviation from reference conditions. In addition, changes documented during the year were similar in magnitude to those reported previously for the region and elsewhere off southern California. Overall, macrofaunal assemblages off Point Loma remain similar to natural indigenous communities characteristic of similar habitats on the southern California continental shelf. There was no evidence that wastewater discharge has caused degradation of the marine benthos at any of the monitoring sites.

## Demersal Fishes and Megabenthic Invertebrates

Comparisons of the 2012 trawl survey results with previous surveys indicate that demersal fish and megabenthic invertebrate communities in the region remain unaffected by wastewater discharge. Although highly variable, patterns in the abundance and distribution of individual species were similar at stations located near the outfall and farther away. Pacific sanddabs continued to dominate Point Loma fish assemblages, occurring at all stations and accounting for 44% of the year's catch. Other common species included longspine combfish, California lizardfish, halfbanded rockfish, Dover sole, pink seaperch, shortspine combfish, English sole, stripetail rockfish, yellowchin sculpin, plainfin midshipman, California tonguefish, bigmouth sole, California skate, and hornyhead turbot. Trawl-caught invertebrate assemblages were dominated by the white sea urchin *Lytechinus pictus*, which also occurred in all trawls and accounted for 69% of all invertebrates captured. The brittle star *Ophiura luetkenii* was also collected in every haul, although in very low numbers at most sites. However, an unusually large number of *O. luetkenii* was collected at the northernmost trawl station during the July 2012 survey. Other common, but far less abundant invertebrates included the sea urchin *Strongylocentrotus fragilis*, the sea stars *Luidia foliolata*, *Luidia asthenosoma* and *Astropecten californicus*, the sea cucumber *Parastichopus californicus*, and the opisthobranch *Pleurobranchaea californica*. Finally, external examinations of the fish captured during the year indicated that local fish populations remain healthy, with <1% of all fish having external parasites or any evidence of disease.

## Contaminants in Fish Tissues

The accumulation of chemical contaminants in local fishes was assessed by analyzing liver tissues from trawl-caught flatfish and muscle tissues from rockfish captured by hook and line. Results from both analyses indicated no evidence that contaminant loads in Point Loma fishes were affected by wastewater discharge in 2012. Although several metals, pesticides, and PCB congeners were detected in both tissue types, these contaminants occurred in fishes distributed throughout the region with no patterns that could be attributed to wastewater discharge. While several muscle samples exceeded state or international standards for a few contaminants, all samples were within federal (USFDA) action limits. Furthermore, concentrations of all contaminants were within ranges reported previously for southern California fishes. The occurrence of some metals and chlorinated hydrocarbons in local fishes may be due to many factors, including the ubiquitous distribution of many contaminants in southern California coastal sediments. Other factors that affect bioaccumulation in marine fishes include differences in physiology and life history traits of various species. In addition, exposure can vary greatly between different species of fish and even among individuals of the same species depending on their migration habits. For example, an individual fish may be exposed to contaminants at a polluted site and then migrate to an area that is less contaminated. This is of particular concern for fishes collected in the vicinity of the PLOO, as there are many other potential point and non-point sources of contamination.

## Conclusions

The findings and conclusions for the ocean monitoring efforts conducted for the Point Loma outfall region during calendar year 2012 were consistent with previous years. Overall, there were few changes to local receiving waters, benthic sediments, and marine invertebrate and fish communities that could be attributed to human activities. Coastal water quality conditions and compliance with Ocean Plan standards were excellent, and there was no evidence that the wastewater plume from the outfall surfaced or was transported inshore to recreational waters along the shore or in the Point Loma kelp beds. There were also no clear outfall related patterns in sediment contaminant distributions, or in differences between invertebrate and fish assemblages at the different monitoring sites. The lack of physical anomalies or other symptoms of disease or stress in local fishes, as well as the low level of contaminants in fish tissues, was also indicative of a healthy marine environment. Finally, benthic habitats in the Point Loma region remain in good condition similar to much of the southern California continental shelf.

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# 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. 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 2012.

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

The average daily flow of effluent through the PLOO in 2012 was 148 million gallons per day (mgd), ranging from a low of 133 mgd in November to a high of about 191 mgd also in November. Overall, this represents about a 5% decrease from the average flow rate in 2011. TSS removal averaged about 89.4% in 2012, while total mass emissions for the year were approximately 7,561 metric tons (see City of San Diego 2013b).

## 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 discharge site are presented in City of San Diego (1995a), while the results of a three-year "recovery study" are summarized in City of San Diego (1998). From 1991 through 1993, the City also conducted a "pre-discharge" study in order to collect baseline data prior to wastewater discharge into these deeper waters (City of San Diego 1995a, b). Results of NPDES mandated monitoring for the extended PLOO from 1994 to 2011 are available in previous annual receiving waters monitoring reports (e.g., City of San Diego 2012). 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, 2013c) 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 core monitoring area off Point Loma extends from stations along the shore seaward to a depth of about 116 m and encompasses an area of approximately 184 km$^2$ (Figure 1.1). A total of 82 core monitoring sites are generally arranged in a grid surrounding the outfall and are sampled for various parameters in accordance with a prescribed schedule as specified in the MRP. A summary of the results for quality assurance procedures performed in 2012 in support of these requirements can be found in City of San Diego (2013a). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the SDRWQCB and United States Environmental Protection Agency (USEPA) throughout the year are available online at the City's website (www.sandiego.gov/mwwd/environment/oceanmonitor.shtml).

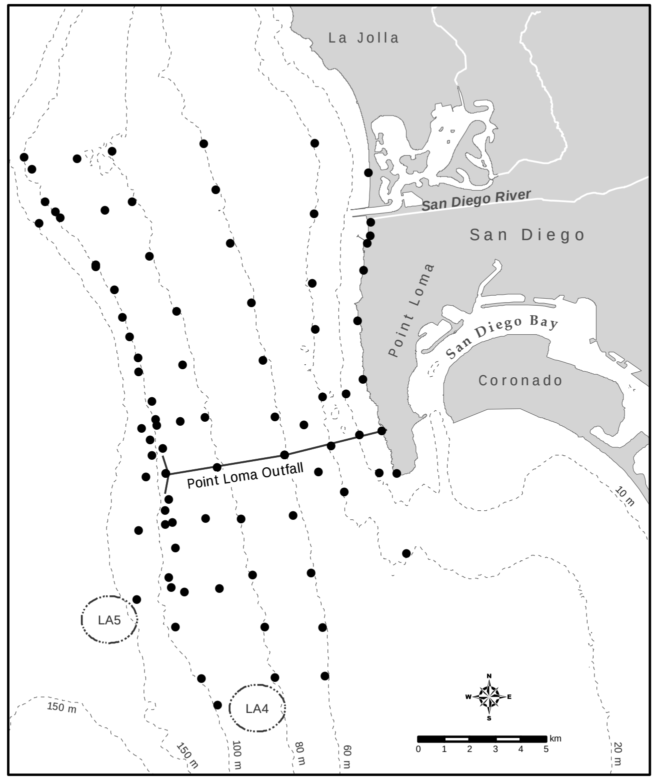


**Figure 1.1**
Receiving waters monitoring stations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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

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

This report presents the results of all regular core receiving waters monitoring activities conducted off Point Loma from January through December 2012. The major components of the monitoring program are covered in the following six chapters: Coastal Oceanographic Conditions, Water Quality Compliance and Plume Dispersion, Sediment Conditions, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, and Bioaccumulation of Contaminants in Fish Tissues.

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# Chapter 2
# Coastal Oceanographic Conditions

# Chapter 2. Coastal Oceanographic Conditions

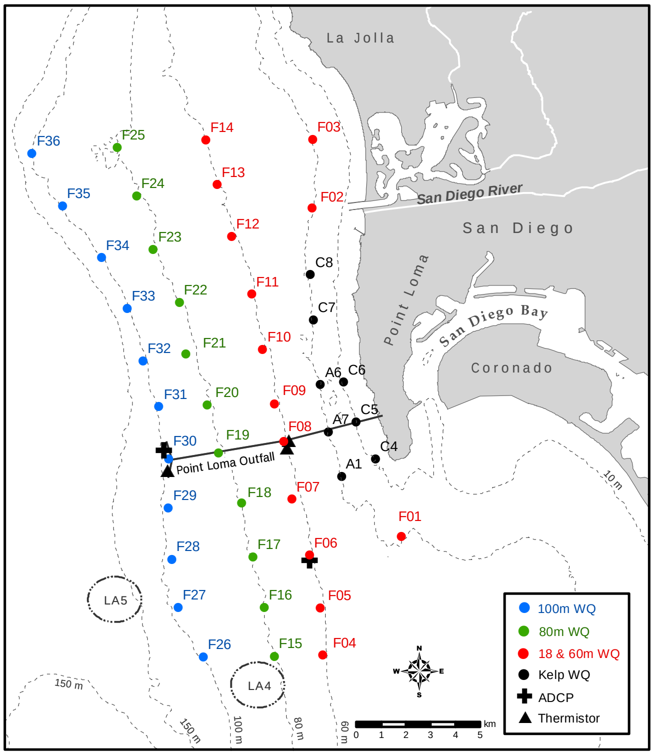
## Introduction

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

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

Understanding changes in oceanographic conditions due to natural processes such as the seasonal patterns described above is important since they can affect the transport and distribution of wastewater, storm water, and other types of water masses (e.g., sediment or turbidity plumes). In the Point Loma outfall region these include plumes associated with outflows from local bays, major rivers, lagoons and estuaries, discharges from storm drains or other point sources, surface runoff from local watersheds, seasonal upwelling, and changing ocean currents or eddies. For example, outflows from the San Diego River, San Diego Bay and the Tijuana River, which are fed by 1140 $km^2$, 1165 $km^2$ and 4483 $km^2$ of watersheds, respectively (Project Clean Water 2012), can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009, Svejkovsky 2010, 2011).

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




## Figure 2.1

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.

## Materials and Methods

### Field Sampling

Oceanographic measurements were collected at 41 monitoring stations arranged in a grid surrounding the PLOO and which encompass a total area of ~146 km$^2$ (Figure 2.1). These include 36 offshore stations (designated F01–F36) located between 1.7 and 10.2 km offshore of Point Loma along or adjacent to the 18, 60, 80, and 100-m depth contours, and eight kelp bed stations (A1, A6, A7, C4–C8) distributed along the inner (9 m) and outer (18 m) edges of the Point Loma kelp forest. Monitoring at the offshore stations occurred quarterly (February, May, August, November) to correspond with similar sampling for the Central Bight Regional Water Quality Monitoring Program conducted off Orange County, Los Angeles County, and Ventura County (e.g., OCSD 2009). For sampling and analysis purposes, the quarterly water quality monitoring sites were grouped by depth contour as follows: (1) "100-m WQ" = stations F26–F36 (n = 11); (2) "80-m WQ" = stations F15–F25 (n = 11); (3) "18 & 60-m WQ" = stations F01–F14 (n = 14). All stations within each of these three groups were sampled on a single day during each quarterly survey. Sampling at the eight kelp bed stations ("Kelp WQ") was conducted five times per month to meet monitoring requirements for fecal indicator bacteria (see Chapter 3). However, only Kelp WQ data collected within 1 day of the quarterly stations are analyzed in this chapter, such that all stations were sampled over a 4-day period (see Table 2.1).

Oceanographic data were collected using a SeaBird (SBE 25) conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, conductivity (used to calculate salinity), pressure (used to calculate depth), dissolved oxygen, pH, transmissivity (a proxy for water clarity), and chlorophyll *a* (a proxy for phytoplankton). Water

## Table 2.1

Sample dates for quarterly oceanographic surveys conducted in the Point Loma outfall region during 2012. 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).

| | 2012 Survey Dates | | | |
|---|---|---|---|---|
| Station Group | Feb | May | Aug | Nov |
| 18 & 60 m WQ | 22 | 8 | 7 | 13 |
| 80 m WQ | 23 | 9 | 8 | 15 |
| 100 m WQ | 24 | 10 | 9 | 16 |
| Kelp WQ | 21 | 7 | 10 | 14 |

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

### Moored Instrument Data Collection

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

Ocean current data were collected throughout 2012 from two benthic-mounted Teledyne RDI Acoustic Doppler Current Profilers (ADCP) placed at the 100-m and southern 60-m sites. 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 with midpoints ranging in depth from just above the surface to 55 m. For the 100-m ADCP, 25 bins were created with midpoints ranging in depth from just above the surface to 95 m. However, the top three bins from each instrument were excluded from all analyses due to surface backscatter interference. Data from the 100-m ADCP were unavailable January 10–13 due to servicing and compass calibration; data were also unavailable May 12–June 15 and September 14–19 due to battery failure. Additional details regarding ADCP data processing and analyses are presented below under 'Data Analysis.'

Temperature data were collected from a vertical series of temperature sensors (thermistors) every 10 minutes throughout 2012 from duplicate arrays located at the 100-m and 60-m outfall mooring sites. The thermistors (Onset Tidbit temperature loggers) were deployed on mooring lines at each site starting at 2 m above the seafloor and extending through the water column every 4 m to within 6 m of the surface. Data from the 60-m site were unavailable for a single depth interval from January 26 to February 1 as a result of an individual thermistor that was lost at sea. Additional details on the specific methodology for both thermistor and ADCP instrumentation are available in Storms et al. (2006).

### Remote Sensing

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

### Data Analysis

Water column parameters measured in 2012 were summarized as means for each quarter pooled over all stations by the following depth layers: 1–20 m, 21–60 m, 61–80 m, 81–100 m. Due to instrumentation issues, pH data from August and chlorophyll *a* data for November were excluded from these and subsequent analyses. For spatial analysis of all parameters, 3-dimensional graphical views were created for each survey using Interactive Geographical Ocean Data System (IGODS) software, which interpolates data between stations along each depth contour.

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

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

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

Additionally, time series of anomalies for temperature, salinity and dissolved oxygen (DO) were created to evaluate regional oceanographic events in context with larger scale processes (i.e., ENSO events). These analyses were limited to data from the 100-m outfall depth stations, with all water column depths combined. Anomalies were then calculated by subtracting the average of all 22 years combined (i.e., 1991–2012) from the monthly means for each year.

Summary statistics for seasonal ocean current data were generated for each depth bin and prevailing current modes were examined by empirical orthogonal function (EOF) analysis using singular value decomposition (Anderson et al. 1999). Since ocean currents in southern California typically vary seasonally (Winant and Bratkovich 1981), ADCP data were subset by season prior to subsequent analyses: winter (December–February); spring (March–May); summer (June–August); and fall (September–November). Although the winter season for 2012 included non-continuous months (i.e., January–February and December), preliminary analysis suggested that the current regimes for these three months were similar enough to justify pooling them together. In addition, since tidal currents are not likely to result in net transport, tides were removed prior to analyses using the PL33 filter (Alessi et al. 1984).

# Results and Discussion

## Oceanographic Conditions in 2012

### *Water Temperature and Density*

Surface water temperature across the entire Point Loma outfall region ranged from 10.8°C in May to 21.6°C in August during 2012, while sub-surface temperatures ranged from 9.6°C in February at bottom depths to 17.9°C in November at mid-water column depths (Appendix A.1). The maximum surface temperature recorded in August was ~2ºC higher than in 2011 (City of San Diego 2012a). Although these data were limited to only four surveys, ocean temperatures varied by season as expected (Figure 2.2). For example, some of the lowest average temperatures (<10.5ºC) occurred during May at depths below 20 m along the 60, 80, and 100-m depth contour; these cold waters were likely indicative of spring upwelling. However, relatively cold water (<12ºC) was also present near the bottom 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 (11.5ºC) occurring during August. The continuous temperature data from the 60-m and 100-m thermistor arrays yielded similar results, thus confirming that the general thermal stratification patterns observed during the quarterly CTD surveys were representative of the overall spatial and temporal temperature patterns

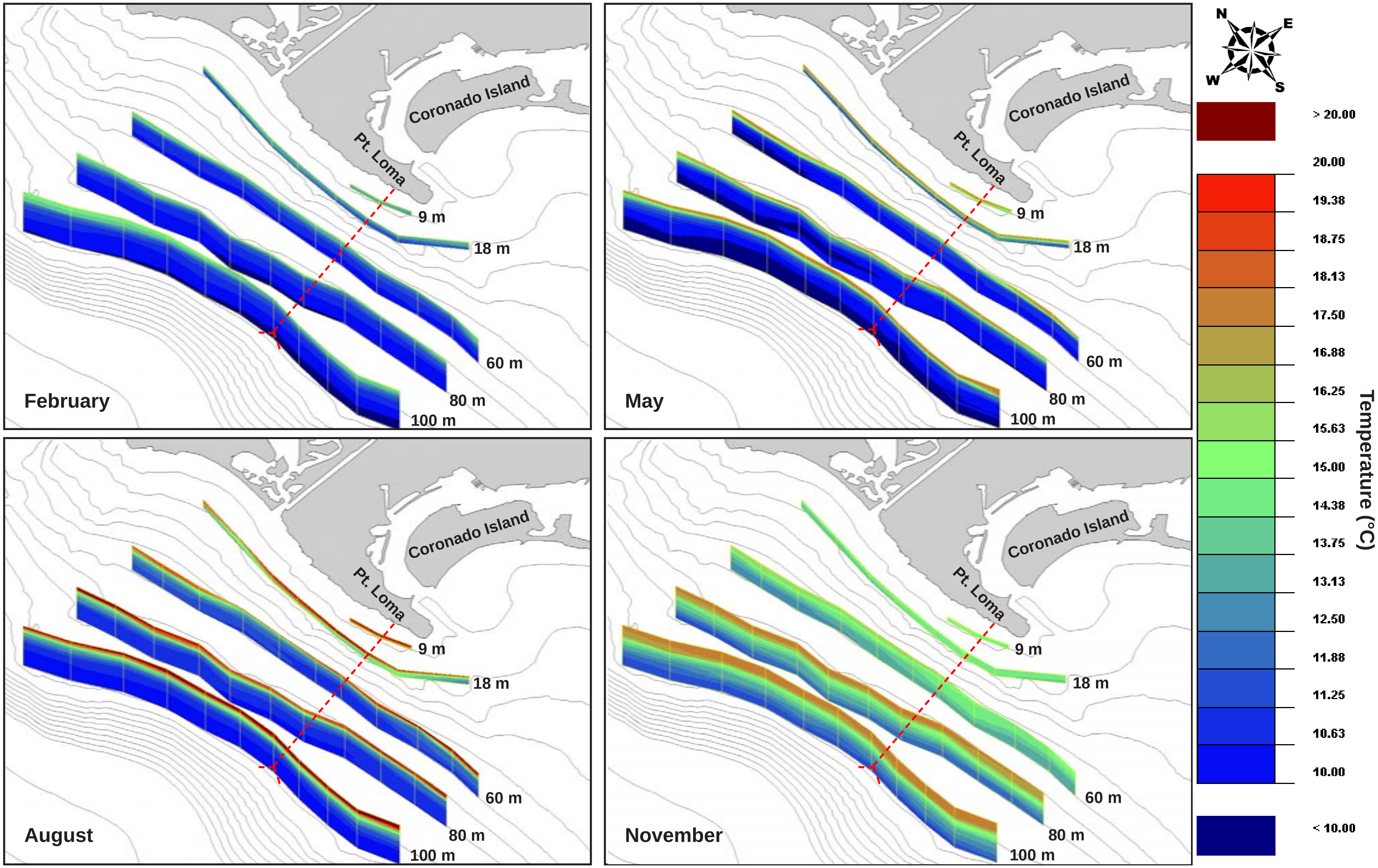



**Figure 2.2**
Ocean temperatures recorded in 2012 for the PLOO region. Data were collected over four consecutive days during each survey. See Table 2.1 and text for specific dates and stations sampled each day.

throughout the year (Figure 2.3). These data also demonstrated that seasonal patterns of water column mixing, as well as surface warming and cooling, were consistent between the 60-m and 100-m moorings.

In the shallower coastal waters of southern California and elsewhere, density is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, seasonal changes in thermal stratification were mirrored by the density stratification of the water column during each survey (Figure 2.4). These vertical density profiles further demonstrated how the water column ranged from weakly stratified during February with a maximum BF of 43 $cycles^2/min^2$, to highly stratified in August with a maximum BF of 124 $cycles^2/min^2$, to weakly stratified again in November with a maximum BF of 42 $cycles^2/min^2$. These results also illustrated how the depth of the pycnocline (i.e., depth layer where the density gradient was greatest) varied by season, with shallower depths tending to correspond with greater stratification.

***Salinity***

Salinities recorded in 2012 were similar to those reported previously in the PLOO region (e.g., City of San Diego 2011a, 2012a). Surface salinity ranged from 33.33 psu in August to 33.81 psu in May, while sub-surface salinities ranged from 33.28 psu mid-column in November to 34.09 psu at bottom depths in February (Appendix A.1). As with ocean temperatures, salinity appeared to vary by season. For example, relatively high salinity (>33.85 psu) was present across most of the region during February and May at depths that corresponded with the lowest water temperatures (Figures 2.2, 2.5). Taken together, low temperatures and high salinity may indicate local coastal upwelling that typically occurs during spring months (Jackson 1986) or may be due to divergent southerly flow in the lee of Point Loma (Roughan et al. 2005).

As in previous years, a layer of relatively low salinity water was evident at sub-surface depths throughout the PLOO region during the summer (August) and fall (November) of 2012 (Figure 2.5). This layer was most apparent between 10 and 20 m during August and between 25 and 50 m during November. It seems unlikely that this sub-surface salinity minimum layer (SSML) was related to wastewater discharge via the PLOO for several reasons. First, a recently published study of the PLOO effluent plume demonstrated that the plume disperses in one direction at any given time and has a very weak salinity signature (Rogowski et al. 2012a, b, 2013). Second, similar SSMLs have been reported previously off San Diego and elsewhere in southern California, including Orange and Ventura Counties, which suggests that this phenomenon is due to a larger-scale oceanographic process (e.g., OCSD 1999, 2009, City of San Diego 2010, 2011a, b, 2012a, b, 2013). Finally, other indicators of the wastewater plume, such as elevated levels of fecal indicator bacteria or colored dissolved organic matter (CDOM), do not correspond to the SSML (see Chapter 3). Further investigation is required to determine the possible source or sources of this phenomenon.

***Dissolved Oxygen and pH***

Overall, DO concentrations and pH levels were within historical ranges throughout the year for the Point Loma region (e.g., City of San Diego 2011a, 2012a). DO ranged from 3.8 to 9.8 mg/L at the surface and from 2.1 to 9.6 mg/L at sub-surface depths, while pH ranged from 7.8 to 8.4 at the surface and 7.7 to 8.2 at sub-surface depths (Appendix A.1). Changes in pH and DO were closely linked since both parameters reflect fluctuations in dissolved carbon dioxide associated with biological activity in coastal waters (Skirrow 1975). Additionally, because these parameters varied similarly across all stations, there was no evidence to indicate that the monthly surveys were not synoptic even though sampling occurred over a 4-day period (e.g., Appendices A.2, A.3).

Changes in DO and pH followed expected patterns that corresponded to seasonal fluctuations in water column stratification and phytoplankton productivity. The greatest variation and maximum stratification occurred predominately during May (Appendices A.2, A.3). Low values for DO and pH

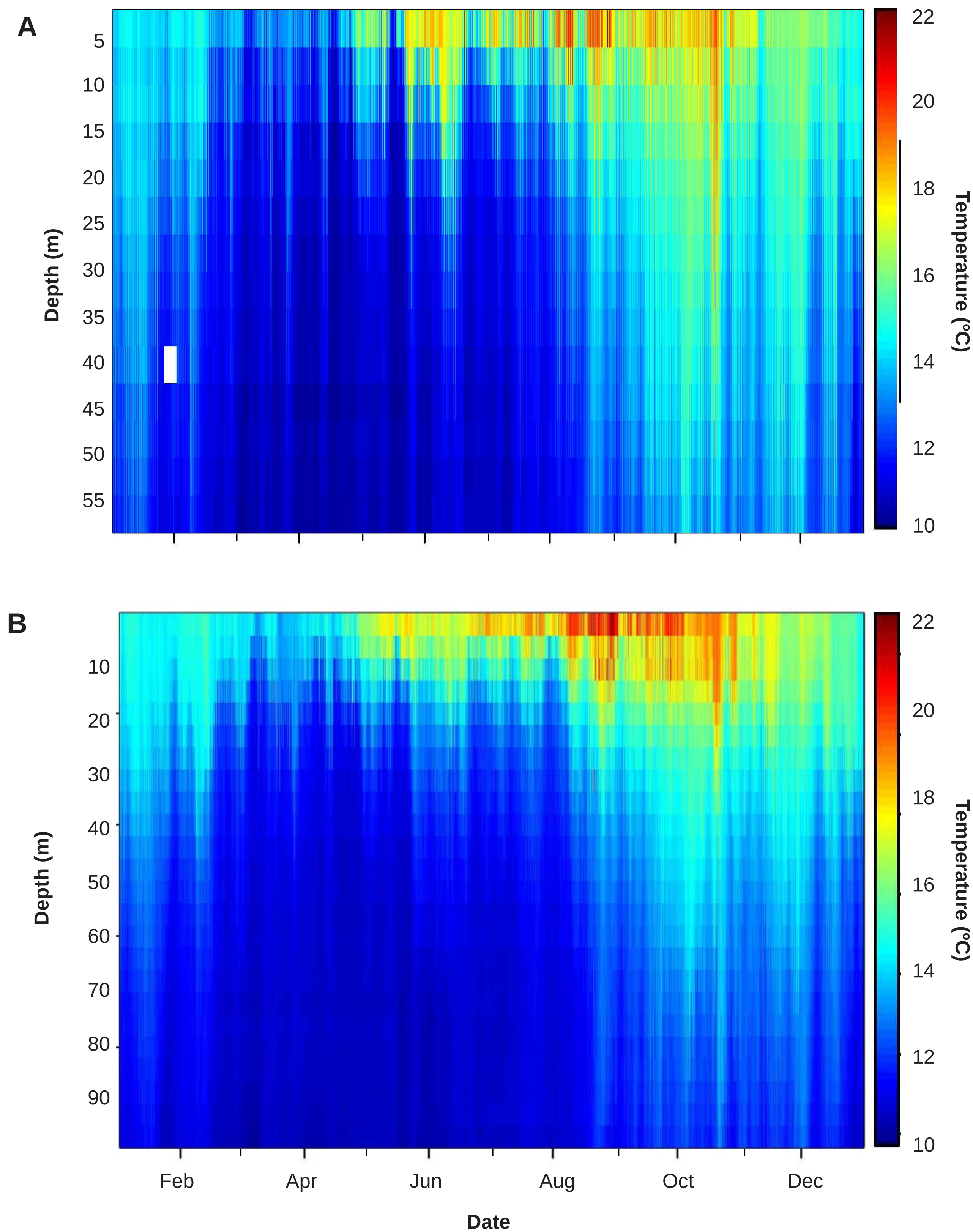



**Figure 2.3**
Temperature logger data collected at the (A) 60-m and (B) 100-m thermistor sites between January and December 2012. Data were collected every 10 minutes. Missing data (white area) are the result of an individual thermistor that was lost at sea.

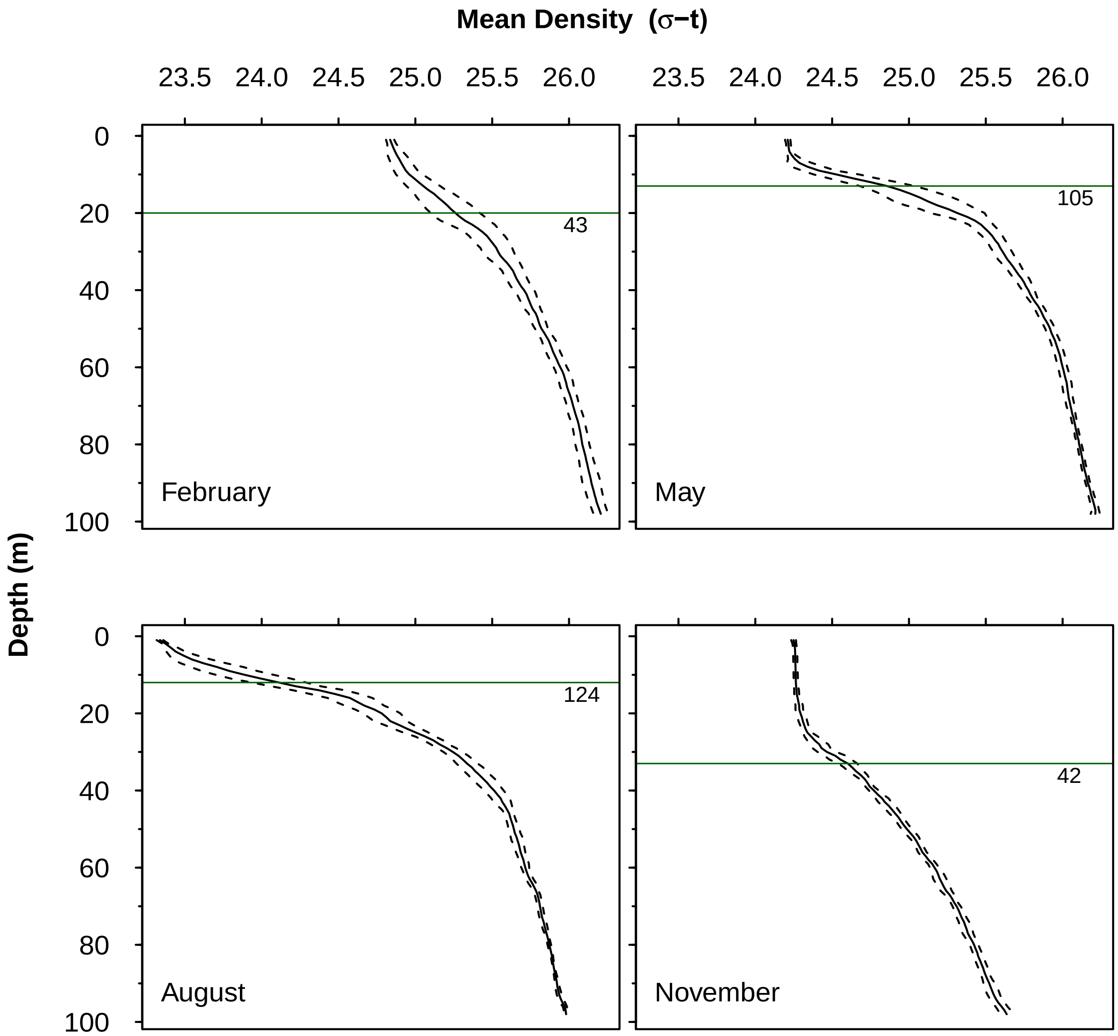



**Figure 2.4**
Density and maximum buoyancy frequency for each quarter at outfall depth stations in the PLOO region during 2012. Solid lines are means, dotted lines are 95% confidence intervals (n = 11). Horizontal lines indicate depth of maximum buoyancy frequency with the number indicating the value in cycles$^2$/min$^2$.

that occurred at depths below 20 m during February and May were likely due to cold, saline, oxygen poor ocean water moving inshore during periods of local upwelling as described above for temperature and salinity. Conversely, high DO concentrations in August were associated with phytoplankton blooms as evident by high chlorophyll *a* concentrations (e.g., mid-water DO = 9.4 mg/L and chlorophyll *a* = 16.0 µg/L at station F20 in August).

***Transmissivity***

Transmissivity levels (%) in Point Loma waters ranged from 71 to 96% at the surface and 78 to 97% at sub-surface depths (Appendix A.1). Overall, maximum water clarity was ~7% higher in 2012 than in 2011 (City of San Diego 2012a) likely due to reduced rainfall (Svejkovsky 2013). Transmissivity was generally lowest inside the kelp bed at 9-m stations during all surveys (Appendix A.4). Outside of the kelp bed, reduced transmissivity at depths <30 m coincided with peaks in chlorophyll *a* concentrations associated with phytoplankton blooms during February, May and August (see following section and Appendices A.1, A.4, A.5). Low transmissivity recorded during winter months may also have been due to wave and storm activity and resultant increases in suspended sediments. For example, turbidity plumes originating from both Mission Bay and San Diego Bay (Figure 2.6) coincided with reduced transmissivity throughout the water column at the

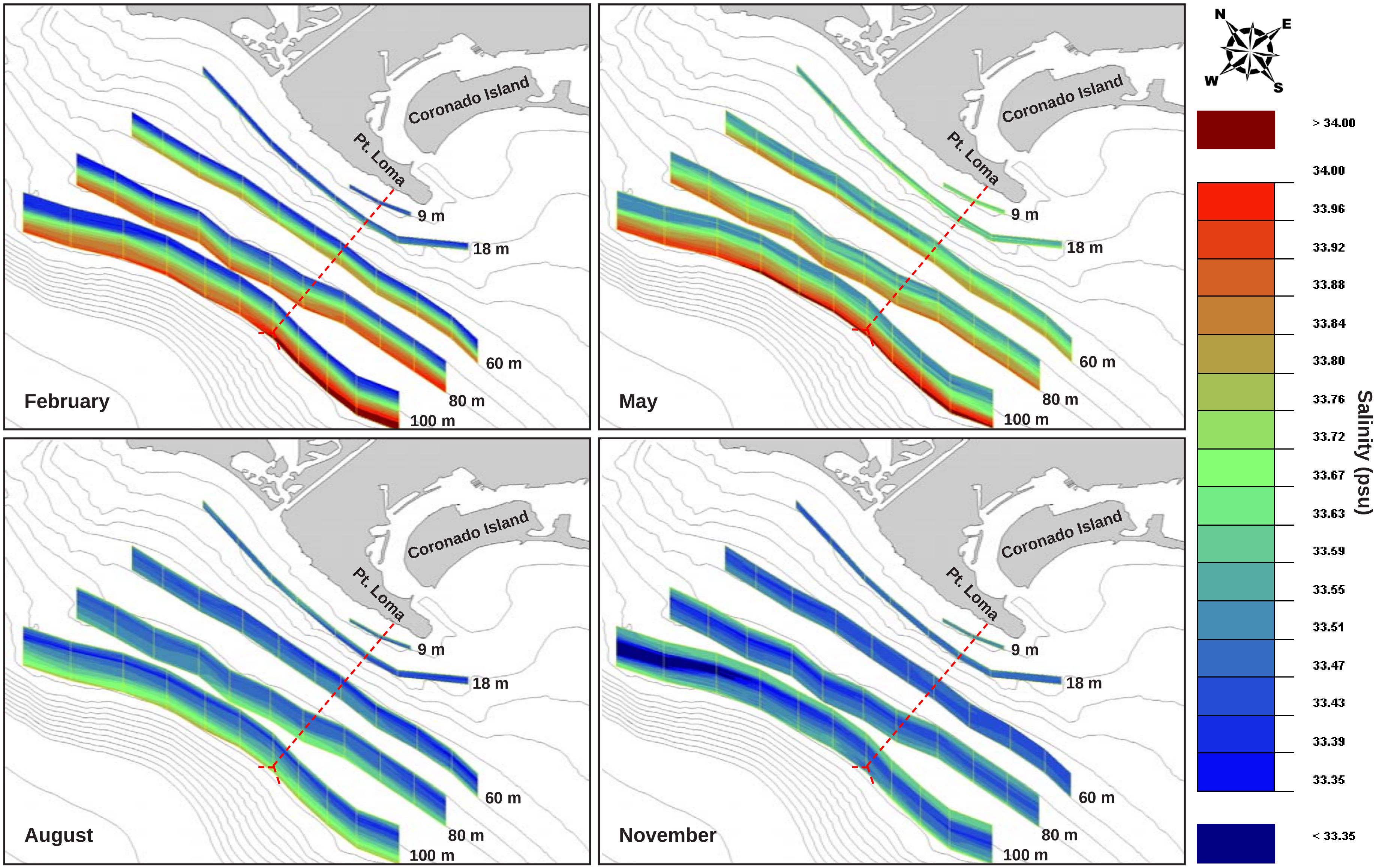



**Figure 2.5**
Ocean salinity recorded in 2012 for the PLOO region. Data were collected over four consecutive days during each survey. See Table 2.1 and text for specific dates and stations sampled each day.

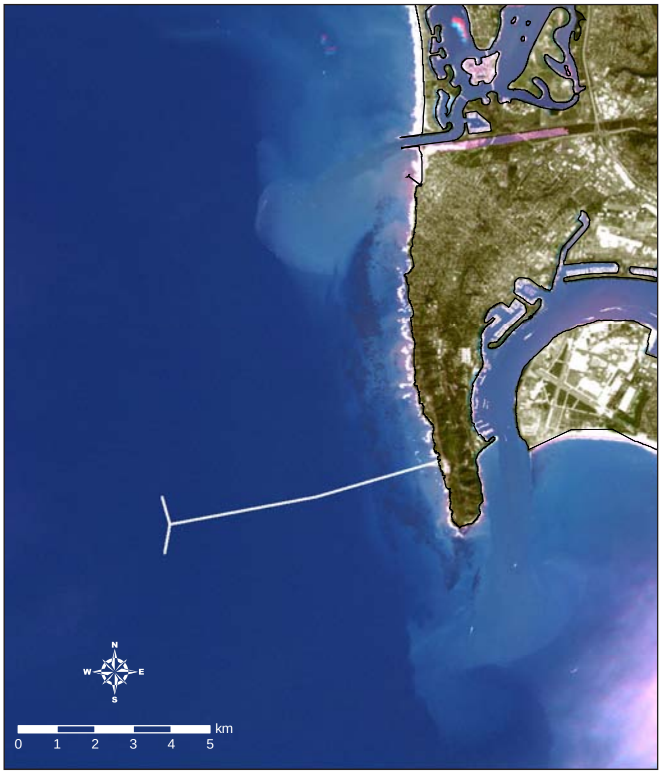



**Figure 2.6**
Rapid Eye satellite image of the Point Loma region acquired February 16, 2012 (Ocean Imaging 2013) showing turbidity plumes originating from Mission Bay, San Diego Bay, and other coastal sources.

20-m stations during February (Appendix A.4), while reduced transmissivity observed along the bottom at the 60-m and 80-m stations during this survey may have been due to significant swell heights > 1.5 m recorded by offshore buoys at the time of sampling (CDIP 2013).

### *Chlorophyll* a

Concentrations of chlorophyll *a* off Point Loma ranged from 0.4 µg/L to 17.8 µg/L during 2012 (Appendix A.1). Thin, patchy layers of high chlorophyll *a* concentrations typically occurred at sub-surface depths during February, May and August (Appendix A.5). These results reflect the tendency for phytoplankton to accumulate along isopycnals where nutrient levels are high and light is not limiting (Lalli and Parsons 1993). Elevated chlorophyll *a* values recorded at surface depths in February corresponded to phytoplankton blooms observed by satellite that extended seaward beyond the end of the PLOO (Figure 2.7; Svejkovsky 2013). Elevated chlorophyll concentrations that occurred during other surveys were also likely associated with phytoplankton blooms, but because the phytoplankton occurred at sub-surface depths, they went un-observed by remote sensing due to the depth-limitations of satellite imagery (Svejkovsky 2013).

## Summary of Ocean Currents in 2012

Current patterns varied by season, depth in the water column, and mooring location in the PLOO region during 2012. The general axis of current flow, as indicated by the dominant current mode (EOF 1), alternated between northeast-southwest and north-south directions depending on season and depth (Figure 2.8). Mean current velocities generally decreased with increasing depth (Appendix A.6). In fall, the EOF axis differed between the two moorings, with flow varying at the 100-m mooring from northeast-southwest to north-south and then back again while flow at the 60-m mooring showed a pattern similar to that of the winter and spring. These results are comparable to those obtained during previous studies in the region (e.g., Parnell and Rasmussen 2010, Rogowski et al. 2012a, b, 2013). The dominant mode accounted for 62–86% of the variance at the 100-m site with the lowest percentage in fall and the highest in winter. In contrast, at the 60-m mooring the first EOF accounted for 86–92% of the variance with the lowest percentage in summer and the highest in spring. This implies that there is more deviation from the dominant EOF axis at the 100-m location than at the 60-m site. Maximum current velocity at the 60-m ADCP was ~385 cm/s during the spring and summer in the 11-m depth bin. In contrast, maximum velocities at the 100-m ADCP (~315 cm/s) occurred in the winter at the 15-m depth bin. At both ADCP locations the lowest mean velocities for the year occurred in the fall while maximum velocities in the bottom layers throughout the year were less than 100 cm/s.

## Historical Assessment of Oceanographic Conditions

A review of temperature, salinity, and DO data from all outfall depth stations sampled between 1991

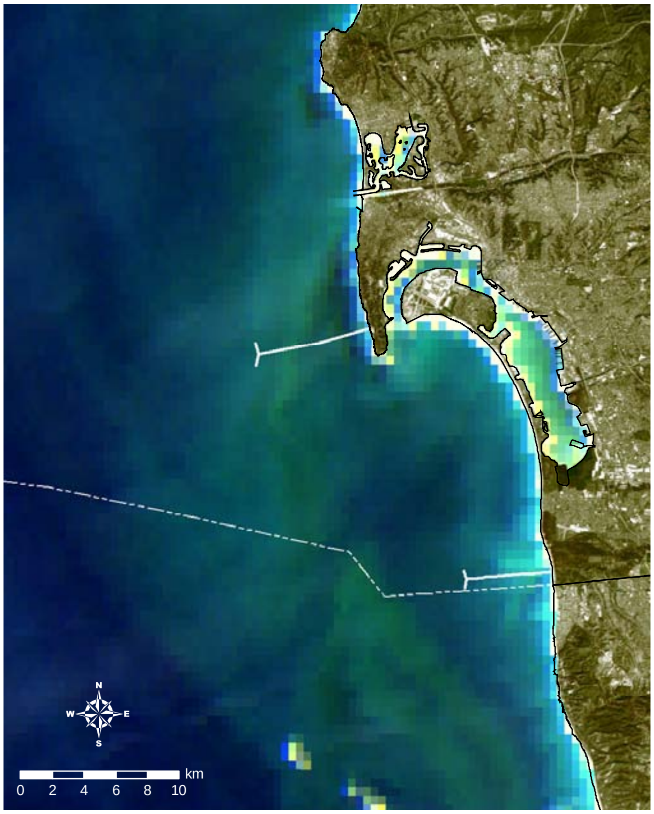



**Figure 2.7**
MODIS image of wide-spread phytoplankton blooms in San Diego's nearshore waters acquired February 22, 2012 (Ocean Imaging 2013).

and 2012 indicated how the PLOO coastal region has responded to long-term climate-related changes in the SCB (Figure 2.9). Despite the change from monthly to quarterly sampling in late 2003, these results are still consistent with large-scale temporal patterns in the California Current System (CCS) associated with ENSO, PDO, and NPGO events (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, NOAA/NWS 2013). For example, six major events have affected SCB coastal waters during the last two decades: (1) the 1997–98 El Niño; (2) a shift to cold ocean conditions reflected in ENSO and PDO indices between 1999 and 2002; (3) a subtle but persistent return to warm ocean conditions in the CCS that began in October 2002 and lasted through 2006; (4) the intrusion of subarctic waters into the CCS that resulted in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña in 2007 that coincided with a PDO cooling event and a return to positive NPGO values indicating an increased flow of cold, nutrient-rich water from the north; (6) development of another La Niña starting in May 2010. Temperature and salinity data for the PLOO region are consistent with all but the third of these CCS events; while the CCS was experiencing a warming trend that lasted through 2006, the PLOO region experienced cooler than normal conditions during much of 2005 and 2006. The conditions in San Diego waters during 2005–2006 were more consistent with observations from northern Baja California where water temperatures were well below the decadal mean (Peterson et al. 2006). With few exceptions, these cooler temperatures were common until warmer than normal temperatures returned in August 2012. This most recent change was consistent with an observed shift of sea surface temperatures across the equatorial eastern Pacific as a slight warming phase began in late spring 2012 (NOAA/NWS 2013). A similar shift in salinity was also observed during this time period. The overall decrease in DO in the PLOO region over the past decade has been observed throughout the entire CCS and may be linked to changing ocean climate (Bjorkstedt et al. 2012).

## Summary

Oceanographic data collected in the Point Loma outfall region were consistent with reports from NOAA that the relatively cool water La Niña conditions of 2011 persisted throughout the first half of 2012 before beginning to warm (Bjorkstedt et al. 2012, NOAA/NWS 2013). Conditions indicative of local coastal upwelling, such as relatively cold, dense, saline waters with low DO and pH at mid-depths and below, were observed during February and May. Due to their depth, cruise-based profiles showed that these plankton blooms covered a greater spatial and temporal extent than was evident from remote sensing alone (Svejkovsky 2013).

Overall, water column stratification in 2012 followed seasonal patterns typical for the San Diego region; maximum stratification of the water column occurred in mid-summer, while weakly-stratified waters were present during winter

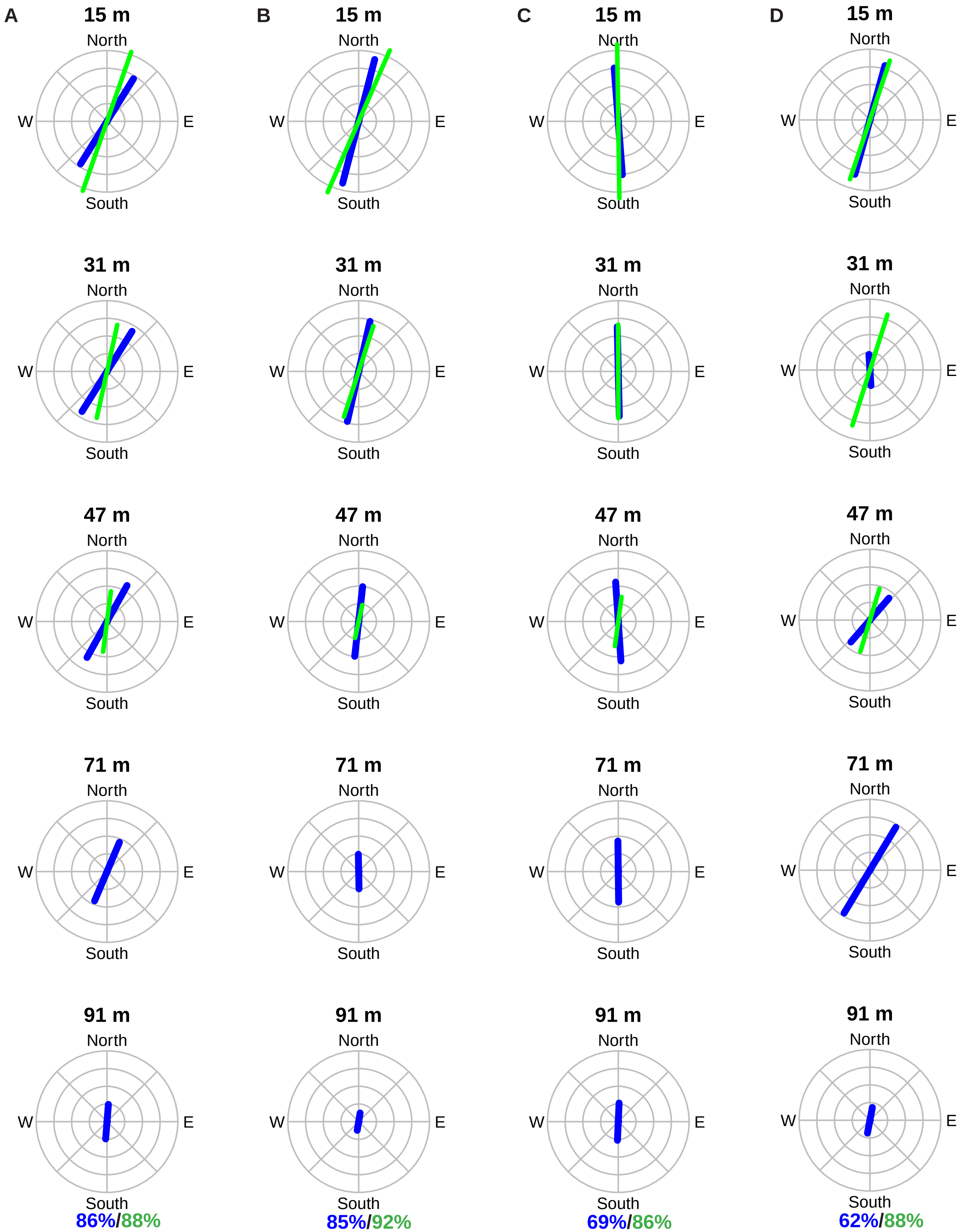



**Figure 2.8**
Dominant current modes (EOF 1) for (A) winter, (B) spring, (C) summer, and (D) fall in 2012 at the 100-m (blue) and 60-m (green) ADCP sites for selected depth bins. Percentages indicate fraction of the total variance accounted for by the EOF for each location. Line length indicates magnitude. Each concentric ring is 0.1 mm/s.

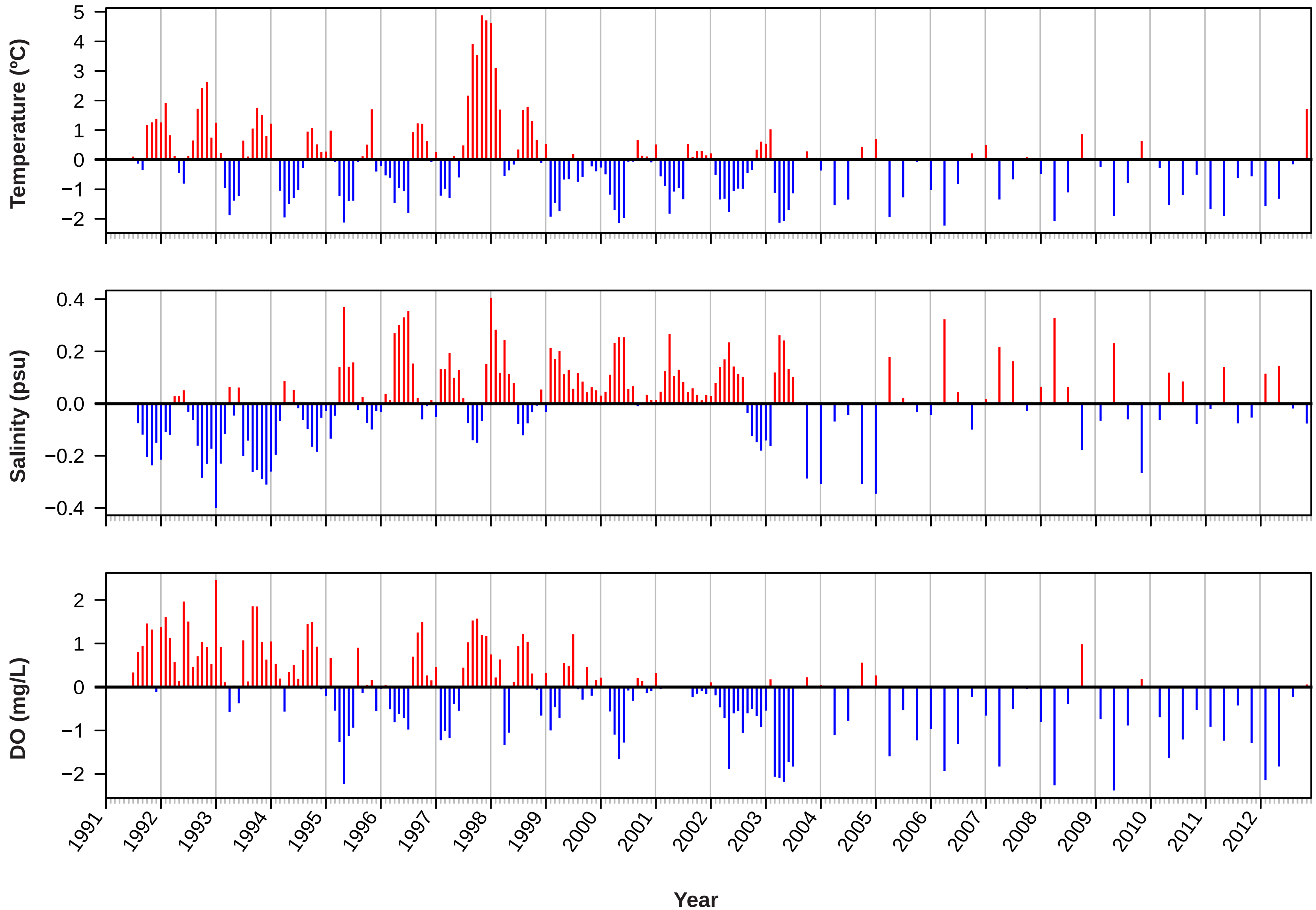



**Figure 2.9**
Time series of temperature, salinity, and dissolved oxygen (DO), anomalies between 1991 and 2012. Anomalies are calculated by subtracting the mean of all years (1991–2012) from monthly or quarterly means of each year; data were limited to outfall depth stations, all depths combined.

and fall. Ocean currents flowed predominantly along a north-south to northeast-southwest axis during most of the year, although these measurements excluded the influence of tidal currents and internal waves. Further, oceanographic conditions were either consistent with long-term trends in the SCB (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, NOAA/NWS 2013) or with conditions in northern Baja California (Peterson et al. 2006). These observations suggest that most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego are explained by a combination of local (e.g., coastal upwelling, rain-related runoff) and large-scale oceanographic processes (e.g., ENSO, PDO, NPGO).

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# Chapter 3
# Water Quality Compliance & Plume Dispersion

# Chapter 3. Water Quality Compliance & Plume Dispersion

## Introduction

The City of San Diego analyzes seawater samples collected along the shoreline and in offshore coastal waters surrounding the Point Loma Ocean Outfall (PLOO) to characterize water quality conditions in the region and to identify possible impacts of wastewater discharge on the marine environment. Densities of fecal indicator bacteria, including total coliforms, fecal coliforms, and *Enterococcus* are measured and evaluated in context with oceanographic data (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged into the Pacific Ocean through the outfall. Evaluation of these data may also help to identify other sources of bacterial contamination. In addition, the City's water quality monitoring efforts in 2012 were designed to assess compliance with the water contact standards specified in the 2005 California Ocean Plan (Ocean Plan), which defines bacterial, physical, and chemical water quality objectives and standards with the intent of protecting the beneficial uses of State ocean waters (SWRCB 2005).

Multiple sources of potential bacterial contamination exist in the Point Loma monitoring region in addition to the outfall. Therefore, being able to separate potential impacts associated with the discharge of wastewater from the outfall from other sources of contamination is challenging. Examples of other local, but non-outfall sources of bacterial contamination include San Diego Bay and the Tijuana and San Diego Rivers (Nezlin et al. 2007, Svejkovsky 2013). Likewise, storm drain discharges and wet-weather runoff from local watersheds can also flush contaminants seaward (Noble et al. 2003, Reeves et al. 2004, Sercu et al. 2009, Griffith et al. 2010). Moreover, beach wrack (e.g., kelp, seagrass), storm drains impacted by tidal flushing, and beach sediments can act as reservoirs, cultivating bacteria until release into nearshore waters by returning tides, rainfall, and/or other disturbances (Gruber et al. 2005, Martin and Gruber 2005, Noble et al. 2006, Yamahara et al. 2007, Phillips et al. 2011). Further, the presence of birds and their droppings has also been associated with bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2010).

In order to better understand potential impacts of a wastewater plume on water quality conditions, analytical tools based on natural chemical tracers can be leveraged to detect effluent from an outfall and separate it from other non-point sources. For example, colored dissolved organic material (CDOM) has previously been used to identify wastewater plumes in the San Diego region (Terrill et al. 2009, Rogowski et al. 2012a, 2012b, 2013). By combining measurements of CDOM with additional metrics that may characterize outfall-derived waters (e.g., low chlorophyll *a*), multiple criteria can be applied to improve the reliability of detection and facilitate the focused quantification of wastewater plume impacts on the coastal environment.

This chapter presents analyses and interpretations of the microbiological, water chemistry, and oceanographic data collected during 2012 at fixed water quality monitoring stations surrounding the 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. Results of remote sensing data are also evaluated to provide insight into wastewater transport and the extent of significant events in surface waters during the year (e.g., turbidity plumes).

## Materials and Methods

### Field Sampling

***Shore stations***

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

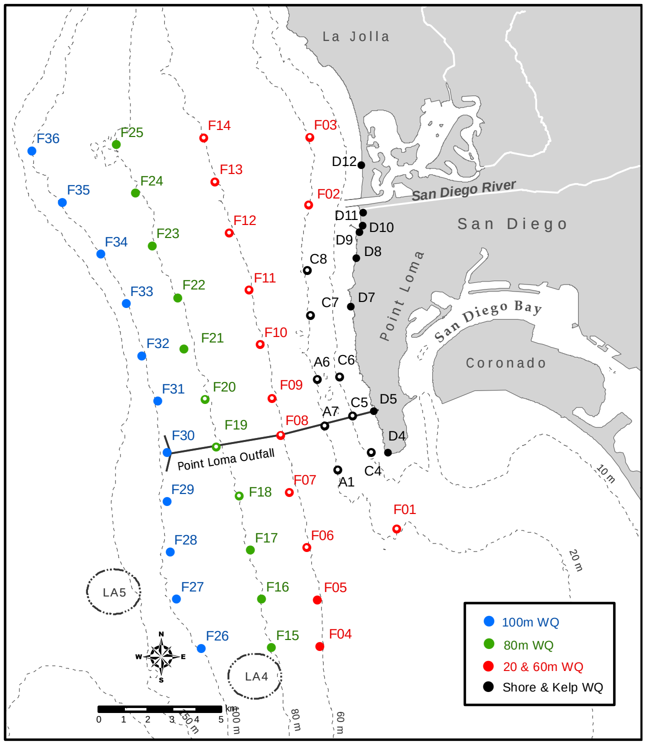



**Figure 3.1**
Water quality (WQ) monitoring station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program. Open circles indicate stations sampled within 3 nautical miles of shore.

monitor fecal indicator bacteria (FIB) concentrations in waters adjacent to public beaches (Figure 3.1) and to evaluate compliance with 2005 Ocean Plan water contact standards (see Box 3.1). Seawater samples from shore stations were collected from the surf zone in sterile 250-mL bottles. In addition, visual observations of water color, surf height, human or animal activity, and weather conditions were also recorded at the time of collection. The samples were then transported on blue ice to the City's Marine Microbiology Laboratory and analyzed to determine concentrations of total coliform, fecal coliform, and *Enterococcus* bacteria.

### *Kelp bed and other offshore stations*

Eight stations located in nearshore waters within the Point Loma kelp forest were monitored weekly 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 the 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, offshore stations were monitored 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 specific survey dates). Bacterial analyses for these offshore stations were limited to *Enterococcus*. Additional monitoring for ammonia occurred at the same discrete depths where bacterial samples were collected at the 15 F stations located within State jurisdictional waters (i.e., within 3 nautical miles of shore).

Seawater samples were collected at three discrete depths at the kelp stations and 18- and 60-m offshore stations, four depths at the 80-m offshore stations, and five depths at the 98-m offshore stations (Table 3.1). These samples were collected using a string of single Van Dorn bottles for sampling in the kelp forest and a Sea-Bird rosette sampler fitted with Niskin bottles when sampling the F stations. Aliquots for ammonia and bacteriological analyses were drawn into sterile sample bottles and refrigerated prior to processing at the City's Toxicology and Marine Microbiology Laboratories, respectively. Visual observations of weather, sea conditions, and human and/or animal activity were also recorded at the time of sampling. Oceanographic data were collected from these stations using a Sea-Bird conductivity, temperature, and depth instrument (CTD) and included measurements of

**Box 3.1**

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

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

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

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

(b) *Single Sample Maximum*:

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

B. Physical Characteristics

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

C. Chemical Characteristics

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

temperature, conductivity (salinity), pressure (depth), chlorophyll *a*, colored dissolved organic matter (CDOM), dissolved oxygen (DO), pH, and light transmissivity (see Chapter 2). Measurements of CDOM were only taken at offshore F stations, therefore subsequent plume detection analyses were limited to these stations (i.e., F1–F36).

## Laboratory Analyses

The City's Marine Microbiology Laboratory follows guidelines issued by the United States Environmental Protection Agency (USEPA) Water Quality Office and the California Department of Public Health (CDPH) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1995, CDPH 2000, USEPA 2006). All bacterial analyses were performed within eight hours of sample collection and conformed to standard membrane filtration techniques (APHA 1995). Plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values when calculating means and in determining compliance with Ocean Plan standards.

Quality assurance tests were performed routinely on seawater samples to ensure that analyses and sampling variability did not exceed acceptable limits. Duplicate and split bacteriological samples were processed according to method requirements to measure analyst precision and variability between samples, respectively. Results of these activities for 2012 were reported previously (City of San Diego 2013a).

Additional seawater samples were analyzed by the City's Toxicology Laboratory to determine ammonia (as nitrogen) concentrations using a

## 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 |

Hach DR850 colorimeter and the Salicylate Method (Bower and Holm-Hansen 1980). Quality assurance tests for these analyses were performed using blanks.

### Data Analyses

***Bacteriology***

FIB densities were summarized as monthly means for each shore station and by depth contour for the kelp bed and offshore stations. To assess temporal and spatial trends, the bacteriological data were summarized as counts of samples in which FIB concentrations exceeded benchmark levels. For this report, water contact limits defined in the 2005 Ocean Plan for densities of total coliforms, fecal coliforms, and *Enterococcus* in individual samples (i.e., single sample maxima, see Box 3.1 and SWRCB 2005) were used as reference points to distinguish elevated FIB values (i.e., benchmark levels). Concentrations of each type of FIB are identified by sample in Appendix B.1. FIB densities were compared to rainfall data from Lindbergh Field, San Diego, CA (see NOAA 2013). Chi-squared Tests ($\chi^2$) were conducted to determine if the frequency of samples with elevated FIB counts differed at the shore and kelp bed stations between wet (January–April and October–December) and dry (May–September) seasons. Satellite images of the PLOO region were provided by Ocean Imaging of Solana Beach, California (Svejkovsky 2013) and were used to aid in the analysis and interpretation of water quality data (see Chapter 2 for remote sensing details). Finally, compliance with Ocean Plan water-contact standards was summarized as the number of times per month that each shore and kelp station exceeded the various standards.

***Plume Detection and Out-of-range Calculations***

The potential presence or absence of wastewater plume was determined at each station using a combination of oceanographic parameters (i.e., detection criteria). If present, a strong alongshore CDOM signal due to coastal runoff could potentially interfere with wastewater plume detection. Pre-screening of CDOM data revealed no such signal within the PLOO region (Appendix B.2); therefore, all 36 offshore F stations were included in these analyses. Previous monitoring has consistently found that the PLOO plume is trapped below the pycnocline with no evidence of surfacing throughout the year (City of San Diego 2009–2012, Rogowski et al. 2012a, b, 2013). Water column stratification and pycnocline depth were quantified using calculations of buoyancy frequency (cycles$^2$/min$^2$) for each quarter (Chapter 2). If the water column was stratified, subsequent analyses were limited to depths below the pycnocline. Identification of potential plume signal at a station relied on multiple criteria, including (1) high CDOM, (2) low chlorophyll *a*, and (3) visual interpretation of the overall water column profile. Detection thresholds were adaptively set for each quarterly sampling period according to the following criteria: CDOM exceeding the 90$^{th}$ percentile and chlorophyll *a* below the 40$^{th}$ percentile. The threshold for chlorophyll *a* was incorporated to exclude CDOM derived from marine phytoplankton (Nelson et al. 1998, Rochelle-Newall and Fisher 2002, Romera-Castillo et al. 2010). It should be noted that these thresholds are based on regional observations of ocean properties and are thus constrained to use within the PLOO region. Finally, water column profiles were visually interpreted to remove stations with spurious signals (e.g., CDOM signals near the benthos due to resuspension of sediments by wave activity).

After identifying the stations and depth-ranges where detection criteria suggested the plume was

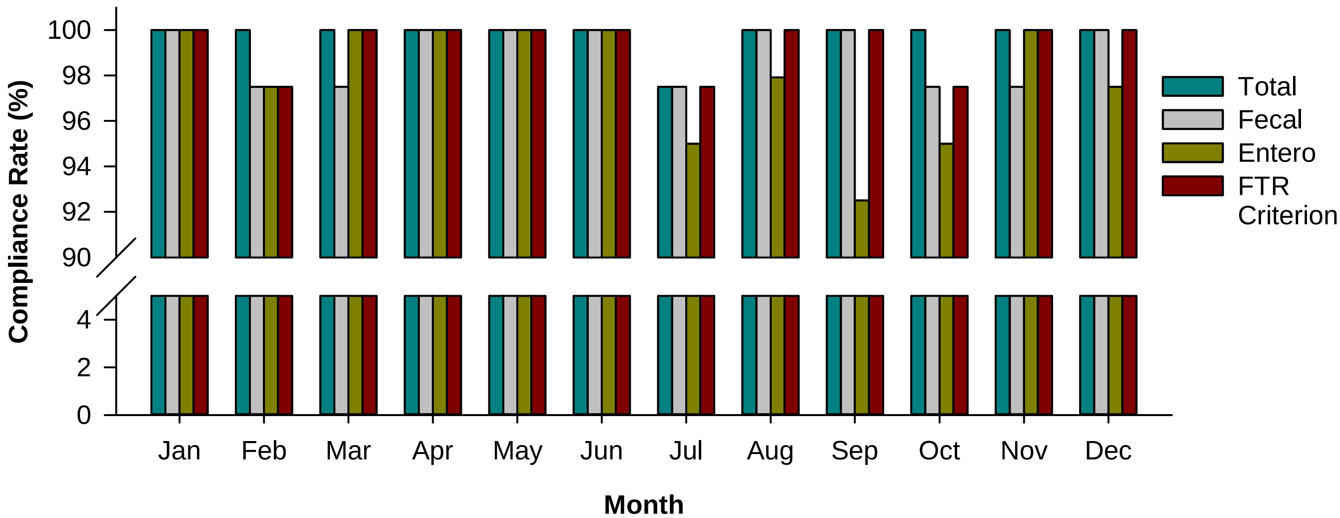



**Figure 3.2**

Compliance rates for the four single sample maximum standards at PLOO shore stations during 2012. See Box 3.1 for standard details.

present, out-of-range thresholds were calculated for water quality parameters of interest, namely DO, pH, and transmissivity. Any stations with CDOM below the 90$^{th}$ percentile were considered to lack the presence of wastewater plume and were used as non-plume reference stations for that quarterly sampling period (Appendix B.3). Stations were designated as out-of-range if DO, pH, or transmissivity within the wastewater plume exceeded water quality standards as defined by the Ocean Plan (Box 3.1). Out-of-range thresholds were determined by comparing geometric means for each parameter at plume stations and depths against the thresholds calculated at similar depths across all non-plume reference stations for each quarterly sampling period (Appendix B.4). Thresholds for non-plume reference DO and pH (10% and 0.2 unit reductions, respectively) were applied to the mean minus one standard deviation, while transmissivity thresholds were calculated as the lower 95% confidence interval from the mean (Box 3.1).

## Results and Discussion

### Bacteriological Compliance and Distribution

***Shore stations***

During 2012, compliance at the eight shore stations in the PLOO region was 100% for the 30-day total coliforms, fecal coliforms, and *Enterococcus* geometric mean standards. Compliance for single sample maximum (SSM) standards ranged from 98 to 100% for total coliforms, 98 to 100% for fecal coliforms, 92 to 100% for *Enterococcus*, and 98 to 100% for the fecal:total coliforms (FTR) criterion (Figure 3.2). In addition, foam was observed at several shore stations throughout the year, while observations of sewage-like odor were only reported during the wet season. Monthly mean FIB densities ranged from 6 to 3892 CFU/100 mL for total coliforms, 2 to 1340 CFU/100 mL for fecal coliforms, and 2 to 5836 CFU/100 mL for *Enterococcus* (Appendix B.5). Of the 486 shore samples analyzed during the year, only eleven (2.3%) had elevated FIB, with six of these samples (55%) collected from station D8 (Table 3.2, Appendix B.1). Although this represents a small increase from the three samples with elevated FIB counts in 2011, the results for 2012 are more similar to previous years (Figure 3.3). A general relationship between rainfall and elevated bacterial levels at shore stations has been evident since water quality monitoring began in the Point Loma region (Figure 3.3). This historical comparison illustrates that the probability of FIB hits in the wet season is only slightly more likely than in the dry season (7% versus 2%, respectively; $n = 7190$, $\chi^2 = 104.902$, $p < 0.0001$). Despite a large disparity in rainfall between the wet and dry seasons in 2012 (6.54 versus 0.02 in, respectively), no effect of season on elevated FIBs was detected.

## Table 3.2

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

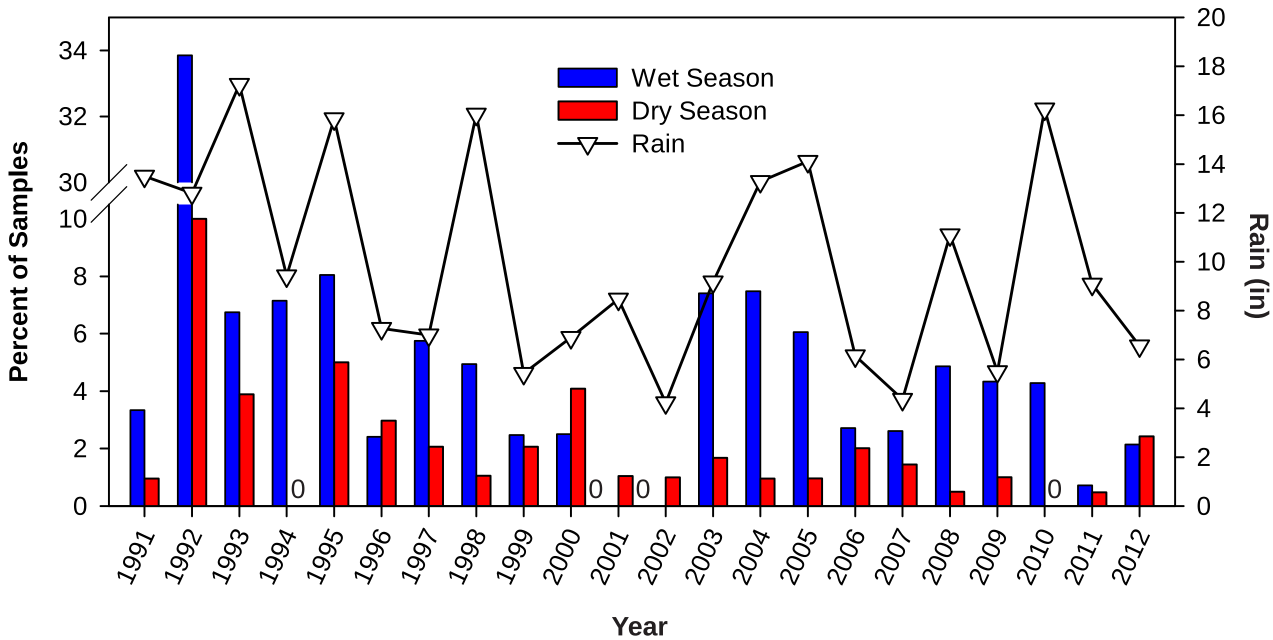
| Station | Seasons: Wet | Seasons: Dry | % Wet |
|---|---|---|---|
| D12 | 2 | 0 | 100 |
| D11 | 0 | 0 | — |
| D10 | 0 | 0 | — |
| D9 | 1 | 1 | 50 |
| D8 | 3 | 3 | 50 |
| D7 | 0 | 1 | 0 |
| D5 | 0 | 0 | — |
| D4 | 0 | 0 | — |
| **Rain (in)** | 6.54 | 0.02 | |
| **Total Counts** | 6 | 5 | 55 |
| **n** | 280 | 206 | |

### *Kelp bed stations*

Compliance at the eight kelp bed stations in the PLOO region was 100% for all 30-day geometric mean and SSM standards during 2012. This represents an increase in SSM compliance from 2011, when the compliance rate was slightly lower at 99.3% (City of San Diego 2012). Further, no signs of wastewater (e.g., foam, sewage-like odor) were observed at any of the kelp stations during the year. Satellite imagery showed that runoff from the San Diego River was typically restricted to the area between the shore and inside of the kelp forest during 2012 (Svejkovsky 2013). Monthly mean FIB densities at the PLOO kelp bed stations were lower than those at the shore stations, ranging from 3 to 20 CFU/100 mL for total coliforms, 2 to 3 CFU/100 mL for fecal coliforms, and 2 to 3 CFU/100 mL for *Enterococcus* (Appendix B.6). This low incidence of elevated FIBs is consistent with water quality results dating back to 1994 after the outfall was extended to its present deepwater discharge site (Figure 3.4). In contrast, FIB levels were much higher at the kelp bed stations prior to the outfall extension. No relationship between rainfall and elevated FIB levels was evident at these stations, as the proportion of samples with high FIBs was similar between wet and dry seasons (~4% for both).

### *Offshore stations*

The maximum concentration of *Enterococcus* bacteria at the 36 offshore stations was




## Figure 3.3

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 2012. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA.

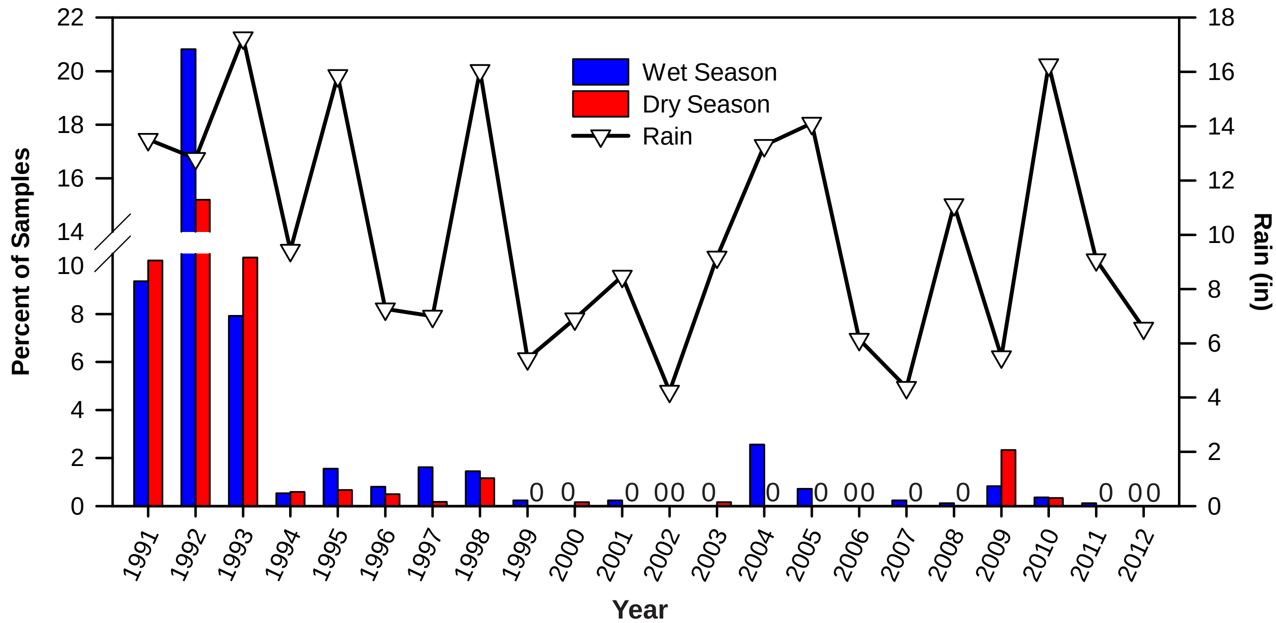


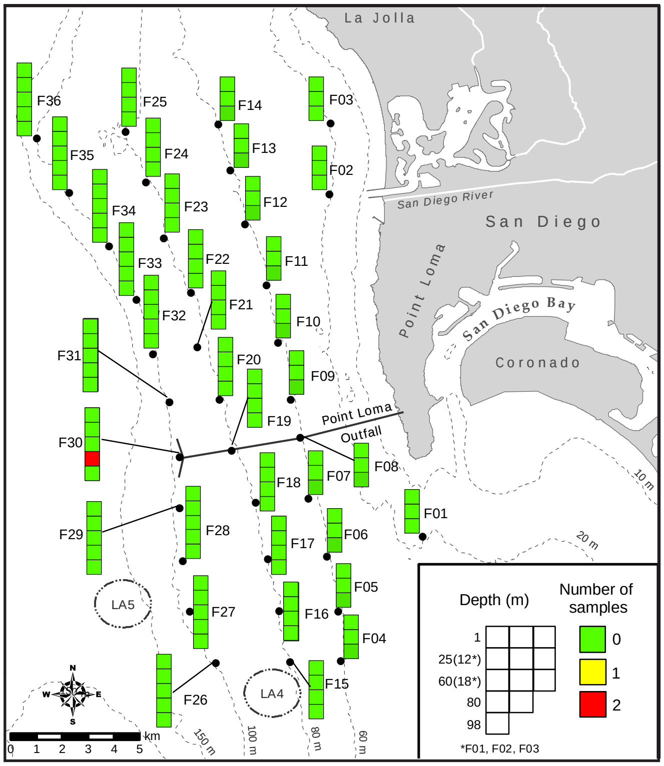

**Figure 3.4**

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 2012. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA.

460 CFU/100 mL in 2012. While foam and organic debris were reported at station F14 on February 22, it is more likely related to outflow from Mission Bay and/or the San Diego River rather than effluent discharged from the PLOO; no other signs of wastewater were observed. Only two of 564 offshore samples (0.4%) had elevated *Enterococcus* levels >104 CFU/100 mL, both of which were collected at station F30 located nearest the discharge site and at a sample depth of 80 m (Figure 3.5). No exceedances occurred within State waters (i.e., within 3 nautical miles of shore). These results suggest that the wastewater plume was restricted to relatively deep, offshore waters throughout the year. This conclusion is consistent with remote sensing observations that provided no evidence of the plume reaching surface waters in 2012 (Svejkovsky 2013). These findings are also consistent with historical analyses, which revealed that <1% of the samples collected between 1991 and 2012 from ≤25 m depths at the eleven stations located along the 98-m discharge depth contour contained elevated levels of *Enterococcus* (Figure 3.6A). Over this time period, collecting a sample with elevated FIBs was significantly more likely at the three stations located near the discharge zone (i.e., F29, F30, F31) than at any other 98-m site (16% versus 5%, respectively; n = 4800, $\chi^2 = 42.23$, $p < 0.0001$) (Figure 3.6B). Following the initiation of chlorination in August 2008, the number of samples with elevated *Enterococcus* also dropped significantly at these three stations (17% before versus 8% after, n = 1661, $\chi^2 = 11.60$, $p = 0.0007$), as well as at the other 98-m stations (6% before versus 0.7% after; n = 3139, $\chi^2 = 32.41$, $p < 0.0001$) (Figure 3.6C).

### *Ammonia*

Seawater samples were analyzed for ammonia at the eight kelp stations and 15 other offshore stations located within State waters. Ammonia concentrations at stations along the 18, 60, and 80-m contours ranged up to a maximum of 0.1 mg/L (Table 3.3). These levels are an order of magnitude lower than the water quality objectives for ammonia defined in the Ocean Plan (i.e., instant maximum of 6.0 mg/L, daily maximum of 2.4 mg/L) (SWRCB 2005). Ammonia was detected at 12 of the 23 stations sampled and in 5.7% of the 288 samples collected during 2012. No ammonia was detected at any station during February or at any of the 9-m kelp stations (Figure 3.7). None of the samples with detectable levels of ammonia corresponded to samples containing elevated concentrations of *Enterococcus* bacteria (see City of San Diego 2013b).




## Figure 3.5

Distribution of seawater samples with elevated *Enterococcus* densities at offshore stations during 2012. Data are number of samples that exceeded concentrations >104 CFU/100 mL. See text and Table 2.1 for sampling details.

### Wastewater Plume: Detection and Impacts

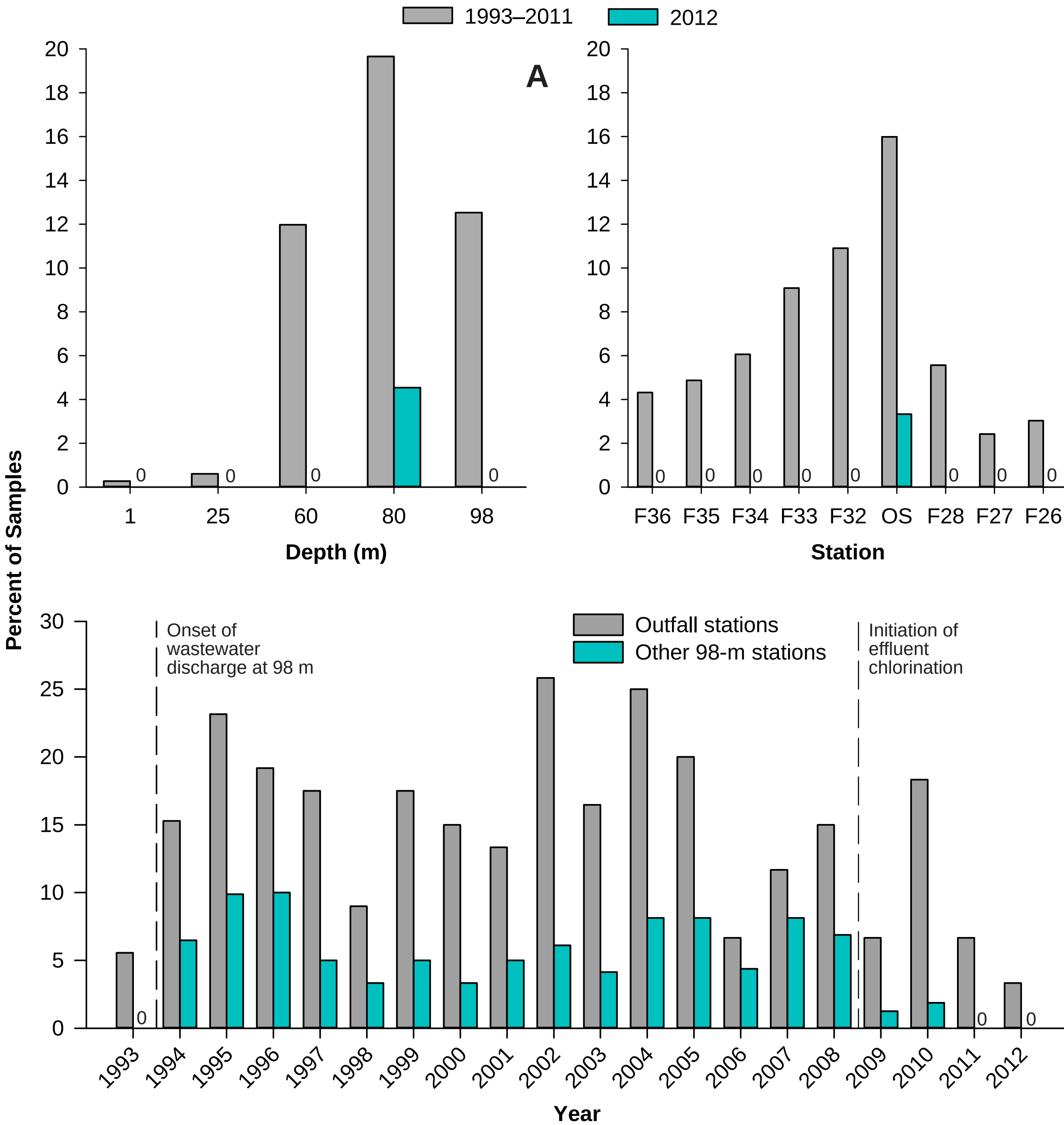
Based on the detection criteria described above (see 'Materials and Methods'), the PLOO wastewater plume was identified during all four quarterly surveys in 2012 from a total of 33 of 144 (22.9%) profile casts (Table 3.4). The wastewater plume was consistently detected at the three stations nearest the discharge zone (F29, F30, F31) as well as at stations F32–F34 north of the outfall along the 98-m depth contour (Figure 3.8). The plume was also detected at stations located along the 80-m depth contour, though its presence at individual stations was not consistent across surveys. The spatial distribution of these plume detections is in agreement with vertically-integrated *Enterococcus* concentrations in the water column at stations along the 60, 80, and 98-m depth contours in the PLOO region, which tended to be higher at stations north of the outfall during 2012 (Appendix B.7). General subsurface current direction and velocity at depths >50 m over the week prior to each quarterly survey supports a northward dispersion of the plume (data not shown). Similar findings of flow-mediated dispersal of wastewater plume in the PLOO region, both to the north and south of the outfall, have been previously reported (Rogowski et al. 2012a, b, 2013).

Plume depth fluctuated through time at station F30, but remained at depths below 50 m even during periods of weak water column stratification (Appendix B.8). This is in agreement with satellite imagery that did not detect visual evidence of the plume surfacing in the PLOO region during 2012 (Svejkovsky 2013). Further, presence of the plume at station F30 was corroborated by water samples with elevated concentrations of *Enterococcus* taken at 80 m on February 24 and August 9 (Figure 3.5, Appendix B.8).

The potential impact of the PLOO plume on water quality was calculated for each station where it was detected. At each of these stations, mean values of DO, pH, and transmissivity within the wastewater plume were compared to thresholds within similar depths from non-plume reference stations (Appendix B.4). Of the 33 total plume detections observed during 2012, there were no out-of-range (OOR) events for either DO or pH. In contrast, 14 OOR events were identified for transmissivity (Table 3.4, Appendices B.9, B.10, and B.11); however, only one of these OORs (station F18, Feb 23) was located within State jurisdictional waters as defined by the Ocean Plan.

## Summary

Water quality conditions in the Point Loma outfall region were excellent during 2012. Overall compliance with 2005 Ocean Plan water-contact standards was 99.9%, which was only marginally higher than the 99.8% compliance observed during the previous year (City of San Diego 2012). In addition, there was no evidence during the year that wastewater discharged into the ocean via the PLOO reached the 18- and 60-m stations or the shoreline. Elevated FIBs were detected in 11 samples from shoreline stations and from no kelp bed samples

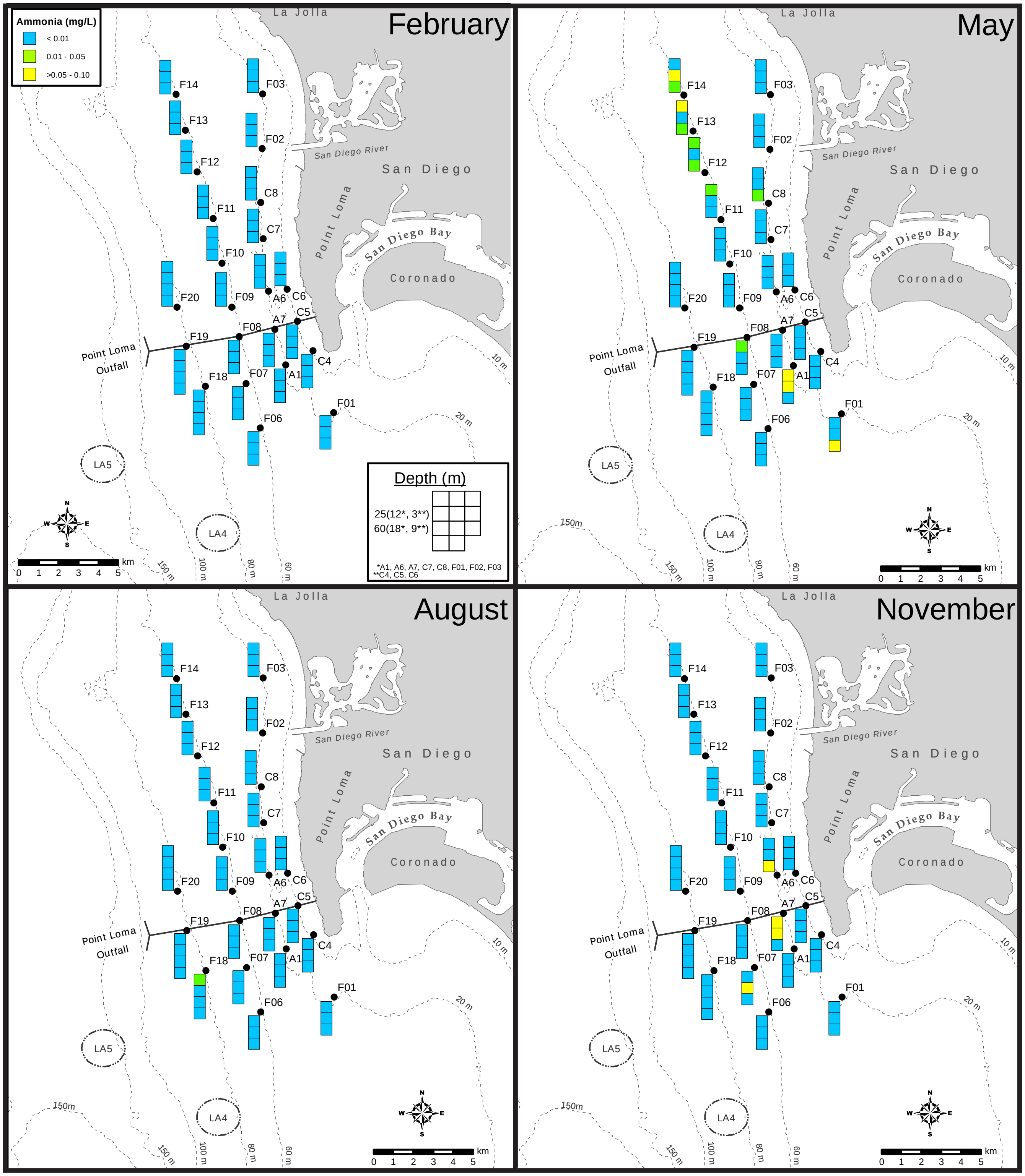



## Figure 3.6

Percent of samples collected from PLOO 98-m offshore stations with elevated bacteria densities. Samples from 2012 are compared to those collected between 1993 and 2011 by (A) sampling depth, (B) station, and (C) year. Stations in panel (B) listed from north to south from left to right. Dashed lines indicate the onset of wastewater discharge and the initiation of effluent chlorination. OS = outfall stations (F29, F30, F31).

during 2012. Over the years, elevated FIBs detected at shore and kelp bed stations have been mostly associated with rainfall events, heavy recreational use, or the presence of seabirds or decaying kelp and surfgrass (e.g., City of San Diego 2009–2012). 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 2007–2012, Rogowski et al. 2012a, b, 2013). This pattern remained true for 2012 with evidence indicating that the wastewater plume was restricted to depths of 50 m or below in offshore waters. Moreover, no visual evidence of the plume




## Figure 3.7

Distribution of ammonia (as nitrogen, mg/L) in seawater samples collected during the PLOO quarterly surveys in 2012. See text and Table 3.1 for sampling details.

surfacing was detected in satellite images taken during the year (Svejkovsky 2013). The deepwater (98-m) location of the discharge site may be the dominant factor that inhibits the plume from reaching surface waters. For example, wastewater released into these deep, cold and dense waters does not appear to mix with the upper 25 m of the water column (Rogowski et al. 2012a, b, 2013). Finally, it

## Table 3.3
Summary of ammonia concentrations in samples collected from the 23 PLOO kelp bed and offshore stations located within State waters during 2012. 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 (%) | 0 | 16.7 | 0 | 12.5 |
| Min | — | nd | — | nd |
| Max | — | 0.10 | — | 0.07 |
| Mean | — | 0.07 | — | 0.06 |
| *60-m Depth Contour* (n = 27) | | | | |
| Detection Rate (%) | 0 | 29.6 | 0 | 3.7 |
| Min | — | nd | — | nd |
| Max | — | 0.10 | — | 0.07 |
| Mean | — | 0.05 | — | 0.07 |
| *80-m Depth Contour* (n = 12) | | | | |
| Detection Rate (%) | 0 | 0 | 8.3 | 0 |
| Min | — | — | nd | — |
| Max | — | — | 0.01 | — |
| Mean | — | — | 0.01 | — |

nd = not detected

appears that not only is the plume from the PLOO being trapped below the pycnocline, but now that effluent is undergoing partial chlorination prior to discharge, densities of indicator bacteria have dropped significantly at all offshore stations along the 98-m depth contour, including those nearest the outfall.

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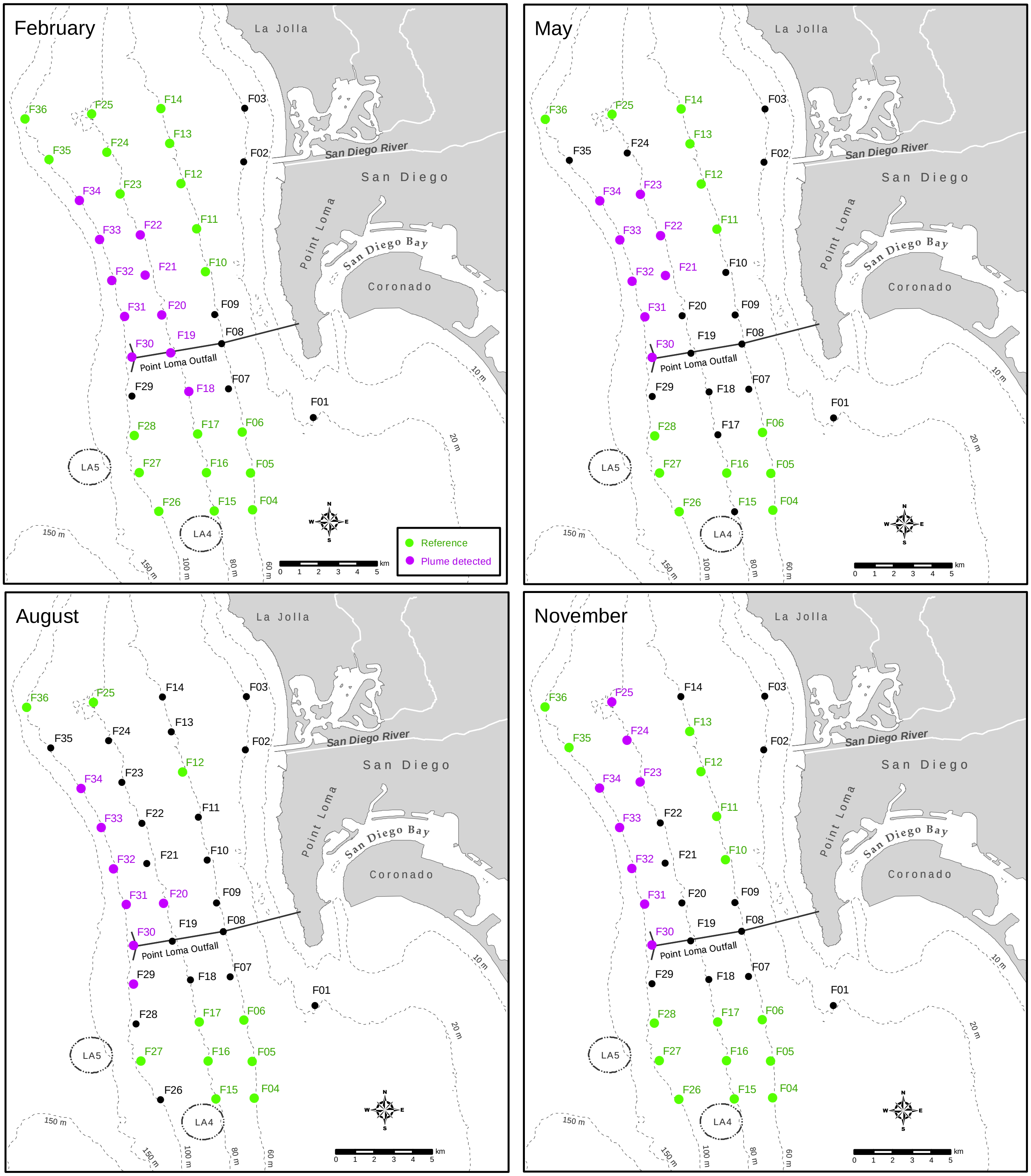


## Figure 3.8

Distribution of stations with potential plume detections (pink) and those used as non-plume reference stations for water quality compliance calculations (green) during the PLOO quarterly surveys in 2012.

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**Table 3.4**
Summary of plume detections and out-of-range values at PLOO offshore stations during 2012. DO = dissolved oxygen; XMS = transmissivity.

| | | Out of Range | | | |
|---|---|---|---|---|---|
| **Month** | **Plume Detections** | **DO** | **pH** | **XMS** | **Stations** |
| Feb | 10 | 0 | 0 | 4 | F18[a], F19, F20, F21, F22, F30, F31[a], F32[a], F33[a], F34 |
| May | 8 | 0 | 0 | 1 | F21, F22, F23, F30, F31, F32[a], F33, F34 |
| Aug | 7 | 0 | — | 1 | F20, F29, F30, F31, F32, F33, F34 |
| Nov | 8 | 0 | 0 | 8 | F23[a], F24[a], F25[a], F30[a], F31[a], F32[a], F33[a], F34[a] |
| **Detection Rate (%)** | 22.9 | 0.0 | 0.0 | 9.7 | |
| **Total Count** | 33 | 0 | 0 | 14 | |
| **n** | 144 | 144 | 144 | 144 | |

[a] Out-of-range value for transmissivity


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# Chapter 4
# Sediment Conditions

# Chapter 4. Sediment Conditions

## Introduction

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

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

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

This chapter presents analyses and interpretations of sediment particle size and chemistry data collected during 2012 at fixed benthic monitoring stations surrounding the PLOO. The primary goals are to: (1) document sediment conditions during the year, (2) identify possible effects of wastewater discharge on sediment quality in the region, and (3) identify other potential natural and anthropogenic sources of sediment contaminants to the local marine ecosystem.

## Materials and Methods

### Field Sampling

Sediment samples were collected at 22 fixed monitoring stations in the PLOO region during 2012 (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 from the distal end of the northern diffuser leg. All stations were sampled during January 2012, while the July survey was limited to 12 ‘primary core’ stations located along the 98-m depth contour to accommodate additional sampling for a special sediment mapping project (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 particle size analyses were performed at the City of San Diego’s Wastewater Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2013a). Briefly, sediment sub-samples were analyzed to determine concentrations of various indictors of organic loading (i.e., biochemical oxygen demand, total organic carbon, total nitrogen, total sulfides, total volatile solids), 18 trace metals, 9 chlorinated pesticides (e.g., DDT), 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis. Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix C.1). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry.

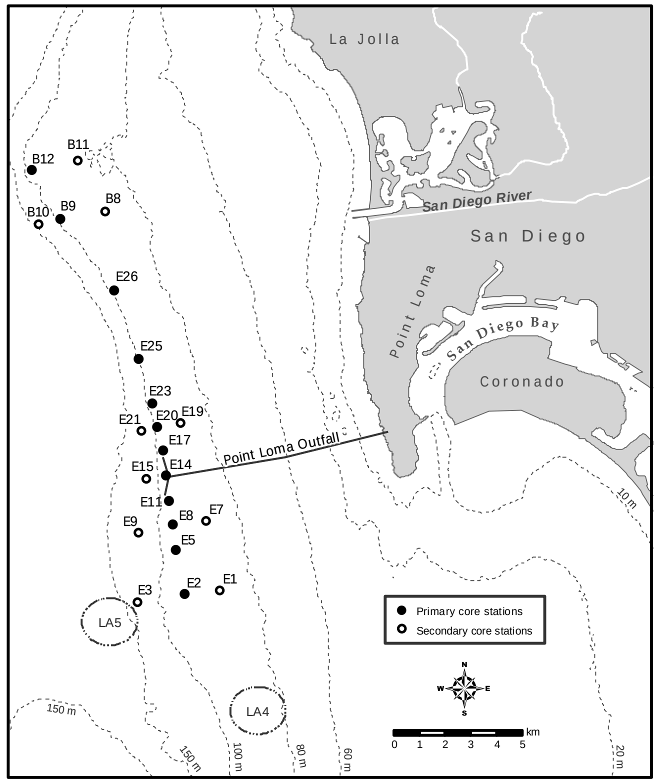



**Figure 4.1**
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego’s Ocean Monitoring Program.

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

### Data Analyses

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

Multivariate analyses were performed using PRIMER software to examine spatio-temporal patterns in the overall particle size composition in the Point Loma outfall region (Clarke and Warwick 2001, Clarke and Gorley 2006). These included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). Proportions of particle size sub-fractions were square-root transformed to limit the influence of the largest fractions, and Euclidean distance was used as the basis for the cluster analysis.

## Results

### Particle Size Distribution

Ocean sediments sampled off Point Loma were composed predominantly of fine particles (i.e., silt and clay; also referred to as percent fines) and fine sand during 2012. Percent fines averaged 44% per sample, while fine sand, coarse sand, and coarser particles (i.e., very coarse sand, granules such as gravel or shell hash) averaged 53%, 3%, and < 1%, respectively (Table 4.1). Visual observations recorded at the time of sampling also revealed the presence of organic debris (e.g., plant material, worm tubes), pea gravel, coarse black sand, gravel, and/or shell hash at different stations (Appendix C.4). For the primary core stations sampled during both the winter (January) and summer (July) surveys, particle size composition varied by as much as 15% per size fraction, with the greatest intra-station differences occurring at station E2 (Figure 4.2, Appendix C.4). Sediments from this station sampled during the winter consisted of 37% fines, 39% fine sand, 15% coarse sand, and 9% coarser particles, while the summer sample consisted of 44% fines, 53% fine sand, 3% coarse sand and no coarser particles. Overall, there were no spatial patterns in sediment composition relative to the PLOO discharge site. For example, sediments collected from the nearfield stations ranged from 36 to 42% fines and 57 to 63% fine sand, while sediments from sites > 1000 m from the outfall ranged from 34 to 66% fines and 33 to 64% fine sand.

Classification (cluster) analysis of the sediment data for the primary core stations sampled in 2012 discriminated three main cluster groups based on the particle size sub-fractions present (Cluster Groups 1–3; Figure 4.3). Cluster Group 1 represented a single grab sample collected from southernmost station E2 in January; sediments in this sample

## Table 4.1

Summary of particle sizes and chemistry concentrations in sediments from PLOO benthic stations sampled during 2012. Data include the detection rate (DR), mean, minimum, median, and maximum values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1991–1993) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold.

| | 2012 Summary[a] | | | | | Pre-discharge | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **DR (%)** | **Mean** | **Min** | **Median** | **Max** | **Max** | **ERL[b]** | **ERM[b]** |
| *Particle Size* | | | | | | | | |
| Coarse particles(%) | — | 0.6 | 0.0 | 0.0 | 12.3 | 26.4 | na | na |
| Coarse sand (%) | — | 2.7 | 0.4 | 1.2 | 21.0 | 41.6 | na | na |
| Fine sand (%) | — | 52.8 | 33.1 | 53.5 | 64.2 | 72.6 | na | na |
| Fines (%) | — | 43.9 | 33.8 | 42.0 | 66.1 | 74.4 | na | na |
| *Organic Indicators* | | | | | | | | |
| BOD (*ppm*)[c] | 100 | 167 | 121 | 166 | 212 | 656 | na | na |
| Sulfides (*ppm*) | 100 | 7.5 | 1.1 | 5.0 | 30.8 | 20 | na | na |
| TN (*% weight*) | 100 | 0.057 | 0.035 | 0.057 | 0.083 | 0.074 | na | na |
| TOC (*% weight*) | 100 | 0.94 | 0.33 | 0.60 | 4.85 | 1.24 | na | na |
| TVS (*% weight*) | 100 | 2.31 | 1.66 | 2.18 | 3.67 | 4.00 | na | na |
| *Trace Metals* (*ppm*) | | | | | | | | |
| Aluminum | 100 | 7187 | 3220 | 7030 | 11,100 | na | na | na |
| Antimony | 53 | 0.42 | nd | 0.30 | 0.92 | 6 | na | na |
| Arsenic | 100 | 2.9 | 2.0 | 2.7 | 6.5 | 5.6 | 8.2 | 70 |
| Barium | 100 | 37.6 | 13.5 | 35.5 | 72.5 | na | na | na |
| Beryllium | 100 | 0.267 | 0.121 | 0.180 | 0.665 | 2.01 | na | na |
| Cadmium | 65 | 0.13 | nd | 0.10 | 0.26 | 6.1 | 1.2 | 9.6 |
| Chromium | 100 | 15.8 | 11.3 | 15.4 | 26.8 | 43.6 | 81 | 370 |
| Copper | 100 | 7.6 | 3.4 | 6.9 | 16.3 | 34 | 34 | 270 |
| Iron | 100 | 11,102 | 7700 | 10,600 | 21,000 | 26,200 | na | na |
| Lead | 100 | 6.60 | 3.86 | 6.63 | 9.68 | 18 | 46.7 | 218 |
| Manganese | 100 | 83.5 | 31.5 | 82.8 | 129.0 | na | na | na |
| Mercury | 100 | 0.029 | 0.017 | 0.026 | 0.065 | 0.096 | 0.15 | 0.71 |
| Nickel | 100 | 7.01 | 3.56 | 6.88 | 10.00 | 14 | 20.9 | 51.6 |
| Selenium | 15 | 0.30 | nd | nd | 0.48 | 0.9 | na | na |
| Silver | 6 | 0.17 | nd | nd | 0.19 | 4 | 1 | 3.7 |
| Thallium | 0 | — | — | — | — | 113 | na | na |
| Tin | 100 | 1.14 | 0.68 | 1.09 | 2.17 | na | na | na |
| Zinc | 100 | 28.9 | 19.3 | 28.1 | 51.1 | 67 | 150 | 410 |
| *Pesticides* (*ppt*) | | | | | | | | |
| Total DDT | 85 | 637 | nd | 300 | 6500 | 13,200 | 1580 | 46,100 |
| Total chlordane | 6 | 255 | nd | nd | 270 | nd | na | na |
| Total HCH | 3 | 370 | nd | nd | 370 | nd | na | na |
| HCB | 3 | 470 | nd | nd | 470 | nd | na | na |
| *Total PCB* (*ppt*) | 21 | 3031 | nd | nd | 10,334 | na | na | na |
| *Total PAH* (*ppb*) | 9 | 86.7 | nd | nd | 138.7 | 199 | 4022 | 44,792 |

na = not available; nd = not detected

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

[b] From Long et al. 1995

[c] BOD values are from July only (n = 12).

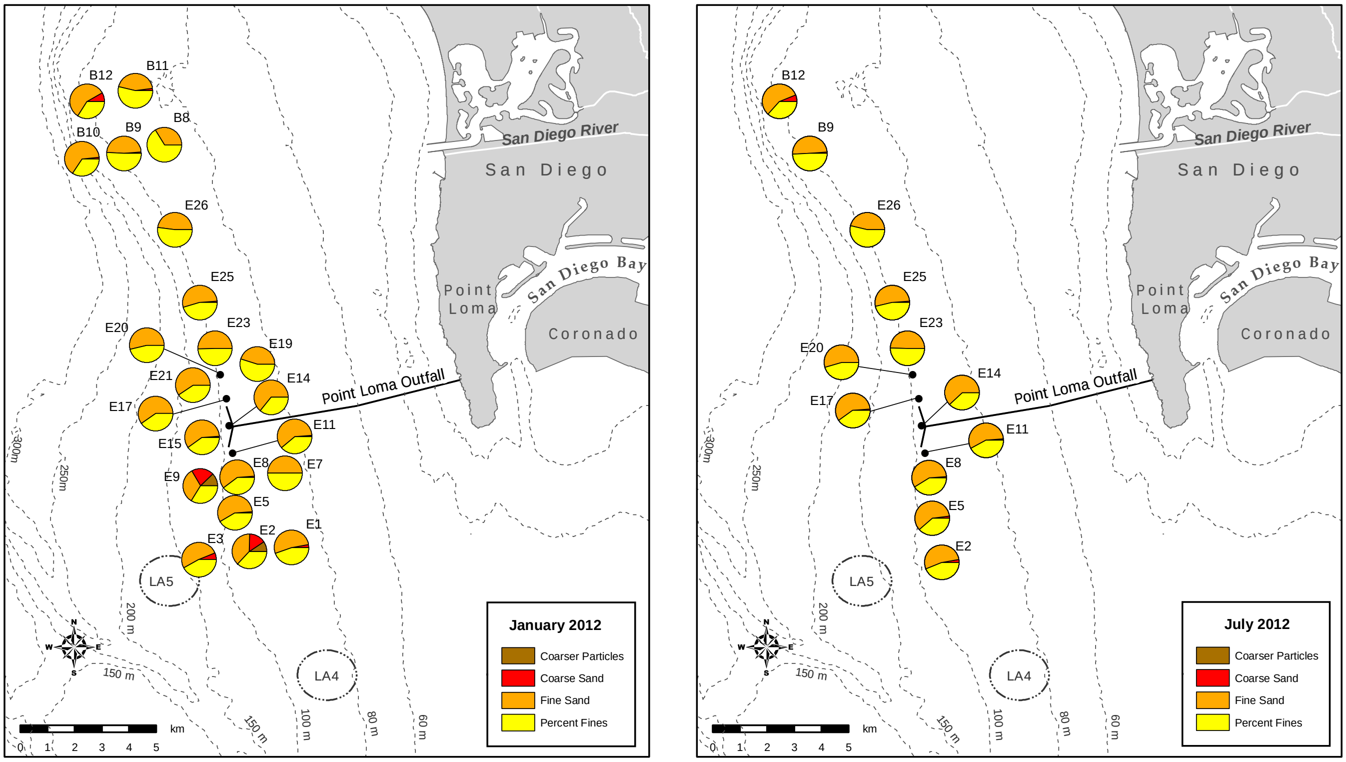



**Figure 4.2**
Sediment composition at PLOO benthic stations sampled in 2012 during January (left) and July (right) surveys.

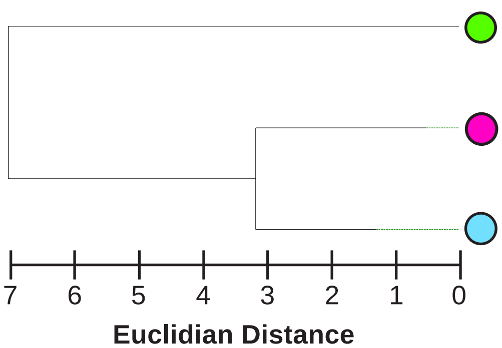
consisted of 8% medium sand, 7% coarse sand, 3% very coarse sand, and 6% granules. Cluster Group 2 represented the two samples collected during both January and July at northernmost station B12; sediments in these samples averaged 11% coarse silt, 25% very fine sand, 32% fine sand, and 7% medium sand. Cluster Group 3 represented the remaining 21 samples collected during the year, including all samples from the three nearfield stations. This group had sediments that were finer than those represented by groups 1 and 2; they averaged 21% coarse silt, 40% very fine sand, and 15% fine sand, and lacked particles coarser than medium sand.

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

## Indicators of Organic Loading

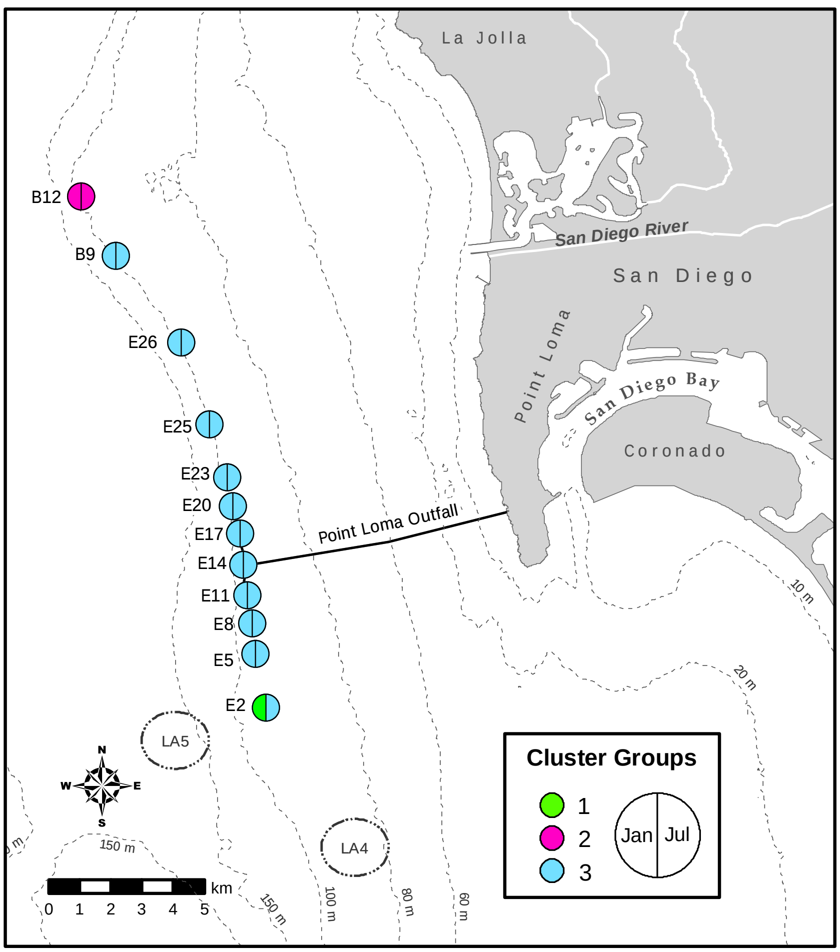
Indicators of organic loading, including biochemical oxygen demand (BOD), sulfides, total nitrogen (TN), total organic carbon (TOC) and total volatile solids (TVS), were detected in all sediment samples collected in the Point Loma outfall region during 2012 (Table 4.1). BOD concentrations ranged from 121 to 212 ppm, while concentrations of sulfides ranged from 1.1 to 30.8 ppm, TN ranged from 0.035 to 0.083% wt, TOC ranged from 0.33 to 4.85% wt, and TVS ranged from 1.66 to 3.67% wt. Of these five indicators only sulfides, TN and TOC were detected

**A**




| | | Percent Fines | | | | | Fine Sand | | Coarse Sand | | Coarser Particles | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cluster Group** | n | CLAY | VFSILT | FSILT | MSILT | CSILT | VFSAND | FSAND | MSAND | CSAND | VCSAND | GRANULES |
| 1 | 1 | 0 | 0 | 0 | 0 | 37 | 25 | 14 | 8 | 7 | 3 | 6 |
| 2 | 2 | 4 | 6 | 8 | 7 | 11 | 25 | 32 | 7 | <1 | 0 | 0 |
| 3 | 21 | 3 | 5 | 7 | 8 | 21 | 40 | 15 | 1 | 0 | 0 | 0 |

**B**




## Figure 4.3

Cluster analysis of particle size sub-fraction data from PLOO primary benthic stations sampled during 2012. Data are presented as: (A) cluster results and (B) spatial distribution of sediment samples as delineated by cluster analysis. Data for particle size sub-fractions are mean percentages calculated over all stations within a cluster group (n). VFSILT=Very Fine Silt; FSILT=Fine Silt; MSILT=Medium Silt; CSILT=Coarse Silt; VFSAND=Very Fine Sand; FSAND=Fine Sand; MSAND=Medium Sand; CSAND=Coarse Sand; VCSAND=Very Coarse Sand.

at concentrations higher than observed prior to wastewater discharge. The highest TN, TOC and TVS concentrations occurred at the northern 'B' stations located at least 10 km north of the outfall (Appendix C.5). In contrast, the highest sulfide and BOD concentrations were from station E14 located nearest the discharge site. In general, only sulfide and BOD concentrations have shown changes near the outfall that appear to be associated with possible organic enrichment (Figure 4.4; see also City of San Diego 2007, 2011, 2012).

### Trace Metals

Thirteen trace metals were detected in all sediment samples collected in the PLOO region during 2012, including aluminum, arsenic, barium, beryllium, chromium, copper, iron, lead, manganese, mercury, nickel, tin and zinc (Table 4.1). Antimony and cadmium were also detected in most samples (53–65%), while selenium and silver occurred much less frequently at rates of 6–15%. Thallium was not detected in any samples collected during the year. All metals were detected at low levels below both ERL and ERM thresholds and within ranges reported elsewhere in the Southern California Bight (SCB; Schiff et al. 2011). Only arsenic occurred at concentrations higher than reported during the pre-discharge period. In addition to overall low concentrations, metal distributions were spatially variable, with no discernible patterns relative to the outfall (Appendix C.6). Instead, 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, E9). For example, the highest concentrations of aluminum, barium, beryllium, chromium, and iron were detected in station B9 sediments, while station E2 sediments contained the highest levels of lead and mercury.

### Pesticides

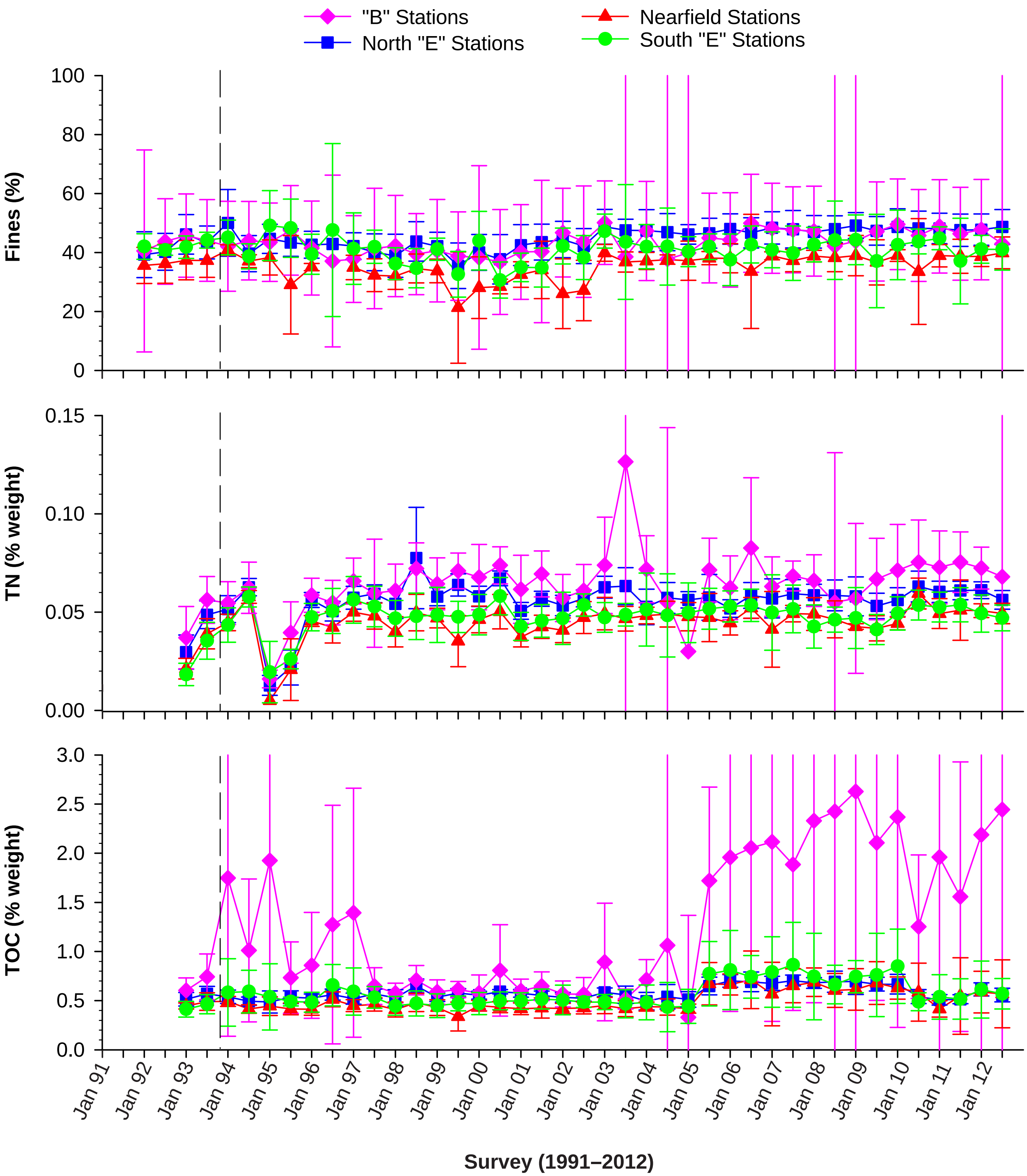
Four chlorinated pesticides were detected in PLOO sediments during 2012, including DDT, chlordane, hexachlorobenzene (HCB), and hexachlorocyclohexane (HCH) (Appendix C.7). Total DDT, composed primarily of p,p-DDE, was detected in 85% of the samples at concentrations up to 6500 ppt (Table 4.1). Although the highest DDT concentrations measured during the year (i.e., at stations E14 in January and E23 in July) exceeded the ERL, all DDT values were below values reported prior to discharge. Total chlordane was detected in just two samples (6%) collected during July at a maximum concentration of 270 ppt; oxychlordane was detected at station E14, while alpha (cis) chlordane was detected at station E26. HCB and HCH (alpha isomer; Appendix C.3) were each detected in only a single sediment sample. HCB was found in sediments from station E7 during January at a concentration of 470 ppt, while HCH was found at station E14 in July at a concentration of 370 ppt.

### PCBs and PAHs

PCBs and PAHs were detected infrequently in PLOO sediments during 2012 (Table 4.1). Total PCB was detected in 21% of the samples (six stations) at concentrations up to 10,334 ppt (Appendix C.7). Although no ERL or ERM thresholds exist for PCBs measured as congeners, all PCB values off Point Loma were within ranges previously reported for the SCB (Schiff et al. 2011). The most commonly detected PCB congeners in PLOO sediments were PCB 153/168, PCB 70, PCB 118, and PCB 138 (Appendix C.3). Total PAH was found at concentrations up to 138.7 ppb in samples from just three stations. Total PAH did not exceed pre-discharge levels, and all values were below ERL and ERM thresholds. Individual PAHs that were detected included 2,6-dimethylnaphthalene, 3,4-benzo (B) fluoranthene, Benzo[A]anthracene, benzo[A]pyrene, fluoranthene, and pyrene. No patterns indicative of an outfall effect were evident in the distribution of either PCBs or PAHs, with both primarily found in sediments from stations located south of the outfall (e.g., E1, E2, E3, E5, E9; Appendix C.7).

## Discussion

Particle size composition at the PLOO stations was similar in 2012 to that reported during recent years




## Figure 4.4

Particle size and organic loading indicators at PLOO benthic stations sampled between 1991 and 2012. Data are expressed as means of detected values ±95% confidence intervals for samples pooled over “B” stations (B8–B11), north “E” stations (E19–E21, E23, E25, E26), nearfield stations (E11, E14, E15, E17), and south “E” stations (E1–E3, E5, E7–E9) for each survey. Data were limited to primary core stations during: January 2005 and 2009; July 2003, 2004, 2008, and 2012. Dashed lines indicate onset of discharge from the PLOO extension.

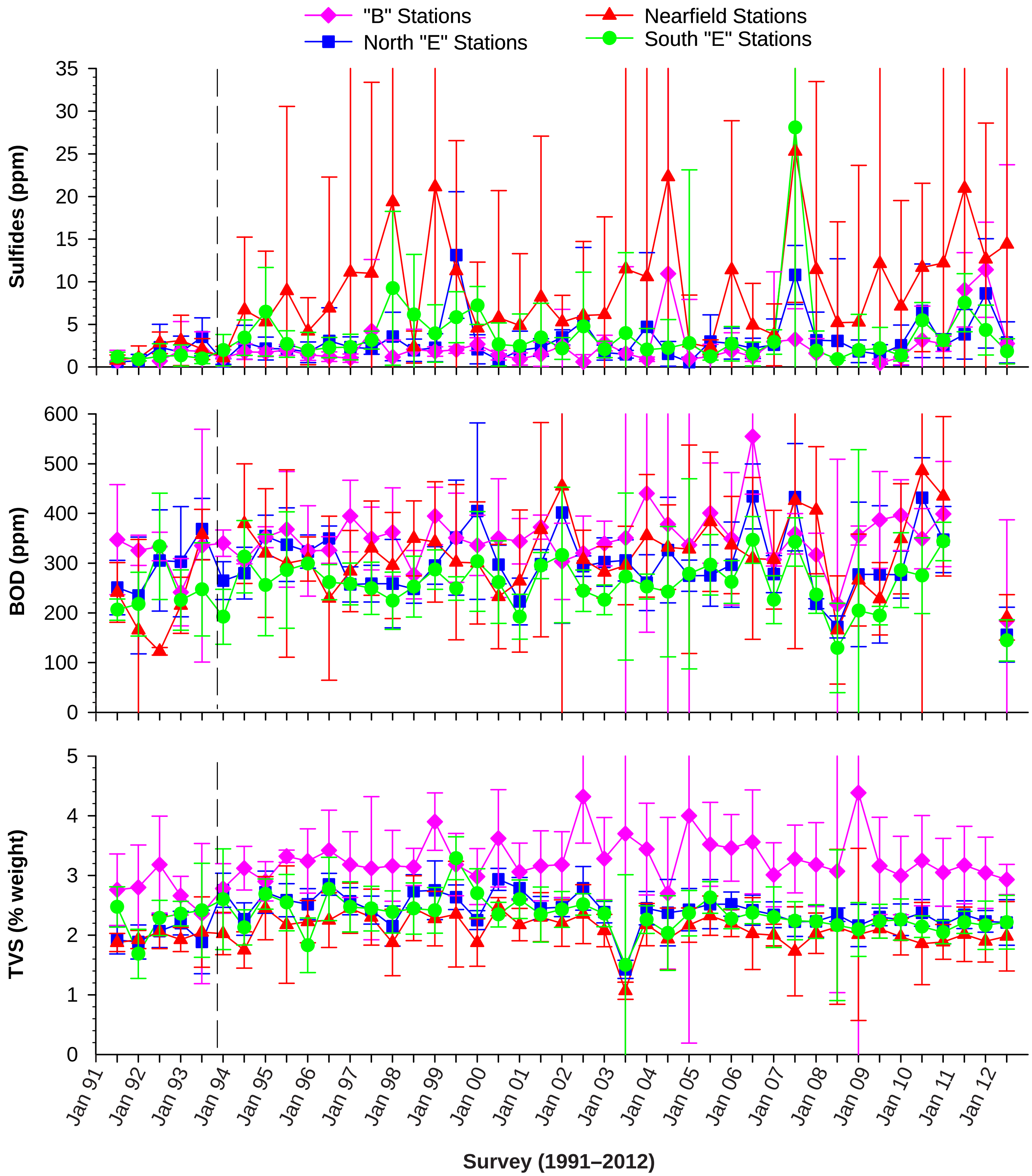



**Figure 4.4** *continued*

(City of San Diego 2007–2012), with percent fines (silt and clay) and fine sands composing the largest proportion of all samples. There was no evident spatial relationship between sediment composition and proximity to the outfall discharge site, nor has there been any substantial increase in percent fines at nearfield stations or throughout the region since wastewater discharge began. Overall, variability in 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

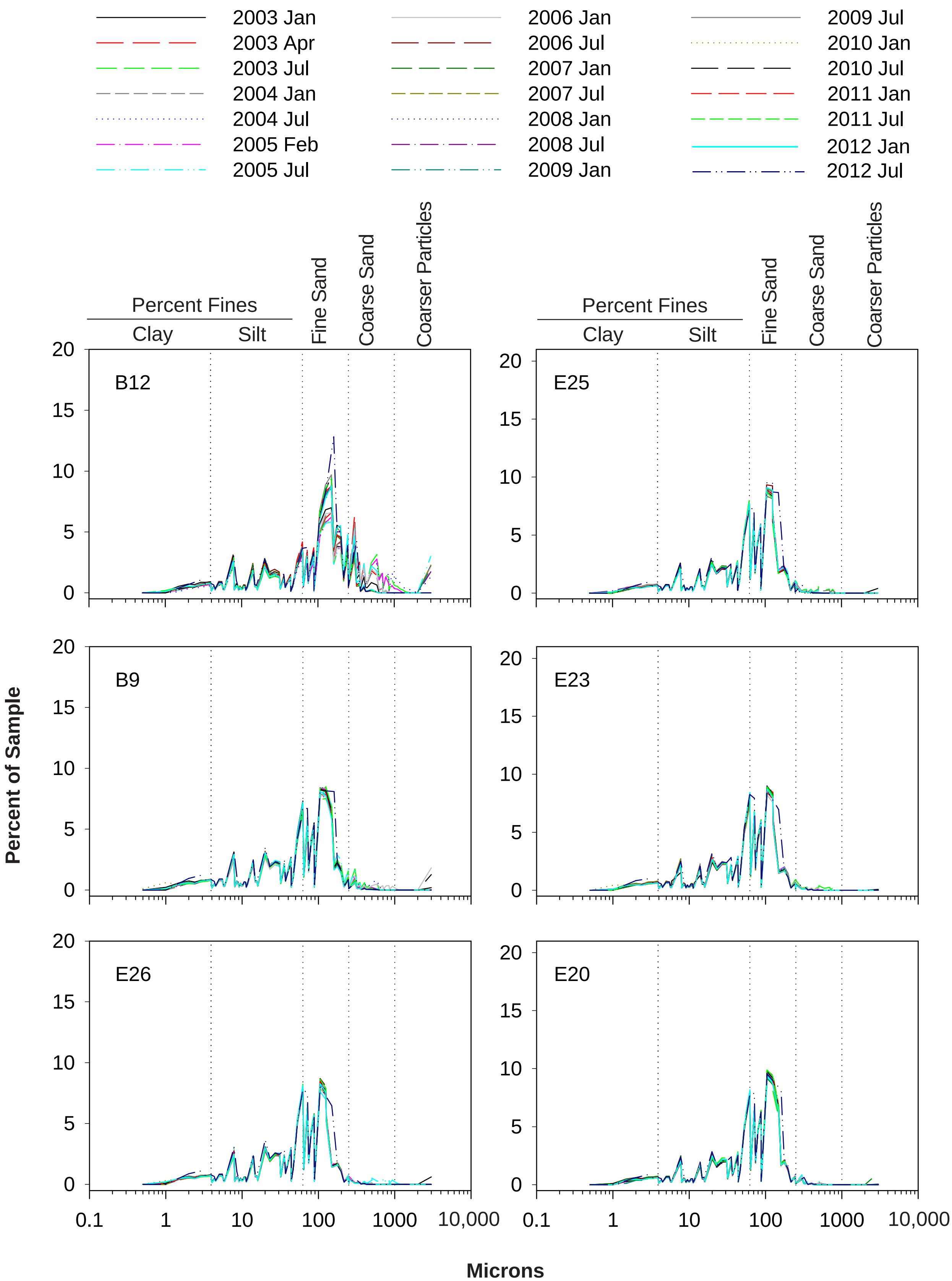



**Figure 4.5**
Plots illustrating historical particle size distributions in sediments from PLOO primary core stations sampled between 2003 and 2012.

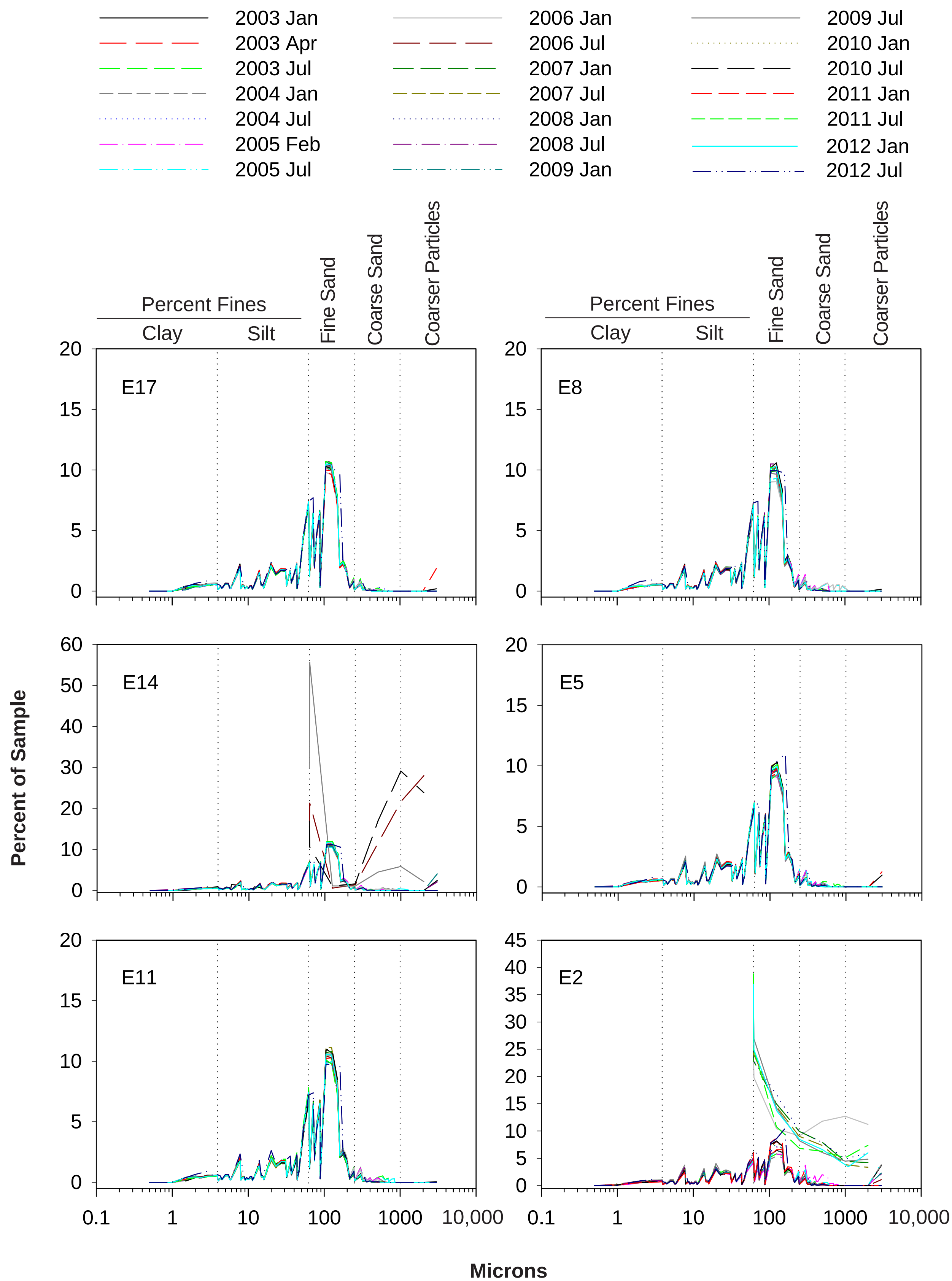



**Figure 4.5** *continued*

geologic origins of different sediment types, and recent deposition of sediment and detrital materials (Emery 1960, City of San Diego 2007, Parnell et al. 2008). The Point Loma outfall lies within the Mission Bay littoral cell (Patsch and Griggs 2007), with natural sources of sediments including outflows from Mission Bay, the San Diego River, and San Diego Bay. However, fine particles may also travel in suspension across littoral cell borders up and down the coast (e.g., Farnsworth and Warrick 2007, Svejkovsky 2013), thus widening the range of potential sediment sources to the region.

Various trace metals, pesticides, PCBs, and organic loading indicators were detected in sediment samples collected throughout the PLOO region in 2012, with highly variable concentrations. Although some contaminants were detected at levels above pre-discharge maxima, 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, 2013b, 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 2012. The only exceptions were slightly higher sulfide and BOD levels near the outfall as described in previous years (City of San Diego 2007–2012). 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 2007–2012). This pattern may be due in part to short dumps of dredged materials destined originally for the LA-5 dumpsite (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) determined that there may be no coastal areas in southern California that are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent surveys of SCB continental shelf habitats (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011). The lack of contaminant-free reference areas clearly pertains to the Point Loma outfall region as demonstrated by the presence of many contaminants in sediments prior to wastewater discharge (see City of San Diego 2007). Further, historical assessments of sediments off of Los Angeles have shown that as wastewater treatment has improved, sediment conditions are more likely affected by other factors (Stein and Cadien 2009). Such factors may include re-exposure of buried legacy sediments due to bioturbation activities (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 (Parnell et al. 2008).

Overall, there is little evidence of contaminant loading or organic enrichment in sediments throughout the PLOO region after 19 years of wastewater discharge. For example, concentrations of most indicators continue to occur at low levels below available thresholds and within the range of variability typical for the San Diego region (e.g., see City of San Diego 2007, City of San Diego 2012). The only sustained effects have been restricted to a few sites located within about 300 m of the outfall (i.e., nearfield stations E11, E14 and E17). These effects include measurable increases in sulfide and BOD concentrations (City of San Diego 2007). However, there is no evidence to suggest that wastewater discharge is affecting the quality of benthic sediments in the region to the point that it will degrade the resident marine biota (e.g., see Chapters 5 and 6).

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# Chapter 5
# Macrobenthic Communities

# Chapter 5. Macrobenthic Communities

## Introduction

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

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

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

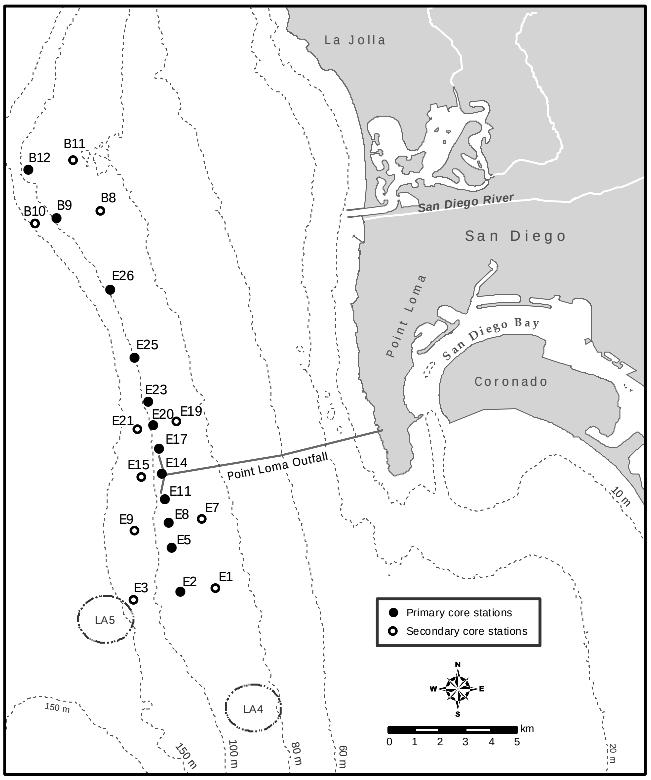



**Figure 5.1**
Benthic station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

This chapter presents analyses and interpretations of macrofaunal data collected at designated benthic monitoring stations surrounding the PLOO during 2012, and includes descriptions and comparisons of the different invertebrate communities in the region. The primary goals are to: (1) document the benthic assemblages present during the year, (2) determine the presence or absence of biological impacts associated with wastewater discharge, and (3) identify other potential natural and anthropogenic sources of variability in the local marine ecosystem.

## Materials and Methods

### Collection and Processing of Samples

Benthic samples were collected at 12 primary core stations in the PLOO region during January and July 2012 (Figure 5.1). An additional 10 secondary core stations were sampled during the winter survey, but were not included in the summer survey in order to accommodate sampling for a sediment mapping project (see Chapter 1). All stations are distributed along or adjacent to three main depth contours, with the primary core stations located along the 98-m contour (i.e., outfall discharge depth), and secondary core stations located along the 88- and 116-m contours. The sample sites include 17 'E' stations ranging from ~5 km south to ~8 km north of the outfall, and five 'B' stations located ~10–12 km north of the tip of the northern diffuser leg (see Chapter 1). The four stations considered to represent "nearfield" conditions (i.e., E11, E14, E15 and E17) are located within 1000 m of the outfall wye or diffuser legs.

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

### Data Analyses

Each grab sample was considered an independent replicate for analysis. The following community structure parameters were calculated for each station per 0.1-$m^2$ grab: species richness (number of species), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (see Swartz et al. 1986, Ferraro et al. 1994) and benthic response index (BRI; see Smith et al. 2001). Additionally, the total (cumulative) number of species identified from all grabs at each station during the year was calculated. Comparisons to tolerance intervals were based on data from the randomized regional stations sampled between 1994 and 2003 (City of San Diego 2007).

To further examine spatial patterns among benthic communities in the PLOO region, multivariate analyses were conducted on macrofaunal grabs that had a corresponding sediment sample using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). Only data from the primary core stations were included since no secondary core stations were sampled during the July survey. These analyses included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). The Bray-Curtis measure of similarity was used as the basis for the cluster analysis, and abundance data were square-root transformed to lessen the influence of the most abundant species and increase the importance of rare species. Major ecologically-relevant clusters supported by SIMPROF were retained, and similarity percentages analysis (SIMPER) was used to determine which organisms were responsible for the greatest contributions to within-group similarity (i.e., characteristic species) and between-group dissimilarity for retained clusters. To determine whether macrofaunal communities varied by sediment particle size fractions or other factors (e.g., increased organics), a RELATE test was used to compare patterns of rank abundance in the macrofauna Bray-Curtis similarity matrix with rank abundance in the sediment Euclidean distance matrix (see Chapter 4). When significant similarity was found, a BEST test using the BIO-ENV amalgamate was conducted to determine which subset of sediment subfractions was the best explanatory variable for similarity between the two resemblance matrices.

A Before-After-Control-Impact-Paired (BACIP) statistical model was used to test the null hypothesis that there have been no changes in community parameters due to operation of the PLOO (Bernstein and Zalinski 1983, Stewart-Oaten et al. 1986, 1992, Osenberg et al. 1994). The BACIP model compares differences between control (reference) and impact stations at times before (July 1991–October 1993) and after (January 1994–July 2012) an impact event, which would be the onset of wastewater discharge in this case. The analyses presented in this report are based on 2.5 years (10 quarterly surveys) of before-impact data and 19 years (57 quarterly or semi-annual surveys) of after-impact data. The 'E' stations, located ~0.1–8 km from the outfall, are considered most likely to be affected by wastewater discharge (Smith and Riege 1994), whereas the 'B' stations located >10 km north of the outfall were originally designed to be control sites. However, benthic communities differed between the 'B' and 'E' stations prior to discharge (Smith and Riege 1994, City of San Diego 1995). Station E14 was selected as the impact site for all analyses due to its proximity to the boundary of the Zone of Initial Dilution (ZID) making it most susceptible to impact. Stations E26 and B9 were selected to represent separate control sites in the BACIP tests. Station E26 is located 8 km north of the outfall and is considered the 'E' station least likely to be impacted, and previous analyses have suggested that station B9 was the most appropriate 'B' station for comparison with the 'E' stations (Smith and Riege 1994, City of San Diego 1995). Six dependent variables were analyzed, including number of species (species richness), macrofaunal abundance, the benthic response index (BRI), and abundances of three taxa considered sensitive to organic enrichment. These indicator taxa include ophiuroids in the genus *Amphiodia* (mostly *A. urtica*), and amphipods in the genera *Ampelisca* and *Rhepoxynius*. All BACIP analyses were interpreted using one-tailed paired t-tests with a type I error rate of $\alpha = 0.05$.

## Table 5.1

Summary of macrofaunal community parameters for PLOO benthic stations sampled during 2012. Tot Spp=cumulative no. of taxa for the year; SR=species richness (no. taxa/0.1 $m^2$); Abun=abundance (no. individuals/0.1 $m^2$); H'=Shannon diversity index; J'=evenness; Dom=Swartz dominance; BRI=benthic response index. Data for each station are expressed as annual means (n=4 grabs for 98-m stations, n=2 for 88-m and 116-m stations) 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 | 170 | 121 | 337 | 4.4 | 0.91 | 50 | 16 |
| | B8 | 127 | 94 | 309 | 3.9 | 0.86 | 36 | 9 |
| | E19 | 119 | 84 | 252 | 4.0 | 0.90 | 32 | 11 |
| | E7 | 121 | 88 | 322 | 3.9 | 0.88 | 32 | 14 |
| | E1 | 147 | 104 | 376 | 3.8 | 0.82 | 34 | 11 |
| *98-m Depth Contour* | B12 | 197 | 106 | 340 | 4.1 | 0.89 | 40 | 17 |
| | B9 | 183 | 93 | 296 | 4.0 | 0.89 | 36 | 10 |
| | E26 | 168 | 90 | 302 | 3.9 | 0.87 | 33 | 13 |
| | E25 | 176 | 94 | 356 | 3.9 | 0.87 | 32 | 12 |
| | E23 | 170 | 88 | 323 | 3.9 | 0.87 | 31 | 14 |
| | E20 | 156 | 90 | 377 | 3.9 | 0.87 | 30 | 13 |
| | E17[a] | 160 | 87 | 356 | 3.9 | 0.88 | 29 | 16 |
| | E14[a] | 192 | 98 | 408 | 3.8 | 0.83 | 28 | 25 |
| | E11[a] | 175 | 95 | 370 | 3.9 | 0.86 | 31 | 16 |
| | E8 | 168 | 88 | 298 | 3.9 | 0.88 | 31 | 14 |
| | E5 | 173 | 96 | 324 | 4.0 | 0.89 | 36 | 11 |
| | E2 | 212 | 107 | 346 | 4.2 | 0.90 | 42 | 14 |
| *116-m Depth Contour* | B10 | 181 | 128 | 382 | 4.3 | 0.89 | 50 | 15 |
| | E21 | 138 | 98 | 418 | 4.1 | 0.88 | 34 | 10 |
| | E15[a] | 163 | 120 | 391 | 4.3 | 0.91 | 46 | 10 |
| | E9 | 187 | 146 | 476 | 4.5 | 0.89 | 58 | 10 |
| | E3 | 140 | 96 | 286 | 4.1 | 0.91 | 41 | 11 |
| **All Grabs** | Mean | 165 | 98 | 345 | 4.0 | 0.88 | 36 | 14 |
| | 95% CI | 11 | 4 | 19 | $<0.1$ | 0.01 | 2 | 1 |
| | Min | 119 | 65 | 202 | 3.4 | 0.74 | 16 | 5 |
| | Max | 212 | 147 | 551 | 4.5 | 0.92 | 58 | 27 |

[a] nearfield station

## Results and Discussion

### Community Parameters

***Species richness***

A total of 518 taxa were identified during the 2012 PLOO surveys. Of these, 421 (81%) were identified to species, while the rest could only be identified to higher taxonomic levels. Most taxa occurred at multiple stations, although 27% (n=140) were recorded only once. Four species not previously reported by the City's Ocean Monitoring Program were encountered, including the nemertean *Amphiporus flavescens,* an unidentified nemertean in the family Valenciniidae, an unidentified lysianassoid amphipod in the genus *Aristias*, and the cnidarian *Edwardsia* sp SD1.

## Table 5.2

Results of BACIP t-tests for species richness (SR), infaunal abundance, BRI, and abundance of several representative taxa around the PLOO (1991–2012). Critical t-value = 1.680 for $\alpha = 0.05$ (one-tailed t-tests, df = 65); ns = not significant.

| Variable | Control vs. Impact | t | *p* |
|---|---|---|---|
| SR | E26 vs E14 | -3.16 | 0.001 |
| | B9 vs E14 | -3.33 | < 0.001 |
| Abundance | E26 vs E14 | -1.59 | ns |
| | B9 vs E14 | -2.74 | 0.004 |
| BRI | E26 vs E14 | -13.52 | < 0.001 |
| | B9 vs E14 | -9.82 | < 0.001 |
| *Ampelisca* spp | E26 vs E14 | -2.30 | 0.012 |
| | B9 vs E14 | -1.63 | ns |
| *Amphiodia* spp | E26 vs E14 | -6.49 | < 0.001 |
| | B9 vs E14 | -4.36 | < 0.001 |
| *Rhepoxynius* spp | E26 vs E14 | -0.53 | ns |
| | B9 vs E14 | -0.46 | ns |

Mean species richness ranged from 84 taxa per 0.1 $m^2$ grab at station E19 to 146 per grab at station E9 (Table 5.1). The lowest and highest species richness values occurred at farfield stations located 1.5 to 3.9 km from the outfall wye, with no clear patterns relative to distance from the discharge site, depth, or sediment characteristics observed. Species richness by grab was within or exceeded the historical range of 36–145 taxa reported from 1991 to 2011, while values for 98% of grabs were within the tolerance interval range of 72–175 taxa/grab calculated for the region (Appendix D.1) (City of San Diego 2007).

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

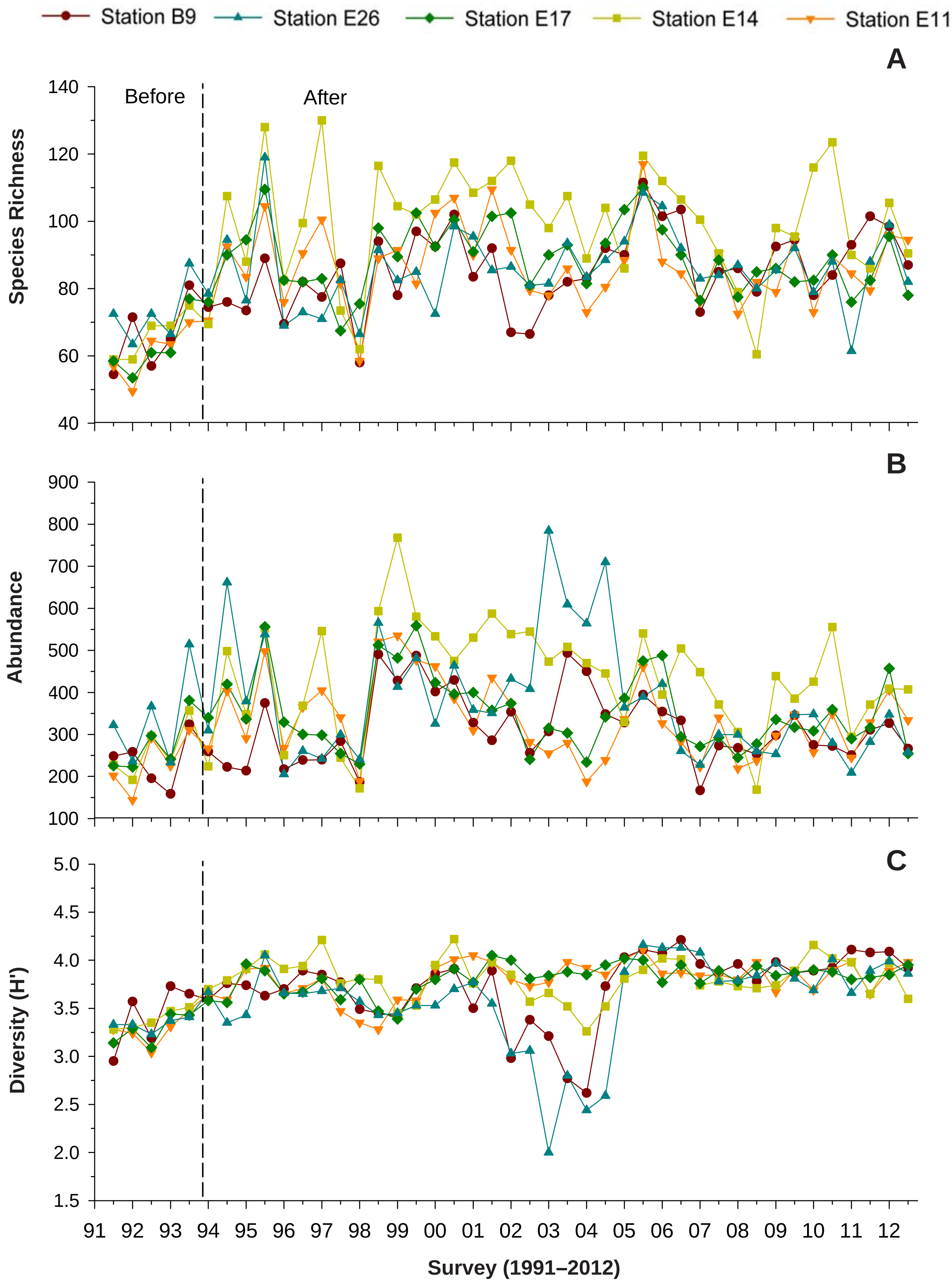
### *Macrofaunal abundance*

A total of 23,493 macrofaunal individuals were counted in 2012. Mean abundance per station ranged from 252 to 476 animals per grab (Table 5.1), with the lowest abundance occurring at station E19 and the highest at station E9, the same two farfield stations where mean species richness was also lowest and highest. No spatial patterns in overall abundance related to distance from the outfall or sediment characteristics were observed, although mean abundance by depth contour progressively increased from 319 animals per station at 88-m depths to 391 animals at 116-m depths. During the past year, macrofaunal abundance at all stations was within the historical range of 79–966 individuals per grab reported from 1991 to 2011 (Appendix D.1). Additionally, abundance values for 97% of grabs were within the tolerance interval range of 230–671 individuals per grab calculated for the region (City of San Diego 2007).

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

### *Species diversity, evenness, and dominance*

Mean Shannon diversity (H') and evenness (J') per station ranged from 3.8 to 4.5 and from 0.82 to 0.91 across the PLOO region in 2012, respectively, indicating that local benthic communities remain characterized by relatively diverse assemblages of evenly distributed species (Table 5.1). Equally low




## Figure 5.2

Comparison of community parameters at nearfield stations (E11, E14, E17) and farfield stations (E26, B9) between 1991 and 2012. Parameters include: (A) species richness; (B) infaunal abundance; (C) diversity (H'); (D) evenness (J'); (E) Swartz dominance; (F) benthic response index (BRI). Data for each station are expressed as means per 0.1 $m^2$ (n=2 per survey). Dashed lines indicate onset of wastewater discharge.

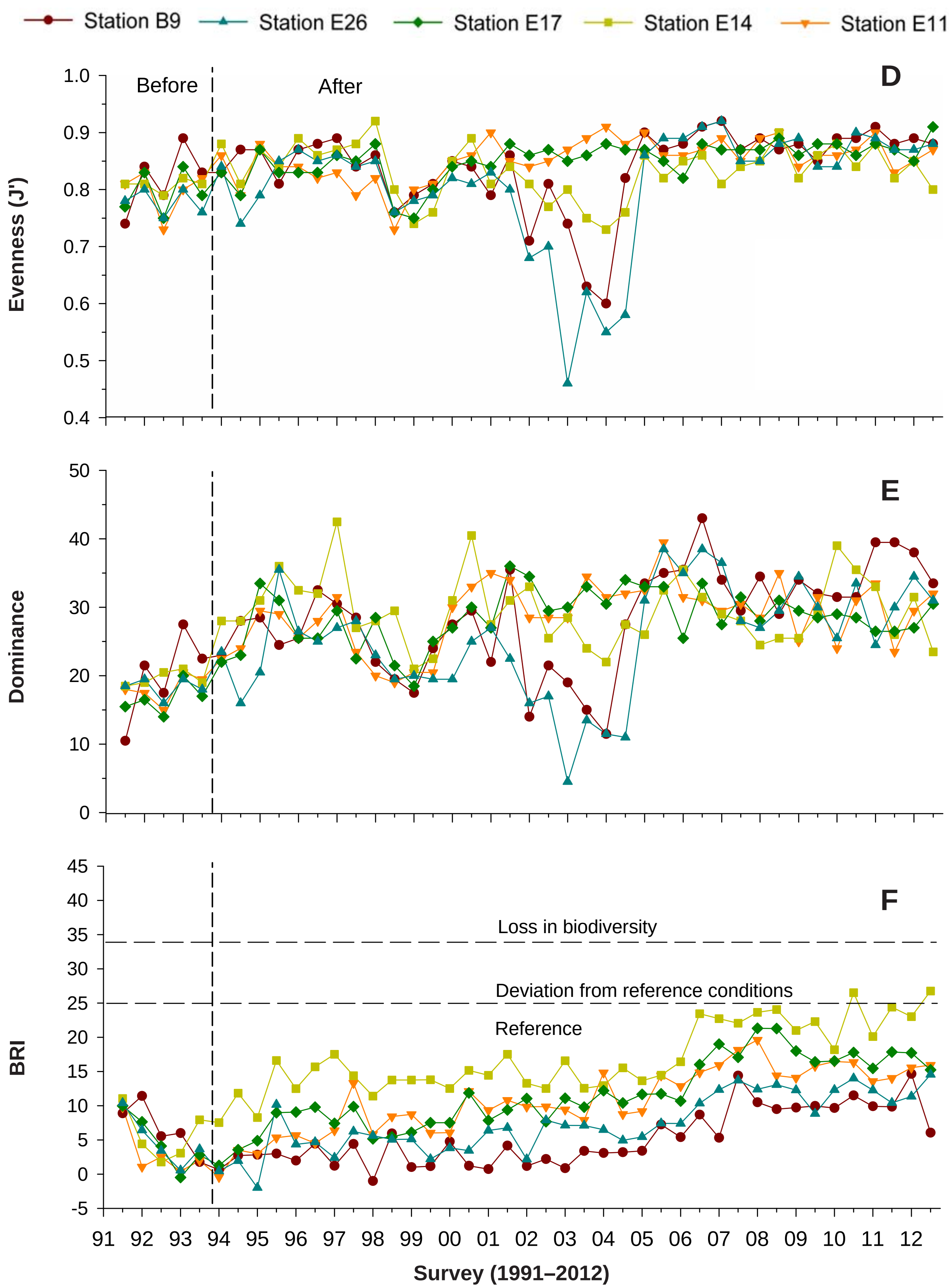



**Figure 5.2** *continued*

diversity occurred at nearfield station E14 located within 120 m of the outfall and farfield station E1, the station that also had lowest evenness. The highest diversity occurred at farfield station E9, whereas highest evenness co-occurred at farfield stations B1, E3 and E15. With the exception of low diversity at station E14, no other patterns relative to wastewater discharge or sediment characteristics were evident; however, mean evenness increased progressively from 0.87 at 88-m stations to 0.90 at 116-m stations. Except for low diversity and evenness associated with high densities of the ophiuroid *Amphiodia urtica* at stations B9 and E26 between 2002 and 2005 (Figures 5.2C, D, 5.3), both parameters recorded during 2012 were similar to historical values. Five grabs (7%) had diversity above the upper tolerance interval bound of 4.3 calculated for the region (Appendix D.1), one of which occurred along the 88-m contour and four of which occurred along the 116-m contour (City of San Diego 2007). In contrast, 74% of the samples (n = 50) had evenness above the upper tolerance interval bound of 0.86, and one grab was below the lower bound of 0.75.

Swartz dominance values averaged from 28 to 58 taxa per station with the lowest dominance (highest index value) occurring at farfield station E9 and the highest dominance (lowest index value) occurring at nearfield station E14 (Table 5.1). Except for the dominance of select species adjacent to the outfall at station E14 (see description of cluster group C under multivariate analyses, below), no other patterns relative to wastewater discharge, depth, or sediment characteristics were evident. Eleven values (16%) were above the tolerance interval range of 7–44 calculated for the region (City of San Diego 2007).

***Benthic response index***

The benthic response index (BRI) is an important tool for gauging possible anthropogenic impacts to marine environments throughout the SCB. Values below 25 are considered indicative of reference conditions, values 25–33 represent "a minor deviation from reference conditions," and values ≥ 34 represent increasing levels of degradation (Smith et al. 2001). All but one of the benthic stations sampled in 2012 had mean BRI values <25 (Table 5.1). Only nearfield station E14, located about 120 m west of the center of the wye, had a mean value that corresponded to a minor deviation from reference conditions (BRI = 25); this value represented the average of two winter samples with BRI values of 22 and 24 and two summer samples with BRI values of 27 each (Appendix D.1). The lowest mean value (BRI = 9) occurred at station B8 located about 10 km north of the PLOO. With the exception of E14, no patterns relative to the outfall, depth or sediments were observed. For example, the next highest average BRI values of 16−17 occurred at both nearfield (E11 and E17) and farfield (B11 and B12) stations along the 88-m or 98-m depth contours. About 71% of the samples collected in 2012 were within the tolerance intervals calculated for the PLOO region using 1994–2003 data (City of San Diego 2007).

BACIP t-test results indicated a net change in the mean difference of BRI values between impact site E14 and both control sites since the onset of wastewater discharge (Table 5.2). These changes are due to increased index values at station E14 since 1994 (Figure 5.2F). For instance, the relatively high BRI values at station E14 in 2012 (BRI = 22–27/grab) were due in part to low abundances of the ophiuroid *Amphiodia urtica* (Figure 5.3) and regionally high abundances of the polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa* (Figure 5.4). No clear pattern linking BRI to ambient concentrations of organic indicators was evident (Appendix D.2).

## Species of Interest

***Dominant taxa***

Although only a subset of species encountered in the PLOO region was present in each grab, annelids (mostly polychaetes) were usually dominant with mean percent composition and abundance values of 55% and 56%, respectively (Table 5.3). Arthropods (mostly crustaceans) followed with a mean percent composition of 26% and mean abundance of 25%. Molluscs, echinoderms, and other phyla (i.e., cnidarians, nemerteans, echiurans, nematodes, sipunculids, phoronids, chordates and platyhelminthes) each contributed to < 10% of total invertebrate composition, and ≤11% of total abundance. Overall, the percentage of taxa that occurred within each major taxonomic grouping and their relative abundances were similar to those observed in 2011 (City of San Diego 2012a).

The 10 most abundant species in 2012 included seven annelid polychaetes, two arthropods, and one echinoderm (Table 5.4). The numerically dominant polychaetes included the spionid *Prionospio* (*Prionospio*) *jubata*, the cirratulid *Chaetozone hartmanae*, the lumbrinerids *Lumbrineris cruzensis* and *Lumbrineris* sp Group I[1], the capitellid *Mediomastus* sp, the paraonid *Aricidea* (*Acmira*) *catherinae*, and the amphinomid *Chloeia pinnata*. The dominant crustaceans included the ostracods *Euphilomedes carcharodonta* and *E. producta*, while the ophiuroid *Amphiodia urtica* was the dominant echinoderm. *Amphioida urtica* was the most abundant species collected overall, accounting for ~6% of total invertebrate abundance in the PLOO region. This species occurred in 96% of grabs, with a mean abundance of ~20 individuals per grab. The most widely distributed species during the year was *Prionospio* (*P.*) *jubata*, which occurred in 100% of samples. With the exceptions of *Lumbrineris* sp Group I and *Mediomastus* sp, the most abundant species in 2012 were also among the most abundant collected in 2011 (City of San Diego 2012a). Although abundances of *P.* (*P.*) *jubata* were higher in 2012 compared to previous years (with the exception of 2005–2007), populations of the other most abundant species were within recent historical ranges (Figure 5.3).

Historically abundant species that did not occur in high densities during 2012 include the following four polychaetes: the oweniid *Myriochele striolata* that had a population spike between 2001 and 2005 (Appendix D.3); the terebellid *Phisidia sanctaemariae* that spiked between 1998 and 2000; the terebellid *Proclea* sp A that has exhibited variable population densities over time (Figure 5.4); the spionid *Spiophanes duplex* whose populations have decreased since monitoring began in 1991. Although remaining untested, it is hypothesized that population fluctuations of these species may either follow cyclical "boom and bust" patterns that take years or decades to complete, or be linked to undetermined natural environmental parameters such as ocean warming and cooling cycles (e.g., *P. sanctaemariae* and *S. duplex* populations possibly influenced by the strong El Niño in 1998; see Chapter 2).

***Indicator species***

Species known to be indicators of environmental change that occur in the PLOO region include the polychaetes *Capitella teleta* and *Proclea* sp A, amphipods in the genera *Ampelisca* and *Rhepoxynius*, the bivalve *Solemya pervernicosa*, and the ophiuroid *Amphiodia urtica*. Increased abundances of *C. teleta* and *S. pervernicosa* often indicate organic enrichment, whereas decreases in numbers of pollution-sensitive species and genera such as *Proclea* sp A, *A. urtica*, *Ampelisca*, and *Rhepoxynius* may indicate habitats impacted by human activity (Barnard and Ziesenhenne 1961, Anderson et al. 1998, Linton and Taghon 2000, Smith et al. 2001, Kennedy et al. 2009, McLeod and Wing 2009).

In 2012, indicator species with similar abundances at nearfield and farfield stations included *Proclea* sp A, *Ampelisca* spp and *Rhepoxynius* spp (Figure 5.4). Historical abundances of these three species follow similar patterns, and suggest limited impact of wastewater discharge to the region. The results of BACIP t-tests support the premise that no net change has occurred since the onset of wastewater discharge in terms of: (1) the mean difference of *Rhepoxynius* spp abundance between "impact" station E14 and "control" stations E26 and B9, and (2) *Ampelisca* spp abundance between stations E14 and B9 (Table 5.2). However, BACIP results indicate a net change has occurred in *Ampelisca* spp abundance between stations E14 and E26. This change began around 2003, although the variable nature of *Ampelisca* populations among stations makes interpretation of the relatively small differences difficult.

Abundances of *Amphiodia urtica* were lower at nearfield stations than at farfield stations in 2012 (Figure 5.3), and are one of the factors driving the relatively higher BRI values for station E14 (Table 5.1, Appendix D.1). Historically, abundances of this species at nearfield stations E11 and E17 have

[1]*Lumbrineris* sp Group I likely represent unidentifiable specimens of *L. cruzensis* that are missing necessary diagnostic characters.

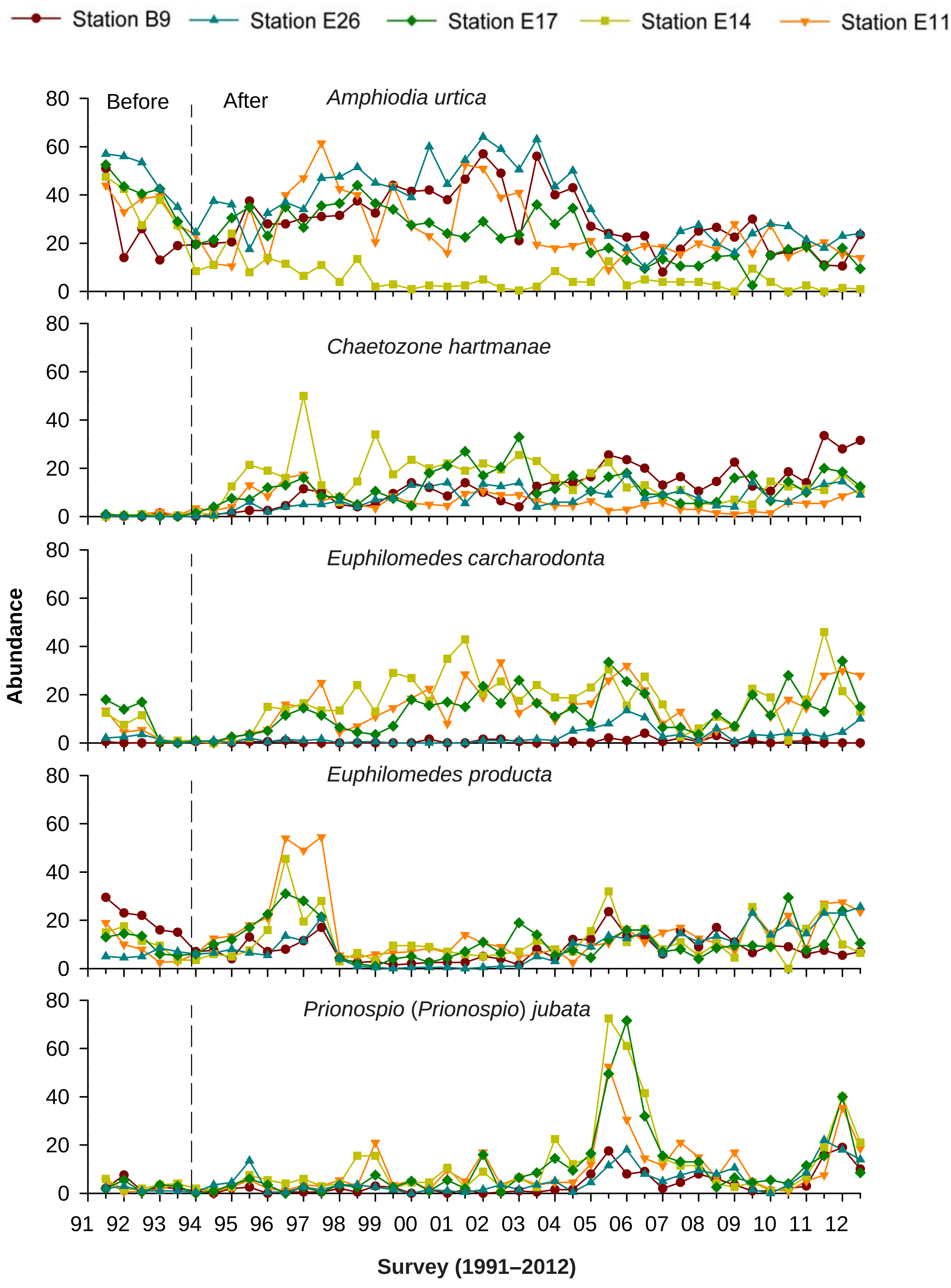



**Figure 5.3**
Historical abundances of the five most numerically dominant species recorded during 2012 at PLOO nearfield (E11, E14, E17) and farfield (E26, B9) stations. Data for each station are expressed as means per 0.1 $m^2$ (n = 2 per survey). Dashed lines indicate onset of wastewater discharge.

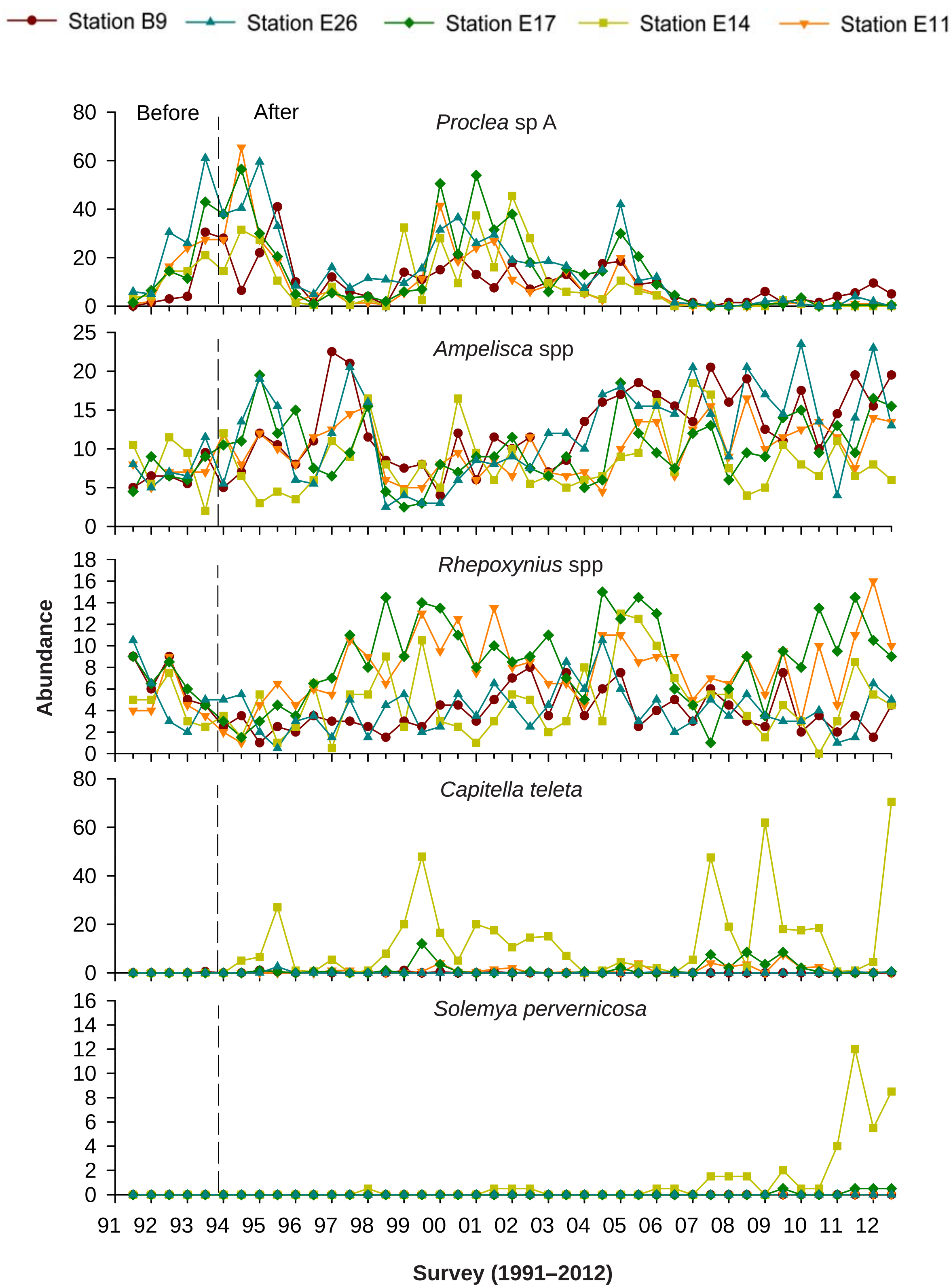



**Figure 5.4**
Historical abundances of ecologically important indicator species at PLOO nearfield (E11, E14, E17) and farfield (E26, B9) stations. Data for each station are expressed as means per 0.1 $m^2$ (n=2 per survey). Dashed lines indicate onset of wastewater discharge.

been similar to farfield stations. However, nearfield station E14 has experienced low abundances of *A. urtica* since 1996, possibly due to altered sediment composition (e.g., coarser sediments) or increased predation pressure near the outfall. Accordingly, BACIP t-test results show a net change in the mean difference of *Amphiodia* spp abundance between station E14 and both control sites since the onset of wastewater discharge (Table 5.2), which is due to both a decrease in the number of *Amphiodia* at E14 and a general increase in abundances at the control stations that occurred until about 2006. In 2012, *A. urtica* densities at station E14 were similar to those reported since about 1999. Overall, the abundance of *A. urtica* has decreased across the entire PLOO region since 2004, but remains within the range of natural variation for SCB populations (Thompson et al. 1993a).

**Table 5.3**
Percent composition and abundance of major taxonomic groups (phyla) in PLOO benthic grabs sampled during 2012. Data are expressed as annual means (range) of all grabs combined; n = 68.

| Phyla | Species (%) | Abundance (%) |
|---|---|---|
| Annelida (Polychaeta) | 55 (45–64) | 56 (37–73) |
| Arthropoda (Crustacea) | 26 (17–33) | 25 (11–39) |
| Mollusca | 9 (3–24) | 6 (2–21) |
| Echinodermata | 6 (1–11) | 11 (< 1–35) |
| Other Phyla | 5 (0–8) | 2 (0–6) |

Opportunistic species such as *Capitella teleta* (previously considered within the *Capitella capitata* species complex) and *Solemya pervernicosa* increase in abundance in areas having high organic content (Linton and Taghon 2000, McLeod and Wing 2009). In 2012, both species had higher abundances at nearfield station E14 than at other sites (Figure 5.4). Specifically, 97% of the 154 individuals of *C. teleta* documented for the entire PLOO region occurred at this single station, with the highest abundance being 120 individuals in one 0.1-m$^2$ grab. However, even at station E14, abundance of this species is considered low and characteristic of relatively undisturbed habitats. For example, *C. teleta* commonly reaches densities as high as 500 individuals per 0.1-m$^2$ grab in polluted sediments (Reish 1957, Swartz et al. 1986). Although populations of this species have fluctuated off Point Loma, the highest annual total of *C. teleta* ever observed across the region occurred in 2009 when 206 individuals were recorded, 97% of which occurred at nearfield stations E11, E14 and E17 (City of San Diego 2010).

## Classification of Macrobenthic Assemblages

***Similarity of Assemblages***

Classification (cluster) analysis was used to discriminate between macrofaunal assemblages from 24 individual grab samples collected at the 12 primary core stations in 2012, resulting in five ecologically-relevant SIMPROF-supported groups (Figure 5.5, Appendix D.4). These assemblages (referred to herein as cluster groups A–E) represented between 1 and 16 grabs each, and exhibited mean species richness ranging from 90 to 114 taxa per grab and mean abundances of 277 to 368 individuals per grab. Groups were primarily distinguished by sediment characteristics and proximity to the outfall as described below.

Cluster group A represented the macrofaunal assemblages at station B12, the northernmost of the primary core stations (Figure 5.5). Mean species richness and abundance values of 114 taxa and 368 individuals per grab, respectively, were the highest recorded for any cluster group. The five most abundant taxa included the polychaetes *Prionospio* (*Prionospio*) *jubata*, *Chloeia pinnata*, *Chaetozone* sp and *Aphelochaeta* sp LA1, and the bivalve *Tellina carpenteri*, all of which had mean abundances ranging from 13 to 27 individuals (Appendix D.4). Taxa contributing to ≥25% of within group similarity included *T. carpenteri*, the polychaetes *P.* (*P.*) *jubata*, *C. pinnata*, *Chaetozone* sp, *Aphelochaeta* sp LA1 and *Aphelochaeta glandaria* Cmplx, the ophiuroid *Amphiodia digitata*, and the ostracods *Euphilomedes producta* and

## Table 5.4

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

| Species | Taxonomic Classification | Abundance per Sample | Percent Occurrence |
|---|---|---|---|
| *Amphiodia urtica* | Echinodermata: Ophiuroidea | 19.9 | 96 |
| *Prionospio* (*Prionospio*) *jubata* | Polychaeta: Spionidae | 18.4 | 100 |
| *Euphilomedes carcharodonta* | Arthropoda: Ostracoda | 12.6 | 90 |
| *Euphilomedes producta* | Arthropoda: Ostracoda | 12.3 | 93 |
| *Chaetozone hartmanae* | Polychaeta: Cirratulidae | 12.2 | 96 |
| *Lumbrineris* sp Group I | Polychaeta: Lumbrineridae | 10.6 | 78 |
| *Mediomastus* sp | Polychaeta: Capitellidae | 9.8 | 96 |
| *Aricidea* (*Acmira*) *catherinae* | Polychaeta: Paraonidae | 8.2 | 88 |
| *Chloeia pinnata* | Polychaeta: Amphinomidae | 7.3 | 87 |
| *Lumbrineris cruzensis* | Polychaeta: Lumbrineridae | 7.2 | 90 |

*E. carcharodonta*. Compared to most other cluster groups, assemblages from group A had non-existent or low abundances of the ophiuroid *Amphiodia urtica* and the amphipod *Rhepoxynius bicuspidatus*, as well as high abundances of *T. carpenteri* and the tanaid *Leptochelia dubia* Cmplx (Figure 5.6). Sediments from the grabs at station B12 were coarser than those found in at stations composing the other cluster groups, with 6–8% coarse sand and only 34–37% fines. Gravel and shell hash were noted in the visual observations of the grunge remaining after all species were removed from the grab samples (Appendix C.4).

Cluster group B represented the assemblage present in a single January grab collected at station E2, the southernmost primary core station (Figure 5.5). This assemblage was characterized by the second highest species richness observed (108 taxa/grab), but lowest abundance of all cluster groups with only 277 individuals. The five most abundant taxa in group B were the polychaetes *Prionospio* (*Prionospio*) *jubata*, *Aricidea* (*Acmira*) *catherinae*, *Lumbrineris* sp Group I, *Prionospio* (*Prionospio*) *dubia* and *Glycera nana*, all of which had abundances ranging from 9 to 18 individuals per grab (Appendix D.4). Compared to most other cluster groups, this assemblage had non-existent or low abundances of the ostracod *Euphilomedes carcharodonta*, the capitellid polychaete *Notomastus* sp A, and the amphipod *Rhepoxynius bicuspidatus* (Figure 5.6). Sediments associated with this grab had the highest percentage of coarse sand recorded (15%) and a relatively low percentage of percent fines (37%). Similar to cluster group A, visual observations of grunge included gravel (Appendix C.4).

Cluster group C represented macrofaunal assemblages at nearfield station E14 located about 120 m of the outfall diffusers (Figure 5.5). Although these assemblages are the most likely to be impacted by wastewater discharge or other factors associated with the outfall structure, mean species richness and abundances were within the range of the other cluster groups at 95 taxa and 346 individuals per grab, respectively. However, mean abundances for key indicator species such as *Amphiodia urtica*, the ampeliscid amphipods *Ampelisca careyi* and *A. pugetica,* and the terebellid polychaete *Proclea* sp A, were lower than found in any other cluster group (Figure 5.6, Appendix D.4). The five most abundant species were the polychaetes *Prionospio* (*Prionospio*) *jubata*, *Lumbrineris* sp Group I, *Chaetozone hartmanae*, *Chloeia pinnata* and *Aricidea* (*Acmira*) *catherinae*, all of which had abundances ranging from 14 to 28 individuals per grab. Species contributing to ≥25% of within group similarity included six polychaetes (*Notomastus* sp A,

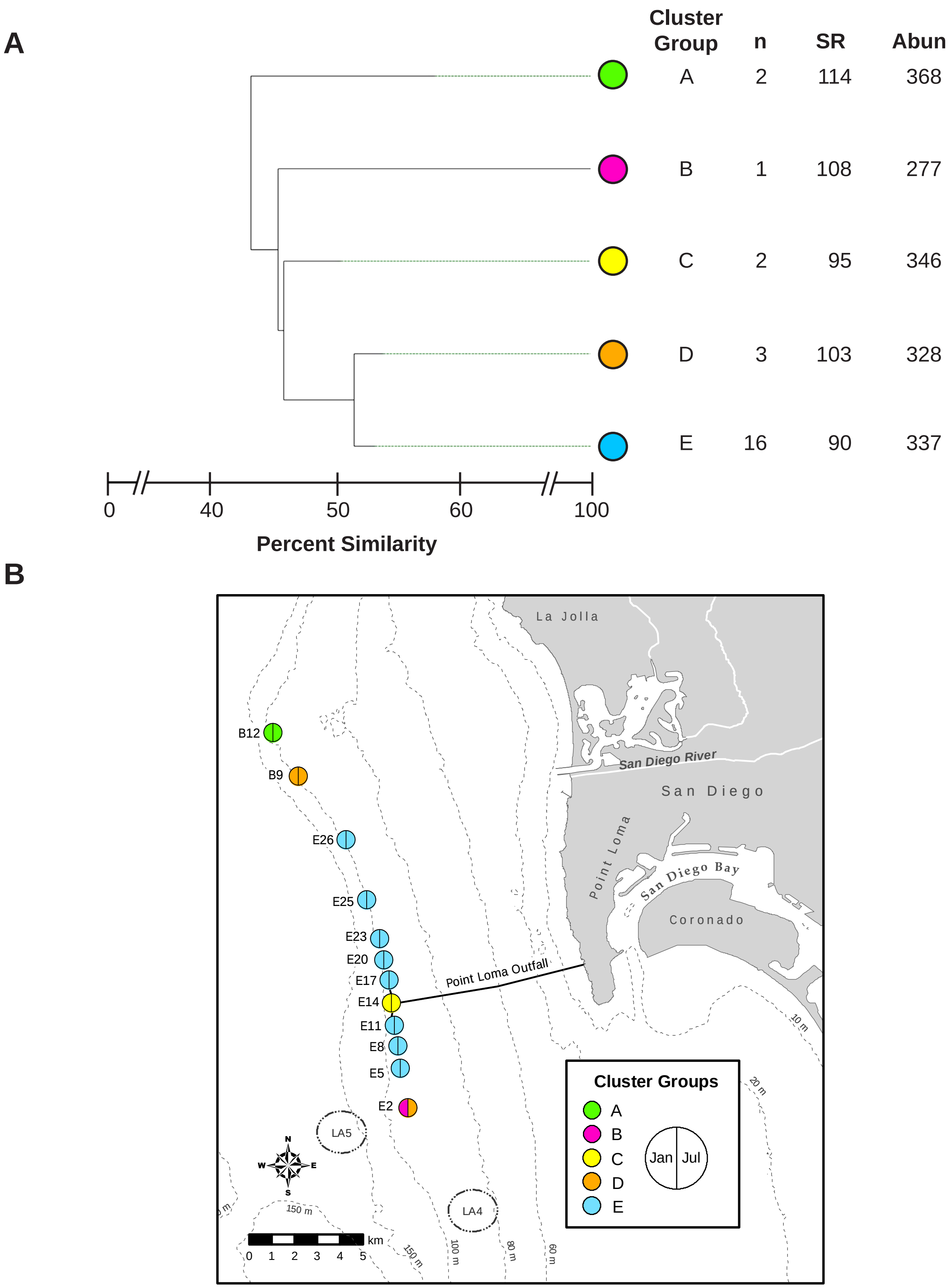



**Figure 5.5**

(A) Cluster analysis of macrofaunal assemblages at PLOO stations sampled during 2012. SIMPROF-supported clades were retained at <51.8% similarly. 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.

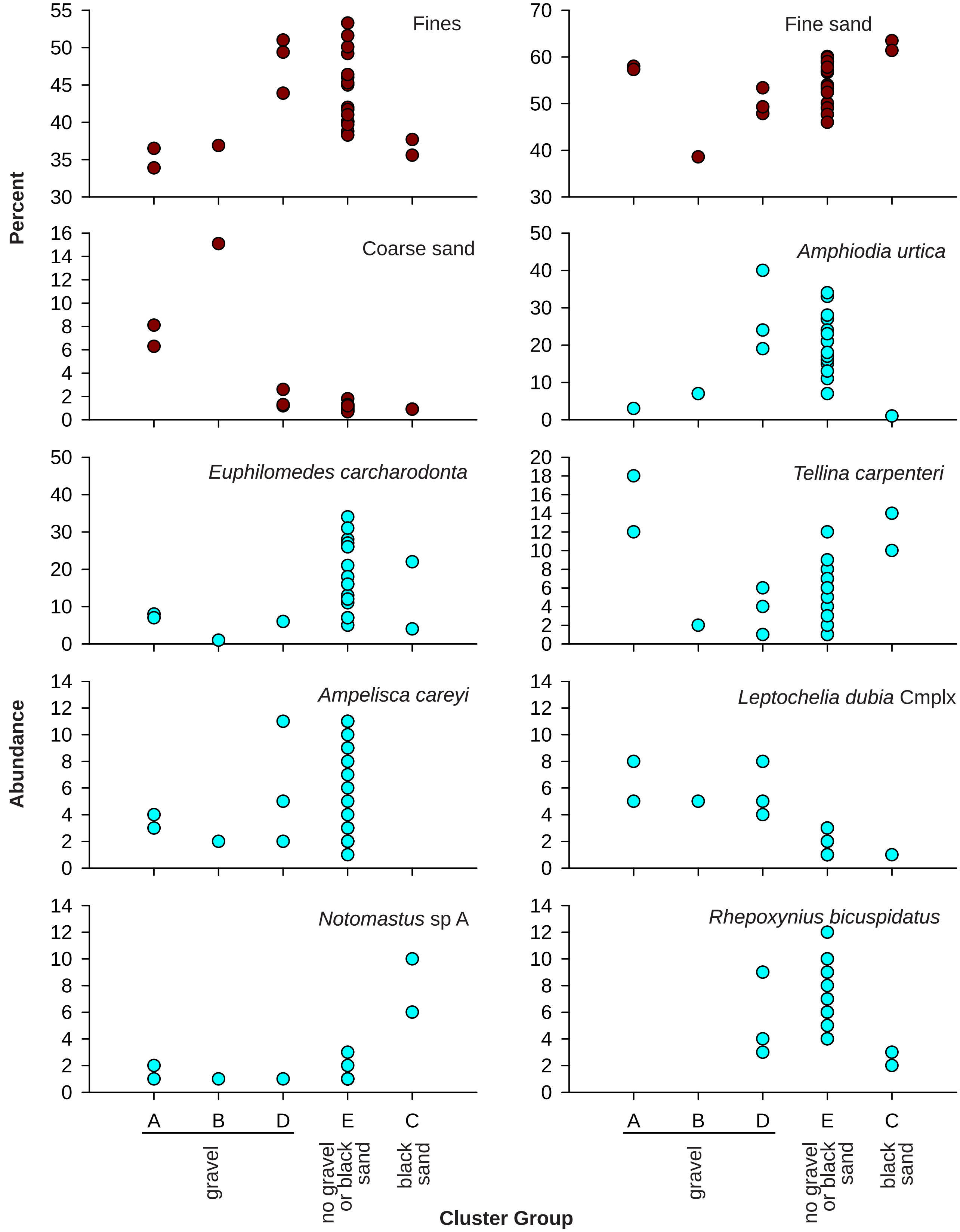
*Prionospio* (*Prionospio*) *jubata*, *Lumbrineris* sp Group I, *Chaetozone hartmanae*, and *Aricidea catherinae*) and the bivalve *Tellina carpenteri*. Percent fines ranged from 36 to 38%, with both grabs having the highest percentage of fine sand (61–64%) found at the primary core stations in 2012. Visual observations of the sample grunge included black sand and shell hash (Appendix C.4).

Cluster group D represented the macrofaunal assemblages at northern station B9 during both surveys, and from the July survey only at southern station E2 (Figure 5.5). This group had mean species richness and abundance values of 103 taxa and 328 individuals per grab. The five most abundant taxa were the ophiuroids *Amphiodia urtica* and *Amphiodia* sp, and the polychaetes *Chaetozone hartmanae*, *Prionospio* (*Prionospio*) *jubata* and *Proclea* sp A, all of which ranged in abundance from 7 to 28 individuals per grab (Appendix D.4). Species contributing to ≥25% of within group similarity included *A. urtica*, the polychaetes *Paraprionospio alata*, *Prionospio* (*P.*) *dubia, Prionospio* (*P.*) *jubata, Chaetozone hartmanae* and *Proclea* sp A, the ostracod *Euphilomedes producta*, the tanaid *Leptochelia dubia* Cmplx, and the amphipod *Eyakia robusta*. Compared to most other grabs, those in group D had high abundances of *Amphiodia urtica* and *Leptochelia dubia* Cmplx (Figure 5.6). Sediments were finer than at the cluster group A and B stations, with percent fines ranging from 49 to 51%, similar to background conditions for the majority of the PLOO region (see cluster group E, below). Visual observations of the sample grunge included gravel at station E2, and compacted mud "gravel" at station B9 (Appendix C.4).

Cluster group E represented the macrofaunal assemblages present at the remaining eight primary core stations sampled during the year (Figure 5.5). Although these assemblages had the lowest average species richness (90 taxa/grab), the mean abundance of 337 individuals per grab was within mid-range of the five cluster groups. The most abundant taxa characteristic of group E included the ophiuroid *Amphiodia urtica*, the ostracods *Euphilomedes producta* and *Euphilomedes carcharodonta*, and the polychaetes *Prionospio* (*P.*) *jubata* and *Chaetozone hartmanae* (Appendix D.4). Mean abundances of these species ranged from 12 to 21 individuals per grab. Species contributing to ≥25% of within group similarity included *A. urtica*, *E. producta*, *E. carcharodonta*, the amphipod *Rhepoxynius bicuspidatus*, and the polychaetes *P.* (*P.*) *jubata*, *C. hartmanae*, and *Lumbrineris* sp Group I. Characteristics of cluster group E are comparable to the clusters representing background conditions described over the past three years (City of San Diego 2010–2012a). Sediments at these stations were composed of 39–53% fines, along with shell hash recorded in most grabs (Appendix C.4). Unlike the other cluster groups, no gravel or coarse black sand was observed in the remaining grunge from these samples.

***Comparison of Macrobenthic and Sediment Assemblages***

Similar patterns of variation occurred in the benthic macrofaunal and sediment similarity/dissimilarity matrices (see Chapter 4) used to generate cluster dendrograms, confirming that macrofaunal assemblages in the PLOO region are highly correlated to sediment composition (RELATE $\rho = 0.643$, $p = 0.0001$). The sediment subfractions that were most highly correlated to macrofaunal communities included very fine sand, very coarse sand, and granules (BEST $\rho = 0.727$, $p = 0.001$) (Appendix C.2). However, because the coarsest sediments can only be quantified for stations measured by sieve analysis (i.e., station E2 in January; see Appendix C.4), very fine sand is the only explanatory variable that occurred across a spectrum of grabs. The macrofaunal and sediment dendrograms presented in this chapter (Figure 5.5) and Chapter 4 (Figure 4.4), respectively, both show the January grab from station E2 and the January/July grabs from station B12 forming distinct cluster groups (i.e., macrofauna cluster group B = sediment cluster group I; macrofauna cluster group A = sediment cluster group 2). This suggests that the macrofaunal assemblages found in these grabs probably form because of the sediment composition present in these locations. However, because macrofaunal cluster




## Figure 5.6

Sediment composition and abundances of select species that contributed to cluster group dissimilarities. Each data point represents a single grab. Grabs from cluster groups A, B, and D all contained gravel, grabs from cluster group C all contained coarse black sand. Grabs from cluster group E contained neither gravel or black sand. Sediments shown in dark red; abundances shown in blue.

groups C–E occur together within sediment cluster group 3, it is unlikely that differences in macrofaunal communities from these grabs are caused solely by differences in sediment subfractions. Additional factors influencing benthic assemblages in cluster groups C–E may include: (1) the presence or absence of extremely coarse sediments (e.g., gravel in grabs from stations B9 and E2, coarse black sand from station E14; Appendix C.4), (2) differences in concentrations of organic material, trace metals, or other pollutants (e.g., highest concentrations of sulfides and total volatile solids occurring at station E14, see Appendices C.5–C.7), (3) differences in oceanographic parameters, or (4) differences in biological factors (e.g., increased predation).

## Summary

Analysis of the 2012 macrofaunal data do not suggest that wastewater discharged through the PLOO has affected macrobenthic communities in the region other than a minor deviation from reference conditions that may be occurring at station E14 located nearest the discharge site. Benthic communities present across the Point Loma outfall region in 2012 were similar to those encountered during previous years, including the period before wastewater discharge (City of San Diego 1995, 2012a). These communities remain dominated by ophiuroid-polychaete based assemblages. As in past years, the brittle star *Amphiodia urtica* was the most abundant species off Point Loma, although its overall population abundances have decreased since monitoring began in 1991. The spionid polychaete *Prionospio* (*Prionospio*) *jubata* was the most widespread benthic invertebrate, which represents a resurgence of this species' prominence in the region. The overall abundance and dominance of most species typically were within historical ranges (see City of San Diego 1995, 1999, 2007, 2012a). As previously reported, most stations along the 98-m contour had sandy sediments with a high fraction of fines that supported similar types of benthic communities. Most of the variability in macrofaunal populations occurred at stations located several kilometers to the north and south of the outfall that had slightly higher fractions of coarse sediments. Put into a broader biogeographical context, most values for species richness, abundance, diversity, evenness and dominance off Point Loma were indicative of natural ranges reported for the San Diego region (see Chapter 9 in City of San Diego 2013) and the entire SCB (Barnard and Ziesenhenne 1961, Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993b, Zmarzly et al. 1994, Diener and Fuller 1995, Bergen et al. 1998, 2000, 2001, Ranasinghe et al. 2003, 2007, 2010).

Changes in populations of pollution-sensitive or pollution-tolerant species or other indicators of benthic condition provide little to no evidence of significant environmental degradation off Point Loma. For instance, the brittle star *Amphiodia urtica* is a well-known dominant of mid-shelf, mostly fine sediment habitats in the SCB that is sensitive to changes near wastewater outfalls. BACIP tests reveal that populations of *A. urtica* have decreased significantly near the discharge site (i.e., station E14) over the past 15 or more years; however, there has also been a concomitant decrease in this species region-wide. 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*, that can reach densities as high as 5000/$m^2$ in polluted sediments (e.g., Reish 1957, Swartz et al. 1986). Although 154 individuals were reported from the PLOO region during the year, the abundance of *C. teleta* remained low at the nearfield stations when compared to other SCB dischargers (e.g., LACSD 2012, OCSD 2012) and were characteristic of healthy habitats. 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 indicate a minor deviation from reference conditions at station E14, 95% of stations surveyed in 2012 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 95% of the sites surveyed in 2012 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 2013), although some minor changes in component species or community structure have appeared near the outfall. However, it is not currently possible to definitively determine whether these observed changes are due to habitat alteration related to organic enrichment, physical structure of the outfall, or a combination of factors. In addition, abundances of soft bottom marine invertebrates exhibit substantial natural spatial and temporal variability that may mask the effects of disturbance events (Morrisey et al. 1992a, 1992b, Otway 1995), and the effects associated with the discharge of advanced primary treated sewage may be difficult to detect in areas subjected to strong currents that facilitate rapid dispersion of the wastewater plume (Diener and Fuller 1995).

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# Chapter 6
# Demersal Fishes and Megabenthic Invertebrates

# Chapter 6. Demersal Fishes and Megabenthic Invertebrates

## Introduction

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

In healthy ecosystems, fish and invertebrate communities are known to be inherently variable and influenced by many natural factors. For example, prey availability, bottom topography, sediment composition, and changes in water temperatures associated with large scale oceanographic events such as El Niño can affect migration of adult fish or the recruitment of juveniles into an area (Cross et al. 1985, Helvey and Smith 1985, Karinen et al. 1985, Murawski 1993, Stein and Cadien 2009). Population fluctuations may also be associated with specific behavioral activities in many species (e.g., schooling fish, urchin aggregations). Therefore, an understanding of natural background conditions is necessary before determining whether observed differences or changes in community structure may be related to anthropogenic activities. Pre-discharge or regional monitoring efforts by the City and other researchers since 1994 provide baseline information on the variability of demersal fish and megabenthic communities in the San Diego region critical for such comparative analysis (e.g., Allen et al. 1998, 2002, 2007, 2011, City of San Diego 2000).

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

This chapter presents analyses and interpretations of demersal fish and megabenthic invertebrate data collected during 2012, as well as a long-term assessment of these communities from 1991 through 2012. The primary goals are to: (1) document assemblages present during the year, (2) determine the presence or absence of biological impacts associated with wastewater discharge, and (3) identify other potential natural and anthropogenic sources of variability to the local marine ecosystem.

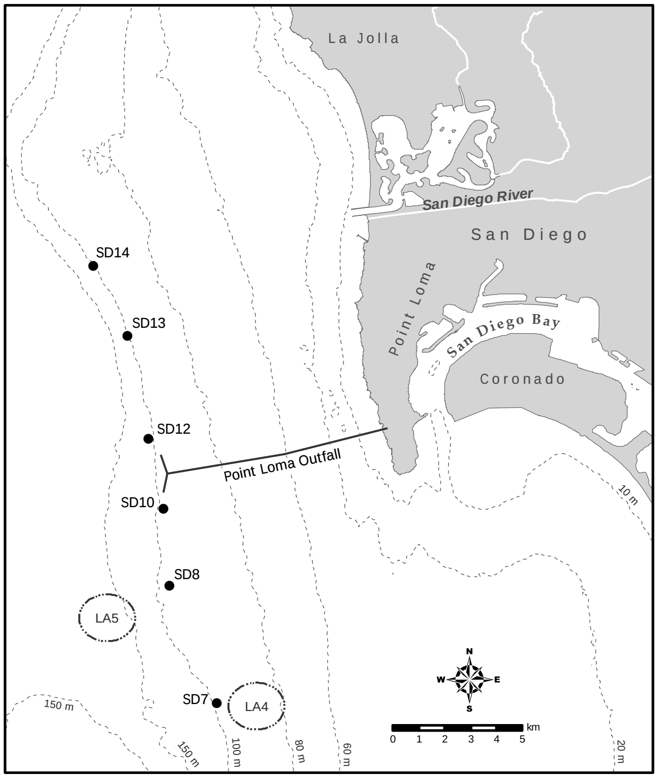



**Figure 6.1**
Otter trawl station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

## Materials and Methods

### Field Sampling

Trawl surveys were conducted at six monitoring stations in the PLOO region during January and July 2012 (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. Stations SD10 and SD12 are located within 1000 m of the outfall wye, and are considered to represent the "nearfield" station group. Stations SD7 and SD8 are located > 3.6 km south of the outfall and represent the "south farfield" station group, while SD13 and SD14 are located > 4.7 km north of the outfall and represent the "north farfield" station group.

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

### Data Analyses

Populations of each fish and invertebrate species were summarized as percent abundance (no. individuals per species/total abundance of all species), frequency of occurrence (percentage of stations at which a species was collected), mean abundance per haul (no. individuals per species/total number sites sampled), and mean abundance per occurrence (no. individuals per species/number of sites at which the species was collected). Additionally, the following community metrics were calculated per trawl for both fishes and invertebrates: species richness (no. of species), total abundance (no. of individuals), and Shannon diversity index (H'). Total biomass was also calculated for each fish species captured.

Multivariate analyses were performed in PRIMER using demersal fish and megabenthic invertebrate data collected from 1991 through 2012 (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). Prior to these analyses, the fish data were limited to summer surveys only to reduce statistical noise due to natural seasonal

## Table 6.1

Demersal fish species collected from 12 trawls conducted in the PLOO region during 2012. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

| Species | PA | FO | MAH | MAO | Species | PA | FO | MAH | MAO |
|---|---|---|---|---|---|---|---|---|---|
| Pacific sanddab | 44 | 100 | 158 | 158 | Hornyhead turbot | <1 | 50 | 1 | 2 |
| Longspine combfish | 21 | 100 | 76 | 76 | Greenspotted rockfish | <1 | 33 | 1 | 2 |
| California lizardfish | 8 | 100 | 28 | 28 | Greenstriped rockfish | <1 | 25 | 1 | 2 |
| Halfbanded rockfish | 7 | 92 | 26 | 28 | Blackbelly eelpout | <1 | 25 | <1 | 2 |
| Dover sole | 4 | 100 | 14 | 14 | Basketweave cusk-eel | <1 | 17 | <1 | 2 |
| Pink seaperch | 3 | 100 | 10 | 10 | Bigfin eelpout | <1 | 17 | <1 | 2 |
| Shortspine combfish | 3 | 100 | 10 | 10 | Blacktip poacher | <1 | 17 | <1 | 2 |
| English sole | 2 | 92 | 9 | 9 | Specklefin midshipman | <1 | 8 | <1 | 3 |
| Stripetail rockfish | 2 | 83 | 6 | 7 | Spotted cusk-eel | <1 | 8 | <1 | 3 |
| Yellowchin sculpin | 1 | 58 | 5 | 8 | Spotted ratfish | <1 | 8 | <1 | 3 |
| Plainfin midshipman | 1 | 75 | 4 | 5 | Bluespotted poacher | <1 | 17 | <1 | 1 |
| California tonguefish | 1 | 67 | 3 | 4 | Flag rockfish | <1 | 17 | <1 | 1 |
| Pacific argentine | 1 | 17 | 2 | 14 | Stripefin ronquil | <1 | 8 | <1 | 2 |
| Roughback sculpin | 1 | 25 | 2 | 9 | Curlfin sole | <1 | 8 | <1 | 1 |
| California scorpionfish | 1 | 33 | 2 | 6 | Fantail sole | <1 | 8 | <1 | 1 |
| Bigmouth sole | <1 | 58 | 2 | 3 | Pacific hagfish | <1 | 8 | <1 | 1 |
| Slender sole | <1 | 42 | 2 | 4 | Starry rockfish | <1 | 8 | <1 | 1 |
| California skate | <1 | 67 | 1 | 2 | Starry skate | <1 | 8 | <1 | 1 |

variation evident from previous studies (City of San Diego 1997). In contrast, for the invertebrate community analyses data collected during both the winter and summer surveys were used. Analyses included hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). The Bray-Curtis measure of similarity was used as the basis for the cluster analysis, and abundance data were square-root transformed to lessen the influence of the most abundant species and increase the importance of rare species. Major ecologically-relevant clusters supported by SIMPROF were retained, and similarity percentages analysis (SIMPER) was used to determine which organisms were responsible for the greatest contributions to within-group similarity (i.e., characteristic species). Additionally, a 2-way crossed analysis of similarity (ANOSIM) was conducted (maximum number of permutations = 9999) for each data set. Station group (i.e., nearfield, north farfield, south farfield) and year were provided as factors in both the fish and invertebrate community analyses. SIMPER analyses were subsequently used to identify which species were most characteristic for each factor level when significant differences were found.

# Results and Discussion

## Demersal Fishes

### *Community Parameters*

Thirty-six species of fish were collected in the area surrounding the PLOO in 2012 (Table 6.1, Appendix E.1). The total catch for the year was 4365 individuals (Appendix E.2), representing an average of ~364 fish per trawl. Of 17 families represented, six accounted for 95% of the total abundance (i.e., Embiotocidae, Hexagrammidae, Paralichthyidae, Pleuronectidae, Scorpaenidae, Synodontidae). As in previous years, Pacific sanddabs (Paralichthyidae) were dominant. This species occurred in every haul and accounted for 44% of all fishes collected at an average of 158 individuals per trawl. No other species contributed to more than 21% of the total catch during the year. For example, longspine combfish, California lizardfish, Dover sole, pink seaperch, and shortspine combfish also occurred in every trawl, but with fewer numbers (10–76 individuals per haul). Other species collected frequently in 50% or more of the trawls, but in relatively low numbers (≤26 fish/haul) included halfbanded rockfish, English sole, stripetail rockfish, yellowchin sculpin, plainfin midshipman, California tonguefish, bigmouth sole, California skate, and hornyhead turbot. No new species for the Point Loma outfall region were recorded during the year.

More than 99% of the fishes collected in 2012 were between 2 and 30 cm in length (Appendix E.1). Larger fishes included seven California skate (31–52 cm) and one spotted ratfish (44 cm). Median lengths per haul for the four most abundant species ranged from 5 to 14 cm for Pacific sanddab, 7 to 12 cm for longspine combfish, 12 to 18 cm for California lizardfish, and 9 to 11 cm for halfbanded rockfish (Figure 6.2). Seasonal and site differences were observed among lengths of these species during the past year. For example, Pacific sanddabs tended to be smaller at stations SD7, SD10 and SD12 (median lengths ≤7 cm per haul) than at stations SD8, SD13 and SD14 (median lengths ≥10 cm per haul) during the summer survey. These site differences were not as evident during the winter. Additionally, California lizardfish tended to be larger during the winter (median lengths >15 cm per haul) than in the summer (median lengths <13 cm per haul) across all stations.

Species richness for fishes ranged from 11 to 21 taxa per haul in 2012, and diversity (H') ranged from 1.2 to 2.0 (Table 6.2). Both species richness and diversity were consistently higher during the winter than in the summer. Total abundance ranged from 220 to 745 fishes per haul, with the three northernmost stations having lower abundances than the three southern stations. This variation in abundance was mostly due to differences in the numbers of Pacific sanddab, longspine combfish, California lizardfish, and halfbanded rockfish (Appendix E.2). Total fish biomass ranged from 5.9 to 18.0 kg per haul, with higher values coincident with either greater numbers of fishes or the presence of a few large individuals (Appendix E.3). For example, 146 Pacific sanddab, 284 longspine combfish, and 113 California lizardfish accounted for only 7.9 kg of the biomass recorded at station SD10, whereas only 18 California scorpionfish accounted for 7.2 kg of the biomass at station SD12 during the winter.

Large population fluctuations of a few dominant species have been the principal factor contributing to the high variation in fish community structure off Point Loma since 1991 (Figure 6.3, 6.4). Over the years, mean diversity and species richness have remained low (i.e., H' <1.9, SR <22 species per haul), while abundance has varied considerably (i.e., 97–1065 fishes per haul). Differences in overall fish abundance primarily track changes in Pacific sanddab populations, since this species has been numerically dominant in the PLOO region since sampling began (see following section and City of San Diego 2007b). In addition, occasional spikes in abundance have been due to large hauls of individual species such as yellowchin sculpin, halfbanded rockfish, and longspine combfish. Overall, none of the observed changes appear to be associated with wastewater discharge.

***Multivariate Analyses of Fish Assemblages***

Fish assemblages sampled from 1991 through 2012 (summer surveys only) differed significantly by both station group and year (Table 6.3). Individual pairwise comparisons by station group showed that south farfield stations were significantly different than nearfield and north farfield stations. Pairwise comparisons by year found that fish communities in 2012 were not significantly different from those in 2004, 2006, and 2009–2011, but did differ significantly from every other year (Appendix E 4). Population fluctuations of common species such as Pacific sanddab, Dover sole, halfbanded rockfish, and California lizardfish contributed substantially to these spatial and temporal differences (Figure 6.5).

Classification (cluster) analysis discriminated eight major types of fish assemblages in the Point Loma outfall region over the past 22 years (cluster groups A–H; Figure 6.6). The distribution

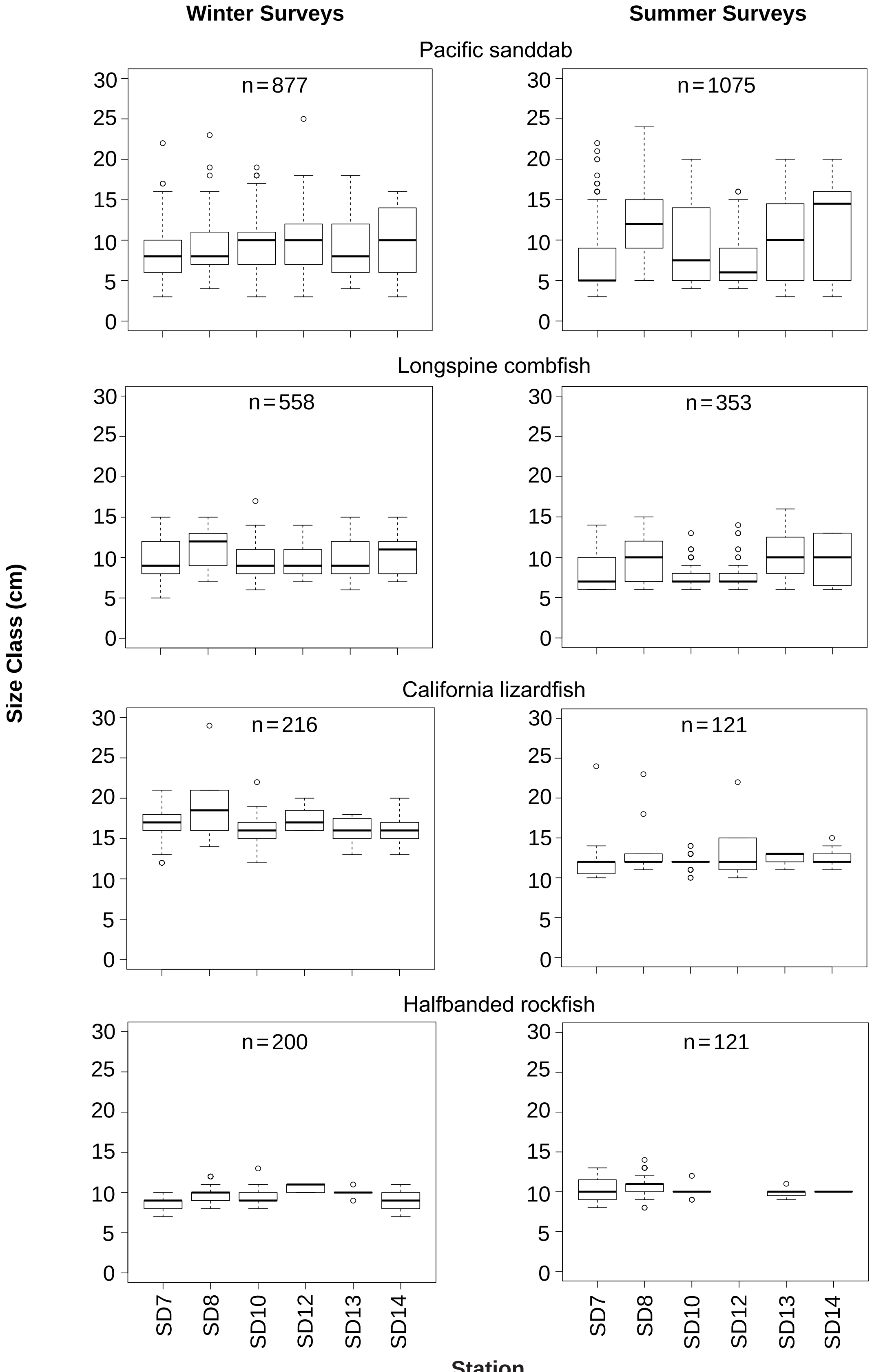



**Figure 6.2**
Summary of fish lengths by survey and station for each of the four most abundant species collected in the PLOO region during 2012. Data are median, upper and lower quartiles, 1.5 times the interquartile range (whiskers), and outliers (open circles).

**Table 6.2**

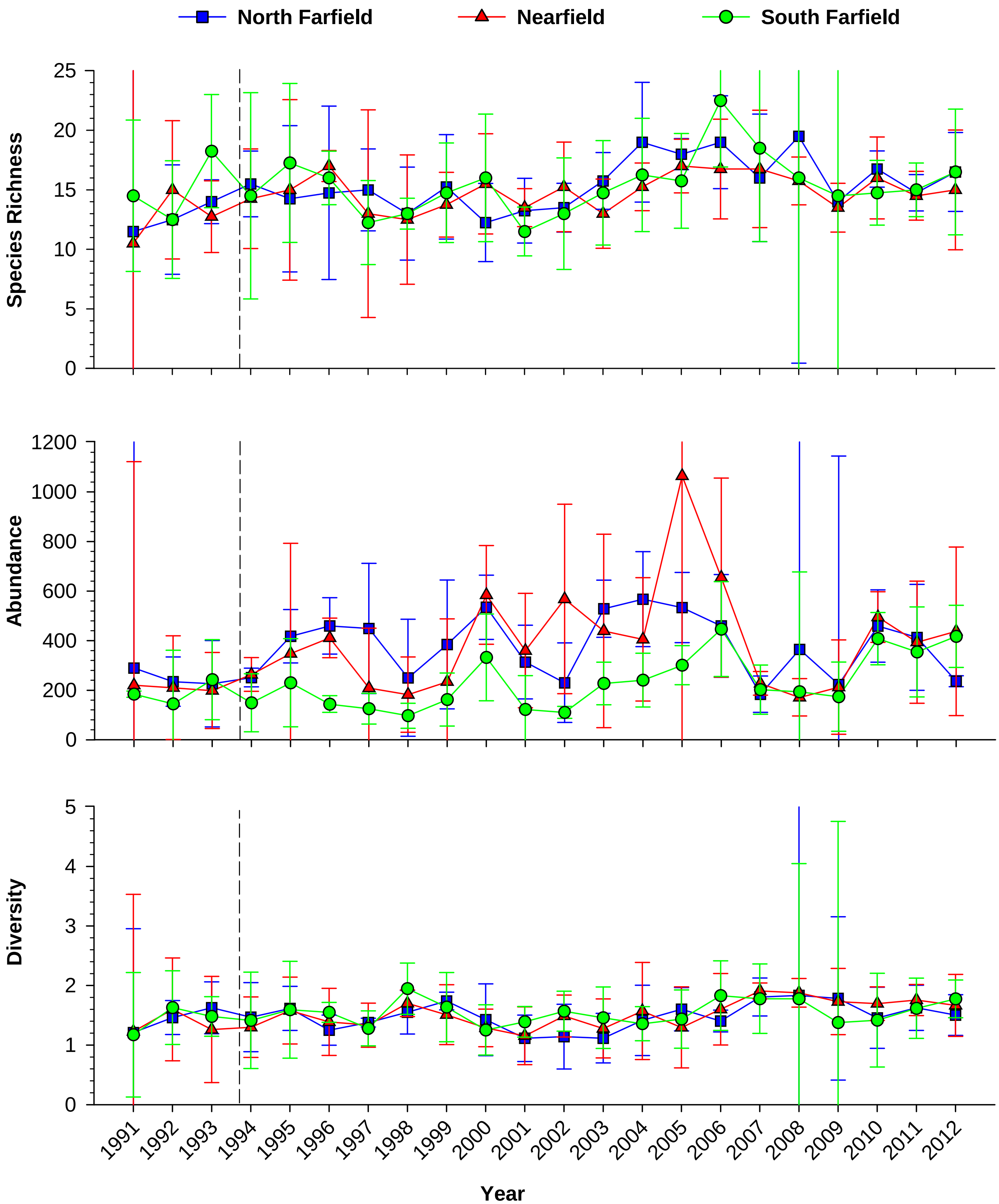
Summary of demersal fish community parameters for PLOO trawl stations sampled during 2012. Data are included for species richness, abundance, diversity (H'), and biomass (kg, wet weight). SD = standard deviation.

| Station | Winter | Summer |
|---|---|---|
| *Species Richness* | | |
| SD7 | 17 | 14 |
| SD8 | 21 | 14 |
| SD10 | 17 | 11 |
| SD12 | 18 | 14 |
| SD13 | 19 | 17 |
| SD14 | 16 | 14 |
| Survey Mean | 18 | 14 |
| Survey SD | 2 | 2 |
| *Abundance* | | |
| SD7 | 430 | 356 |
| SD8 | 524 | 360 |
| SD10 | 745 | 406 |
| SD12 | 257 | 342 |
| SD13 | 254 | 236 |
| SD14 | 220 | 235 |
| Survey Mean | 405 | 323 |
| Survey SD | 205 | 71 |
| *Diversity* | | |
| SD7 | 2.0 | 1.5 |
| SD8 | 1.9 | 1.8 |
| SD10 | 1.9 | 1.4 |
| SD12 | 2.0 | 1.4 |
| SD13 | 1.7 | 1.6 |
| SD14 | 1.5 | 1.2 |
| Survey Mean | 1.8 | 1.5 |
| Survey SD | 0.2 | 0.2 |
| *Biomass* | | |
| SD7 | 7.8 | 6.5 |
| SD8 | 9.2 | 13.1 |
| SD10 | 18.0 | 6.7 |
| SD12 | 15.3 | 7.5 |
| SD13 | 5.9 | 8.1 |
| SD14 | 6.6 | 11.8 |
| Survey Mean | 10.5 | 7.2 |
| Survey SD | 5.0 | 2.6 |

of assemblages in 2012 was generally similar to that seen previously, especially during 2006–2011, and there were no discernible patterns associated with proximity to the outfall. Instead, assemblages appeared influenced by large-scale oceanographic events (e.g., El Niño in 1998) or 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. The composition and main characteristics of each cluster group are described below (see also Table 6.4).

Cluster groups A–E each comprised one to two trawls. Overall, mean species richness and abundance for these groups ranged from 7 to 19 species and 44 to 261 individuals per haul. These groups typically differed from the three main cluster groups (groups F, G, and H, described below) because of either the exceptionally high abundances of one or two uncommon species, or the exceptionally low abundance of common species. 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 (23 fish). Group B comprised hauls from stations SD7 and SD8 in 2001, while group C comprised stations SD8 in 1994 and SD14 in 1998; these assemblages also had low species richness, total abundance and low numbers of Pacific sanddabs compared to other cluster groups. Group B was further characterized by yellowchin sculpin, California tonguefish, and bigmouth sole, whereas group C was further characterized by greenblotched rockfish and Dover sole. The assemblage at station SD12 in 1998 (group D) contained 116 plainfin midshipman, a species that had mean abundances $\leq 15$ in every other cluster group. Similarly, the assemblage at station SD12 in 1997 (group E) contained 23 squarespot rockfish and 6 vermillion rockfish; these species were absent or occurred in very low numbers in all other cluster groups.

Cluster group F comprised 42 hauls, including 97% of the trawls conducted in the PLOO region over the past seven years, as well as hauls from station SD12 sampled in 2003 and 2004 and station SD8 sampled between 2003 and 2005. Assemblages represented by this group averaged 16 species, 330 fishes and 174 Pacific sanddabs per haul. Other characteristic species included halfbanded rockfish, Dover sole, and longspine combfish.




## Figure 6.3

Species richness, abundance, and diversity of demersal fishes collected from PLOO trawl stations sampled between 1991 and 2012. Data are means with 95% confidence intervals for nearfield stations (SD10, SD12), north farfield stations (SD13, SD14), and south farfield stations (SD7, SD8); n = 4 except: n = 2 in 1995 (all station groups); n = 2 in 2008 and 2009 for the farfield stations. Dashed lines indicate onset of wastewater discharge.

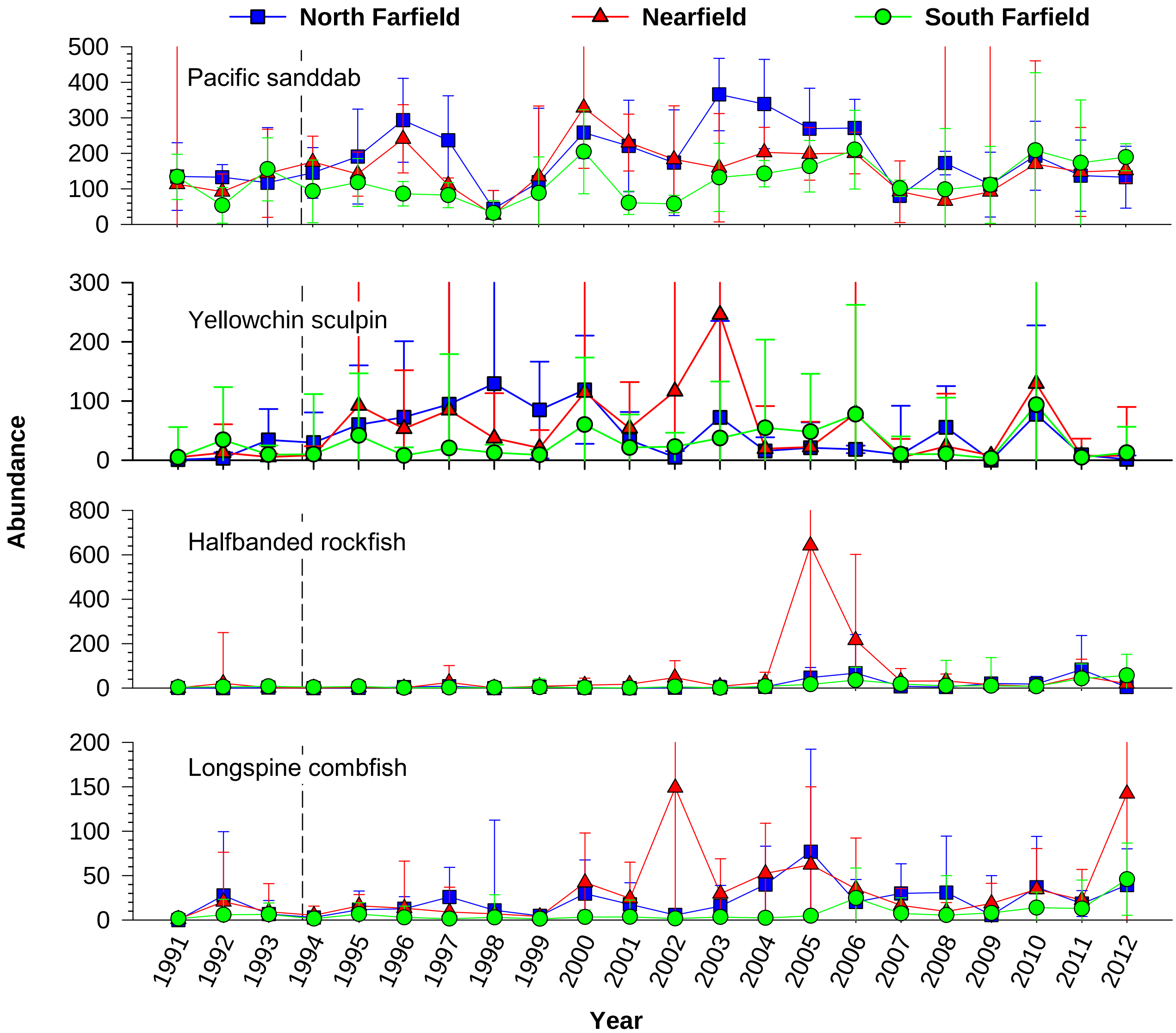



**Figure 6.4**
The eight most abundant fish species (presented in order) collected from PLOO trawl stations sampled between 1991 and 2012. Data are means with 95% confidence intervals for nearfield stations (SD10, SD12), north farfield stations (SD13, SD14), and south farfield stations (SD7, SD8); n = 4 except: n = 2 in 1995 (all station groups); n = 2 in 2008 and 2009 for the farfield stations. Dashed lines indicate onset of wastewater discharge.

Cluster group G represented 83% of the trawls conducted at the north farfield and nearfield stations sampled between 1993 and 2005. This group also included hauls from station SD7 sampled in 2000, and 2003–2005 and station SD8 sampled in 1991–1992. Group G assemblages averaged 15 species, 363 fishes, and 239 Pacific sanddabs per haul. Other characteristic species included Dover sole, yellowchin sculpin, longspine combfish, and plainfin midshipman.

Group H comprised 30 trawls, including 75% of the hauls from stations SD7 and SD8 between 1991 and 2002, as well as hauls from: (1) stations SD10–SD14 sampled during 1991–1992, (2) stations SD10 and SD12 sampled in 1995, (3) station SD10 sampled in 1998, and (4) station SD7 sampled in 2007. Overall, this cluster group averaged 13 species, 162 individuals per haul and was characterized by Pacific sanddab, plainfin midshipman, Dover sole, longfin sanddab, and California tonguefish.

***Physical Abnormalities and Parasitism***

Demersal fish populations appeared healthy in the PLOO region during 2012. There were no

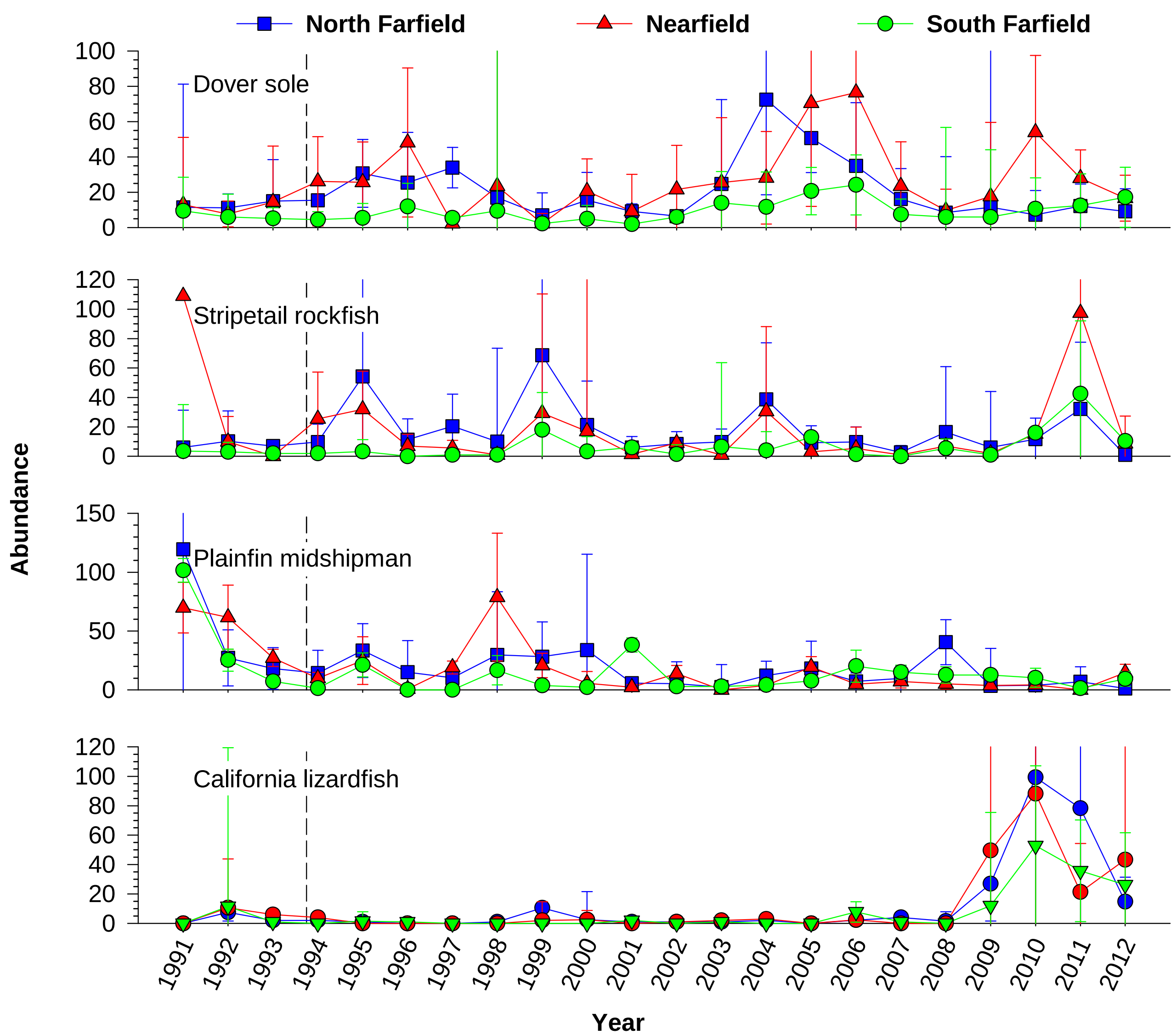



**Figure 6.4** *continued*

incidences of fin rot, discoloration, or skin lesions among fishes collected during the year; however, tumors were observed on 1.1% of Dover sole (2 individuals). 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 (12 individuals) collected during the year; this eye parasite was found on fish from all stations. In addition, a single leech (class Hirudinea) was found on one California tonguefish collected from station SD8 in January. Finally, five individuals of the cymothoid isopod, *Elthusa vulgaris*, were identified as part of other trawl catches during the year (see Appendix E.5). Since cymothoids often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these isopods. However, *E. vulgaris* is known to be especially common on sanddabs and California lizardfish in southern California waters, where it may reach infestation rates of 3% and 80%, respectively (see Brusca 1978, 1981).

## Megabenthic Invertebrates

### *Community Parameters*

A total of 15,320 megabenthic invertebrates (~1277 per trawl) representing 47 taxa from 39 families were collected in 2012 (Table 6.5, Appendix E.5). The sea urchin *Lytechinus pictus* was the most abundant and most frequently captured trawl-caught invertebrate, averaging 882 individual

## Table 6.3

Results of a two-way crossed ANOSIM (with replicates) for demersal fish assemblages sampled around the PLOO between 1991 and 2012. Data are limited to summer surveys.

**Global Test: Factor A** (station groups)

*Tests for differences between station group (across all years)*

| | |
|---|---|
| Sample statistic (Rho): | 0.344 |
| Significance level of sample statistic: | 0.01% |
| Number of permutations: | 9999 |
| Number of permuted statistics greater than or equal to Rho: | 0 |

**Pairwise Tests: Factor A**

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

| | Nearfield | South Farfield |
|---|---|---|
| **North Farfield** | 0.163 (3.2) | 0.679 (0.01) |
| **South farfield** | 0.226 (0.5) | |

**Global Test: Factor B** (years)

*Tests for differences between years (across all station groups)*

| | |
|---|---|
| Sample statistic (Rho): | 0.632 |
| Significance level of sample statistic: | 0.01% |
| Number of permutations: | 9999 |
| Number of permuted statistics greater than or equal to Rho: | 0 |

per hauls (=69% of total abundance) and occurring in 100% of the trawls. The brittle star *Ophiura luetkenii* and the sea star *Luidia foliolata* were also collected in every haul, but in much lower numbers averaging 262 and 10 individuals per haul, respectively. Other species collected during the year in at least 50% of the trawls but in mostly low numbers included the sea urchin *Strongylocentrotus fragilis* (mean = 93/haul), the sea stars *Astropecten californicus* and *Luidia asthenosoma* (mean = 2 per haul each), the sea cucumber *Parastichopus californicus* (mean = 2/haul), and the opisthobranch *Pleurobranchaea californica* (mean = 5/haul).

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.6). For each haul, species richness ranged from 10 to 17 species and total abundance ranged from 377 to 3205 individuals. Patterns in total invertebrate abundance mirrored variation in populations of *Lytechinus pictus* because of its overwhelming dominance (Appendix E.6). For example, relatively high invertebrate abundances (1085–3200 individuals per haul) recorded during the winter at stations SD7, SD8 and SD12 and during the summer at stations SD7 and SD10 reflect large hauls of *L. pictus* (i.e., ≥1032/haul). In contrast, the relatively high invertebrate abundance (3205 individuals) recorded during the summer at station SD14 reflects the unusually large number of *Ophiura luetkenii* (2640 individuals) that were collected in that trawl. Low diversity values (≤1.6) for the region were caused by the numerical dominance of one of these two species.

Large population fluctuations of a few dominant species have been the principal factor contributing to the high variation in trawled invertebrate community structure off Point Loma since 1991 (Figure 6.7, 6.8). Over the years, mean diversity and species richness have remained low (i.e., H' < 1.4, SR < 24 species per haul), while abundance has varied considerably (i.e., 79–5613 individuals per haul). Differences in overall invertebrate abundance, especially at nearfield and south farfield stations, primarily track changes in *Lytechinus pictus* populations, since this species has been numerically dominant in the PLOO region since sampling began (see following section and City of San Diego 2007b). Other influential species include *Acanthoptilum* sp,

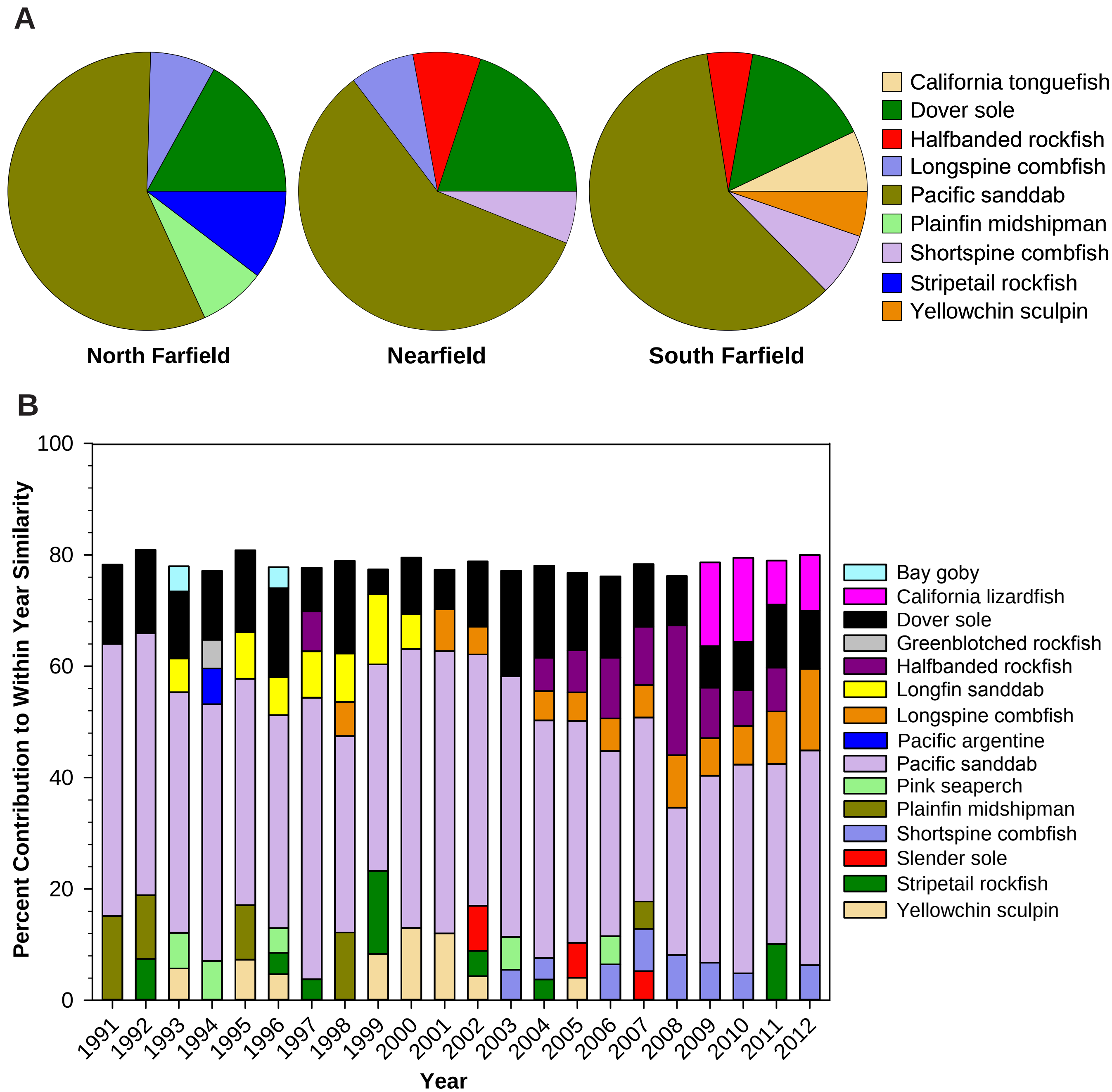



**Figure 6.5**
Percent contribution of individual species that cumulatively equal 75% similarity for (A) each station group (Factor A, see Table 6.4), and (B) each year group (Factor B) according to SIMPER analysis.

*Strongylocentrotus fragilis*, and *Ophiura luetkenii*. For example, fluctuations of *S. fragilis* populations have contributed greatly to changes in abundance at the north farfield stations. These results are likely due to differences in sediment composition between the north and south regions of the PLOO survey area (see Chapter 4) and to the narrowness of the continental shelf in the north region that may allow deep-water *S. fragilis* to move into shallower depths. Overall, none of the observed changes appear to be associated with wastewater discharge.

### *Multivariate Analysis of Invertebrate Assemblages*

Megabenthic invertebrate assemblages sampled from 1991 through 2012 (summer and winter surveys only) differed significantly by station group (i.e., nearfield versus north/south farfield) but not by

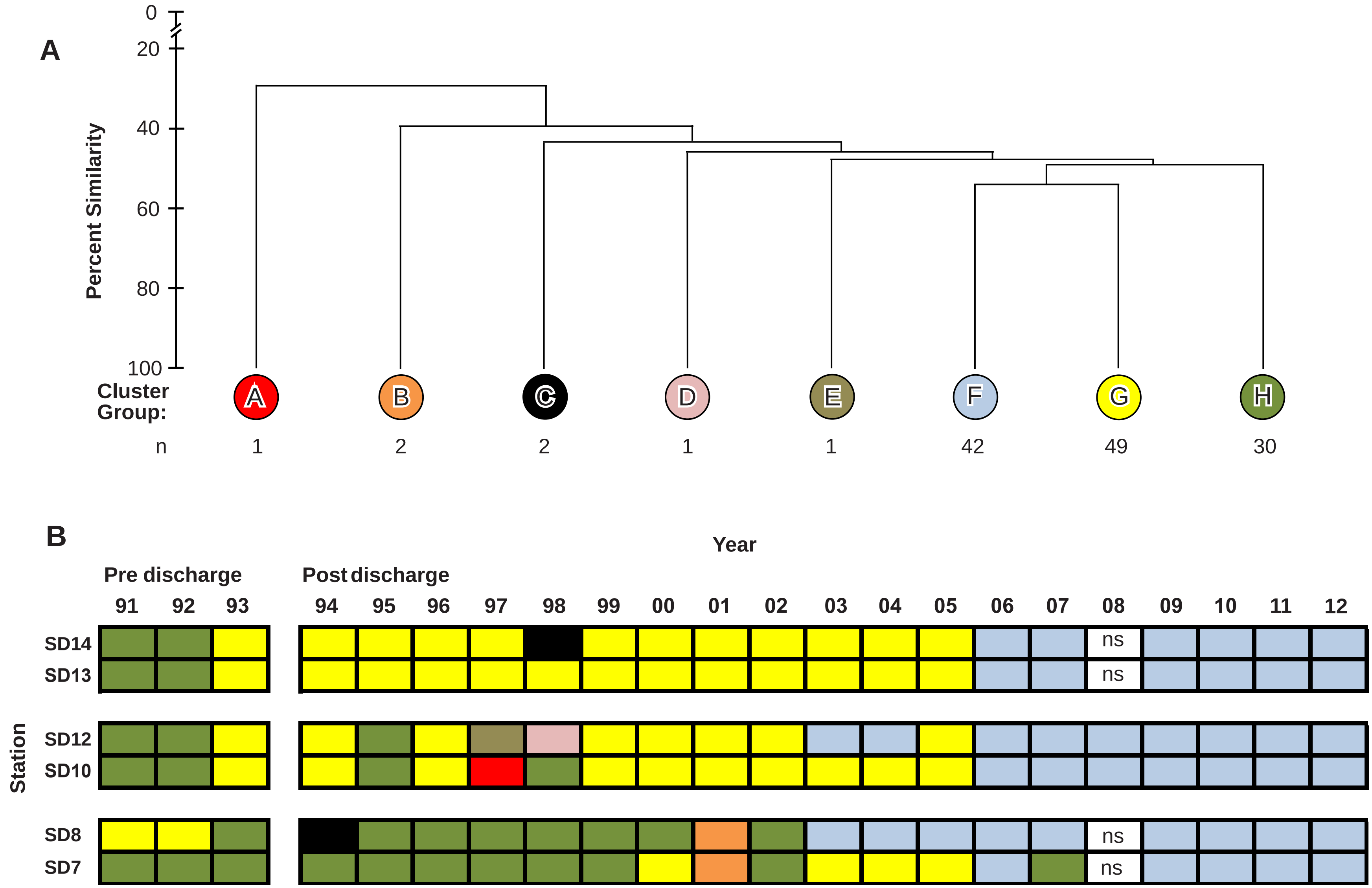



**Figure 6.6**
Results of cluster analysis of demersal fish assemblages from PLOO trawl stations sampled between 1991 and 2012. Data are limited to summer surveys and are presented as (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time. Major ecologically relevant SIMPROF supported clades with <55% similarity were retained. n=number of hauls; ns=not sampled.

## Table 6.4

Description of demersal fish cluster groups A–H defined in Figure 6.5. Data are mean abundance and species richness. Species included represent the five most abundant taxa recorded for each cluster group. Bold values indicate species that were considered most characteristic of that group according to SIMPER analysis.

| | Cluster Group | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A[a] | B | C | D[a] | E[a] | F | G | H |
| **Number of Hauls** | 1 | 2 | 2 | 1 | 1 | 42 | 49 | 30 |
| **Mean Species Richness** | 7 | 11 | 11 | 16 | 19 | 16 | 15 | 13 |
| **Mean Abundance** | 44 | 68 | 74 | 261 | 231 | 330 | 363 | 162 |
| **Taxa** | **Mean Abundance** | | | | | | | |
| Pacific sanddab | 23 | **46** | **48** | 75 | 110 | **174** | **239** | **97** |
| Halfbanded rockfish | 16 | | | | 60 | **45** | 7 | 2 |
| Longfin sanddab | 1 | **3** | 1 | | | <1 | 6 | **7** |
| Pink seaperch | 1 | 1 | 2 | 4 | 1 | 4 | 5 | 1 |
| Greenblotched rockfish | 1 | 1 | **2** | | 8 | <1 | 1 | 1 |
| Spotfin sculpin | 1 | | 2 | | | 1 | <1 | 2 |
| Yellowchin sculpin | | **5** | | | | 2 | **17** | 4 |
| California tonguefish | | **3** | | | | 1 | 1 | **3** |
| Bigmouth sole | | **3** | | | | 1 | 1 | 1 |
| Longspine combfish | | 3 | 2 | 7 | 2 | **20** | **14** | 1 |
| Dover sole | | 1 | **6** | 36 | 1 | **23** | **29** | **10** |
| California lizardfish | | 1 | | | | 21 | <1 | <1 |
| Plainfin midshipman | | | 2 | 116 | 4 | 3 | **9** | **15** |
| Stripetail rockfish | | | 8 | 1 | 5 | 7 | 13 | 8 |
| Squarespot rockfish | | 1 | | | 23 | 1 | | <1 |
| Vermilion rockfish | | | | | 6 | | | |

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

year (Table 6.7). Individual pairwise comparisons by station group found that north farfield stations were significantly different than nearfield and south farfield stations. As discussed in the previous section, population fluctuations of common species such as the sea urchins *Lytechinus pictus* and *Strongylocentrotus fragilis* contributed substantially to station group differences (Figure 6.9).

Classification (cluster) analysis discriminated six main types of invertebrate assemblages in the Point Loma outfall region between 1991 and 2012 (cluster groups A–F; Figure 6.10). The distribution of invertebrate assemblages in 2012 was similar to that seen in previous years and there were no discernible patterns associated with proximity to the outfall. Instead, most differences were driven by the distribution of the two urchin species as described above and in the previous section. The composition and main characteristics of each cluster group are described below (see also Table 6.8).

Cluster groups A and C comprised one haul each. The assemblage at station SD12 sampled in winter 2008 (group A) had very low species richness (5 species), low abundance (55 individuals), and was composed almost entirely of the sea pen *Acanthoptilum* sp (50 individuals). The assemblage at station SD14 sampled in summer 2012 (group C) was comprised of 10 species and 3205 individuals, 2640 of which were the brittle star *Ophiura luetkenii*.

Cluster group B represented assemblages from 10 sites that included: three hauls from station SD14 sampled in the winters of 1992, 1993, and 2001, three hauls from station SD13 sampled between

## Table 6.5

Species of megabenthic invertebrates collected from 12 trawls conducted in the PLOO region during 2012. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

| Species | PA | FO | MAH | MAO | Species | PA | FO | MAH | MAO |
|---|---|---|---|---|---|---|---|---|---|
| *Lytechinus pictus* | 69 | 100 | 882 | 882 | *Philine alba* | <1 | 25 | <1 | 1 |
| *Ophiura luetkenii* | 21 | 100 | 262 | 262 | *Thesea* sp B | <1 | 17 | <1 | 2 |
| *Strongylocentrotus fragilis* | 7 | 50 | 93 | 186 | *Armina californica* | <1 | 17 | <1 | 1 |
| *Luidia foliolata* | 1 | 100 | 10 | 10 | *Austrotrophon catalinensis* | <1 | 17 | <1 | 1 |
| *Pleurobranchaea californica* | <1 | 92 | 5 | 5 | *Calliostoma turbinum* | <1 | 8 | <1 | 2 |
| *Philine auriformis* | <1 | 42 | 4 | 8 | *Cancellaria cooperii* | <1 | 17 | <1 | 1 |
| *Astropecten californicus* | <1 | 83 | 2 | 3 | *Paralithodes rathbuni* | <1 | 17 | <1 | 1 |
| *Chloeia pinnata* | <1 | 8 | 2 | 29 | *Platydoris macfarlandi* | <1 | 17 | <1 | 1 |
| *Florometra serratissima* | <1 | 42 | 2 | 5 | *Adelogorgia phyllosclera* | <1 | 8 | <1 | 1 |
| *Parastichopus californicus* | <1 | 67 | 2 | 3 | *Cancellaria crawfordiana* | <1 | 8 | <1 | 1 |
| *Luidia asthenosoma* | <1 | 75 | 2 | 2 | *Euspira draconis* | <1 | 8 | <1 | 1 |
| *Arctonoe pulchra* | <1 | 25 | 2 | 7 | *Lepidozona golischi* | <1 | 8 | <1 | 1 |
| *Octopus rubescens* | <1 | 42 | 1 | 3 | *Loxorhynchus crispatus* | <1 | 8 | <1 | 1 |
| *Acanthoptilum* sp | <1 | 17 | 1 | 6 | *Loxorhynchus grandis* | <1 | 8 | <1 | 1 |
| *Rossia pacifica* | <1 | 33 | 1 | 2 | *Megasurcula carpenteriana* | <1 | 8 | <1 | 1 |
| *Sicyonia ingentis* | <1 | 33 | 1 | 2 | *Octopus californicus* | <1 | 8 | <1 | 1 |
| *Astropecten ornatissimus* | <1 | 17 | <1 | 3 | *Ophiacantha diplasia* | <1 | 8 | <1 | 1 |
| *Acanthodoris brunnea* | <1 | 25 | <1 | 2 | *Ophiopholis bakeri* | <1 | 8 | <1 | 1 |
| *Crangon alaskensis* | <1 | 8 | <1 | 5 | *Paguristes bakeri* | <1 | 8 | <1 | 1 |
| *Elthusa vulgaris* | <1 | 42 | <1 | 1 | *Paguristes turgidus* | <1 | 8 | <1 | 1 |
| *Hinea insculpta* | <1 | 17 | <1 | 2 | *Platymera gaudichaudii* | <1 | 8 | <1 | 1 |
| *Neocrangon zacae* | <1 | 8 | <1 | 4 | *Protula superba* | <1 | 8 | <1 | 1 |
| *Metridium farcimen* | <1 | 8 | <1 | 3 | *Spatangus californicus* | <1 | 8 | <1 | 1 |
| *Ophiothrix spiculata* | <1 | 17 | <1 | 2 | | | | | |

January 1992 and January 1993, three hauls from station SD12 sampled in the summer of 1994 and 1998, as well as the winter of 1998, and a single haul from station SD8 sampled in the winter of 1995. The assemblages represented by group B averaged 10 species and 64 individuals, and were characterized by very low abundances of *L. pictus* (~6). Other characteristic species for this group included the shrimp *Sicyonia ingentis*, the sea star *Astropecten californicus*, and the sea cucumber *Parastichopus californicus*.

Cluster group D comprised assemblages that occurred at one to four sites during almost every survey between the winter of 1994 and the winter of 2011 (total of 50 hauls). This group averaged 12 species and 749 individuals per haul and was characterized by intermediate numbers of *Lytechinus pictus* (~658/haul). Other characteristic species included *Acanthoptilum* sp, *Astropecten californicus*, *Parastichopus californicus*, and the sea star *Luidia foliolata*.

Cluster group E represented 72% of the trawls conducted at the south farfield and nearfield stations since sampling began in 1991. This group also included 8% of the hauls from the north farfield stations during this same time period. Assemblages represented by this group averaged 12 species, 2892 individuals, and 2801 *Lytechinus pictus* per haul. Other characteristic species included *Astropecten californicus* and *Parastichopus californicus*.

In contrast to group E, cluster group F represented assemblages from 52% of trawls conducted at north farfield stations SD13 and SD14 since 1991. This

**Table 6.6**
Summary of megabenthic invertebrate community parameters for PLOO trawl stations sampled during 2012. Data are included for species richness, abundance, and diversity (H'). SD = standard deviation.

| Station | Winter | Summer |
|---|---|---|
| *Species Richness* | | |
| SD7 | 16 | 16 |
| SD8 | 13 | 17 |
| SD10 | 16 | 12 |
| SD12 | 10 | 10 |
| SD13 | 14 | 11 |
| SD14 | 12 | 10 |
| Survey Mean | 14 | 13 |
| Survey SD | 2 | 3 |
| *Abundance* | | |
| SD7 | 1565 | 1132 |
| SD8 | 1085 | 812 |
| SD10 | 833 | 1427 |
| SD12 | 3200 | 453 |
| SD13 | 568 | 663 |
| SD14 | 377 | 3205 |
| Survey Mean | 1271 | 1282 |
| Survey SD | 1032 | 1003 |
| *Diversity* | | |
| SD7 | 0.4 | 0.5 |
| SD8 | 0.3 | 0.4 |
| SD10 | 0.4 | 0.3 |
| SD12 | 0.1 | 1.0 |
| SD13 | 1.1 | 1.2 |
| SD14 | 1.6 | 0.6 |
| Survey Mean | 0.6 | 0.7 |
| Survey SD | 0.6 | 0.4 |

group averaged 12 species, 396 individuals, and 194 *Lytechinus pictus* per haul. *Strongylocentrotus fragilis* was the second most abundant species for this group (94 individuals/haul). Other characteristic species included *Acanthoptilum* sp, *Luidia foliolata*, and *Astropecten californicus*.

## Summary

Pacific sanddabs dominated fish assemblages surrounding the PLOO in 2012 as they have since monitoring began. This species occurred at all stations and accounted for 44% of the total catch. Other commonly captured, but less abundant species, included longspine combfish, California lizardfish, halfbanded rockfish, Dover sole, pink seaperch, shortspine combfish, English sole, stripetail rockfish, yellowchin sculpin, plainfin midshipman, California tonguefish, bigmouth sole, California skate, and hornyhead turbot. The majority of these fishes tended to be relatively small with an average length < 30 cm. Although the composition and structure of the fish assemblages varied among stations and surveys, these differences appear to be due to natural fluctuations of common species.

During 2012, assemblages of trawl-caught invertebrates were dominated by the sea urchin *Lytechinus pictus*, which occurred in all trawls and accounted for 69% of the total invertebrate abundance. The brittle star *Ophiura luetkenii* and the sea star *Luidia foliolata* were also collected in every haul, typically in much lower numbers. However, an unusually large number of *Ophiura luetkenii* were collected at station SD14 during the summer. Other megabenthic invertebrates collected frequently included the sea urchin *Strongylocentrotus fragilis*, the sea stars *Luidia asthenosoma* and *Astropecten californicus*, the opisthobranch *Pleurobranchaea californica*, and the sea cucumber *Parastichopus californicus*. As with demersal fishes in the region, the composition and structure of the trawl-caught invertebrate assemblages varied among stations and surveys, generally reflecting population fluctuations in the species mentioned above. Spatial differences among station groups also appear related, in part, to physical characteristics of the benthos such as topography and sediment composition (see Chapter 4).

Overall, no evidence exists that wastewater discharged through the PLOO has affected either demersal fish or megabenthic invertebrate communities in 2012. Although highly variable, patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away, with no discernible changes in the region following the onset of wastewater discharge through the PLOO in 1994. Instead, the high degree of variability present during the year was similar to that observed in previous years

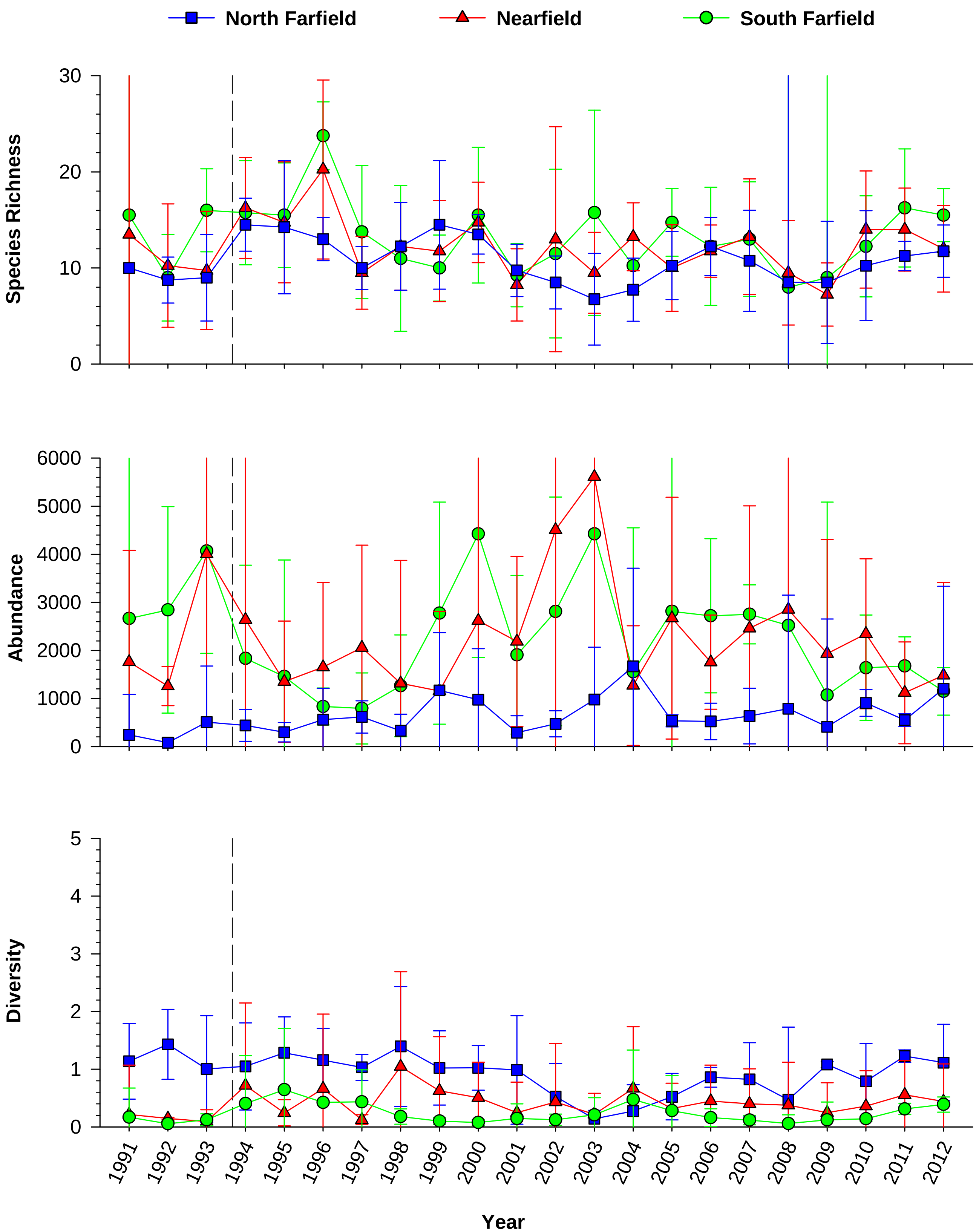



**Figure 6.7**
Species richness, abundance, and diversity of megabenthic invertebrates collected from PLOO trawl stations between 1991 and 2012. Data are means with 95% confidence intervals for nearfield stations (SD10, SD12), north farfield stations (SD13, SD14), and south farfield stations (SD7, SD8), n = 4 except: n = 2 in 1995 (all station groups); n = 2 in 2008 and 2009 for the farfield stations. Dashed lines indicate onset of wastewater discharge.

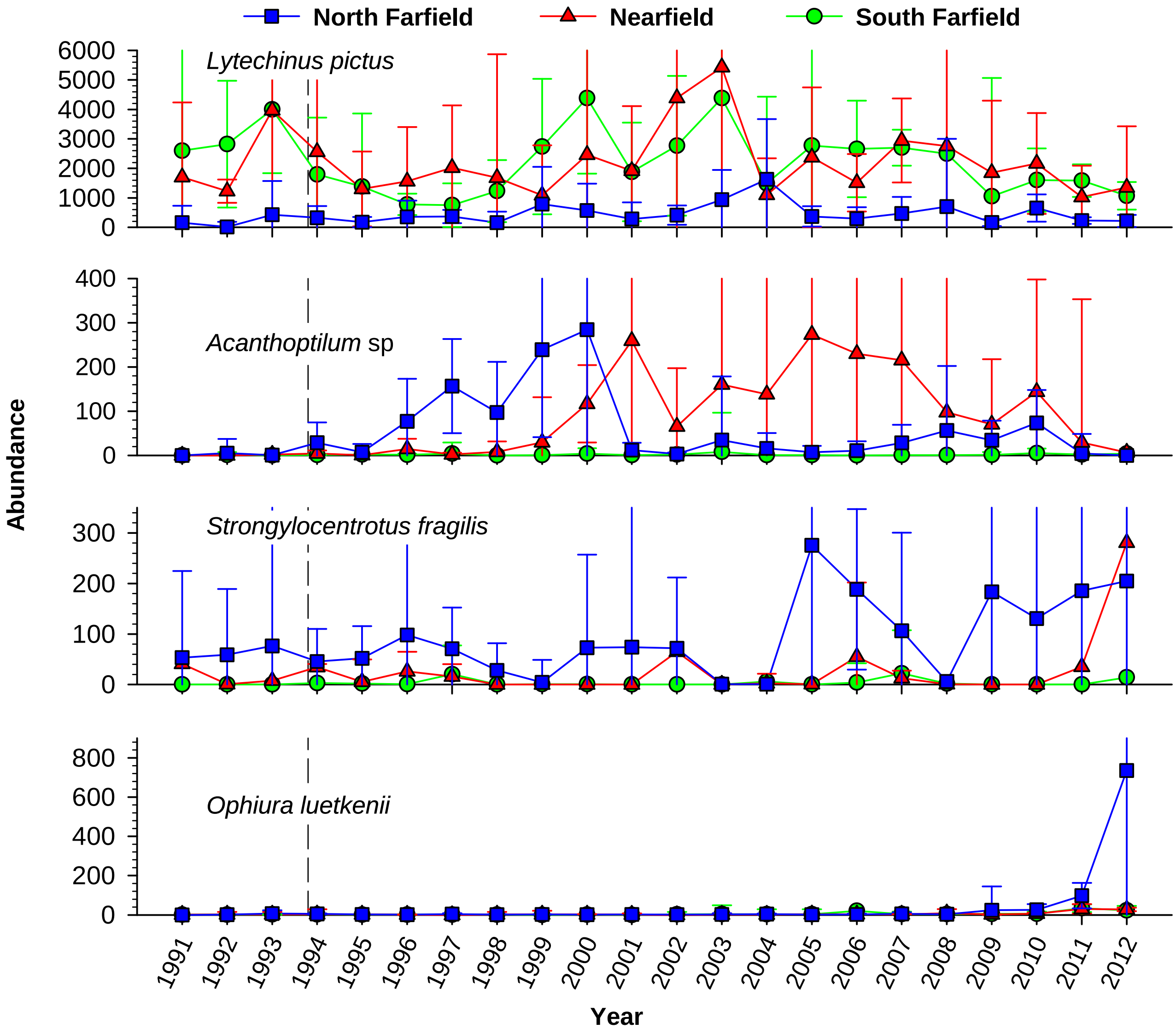



**Figure 6.8**
The eight most abundant invertebrate species (presented in order) collected from PLOO trawl stations sampled between 1991 and 2012. Data are means with 95% confidence intervals for nearfield stations (SD10, SD12), north farfield stations (SD13, SD14), and south farfield stations (SD7, SD8); n = 4 except: n = 2 in 1995 (all station groups); n = 2 in 2008 and 2009 for the farfield stations. Dashed lines indicate onset of wastewater discharge.

(City of San Diego 2005, 2006, 2007a, 2008–2012), including the period before initiation of wastewater discharge (City of San Diego 2007b). Further, this sort of variability has also been observed in similar benthic habitats elsewhere in the Southern California Bight (Allen et al. 1998, 2002, 2007, 2011). Changes in these communities are more likely due to natural factors such as changes in ocean water temperatures associated with large-scale oceanographic events (e.g., ENSO), 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 Point Loma outfall region continue to be healthy.

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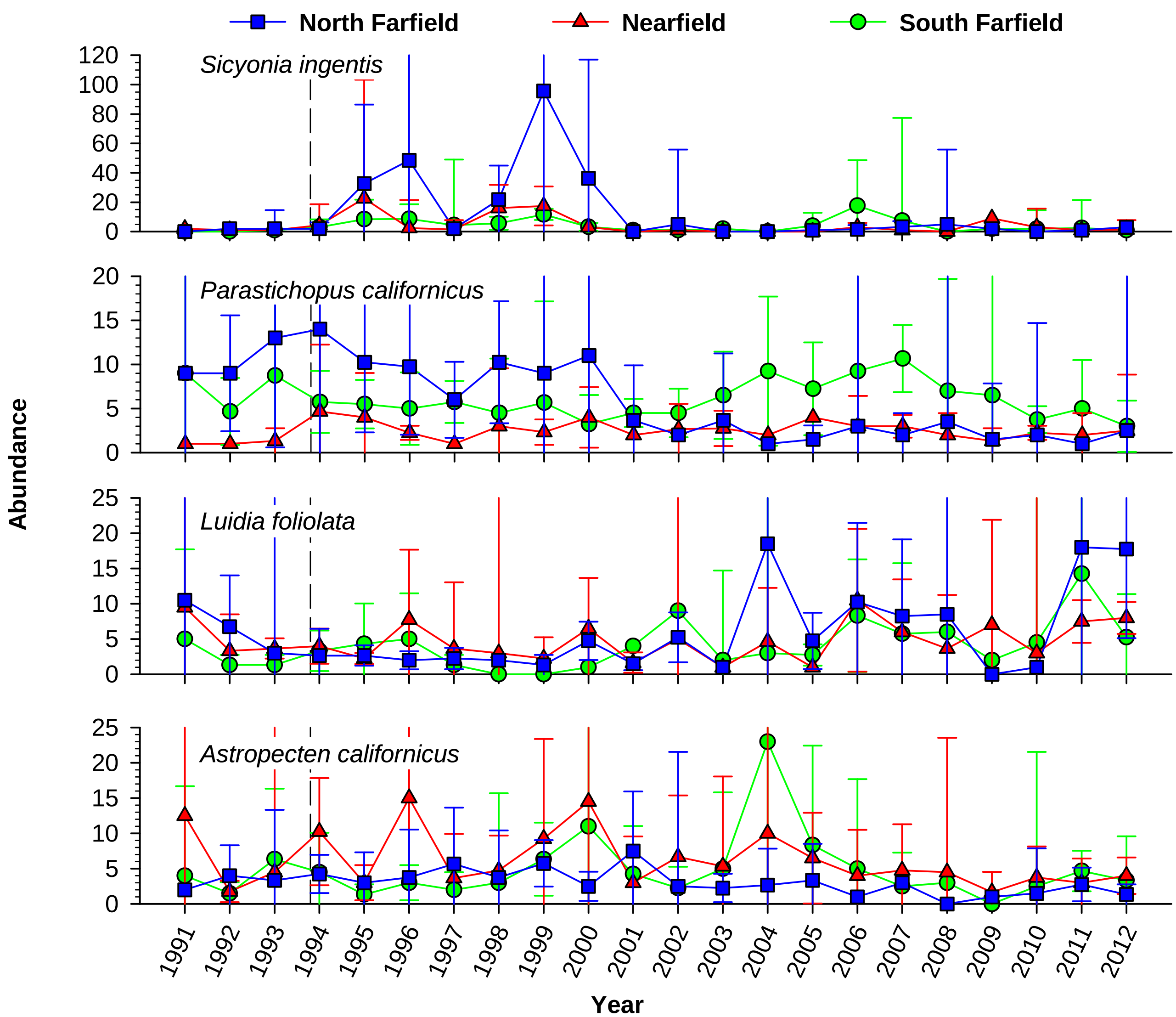


**Figure 6.8** *continued*


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## Table 6.7

Results of a two-way crossed ANOSIM (with replicates) for megabenthic invertebrate assemblages sampled around the PLOO between 1991 and 2012. Data are limited to summer and winter surveys.

**Global Test: Factor A** (station groups)

*Tests for differences between station group (across all years)*

| | |
|---|---|
| Sample statistic (Rho): | 0.373 |
| Significance level of sample statistic: | 0.01% |
| Number of permutations: | 9999 |
| Number of permuted statistics greater than or equal to Rho: | 0 |

**Pairwise Tests: Factor A**

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

| | North Farfield | South Farfield |
|---|---|---|
| **Nearfield** | 0.433 (0.01) | 0.108 (0.2) |
| **South farfield** | 0.623 (0.01) | |

**Global Test: Factor B** (years)

*Tests for differences between years (across all station groups)*

| | |
|---|---|
| Sample statistic (Rho): | 0.244 |
| 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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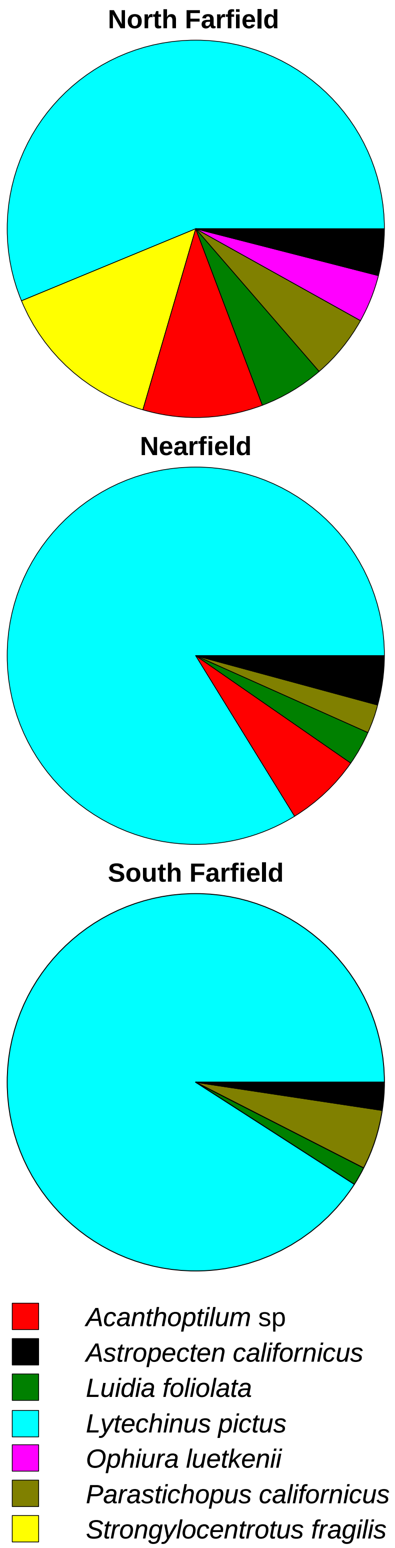


**Figure 6.9**
Percent contribution of individual species that cumulatively equal 90% similarity for each year group (Factor A, see Table 6.8) according to SIMPER analysis.

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**Figure 6.10**
Results of cluster analysis of megabenthic invertebrate assemblages from PLOO trawl stations sampled between 1991 and 2012. Data are limited to winter (W) and summer (S) surveys and presented as (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time. Major ecologically relevant SIMPROF supported clades with <55% similarity were retained. n = number of hauls; ns = not sampled.

## Table 6.8

Description of megabenthic invertebrate cluster groups A–F defined in Figure 6.10. Data are mean abundance and species richness. Species included represent the five most abundant taxa recorded for each cluster group. Bold values indicate species that were considered most characteristic of that group according to SIMPER analysis.

| | Cluster Group | | | | | |
|---|---|---|---|---|---|---|
| | A[a] | B | C[a] | D | E | F |
| **Number of Hauls** | 1 | 10 | 1 | 50 | 129 | 59 |
| **Mean Species Richness** | 5 | 10 | 10 | 12 | 12 | 12 |
| **Mean Abundance** | 55 | 64 | 3205 | 749 | 2892 | 396 |
| **Taxa** | **Mean Abundance** | | | | | |
| *Lytechinus pictus* | 2 | **6** | 102 | **658** | **2801** | **194** |
| *Strongylocentrotus fragilis* | | 11 | 442 | 14 | 3 | **94** |
| *Acanthoptilum* sp | 50 | 4 | | **44** | 49 | **51** |
| *Luidia foliolata* | | **3** | 11 | **3** | 4 | **6** |
| *Astropecten californicus* | | **4** | 1 | **4** | **4** | **4** |
| *Parastichopus californicus* | | **4** | | **4** | **4** | 5 |
| *Ophiura luetkenii* | | **1** | 2640 | 3 | 5 | 15 |
| *Sicyonia ingentis* | | **6** | | 4 | 3 | 13 |
| *Doryteuthis opalescens* | | 2 | | 2 | 1 | 1 |
| *Megasurcula carpenteriana* | 1 | 1 | | <1 | <1 | <1 |

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


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# Chapter 7
# Bioaccumulation of Contaminants in Fish Tissues

# Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

## Introduction

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

The bioaccumulation portion of the City's ocean monitoring program consists of two components: (1) analyzing liver tissues from trawl-caught fishes; (2) analyzing muscle tissues from fishes collected by hook and line (rig fishing). Species collected by trawling activities (see Chapter 6) are considered representative of the general demersal fish community off San Diego, and specific species are targeted based on their prevalence and ecological significance. The chemical analysis of liver tissues in these trawl-caught fishes is important for assessing population effects because this is the organ where contaminants typically bioaccumulate. In contrast, species targeted for capture by rig fishing represent fish that are more characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance and more directly relevant to human health concerns. Consequently, muscle samples are analyzed from these fishes because this is the tissue most often consumed by humans. All liver and muscle tissue samples collected during the year are analyzed for contaminants as specified in the NPDES discharge permit that governs monitoring requirements for the PLOO (see Chapter 1). Most of these contaminants are also sampled for the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program, which was initiated to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants of environmental concern (Lauenstein and Cantillo 1993).

This chapter presents the results of all chemical analyses performed on the tissues of fishes collected in the Point Loma outfall region during 2012. The primary goals are to: (1) document levels of contaminant loading in local demersal fishes, (2) identify whether any contaminant bioaccumulation in fishes collected around the PLOO may be due to the outfall discharge, and (3) identify other potential natural and anthropogenic sources of pollutants to the local marine ecosystem.

## Materials and Methods

### Field Collection

Fishes were collected during October 2012 from four trawl zones and two rig fishing stations (Figure 7.1). Each trawl zone represents an area centered on one or two specific trawl stations as specified in Chapter 6. Trawl Zone 1 includes the "nearfield" area within a 1-km radius of stations SD10 and SD12 located just south and north of the PLOO, respectively. Trawl Zone 2 includes the area within a 1-km radius surrounding northern "farfield" stations SD13 and SD14. Trawl Zone 3 represents the area within a

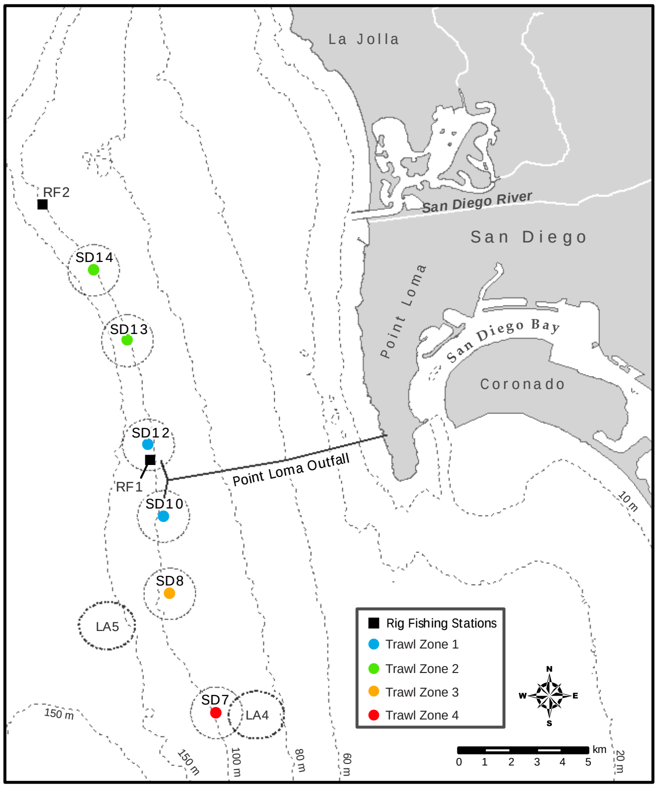



**Figure 7.1**
Otter trawl and rig fishing station locations sampled around the Point Loma Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

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

Pacific sanddabs (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawl zones, while six species of rockfish were collected for analysis of muscle tissues at the rig fishing stations, including chilipepper rockfish (*Sebastes goodei*), copper rockfish (*Sebastes caurinus*), greenspotted rockfish (*Sebastes chlorostictus*), rosy rockfish (*Sebastes rosaceus*), starry rockfish (*Sebastes constellatus*), and vermilion rockfish (*Sebastes miniatus*) (Table 7.1).

Only fish with a standard length $\geq 13$ cm were retained in order to facilitate collection of sufficient tissue for chemical analysis. These fishes were sorted into three composite samples per station, with a minimum of three individuals in each composite. All fishes were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were stored at -80°C prior to dissection and tissue processing.

## Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis. A brief summary follows, but see City of San Diego (in prep) for additional details. Prior to dissection, each fish was partially defrosted, cleaned with a paper towel to remove loose scales and excess mucus, and the standard length (cm) and weight (g) were recorded (Appendix F.1). Dissections were carried out on Teflon® pads that were cleaned between samples. The liver or muscle tissues from each fish were removed and placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City's Wastewater Chemistry Services Laboratory within 10 days of dissection.

Chemical constituents were measured on a wet weight basis, and included 17 trace metals (mercury was not analyzed in October 2012), 9 chlorinated pesticides (e.g., DDT), and 40 polychlorinated biphenyl compound congeners (PCBs) (see Appendix F.2). Data were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols

**Table 7.1**
Species of fish collected from each PLOO trawl zone and rig fishing station during October 2012.

| Station/Zone | Composite 1 | Composite 2 | Composite 3 |
|---|---|---|---|
| Trawl Zone 1 | Pacific sanddab | Pacific sanddab | Pacific sanddab |
| Trawl Zone 2 | Pacific sanddab | Pacific sanddab | Pacific sanddab |
| Trawl Zone 3 | Pacific sanddab | Pacific sanddab | Pacific sanddab |
| Trawl Zone 4 | Pacific sanddab | Pacific sanddab | Pacific sanddab |
| Rig Fishing 1 | Vermilion rockfish | Copper rockfish | Mixed rockfish[a] |
| Rig Fishing 2 | Starry rockfish | Greenspotted rockfish | Mixed rockfish[b] |

[a] Includes rosy, starry and copper rockfish; [b] Includes vermilion, copper and chilipepper rockfish.

is provided by the Wastewater Chemistry Services Laboratory (City of San Diego 2013a).

### Data Analyses

Data summaries for each contaminant include detection rates, minimum, maximum, and mean detected values of each parameter by species. All means were calculated using detected values only; no substitutions were made for non-detects (i.e., analyte concentrations < MDL) in the data. Total DDT (tDDT), total hexachlorocyclohexane (tHCH), total chlordane (tChlor), and total PCB (tPCB) were calculated for each sample as the sum of all constituents with reported values (see Appendix F.3 for individual constituent values). In addition, the distribution of contaminants with detection rates ≥20% was assessed by comparing values for "nearfield" (Trawl Zone 1, Rig Fishing Station RF1) and "farfield" fishes (Trawl Zones 2–4, Rig Fishing Station RF2).

Contaminant levels in muscle tissue samples collected in 2012 were compared to the following state, national, and international limits and standards to address seafood safety and public health issues: (1) 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) United States Food and Drug Administration (USFDA), which has set limits on the amount of mercury, total DDT, and chlordane in seafood to be sold for human consumption (Mearns et al. 1991); (3) international standards for acceptable concentrations of various metals and DDT (Mearns et al. 1991).

## Results

### Contaminants in Trawl-Caught Fishes

***Trace Metals***
Eleven trace metals occurred in all liver tissue samples collected from trawl-caught Pacific sanddabs in the Point Loma outfall region during 2012. These included aluminum, arsenic, cadmium, chromium, copper, iron, manganese, selenium, thallium, tin and zinc (Table 7.2). Barium, lead, nickel, and silver were also detected, but at rates ≤50%. Neither antimony nor beryllium was detected in any liver sample collected during the year. Most metals occurred at concentrations ≤7 ppm, though higher concentrations up to 36 ppm for aluminum, 18 ppm for cadmium, 112 ppm for iron, and 37 ppm for zinc were recorded. Overall, frequently detected metals had variable concentrations and occurred across all stations. Exceptions included the highest values of aluminum, cadmium, copper, and iron, all of which occurred in one of three samples from Trawl Zone 1 (Figure 7.2).

***Pesticides***
Only three chlorinated pesticides were detected in fish liver tissues during 2012 (Table 7.2). Hexachlorobenzene (HCB) and DDT were found in every sample at concentrations up to 7 and 438 ppb,

respectively. The DDT metabolites p,p-DDE and p,p-DDMU were also found in 100% of the samples, whereas o,p-DDE, p,p-DDD, and p,p-DDT had detection rates between 67 and 83% (Appendix F.3). Chlordane (consisting solely of trans-nonachlor) was detected in a single sample at a concentration of 15 ppb. Although the highest tDDT value was from Trawl Zone 1, overall HCB and tDDT had variable concentrations and occurred across all stations (Figure 7.3).

***PCBs***

PCBs occurred in all liver tissue samples analyzed during 2012 at concentrations up to 461 ppb (Table 7.2). Seventeen of the 26 detected congeners occurred in 100% of the samples, including PCB 49, PCB 70, PCB 74, PCB 99, PCB 101, PCB 105, PCB 110, PCB 118, PCB 128, PCB 138, PCB 149, PCB 151, PCB 153/168, PCB 170, PCB 180, PCB 183, and PCB 187 (Appendix F.3). Another nine congeners were found in at least 25% of the samples. Overall, there was no clear relationship between total PCB and proximity to the outfall (Figure 7.3).

## Contaminants in Fishes Collected by Rig Fishing in 2012

Only four trace metals occurred in all rockfish muscle tissue samples collected at stations RF1 and RF2 in 2012, including arsenic, chromium, selenium and zinc (Table 7.3). Aluminum, iron, and thallium were also detected, but at lower rates between 33 and 83%. In contrast, antimony, barium, beryllium, cadmium, copper, lead, manganese, nickel, silver, and tin were not detected in any samples. The metals present in the highest concentrations were aluminum (≤5.0 ppm), zinc (≤4.6 ppm), iron (≤3.0 ppm), and arsenic (≤2.2 ppm). Concentrations of all remaining metals were less than 1 ppm. Metal concentrations appeared similar in tissue samples from rockfish at the two rig fishing stations (Figure 7.4). Exceptions included the highest concentrations of aluminum, chromium, and selenium that were found in one or two samples from RF1.

Every rockfish muscle tissue sample collected during 2012 contained detectable levels of tDDT, HCB, and tPCB (Table 7.4). For all three contaminants, concentrations were ≤16.3 ppb and none demonstrated a clear relationship with proximity to the outfall, although the highest concentrations of HCB and tDDT were found in one or two samples from RF1 (Figure 7.4). The DDT metabolite p,p-DDE and the PCB congeners PCB 138 and PCB 153/168 were found in all samples (Appendix F.3). Another 10 PCB congeners were detected ≤16.6% of the time.

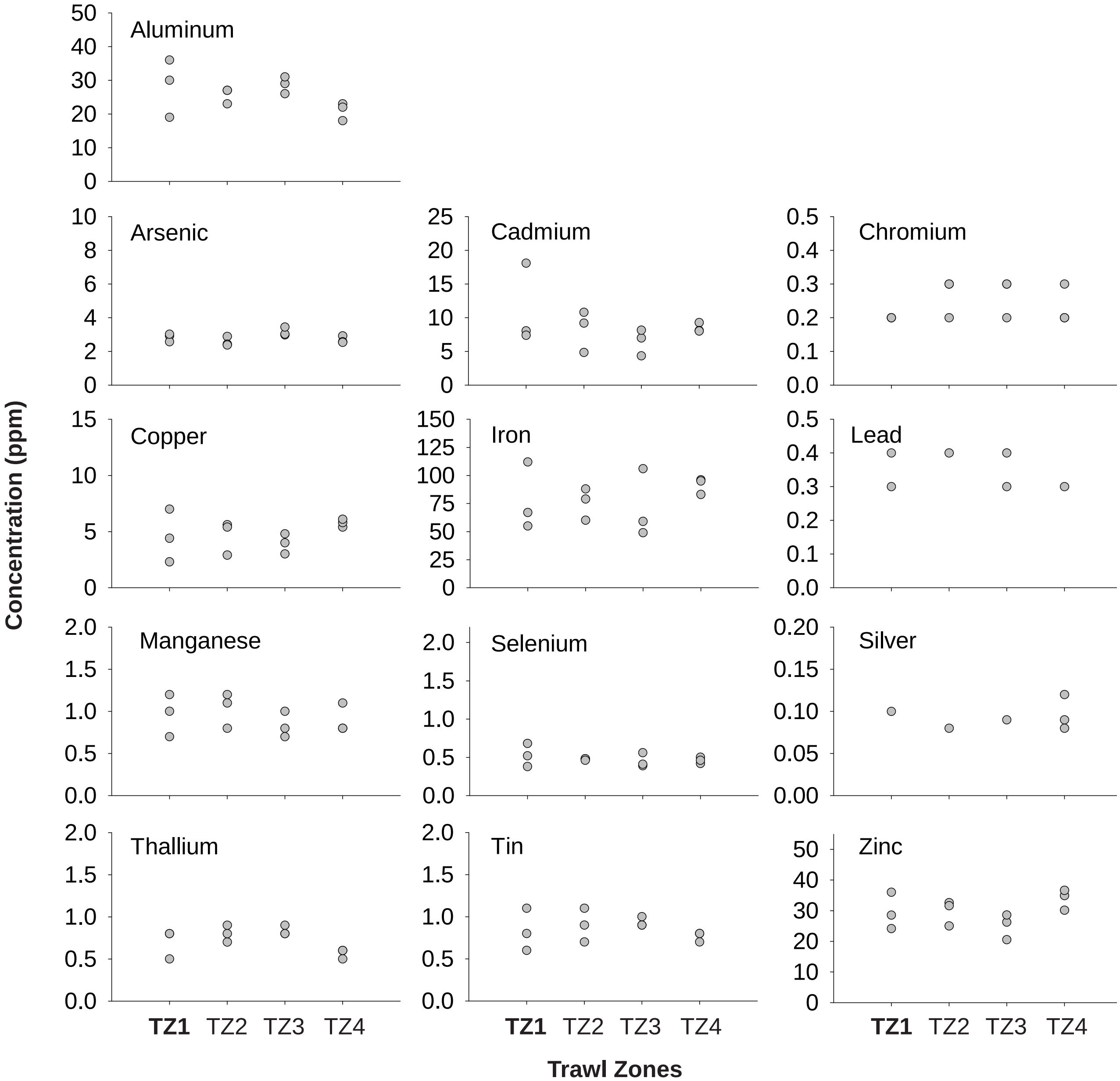
### Table 7.2

Summary of metals, pesticides, total PCBs, and lipids in liver tissues of Pacific sanddabs collected from PLOO trawl zones during 2012. 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 | 100 | 18.0 | 36.0 | 25.9 |
| Antimony | 0 | — | — | — |
| Arsenic | 100 | 2.4 | 3.4 | 2.8 |
| Barium | 17 | nd | 0.540 | 0.300 |
| Beryllium | 0 | — | — | — |
| Cadmium | 100 | 4.34 | 18.10 | 8.60 |
| Chromium | 100 | 0.20 | 0.30 | 0.24 |
| Copper | 100 | 2.3 | 7.0 | 4.7 |
| Iron | 100 | 49.0 | 112.0 | 79.1 |
| Lead | 50 | nd | 0.40 | 0.35 |
| Manganese | 100 | 0.7 | 1.2 | 0.9 |
| Nickel | 8 | nd | 0.300 | 0.300 |
| Selenium | 100 | 0.38 | 0.68 | 0.48 |
| Silver | 50 | nd | 0.120 | 0.093 |
| Thallium | 100 | 0.50 | 0.90 | 0.72 |
| Tin | 100 | 0.600 | 1.100 | 0.858 |
| Zinc | 100 | 20.5 | 36.6 | 29.6 |
| *Pesticides* (*ppb*) | | | | |
| HCB | 100 | 4.2 | 7.2 | 5.7 |
| Total chlordane | 8 | nd | 15.0 | 15.0 |
| Total DDT | 100 | 181.7 | 438.1 | 230.2 |
| *Total PCB* (*ppb*) | 100 | 154.2 | 460.7 | 299.1 |
| *Lipids* (*% weight*) | 100 | 25.2 | 55.3 | 38.5 |

na = not available; nd = not detected

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




## Figure 7.2

Concentrations of metals with detection rates ≥20% in liver tissues of Pacific sanddabs collected from each PLOO trawl zone during 2012. Trawl Zone 1 is considered nearfield (bold; see text). TZ = trawl zone.

Most contaminants detected in fish muscle tissues during 2012 occurred at concentrations below state, national, and international limits or standards (Tables 7.3, 7.4). Exceptions included: (1) arsenic, which occurred at levels higher than median international standards in samples of greenspotted, vermilion, and mixed rockfish; (2) selenium, which exceeded international standards in all samples; (3) total PCB, which exceeded state OEHHA fish contaminant goals in samples of copper, starry, and mixed rockfish.

## Discussion

Several trace metals, PCB congeners, and the chlorinated pesticides DDT, HCB, and chlordane were detected in liver tissues from Pacific sanddabs collected in the Point Loma outfall region during 2012. Many of the same metals, PCBs, DDT and HCB were also detected in rockfish muscle tissues during the year, although often less frequently and/or in lower concentrations. Although tissue contaminant concentrations varied among different species of fish and between stations, all values were within ranges reported previously for Southern California Bight (SCB) fishes (see Mearns et al. 1991, Allen et al. 1998, City of San Diego 2000, City of San Diego 2007). Additionally, all muscle tissue samples from rockfish collected in the region had DDT concentrations below USFDA action limits, OEHHA fish contaminant goals, and international standards. However, several rockfish composite samples had concentrations of arsenic and selenium above the median international standards for human consumption, and several had PCB concentrations that exceeded OEHHA fish contaminant goals. Elevated levels of arsenic, selenium, and PCBs are not uncommon in sportfish from the PLOO survey area (City of San Diego 2007–2012) or from the rest of the San Diego region (see City of San Diego 2013b and references therein). For example, muscle tissue samples from fishes collected over the years in the South Bay outfall survey area since 1995, including the Coronado Islands, have occasionally had concentrations of metals such as arsenic, selenium and mercury that exceeded different consumption limits.

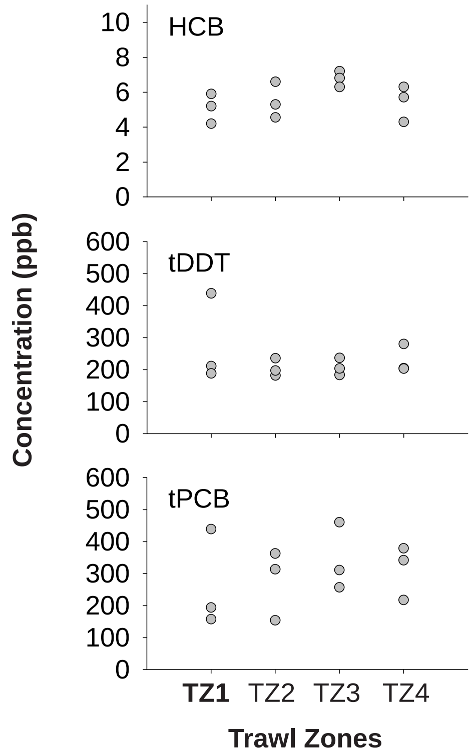



**Figure 7.3**
Concentrations of HCB, tDDT, and tPCB in liver tissues of Pacific sanddabs collected from each PLOO trawl zone during 2012. Trawl Zone 1 is considered nearfield (bold; see text). TZ = trawl zone.

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

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

Overall, there was no evidence of contaminant bioaccumulation in PLOO fishes during 2012 that could be associated with wastewater discharge from the outfall. Concentrations of most contaminants

## Table 7.3

Summary of metals in muscle tissues of fishes collected from PLOO rig fishing stations during 2012. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the detection rate and maximum value for all species. 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 | Ni | Se | Ag | Tl | Sn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Copper rockfish | | | | | | | | | | | | | | | | | |
| n (out of 1) | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| Min | 5.0 | — | 1.1 | — | — | — | 0.35 | — | 2.5 | — | — | — | **0.62** | — | 0.55 | — | 4.6 |
| Max | 5.0 | — | 1.1 | — | — | — | 0.35 | — | 2.5 | — | — | — | **0.62** | — | 0.55 | — | 4.6 |
| Mean | 5.0 | — | 1.1 | — | — | — | 0.35 | — | 2.5 | — | — | — | **0.62** | — | 0.55 | — | 4.6 |
| Greenspotted rockfish | | | | | | | | | | | | | | | | | |
| n (out of 1) | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| Min | — | — | **2.2** | — | — | — | 0.20 | — | 3.0 | — | — | — | **0.37** | — | 0.50 | — | 3.9 |
| Max | — | — | **2.2** | — | — | — | 0.20 | — | 3.0 | — | — | — | **0.37** | — | 0.50 | — | 3.9 |
| Mean | — | — | **2.2** | — | — | — | 0.20 | — | 3.0 | — | — | — | **0.37** | — | 0.50 | — | 3.9 |
| Mixed rockfish | | | | | | | | | | | | | | | | | |
| n (out of 2) | 1 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 2 |
| Min | nd | — | 1.1 | — | — | — | 0.15 | — | nd | — | — | — | **0.45** | — | 0.50 | — | 3.6 |
| Max | 3.0 | — | **2.0** | — | — | — | 0.20 | — | 2.0 | — | — | — | **0.73** | — | 0.50 | — | 4.0 |
| Mean | 3.0 | — | **1.6** | — | — | — | 0.17 | — | 2.0 | — | — | — | **0.59** | — | 0.50 | — | 3.8 |
| Starry rockfish | | | | | | | | | | | | | | | | | |
| n (out of 1) | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| Min | — | — | 1.0 | — | — | — | 0.20 | — | 2.0 | — | — | — | **0.43** | — | 0.50 | — | 3.8 |
| Max | — | — | 1.0 | — | — | — | 0.20 | — | 2.0 | — | — | — | **0.43** | — | 0.50 | — | 3.8 |
| Mean | — | — | 1.0 | — | — | — | 0.20 | — | 2.0 | — | — | — | **0.43** | — | 0.50 | — | 3.8 |
| Vermilion rockfish | | | | | | | | | | | | | | | | | |
| n (out of 1) | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Min | — | — | **1.4** | — | — | — | 0.20 | — | — | — | — | — | **0.31** | — | — | — | 4.0 |
| Max | — | — | **1.4** | — | — | — | 0.20 | — | — | — | — | — | **0.31** | — | — | — | 4.0 |
| Mean | — | — | **1.4** | — | — | — | 0.20 | — | — | — | — | — | **0.31** | — | — | — | 4.0 |
| All Species: | | | | | | | | | | | | | | | | | |
| Detection Rate (%) | 33 | 0 | 100 | 0 | 0 | 0 | 100 | 0 | 67 | 0 | 0 | 0 | 100 | 0 | 83 | 0 | 100 |
| Max | 5.0 | nd | **2.2** | nd | nd | nd | 0.35 | nd | 3.0 | nd | nd | nd | **0.73** | nd | 0.55 | nd | 4.59 |
| OEHHA[b] | na | na | na | na | na | na | na | na | na | na | na | na | 7.4 | na | na | na | na |
| AL[c] | na | na | na | na | na | na | na | na | na | na | na | na | na | na | na | na | na |
| IS[c] | na | na | 1.4 | na | na | 1.0 | 1.0 | 20 | na | 2.0 | na | na | 0.3 | na | na | 175 | 70 |

na = not available; nd = not detected

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

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

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

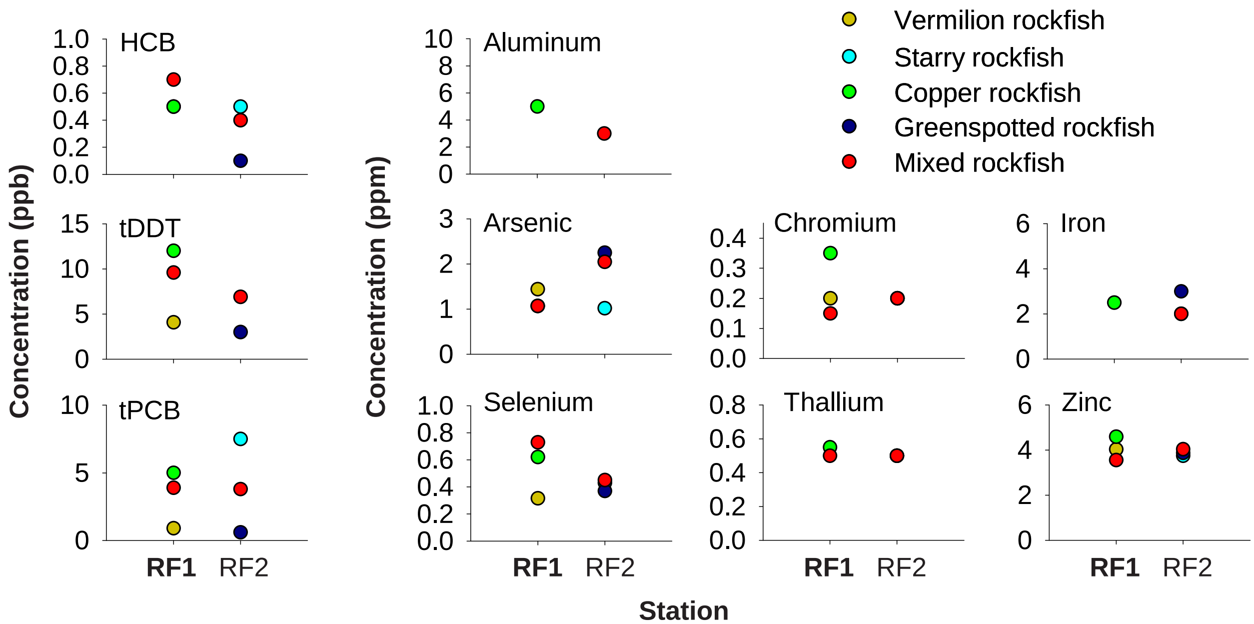



**Figure 7.4**
Concentrations of contaminants with detection rates ≥20% in muscle tissues of fishes collected from each PLOO rig fishing station during 2012. Station RF1 is considered nearfield (bold; see text).

were generally 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). 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 7.4

Summary of pesticides, tPCB, and lipids in muscle tissues of fishes collected from PLOO rig fishing stations during 2012. 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 | | | |
|---|---|---|---|---|
| | tDDT (ppb) | HCB (ppb) | tPCB (ppb) | Lipids (% weight) |
| Copper rockfish | | | | |
| n (out of 1) | 1 | 1 | 1 | 1 |
| Min | 12.0 | 0.5 | **5.0** | 2.2 |
| Max | 12.0 | 0.5 | **5.0** | 2.2 |
| Mean | 12.0 | 0.5 | **5.0** | 2.2 |
| Greenspotted rockfish | | | | |
| n (out of 1) | 1 | 1 | 1 | 1 |
| Min | 3.0 | 0.1 | 0.6 | 0.4 |
| Max | 3.0 | 0.1 | 0.6 | 0.4 |
| Mean | 3.0 | 0.1 | 0.6 | 0.4 |
| Mixed rockfish | | | | |
| n *(out of 2)* | 2 | 2 | 2 | 2 |
| Min | 6.9 | 0.4 | **3.8** | 1.1 |
| Max | 9.6 | 0.7 | **3.9** | 1.1 |
| Mean | 8.3 | 0.6 | **3.9** | 1.1 |
| Starry rockfish | | | | |
| n *(out of 1)* | 1 | 1 | 1 | 1 |
| Min | 16.3 | 0.5 | **7.5** | 1.8 |
| Max | 16.3 | 0.5 | **7.5** | 1.8 |
| Mean | 16.3 | 0.5 | **7.5** | 1.8 |
| Vermilion rockfish | | | | |
| n (out of 1) | 1 | 1 | 1 | 1 |
| Min | 4.1 | 0.5 | 0.9 | 0.5 |
| Max | 4.1 | 0.5 | 0.9 | 0.5 |
| Mean | 4.1 | 0.5 | 0.9 | 0.5 |
| All Species: | | | | |
| DR(%) | 100 | 100 | 100 | 100 |
| Max | 16.3 | 0.7 | **7.5** | 2.2 |
| OEHHA[b] | 21 | na | 3.6 | na |
| AL[c] | 5000 | 300 | na | na |
| IS[c] | 5000 | 100 | na | na |

na = not available; nd = not detected

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

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

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

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# Appendices

# Appendix A

# Supporting Data

# 2012 PLOO Stations

# Coastal Oceanographic Conditions

## Appendix A.1

Summary of temperature, salinity, dissolved oxygen (DO), pH, transmissivity, and chlorophyll *a* for various depth layers as well as the entire water column for all PLOO stations during 2012. For each quarter n = 831 (1–20 m), n = 1320 (21–60 m), n = 440 (61–80 m), n = 198 (81–100 m).

| | | Depth (m) | | | | |
|---|---|---|---|---|---|---|
| **Temperature (°C)** | | **1–20** | **21–60** | **61–80** | **81–100** | **1–100** |
| *February* | min | 11.1 | 10.0 | 9.9 | 9.6 | 9.6 |
| | max | 14.8 | 14.1 | 10.7 | 10.4 | 14.8 |
| | mean | 13.2 | 10.9 | 10.2 | 9.9 | 11.4 |
| | 95% CI | 0.1 | < 0.1 | < 0.1 | < 0.1 | 0.1 |
| *May* | min | 10.8 | 9.9 | 9.9 | 9.8 | 9.8 |
| | max | 18.4 | 14.7 | 10.2 | 10.0 | 18.4 |
| | mean | 15.1 | 10.5 | 10.0 | 9.9 | 11.8 |
| | 95% CI | 0.2 | < 0.1 | < 0.1 | < 0.1 | 0.1 |
| *August* | min | 12.0 | 10.5 | 10.2 | 10.1 | 10.1 |
| | max | 21.6 | 16.1 | 11.0 | 10.3 | 21.6 |
| | mean | 17.3 | 11.7 | 10.6 | 10.2 | 13.1 |
| | 95% CI | 0.2 | 0.1 | < 0.1 | < 0.1 | 0.1 |
| *November* | min | 13.7 | 12.6 | 11.7 | 11.2 | 11.2 |
| | max | 18.0 | 17.9 | 13.4 | 12.5 | 18.0 |
| | mean | 16.5 | 14.5 | 12.5 | 11.8 | 14.6 |
| | 95% CI | 0.1 | 0.1 | < 0.1 | < 0.1 | 0.1 |
| **Annual** | min | 10.8 | 9.9 | 9.9 | 9.6 | 9.6 |
| | max | 21.6 | 17.9 | 13.4 | 12.5 | 21.6 |
| | mean | 15.5 | 11.9 | 10.8 | 10.5 | 12.7 |
| | 95% CI | 0.1 | < 0.1 | < 0.1 | 0.1 | < 0.1 |

## Appendix A.1 *continued*

| Salinity (psu) | | Depth (m) 1–20 | 21–60 | 61–80 | 81–100 | 1–100 |
|---|---|---|---|---|---|---|
| *February* | min | 33.36 | 33.39 | 33.72 | 33.85 | 33.36 |
| | max | 33.59 | 33.90 | 34.00 | 34.09 | 34.09 |
| | mean | 33.43 | 33.67 | 33.87 | 33.95 | 33.65 |
| | 95% CI | < 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| *May* | min | 33.50 | 33.49 | 33.68 | 33.88 | 33.49 |
| | max | 33.81 | 33.87 | 33.96 | 34.08 | 34.08 |
| | mean | 33.57 | 33.68 | 33.85 | 33.97 | 33.70 |
| | 95% CI | < 0.01 | < 0.01 | < 0.01 | 0.01 | 0.01 |
| *August* | min | 33.33 | 33.35 | 33.53 | 33.64 | 33.33 |
| | max | 33.62 | 33.63 | 33.69 | 33.81 | 33.81 |
| | mean | 33.51 | 33.50 | 33.61 | 33.72 | 33.54 |
| | 95% CI | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 |
| *November* | min | 33.42 | 33.29 | 33.28 | 33.48 | 33.28 |
| | max | 33.63 | 33.61 | 33.60 | 33.69 | 33.69 |
| | mean | 33.54 | 33.46 | 33.51 | 33.57 | 33.50 |
| | 95% CI | < 0.01 | < 0.01 | < 0.01 | 0.01 | < 0.01 |
| **Annual** | min | 33.33 | 33.29 | 33.28 | 33.48 | 33.28 |
| | max | 33.81 | 33.90 | 34.00 | 34.09 | 34.09 |
| | mean | 33.51 | 33.58 | 33.71 | 33.80 | 33.60 |
| | 95% CI | < 0.01 | < 0.01 | 0.01 | 0.01 | < 0.01 |

## Appendix A.1 *continued*

| DO (mg/L) | | Depth (m) | | | | |
|---|---|---|---|---|---|---|
| | | 1–20 | 21–60 | 61–80 | 81–100 | 1–100 |
| *February* | min | 4.2 | 2.6 | 2.5 | 2.4 | 2.4 |
| | max | 8.6 | 8.0 | 3.8 | 3.3 | 8.6 |
| | mean | 6.9 | 4.0 | 3.0 | 2.7 | 4.6 |
| | 95% CI | 0.1 | <0.1 | <0.1 | <0.1 | 0.1 |
| *May* | min | 3.8 | 2.5 | 2.5 | 2.1 | 2.1 |
| | max | 9.2 | 8.9 | 4.4 | 3.0 | 9.2 |
| | mean | 7.7 | 4.2 | 3.0 | 2.5 | 4.9 |
| | 95% CI | 0.1 | <0.1 | <0.1 | <0.1 | 0.1 |
| *August* | min | 6.9 | 4.7 | 4.0 | 3.9 | 3.9 |
| | max | 9.8 | 9.6 | 5.7 | 4.9 | 9.8 |
| | mean | 8.5 | 6.6 | 4.8 | 4.3 | 6.7 |
| | 95% CI | <0.1 | 0.1 | <0.1 | <0.1 | 0.1 |
| *November* | min | 6.2 | 5.1 | 4.5 | 4.2 | 4.2 |
| | max | 8.7 | 8.2 | 7.4 | 5.6 | 8.7 |
| | mean | 7.7 | 6.9 | 5.3 | 4.7 | 6.7 |
| | 95% CI | <0.1 | <0.1 | 0.1 | <0.1 | <0.1 |
| **Annual** | min | 3.8 | 2.5 | 2.5 | 2.1 | 2.1 |
| | max | 9.8 | 9.6 | 7.4 | 5.6 | 9.8 |
| | mean | 7.7 | 5.4 | 4.0 | 3.5 | 5.7 |
| | 95% CI | <0.1 | <0.1 | 0.1 | 0.1 | <0.1 |

## Appendix A.1 *continued*

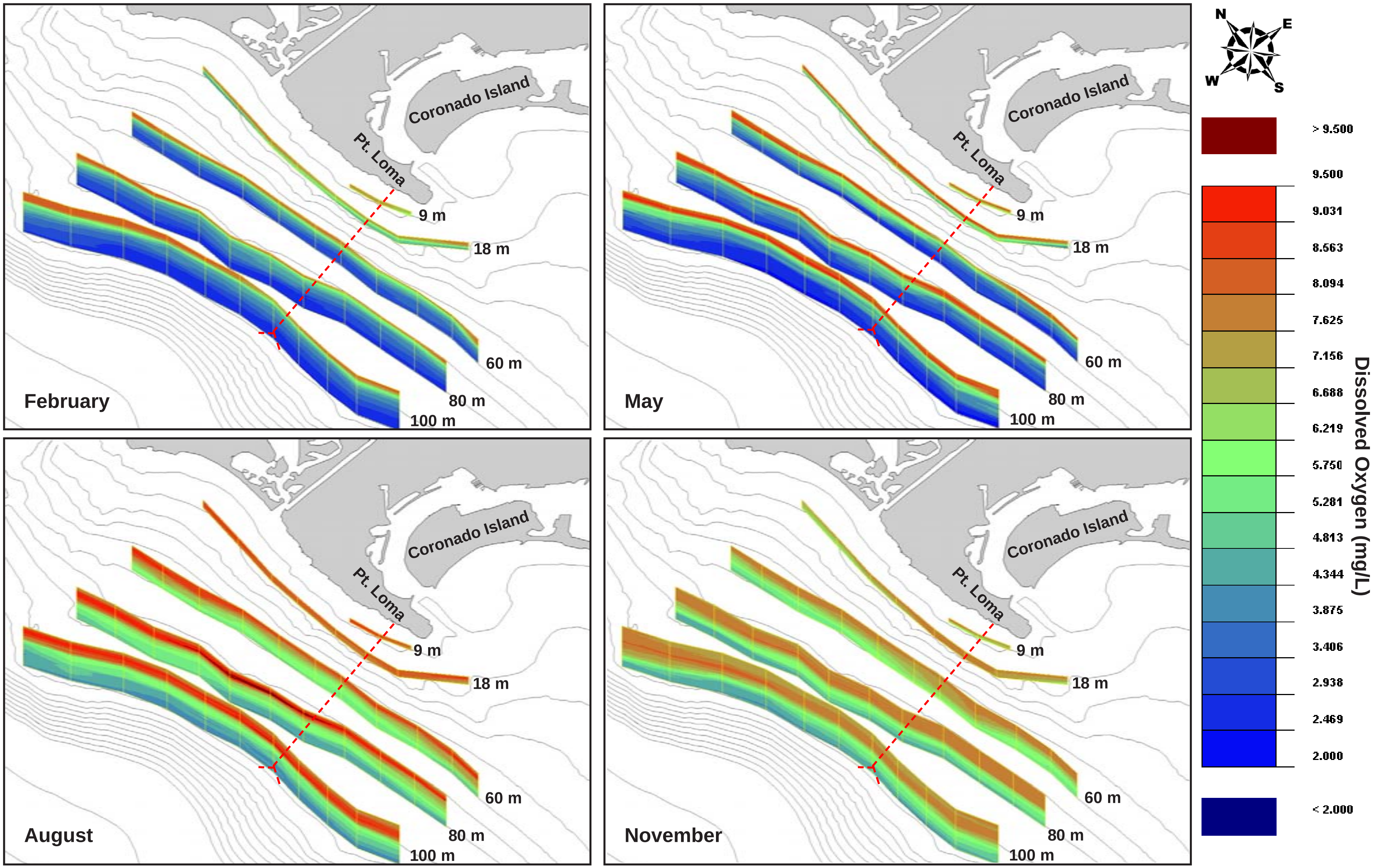
| pH | | Depth (m) | | | | |
|---|---|---|---|---|---|---|
| | | 1–20 | 21–60 | 61–80 | 81–100 | 1–100 |
| *February* | min | 7.8 | 7.7 | 7.7 | 7.7 | 7.7 |
| | max | 8.2 | 8.1 | 7.8 | 7.7 | 8.2 |
| | mean | 8.0 | 7.8 | 7.7 | 7.7 | 7.9 |
| | 95% CI | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| *May* | min | 7.8 | 7.8 | 7.7 | 7.7 | 7.7 |
| | max | 8.3 | 8.2 | 7.9 | 7.8 | 8.3 |
| | mean | 8.2 | 7.9 | 7.8 | 7.7 | 7.9 |
| | 95% CI | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| *August* | min | — | — | — | — | — |
| | max | — | — | — | — | — |
| | mean | — | — | — | — | — |
| | 95% CI | — | — | — | — | — |
| *November* | min | 8.0 | 7.9 | 7.9 | 7.9 | 7.9 |
| | max | 8.4 | 8.2 | 8.1 | 8.0 | 8.4 |
| | mean | 8.2 | 8.1 | 8.0 | 7.9 | 8.1 |
| | 95% CI | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| **Annual** | min | 7.8 | 7.7 | 7.7 | 7.7 | 7.7 |
| | max | 8.4 | 8.2 | 8.1 | 8.0 | 8.4 |
| | mean | 8.1 | 7.9 | 7.8 | 7.8 | 8.0 |
| | 95% CI | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |

## Appendix A.1 *continued*

| Transmissivity (%) | | Depth (m) | | | | |
|---|---|---|---|---|---|---|
| | | 1–20 | 21–60 | 61–80 | 81–100 | 1–100 |
| *February* | min | 73 | 78 | 80 | 84 | 73 |
| | max | 90 | 92 | 92 | 92 | 92 |
| | mean | 82 | 88 | 88 | 88 | 87 |
| | 95% CI | < 1 | < 1 | < 1 | < 1 | < 1 |
| *May* | min | 71 | 78 | 82 | 85 | 71 |
| | max | 96 | 97 | 95 | 94 | 97 |
| | mean | 87 | 91 | 89 | 89 | 89 |
| | 95% CI | < 1 | < 1 | < 1 | < 1 | < 1 |
| *August* | min | 79 | 80 | 79 | 87 | 79 |
| | max | 90 | 92 | 92 | 92 | 92 |
| | mean | 88 | 90 | 89 | 90 | 89 |
| | 95% CI | < 1 | < 1 | < 1 | < 1 | < 1 |
| *November* | min | 77 | 82 | 83 | 85 | 77 |
| | max | 90 | 90 | 91 | 91 | 91 |
| | mean | 87 | 88 | 89 | 88 | 88 |
| | 95% CI | < 1 | < 1 | < 1 | < 1 | < 1 |
| **Annual** | min | 71 | 78 | 79 | 84 | 71 |
| | max | 96 | 97 | 95 | 94 | 97 |
| | mean | 86 | 89 | 89 | 89 | 88 |
| | 95% CI | < 1 | < 1 | < 1 | < 1 | < 1 |

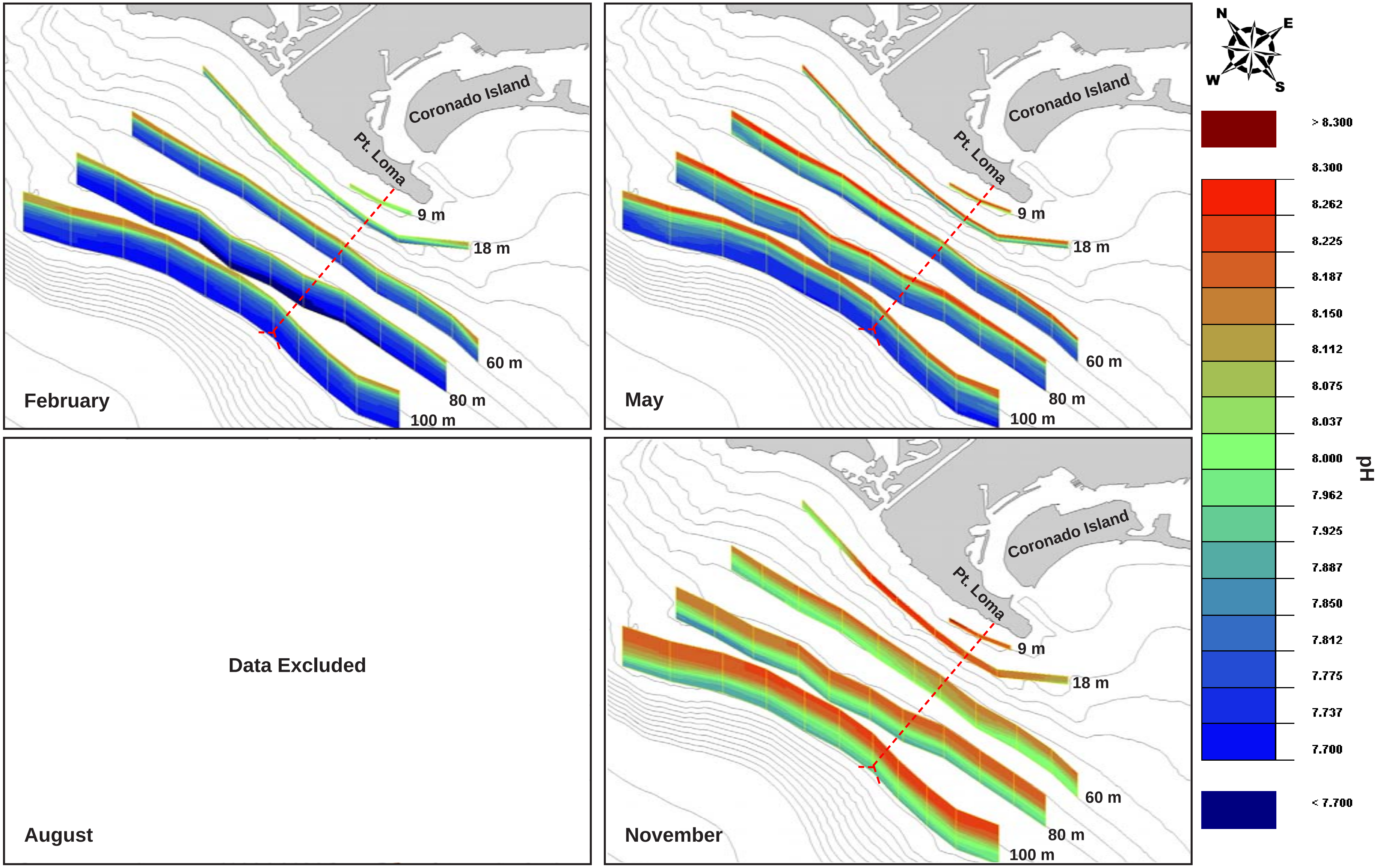
## Appendix A.1 *continued*

| Chlorophyll *a* (μg/L) | | Depth (m) 1–20 | 21–60 | 61–80 | 81–100 | 1–100 |
|---|---|---|---|---|---|---|
| *February* | min | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 |
| | max | 14.2 | 6.4 | 0.7 | 0.6 | 14.2 |
| | mean | 5.0 | 1.4 | 0.5 | 0.4 | 2.3 |
| | 95% CI | 0.2 | 0.1 | < 0.1 | < 0.1 | 0.1 |
| *May* | min | 0.4 | 0.5 | 0.4 | 0.4 | 0.4 |
| | max | 12.1 | 10.7 | 2.2 | 0.8 | 12.1 |
| | mean | 3.6 | 2.4 | 0.8 | 0.5 | 2.4 |
| | 95% CI | 0.2 | 0.1 | < 0.1 | < 0.1 | 0.1 |
| *August* | min | 0.5 | 0.5 | 0.4 | 0.4 | 0.4 |
| | max | 9.6 | 17.8 | 1.9 | 1.0 | 17.8 |
| | mean | 1.7 | 2.8 | 0.9 | 0.5 | 2.0 |
| | 95% CI | 0.1 | 0.1 | < 0.1 | < 0.1 | 0.1 |
| *November* | min | — | — | — | — | — |
| | max | — | — | — | — | — |
| | mean | — | — | — | — | — |
| | 95% CI | — | — | — | — | — |
| **Annual** | min | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | max | 14.2 | 17.8 | 2.2 | 1.0 | 17.8 |
| | mean | 3.4 | 2.2 | 0.7 | 0.5 | 2.2 |
| | 95% CI | 0.1 | 0.1 | < 0.1 | < 0.1 | < 0.1 |




## Appendix A.2

Dissolved oxygen recorded in 2012 for the PLOO region. Data were collected over four consecutive days during each survey. See Table 2.1 and text for specific dates and stations sampled each day.




## Appendix A.3

Measurements of pH recorded in 2012 for the PLOO region. Data were collected over four consecutive days during each survey. See Table 2.1 and text for specific dates and stations sampled each day. Data from August were excluded due to instrumentation issues.

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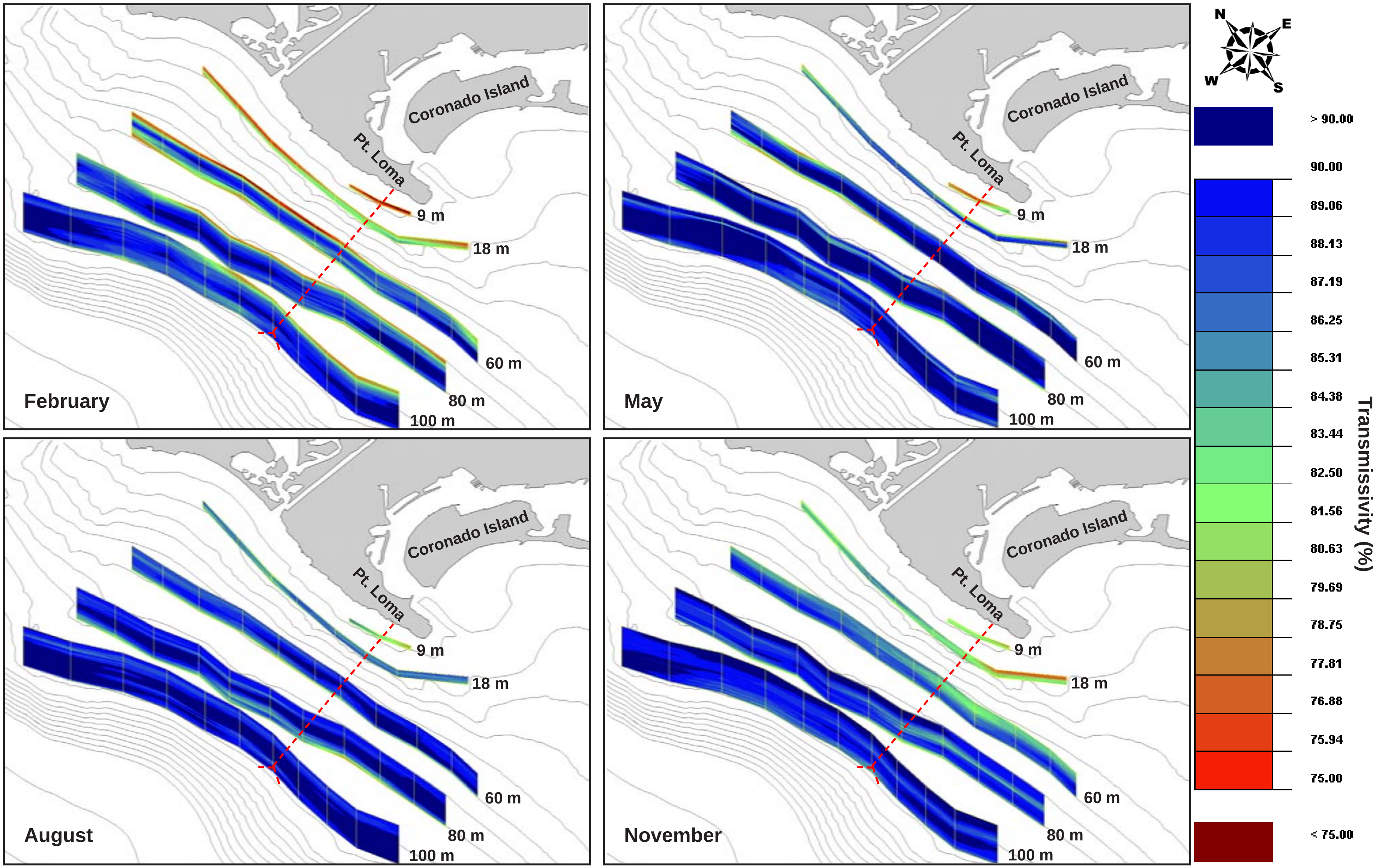


## Appendix A.4

Transmissivity recorded in 2012 for the PLOO region. Data were collected over four consecutive days during each survey. See Table 2.1 and text for specific dates and stations sampled each day.

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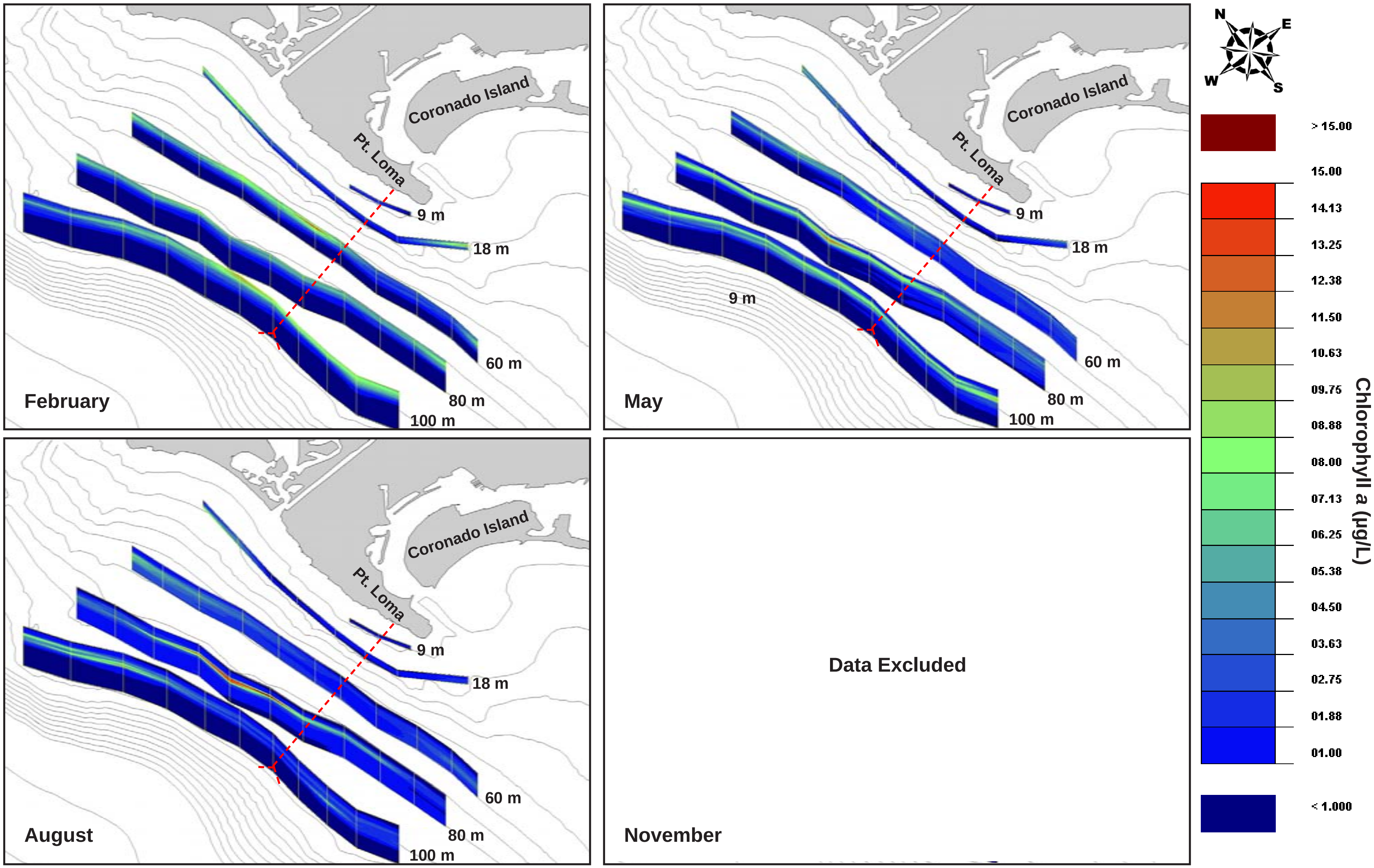


## Appendix A.5
Concentrations of chlorophyll *a* recorded in 2012 for the PLOO region. Data were collected over four consecutive days during each survey. See Table 2.1 and text for specific dates and stations sampled each day. Data from November were excluded due to instrumentation issues.

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## Appendix A.6

Summary of current velocity magnitude and direction from the 60- and 100-m ADCP instruments. Data are presented as seasonal means with 95% confidence intervals. Minimum and maximum angles of velocity are not shown due to the circular nature of the measurement.

**60-m ADCP**

| | | Magnitude (cm/s) | | | | Angle (°) | |
|---|---|---|---|---|---|---|---|
| | **Depth (m)** | **Min** | **Max** | **Mean** | **95% CI** | **Mean** | **95% CI** |
| *Winter* | 11 | 13 | 246 | 104 | 3 | 177 | 4 |
| | 15 | 5 | 222 | 90 | 2 | 178 | 4 |
| | 19 | 3 | 191 | 77 | 2 | 180 | 4 |
| | 23 | 2 | 151 | 67 | 2 | 186 | 5 |
| | 27 | 2 | 111 | 59 | 1 | 196 | 5 |
| | 31 | 0 | 104 | 54 | 1 | 193 | 5 |
| | 35 | 0 | 114 | 52 | 1 | 185 | 5 |
| | 39 | 2 | 116 | 50 | 1 | 175 | 5 |
| | 43 | 1 | 114 | 47 | 1 | 168 | 5 |
| | 47 | 0 | 109 | 42 | 1 | 184 | 5 |
| | 51 | 0 | 101 | 35 | 1 | 228 | 5 |
| | 55 | 3 | 84 | 33 | 1 | 273 | 3 |
| *Spring* | 11 | 14 | 385 | 105 | 3 | 175 | 3 |
| | 15 | 8 | 322 | 83 | 3 | 198 | 3 |
| | 19 | 3 | 269 | 67 | 2 | 229 | 3 |
| | 23 | 2 | 221 | 58 | 2 | 244 | 3 |
| | 27 | 0 | 171 | 51 | 2 | 256 | 3 |
| | 31 | 1 | 125 | 45 | 1 | 266 | 3 |
| | 35 | 2 | 117 | 41 | 1 | 270 | 4 |
| | 39 | 5 | 107 | 39 | 1 | 262 | 5 |
| | 43 | 4 | 96 | 37 | 1 | 259 | 5 |
| | 47 | 2 | 91 | 33 | 1 | 277 | 5 |
| | 51 | 0 | 82 | 29 | 1 | 295 | 4 |
| | 55 | 1 | 68 | 25 | 1 | 307 | 2 |

## Appendix A.6 *continued*

**60-m ADCP**

| | | Magnitude (cm/s) | | | | Angle (°) | |
|---|---|---|---|---|---|---|---|
| | **Depth (m)** | **Min** | **Max** | **Mean** | **95% CI** | **Mean** | **95% CI** |
| *Summer* | 11 | 8 | 384 | 91 | 3 | 159 | 3 |
| | 15 | 4 | 318 | 71 | 2 | 176 | 4 |
| | 19 | 2 | 263 | 65 | 2 | 221 | 4 |
| | 23 | 5 | 213 | 63 | 1 | 262 | 4 |
| | 27 | 0 | 162 | 63 | 1 | 267 | 4 |
| | 31 | 4 | 125 | 63 | 1 | 258 | 5 |
| | 35 | 5 | 129 | 64 | 1 | 272 | 5 |
| | 39 | 3 | 126 | 63 | 1 | 272 | 5 |
| | 43 | 6 | 118 | 58 | 1 | 273 | 5 |
| | 47 | 1 | 107 | 50 | 1 | 293 | 4 |
| | 51 | 1 | 92 | 40 | 1 | 303 | 3 |
| | 55 | 2 | 69 | 30 | 1 | 306 | 2 |
| *Fall* | 11 | 9 | 127 | 55 | 1 | 200 | 4 |
| | 15 | 1 | 106 | 51 | 1 | 214 | 4 |
| | 19 | 13 | 115 | 53 | 1 | 224 | 5 |
| | 23 | 6 | 120 | 55 | 1 | 231 | 5 |
| | 27 | 2 | 118 | 56 | 1 | 227 | 5 |
| | 31 | 7 | 104 | 56 | 1 | 216 | 6 |
| | 35 | 4 | 88 | 53 | 1 | 214 | 6 |
| | 39 | 4 | 83 | 48 | 1 | 204 | 6 |
| | 43 | 3 | 74 | 42 | 1 | 187 | 6 |
| | 47 | 1 | 64 | 34 | 1 | 199 | 6 |
| | 51 | 1 | 54 | 26 | 1 | 255 | 5 |
| | 55 | 6 | 54 | 22 | 1 | 282 | 2 |

## Appendix A.6 *continued*

**100-m ADCP**

| | | Magnitude (cm/s) | | | | Angle (°) | |
|---|---|---|---|---|---|---|---|
| | Depth (m) | Min | Max | Mean | 95% CI | Mean | 95% CI |
| *Winter* | 11 | 11 | 208 | 113 | 3 | 144 | 2 |
| | 15 | 1 | 315 | 139 | 4 | 168 | 3 |
| | 19 | 1 | 304 | 127 | 3 | 157 | 3 |
| | 23 | 2 | 292 | 114 | 3 | 158 | 3 |
| | 27 | 1 | 276 | 104 | 3 | 170 | 4 |
| | 31 | 1 | 253 | 95 | 3 | 175 | 4 |
| | 35 | 0 | 223 | 86 | 2 | 175 | 4 |
| | 39 | 2 | 196 | 80 | 2 | 173 | 4 |
| | 43 | 1 | 177 | 76 | 2 | 172 | 5 |
| | 47 | 0 | 165 | 75 | 2 | 172 | 5 |
| | 51 | 1 | 154 | 73 | 2 | 168 | 5 |
| | 55 | 2 | 143 | 70 | 2 | 162 | 5 |
| | 59 | 2 | 145 | 67 | 2 | 164 | 5 |
| | 63 | 2 | 147 | 64 | 2 | 163 | 5 |
| | 67 | 3 | 148 | 62 | 2 | 167 | 5 |
| | 71 | 6 | 146 | 59 | 2 | 167 | 5 |
| | 75 | 7 | 143 | 55 | 2 | 161 | 5 |
| | 79 | 2 | 138 | 52 | 1 | 142 | 5 |
| | 83 | 6 | 132 | 50 | 1 | 154 | 5 |
| | 87 | 1 | 125 | 48 | 1 | 154 | 5 |
| | 91 | 6 | 115 | 44 | 1 | 140 | 5 |
| | 95 | 3 | 95 | 37 | 1 | 154 | 4 |

## Appendix A.6 *continued*

**100-m ADCP**

| | Depth (m) | Magnitude (cm/s) Min | Max | Mean | 95% CI | Angle (°) Mean | 95% CI |
|---|---|---|---|---|---|---|---|
| *Spring* | 11 | 12 | 256 | 137 | 3 | 151 | 2 |
| | 15 | 7 | 249 | 141 | 3 | 155 | 3 |
| | 19 | 13 | 218 | 117 | 3 | 148 | 3 |
| | 23 | 5 | 204 | 98 | 2 | 141 | 3 |
| | 27 | 5 | 181 | 82 | 2 | 158 | 4 |
| | 31 | 4 | 154 | 69 | 2 | 168 | 4 |
| | 35 | 5 | 128 | 59 | 2 | 170 | 4 |
| | 39 | 2 | 109 | 54 | 1 | 169 | 5 |
| | 43 | 4 | 103 | 50 | 1 | 167 | 5 |
| | 47 | 5 | 100 | 45 | 1 | 204 | 5 |
| | 51 | 0 | 96 | 41 | 1 | 215 | 6 |
| | 55 | 3 | 94 | 37 | 1 | 223 | 6 |
| | 59 | 2 | 94 | 35 | 1 | 252 | 5 |
| | 63 | 1 | 91 | 32 | 1 | 259 | 5 |
| | 67 | 0 | 87 | 30 | 1 | 249 | 6 |
| | 71 | 1 | 81 | 27 | 1 | 227 | 6 |
| | 75 | 0 | 75 | 25 | 1 | 159 | 6 |
| | 79 | 3 | 70 | 25 | 1 | 119 | 5 |
| | 83 | 6 | 66 | 27 | 1 | 75 | 2 |
| | 87 | 13 | 63 | 31 | 1 | 88 | 2 |
| | 91 | 18 | 56 | 34 | 1 | 97 | 1 |
| | 95 | 16 | 52 | 31 | 0 | 106 | 1 |

## Appendix A.6 *continued*

**100-m ADCP**

| | Depth (m) | Magnitude (cm/s) Min | Max | Mean | 95% CI | Angle (°) Mean | 95% CI |
|---|---|---|---|---|---|---|---|
| *Summer* | 11 | 23 | 227 | 127 | 2 | 150 | 2 |
| | 15 | 4 | 222 | 121 | 2 | 151 | 2 |
| | 19 | 6 | 178 | 99 | 2 | 148 | 2 |
| | 23 | 10 | 145 | 81 | 2 | 147 | 3 |
| | 27 | 6 | 118 | 68 | 1 | 143 | 3 |
| | 31 | 3 | 115 | 57 | 1 | 136 | 3 |
| | 35 | 1 | 115 | 48 | 1 | 123 | 3 |
| | 39 | 1 | 116 | 43 | 1 | 110 | 3 |
| | 43 | 0 | 118 | 40 | 1 | 99 | 4 |
| | 47 | 8 | 118 | 41 | 1 | 80 | 4 |
| | 51 | 8 | 116 | 46 | 1 | 67 | 4 |
| | 55 | 6 | 113 | 52 | 1 | 80 | 6 |
| | 59 | 10 | 110 | 58 | 1 | 242 | 7 |
| | 63 | 4 | 105 | 63 | 1 | 321 | 3 |
| | 67 | 1 | 100 | 66 | 1 | 323 | 3 |
| | 71 | 5 | 96 | 65 | 1 | 311 | 4 |
| | 75 | 7 | 91 | 63 | 1 | 289 | 5 |
| | 79 | 5 | 87 | 58 | 1 | 215 | 7 |
| | 83 | 0 | 86 | 53 | 1 | 100 | 6 |
| | 87 | 7 | 86 | 48 | 1 | 49 | 2 |
| | 91 | 13 | 82 | 43 | 1 | 61 | 2 |
| | 95 | 11 | 69 | 32 | 1 | 73 | 2 |

# Appendix A.6 *continued*

**100-m ADCP**

| | | Magnitude (cm/s) | | | | Angle (°) | |
|---|---|---|---|---|---|---|---|
| | **Depth (m)** | **Min** | **Max** | **Mean** | **95% CI** | **Mean** | **95% CI** |
| *Fall* | 11 | 26 | 157 | 68 | 1 | 110 | 2 |
| | 15 | 1 | 184 | 54 | 2 | 169 | 5 |
| | 19 | 1 | 144 | 45 | 2 | 191 | 5 |
| | 23 | 5 | 113 | 42 | 1 | 216 | 6 |
| | 27 | 3 | 102 | 38 | 1 | 203 | 6 |
| | 31 | 3 | 99 | 32 | 1 | 193 | 6 |
| | 35 | 0 | 94 | 29 | 1 | 165 | 6 |
| | 39 | 1 | 91 | 27 | 1 | 157 | 6 |
| | 43 | 0 | 89 | 28 | 1 | 158 | 5 |
| | 47 | 4 | 87 | 33 | 1 | 159 | 5 |
| | 51 | 9 | 89 | 41 | 1 | 157 | 4 |
| | 55 | 13 | 94 | 48 | 1 | 152 | 4 |
| | 59 | 15 | 93 | 51 | 1 | 157 | 4 |
| | 63 | 13 | 90 | 52 | 1 | 162 | 4 |
| | 67 | 9 | 84 | 49 | 1 | 164 | 5 |
| | 71 | 2 | 77 | 46 | 1 | 159 | 5 |
| | 75 | 5 | 76 | 41 | 1 | 153 | 4 |
| | 79 | 3 | 73 | 36 | 1 | 145 | 4 |
| | 83 | 1 | 68 | 31 | 1 | 128 | 4 |
| | 87 | 1 | 64 | 28 | 1 | 141 | 3 |
| | 91 | 5 | 59 | 27 | 1 | 147 | 2 |
| | 95 | 2 | 54 | 27 | 1 | 172 | 2 |

# Appendix B

# Supporting Data

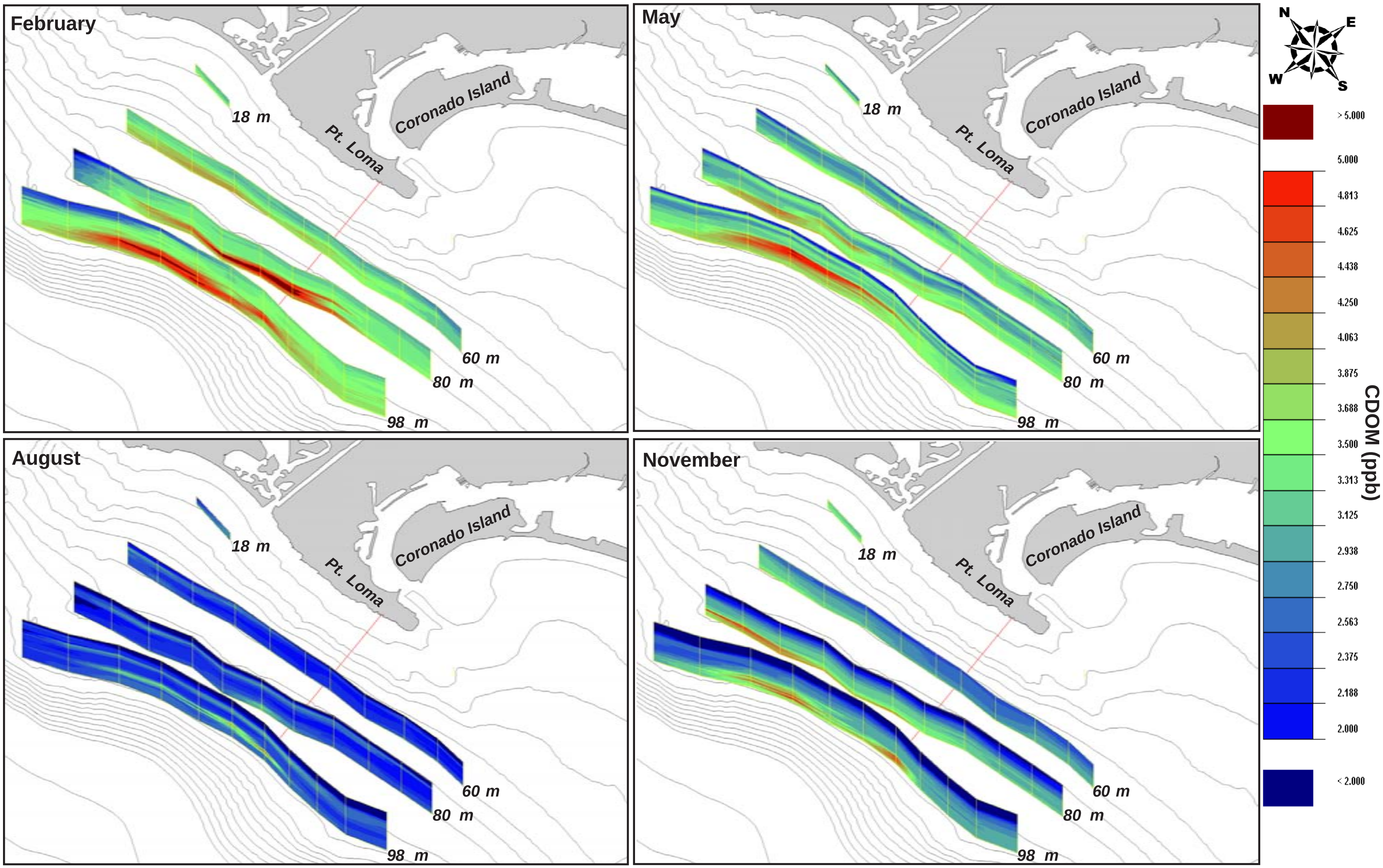
# 2012 PLOO Stations

# Water Quality Compliance & Plume Dispersion

## Appendix B.1

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

| Station | Date | Depth (m) | Total | Fecal | Entero | F:T |
|---|---|---|---|---|---|---|
| ***Shore Stations*** | | | | | | |
| D12 | 9 Feb 12 | — | 4000 | **2200** | **4200** | **0.55** |
| D8 | 22 Mar 12 | — | 460 | **440** | 34 | 0.96 |
| D8 | 8 Jul 12 | — | **19,000** | **6600** | **29,000** | **0.35** |
| D8 | 20 Jul 12 | — | 400 | 80 | **170** | 0.20 |
| D8 | 31 Aug 12 | — | 220 | 200 | **520** | 0.91 |
| D7 | 18 Sep 12 | — | — | 40 | **160** | — |
| D9 | 18 Sep 12 | — | 1800 | 30 | **240** | 0.02 |
| D8 | 17 Nov 12 | — | 400 | **520** | 44 | 1.30 |
| D12 | 11 Dec 12 | — | 80 | 20 | **260** | 0.25 |
| ***Kelp Bed Stations*** | | | | | | |
| no exceedances | | | | | | |
| ***Offshore Stations*** | | | | | | |
| F30 | 24 Feb 12 | 80 | — | — | **460** | — |
| F30 | 9 Aug 12 | 80 | — | — | **220** | — |




## Appendix B.2

CDOM values recorded in 2012 for the PLOO region. Data were collected over 3–4 days during each quarterly survey. See Table 2.1 and text for specific dates and stations sampled each day.

## Appendix B.3

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

| Month | Stations |
|---|---|
| February | F04, F05, F06, F10, F11, F12, F13, F14, F15, F16, F17, F23, F24, F25,F26, F27, F28, F32, F35, F36 |
| May | F04, F05, F06, F11, F12, F13, F14, F16, F25, F26, F27, F28, F36 |
| August | F04, F05, F06, F12, F15, F16, F17, F25, F27, F36 |
| November | F04, F05, F06, F10, F11, F12, F13, F15, F16, F17, F26, F27, F28, F35, F36 |

## Appendix B.4

Summary of oceanographic data from plume detections at PLOO offshore stations and corresponding non-plume reference stations during 2012. Bold values indicate out of range values. DO = dissolved oxygen; XMS = transmissivity; SD = standard deviation; CI = confidence interval.

| | | | Plume | | | Reference | | |
|---|---|---|---|---|---|---|---|---|
| Station | Date | Plume Width (m) | Mean DO | Mean pH | Mean XMS | DO (Mean - SD) | pH (Mean - SD) | XMS (Mean - 95% CI) |
| F18 | 23 Feb 12 | 9 | 2.7 | 7.70 | **84.4** | 2.8 | 7.71 | 86.3 |
| F19 | 23 Feb 12 | 30 | 2.8 | 7.70 | 87.8 | 3.0 | 7.73 | 86.8 |
| F20 | 23 Feb 12 | 25 | 2.8 | 7.70 | 88.1 | 2.9 | 7.72 | 86.8 |
| F21 | 23 Feb 12 | 12 | 2.7 | 7.69 | 87.9 | 2.8 | 7.71 | 87.5 |
| F22 | 23 Feb 12 | 9 | 2.9 | 7.70 | 89.1 | 2.9 | 7.72 | 88.5 |
| F30 | 24 Feb 12 | 14 | 2.8 | 7.72 | 87.9 | 2.8 | 7.71 | 86.9 |
| F31 | 24 Feb 12 | 14 | 2.6 | 7.71 | **85.3** | 2.5 | 7.72 | 88.5 |
| F32 | 24 Feb 12 | 34 | 2.8 | 7.72 | **87.1** | 2.7 | 7.71 | 87.9 |
| F33 | 24 Feb 12 | 25 | 2.8 | 7.72 | **87.6** | 2.7 | 7.71 | 87.7 |
| F34 | 24 Feb 12 | 24 | 2.8 | 7.72 | 88.0 | 2.7 | 7.71 | 87.6 |
| F21 | 9 May 12 | 15 | 3.3 | 7.83 | 94.1 | 3.0 | 7.80 | 89.0 |
| F22 | 9 May 12 | 10 | 3.6 | 7.84 | 94.8 | 3.0 | 7.79 | 88.9 |
| F23 | 9 May 12 | 25 | 2.9 | 7.82 | 90.2 | 2.8 | 7.77 | 87.5 |
| F30 | 10 May 12 | 7 | 3.1 | 7.77 | 88.9 | 2.7 | 7.77 | 87.0 |
| F31 | 10 May 12 | 23 | 2.9 | 7.76 | 87.8 | 2.7 | 7.77 | 87.5 |
| F32 | 10 May 12 | 36 | 2.8 | 7.76 | **87.3** | 2.7 | 7.76 | 87.6 |
| F33 | 10 May 12 | 37 | 2.7 | 7.77 | 90.2 | 2.7 | 7.76 | 87.5 |
| F34 | 10 May 12 | 37 | 2.7 | 7.78 | 91.4 | 2.7 | 7.76 | 87.4 |
| F20 | 8 Aug 12 | 16 | 4.4 | — | 87.1 | 4.5 | — | 84.4 |
| F29 | 9 Aug 12 | 8 | 4.3 | — | 89.1 | 4.3 | — | 85.7 |
| F30 | 9 Aug 12 | 15 | 4.4 | — | 88.0 | 4.5 | — | 84.9 |
| F31 | 9 Aug 12 | 22 | 4.6 | — | 88.5 | 4.6 | — | 85.1 |
| F32 | 9 Aug 12 | 10 | 4.7 | — | 90.1 | 4.6 | — | 86.9 |
| F33 | 9 Aug 12 | 14 | 4.5 | — | 89.0 | 4.7 | — | 86.8 |
| F34 | 9 Aug 12 | 11 | 4.6 | — | 89.1 | 4.6 | — | 86.7 |
| F23 | 15 Nov 12 | 20 | 4.7 | 7.90 | **86.6** | 5.0 | 7.96 | 88.6 |
| F24 | 15 Nov 12 | 22 | 4.7 | 7.90 | **87.3** | 5.0 | 7.96 | 88.3 |
| F25 | 15 Nov 12 | 20 | 4.8 | 7.90 | **88.1** | 5.0 | 7.96 | 88.6 |

## Appendix B.4 *continued*

| | | | Plume | | | Reference | | |
|---|---|---|---|---|---|---|---|---|
| Station | Date | Plume Width (m) | Mean DO | Mean pH | Mean XMS | DO (Mean - SD) | pH (Mean - SD) | XMS (Mean - 95% CI) |
| F30 | 16 Nov 12 | 22 | 4.8 | 7.95 | **86.5** | 4.7 | 7.93 | 88.2 |
| F31 | 16 Nov 12 | 10 | 4.5 | 7.92 | **86.9** | 4.5 | 7.91 | 88.4 |
| F32 | 16 Nov 12 | 19 | 4.7 | 7.94 | **87.6** | 4.8 | 7.94 | 88.5 |
| F33 | 16 Nov 12 | 30 | 4.5 | 7.93 | **87.4** | 4.8 | 7.94 | 88.5 |
| F34 | 16 Nov 12 | 26 | 4.6 | 7.93 | **87.8** | 4.7 | 7.93 | 88.3 |

## Appendix B.5

Summary of rainfall and bacteria levels at PLOO shore stations during 2012. Total coliform, fecal coliform, and *Enterococcus* densities are expressed as mean CFU/100 mL per month and for the entire year. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom; n = total number of samples.

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2012 Total Rain (in):** | | 0.40 | 1.19 | 0.97 | 0.88 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 | 0.29 | 2.11 |
| **D12** | *Total* | 21 | 808 | 9 | 13 | 50 | 9 | 50 | 20 | 46 | 85 | 28 | 28 |
| | *Fecal* | 8 | 444 | 2 | 3 | 4 | 2 | 2 | 7 | 3 | 6 | 18 | 10 |
| | *Entero* | 6 | 842 | 2 | 2 | 10 | 3 | 2 | 5 | 3 | 8 | 2 | 54 |
| **D11** | *Total* | 22 | 249 | 30 | 1624 | 124 | 34 | 60 | 20 | 22 | 88 | 36 | 69 |
| | *Fecal* | 8 | 9 | 7 | 38 | 5 | 8 | 28 | 6 | 5 | 12 | 22 | 19 |
| | *Entero* | 8 | 12 | 3 | 4 | 4 | 5 | 10 | 4 | 6 | 24 | 11 | 14 |
| **D10** | *Total* | 20 | 76 | 10 | 96 | 20 | 20 | 68 | 63 | 420 | 172 | 28 | 24 |
| | *Fecal* | 8 | 5 | 4 | 7 | 5 | 4 | 6 | 4 | 19 | 66 | 23 | 7 |
| | *Entero* | 10 | 11 | 2 | 3 | 3 | 2 | 3 | 4 | 24 | 19 | 3 | 2 |
| **D9** | *Total* | 60 | 18 | 9 | 32 | 14 | 16 | 13 | 14 | 413 | 507 | 20 | 20 |
| | *Fecal* | 4 | 2 | 2 | 2 | 2 | 2 | 8 | 2 | 17 | 282 | 7 | 3 |
| | *Entero* | 6 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 52 | 74 | 8 | 2 |
| **D8** | *Total* | 53 | 32 | 220 | 56 | 60 | 20 | 3892 | 57 | 155 | 250 | 252 | 108 |
| | *Fecal* | 5 | 6 | 106 | 2 | 4 | 3 | 1340 | 38 | 103 | 88 | 123 | 24 |
| | *Entero* | 2 | 2 | 28 | 2 | 3 | 3 | 5836 | 89 | 23 | 132 | 30 | 12 |
| **D7** | *Total* | 46 | 13 | 8 | 54 | 20 | 29 | 80 | 207 | 70 | 360 | 72 | 151 |
| | *Fecal* | 3 | 3 | 2 | 2 | 2 | 19 | 23 | 24 | 21 | 77 | 34 | 33 |
| | *Entero* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 10 | 51 | 7 | 8 | 3 |
| **D5** | *Total* | 56 | 13 | 6 | 56 | 16 | 56 | 96 | 27 | 92 | 136 | 132 | 20 |
| | *Fecal* | 3 | 2 | 2 | 26 | 2 | 3 | 2 | 5 | 3 | 14 | 21 | 6 |
| | *Entero* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 2 | 8 | 3 | 4 |
| **D4** | *Total* | 9 | 14 | 6 | 13 | 11 | 17 | 60 | 52 | 56 | 56 | 20 | 9 |
| | *Fecal* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 7 | 3 | 2 | 2 |
| | *Entero* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 18 | 4 | 2 | 2 |
| | n | 40 | 40 | 40 | 40 | 39 | 40 | 40 | 47 | 40 | 40 | 40 | 40 |
| **Monthly Means** | *Total* | 36 | 153 | 37 | 243 | 40 | 25 | 540 | 58 | 162 | 206 | 74 | 54 |
| | *Fecal* | 5 | 59 | 16 | 10 | 3 | 5 | 176 | 12 | 22 | 69 | 31 | 13 |
| | *Entero* | 5 | 110 | 5 | 2 | 3 | 3 | 732 | 16 | 22 | 34 | 8 | 12 |

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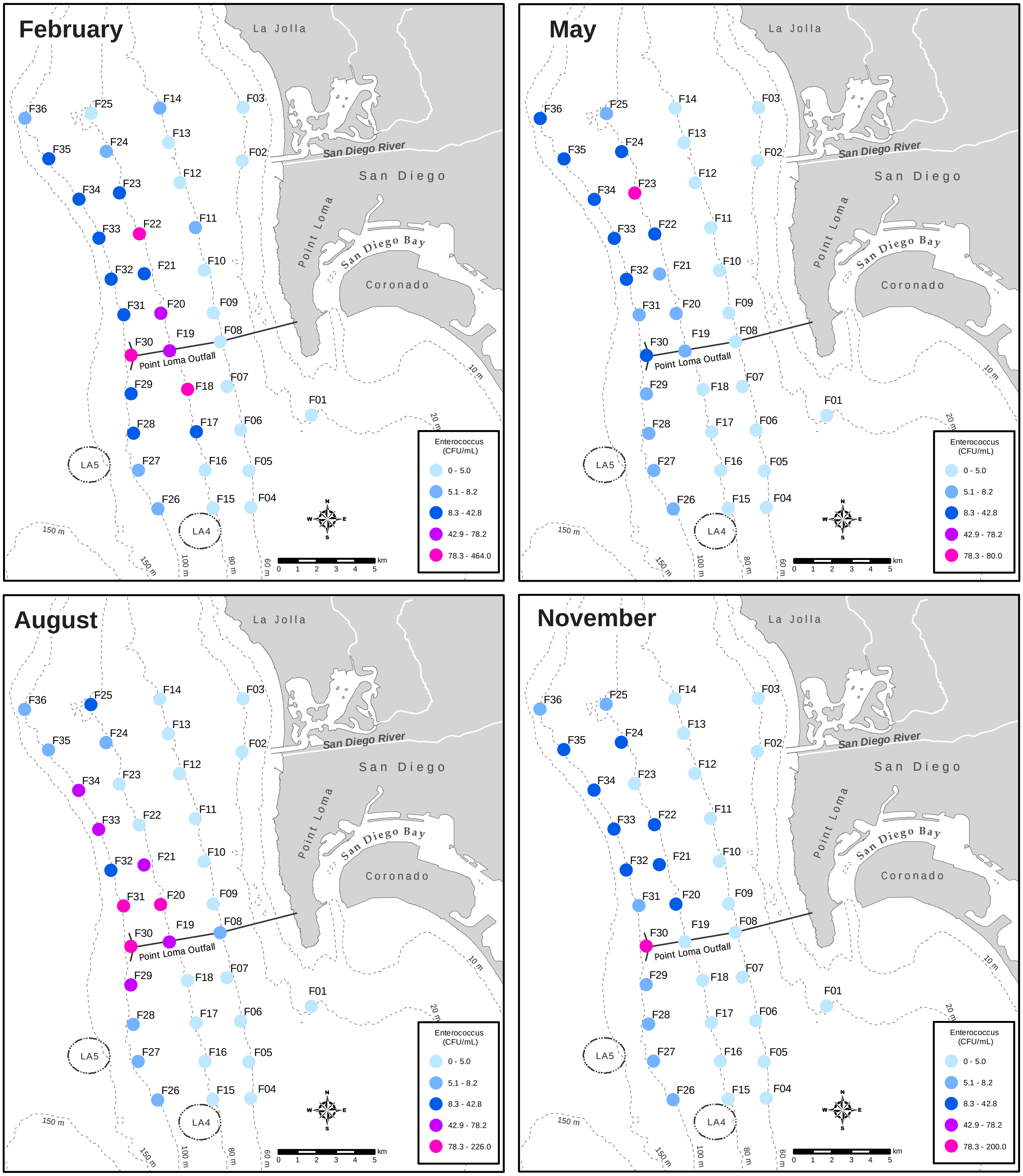
## Appendix B.6

Summary of bacteria levels at PLOO kelp bed and offshore stations. 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2012 Total Rain (in)** | 0.40 | 1.19 | 0.97 | 0.88 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.70 | 0.29 | 2.11 |
| **Kelp Bed Stations** | | | | | | | | | | | | |
| 9-m Contour (n=45) | | | | | | | | | | | | |
| *Total* | 3 | 3 | 4 | 9 | 6 | 3 | 4 | 4 | 4 | 14 | 5 | 20 |
| *Fecal* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| *Entero* | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 18-m Contour (n=75) | | | | | | | | | | | | |
| *Total* | 7 | 5 | 3 | 11 | 3 | 4 | 6 | 8 | 3 | 13 | 17 | 17 |
| *Fecal* | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 |
| *Entero* | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 |
| **Offshore Stations**[a] | | | | | | | | | | | | |
| 18-m Contour (n=9) | — | 2 | — | — | 2 | — | — | 2 | — | — | 2 | — |
| 60-m Contour (n=33) | — | 3 | — | — | 2 | — | — | 2 | — | — | 2 | — |
| 80-m Contour (n=40) | — | 10 | — | — | 3 | — | — | 8 | — | — | 4 | — |
| 98-m Contour (n=55) | — | 13 | — | — | 3 | — | — | 11 | — | — | 7 | — |

[a] *Enterococcus* only




# Appendix B.7

Distribution of vertically integrated concentrations of *Enterococcus* from 60, 80, and 98-m depths collected during PLOO quarterly surveys in 2012. Colors represent concentration ranges that correspond to <50th, >50th, >70th, >90th, and >95th percentiles for *Enterococcus* during 2012.

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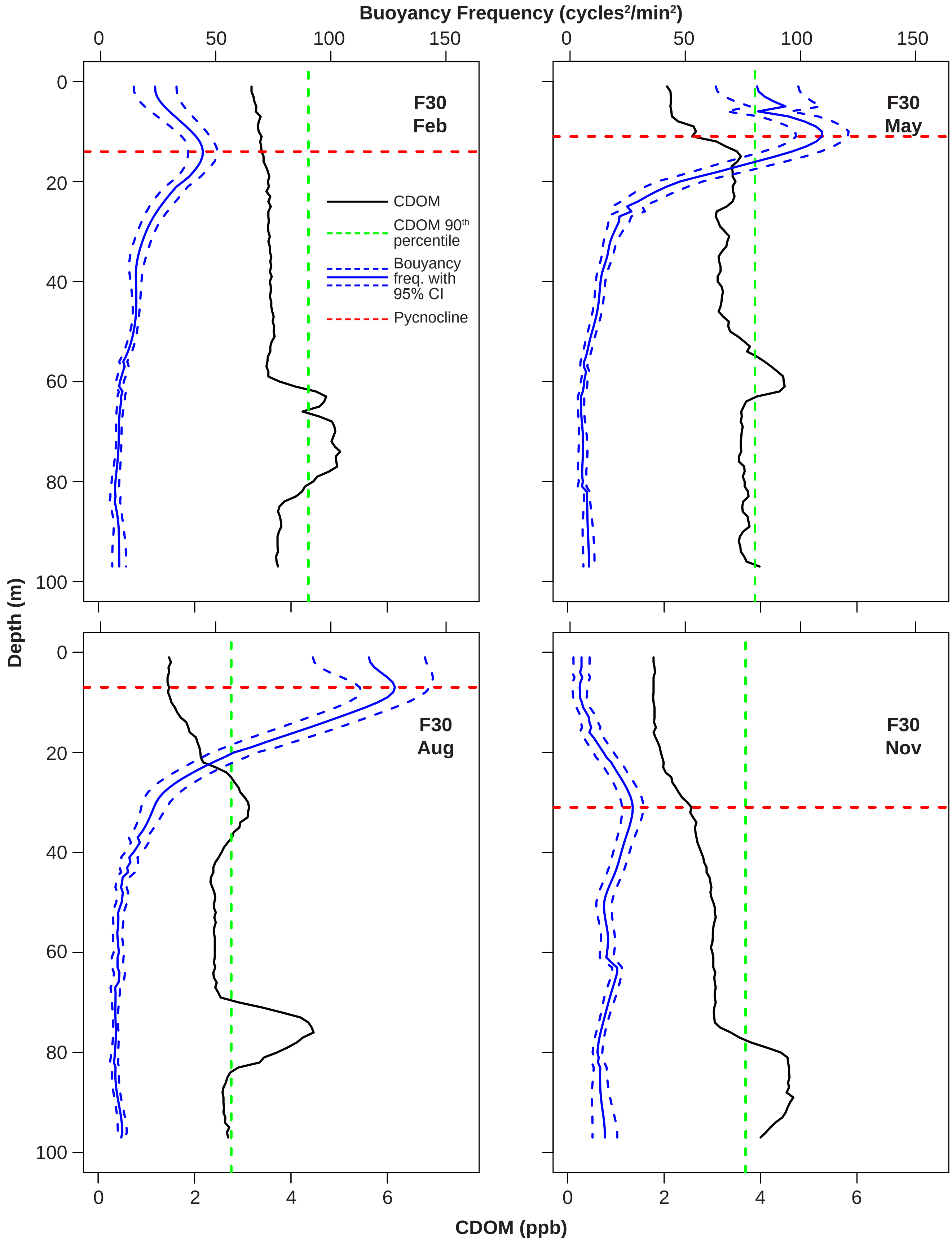
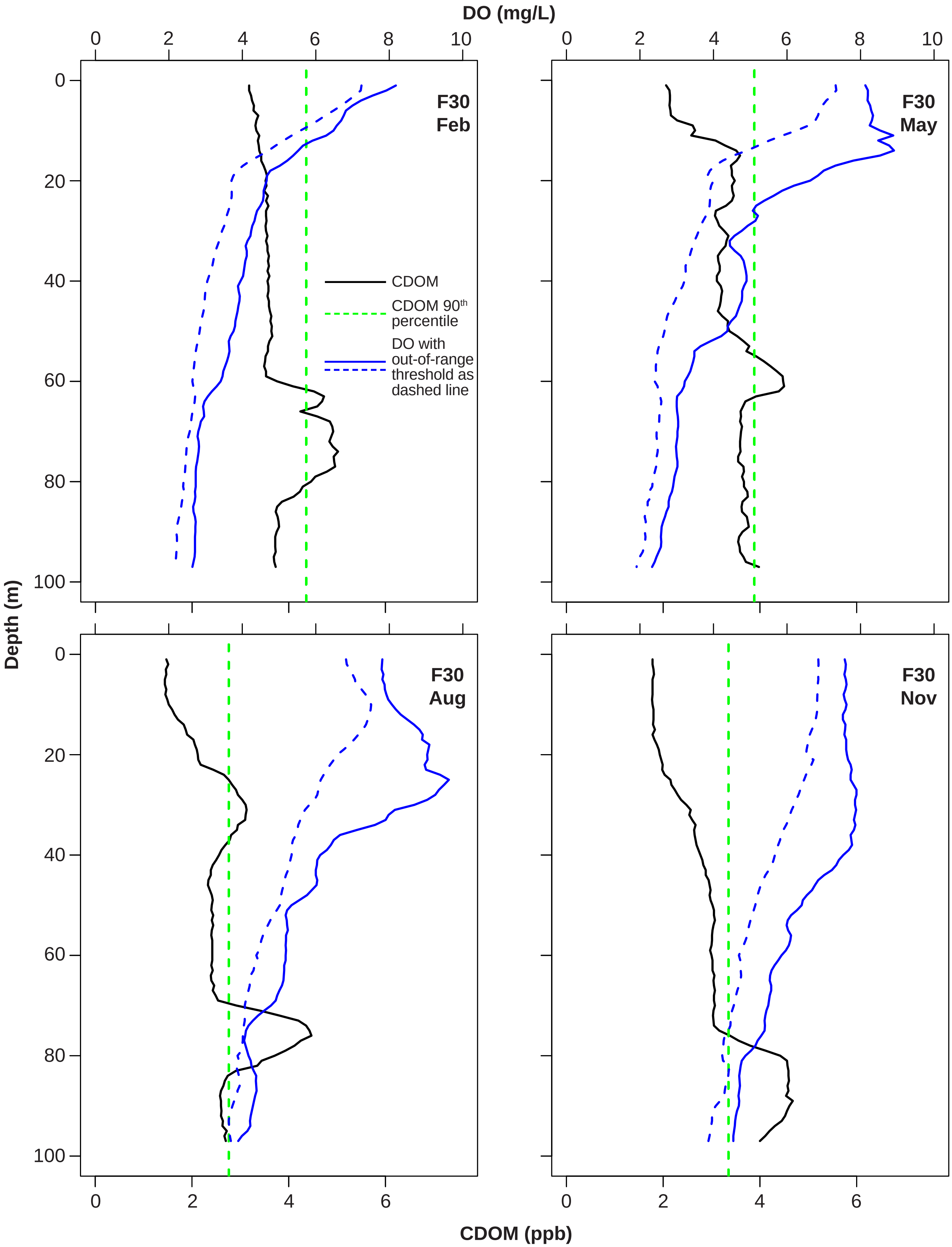



# Appendix B.8

Representative vertical profiles of CDOM and buoyancy frequency from outfall station F30 during 2012.




## Appendix B.9

Representative vertical profiles of CDOM and dissolved oxygen (DO) from outfall station F30 during 2012.

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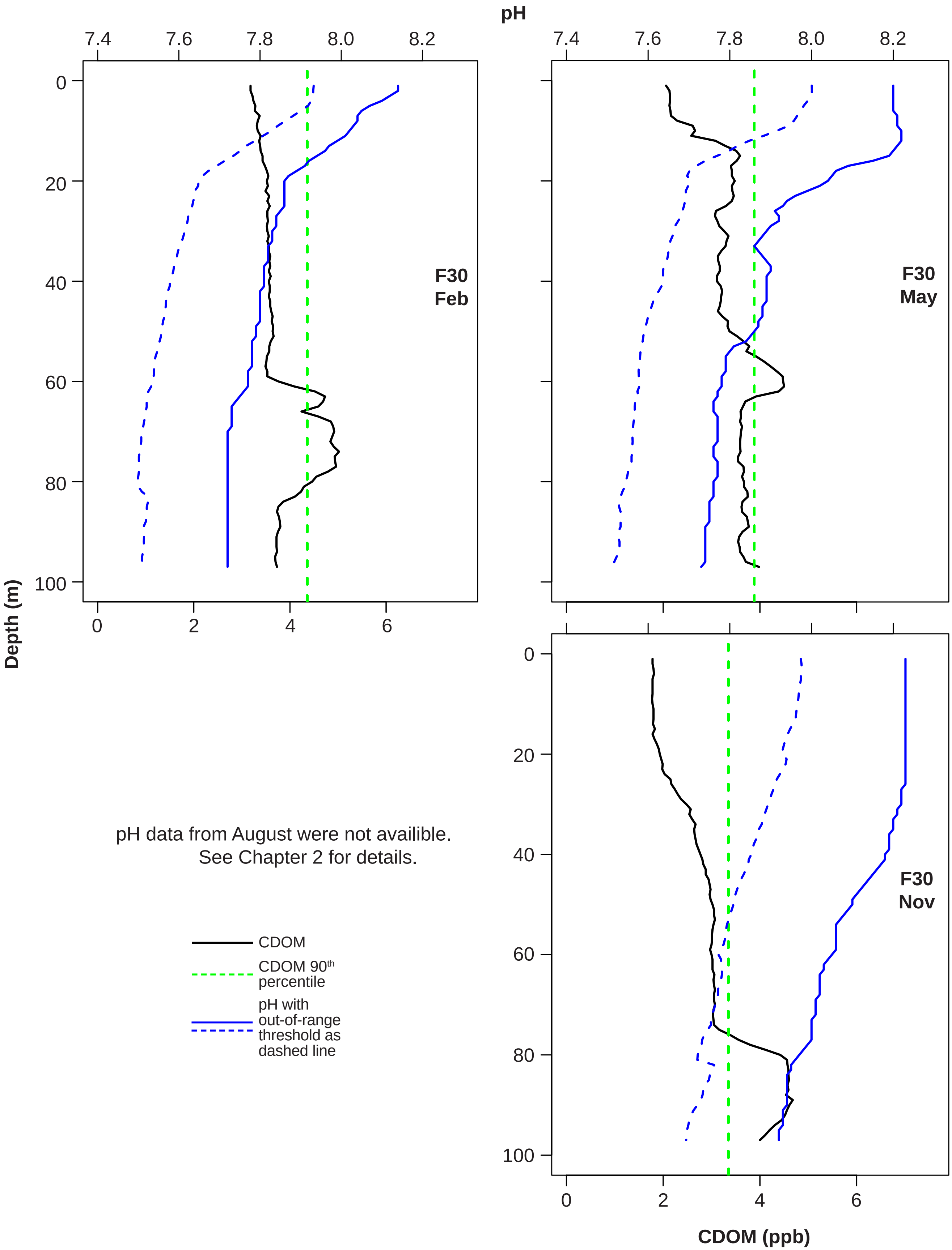


## Appendix B.10

Representative vertical profiles of CDOM and pH from outfall station F30 during 2012.

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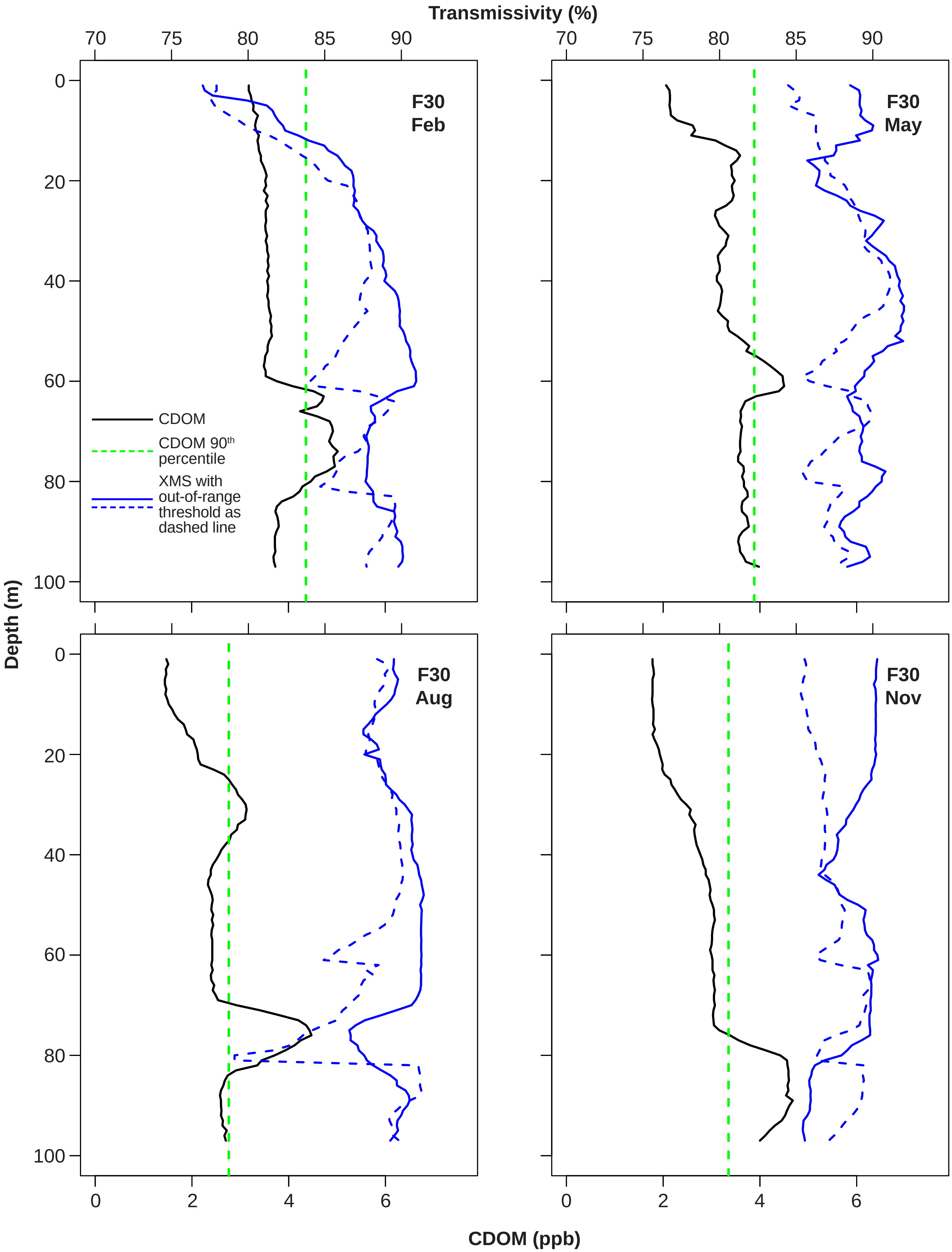



## Appendix B.11

Representative vertical profiles of CDOM and transmissivity from outfall station F30 during 2012. XMS = transmissivity.

# Appendix C

# Supporting Data

# 2012 PLOO Stations

# Sediment Conditions

# Appendix C.1

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

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

[a] No MDL available for this parameter.

## Appendix C.1 *continued*

| Parameter | MDL | | MDL |
|---|---|---|---|
| **Polychlorinated Biphenyl Congeners (PCBs) (ppt)** | | | |
| PCB 18 | 540 | PCB 126 | 720 |
| PCB 28 | 660 | PCB 128 | 570 |
| PCB 37 | 340 | PCB 138 | 590 |
| PCB 44 | 890 | PCB 149 | 500 |
| PCB 49 | 850 | PCB 151 | 640 |
| PCB 52 | 1000 | PCB 153/168 | 600 |
| PCB 66 | 920 | PCB 156 | 620 |
| PCB 70 | 1100 | PCB 157 | 700 |
| PCB 74 | 900 | PCB 158 | 510 |
| PCB 77 | 790 | PCB 167 | 620 |
| PCB 81 | 590 | PCB 169 | 610 |
| PCB 87 | 600 | PCB 170 | 570 |
| PCB 99 | 660 | PCB 177 | 650 |
| PCB 101 | 430 | PCB 180 | 530 |
| PCB 105 | 720 | PCB 183 | 530 |
| PCB 110 | 640 | PCB 187 | 470 |
| PCB 114 | 700 | PCB 189 | 620 |
| PCB 118 | 830 | PCB 194 | 420 |
| PCB 119 | 560 | PCB 201 | 530 |
| PCB 123 | 660 | PCB 206 | 510 |
| **Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)** | | | |
| 1-methylnaphthalene | 20 | Benzo[G,H,I]perylene | 20 |
| 1-methylphenanthrene | 20 | Benzo[K]fluoranthene | 20 |
| 2,3,5-trimethylnaphthalene | 20 | Biphenyl | 30 |
| 2,6-dimethylnaphthalene | 20 | Chrysene | 40 |
| 2-methylnaphthalene | 20 | Dibenzo(A,H)anthracene | 20 |
| 3,4-benzo(B)fluoranthene | 20 | Fluoranthene | 20 |
| Acenaphthene | 20 | Fluorene | 20 |
| Acenaphthylene | 30 | Indeno(1,2,3-CD)pyrene | 20 |
| Anthracene | 20 | Naphthalene | 30 |
| Benzo[A]anthracene | 20 | Perylene | 30 |
| Benzo[A]pyrene | 20 | Phenanthrene | 30 |
| Benzo[e]pyrene | 20 | Pyrene | 20 |

## Appendix C.2

Particle size classification schemes (based on Folk 1980) used in the analysis of sediments collected from the PLOO region in 2012. Included is a subset of the Wentworth scale presented as “phi” categories with corresponding Horiba channels, sieve sizes, and size fractions.

**Wentworth Scale**

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

[a] values correspond to Horiba channels; particles > 2000 µm measured by sieve
[b] sum of all silt and clay, also referred to as percent fines

## Appendix C.3

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

| Station | Class | Constituent | January | July | Units |
|---|---|---|---|---|---|
| B8 | DDT | p,p-DDE | 330 | ns | ppt |
| B9 | DDT | p,p-DDE | 300 | 320 | ppt |
| B10 | DDT | p,p-DDE | 220 | ns | ppt |
| B11 | DDT | p,p-DDE | 260 | ns | ppt |
| B12 | DDT | p,p-DDE | 210 | nd | ppt |
| E1 | DDT | p,p-DDE | 360 | ns | ppt |
| E1 | PCB | PCB 118 | 130 | ns | ppt |
| E1 | PCB | PCB 138 | 150 | ns | ppt |
| E1 | PCB | PCB 153/168 | 240 | ns | ppt |
| E1 | PCB | PCB 180 | 160 | ns | ppt |
| E2 | DDT | p,p-DDE | 350 | 350 | ppt |
| E2 | PAH | 3,4-benzo(B)fluoranthene | 35.1 | nd | ppb |
| E2 | PAH | Benzo[A]anthracene | 24.9 | nd | ppb |
| E2 | PAH | Benzo[A]pyrene | 27 | nd | ppb |
| E2 | PAH | Fluoranthene | 25.5 | nd | ppb |
| E2 | PAH | Pyrene | 26.2 | nd | ppb |
| E2 | PCB | PCB 44 | 270 | nd | ppt |
| E2 | PCB | PCB 49 | 140 | nd | ppt |
| E2 | PCB | PCB 52 | 560 | 110 | ppt |
| E2 | PCB | PCB 66 | 140 | nd | ppt |
| E2 | PCB | PCB 70 | 340 | 76 | ppt |
| E2 | PCB | PCB 74 | 91 | nd | ppt |
| E2 | PCB | PCB 87 | 810 | nd | ppt |
| E2 | PCB | PCB 99 | 340 | nd | ppt |
| E2 | PCB | PCB 101 | 1000 | 190 | ppt |
| E2 | PCB | PCB 105 | 380 | nd | ppt |
| E2 | PCB | PCB 118 | 920 | 290 | ppt |
| E2 | PCB | PCB 123 | 87 | nd | ppt |
| E2 | PCB | PCB 128 | 220 | nd | ppt |
| E2 | PCB | PCB 138 | 640 | 230 | ppt |
| E2 | PCB | PCB 149 | 550 | 190 | ppt |
| E2 | PCB | PCB 153/168 | 780 | 330 | ppt |
| E2 | PCB | PCB 156 | 110 | nd | ppt |
| E2 | PCB | PCB 180 | 260 | nd | ppt |
| E3 | DDT | p,p-DDE | 210 | ns | ppt |
| E3 | PAH | 3,4-benzo(B)fluoranthene | 29.7 | ns | ppb |
| E3 | PAH | Benzo[A]pyrene | 23.2 | ns | ppb |
| E3 | PAH | Fluoranthene | 21.2 | ns | ppb |
| E3 | PAH | Pyrene | 23.9 | ns | ppb |
| E3 | PCB | PCB 52 | 110 | ns | ppt |
| E3 | PCB | PCB 66 | 94 | ns | ppt |
| E3 | PCB | PCB 70 | 120 | ns | ppt |
| E3 | PCB | PCB 99 | 170 | ns | ppt |
| E3 | PCB | PCB 101 | 260 | ns | ppt |

nd = not detected; ns = not sampled

## Appendix C.3 *continued*

| Station | Class | Constituent | January | July | Units |
|---|---|---|---|---|---|
| E3 | PCB | PCB 118 | 320 | ns | ppt |
| E3 | PCB | PCB 138 | 300 | ns | ppt |
| E3 | PCB | PCB 149 | 430 | ns | ppt |
| E3 | PCB | PCB 151 | 180 | ns | ppt |
| E3 | PCB | PCB 153/168 | 750 | ns | ppt |
| E3 | PCB | PCB 177 | 290 | ns | ppt |
| E3 | PCB | PCB 180 | 1300 | ns | ppt |
| E3 | PCB | PCB 183 | 310 | ns | ppt |
| E3 | PCB | PCB 187 | 1400 | ns | ppt |
| E3 | PCB | PCB 194 | 1100 | ns | ppt |
| E3 | PCB | PCB 201 | 1600 | ns | ppt |
| E3 | PCB | PCB 206 | 1600 | ns | ppt |
| E5 | DDT | p,p-DDE | 180 | 260 | ppt |
| E5 | PCB | PCB 153/168 | 600 | nd | ppt |
| E7 | DDT | p,p-DDE | 340 | ns | ppt |
| E8 | DDT | p,p-DDE | nd | 240 | ppt |
| E9 | DDT | p,p-DDE | 370 | ns | ppt |
| E9 | PCB | PCB 66 | 80 | ns | ppt |
| E9 | PCB | PCB 70 | 88 | ns | ppt |
| E9 | PCB | PCB 153/168 | 230 | ns | ppt |
| E11 | DDT | p,p-DDE | nd | 240 | ppt |
| E14 | HCH | HCH, Alpha isomer | nd | 370 | ppt |
| E14 | Chlordane | Oxychlordane | nd | 270 | ppt |
| E14 | DDT | o,p-DDT | 330 | nd | ppt |
| E14 | DDT | p,p-DDE | 850 | 200 | ppt |
| E14 | DDT | p,p-DDT | 1800 | nd | ppt |
| E15 | DDT | p,p-DDE | 210 | ns | ppt |
| E17 | DDT | p,p-DDE | nd | 180 | ppt |
| E19 | DDT | p,p-DDE | 500 | ns | ppt |
| E19 | PAH | 2,6-dimethylnaphthalene | 23.4 | ns | ppb |
| E19 | PCB | PCB 153/168 | 150 | ns | ppt |
| E20 | DDT | p,p-DDE | 260 | nd | ppt |
| E20 | DDT | p,p-DDT | 960 | nd | ppt |
| E21 | DDT | p,p-DDE | 290 | ns | ppt |
| E23 | DDT | p,p-DDE | 320 | 300 | ppt |
| E23 | DDT | p,p-DDT | nd | 6200 | ppt |
| E25 | DDT | p,p-DDE | 330 | 240 | ppt |
| E26 | Chlordane | Alpha (cis) Chlordane | nd | 240 | ppt |
| E26 | DDT | p,p-DDE | 300 | 275 | ppt |

nd = not detected; ns = not sampled

## Appendix C.4

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

| | | Coarser Particles | | Coarse Sand | | Fine Sand | | Percent Fines | | | | | Visual Observations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Granules | VC Sand | C Sand | M Sand | F Sand | VF Sand | C Silt | M Silt | F Silt | VF Silt | Clay | |
| *88-m Stations* | B11 | 0.0 | 0.0 | 0.0 | 2.3 | 15.9 | 28.1 | 19.5 | 11.6 | 10.6 | 7.4 | 4.6 | pea gravel/shell hash |
| | B8 | 0.0 | 0.0 | 0.0 | 0.4 | 6.1 | 27.5 | 29.9 | 15.2 | 10.2 | 6.3 | 4.4 | |
| | E19 | 0.0 | 0.0 | 0.0 | 0.9 | 9.2 | 35.5 | 28.4 | 10.8 | 7.1 | 4.7 | 3.5 | shell hash/organic debris |
| | E7 | 0.0 | 0.0 | 0.0 | 0.9 | 12.0 | 37.6 | 25.5 | 10.1 | 6.6 | 4.3 | 3.1 | shell hash |
| | E1 | 0.0 | 0.0 | 0.0 | 2.7 | 21.9 | 30.9 | 18.6 | 10.1 | 7.4 | 4.9 | 3.4 | large shell hash |
| *98-m Stations* | B12 | 0.0 | 0.0 | 0.1 | 8.0 | 33.4 | 24.7 | 10.7 | 6.6 | 7.1 | 5.7 | 3.8 | pea gravel/shell hash |
| | B9 | 0.0 | 0.0 | 0.0 | 1.2 | 12.5 | 35.4 | 21.5 | 10.2 | 8.8 | 6.3 | 4.1 | mud pea-gravel |
| | E26 | 0.0 | 0.0 | 0.0 | 0.7 | 10.7 | 37.0 | 24.4 | 10.5 | 7.8 | 5.3 | 3.8 | shell hash |
| | E25 | 0.0 | 0.0 | 0.0 | 1.1 | 14.3 | 39.3 | 22.3 | 8.8 | 6.5 | 4.5 | 3.2 | shell hash |
| | E23 | 0.0 | 0.0 | 0.0 | 0.8 | 11.2 | 38.8 | 24.4 | 9.5 | 7.0 | 4.8 | 3.3 | |
| | E20 | 0.0 | 0.0 | 0.0 | 0.8 | 12.6 | 40.6 | 23.2 | 8.8 | 6.5 | 4.5 | 3.0 | |
| | E17[a] | 0.0 | 0.0 | 0.0 | 0.9 | 15.4 | 43.6 | 19.9 | 7.3 | 5.8 | 4.2 | 2.9 | shell hash/organic debris |
| | E14[a] | 0.0 | 0.0 | 0.0 | 0.9 | 16.9 | 46.6 | 17.4 | 6.0 | 5.3 | 4.1 | 2.7 | coarse black sand/shell hash/organic debris |
| | E11[a] | 0.0 | 0.0 | 0.0 | 1.2 | 16.3 | 43.8 | 20.0 | 6.9 | 5.3 | 3.9 | 2.8 | shell hash |
| | E8 | 0.0 | 0.0 | 0.0 | 1.3 | 17.2 | 41.8 | 19.8 | 7.5 | 5.6 | 3.9 | 2.8 | shell hash |
| | E5 | 0.0 | 0.0 | 0.0 | 1.3 | 16.9 | 40.1 | 19.7 | 8.0 | 6.3 | 4.6 | 3.1 | shell hash |
| | E2[s] | 6.0 | 3.4 | 6.6 | 8.5 | 13.7 | 24.9 | 36.9 | 0.0 | 0.0 | 0.0 | 0.0 | pea gravel |
| *116-m Stations* | B10 | 0.0 | 0.0 | 0.0 | 1.4 | 20.7 | 43.5 | 13.8 | 6.1 | 6.3 | 5.0 | 3.2 | shell hash |
| | E21 | 0.0 | 0.0 | 0.0 | 0.8 | 14.9 | 44.2 | 18.8 | 7.5 | 6.2 | 4.6 | 3.1 | |
| | E15[a] | 0.0 | 0.0 | 0.0 | 1.1 | 15.9 | 42.8 | 18.5 | 7.4 | 6.4 | 4.8 | 3.2 | |
| | E9[s] | 0.8 | 11.5 | 16.8 | 4.2 | 5.9 | 27.2 | 33.8 | 0.0 | 0.0 | 0.0 | 0.0 | shell hash |
| | E3 | 0.0 | 0.0 | 0.1 | 6.5 | 32.1 | 19.4 | 11.5 | 9.2 | 9.4 | 7.1 | 4.7 | shell hash |

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

## Appendix C.4 *continued*

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

| | | Coarser Particles | | Coarse Sand | | Fine Sand | | Percent Fines | | | | | Visual Observations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Granules | VC Sand | C Sand | M Sand | F Sand | VF Sand | C Silt | M Silt | F Silt | VF Silt | Clay | |
| *88-m Stations* | B11 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| | B8 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| | E19 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| | E7 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| | E1 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| *98-m Stations* | B12 | 0.0 | 0.0 | 0.1 | 6.2 | 31.2 | 26.1 | 11.2 | 7.3 | 8.4 | 6.4 | 3.2 | gravel/shell hash |
| | B9 | 0.0 | 0.0 | 0.0 | 1.3 | 13.8 | 35.5 | 19.7 | 9.8 | 9.4 | 6.8 | 3.8 | compacted mud gravel |
| | E26 | 0.0 | 0.0 | 0.0 | 0.7 | 10.3 | 35.7 | 23.3 | 10.8 | 9.4 | 6.3 | 3.5 | shell hash |
| | E25 | 0.0 | 0.0 | 0.0 | 1.2 | 14.4 | 38.0 | 21.3 | 9.2 | 7.8 | 5.3 | 2.8 | shell hash |
| | E23 | 0.0 | 0.0 | 0.0 | 0.8 | 11.1 | 38.0 | 24.1 | 9.9 | 7.8 | 5.2 | 3.1 | shell hash |
| | E20 | 0.0 | 0.0 | 0.0 | 1.0 | 13.1 | 40.9 | 21.6 | 8.6 | 7.3 | 5.0 | 2.6 | shell hash |
| | E17[a] | 0.0 | 0.0 | 0.0 | 1.0 | 15.4 | 43.5 | 19.8 | 7.2 | 6.1 | 4.4 | 2.6 | shell hash |
| | E14[a] | 0.0 | 0.0 | 0.0 | 0.9 | 16.5 | 44.9 | 17.3 | 6.6 | 6.4 | 4.8 | 2.6 | coarse black sand/shell hash |
| | E11[a] | 0.0 | 0.0 | 0.0 | 1.3 | 15.8 | 40.9 | 19.7 | 7.8 | 6.9 | 4.9 | 2.7 | shell hash |
| | E8 | 0.0 | 0.0 | 0.0 | 1.2 | 16.1 | 41.7 | 20.1 | 7.6 | 6.0 | 4.4 | 2.9 | shell hash |
| | E5 | 0.0 | 0.0 | 0.0 | 1.8 | 19.0 | 40.9 | 18.3 | 7.2 | 6.1 | 4.4 | 2.3 | shell hash |
| | E2[s] | 0.0 | 0.0 | 0.0 | 2.6 | 20.2 | 33.2 | 18.4 | 9.0 | 7.6 | 5.5 | 3.4 | gravel/shell hash |
| *116-m Stations* | B10 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| | E21 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| | E15[a] | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| | E9 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |
| | E3 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | |

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

## Appendix C.5

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

| | 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 | nr | 8.1 | 0.078 | 3.25 | 3.67 | ns | ns | ns | ns | ns |
| B8 | nr | 9.7 | 0.083 | 0.82 | 3.02 | ns | ns | ns | ns | ns |
| E19 | nr | 5.3 | 0.069 | 0.66 | 2.39 | ns | ns | ns | ns | ns |
| E7 | nr | 4.3 | 0.057 | 0.55 | 2.16 | ns | ns | ns | ns | ns |
| E1 | nr | 1.4 | 0.057 | 0.54 | 1.88 | ns | ns | ns | ns | ns |
| *98-m Depth Contour* | | | | | | | | | | |
| B12 | nr | 10.4 | 0.066 | 4.85 | 3.28 | 168 | 4.4 | 0.058 | 3.92 | 3.21 |
| B9 | nr | 9.6 | 0.073 | 0.96 | 2.86 | 200 | 1.1 | 0.078 | 0.97 | 2.82 |
| E26 | nr | 5.1 | 0.062 | 0.72 | 2.41 | 204 | 5.0 | 0.060 | 0.62 | 2.54 |
| E25 | nr | 11.6 | 0.058 | 0.55 | 2.33 | 121 | 2.7 | 0.053 | 0.55 | 2.63 |
| E23 | nr | 3.0 | 0.060 | 0.58 | 2.17 | 150 | 1.4 | 0.057 | 0.54 | 2.21 |
| E20 | nr | 19.6 | 0.059 | 0.57 | 2.09 | 150 | 2.4 | 0.055 | 0.52 | 2.07 |
| E17[a] | nr | 17.6 | 0.050 | 0.46 | 1.82 | 183 | 5.3 | 0.051 | 0.48 | 1.99 |
| E14[a] | nr | 24.2 | 0.048 | 0.50 | 1.66 | 212 | 30.8 | 0.050 | 0.50 | 1.64 |
| E11[a] | nr | 2.4 | 0.053 | 0.75 | 1.93 | 178 | 7.1 | 0.047 | 0.73 | 2.09 |
| E8 | nr | 3.4 | 0.047 | 0.58 | 2.00 | 135 | 2.3 | 0.045 | 0.50 | 2.06 |
| E5 | nr | 3.5 | 0.036 | 0.33 | 1.95 | 164 | 1.2 | 0.046 | 0.62 | 2.16 |
| E2 | nr | 11.1 | 0.060 | 0.69 | 3.06 | 135 | 2.0 | 0.050 | 0.59 | 2.48 |
| *116-m Depth Contour* | | | | | | | | | | |
| B10 | nr | 19.3 | 0.062 | 1.06 | 2.38 | ns | ns | ns | ns | ns |
| E21 | nr | 7.3 | 0.059 | 0.61 | 1.99 | ns | ns | ns | ns | ns |
| E15[a] | nr | 6.5 | 0.052 | 0.64 | 2.18 | ns | ns | ns | ns | ns |
| E9 | nr | 4.3 | 0.053 | 1.26 | 2.34 | ns | ns | ns | ns | ns |
| E3 | nr | 2.3 | 0.035 | 0.34 | 1.76 | ns | ns | ns | ns | ns |
| Detection Rate (%) | — | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

[a] nearfield station; nr = not reportable; ns = not sampled

## Appendix C.6

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during January 2012. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted (see Table 4.1).

| | Al | Sb | As | Ba | Be | Cd | Cr | Cu | Fe | Pb | Mn | Hg | Ni | Se | Ag | Tl | Sn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *88-m Depth Contour* | | | | | | | | | | | | | | | | | | |
| B11 | 8040 | nd | 4.1 | 44.8 | 0.236 | 0.18 | 22.2 | 9.6 | 16,900 | 8.20 | 129.0 | 0.029 | 9.01 | nd | nd | nd | 1.24 | 38.2 |
| B8 | 6370 | 0.36 | 3.1 | 54.8 | 0.189 | 0.14 | 17.6 | 9.5 | 11,100 | 7.92 | 103.0 | 0.038 | 8.76 | 0.48 | 0.19 | nd | 1.15 | 34.0 |
| E19 | 10,200 | 0.57 | 3.2 | 51.4 | 0.194 | 0.15 | 19.3 | 10.0 | 12,800 | 8.57 | 119.0 | 0.036 | 10.00 | nd | nd | nd | 1.78 | 38.2 |
| E7 | 8050 | 0.43 | 2.7 | 40.0 | 0.158 | 0.10 | 15.5 | 7.6 | 10,500 | 7.02 | 96.9 | 0.029 | 7.70 | nd | nd | nd | 1.52 | 27.2 |
| E1 | 6780 | nd | 2.8 | 43.3 | 0.155 | 0.10 | 15.7 | 9.2 | 10,800 | 8.28 | 85.8 | 0.049 | 6.91 | nd | nd | nd | 2.17 | 29.8 |
| *98-m Depth Contour* | | | | | | | | | | | | | | | | | | |
| B12 | 3220 | nd | 4.7 | 13.5 | 0.176 | 0.26 | 13.4 | 3.4 | 10,300 | 3.86 | 31.5 | 0.020 | 3.56 | 0.27 | nd | nd | 0.68 | 19.3 |
| B9 | 5190 | nd | 2.6 | 45.3 | 0.184 | 0.13 | 16.9 | 7.3 | 10,600 | 6.47 | 82.8 | 0.029 | 7.30 | nd | 0.15 | nd | 1.01 | 31.6 |
| E26 | 8840 | nd | 2.6 | 42.1 | 0.176 | 0.12 | 16.9 | 8.1 | 11,300 | 7.17 | 94.9 | 0.029 | 7.87 | nd | nd | nd | 1.08 | 29.0 |
| E25 | 8120 | nd | 2.3 | 37.6 | 0.170 | 0.10 | 16.0 | 7.1 | 10,700 | 6.69 | 88.2 | 0.026 | 7.10 | nd | nd | nd | 0.96 | 28.1 |
| E23 | 6560 | nd | 2.5 | 30.4 | 0.148 | 0.12 | 14.3 | 6.6 | 9250 | 5.68 | 72.7 | 0.031 | 6.61 | nd | nd | nd | 0.92 | 24.7 |
| E20 | 6920 | 0.45 | 2.4 | 43.7 | 0.163 | 0.18 | 16.7 | 8.2 | 10,700 | 6.73 | 88.6 | 0.028 | 8.07 | nd | nd | nd | 1.11 | 29.8 |
| E17[a] | 6940 | 0.45 | 2.2 | 31.2 | 0.143 | 0.13 | 14.1 | 6.7 | 9230 | 5.66 | 80.9 | 0.021 | 7.08 | 0.28 | nd | nd | 1.23 | 25.0 |
| E14[a] | 5110 | 0.43 | 2.7 | 27.7 | 0.136 | 0.10 | 12.9 | 5.9 | 8090 | 4.90 | 63.9 | 0.018 | 6.69 | nd | nd | nd | 0.92 | 22.1 |
| E11[a] | 5260 | 0.41 | 3.2 | 25.7 | 0.121 | 0.14 | 11.9 | 6.2 | 7940 | 4.35 | 63.0 | 0.023 | 6.17 | nd | nd | nd | 0.90 | 21.3 |
| E8 | 5040 | 0.44 | 2.6 | 27.8 | 0.133 | 0.08 | 12.1 | 6.4 | 8280 | 5.46 | 66.7 | 0.021 | 6.23 | nd | nd | nd | 1.54 | 22.1 |
| E5 | 5450 | 0.39 | 2.6 | 32.2 | 0.135 | 0.08 | 13.1 | 6.5 | 9010 | 5.64 | 71.3 | 0.027 | 6.14 | nd | nd | nd | 1.07 | 23.7 |
| E2 | 8820 | nd | 3.2 | 60.8 | 0.190 | 0.13 | 18.4 | 16.3 | 15,200 | 9.68 | 117.0 | 0.065 | 8.20 | nd | nd | nd | 1.52 | 40.1 |
| *116-m Depth Contour* | | | | | | | | | | | | | | | | | | |
| B10 | 4320 | nd | 2.0 | 27.1 | 0.163 | 0.16 | 15.4 | 5.8 | 9260 | 5.63 | 59.6 | 0.022 | 5.80 | nd | nd | nd | 0.73 | 26.3 |
| E21 | 7850 | nd | 2.3 | 37.1 | 0.164 | 0.15 | 16.9 | 7.8 | 10,900 | 7.06 | 86.9 | 0.025 | 7.70 | nd | nd | nd | 1.15 | 29.3 |
| E15[a] | 7070 | 0.38 | 2.1 | 28.7 | 0.146 | 0.11 | 14.0 | 6.5 | 9670 | 5.70 | 78.8 | 0.027 | 6.86 | nd | nd | nd | 1.24 | 24.0 |
| E9 | 6560 | 0.92 | 3.3 | 36.0 | 0.176 | 0.12 | 18.3 | 15.1 | 12,300 | 8.34 | 80.3 | 0.052 | 8.06 | nd | nd | nd | 1.34 | 51.1 |
| E3 | 7440 | 0.31 | 2.1 | 61.7 | 0.130 | 0.11 | 13.7 | 11.7 | 11,500 | 9.65 | 97.9 | 0.049 | 5.38 | nd | nd | nd | 1.18 | 32.8 |
| Detection Rate (%) | 100 | 54 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 14 | 9 | 0 | 100 | 100 |

[a] nearfield stations; nd = not detected

## Appendix C.6 *continued*

Concentrations of trace metals (ppm) in sediments from PLOO stations sampled during July 2012. See Appendix C.1 for MDLs and translation of periodic table symbols. Values that exceed thresholds are highlighted (see Table 4.1).

| | Al | Sb | As | Ba | Be | Cd | Cr | Cu | Fe | Pb | Mn | Hg | Ni | Se | Ag | Tl | Sn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *88-m Depth Contour* | | | | | | | | | | | | | | | | | | |
| B11 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| B8 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| E19 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| E7 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| E1 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| 98-m Depth Contour | | | | | | | | | | | | | | | | | | |
| B12 | 6440 | nd | 6.5 | 30.5 | 0.660 | nd | 26.1 | 3.9 | 21,000 | 6.74 | 64.0 | 0.017 | 6.09 | 0.25 | nd | nd | 1.30 | 36.3 |
| B9 | 11,100 | 0.37 | 4.4 | 72.5 | 0.665 | nd | 26.8 | 7.8 | 21,000 | 9.17 | 114.0 | 0.029 | 9.35 | nd | nd | nd | 1.40 | 42.6 |
| E26 | 9600 | 0.36 | 2.8 | 39.3 | 0.469 | nd | 16.3 | 7.2 | 11,500 | 6.76 | 97.5 | 0.026 | 8.30 | nd | nd | nd | 1.06 | 28.8 |
| E25 | 8820 | 0.32 | 2.6 | 35.1 | 0.435 | nd | 15.6 | 6.4 | 10,600 | 6.58 | 92.4 | 0.026 | 7.26 | nd | nd | nd | 1.00 | 30.2 |
| E23 | 9030 | 0.34 | 2.7 | 38.8 | 0.456 | nd | 16.2 | 7.3 | 11,100 | 6.93 | 94.1 | 0.029 | 7.71 | nd | nd | nd | 1.13 | 28.2 |
| E20 | 8220 | 0.30 | 3.0 | 32.2 | 0.403 | nd | 13.8 | 6.0 | 9540 | 5.83 | 82.8 | 0.024 | 6.57 | nd | nd | nd | 0.86 | 24.3 |
| E17[a] | 6300 | nd | 2.4 | 27.7 | 0.351 | nd | 12.0 | 5.8 | 8160 | 4.96 | 66.2 | 0.023 | 5.80 | nd | nd | nd | 0.85 | 21.8 |
| E14[a] | 5960 | nd | 2.8 | 24.0 | 0.403 | nd | 11.3 | 5.8 | 7700 | 4.41 | 61.9 | 0.022 | 5.40 | nd | nd | nd | 0.86 | 21.2 |
| E11[a] | 6990 | nd | 2.9 | 29.3 | 0.372 | nd | 12.7 | 5.8 | 9200 | 5.22 | 69.1 | 0.019 | 5.94 | nd | nd | nd | 0.82 | 23.2 |
| E8 | 7230 | nd | 2.5 | 30.9 | 0.376 | nd | 12.9 | 5.8 | 9360 | 5.42 | 72.1 | 0.022 | 6.03 | nd | nd | nd | 0.90 | 23.7 |
| E5 | 7880 | nd | 2.5 | 30.3 | 0.442 | nd | 13.8 | 5.9 | 9790 | 5.93 | 76.2 | 0.023 | 6.13 | nd | nd | nd | 1.10 | 24.5 |
| E2 | 8640 | nd | 3.0 | 46.1 | 0.448 | nd | 15.0 | 9.3 | 12,200 | 7.67 | 90.0 | 0.043 | 6.49 | nd | nd | nd | 1.03 | 29.4 |
| 116-m Depth Contour | | | | | | | | | | | | | | | | | | |
| B10 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| E21 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| E15[a] | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| E9 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| E3 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| Detection Rate (%) | 100 | 42 | 100 | 100 | 100 | 0 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 8 | 0 | 0 | 100 | 100 |

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

## Appendix C.7

Concentrations of hexachlorobenzene (HCB), total HCH, total chlordane (tChlor), total DDT, total PCB, and total PAH detected in sediments from PLOO stations sampled during January and July 2012. Values that exceed thresholds are highlighted (see Table 4.1).

| | January | | | | | | July | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HCB (ppt) | tHCH (ppt) | tChlor (ppt) | tDDT (ppt) | tPCB (ppt) | tPAH (ppb) | HCB (ppt) | tHCH (ppt) | tChlor (ppt) | tDDT (ppt) | tPCB (ppt) | tPAH (ppb) |
| *88-m Stations* | | | | | | | | | | | | |
| B11 | nd | nd | nd | 260 | nd | nd | ns | ns | ns | ns | ns | ns |
| B8 | nd | nd | nd | 330 | nd | nd | ns | ns | ns | ns | ns | ns |
| E19 | nd | nd | nd | 500 | 150 | 23.4 | ns | ns | ns | ns | ns | ns |
| E7 | 470 | nd | nd | 340 | nd | nd | ns | ns | ns | ns | ns | ns |
| E1 | nd | nd | nd | 360 | 680 | nd | ns | ns | ns | ns | ns | ns |
| *98-m Stations* | | | | | | | | | | | | |
| B12 | nd | nd | nd | 210 | nd | nd | nd | nd | nd | nd | nd | nd |
| B9 | nd | nd | nd | 300 | nd | nd | nd | nd | nd | 320 | nd | nd |
| E26 | nd | nd | nd | 300 | nd | nd | nd | nd | 240 | 275 | nd | nd |
| E25 | nd | nd | nd | 330 | nd | nd | nd | nd | nd | 240 | nd | nd |
| E23 | nd | nd | nd | 320 | nd | nd | nd | nd | nd | 6500 | nd | nd |
| E20 | nd | nd | nd | 1220 | nd | nd | nd | nd | nd | nd | nd | nd |
| E17[a] | nd | nd | nd | nd | nd | nd | nd | nd | nd | 180 | nd | nd |
| E14[a] | nd | nd | nd | 2980 | nd | nd | nd | 370 | 270 | 200 | nd | nd |
| E11[a] | nd | nd | nd | nd | nd | nd | nd | nd | nd | 240 | nd | nd |
| E8 | nd | nd | nd | nd | nd | nd | nd | nd | nd | 240 | nd | nd |
| E5 | nd | nd | nd | 180 | 600 | nd | nd | nd | nd | nd | nd | nd |
| E2 | nd | nd | nd | 350 | 7638 | 138.7 | nd | nd | nd | 350 | 1416 | nd |
| *116-m Stations* | | | | | | | | | | | | |
| B10 | nd | nd | nd | 220 | nd | nd | ns | ns | ns | ns | ns | ns |
| E21 | nd | nd | nd | 290 | nd | nd | ns | ns | ns | ns | ns | ns |
| E15[a] | nd | nd | nd | 210 | nd | nd | ns | ns | ns | ns | ns | ns |
| E9 | nd | nd | nd | 370 | 398 | nd | ns | ns | ns | ns | ns | ns |
| E3 | nd | nd | nd | 210 | 10,334 | 98 | ns | ns | ns | ns | ns | ns |
| Detection Rate (%) | 5 | 0 | 0 | 86 | 27 | 14 | 0 | 8 | 17 | 75 | 8 | 0 |

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

# Appendix D

# Supporting Data

# 2012 PLOO Stations

# Macrobenthic Communities

# Appendix D.1

Macrofaunal community parameters by grab for PLOO benthic stations sampled during 2012. SR=species richness (no. taxa/0.1 $m^2$); Abun=abundance (no. individuals/0.1 $m^2$); H'=Shannon diversity index; J'=evenness; Dom=Swartz dominance; BRI=benthic response index. Stations are listed north to south from top to bottom.

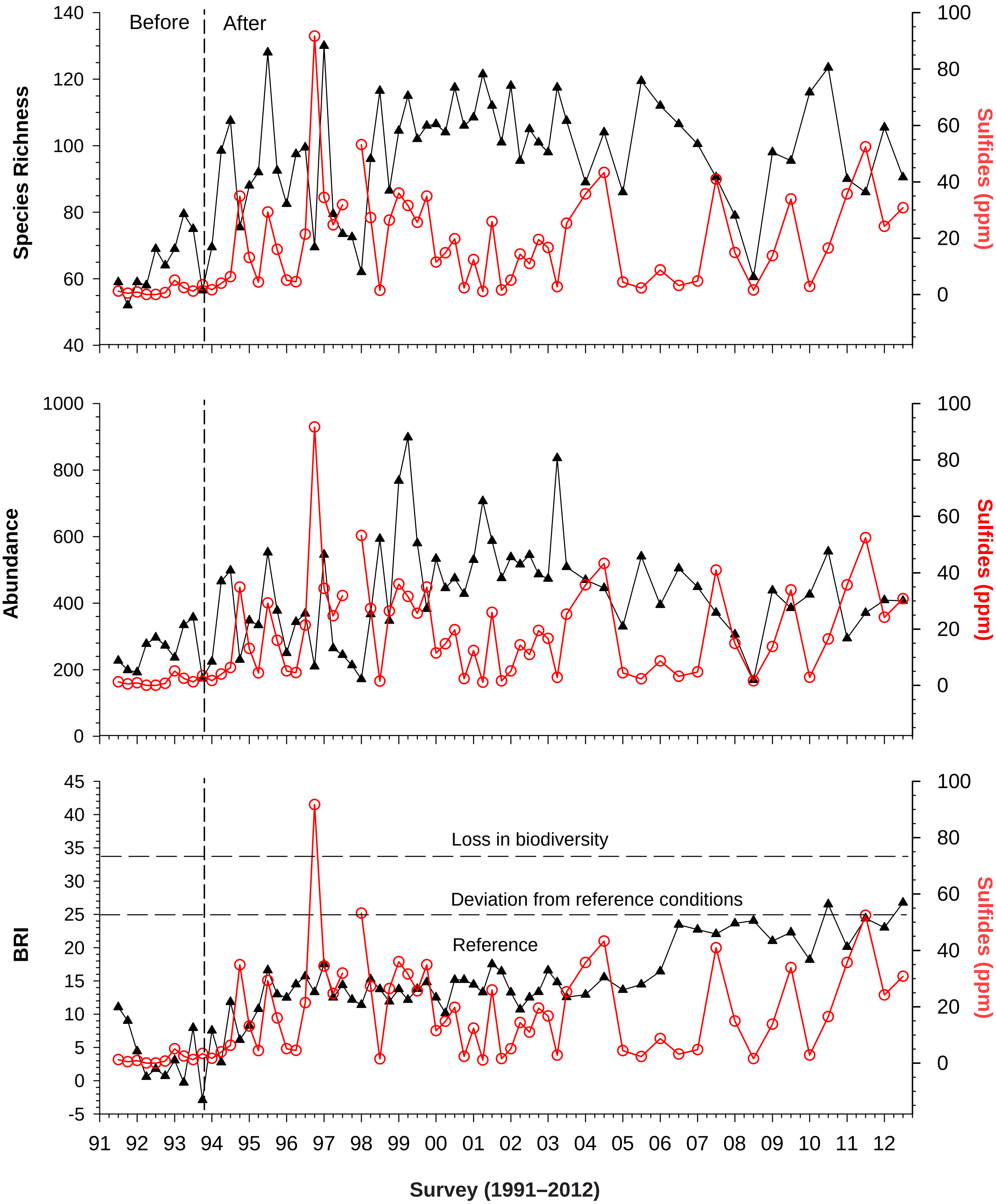
| Depth Contour | Station | Quarter | Grab | SR | Abun | H' | J' | Dom | BRI |
|---|---|---|---|---|---|---|---|---|---|
| *88-m* | B11 | winter | 1 | 118 | 335 | 4.3 | 0.91 | 51 | 16 |
| | | | 2 | 124 | 339 | 4.4 | 0.91 | 50 | 17 |
| | B8 | winter | 1 | 89 | 281 | 3.8 | 0.85 | 36 | 10 |
| | | | 2 | 100 | 337 | 4.0 | 0.86 | 35 | 8 |
| | E19 | winter | 1 | 81 | 232 | 4.0 | 0.91 | 33 | 11 |
| | | | 2 | 88 | 273 | 3.9 | 0.88 | 32 | 11 |
| | E7 | winter | 1 | 83 | 320 | 3.9 | 0.88 | 30 | 11 |
| | | | 2 | 92 | 323 | 4.0 | 0.88 | 35 | 16 |
| | E1 | winter | 1 | 95 | 348 | 3.7 | 0.82 | 31 | 10 |
| | | | 2 | 112 | 405 | 3.9 | 0.82 | 37 | 12 |
| *98-m* | B12 | winter | 1 | 88 | 259 | 4.0 | 0.89 | 34 | 22 |
| | | | 2 | 126 | 451 | 4.3 | 0.90 | 47 | 17 |
| | | summer | 1 | 102 | 285 | 4.1 | 0.89 | 39 | 15 |
| | | | 2 | 110 | 367 | 4.1 | 0.88 | 42 | 15 |
| | B9 | winter | 1 | 116 | 393 | 4.3 | 0.90 | 46 | 11 |
| | | | 2 | 81 | 260 | 3.9 | 0.88 | 30 | 18 |
| | | summer | 1 | 94 | 304 | 4.0 | 0.88 | 36 | 5 |
| | | | 2 | 80 | 228 | 3.8 | 0.88 | 31 | 7 |
| | E26 | winter | 1 | 97 | 310 | 4.0 | 0.87 | 35 | 11 |
| | | | 2 | 101 | 385 | 4.0 | 0.86 | 34 | 12 |
| | | summer | 1 | 77 | 255 | 3.8 | 0.87 | 27 | 15 |
| | | | 2 | 87 | 260 | 3.9 | 0.88 | 35 | 14 |
| | E25 | winter | 1 | 114 | 435 | 4.1 | 0.87 | 36 | 12 |
| | | | 2 | 104 | 405 | 4.0 | 0.87 | 36 | 13 |
| | | summer | 1 | 84 | 303 | 3.9 | 0.87 | 31 | 13 |
| | | | 2 | 72 | 282 | 3.7 | 0.86 | 27 | 12 |
| | E23 | winter | 1 | 106 | 400 | 4.1 | 0.88 | 36 | 17 |
| | | | 2 | 100 | 393 | 4.1 | 0.89 | 36 | 13 |
| | | summer | 1 | 75 | 253 | 3.7 | 0.85 | 26 | 15 |
| | | | 2 | 73 | 245 | 3.7 | 0.87 | 27 | 11 |
| | E20 | winter | 1 | 111 | 551 | 4.0 | 0.84 | 30 | 16 |
| | | | 2 | 88 | 350 | 3.9 | 0.87 | 32 | 12 |
| | | summer | 1 | 79 | 294 | 3.9 | 0.89 | 27 | 11 |
| | | | 2 | 84 | 312 | 3.8 | 0.87 | 29 | 11 |
| | E17[a] | winter | 1 | 82 | 403 | 3.7 | 0.85 | 23 | 20 |
| | | | 2 | 109 | 511 | 4.0 | 0.85 | 31 | 16 |
| | | summer | 1 | 65 | 202 | 3.8 | 0.92 | 27 | 14 |
| | | | 2 | 91 | 307 | 4.1 | 0.90 | 34 | 16 |

[a] = nearfield station

## Appendix D.1 *continued*

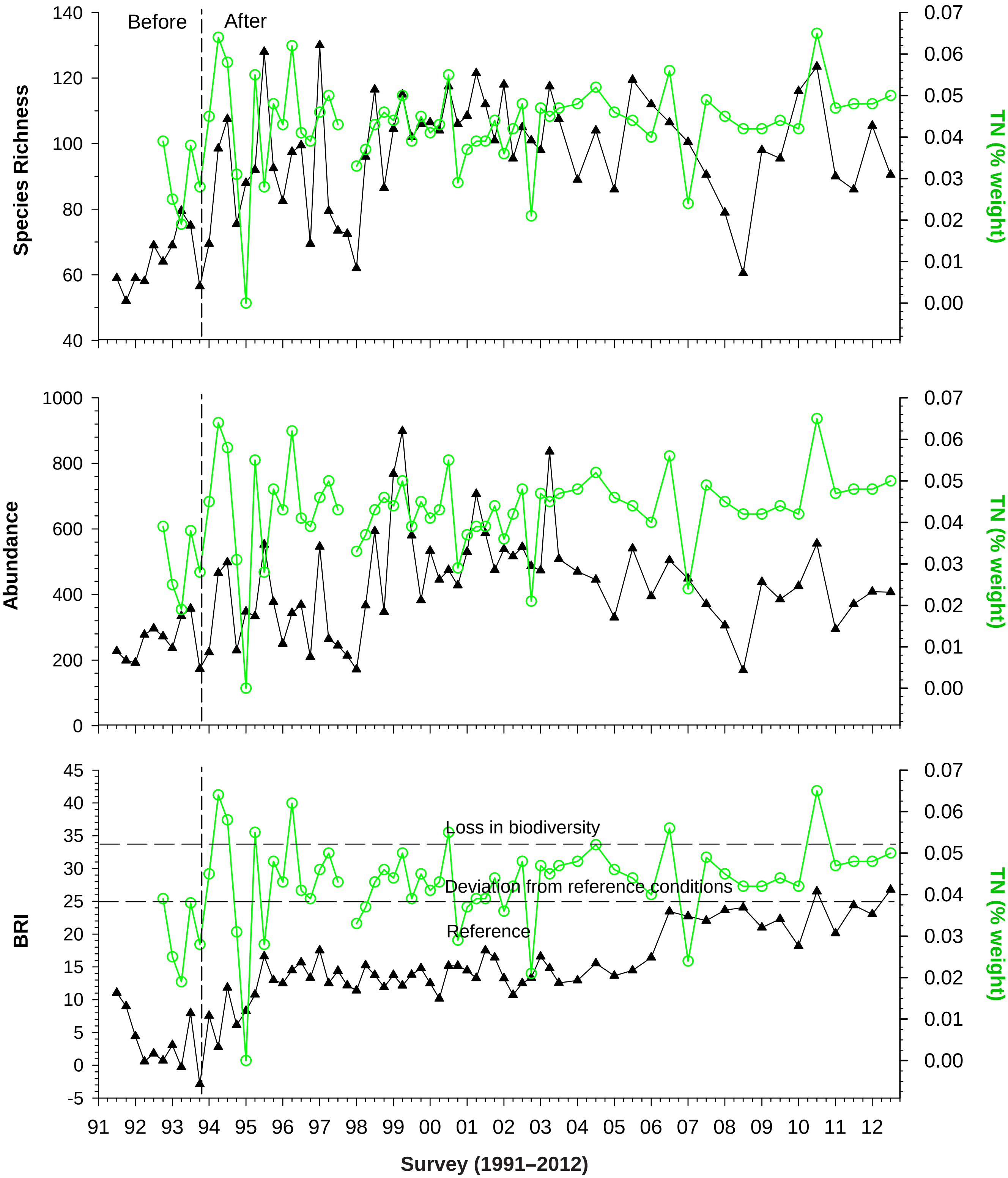
| Depth Contour | Station | Quarter | Grab | SR | Abun | H' | J' | Dom | BRI |
|---|---|---|---|---|---|---|---|---|---|
| *98-m* | E14[a] | winter | 1 | 103 | 412 | 4.0 | 0.86 | 32 | 24 |
| | | | 2 | 108 | 406 | 3.9 | 0.84 | 31 | 22 |
| | | summer | 1 | 86 | 279 | 3.8 | 0.86 | 31 | 27 |
| | | | 2 | 95 | 536 | 3.4 | 0.74 | 16 | 27 |
| | E11[a] | winter | 1 | 92 | 383 | 3.9 | 0.86 | 31 | 15 |
| | | | 2 | 100 | 429 | 3.9 | 0.85 | 28 | 16 |
| | | summer | 1 | 93 | 330 | 4.1 | 0.90 | 33 | 16 |
| | | | 2 | 96 | 338 | 3.9 | 0.85 | 31 | 15 |
| | E8 | winter | 1 | 78 | 277 | 3.7 | 0.86 | 25 | 16 |
| | | | 2 | 85 | 286 | 3.9 | 0.89 | 32 | 15 |
| | | summer | 1 | 83 | 287 | 4.0 | 0.90 | 32 | 13 |
| | | | 2 | 104 | 344 | 4.1 | 0.87 | 36 | 11 |
| | E5 | winter | 1 | 112 | 430 | 4.2 | 0.89 | 40 | 10 |
| | | | 2 | 99 | 349 | 4.1 | 0.88 | 36 | 11 |
| | | summer | 1 | 90 | 286 | 4.0 | 0.89 | 34 | 11 |
| | | | 2 | 81 | 232 | 3.9 | 0.89 | 32 | 14 |
| | E2 | winter | 1 | 108 | 277 | 4.3 | 0.92 | 50 | 17 |
| | | | 2 | 120 | 498 | 4.3 | 0.89 | 42 | 14 |
| | | summer | 1 | 98 | 286 | 4.1 | 0.89 | 39 | 10 |
| | | | 2 | 101 | 324 | 4.1 | 0.89 | 38 | 16 |
| *116-m* | B10 | winter | 1 | 119 | 328 | 4.2 | 0.88 | 45 | 15 |
| | | | 2 | 136 | 437 | 4.4 | 0.90 | 54 | 14 |
| | E21 | winter | 1 | 103 | 403 | 4.1 | 0.88 | 35 | 9 |
| | | | 2 | 94 | 432 | 4.0 | 0.89 | 32 | 11 |
| | E15[a] | winter | 1 | 120 | 385 | 4.3 | 0.90 | 46 | 10 |
| | | | 2 | 121 | 397 | 4.4 | 0.92 | 47 | 9 |
| | E9 | winter | 1 | 144 | 452 | 4.5 | 0.90 | 58 | 10 |
| | | | 2 | 147 | 501 | 4.4 | 0.89 | 58 | 10 |
| | E3 | winter | 1 | 100 | 265 | 4.3 | 0.92 | 44 | 10 |
| | | | 2 | 92 | 308 | 4.0 | 0.89 | 38 | 13 |

[a] = nearfield station

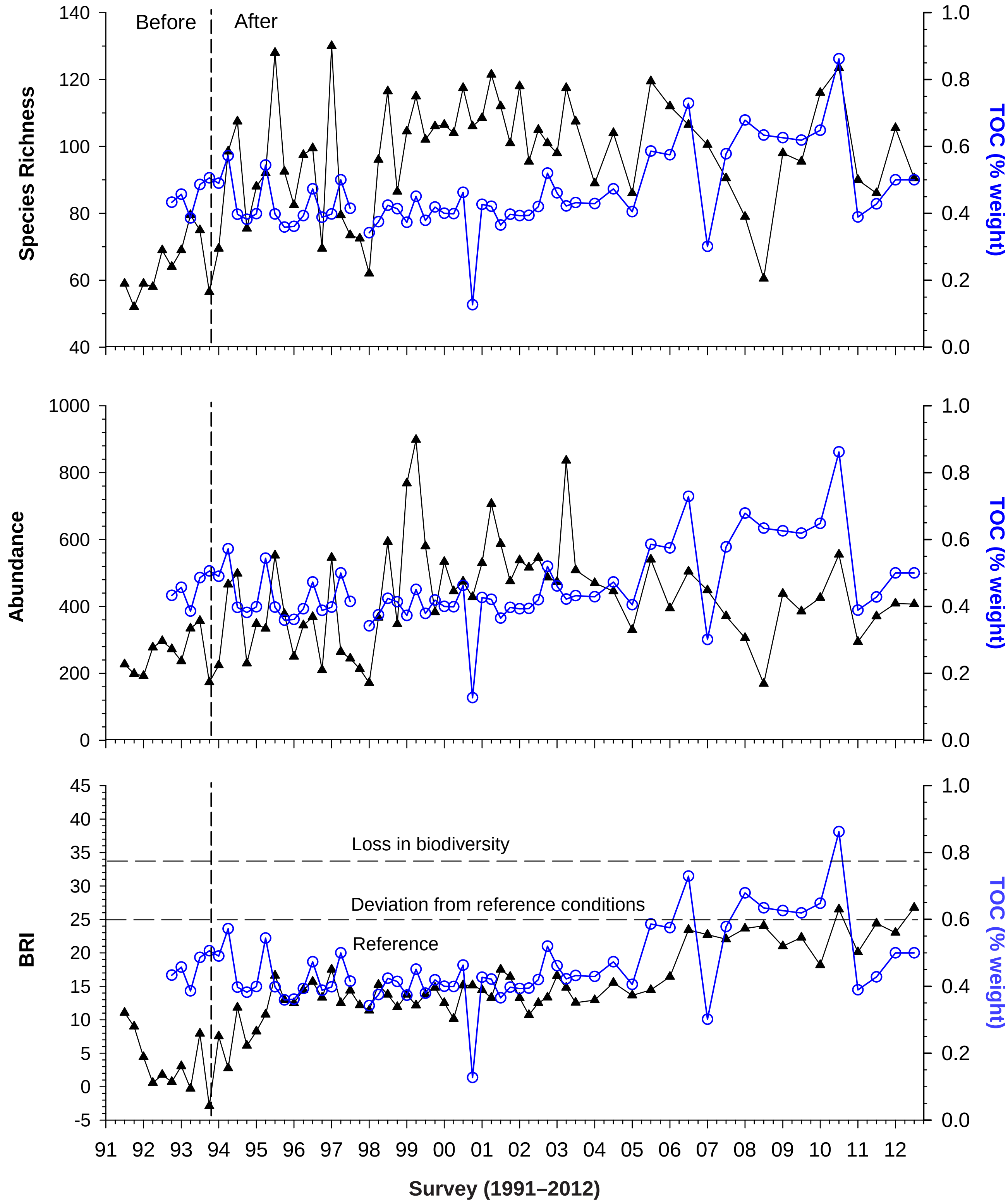



## Appendix D.2

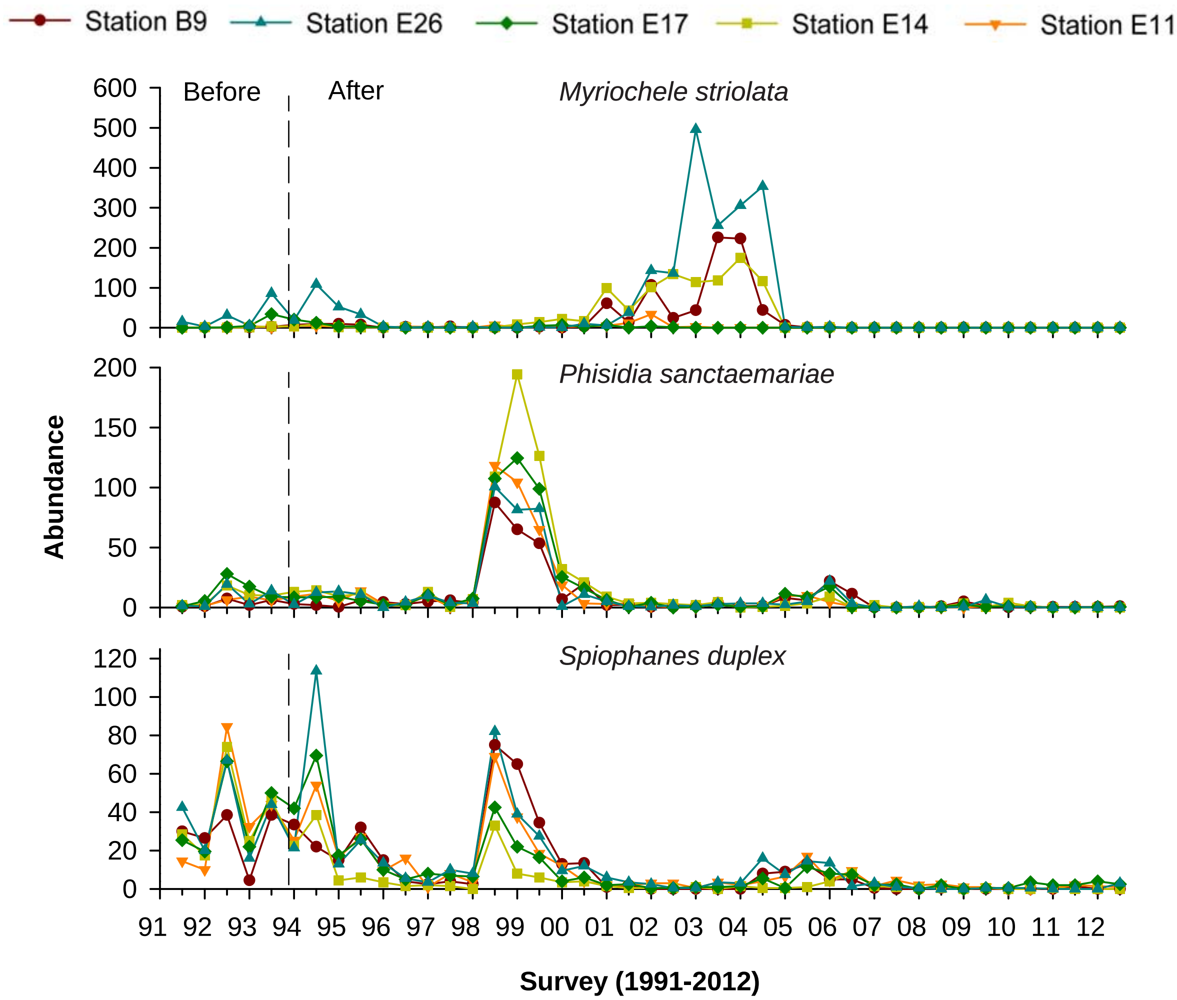
Comparison of community parameters and various organic indicators at nearfield station E14 between 1991 and 2012. Organic indicators include: sulfides, total nitrogen (TN) and total organic carbon (TOC). Parameters include: species richness, infaunal abundance and benthic response index (BRI). Data for community parameters are expressed as means per 0.1 $m^2$ (n = 2 per survey). Data for organic indicators are expressed as a single value (n = 1). Dashed lines indicate onset of wastewater discharge.




## Appendix D.2 *continued*




**Appendix D.2** *continued*




## Appendix D.3

Three of the five historically most abundant species recorded from 1991 through 2012 at PLOO nearfield (E11, E14, E17) and farfield (E26, B9) stations. *Amphiodia urtica* and *Proclea* sp A are shown in Figures 5.3 and 5.4. Data for each station are expressed as means per 0.1 $m^2$ (n=2 per survey). Dashed lines indicate onset of wastewater discharge.

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# Appendix D.4

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

| | Cluster Groups | | | | |
|---|---|---|---|---|---|
| Taxa | A | B[a] | C | D | E |
| *Prionospio* (*Prionospio*) *jubata* | **26.5** | 18.0 | **28.5** | **12.7** | **17.7** |
| *Chloeia pinnata* | **20.5** | 1.0 | 16.0 | 4.3 | 7.1 |
| *Tellina carpenteri* | **15.0** | 2.0 | **12.0** | 3.7 | 5.8 |
| *Chaetozone* sp | **14.0** | 2.0 | 0.0 | 3.7 | 0.3 |
| *Aphelochaeta* sp LA1 | **13.0** | 5.0 | 0.0 | 2.3 | 1.9 |
| *Photis lacia* | 11.5 | 0.0 | 1.5 | 2.3 | 0.4 |
| *Amphiodia digitata* | **9.5** | 0.0 | 0.0 | 0.7 | 0.3 |
| *Euphilomedes carcharodonta* | **7.5** | 1.0 | 13.0 | 2.0 | **18.6** |
| *Euphilomedes producta* | **7.5** | 0.0 | 6.5 | **6.7** | **20.9** |
| *Urothoe elegans* Cmplx | 7.0 | 0.0 | 0.0 | 1.7 | 0.0 |
| *Leptochelia dubia* Cmplx | 6.5 | 5.0 | 0.5 | **5.7** | 1.1 |
| *Aphelochaeta glandaria* Cmplx | **5.0** | 4.0 | 4.5 | 3.7 | 4.1 |
| *Scoloplos armiger* Cmplx | 5.0 | 0.0 | 2.5 | 1.3 | 6.1 |
| *Caecognathia crenulatifrons* | 4.5 | 0.0 | 2.5 | 3.3 | 4.0 |
| *Ampelisca pugetica* | 3.5 | 6.0 | 1.0 | 1.7 | 1.4 |
| *Ampelisca careyi* | 3.5 | 2.0 | 0.0 | 6.0 | 5.8 |
| *Aricidea* (*Acmira*) *catherinae* | 3.0 | 16.0 | **14.5** | 4.3 | 9.5 |
| *Lumbrineris* sp GROUP I | 0.0 | 12.0 | **19.0** | 4.0 | **10.1** |
| *Prionospio* (*Prionospio*) *dubia* | 4.0 | 10.0 | 2.5 | **6.0** | 6.0 |
| *Glycera nana* | 4.0 | 9.0 | 5.0 | 4.3 | 3.3 |
| *Chaetozone hartmanae* | 3.5 | 7.0 | **17.5** | **24.7** | **12.5** |
| *Amphiodia urtica* | 1.5 | 7.0 | 0.5 | **27.7** | **20.9** |
| *Paraprionospio alata* | 3.5 | 6.0 | 4.5 | **6.3** | 2.5 |
| *Spiophanes kimballi* | 2.0 | 6.0 | 2.0 | 1.7 | 2.1 |
| *Aricidea* (*Acmira*) *simplex* | 0.5 | 5.0 | 1.0 | 3.0 | 1.7 |
| *Lysippe* sp A | 2.5 | 4.0 | 2.0 | 5.3 | 2.2 |
| *Ampelisca brevisimulata* | 1.0 | 4.0 | 2.0 | 2.7 | 2.3 |
| *Maldane sarsi* | 0.0 | 4.0 | 3.5 | 1.3 | 1.7 |
| *Photis* sp | 3.5 | 4.0 | 0.0 | 0.7 | 0.6 |
| *Tanaella propinquus* | 0.0 | 4.0 | 0.0 | 2.0 | 1.8 |
| *Mediomastus* sp | 4.5 | 3.0 | 10.5 | 2.7 | 9.2 |
| *Nuculana* sp A | 0.5 | 0.0 | 8.5 | 0.7 | 3.0 |
| *Notomastus* sp A | 1.5 | 1.0 | **8.0** | 0.3 | 0.6 |
| *Lumbrineris cruzensis* | 3.0 | 0.0 | 6.5 | 3.7 | 8.8 |
| *Amphissa undata* | 2.0 | 0.0 | 3.5 | 0.0 | 0.1 |
| *Proclea* sp A | 0.5 | 1.0 | 0.0 | **9.0** | 1.8 |
| *Amphiodia* sp | 1.5 | 3.0 | 0.0 | 7.3 | 5.9 |
| *Rhepoxynius bicuspidatus* | 0.0 | 0.0 | 2.5 | 5.3 | **7.0** |
| *Ampelisca pacifica* | 0.5 | 3.0 | 1.5 | 5.3 | 3.4 |
| *Clymenura gracilis* | 3.0 | 2.0 | 0.5 | 5.0 | 1.5 |
| *Eyakia robusta* | 3.0 | 1.0 | 1.0 | **5.0** | 2.2 |
| *Terebellides californica* | 0.5 | 1.0 | 1.0 | 4.3 | 1.4 |
| Amphiuridae | 3.0 | 1.0 | 0.5 | 2.7 | 6.0 |

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

# Appendix E

# Supporting Data

# 2012 PLOO Stations

# Demersal Fishes and Megabenthic Invertebrates

## Appendix E.1

Taxonomic listing of demersal fish species captured during 2012 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** |
| MYXINIFORMES | | | | | | |
| Myxinidae | | | | | | |
| *Eptatretus stoutii* | Pacific hagfish [a] | 1 | 0.1 | 23 | 23 | 23 |
| CHIMAERIFORMES | | | | | | |
| Chimaeridae | | | | | | |
| *Hydrolagus colliei* | Spotted ratfish [a] | 3 | 0.9 | 24 | 44 | 33 |
| RAJIFORMES | | | | | | |
| Rajidae | | | | | | |
| *Raja inornata* | California skate [a] | 15 | 5.1 | 13 | 52 | 29 |
| *Raja stellulata* | Starry skate [a] | 1 | 0.1 | 15 | 15 | 15 |
| ARGENTINIFORMES | | | | | | |
| Argentinidae | | | | | | |
| *Argentina sialis* | Pacific argentine | 28 | 0.2 | 4 | 12 | 10 |
| AULOPIFORMES | | | | | | |
| Synodontidae | | | | | | |
| *Synodus lucioceps* | California lizardfish | 337 | 8.9 | 10 | 29 | 15 |
| OPHIDIIFORMES | | | | | | |
| Ophidiidae | | | | | | |
| *Chilara taylori* | Spotted cusk-eel | 3 | 0.1 | 16 | 20 | 18 |
| *Ophidion scrippsae* | Basketweave cusk-eel | 4 | 0.2 | 15 | 17 | 16 |
| BATRACHOIDIFORMES | | | | | | |
| Batrachoididae | | | | | | |
| *Porichthys myriaster* | Specklefin midshipman | 3 | 0.1 | 10 | 16 | 14 |
| *Porichthys notatus* | Plainfin midshipman | 45 | 1.4 | 7 | 19 | 12 |
| SCORPAENIFORMES | | | | | | |
| Scorpaenidae | | | | | | |
| *Scorpaena guttata* | California scorpionfish | 22 | 9.0 | 19 | 30 | 22 |
| *Sebastes chlorostictus* | Greenspotted rockfish | 7 | 0.4 | 5 | 17 | 10 |
| *Sebastes constellatus* | Starry rockfish | 1 | 0.1 | 10 | 10 | 10 |
| *Sebastes elongatus* | Greenstriped rockfish | 7 | 0.4 | 7 | 15 | 11 |
| *Sebastes rubrivinctus* | Flag rockfish | 2 | 0.2 | 5 | 6 | 6 |
| *Sebastes saxicola* | Stripetail rockfish | 69 | 1.5 | 4 | 12 | 9 |
| *Sebastes semicinctus* | Halfbanded rockfish | 312 | 7.0 | 7 | 14 | 10 |
| Hexagrammidae | | | | | | |
| *Zaniolepis frenata* | Shortspine combfish | 116 | 3.3 | 6 | 17 | 13 |
| *Zaniolepis latipinnis* | Longspine combfish | 911 | 8.3 | 5 | 17 | 9 |
| Cottidae | | | | | | |
| *Chitonotus pugetensis* | Roughback sculpin | 26 | 0.3 | 4 | 12 | 8 |
| *Icelinus quadriseriatus* | Yellowchin sculpin | 56 | 0.7 | 4 | 10 | 7 |
| Agonidae | | | | | | |
| *Xeneretmus latifrons* | Blacktip poacher | 3 | 0.2 | 14 | 14 | 14 |
| *Xeneretmus triacanthus* | Bluespotted poacher | 2 | 0.2 | 10 | 16 | 13 |
| PERCIFORMES | | | | | | |
| Embiotocidae | | | | | | |
| *Zalembius rosaceus* | Pink seaperch | 118 | 4.3 | 4 | 14 | 9 |

[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 |
|---|---|---|---|---|---|---|
| Bathymasteridae | | | | | | |
| *Rathbunella alleni* | Stripefin ronquil | 2 | 0.1 | 10 | 15 | 12 |
| Zoarcidae | | | | | | |
| *Lycodes cortezianus* | Bigfin eelpout | 3 | 0.2 | 14 | 21 | 19 |
| *Lycodes pacificus* | Blackbelly eelpout | 5 | 0.3 | 14 | 26 | 20 |
| PLEURONECTIFORMES | | | | | | |
| Paralichthyidae | | | | | | |
| *Citharichthys sordidus* | Pacific sanddab | 1902 | 37.5 | 3 | 25 | 9 |
| *Hippoglossina stomata* | Bigmouth sole | 19 | 3.0 | 15 | 26 | 20 |
| *Xystreurys liolepis* | Fantail sole | 1 | 0.1 | 18 | 18 | 18 |
| Pleuronectidae | | | | | | |
| *Lyopsetta exilis* | Slender sole | 19 | 0.9 | 14 | 17 | 15 |
| *Microstomus pacificus* | Dover sole | 173 | 8.9 | 5 | 20 | 14 |
| *Parophrys vetulus* | English sole | 103 | 9.5 | 13 | 23 | 17 |
| *Pleuronichthys decurrens* | Curlfin sole | 1 | 0.1 | 14 | 14 | 14 |
| *Pleuronichthys verticalis* | Hornyhead turbot | 9 | 1.7 | 14 | 22 | 18 |
| Cynoglossidae | | | | | | |
| *Symphurus atricaudus* | California tonguefish | 36 | 1.2 | 10 | 16 | 14 |

## Appendix E.2

Total abundance by species and station for demersal fish at the PLOO trawl stations during 2012.

| | Winter 2012 | | | | | | |
|---|---|---|---|---|---|---|---|
| Name | SD7 | SD8 | SD10 | SD12 | SD13 | SD14 | Species Abundance by Survey |
| Pacific sanddab | 197 | 216 | 146 | 79 | 120 | 119 | 877 |
| Longspine combfish | 35 | 56 | 284 | 78 | 65 | 40 | 558 |
| California lizardfish | 51 | 6 | 113 | 8 | 8 | 30 | 216 |
| Halfbanded rockfish | 13 | 127 | 43 | 7 | 6 | 4 | 200 |
| Dover sole | 7 | 30 | 28 | 17 | 4 | 1 | 87 |
| Pink seaperch | 5 | 13 | 37 | 2 | 21 | 6 | 84 |
| English sole | 9 | 1 | 19 | 23 | 5 | 2 | 59 |
| Shortspine combfish | 10 | 23 | 4 | 8 | 5 | 4 | 54 |
| Yellowchin sculpin | 33 | 4 | 14 | | 2 | 1 | 54 |
| Stripetail rockfish | 12 | 10 | 26 | 1 | 1 | 1 | 51 |
| Plainfin midshipman | 9 | 8 | 14 | 3 | 2 | 1 | 37 |
| California tonguefish | 7 | 11 | 6 | 2 | 2 | 3 | 31 |
| Pacific argentine | 22 | 6 | | | | | 28 |
| California scorpionfish | | | 1 | 18 | 2 | 1 | 22 |
| Roughback sculpin | 14 | 5 | | | | | 19 |
| Bigmouth sole | 1 | | 3 | 1 | 5 | 4 | 14 |
| Greenstriped rockfish | | 2 | | 4 | 1 | | 7 |
| Hornyhead turbot | 3 | 1 | 1 | | | 2 | 7 |
| California skate | 2 | 1 | | 1 | 2 | | 6 |
| Greenspotted rockfish | | | 3 | 2 | | | 5 |
| Bigfin eelpout | | | | 2 | 1 | | 3 |
| Spotted ratfish | | | 3 | | | | 3 |
| Slender sole | | | | 1 | 1 | | 2 |
| Blackbelly eelpout | | | | | 1 | | 1 |
| Blacktip poacher | | | | | | 1 | 1 |
| Bluespotted poacher | | 1 | | | | | 1 |
| Fantail sole | | 1 | | | | | 1 |
| Flag rockfish | | 1 | | | | | 1 |
| Starry skate | | 1 | | | | | 1 |
| Survey Total | 430 | 524 | 745 | 257 | 254 | 220 | 2430 |

## Appendix E.2 *continued*

| Name | Summer 2012 | | | | | | Species Abundance by Survey |
|---|---|---|---|---|---|---|---|
| | SD7 | SD8 | SD10 | SD12 | SD13 | SD14 | |
| Pacific sanddab | 186 | 159 | 182 | 204 | 128 | 166 | 1025 |
| Longspine combfish | 76 | 17 | 143 | 65 | 48 | 4 | 353 |
| California lizardfish | 39 | 9 | 43 | 9 | 8 | 13 | 121 |
| Halfbanded rockfish | 3 | 87 | 12 | | 8 | 2 | 112 |
| Dover sole | 10 | 22 | 9 | 13 | 14 | 18 | 86 |
| Shortspine combfish | 13 | 22 | 1 | 17 | 4 | 5 | 62 |
| English sole | | 11 | 2 | 5 | 10 | 16 | 44 |
| Pink seaperch | 9 | 16 | 2 | 2 | 3 | 2 | 34 |
| Stripetail rockfish | 9 | | 6 | 2 | 1 | | 18 |
| Slender sole | | | | 11 | 2 | 4 | 17 |
| California skate | 1 | | | 5 | 2 | 1 | 9 |
| Plainfin midshipman | | 2 | 5 | | 1 | | 8 |
| Roughback sculpin | | 7 | | | | | 7 |
| Bigmouth sole | | 2 | | | 3 | | 5 |
| California tonguefish | 2 | 3 | | | | | 5 |
| Basketweave cusk-eel | | | | 3 | | 1 | 4 |
| Blackbelly eelpout | | | | 3 | 1 | | 4 |
| Specklefin midshipman | 3 | | | | | | 3 |
| Spotted cusk-eel | 3 | | | | | | 3 |
| Blacktip poacher | | | | 2 | | | 2 |
| Greenspotted rockfish | | | | 1 | 1 | | 2 |
| Hornyhead turbot | | | | | 1 | 1 | 2 |
| Stripefin ronquil | | 2 | | | | | 2 |
| Yellowchin sculpin | 1 | | 1 | | | | 2 |
| Bluespotted poacher | | | | | | 1 | 1 |
| Curlfin sole | | | | | 1 | | 1 |
| Flag rockfish | | 1 | | | | | 1 |
| Pacific hagfish | | | | | | 1 | 1 |
| Starry rockfish | 1 | | | | | | 1 |
| Survey Total | 356 | 360 | 406 | 342 | 236 | 235 | 1935 |
| **Annual Total** | **786** | **884** | **1151** | **599** | **490** | **455** | **4365** |

## Appendix E.3

Biomass (kg) by species and station for demersal fish at the PLOO trawl stations during 2012.

| | Winter 2012 | | | | | | |
|---|---|---|---|---|---|---|---|
| **Name** | **SD7** | **SD8** | **SD10** | **SD12** | **SD13** | **SD14** | **Biomass by Survey** |
| Pacific sanddab | 2.2 | 2.5 | 2.5 | 1.8 | 0.2 | 2.5 | 11.7 |
| California scorpionfish | | | 0.4 | 7.2 | 0.9 | 0.5 | 9.0 |
| California lizardfish | 1.9 | 0.3 | 2.9 | 0.5 | 0.4 | 0.9 | 6.9 |
| English sole | 0.7 | 0.1 | 2.0 | 2.2 | 0.4 | 0.4 | 5.8 |
| Longspine combfish | 0.5 | 0.8 | 2.5 | 0.8 | 0.7 | 0.5 | 5.8 |
| Halfbanded rockfish | 0.1 | 2.2 | 0.8 | 0.3 | 0.2 | 0.1 | 3.7 |
| Pink seaperch | 0.1 | 0.2 | 2.5 | 0.1 | 0.5 | 0.1 | 3.5 |
| Dover sole | 0.2 | 0.7 | 1.0 | 0.5 | 0.4 | 0.1 | 2.9 |
| Bigmouth sole | 0.1 | | 0.6 | 0.4 | 0.8 | 0.4 | 2.3 |
| Shortspine combfish | 0.3 | 0.7 | 0.2 | 0.3 | 0.2 | 0.1 | 1.8 |
| Hornyhead turbot | 0.6 | 0.1 | 0.3 | | | 0.5 | 1.5 |
| California skate | 0.4 | 0.3 | | 0.2 | 0.4 | | 1.3 |
| Plainfin midshipman | 0.2 | 0.1 | 0.4 | 0.2 | 0.1 | 0.1 | 1.1 |
| Stripetail rockfish | 0.1 | 0.1 | 0.6 | 0.1 | 0.1 | 0.1 | 1.1 |
| California tonguefish | 0.1 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 | 1.0 |
| Spotted ratfish | | | 0.9 | | | | 0.9 |
| Yellowchin sculpin | 0.1 | 0.1 | 0.1 | | 0.1 | 0.1 | 0.5 |
| Greenstriped rockfish | | 0.1 | | 0.2 | 0.1 | | 0.4 |
| Bigfin eelpout | | | | 0.1 | 0.1 | | 0.2 |
| Greenspotted rockfish | | | 0.1 | 0.1 | | | 0.2 |
| Pacific argentine | 0.1 | 0.1 | | | | | 0.2 |
| Roughback sculpin | 0.1 | 0.1 | | | | | 0.2 |
| Slender sole | | | | 0.1 | 0.1 | | 0.2 |
| Blackbelly eelpout | | | | | 0.1 | | 0.1 |
| Blacktip poacher | | | | | | 0.1 | 0.1 |
| Bluespotted poacher | | 0.1 | | | | | 0.1 |
| Fantail sole | | 0.1 | | | | | 0.1 |
| Flag rockfish | | 0.1 | | | | | 0.1 |
| Starry skate | | 0.1 | | | | | 0.1 |
| Survey Total | 7.8 | 9.2 | 18.0 | 15.3 | 5.9 | 6.6 | 62.8 |

## Appendix E.3 *continued*

| Name | Summer 2012 | | | | | | Biomass by Survey |
|---|---|---|---|---|---|---|---|
| | SD7 | SD8 | SD10 | SD12 | SD13 | SD14 | |
| Pacific sanddab | 2.8 | 6.5 | 4.2 | 1.8 | 3.1 | 7.4 | 25.8 |
| Dover sole | 0.7 | 1.2 | 0.3 | 1.0 | 1.0 | 1.8 | 6.0 |
| California skate | 0.4 | | | 2.5 | 0.8 | 0.1 | 3.8 |
| English sole | | 1.0 | 0.1 | 0.5 | 1.0 | 1.1 | 3.7 |
| Halfbanded rockfish | 0.1 | 2.5 | 0.2 | | 0.4 | 0.1 | 3.3 |
| Longspine combfish | 0.7 | 0.1 | 0.8 | 0.4 | 0.4 | 0.1 | 2.5 |
| California lizardfish | 0.7 | 0.2 | 0.6 | 0.1 | 0.1 | 0.3 | 2.0 |
| Shortspine combfish | 0.4 | 0.5 | 0.1 | 0.3 | 0.1 | 0.1 | 1.5 |
| Pink seaperch | 0.1 | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.8 |
| Bigmouth sole | | 0.3 | | | 0.4 | | 0.7 |
| Slender sole | | | | 0.3 | 0.1 | 0.3 | 0.7 |
| Stripetail rockfish | 0.1 | | 0.1 | 0.1 | 0.1 | | 0.4 |
| Plainfin midshipman | | 0.1 | 0.1 | | 0.1 | | 0.3 |
| Basketweave cusk-eel | | | | 0.1 | | 0.1 | 0.2 |
| Blackbelly eelpout | | | | 0.1 | 0.1 | | 0.2 |
| California tonguefish | 0.1 | 0.1 | | | | | 0.2 |
| Greenspotted rockfish | | | | 0.1 | 0.1 | | 0.2 |
| Hornyhead turbot | | | | | 0.1 | 0.1 | 0.2 |
| Yellowchin sculpin | 0.1 | | 0.1 | | | | 0.2 |
| Blacktip poacher | | | | 0.1 | | | 0.1 |
| Bluespotted poacher | | | | | | 0.1 | 0.1 |
| Curlfin sole | | | | | 0.1 | | 0.1 |
| Flag rockfish | | 0.1 | | | | | 0.1 |
| Pacific hagfish | | | | | | 0.1 | 0.1 |
| Roughback sculpin | | 0.1 | | | | | 0.1 |
| Specklefin midshipman | 0.1 | | | | | | 0.1 |
| Spotted cusk-eel | 0.1 | | | | | | 0.1 |
| Starry rockfish | 0.1 | | | | | | 0.1 |
| Stripefin ronquil | | 0.1 | | | | | 0.1 |
| Survey Total | 6.5 | 13.1 | 6.7 | 7.5 | 8.1 | 11.8 | 53.7 |
| **Annual Total** | **14.3** | **22.3** | **24.7** | **22.8** | **14.0** | **18.4** | **116.5** |

# Appendix E.4

Pairwise r- and significance values for all year comparisons (Factor B) from the PLOO two-way crossed ANOSIM for demersal fish assemblages sampled between 1991 and 2012. Data are limited to summer surveys. Shading indicates significant difference.

| | | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1992 | r-value | 0.083 | | | | | | | | | | | | | | | | | | | | |
| | sig value | 55.6 | | | | | | | | | | | | | | | | | | | | |
| 1993 | r-value | 0.833 | 0.750 | | | | | | | | | | | | | | | | | | | |
| | sig value | 3.7 | 3.7 | | | | | | | | | | | | | | | | | | | |
| 1994 | r-value | 0.583 | 0.583 | 0.250 | | | | | | | | | | | | | | | | | | |
| | sig value | 11.1 | 11.1 | 22.2 | | | | | | | | | | | | | | | | | | |
| 1995 | r-value | 0.167 | 0.083 | 0.250 | 0.417 | | | | | | | | | | | | | | | | | |
| | sig value | 44.4 | 55.6 | 14.8 | 14.8 | | | | | | | | | | | | | | | | | |
| 1996 | r-value | 0.667 | 0.750 | 0.417 | 0.417 | 0.167 | | | | | | | | | | | | | | | | |
| | sig value | 3.7 | 3.7 | 22.2 | 14.8 | 29.6 | | | | | | | | | | | | | | | | |
| 1997 | r-value | 0.667 | 0.167 | 0.500 | 0.417 | 0.167 | 0.167 | | | | | | | | | | | | | | | |
| | sig value | 7.4 | 37 | 3.7 | 14.8 | 29.6 | 25.9 | | | | | | | | | | | | | | | |
| 1998 | r-value | 0.583 | 0.167 | 0.667 | 0.583 | 0 | 0.667 | 0.333 | | | | | | | | | | | | | | |
| | sig value | 7.4 | 22.2 | 3.7 | 3.7 | 59.3 | 3.7 | 25.9 | | | | | | | | | | | | | | |
| 1999 | r-value | 0.833 | 0.833 | 1.000 | 0.833 | 0.667 | 0.917 | 0.500 | 1.000 | | | | | | | | | | | | | |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 11.1 | 3.7 | 7.4 | 3.7 | | | | | | | | | | | | | |
| 2000 | r-value | 1.000 | 0.917 | 0.833 | 0.750 | 0.583 | 0.667 | 0.750 | 0.500 | 0.667 | | | | | | | | | | | | |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 11.1 | 3.7 | 3.7 | 7.4 | 7.4 | | | | | | | | | | | | |
| 2001 | r-value | 1.000 | 0.750 | 0.917 | 1.000 | 0.667 | 1.000 | 0.500 | 0.500 | 1.000 | 0.667 | | | | | | | | | | | |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 7.4 | 3.7 | 7.4 | 7.4 | 3.7 | 7.4 | | | | | | | | | | | |
| 2002 | r-value | 0.917 | 0.583 | 0.833 | 0.667 | 0.583 | 0.500 | 0.500 | 0.500 | 0.917 | 0.750 | 0.417 | | | | | | | | | | |
| | sig value | 3.7 | 7.4 | 3.7 | 3.7 | 7.4 | 11.1 | 11.1 | 3.7 | 3.7 | 7.4 | 14.8 | | | | | | | | | | |
| 2003 | r-value | 0.917 | 0.833 | 0.833 | 0.667 | 0.750 | 0.500 | 0.667 | 0.750 | 1.000 | 0.583 | 0.750 | 0.583 | | | | | | | | | |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 7.4 | 11.1 | 3.7 | 3.7 | 3.7 | 7.4 | 3.7 | 11.1 | | | | | | | | | |
| 2004 | r-value | 0.417 | 0.500 | 0.500 | 0.417 | 0.333 | 0.167 | 0.500 | 0.250 | 0.583 | 0.167 | 0.750 | 0.417 | -0.250 | | | | | | | | |
| | sig value | 11.1 | 3.7 | 11.1 | 14.8 | 22.2 | 33.3 | 14.8 | 18.5 | 7.4 | 37 | 7.4 | 25.9 | 77.8 | | | | | | | | |
| 2005 | r-value | 0.667 | 0.750 | 0.917 | 0.833 | 0.833 | 0.667 | 0.667 | 0.750 | 1.000 | 0.583 | 0.750 | 0.500 | 0.250 | 0.083 | | | | | | | |
| | sig value | 11.1 | 7.4 | 3.7 | 3.7 | 3.7 | 7.4 | 7.4 | 3.7 | 3.7 | 14.8 | 3.7 | 11.1 | 22.2 | 44.4 | | | | | | | |
| 2006 | r-value | 0.917 | 0.917 | 1.000 | 0.833 | 0.917 | 1.000 | 0.833 | 0.750 | 1.000 | 0.833 | 0.917 | 0.750 | 0.417 | 0.167 | 0.250 | | | | | | |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 7.4 | 3.7 | 7.4 | 18.5 | 29.6 | 25.9 | | | | | | |
| 2007 | r-value | 1.000 | 0.750 | 0.917 | 0.833 | 0.667 | 0.833 | 0.500 | 0.750 | 1.000 | 0.917 | 1.000 | 0.917 | 0.583 | 0.083 | 0.500 | 0.250 | | | | | |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 7.4 | 7.4 | 11.1 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 11.1 | 55.6 | 14.8 | 29.6 | | | | | |
| 2008 | r-value | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.500 | 0.500 | 1.000 | 1.000 | 1.000 | 0.750 | 0.500 | 0 | 1.000 | 0 | 0.500 | | | | |
| | sig value | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 66.7 | 33.3 | 66.7 | 33.3 | | | | |
| 2009 | r-value | 0.833 | 0.833 | 1.000 | 0.750 | 0.667 | 1.000 | 0.583 | 0.750 | 1.000 | 1.000 | 0.917 | 0.917 | 0.667 | 0.583 | 0.583 | 0.667 | 0.417 | 0.250 | | | |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 7.4 | 3.7 | 7.4 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 11.1 | 14.8 | 7.4 | 3.7 | 7.4 | 66.7 | | | |
| 2010 | r-value | 1.000 | 0.833 | 1.000 | 0.833 | 0.917 | 0.833 | 0.833 | 0.833 | 1.000 | 0.917 | 0.917 | 0.917 | 0.833 | 0.417 | 0.583 | 0.583 | 0.833 | 1.000 | 0.583 | | |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 7.4 | 14.8 | 7.4 | 7.4 | 3.7 | 33.3 | 7.4 | | |
| 2011 | r-value | 1.000 | 0.917 | 1.000 | 0.833 | 0.917 | 1.000 | 0.833 | 0.750 | 1.000 | 1.000 | 0.833 | 0.750 | 0.833 | 0.417 | 0.417 | 0.083 | 0.917 | 1.000 | 0.417 | 0.333 | |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 7.4 | 3.7 | 22.2 | 11.1 | 44.4 | 3.7 | 33.3 | 7.4 | 25.9 | |
| 2012 | r-value | 1.000 | 0.917 | 1.000 | 0.833 | 1.000 | 1.000 | 0.833 | 0.750 | 1.000 | 1.000 | 0.833 | 0.917 | 0.917 | 0.583 | 1.000 | 0.583 | 0.833 | 1.000 | 0.167 | 0.500 | 0.083 |
| | sig value | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 7.4 | 3.7 | 11.1 | 3.7 | 33.3 | 33.3 | 7.4 | 44.4 |

## Appendix E.5

Taxonomic listing of megabenthic invertebrate taxa captured during 2012 at PLOO trawl stations. Data are number of individuals (n). Taxonomic arrangement from SCAMIT (2012).

| Taxon/Species | | | | | n |
|---|---|---|---|---|---|
| **CNIDARIA** | | | | | |
| | ANTHOZOA | | | | |
| | | Alcyonacea | | | |
| | | | Gorgoniidae | | |
| | | | | *Adelogorgia phyllosclera* | 1 |
| | | | Plexauridae | | |
| | | | | *Thesea* sp B | 3 |
| | | Pennatulacea | | | |
| | | | Virgulariidae | | |
| | | | | *Acanthoptilum* sp | 11 |
| | | Actiniaria | | | |
| | | | Metridiidae | | |
| | | | | *Metridium farcimen* | 3 |
| **MOLLUSCA** | | | | | |
| | POLYPLACOPHORA | | | | |
| | | Chitonida | | | |
| | | | Ischnochitonidae | | |
| | | | | *Lepidozona golischi* | 1 |
| | GASTROPODA | | | | |
| | | | Calliostomatidae | | |
| | | | | *Calliostoma turbinum* | 2 |
| | | Hypsogastropoda | | | |
| | | | Naticidae | | |
| | | | | *Euspira draconis* | 1 |
| | | | Nassriidae | | |
| | | | | *Hinea insculpta* | 4 |
| | | | Muricidae | | |
| | | | | *Austrotrophon catalinensis* | 2 |
| | | | Turridae | | |
| | | | | *Megasurcula carpenteriana* | 1 |
| | | | Cancellariidae | | |
| | | | | *Cancellaria cooperii* | 2 |
| | | | | *Cancellaria crawfordiana* | 1 |
| | | Opisthobranchia | | | |
| | | | Philinidae | | |
| | | | | *Philine alba* | 3 |
| | | | | *Philine auriformis* | 42 |
| | | | Pleurobranchidae | | |
| | | | | *Pleurobranchaea californica* | 55 |

## Appendix E.5 *continued*

| Taxon/Species | | | | n |
|---|---|---|---|---|
| | | | Discodorididae | | |
| | | | | *Platydoris macfarlandi* | 2 |
| | | | Onchidorididae | | |
| | | | | *Acanthodoris brunnea* | 5 |
| | | | Arminidae | | |
| | | | | *Armina californica* | 2 |
| | CEPHALOPODA | | | | |
| | | Sepiolida | | | |
| | | | Sepiolidae | | |
| | | | | *Rossia pacifica* | 9 |
| | | Octopoda | | | |
| | | | Octopodidae | | |
| | | | | *Octopus californicus* | 1 |
| | | | | *Octopus rubescens* | 15 |
| **ANNELIDA** | | | | | |
| | POLYCHAETA | | | | |
| | | Aciculata | | | |
| | | | Polynoidae | | |
| | | | | *Arctonoe pulchra* | 20 |
| | | | Amphinomidae | | |
| | | | | *Chloeia pinnata* | 29 |
| | | Canalipalpata | | | |
| | | | Serpulidae | | |
| | | | | *Protula superba* | 1 |
| **ARTHROPODA** | | | | | |
| | MALACOSTRACA | | | | |
| | | Isopoda | | | |
| | | | Cymothoidae | | |
| | | | | *Elthusa vulgaris* | 5 |
| | | Decapoda | | | |
| | | | Sicyoniidae | | |
| | | | | *Sicyonia ingentis* | 7 |
| | | | Crangonidae | | |
| | | | | *Crangon alaskensis* | 5 |
| | | | | *Neocrangon zacae* | 4 |
| | | | Diogenidae | | |
| | | | | *Paguristes bakeri* | 1 |
| | | | | *Paguristes turgidus* | 1 |

## Appendix E.5 *continued*

| Taxon/Species | | | | | n |
|---|---|---|---|---|---|
| | | | Lithodidae | | |
| | | | | *Paralithodes rathbuni* | 2 |
| | | | Calappidae | | |
| | | | | *Platymera gaudichaudii* | 1 |
| | | | Epialtidae | | |
| | | | | *Loxorhynchus crispatus* | 1 |
| | | | | *Loxorhynchus grandis* | 1 |
| **ECHINODERMATA** | | | | | |
| | CRINOIDEA | | | | |
| | | Comatulida | | | |
| | | | Antedonidae | | |
| | | | | *Florometra serratissima* | 26 |
| | ASTEROIDEA | | | | |
| | | Paxillosida | | | |
| | | | Luidiidae | | |
| | | | | *Luidia asthenosoma* | 21 |
| | | | | *Luidia foliolata* | 124 |
| | | | Astropectinidae | | |
| | | | | *Astropecten ornatissimus* | 6 |
| | | | | *Astropecten californicus* | 30 |
| | OPHIUROIDEA | | | | |
| | | Ophiurida | | | |
| | | | Ophiacanthidae | | |
| | | | | *Ophiacantha diplasia* | 1 |
| | | | Ophiactidae | | |
| | | | | *Ophiopholis bakeri* | 1 |
| | | | Ophiotricidae | | |
| | | | | *Ophiothrix spiculata* | 3 |
| | | | Ophiuridae | | |
| | | | | *Ophiura luetkenii* | 3144 |
| | ECHINOIDEA | | | | |
| | | Camarodonta | | | |
| | | | Toxopneustidae | | |
| | | | | *Lytechinus pictus* | 10,582 |
| | | | Strongylocentrotidae | | |
| | | | | *Strongylocentrotus fragilis* | 1115 |
| | | | Spatangidae | | |
| | | | | *Spatangus californicus* | 1 |

## Appendix E.5 *continued*

| Taxon/Species | n |
| --- | --- |
| HOLOTHUROIDEA | |
| Aspidochirotida | |
| Stichopodidae | |
| *Parastichopus californicus* | 22 |

## Appendix E.6

Total abundance by species and station for megabenthic invertebrates at the PLOO trawl stations during 2012.

| | Winter 2012 | | | | | | |
|---|---|---|---|---|---|---|---|
| **Species** | **SD7** | **SD8** | **SD10** | **SD12** | **SD13** | **SD14** | **Species Abundance by Survey** |
| *Lytechinus pictus* | 1463 | 1035 | 775 | 3156 | 402 | 184 | 7015 |
| *Ophiura luetkenii* | 37 | 6 | 27 | 22 | 80 | 49 | 221 |
| *Strongylocentrotus fragilis* | | | | | 40 | 66 | 106 |
| *Luidia foliolata* | 8 | 9 | 7 | 7 | 20 | 28 | 79 |
| *Philine auriformis* | 13 | 4 | 1 | | 5 | 19 | 42 |
| *Pleurobranchaea californica* | 7 | 10 | 2 | 3 | 5 | 10 | 37 |
| *Arctonoe pulchra* | | | 1 | | 5 | 14 | 20 |
| *Astropecten californicus* | 6 | | 6 | 4 | 1 | | 17 |
| *Octopus rubescens* | 3 | 9 | 1 | | 1 | | 14 |
| *Florometra serratissima* | 9 | 2 | | | | | 11 |
| *Parastichopus californicus* | 2 | 1 | 2 | | 4 | 1 | 10 |
| *Luidia asthenosoma* | 2 | 2 | | 1 | 2 | 1 | 8 |
| *Rossia pacifica* | 6 | | | | 1 | | 7 |
| *Sicyonia ingentis* | 1 | | 1 | 2 | | 3 | 7 |
| *Crangon alaskensis* | | | 5 | | | | 5 |
| *Hinea insculpta* | 1 | | | 3 | | | 4 |
| *Neocrangon zacae* | | 4 | | | | | 4 |
| *Acanthodoris brunnea* | 3 | | | | | | 3 |
| *Elthusa vulgaris* | | | 1 | | 1 | 1 | 3 |
| *Calliostoma turbinum* | 2 | | | | | | 2 |
| *Thesea* sp B | 2 | | | | | | 2 |
| *Armina californica* | | | | | | 1 | 1 |
| *Cancellaria cooperii* | | | | 1 | | | 1 |
| *Cancellaria crawfordiana* | | | 1 | | | | 1 |
| *Loxorhynchus grandis* | | 1 | | | | | 1 |
| *Megasurcula carpenteriana* | | | 1 | | | | 1 |
| *Octopus californicus* | | | 1 | | | | 1 |
| *Ophiopholis bakeri* | | | | | 1 | | 1 |
| *Ophiothrix spiculata* | | | | 1 | | | 1 |
| *Paguristes bakeri* | | 1 | | | | | 1 |
| *Paguristes turgidus* | | | 1 | | | | 1 |
| *Philine alba* | | 1 | | | | | 1 |
| Survey Total | 1565 | 1085 | 833 | 3200 | 568 | 377 | 7628 |

## Appendix E.6 *continued*

| Species | SD7 | SD8 | SD10 | SD12 | SD13 | SD14 | Species Abundance by Survey |
|---|---|---|---|---|---|---|---|
| | **Summer 2012** | | | | | | |
| *Lytechinus pictus* | 1032 | 752 | 1360 | 126 | 195 | 102 | 3567 |
| *Ophiura luetkenii* | 16 | 32 | 35 | 25 | 175 | 2640 | 2923 |
| *Strongylocentrotus fragilis* | 14 | | | 281 | 272 | 442 | 1009 |
| *Luidia foliolata* | 1 | 3 | 10 | 8 | 12 | 11 | 45 |
| *Chloeia pinnata* | 29 | | | | | | 29 |
| *Pleurobranchaea californica* | 6 | 3 | 3 | 5 | | 1 | 18 |
| *Florometra serratissima* | 12 | 2 | 1 | | | | 15 |
| *Astropecten californicus* | 3 | 1 | 2 | 4 | 2 | 1 | 13 |
| *Luidia asthenosoma* | 7 | | 3 | 1 | 2 | | 13 |
| *Parastichopus californicus* | 5 | 4 | 3 | | | | 12 |
| *Acanthoptilum* sp | | 4 | 7 | | | | 11 |
| *Astropecten ornatissimus* | | | | 1 | | 5 | 6 |
| *Metridium farcimen* | | 3 | | | | | 3 |
| *Acanthodoris brunnea* | 1 | 1 | | | | | 2 |
| *Austrotrophon catalinensis* | | 1 | 1 | | | | 2 |
| *Elthusa vulgaris* | | 1 | | | | 1 | 2 |
| *Ophiothrix spiculata* | 2 | | | | | | 2 |
| *Paralithodes rathbuni* | 1 | | | | 1 | | 2 |
| *Philine alba* | 1 | 1 | | | | | 2 |
| *Platydoris macfarlandi* | 1 | | 1 | | | | 2 |
| *Rossia pacifica* | | | | 1 | 1 | | 2 |
| *Adelogorgia phyllosclera* | | | | | 1 | | 1 |
| *Armina californica* | | | | | | 1 | 1 |
| *Cancellaria cooperii* | | | | 1 | | | 1 |
| *Euspira draconis* | | | | | | 1 | 1 |
| *Lepidozona golischi* | | 1 | | | | | 1 |
| *Loxorhynchus crispatus* | 1 | | | | | | 1 |
| *Octopus rubescens* | | | | | 1 | | 1 |
| *Ophiacantha diplasia* | | 1 | | | | | 1 |
| *Platymera gaudichaudii* | | 1 | | | | | 1 |
| *Protula superba* | | 1 | | | | | 1 |
| *Spatangus californicus* | | | | | 1 | | 1 |
| *Thesea* sp B | | | 1 | | | | 1 |
| Survey Total | 1132 | 812 | 1427 | 453 | 663 | 3205 | 7692 |
| **Annual Total** | **2697** | **1897** | **2260** | **3653** | **1231** | **3582** | **15,320** |

# Appendix F

# Supporting Data

# 2012 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 2012. Data are summarized as number of individuals (n), minimum, maximum, and mean values.

| | | | | Length (cm, size class) | | | Weight (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| Station | Comp | Species | n | Min | Max | Mean | Min | Max | Mean |
| Rig Fishing 1 | 1 | Vermilion rockfish | 3 | 21 | 23 | 22 | 229 | 283 | 250 |
| Rig Fishing 1 | 2 | Copper rockfish | 3 | 32 | 37 | 35 | 941 | 1392 | 1206 |
| Rig Fishing 1 | 3 | Mixed rockfish | 3 | 16 | 28 | 23 | 86 | 587 | 374 |
| Rig Fishing 2 | 1 | Starry rockfish | 3 | 23 | 27 | 26 | 334 | 608 | 496 |
| Rig Fishing 2 | 2 | Greenspotted rockfish | 3 | 16 | 29 | 25 | 96 | 568 | 397 |
| Rig Fishing 2 | 3 | Mixed rockfish | 3 | 26 | 36 | 31 | 463 | 1504 | 963 |
| Trawl Zone 1 | 1 | Pacific sanddab | 6 | 19 | 23 | 20 | 70 | 183 | 113 |
| Trawl Zone 1 | 2 | Pacific sanddab | 5 | 18 | 20 | 19 | 84 | 126 | 100 |
| Trawl Zone 1 | 3 | Pacific sanddab | 6 | 17 | 19 | 18 | 62 | 93 | 76 |
| Trawl Zone 2 | 1 | Pacific sanddab | 5 | 19 | 20 | 19 | 94 | 166 | 122 |
| Trawl Zone 2 | 2 | Pacific sanddab | 7 | 15 | 18 | 16 | 61 | 101 | 74 |
| Trawl Zone 2 | 3 | Pacific sanddab | 6 | 16 | 19 | 18 | 67 | 106 | 90 |
| Trawl Zone 3 | 1 | Pacific sanddab | 6 | 16 | 18 | 17 | 64 | 88 | 79 |
| Trawl Zone 3 | 2 | Pacific sanddab | 6 | 16 | 17 | 17 | 67 | 80 | 74 |
| Trawl Zone 3 | 3 | Pacific sanddab | 6 | 17 | 18 | 17 | 63 | 86 | 72 |
| Trawl Zone 4 | 1 | Pacific sanddab | 4 | 18 | 20 | 19 | 91 | 163 | 130 |
| Trawl Zone 4 | 2 | Pacific sanddab | 5 | 16 | 20 | 18 | 78 | 132 | 98 |
| Trawl Zone 4 | 3 | Pacific sanddab | 6 | 17 | 20 | 18 | 64 | 131 | 97 |

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## Appendix F.2

Constituents and method detection limits (MDL) used for the analysis of liver and muscle tissues of fishes collected from the PLOO region during October 2012.

| | MDL | | | MDL | |
|---|---|---|---|---|---|
| **Parameter** | **Liver** | **Muscle** | **Constituent** | **Liver** | **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 | Nickel (Ni) | 0.2 | 0.2 |
| Barium (Ba) | 0.03 | 0.03 | Selenium (Se) | 0.06 | 0.06 |
| Beryllium (Be) | 0.006 | 0.006 | Silver (Ag) | 0.05 | 0.05 |
| Cadmium (Cd) | 0.06 | 0.06 | Thallium (Ti) | 0.4 | 0.4 |
| Chromium (Cr) | 0.1 | 0.1 | Tin (Sn) | 0.2 | 0.2 |
| Copper (Cu) | 0.3 | 0.3 | Zinc (Zn) | 0.15 | 0.15 |
| Iron (Fe) | 2 | 2 | | | |
| **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 | Endrin | 14.20 | 1.42 |
| Alpha endosulfan | 118.00 | 11.80 | Hexachlorobenzene (HCB) | 1.32 | 0.13 |
| Dieldrin | 17.10 | 1.71 | Mirex | 1.49 | 0.15 |

## Appendix F.2 *continued*

| Parameter | MDL Liver | MDL Muscle | Constituent | 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 2012. RF = rig fishing; TZ = trawl zone.

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Constituent | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2012-4 | RF1 | 1 | Vermilion rockfish | Muscle | PCB | PCB 138 | 0.2 | ppb |
| 2012-4 | RF1 | 1 | Vermilion rockfish | Muscle | PCB | PCB 153/168 | 0.5 | ppb |
| 2012-4 | RF1 | 1 | Vermilion rockfish | Muscle | PCB | PCB 180 | 0.2 | ppb |
| 2012-4 | RF1 | 1 | Vermilion rockfish | Muscle | DDT | p,p-DDE | 4.1 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | PCB | PCB 101 | 0.6 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | PCB | PCB 118 | 0.6 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | PCB | PCB 138 | 0.7 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | PCB | PCB 149 | 0.5 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | PCB | PCB 153/168 | 1.3 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | PCB | PCB 180 | 0.5 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | PCB | PCB 187 | 0.3 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | PCB | PCB 99 | 0.5 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | DDT | p,p-DDMU | 0.9 | ppb |
| 2012-4 | RF1 | 2 | Copper rockfish | Muscle | DDT | p,p-DDE | 12.0 | ppb |
| 2012-4 | RF1 | 3 | Mixed rockfish | Muscle | PCB | PCB 101 | 0.4 | ppb |
| 2012-4 | RF1 | 3 | Mixed rockfish | Muscle | PCB | PCB 138 | 0.6 | ppb |
| 2012-4 | RF1 | 3 | Mixed rockfish | Muscle | PCB | PCB 149 | 0.4 | ppb |
| 2012-4 | RF1 | 3 | Mixed rockfish | Muscle | PCB | PCB 153/168 | 1.2 | ppb |
| 2012-4 | RF1 | 3 | Mixed rockfish | Muscle | PCB | PCB 180 | 0.6 | ppb |
| 2012-4 | RF1 | 3 | Mixed rockfish | Muscle | PCB | PCB 187 | 0.3 | ppb |
| 2012-4 | RF1 | 3 | Mixed rockfish | Muscle | PCB | PCB 99 | 0.4 | ppb |
| 2012-4 | RF1 | 3 | Mixed rockfish | Muscle | DDT | p,p-DDMU | 0.4 | ppb |
| 2012-4 | RF1 | 3 | Mixed rockfish | Muscle | DDT | p,p-DDE | 9.6 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 101 | 0.7 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 110 | 0.4 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 118 | 0.8 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 128 | 0.2 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 138 | 0.9 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 149 | 0.7 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 153/168 | 1.9 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 180 | 0.5 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 183 | 0.2 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 187 | 0.5 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 66 | 0.1 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | PCB | PCB 99 | 0.6 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | DDT | o,p-DDE | 0.3 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | DDT | p,p-DDMU | 0.7 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | DDT | p,p-DDD | 0.6 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | DDT | p,p-DDE | 15.0 | ppb |
| 2012-4 | RF2 | 1 | Starry rockfish | Muscle | DDT | p,p-DDT | 0.4 | ppb |
| 2012-4 | RF2 | 2 | Greenspotted rockfish | Muscle | PCB | PCB 138 | 0.2 | ppb |
| 2012-4 | RF2 | 2 | Greenspotted rockfish | Muscle | PCB | PCB 153/168 | 0.4 | ppb |
| 2012-4 | RF2 | 2 | Greenspotted rockfish | Muscle | DDT | p,p-DDE | 3.0 | ppb |
| 2012-4 | RF2 | 3 | Mixed rockfish | Muscle | PCB | PCB 101 | 0.5 | ppb |
| 2012-4 | RF2 | 3 | Mixed rockfish | Muscle | PCB | PCB 118 | 0.5 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Constituent | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2012-4 | RF2 | 3 | Mixed rockfish | Muscle | PCB | PCB 138 | 0.6 | ppb |
| 2012-4 | RF2 | 3 | Mixed rockfish | Muscle | PCB | PCB 149 | 0.3 | ppb |
| 2012-4 | RF2 | 3 | Mixed rockfish | Muscle | PCB | PCB 153/168 | 1.1 | ppb |
| 2012-4 | RF2 | 3 | Mixed rockfish | Muscle | PCB | PCB 187 | 0.3 | ppb |
| 2012-4 | RF2 | 3 | Mixed rockfish | Muscle | PCB | PCB 66 | 0.1 | ppb |
| 2012-4 | RF2 | 3 | Mixed rockfish | Muscle | PCB | PCB 99 | 0.4 | ppb |
| 2012-4 | RF2 | 3 | Mixed rockfish | Muscle | DDT | p,p-DDE | 6.9 | ppb |
| | | | | | | | | |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 101 | 7.6 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 105 | 4.3 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 110 | 6.6 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 118 | 16.0 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 128 | 4.2 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 138 | 25.0 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 149 | 6.8 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 151 | 3.8 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 153/168 | 48.0 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 170 | 5.3 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 180 | 18.0 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 183 | 4.8 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 187 | 14.0 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 201 | 5.4 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 206 | 4.5 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 49 | 2.4 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 66 | 2.7 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 70 | 2.4 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 74 | 1.5 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | PCB | PCB 99 | 11.0 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | DDT | o,p-DDE | 2.2 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | DDT | p,p-DDMU | 8.7 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | DDT | p,p-DDD | 4.3 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | DDT | p,p-DDE | 200.0 | ppb |
| 2012-4 | TZ1 | 1 | Pacific sanddab | Liver | DDT | p,p-DDT | 4.5 | ppb |
| | | | | | | | | |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 101 | 6.4 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 105 | 3.0 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 110 | 6.2 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 118 | 12.0 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 128 | 4.0 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 138 | 20.0 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 149 | 5.7 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 151 | 3.3 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 153/168 | 36.0 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 170 | 4.7 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 180 | 14.0 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 183 | 3.8 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 187 | 10.0 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 194 | 3.8 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 201 | 3.4 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 206 | 3.4 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 28 | 1.2 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Constituent | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 49 | 2.1 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 66 | 2.4 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 70 | 2.0 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 74 | 1.5 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | PCB | PCB 99 | 8.7 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | DDT | o,p-DDE | 3.1 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | DDT | p,p-DDMU | 9.6 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | DDT | p,p-DDD | 5.1 | ppb |
| 2012-4 | TZ1 | 2 | Pacific sanddab | Liver | DDT | p,p-DDE | 180.0 | ppb |
| | | | | | | | | |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 101 | 13.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 105 | 8.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 110 | 12.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 118 | 32.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 128 | 11.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 138 | 58.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 149 | 11.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 151 | 8.2 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 153/168 | 100.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 158 | 4.7 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 167 | 3.1 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 170 | 14.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 180 | 44.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 183 | 11.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 187 | 34.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 194 | 11.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 201 | 12.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 206 | 8.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 28 | 1.2 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 49 | 3.4 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 52 | 5.4 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 66 | 3.7 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 70 | 3.6 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 74 | 2.5 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | PCB | PCB 99 | 24.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | tChlor | Trans Nonachlor | 15.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | DDT | o,p-DDE | 4.3 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | DDT | p,p-DDMU | 14.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | DDT | p,p-DDD | 7.7 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | DDT | p,p-DDE | 420.0 | ppb |
| 2012-4 | TZ1 | 3 | Pacific sanddab | Liver | DDT | p,p-DDT | 6.1 | ppb |
| | | | | | | | | |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 101 | 8.9 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 105 | 3.8 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 110 | 8.4 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 118 | 14.2 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 128 | 3.8 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 138 | 17.5 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 149 | 5.8 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 151 | 2.6 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 153/168 | 32.5 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Constituent | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 170 | 4.0 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 180 | 13.5 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 183 | 3.8 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 187 | 10.0 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 194 | 3.1 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 206 | 3.1 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 49 | 2.4 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 70 | 3.2 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 74 | 1.0 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 87 | 3.0 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | PCB | PCB 99 | 9.3 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | DDT | o,p-DDE | 2.1 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | DDT | p,p-DDMU | 9.8 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | DDT | p,p-DDE | 175.0 | ppb |
| 2012-4 | TZ2 | 1 | Pacific sanddab | Liver | DDT | p,p-DDT | 4.6 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 101 | 12.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 105 | 5.4 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 110 | 11.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 118 | 24.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 128 | 8.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 138 | 38.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 149 | 14.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 151 | 6.4 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 153/168 | 70.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 158 | 4.2 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 167 | 2.2 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 170 | 8.7 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 180 | 29.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 183 | 7.6 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 187 | 20.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 194 | 7.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 201 | 5.5 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 206 | 5.5 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 28 | 1.4 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 49 | 2.8 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 52 | 4.7 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 66 | 3.7 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 70 | 2.7 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 74 | 1.8 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | PCB | PCB 99 | 18.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | DDT | o,p-DDE | 4.2 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | DDT | p,p-DDMU | 11.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | DDT | p,p-DDD | 6.3 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | DDT | p,p-DDE | 220.0 | ppb |
| 2012-4 | TZ2 | 2 | Pacific sanddab | Liver | DDT | p,p-DDT | 4.8 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 101 | 18.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 105 | 6.4 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 110 | 19.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 118 | 35.0 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Constituent | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 128 | 9.1 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 138 | 45.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 149 | 11.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 151 | 6.1 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 153/168 | 78.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 158 | 4.5 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 167 | 3.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 170 | 7.5 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 180 | 23.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 183 | 6.1 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 187 | 17.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 194 | 4.9 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 201 | 5.6 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 206 | 4.8 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 28 | 1.6 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 49 | 6.5 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 52 | 10.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 66 | 5.1 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 70 | 4.4 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 74 | 2.3 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | PCB | PCB 99 | 29.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | DDT | o,p-DDE | 2.4 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | DDT | p,p-DDMU | 12.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | DDT | p,p-DDD | 5.0 | ppb |
| 2012-4 | TZ2 | 3 | Pacific sanddab | Liver | DDT | p,p-DDE | 190.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 101 | 17.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 105 | 11.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 110 | 22.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 118 | 44.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 128 | 12.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 138 | 60.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 149 | 11.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 151 | 7.1 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 153/168 | 99.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 158 | 6.2 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 167 | 3.7 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 170 | 11.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 180 | 37.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 183 | 9.9 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 187 | 29.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 194 | 7.8 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 201 | 7.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 206 | 8.6 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 28 | 1.3 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 49 | 4.3 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 52 | 6.5 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 66 | 4.5 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 70 | 4.9 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 74 | 2.7 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 87 | 5.2 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Constituent | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | PCB | PCB 99 | 28.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | DDT | o,p-DDE | 4.3 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | DDT | p,p-DDMU | 12.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | DDT | p,p-DDD | 5.5 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | DDT | p,p-DDE | 220.0 | ppb |
| 2012-4 | TZ3 | 1 | Pacific sanddab | Liver | DDT | p,p-DDT | 6.7 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 101 | 11.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 105 | 5.8 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 110 | 11.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 118 | 21.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 128 | 5.6 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 138 | 32.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 149 | 8.7 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 151 | 3.8 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 153/168 | 54.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 158 | 2.7 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 167 | 1.9 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 170 | 7.8 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 180 | 22.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 183 | 6.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 187 | 14.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 194 | 5.1 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 201 | 4.5 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 206 | 5.2 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 28 | 1.6 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 49 | 3.9 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 52 | 5.2 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 66 | 3.7 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 70 | 3.5 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 74 | 2.4 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | PCB | PCB 99 | 15.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | DDT | o,p-DDE | 3.6 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | DDT | p,p-DDMU | 12.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | DDT | p,p-DDD | 5.7 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | DDT | p,p-DDE | 170.0 | ppb |
| 2012-4 | TZ3 | 2 | Pacific sanddab | Liver | DDT | p,p-DDT | 4.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 101 | 15.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 105 | 6.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 110 | 13.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 118 | 25.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 128 | 6.7 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 138 | 37.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 149 | 12.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 151 | 4.9 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 153/168 | 69.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 158 | 2.9 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 167 | 1.9 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 170 | 7.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 180 | 27.0 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Constituent | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 183 | 5.8 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 187 | 23.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 194 | 5.7 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 201 | 5.9 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 206 | 5.2 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 28 | 1.6 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 49 | 4.8 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 52 | 6.8 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 66 | 3.9 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 70 | 3.9 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 74 | 2.4 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | PCB | PCB 99 | 15.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | DDT | o,p-DDE | 4.3 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | DDT | p,p-DDMU | 8.9 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | DDT | p,p-DDD | 5.6 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | DDT | p,p-DDE | 190.0 | ppb |
| 2012-4 | TZ3 | 3 | Pacific sanddab | Liver | DDT | p,p-DDT | 3.6 | ppb |
| | | | | | | | | |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 101 | 21.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 105 | 6.3 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 110 | 16.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 118 | 25.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 128 | 7.4 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 138 | 33.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 149 | 16.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 151 | 6.2 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 153/168 | 73.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 158 | 3.6 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 167 | 2.4 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 170 | 7.1 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 180 | 26.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 183 | 7.8 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 187 | 23.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 194 | 4.5 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 201 | 6.4 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 206 | 4.9 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 28 | 1.3 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 49 | 5.4 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 52 | 7.6 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 66 | 5.3 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 70 | 5.2 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 74 | 2.4 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 87 | 4.2 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | PCB | PCB 99 | 21.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | DDT | p,p-DDMU | 11.0 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | DDT | p,p-DDD | 4.2 | ppb |
| 2012-4 | TZ4 | 1 | Pacific sanddab | Liver | DDT | p,p-DDE | 200.0 | ppb |
| | | | | | | | | |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 101 | 9.8 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 105 | 6.2 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 110 | 9.8 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Constituent | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 118 | 23.0 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 128 | 5.1 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 138 | 26.0 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 149 | 5.4 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 151 | 3.0 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 153/168 | 53.0 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 158 | 2.2 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 170 | 5.5 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 180 | 19.0 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 183 | 4.6 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 187 | 14.0 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 194 | 4.1 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 49 | 2.3 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 52 | 3.1 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 66 | 3.0 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 74 | 1.9 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | PCB | PCB 99 | 14.0 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | DDT | p,p-DDMU | 13.0 | ppb |
| 2012-4 | TZ4 | 2 | Pacific sanddab | Liver | DDT | p,p-DDE | 280.0 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 101 | 21.5 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 105 | 7.5 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 110 | 21.0 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 118 | 33.0 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 128 | 7.3 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 138 | 38.0 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 149 | 23.0 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 151 | 10.4 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 153/168 | 80.5 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 158 | 4.3 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 170 | 8.8 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 180 | 27.5 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 183 | 7.3 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 187 | 20.0 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 194 | 5.4 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 201 | 5.7 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 206 | 4.4 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 28 | 1.2 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 49 | 6.5 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 52 | 8.6 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 66 | 4.4 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 70 | 4.6 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 74 | 2.2 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | PCB | PCB 99 | 25.5 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | DDT | o,p-DDE | 3.0 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | DDT | p,p-DDMU | 12.0 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | DDT | p,p-DDD | 5.9 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | DDT | p,p-DDE | 190.0 | ppb |
| 2012-4 | TZ4 | 3 | Pacific sanddab | Liver | DDT | p,p-DDT | 4.2 | ppb |