The City of San Diego

# Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant) 2011

## City of San Diego
## Ocean Monitoring Program

Public Utilities Department
Environmental Monitoring and Technical Services Division

**THE CITY OF SAN DIEGO**

June 29, 2012

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

Attention: POTW Compliance Unit

Dear Sir:

Enclosed on CD is the 2011 Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, South Bay Water Reclamation Plant as required per NPDES Permit No. CA0109045, Order No. R9-2006-067. This report contains data summaries, analyses and interpretations of the various portions of the ocean monitoring program, including oceanographic conditions, water quality, sediment characteristics, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues. These data are also presented in the International Boundary and Water Commission's annual report for discharge from the International Wastewater Treatment Plant (NPDES Permit No. CA0108928, Order No. 96-50).

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

Sincerely,

Steve Meyer
Deputy Public Utilities Director

TDS/akl

Enclosure: CD containing PDF file of this report

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

DIVERSITY
BRINGS US ALL TOGETHER

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# Annual Receiving Waters Monitoring Report

for the

# South Bay Ocean Outfall

(South Bay Water Reclamation Plant)

**2011**

Prepared by:

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

June 2012

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

**How to cite this document:**
City of San Diego. (2012). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2011. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

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# Acronyms and Abbreviations

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

## Acronyms and Abbreviations

| | |
|---|---|
| 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 |
| *p* | probability |
| PAH | Polycyclic Aromatic Hydrocarbons |
| PCB | Polychlorinated Biphenyls |
| PDO | Pacific Decadal Oscillation |
| pH | Acidity/Alkalinity value |
| PLOO | Point Loma Ocean Outfall |
| PLWTP | Point Loma Wastewater Treatment Plant |
| ppb | parts per billion |
| ppm | parts per million |
| ppt | parts per trillion |
| PRIMER | Plymouth Routines in Multivariate Ecological Research |
| psu | practical salinity units |
| r | ANOSIM test value that examines for differences among levels within a factor |
| $r_s$ | Spearman rank correlation coefficient |
| ROV | Remotely Operated Vehicle |
| SABWTP | San Antonio de los Buenos Wastewater Treatment Plant |
| SBOO | South Bay Ocean Outfall |
| SBWRP | South Bay Water Reclamation Plant |
| SCB | Southern Califonia Bight |
| SCBPP | Southern California Bight Pilot Project |
| SD | Standard Deviation |
| SDRWQCB | San Diego Regional Water Quiality Control Board |

# Acronyms and Abbreviations

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

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# Executive Summary

# Executive Summary

The City of San Diego (City) conducts an extensive ocean monitoring program to evaluate potential environmental effects from the discharge of treated wastewater to the Pacific Ocean via the South Bay Ocean Outfall (SBOO). The data collected are used to determine compliance with receiving water conditions as specified in NPDES regulatory permits for the City's South Bay Water Reclamation Plant (SBWRP) and the International Wastewater Treatment Plant (IWTP) operated by the U.S. International Boundary and Water Commission (USIBWC). Since treated effluent from these two facilities commingle before being discharged to the ocean, a single monitoring and reporting program approved by the San Diego Regional Water Quality Control Board and U.S. EPA is conducted to comply with both permits.

The primary objectives of the ocean monitoring efforts for the South Bay outfall region are to: (a) measure compliance with NPDES permit requirements and 2005 California Ocean Plan (Ocean Plan) water-contact standards, (b) monitor changes in ocean conditions over space and time, and (c) assess any impacts of wastewater discharge or other man-made or natural influences on the local marine environment, including effects on water quality, sediment conditions and marine life. Regular fixed monitoring sites that are sampled on a weekly, monthly, quarterly or semiannual basis are centered around the SBOO discharge site located approximately 5.6 km offshore at a depth of 27 m. Shoreline monitoring extends from Coronado, San Diego (USA) southward to Playa Blanca in northern Baja California (Mexico), while regular offshore monitoring occurs in adjacent waters overlying the continental shelf at depths of about 9 to 55 m.

Prior to the initiation of wastewater discharge though the SBOO in 1999, the City conducted a 3½ year baseline study designed to characterize background conditions in the region. In addition to regular fixed-site monitoring, a broader regional survey of benthic conditions is conducted each year at randomly selected sites that range from northern San Diego County to the USA/Mexico border and that extend further offshore to waters as deep as 500 m. These regional surveys are useful for evaluating patterns and trends over a larger geographic area, and thus provide additional information for distinguishing reference from impact areas.

The results and conclusions of all ocean monitoring activities conducted for the South Bay outfall monitoring program from January through December 2011 are organized into nine chapters in this report. Chapter 1 presents a general introduction and overview of the ocean monitoring program, while chapters 2–7 include results of all fixed site monitoring conducted during the year. In Chapter 2, data characterizing oceanographic conditions and water mass transport for the region are evaluated. Chapter 3 presents the results of shoreline and offshore water quality monitoring, including measurements of fecal indicator bacteria to determine compliance with Ocean Plan standards. Assessments of benthic sediment quality and the status of macrobenthic invertebrate communities are presented in Chapters 4 and 5, respectively. Chapter 6 presents the results of trawling activities designed to monitor communities of bottom dwelling (demersal) fishes and megabenthic invertebrates. Bioaccumulation assessments to determine contaminant loads in the tissues of local fishes are presented in Chapter 7. Results of the summer 2011 San Diego regional survey of sediment conditions and benthic macrofaunal communities are presented in Chapters 8 and 9, respectively. In addition to the above activities, the City and USIBWC support other projects relevant to assessing the quality and movement of ocean waters in the region. One such project involves satellite imaging of the San Diego/Tijuana coastal region, the results for 2011 which are incorporated into Chapters 2 and 3. A summary of the main findings for each of the above components is included below.

## Oceanographic Conditions

Oceanographic data collected in the South Bay outfall region support reports that describe 2011 as a La Niña year characterized by the early onset of relatively strong upwelling. Conditions indicative of local upwelling were most evident during March and June. Additionally, satellite images revealed colder-than-normal sea surface temperatures during the summer as would be expected during a La Niña. As is typical for the area, maximum stratification (layering) of the water column occurred in mid-summer, while well-mixed waters occurred during the winter. The only indication of the wastewater plume from the oceanographic data was relatively low salinity and high CDOM values measured near the discharge site. Changes in dissolved oxygen concentrations, pH and water clarity (transmissivity) relative to wastewater discharge were not discernible. Satellite imagery results indicated that the plume reached near-surface waters directly over the discharge site from January through March and from mid-October through December when the water column was not strongly stratified. Satellite observations also showed the furthest extent of the visible plume to be ~700 meters from the discharge area, thus supporting conclusions that inshore plume dispersion is minimal. In contrast, the plume remained deeply submerged from April through September when water column stratification was greater. Overall, ocean conditions during the year were consistent with well documented patterns for southern California and northern Baja California. These findings suggest that natural factors such as upwelling of deep ocean waters and effects of widespread 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

There was no evidence that the SBOO wastewater plume reached nearshore recreational waters in 2011. Although elevated levels of fecal indicator bacteria (FIB) were detected along or near the shore, this did not appear related to shoreward transport of the plume. Instead, most nearshore bacterial contamination was rainfall related and associated with turbidly plumes resulting from increased outflows from the Tijuana River (USA) and Los Buenos Creek (Mexico) during and after storm events. For example, about 88% of all elevated FIBs at the shore and kelp stations occurred during the wet season. This relationship between increased rainfall and high FIB counts in local waters has remained consistent since monitoring began several years prior to wastewater discharge. Most elevated FIB counts reported during the dry season occurred south of the international border at shore stations located near other sources of contamination not associated with the SBOO. In contrast, only a single sample with elevated FIBs was collected near (within 1000 m) of the SBOO discharge zone during the year. The overall low incidence of contaminated waters related to the SBOO plume is likely due to continued seasonal disinfection and the commencement of full secondary treatment at the IWTP in early 2011.

Overall compliance with the 2005 Ocean Plan standards was 91% in 2011, which was slightly higher than the 87% compliance observed in 2010. Compliance with the total coliform, fecal coliform and enterococcus geometric mean standards ranged from 59% to 100% at the shore stations and from 92% to 100% at kelp stations. Compliance with the four single sample maximum standards ranged from 87% to 91% at the shore stations, and from 98% to 99.5% at the kelp stations. Since compliance rates reflect the presence of elevated FIBs, compliance was generally lowest during the wet season ( January–April, November–December) when rainfall was greatest.

## Sediment Conditions

The composition of benthic sediments at the regular SBOO stations was similar in 2011 to previous years and varied from fine silts to very coarse sands or other large particles. There was no apparent relationship between sediment grain size distributions and proximity to the discharge site, nor has there been any substantial increase in fine sediments near the outfall or throughout the region since wastewater discharge began. Instead, the range of sediment types present reflects multiple geological origins or complex patterns of transport and deposition from sources such as the Tijuana River and San Diego Bay.

Sediment quality in the region was also similar in 2011 to previous years with overall contaminant loads remaining low compared to other southern California coastal areas. There was no evidence of contaminant accumulation associated with wastewater discharge. Concentrations of the various organic loading indicators, trace metals, pesticides and PCBs varied widely throughout the region, and there were no patterns that could be attributed to the outfall or other point sources. Instead, the distribution of contaminants in sediments continued to be linked to natural environmental heterogeneity. For example, concentrations of total organic carbon, total nitrogen, total volatile solids, and several metals were usually higher at sites characterized by finer sediments, a pattern consistent with results from other studies. Finally, the potential for environmental degradation by the various contaminants was evaluated using the effects-range low (ERL) and effects-range median (ERM) sediment quality guidelines when available. The only exceedances of either threshold in 2011 were for arsenic, which exceeded the ERL at one station during the January and July surveys.

## Macrobenthic Communities

Benthic macrofaunal assemblages surrounding the SBOO were similar in 2011 to previous years, and there were no significant differences between those occurring at nearfield and farfield sites. These assemblages were typical of those that occur in similar habitats throughout the Southern California Bight (SCB). For example, most of the relatively shallow, coarse sand sites had high abundances of *Spiophanes norrisi*, a polycheate worm characteristic of similar habitats throughout the SCB. In contrast, slightly different assemblages were found at mid-depth stations with somewhat finer sediments characteristic of much of the southern California mainland shelf.

Species richness and total abundance of the SBOO macrobenthic assemblages varied with depth and sediment type, but showed no clear patterns relative to the discharge area. Instead, spatial patterns in abundance were driven mostly by changes in *S. norrisi* populations similar to that observed in 2010. Benthic response index (BRI) values were also mostly characteristic of non-impacted macrofaunal communities. Additionally, changes that did occur during the year were similar in magnitude to those seen previously in southern California waters, and correspond to large-scale oceanographic processes or other natural events. Overall, macrofaunal assemblages in the region remain similar to 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 in the region.

## Demersal Fishes And Megabenthic Invertebrates

Speckled sanddabs dominated fish assemblages surrounding the SBOO in 2011 as they have in previous years, occurring at almost all stations and accounting for 66% of the total year's catch. Other species collected in at least half the trawls included yellowchin sculpin, longspine combfish, English sole, roughback sculpin, California tonguefish, and longfin sanddab. Although the composition and structure of fish assemblages varied among stations, these differences were mostly due to natural variation in populations of speckled sanddab, California lizardfish, white croaker, yellowchin sculpin and English sole.

Trawl-caught invertebrate assemblages were dominated by the sea star *Astropecten californicus*, which occurred in almost all trawls and accounted for 35% of the total invertebrate abundance. Other less abundant but common species included the parasitic isopod *Elthusa vulgaris*, the crab *Metacarcinus gracilis*, the nudibranch *Acanthodoris brunnea*, the opisthobranch *Pleurobranchaea californica*, and the octopus *Octopus rubescens*. As with fishes, the composition and structure of the invertebrate assemblages varied among stations, reflecting mostly large fluctuations in populations of the above species.

Comparisons of the 2011 trawl survey results with previous surveys (1995–2010) indicate that demersal fish and megabenthjic invertebrate communities in the region remain unaffected by wastewater discharge. The relatively low species richness and small populations of trawl-caught fishes and invertebrates are consistent with the shallow, sandy habitat surveyed. Patterns in the abundance and distribution of individual species were similar at stations located near the outfall and farther away, suggesting a lack of significant anthropogenic influence. Finally, external examinations of all fishes captured during the year indicated that local fish populations remain healthy, with there being no evidence of physical anomalies or disease.

## Contaminants In Fish Tissues

The accumulation of contaminants in marine fishes may be due to direct exposure to contaminated water or sediments or to the ingestion of contaminated prey. Consequently the bioaccumulation of chemical contaminants in local fishes was assessed by analyzing liver tissues from trawl-caught fishes and muscle tissues from species captured by hook and line. Results from both analyses indicated no evidence to suggest that contaminant loads in fishes captured in the region were affected by wastewater discharge in 2011. Although a few tissue samples contained metal concentrations that exceeded pre-discharge maximums or international standards, concentrations of most contaminants were generally similar to that observed prior to discharge. Additionally, tissue samples that did exceed pre-discharge contaminant levels were found in fishes from sites that were widely distributed throughout the region. Furthermore, all contaminant concentrations 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 the bioaccumulation of contaminants in fish include the different physiologies and life history traits of various species. Additionally, exposure to contaminants can vary greatly between fish species and even among individuals of the same species depending on migration habits. For example, a fish may be exposed to contaminants in a polluted area and then migrate to a region that is less contaminated. This is of particular concern for fishes collected in the vicinity of the SBOO, as there are many other point and non-point sources that may contribute to contamination.

## San Diego Regional Survey

The summer 2011 San Diego regional benthic survey covered an area ranging from offshore of Del Mar south to the USA/Mexico border. A total of 41 randomly selected sites were sampled at depths ranging from 10 to 427 m and that spanned four distinct depth strata (i.e., inner shelf, mid-shelf, outer shelf, upper slope). Included below is a summary of the sediment conditions and soft-bottom macrobenthic assemblages present during the 2011 survey, along with a comparison to conditions present during 2009 and 2010 for a three-year assessment.

### Regional Sediments

The composition of sediments at the regional stations sampled in 2011 was typical for continental shelf and upper slope benthic habitats off southern California, and consistent with results from previous surveys. Overall, sediment types varied as expected by region and depth. For example, stations sampled within the regular SBOO fixed-station grid tended to have sediments composed predominantly of sand, whereas stations sampled within the regular Point Loma Ocean Outfall (PLOO) monitoring grid tended to have much finer sediments dominated by silts and clay. Exceptions to this pattern did occur, particularly at outer shelf sites located along the Coronado Bank, a southern rocky ridge located southwest of Point Loma. Sediment composition in this area is generally coarser than stations located at similar depths west of Point Loma and further to the north.

As with grain size composition, the quality of regional sediments sampled in 2011 was similar to previous years, and there was no evidence of degraded sediment quality. While various organic loading indicators trace metals, chlorinated pesticides, PCBs and PAHs were detected, contaminant concentrations were relatively low compared to many other coastal areas of the SCB. Almost all contaminants occurred at levels below ERL and ERM thresholds. Further, although contaminant concentrations in San Diego sediments have been highly variable over the past three years, there was no evidence of disturbance that could be attributed to local wastewater discharges from either the SBOO or the PLOO. Instead, concentrations of total nitrogen, total volatile solids and several trace metals were found to increase with increasing amounts of fine sediments (percent fines). As percent fines also increased with depth, many contaminants were detected at higher concentrations in deeper strata compared to shallower inner and mid-shelf regions. For example, the highest levels of most contaminants were found in sediments along the upper slope where some of the finest sediments occurred.

### Regional Macrofauna

The SCB benthos has long been considered to be composed of heterogeneous or "patchy" habitats, with the distribution of invertebrate species and communities exhibiting considerable spatial variability. Results of the summer 2011 regional survey, coupled with data from 2009 and 2010, support this characterization, with the major assemblages segregating by habitat characteristics such as depth and sediment type.

The inner to mid-shelf macrofaunal assemblages off San Diego were similar to those found in other shallow, sandy habitats across the SCB, and were characterized by species such as the polychaete worms *Owenia collaris* and *Spiophanes norrisi*, and the bivalve *Tellina modesta*. Assemblages occurring in somewhat finer but more mixed sediments at mid- to outer shelf depths were dominated by the brittle star *Amphiodia urtica*, and corresponded to the *Amphiodia* "mega-community" described previously for the SCB. Although also occurring at outer shelf depths, coarser sediment sites along the Coronado Bank were instead dominated by several other distinct species of polychaetes (e.g., *Aphelochaeta glandaria* Cmplx, *Monticellina siblina, Chaetozone* sp SD5). Upper slope habitats were characterized by species assemblages characteristic of much finer sediments that are distinct from most shelf areas. These upper slope assemblages were often characterized by relatively high abundances of specific bivalves (e.g., *Yoldiella nana*, *Nuculana conceptionis,* and *Tellina carpenteri*), as well as the presence of a few distinctive polychaetes (e.g., *Spiophanes kimballi* and *Maldane sarsi*)

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2009−2011 regional surveys that could be attributed to wastewater discharges, disposal sites or other point sources. Benthic habitats appear to be in good condition throughout the region, with 90% of the sites surveyed in 2011 being in reference condition based on assessments using the benthic response index (BRI). This pattern is consistent with recent findings for the entire SCB mainland shelf.

## Conclusions

The findings and conclusions for the ocean monitoring efforts conducted for the South Bay outfall region during calendar year 2011, as well as the summer 2011 San Diego regional benthic survey, were consistent with previous years. Overall, there were limited impacts to local receiving waters, benthic sediments, and marine invertebrate and fish communities. There was no evidence that the wastewater plume from the SBOO reached recreational waters during the year. Although elevated bacterial levels did occur in nearshore areas, such instances were largely associated with rain driven outflows from local rivers and creeks and not to shoreward transport of the plume. There were also no outfall related patterns in sediment contaminant distributions, or in differences between the various macrobenthic invertebrate and fish assemblages. The lack of disease symptoms in local fish populations, as well as the low level of contaminants detected in fish tissues, was also indicative of a healthy marine environment. Finally, results of the regional benthic survey conducted during the year also revealed no outfall related effects, and that benthic habitats in the region remain in good condition similar to much of the southern California continental shelf.

# Chapter 1
# General Introduction

# Chapter 1. General Introduction

The South Bay Ocean Outfall (SBOO) discharges treated effluent to the Pacific Ocean that originates from two separate sources: the International Wastewater Treatment Plant (IWTP) and the South Bay Water Reclamation Plant (SBWRP). Wastewater discharge from the IWTP, which is owned and operated by the International Boundary and Water Commission (USIBWC), began in January 1999 and is performed under the terms and conditions set forth in Order No. 96-50, Cease and Desist Order No. 96-52 for National Pollutant Discharge Elimination System (NPDES) Permit No. CA0108928. Discharge from the City of San Diego's SBWRP began in May 2002 and is currently performed according to provisions set forth in Order No. R9-2006-0067 for NPDES Permit No. CA0109045. The Monitoring and Reporting Programs (MRPs), specified in the above orders define the receiving waters monitoring requirements for the South Bay coastal region, including sampling design, compliance criteria, types of laboratory analyses, and data analysis and reporting guidelines.

All MRP mandated monitoring for the SBOO region has been performed by the City of San Diego since wastewater discharge began in 1999. The City also conducted 3½ years of pre-discharge monitoring in order to provide information against which post-discharge conditions may be compared (City of San Diego 2000a). Additionally, the City has conducted region-wide surveys off the coast of San Diego each summer since 1994 as part of regular annual monitoring requirements (e.g., City of San Diego 1998, 1999, 2000b, 2001–2003, 2006–2011) or during participation in larger, multi-agency surveys of the entire Southern California Bight that occur approximately every five years (e.g., Bergen et al. 1998, 2001, Noblet et al. 2002, Ranasinghe et al. 2003, 2007, 2012, Schiff et al. 2006). Such large-scale surveys are useful in characterizing the ecological health of diverse coastal environments and in distinguishing reference areas from sites impacted by wastewater discharges, stormwater discharges, urban runoff, or other sources of contamination.

Finally, the City and USIBWC also fund a remote sensing program for the San Diego/Tijuana region as part of the monitoring efforts for the Point Loma and South Bay outfall areas. This program, conducted by Ocean Imaging, Inc. (Solana Beach, CA) uses satellite and aerial imagery data to produce a synoptic picture of surface water clarity that is not possible using shipboard sampling alone. With public health issues being of paramount concern for ocean monitoring programs in general, any information that helps to provide a clearer and more complete picture of water conditions is beneficial to the general public as well as to program managers and regulators. Complete results of the remote sensing program conducted during calendar year 2011 are summarized in Svejkovsky (2012).

This report presents the results of all receiving waters monitoring activities conducted for the South Bay outfall monitoring region in 2011. Included are results from all fixed stations that comprise a grid surrounding the SBOO, as well as results from the July 2011 regional benthic survey of randomly selected sites off San Diego. Satellite imagery observations made during the year as reported by Svejkovsky (2012) are also considered and integrated into interpretations of oceanographic and water quality data. Comparisons are also made to conditions present during previous years in order to evaluate spatial and temporal changes that may be related to wastewater plume dispersion or to other anthropogenic or natural factors. The major components of the monitoring program are covered in the following chapters: Oceanographic Conditions, Water Quality, Sediment Conditions, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, Bioaccumulation of Contaminants in Fish Tissues, Regional Sediment Conditions, and Regional Macrobenthic Communities. Some general background information on program design and sampling procedures for the regular fixed-grid monitoring and regional surveys are given below and in subsequent chapters and appendices.

## Regular Fixed-Grid Monitoring

The SBOO is located just north of the border between the United States and Mexico. The outfall terminates approximately 5.6 km offshore at a depth of about 27 m. Unlike other southern California ocean outfalls that lie on the surface of the seabed, the pipeline first begins as a tunnel on land and then continues under the seabed to a distance of about 4.3 km offshore. From there it connects to a vertical riser assembly that conveys effluent to a pipeline buried just beneath the surface of the seabed. This subsurface pipeline then splits into a Y-shaped multiport diffuser system (i.e., wye), with the two diffuser legs extending an additional 0.6 km to the north and south. The outfall was originally designed to discharge wastewater through 165 diffuser ports and risers, which included one riser at the center of the wye and 82 others spaced along each diffuser leg. However, persistently low flow rates have required closure of all ports along the northern diffuser leg and many along the southern diffuser since discharge began in order for the outfall to operate effectively. Consequently, wastewater discharge is restricted primarily to the distal end of the southern diffuser leg, with the exception of a few intermediate points at or near the center of the wye.

The regular sampling area for the SBOO region extends from the tip of Point Loma southward to Playa Blanca, northern Baja California (Mexico), and from the shoreline seaward to a depth of about 61 m (Figure 1.1). The offshore monitoring sites are arranged in a grid surrounding the outfall, with each station being sampled in accordance with NPDES permit requirements. Sampling at these fixed (core) stations includes monthly seawater measurements of physical, chemical, and bacteriological parameters to document water quality conditions in the area. Benthic sediment samples are collected

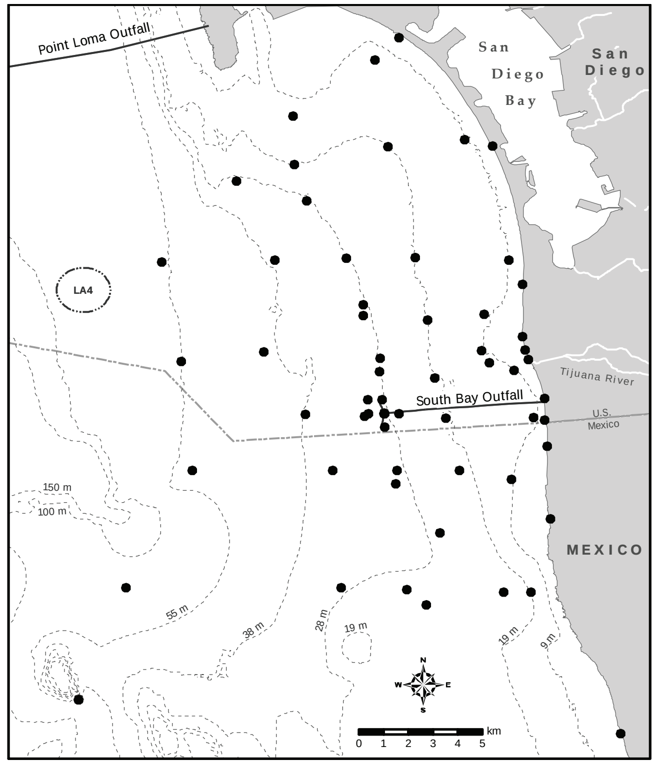


**Figure 1.1**
Receiving waters monitoring stations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

semiannually to evaluate macrobenthic invertebrate communities and sediment conditions. Trawl surveys are performed quarterly to monitor communities of demersal fish and large, bottom-dwelling invertebrates (megabenthos). Additionally, analyses of fish muscle and liver tissues are performed semiannually to assess the bioaccumulation of chemical constituents that may have ecological or public health implications.

## Random Sample Regional Surveys

In addition to the core fixed-station sampling, the City typically conducts a summer benthic survey of sites distributed throughout the entire San Diego region as part of the monitoring requirements for the South Bay outfall program. These surveys are based on an array of stations that are randomly selected by the United States Environmental Protection Agency (USEPA) using the probability-based Environmental Monitoring and Assessment Program (EMAP) design. Benthic surveys conducted in 1994, 1998, 2003, and 2008 were broader in scope, involved other major southern California dischargers, and included sites representing the entire Southern California Bight (SCB) from Point Conception, California to Cabo Colonet, Northern Baja California. These surveys included the Southern California Bight Pilot Project (SCBPP) in 1994, and the SCB Regional Monitoring Programs in 1998, 2003 and 2008 (Bight'98, Bight'03, and Bight'08, respectively). Results of the 1994–2008 regional programs are available in Bergen et al. (1998, 2001), Schiff and Gossett (1998), Noblet et al. (2002), Ranasinghe et al. (2003, 2007, 2012), and Schiff et al. (2006, 2011). A separate regional survey for San Diego was not conducted in 2004 in order to conduct the first phase of a sediment mapping study (see Stebbins et al. 2004, City of San Diego 2005).

The same randomized sampling design was used to select 40 new stations per year for each of the summer surveys restricted to the San Diego region in 1995–1997 and 1999–2002. Beginning in 2005, however, an agreement was reached between the City, USEPA and San Diego Regional Water Quality Control Board to revisit sites successfully sampled 10 years earlier in order to facilitate comparisons of long-term changes in benthic conditions. During some of these follow-up surveys, a limited number of stations could not be revisited due to the presence of rocky substrates that made it impossible to collect benthic grab samples. Thus, 36 sites were revisited in 2005, 34 sites in 2006, and 39 sites in 2007. As indicated above, a separate survey for the San Diego region was not conducted in 2008 due to participation in Bight'08. In 2009, sampling was conducted at the 34 sites originally sampled in 1999 as well as six additional new sites located further offshore in waters deeper than 200 m (see City of San Diego 2010). These latter six stations were added to provide information on deeper continental slope habitats off San Diego. The summer 2010 regional survey involved sampling 40 new randomly selected stations provided by EPA and distributed between continental shelf (< 200 m) and upper slope (~200–500 m) depths.

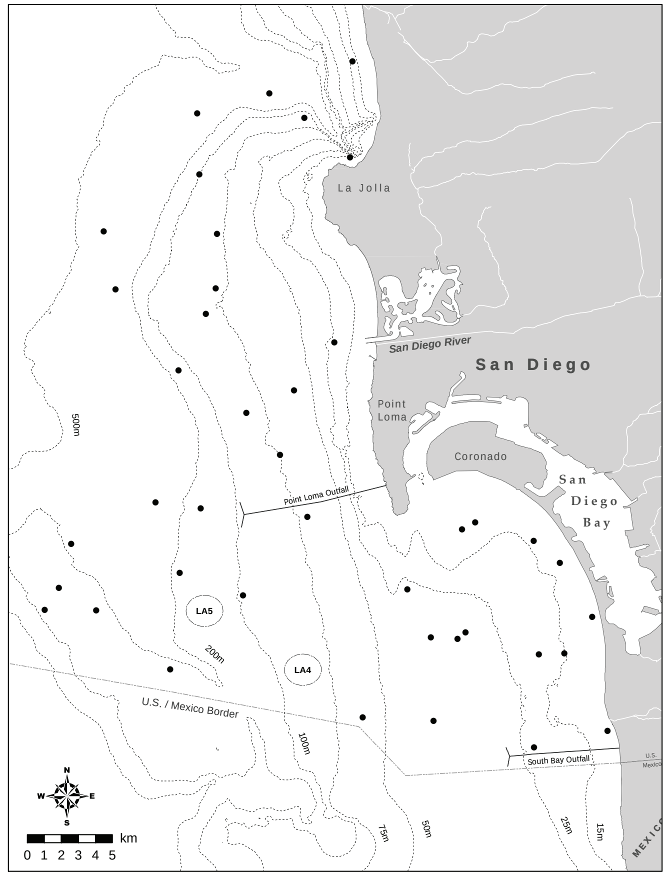


**Figure 1.2**
Regional benthic survey stations sampled during July 2011 as part of the City of San Diego's Ocean Monitoring Program.

The summer 2011 regional survey reported herein also involved sampling a total of 41 new randomly selected stations (Figure 1.2), which extended offshore from depths of about 10 to 427 m (see Chapters 8–9 for details).

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# Chapter 2
# Oceanographic Conditions

# *Chapter 2. Oceanographic Conditions*

## Introduction

The City of San Diego collects a comprehensive suite of oceanographic data from offshore ocean waters surrounding both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively) to characterize conditions in the region and to identify possible impacts of wastewater discharge. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen (DO), pH, chlorophyll *a*, and colored dissolved organic matter (CDOM) are important indicators of physical and biological oceanographic processes (e.g., Skirrow 1975) 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 discharge, but also by oceanographic factors that govern water mass movement (e.g., water column mixing, ocean currents), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping. Further, previous studies have shown that wastewater plumes can often be identified by having lower salinity and higher CDOM values than background conditions (e.g., Terrill et al. 2009, Todd et al. 2009).

In nearshore coastal waters of the Southern California Bight (SCB) such as the South Bay outfall region, oceanographic conditions are strongly influenced by several factors, including (1) global and regional climate processes such as El Niño/La Niña, Pacific Decadal and North Pacific Gyre oscillations that can affect long-term (~10–20 years) trends (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, 2011, NOAA/NWS 2011), (2) the California Current System (CCS) coupled with local gyres that transport distinct water masses throughout the SCB (Lynn and Simpson 1987), and (3) seasonal changes in local weather patterns (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Southern California weather is classified into a wet or winter season (typically December through February) and a dry summer season (typically July through September) (WRCC 2012), with differences between these seasons affecting oceanographic conditions such as water column stratification and current patterns. For example, storm activity during southern California winters brings higher winds, rain, and waves that often contribute to the formation of a well-mixed, non-stratified water column (Jackson 1986). The chance of wastewater plumes from sources such as the SBOO reaching surface waters is highest during these times since no barriers (temperature, salinity gradients) exist. These winter conditions often extend into spring until the frequency of storms decreases and the transition from wet to dry conditions begins. In late spring the surface waters begin to warm, which results in increased surface evaporation (Jackson 1986). Once the water column becomes stratified, minimal mixing conditions typically remain throughout the summer and early fall months. In the fall, cooler temperatures, along with increases in stormy weather, begin to cause the return of well-mixed water column conditions.

Understanding changes in oceanographic conditions due to natural processes such as the seasonal patterns described above is important since they can affect the transport and distribution of wastewater, storm water and other types of turbidity (e.g., sediment) plumes. In the SBOO region these include plumes associated with tidal exchange from San Diego Bay, outflows from the Tijuana River in California waters and Los Buenos Creek in northern Baja California, storm water discharges, and runoff from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1165 km$^2$ and 4483 km$^2$ of watersheds, respectively (Project Clean Water 2012), and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009).

This chapter presents analyses and interpretations of the oceanographic data collected during 2011 at fixed monitoring stations surrounding the SBOO. The primary goals are to: (1) summarize oceanographic conditions in the SBOO region, (2) identify potential natural and anthropogenic sources of variability, (3) assess possible influence of the SBOO wastewater discharge relative to other input sources, and (4) determine the extent to which water mass movement or water column mixing affects the dispersion/dilution potential for discharged materials. Results of remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of surface waters (Pickard and Emery 1990, Svejkovsky 2012). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site. The results reported herein are also referred to in subsequent chapters to explain patterns of indicator bacteria distributions (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

## Materials and Methods

### Field Sampling

Oceanographic measurements were collected at 40 fixed sampling sites arranged in a grid pattern surrounding the SBOO and encompassing an area of ~300 km$^2$ (Figure 2.1). These stations (designated I1–I40) are located between about 3.4–14.6 km offshore along or adjacent to the 9, 19, 28, 38 and 55-m depth contours. The stations were sampled monthly over a 3-day period (see Table 2.1). Sites

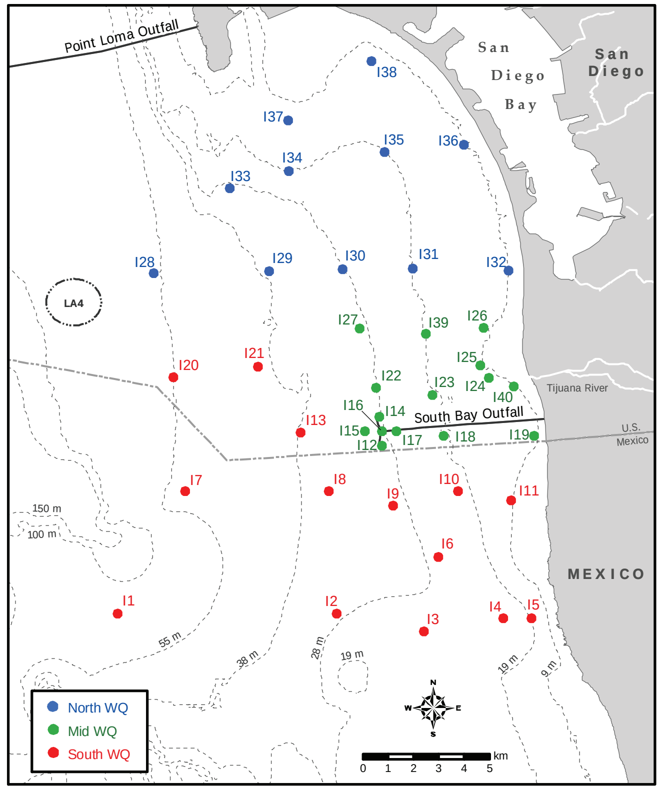



**Figure 2.1**
Water quality (WQ) monitoring station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

were grouped together during each sampling period as follows: "North Water Quality" stations I28–I38 ($n = 11$); "Mid Water Quality" stations I12, I14–I19, I22–I27, I39, I40 ($n = 15$); "South Water Quality" stations I1–I11, I13, I20, I21 ($n = 14$).

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

**Table 2.1**
Sample dates for monthly oceanographic surveys conducted in the South Bay outfall region during 2011. Each survey was conducted over three consecutive days with all stations in each station group sampled on a single day (see text and Figure 2.1 for a list of stations and station locations).

| Station Group | 2011 Monthly Sampling Dates | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| North WQ | 3 | 3 | 1 | 4 | 11 | 6 | 7 | 22 | 15 | 3 | 7 | 5 |
| Mid WQ | 4 | 1 | 2 | 6 | 10 | 8 | 6 | 23 | 14 | 5 | 8 | 6 |
| South WQ | 5 | 2 | 3 | 5 | 12 | 7 | 5 | 24 | 13 | 4 | 9 | 7 |

and water conditions were recorded just prior to each CTD cast.

### Remote Sensing

Coastal monitoring of the SBOO region during 2011 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite imaging data collected during the year were made available for review and download from OI's website (Ocean Imaging 2012), while a separate annual report summarizing results for the year was also produced (Svejkovsky 2012). Several different types of satellite imagery were analyzed during the past year including Moderate Resolution Imaging Spectroradiometer (MODIS), Thematic Mapper TM7 color/thermal, and high resolution Rapid Eye images. These technologies differ in terms of their capabilities as described in the "Technology Overview" section of Svejkovsky (2012), but are generally useful for revealing patterns in surface waters as deep as 12 m, depending on conditions (e.g., water clarity).

### Data Analysis

With the exception of CDOM, the various water column parameters measured in 2011 were summarized as means of surface (top 2 m) and bottom (bottom 2 m) waters for each month pooled over all stations along each of the 9, 19, 28, 38 and 55-m depth contours. Additionally, data from the 28-m depth contour stations (stations I2, I3, I6, I9, I12, I14, I15, I16, I17, I22, I27, I30, I33) were averaged for each 1-m depth bin by month to identify seasonal trends. Data were limited to these 13 stations to prevent masking trends that might occur when data from all depth contours are combined. CDOM data were not included in these analyses due to calibration issues with the individual CDOM probes, which make absolute (measured) values unreliable. Because of this limitation, only relative scales are used for CDOM in this report (see below).

For spatial analysis of all parameters, 3-dimensional graphical views were created for each month using Interactive Geographical Ocean Data System software (IGODS), which interpolates data across all depths at each site and between stations along each depth contour. CDOM data were included as part of these spatial analyses using relative values that were not affected by the calibration issues mentioned above. In most cases, the IGODS analyses reported herein are limited to the four monthly surveys most representative of the winter (February), spring (May), summer (August), and fall (November) seasons, and which corresponded to the quarterly water quality surveys conducted as part of the coordinated Point Loma Ocean Outfall and Central Bight Regional monitoring efforts.

Finally, a time series of anomalies for each parameter was created to evaluate significant oceanographic events that have occurred in the region. Anomalies were calculated by subtracting the mean of all 17 years combined (i.e., 1995–2011) from the monthly means for each year. These mean values were calculated using data from just the 28-m depth contour stations, with all water column depths combined.

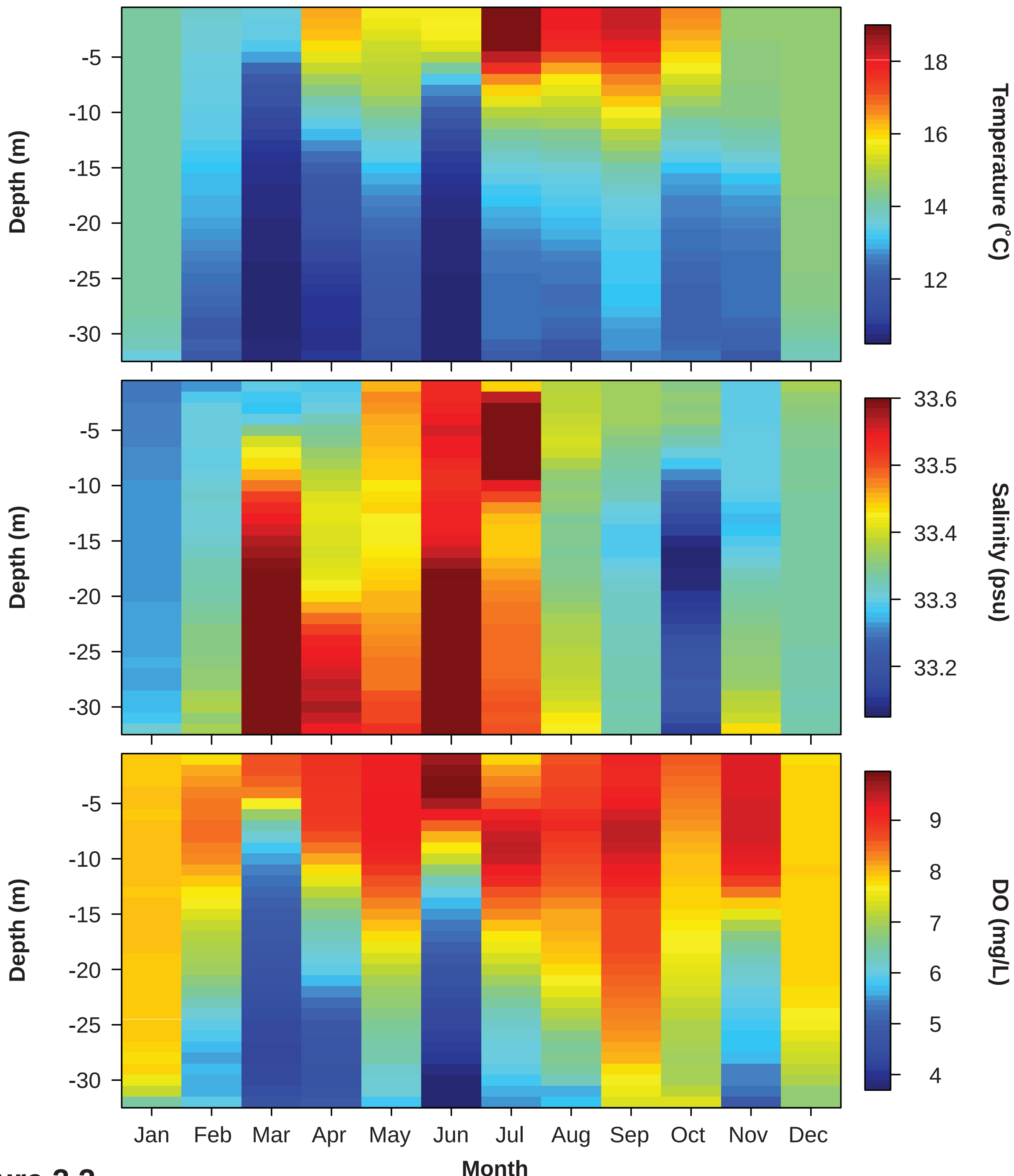



**Figure 2.2**
Temperature, salinity, dissolved oxygen (DO), pH, transmissivity, and chlorophyll *a* (Chl) values recorded at SBOO 28-m stations during 2011. Data are expressed as mean values for each 1-m depth bin, pooled over all stations.

## Results and Discussion

### Oceanographic Conditions in 2011

***Water Temperature***

Surface temperatures across the entire SBOO region in 2011 averaged from 12.4˚C in March to 20.3˚C in July, while bottom temperatures averaged from 10.0˚C in March to 15.6˚C in August (Appendix A.1). The maximum average surface temperature recorded during the year was ~1º higher than in 2010, and occurred earlier in the year (i.e., July versus October; City of San Diego 2011a). Water temperatures varied by season as expected. For example, colder bottom waters likely indicative

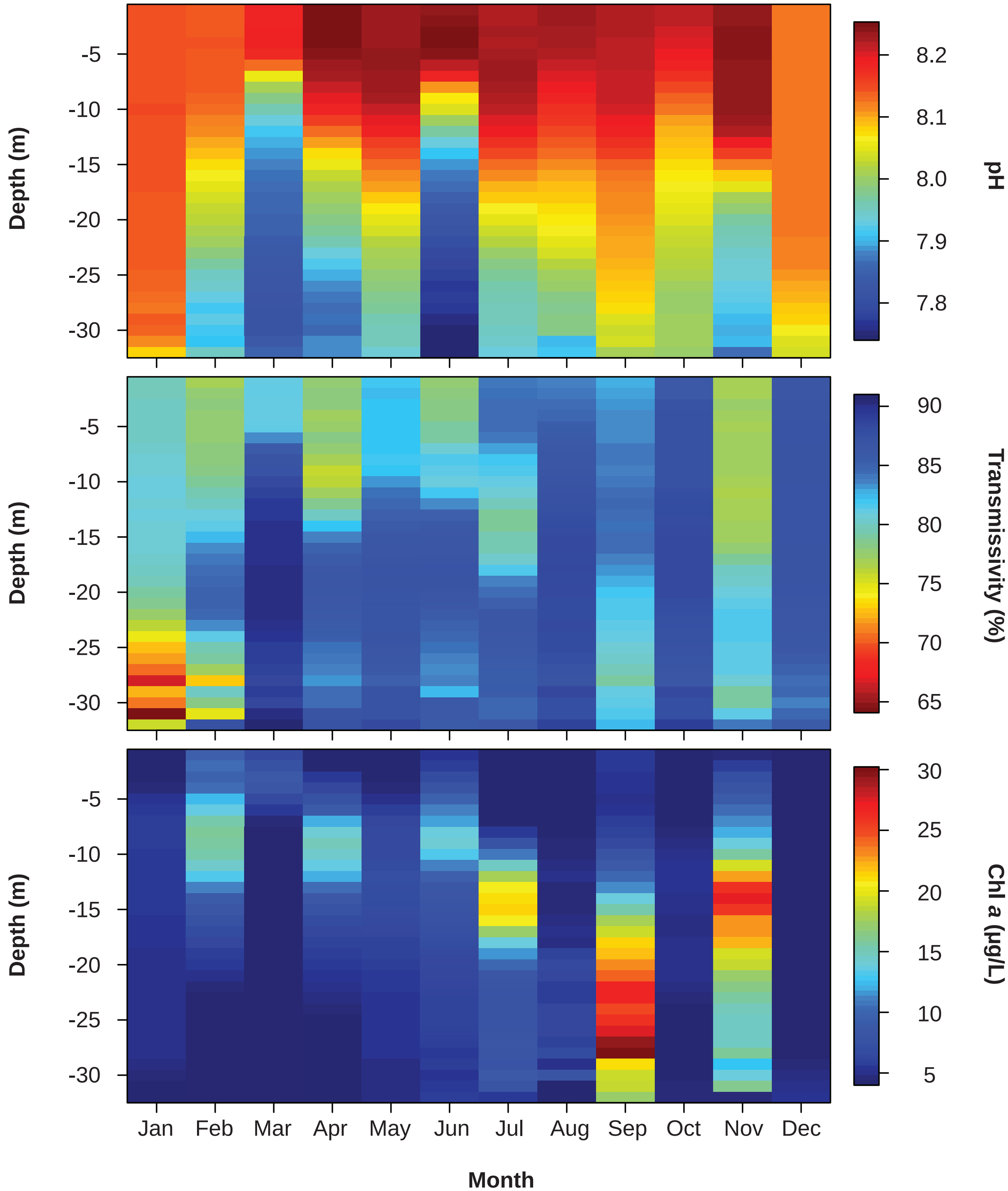



**Figure 2.2** *continued*

of upwelling (e.g., <12ºC at 28-m stations) occurred during the spring, with the lowest temperatures of the year recorded in March and June (Figure 2.2, Figure 2.3, Appendix A.1). Thermal stratification of the water column also varied as expected, ranging from mixed in the winter, to highly stratified in the summer, to less stratified in the fall. Since temperature is the main contributor to water column stratification in southern California (Dailey et al. 1993, Largier et al. 2004), differences between surface and bottom temperatures were important to limiting the surfacing potential of the wastewater plume during certain times of the year. Results from remote sensing observations indicated presence of the plume in surface or near-surface waters during January, February, March,

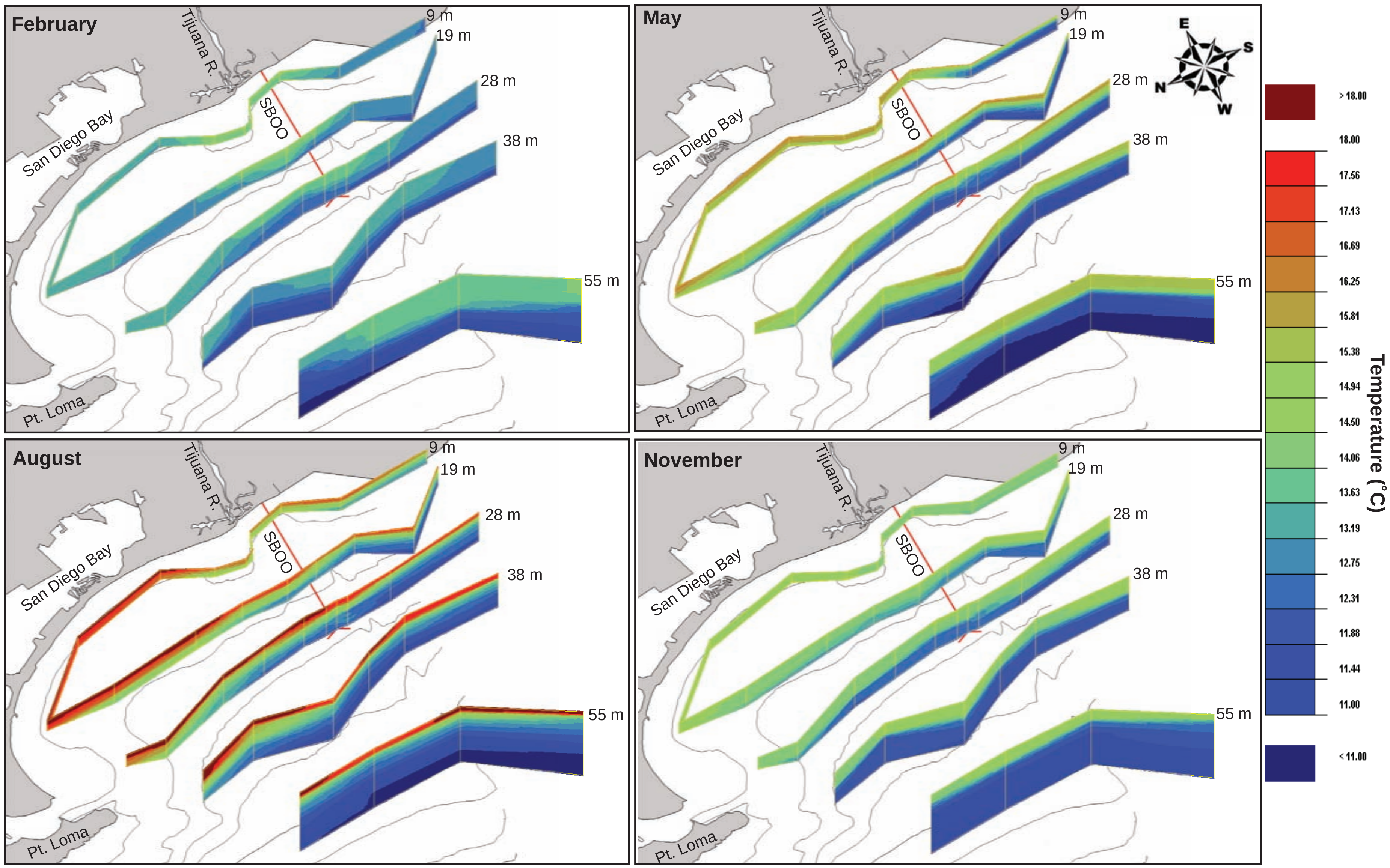
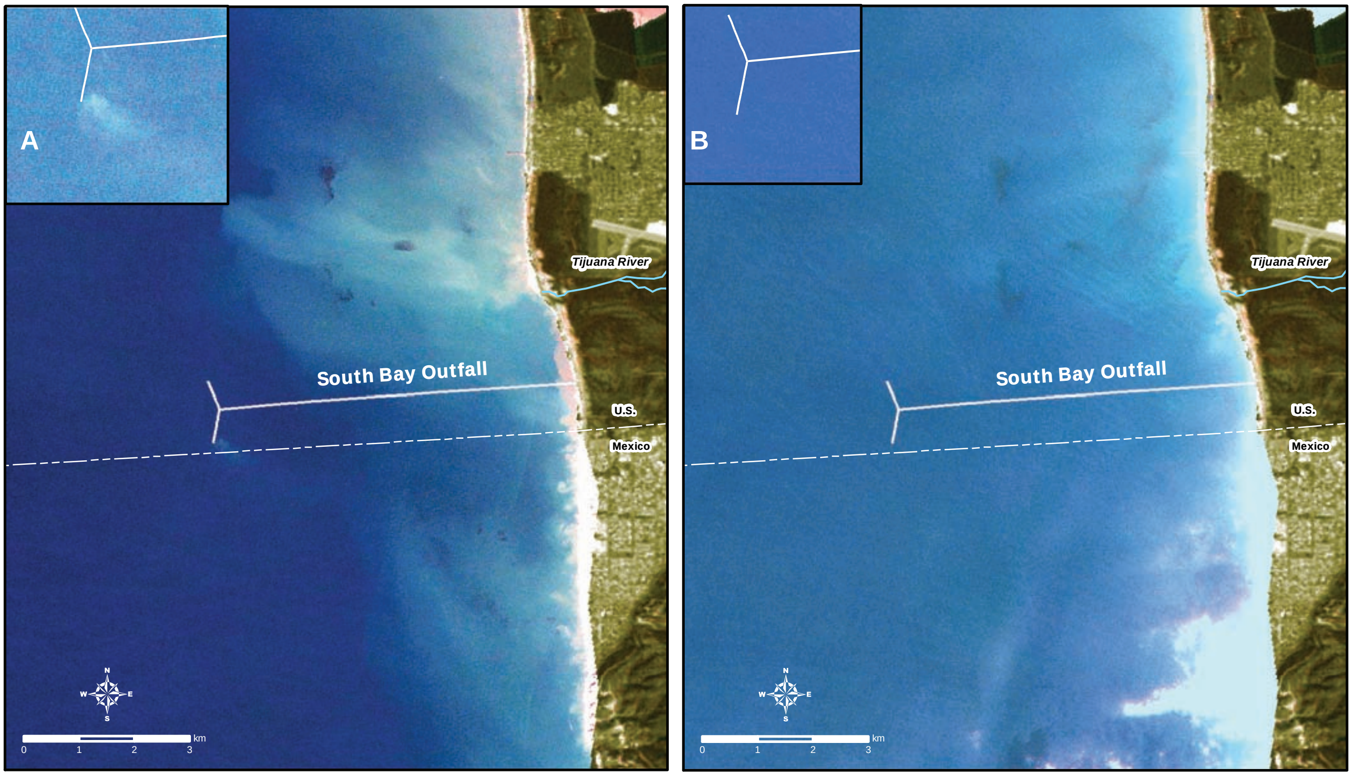



**Figure 2.3**
Ocean temperatures recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.




## Figure 2.4

Rapid Eye images of the SBOO and coastal region acquired on December 21, 2011, demonstrating when the SBOO plume is visible at the surface (left; inset A), and on October 26, 2011, demonstrating when the SBOO plume is submerged under the thermocline (right; inset B) (see text; images from Ocean Imaging 2012).

October, November and December when the water column was more mixed, but not between April and September when the water column was stratified enough to keep the plume submerged (e.g., Figure 2.4; see also Svejkovsky 2012). Satellite observations also showed the furthest extent of the visible plume to be about 700 meters from the discharge area and was not likely to have reached the shoreline.

***Salinity***

Average salinities for the SBOO region in 2011 ranged from a low of 33.21 psu in March to a high of 33.60 psu in July for surface waters, and from 33.21 psu in October to 33.87 psu in June at bottom depths (Appendix A.1). Salinity also varied as expected by season, with the narrow range of values during January and December reflecting mixed conditions during these months. Additionally, relatively high salinity values were present across most of the region at bottom depths from March to July, with the highest values recorded during March and June at stations along the 19, 28, 38, and 55-m stations (Appendix A.1). For example, salinity values were ≥33.49 psu at the 28-m stations during these months (Figure 2.2, Appendix A.1). Higher salinity values tended to correspond with lower temperatures found at bottom depths as described above. Taken together, these factors are likely indicative of local coastal upwelling typical for this time of year (Jackson 1986).

As in previous years, a thin layer of relatively low salinity values was evident at sub-surface depths during the spring, summer, and fall of 2011 (e.g., Figure 2.2, Figure 2.5). For example, salinity values were below about 33.37 psu between ~10 and 20 m depths at the 28-m contour stations during August (Figure 2.2). It seems unlikely that this sub-surface low salinity layer (SSL) is related to SBOO discharge for several reasons. First, no evidence has ever been reported of the plume extending simultaneously throughout the region in so many directions. Instead, previous remote

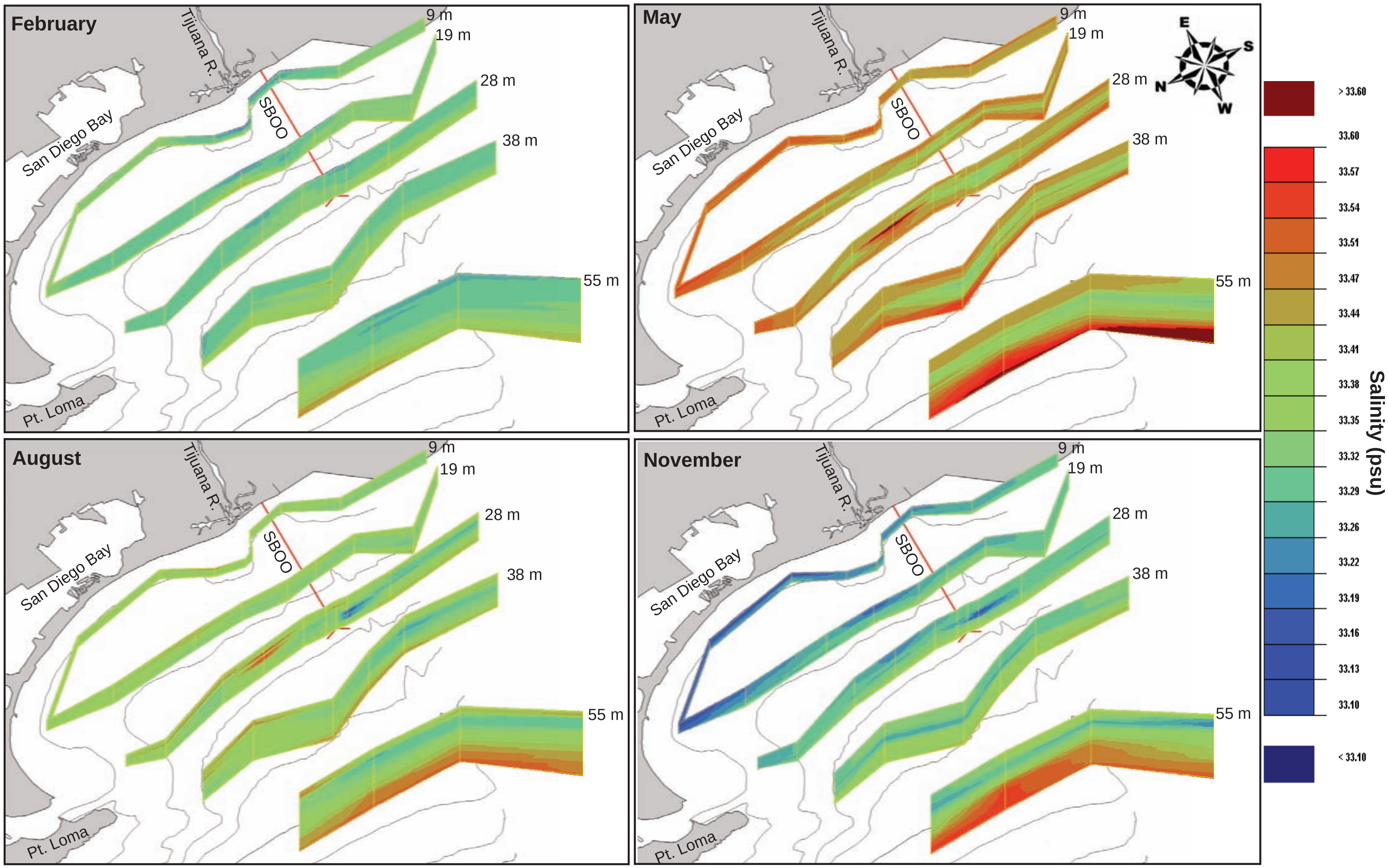



**Figure 2.5**
Ocean salinity recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.

sensing observations (Svejkovsky 2010) and other oceanographic studies (e.g., Terrill et al. 2009) have demonstrated that the SBOO plume disperses in one specific direction at any given time (e.g., south, southeast, north). Second, similar SSLs have been reported previously off San Diego and elsewhere in southern California, including: (a) the Point Loma monitoring region during 2009, 2010 and 2011 (City of San Diego 2010a, 2011b, 2012); (b) coastal waters off Orange County for many years (e.g., OCSD 1999); (c) coastal waters extending as far north as Ventura County (OCSD 2009). Further investigations are required to determine the possible source(s) of this phenomenon.

When compared to the region-wide phenomena described above, salinity levels were found to be even lower at a few stations located near the SBOO discharge area at mid-water depths during almost every survey. For example, salinity values at station I12 were <33.33 psu between 10–13 m depths in May, <33.26 psu between 14–21 m depths in August, and <33.23 psu between 12–16 m depths in November (Figure 2.5). The lowest salinity reported at I12 during these months was as much as 8 psu lower than the lowest salinity recorded for nearby 28-m stations (e.g., I9, I14, I16, and I22). These relatively low salinity values were likely indicative of the SBOO wastewater plume, and are corroborated by relatively high CDOM values at station I12 during the same months (e.g., Figure 2.6).

***Dissolved oxygen and pH***

DO concentrations averaged from 7.3 to 10.1 mg/L in surface waters and from 3.3 to 9.1 mg/L in bottom waters across the South Bay outfall region in 2011, while pH values averaged from 8.0 to 8.3 in surface waters and from 7.7 to 8.2 in bottom waters (Appendix A.1). Changes in pH were closely linked to changes in DO (e.g., Figure 2.2) since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975). Similar distributions of both DO and pH values across all stations and along each depth contour indicate that the monthly surveys were synoptic even though sampling occurred over a 3-day period (Table 2.1, Appendices A.2, A.3).

Stratification of the water column followed normal seasonal patterns for DO and pH, with the greatest variations and maximum stratification occurring predominantly during the spring and summer (e.g., Figure 2.2, Appendices A.2, A.3). Low DO and pH values at mid- and deeper depths during spring months were likely due to cold, saline and oxygen poor ocean water moving inshore during periods of local upwelling as described above for temperature and salinity. Concentrations of DO and pH were also very low at bottom depths during November, but these values did not correspond to lower temperatures or higher salinity values. Changes in DO and pH levels relative to wastewater discharge were not discernible during the year.

***Transmissivity***

Transmissivity appeared to be within historical ranges in the SBOO region during 2011 with average values of 46–88% on the surface and 47–91% in bottom waters (Appendix A.1). Water clarity was consistently greater at the offshore monitoring sites than in nearshore waters by as much as 43%, and changes in transmissivity levels relative to wastewater discharge were not discernible during the year. Instead, lower transmissivity along the 9, 19 and 28-m depth contours during the winter and fall months (Figure 2.2, Appendix A.4) may have been caused by wave and storm activity stirring up bottom sediments or particulate-laden runoff. For example, remote sensing observations revealed substantial turbidity plumes throughout the study area on January 1, 2011 and again on February 21, 2011 following major rain events (Figure 2.7). The turbidity plume that occurred during February was massive enough to extend past the end of the SBOO, and corresponded to lower water clarity that reached at least as far as the 38-m stations at surface depths (Appendix A.4). In previous years, reductions in water clarity have also co-occurred with peaks in chlorophyll concentrations associated with phytoplankton blooms (e.g., City of San Diego 2011a, Svejkovsky 2011). During 2011, this relationship was most apparent during February,

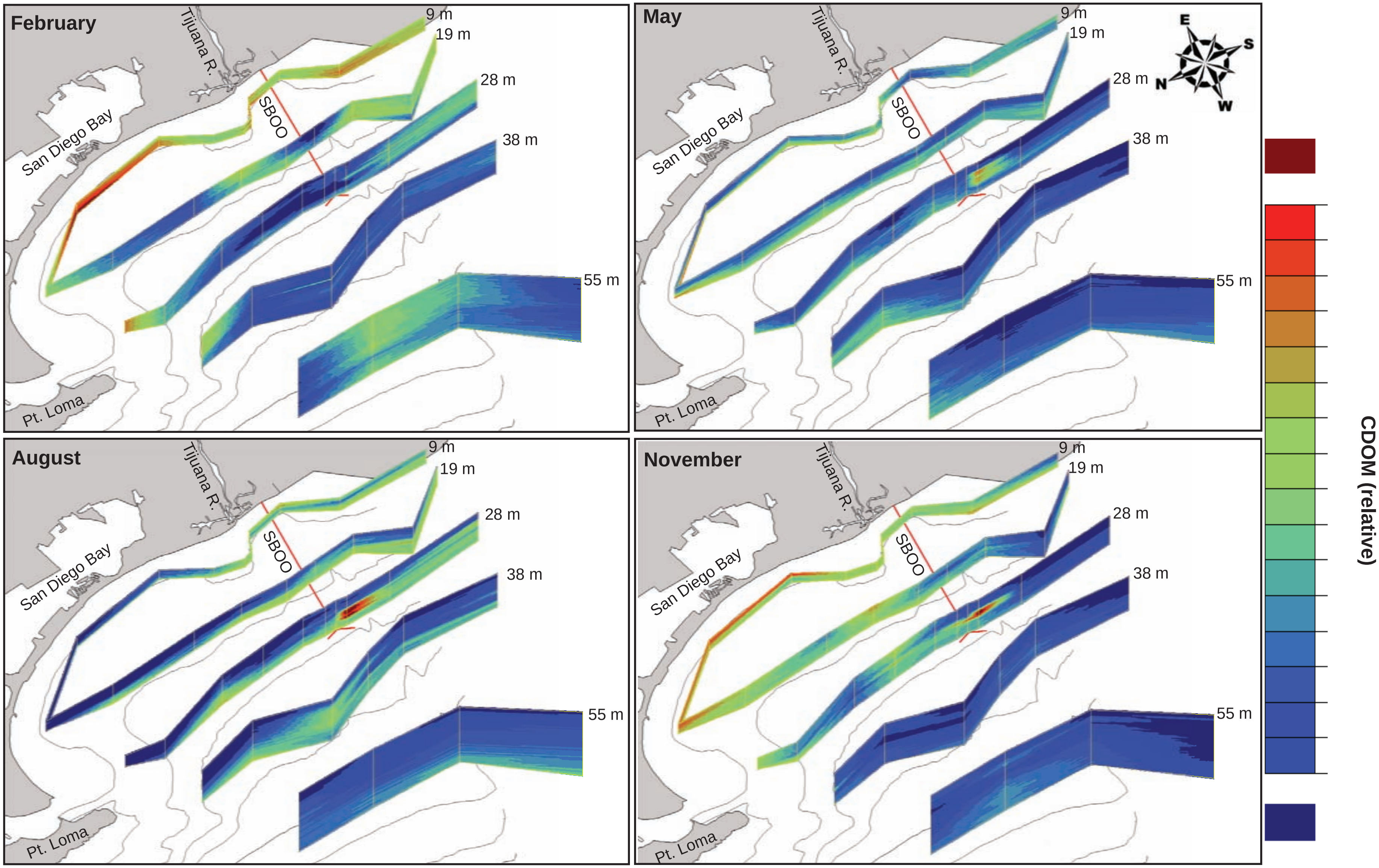



**Figure 2.6**
Relative CDOM values recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day. For each month, the highest value recorded is set as dark red and the lowest as dark blue.

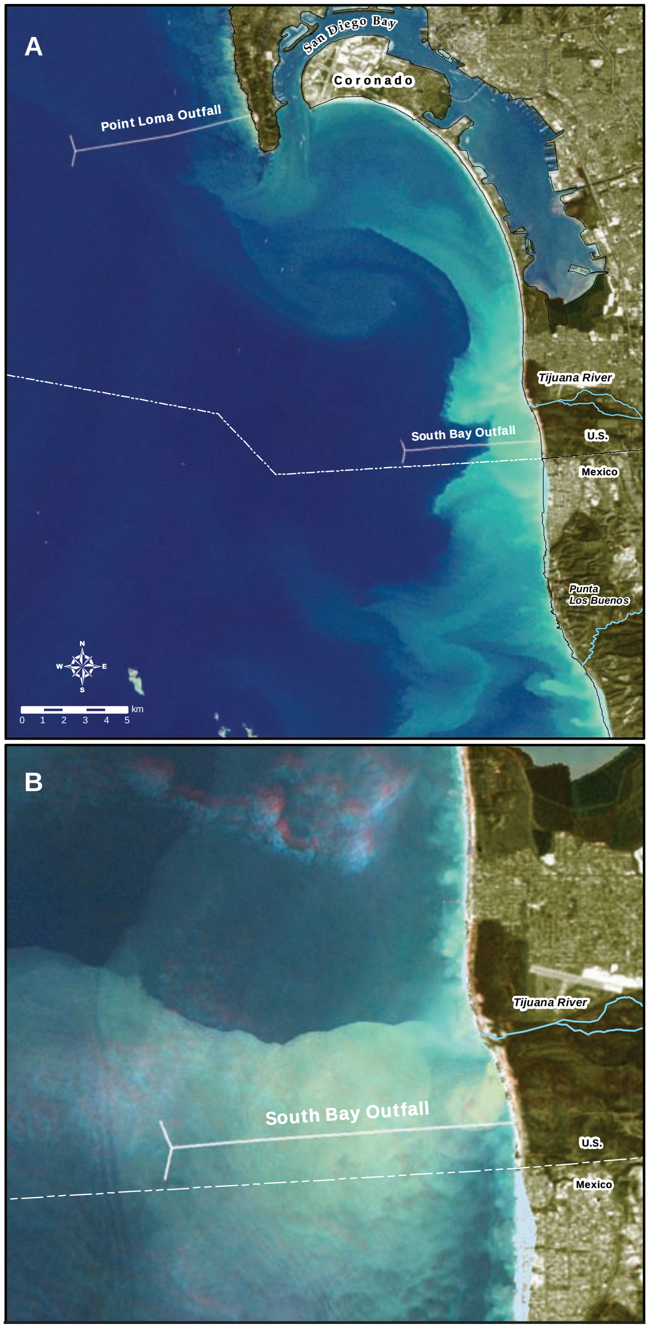



**Figure 2.7**
Rapid Eye images of the SBOO and coastal region depicting turbidity plumes in the study area following storm events on January 1, 2011 (top) and February 21, 2011 (bottom) (from Ocean imaging 2012).

April, June, July, September and November (e.g., Figure 2.2, Appendices A.4, A.5).

***Chlorophyll a***
Surface concentrations of chlorophyll *a* averaged from 1.7 mg/L in December to 10.7 mg/L in June, while chlorophyll concentrations in bottom waters averaged from 0.4 mg/L in March to 26.9 mg/L in September (Appendix A.1). However further analysis clearly showed that the highest chlorophyll values tended to occur at mid- and deeper depths (e.g., Figure 2.2, Appendix A.5), reflecting the fact that phytoplankton tend to mass at the bottom of the pycnocline where nutrient levels are greatest (Lalli and Parsons 1993). The highest concentrations of chlorophyll occurred at these mid-depths during June, July, September, and November, primarily along the 19, 28, and 38-m depth contours (Appendix A.5; see also Figure 2.2). Seawater samples collected during the spring indicated a predominance of chain-forming diatoms in the genera *Chaetoceros*, *Pseudo-nitzschia*, and *Guinardia*, whereas samples collected during the fall were dominated by the dinoflagellate *Lingulodinium polyedrum*. The latter corresponds to the extensive dinoflagellate bloom observed by satellite that occurred throughout the San Diego region during September 2011 (Figure 2.8). In contrast to previous years, the occurrence of phytoplankton blooms in the SBOO region did not correspond as strongly to local upwelling events that were most evident between March and July (see above). A possible explanation for this disconnect is that several of the major phytoplankton blooms that occurred during 2011 off San Diego originated along the north county coast or Orange County and then spread southward, at times extending into the South Bay outfall region (Svejkovsky 2012).

## Historical Assessment of Oceanographic Conditions

A review of oceanographic data from all stations along the 28-m depth contour sampled between 1995 and 2011 did not reveal any measurable impact that could be attributed to the beginning of wastewater discharge via the SBOO in January 1999 (Figure 2.9). Instead, these data tend to track long-term trends in the SCB, including conditions associated with the El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and North Pacific Gyre Oscillation (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, 2011, NOAA/NWS 2011). For example, six major


**Figure 2.8**
Wide-spread phytoplankton blooms in San Diego's nearshore waters in the South Bay outfall region acquired with MODIS imagery September 8, 2011 (from Ocean Imaging 2012).

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 1999–2002; (3) a subtle but persistent return to warm ocean conditions in the California Current System (CCS) that began in October 2002 and lasted through 2006; (4) 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 cooling of the PDO; (6) development of a second La Niña starting in May 2010. Temperature and salinity data for the South Bay outfall region are consistent with all but the third of these events; i.e., while the CCS was experiencing a warming trend that lasted through 2006, the SBOO region experienced cooler than normal conditions during 2005 and 2006. The conditions in southern San Diego waters during these two years were more consistent with observations from northern Baja California (Mexico) where water temperatures were well below the decadal mean (Peterson et al. 2006). Further, below normal salinities that occurred after the subartic intrusion were likely associated with increased rainfall (Goericke et al. 2007, NWS 2011). During 2011, temperatures remained colder than normal through the end of the year.

Water clarity (transmissivity) has generally remained of high-quality in the South Bay outfall region since wastewater discharge began in 1999, although there have been several intermittent periods when clarity was below normal (Figure 2.9). As discussed in the previous section, periods of low transmissivity during winter and late fall may have been caused by wave and storm activity that stirred up bottom sediments or particulate-laden runoff, whereas decreased transmissivity during the spring, summer or early fall may have been related to phytoplankton blooms.

There have been no apparent long-term trends in DO concentrations or pH values related to the SBOO discharge (Figure 2.9). Instead, there have been several periods during which lower than normal DO and pH values aligned with low water temperatures and high salinity, thus indicating the cold, saline and oxygen poor ocean water associated with local coastal upwelling as discussed above (e.g., 2002, 2005–2011).

## Summary and Conclusions

Oceanographic data collected in the South Bay outfall region concur with reports that describe 2011 as a La Niña year for the CCS characterized by the early onset of relatively strong upwelling (Bjorkstedt et al. 2011). For example, colder-than-normal sea surface temperatures were observed during summer months as would be expected during La Niña conditions; these results were evident in data collected by the City and corroborated by remote sensing observations (Svejkovsky 2012). Conditions indicative of local coastal upwelling, such as relatively cold, dense, saline waters with low DO and pH levels at mid-depths and below, were observed during the spring, but were most evident

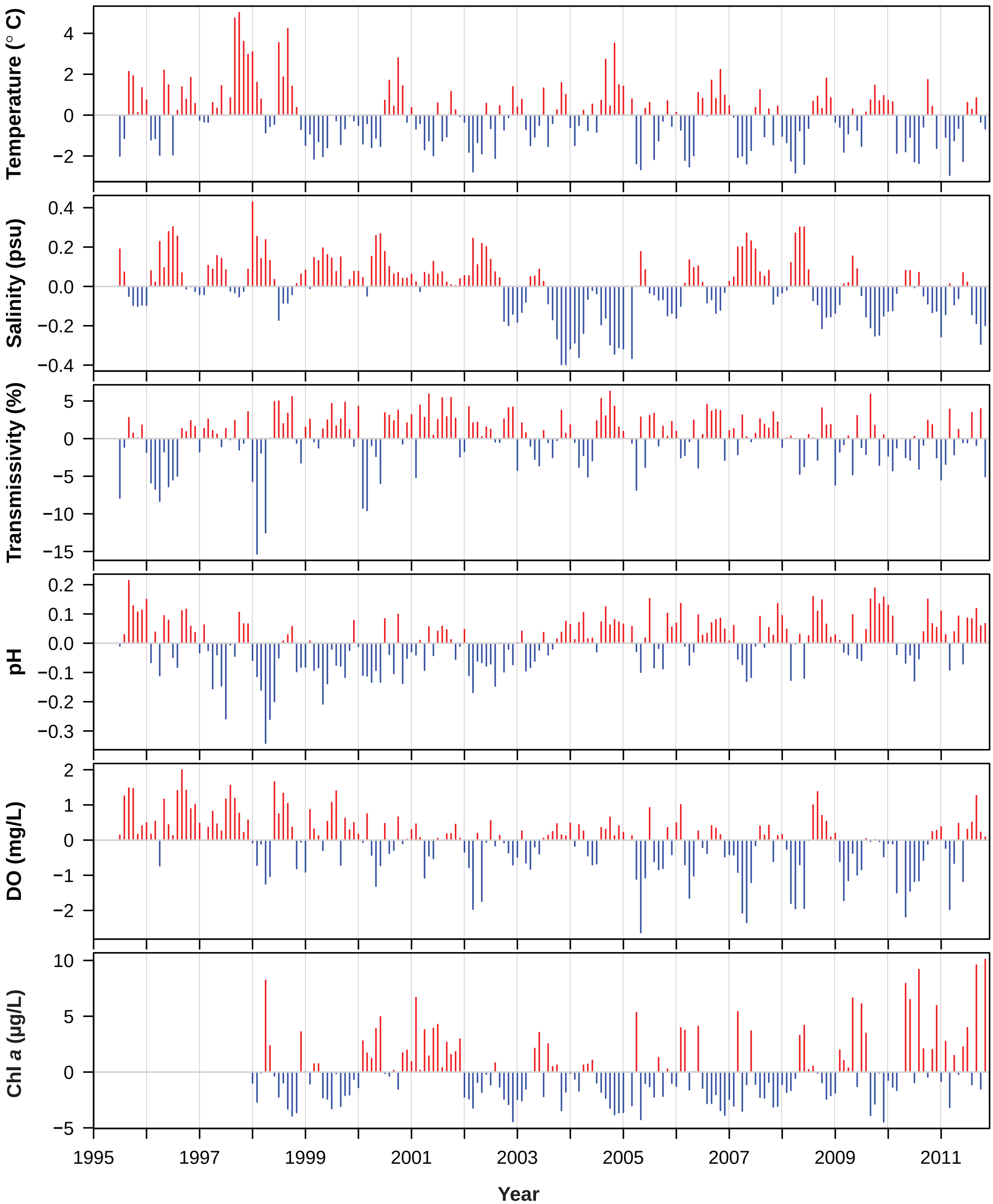



**Figure 2.9**

Time series of temperature, salinity, transmissivity, pH, dissolved oxygen (DO), and chlorophyll *a* (Chl *a*) anomalies between 1995–2011. Anomalies were calculated by subtracting means for all years combined (1995–2011) from monthly means of each year; data were limited to all stations located along the 28-m depth contour, all depths combined.

during March and June. Phytoplankton blooms, indicated by high chlorophyll concentrations and confirmed by satellite imagery were present throughout the region during much of the year. Additionally, water column stratification followed typical patterns for the San Diego region, ranging from mixed waters during the winter, to highly stratified waters in the summer, to less stratified in the fall. Further, oceanographic conditions were consistent with long-term trends in the SCB (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjokstedt et al. 2010, 2011, NOAA/NWS 2011) or with data from northern Baja California (Peterson et al. 2006). These observations suggest that other factors such as upwelling of deeper offshore waters and large-scale oceanographic events (e.g., El Niño, La Niña) continue to explain most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego.

As expected, results of satellite imagery detected the presence (signature) of the SBOO wastewater plume in near-surface waters over the discharge site on several occasions between January–March and October–December when the water column was not strongly stratified (Svejkovsky 2012). Bacteriological sampling results for the same region described herein resulted in very few samples with elevated concentrations of fecal indicator bacteria in 2011 (see Chapter 3); the lack of bacteriological contamination was most likely due to initiation of full secondary treatment at the IWTP in January, 2011. Therefore, these data may no longer be useful for plume tracking. However, historical analysis of remote sensing observations made between 2003 and 2009 provided no evidence that the wastewater plume from the SBOO has ever reached the shoreline (Svejkovsky 2010). These findings have been supported in subsequent years of remote sensing reporting (Svejkovsky 2011, 2012) and by the application of IGODS analytical techniques to oceanographic data collected by the City's ocean monitoring program for the past three years (City of San Diego 2010b, 2011a). For example, although small salinity differences have been observed at stations close to the outfall discharge site, and corroborated by relative CDOM data this year, it was clear from all analyses that variations among stations at any particular depth were very slight and highly localized. Further, high resolution satellite images suggest that the wastewater plume typically remains within approximately 700 m of the outfall.

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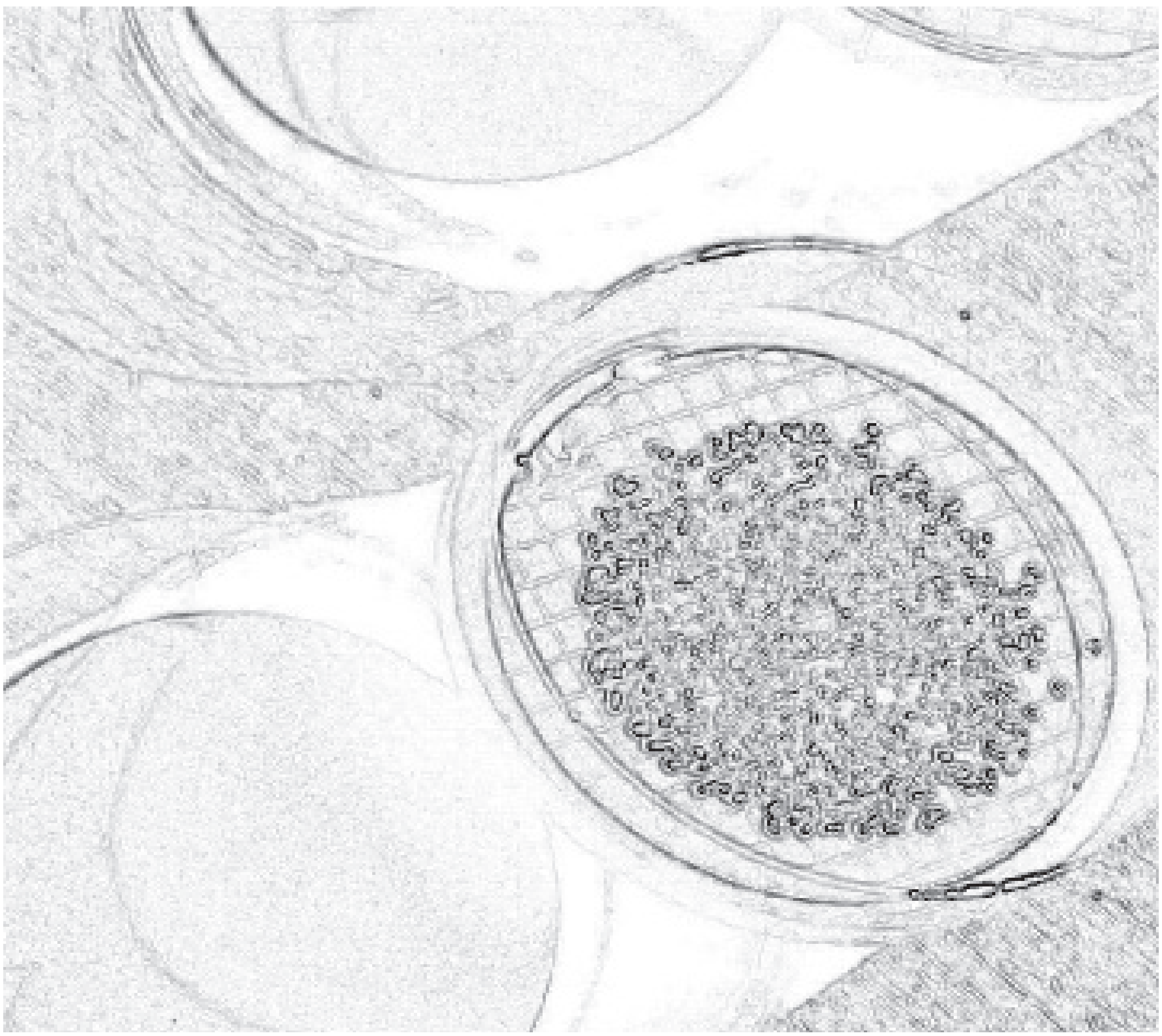
# Chapter 3
# Water Quality



# Chapter 3. Water Quality

## Introduction

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

In the SBOO region, multiple natural and anthropogenic point and non-point sources of potential bacterial contamination exist in addition to the outfall. Therefore, being able to separate the impacts associated with a wastewater plume from other sources of contamination in ocean waters is often challenging. Examples of other local, but non-outfall sources include San Diego Bay, the Tijuana River and Los Buenos Creek in northern Baja California (Largier et al. 2004, Nezlin et al. 2007, Gersberg et al. 2008, Terrill et al. 2009). Likewise, storm water discharges and wet-weather runoff from local watersheds can also flush contaminants seaward (Noble et al. 2003, Reeves et al. 2004, Griffith et al. 2010, Sercu et al. 2009). Moreover, beach wrack (e.g., kelp, seagrass), storm drains impacted by tidal flushing, and beach sediments can act as reservoirs, cultivating bacteria until release into nearshore waters by a returning tide, rainfall, and/or other disturbances (Gruber et al. 2005, Martin and Gruber 2005, Noble et al. 2006, Yamahara et al. 2007, Phillips et al. 2011). The presence of birds and their droppings have also been associated with bacterial exceedances that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2010).

This chapter presents analyses and interpretations of the microbiological and water chemistry data collected during 2011 at fixed water quality monitoring stations surrounding the SBOO. The primary goals are to: (1) document overall water quality conditions in the region during the year, (2) distinguish between the SBOO 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 weekly at 11 shore stations to monitor FIB concentrations in waters adjacent to public beaches (Figure 3.1). Of these, stations S4–S6 and S8–S12 are located in California waters between the USA/Mexico border and Coronado and are subject to Ocean Plan water contact standards (see Box 3.1). The other three stations (i.e., S0, S2, S3) are located in northern Baja California, Mexico and are not subject to Ocean Plan requirements. Seawater samples for shore stations were collected from the

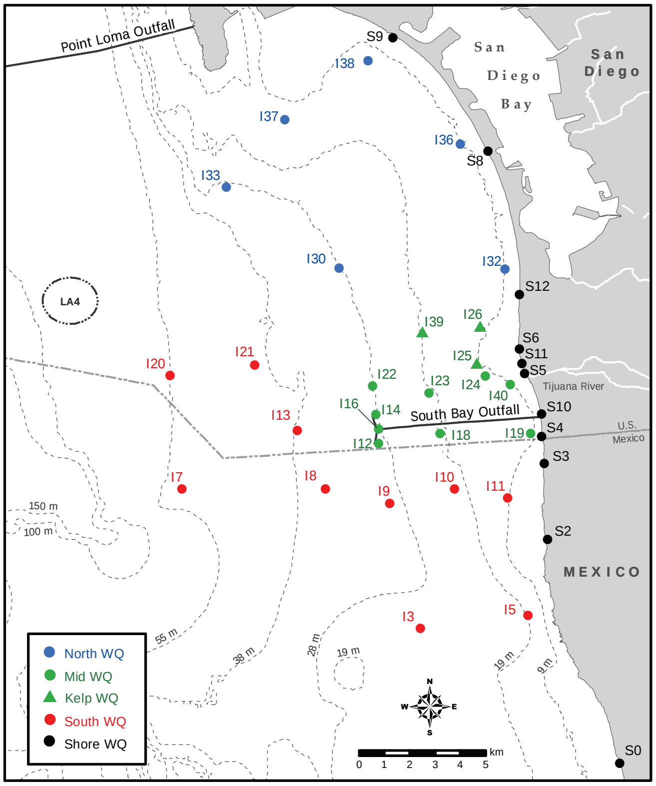



**Figure 3.1**
Water quality (WQ) monitoring station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

surf zone in sterile 250-mL bottles. In addition, visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. The samples were then transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML) and analyzed to determine concentrations of total coliform, fecal coliform, and enterococcus bacteria.

***Kelp bed and other offshore stations***

Three stations located in nearshore waters within the Imperial Beach kelp forest were monitored five times a month to assess water quality conditions and Ocean Plan compliance in areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking. These included two stations located near the inner edge of the kelp bed along the 9-m depth contour (I25 and I26), and one station located near the outer edge of the kelp bed along the 18-m depth contour (I39). An additional 25 stations located further offshore in deeper waters were sampled once a month to monitor FIB levels and estimate the spatial extent of the wastewater plume. These non-kelp offshore stations are arranged in a grid surrounding the discharge site distributed along the 9, 19, 28, 38, and 55-m depth contours (Figure 3.1). Sampling of these offshore stations generally occurred over a 3-day period within each month (see Chapter 2).

Seawater samples were collected at each of the kelp bed and non-kelp bed offshore stations using either an array of Van Dorn bottles or a rosette sampler fitted with Niskin bottles at three discrete depths for FIBs and total suspended solids (TSS). Additional samples for oil and grease (O&G) analysis were collected from surface waters only. Aliquots for each analysis were drawn into appropriate sample containers. All bacterial seawater samples were refrigerated onboard ship and transported to the CSDMML for processing and analysis. TSS and O&G samples were taken to the City's Wastewater Chemistry Services Laboratory for analysis. Visual observations of weather and sea conditions, and human and/or animal activity were also recorded at the time of sampling.

## Laboratory Analyses

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

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

**Box 3.1**

Bacteriological compliance standards for water contact areas, 2005 California Ocean Plan (SWRCB 2005). CFU = colony forming units.

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

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

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

### Data Analyses

Densities of bacteria were summarized as monthly averages for each shore station and by depth contour for the kelp bed and non-kelp bed offshore stations. TSS concentrations were also summarized by month for the offshore stations. To assess temporal and spatial trends, 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 FIB are identified by sample in Appendices B.1, B.2, and B.3. Bacterial densities were compared to rain data from Lindbergh Field, San Diego, CA (see NOAA 2012). Remote sensing images of the SBOO region were provided by Ocean Imaging of Solana Beach, California (Svejkovsky 2012) and were used to aid in the analysis and interpretation of water quality data (see Chapter 2 for remote sensing details). Fisher's Exact Tests (FET) were conducted to determine if the frequency of samples with elevated FIBs differed at shore and kelp bed stations between wet (January–April and October–December) versus dry (May–September) seasons. Finally, compliance with Ocean Plan water-contact standards was summarized as the number of times per month that each of the eight shore stations located north of the USA/Mexico border and all three of the kelp bed stations exceeded the various standards.

## Results

### Distribution of Fecal Indicator Bacteria

***Shore stations***

During 2011, FIB densities at the individual shore stations averaged from 7 to 12,000, 2 to 6048, and 2 to 4236 CFU/100 mL per month for total coliforms, fecal coliforms, and enterococcus, respectively (Table 3.1). The highest values for each of these indicators occurred during the wet season. In addition, 88% of the shore station samples with elevated FIBs were collected during

## Table 3.1

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

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total Rain (in):** | | 0.30 | 2.10 | 1.46 | 0.26 | 0.36 | 0.03 | 0.00 | 0.00 | 0.13 | 0.46 | 3.12 | 0.86 |
| **S9** | *Total* | 11 | 7 | 1772 | 20 | 20 | 60 | 110 | 92 | 35 | 16 | 68 | 20 |
| | *Fecal* | 2 | 2 | 130 | 8 | 2 | 6 | 6 | 3 | 7 | 6 | 2 | 2 |
| | *Entero* | 12 | 2 | 54 | 4 | 5 | 4 | 8 | 4 | 15 | 5 | 2 | 2 |
| **S8** | *Total* | 16 | 12 | 2610 | 12 | 20 | 16 | 20 | 20 | 16 | 60 | 1456 | 7 |
| | *Fecal* | 2 | 2 | 154 | 2 | 2 | 2 | 2 | 4 | 2 | 4 | 86 | 2 |
| | *Entero* | 3 | 2 | 90 | 2 | 2 | 2 | 2 | 3 | 12 | 9 | 7 | 6 |
| **S12** | *Total* | 122 | 35 | 3216 | 1512 | 14 | 45 | 20 | 56 | 70 | 16 | 1140 | 126 |
| | *Fecal* | 2 | 2 | 202 | 246 | 2 | 4 | 6 | 6 | 6 | 8 | 70 | 26 |
| | *Entero* | 20 | 8 | 162 | 19 | 3 | 4 | 2 | 3 | 14 | 12 | 7 | 10 |
| **S6** | *Total* | 335 | 481 | 3220 | 485 | 64 | 16 | 20 | 16 | 36 | 20 | 544 | 4015 |
| | *Fecal* | 11 | 18 | 602 | 62 | 5 | 7 | 2 | 3 | 22 | 2 | 30 | 1053 |
| | *Entero* | 12 | 11 | 204 | 2 | 6 | 2 | 2 | 2 | 8 | 2 | 12 | 3006 |
| **S11** | *Total* | 645 | 480 | 5068 | 4225 | 488 | 56 | 20 | 13 | 16 | 7 | 3164 | 3010 |
| | *Fecal* | 16 | 30 | 938 | 258 | 26 | 2 | 3 | 3 | 2 | 2 | 297 | 82 |
| | *Entero* | 10 | 29 | 442 | 26 | 2 | 2 | 4 | 2 | 2 | 2 | 15 | 192 |
| **S5** | *Total* | 4250 | 2018 | 6416 | 9000 | 3476 | 60 | 20 | 16 | 20 | 12 | 7008 | 1960 |
| | *Fecal* | 3012 | 36 | 4801 | 6048 | 1300 | 8 | 2 | 3 | 2 | 6 | 4825 | 92 |
| | *Entero* | 3754 | 32 | 2426 | 3253 | 167 | 5 | 2 | 2 | 3 | 6 | 3006 | 3004 |
| **S10** | *Total* | 9400 | 4130 | 8108 | 8010 | 157 | 460 | 16 | 48 | 66 | 14 | 6924 | 4856 |
| | *Fecal* | 5332 | 3013 | 1572 | 2205 | 14 | 22 | 2 | 4 | 4 | 8 | 1845 | 176 |
| | *Entero* | 1859 | 626 | 160 | 452 | 2 | 12 | 2 | 2 | 2 | 12 | 234 | 116 |
| **S4** | *Total* | 5650 | 4086 | 6844 | 4012 | 58 | 2370 | 20 | 114 | 110 | 16 | 3231 | 1501 |
| | *Fecal* | 282 | 3003 | 644 | 55 | 12 | 34 | 2 | 7 | 9 | 4 | 1448 | 141 |
| | *Entero* | 71 | 458 | 59 | 2 | 2 | 18 | 2 | 2 | 8 | 8 | 60 | 122 |
| **S3** | *Total* | 5300 | 930 | 3002 | 4063 | 292 | 3760 | 16 | 94 | 18 | 58 | 4096 | 4026 |
| | *Fecal* | 160 | 22 | 174 | 305 | 26 | 136 | 2 | 9 | 13 | 20 | 162 | 456 |
| | *Entero* | 59 | 26 | 64 | 2 | 2 | 202 | 3 | 5 | 36 | 62 | 54 | 362 |
| **S2** | *Total* | 2530 | 1690 | 1341 | 556 | 1534 | 1265 | 16 | 137 | 221 | 13 | 2765 | 861 |
| | *Fecal* | 245 | 109 | 49 | 21 | 66 | 22 | 2 | 10 | 4 | 8 | 99 | 38 |
| | *Entero* | 240 | 21 | 21 | 46 | 14 | 29 | 2 | 2 | 5 | 3 | 45 | 74 |
| **S0** | *Total* | 2235 | 8365 | 1616 | 425 | 784 | 1158 | 760 | 44 | 155 | 246 | 1732 | 12,000 |
| | *Fecal* | 170 | 2013 | 276 | 78 | 125 | 112 | 29 | 3 | 10 | 56 | 112 | 3330 |
| | *Entero* | 68 | 3370 | 190 | 198 | 130 | 77 | 70 | 2 | 14 | 28 | 44 | 4236 |
| | *n* | 44 | 44 | 55 | 44 | 55 | 44 | 44 | 55 | 44 | 44 | 55 | 44 |
| **Annual** | *Total* | 2772 | 2021 | 3928 | 2938 | 628 | 842 | 94 | 59 | 69 | 43 | 2921 | 2944 |
| **Means** | *Fecal* | 840 | 750 | 867 | 844 | 144 | 32 | 5 | 5 | 8 | 11 | 816 | 491 |
| | *Entero* | 555 | 417 | 352 | 364 | 30 | 33 | 9 | 3 | 11 | 14 | 317 | 1012 |

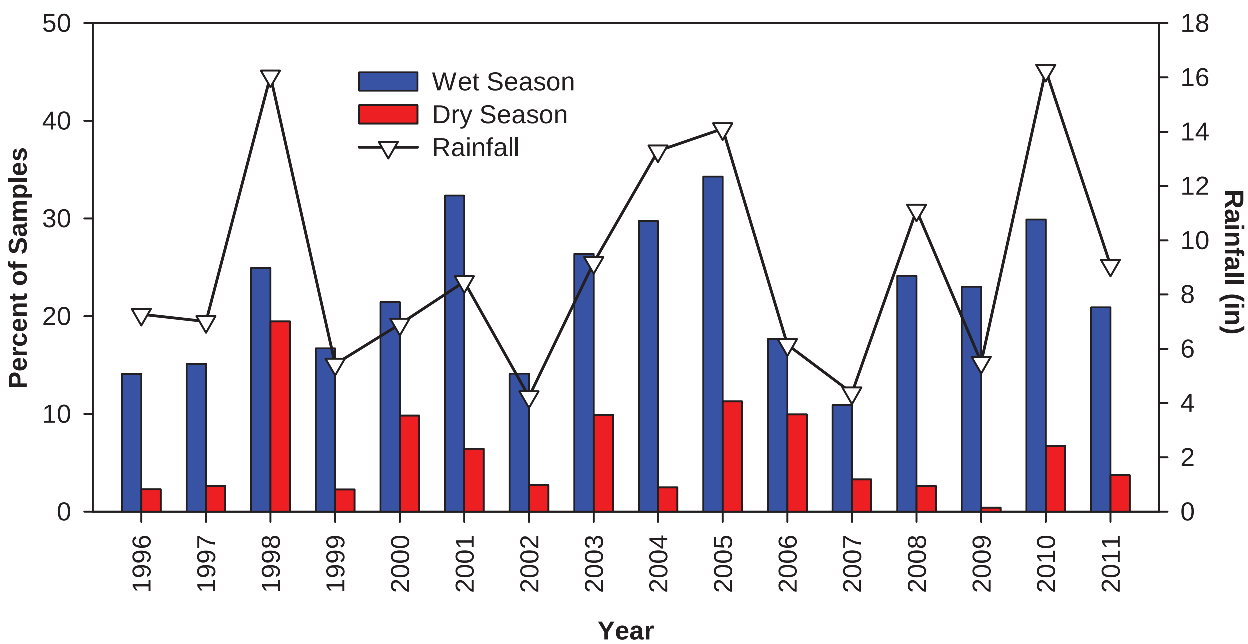
these wet months when rainfall totaled 8.56 inches (versus 0.52 inches in the dry season; Table 3.2). This general relationship between rainfall and elevated bacterial levels has been evident since water quality monitoring in the South Bay outfall region began (Figure 3.2, Appendix B.4). These data indicate that collecting a sample with elevated FIBs was significantly more likely during the wet season than during the dry (22% versus 7%, respectively; $n = 9960$, $p < 0.0001$, FET).

Samples collected during the wet season with elevated FIBs were taken primarily at the shore stations close to the mouth of the Tijuana River (S4, S5, S10, S11) and farther south (S0, S2, S3; Table 3.2, Appendix B.1). Samples from some of these stations (e.g., S0, S2, S3, S5) also had high levels of bacterial contamination during dry conditions between May–September. For example, four of the nine dry weather samples with elevated FIB densities were collected at station S0 that is located south of the international border and is the station closest to Los Buenos Creek. Analyses of historical data, including from years prior to wastewater discharge, corroborated this finding (Appendix B.4). Over the past several years, high FIB counts at these stations have consistently corresponded to turbidity flows from the Tijuana River and Los Buenos Creek, typically

## Table 3.2

The number of samples with elevated bacteria densities collected at SBOO shore stations during 2011. 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.

| | Seasons | | |
|---|---|---|---|
| **Station** | **Wet** | **Dry** | **% Wet** |
| S9 | 1 | 0 | 100 |
| S8 | 2 | 0 | 100 |
| S12 | 2 | 0 | 100 |
| S6 | 2 | 0 | 100 |
| S11 | 5 | 0 | 100 |
| S5 | 9 | 2 | 82 |
| S10 | 12 | 0 | 100 |
| S4 | 9 | 0 | 100 |
| S3 | 7 | 2 | 78 |
| S2 | 8 | 1 | 89 |
| S0 | 12 | 4 | 75 |
| **Rain (in)** | 8.56 | 0.52 | |
| **Total Counts** | 69 | 9 | 88 |
| ***n*** | 330 | 242 | |




## Figure 3.2

Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet versus dry seasons at SBOO shore stations between 1996 and 2011. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA. Data from 1995 were excluded as sampling did not occur the entire year.


**Figure 3.3**
Rapid Eye satellite image showing the SBOO region on March 24, 2011 (Ocean Imaging 2012) combined with bacteria levels at shore stations sampled on March 22, 2011. Turbid waters from the Tijuana River and Los Buenos Creek can be seen overlapping stations with elevated FIBs (indicated by red circles).

after rain events (City of San Diego 2008–2011). At times, however, impacts from these two sources can extend beyond these seven stations. For example, a satellite image taken March 24, 2011 showed turbidity plumes encompassing all of the shore stations, nine of which had elevated FIB concentrations two days prior (Figure 3.3). While the image in this figure was taken after the contaminated samples were collected, the plumes that are evident likely originated earlier in the week due to significant runoff caused by a rainstorm that began March 20, 2011.

***Kelp bed stations***

On average, FIB densities at the SBOO kelp bed stations were lower than those at the shore stations, ranging between 2 and 1312, 2 and 71, and 2 and 42 CFU/100 mL per month for total coliforms, fecal coliforms, and enterococcus, respectively (Table 3.3). The highest concentrations of these bacteria occurred during the wettest months of 2011, similar to the pattern exhibited at the shore stations. For example, 87% of kelp bed samples with elevated FIBs were collected during the wet season (Table 3.4, Appendix B.2). These results are consistent with historical water quality monitoring data from the South Bay outfall region (Figure 3.4, Appendix B.5). These data indicate that collecting a sample with elevated FIBs was significantly more likely during the wet season than during the dry (8% versus 1%, respectively; $n = 7376$, $p < 0.0001$, FET).

High bacteria counts in the kelp bed during the wet season also appeared to correspond with turbidity plumes from the Tijuana River. For example, another satellite image taken January 1, 2011 shows plumes that persisted throughout the SBOO region during January and into February following heavy rainfall in late December, plus additional rainfall in January, which caused large volumes of runoff from the river (Figure 3.5; Ocean Imaging 2012, Svejkovsky 2012). This image demonstrates how these plumes encompassed stations I25 and I26, both of which had elevated FIBs during this period (Appendix B.2). The kelp bed stations had a higher rate of elevated FIB detection than most of the other offshore stations, including their closest neighbors, because they were sampled more often and therefore had a greater chance of being sampled during (or following) rain events (Figure 3.6).

Oil and grease and total suspended solids were also measured at the kelp bed stations as potential indicators of wastewater. None of the samples collected during 2011 contained detectable levels of O&G (detection limit = 0.2 mg/L). In contrast, TSS were detected 100% of the time at concentrations ranging between 1.49–22.80 mg/L per sample (Table 3.5). Of the 26 seawater samples with elevated TSS concentrations (≥8.0 mg/L), none co-occurred with elevated FIB levels.

***Non-kelp bed stations***

Concentrations of bacteria were also low in samples collected from the 25 non-kelp bed offshore stations during 2011, averaging from 2 to 2203, 2 to 202, and 2 to 49 CFU/100 mL per month for total coliforms, fecal coliforms,

## Table 3.3

Summary of bacteria levels at SBOO kelp bed and other offshore stations during 2011. Total coliform, fecal coliform, and enterococcus densities are expressed as mean CFU/100 mL for all stations along each depth contour by month; *n* = total number of samples per month.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2011 Kelp Bed Stations** | | | | | | | | | | | | |
| 9-m Depth Contour (*n* = 30) | | | | | | | | | | | | |
| *Total* | 729 | 244 | 1312 | 18 | 471 | 19 | 4 | 3 | 7 | 3 | 79 | 1144 |
| *Fecal* | 53 | 19 | 39 | 3 | 54 | 2 | 2 | 2 | 2 | 2 | 6 | 71 |
| *Entero* | 32 | 6 | 23 | 3 | 6 | 2 | 2 | 2 | 2 | 2 | 8 | 42 |
| 19-m Depth Contour (*n* = 15) | | | | | | | | | | | | |
| *Total* | 313 | 7 | 339 | 37 | 26 | 3 | 19 | 6 | 4 | 2 | 254 | 166 |
| *Fecal* | 18 | 2 | 15 | 4 | 7 | 2 | 3 | 2 | 2 | 2 | 18 | 12 |
| *Entero* | 13 | 3 | 32 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 7 | 12 |
| **2011 Non-Kelp Bed Stations** | | | | | | | | | | | | |
| 9-m Depth Contour (*n* = 27) | | | | | | | | | | | | |
| *Total* | 1749 | 1054 | 1813 | 703 | 3 | 14 | 10 | 3 | 3 | 3 | 787 | 2 |
| *Fecal* | 56 | 68 | 75 | 24 | 2 | 2 | 2 | 2 | 2 | 2 | 39 | 2 |
| *Entero* | 42 | 14 | 16 | 10 | 2 | 2 | 2 | 2 | 2 | 2 | 12 | 2 |
| 19-m Depth Contour (*n* = 9) | | | | | | | | | | | | |
| *Total* | 180 | 110 | 2203 | 5 | 98 | 3 | 4 | 2 | 2 | 5 | 17 | 2 |
| *Fecal* | 9 | 4 | 202 | 2 | 33 | 2 | 2 | 2 | 2 | 2 | 3 | 2 |
| *Entero* | 10 | 2 | 49 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 28-m Depth Contour (*n* = 24) | | | | | | | | | | | | |
| *Total* | 80 | 199 | 55 | 32 | 69 | 6 | 187 | 39 | 4 | 4 | 30 | 6 |
| *Fecal* | 11 | 13 | 4 | 3 | 33 | 2 | 27 | 10 | 2 | 3 | 8 | 2 |
| *Entero* | 5 | 3 | 2 | 2 | 6 | 2 | 9 | 4 | 2 | 2 | 3 | 2 |
| 38-m Depth Contour (*n* = 9) | | | | | | | | | | | | |
| *Total* | 3 | 17 | 57 | 2 | 26 | 3 | 2 | 2 | 2 | 2 | 4 | 2 |
| *Fecal* | 2 | 2 | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| *Entero* | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 55-m Depth Contour (*n* = 6) | | | | | | | | | | | | |
| *Total* | 2 | 2 | 141 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 |
| *Fecal* | 2 | 2 | 7 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| *Entero* | 2 | 2 | 6 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 |

and enterococcus, respectively (Table 3.3). Only about 1.3% (n = 12) of the 900 samples collected at these sites contained elevated FIBs (Table 3.4, Appendix B.3). For stations located along the 9 and 19-m depth contours (i.e., I10, I11, I19, I24, I32, I40), 100% of the samples with elevated FIBs were collected during the wet season. As with the shore and kelp bed stations, satellite imagery showed turbidity flows originating from the Tijuana River can extend into the offshore sampling region around the SBOO. For example, the plumes depicted in the image taken on January 1, 2011 also encompassed stations relatively close to the mouth of the river (I10, I11, I19, I24, I32, I40), many of which had elevated FIBs during the same period discussed above (Figure 3.5, Appendix B.3). In combination with the kelp bed stations, these sites had the highest elevated FIBs detection rates throughout the year (Figure 3.6).

The proportion of samples from the 28-m offshore stations with elevated FIBs was much lower in 2011 than previous years (Figure 3.7). Only one sample with high bacteria counts was collected from these stations; the sample was taken from I12 at 18 m (Table 3.4, Figure 3.6, Appendix B.3).

## Table 3.4

The number of samples with elevated bacteria collected at SBOO kelp bed and other offshore stations during 2011. Wet = January–April and October–December; Dry = May–September; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Missing offshore stations had no samples with elevated FIB concentrations in 2011.

| | Wet | Dry | % Wet |
|---|---|---|---|
| **2011 Kelp Bed Stations** | | | |
| *9-m Depth Contour* | | | |
| I25 | 4 | 0 | 100 |
| I26 | 8 | 2 | 80 |
| *19-m Depth Contour* | | | |
| I39 | 1 | 0 | 100 |
| **Total Counts** | 13 | 2 | 87 |
| ***n*** | 315 | 225 | |
| **2011 Non-Kelp Bed Stations** | | | |
| *9-m Depth Contour* | | | |
| I11 | 1 | 0 | 100 |
| I19 | 5 | 0 | 100 |
| I24 | 1 | 0 | 100 |
| I32 | 1 | 0 | 100 |
| I40 | 1 | 0 | 100 |
| *19-m Depth Contour* | | | |
| I10 | 1 | 0 | 100 |
| *28-m Depth Contour* | | | |
| I12 | 0 | 1 | 0 |
| I22 | 0 | 1 | 0 |
| **Total Counts** | 10 | 2 | 83 |
| ***n*** | 525 | 375 | |

Historically, samples with elevated bacterial levels have been collected more often at the two stations closest to the SBOO south diffuser leg (i.e., stations I12 and I16) when compared to other stations along the 28-m depth contour; most of these samples were collected from a depth of 18 m or greater (Figure 3.7). Consequently, it appears likely that these FIB densities were associated with wastewater discharge from the outfall.

Oil and grease and total suspended solids were also measured at the non-kelp bed stations as potential indicators of wastewater. None of the samples collected during 2011 contained detectable levels of O&G, whereas TSS were detected at a rate of 94%. Concentrations of TSS ranged from 1.74 to 49.00 mg/L per sample (Table 3.5). Of the 155 seawater samples with elevated TSS concentrations (≥8.0 mg/L), only 7 corresponded to samples with elevated FIBs.

### California Ocean Plan Compliance

Overall compliance with Ocean Plan standards was 91% during 2011. Compliance at the shore stations ranged from 63 to 100% for the 30-day total coliform geometric mean standard, from 73 to 100% for the fecal coliform geometric mean standard, and from 59 to 100% for the enterococcus geometric mean standard (Appendix B.6). In addition, the single sample maximum (SSM) standards for total coliforms, fecal coliforms, enterococcus, and the FTR criterion were exceeded 63, 61, 65 and 44 times, respectively, at these sites. Compliance at the three kelp stations was 100% with the 30-day total and 30-day fecal coliform geometric mean standards, and ranged from 92 to 100% for the 30-day enterococcus geometric mean standard. The SSM standards were exceeded from 2 to 10 times across all kelp bed stations. Since compliance rates reflect the presence of elevated FIBs, rates were lowest between the months of January–April and November–December when rainfall was greatest.

## Discussion

Water quality conditions in the South Bay outfall region were excellent during 2011. Overall compliance with 2005 Ocean Plan water-contact standards was 91%, which was slightly higher than the 87% compliance observed during the previous year (City of San Diego 2011). This improvement likely reflects lower rainfall, which totaled about 9.1 inches in 2011 versus 16.3 inches in 2010. Additionally, only about 5% ($n = 105$) of all water samples analyzed in 2011 had elevated FIBs, of which about 88% ($n = 92$) occurred during the wet season. Most of these high counts ($n = 69$) were from samples collected at the shore stations. This pattern of relatively higher contamination along the shore during the wet season is similar to that observed during previous years (e.g., City of San Diego 2011). The few samples with high bacteria counts taken during dry weather periods

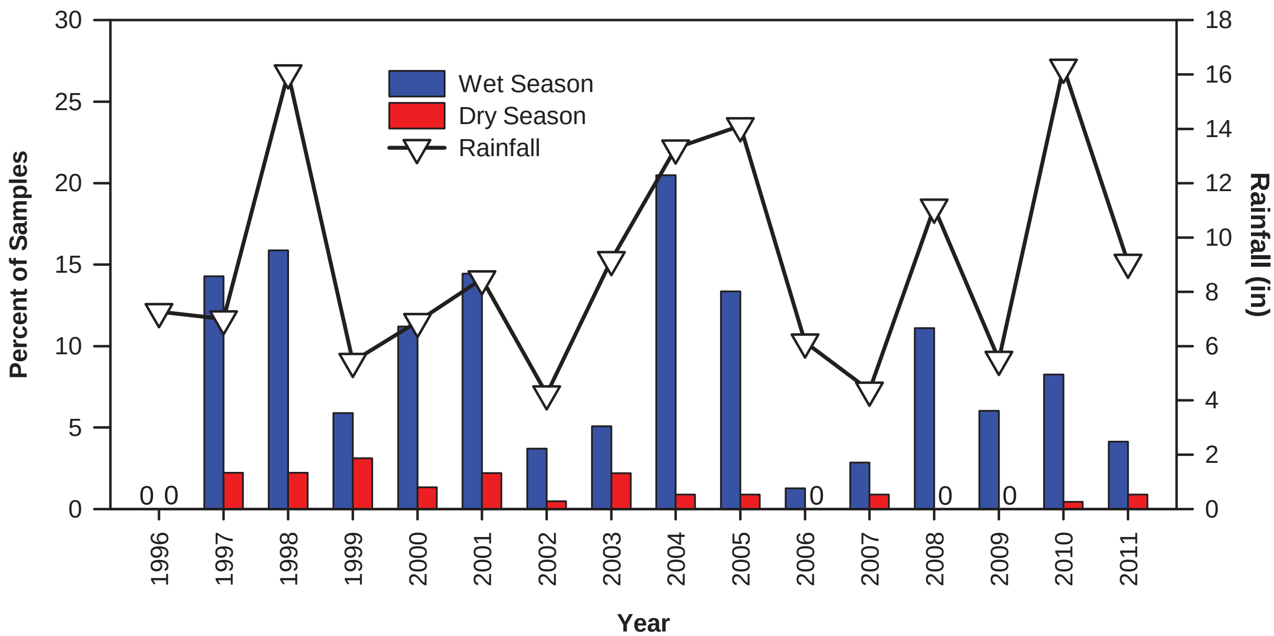



**Figure 3.4**
Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet versus dry seasons at SBOO kelp bed stations between 1996 and 2011. Wet = January–April and October–December; Dry = May–September. Rain data are from Lindbergh Field, San Diego, CA. Data from 1995 were excluded as sampling did not occur the entire year.

tended to occur at shore stations located south of the border near other known sources of coastal contamination (see below).

There was no evidence that wastewater discharge to the ocean via the SBOO reached the shoreline or nearshore recreational waters during the year. Although elevated FIBs were detected along the shore and occasionally at kelp bed or other nearshore stations, these results did not indicate shoreward transport of the wastewater plume, a conclusion consistently supported by remote sensing observations (e.g., Svejkovsky 2010, 2011, 2012). Instead, comparisons of FIB distribution patterns with corresponding satellite images suggest that other sources such as outflows (turbidity plumes) from rivers and creeks are more likely to impact coastal water quality in the South Bay outfall region, especially during the wet season. For example, the shore stations located near the mouths of the Tijuana River and Los Buenos Creek have historically had higher numbers of contaminated samples than stations located farther to the north (City of San Diego 2008–2011). It is also well established that sewage-laden discharges from the Tijuana River and Los Buenos Creek are likely sources of bacteria during storms or other periods of increased flows (Svejkovsky and Jones 2001, Noble et al. 2003, Gersberg et al. 2004, 2006, 2008, Largier et al. 2004, Terrill et al. 2009, Svejkovsky 2010). Further, the general relationship between rainfall and elevated bacterial levels in the SBOO region existed before wastewater discharge began in 1999 (see also City of San Diego 2000).

Finally, bacterial contamination in offshore waters was very low in the SBOO region during 2011, with about 1.3% (n = 12) of all samples collected having elevated FIBs. These high counts included 10 samples from the wet season and two samples from dry season. Only a single sample with elevated FIBs was collected near the discharge site (i.e., at station I12 near the tip of the southern diffuser leg). The lack of bacteriological contamination detected near the outfall is likely due to chlorination of IWTP effluent (typically between November–April), and to initiation of full secondary treatment at the IWTP beginning

## Table 3.5

Summary of total suspended solid (TSS) concentrations in samples collected from the SBOO kelp bed and other offshore stations in 2011. Data include the number samples per month (*n*) and detection rate, as well as the minimum, maximum, and mean of detected concentrations for each month. The method detection limit = 0.2 mg/L for TSS.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2011 Kelp Bed Stations (*n* = 9)** | | | | | | | | | | | | |
| Detection Rate (%) | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Min | 7.74 | 4.52 | 1.77 | 2.16 | 3.26 | 7.64 | 1.98 | 2.60 | 3.73 | 1.49 | 3.43 | 2.53 |
| Max | 18.80 | 21.60 | 13.40 | 6.78 | 22.80 | 22.50 | 4.81 | 6.44 | 7.62 | 3.71 | 7.75 | 4.81 |
| Mean | 13.37 | 11.50 | 7.05 | 4.79 | 10.15 | 10.80 | 3.51 | 4.53 | 5.07 | 2.67 | 4.83 | 3.85 |
| **2011 Non-Kelp Bed Stations (*n* = 75)** | | | | | | | | | | | | |
| Detection Rate (%) | 96 | 99 | 100 | 100 | 99 | 100 | 100 | 99 | 100 | 79 | 99 | 60 |
| Min | nd | nd | 1.74 | 1.85 | nd | 2.23 | 1.58 | nd | 1.57 | nd | nd | nd |
| Max | 21.50 | 26.80 | 49.00 | 20.00 | 20.60 | 20.50 | 10.90 | 9.53 | 12.20 | 15.50 | 8.29 | 9.11 |
| Mean | 7.92 | 7.04 | 6.98 | 5.17 | 5.39 | 7.83 | 3.94 | 4.00 | 4.21 | 3.35 | 3.90 | 3.60 |

nd = not detected

in January 2011. Consequently, bacteriological data may no longer be useful for plume tracking in this region. Instead, remote sensing observations may prove more useful. For example, satellite images captured during 2011 were able to detect the signature of the SBOO wastewater plume in near-surface waters over the discharge site on several occasions between January–March and October–December (Svejkovsky 2012). These findings have been supported by other high resolution satellite images that suggest the wastewater plume typically remains within approximately 700 m of the outfall, and analyses of oceanographic data collected by the City's ocean monitoring program for the past several years (see Chapter 2).

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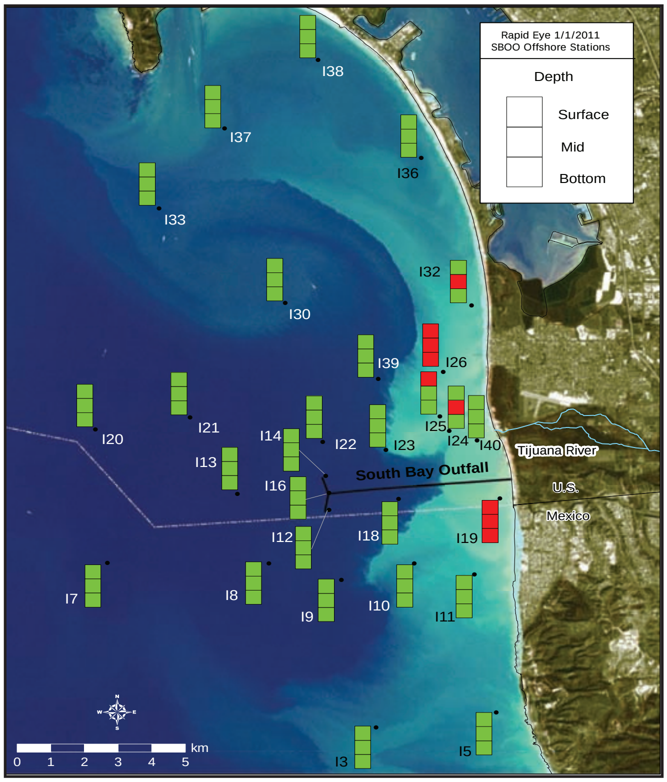
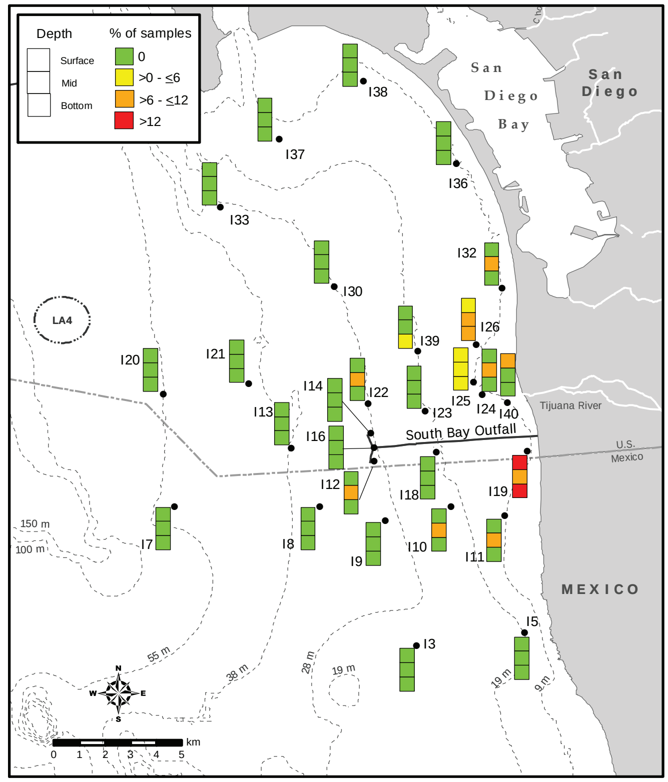



## Figure 3.5

Rapid Eye satellite image showing the SBOO region on January 1, 2011 (Ocean Imaging 2012) combined with bacteria levels at kelp bed and other offshore stations sampled between the first of the year and February 1, 2011. Red squares indicate at least one sample was collected during this period with elevated FIBs (see Appendix B.2, B.3); these correspond to turbid waters that persisted throughout the month and into February (Ocean Imaging 2012, Svejkovsky 2012).




## Figure 3.6

Distribution of seawater samples with elevated FIBs at kelp bed and other offshore stations during 2011. Data are the percent of samples that contained elevated bacteria densities. See text and Table 2.1 for sampling details.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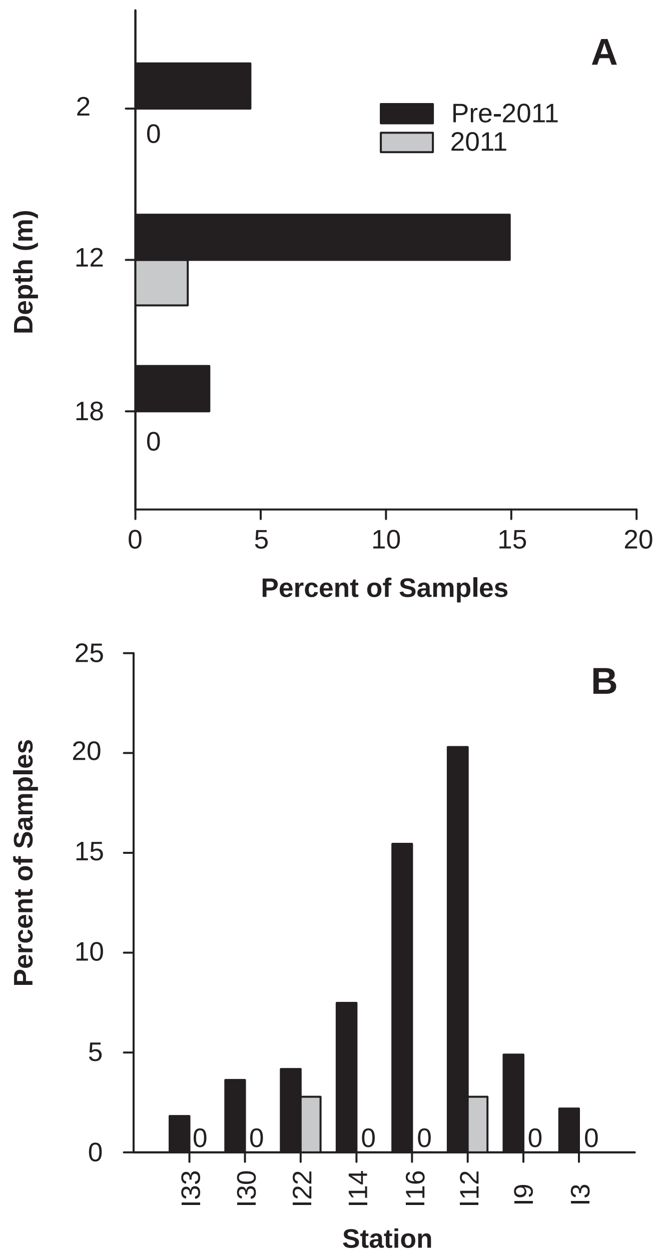


**Figure 3.7**

Percent of samples collected from SBOO 28-m offshore stations with elevated bacteria densities. Samples from 2011 are compared to those collected between 1995–2010 by (A) sampling depth and by (B) station.

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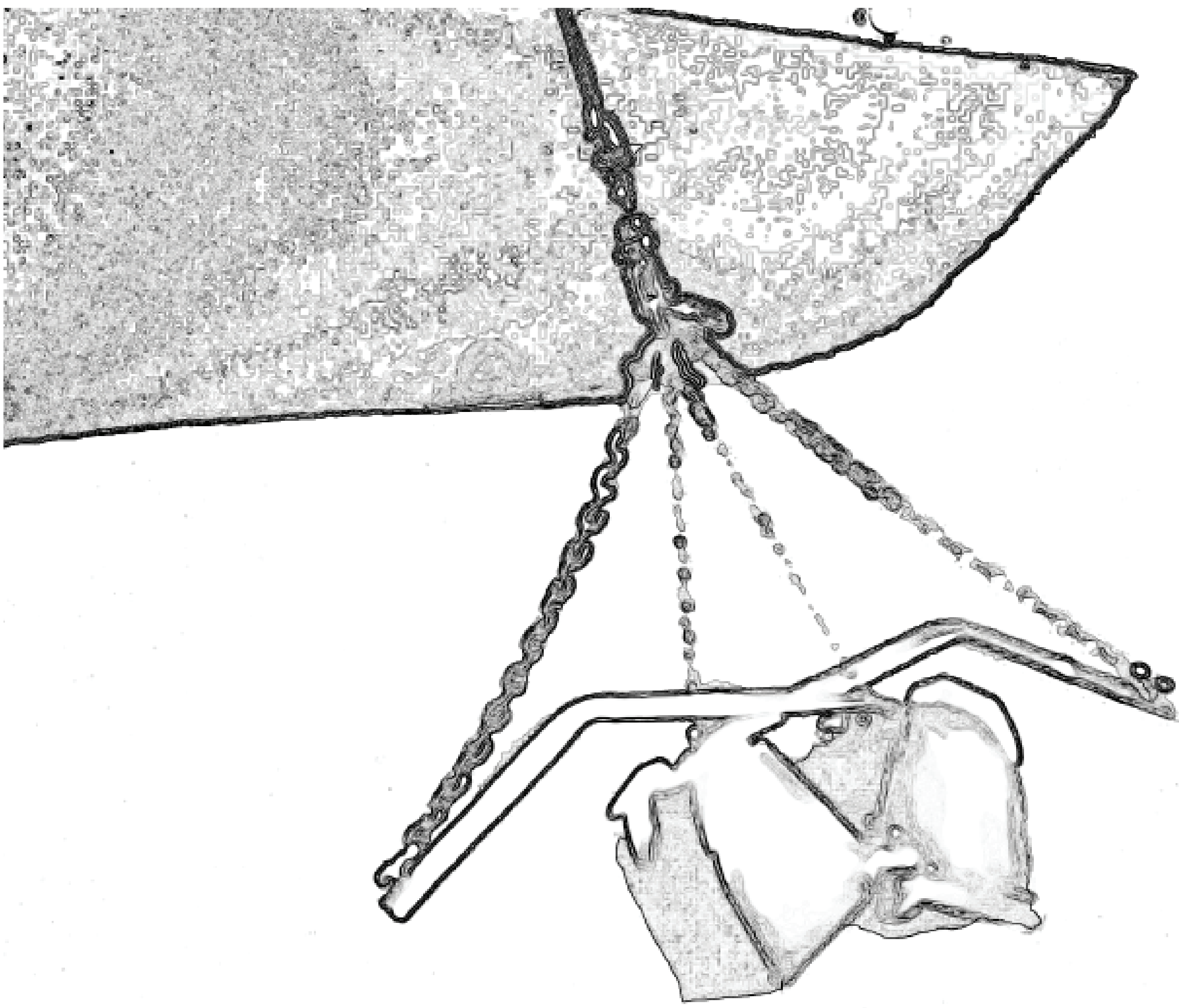
# Chapter 4
# Sediment Conditions



# Chapter 4. Sediment Conditions

## Introduction

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

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

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

This chapter presents analyses and interpretations of sediment grain size and chemistry data collected

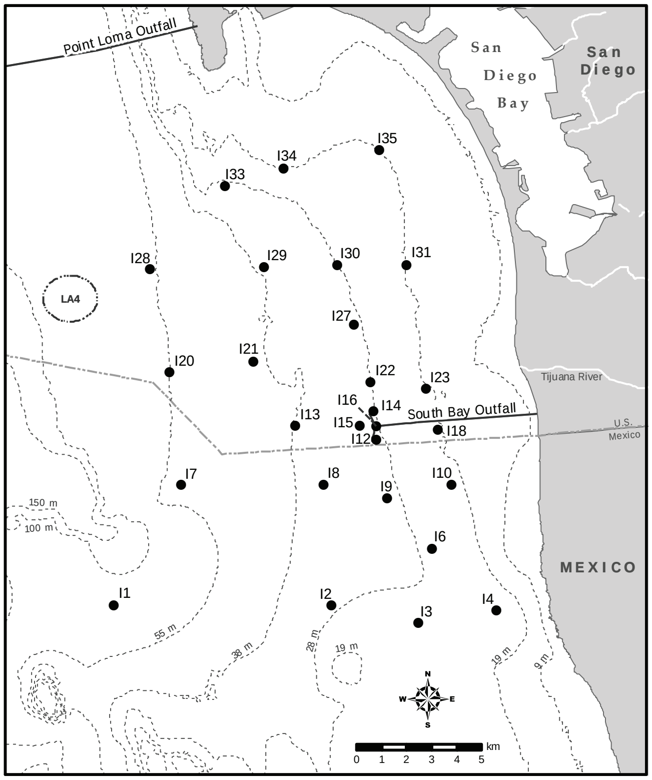



**Figure 4.1**
Benthic station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

in 2011 at fixed benthic monitoring stations surrounding the SBOO. The primary goals are to: (1) document sediment conditions during the year, (2) identify possible effects of wastewater discharge on sediment conditions in the region, and (3) identify other potential natural and anthropogenic sources of sediment contaminants to the local marine ecosystem.

## Materials and Methods

### Field Sampling

Sediment samples were collected at 27 benthic stations in the SBOO region during January and July 2011 (Figure 4.1). These stations range in depth from 18 to 60 m and are distributed along or adjacent to four main depth contours. The four stations considered to represent "nearfield" conditions (i.e., I12, I14, I15, I16) are located within 1000 m of the outfall wye. Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-$m^2$ surface area; the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 5) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987).

### Laboratory Analyses

All sediment chemistry and grain size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Grain size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of nested sieves. The Horiba measures particles ranging in size from about 0.5 to 2000 µm. Coarser sediments were removed and quantified prior to laser analysis by screening samples through a 2000 µm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%. When a sample contained substantial amounts of coarse sand, gravel, or shell hash that could damage the Horiba analyzer and/or where the general distribution of sediments would be poorly represented by laser analysis, a set of sieves with mesh sizes of 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, and 63 µm was used to divide the samples into seven fractions. Sieve results and output from the Horiba were converted into grain size fractions (e.g., percent sand, silt, clay) based on the Wentworth scale (Appendix C.1). The proportion of fine particles (percent fines) was calculated as the sum of silt and clay fractions for each sample, and each sample was then categorized as a "sediment type" based on relative proportions of percent fines, sand, and coarser particles (Appendix C.2). The distribution of grain sizes within each sample was also summarized as mean particle size in microns, and the median, mean, and standard deviations of phi sizes. The latter values were calculated by converting raw data measured in microns into phi sizes, fitting appropriate distribution curves (e.g., normal probability curve for most Horiba samples), and then determining the descriptive statistics mentioned above.

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

### Data Analyses

Data summaries for the various sediment parameters measured included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values. Total DDT (tDDT), PCB (tPCB), and PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix C.4 for individual constituent values). Spearman rank correlation was used to identify any association of percent fines with each chemical parameter. This non-parametric analysis accounts for non-detects in the data (i.e., analyte concentrations <MDL) without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (Conover 1980). Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis.

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).

In order to examine spatial and temporal patterns in overall sediment condition in the SBOO region, a cluster analysis was performed using a 5-year data matrix comprised of the main chemical parameters analyzed for each site (i.e., trace metals, indicators of organic loading, pesticides, total PCBs, total PAHs). This analysis was conducted for all data collected between 2007 and 2011 using PRIMER software (see Clarke and Warwick 2001, Clarke and Gorley 2006). Any non-detects (see above) were first converted to "0" values to avoid data deletion issues with the clustering program, after which the data were normalized and a Euclidean distance matrix was created. Similarity profile (SIMPROF) analyses were used to confirm the non-random structure of the resultant dendrogram (Clarke et al. 2008). Major ecologically-relevant clusters supported by SIMPROF were retained at >15.99% dissimilarity. Similarity percentages (SIMPER) analysis was subsequently used to identify which parameters primarily accounted for observed differences among cluster groups, as well as to identify the parameters typical of each group.

## Results

### Sediment Grain Size Distribution

Ocean sediments were diverse at the benthic stations sampled around the SBOO in 2011. Sands made up the largest proportion of sediments at all stations, ranging from 61% to about 98% of each sample. In contrast, the fine and coarse sediment fractions ranged between 0–34% and 0–38%, respectively (Table 4.1). Additionally, observations recorded for benthic infauna samples revealed the presence of coarse red relict sands, coarse black sands, gravel, and/or shell hash at different

## Table 4.1

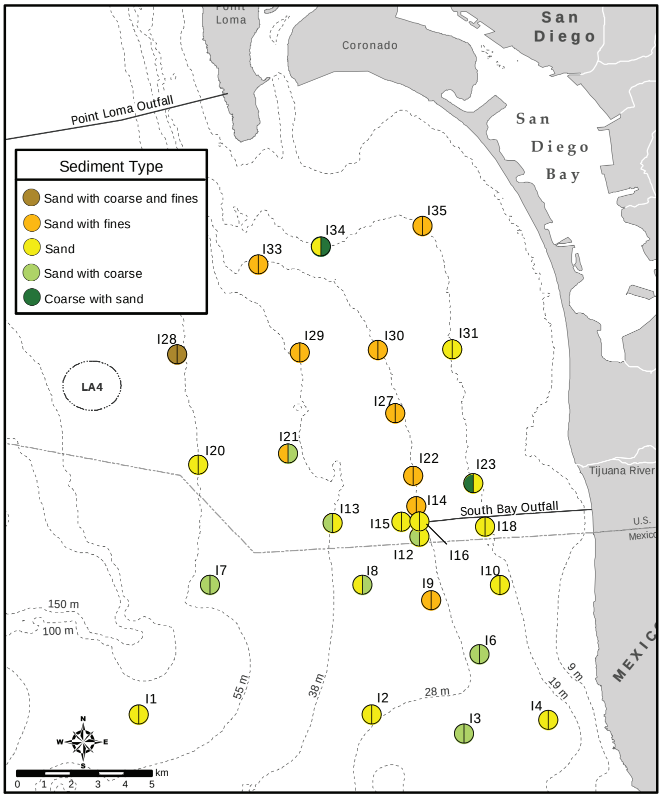
Summary of sediment grain sizes and sediment chemistry concentrations in sediments from SBOO benthic stations sampled during 2011. Data include the detection rate (DR), areal mean of detected values, and minimum, median, and maximum values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1995–1998) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold; SD = standard deviation.

| | 2011 Summary[a] | | | | | Pre-discharge | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **DR (%)** | **Areal Mean** | **Min** | **Median** | **Max** | **Max** | **ERL[b]** | **ERM[b]** |
| *Sediment Grain Size* | | | | | | | | |
| Mean (*µm*) | — | 279 | 2 | 177 | 754 | na | na | na |
| Mean (*phi*) | — | 2.5 | 0.9 | 2.8 | 3.9 | na | na | na |
| SD (*phi*) | — | 1.1 | 0.7 | 1.1 | 1.8 | na | na | na |
| Coarse (%) | — | 3.8 | 0.0 | 0.0 | 38.5 | 52.5 | na | na |
| Sand (%) | — | 86.9 | 61.0 | 90.5 | 98.2 | 100.0 | na | na |
| Fines (%) | — | 9.2 | 0.0 | 8.4 | 33.7 | 47.2 | na | na |
| *Organic Indicators* | | | | | | | | |
| Sulfides (*ppm*) | 89 | 2.14 | nd | 1.27 | 9.09 | 222.00 | na | na |
| TN (*% weight*) | 100 | 0.021 | 0.011 | 0.018 | 0.051 | 0.077 | na | na |
| TOC (*% weight*) | 100 | 0.17 | 0.03 | 0.11 | 1.92 | 0.638 | na | na |
| TVS (*% weight*) | 100 | 0.80 | 0.41 | 0.72 | 1.89 | 9.20 | na | na |
| *Trace Metals (ppm)* | | | | | | | | |
| Aluminum | 100 | 3848 | 503 | 2980 | 20,900 | 15,800 | na | na |
| Antimony | 35 | 0.54 | nd | nd | 0.85 | 5.60 | na | na |
| Arsenic | 98 | 2.3 | nd | 1.6 | 9.5 | 10.90 | 8.2 | 70 |
| Barium | 100 | 20.1 | 1.7 | 16.7 | 77.4 | 54.30 | na | na |
| Beryllium | 81 | 0.053 | nd | 0.033 | 0.222 | 2.14 | na | na |
| Cadmium | 41 | 0.21 | nd | nd | 0.47 | 0.41 | 1.2 | 9.6 |
| Chromium | 100 | 9.3 | 2.5 | 8.7 | 38.2 | 33.8 | 81 | 370 |
| Copper | 98 | 2.8 | nd | 2.4 | 15.8 | 11.10 | 34 | 270 |
| Iron | 100 | 5548 | 1080 | 4750 | 28,700 | 17,100 | na | na |
| Lead | 94 | 2.67 | nd | 2.06 | 10.40 | 6.80 | 46.7 | 218 |
| Manganese | 100 | 44.0 | 5.3 | 32.9 | 246.0 | 162.00 | na | na |
| Mercury | 48 | 0.009 | nd | nd | 0.024 | 0.078 | 0.15 | 0.71 |
| Nickel | 70 | 2.85 | nd | 1.46 | 10.10 | 13.60 | 20.9 | 51.6 |
| Selenium | 2 | 0.30 | nd | nd | 0.30 | 0.620 | na | na |
| Silver | 0 | — | — | — | — | nd | 1.0 | 3.7 |
| Thallium | 17 | 1.63 | nd | nd | 3.26 | 17.00 | na | na |
| Tin | 61 | 0.83 | nd | 0.36 | 2.23 | nd | na | na |
| Zinc | 100 | 12.9 | 2.3 | 9.6 | 66.4 | 46.90 | 150 | 410 |
| *Pesticides (ppt)* | | | | | | | | |
| Total DDT | 15 | 1004 | nd | nd | 5270 | 23,380 | 1580 | 46,100 |
| HCB | 4 | 1595 | nd | nd | 2700 | nd | na | na |
| *Total PCB (ppt)* | 2 | 1220 | nd | nd | 1220 | na | na | na |
| *Total PAH (ppb)* | 0 | — | — | — | — | 636.5 | 4022 | 44,792 |

na = not available; nd = not detected

[a] Minimum, median, and maximum values were calculated based on all samples ($n = 54$), whereas means were calculated on detected values only ($n \leq 54$).

[b] From Long et al. 1995.




## Figure 4.2

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

stations (see Appendix C.5). Differences in grain size composition between the winter and summer surveys tended to be minimal. For example, the percent of fine material at any one station differed by ≤8% between the January and July surveys, while coarse fractions differed by ≤7% with only a few exceptions. These exceptions included samples from stations I21 and I34, which had substantial coarse fractions in July (i.e., 12% and 39%, respectively) but no coarse sediments in January. In contrast, station I23 had 32% coarse sediments in January but none in July.

During 2011, there were no spatial patterns in the categorization of stations by sediment type relative to the SBOO discharge site (Figure 4.2). For example, sediments collected from the nearfield stations were similar to those from surrounding areas in containing low levels of fine material (i.e., <15% fines; Appendix C.5). Most stations located near or to the south of the outfall had sediments composed predominantly of sand with variable amounts of coarse material. In contrast, several stations to the north had mostly sandy sediments with variable amounts of fine material. One exception to these patterns occurred at station I9, which had sediments with a higher percent fines content compared to other nearby sites. Other exceptions occurred at station I28 which had relatively high proportions of both coarse and fine materials, and station I34 which had more coarse and less fine material than other nearby stations in July only.

There was no evidence that the amount of fine particles has increased at any of the nearfield or farfield 28-m contour stations since the onset of wastewater discharge in 1999 (Figure 4.3). Instead, the patterns described above appear to be consistent over time (Appendix C.6). For example, historical analyses reveal sediments throughout the SBOO region have predominantly consisted of sand with variable amounts fine and coarse materials. The highest percent fines have consistently occurred at northern stations I29, I30 and I35. Additionally, station I9 has consistently had higher percent fines versus other nearby stations, and station I28 has consistently had relatively high proportions of both coarse and fine materials. These results indicate that there is some stability in the region over time in terms of the overall proportions of the major sediment grain size fractions.

There also appears to be stability within sediment size fractions (e.g., types of sand present) at some stations, including I1, I2, I7, I9, I10, I30 and I35 (Appendix C.6). In contrast, sediments from other stations (e.g., I4, I12, I20, I28, I29) show significant variability within sediment size categories, especially the size ranges indicative of sand and coarse fractions. This variability likely corresponds to patches of red relict sands, coarse black sands and other coarse materials (e.g., pea gravel, shell hash, pebbles, rocks) that are encountered at various times.

The sorting coefficient is calculated as the standard deviation (SD) in phi size units for each sample,

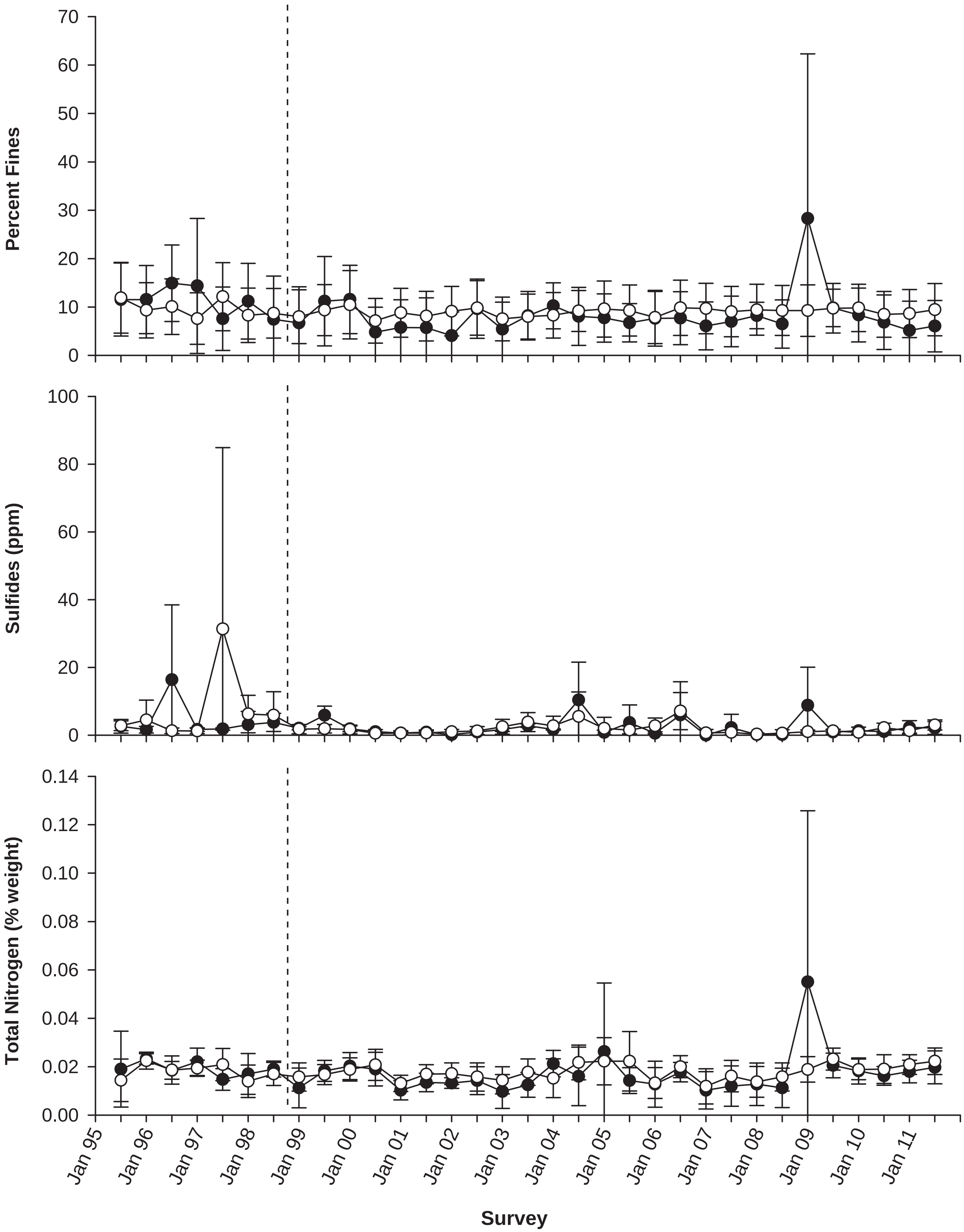



**Figure 4.3**
Sediment grain size and organic loading indicators at SBOO 28-m benthic stations sampled between 1995–2011. Data are expressed as means of detected values ±95% confidence intervals for samples pooled over nearfield stations (filled circles; *n*=4) versus farfield stations (open circles; *n*=8) for each survey. Dashed lines indicate onset of discharge from the SBOO.

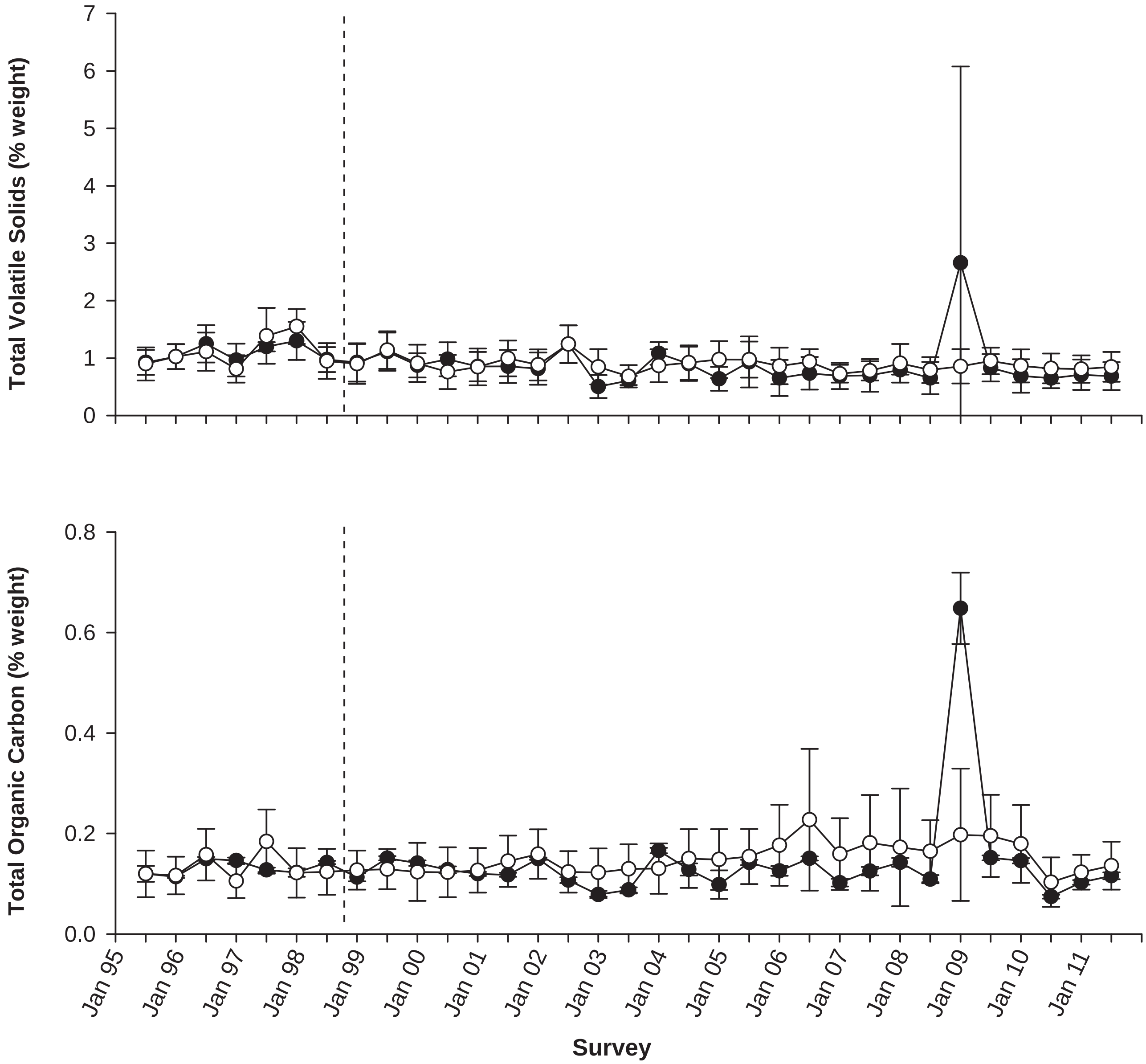



**Figure 4.3** *continued*

therefore reflecting the range of sediment grain sizes present, and is considered indicative of the level of disturbance (e.g., fluctuating or variable currents and sediment deposition) in an area. Sediments collected throughout the South Bay outfall region during 2011, including at stations located near the outfall, were moderately well to poorly sorted with sorting coefficients ranging from 0.7 to 1.8 phi (Table 4.1). The sediments most likely exposed to higher levels of disturbance (i.e., SD >1.5 phi) occurred at station I28 during both the January and July surveys, and at station I29 during July (Appendix C.5).

### Indicators of Organic Loading

There was no evidence of organic enrichment in SBOO sediments that could be associated with wastewater discharge in sediments in 2011. Although detection rates were high (≥89%) for sulfides, total nitrogen (TN), total organic carbon (TOC) and total volatile solids (TVS; Table 4.1), concentrations of all but TOC were far below maximum values detected prior to wastewater discharge. For example, values were ≤9.09 ppm for sulfides, ≤0.051% wt for TN, and ≤1.89% wt for TVS. As already mentioned, the maximum TOC value of 1.92% wt exceeded pre-discharge values; this value was also relatively high compared to the areal mean and median values for this and previous years (e.g., City of San Diego 2011).

Further evidence of the lack of organic enrichment included the absence of spatial patterns relative to the discharge site during the year. Instead, higher TN, TOC and TVS concentrations tended to correspond to relatively high proportions of fine sediments in the SBOO region. For example, TN and TVS were positively correlated with the percent fines in each sample (Figure 4.4A, 4.4B). Although sulfides did not co-vary with percent fines, the highest sulfide concentrations occurred far north of the outfall at station I33 in July and station I35 in both January and July (Appendix C.7). Additionally, there was no evidence of organic enrichment at any of the nearfield or farfield 28-m depth contour stations since discharge began, despite a spike in values at nearfield stations in January 2009 (Figure 4.3). This spike was due to an anomalous sample with ~79% fines collected at station I16 during this survey (see multi-year analyses below).

### Trace Metals

Twelve trace metals occurred in ≥61% of sediment samples collected in 2011, including aluminum, arsenic, barium, beryllium, chromium, copper, iron, lead, manganese, nickel, tin, and zinc (Table 4.1, Appendix C.8). Another five metals (antimony, cadmium, mercury, selenium, thallium) were also detected, but less frequently at rates between 2–48%. Silver went undetected. Almost all metals were detected at low levels below both ERL and ERM thresholds. The only exception was arsenic, which exceeded the ERL (but not ERM) at station I21 during both surveys. In contrast to previous years, 50% of the metals were found to exceed levels reported prior to wastewater discharge (Table 4.1), and only concentrations of nickel correlated positively with percent fines (Figure 4.4C). However, these relatively high values tended to be wide-spread throughout the region and several of the highest values corresponded to samples with percent fines >20%. No patterns indicative of an outfall effect were evident in the distribution of metals; a conclusion further supported by multi-year analyses (see below).

### Pesticides, PCBs, and PAHs

Chlorinated pesticides were detected infrequently in SBOO sediments in 2011, with detection rates ≤15% (Table 4.1, Appendix C.9). Total DDT (primarily p,p-DDE; Appendix C.4) occurred in sediments from 5 of 27 stations at concentrations up to 5270 ppt. Although the highest DDT concentration exceeded its ERL threshold (detected at station I29 in January), all DDT values were below values reported prior to discharge. The only other pesticide detected during the year was hexachlorobenzene (HCB), which was found in just two samples at concentrations up to 2700 ppt. These samples were collected at stations I30 and I8 in July. Similarly, PCBs were very rarely detected, occurring in a single sample from station I29 in January. No PAHs were detected in any sediment samples collected during the year. No patterns indicative of an outfall effect were evident in the distribution of pesticides or PCBs during 2011.

### Classification of Sediment Conditions

Results of cluster analyses performed on all sediment chemistry data collected between 2007 and 2011 discriminated six groups of sediment samples (Figure 4.5). These groups (cluster groups A–F) differed in relative concentrations of metals, pesticides, total PCB, and total PAH in each sample (Appendices C.10, C.11). Contaminant levels present in 2011 were generally similar to previous years, and no spatial patterns were apparent relative to the outfall. Over 97% of the 270 samples, including all but two of the samples collected in 2011 comprised a single group (cluster group F). This group represents typical background conditions for the region with highly variable amounts of fine sediments (0–50%) and contaminant levels. Only about 16% of the samples in group F had contaminant concentrations that exceeded accepted thresholds; these included arsenic, silver,

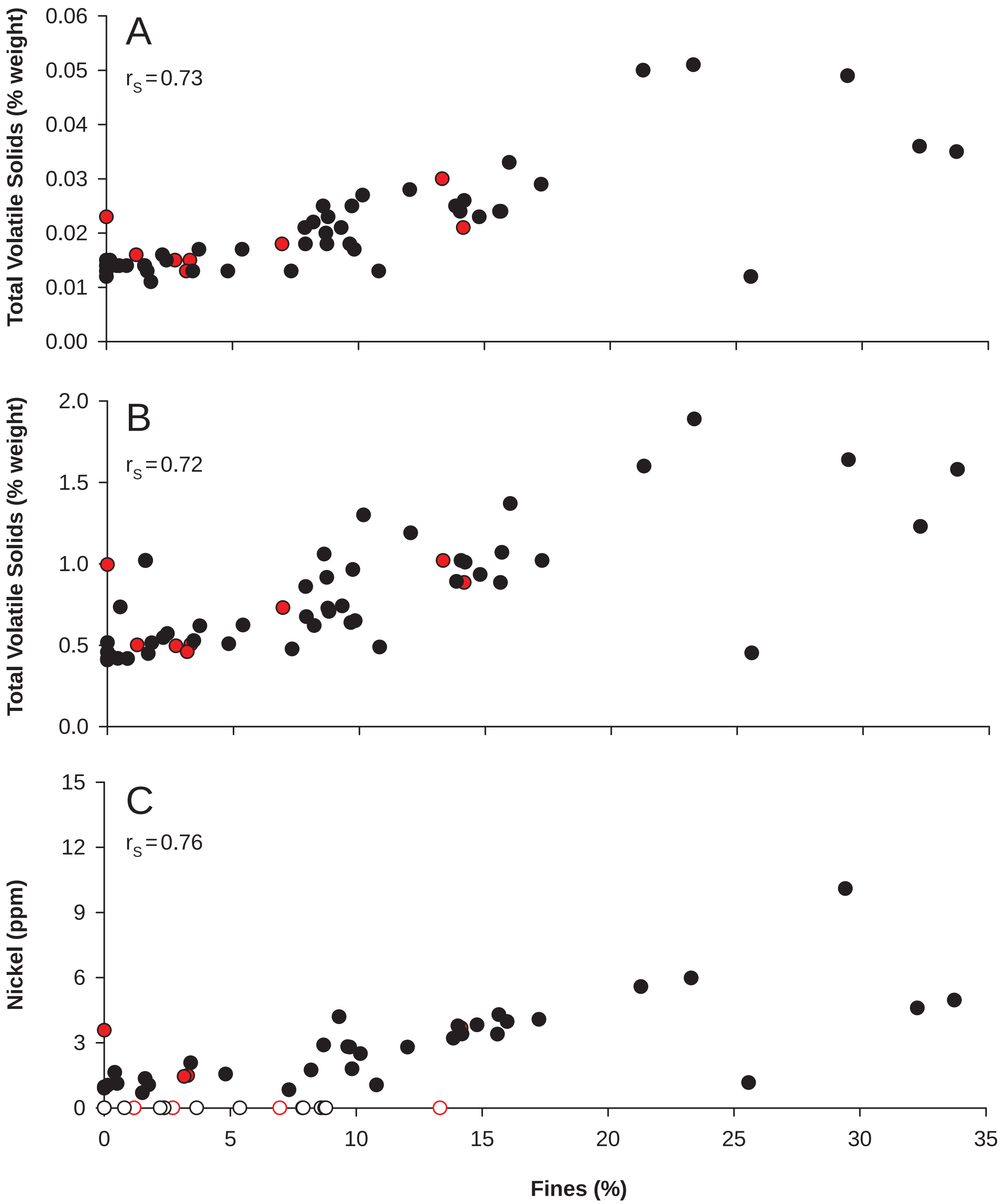
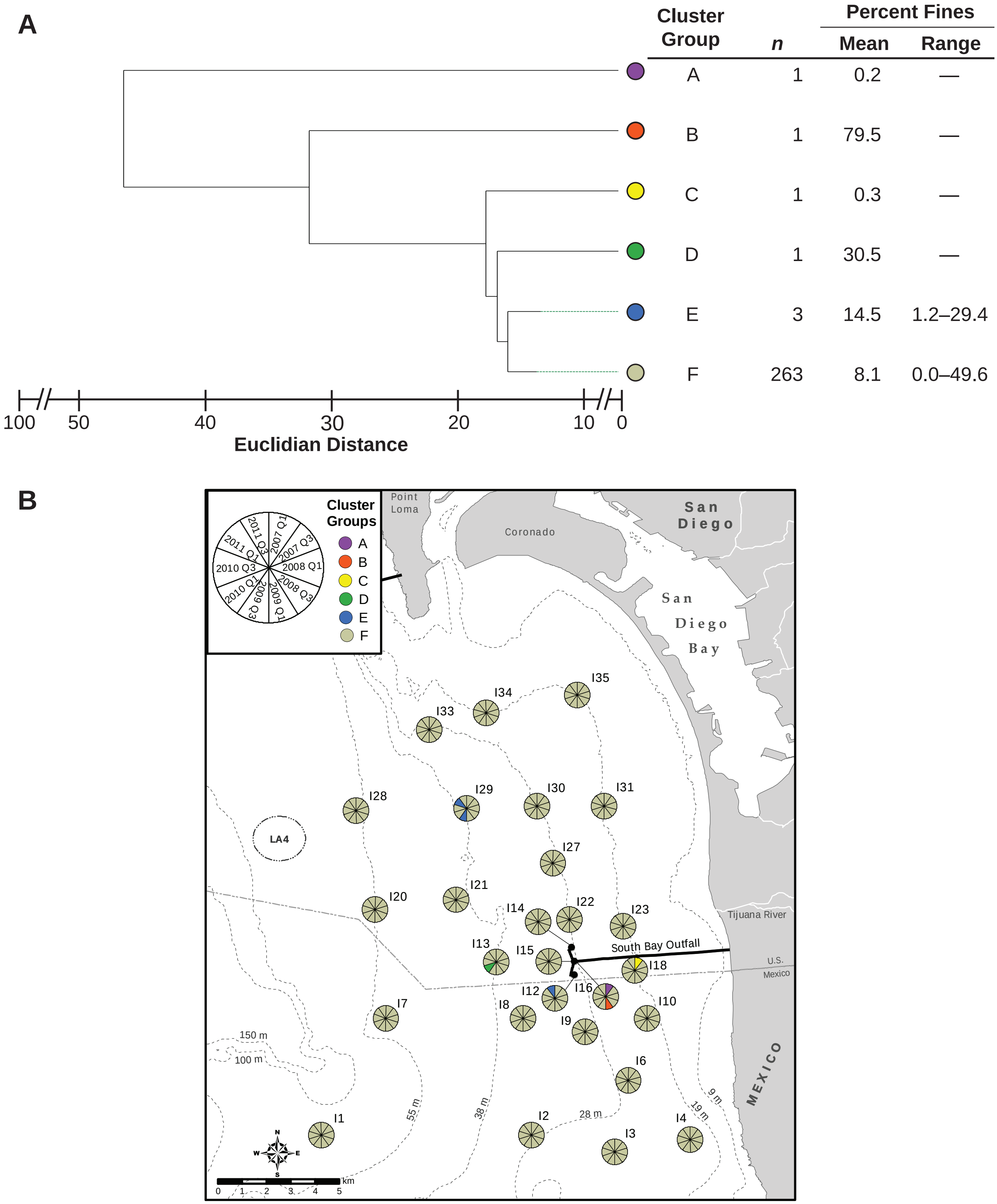



**Figure 4.4**
Scatterplots of percent fines versus concentrations of (A) total nitrogen, (B) total volatile solids, and (C) nickel in sediments from SBOO stations sampled during 2011. These are the only three parameters that were stongly correlated with percent fines during 2011 (i.e., $r_s \geq 0.70$, $p < 0.001$). Samples collected from nearfield stations are indicated in red. Open circles indicate samples with analyte concentrations below the method detection limit.

and DDT, which exceeded their ERLs in 7, 31, and 3 samples, respectively. Three of the silver values also exceeded the ERM for this parameter. Cluster group E represented the remaining two 2011 samples collected at station I29 in January and station I12 in July, along with a sample collected




| Cluster Group | *n* | Percent Fines Mean | Percent Fines Range |
|---|---|---|---|
| A | 1 | 0.2 | — |
| B | 1 | 79.5 | — |
| C | 1 | 0.3 | — |
| D | 1 | 30.5 | — |
| E | 3 | 14.5 | 1.2–29.4 |
| F | 263 | 8.1 | 0.0–49.6 |

**Figure 4.5**
Cluster analyses of sediment chemistry data from SBOO benthic stations sampled between 2007–2011. Data are presented as: (A) cluster results; (B) spatial distribution of sediment samples as delinated by cluster analysis. Data for percent fines include the mean and range of values calculated over all stations within each group (*n*).

at station I29 in July 2009. While sediments in this small group had concentrations of most chemistry parameters that were intermediate to those characteristic of groups F and B (see below), the two samples from I29 had DDT levels higher than its ERL. The four remaining cluster groups represented single sample outliers collected during 2007 or 2010, which differed from group F primarily by having higher values of a few select contaminants. The outliers from station I16 in January 2007 (group A), station I18 in January 2007 (group C), and station I13 in January 2010 (group D) were characterized by sediments of ≤30% fines, low concentrations of most organic indictors and metals (i.e., none that exceeded ERLs), but relatively high concentrations of pesticides, tPCB and tPAH or TVS (groups A, C, D, respectively). In contrast, the fourth outlier collected at station I16 in January 2009 (group B) had the highest percent fines reported over the 5-year period (~79%), and also contained the highest concentrations of sulfides, TN, TOC, and several metals; a number of these metals, including aluminum, antimony, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, zinc have been known to co-vary with percent fines (see City of San Diego 2011, and Chapter 8 herein).

## Discussion

Sediment grain size composition at the SBOO stations sampled in 2011 was similar to that seen historically (Emery 1960, MBC-ES 1988) and in recent survey years (City of San Diego 2007–2011). Sands made up the largest proportion of all samples, with the amounts of coarser and finer particles varying among sites. There was no evident spatial relationship between sediment composition and proximity to the outfall discharge site, nor has there been any substantial increase in fine sediments at nearfield stations or throughout the region since wastewater discharge began in 1999. Instead, the diversity of these sediments reflects multiple geologic origins and complex patterns of transport and deposition. In particular, the presence of red relict sands at some stations is indicative of minimal sediment deposition in recent years. Several other stations are located near or within an accretion zone for sediments moving within the Silver Strand littoral cell (MBC-ES 1988, Patsch and Griggs 2007). Therefore, the higher proportions of fine sands, silts, and clays that occur at these sites are likely associated with the transport of fine materials originating from the Tijuana River, the Silver Strand beach, and to a lesser extent from San Diego Bay (MBC-ES 1988). The diverse sediment composition within the region was further emphasized by sorting coefficients that ranged from moderately well to poorly sorted in 2011. Well-sorted sediments (i.e., SD ≤ 0.5 phi) are composed of particles of similar size and are indicative of areas subject to consistent, moderate currents. In contrast, poorly sorted sediments (i.e., SD ≥ 1.0 phi) typically indicate areas of fluctuating weak to violent currents or rapid deposition (e.g., dredged material dumping) that often result in highly variable or patchy particle size distributions (Folk 1980). In general, sediment composition has been highly diverse throughout the South Bay outfall region since sampling first began in 1995 (City of San Diego 2000).

Various trace metals, pesticides, PCBs, and organic loading indicators were detected in sediment samples collected throughout the SBOO region in 2011, but in highly variable concentrations. Although several contaminants were detected at levels above pre-discharge maximums, there were very few exceedances of either ERL or ERM thresholds. Additionally, there have been no spatial patterns indicative of an outfall impact over the past several years, with concentrations of most contaminants at nearfield stations falling within the range of values at the farfield stations. Instead, relatively high values of most parameters were spread throughout the region, and several co-occurred at sites characterized by finer sediments. This association is expected due to the known correlation between particle size and concentration of organics and trace metals (Eganhouse and Venkatesan 1993).

The frequent and wide-spread occurrences of various contaminants in sediments from the SBOO 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 no areas off southern California 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 South Bay outfall region as demonstrated by the presence of many contaminants in sediments prior to wastewater discharge (see City of San Diego 2000). 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 include bioturbative re-exposure of buried legacy sediments (Niederoda et al. 1996, Stull et al. 1996), large storms that assist redistribution of legacy contaminants (Sherwood et al. 2002), and stormwater discharges (Schiff et al. 2006, Nezlin et al. 2007). Possible non-outfall sources and pathways of contaminant dispersal off San Diego include transport of contaminated sediments from San Diego Bay via tidal exchange, offshore disposal of sediments dredged from the Bay, and surface runoff from local watersheds (see Parnell et al. 2008).

In summary, sediment conditions in the South Bay outfall region were diverse in 2011, although temporal differences in the sediment grain size composition at many individual stations were minimal. Generally, the distribution of sediment types in the region is indicative of a diverse geologic history and complex transport patterns along this section of the coast. There was no evidence of fine-particle loading related to wastewater discharge during the year. Likewise, contaminant concentrations at nearfield stations were within the range of variability observed throughout the region and do not appear organically enriched. Finally, the quality of SBOO sediments in 2011 was similar to previous years, and overall concentrations of all chemical contaminants remained relatively low compared to other southern California coastal areas (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

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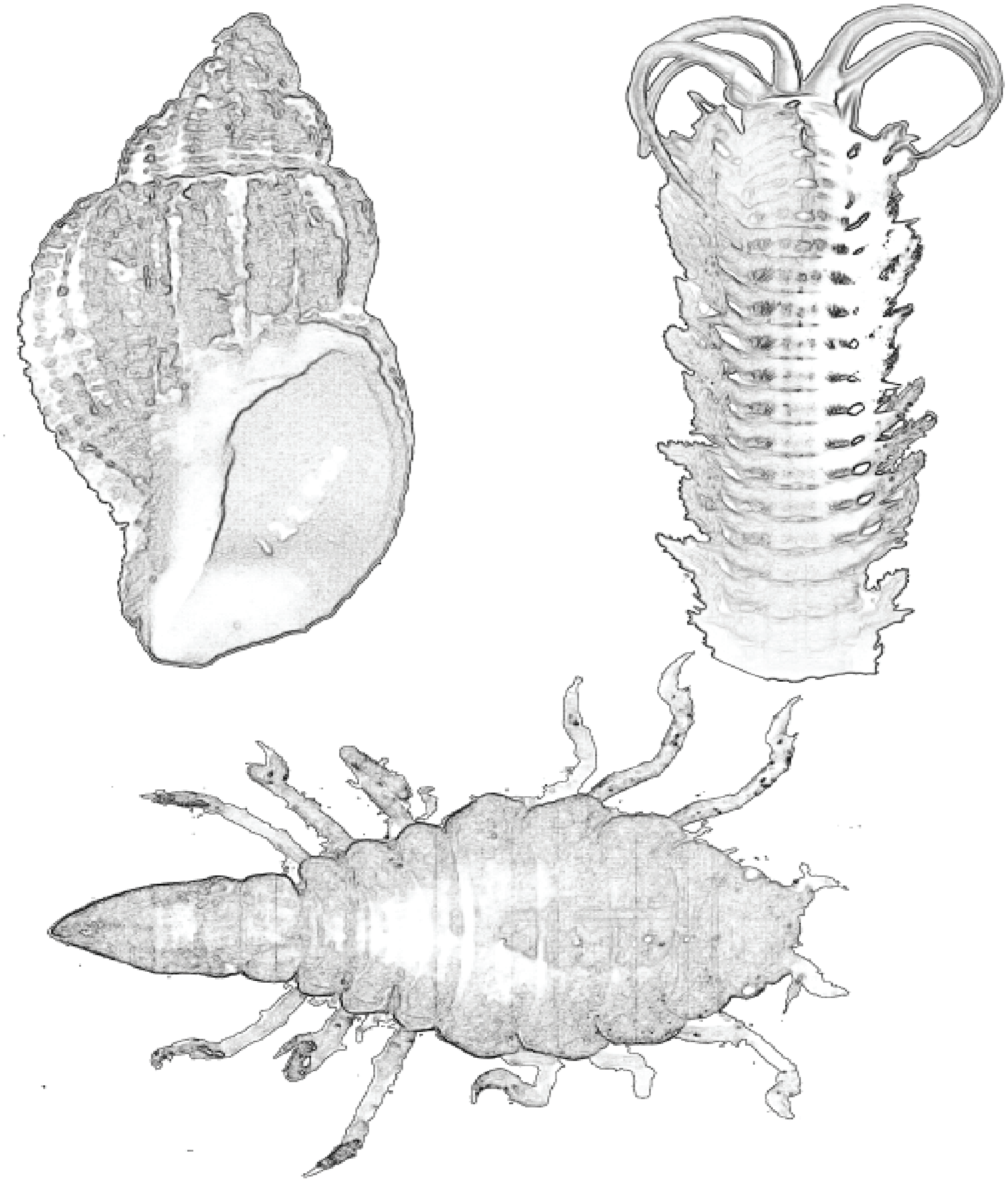
# Chapter 5
# Macrobenthic Communities



# Chapter 5. Macrobenthic Communities

## Introduction

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

The structure of marine macrobenthic communities is influenced by natural factors such as ocean depth, sediment composition (e.g., percent of fine vs. coarse sediments), sediment quality (e.g., contaminant loads, toxicity), oceanographic conditions (e.g., temperature, dissolved oxygen and nutrient levels, currents), and biological interactions (e.g., competition, predation). For example, assemblages on the SCB coastal shelf typically vary along depth gradients and/or with sediment grain size (Bergen et al. 2001). Therefore, an understanding of background or reference conditions is necessary before determining whether observed differences in community structure may be related to anthropogenic activities. Pre-discharge or regional monitoring efforts by the City and other agencies since 1994 provide baseline information on spatial variability of invertebrate communities in the San Diego region critical for comparative analysis (e.g., see Chapter 9 herein and City of San Diego 1999, 2011, Ranasinghe et al. 2003, 2007, 2010, 2012).

To detect potential wastewater impacts on invertebrate communities, the City relies on a suite of scientifically-accepted community parameters and statistical analyses. Indices such as the Benthic Response Index (BRI), the Shannon diversity index, and Swartz dominance are used as metrics of invertebrate community structure, while multivariate analyses are used to detect spatial and temporal differences among communities (e.g., Warwick 1993, Smith et al. 2001). The use of multiple analyses provides better resolution than single parameters and some include established benchmarks for determining anthropogenically-induced environmental impacts. For example, the BRI was developed specifically for use in the SCB, which enhances its interpretability for the region. All together, the data are used to determine whether invertebrate populations in the San Diego region are similar to populations from habitats with similar depth and sediment characteristics, or whether observable impacts from outfalls or other sources occur. Minor organic enrichment caused by wastewater discharge should be evident through an increase in species richness and abundance, whereas major impacts to the environment will eventually lead to decreases in overall species diversity and richness coupled with dominance of a few pollution tolerant species (Pearson and Rosenberg 1978). Additionally, high BRI values (>34) will typically occur in impacted areas. This weight-of-evidence approach is the basis by which the City attains its monitoring objectives.

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

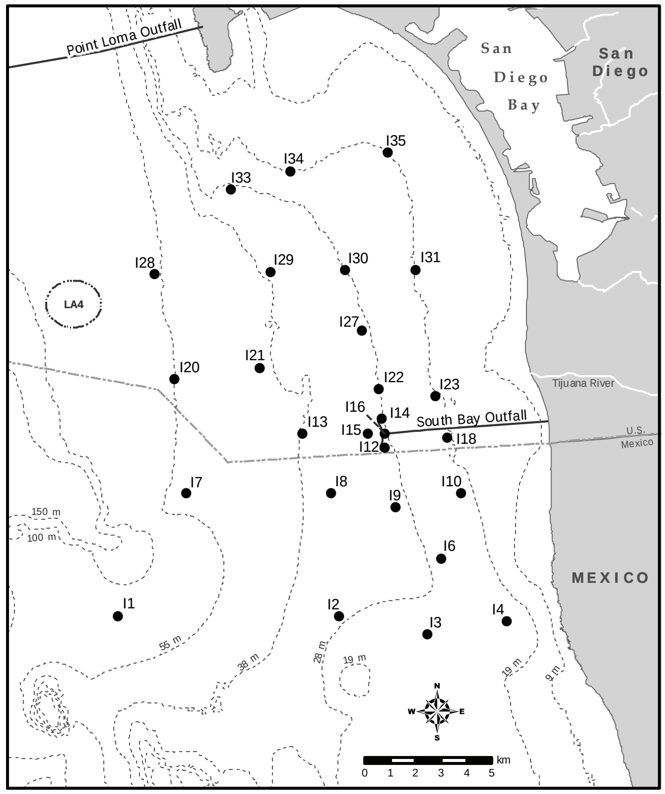


**Figure 5.1**
Benthic station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

## Materials and Methods

### Collection and Processing of Samples

Benthic samples were collected at 27 stations in the SBOO region during January and July 2011 (Figure 5.1). These stations range in depth from 18 to 60 m and are distributed along or adjacent to four main depth contours. The four stations considered to represent “nearfield” conditions (i.e., I12, I14, I15, I16) are located within 1000 m of the outfall wye.

Two replicate samples for benthic community analyses were collected per station during each survey using a double 0.1-m$^2$ Van Veen grab. The first sample was used for analysis of macrofauna, while the adjacent grab in the same cast 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, returned to the City of San Diego Marine Biology Laboratory, and then identified to species (or the lowest taxon possible) and enumerated by staff marine biologists. All identifications followed current nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT 2011).

### Data Analyses

Samples from each grab were considered independent replicates, even if retrieved from the same station. The following community structure parameters were calculated for each station per 0.1-m$^2$ grab: species richness (number of species), abundance (number of individuals), Shannon diversity index (H'), Pielou’s evenness index (J'), Swartz dominance (see Swartz et al. 1986, Ferraro et al. 1994), and benthic response index (BRI; see Smith et al. 2001). Additionally, the total or cumulative number of species over all grabs was calculated for each station.

To further examine spatial patterns among benthic communities in the SBOO region, multivariate analyses were conducted using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). Macrofaunal abundance data were square-root transformed to lessen the influence of common species and increase the importance of rare species, and a Bray-Curtis similarity matrix was created using depth stratum (i.e., inner and mid-shelf), and sediment type (see Appendix C.2) as factors. A 2-way crossed ANOSIM (maximum number of permutations = 9999) was conducted to determine whether communities varied by depth and/or sediment type across the region. To visually depict the relationship of individual grab samples to each other based on macrofaunal composition, a cluster dendrogram was created. Similarity profile (SIMPROF) analysis was used to confirm non-random structure of resultant clades in the dendrogram (Clarke et al. 2008), and major ecologically-relevant clusters supported by SIMPROF were retained at > 32.2% similarly. Similarity percentages (SIMPER) analyses were used to determine which organisms were responsible for the greatest contribution to within-group similarities (i.e. characteristic species), and to identify which species accounted for: (1) significant differences identified through ANOSIM, and (2) differences among clades occurring in the dendrogram.

# Results

## Community Parameters

### *Species richness*
A total of 822 taxa were identified during the 2011 SBOO surveys. Of these, 539 taxa (66%) were identified to species level, 203 to genus, 42 to family, 19 to order, 15 to class, and 4 to phylum. Most taxa occurred at multiple sites, although about 21% (*n* = 172) represented unique taxa recorded only once. Three species new to the San Diego region were collected: the sigalionid polychaete *Sthenelais berkeleyi*, the sabellid polychaete *Pseudofabriciola californica*, and the gastropod *Astyris gausapata*. From 1995 to 2010, species richness in the region has ranged from 16 to 172 taxa per sample, with a mean of 62 taxa per 0.1 $m^2$ grab. Average species richness in 2011 was within this historical range, with a low of 45 taxa per grab at farfield stations I2 and I18 to a high of 158 taxa per grab at farfield station I28 (Table 5.1). Although the number of species occurring per site varied spatially, there were no apparent patterns relative to distance from the discharge site (Figure 5.2A).

### *Macrofaunal abundance*
A total of 37,695 macrofaunal individuals were identified in 2011, with mean abundance values ranging from 118 to 579 animals per 0.1 $m^2$ (Table 5.1). The greatest number of animals occurred at farfield station I28, the same station that also possessed the highest species richness. Similarly, the fewest number of animals occurred at station I18 that also had the lowest species richness. No spatial patterns in abundance related to the outfall were observed, and substantial overlap existed among sites from different depth contours. Overall, values from 2011 are within range of historical data collected from 1995–2010, where total macrofaunal abundance varied from 39 to 1579 individuals with an average of 248 animals per 0.1 $m^2$.

Macrofaunal abundances across the region increased starting in 2007, and subsequent observed fluctuations were primarily associated with variation in *Spiophanes norrisi* populations (Figures 5.2B, 5.3; see Chapter 9). Since this trend in macrofaunal abundance was observed at both nearfield and farfield stations (Figure 5.2B), variation in *S. norrisi* abundances represents a regional trend that is not likely caused by outfall impacts. Starting in 2011, populations of *S. norrisi* and overall macrofaunal abundance

## Table 5.1

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

| Station | | Tot Spp | SR | Abun | H' | J' | Dom | BRI |
|---|---|---|---|---|---|---|---|---|
| *19-m Stations* | | | | | | | | |
| I35 | | 183 | 87 | 276 | 3.9 | 0.88 | 33 | 30 |
| I34 | | 167 | 62 | 562 | 2.2 | 0.53 | 6 | 14 |
| I31 | | 117 | 50 | 128 | 3.3 | 0.86 | 22 | 21 |
| I23 | | 194 | 69 | 513 | 3.4 | 0.81 | 22 | 21 |
| I18 | | 110 | 45 | 118 | 3.2 | 0.85 | 20 | 20 |
| I10 | | 154 | 74 | 183 | 3.9 | 0.90 | 33 | 20 |
| I4 | | 141 | 55 | 170 | 3.3 | 0.83 | 21 | 13 |
| *28-m Stations* | | | | | | | | |
| I33 | | 204 | 99 | 378 | 3.7 | 0.81 | 32 | 26 |
| I30 | | 178 | 86 | 229 | 4.0 | 0.89 | 36 | 26 |
| I27 | | 151 | 68 | 178 | 3.7 | 0.87 | 28 | 25 |
| I22 | | 246 | 116 | 426 | 4.0 | 0.85 | 40 | 27 |
| I14[a] | | 160 | 72 | 205 | 3.6 | 0.84 | 29 | 25 |
| I16[a] | | 161 | 67 | 374 | 2.8 | 0.67 | 16 | 21 |
| I15[a] | | 200 | 79 | 366 | 3.3 | 0.77 | 20 | 24 |
| I12[a] | | 252 | 104 | 529 | 3.5 | 0.75 | 23 | 24 |
| I9 | | 224 | 115 | 465 | 4.1 | 0.87 | 38 | 25 |
| I6 | | 126 | 56 | 535 | 2.1 | 0.53 | 7 | 15 |
| I2 | | 101 | 45 | 206 | 2.7 | 0.71 | 12 | 19 |
| I3 | | 111 | 50 | 477 | 2.3 | 0.58 | 7 | 16 |
| *38-m Stations* | | | | | | | | |
| I29 | | 296 | 126 | 552 | 4.0 | 0.82 | 36 | 22 |
| I21 | | 151 | 62 | 319 | 3.3 | 0.80 | 18 | 10 |
| I13 | | 168 | 67 | 335 | 3.1 | 0.75 | 17 | 14 |
| I8 | | 133 | 61 | 306 | 2.9 | 0.72 | 14 | 21 |
| *55-m Stations* | | | | | | | | |
| I28 | | 320 | 158 | 579 | 4.3 | 0.86 | 52 | 16 |
| I20 | | 234 | 103 | 527 | 3.7 | 0.79 | 26 | 10 |
| I7 | | 143 | 61 | 201 | 3.4 | 0.82 | 20 | 9 |
| I1 | | 203 | 92 | 288 | 4.0 | 0.88 | 34 | 16 |
| **All Grabs** | Mean | 179 | 79 | 349 | 3.4 | 0.79 | 24 | 20 |
| | 95% CI | 22 | 6 | 41 | 0.13 | 0.02 | 2 | 1.2 |
| | Minimum | 101 | 38 | 64 | 1.3 | 0.31 | 1 | 6 |
| | Maximum | 320 | 182 | 1425 | 4.5 | 0.97 | 57 | 31 |

[a] nearfield station

appears to be returning to lower historical means observed prior to 2007.

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

Average species diversity (H') ranged from 2.1 at station I6 to 4.3 at station I28 during 2011 (Table 5.1). Historically, H' values have mostly been similar between nearfield and farfield stations (Figure 5.2C). Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed and that the community is not dominated by a few highly abundant species. During 2011, J' values averaged between 0.53 at stations I6 and I34 and 0.9 at station I10 with spatial patterns similar to those for diversity (Figures 5.2C, D). Swartz dominance values averaged from 6 to 52 species per station during the year (Table 5.1). This range reflects the dominance of a few species at some sites (e.g., low values at stations I3, I6, and I34) versus other stations where many taxa contributed to the overall abundance (e.g., high values at stations I22 and I28).

***Benthic response index***

Benthic response index (BRI) values are an important tool for gauging possible anthropogenic impacts to marine environments throughout the SCB. Values below 25 are considered indicative of reference conditions, values within 25–33 represent "a minor deviation from reference conditions" that should be corroborated with additional information, while values ≥34 represent different levels of degradation (Smith et al. 2001). Historically, mean BRI values at the four nearfield stations in the SBOO region have been similar to mean values for 28-m contour farfield stations (Figure 5.2F), suggesting no immediate impact of the SBOO on the marine environment. In 2011, seven sites across the SBOO monitoring region possessed BRI values between 25 to 30. As in previous years, farfield station I35, located on the 19-m depth contour near the mouth of San Diego Bay, had the highest average BRI value encountered (BRI = 30). All remaining sites possessing values ≥25 were situated along the 28-m isobath where sediments differ from the surrounding area (see Chapter 4). Of these sites, I14 was the only nearfield site to possess a value of 25, with all remaining sites representing farfield stations situated north (four sites) or south (one site) of the outfall. Sites located along the 55-m depth contour exhibited among the lowest BRI values, with site I7 possessing the lowest value (BRI = 9) recorded for 2011.

## Dominant Species

Macrofaunal communities in the SBOO region were dominated by polychaete worms in 2011, which accounted for 45% of all species collected (Table 5.2). Crustaceans accounted for 24% of species reported, while molluscs, echinoderms, and all other taxa combined accounted for the remaining 17%, 3%, and 11%, respectively. Polychaetes were also the most numerous animals, accounting for 71% of the total abundance. Crustaceans accounted for 14% of the animals collected, molluscs 6%, echinoderms 3%, and the remaining phyla 6%. Overall, the above distributions were very similar to those observed in 2010 (see City of San Diego 2011).

The 10 most abundant macroinvertebrates sampled during the year were all polychaetes (Table 5.3). The most abundant species was the spionid *Spiophanes norrisi*, which averaged 75 individuals per sample and occurred at 98% of the stations. Although widely distributed, *S. norrisi* abundances varied considerably among sites (range: 1–898). For example, four stations (I3, I6, I16, and I34) supported higher abundances of this species than the other sites, with a combined abundance of 3958 individuals out of a total of 8068 reported for the entire SBOO region. Overall, *S. norrisi* accounted for about 21% of the macrobenthic fauna sampled during 2011 and has been the most abundant species collected since monitoring began (Figure 5.3). Few other species were as ubiquitous as *S. norrisi* (Table 5.3), with only two other taxa, the chaetopterid and orbiniid polychaetes *Spiochaetopterus costarum* and *Scoloplos armiger* (both species complexes), respectively, occurring in at least 80% of the samples.

Some of the most abundant species collected in 2011 have been dominant in past years as well. For example, the capitellid polychaete *Mediomastus* sp and cirratulid polychaete *Monticellina siblina* were among the five most abundant taxa collected both historically and in 2011 (Figure 5.3). In contrast, other species occur in relatively high abundances only occasionally, and are often limited in distribution. For example, in 2011, the saccocirrid polychaete *Saccocirrus* sp occurred in abundances exceeding 220 individual/grab at station I23, but never occurred in densities >7 individuals/grab at any other station.

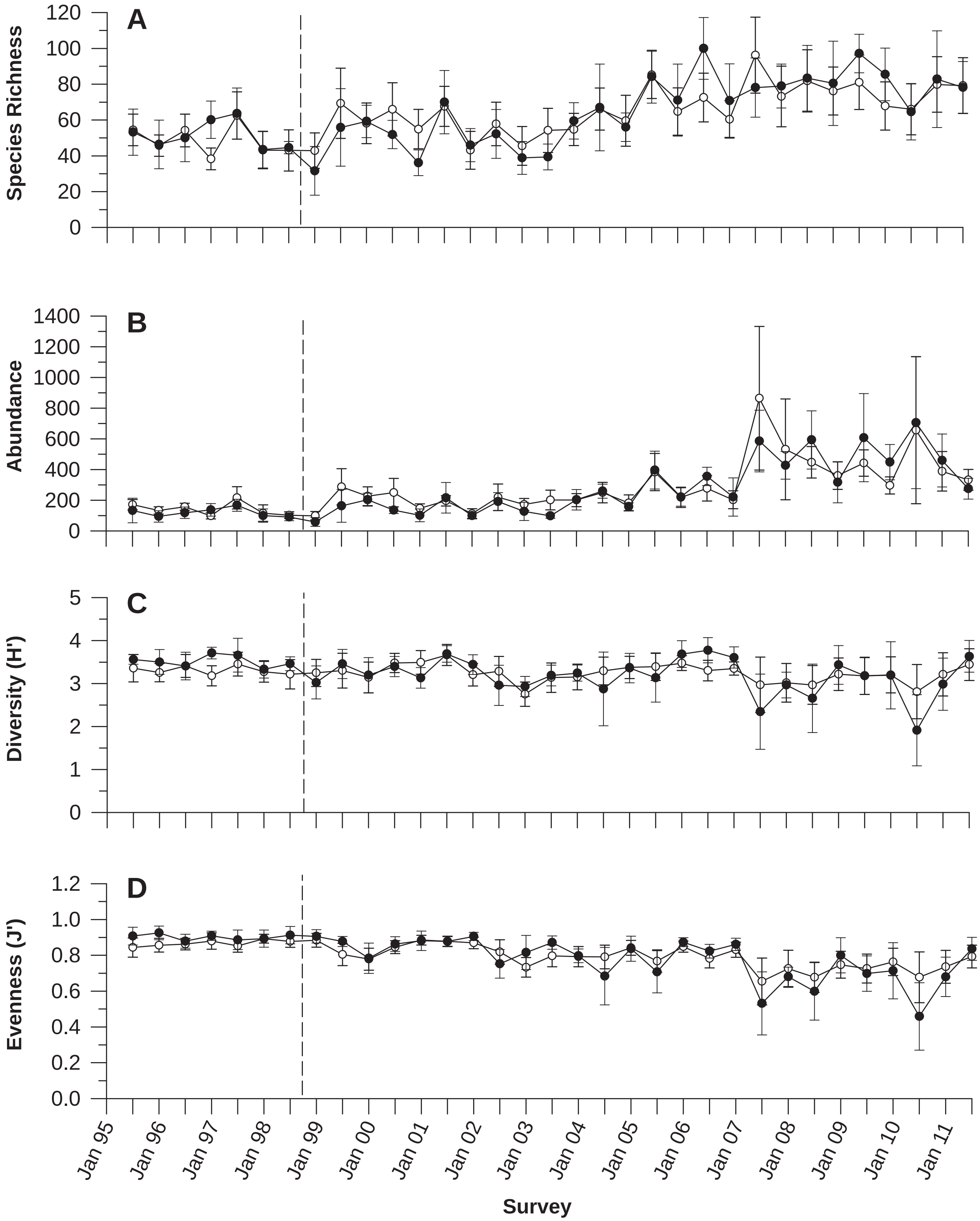



**Figure 5.2**

Macrofaunal community parameters at SBOO 28-m benthic stations sampled between 1995–2011. Data are expressed as means ± 95% confidence intervals per 0.1 $m^2$ pooled over nearfield station grabs (filled circles; *n* = 8) versus farfield station grabs (open circles; *n* = 16) for each survey. Dashed lines indicate onset of discharge from the SBOO.

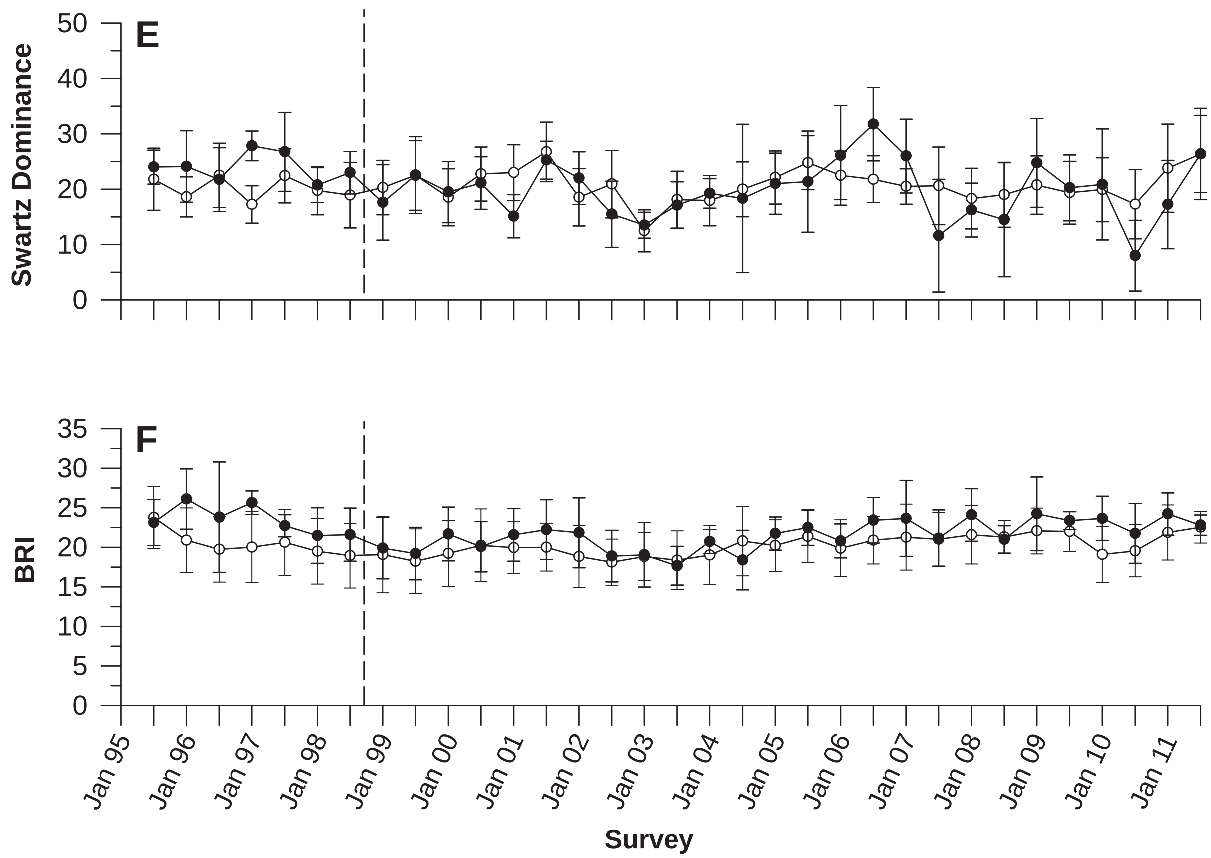



**Figure 5.2** *continued*

## Classification of Macrobenthic Assemblages

ANOSIM results revealed that benthic invertebrate communities in the South Bay outfall region differed significantly between inner shelf and mid-shelf depth strata and by sediment type (Appendix D.1). Differences between depth strata were due to minor variations in abundance of many common taxa rather than the presence or absence of discrete species. Similarly, relative abundances of common species such as *S. norrisi* were cumulatively responsible for the majority of differences among sediment types, the one exception to this generalization being coarse sediments with substantial sand fractions and high amounts of shell hash. These coarse sediments housed a unique fauna dissimilar from other sediment types, and were characterized by high population numbers of nematodes and the polychaetes *Hesionura coineaui difficilis*, *Pareurythoe californica*, *Pisione* sp, and *Saccocirrus* sp (see Cluster Group G description below). Pair-wise comparisons indicated the only two sediment types not to possess statistically distinct invertebrate communities were sand with a substantial fraction of fines, and sand with substantial fractions of both fine and coarse sediments.

### ***Discrimination of cluster groups***

Classification (cluster) analysis discriminated nine ecologically-relevant SIMPROF-supported groups (Figures 5.4. 5.5). These "assemblages," referred to herein as cluster groups A through I contained between 2−35 grabs each, and exhibited mean species richness values ranging from 48 to 158 taxa per grab and mean abundances of 101 to 579 individuals per grab (Table 5.4). Grabs within each cluster generally were collected from sites with similar depth or sediment characteristics or both (Appendix D.2).

<u>Inner shelf assemblages</u>

Macrofaunal communities were most similar between inner shelf cluster groups E and F, which shared 36 taxa not occurring in any of the other

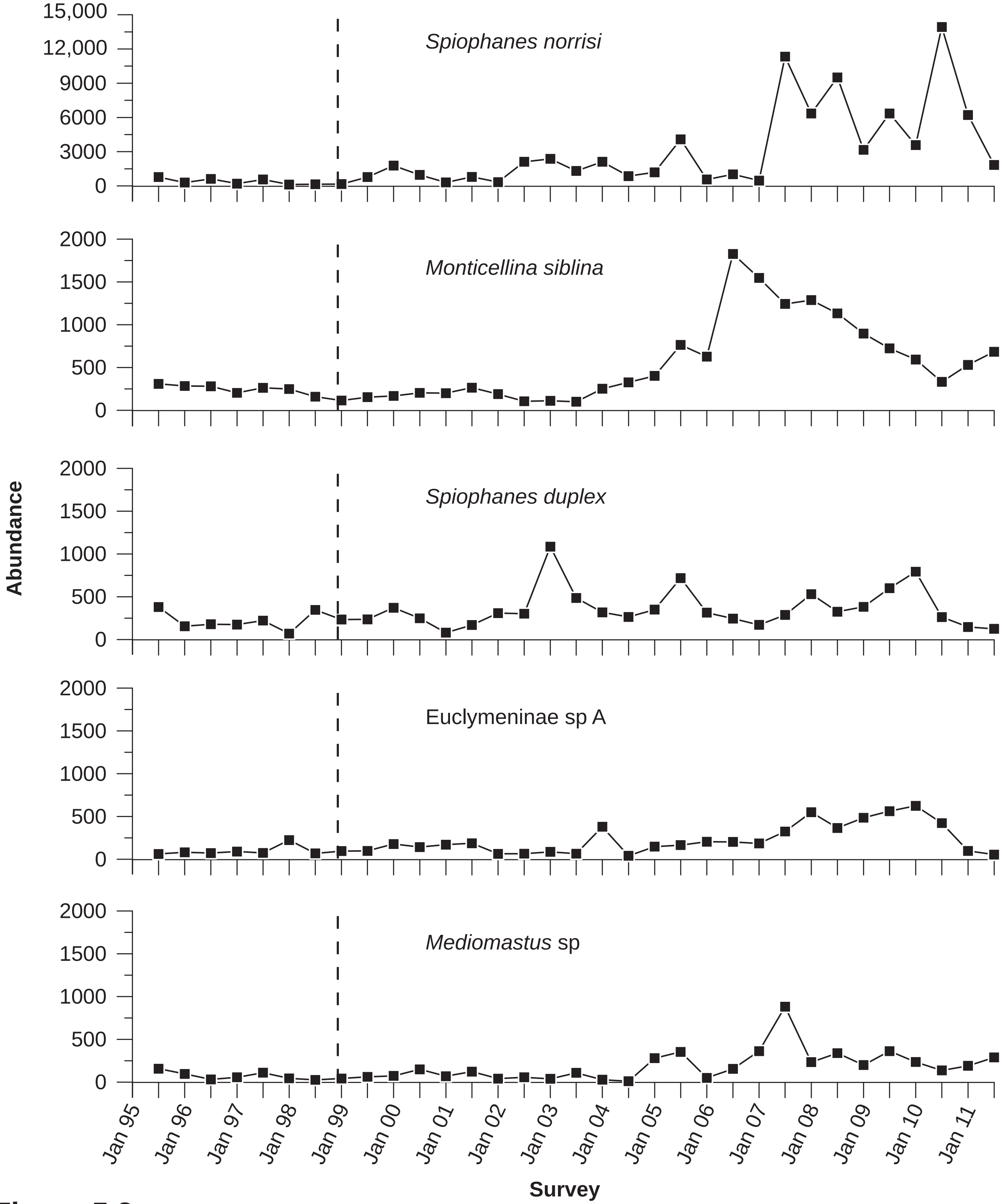



**Figure 5.3**
Total abundance per survey for each of the five most abundant species (taxa) at the SBOO benthic stations sampled between 1995–2011; note expanded scale for *Spiophanes norrisi.* Dashed lines indicate onset of wastewater discharge.

seven clusters (Figure 5.4, Appendix D.2). Together, these two cluster groups encompassed 46% of the 2011 grab samples and, except for four grabs collected along the 38-m isobath at stations I13 and I29, occurred along the 19-m and 28-m isobaths. All grabs from the 28-m sites located north of the outfall belonged to cluster group E, while grabs from 28-m sites surrounding or occurring south of the outfall belonged to either cluster group E or cluster group I (discussed below). The majority of

**Table 5.2**

Percent composition of species and abundance by major taxonomic group (phylum) for SBOO benthic stations sampled during 2011. Data are expressed as annual means (range) for all stations combined; $n = 27$.

| Phyla | Species (%) | Abundance (%) |
|---|---|---|
| Annelida (Polychaeta) | 45 (33–62) | 71 (35–93) |
| Arthropoda (Crustacea) | 24 (3–39) | 14 (1–55) |
| Mollusca | 17 (3–23) | 6 (1–23) |
| Echinodermata | 3 (1–18) | 3 (1–27) |
| Other Phyla | 11 (3–29) | 6 (1–15) |

grabs from the shallowest, 19-m isobath contained assemblages belonging to cluster group F. In addition to obvious depth differences between sites in these two cluster groups, group E typically contained sites possessing a higher percentage of fine sediments than cluster group F.

The remaining three inner shelf assemblages (cluster groups C, D and G) only possessed two to four grabs each. Sites in groups C and D occurred strictly in shallow sandy areas, and only during the July survey (Figure 5.4, Appendix D.2). Cluster group G possessed sites from varying depths and was characterized by coarse sediments with considerable shell hash.

Inner to mid-shelf transition zone assemblages

The assemblages comprising cluster groups H and I shared nine taxa not occurring in any other cluster group, and encompassed 37% of the grabs collected in 2011 (Figure 5.4, Appendix D.2). These two cluster groups were restricted to the southern half of the SBOO monitoring region, including areas immediately adjacent to the outfall (together with cluster group E, above). However, whereas cluster group I contained sites shallower than 36-m, cluster group H spanned 38-m to 55-m depths.

Mid-shelf shelf assemblages

Macrofaunal communities from mid-shelf groups A and B exhibited the second highest degree of similarity (30.4%) in the cluster analysis, and shared 12 taxa not occurring in any other cluster group. The nine grabs included in these two groups occurred at depths ≥55 m (Figure 5.4, Appendix D.2), with each cluster possessing different sediment habitats. For example, cluster group A included sites possessing a high fraction of coarse black sediments while several sites in cluster group B occurred in sandy areas with limited amounts of coarse sediment.

***Description of cluster groups***

Cluster group A consisted of all four grabs from station I28, located at a 55-m depth in the northern section of the South Bay outfall region (Figure 5.4). Grabs within this cluster exhibited the highest average species richness among all cluster groups, averaging 158 taxa/grab. Average abundance was 579 individuals/grab (Table 5.4). Sediments were composed of black sand with the highest percentage of fines found in any cluster group (21.3% to 23.3%; Appendix D.2). The five most abundant species were the polychaetes *Spiophanes norrisi*, *Monticellina siblina*, *Prionospio* (*Prionospio*) *dubia* and *Prionospio* (*Prionospio*) *jubata*, and the amphipod *Photis californica*; these species averaged between about 15–57 individuals/grab. No other species occurred at densities > 12 individuals/grab. SIMPER revealed that *S. norrisi*, *P.* (*P.*) *dubia*, *P.* (*P.*) *jubata*, and another polychaete, *Glycera nana*, plus the amphipod *P. californica* to be the five most characteristic species that defined the clade.

Cluster group B consisted of all four grabs from station I1 and one July grab from station I20, located at 55-m and 60-m depths, respectively (Figure 5.4). Average species richness and abundance were 99 taxa and 326 individuals/grab, respectively (Table 5.4). Sediments were sandy with percent fines ranging from 8.6% to 9.7% (Appendix D.2). The five most abundant species were the polychaetes *Pista estevanica*, *Chloeia pinnata*, *Spiophanes norrisi*, and *Aricidea* (*Acmira*) *simplex*, and the amphipod *Photis*

**Table 5.3**
The 10 most abundant macroinvertebrates collected at the SBOO benthic stations during 2011. Abundance values are expressed as mean number of individuals per 0.1-$m^2$ grab sample. Percent occurrence = percent of total samples where the species was collected.

| Species | Taxonomic Classification | Abundance per Sample | Percent Occurrence |
|---|---|---|---|
| *Spiophanes norrisi* | Polychaeta: Spionidae | 74.7 | 98 |
| *Monticellina siblina* | Polychaeta: Cirratulidae | 11.3 | 59 |
| *Spio maculata* | Polychaeta: Spionidae | 9.8 | 35 |
| *Notomastus latericeus* | Polychaeta: Capitellidae | 7.3 | 65 |
| *Prionospio* (*Prionospio*) *jubata* | Polychaeta: Spionidae | 6.5 | 72 |
| *Spiochaetopterus costarum* Cmplx | Polychaeta: Chaetopteridae | 5.4 | 81 |
| *Mooreonuphis nebulosa* | Polychaeta: Onuphidae | 5.0 | 36 |
| *Mediomastus* sp | Polychaeta: Capitellidae | 4.4 | 61 |
| *Hesionura coineaui difficilis* | Polychaeta: Phyllodocidae | 4.0 | 7 |
| *Pista estevanica* | Polychaeta: Terebellidae | 4.0 | 39 |

*californica*; these species averaged between about 8–25 individuals/grab. No other species exhibited >5 individuals/grab. SIMPER revealed four of the above species (*P. estevanica*, *S. norrisi*, *A* (*A.*) *simplex*, and *P. californica*) plus another polychaete, *Scoloplos armiger* Cmplx, to be the five most characteristic species that defined the clade.

Cluster group C consisted of four July grabs from three adjacent sites (stations I18, I23, and I31) located along the 19-m isobath (Figure 5.4). Average values for species richness and abundance were lower in this cluster group than any other, consisting of only 48 taxa and 101 individuals/grab, respectively (Table 5.4). Sediments were sandy with the amount of percent fines ranging from 8.8% to 9.3% (Appendix D.2). Unlike other cluster groups where the most abundant species were primarily polychaete worms, this group was dominated by gammarid amphipods, including *Photis* sp OC1, *Gibberosus myersi*, *Gammaropsis thompsoni*, and *Aoroides inermis*, although the polychaete *Mediomastus* sp was also fairly abundant; these species averaged between 3–9 individuals/grab. No other species had average abundances >2/grab. The five most characteristic invertebrates found in these assemblages included *Photis* sp OC1 and *Mediomastus* sp as mentioned above, as well as the cumacean *Diastylopsis tenuis*, and the polychaetes Euclymeninae sp B and *Glycinde armigera*.

Cluster group D was the smallest of all cluster groups, consisting of only the two July grabs from station I4, the southernmost site along the 19-m isobath (Figure 5.4). Species richness and abundance were the second lowest of all cluster groups, averaging 56 taxa and 127 individuals/grab, respectively. Sediments were sandy with percent fines equaling 5.4% (Appendix D.2). The polychaetes *Spiophanes norrisi*, *Magelona sacculata*, *Ophelia pulchella* and *Mediomastus acutus*, and the amphipod *Ampelisca brachycladus* were the most abundant species encountered; these species averaged between about 5–11 individuals/grab. No other species averaged >4.0 individuals per grab. In addition to *S. norrisi*, *M. sacculata* and *M. acutus*, the polychaete *Lumbrinerides platypygos* and the cumacean *Hemilamprops californicus* constituted the five most characteristic species defining the group.

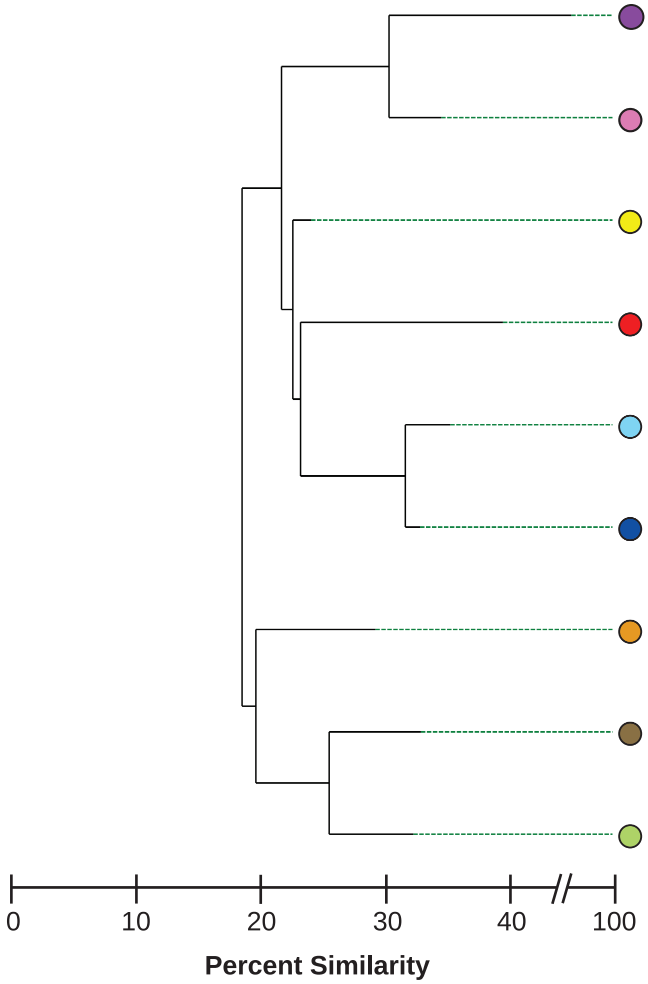
Cluster group E was the largest cluster group, containing 35 grabs from 11 nearfield (stations I12, I14, I15, I16) and farfield (stations I9, I13, I22, I27, I29, I30, I33) sites at depths from 28 m to 38 m (Figure 5.5). This group represents typical inner shelf assemblages for the SCB, and corresponds to cluster group D of the regional survey (see Chapter 9). Average species richness and abundance were 98 taxa and 377 individuals/grab, respectively. Most sites were characterized as sand mixed with fines with the percent fines ranging from 0% to 29% (Appendix D.2). The five most abundant species in this group were the polychaetes *Spiophanes norrisi*, *Monticellina siblina*, *Mooreonuphis nebulosa*, *Notomastus latericeus*, and *Prionospio* (*Prionospio*) *jubata*, which occurred at average densities between about 13–44 individuals/grab. No other species exhibited >8 individuals/grab. SIMPER revealed the same five species listed above to also be the five most characteristic species for the group.

Cluster group F contained 15 grabs from five sites (stations I10, I18, I23, I31, I35) that occurred along the 19-m isobath (Figure 5.4). Consistent with all other cluster groups co-occurring in this area, species richness and abundance were relatively low, averaging 70 taxa and 203 individuals/grab, respectively (Table 5.4). Sediments were sandy with percent fines ranging from 7.9% to 33.8% (Appendix D.2). The most abundant species in these samples were the polychaetes *Spiophanes norrisi*, *Mediomastus* sp, *Nereis* sp A and *Glycinde armigera*, and the nemertean *Carinoma mutabilis*; these species averaged between about 5–22 individuals/grab. No other taxon averaged >4 individuals/grab. SIMPER revealed four of the above species (*S. norrisi*, *Mediomastus* sp, *Nereis* sp A, *G. armigera*) to be among the five most characteristic species for the clade, with the fifth most characteristic species being another polychaete, *Monticellina siblina*.

Cluster group G comprised three grabs that possessed coarse sediments with substantial quantities of shell hash from stations I23, I29 and I34 (Figure 5.5). The macrofaunal communities that occur in these high energy environments are often referred to as "*Branchiostoma* communities" because of the relatively high abundance of these animals (see also cluster group A in Chapter 9). Grabs within this cluster averaged the highest abundance among all cluster groups at 823 individuals/grab. Average species richness was 77 taxa/grab (Table 5.4). Percent fines ranged from 0.5% to 25.6% (Appendix D.2). The polychaetes *Hesionura coineaui difficilis*, *Pisione* sp, *Saccocirrus* sp and *Spiophanes norrisi*, and unidentified nematodes were the most abundant taxa encountered; these taxa averaged between about 62–141 individuals/grab. No other taxon averaged >21 organisms/grab. The five most characteristic taxa for this clade included *H. coineaui difficilis, Pisione* sp, nematodes and *S. norrisi* listed above, plus the polychaete *Spio maculata*.

Cluster group H consisted of 14 grabs, including four grabs each from stations I7 and I21, and three grabs each from stations I13 and I20. Depths ranged from 38 to 55 m (Figure 5.4). Average species richness and abundance were 69 taxa and 318 individuals/grab, respectively (Table 5.4). Sediments were primarily sandy with a substantial coarse fraction, and percent fines ranged from 0% to 10.8% (Appendix D.2). The five most abundant species were the polychaetes *Spiophanes norrisi*, *Spio maculata*, *Lanassa venusta venusta*, and *Mooreonuphis* sp SD1, and the ophiuroid *Ophiuroconis bispinosa*; these species averaged between about 12–43 individuals/grab. No other species averaged >6 individuals/grab. SIMPER revealed three of the above species, *S. maculata*, *S. norrisi* and *L. venusta venusta*, plus the isopod *Eurydice caudata* and the amphipod *Ampelisca cristata cristata* to be the five most characteristic species that defined the clade.

Cluster group I was the second largest cluster, consisting of 26 grabs from nine sites (stations I2, I3, I4, I6, I8, I12, I14, I15, and I34) at depths ranging from 18 to 36 m (Figure 5.4). Average species richness and abundance were 55 taxa and 383 individuals/grab, respectively (Table 5.4). Sediment composition varied widely, but was predominantly characterized as sandy, with a percent fines component <5% (Appendix D.2). Abundance of the polychaete *Spiophanes norrisi* (196/grab) was over twice as high as any other cluster group. The other most abundant species at average densities between about 7–18 individuals/grab included the polychaetes *Spio maculata*, *Notomastus latericeus*, *Glycera oxycephala*, and *Lumbrinerides platypygos*. No other species averaged >4 individuals/grab.



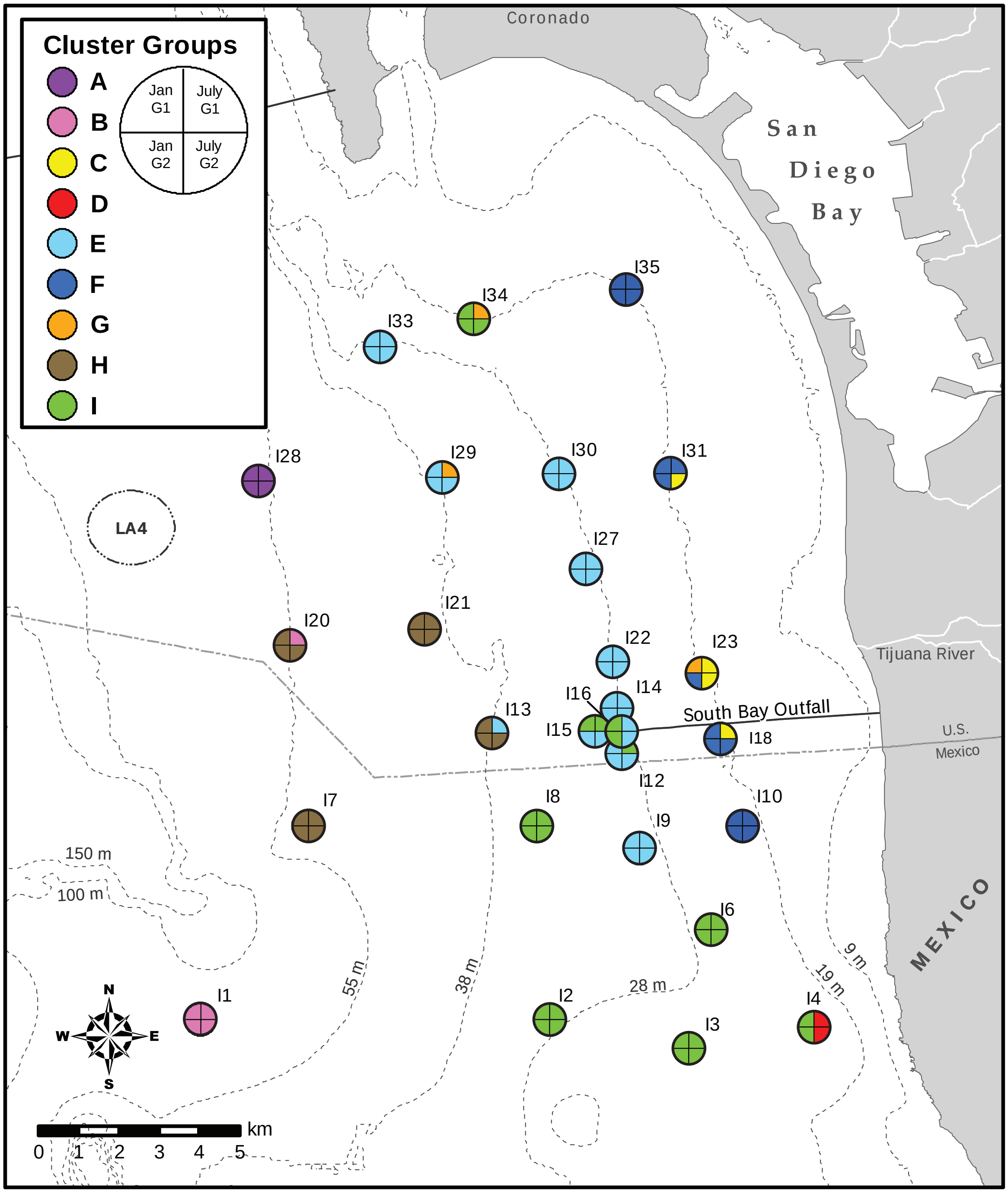

| Cluster Group | *n* | SR | Abun | Description |
|---|---|---|---|---|
| A | 4 | 158 | 579 | Mid-shelf |
| B | 5 | 99 | 326 | Mid-shelf |
| C | 4 | 48 | 101 | Inner shelf |
| D | 2 | 56 | 127 | Inner shelf |
| E | 35 | 98 | 377 | Inner shelf |
| F | 15 | 70 | 203 | Inner shelf |
| G | 3 | 77 | 823 | Inner shelf |
| H | 14 | 69 | 318 | Inner to mid-shelf transition zone |
| I | 26 | 55 | 383 | Inner to mid-shelf transition zone |

**Figure 5.4**
Cluster analysis of macrofaunal assemblages at SBOO stations sampled during 2011. Data for species richness (SR) and infaunal abundance (Abun) are expressed as mean values per 0.1-$m^2$ over all stations in each group (*n*).

SIMPER revealed three of the above species (*S. norrisi*, *G. oxycephala*, and *N. latericeus*) plus two other polychaetes, *Scoloplos armiger* Cmplx and *Phyllodoce hartmanae*, to be the five most characteristic taxa that defined the clade.

## Discussion

There was no evidence that wastewater discharged through the SBOO in 2011 affected macrobenthic communities in the region. For example, multivariate cluster analysis found all nearfield stations to possess invertebrate communities similar to farfield stations occurring along the 28-m isobath (the depth at which the outfall terminates). Additionally, species richness along the 28-m isobath in 2011 was similar to historical values, and any observed temporal fluctuations in macrofaunal abundances have co-occurred at both nearfield and farfield sites. Similarly, diversity and evenness values have remained relatively stable at both nearfield and farfield sites since monitoring began in 1995; however, farfield stations with high abundances of the spionid polychaete *Spiophanes norrisi* in 2011 exhibited relatively lower species diversity, evenness, and Swartz dominance values compared to other stations.




# Figure 5.5

Spatial distribution of cluster groups in the SBOO region. Colors of each circle correspond to colors in Figure 5.4.

Benthic macrofaunal assemblages observed across the entire South Bay outfall region in 2011 were similar to those observed during previous years (City of San Diego 2000, 2011). These assemblages were also typical of those that occur in other sandy, shallow to mid-depth habitats throughout the SCB (Thompson et al. 1987, 1993b, City of San Diego 1999, Bergen et al. 2001, Ranasinghe et al. 2003, 2007, 2012, Mikel et al. 2007), and which often contain high population numbers of *Spiophanes norrisi* (Bergen et al. 2001). Benthic response index (BRI) values reported at most sites during the year were characteristic of undisturbed habitats, while the

## Table 5.4

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

| | Cluster Group | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Taxa** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
| *Spiophanes norrisi* | **57.0** | **14.2** | 1.3 | **11.0** | **43.7** | **21.9** | **61.7** | **42.6** | **196.3** |
| *Photis californica* | **21.3** | **8.6** | | | 0.3 | | 0.3 | 4.2 | |
| *Monticellina siblina* | 19.0 | 0.4 | 1.3 | 2.0 | **30.0** | **4.3** | | 0.1 | 0.5 |
| *Prionospio* (*Prionospio*) *dubia* | **16.8** | 1.0 | | | 0.1 | | | | |
| *Prionospio* (*Prionospio*) *jubata* | **15.5** | 5.0 | 2.0 | 1.5 | **13.0** | 2.3 | 2.3 | 2.0 | 3.1 |
| *Pista estevanica* | | **25.2** | | | 7.5 | | | 1.4 | 0.9 |
| *Chloeia pinnata* | 9.8 | 20.0 | | 0.5 | | | | 5.7 | 0.0 |
| *Aricidea* (*Acmira*) *simplex* | 12.3 | **8.4** | | | 0.1 | 0.1 | | 0.1 | 0.1 |
| *Photis* sp OC1 | | 0.4 | **9.3** | 1.0 | 2.6 | 2.9 | | 0.1 | 0.8 |
| *Mediomastus* sp | 6.0 | 0.8 | **7.5** | | 6.7 | **10.3** | 5.3 | 0.1 | 0.6 |
| *Gibberosus myersi* | | 0.6 | 4.5 | 3.5 | 0.3 | 0.7 | 0.3 | 0.1 | 0.8 |
| *Gammaropsis thompsoni* | 1.3 | 0.2 | 3.3 | | 0.5 | 0.6 | | | 0.1 |
| *Aoroides inermis* | | | 2.5 | | 0.0 | 0.1 | | 0.2 | 0.5 |
| *Magelona sacculata* | | | 0.5 | **8.0** | 2.9 | 3.9 | | | 4.0 |
| *Ophelia pulchella* | | | | 8.0 | | | 0.3 | 0.4 | 2.4 |
| *Mediomastus acutus* | | | | **4.5** | | 0.1 | | | |
| *Ampelisca brachycladus* | | | | 4.5 | 0.4 | 0.8 | | | 0.1 |
| *Mooreonuphis nebulosa* | 2.5 | | | | **15.1** | | | | 0.2 |
| *Notomastus latericeus* | 0.3 | 1.4 | | 0.5 | **13.6** | 0.9 | | 0.2 | **10.8** |
| *Nereis* sp A | 0.3 | | 1.8 | 3.0 | 4.6 | **8.8** | | | 1.2 |
| *Glycinde armigera* | 0.3 | | **2.0** | 2.0 | 5.7 | **7.6** | | 0.3 | 0.7 |
| *Carinoma mutabilis* | | 0.6 | 1.8 | | 1.9 | 5.2 | 0.7 | 0.4 | 2.6 |
| *Hesionura coineaui difficilis* | | | | | | | **141.0** | 0.7 | |
| *Pisione* sp | | | | | 0.0 | 0.1 | **95.3** | 1.6 | |
| *Saccocirrus* sp | | | | | | | 76.0 | | |
| Nematoda | 2.0 | | 0.8 | | 1.3 | 0.7 | **68.3** | 3.2 | 1.0 |
| *Spio maculata* | 0.3 | | | | | 0.1 | **17.0** | **38.8** | 17.6 |
| *Lanassa venusta venusta* | 0.5 | 0.2 | | | 0.1 | 0.1 | 1.3 | **24.9** | 0.0 |
| *Ophiuroconis bispinosa* | 11.5 | 0.4 | | | 1.0 | | 0.7 | 14.9 | 2.7 |
| *Mooreonuphis* sp SD1 | | 0.2 | | | 0.0 | | | 11.9 | 0.5 |
| *Glycera oxycephala* | | 2.4 | | 1.0 | 2.1 | 0.1 | | 1.6 | **8.4** |
| *Lumbrinerides platypygos* | | 0.2 | 0.3 | **4.0** | 0.2 | | 21.0 | 2.7 | 6.9 |

results for only a few stations were suggestive of possible minor deviation from reference conditions. Since monitoring first began around the SBOO in 1995, mean BRI values at the 19-m and 28-m depth contour stations have typically been higher than along the deeper 38-m and 55-m contours. This pattern may occur because the BRI was developed to assess a depth gradient spanning 30–120 meters and is less efficient in shallower and deeper areas. Higher BRI values occurring at 19-m and 28-m depth contours in the SBOO region were observed prior to wastewater discharge and have remained consistent over time. A similar phenomenon is reported across the SCB where Smith et al. (2001) found a pattern of lower index values at mid-depth stations (25–130 m) versus shallower (10–35 m) or deeper (110–324 m) stations.

Although spionid polychaetes have been observed to form extensive communities in other areas of the world that naturally possess high organic matter (Díaz-Jaramillo et al. 2008), they are known to be a stable dominant component of many healthy environments in the SCB (Rodríguez-Villanueva et al. 2003). Thus, ubiquitous, high populations of *S. norrisi* observed at most SBOO stations from 2007–2011 suggest that their distribution is not indicative of habitat degradation related to wastewater discharge, and that population fluctuations of this species over the past few years likely correspond to natural changes in large-scale oceanographic conditions. Likewise, although fluctuations in populations of capitellid polychaetes have been shown to be possible indicators of polluted sediments near wastewater treatment plants in certain areas of the world (Swartz et al. 1986, Rodríguez-Villanueva et al. 2003), the abundance of *Mediomastus* sp in the SBOO region in 2011 was within the natural range of variation expected, with the highest abundances occurring along the 19-m isobath inshore of the outfall. Specifically, 21% of all *Mediomastus* enumerated (mean = 25.3/grab) occurred at station I35, which also possessed total sulfide and nitrogen values that were among the highest measured during the past year (see Chapter 4). The highest BRI value was also recorded at this site. It is unclear what is causing these effects at I35, but its location may be acting as a sediment sink for deposits from the Tijuana River and San Diego Bay.

In conclusion, anthropogenic impacts in marine environments are known to have spatial and temporal dimensions that can vary depending on a range of biological and physical factors. Such impacts can be difficult to detect, and specific effects of wastewater discharge via the SBOO on the local macrobenthic community could not be identified during 2011. Furthermore, populations and communities of benthic invertebrates exhibit substantial natural spatial and temporal variability that may mask the effects of any disturbance event (Morrisey et al. 1992a, b, Otway 1995). Although some changes have occurred near the SBOO over time, benthic assemblages in the region remain similar to those observed prior to outfall operations and to natural indigenous communities characteristic of similar habitats on the southern California continental shelf.

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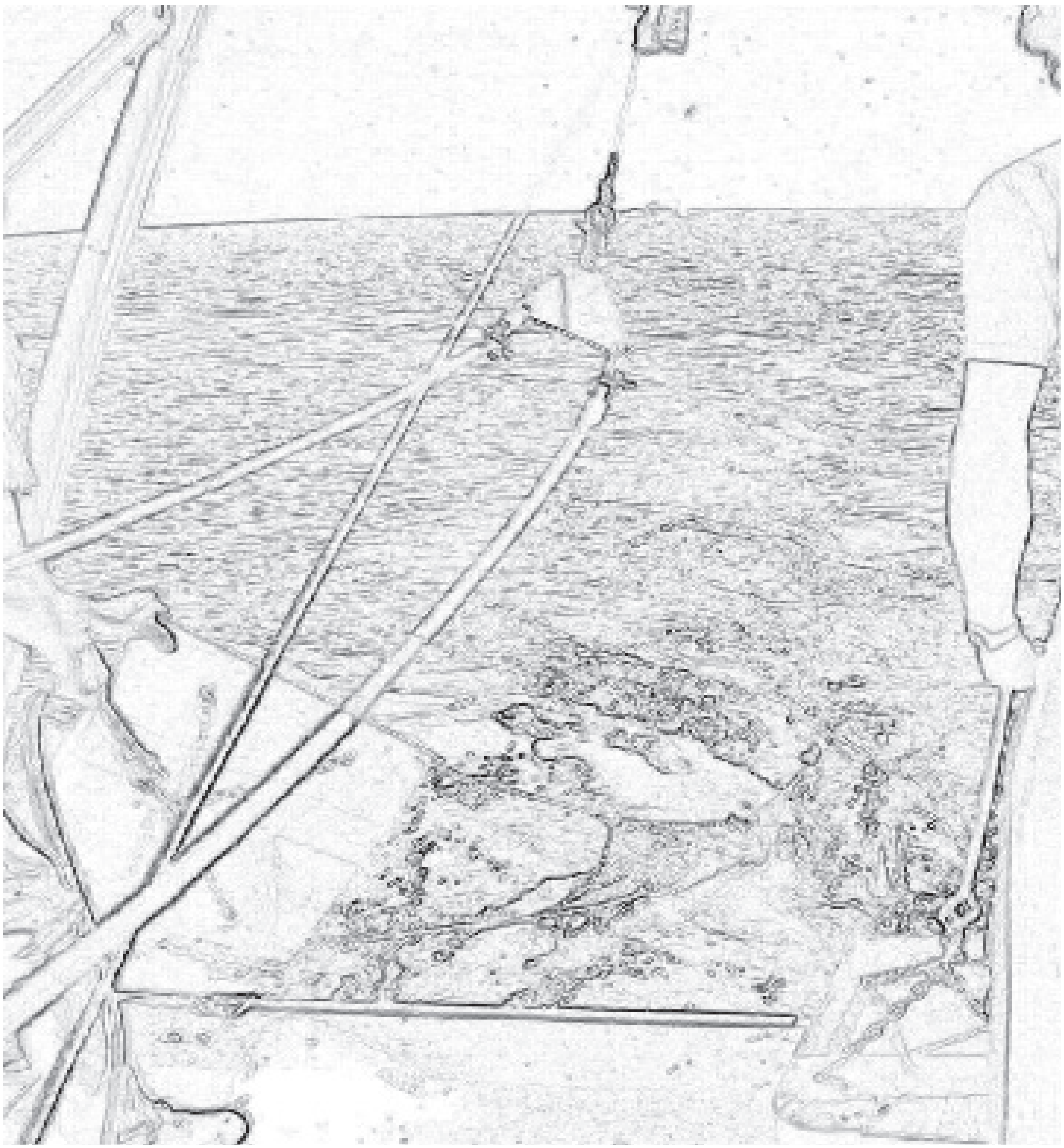
# Chapter 6
# Demersal Fishes and Megabenthic Invertebrates



# Chapter 6. Demersal Fishes and Megabenthic Invertebrates

## Introduction

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

In healthy ecosystems, fish and invertebrate communities are known to be inherently variable and influenced by many natural factors. These factors include prey availability (Cross et al. 1985), bottom relief and sediment structure (Helvey and Smith 1985), and changes in water temperatures associated with large scale oceanographic events such as El Niño/La Niña oscillations (Karinen et al. 1985, Stein and Cadien 2009). The mobile nature of many species allows them to migrate toward or away from different habitats, and natural ambient conditions throughout the SCB affect migration patterns of adult fishes and the recruitment of juveniles into different areas (Murawski 1993). Therefore, an understanding of background or reference conditions is necessary before determining whether observed differences in community structure may be related to anthropogenic activities. Pre-discharge or regional monitoring efforts by the City and other researchers since 1994 provide baseline information on spatial variability of demersal fish and megabenthic communities in the San Diego region critical for comparative analysis (e.g., City of San Diego 2000, Allen et al. 1998, 2002, 2007, 2011).

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

This chapter presents analyses and interpretations of trawl survey data collected during 2011, as well as a long-term assessment of these communities from 1995 through 2011. The primary goals are to: (1) document the demersal fish and megabenthic invertebrate communities present during the year,

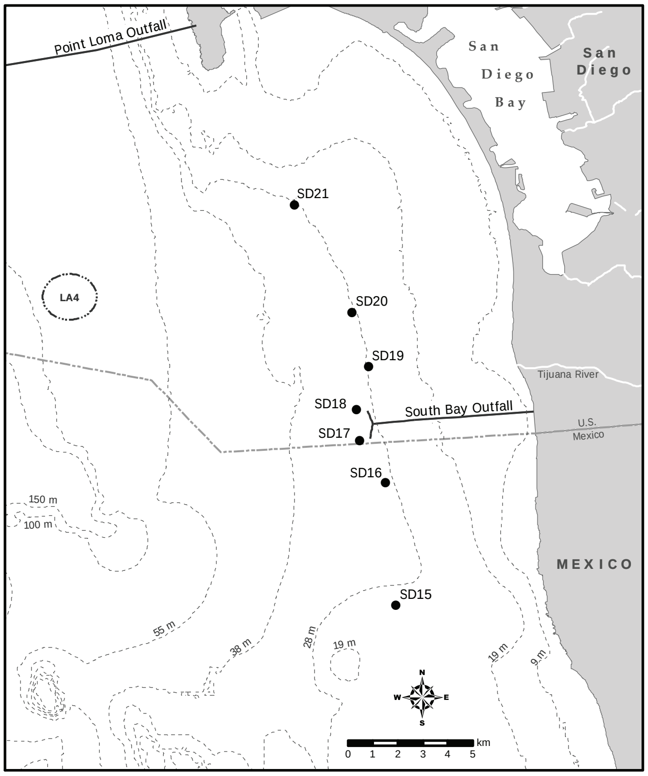



**Figure 6.1**
Otter trawl station locations sampled around the South Bay Ocean Outfall as part of City of San Diego's Ocean Monitoring Program.

(2) determine the presence or absence of biological impacts associated with wastewater discharge, and (3) identify other potential natural and anthropogenic sources of variability to the local marine ecosystem.

## Materials and Methods

### Field Sampling

Trawl surveys were conducted at seven fixed monitoring sites in the SBOO region during January, April, July, and October 2011 (Figure 6.1). These trawl stations, designated SD15, SD16, SD17, SD18, SD19, SD20 and SD21, are located along the 28-m depth contour, and encompass an area ranging from 7 km south to 8.5 km north of the SBOO. The two stations considered to represent "nearfield" conditions (i.e., SD17, SD18) are located within 1000 m of the outfall wye. A single trawl was performed at each station during each survey using a 7.6-m Marinovich otter trawl fitted with a 1.3-cm cod-end mesh net. The net was towed for 10 minutes of bottom time at a speed of about 2.0 knots along a predetermined heading.

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

### Data Analyses

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

Multivariate analyses of demersal fish communities sampled in the region were performed using data collected from 1995 through 2011. In order to reduce statistical noise due to seasonal variation in population abundances, analyses were limited to

## Table 6.1

Demersal fish species collected in 28 trawls conducted in the SBOO region during 2011. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

| Species | PA | FO | MAH | MAO | Species | PA | FO | MAH | MAO |
|---|---|---|---|---|---|---|---|---|---|
| Speckled sanddab | 66 | 100 | 119 | 119 | California scorpionfish | <1 | 21 | <1 | 2 |
| California lizardfish | 12 | 93 | 22 | 24 | California halibut | <1 | 25 | <1 | 1 |
| Longspine combfish | 3 | 64 | 6 | 9 | Fantail sole | <1 | 21 | <1 | 1 |
| Yellowchin sculpin | 3 | 64 | 6 | 9 | Kelp pipefish | <1 | 14 | <1 | 1 |
| Hornyhead turbot | 3 | 100 | 5 | 5 | Pacific sanddab | <1 | 4 | <1 | 5 |
| Roughback sculpin | 2 | 82 | 4 | 5 | California skate | <1 | 14 | <1 | 1 |
| California tonguefish | 2 | 75 | 4 | 5 | Round stingray | <1 | 4 | <1 | 3 |
| Longfin sanddab | 2 | 61 | 3 | 6 | Pacific pompano | <1 | 7 | <1 | 1 |
| English sole | 2 | 75 | 3 | 4 | Pacific staghorn sculpin | <1 | 7 | <1 | 1 |
| White croaker | 2 | 18 | 3 | 16 | Copper rockfish | <1 | 4 | <1 | 2 |
| Curlfin sole | <1 | 36 | 1 | 2 | Spotfin sculpin | <1 | 4 | <1 | 2 |
| Plainfin midshipman | <1 | 39 | 1 | 2 | Basketweave cusk-eel | <1 | 4 | <1 | 1 |
| Shiner perch | <1 | 18 | 1 | 4 | Bigmouth sole | <1 | 4 | <1 | 1 |
| Pygmy poacher | <1 | 29 | 1 | 2 | Bluebanded ronquil | <1 | 4 | <1 | 1 |
| Spotted turbot | <1 | 18 | <1 | 3 | Greenstriped rockfish | <1 | 4 | <1 | 1 |
| Spotted cusk-eel | <1 | 32 | <1 | 1 | Vermilion rockfish | <1 | 4 | <1 | 1 |

data from July surveys only. PRIMER software was used to examine spatio-temporal patterns among fish assemblages (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). Abundance data were square-root transformed to lessen the influence of common species and increase the importance of rare species, and a Bray-Curtis similarity matrix was created using station and year as factors. Because species composition was sparse at some stations, a “dummy” species with an abundance value of 1 was added to all samples prior to computing similarities (Clarke and Gorley 2006). A 2-way crossed ANOSIM (maximum number of permutations = 9999) was conducted to determine whether communities varied by station or year across the region. To visually depict the relationship of individual trawls to each other based on fish composition, a cluster dendrogram was created. Similarity profile (SIMPROF) analyses were used to confirm the non-random structure of the resultant cluster dendrograms (Clarke et al. 2008). Major ecologically-relevant SIMPROF-supported clades with < 55.99% similarity were retained. Similarity percentages (SIMPER) analysis was used to identify which species were responsible for the greatest contribution to within-group similarities (i.e., characteristic species).

# Results

## Demersal Fish Communities

Thirty-two species of fish were collected in the area surrounding the SBOO in 2011, with no new species recorded (Table 6.1, Appendix E.1). The total catch for the year was 5055 individuals (Appendix E.2), representing an average of 181 fish per trawl. As in previous years, speckled sanddabs were dominant. This species occurred in every haul and accounted for 66% of all fishes collected at an average of 119 individuals per trawl. No other species contributed to more than 12% of the total catch during the year. For example, hornyhead turbots also occurred in every trawl, but at much lower numbers (~5/haul). Other species collected frequently (≥50% of the trawls) but in relatively low numbers (≤22/haul) included California lizardfish, California tonguefish, English sole, longfin sanddab, longspine combfish, roughback sculpin, and yellowchin sculpin. Although the majority of fishes captured in the region tended to be relatively small with an average length ≤ 21 cm, small numbers of three relatively large species were also documented (Appendix E.1). These

**Table 6.2**

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

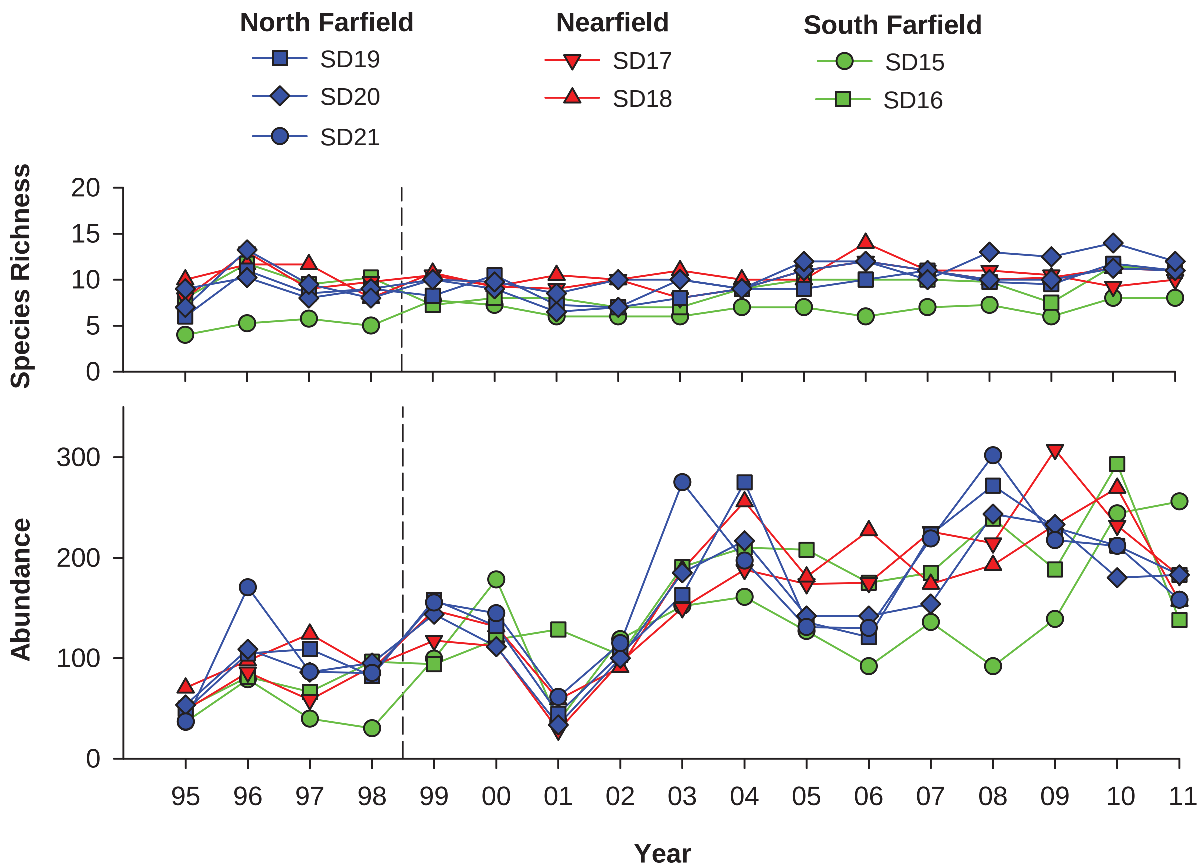
| Station | Jan | Apr | Jul | Oct | Annual Mean | Annual SD | Station | Jan | Apr | Jul | Oct | Annual Mean | Annual SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Species richness* | | | | | | | *Abundance* | | | | | | |
| SD15 | 8 | 7 | 9 | 9 | 8 | 1 | SD15 | 73 | 267 | 392 | 293 | 256 | 134 |
| SD16 | 9 | 11 | 9 | 13 | 11 | 2 | SD16 | 58 | 129 | 131 | 235 | 138 | 73 |
| SD17 | 9 | 13 | 8 | 11 | 10 | 2 | SD17 | 33 | 244 | 218 | 232 | 182 | 100 |
| SD18 | 10 | 14 | 9 | 10 | 11 | 2 | SD18 | 47 | 205 | 187 | 189 | 157 | 74 |
| SD19 | 13 | 9 | 9 | 11 | 11 | 2 | SD19 | 260 | 162 | 130 | 180 | 183 | 55 |
| SD20 | 13 | 9 | 9 | 11 | 10 | 2 | SD20 | 204 | 227 | 128 | 173 | 183 | 43 |
| SD21 | 10 | 10 | 15 | 15 | 13 | 3 | SD21 | 96 | 129 | 243 | 190 | 165 | 65 |
| Survey Mean | 10 | 10 | 10 | 11 | | | Survey Mean | 110 | 195 | 204 | 213 | | |
| Survey SD | 2 | 2 | 2 | 2 | | | Survey SD | 87 | 56 | 95 | 43 | | |

| Station | Jan | Apr | Jul | Oct | Annual Mean | Annual SD | Station | Jan | Apr | Jul | Oct | Annual Mean | Annual SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Diversity* | | | | | | | *Biomass* | | | | | | |
| SD15 | 0.7 | 0.3 | 0.5 | 0.4 | 0.5 | 0.2 | SD15 | 1.5 | 2.4 | 7.6 | 7.6 | 4.8 | 3.3 |
| SD16 | 1.5 | 1.5 | 1.0 | 1.2 | 1.3 | 0.2 | SD16 | 3.5 | 2.7 | 5.0 | 5.4 | 4.1 | 1.3 |
| SD17 | 1.6 | 1.1 | 0.8 | 1.2 | 1.2 | 0.3 | SD17 | 1.3 | 8.5 | 2.5 | 7.6 | 5.0 | 3.6 |
| SD18 | 1.8 | 1.0 | 0.8 | 1.0 | 1.1 | 0.5 | SD18 | 10.1 | 4.5 | 4.2 | 4.9 | 5.9 | 2.8 |
| SD19 | 1.2 | 1.2 | 1.2 | 1.4 | 1.3 | 0.1 | SD19 | 7.5 | 1.8 | 2.8 | 4.8 | 4.2 | 2.5 |
| SD20 | 1.5 | 1.2 | 1.1 | 1.1 | 1.2 | 0.2 | SD20 | 3.6 | 3.5 | 3.0 | 3.8 | 3.5 | 0.3 |
| SD21 | 1.6 | 1.2 | 1.9 | 1.7 | 1.6 | 0.3 | SD21 | 1.9 | 3.7 | 9.6 | 5.6 | 5.2 | 3.3 |
| Survey Mean | 1.4 | 1.1 | 1.0 | 1.1 | | | Survey Mean | 4.2 | 3.9 | 5.0 | 5.7 | | |
| Survey SD | 0.4 | 0.4 | 0.4 | 0.4 | | | Survey SD | 3.4 | 2.2 | 2.7 | 1.4 | | |

large fishes included eight California halibut that measured 30–67 cm in length, four California skate that were 36–53 cm long, and three round stingray that were 32–38 cm long.

No more than 15 species of fish occurred in any one haul during 2011, and the corresponding diversity (H') values were all ≤1.9 (Table 6.2). Total abundance for all species combined ranged from 33 to 392 fishes per haul. This high variation in abundance was mostly due to differences in the numbers of speckled sanddab and California lizardfish captured at each station (Appendix E.2). Total fish biomass ranged from 1.3 to 10.1 kg per haul, with higher values coincident with either greater numbers of fishes or the presence of large individuals (Appendix E.3). For example, two California halibut accounted for about 8 kg of the total biomass at station SD18 in January, whereas 175 speckled and 6 longfin sanddabs accounted for about 5 kg of the biomass at station SD17 in April. No spatial patterns related to the outfall were observed for species richness, diversity, abundance, or biomass.

Although average species richness values for SBOO trawl-caught demersal fish assemblages have remained within a narrow range over the years (i.e., 4–14 species/station/year), the average abundance per haul has varied considerably (i.e., 28–308 fish/station/year), mostly in response to population changes of a few dominant species (Figures 6.2, 6.3). Whereas oscillations of common species such as speckled sanddab, California lizardfish, roughback sculpin, hornyhead turbot, and yellowchin sculpin tend to occur across large portions of the study area (i.e., over multiple stations), intra-station variability is most often associated with large hauls of schooling species that occur less frequently. Examples of this include: (1) large hauls of white croaker that occurred primarily at station SD21 in 1996; (2) a large haul




## Figure 6.2

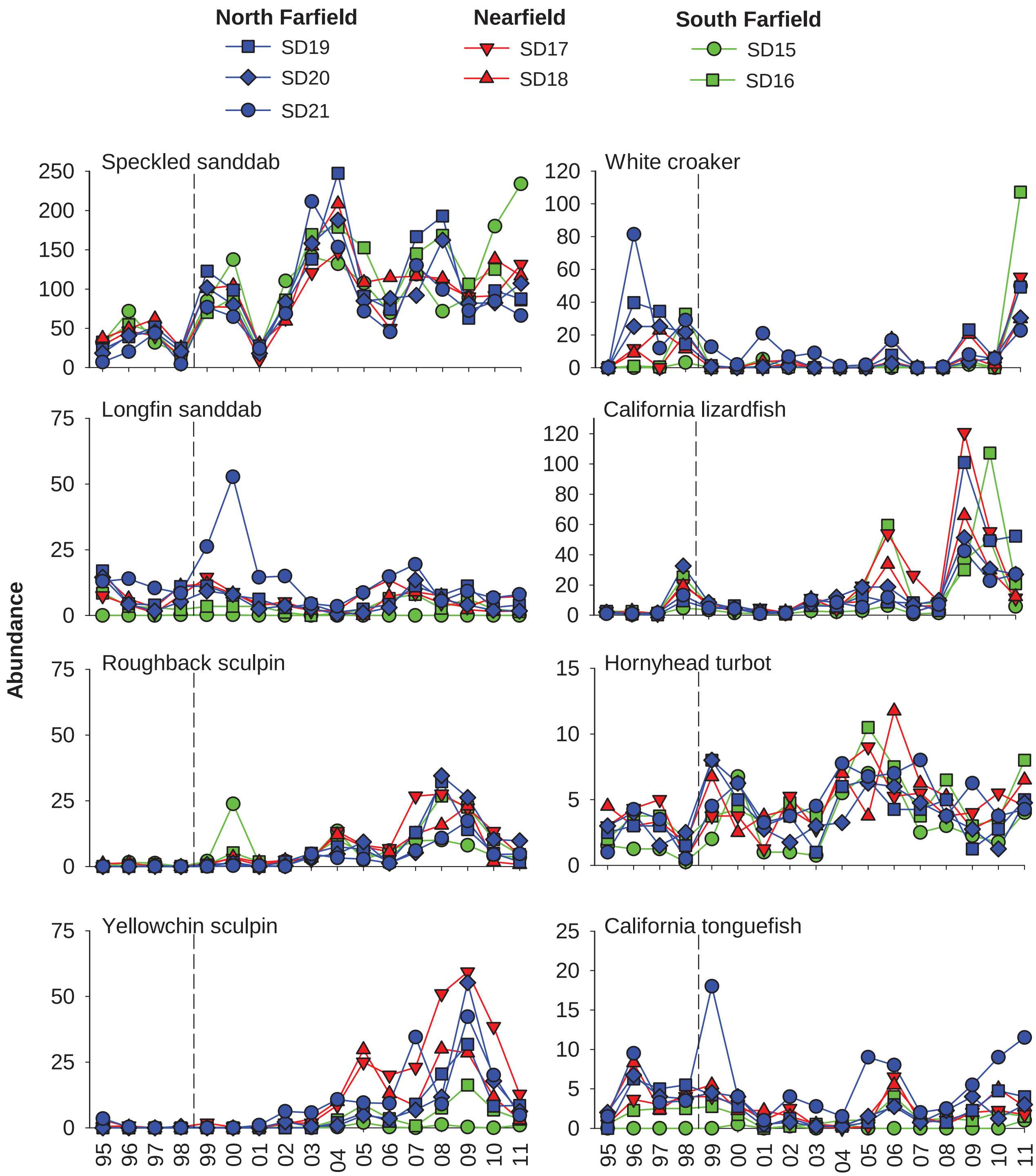
Species richness and abundance of demersal fish collected at each SBOO trawl station between 1995–2011. Data for each station are expressed as annual means ($n$=4) except: $n$=2 in 1995 (all stations); $n$=3 for SD17 and SD18 in 1996; $n$=2 for SD7 in 1997; $n$=3 for SD18 in 1997. Dashed lines indicate onset of wastewater discharge.

of northern anchovy that occurred in a single haul from station SD16 in 2001; (3) a large haul of Pacific pompano that was captured in a single haul at station SD21 in 2008. Overall, none of the observed changes appear to be associated with wastewater discharge.

### Classification of Fish Assemblages

Multivariate analyses performed on data collected between 1995 and 2011 (July surveys only) discriminated between five main types of fish assemblages in the South Bay outfall region (Figure 6.4). ANOSIM results revealed that fish communities in the region differed significantly by site and by year (Appendix E.4). However, the distribution of assemblages in 2011 was generally similar to that seen in previous years, especially between 2003–2010, and there were no discernible patterns associated with proximity to the outfall. Instead, most differences appear more closely related to large-scale oceanographic events (e.g., El Niño in 1998) or the unique characteristics of a specific station location. For example, station SD15 located far south of the outfall off northern Baja California often grouped apart from the remaining stations. These assemblages (cluster groups A–E) were distinguished by differences in the relative abundances of the common species present, although most were dominated by speckled sanddabs. The composition and main characteristics of each cluster group are described below.

Cluster group A comprised four outliers; three trawls from SD15 in 1997, 1998, and 2001, and one from SD17 in 2001 (Figure 6.4). This group had the lowest species richness (~5 species/haul) and the lowest abundance (~22 fishes/haul) of any cluster group (Table 6.3). These low values reflect




## Figure 6.3

The eight most abundant fish species collected in the SBOO region between 1995–2011. Data for each station are expressed as annual means (*n* = 4) except: *n* = 2 in 1995 (all stations); *n* = 3 for SD17 and SD18 in 1996; *n* = 2 for SD7 in 1997; *n* = 3 for SD18 in 1997. Dashed lines indicate onset of wastewater discharge.

the absence of common species such as English sole, California tonguefish, and yellowchin sculpin, as well as relatively low numbers of hornyhead turbot and longfin sanddab, and the second lowest abundance of speckled sanddab (Table 6.3). SIMPER revealed speckled sanddab, spotted turbot, and hornyhead turbot to be the three most characteristic species for this group.

Cluster group B consisted of a single outlier from station SD21 in 2011 (Figure 6.4). This haul contained the most species (~14 species/haul), and

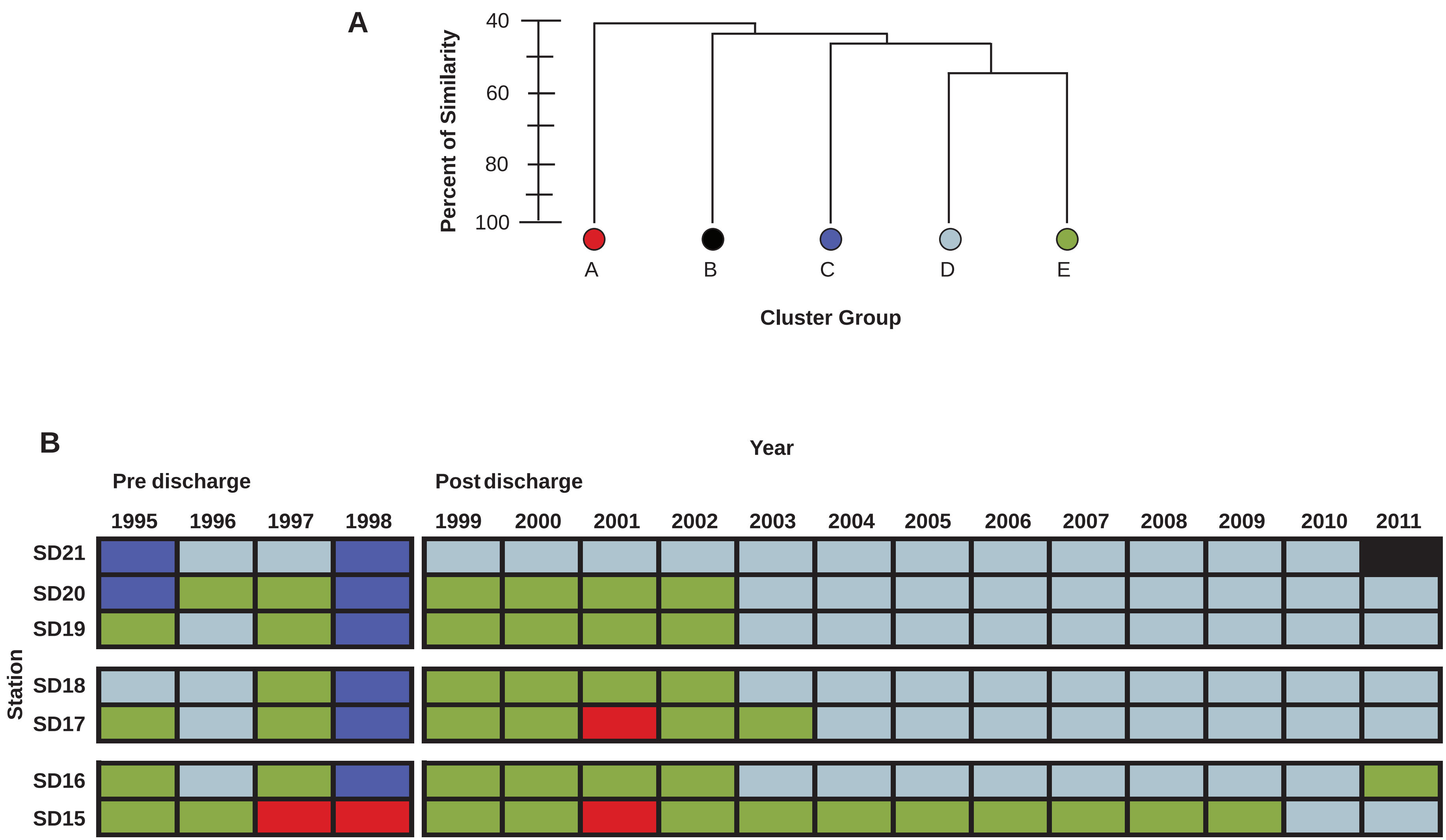



**Figure 6.4**
Results of cluster analysis of demersal fish assemblages collected at SBOO trawl stations between 1995–2011 (July surveys only). Data are presented as (A) a dendrogram of major cluster groups and (B) a matrix showing distribution of cluster groups over time.

## Table 6.3

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

| | Cluster Groups | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| **Number of Hauls** | 4 | 1 | 8 | 64 | 42 |
| **Mean Species Richness** | 5 | 14 | 9 | 10 | 7 |
| **Mean Abundance** | 22 | 218 | 64 | 235 | 97 |
| **Species** | Mean Abundance | | | | |
| Speckled sanddab | **14** | 26 | **12** | **138** | **81** |
| California lizardfish | 4 | 75 | **24** | **31** | **4** |
| Spotted turbot | **1** | | <1 | <1 | **2** |
| Hornyhead turbot | **1** | 3 | **3** | **5** | **4** |
| California scorpionfish | <1 | 2 | <1 | 1 | 1 |
| Fantail sole | <1 | | 1 | <1 | <1 |
| Longfin sanddab | <1 | 8 | **12** | **13** | 2 |
| Longspine combfish | | 79 | **<1** | **<1** | |
| White croaker | | 22 | | 1 | |
| California tonguefish | | 6 | **2** | **3** | <1 |
| English sole | | 6 | **5** | **3** | <1 |
| Roughback sculpin | | 5 | | **8** | <1 |
| Yellowchin sculpin | | 5 | 1 | **26** | <1 |

the second highest abundance (~218 fishes/haul) compared to the other groups (Table 6.3). It was also unique in that it had 79 longspine combfish, more than an order of magnitude greater than in any other cluster group. California lizardfish and white croaker were also present in relatively high numbers (75 and 22, respectively). Conversely, numbers of most other species were low, including speckled sanddabs.

Cluster group C comprised eight outliers from two years associated with warmer water conditions, including two hauls from stations SD20 and SD21 in 1995 and seven hauls in 1998 from all stations except SD15 (Figure 6.4). This group was characterized by relatively few species per haul (~9 species/haul), the second lowest overall abundance (~64 fishes/haul) and the fewest speckled sanddabs (~12 individuals/haul) (Table 6.3). SIMPER revealed that speckled and longfin sanddabs, California lizardfish, hornyhead turbot, longspine combfish, California tonguefish and English sole were the characteristic species for this group.

Cluster groups D and E may represent "normal" or "background" conditions in the SBOO region during two different periods. Together, these groups comprise 89% of all trawls taken over the past 17 years. Group D consisted of 64 hauls and occurred at a mix of sites sampled during all years except 1998 (Figure 6.4). The assemblages represented by this group were sampled at just station SD18 in 1995 and only at station SD21 between 1997–2002; however, it occurred at five to seven stations per year in 1996 and between 2003–2011. This group had the highest overall abundance (~235 fishes/haul) and the highest numbers of the following species: speckled sanddabs (~138 individuals/haul), yellowchin sculpin (~26 individuals/haul), longfin sanddabs (~13 individuals/haul), roughback sculpin (~8 individuals/haul), and hornyhead turbot

(~5 individuals/haul). SIMPER revealed that these and several other species (California lizardfish, longspine combfish, California tonguefish, English sole) were characteristic of the assemblages represented by group D.

Cluster group E consisted of 42 trawls, including hauls from four to seven stations sampled in 1995 and between 1997–2002, as well as seven of nine hauls from SD15 between 2003–2011. This group had the second lowest species richness (~7 species/haul) and the third lowest abundance (~97 fishes/haul). It had the second highest number of speckled sanddabs (~81 individuals/haul) but relatively low numbers of most other species. SIMPER revealed that speckled sanddabs, California lizardfish, spotted turbot, and hornyhead turbot were characteristic of the assemblages represented by group E.

### Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the SBOO region during 2011. There were no incidences of fin rot, discoloration, skin lesions, tumors, or any other indicators of disease among fishes collected during the year. Evidence of parasitism was also very low for trawl-caught fishes in the region. Only three external parasites were observed associated with their hosts, including the one eye parasite *Phrixocephalus cincinnatus* found attached to a hornyhead turbot at station SD20 in April, and two individuals of the parasitic cymothoid isopod *Elthusa vulgaris* found attached to a hornyhead turbot and an English sole at stations SD20 in January and SD17 in April, respectively. Additionally, 58 *E. vulgaris* were identified as part of the trawl catch 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 Invertebrate Communities

A total of 1811 megabenthic invertebrates (~65 per trawl) representing 61 taxa were collected in 2011, with no new species recorded (Table 6.4, Appendix E.5). The sea star *Astropecten californicus* was the most abundant and most frequently captured species, accounting for 35% of the total invertebrate abundance and occurring in 96% of the trawls. Other species collected frequently (≥50% of the trawls) but in relatively low numbers (≤6/haul) included the parasitic isopod *Elthusa vulgaris*, the crab *Metacarcinus gracilis*, the nudibranch *Acanthodoris brunnea*, the opisthobranch *Pleurobranchaea californica*, and the octopus *Octopus rubescens*.

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.5). For each haul, species richness ranged from 5 to 17 species, diversity (H') ranged from 0.3 to 2.3 units, biomass ranged from 0.2 to 2.6, and total abundance ranged from 16 to 219 individuals. Elevated numbers of invertebrates (≥107) occurred primarily at station SD15 during all four surveys, but the largest haul was taken at station SD17 in April. Two species, *A. californicus* and *Dendraster terminalis*, primarily drove abundances at station SD15, while *Ophiura luetkenii* dominated the haul at station SD17 (Appendix E.6).

Variations in megabenthic invertebrate community structure in the South Bay outfall region generally reflect changes in species abundance (Figure 6.5, 6.6). Although species richness has varied little over the years (e.g., 4–16 species/trawl), annual abundance values have averaged between 7 and 548 individuals per haul. These large differences typically have been due to fluctuations in populations of several dominant species, including the sea urchin *Lytechinus pictus*, as well as *A. californicus* and *D. terminalis* as previously mentioned. For example, station SD15 has had the highest average abundance for 10 of the last 17 years due to relatively large hauls of the latter two species. In addition, the high abundances

**Table 6.4**
Species of megabenthic invertebrates collected in 28 trawls conducted in the SBOO region during 2011. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

| Species | PA | FO | MAH | MAO | Species | PA | FO | MAH | MAO |
|---|---|---|---|---|---|---|---|---|---|
| *Astropecten californicus* | 35 | 96 | 22 | 23 | *Podochela hemphillii* | <1 | 7 | <1 | 2 |
| *Ophiura luetkenii* | 15 | 39 | 10 | 25 | *Doryteuthis opalescens* | <1 | 4 | <1 | 3 |
| *Philine auriformis* | 11 | 46 | 7 | 15 | *Heptacarpus palpator* | <1 | 7 | <1 | 2 |
| *Dendraster terminalis* | 7 | 18 | 4 | 25 | *Calliostoma tricolor* | <1 | 4 | <1 | 2 |
| *Metacarcinus gracilis* | 6 | 64 | 4 | 6 | *Pagurus spilocarpus* | <1 | 7 | <1 | 1 |
| *Elthusa vulgaris* | 3 | 75 | 2 | 3 | *Loxorhynchus grandis* | <1 | 7 | <1 | 1 |
| *Acanthodoris brunnea* | 3 | 54 | 2 | 4 | *Calliostoma canaliculatum* | <1 | 7 | <1 | 1 |
| *Heterocrypta occidentalis* | 2 | 25 | 1 | 5 | *Euspira lewisii* | <1 | 4 | <1 | 2 |
| *Pyromaia tuberculata* | 2 | 39 | 1 | 3 | *Paguristes ulreyi* | <1 | 7 | <1 | 1 |
| *Pleurobranchaea californica* | 2 | 50 | 1 | 2 | *Aphrodita* sp | <1 | 4 | <1 | 1 |
| *Octopus rubescens* | 2 | 50 | 1 | 2 | *Stylatula elongata* | <1 | 4 | <1 | 1 |
| *Luidia foliolata* | 2 | 29 | 1 | 4 | *Paguristes bakeri* | <1 | 4 | <1 | 1 |
| *Caesia perpinguis* | <1 | 14 | <1 | 4 | *Megasurcula carpenteriana* | <1 | 4 | <1 | 1 |
| *Hamatoscalpellum californicum* | <1 | 7 | <1 | 8 | *Sinum scopulosum* | <1 | 4 | <1 | 1 |
| *Kelletia kelletii* | <1 | 43 | <1 | 1 | *Armina californica* | <1 | 4 | <1 | 1 |
| *Ophiothrix spiculata* | <1 | 32 | <1 | 2 | *Aglaja ocelligera* | <1 | 4 | <1 | 1 |
| *Hemisquilla californiensis* | <1 | 32 | <1 | 2 | *Strongylocentrotus purpuratus* | <1 | 4 | <1 | 1 |
| *Heptacarpus stimpsoni* | <1 | 4 | <1 | 12 | *Aphrodita refulgida* | <1 | 4 | <1 | 1 |
| *Sicyonia ingentis* | <1 | 14 | <1 | 2 | *Acanthodoris rhodoceras* | <1 | 4 | <1 | 1 |
| *Pisaster brevispinus* | <1 | 21 | <1 | 2 | *Pandalus platyceros* | <1 | 4 | <1 | 1 |
| *Crangon alba* | <1 | 14 | <1 | 2 | *Metacarcinus anthonyi* | <1 | 4 | <1 | 1 |
| *Platymera gaudichaudii* | <1 | 25 | <1 | 1 | *Farfantepenaeus californiensis* | <1 | 4 | <1 | 1 |
| *Lytechinus pictus* | <1 | 14 | <1 | 2 | *Sicyonia penicillata* | <1 | 4 | <1 | 1 |
| *Loxorhynchus crispatus* | <1 | 21 | <1 | 1 | *Pandalus danae* | <1 | 4 | <1 | 1 |
| *Flabellina iodinea* | <1 | 18 | <1 | 1 | *Aphrodita armifera* | <1 | 4 | <1 | 1 |
| *Luidia armata* | <1 | 18 | <1 | 1 | *Megastraea undosa* | <1 | 4 | <1 | 1 |
| *Crangon nigromaculata* | <1 | 11 | <1 | 2 | *Pteropurpura festiva* | <1 | 4 | <1 | 1 |
| *Randallia ornata* | <1 | 14 | <1 | 1 | *Spirontocaris prionota* | <1 | 4 | <1 | 1 |
| *Crossata californica* | <1 | 14 | <1 | 1 | *Pagurus armatus* | <1 | 4 | <1 | 1 |
| *Dendronotus iris* | <1 | 7 | <1 | 2 | *Pugettia producta* | <1 | 4 | <1 | 1 |
| *Halosydna latior* | <1 | 11 | <1 | 1 | | | | | |

recorded at station SD17 in 1996 were due to large hauls of *L. pictus*. None of the observed variability in the trawl-caught invertebrate communities appears to be related to the South Bay outfall.

## Discussion

Speckled sanddabs dominated fish assemblages surrounding the SBOO in 2011 as they have since monitoring began in 1995. This species occurred at all stations and accounted for 66% of the total catch. Other commonly captured, but less abundant species, included California lizardfish, California tonguefish, English sole, hornyhead turbot, longfin sanddab, longspine combfish, roughback sculpin, and yellowchin sculpin. The majority of these fishes tended to be relatively small with an average length ≤21 cm. Although the composition and structure of the fish assemblages varied among stations, these differences were mostly due to natural fluctuations of common fish populations.

**Table 6.5**
Summary of megabenthic invertebrate community parameters for SBOO stations sampled during 2011. Data are included for species richness, abundance, and diversity (H') and biomass(kg, wet weight). SD = standard deviation..

| Station | Jan | Apr | Jul | Oct | Annual Mean | Annual SD | Station | Jan | Apr | Jul | Oct | Annual Mean | Annual SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species richness | | | | | | | *Abundance* | | | | | | |
| SD15 | 5 | 11 | 6 | 8 | 8 | 3 | SD15 | 107 | 139 | 144 | 123 | 128 | 17 |
| SD16 | 8 | 6 | 11 | 16 | 10 | 4 | SD16 | 16 | 27 | 34 | 48 | 31 | 13 |
| SD17 | 11 | 14 | 16 | 11 | 13 | 2 | SD17 | 55 | 219 | 63 | 54 | 98 | 81 |
| SD18 | 7 | 13 | 14 | 11 | 11 | 3 | SD18 | 25 | 89 | 56 | 64 | 59 | 26 |
| SD19 | 10 | 10 | 7 | 10 | 9 | 2 | SD19 | 61 | 51 | 24 | 28 | 41 | 18 |
| SD20 | 10 | 11 | 9 | 9 | 10 | 1 | SD20 | 33 | 48 | 20 | 35 | 34 | 11 |
| SD21 | 8 | 13 | 17 | 12 | 13 | 4 | SD21 | 87 | 63 | 62 | 36 | 62 | 21 |
| Survey Mean | 8 | 11 | 11 | 11 | | | Survey Mean | 55 | 91 | 58 | 55 | | |
| Survey SD | 2 | 3 | 4 | 3 | | | Survey SD | 33 | 67 | 42 | 32 | | |
| Diversity | | | | | | | *Biomass* | | | | | | |
| SD15 | 0.3 | 1.2 | 0.8 | 0.5 | 0.7 | 0.4 | SD15 | 0.4 | 1.7 | 0.4 | 2.6 | 1.3 | 1.1 |
| SD16 | 1.8 | 1.3 | 1.7 | 1.8 | 1.6 | 0.2 | SD16 | 0.2 | 1.1 | 1.6 | 2.1 | 1.2 | 0.8 |
| SD17 | 1.5 | 1.1 | 2.2 | 1.7 | 1.6 | 0.5 | SD17 | 2.0 | 0.7 | 0.2 | 2.0 | 1.2 | 0.9 |
| SD18 | 1.5 | 1.7 | 2.3 | 1.9 | 1.8 | 0.4 | SD18 | 0.2 | 1.4 | 0.1 | 0.5 | 0.5 | 0.6 |
| SD19 | 1.7 | 1.4 | 1.6 | 2.1 | 1.7 | 0.3 | SD19 | 0.3 | 0.4 | 0.1 | 0.7 | 0.4 | 0.2 |
| SD20 | 1.8 | 1.6 | 1.9 | 1.9 | 1.8 | 0.1 | SD20 | 0.9 | 1.0 | 0.4 | 1.8 | 1.0 | 0.6 |
| SD21 | 0.5 | 1.8 | 2.3 | 2.2 | 1.7 | 0.8 | SD21 | 0.5 | 2.1 | 1.8 | 1.5 | 1.5 | 0.7 |
| Survey Mean | 1.3 | 1.4 | 1.8 | 1.7 | | | Survey Mean | 0.6 | 1.2 | 0.7 | 1.6 | | |
| Survey SD | 0.6 | 0.3 | 0.6 | 0.6 | | | Survey SD | 0.6 | 0.6 | 0.7 | 0.8 | | |

Assemblages of megabenthic, trawl-caught invertebrates in the region were dominated by the sea star *Astropecten californicus*, which occurred in 96% of trawls and accounted for 35% of the total invertebrate abundance. Other species collected frequently included the parasitic isopod *Elthusa vulgaris*, the crab *Metacarcinus gracilis*, the nudibranch *Acanthodoris brunnea*, the opisthobranch *Pleurobranchaea californica*, and the octopus *Octopus rubescens*. As with demersal fishes in the SBOO region, the composition and structure of megabenthic assemblages varied among stations, reflecting population fluctuations in the species mentioned above.

Overall, results of the 2011 trawl surveys provide no evidence that wastewater discharged through the SBOO has affected either demersal fish or megabenthic invertebrate communities in the region. Although highly variable, patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away, with no discernible changes in the region following the onset of wastewater discharge through the SBOO in January 1999. Instead, the high degree of variability present during the year was similar to that observed in previous years (City of San Diego 2006–2011), including the period before initiation of wastewater discharge (City of San Diego 2000). In addition, low species richness and abundances of fish and invertebrates are consistent with what is expected for the relatively shallow, sandy habitats in which the SBOO stations are located (Allen 2005, Allen et al. 1998, 2002, 2007). Changes in these communities appear to be more likely due to natural factors such as changes in ocean water temperatures associated with large-scale oceanographic events (e.g., El Niño or La Niña) or to the mobile nature of many of the resident species collected. Finally, the absence of disease or other physical abnormalities in local fishes suggests that populations in the area continue to be healthy.

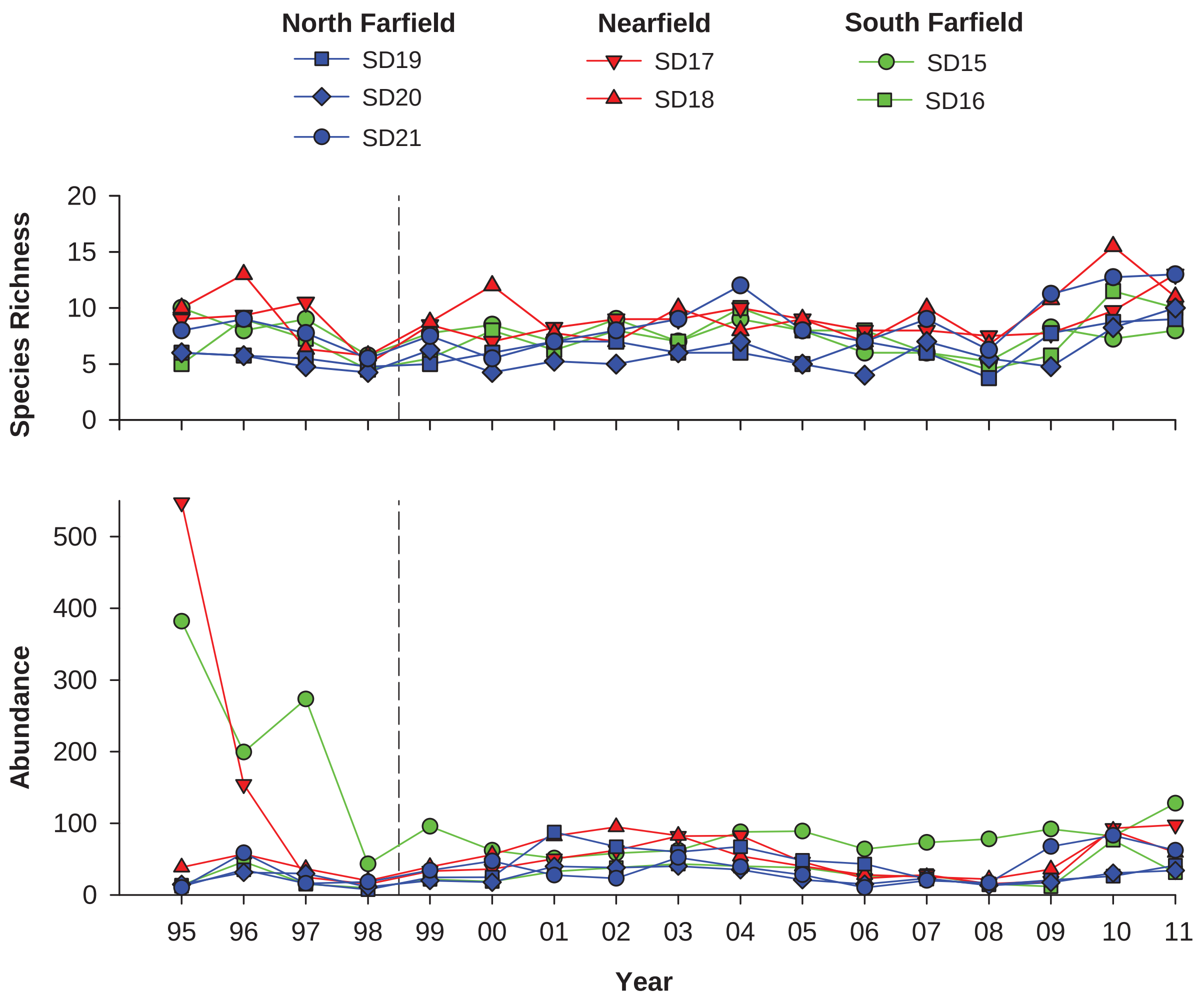



**Figure 6.5**

Species richness and abundance of megabenthic invertebrates collected at each trawl station between 1995–2011. Data for each station are expressed as annual means ($n=4$) except: $n=2$ in 1995 (all stations); $n=3$ for SD17 and SD18 in 1996; $n=2$ for SD7 in 1997; $n=3$ for SD18 in 1997. Dashed lines indicate onset of wastewater discharge.

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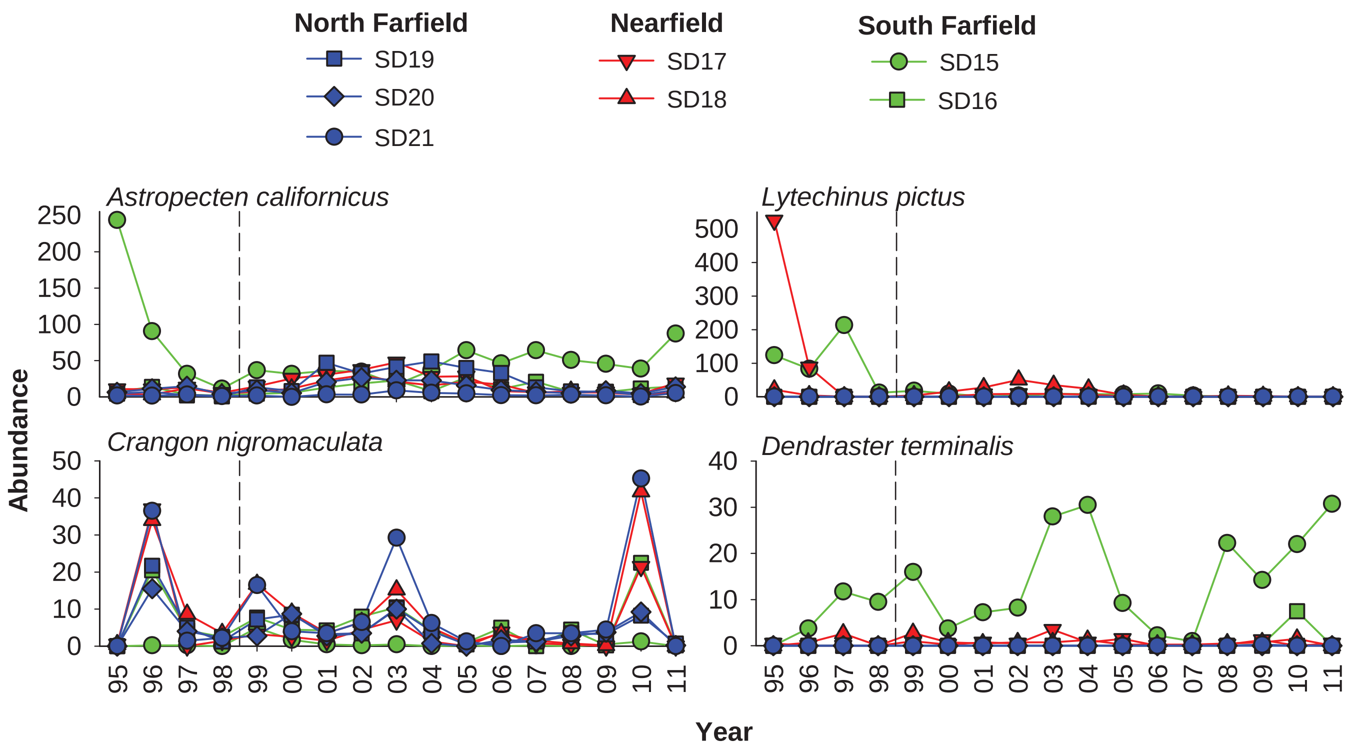


**Figure 6.6**
The four most abundant megabenthic invertebrate species collected in the SBOO region between 1995–2011. Data for each station are expressed as annual means ($n = 4$) except: $n = 2$ in 1995 (all stations); $n = 3$ for SD17 and SD18 in 1996; $n = 2$ for SD7 in 1997; $n = 3$ for SD18 in 1997. Dashed lines indicate onset of wastewater discharge.


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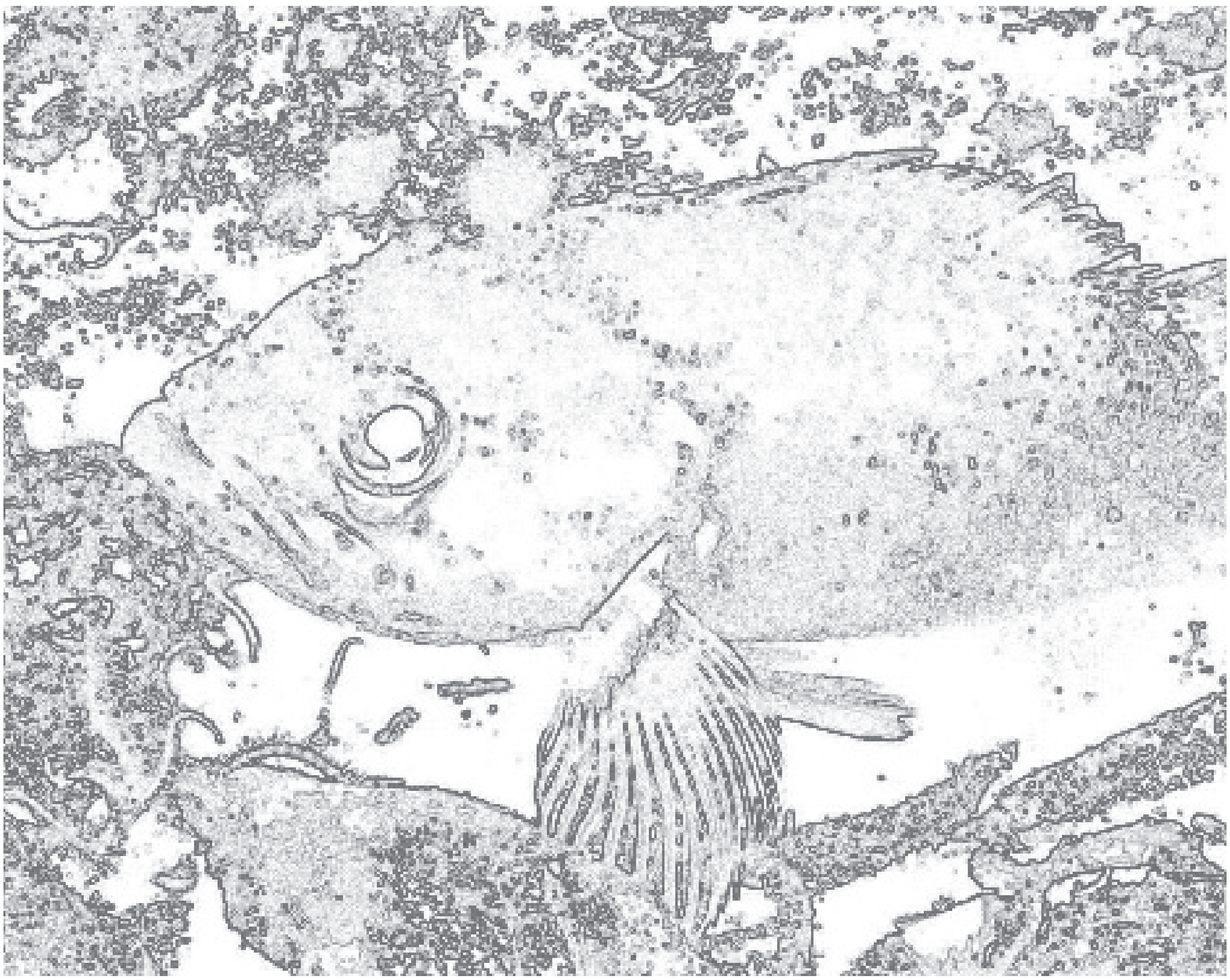
# Chapter 7
# Bioaccumulation of Contaminants in Fish Tissues



# Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

## Introduction

Fish tissue samples are analyzed as part of the City of San Diego's (City) Ocean Monitoring Program to evaluate if contaminants in wastewater discharged from the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively) are impacting bottom-dwelling (demersal) fish communities, and to determine if fishes collected for human consumption contain levels of contaminants that are harmful to human health. Anthropogenic inputs to the marine ecosystem (including municipal wastewater outfalls) can lead to increased concentrations of pollutants within the local environment, and subsequently in the tissues of fishes and their prey. This accumulation occurs through the biological uptake and retention of chemicals derived via various exposure pathways like the absorption of dissolved chemicals directly from seawater and the ingestion and assimilation of pollutants contained in different food sources (Connell 1988, Cardwell 1991, Rand 1995, USEPA 2000). In addition, demersal fishes may accumulate contaminants through the ingestion of suspended particulates or sediments because of their proximity to the seafloor. For this reason, contaminant levels in the tissues of these fish are often related to those found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

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

This chapter presents summaries and interpretations of all chemical analyses that were performed on the tissues of fishes collected in the SBOO region during 2011. The primary goals are to: (1) document levels of contaminant loading in local demersal fishes, (2) identify possible effects of wastewater discharge on contaminant bioaccumulation in fishes from the SBOO region, and (3) identify other potential natural and anthropogenic sources of pollutants to the local marine ecosystem.

## Materials and Methods

### Field Collection

Fishes were collected during April and October of 2011 at seven trawl and two rig fishing stations (Figure 7.1). English sole (*Parophrys vetulus*),

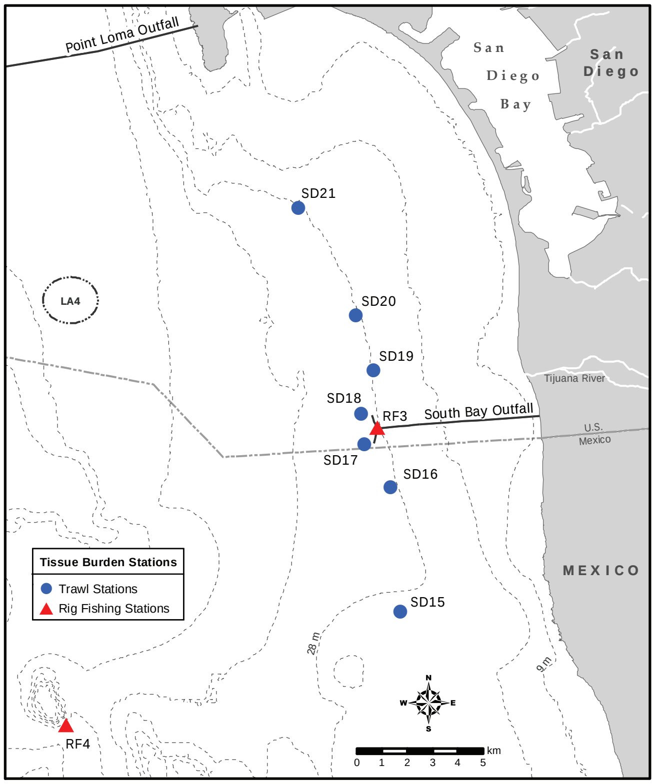



**Figure 7.1**
Otter trawl and rig fishing station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

hornyhead turbot (*Pleuronichthys verticalis*), longfin sanddab (*Citharichthys xanthostigma*), and Pacific sanddab (*Citharichthys sordidus*) were collected for analysis of liver tissues from the trawling stations, while California scorpionfish (*Scorpaena guttata*), brown rockfish (*Sebastes auriculatus*), bocaccio (*Sebastes paucispinis*) and vermilion rockfish (*Sebastes miniatus*) were collected for analysis of muscle tissues at the two rig fishing stations (Table 7.1). All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for collection methods). Efforts to collect target species at the trawl stations were limited to five 10-minute (bottom time) trawls per site. Fishes collected at the two rig fishing stations were caught within 1 km of the station location using standard rod and reel procedures; fishing effort was limited to 5 hours at each station. Occasionally, insufficient numbers of the target species were obtained despite this effort, which resulted in a reduced number of composite samples at a particular station, or inadequate amounts of tissue to complete the full suite of chemical analyses.

In order to facilitate collection of sufficient tissue for chemical analysis, only fish ≥13 cm in standard length were retained. These fish were sorted into three composite samples per station, with each composite containing a minimum of three individuals. Composite samples were typically made up of a single species; the only exceptions were samples that consisted of mixed species of rockfish (Table 7.1). 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 until dissection and tissue processing.

## Tissue Processing and Chemical Analyses

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

Each tissue sample was chemically analyzed to determine concentrations of trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a wet weight basis. Reported values were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix F.2). However,

**Table 7.1**
Species of fish collected from each SBOO trawl and rig fishing station during April and October 2011.

| Survey | Station | Composite 1 | Composite 2 | Composite 3 |
|---|---|---|---|---|
| April 2011 | RF3 | Brown rockfish | Brown rockfish | Vermilion rockfish |
| | RF4 | California scorpionfish | California scorpionfish | California scorpionfish |
| | SD15 | Hornyhead turbot [a,c] | English sole [a,b] | No sample [d] |
| | SD16 | Hornyhead turbot | Longfin sanddab | No sample [d] |
| | SD17 | Longfin sanddab | English sole | Hornyhead turbot |
| | SD18 | Longfin sanddab | Hornyhead turbot | English sole |
| | SD19 | Longfin sanddab | English sole | Hornyhead turbot |
| | SD20 | English sole | Longfin sanddab | Longfin sanddab |
| | SD21 | Longfin sanddab | Hornyhead turbot | No sample [d] |
| October 2011 | RF3 | Brown rockfish | Vermilion rockfish | Mixed rockfish [e] |
| | RF4 | California scorpionfish | California scorpionfish | California scorpionfish |
| | SD15 | Hornyhead turbot | Hornyhead turbot | Pacific sanddab |
| | SD16 | Hornyhead turbot | Hornyhead turbot | Longfin sanddab |
| | SD17 | Longfin sanddab | Longfin sanddab | Longfin sanddab |
| | SD18 | Hornyhead turbot | Hornyhead turbot | Hornyhead turbot |
| | SD19 | Longfin sanddab | Longfin sanddab | Longfin sanddab |
| | SD20 | Longfin sanddab | Longfin sanddab | Longfin sanddab |
| | SD21 | Hornyhead turbot | Longfin sanddab | Longfin sanddab |

[a] no PAHs analyzed for these samples; [b] no metals analyzed for this sample;
[c] only metal analyzed for this sample was mercury; [d] insufficient fish collected (see text);
[e] includes vermillion rockfish and bocaccio

concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemical Services Laboratory (City of San Diego 2012a).

### Data Analyses

Data summaries for each contaminant include detection rates, minimum, maximum, and mean detected values of each parameter by species. Total chlordane, DDT (tDDT), PCB (tPCB), and PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix F.3 for individual constituent values). In addition, the distribution of contaminants with detection rates ≥20% was assessed by comparing values in fishes collected from "nearfield" stations located within 1000 m of the outfall wye or diffuser legs (SD17, SD18, RF3) to those from "farfield" stations located farther away to the south (SD15, SD16), north (SD19–SD21), and west (RF4). Concentrations were also compared to maximum values reported during the pre-discharge period if available. Because contaminant levels can vary so much among different species of fish, only intra-species comparisons were used for these evaluations.

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

In order to examine spatial and temporal patterns in contaminant loading of fishes collected from the SBOO region, multivariate analyses were performed using a 3-year data matrix comprised of the main chemical parameters analyzed for each tissue sample (i.e., trace metals, pesticides, total PCBs, total PAHs). This analysis was conducted for all data collected between 2009 and 2011 using PRIMER software (see Clarke and Warwick 2001, Clarke and Gorley 2006). Data were limited to these three years to limit the influence of differing MDLs (Appendix F.2). Any non-detects (i.e., analyte concentrations < MDL) were first converted to "0" values to avoid data deletion issues with the clustering program, after which the data were normalized and two Euclidean distance matrices created: one for liver tissue and one for muscle tissue. For liver tissue analyses, a 3-way PERMANOVA was conducted to determine if significant differences occurred among survey period, species, or lipid content. For muscle tissue analyses, a two-way crossed analysis of similarity (ANOSIM; maximum number of permutations = 9999) was conducted to determine if significant differences occurred among survey period or species (lipids not tested since all values fell within same lipid bin). Similarity percentages (SIMPER) analyses were used to determine which parameters accounted for significant differences identified through ANOSIM.

# Results

## Contaminants in Trawl-Caught Fishes

### *Trace Metals*

Eleven trace metals occurred in ≥78% of the liver tissue samples from trawl-caught fishes in 2011, including arsenic, cadmium, chromium, copper, iron, manganese, mercury, selenium, silver, tin, and zinc (Table 7.2). Another six metals (aluminum, antimony, barium, lead, nickel, thallium) were also detected, but less frequently at rates between 3–59%. Beryllium was not detected in any of the liver samples collected during the year. Several metals were found at levels that exceeded pre-discharge values (Figure 7.2). These included arsenic, cadmium, manganese and mercury, which exceeded pre-discharge values in 14–43% of the samples, and aluminum, copper, selenium and zinc, which exceeded pre-discharge values in ≤8% of the samples. However, intra-species comparisons between nearfield and farfield stations suggest that there was no clear relationship between metal concentrations in fish liver tissues and proximity to the outfall. For example, most of the pre-discharge exceedances occurred in samples of English sole and hornyhead turbot that were collected throughout the region.

### *Pesticides*

Four chlorinated pesticides were detected in fish liver tissues during 2011 (Table 7.3). DDT was found in every tissue sample with tDDT concentrations ranging from 8 to 575 ppb. The DDT derivative p,p-DDE was found in 100% of the samples, whereas p,pDDMU, p,p-DDD, o,p-DDE, and p,p-DDT were detected in at least 40% (Appendix F.3). Hexachlorobenzene (HCB) occurred at a rate of 92%, while chlordane and Mirex occurred at rates of 23% and 3%, respectively. Concentrations of these three pesticides tended to be much lower than tDDT; HCB was found at levels ≤41 ppb, chlordane was ≤36 ppb, and Mirex = 1.5 ppb. Total chlordane consisted of one or more of the following constituents: alpha (cis) chlordane, cis-nonachlor, heptachlor, and trans-nonachlor.

During the past year, all values of total DDT and total chlordane were below the maximum levels detected in the same species prior to wastewater discharge (Figure 7.3). This evaluation could not be made for HCB, as this pesticide was not detected during the pre-discharge period. Overall, there were no clear relationships between pesticide concentrations in fish tissues and proximity to the outfal1.

### *PAHs and PCBs*

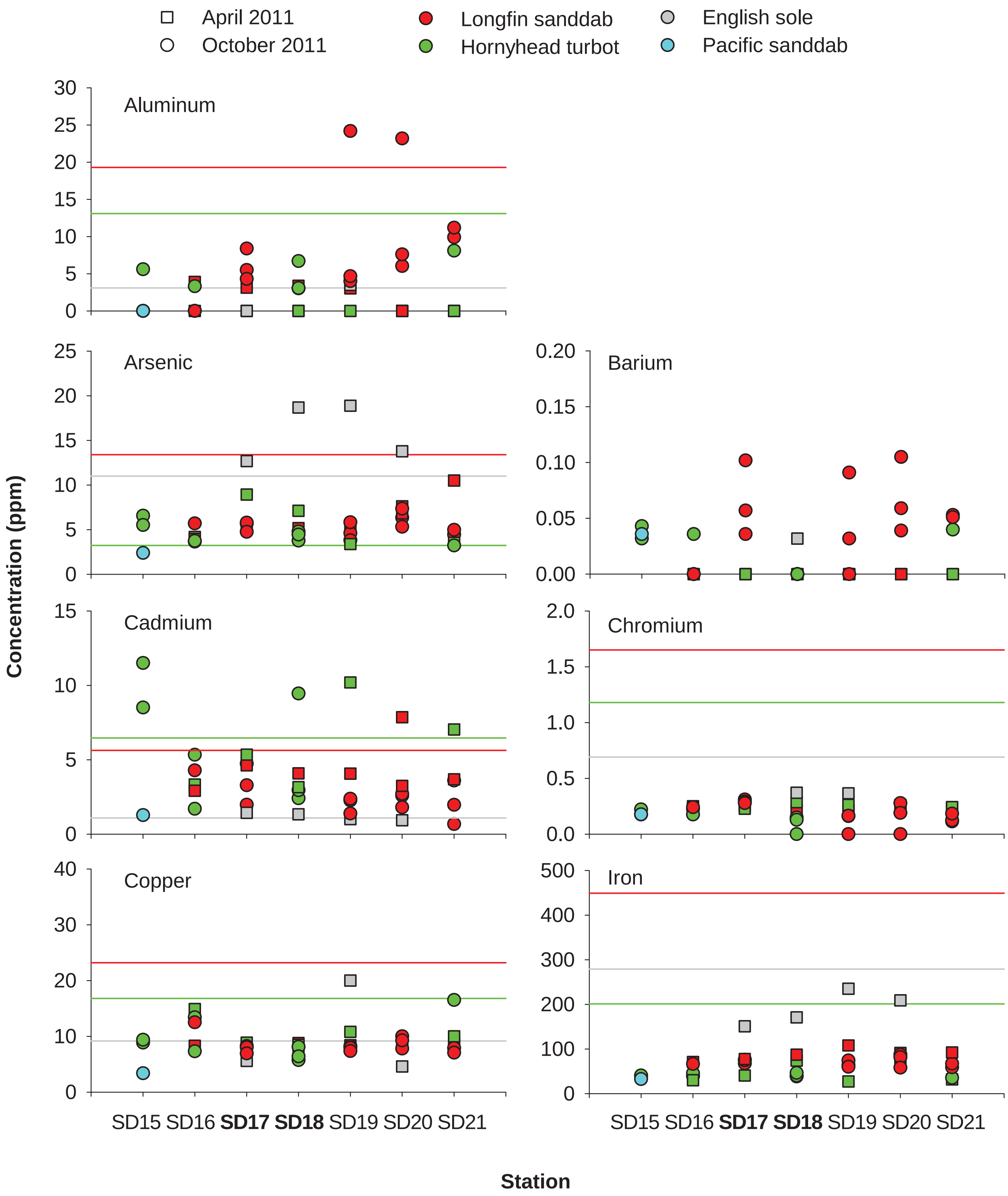
PAHs were not detected in fish liver tissues during 2011. In contrast, PCBs occurred in

## Table 7.2

Summary of metals in liver tissues of fishes collected from SBOO trawl stations during 2011. Data include the number of detected values (*n*), minimum, maximum and mean[a] detected concentrations per species, and the detection rate and max value for all species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses. See Appendix F.2 for MDLs and names for each metal represented by periodic table symbol.

| | Al | Sb | As | Ba | Be | Cd | Cr | Cu | Fe | Pb | Mn | Hg | Ni | Se | Ag | Tl | Sn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| English sole | | | | | | | | | | | | | | | | | | |
| *n (out of 4)* | 1 | 0 | 4 | 1 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 0 | 4 | 4 |
| Min | nd | — | 12.7 | nd | — | 0.94 | 0.24 | 4.6 | 151.0 | 0.27 | 1.7 | 0.051 | nd | 1.05 | nd | — | 0.354 | 28.6 |
| Max | 3.5 | — | 18.9 | 0.032 | — | 1.44 | 0.37 | 20.0 | 235.0 | 1.53 | 2.4 | 0.095 | 0.297 | 6.06 | 0.413 | — | 0.769 | 40.4 |
| Mean | 3.5 | — | 16.0 | 0.032 | — | 1.18 | 0.31 | 9.4 | 191.5 | 0.71 | 2.0 | 0.078 | 0.254 | 2.49 | 0.214 | — | 0.520 | 33.4 |
| Hornyhead turbot | | | | | | | | | | | | | | | | | | |
| *n (out of 13)*[b] | 6 | 0 | 13 | 4 | 0 | 13 | 12 | 13 | 13 | 0 | 13 | 14 | 2 | 13 | 13 | 5 | 7 | 13 |
| Min | nd | — | 3.2 | nd | — | 1.70 | nd | 5.7 | 27.3 | — | 0.9 | 0.040 | nd | 0.49 | 0.072 | nd | nd | 40.5 |
| Max | 8.1 | — | 8.9 | 0.043 | — | 11.50 | 0.29 | 16.5 | 74.0 | — | 2.1 | 0.176 | 0.285 | 1.20 | 0.255 | 0.75 | 0.547 | 58.9 |
| Mean | 5.0 | — | 4.8 | 0.038 | — | 5.73 | 0.20 | 9.9 | 40.5 | — | 1.5 | 0.107 | 0.245 | 0.82 | 0.126 | 0.60 | 0.418 | 48.1 |
| Longfin sanddab | | | | | | | | | | | | | | | | | | |
| *n (out of 19)* | 15 | 0 | 19 | 10 | 0 | 19 | 17 | 19 | 19 | 1 | 19 | 19 | 6 | 19 | 18 | 10 | 17 | 19 |
| Min | nd | — | 3.8 | nd | — | 0.67 | nd | 6.9 | 57.7 | nd | 0.6 | 0.060 | nd | 0.80 | nd | nd | nd | 21.7 |
| Max | 24.2 | — | 10.5 | 0.105 | — | 7.86 | 0.31 | 12.5 | 108.0 | 0.36 | 1.9 | 0.160 | 0.300 | 1.61 | 0.258 | 1.36 | 1.270 | 33.9 |
| Mean | 8.2 | — | 5.8 | 0.062 | — | 3.19 | 0.23 | 8.5 | 75.8 | 0.36 | 1.2 | 0.116 | 0.243 | 1.12 | 0.133 | 0.72 | 0.634 | 27.6 |
| Pacific sanddab | | | | | | | | | | | | | | | | | | |
| *n (out of 1)* | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| Min | — | 0.256 | 2.4 | 0.036 | — | 1.28 | 0.18 | 3.4 | 32.4 | — | 1.1 | 0.041 | — | 0.54 | — | 0.70 | 0.436 | 19.7 |
| Max | — | 0.256 | 2.4 | 0.036 | — | 1.28 | 0.18 | 3.4 | 32.4 | — | 1.1 | 0.041 | — | 0.54 | — | 0.70 | 0.436 | 19.7 |
| Mean | — | 0.256 | 2.4 | 0.036 | — | 1.28 | 0.18 | 3.4 | 32.4 | — | 1.1 | 0.041 | — | 0.54 | — | 0.70 | 0.436 | 19.7 |
| All Species: | | | | | | | | | | | | | | | | | | |
| Detection Rate (%) | 59 | 3 | 100 | 43 | 0 | 100 | 92 | 100 | 100 | 14 | 100 | 100 | 30 | 100 | 92 | 43 | 78 | 100 |
| Max Value | 24.2 | 0.256 | 18.9 | 0.105 | — | 11.5 | 0.371 | 20 | 235.0 | 1.5 | 2.4 | 0.176 | 0.300 | 6.06 | 0.413 | 1.36 | 1.27 | 58.9 |

[a] Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only.
[b] 14 hornyhead turbot samples analyzed for mercury
nd = not detected




## Figure 7.2

Concentrations of metals with detected rates ≥20% in liver tissues of fishes collected from each SBOO trawl station during 2011. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate metals were not detected in that species pre-discharge. To differentiate between missing values (i.e., samples that were not collected; see Table 7.1) and non-detects, zeros were added as placeholders for non-detected values. Stations SD17 and SD18 are considered "nearfield" (bold; see text).

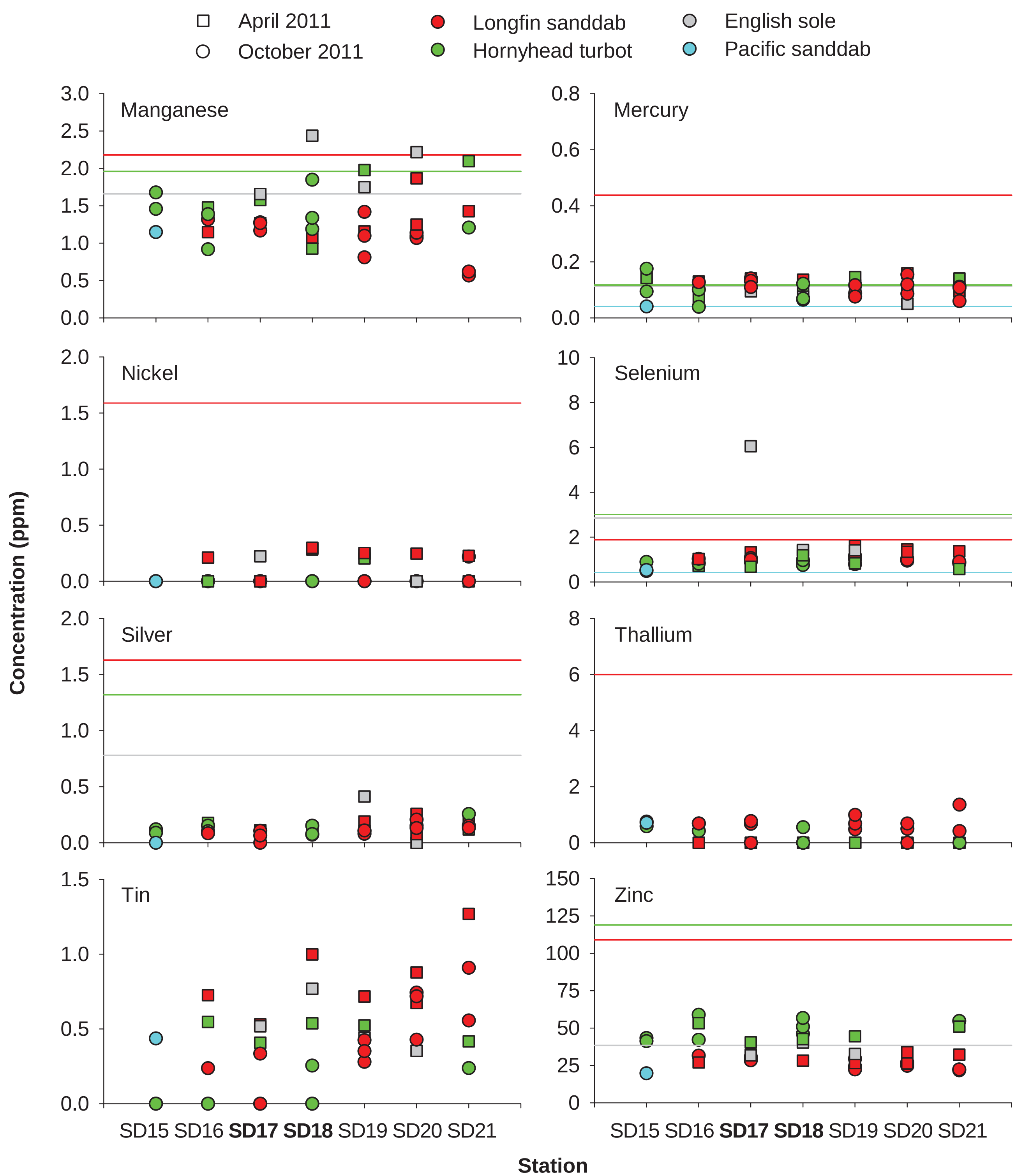



**Figure 7.2** *continued*

every liver sample (Table 7.3). Total PCB concentrations were highly variable, ranging from 8.1 to 412.1 ppb. The congeners PCB 180, PCB 187 and PCB 153/168 occurred in all samples, while another 15 congeners were detected ≥41% of the time (Appendix F.3). Almost all PCB concentrations were less than pre-discharge values, with no clear relationship with proximity to the outfall (Figure 7.3). The only exception was the single Pacific sanddab sample from station SD15, which just barely exceeded the predischarge value of 38 ppb.

## Table 7.3

Summary of pesticides, tPCB, and lipids in liver tissues of fishes collected from SBOO trawl stations during 2011. Data include the number of detected values (*n*), minimum, maximum, and mean[a] detected concentrations for each species, and the detection rate (DR) and max value for all species. Data are expressed in ppb for all parameters except lipids, which are presented as % weight; the number of samples per species is indicated in parentheses. See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT, chlordane (tChlor), and PCB.

| | Pesticides | | | | | |
|---|---|---|---|---|---|---|
| | **HCB** | **tDDT** | **tChlor** | **Mirex** | **tPCB** | **Lipids** |
| English sole | | | | | | |
| *n (out of 5)* | 5 | 5 | 1 | 0 | 5 | 5 |
| Min | 1.0 | 12.0 | nd | — | 52.3 | 3.8 |
| Max | 3.8 | 490.8 | 12.0 | — | 99.3 | 8.2 |
| Mean | 2.0 | 134.3 | 12.0 | — | 73.3 | 6.0 |
| Hornyhead turbot | | | | | | |
| *n (out of 14)* | 12 | 14 | 1 | 0 | 14 | 14 |
| Min | nd | 8.1 | nd | — | 8.1 | 0.1 |
| Max | 41.0 | 79.3 | 13.0 | — | 45.9 | 12.1 |
| Mean | 5.7 | 34.1 | 13.0 | — | 22.1 | 6.3 |
| Longfin sanddab | | | | | | |
| *n (out of 19)* | 18 | 19 | 7 | 1 | 19 | 19 |
| Min | nd | 47.6 | nd | nd | 42.3 | 6.8 |
| Max | 6.5 | 575.4 | 35.8 | 1.5 | 412.1 | 47.8 |
| Mean | 2.7 | 219.7 | 9.8 | 1.5 | 177.3 | 23.7 |
| Pacific sanddab | | | | | | |
| *n (out of 1)* | 1 | 1 | 0 | 0 | 1 | 1 |
| Min | 4.8 | 82.0 | — | — | 64.8 | 32.3 |
| Max | 4.8 | 82.0 | — | — | 64.8 | 32.3 |
| Mean | 4.8 | 82.0 | — | — | 64.8 | 32.3 |
| All Species: | | | | | | |
| DR (%) | 92 | 100 | 23 | 3 | 100 | 100 |
| Max Value | 41.0 | 575.4 | 35.8 | 1.5 | 412.1 | 47.8 |

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

### Contaminants in Fishes Collected by Rig Fishing

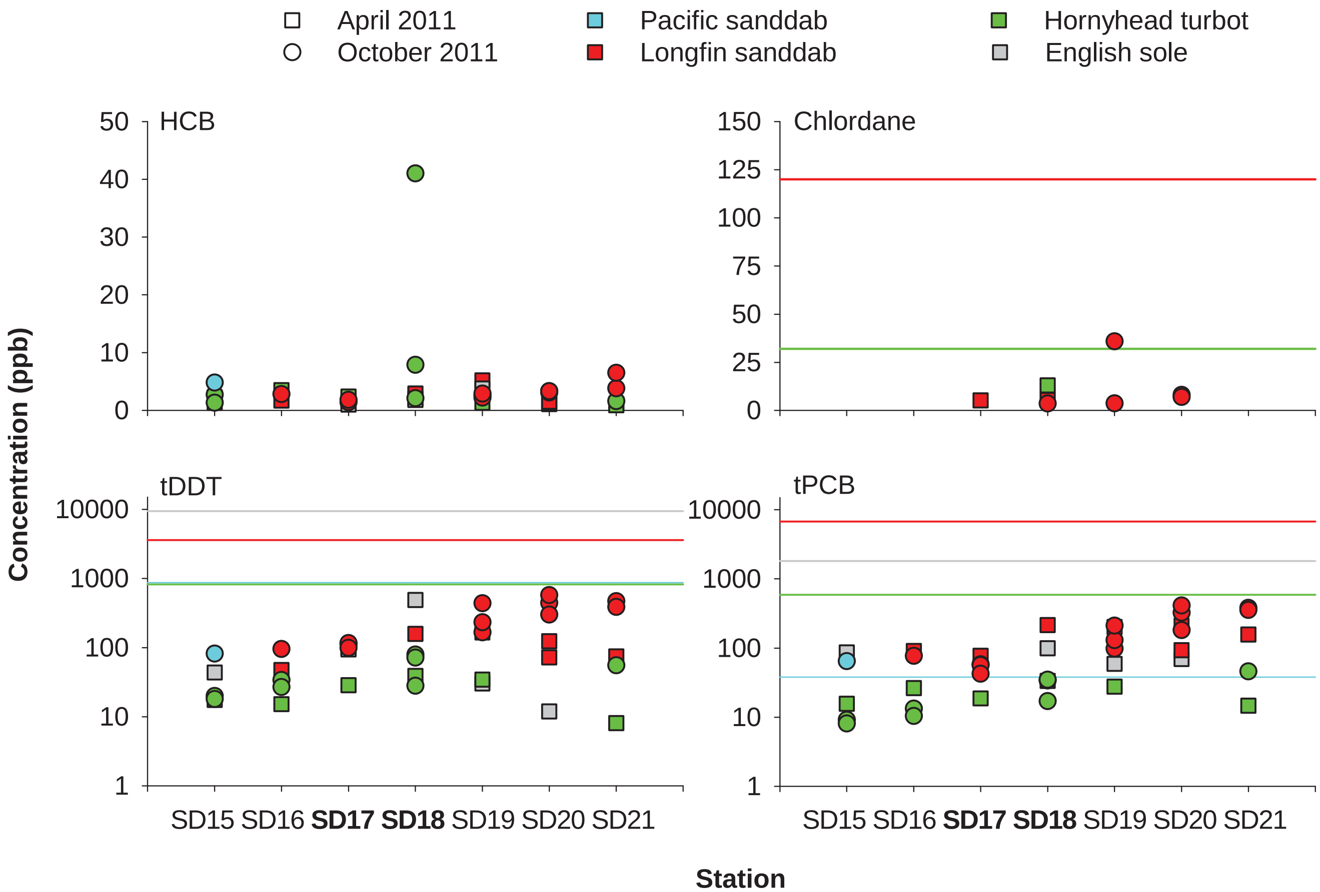
Eight trace metals occurred in ≥67% of the muscle tissue samples from fishes collected at the two rig fishing stations in 2011, including arsenic, chromium, copper, iron, mercury, selenium, tin, and zinc (Table 7.4). Another eight metals (aluminum, antimony, barium, beryllium, manganese, nickel, silver, thallium) were also detected, but less frequently at rates between 8–42%. Cadmium and lead went undetected. Overall, metal values were fairly similar between the two stations and mostly occurred at concentrations less than those measured prior to discharge (Figure 7.4). Exceptions to this included arsenic, mercury, and zinc, each of which exceeded pre-discharge maxima in one or two samples (out of 12 total), primarily at station RF4.

Detection rates for DDT, HCB, and PCBs were very in high muscle tissues during 2011. Total DDT and PCB were both detected in 100% of the samples, while the pesticide HCB was detected in 92% (Table 7.5). Concentrations of all three contaminants were below 5 ppb. Neither tDDT nor tPCB exceeded pre-discharge values, whereas HCB was undetected during that period. None of the parameters demonstrated a clear relationship with proximity to the outfall (Figure 7.4). Total DDT was composed primarily of p,p-DDE (Appendix F.3). PCB 153/168 was detected in all samples, while another nine congeners were detected at rates ≥25%. As with liver tissues, no PAHs were detected in muscle tissues during 2011.

Most of the contaminants detected in fish muscle tissues occurred at concentrations below state, national, and international limits and standards (Tables 7.4, 7.5). Only arsenic and selenium were detected in concentrations higher than median international standards, while mercury (as a proxy for methylmercury) exceeded OEHHA fish contaminant goals. Vermilion rockfish had elevated concentrations (i.e., higher than threshold values) of arsenic and selenium, brown rockfish had elevated concentrations of selenium, and California scorpionfish had elevated concentrations of arsenic, selenium and mercury.

### Historical Assessment of Contaminants in Fish Tissues

PERMANOVA results revealed significantly different contaminant levels in fish liver tissues based on survey period and lipid content, but not




## Figure 7.3

Concentrations of HCB, total chlordane, tDDT, and tPCBs in liver tissues of fishes collected from each SBOO trawl station during 2011. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate parameters were not detected in that species pre-discharge. All missing values = non-detects. Stations SD17 and SD18 are considered "nearfield" (bold; see text).

among species (Appendix F.5). Interactions among factors were not significant. SIMPER demonstrated that although concentrations of contaminants varied significantly among fishes collected during different sampling periods, temporal trends of decreasing or increasing concentrations were not evident for any of the parameters tested (Table 7.6, Figure 7.5). Instead, high concentrations of select metals, pesticides, PAHs, or PCBs appeared to spike randomly (e.g., iron in April 2010, zinc in October 2009, tPCB in April 2009) and drove observed differences among contaminant levels in fishes collected at various times. Alternatively, contaminant concentrations in liver tissues were related to lipid content. For example, many metals including arsenic, cadmium, iron, lead, manganese, mercury, selenium and zinc tended to decrease in concentration with increasing lipid content, while pesticides such as HCB, DDT and PCBs increased in concentration with increasing lipid content. Although there were no significant differences among chemical concentrations in liver tissues based on species, the data suggest that English sole had differing levels of contaminants than all other species tested except for Pacific sanddab (Figure 7.5). Similarly, California scorpionfish appeared to have differing levels of contaminants than longfin sanddab, hornyhead turbot, and English sole.

ANOSIM results revealed significantly different contaminant levels in fish muscle tissues based on survey period, but not among species (Appendix F.6). As with liver tissues, no temporal trend of decreasing or increasing concentration was evident for any contaminant tested (Table 7.7, Figure 7.6). Based on pairwise comparisons, almost all survey periods

## Table 7.4

Summary of metals in muscle tissues of fishes collected from SBOO rig fishing stations during 2011. Data include the number of detected values (*n*), minimum, maximum, and mean[a] detected concentrations for each 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, or median international standards (IS). See Appendix F.2 for MDLs and names for each metal represented by periodic table symbol.

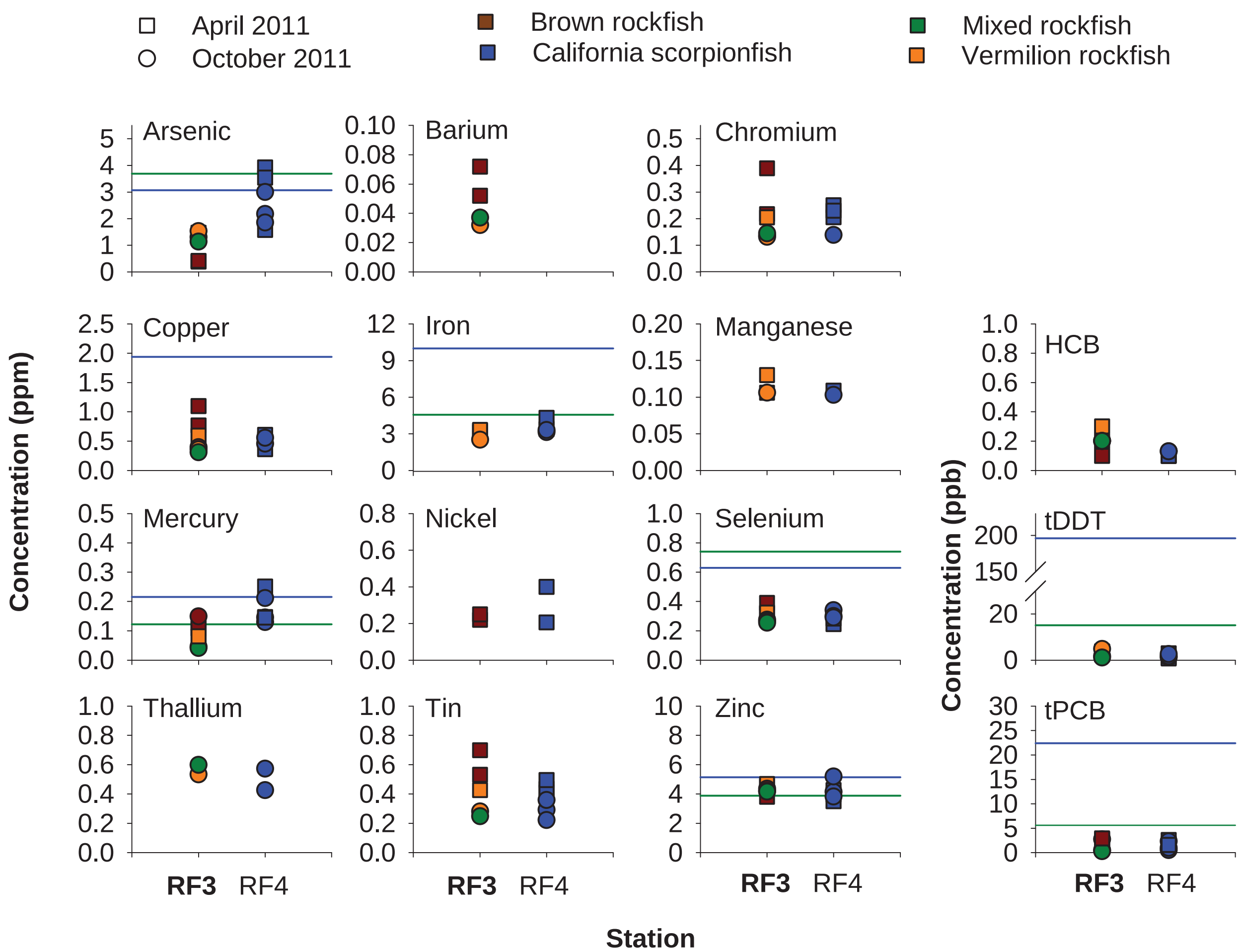
| | Al | Sb | As | Ba | Be | Cd | Cr | Cu | Fe | Pb | Mn | Hg | Ni | Se | Ag | Tl | Sn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brown rockfish | | | | | | | | | | | | | | | | | | |
| *n (out of 3)* | 0 | 1 | 3 | 2 | 0 | 0 | 3 | 3 | 2 | 0 | 1 | 3 | 2 | 3 | 1 | 0 | 2 | 3 |
| Min | — | nd | 0.4 | nd | — | — | 0.14 | 0.4 | nd | — | nd | 0.108 | nd | 0.27 | nd | — | nd | 3.8 |
| Max | — | 0.496 | 1.3 | 0.072 | — | — | 0.39 | 1.1 | 3.3 | — | 0.1 | 0.149 | 0.250 | **0.39** | 0.098 | — | 0.698 | 4.5 |
| Mean | — | 0.496 | 0.7 | 0.062 | — | — | 0.25 | 0.8 | 3.2 | — | 0.1 | 0.128 | 0.235 | **0.33** | 0.098 | — | 0.614 | 4.2 |
| California scorpionfish | | | | | | | | | | | | | | | | | | |
| *n (out of 6)* | 1 | 0 | 6 | 0 | 1 | 0 | 4 | 5 | 4 | 0 | 2 | 6 | 2 | 6 | 0 | 2 | 6 | 6 |
| Min | nd | — | **1.6** | — | nd | — | nd | nd | nd | — | nd | 0.129 | nd | 0.25 | — | nd | 0.222 | 3.5 |
| Max | 3.5 | — | **3.9** | — | 0.01 | — | 0.25 | 0.6 | 4.3 | — | 0.1 | **0.251** | 0.400 | **0.34** | — | 0.57 | 0.495 | 5.2 |
| Mean | 3.5 | — | **2.7** | — | 0.01 | — | 0.21 | 0.5 | 3.5 | — | 0.1 | 0.171 | 0.303 | 0.29 | — | 0.50 | 0.369 | 4.1 |
| Mixed rockfish | | | | | | | | | | | | | | | | | | |
| *n (out of 1)* | 0 | 0 | 1 | 1 | 0 | 0 | nd | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| Min | — | — | 1.1 | 0.037 | — | — | 0.15 | 0.3 | — | — | — | 0.041 | — | 0.25 | — | 0.60 | 0.248 | 4.2 |
| Max | — | — | 1.1 | 0.037 | — | — | 0.15 | 0.3 | — | — | — | 0.041 | — | 0.25 | — | 0.60 | 0.248 | 4.2 |
| Mean | — | — | 1.1 | 0.037 | — | — | 0.15 | 0.3 | — | — | — | 0.041 | — | 0.25 | — | 0.60 | 0.248 | 4.2 |
| Vermilion rockfish | | | | | | | | | | | | | | | | | | |
| *n (out of 2)* | 1 | 0 | 2 | 1 | 0 | 0 | 2 | 2 | 2 | 0 | 2 | 2 | 0 | 2 | 0 | 1 | 2 | 2 |
| Min | nd | — | **1.5** | nd | — | — | 0.13 | 0.4 | 2.5 | — | 0.1 | 0.045 | — | 0.26 | — | nd | 0.280 | 4.2 |
| Max | 3.2 | — | **1.5** | 0.032 | — | — | 0.21 | 0.6 | 3.3 | — | 0.1 | 0.081 | — | **0.32** | — | 0.53 | 0.427 | 4.7 |
| Mean | 3.2 | — | **1.5** | 0.032 | — | — | 0.17 | 0.5 | 2.9 | — | 0.1 | 0.063 | — | 0.29 | — | 0.53 | 0.353 | 4.4 |
| All Species: | | | | | | | | | | | | | | | | | | |
| Detection Rate (%) | 17 | 8 | 100 | 33 | 8 | 0 | 83 | 92 | 67 | 0 | 42 | 100 | 33 | 100 | 8 | 33 | 92 | 100 |
| Max Value | 3.5 | 0.496 | **3.9** | 0.072 | 0.01 | — | 0.39 | 1.1 | 4.3 | — | 0.1 | **0.251** | 0.400 | **0.39** | 0.098 | 0.60 | 0.698 | 5.2 |
| OEHHA[b] | na | na | na | na | na | na | na | na | na | na | na | 0.22 | na | 7.4 | na | na | na | na |
| USFDA Action Limit[c] | na | na | na | na | na | na | na | na | na | na | na | 1 | na | na | na | na | na | na |
| Median IS[c] | na | na | 1.4 | na | na | na | 1 | 20 | na | na | na | 0.5 | na | 0.3 | na | na | 175 | 70 |

na = not available; nd = not detected

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

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

[c] From Mearns et al. 1991. USFDA mercury action limits and all international standards (IS) 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 SBOO rig fishing station during 2011. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; missing lines indicate parameters were not detected in that species prior to discharge, or the species was not collected during those surveys. All missing values = non-detects. Station RF3 is considered "nearfield" (bold; see text).

differed from each other, the only exceptions being October 2009 versus October 2011 and April 2011 versus October 2011.

## Discussion

Several trace metals, pesticides (e.g., DDT, HCB, chlordane, Mirex) and PCB congeners were detected in liver tissue samples from four different species of fish collected in the SBOO region during 2011. Many of the same metals, DDT, HCB, and PCBs were also detected in muscle tissues during the year, although often less frequently and/or in lower concentrations. Although tissue contaminant concentrations varied among different fish species and stations, all values were within ranges reported previously for Southern California Bight (SCB) fishes (see Mearns et al. 1991, Allen et al. 1998, City of San Diego 2007a). Additionally, all muscle tissue samples from sport fish collected in the area had concentrations of mercury and DDT below FDA human consumption limits. However, some muscle tissues had concentrations of arsenic and selenium above the median international standards for human consumption, and some had concentrations of mercury that exceeded OEHHA fish contaminant goals. Elevated levels of these contaminants are not uncommon in sport fish from

## Table 7.5

Summary of pesticides, tPCB, and lipids in muscle tissues of fishes collected from SBOO rig fishing stations during 2011. Data include the number of detected values (*n*), minimum, maximum, and mean[a] detected concentrations per species and the detection rate and max 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, or median international standards (IS). See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT and PCB.

| | Pesticides | | | |
|---|---|---|---|---|
| | HCB (ppb) | tDDT (ppb) | tPCB (ppb) | Lipids (% wt) |
| Brown rockfish | | | | |
| *n (out of 3)* | 3 | 3 | 3 | 3 |
| Min | 0.1 | 1.7 | 0.5 | 0.3 |
| Max | 0.2 | 3.8 | 2.9 | 2.8 |
| Mean | 0.2 | 3.1 | 2.0 | 1.7 |
| California scorpionfish | | | | |
| *n (out of 6)* | 5 | 6 | 6 | 6 |
| Min | nd | 0.7 | 0.5 | 0.3 |
| Max | 0.1 | 2.9 | 2.6 | 1.9 |
| Mean | 0.1 | 1.7 | 1.6 | 1.0 |
| Mixed rockfish | | | | |
| *n (out of 1)* | 1 | 1 | 1 | 1 |
| Min | 0.2 | 1.0 | 0.3 | 0.6 |
| Max | 0.2 | 1.0 | 0.3 | 0.6 |
| Mean | 0.2 | 1.0 | 0.3 | 0.6 |
| Vermilion rockfish | | | | |
| *n (out of 2)* | 2 | 2 | 2 | 2 |
| Min | 0.2 | 2.4 | 2.1 | 1.0 |
| Max | 0.3 | 4.7 | 2.7 | 1.6 |
| Mean | 0.2 | 3.6 | 2.4 | 1.3 |
| All Species: | | | | |
| Detection Rate (%) | 92 | 100 | 100 | 100 |
| Max Value | 0.3 | 4.7 | 2.9 | 2.8 |
| OEHHA[b] | na | 21 | 3.6 | na |
| U.S. FDA Action Limit[c] | na | 5000 | na | na |
| Median IS[c] | na | 5000 | na | na |

na = not available; nd = not detected

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

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

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

the SBOO survey area (City of San Diego 2000–2011) or from the rest of the San Diego region (see City of San Diego 2012b and references therein). For example, muscle tissue samples from fishes collected in the Point Loma outfall survey area over the years have also had concentrations of contaminants such as selenium, mercury, and PCB that exceeded different consumption limits.

The frequent occurrence of metals and chlorinated hydrocarbons in SBOO fish tissues may be due to multiple factors. Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB. In fact, many metals occur naturally in the environment, although little information is available on background levels in fish tissues. Brown et al. (1986) determined that no areas of the SCB are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent work regarding PCBs and DDTs (e.g., Allen et al. 1998, 2002). The lack of contaminant-free reference areas in the SCB clearly pertains to the South Bay outfall region, as demonstrated by the presence of many contaminants in fish tissues prior to the initiation of wastewater discharge in 1999 (see City of San Diego 2000).

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 and among individuals of the same species depending on migration habits (Otway 1991). Fishes may be exposed to contaminants in an area that is highly polluted and then move into an area that is not. For example, California scorpionfish tagged in contaminant-laden 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 SBOO, as there are many point and non-point sources that may contribute to contamination in the region, including at some monitoring stations, such as the Tijuana River,

**Table 7.6**

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

| | Year-Quarter | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | **2009-2** | **2009-4** | **2010-2** | **2010-4** | **2011-2** | **2011-4** |
| *Trace Metals (ppm)* | | | | | | |
| Aluminum | 24.50 | 5.67 | **27.10** | 5.26 | 1.06 | 6.62 |
| Antimony | **0.19** | 0.00 | 0.00 | **0.12** | 0.00 | 0.01 |
| Arsenic | **10.90** | 3.94 | **12.30** | 5.26 | 8.51 | 4.90 |
| Barium | **0.35** | 0.04 | **0.02** | 0.02 | 0.00 | 0.04 |
| Beryllium | 0.000 | **0.001** | 0.001 | 0.000 | 0.000 | 0.000 |
| Cadmium | 3.31 | 3.56 | 4.60 | **3.02** | **4.02** | **3.66** |
| Chromium | 0.289 | 0.074 | 0.138 | 0.085 | 0.262 | 0.171 |
| Copper | 8.60 | 7.79 | 7.87 | 7.65 | **9.43** | 8.58 |
| Iron | 126.00 | 85.90 | **147.00** | 72.50 | **98.50** | 56.60 |
| Lead | 0.33 | 0.03 | **0.57** | 0.00 | 0.18 | 0.02 |
| Manganese | 1.890 | 0.961 | 1.690 | 1.110 | 1.580 | 1.190 |
| Mercury | 0.099 | **0.146** | 0.139 | 0.080 | 0.111 | 0.102 |
| Nickel | 0.00 | 0.00 | 0.00 | **0.07** | **0.16** | 0.01 |
| Selenium | 1.310 | 1.060 | 1.910 | 0.988 | **1.470** | 0.898 |
| Silver | 0.05 | 0.15 | 0.24 | 0.21 | 0.15 | 0.11 |
| Thallium | 0.000 | 0.093 | 0.101 | 0.447 | 0.000 | **0.520** |
| Tin | 2.500 | 0.332 | 0.198 | 0.175 | 0.644 | 0.281 |
| Zinc | 31.80 | **52.80** | 37.20 | **36.90** | 35.80 | 34.80 |
| *Chlorinated Pesticides (ppb)* | | | | | | |
| Endrin | **17.50** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| HCB | 2.03 | 2.24 | 1.52 | 2.84 | 2.07 | **4.53** |
| Mirex | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | **0.07** |
| Total chlordane | 0.00 | **2.90** | 0.00 | 0.00 | 2.23 | **2.75** |
| Total DDT | 590 | **523** | 120 | 118 | 93 | 183 |
| *Total PCB (ppb)* | **415** | 236 | 68 | 174 | 90 | 122 |
| *Total PAH (ppb)* | 0.00 | 0.00 | 0.00 | **2.09** | 0.00 | 0.00 |

San Diego Bay, and dredged materials disposal sites (see Chapters 2–4; Parnell et al. 2008). In contrast, assessments of contaminant loading in sediments surrounding the outfall reveal no evidence that the SBOO is a major source of pollutants to the area (Chapter 4).

There was no evidence of contaminant bioaccumulation in SBOO fishes during 2011 that could be associated with wastewater discharge from the outfall. Although several tissue samples had concentrations of some trace metals that exceeded pre-discharge maxima, concentrations of most contaminants were generally similar to or below pre-discharge levels (see City of San Diego 2000). In addition, most tissue samples that did exceed pre-discharge values were widely distributed among stations and showed no outfall-related patterns. Results of multivariate analyses confirmed that although there have been significant fluctuations in fish tissue contaminant levels over time, no relevant spatial or temporal trends were apparent. Instead, the occasional spikes in tissue contaminants appear random and may be due to

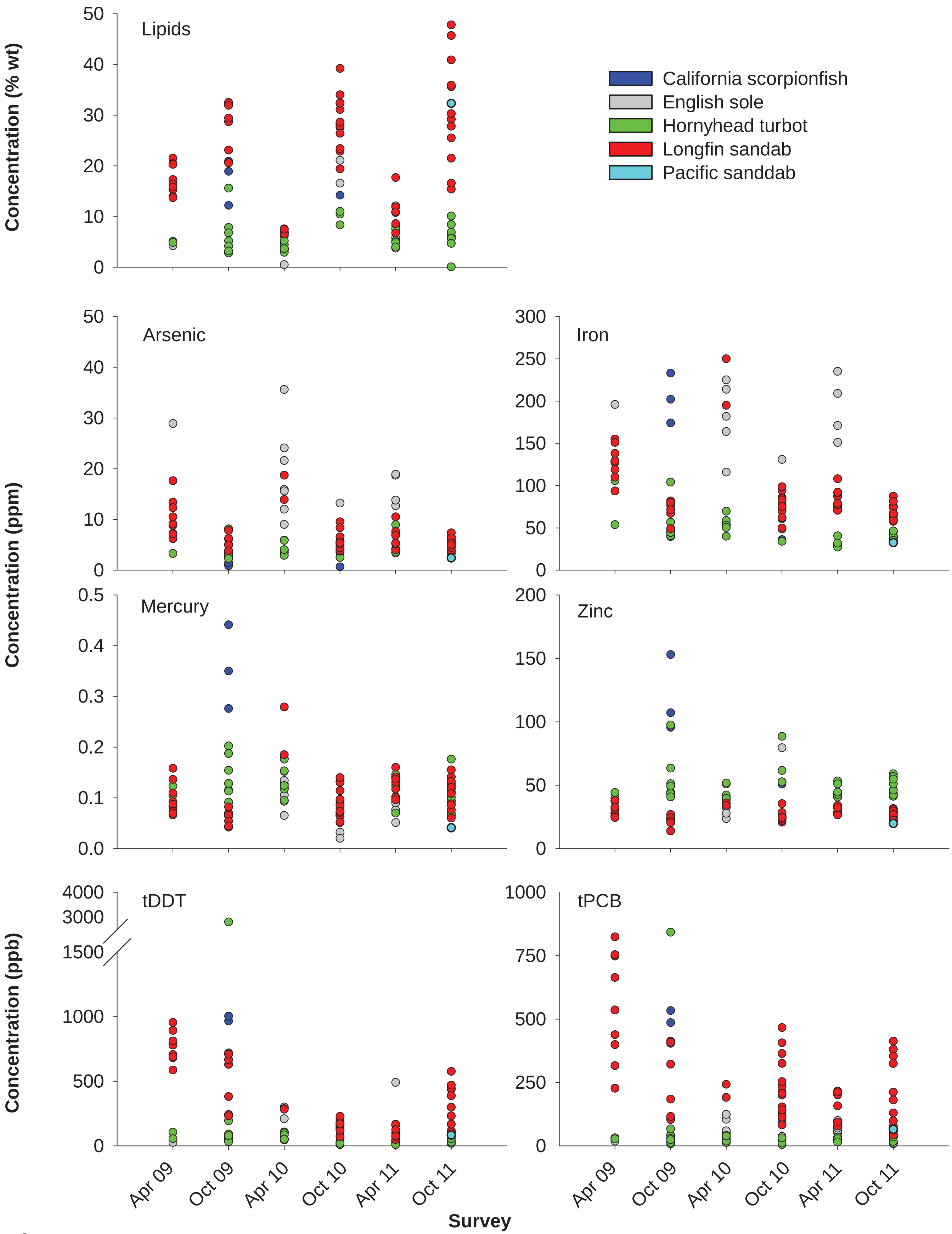



**Figure 7.5**
Concentrations of select parameters in liver tissues of fishes collected in the SBOO region between 2009 and 2011.

**Table 7.7**

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

| Parameter | Year-Quarter 2009-2 | 2009-4 | 2010-2 | 2010-4 | 2011-2 | 2011-4 |
|---|---|---|---|---|---|---|
| *Trace Metals (ppm)* | | | | | | |
| Aluminum | 14.10 | 5.44 | 7.80 | 0.00 | 0.53 | 0.58 |
| Antimony | 0.05 | 0.02 | 0.00 | 0.00 | **0.08** | 0.00 |
| Arsenic | **2.01** | 1.45 | 1.75 | **1.72** | **1.89** | **1.83** |
| Barium | **0.11** | 0.06 | 0.01 | 0.00 | 0.02 | 0.01 |
| Beryllium | 0.00 | **0.01** | 0.00 | 0.00 | 0.00 | 0.00 |
| Cadmium | **0.01** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Chromium | 0.178 | **0.225** | 0.023 | **0.065** | 0.249 | 0.092 |
| Copper | **1.150** | 0.390 | 0.432 | 0.322 | 0.661 | 0.345 |
| Iron | 4.52 | 1.29 | 1.24 | 0.00 | 2.91 | **1.49** |
| Lead | 0.00 | 0.00 | **0.04** | 0.00 | 0.00 | 0.00 |
| Manganese | 0.153 | 0.000 | 0.000 | 0.000 | **0.058** | **0.035** |
| Mercury | 0.150 | **0.170** | 0.172 | **0.194** | 0.143 | **0.120** |
| Nickel | 0.00 | 0.02 | 0.00 | 0.00 | **0.18** | 0.00 |
| Selenium | 0.233 | 0.278 | **0.388** | 0.204 | 0.312 | 0.287 |
| Silver | 0.00 | **0.06** | 0.00 | 0.00 | **0.02** | 0.00 |
| Thallium | 0.000 | **0.203** | 0.083 | 0.500 | 0.000 | **0.355** |
| Tin | 1.450 | 0.000 | 0.172 | 0.000 | 0.500 | 0.233 |
| Zinc | 5.44 | 3.13 | 3.97 | **3.54** | 4.13 | 4.31 |
| *Chlorinated Pesticides (ppb)* | | | | | | |
| HCB | **0.050** | 0.000 | **0.175** | 0.000 | 0.150 | 0.143 |
| Total DDT | 3.29 | 3.58 | **5.58** | **2.37** | 2.44 | 2.12 |
| *Total PCB (ppb)* | 0.46 | 1.13 | **4.97** | 0.50 | 2.28 | 1.20 |

exposure in other areas. Finally, there were no other indications of poor fish health in the region, such as the presence of fin rot, other indicators of disease, or any physical anomalies (see Chapter 6).

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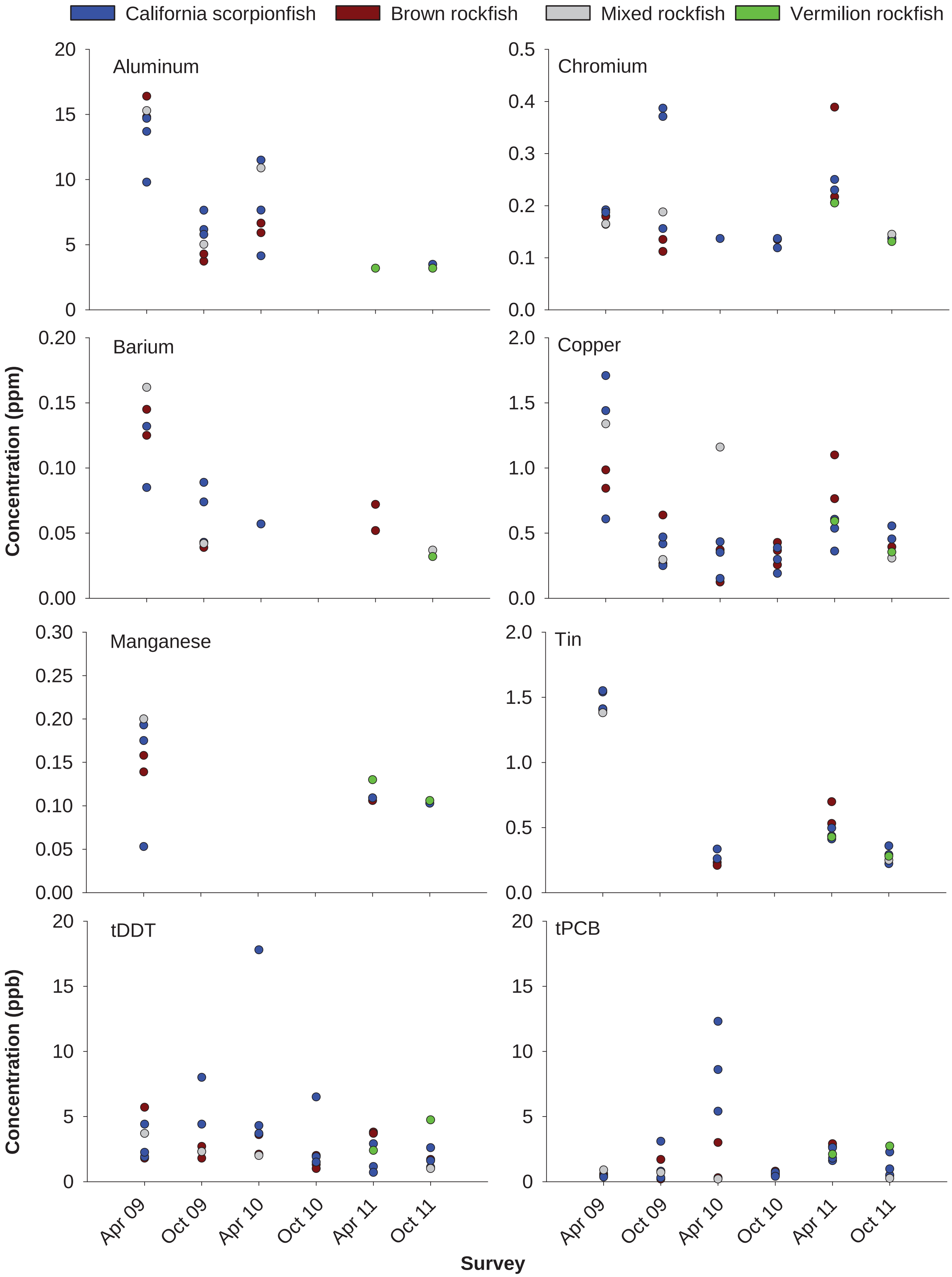


**Figure 7.6**
Concentrations of select parameters in muscle tissues of fishes collected in the SBOO region between 2009 and 2011.

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# Chapter 8
# San Diego Regional Survey
# Sediment Conditions

# Chapter 8. San Diego Regional Survey Sediment Conditions

## Introduction

Ocean sediments are the primary habitat for macrobenthic invertebrate and demersal fish communities on the coastal shelf and slope. The physical and chemical conditions of these sediments can therefore influence the ecological health of marine communities by affecting the distribution and presence of various species (Gray 1981, Cross and Allen 1993, Snelgrove and Butman 1994). For this reason, sediments have been sampled extensively near Southern California Bight (SCB) ocean outfalls in order to monitor benthic conditions around these and other point sources over the past several decades (Swartz et al. 1986, Anderson and Gossett 1987, Finney and Huh 1989, Stull 1995, Bay and Schiff 1997). Examples of such local assessments include the regular ongoing surveys conducted each year around the ocean outfalls operated by the City of Los Angeles, the City of San Diego, the Los Angeles County Sanitation District, and the Orange County Sanitation District, the four largest wastewater dischargers in the region (City of Los Angeles 2007, 2008, City of San Diego 2011a, b, LACSD 2010, OCSD 2011). In order to place data from these localized surveys into a broader biogeographic context, larger-scale regional monitoring efforts have also become an important tool for evaluating benthic conditions and sediment quality in southern California (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

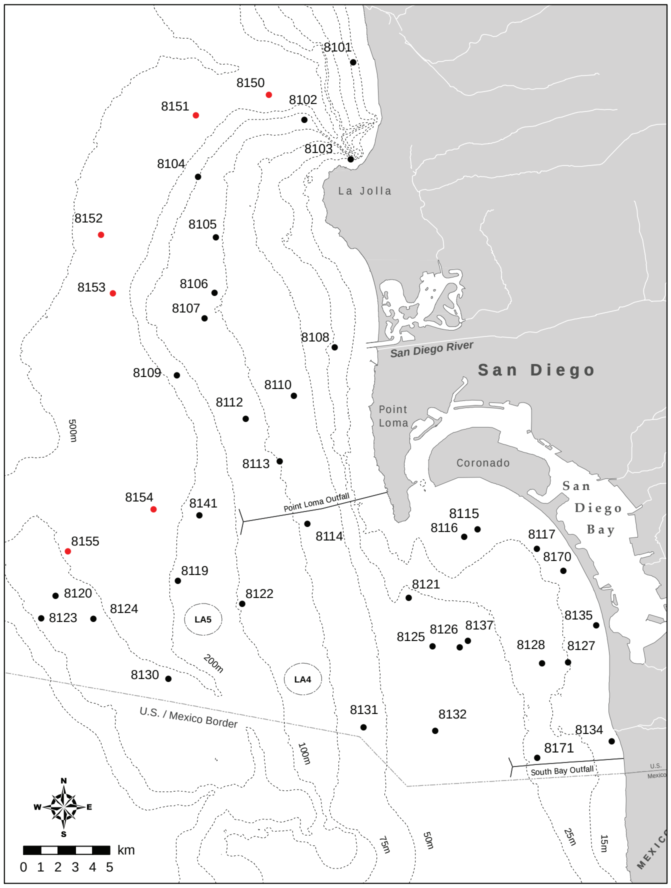
The City of San Diego has conducted annual regional benthic surveys off the coast of San Diego since 1994 (see Chapter 1). The primary objectives of these summer surveys, which typically range from Del Mar to the USA/Mexico border, are to (1) describe the overall condition and quality of the diverse benthic habitats that occur off San Diego, (2) characterize the ecological health of the soft-bottom marine benthos in the region, and (3) gain a better understanding of regional variation in order to distinguish anthropogenically-driven changes from natural fluctuations. These surveys typically occur at an array of 40 stations selected each year using a probability-based, random stratified sampling design as described in Bergen (1996), Stevens (1997), and Stevens and Olsen (2004). During 1995–1997, 1999–2002 and 2005–2007, the surveys off San Diego were restricted to continental shelf depths (<200 m), while the area of coverage was expanded beginning in 2009 to also include deeper habitats along the upper slope (200–500 m). No survey of randomly selected sites was conducted in 2004 due to sampling for a special sediment mapping project (Stebbins et al. 2004), while surveys in 1994, 1998, 2003 and 2008 were conducted as part of larger, multi-agency surveys of the entire SCB (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009).

This chapter presents analyses and interpretations of the sediment grain size and chemistry data collected during the 2011 regional survey of the continental shelf and upper slope off San Diego. Included are descriptions of the region's sediment conditions during the year, and comparisons of sediment characteristics and quality across the major depth strata defined by the SCB regional programs. Additionally, a multivariate analysis of sediment chemistry data collected from the 2009–2011 regional surveys is presented. Although regional data exist prior to this time period, 2009 represents the first year where upper slope sites were included as a fourth depth stratum, allowing this region to be comparable to the three continental shelf strata. Results of macrofaunal community analyses for these same sites are presented in Chapter 9.

## Materials and Methods

### Field Sampling

The July 2011 regional survey covered an area ranging from Del Mar in northern San Diego County




## Figure 8.1

Regional benthic survey stations sampled during July 2011 as part of the City of San Diego's Outfall Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

south to the USA/Mexico border (Figure 8.1). Overall, this survey included 41 stations ranging in depth from 10 to 427 m and spanning 4 distinct depth strata as characterized by the SCB regional monitoring programs (Schiff et al. 2006). These included 14 stations along the inner shelf (5–30 m), 14 stations along the mid-shelf (>30–120 m), 7 stations along the outer shelf (>120–200 m), and 6 stations on the upper slope (>200–500 m).

Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-$m^2$ surface area; the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 9) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987).

### Laboratory Analyses

All sediment chemistry and grain size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Grain size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of nested sieves. The Horiba measures particles ranging in size from about 0.5 to 2000 μm. Coarser sediments were removed and quantified prior to laser analysis by screening samples through a 2000 μm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%. When a sample contained substantial amounts of coarse sand, gravel, or shell hash that could damage the Horiba analyzer and/or where the general distribution of sediments would be poorly represented by laser analysis, a set of sieves with mesh sizes of 2000 μm, 1000 μm, 500 μm, 250 μm, 125 μm, and 63 μm was used to divide the samples into seven fractions. Sieve results and output from the Horiba were converted into grain size fractions (e.g., percent sand, silt, clay) based on the Wentworth scale (Appendix C.1). The proportion of fine particles (percent fines) was calculated as the sum of silt and clay fractions for each sample, and each sample was then categorized as a "sediment type" based on relative proportions of percent fines, sand, and coarser particles (Appendix C.2). The distribution of grain sizes within each sample was also summarized as mean particle size in microns, and the median, mean, and standard deviations of phi sizes. The latter values were calculated by converting raw data measured in microns into phi sizes, fitting appropriate distribution curves (e.g., normal probability curve for most Horiba samples), and then determining the descriptive statistics mentioned above.

Each sediment sample was also analyzed to determine concentrations of total organic carbon, total nitrogen, total sulfides, total volatile solids, trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis. Data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix G.1). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemical Services Laboratory (City of San Diego 2012).

### Data Analyses

Data summaries for the various sediment parameters measured included detection rates, means of detected values for all stations combined, and minimum, median, and maximum values. In addition, means of detected vales were calculated for each depth stratum. Total DDT (tDDT), PCB (tPCB), and PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix G.2 for individual constituent values). Spearman rank correlation was used to identify any association of percent fines with depth and each chemical parameter. This non-parametric analysis accounts for non-detects in the data (i.e., analyte concentrations < MDL) without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (Conover 1980). Therefore, a criterion of < 50% non-detects was used to screen eligible constituents for this analysis.

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).

In order to examine spatial and temporal patterns in overall sediment condition in the San Diego region, a cluster analysis was performed using a 3-year data matrix comprised of the main chemical parameters analyzed for each site (i.e., trace metals, indicators of organic loading, pesticides, total PCBs, total PAHs). This analysis was conducted for all data collected between 2009 and 2011 using PRIMER software (see Clarke and Warwick 2001, Clarke and Gorley 2006). Any non-detects (see above) were first converted to "0" values to avoid data deletion issues with the clustering program, after which the data were normalized and a Euclidean distance matrix was created. Similarity profile (SIMPROF) analyses were used to confirm the non-random structure of the resultant dendrogram (Clarke et al. 2008), and major ecologically-relevant clusters supported by SIMPROF were retained at 5.78% dissimilarity. Similarity percentages (SIMPER) analysis was subsequently used to identify which parameters primarily accounted for observed differences among cluster groups, as well as to identify the parameters typical of each group.

## Results

### Sediment Grain Size Composition

Ocean sediments were diverse at the benthic stations sampled during the summer 2011 regional survey (Table 8.1). The fine, sand, and coarse sediment fractions ranged between 0–79%, 21–96%, and 0–49%, respectively. Additionally, observations recorded for benthic infauna samples revealed the presence of coarse red relict sands, coarse black sands, gravel, rock, shell hash and/or organic debris at different stations (see Appendix G.3). Overall, sediment composition varied as expected by region and depth stratum (Figure 8.2, Appendices G.3, G.4). For example, sediments from regional sites collected along the inner and middle shelf in the SBOO region tended to be predominantly sand (~84%), whereas those collected along the middle and outer shelf in the PLOO region generally had much finer sediments (~55% fines). Correlation analysis confirmed that percent fines generally increased with depth (Table 8.2, Figure 8.3A), a pattern that has been consistent over the past three years (Figure 8.4A). Notable

## Table 8.1

Summary of sediment grain sizes and sediment chemistry concentrations in sediments from regional benthic stations sampled during 2011. Data include detected values averaged by depth stratum, as well as the detection rate (DR), minimum, median, maximum, and mean values for the entire survey area; *n* = number of stations; SD = standard deviation.

| | Depth Strata | | | | 2011 Survey Area[a] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Inner Shelf | Mid-shelf | Outer Shelf | Upper Slope | | | | | |
| | *n* = 14 | *n* = 14 | *n* = 7 | *n* = 6 | DR (%) | Min | Median | Max | Mean |
| *Sediment Grain Size* | | | | | | | | | |
| Mean (*µm*) | 226 | 107 | 176 | 54 | — | 38 | 106 | 848 | 151 |
| Mean (*phi*) | 2.8 | 4.2 | 3.5 | 5.1 | — | 0.6 | 3.8 | 5.6 | 3.7 |
| SD (*phi*) | 1.0 | 1.5 | 1.6 | 1.7 | — | 0.9 | 1.5 | 2.1 | 1.4 |
| Coarse (*%*) | 4.4 | 0.4 | 2.6 | 0.0 | — | 0.0 | 0.0 | 48.5 | 2.1 |
| Sand (*%*) | 84.4 | 57.3 | 65.8 | 32.4 | — | 20.7 | 66.2 | 96.2 | 64.4 |
| Fines (*%*) | 11.2 | 42.3 | 31.6 | 67.6 | — | 0.0 | 30.7 | 79.3 | 33.5 |
| *Organic Indicators* | | | | | | | | | |
| Sulfides (*ppm*) | 10.7 | 6.9 | 9.2 | 88.0 | 98 | nd | 7.7 | 444.0 | 20.7 |
| TN (*% weight*) | 0.031 | 0.094 | 0.086 | 0.163 | 100 | 0.011 | 0.048 | 0.268 | 0.081 |
| TOC (*% weight*) | 0.28 | 0.53 | 1.66 | 1.85 | 100 | 0.03 | 0.63 | 4.71 | 0.83 |
| TVS (*% weight*) | 0.85 | 2.35 | 3.36 | 5.87 | 100 | 0.44 | 2.43 | 7.15 | 2.53 |
| *Trace Metals* (*ppm*) | | | | | | | | | |
| Aluminum | 3472 | 7645 | 5011 | 13,775 | 100 | 791 | 5430 | 17,000 | 6668 |
| Antimony | 0.42 | 0.63 | 0.48 | 0.68 | 63 | nd | 0.46 | 0.86 | 0.58 |
| Arsenic | 2.45 | 4.62 | 5.51 | 6.00 | 100 | 1.28 | 4.57 | 10.50 | 4.23 |
| Barium | 26.8 | 44.6 | 33.7 | 75.4 | 100 | 2.4 | 39.4 | 97.6 | 41.1 |
| Beryllium | 0.066 | 0.157 | 0.189 | 0.244 | 100 | 0.021 | 0.143 | 0.308 | 0.144 |
| Cadmium | 0.178 | 0.171 | 0.161 | 0.377 | 73 | nd | 0.145 | 0.610 | 0.211 |
| Chromium | 7.8 | 16.3 | 17.4 | 26.1 | 100 | 2.8 | 13.9 | 30.4 | 15.0 |
| Copper | 2.88 | 7.60 | 8.45 | 15.20 | 100 | 0.21 | 5.78 | 20.40 | 7.25 |
| Iron | 5025 | 11,235 | 10,573 | 17,035 | 100 | 2070 | 9310 | 23,200 | 9850 |
| Lead | 2.51 | 6.62 | 5.88 | 9.36 | 100 | 1.09 | 5.39 | 12.50 | 5.49 |
| Manganese | 46.9 | 91.5 | 62.3 | 137.2 | 100 | 10.4 | 70.0 | 201.0 | 78.0 |
| Mercury | 0.015 | 0.038 | 0.038 | 0.061 | 83 | nd | 0.021 | 0.124 | 0.036 |
| Nickel | 2.84 | 8.23 | 7.60 | 14.81 | 93 | nd | 5.04 | 20.40 | 7.31 |
| Selenium | nd | nd | nd | 0.372 | 12 | nd | nd | 0.600 | 0.372 |
| Silver | nd | 0.083 | nd | 0.051 | 5 | nd | nd | 0.083 | 0.067 |
| Thallium | nd | nd | nd | nd | 0 | — | — | — | — |
| Tin | 0.563 | 1.426 | 0.869 | 1.443 | 90 | nd | 0.780 | 2.020 | 1.044 |
| Zinc | 13.3 | 28.4 | 26.5 | 48.1 | 100 | 5.0 | 25.1 | 64.0 | 25.8 |
| *Pesticides* (*ppt*) | | | | | | | | | |
| Total DDT | 635 | 538 | 572 | 970 | 56 | nd | 380 | 1500 | 626 |
| *Total PCB (ppt)* | nd | 3460 | 4530 | nd | 5 | nd | nd | 4530 | 3995 |
| *Total PAH (ppb)* | 21.2 | 49.1 | 473.7 | 28.6 | 29 | nd | nd | 473.7 | 80.4 |

nd = not detected

[a] Minimum, median, and maximum values were calculated based on all samples ($n = 41$), whereas means were calculated on detected values only ($n \leq 41$).

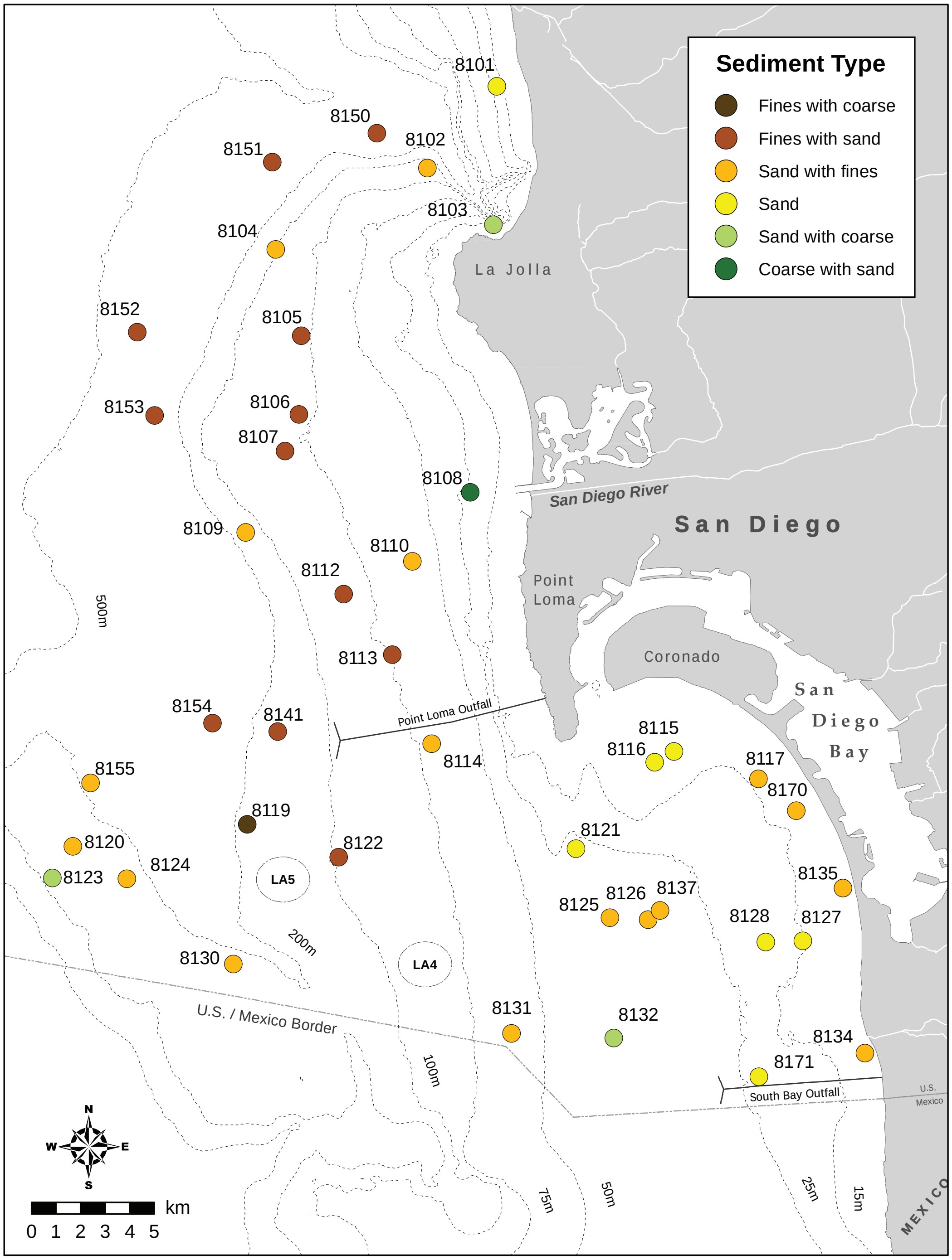



**Figure 8.2**
Distribution of sediment types at regional benthic stations sampled during July 2011.

exceptions to this pattern included samples from inner shelf station 8170 (located off Coronado beach), which had relatively high percent fines compared to nearby stations (46% versus ≤18.6%), and samples from outer shelf/upper slope stations located on the Coronado Bank (8120, 8123 8124, 8130, 8155), each of which had lower percent fines (≤46%) than other stations at similar depths (Figure 8.2, Appendicies G.3, G.4).

The sorting coefficient is calculated as the standard deviation (SD) in phi size units for each sample,

**Table 8.2**
Results of Spearman rank correlation analyses of percent fines versus depth and various sediment chemistry parameters from regional benthic samples collected in 2011. Shown are analytes that had correlation coefficients $r_s \geq 0.70$. For all analyses $p < 0.0001$; $n$ = the number of detected values. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 8.3.

| Analyte | *n* | $r_s$ |
|---|---|---|
| *Depth* | 41 | 0.71 |
| *Organic Indicators (% weight)* | | |
| Total Nitrogen | 41 | 0.78 |
| Total Volatile Solids | 41 | 0.90 |
| *Trace Metals (ppm)* | | |
| Aluminum | 41 | 0.93 |
| Antimony | 26 | 0.83 |
| Barium | 41 | 0.87 |
| Beryllium | 41 | 0.87 |
| Chromium | 41 | 0.88 |
| Copper | 41 | 0.94 |
| Iron | 41 | 0.92 |
| Lead | 41 | 0.92 |
| Manganese | 41 | 0.86 |
| Mercury | 34 | 0.87 |
| Nickel | 38 | 0.94 |
| Tin | 37 | 0.85 |
| Zinc | 41 | 0.94 |

therefore reflecting the range of sediment grain sizes present, and is considered indicative of the level of disturbance (e.g., fluctuating or variable currents and sediment deposition) in an area. Regionally, sediments ranged from moderately to very poorly sorted during 2011, with sorting coefficients ranging from 0.9 to 2.1 phi (Table 8.1, Appendix G.3). The most well sorted sediments (i.e., SD < 1.0 phi) were collected from seven inner shelf stations located throughout the region (8101, 8103, 8115, 8116, 8127, 8128, 8171). The sediments most likely exposed to higher levels of disturbance (i.e., SD ≥ 2.0 phi) occurred at two mid-shelf and one upper slope station (8131, 8122, 8155). These sites were located offshore of the SBOO, inshore of the LA5 dredge spoils dumpsite, and on the Coronado Bank, respectively.

### Indicators of Organic Loading

Sulfides were detected in 98% of the 2011 regional sediment samples at concentrations between 0.78–444 ppm with no discernible spatial or depth patterns (Table 8.1, Appendix G.5). Unusually high sulfide values occurred at the upper slope station 8150, located within La Jolla canyon, upper slope station 8153, located offshore of Mission Beach, and inner shelf station 8134, located near the mouth of the Tijuana River. These values (444, 52, 85 ppm, respectively) were at least seven times higher than all other sulfide concentrations reported off San Diego over the past three years (Figure 8.4B), as well as those reported for SBOO or PLOO fixed grid stations in 2011 (see Chapter 4, City of San Diego 2011a).

Total nitrogen (TN), total organic carbon (TOC) and total volatile solids (TVS) were detected in all regional samples and concentrations of these parameters increased across depth strata (Table 8.1). For example, TN averaged 0.031% wt at the inner shelf stations versus 0.163% wt at upper slope stations, while TOC averaged 0.28% wt versus 1.85% wt and TVS averaged 0.85% wt versus 5.87% wt. Additionally, TN and TVS were positively correlated with the percent fines in each sample (Table 8.2, Figure 8.3B) and mirrored changes in percent fines from 2009 to 2011 (Figure 8.4A). In contrast, TOC has been more variable over this 3-year period (Figure 8.4C).

### Trace Metals

Ten trace metals were found in all sediment samples collected during the 2011 regional survey, including aluminum, arsenic, barium, beryllium, chromium, copper, iron, lead, manganese, and zinc (Table 8.1). Antimony, cadmium, mercury, nickel, and tin were also detected frequently at rates between 63–93%, while selenium and silver occurred in ≤12% of the samples. Thallium was not detected during this survey. Almost all metals were found at low levels below both ERL and ERM thresholds. The only exception

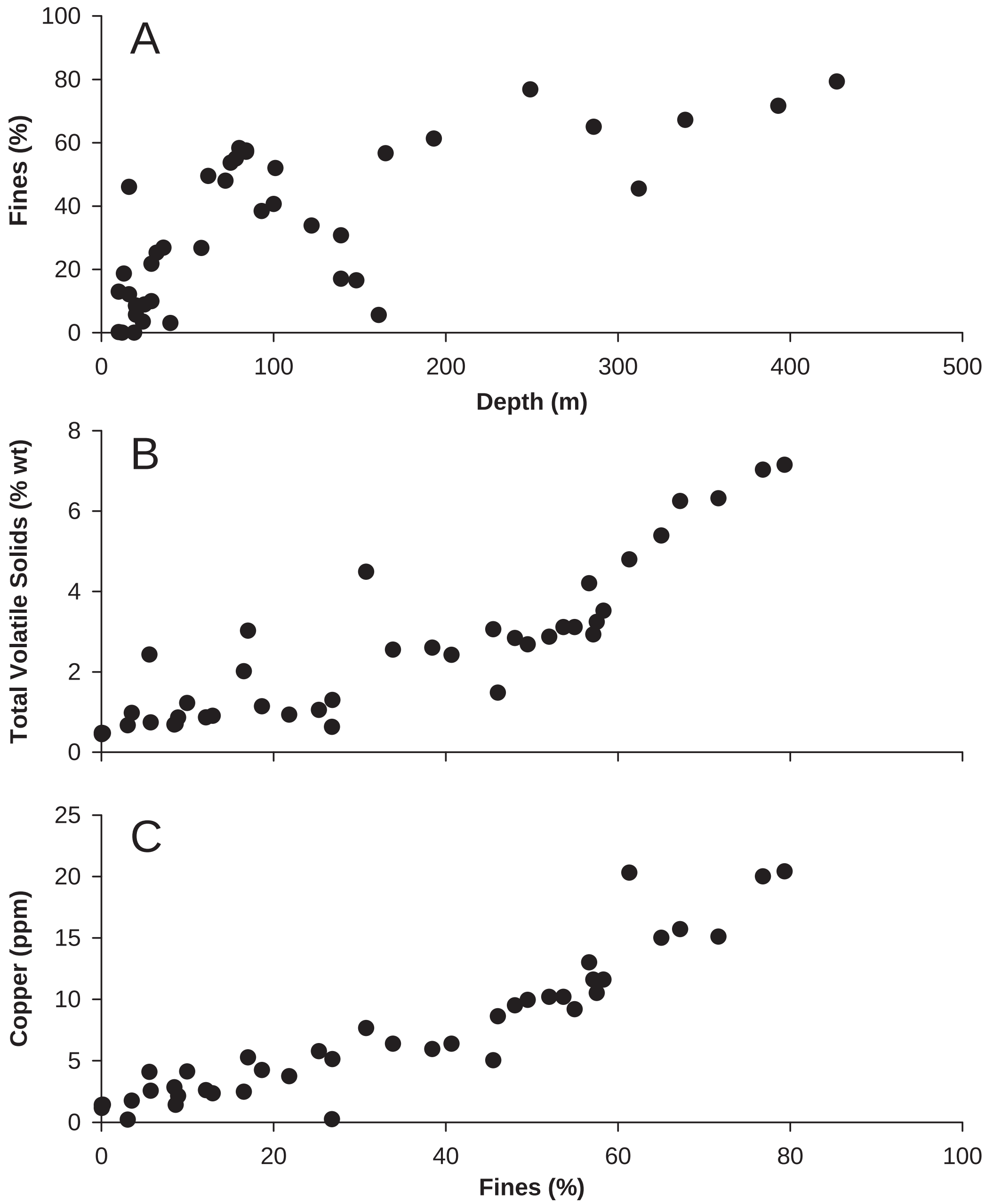
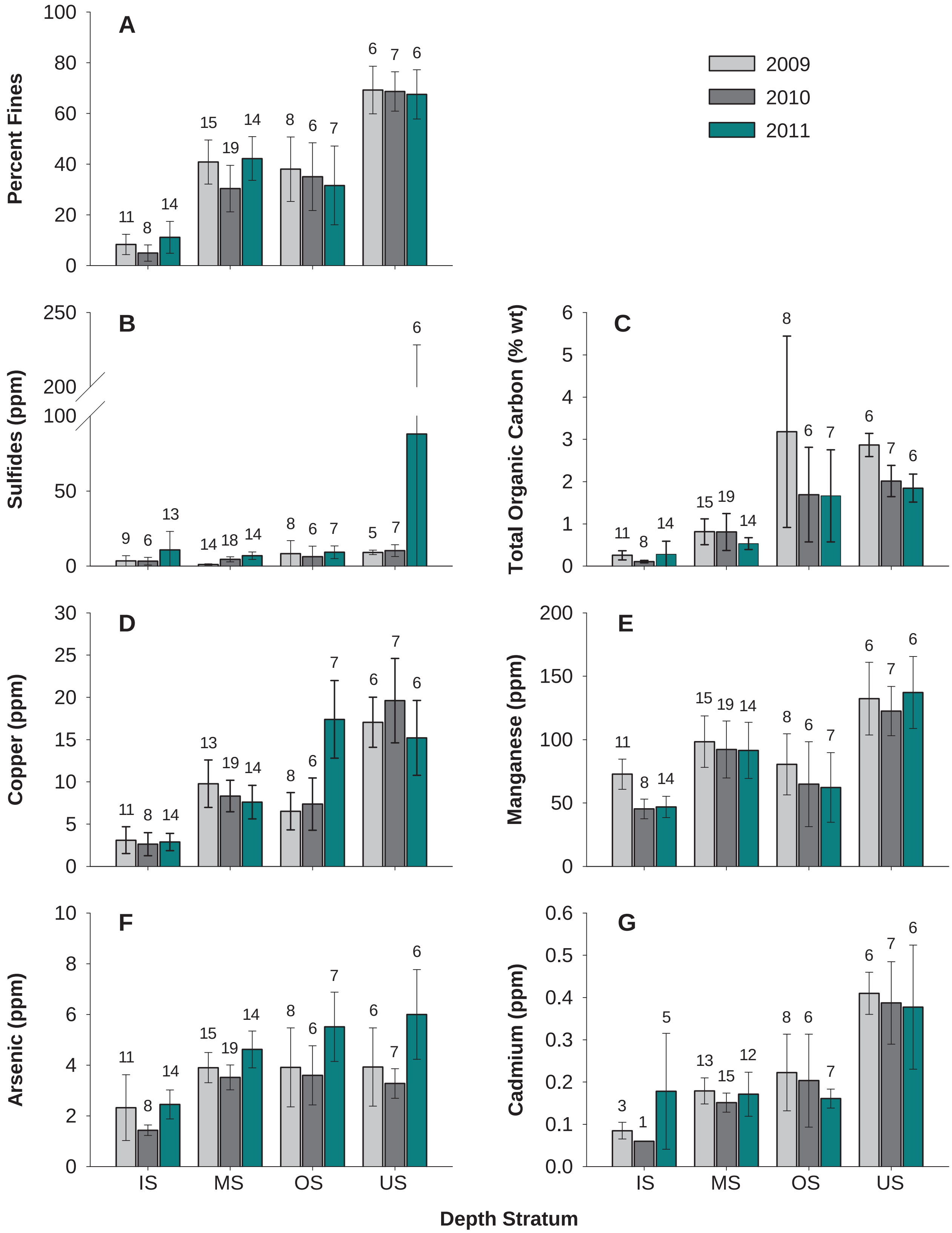



**Figure 8.3**
Scatterplot of percent fines versus (A) depth, (B) total volatile solids, and (C) copper in sediments from regional benthic stations sampled during 2011.

was arsenic, which exceeded its ERL (but not ERM) at stations 8130 and 8150 (Appendix G.5). Concentrations of aluminum, antimony, barium, beryllium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, zinc were positively correlated with percent fines (Table 8.2, Figure 8.3). Therefore the highest concentrations of these metals tended to occur at the upper slope stations where the greatest proportions of fine material were found (e.g., stations 8150, 8153, 8154; Appendix G.5). These results were somewhat consistent with those reported during 2009 and 2010 (e.g., Figure 8.4A, D, E). Although arsenic and cadmium were not correlated as strongly with percent fines (i.e., $r_s < 0.70$), their concentrations also tended to increase across depth strata (i.e., inner shelf versus upper slope) during 2009, 2010, and 2011 (Table 8.1, Figure 8.4F, G).




## Figure 8.4

Comparison of representative sediment grain size and chemistry parameters in sediments from the four major depth strata sampled during regional surveys between 2009–2011. Data are expressed as means ±95% confidence intervals calculated on detected values only; IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope. Numbers above bars represent number of detected values.

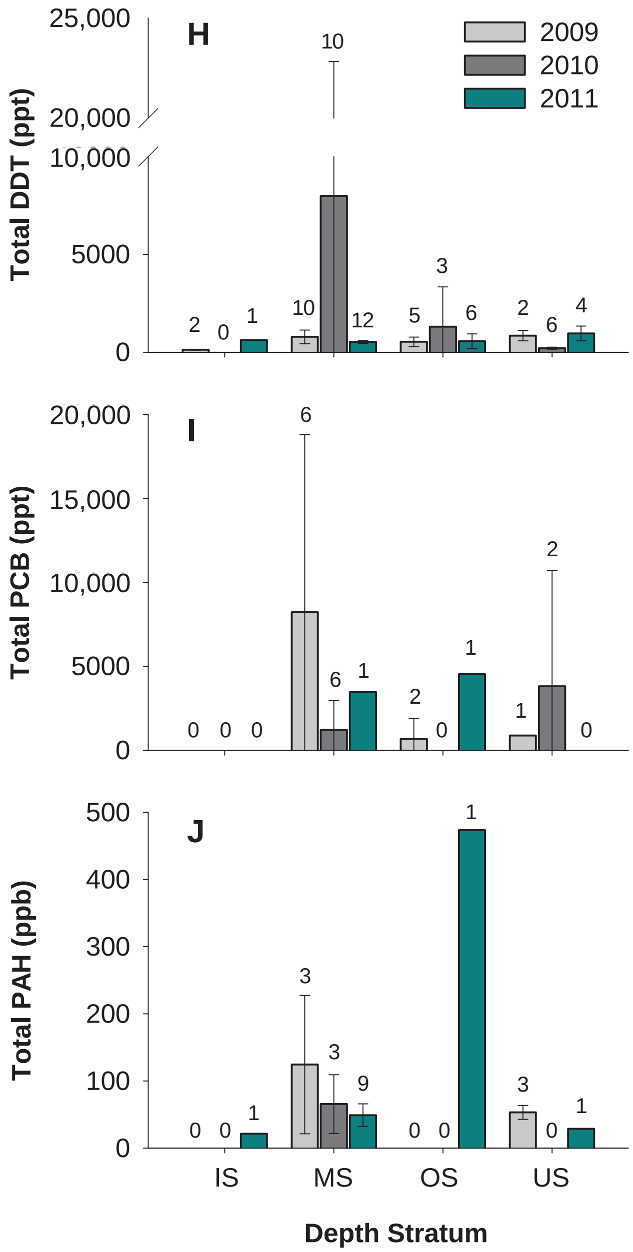



**Figure 8.4** *continued*

### Pesticides

Total DDT, consisting solely of p,p-DDE, was the only pesticide detected during the 2011 regional survey. It was detected at a rate of 56% at concentrations below threshold values (i.e., <1580 ppt; Table 8.1, Appendix G.5). This pesticide was found at 86% of the middle and outer shelf stations, 67% of the upper slope stations, but only 7% of the inner shelf stations. Concentrations ≥1000 ppt occurred at outer shelf station 8141 and upper slope stations 8151 and 8153. In contrast, tDDT was below 770 ppt at all inner and mid-shelf stations. From 2009 to 2011, DDT levels were variable, with no discernible spatial patterns except low detection rates at inner shelf stations (Figure 8.4H).

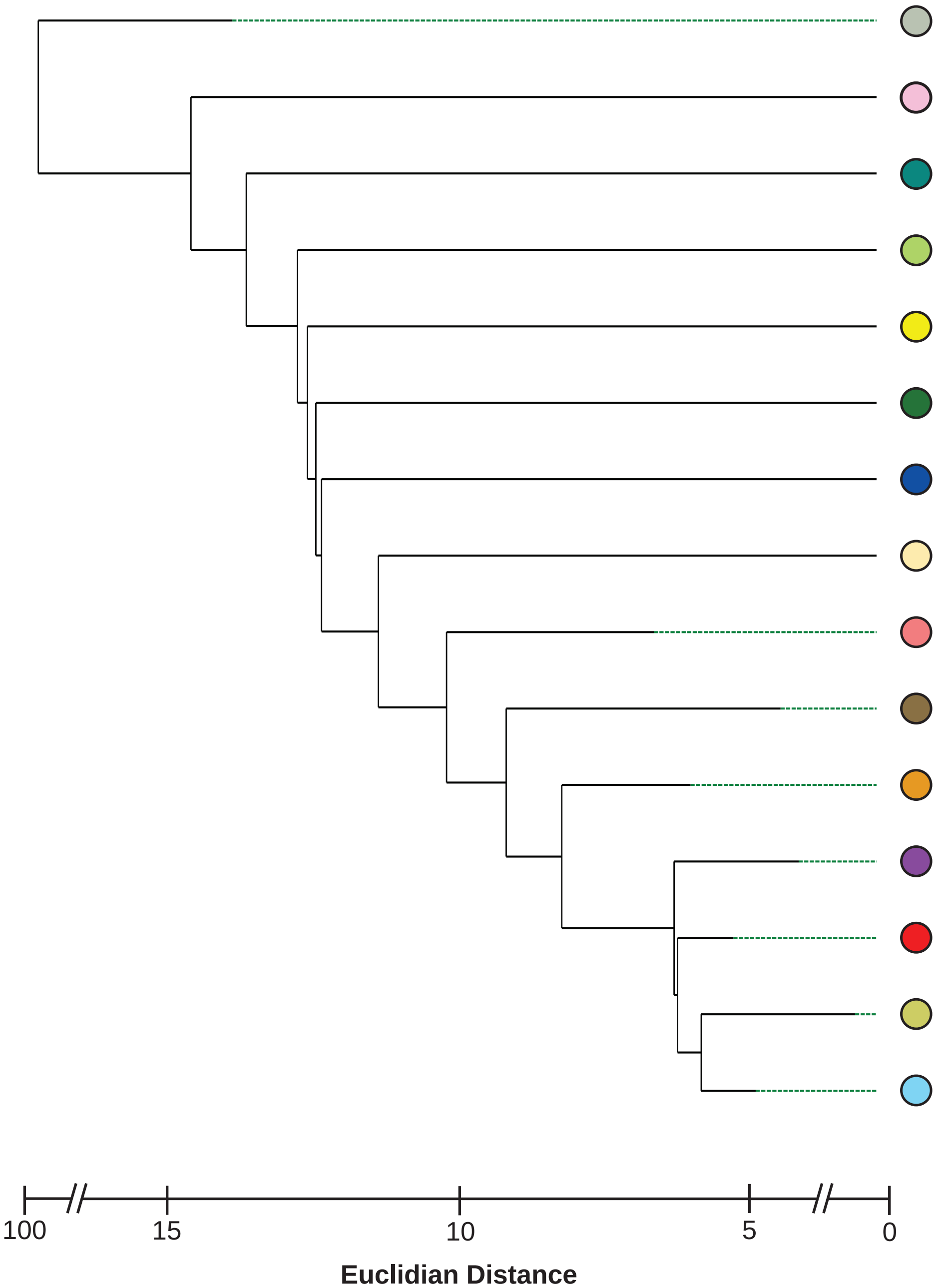
### PCBs and PAHs

PCBs were detected in sediments from just two regional stations (8126, 8119), at concentrations of 3460 and 4530 ppt, respectively (Table 8.1, Appendix G.5). Total PCB from these samples primarily consisted of congeners PCB 101, PCB 110, PCB 138, and PCB 149 (Appendix G.2). As with tDDT, tPCB levels have been variable over the past three years, with no detected values found in sediments from the inner shelf (Figure 8.4I).

PAHs were detected at 29% of the regional stations at concentrations well below threshold values (i.e., <4022 ppb; Table 8.1, Appendix G.5). PAHs occurred primarily at middle shelf stations, at a rate of 64%. In contrast, PAHs were found in only one sample from the inner shelf (8101), outer shelf (8119) and upper slope (8150). Sediments from station 8119 had the highest concentration of tPAH at about 474 ppb. The compounds dibenzo (A,H) anthracene, 2,6-dimethylnaphthalene, benzo [G,H,I] perylene, and indeno (1,2,3-CD) pyrene had detection rates between 7 and 17%, whereas fluoranthene, pyrene, anthracene, benzo [A] anthracene, benzo [e] pyrene, benzo [A] pyrene, and chrysene were each reported only once (Appendix G.2). As with tDDT and tPCB, the occurrence and concentrations of tPAH have been variable over the past three years (Figure 8.4J).

### Classification of Sediment Conditions

Results of cluster analyses performed on all sediment chemistry data collected between 2009 and 2011 discriminated 15 groups of sediment samples (Figures 8.5, 8.6). These groups (cluster groups A–O) differed in relative

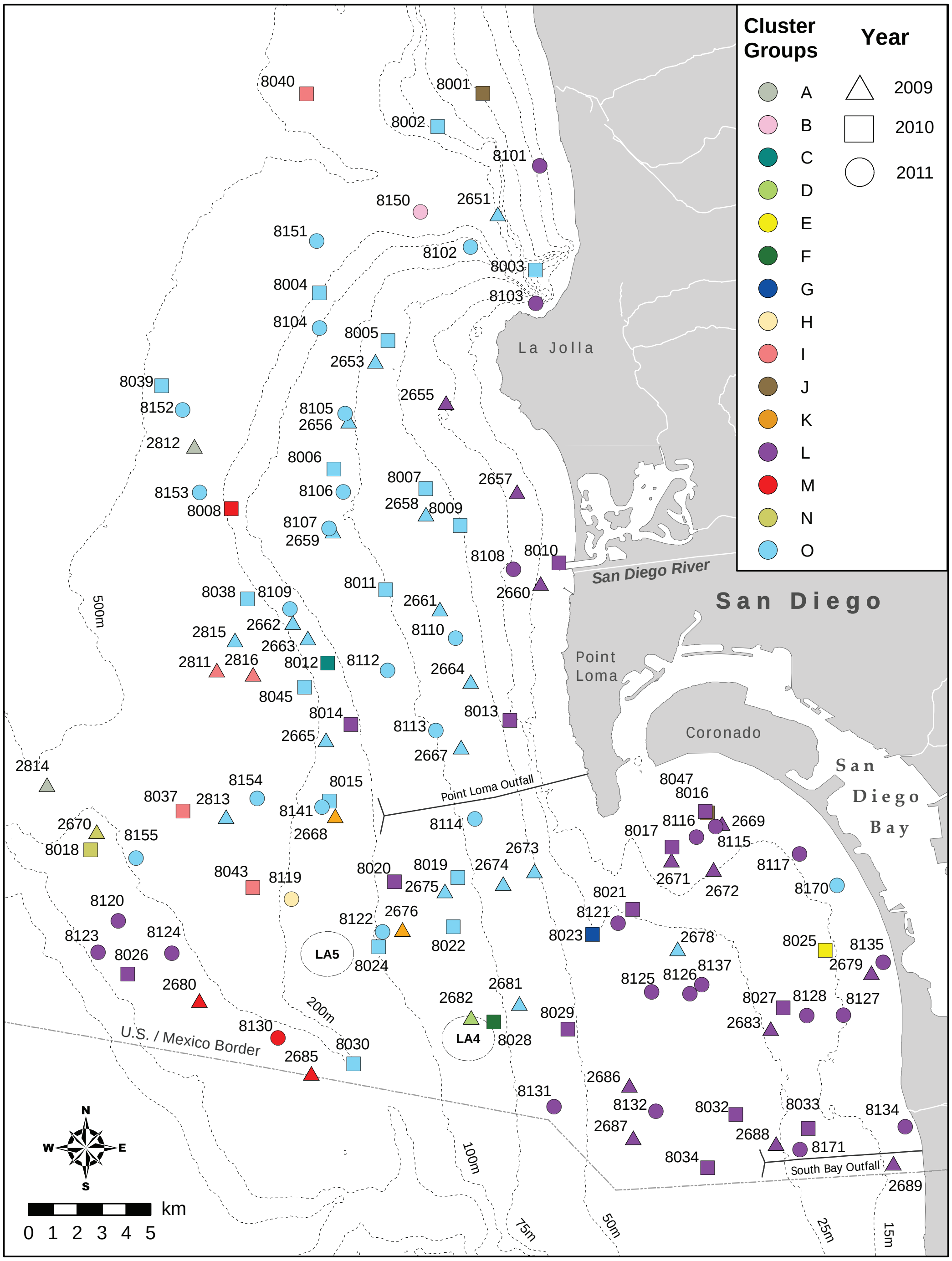



| Cluster Group | *n* | % Fines | Depth (m) |
|---|---|---|---|
| A | 2 | 58.5 (49.4–67.7) | 385 (357–413) |
| B | 1 | 79.3 — | 427 — |
| C | 1 | 35.7 — | 123 — |
| D | 1 | 41.7 — | 84 — |
| E | 1 | 12.6 — | 17 — |
| F | 1 | 43.7 — | 80 — |
| G | 1 | 6.1 — | 31 — |
| H | 1 | 61.3 — | 193 — |
| I | 5 | 79.5 (78.0–82.5) | 340 (222–421) |
| J | 2 | 15.2 (0.5–29.9) | 30 (9–50) |
| K | 2 | 46.1 (43.3–48.8) | 123 (95–151) |
| L | 45 | 10.1 (0.0–39.5) | 39 (9–161) |
| M | 4 | 26.6 (18.2–33.4) | 131 (122–139) |
| N | 2 | 11.2 (5.3–17.0) | 165 (161–169) |
| O | 52 | 50.2 (3.7–76.8) | 133 (16–433) |

## Figure 8.5

Cluster analyses of sediment chemistry data from regional benthic stations sampled between 2009−2011. Data for depth and percent fines include the mean (range) of values calculated over all stations within each group (*n*).

concentrations of metals, pesticides, total PCB and total PAH in each sample (Appendices G.6, G.7). Contaminant levels present in 2011 were generally similar to previous years. They varied along a general depth gradient, as well as by region. The two main groups (cluster groups L and O) contained 80% of the 121 samples. Group L comprised 45 sites primarily located either within the South Bay monitoring region, or at depths < 25 m from Del Mar to Point Loma, and were characterized by relatively coarse/sandy sediments (e.g., ~10% fines). This group corresponds to cluster group F described in Chapter 4. Group O comprised 52 mid-depth sites with finer sandy




## Figure 8.6

Spatial distribution of cluster groups in the San Diego region. Colors of each circle correspond to colors in Figure 8.5 dendrogram.

sediments (e.g., ~50% fines) located in the "mud belt" of the PLOO region (see Chapter 5, Chapter 9, and Thompson et al. 1993). With one exception, contaminant levels were below accepted thresholds in both cluster group L and O. The exception was arsenic, which exceeded the ERL for this parameter. Together, these two groups represent typical background conditions for the San Diego region.

The thirteen remaining cluster groups each comprised 1–5 outlier samples, which differed from groups L and O primarily by having higher values of a few select contaminants (Figure 8.5, Appendices G.6, G.7). For example, 42% of these samples contained at least one contaminant that exceeded its ERL or ERM. Eight outliers (groups A, B, I) were found along the upper slope at depths between 222–427 m and were characterized by the highest proportions of fine material (49–82%) and the highest concentrations of aluminum, antimony, arsenic, chromium, iron, nickel, selenium, and tin. Additionally, sediments from stations 2812 and 2814 (group A) were the only to contain chlordane and the gamma isomer of HCH. Another five outliers from groups M and N (sites 2670, 2680, 2685, 8018, 8130) were collected on the Coronado Bank at depths between 122–169 m. Sediments from these sites had low percent fines (≤33%) compared to other sites at similar depths (see discussion in Chapter 4), and were characterized by relatively high concentrations of TOC, arsenic, barium, chromium or iron. The two outliers represented by groups D and F (sites 2682 and 8028, respectively) were collected at the LA4 dredge spoils dumpsite at about 80 m. These had the highest concentrations of tPCBs and tDDTs found during 2009−2011 surveys. At station 2682, tDDT exceeded its ERL, while tDDT exceeded its ERM at station 8028. Four outliers represented by groups C, H, and K occurred throughout the PLOO monitoring region and three outliers represented by groups E, G and J occurred throughout the SBOO monitoring region. These samples were characterized by concentrations of chemistry parameters that were intermediate to those characteristic of groups L and O versus those described above.

## Discussion

Sediment grain size composition at the regional benthic stations sampled in 2011 were typical for the continental shelf and upper slope off the coast of southern California (Emery 1960), and consistent with results from previous surveys (e.g., City of San Diego 2008–2011b). Overall, sediments varied as expected by region and depth stratum. For example, regional stations sampled along the inner and middle shelf within the vicinity of SBOO fixed-grid stations (see Chapter 4) tended to be predominantly sand (~84%), whereas regional stations sampled along the middle and outer shelf within the vicinity of PLOO fixed-grid stations (see City of San Diego 2011a) tended have much finer sediments (~55% fines). However, exceptions to this overall pattern occurred throughout the region, particularly along the Coronado Bank, a southern rocky ridge located southwest of Point Loma at depths of 150–170 m. Sediment composition at stations from this area tend to be coarser than stations at similar depths located off of Point Loma and further to the north. Much of the variability in sediment grain size composition throughout the region may be due to the complexities of seafloor topography and current patterns, both of which affect sediment transport and deposition (Emery 1960, Patsch and Griggs 2007). Additionally, several other stations lie within accretion zones of coastal littoral cells and receive more frequent deposition of sands and fine sediments. The diverse sediment transport and deposition patterns are further illustrated by the range of sorting coefficients measured in regional sediments in 2011. The most well sorted sediments (i.e., with the lowest sorting coefficients) were collected from inner shelf stations and are indicative of areas subject to consistent, moderate currents. In contrast, the sediments most likely exposed to higher levels of disturbance (i.e., with the highest sorting coefficients) occurred at deeper stations of the middle shelf and upper slope located near the LA5 dredge spoils dumpsite and along the Coronado Bank. This level of sorting is typical of areas with fluctuating weak to violent currents or rapid deposition (e.g., resulting from storm surge or dredge material dumping) that often result in highly variable or patchy sediment grain size distributions (Folk 1980).

As with sediment grain size composition, regional patterns of sediment contamination in 2011 were similar to patterns seen in previous years. There was no evidence of degraded sediment quality in the general San Diego region. While various indicators of organic loading, trace metals, chlorinated pesticides, PCBs and PAHs were detected at variable concentrations in sediment samples collected throughout the region, almost all contaminants occurred at levels below both ERL and ERM thresholds, as they have in previous years (City of San Diego 2008–2011b). The only exception during 2011 was arsenic, which exceeded the ERL threshold at two stations. Further, there was no evidence of disturbance during the 2009−2011 regional surveys that could be attributed to local wastewater discharges. Instead, concentrations of total nitrogen, total volatile solids and several trace metals were found to increase with increasing amounts of fine sediments (percent fines). As percent fines also increased with depth in the region, many contaminants were detected at higher concentrations in deeper strata compared to the shallow and mid-shelf regions. For example, the highest concentrations of most contaminants occurred in sediments along the upper slope, where some of the finest sediments were measured. This association is expected due to the known correlation between sediment size and concentration of organics and trace metals (Eganhouse and Venkatesan 1993). Finally, concentrations of these contaminants remained relatively low compared to many other coastal areas located off southern California (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, City of San Diego 2007, Maruya and Schiff 2009).

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# Chapter 9
# San Diego Regional Survey
# Macrobenthic Communities

# *Chapter 9. San Diego Regional Survey Macrobenthic Communities*

## Introduction

Macrobenthic invertebrates fulfill essential roles as nutrient recyclers and bioeroders in marine ecosystems throughout the world (Fauchald and Jones 1979, Thompson et al. 1993, Snelgrove et al. 1997). In the Southern California Bight (SCB), the structure of these communities is influenced by numerous natural factors (see Chapter 5), especially depth gradients and/or sediment grain size (Bergen et al. 2001). Because of their ability to serve as reliable indicators of pollution or other environmental stressors, benthic macrofauna have been sampled extensively for the past several decades in order to monitor potential changes around SCB ocean outfalls and other point sources at small spatial scales (Stull et al. 1986, 1996, Swartz et al. 1986, Ferraro et al. 1994, Zmarzly et al. 1994, Diener and Fuller 1995, Diener et al., 1995, Stull 1995). Examples of such local assessments include the regular ongoing surveys conducted each year around the ocean outfalls operated by the City of Los Angeles, the City of San Diego, the Los Angeles County Sanitation District, and the Orange County Sanitation District, the four largest wastewater dischargers in the region (City of Los Angeles 2007, 2008, City of San Diego 2011a, b, LACSD 2010, OCSD 2011). In order to place data from these localized surveys into a broader biogeographic context, larger-scale regional monitoring efforts have also become an important tool for evaluating benthic conditions and sediment quality in southern California (Bergen et al. 1998, 2000, Hyland et al. 2003, Ranasinghe et al. 2003, 2007, 2012, USEPA 2004).

The City of San Diego has conducted annual regional benthic surveys off the coast of San Diego since 1994 (see Chapter 1). The primary objectives of these summer surveys, which typically range from Del Mar to the USA/Mexico border, are to (1) describe the overall condition and quality of the diverse benthic habitats that occur off San Diego, (2) characterize the ecological health of the soft-bottom marine benthos in the region, and (3) gain a better understanding of regional variation in order to distinguish anthropogenically-driven changes from natural fluctuations. These surveys typically occur at an array of 40 stations selected each year using a probability-based, random stratified sampling design as described in Bergen (1996), Stevens (1997), and Stevens and Olsen (2004). During 1995–1997, 1999–2002 and 2005–2007, the surveys off San Diego were restricted to continental shelf depths (<200 m), while the area of coverage was expanded beginning in 2009 to also include deeper habitats along the upper slope (200–500 m). No survey of randomly selected sites was conducted in 2004 due to sampling for a special sediment mapping project (Stebbins et al. 2004), while surveys in 1994, 1998, 2003 and 2008 were conducted as part of larger, multi-agency surveys of the entire SCB (Bergen et al. 1998, 2001, Ranasinghe et al. 2003, 2007, 2010, 2012).

This chapter presents analyses and interpretations of the benthic macrofaunal data collected during the 2011 regional survey of the continental shelf and upper slope off San Diego. Included are descriptions and comparisons of the soft-bottom macrobenthic assemblages present, as well as the corresponding analyses of benthic community structure for the region. Additionally, a multivariate analysis of benthic macrofaunal data collected from the 2009–2011 regional surveys is presented. Although regional data exist prior to this time period, 2009 represents the first year where upper slope sites were included as a fourth depth stratum, allowing this region to be comparable to the three continental shelf strata. Results of benthic sediment quality analyses at the same sites are presented in Chapter 8.

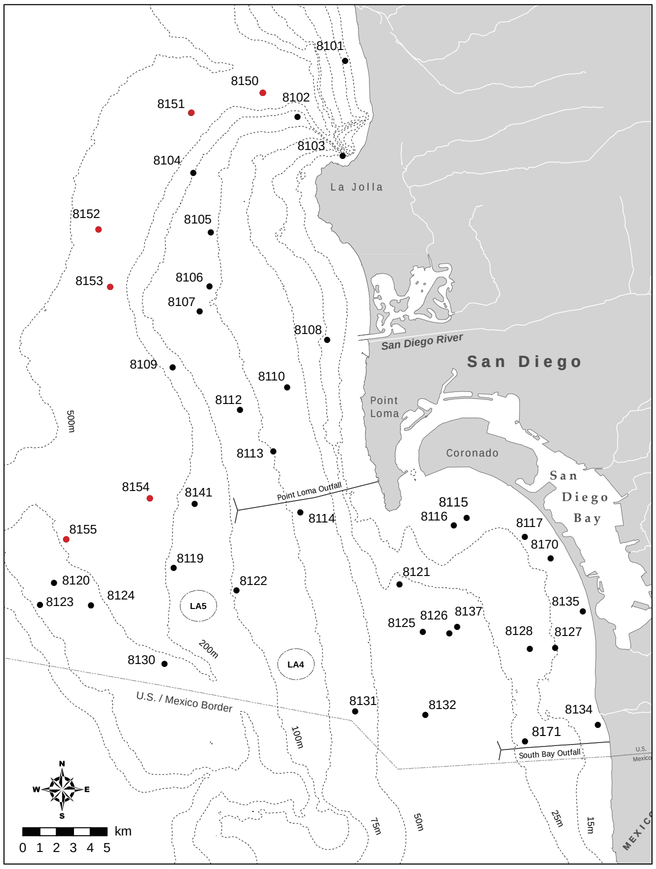



**Figure 9.1**

Regional benthic survey stations sampled during July 2011 as part of the City of San Diego's Ocean Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

## Materials and Methods

### Collection and Processing of Samples

The July 2011 regional survey covered an area ranging from off Del Mar in northern San Diego County south to the USA/Mexico border (Figure 9.1). Overall, this survey included 41 stations ranging in depth from 10 to 427 m and spanning four distinct depth strata characterized by the SCB regional monitoring programs (Ranasinghe et al. 2007) were sampled. These included 14 stations along the inner shelf (5–30 m), 14 stations along the mid-shelf (>30–120 m), 7 stations along the outer shelf (>120–200 m), and 6 stations on the upper slope (>200–500 m).

Samples for benthic community analysis were collected at each station using a double 0.1-m$^2$ Van Veen grab; one grab from each cast was used to sample macrofauna, while the adjacent grab was used to assess sediment quality (see Chapter 8). To ensure consistency of grab samples, protocols established by the United States Environmental Protection Agency (USEPA) were followed to standardize sample disturbance and depth of penetration (USEPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen, and organisms retained on the screen were collected and relaxed for 30 minutes in a magnesium sulfate solution before fixing in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the debris into major taxonomic groups by a subcontracted laboratory and then identified to species (or the lowest taxon possible) following SCAMIT (2011) nomenclature and enumerated by City of San Diego marine biologists.

### Data Analyses

For 2011 data, 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).

To explore spatial and temporal patterns in the regional benthic macrofaunal data collected from 2009−2011, multivariate analyses were conducted using PRIMER (Clarke and Warwick 2001, Clarke and Gorley 2006). Data were square-root transformed to lessen the influence of common species and increase the importance of rare species, and a Bray-Curtis similarity matrix created using year, depth category (i.e., inner shelf, mid-shelf, outer shelf, and upper slope), and sediment type (see Chapter 4) as factors. Three-way permutational multivariate analysis of variance (PERMANOVA, maximum number of permutations = 9999) was conducted to determine whether benthic communities varied by sediment type, depth or year across the region. To visually depict the relationship of individual grab samples to each other based on macrofaunal composition, a cluster dendrogram was created. Similarity profile (SIMPROF) analysis was used to confirm non-random structure of resultant clades in the dendrogram (Clarke et al. 2008), and major ecologically-relevant clusters supported by SIMPROF were retained at >22.43% similarly. Similarity percentages (SIMPER) analyses were used to determine which organisms were responsible for the greatest contribution to within-group similarities (i.e., characteristic species) and to identify which species accounted for differences among clades occurring in the dendrogram.

## Results

### Community Parameters

***Species richness***

A total of 713 macrobenthic taxa (mostly species) were identified during the summer 2011 regional survey. Of these, 271 (38%) represented taxa that occurred only once, and which may include rare species, unidentifiable juveniles of other documented species, or damaged specimens that cannot be identified. A total of six species not previously collected during the San Diego regional surveys were recorded: the anthozoan *Scolanthus triangulus*, the oweniid polychaete *Myriochele olgae*, the phyllodocid polychaete *Phyllodoce williamsi*, the polynoid polychaete *Malmgreniella liei*, the bivalve *Tivela stultorum*, and the sand dollar *Dendraster excentricus*. Species richness values from all four strata combined ranged from 20–118 species per station, with the range of values found within each stratum overlapping considerably (Table 9.1). However, average species richness values indicated that mid-shelf sites typically had more taxa than other strata, while the inner shelf and upper slope strata both contained sites with the lowest species richness (Figure 9.2A). In particular, inner shelf stations 8115 and 8116 and upper slope station 8150 had only 20 taxa/grab, while mid-shelf stations 8125 and 8131 each contained 118 taxa/grab. From 2009 to 2011, only slight differences in total species richness occurred within each stratum, with the greatest percent change (~25% increase) occurring at stations from the upper slope during 2009 and 2010.

***Macrofaunal abundance***

Macrofaunal abundance across all four strata ranged from 47–778 animals per site in 2011, with ranges within each stratum exhibiting some degree of overlap (Table 9.1). Abundance varied by depth with the inner shelf, mid-shelf, outer shelf and upper slope assemblages averaging ~191, 337, 181 and 115 animals/grab, respectively (Figure 9.2B). Although overall abundance was highest at mid-shelf depths, the greatest number of animals (778/grab) occurred at inner shelf station 8108 (Table 9.1). Only one other site, mid-shelf station 8131, had abundances >450 animals per grab. In contrast, upper slope station 8150 had the lowest abundance with 47 animals/grab (Table 9.1). Temporal differences from 2009 to 2011 varied within each stratum (Figure 9.2B), with the greatest change occurring on the inner shelf where a 40% reduction in mean abundance was observed over this 3-year period.

***Diversity and evenness***

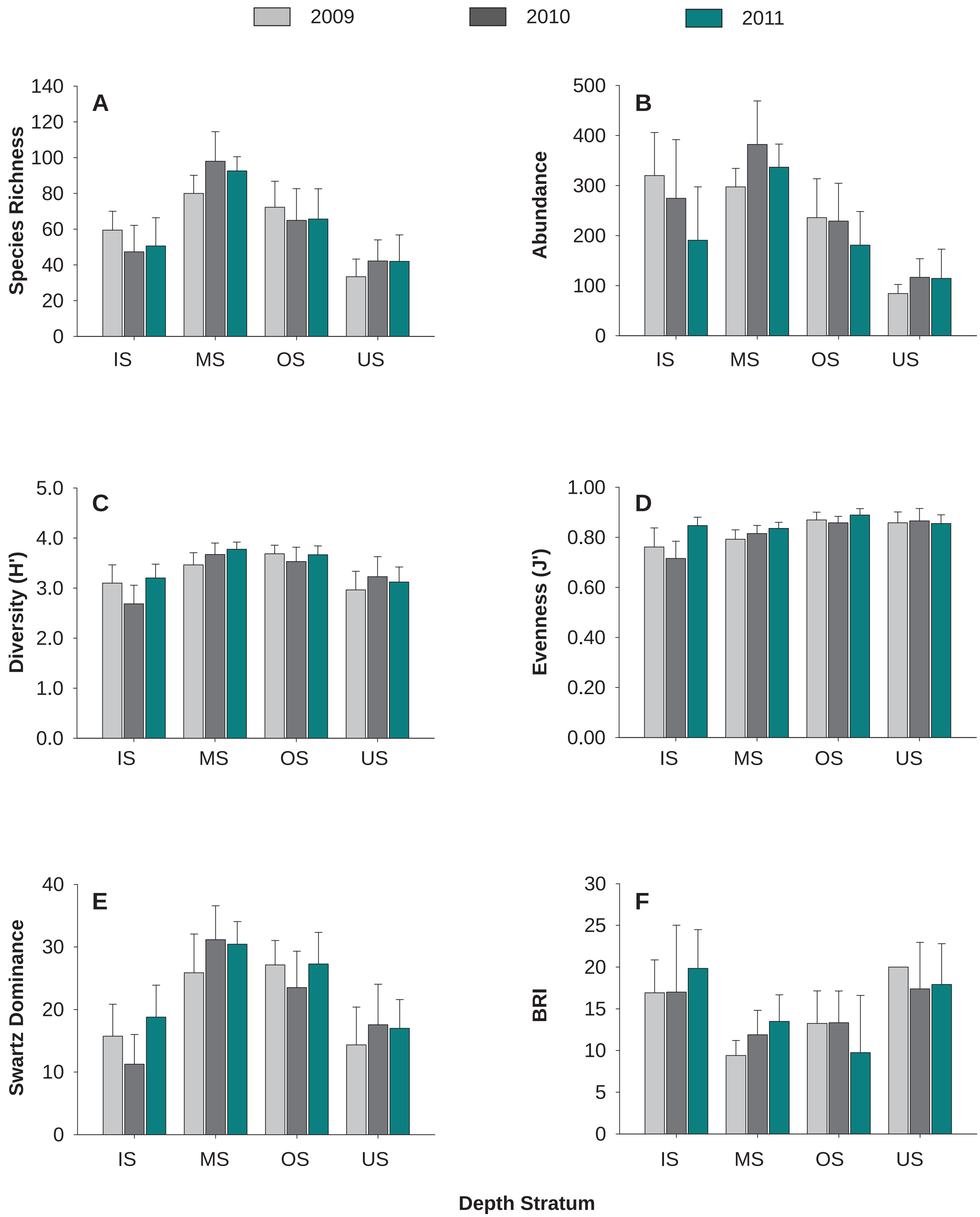
During 2011, diversity (H') ranged from 2.2 to 4.3 across all strata (Table 9.1). Although diversity ranges overlapped among strata, average values indicate that sites along the upper slope had lower diversity than at shelf depths (Figure 9.2C). The five stations with the highest diversity (i.e., H'≥4.0) occurred along the mid- and outer shelf strata, while the lowest diversity occurred at inner shelf station 8116 located near the mouth of San Diego Bay. Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed and that an assemblage is not dominated by a few highly abundant species. J' values ranged between 0.73–0.95 during 2011 (Table 9.1), with evenness not varying much with depth (Figure 9.2D). Diversity and evenness values have remained relatively stable from 2009 to 2011, and exhibited little variability within each stratum.

## Table 9.1

Macrofaunal community parameters calculated per 0.1-m$^2$ grab at regional stations sampled during 2011. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; *n* = 1.

| | Station | Depth (m) | SR | Abun | H' | J' | Dom | BRI |
|---|---|---|---|---|---|---|---|---|
| Inner Shelf | 8116 | 10 | 20 | 140 | 2.2 | 0.75 | 6 | 6 |
| | 8134 | 10 | 26 | 65 | 2.7 | 0.83 | 10 | 21 |
| | 8103 | 12 | 33 | 105 | 2.8 | 0.79 | 11 | 20 |
| | 8135 | 13 | 39 | 92 | 3.2 | 0.87 | 17 | 22 |
| | 8117 | 16 | 39 | 68 | 3.4 | 0.92 | 23 | 24 |
| | 8170 | 16 | 33 | 120 | 2.8 | 0.79 | 9 | 34 |
| | 8115 | 19 | 20 | 63 | 2.5 | 0.85 | 8 | -2 |
| | 8101 | 20 | 64 | 170 | 3.7 | 0.88 | 26 | 16 |
| | 8127 | 20 | 57 | 105 | 3.8 | 0.95 | 31 | 22 |
| | 8128 | 20 | 38 | 76 | 3.4 | 0.92 | 20 | 20 |
| | 8108 | 24 | 73 | 778 | 3.3 | 0.76 | 13 | 22 |
| | 8171 | 25 | 43 | 91 | 3.4 | 0.91 | 21 | 19 |
| | 8121 | 29 | 114 | 443 | 3.9 | 0.82 | 33 | 27 |
| | 8137 | 29 | 110 | 358 | 3.8 | 0.82 | 35 | 27 |
| Mid-shelf | 8126 | 32 | 101 | 395 | 3.9 | 0.84 | 28 | 28 |
| | 8125 | 36 | 118 | 369 | 4.3 | 0.91 | 47 | 23 |
| | 8132 | 40 | 83 | 301 | 3.7 | 0.83 | 24 | 17 |
| | 8131 | 58 | 118 | 515 | 3.7 | 0.78 | 31 | 10 |
| | 8110 | 62 | 96 | 377 | 3.8 | 0.82 | 29 | 16 |
| | 8114 | 72 | 84 | 396 | 3.2 | 0.73 | 19 | 13 |
| | 8113 | 75 | 102 | 427 | 3.8 | 0.82 | 32 | 14 |
| | 8105 | 78 | 66 | 195 | 3.5 | 0.83 | 25 | 5 |
| | 8106 | 80 | 87 | 284 | 3.7 | 0.82 | 29 | 11 |
| | 8107 | 84 | 70 | 238 | 3.5 | 0.82 | 25 | 7 |
| | 8112 | 84 | 91 | 324 | 3.8 | 0.85 | 33 | 9 |
| | 8102 | 93 | 93 | 358 | 3.9 | 0.87 | 29 | 12 |
| | 8104 | 100 | 99 | 327 | 4.0 | 0.87 | 36 | 13 |
| | 8122 | 101 | 90 | 213 | 4.1 | 0.91 | 39 | 11 |
| Outer Shelf | 8109 | 122 | 98 | 318 | 4.0 | 0.86 | 34 | 15 |
| | 8124 | 139 | 67 | 213 | 3.5 | 0.83 | 24 | 8 |
| | 8130 | 139 | 94 | 277 | 4.0 | 0.87 | 37 | 9 |
| | 8120 | 148 | 42 | 97 | 3.4 | 0.90 | 18 | 1 |
| | 8123 | 161 | 51 | 130 | 3.6 | 0.91 | 24 | -5 |
| | 8141 | 165 | 43 | 83 | 3.5 | 0.94 | 23 | 21 |
| | 8119 | 193 | 65 | 152 | 3.8 | 0.90 | 31 | 19 |
| Upper Slope | 8154 | 249 | 36 | 66 | 3.3 | 0.93 | 20 | 22 |
| | 8151 | 286 | 55 | 146 | 3.3 | 0.83 | 21 | 19 |
| | 8155 | 312 | 72 | 247 | 3.5 | 0.81 | 24 | 13 |
| | 8153 | 339 | 32 | 84 | 3.0 | 0.86 | 12 | na |
| | 8152 | 393 | 37 | 98 | 3.2 | 0.88 | 16 | na |
| | 8150 | 427 | 20 | 47 | 2.5 | 0.82 | 9 | na |

na = not applicable




## Figure 9.2

Comparison of macrofaunal community structure metrics for the four major depth strata sampled during regional surveys between 2009–2011. Data are expressed as means + 95% confidence interval (per 0.1 $m^2$). IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope.

***Dominance***

Swartz dominance values across all strata ranged between 6–47 taxa per station during 2011 (Table 9.1). Average dominance was notably higher (i.e., lower index values) at inner shelf and upper slope sites than at mid- and outer slope sites (Figure 9.2E). Typically, dominance values were inversely related to diversity. For example, sites 8125, 8122, and 8130 had the lowest dominance with index values ≥37, but exhibited high diversity values ≥4.0. Conversely, stations 8116, 8170, 8115, and 8150 possessed the highest dominance with index values <10, but had relatively low diversity values of 2.2 to 2.8 (Table 9.1). Within strata, temporal differences between 2009–2011 were variable, with the largest changes in dominance occurring along the inner shelf between 2010 and 2011 (Figure 9.2E).

***Benthic response index (BRI)***

The benthic response index (BRI) is an important tool for evaluating possible anthropogenic impacts to marine environments throughout the SCB. BRI values <25 are considered indicative of reference conditions, while values between 25–34 represent "a minor deviation from reference conditions" and should be corroborated with additional information. BRI values >34 represent different levels of degradation including losses in biodiversity or community function, and ultimately defaunation (Smith et al. 2001). During 2011, BRI values ranged from -5 to 34 at the regional stations (Table 9.1), and varied by depth stratum with the inner shelf, mid-shelf, outer shelf and upper slope sites having average BRI values of 20, 13, 10 and 18, respectively (Figure 9.2F). BRI values were not calculated for the three deepest upper slope stations >324 m because their depths are out of acceptable range for BRI calculations. Overall, 90% of the sites where the BRI was calculated had values indicative of reference conditions. However, stations 8121, 8137, 8126, and 8170 located north of the South Bay Ocean Outfall (SBOO) had BRI values between 27–34, which suggests a marginal deviation from reference conditions. BRI values varied from 2009 to 2011 depending on depth stratum. For example, mean BRI values at the inner and mid-shelf sites were higher in 2011 than those sampled in 2009, while outer shelf and upper slope values were lower (Figure 9.2F).

**Table 9.2**

The percent composition of species and abundance by major taxonomic group (phylum) for regional stations sampled during 2011. Data are expressed as means (range) for all stations combined; $n = 41$.

| Phyla | Species (%) | Abundance (%) |
|---|---|---|
| Annelida (Polychaeta) | 45 (30–78) | 60 (15–83) |
| Arthropoda (Crustacea) | 24 (2–45) | 14 (1–65) |
| Mollusca | 17 (4–36) | 10 (1–68) |
| Echinodermata | 5 (1–15) | 11 (1–33) |
| Other Phyla | 9 (2–22) | 5 (1–14) |

## Dominant Taxa

As in previous years, annelid worms (mostly polychaetes) were the largest contributors to macrofaunal diversity in the San Diego region during 2011 (Table 9.2), and accounted for 45% of all species collected. Arthropods (mostly crustaceans, but also including pycnogonids) and molluscs were the next two most diverse phyla, accounting for 24% and 17% of species, respectively. Echinoderms accounted for 5% of all taxa, while all other phyla combined (e.g., Chordata, Cnidaria, Nematoda, Nemertea, Phoronida, Platyhelminthes, Sipuncula) accounted for the remaining 9%. Patterns apparent in the proportions of major taxa across shelf strata include: (1) the contribution of polychaetes to overall macroinvertebrate species richness increased from 46% along the inner shelf to 56% along the outer shelf, (2) the percentage of echinoderms increased slightly as depth increased, and (3) the proportions of crustaceans and the other phyla typically decreased with depth (Figure 9.3A). The greatest difference in invertebrate assemblages occurred between the continental shelf and upper slope where the percentage of molluscs increased sharply and the proportion of arthropods decreased.

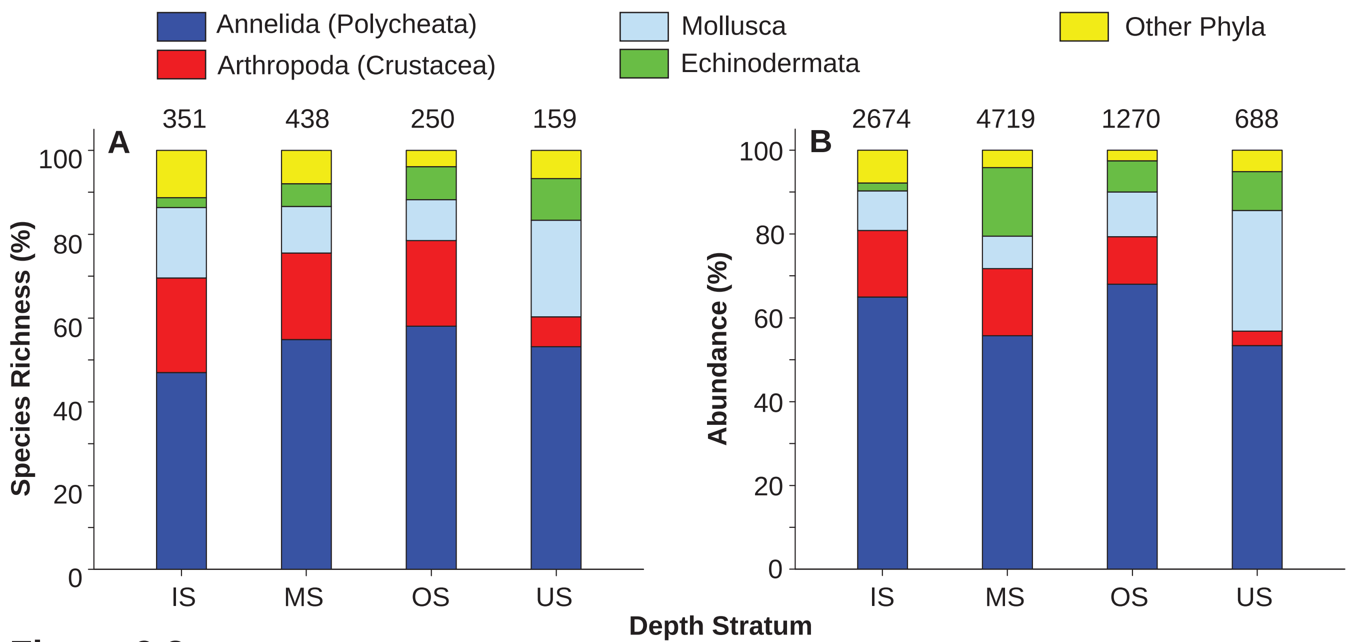



**Figure 9.3**
Comparison of percent composition of species and abundance by major phylum for each depth stratum sampled during 2011. IS = inner shelf (*n* = 14); MS = mid-shelf (*n* = 14); OS = outer shelf (*n* = 7); US = upper slope (*n* = 6). Numbers above bars represent total number of individual organisms enumerated for each stratum.

The proportion of echinoderms remained about the same between upper slope and outer shelf sites.

Polychaetes were also the most numerous invertebrates collected during 2011, accounting for 60% of the total abundance (Table 9.2). Crustaceans accounted for 14% of the animals, molluscs 10%, echinoderms 11%, and the remaining phyla 5%. Abundance patterns varied among strata (Figure 9.3B) with the proportion of polychaetes being lower at upper slope and mid-shelf stations (i.e., 53% and 56%, respectively) than along either the inner shelf or outer shelf (i.e., 65% and 68%, respectively). The lower proportional abundance of polychaetes along mid- shelf and upper slope sites corresponded to considerably higher numbers of echinoderms (i.e., 16%) and molluscs (i.e., 29%) at these depths, respectively.

The dominant species encountered in 2011 varied among strata (Table 9.3). Along the inner shelf, the 10 most abundant species were all polychaetes. Of these, the cirratulid *Monticellina siblina* was dominant averaging about 10 individuals per 0.1-m$^2$ grab. All other species averaged <8 animals/grab. The top 10 dominant species along the mid-shelf included three ophiuroids (brittle stars) and seven polychaetes. The brittle star *Amphiodia urtica* was the most common species, averaging about 40 animals per grab and occurring at 71% of the sites. The capitellid polychaete *Mediomastus* was the next most abundant taxon, averaging about 9 animals per grab. All other species averaged <9 animals/grab. On the outer shelf, the top 10 species included eight polychaetes and two bivalves. Individuals in the cirratulid polychaete *Aphelochaeta glandaria* Cmplx were most abundant, averaging 13 animals per grab, while none of the other dominant outer shelf species exceeded mean densities of 8 animals per grab. The 10 most abundant taxa along the upper slope included five polychaetes, two bivalves, a scaphopod, and one ophiuroid. The maldanid polychaete *Maldane sarsi* was the most abundant upper slope species with an average of 11 animals/grab, while the second most abundant species was the polychaete *Fauveliopsis glabra*, which averaged 10 animals/grab.

## Regional Macrobenthic Assemblages (2009–2011)

***Effect of depth, sediment type and year***

PERMANOVA results revealed that benthic invertebrate communities across the San Diego

## Table 9.3

The 10 most abundant macroinvertebrates per depth strata collected at regional benthic stations sampled during 2011. AS = abundance/survey; PO = percent occurrence (percent of total annual sites at which the species was collected); AO = abundance/occurrence. Abundance values are expressed as mean number of individuals per 0.1-$m^2$ grab sample.

| Strata | Species | Taxonomic Classification | AS | PO | AO |
|---|---|---|---|---|---|
| Inner Shelf | *Monticellina siblina* | Polychaeta: Cirratulidae | 10.0 | 43 | 23.3 |
| | *Pareurythoe californica* | Polychaeta: Amphinomidae | 7.9 | 7 | 110.0 |
| | *Polycirrus* sp | Polychaeta: Terebellidae | 6.6 | 7 | 92.0 |
| | *Mediomastus* sp | Polychaeta: Capitellidae | 6.1 | 71 | 8.6 |
| | *Spiophanes norrisi* | Polychaeta: Spionidae | 5.9 | 64 | 9.1 |
| | *Mooreonuphis nebulosa* | Polychaeta: Onuphidae | 5.7 | 14 | 40.0 |
| | *Lumbrineris latreilli* | Polychaeta: Lumbrineridae | 4.4 | 7 | 62.0 |
| | *Pisione* sp | Polychaeta: Pisionidae | 4.4 | 7 | 61.0 |
| | *Apoprionospio pygmaea* | Polychaeta: Spionidae | 3.5 | 29 | 12.2 |
| | *Scoletoma tetraura* Cmplx | Polychaeta: Lumbrineridae | 3.4 | 29 | 12.0 |
| Mid-shelf | *Amphiodia urtica* | Echinodermata: Ophiuroidea | 40.0 | 71 | 56.0 |
| | *Mediomastus* sp | Polychaeta: Capitellidae | 9.0 | 86 | 10.5 |
| | *Mooreonuphis* sp | Polychaeta: Onuphidae | 8.4 | 14 | 59.0 |
| | *Prionospio* (*Prionospio*) *jubata* | Polychaeta: Spionidae | 8.2 | 100 | 8.2 |
| | *Spiophanes norrisi* | Polychaeta: Spionidae | 7.9 | 57 | 13.9 |
| | *Mooreonuphis* sp SD1 | Polychaeta: Onuphidae | 5.5 | 14 | 38.5 |
| | *Amphiodia* sp | Echinodermata: Ophiuroidea | 5.1 | 79 | 6.5 |
| | Amphiuridae | Echinodermata: Ophiuroidea | 4.8 | 79 | 6.1 |
| | *Monticellina siblina* | Polychaeta: Cirratulidae | 4.8 | 43 | 11.2 |
| | *Prionospio* (*Prionospio*) *dubia* | Polychaeta: Spionidae | 4.7 | 86 | 5.5 |
| Outer Shelf | *Aphelochaeta glandaria* Cmplx | Polychaeta: Cirratulidae | 12.7 | 71 | 17.8 |
| | *Chaetozone* sp SD5 | Polychaeta: Cirratulidae | 8.1 | 43 | 19.0 |
| | *Spiophanes kimballi* | Polychaeta: Spionidae | 7.4 | 57 | 13.0 |
| | *Chloeia pinnata* | Polychaeta: Amphinomidae | 7.1 | 57 | 12.5 |
| | *Prionospio* (*Prionospio*) *jubata* | Polychaeta: Spionidae | 6.7 | 86 | 7.8 |
| | *Paraprionospio alata* | Polychaeta: Spionidae | 5.9 | 86 | 6.8 |
| | *Tellina carpenteri* | Mollusca: Bivalvia | 5.4 | 100 | 5.4 |
| | *Huxleyia munita* | Mollusca: Bivalvia | 4.0 | 57 | 7.0 |
| | *Lysippe* sp A | Polychaeta: Ampharetidae | 3.6 | 86 | 4.2 |
| | *Exogone lourei* | Polychaeta: Syllidae | 3.4 | 57 | 6.0 |
| Upper Slope | *Maldane sarsi* | Polychaeta: Maldanidae | 11.3 | 83 | 13.6 |
| | *Fauveliopsis glabra* | Polychaeta: Fauveliopsidae | 9.8 | 33 | 29.5 |
| | *Yoldiella nana* | Mollusca: Bivalvia | 5.5 | 33 | 16.5 |
| | Amphiuridae | Echinodermata: Ophiuroidea | 4.3 | 67 | 6.5 |
| | *Macoma carlottensis* | Mollusca: Bivalvia | 4.2 | 67 | 6.2 |
| | *Compressidens stearnsii* | Mollusca: Scaphopoda | 3.7 | 83 | 4.4 |
| | *Paraprionospio alata* | Polychaeta: Spionidae | 3.0 | 67 | 4.5 |
| | *Spiophanes kimballi* | Polychaeta: Spionidae | 2.8 | 50 | 5.7 |
| | *Mediomastus* sp | Polychaeta: Capitellidae | 2.7 | 67 | 4.0 |
| | *Ennucula tenuis* | Mollusca: Bivalvia | 2.5 | 50 | 5.0 |

region differed significantly by depth stratum, sediment type and year (Appendix H.1). These differences were due to minor variations in abundance of many species, with no single species accounting for more than 3% of the observed variation. Results also revealed select species as being representative of specific habitat types (Table 9.4). For instance, the oweniid polychaete *Owenia collaris* only occurred at inner shelf depths, polychaetes in the *Aphelochaeta glandaria* Cmplx appeared to occur and dominate only at outer shelf sites, and the bivalve *Macoma carlottensis* only inhabited the deepest upper slope sites. Other taxa exhibited broader habitat ranges, with species such as the spionid *Spiophanes kimballi* and the bivalve *Tellina carpenteri* occurring in more than one stratum. Limited sampling in environments characterized by fine sediments with a substantial coarse constituent (one mid-shelf site), sand mixed with both fine and coarse sediments (one inner shelf site), and coarse sediments mixed with sand (one inner shelf and one mid-shelf site) hindered a complete understanding of how sediment types may influence species distributions (see Table 9.4). Despite this constraint, it is suggestive that organisms such as the brittle star *Amphiodia urtica*, the bivalve *Axinopsida serricata*, and the spionid *Spiophanes berkeleyorum* dominated only mid-shelf habitats typically characterized by fine sediments mixed with sand; these species were less common or completely lacking in habitats with coarser sediments. Similarly, many species found in coarse sediments that were mixed with sand were restricted to this sediment type, and were not commonly found in finer sediments (e.g., *Spiophanes norrisi*).

***Discrimination of cluster groups***

Classification (cluster) analysis discriminated 15 ecologically-relevant SIMPROF-supported groups (Figures 9.4, 9.5, Appendix H.2). These "assemblages," referred to herein as cluster groups A through O contained between 1–40 samples (sites) each. Species richness averaged 27–135 taxa per grab and abundances averaged 78–650 individuals per grab for the different groups (Table 9.5).

The 15 cluster groups formed three distinct main clusters defined primarily by depth (Figures 9.4, 9.5). These included: (1) Cluster group A, that represented a small cluster of inner shelf sites that shared about a 4% similarity with the other two main clusters; (2) Groups B–I represented a large "megacluster," that contained most sites located at inner to mid-shelf depths between 9–58 m; and (3) Groups J–O represented a second megacluster comprising primarily sites located at depths >50 m (Figures 9.4, 9.5). The two latter megaclusters shared only about an 8% similarity with each other. As indicated previously by the PERMANOVA and SIMPER results, depth and sediment type were the primary factors responsible for driving individual cluster group formation within the megaclusters (Figure 9.4, Table 9.5, Appendices H.1 and H.2). The ecological relevance of each of the cluster groups is described below in terms of whether they represent inner shelf, mid-shelf, outer shelf, upper slope or between-strata transitional assemblages.

<u>Inner shelf assemblages</u>

Cluster group A comprised two sites located along the 25-m isobath north of Point Loma that were distinct from the other 119 sites sampled (Figures 9.4, 9.5, Appendix H.2). In this cluster, a high fraction of coarse sediments containing substantial shell hash supported a faunal community characterized by large populations of nematodes, the polychaetes *Pareurythoe californica*, *Pisione* sp, *Polycirrus* sp, *Lumbrineris latreilli*, *Hesionura coineaui difficilis* and *Protodorvillea gracilis*, and the isopod *Eurydice caudata* (Table 9.5). The remaining inner shelf assemblages were represented by cluster groups B and F–I, which occurred at depths between 9–20 m. Within these groups, cluster group B comprised a single site (station 8103) with coarse sand sediments located at the head of the La Jolla Canyon. Group B was unique in possessing the only recorded individuals of the gastropod *Balcis oldroydae*, the bivalve *Tivela stultorum*, the polychaete *Paraonella platybranchia*, and the sea pen *Stylatula elongata* (Appendix H.3). Groups F and G together contained nine sandy, shallow water sites located close to the mouths of the San Diego River and San Diego Bay that lacked almost any fine sediments. The group F and G

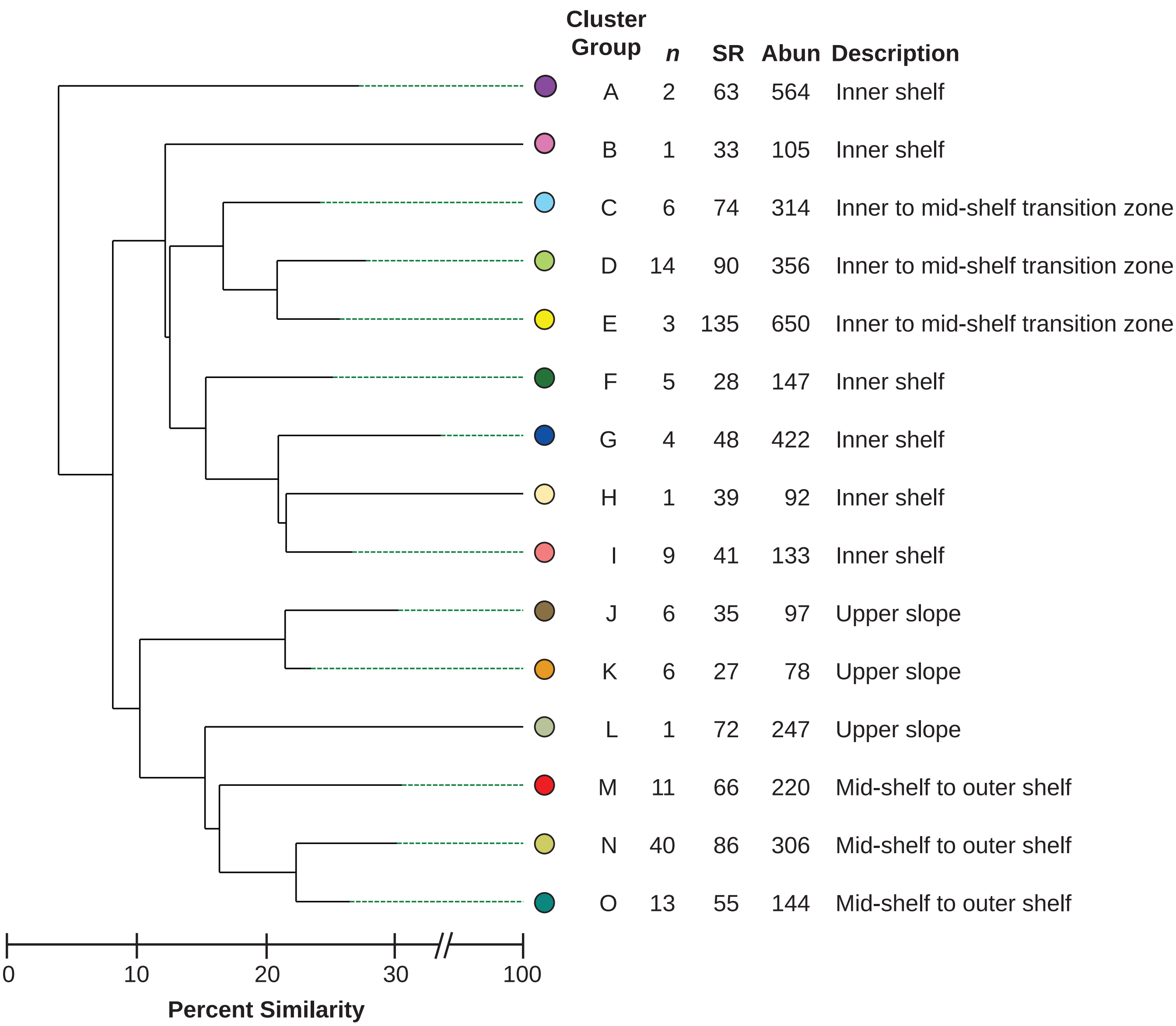
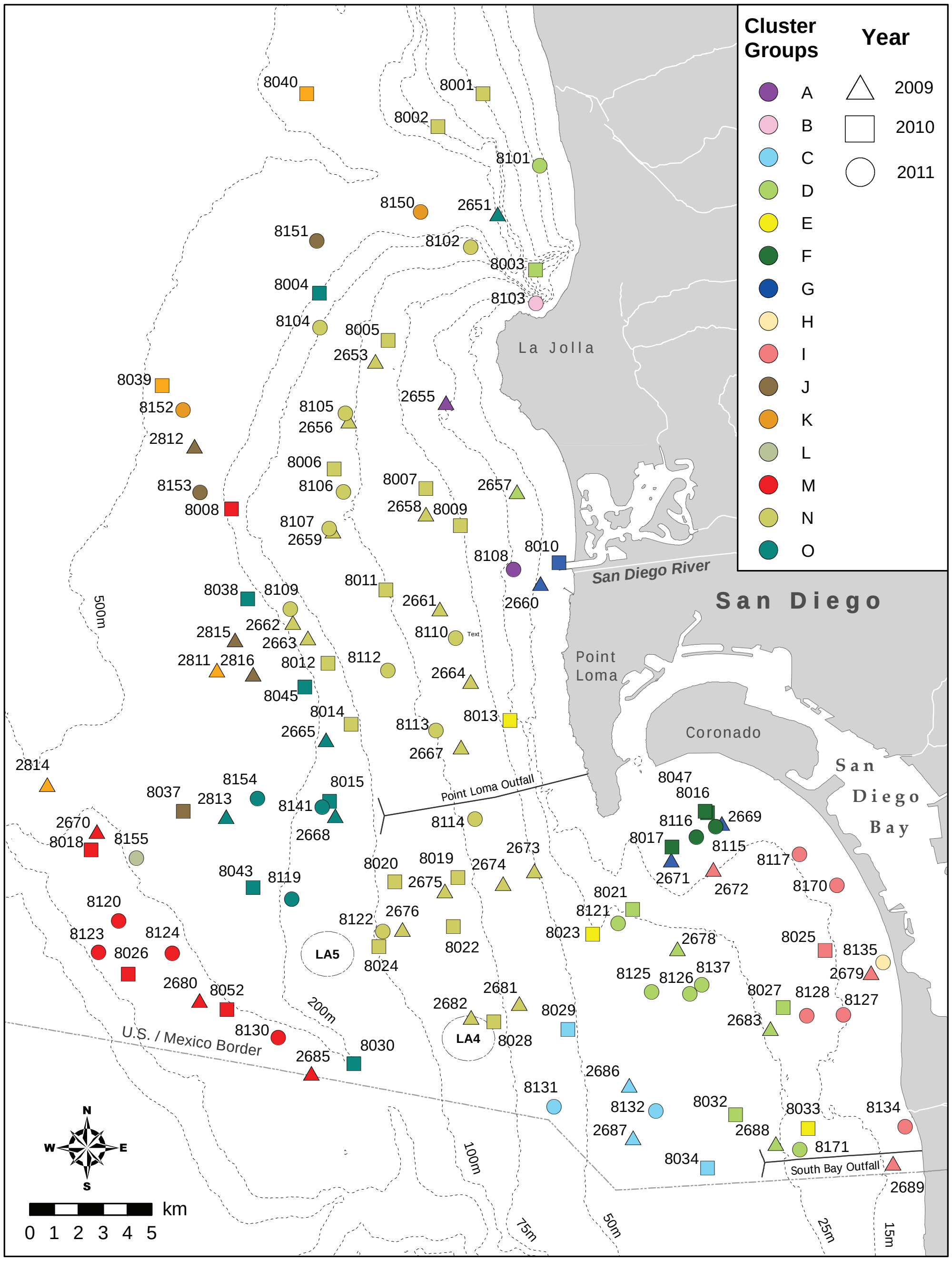



**Figure 9.4**
Cluster analysis of macrofaunal assemblages at regional benthic stations sampled between 2009–2011. Data for species richness (SR) and infaunal abundance (Abund) are expressed as mean values per 0.1-$m^2$ over all stations in each group (*n*).

assemblages possessed 14 and 9 taxa, respectively, that were unique compared to any other cluster group (Appendix H.3) and that might include species tolerant of nearshore high energy environments. The group H and I assemblages occurred at a total of 10 inner shelf sites in the regular SBOO monitoring region that had sediments dominated by sand mixed with a substantial percentage of fines. Group H represented the assemblage from a single site (station 8135) that was the only location where the gastropod *Astyris gausapata*, the mysids *Exacanthomysis davisi* and *Mysidopsis intii*, and the polychaete *Cirriformia* sp B were recorded.

<u>Inner to mid-shelf transition zone assemblages</u>
Cluster groups C, D and E spanned inner to mid-shelf locations at 21–58 m depths. Group C was a sister group to the clade containing groups D and E (Figure 9.4). Although all three clusters occurred in the South Bay outfall region, sites in cluster group C tended to have coarser sediments and be located in deeper water than those in groups D and E




## Figure 9.5

Spatial distribution of cluster groups in the San Diego region. Colors of each circle correspond to colors in Figure 9.4.

(Appendix H.3). Several taxa were unique to cluster group C, including the tunicate *Agnezia septentrionalis*, the amphipod *Laticorophium baconi*, and the polychaetes *Polycirrus* sp I, *Aphelochaeta* sp SD5, *Poecilochaetus* sp and *Aricidea* (*Allia*) sp SD1. The cluster groups D and E typically occurred at sites located on the broad, gently sloping inner to mid-shelf area mostly north to northwest of the SBOO. Eighteen taxa were restricted entirely to these two cluster groups, including the polychaetes *Paradoneis* sp SD1, *Streblosoma* sp SF1, the hydrozoan *Euphysa* sp A, and the bivalve *Rochefortia grippi*.

<u>Mid-shelf to outer shelf assemblages</u>

On the mid- to outer continental shelf, macrofaunal communities were most similar between cluster

## Table 9.4

Most abundant taxa from each sediment type/depth stratum combination sampled between 2009–2011. Values correspond to average number of individuals of each taxon per 0.1-$m^2$ grab sample.

| | **Inner Shelf** | | **Mid-shelf** | |
|---|---|---|---|---|
| **Fines with coarse** | *n* = 0 | | *n* = 1 | |
| | | | *Spiophanes kimballi* | 22.0 |
| | | | *Paraprionospio alata* | 9.0 |
| | | | *Melinna heterodonta* | 8.0 |
| | | | *Glycera nana* | 7.0 |
| | | | *Pectinaria californiensis* | 5.0 |
| **Fines with sand** | *n* = 0 | | *n* = 13 | |
| | | | *Amphiodia urtica* | 68.9 |
| | | | *Axinopsida serricata* | 9.8 |
| | | | *Proclea* sp A | 6.7 |
| | | | *Travisia brevis* | 5.5 |
| | | | *Amphiodia* sp | 5.2 |
| | | | *Spiophanes berkeleyorum* | 5.2 |
| **Sand with fines** | *n* = 11 | | *n* = 25 | |
| | *Spiophanes norrisi* | 16.5 | *Amphiodia urtica* | 48.9 |
| | *Mooreonuphis nebulosa* | 13.8 | *Axinopsida serricata* | 14.0 |
| | *Owenia collaris* | 10.7 | *Spiophanes norrisi* | 11.5 |
| | *Monticellina siblina* | 9.3 | *Mediomastus* sp | 7.3 |
| | *Mediomastus* sp | 7.7 | *Spiophanes berkeleyorum* | 6.9 |
| | *Spiophanes duplex* | 5.9 | *Amphiodia* sp | 6.5 |
| **Sand with coarse and fines** | *n* = 1 | | *n* = 0 | |
| | *Spiophanes norrisi* | 137.0 | | |
| | *Apoprionospio pygmaea* | 129.0 | | |
| | *Ampharete labrops* | 18.0 | | |
| | *Mediomastus* sp | 17.0 | | |
| | Nematoda | 16.0 | | |
| | *Spiophanes duplex* | 15.0 | | |
| | *Typosyllis hyperioni* | 15.0 | | |
| **Sand** | *n* = 18 | | *n* = 3 | |
| | *Owenia collaris* | 41.1 | *Spiophanes norrisi* | 29.7 |
| | *Spiophanes norrisi* | 25.1 | *Spio maculata* | 12.3 |
| | *Monticellina siblina* | 10.1 | *Polycirrus* sp A | 11.7 |
| | *Gibberosus myersi* | 8.3 | *Amphiodia urtica* | 11.3 |
| | *Zaolutus actius* | 7.3 | *Eurydice caudata* | 4.3 |
| | *Apoprionospio pygmaea* | 6.3 | *Mediomastus* sp | 3.7 |
| **Sand with coarse** | *n* = 3 | | *n* = 5 | |
| | *Spiophanes norrisi* | 56.7 | *Spiophanes norrisi* | 83.4 |
| | *Apoprionospio pygmaea* | 43.3 | *Mooreonuphis* sp | 14.8 |
| | *Lumbrinerides platypygos* | 14.0 | *Mooreonuphis* sp SD1 | 14.8 |
| | Nematoda | 13.0 | *Lysippe* sp A | 8.8 |
| | *Protodorvillea gracilis* | 7.0 | Amphiuridae | 8.2 |
| | *Ophelia pulchella* | 2.3 | *Ophiuroconis bispinosa* | 7.6 |
| **Coarse with sand** | *n* = 1 | | *n* = 1 | |
| | *Pareurythoe californica* | 110.0 | *Spiophanes norrisi* | 68.0 |
| | *Polycirrus* sp | 92.0 | *Chaetozone* sp SD5 | 50.0 |
| | *Lumbrineris latreilli* | 62.0 | *Lumbrineris latreilli* | 31.0 |
| | *Pisione* sp | 61.0 | *Typosyllis heterochaeta* | 29.0 |
| | *Polycirrus californicus* | 48.0 | *Micropodarke dubia* | 27.0 |
| | *Polycirrus* sp SD3 | 42.0 | *Lumbrineris ligulata* | 24.0 |
| | Rhabdocoela sp A | 42.0 | | |

**Table 9.4** *continued*

| | Outer Shelf | | Upper Slope | |
|---|---|---|---|---|
| **Fines with coarse** | *n* = 0 | | *n* = 0 | |
| **Fines with sand** | *n* = 5 | | *n* = 15 | |
| | *Axinopsida serricata* | 15.6 | *Maldane sarsi* | 9.2 |
| | *Spiophanes kimballi* | 10.0 | *Yoldiella nana* | 4.9 |
| | *Tellina carpenteri* | 7.4 | *Macoma carlottensis* | 4.9 |
| | *Mediomastus* sp | 6.0 | *Nuculana conceptionis* | 4.7 |
| | *Parvilucina tenuisculpta* | 4.6 | *Spiophanes kimballi* | 3.3 |
| | *Paradiopatra parva* | 4.6 | *Eclysippe trilobata* | 2.5 |
| **Sand with fines** | *n* = 14 | | *n* = 2 | |
| | *Aphelochaeta glandaria* Cmplx | 18.9 | *Fauveliopsis glabra* | 29.0 |
| | *Chaetozone* sp SD5 | 10.4 | *Maldane sarsi* | 9.5 |
| | *Monticellina siblina* | 8.1 | *Tellina carpenteri* | 5.0 |
| | *Tellina carpenteri* | 7.6 | *Mediomastus* sp | 4.0 |
| | *Amphiodia digitata* | 5.6 | *Phyllochaetopterus limicolus* | 2.5 |
| | *Micranellum crebricinctum* | 5.4 | Lineidae | 2.0 |
| **Sand with coarse and fines** | *n* = 0 | | *n* = 0 | |
| **Sand** | *n* = 0 | | *n* = 2 | |
| | | | *Macoma carlottensis* | 11.5 |
| | | | *Maldane sarsi* | 8.0 |
| | | | *Paraprionospio alata* | 4.0 |
| | | | *Mediomastus* sp | 3.5 |
| | | | *Compressidens stearnsii* | 3.0 |
| | | | *Lumbrineris cruzensis* | 3.0 |
| **Sand with coarse** | *n* = 2 | | *n* = 0 | |
| | *Aphelochaeta glandaria* Cmplx | 19.0 | | |
| | *Tellina carpenteri* | 15.5 | | |
| | *Huxleyia munita* | 7.0 | | |
| | *Exogone lourei* | 7.0 | | |
| | *Chaetozone* sp | 6.5 | | |
| | *Ampelisca careyi* | 6.0 | | |
| **Coarse with sand** | *n* = 0 | | *n* = 0 | |

## Table 9.5

Mean abundance of the most common species found in cluster groups A−O (defined in Figure 9.4). Bold values indicate taxa that were considered among the most characteristic of that group according to SIMPER analysis.

| | Cluster Group | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Taxa** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** | **O** |
| *Pareurythoe californica* | 55.0 | | | | | | | | | | | | | | |
| *Pisione* sp | **49.5** | | 0.5 | | 0.3 | | | | | | | | | | |
| *Polycirrus* sp | 46.0 | | 1.3 | 0.4 | 0.7 | | | | | | 0.2 | 1.0 | 0.2 | 0.5 | 0.3 |
| *Lumbrineris latreilli* | 31.0 | | 2.2 | | 10.7 | | | | | | | | | 0.3 | 0.3 |
| *Spio maculata* | 30.5 | | 12.0 | | | | | | | | | | | 0.1 | |
| *Spiophanes norrisi* | 2.5 | 31.0 | **54.2** | **50.0** | **144.0** | **4.0** | **18.0** | 1.0 | 8.8 | | 0.3 | | 0.2 | 0.4 | |
| *Dendraster excentricus* | | 16.0 | | | | 1.0 | | | | | | | | | |
| *Aphelochaeta glandaria* Cmplx | | 7.0 | | 0.2 | | | | | 0.1 | | | 3.0 | **24.1** | 1.9 | 2.5 |
| *Aphelochaeta* sp SD13 | | 4.0 | | | | | | | | | 0.2 | | 0.5 | 0.1 | |
| *Chaetozone commonalis* | | 4.0 | | | | | | | | | | | | 0.1 | 1.2 |
| *Mooreonuphis* sp | 2.0 | | **27.3** | | | | | | | | | | 3.4 | 0.0 | 0.1 |
| *Mooreonuphis* sp SD1 | 2.5 | | **24.2** | | | | | | | | | | 0.1 | | |
| *Lanassa venusta venusta* | | | 12.0 | | 0.3 | | | | | | | | 0.4 | 0.2 | 0.6 |
| *Monticellina siblina* | | 2.0 | 0.5 | **26.6** | 0.7 | 0.2 | | | 0.4 | 0.2 | | | 7.9 | 1.6 | 0.3 |
| *Mooreonuphis nebulosa* | | | | 16.6 | 2.3 | | | | | | | | | 0.4 | |
| *Mediomastus* sp | 2.5 | | 0.3 | **12.4** | **14.0** | 0.4 | 0.8 | 1.0 | **6.7** | 1.7 | 0.7 | 5.0 | 3.7 | 5.2 | **5.2** |
| *Spiophanes duplex* | | | 1.3 | 9.7 | 6.0 | | 1.0 | | **7.2** | 0.3 | | | 0.1 | 2.2 | 0.2 |
| *Apoprionospio pygmaea* | | 1.0 | | 1.8 | 43.3 | **10.4** | 9.3 | | 0.8 | | | | | 0.1 | |
| *Chaetozone* sp SD5 | | | 0.3 | 1.0 | 18.3 | | 0.8 | | 1.0 | | | | **13.9** | 0.1 | 0.1 |
| *Apionsoma misakianum* | 10.0 | | 0.3 | | 16.0 | | | | | | | 1.0 | 0.1 | | |
| *Gibberosus myersi* | | | 0.3 | 0.2 | 1.7 | **20.8** | 9.0 | 2.0 | 0.8 | | | | | | |
| Actiniaria | 0.5 | | | 0.3 | 1.3 | 16.8 | 0.5 | | | | 0.2 | | | 0.1 | |
| *Metharpinia jonesi* | | | | | | **14.8** | 1.3 | | | | | | | | |
| *Anchicolurus occidentalis* | | | | | | **11.6** | 3.5 | | | | | | | | |
| *Owenia collaris* | | | | | | | **184.5** | | 13.3 | | | | | 0.1 | |
| *Zaolutus actius* | | | | | | | **32.5** | | | | | | | | |

**Table 9.5** *continued*

| Taxa | Cluster Group | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
| *Diastylopsis tenuis* | | | | 0.2 | | 1.8 | 15.0 | 2.0 | 3.1 | | | | | | |
| *Rhepoxynius abronius* | | | | 0.4 | | 1.4 | 11.8 | | 0.4 | | | | | | |
| *Scoletoma tetraura* Cmplx | | | | 0.2 | | 0.4 | 9.3 | 18.0 | 4.2 | 0.5 | 0.3 | | | 0.9 | 1.9 |
| *Ampharete labrops* | | | 0.3 | 1.3 | **9.0** | | | 11.0 | 2.9 | | | | | 0.1 | |
| *Astyris gausapata* | | | | | | | | 5.0 | | | | | | | |
| *Exacanthomysis davisi* | | | | | | | | 4.0 | | | | | | | |
| *Rictaxis punctocaelatus* | | | | | | | | 4.0 | | | | | | | |
| *Polydora cirrosa* | | | | 0.1 | | | 1.0 | 1.0 | 7.7 | | | | | | |
| *Macoma carlottensis* | | | | | | | | | | **13.5** | 0.8 | | | 0.0 | 1.5 |
| *Maldane sarsi* | | | | 0.2 | | | | | | **13.3** | 9.3 | 13.0 | | 1.8 | 3.2 |
| *Nuculana conceptionis* | | | | | | | | | | 5.5 | 7.0 | | | | |
| *Compressidens stearnsii* | | | | | | | | | | **4.5** | 0.8 | 8.0 | 0.4 | 0.2 | 0.9 |
| Maldanidae | | | 1.3 | 1.6 | 0.7 | | | | 0.1 | 4.5 | 0.2 | | 0.2 | 1.5 | 0.6 |
| *Yoldiella nana* | | | | | | | | | | | 12.2 | | | | |
| *Eclysippe trilobata* | | | | | | | | | | | 7.5 | | 0.7 | 0.7 | 0.2 |
| *Myriochele gracilis* | | | | | | | | | | | 3.3 | | 0.2 | 0.7 | 0.6 |
| *Fauveliopsis glabra* | | | | | | | | | | 0.3 | 2.7 | 55.0 | | <0.5 | |
| Amphiuridae | | 1.0 | 4.3 | 1.1 | 2.7 | | 0.5 | 1.0 | 0.2 | 1.0 | 1.0 | 21.0 | 1.5 | 3.4 | 0.4 |
| *Adontorhina cyclia* | | | | | | | | | | 0.7 | | 10.0 | 0.6 | 2.9 | 2.8 |
| *Nephasoma diaphanes* | | | | | 0.3 | | | | | | 0.4 | 10.0 | 0.1 | 0.4 | |
| *Tellina carpenteri* | | | | | | | | | | 0.2 | 0.3 | 8.0 | **8.7** | 1.3 | **6.8** |
| *Micranellum crebricinctum* | 1.0 | | 0.2 | | 0.7 | | | | | | | | 7.5 | | |
| *Amphiodia urtica* | | | 0.2 | 1.1 | 0.7 | | | | | | | | | **56.1** | 1.1 |
| *Axinopsida serricata* | | | | | | | | | | 0.2 | | | 1.5 | **13.1** | 7.2 |
| *Amphiodia* sp | | | 0.2 | 0.6 | 0.7 | 0.6 | | 2.0 | 0.2 | | | | 1.7 | **6.0** | 0.3 |
| *Spiophanes berkeleyorum* | | | 0.8 | 5.1 | 1.3 | | | | 0.2 | 0.7 | | | 0.2 | 5.5 | 0.9 |
| *Spiophanes kimballi* | | | | | | | | | | 2.8 | | | 1.0 | 1.9 | **8.8** |
| *Melinna heterodonta* | | | | | | | | | | 0.7 | | | 0.2 | | **3.5** |

groups N and O, which shared 22.4% similarity and 21 taxa not occurring in any other cluster groups (Figure 9.4, Appendix H.3). Together, these two groups encompassed about 44% of the samples collected between 2009−2011 and contained the vast majority of sites characterized by fine sediments mixed with sand (Figure 9.5). Cluster group N comprised primarily mid-shelf sites that correspond to the well-characterized "*Amphiodia urtica* zone" described previously by Thompson et al. (1993), whereas cluster group O consisted mostly of sites on the outer shelf. Cluster group M possessed all outer shelf sites located on the Coronado Bank plus one additional outer shelf site located north of sites contained in group O. Although all three of the mid- to outer shelf groups (M−O) possessed fine sediments mixed with sand, the percent fines in cluster group M was lower than in groups N and O. The group M assemblage also contained 34 unique taxa that were not encountered in any of the other cluster groups (Appendix H.3).

<u>Upper slope assemblages</u>

Although occurring on the upper slope, the cluster group L assemblage was more closely related to outer shelf groups M through O than to the other slope sites in cluster groups J and K. Group L represented the assemblage from a single site (station 8155) located off the northeast corner of the Coronado Bank at a depth of 312 m (Figure 9.5, Appendix H.2). This station was the only location recorded for several taxa, including the scaphopod *Cadulus californicus*, the pycnogonid *Anoplodactylus* sp, the sipunculid *Apionsoma* sp, and the cirratulid polychaete *Dodecaceria* sp (Appendix H.3). Macrofaunal communities from the six upper slope sites in each of cluster groups J and K supported populations of the bivalve *Nuculana conceptions*, an organism not present in any other cluster groups (Figure 9.4, Appendix H.3). Depths for cluster groups J and K ranged between 286−357 m and 393−433 m, respectively, with sediments for both groups containing the highest percent fines (71–72%) recorded during the 2009−2011 surveys.

## Discussion

The SCB benthos has long been considered to be composed of "patchy" habitats, with the distribution of species and communities exhibiting considerable spatial variability. Results of regional surveys off San Diego support this characterization. Benthic assemblages surveyed between 2009–2011 varied between years and segregated by habitat characteristics such as depth and sediment grain size, and were similar to macrofaunal assemblages observed during regional surveys conducted between 1994−2003 (City of San Diego 2007). No unique infaunal assemblages occurred near either the Point Loma or South Bay Ocean Outfalls, suggesting that the presence of these outfalls has not affected invertebrate community population dynamics.

Many inner to mid-shelf (10–40 m depths) macrofaunal assemblages off San Diego were similar to those found in shallow, sandy habitats across the SCB (Barnard 1963, Jones 1969, Thompson et al. 1987, 1992, ES Engineering Science 1988, Mikel et al. 2007). These assemblages were characterized by sandy sediments that shared populations of polychaetes such as *Owenia collaris*, *Spiophanes norrisi*, and the bivalve *Tellina modesta* (e.g., cluster groups D, E, G, I). However, each cluster group had species that clearly differentiated it from other clusters, with organismal differences likely caused by either sediment or oceanographic characteristics.

The largest number of sites sampled off San Diego between 2009–2011 occurred in mid- to outer shelf areas (30–200 m depths), and were characterized by sandy sediments with a large percentage of fines. Macrofaunal assemblages in these areas were dominated by the brittle star *Amphiodia urtica*. For example, sites from cluster group N correspond to the *Amphiodia* "mega-community" described by Barnard and Ziesenhenne (1961), and are common in the Point Loma region off San Diego as well as other parts of the southern California mainland shelf (Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993, Zmarzly et al. 1994, Diener and Fuller 1995, Bergen et al. 1998, 2000, 2001, Mikel et al. 2007, City of San Diego 2011a, b). Deeper outer shelf stations (e.g., the Coronado Bank) were typically devoid of *A. urtica*, and were instead dominated by polychaete worms such as the cirratulids *Aphelochaeta glandaria* Cmplx, *Monticellina siblina* and *Chaetozone* sp SD5 (i.e., cluster group M).

Similar to patterns described in past monitoring reports (City of San Diego 2011b, Ranasinghe et al. 2012), upper slope habitats off San Diego were characterized by a high percentage of fine sediments with associated macrofaunal assemblages that were distinct from most shelf stations surveyed. Macrofaunal assemblages from upper slope stations were often characterized by relatively high abundances of bivalves such as *Yoldiella nana*, *Nuculana conceptionis*, and *Tellina carpenteri*.

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2009−2011 regional surveys that could be attributed to wastewater discharges, disposal sites or other point sources. Benthic macrofauna appear to be in good condition throughout the region, with 90% of the sites surveyed from 2009−2011 being in reference condition based on assessments using the BRI. This is not unexpected as Ranasinghe et al. (2012) recently reported that 99.7% of the entire SCB was in good condition based on assessment data gathered during the 2008 bight-wide survey.

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# Glossary

# *Glossary*

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

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

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

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

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

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

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

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

**Biota**
The living organisms within a habitat or region.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Epifauna**
Animals living upon the surface of marine sediments.

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

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

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

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

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

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

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

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

**Megabenthic invertebrate**
A larger, usually epibenthic and often motile,

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

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

**Motile**
Self-propelled or actively moving.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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# Appendices

# Appendix A

## Supporting Data

## 2011 SBOO Stations

## Oceanographic Conditions

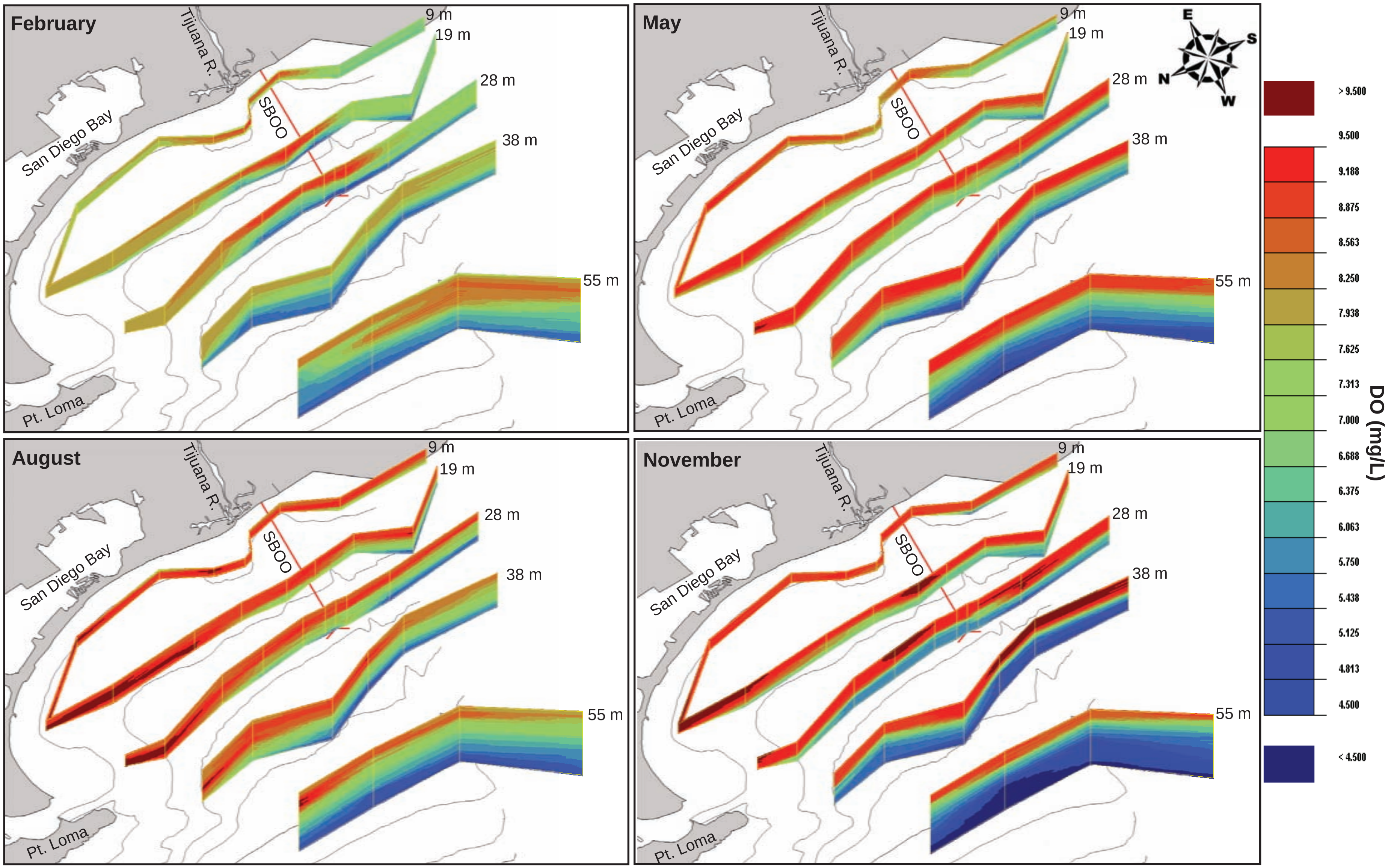
## Appendix A.1

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

| Contour | Depth | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Temperature (°C)* | | | | | | | | | | | | | |
| 9-m | Surface | 14.0 | 13.8 | 12.4 | 15.8 | 16.1 | 15.0 | 19.3 | 17.4 | 17.5 | 15.5 | 14.6 | 14.6 |
| | Bottom | 14.0 | 13.5 | 11.3 | 13.6 | 14.8 | 11.3 | 15.5 | 15.6 | 15.4 | 13.3 | 14.5 | 14.4 |
| 19-m | Surface | 14.2 | 13.5 | 12.8 | 16.1 | 15.8 | 15.0 | 19.9 | 17.5 | 17.8 | 15.8 | 14.5 | 14.6 |
| | Bottom | 14.1 | 12.7 | 10.5 | 11.1 | 12.5 | 10.5 | 13.0 | 13.3 | 13.9 | 12.4 | 13.1 | 14.6 |
| 28-m | Surface | 14.2 | 13.6 | 13.5 | 16.4 | 15.7 | 15.8 | 20.0 | 18.0 | 18.3 | 16.6 | 14.5 | 14.6 |
| | Bottom | 14.1 | 12.1 | 10.3 | 10.6 | 11.7 | 10.3 | 12.4 | 12.2 | 13.0 | 12.1 | 12.4 | 14.3 |
| 38-m | Surface | 14.2 | 13.4 | 14.1 | 16.3 | 15.8 | 16.2 | 20.3 | 18.1 | 18.2 | 17.7 | 14.6 | 14.7 |
| | Bottom | 12.5 | 11.3 | 10.2 | 10.4 | 10.9 | 10.1 | 11.9 | 11.5 | 12.4 | 11.9 | 11.9 | 13.9 |
| 55-m | Surface | 14.2 | 13.8 | 14.1 | 16.2 | 15.5 | 15.8 | 20.0 | 18.1 | 18.3 | 17.8 | 14.2 | 14.5 |
| | Bottom | 10.8 | 11.0 | 10.0 | 10.3 | 10.3 | 10.0 | 11.2 | 10.8 | 11.6 | 11.2 | 11.3 | 12.6 |
| *Salinity (psu)* | | | | | | | | | | | | | |
| 9-m | Surface | 33.23 | 33.27 | 33.46 | 33.29 | 33.51 | 33.55 | 33.54 | 33.38 | 33.34 | 33.32 | 33.22 | 33.49 |
| | Bottom | 33.23 | 33.32 | 33.51 | 33.45 | 33.49 | 33.54 | 33.55 | 33.36 | 33.32 | 33.27 | 33.25 | 33.40 |
| 19-m | Surface | 33.25 | 33.29 | 33.41 | 33.44 | 33.49 | 33.54 | 33.52 | 33.38 | 33.36 | 33.34 | 33.25 | 33.47 |
| | Bottom | 33.25 | 33.34 | 33.60 | 33.53 | 33.47 | 33.59 | 33.51 | 33.36 | 33.31 | 33.23 | 33.32 | 33.35 |
| 28-m | Surface | 33.25 | 33.28 | 33.29 | 33.29 | 33.47 | 33.53 | 33.51 | 33.38 | 33.37 | 33.36 | 33.29 | 33.37 |
| | Bottom | 33.27 | 33.36 | 33.67 | 33.56 | 33.49 | 33.69 | 33.49 | 33.40 | 33.33 | 33.21 | 33.36 | 33.33 |
| 38-m | Surface | 33.27 | 33.31 | 33.26 | 33.41 | 33.48 | 33.52 | 33.60 | 33.41 | 33.37 | 33.36 | 33.32 | 33.38 |
| | Bottom | 33.37 | 33.41 | 33.71 | 33.61 | 33.54 | 33.81 | 33.52 | 33.44 | 33.34 | 33.24 | 33.39 | 33.33 |
| 55-m | Surface | 33.29 | 33.27 | 33.21 | 33.29 | 33.46 | 33.51 | 33.58 | 33.42 | 33.40 | 33.38 | 33.31 | 33.41 |
| | Bottom | 33.49 | 33.45 | 33.77 | 33.67 | 33.65 | 33.87 | 33.56 | 33.51 | 33.39 | 33.47 | 33.55 | 33.38 |
| *Dissolved Oxygen (mg/L)* | | | | | | | | | | | | | |
| 9-m | Surface | 8.0 | 7.7 | 7.3 | 8.6 | 8.7 | 9.4 | 8.2 | 8.7 | 8.7 | 8.7 | 9.3 | 8.0 |
| | Bottom | 7.9 | 7.7 | 5.3 | 7.0 | 8.2 | 5.5 | 8.0 | 9.0 | 8.9 | 7.1 | 9.1 | 7.9 |
| 19-m | Surface | 8.0 | 7.7 | 8.2 | 8.8 | 8.9 | 10.1 | 8.3 | 8.9 | 9.1 | 8.5 | 9.4 | 7.9 |
| | Bottom | 7.9 | 6.5 | 4.5 | 5.0 | 7.1 | 4.4 | 6.1 | 7.9 | 8.7 | 6.9 | 6.5 | 7.8 |
| 28-m | Surface | 8.0 | 7.9 | 8.7 | 8.9 | 9.1 | 9.8 | 8.0 | 8.7 | 9.0 | 8.6 | 9.4 | 7.8 |
| | Bottom | 7.8 | 5.7 | 4.3 | 4.6 | 6.4 | 4.0 | 6.0 | 6.5 | 8.0 | 7.0 | 5.8 | 7.3 |
| 38-m | Surface | 8.0 | 7.6 | 8.9 | 8.9 | 9.2 | 10.0 | 8.5 | 8.6 | 9.0 | 9.0 | 9.1 | 7.8 |
| | Bottom | 6.3 | 5.6 | 4.2 | 4.5 | 5.2 | 3.5 | 5.7 | 5.6 | 7.4 | 6.8 | 5.4 | 6.8 |
| 55-m | Surface | 8.0 | 7.9 | 8.9 | 8.7 | 9.1 | 9.3 | 8.2 | 8.4 | 8.7 | 8.5 | 9.2 | 7.8 |
| | Bottom | 5.6 | 5.5 | 4.2 | 4.3 | 4.6 | 3.3 | 5.2 | 5.1 | 6.1 | 5.4 | 4.3 | 5.5 |

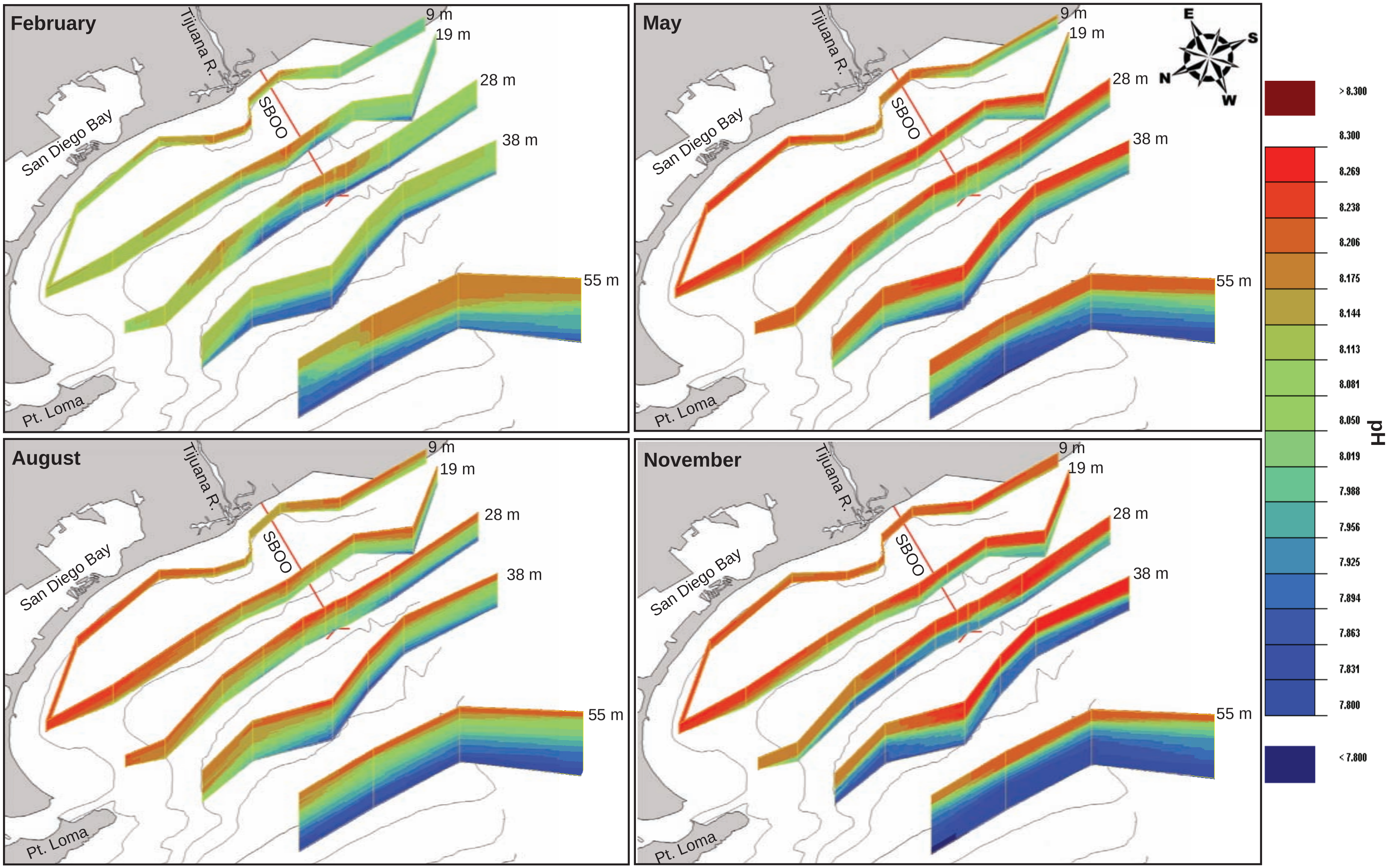
## Appendix A.1 *continued*

| Contour | Depth | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *pH* | | | | | | | | | | | | | |
| 9-m | Surface | 8.1 | 8.2 | 8.0 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.1 |
| | Bottom | 8.1 | 8.1 | 7.9 | 8.1 | 8.2 | 7.9 | 8.2 | 8.2 | 8.2 | 8.0 | 8.2 | 8.1 |
| 19-m | Surface | 8.2 | 8.1 | 8.1 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.1 |
| | Bottom | 8.1 | 8.0 | 7.8 | 7.9 | 8.0 | 7.8 | 8.0 | 8.1 | 8.1 | 8.0 | 8.0 | 8.1 |
| 28-m | Surface | 8.1 | 8.1 | 8.2 | 8.3 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.1 |
| | Bottom | 8.1 | 7.9 | 7.8 | 7.9 | 8.0 | 7.8 | 8.0 | 8.0 | 8.1 | 8.0 | 7.9 | 8.1 |
| 38-m | Surface | 8.2 | 8.1 | 8.2 | 8.2 | 8.2 | 8.3 | 8.2 | 8.2 | 8.2 | 8.3 | 8.2 | 8.1 |
| | Bottom | 8.0 | 7.9 | 7.8 | 7.8 | 7.9 | 7.7 | 7.9 | 7.9 | 8.0 | 8.0 | 7.9 | 8.0 |
| 55-m | Surface | 8.1 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.1 |
| | Bottom | 7.9 | 7.9 | 7.8 | 7.8 | 7.8 | 7.7 | 7.9 | 7.8 | 7.9 | 7.9 | 7.8 | 7.9 |
| *Transmissivity (%)* | | | | | | | | | | | | | |
| 9-m | Surface | 46 | 65 | 66 | 73 | 74 | 71 | 75 | 76 | 78 | 80 | 69 | 70 |
| | Bottom | 47 | 60 | 67 | 66 | 70 | 64 | 70 | 80 | 81 | 76 | 71 | 69 |
| 19-m | Surface | 61 | 73 | 76 | 73 | 79 | 71 | 80 | 83 | 83 | 84 | 74 | 82 |
| | Bottom | 55 | 74 | 86 | 78 | 80 | 77 | 80 | 85 | 84 | 83 | 71 | 81 |
| 28-m | Surface | 80 | 77 | 81 | 78 | 82 | 78 | 84 | 84 | 83 | 86 | 77 | 87 |
| | Bottom | 70 | 77 | 89 | 84 | 86 | 84 | 86 | 88 | 80 | 87 | 80 | 85 |
| 38-m | Surface | 87 | 81 | 81 | 80 | 83 | 78 | 80 | 84 | 84 | 87 | 75 | 88 |
| | Bottom | 72 | 86 | 91 | 88 | 87 | 85 | 87 | 88 | 81 | 88 | 85 | 84 |
| 55-m | Surface | 88 | 82 | 81 | 84 | 83 | 82 | 81 | 84 | 85 | 88 | 74 | 88 |
| | Bottom | 90 | 88 | 91 | 90 | 89 | 89 | 89 | 90 | 88 | 90 | 90 | 87 |
| *Chlorophyll* a *(µg/L)* | | | | | | | | | | | | | |
| 9-m | Surface | 6.8 | 10.4 | 3.7 | 5.8 | 4.7 | 10.7 | 8.4 | 8.0 | 9.6 | 6.6 | 10.1 | 6.1 |
| | Bottom | 6.7 | 12.0 | 5.4 | 7.8 | 10.7 | 25.4 | 21.5 | 10.7 | 8.9 | 7.0 | 20.8 | 8.5 |
| 19-m | Surface | 5.5 | 8.0 | 6.6 | 5.1 | 3.8 | 9.0 | 4.6 | 3.1 | 5.2 | 4.9 | 7.9 | 2.8 |
| | Bottom | 5.9 | 5.2 | 1.7 | 5.0 | 5.8 | 11.1 | 13.1 | 9.7 | 11.9 | 4.5 | 26.2 | 5.1 |
| 28-m | Surface | 3.3 | 9.8 | 6.9 | 3.9 | 3.1 | 5.5 | 2.1 | 2.5 | 5.3 | 2.9 | 5.9 | 1.9 |
| | Bottom | 4.8 | 2.3 | 0.9 | 3.3 | 5.1 | 5.7 | 8.0 | 6.1 | 26.9 | 4.1 | 16.4 | 4.1 |
| 38-m | Surface | 2.0 | 5.7 | 5.2 | 1.8 | 3.0 | 3.3 | 2.3 | 3.0 | 2.7 | 2.6 | 10.2 | 1.7 |
| | Bottom | 3.2 | 1.2 | 0.5 | 2.0 | 6.5 | 4.1 | 4.1 | 3.3 | 20.8 | 3.1 | 4.6 | 4.0 |
| 55-m | Surface | 3.4 | 7.6 | 7.1 | 2.2 | 5.2 | 3.5 | 2.9 | 3.5 | 4.2 | 1.8 | 9.9 | 2.5 |
| | Bottom | 1.0 | 0.9 | 0.4 | 1.2 | 1.5 | 1.6 | 1.9 | 1.5 | 4.4 | 1.3 | 1.2 | 2.4 |



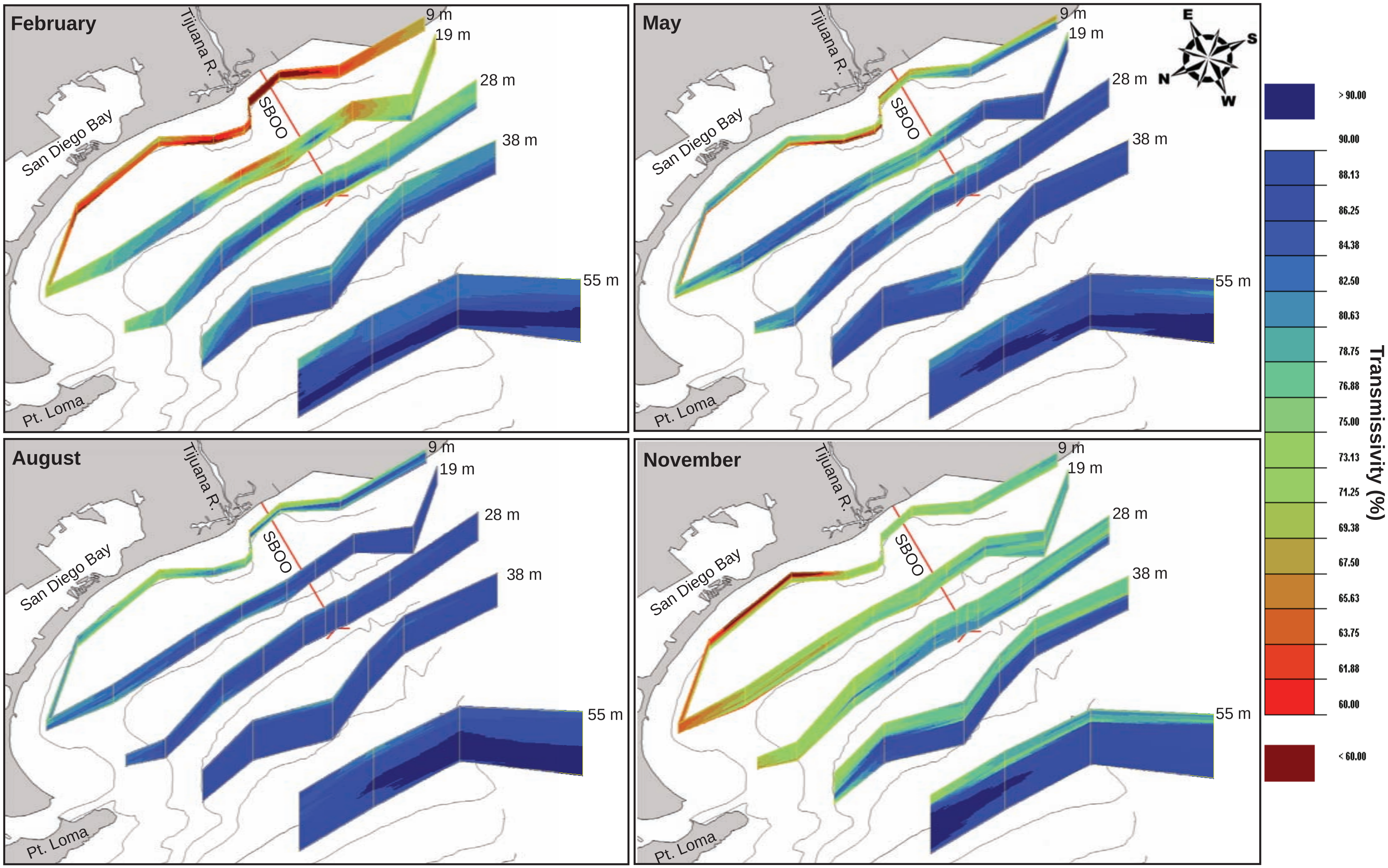

# Appendix A.2

Dissolved oxygen recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.



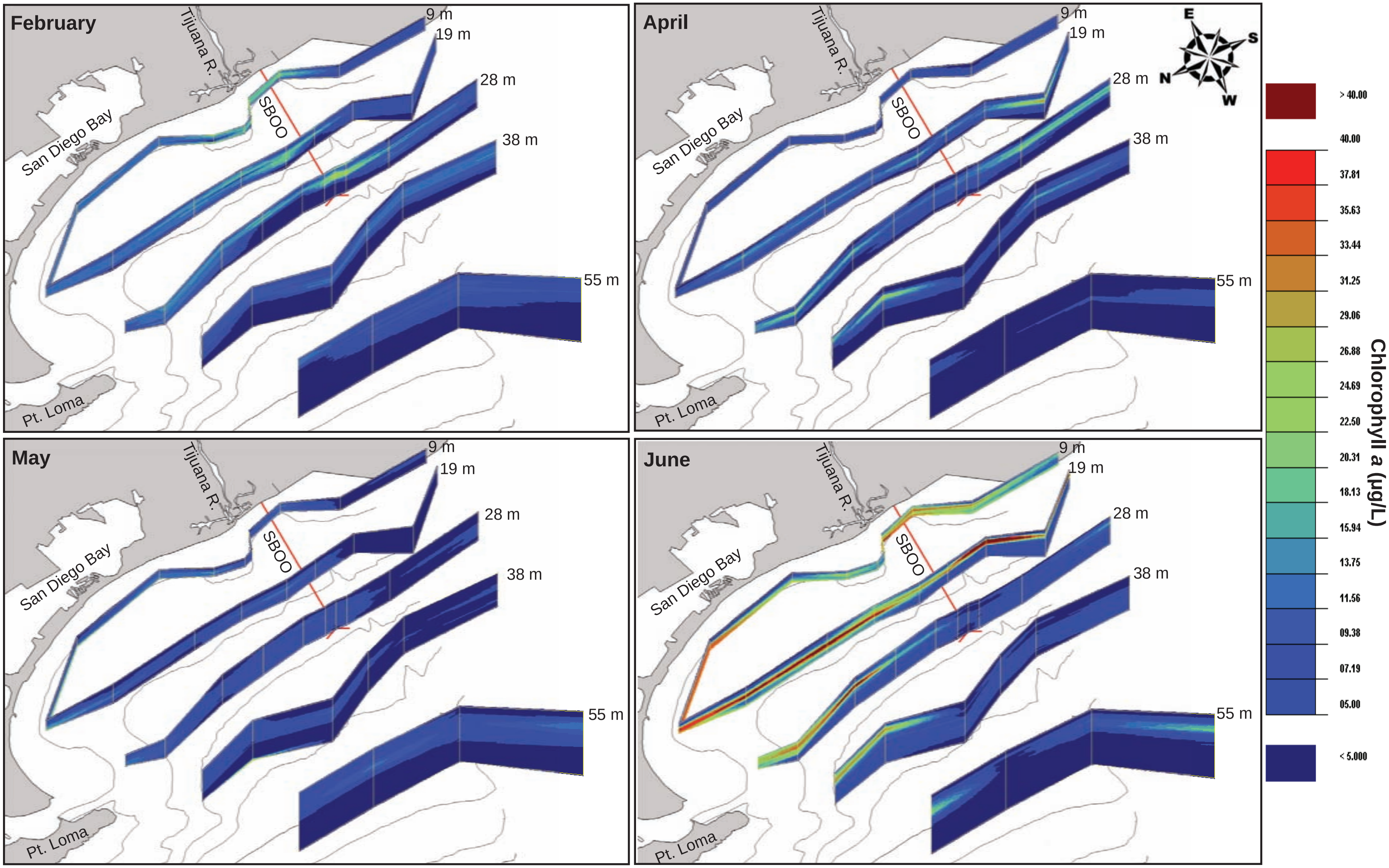

## Appendix A.3

Measurements of pH recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.



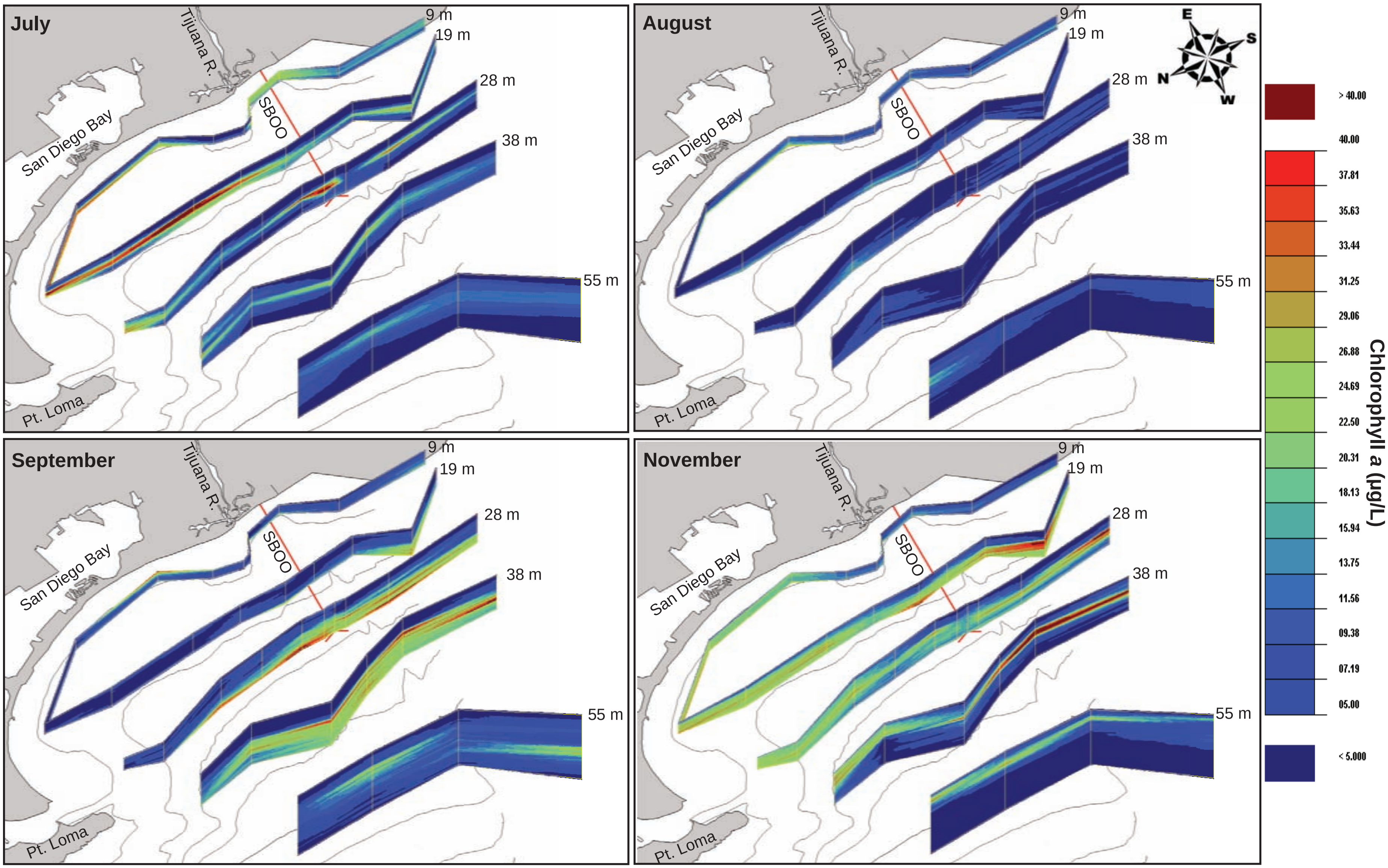

## Appendix A.4

Transmissivity recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.




## Appendix A.5

Concentrations of chlorophyll *a* recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.




**Appendix A.5** *continued*

# Appendix B

# Supporting Data

# 2011 SBOO Stations

# Water Quality

## Appendix B.1

Summary of elevated bacteria densities in samples collected at SBOO shore stations during 2011. 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 | Total | Fecal | Entero | F:T |
|---|---|---|---|---|---|
| S2 | 4 Jan 2011 | 8000 | **440** | **460** | 0.06 |
| S3 | 4 Jan 2011 | **15,000** | 240 | 100 | 0.02 |
| S4 | 4 Jan 2011 | **>16,000** | **900** | **200** | 0.06 |
| S5 | 4 Jan 2011 | **>16,000** | **>12,000** | **15,000** | **0.75** |
| S10 | 4 Jan 2011 | **>16,000** | **9200** | **2800** | **0.57** |
| S2 | 11 Jan 2011 | 600 | 320 | **120** | 0.53 |
| S0 | 18 Jan 2011 | 2600 | **500** | 80 | **0.19** |
| S2 | 18 Jan 2011 | 1200 | 160 | **260** | **0.13** |
| S10 | 18 Jan 2011 | **>16,000** | **>12,000** | **4600** | **0.75** |
| S2 | 25 Jan 2011 | 320 | 60 | **120** | 0.19 |
| S0 | 1 Feb 2011 | **>16,000** | **7600** | **9800** | **0.48** |
| S2 | 1 Feb 2011 | 6200 | **420** | 60 | 0.07 |
| S4 | 1 Feb 2011 | **>16,000** | **>12,000** | **1800** | **0.75** |
| S10 | 1 Feb 2011 | **>16,000** | **>12,000** | **2400** | **0.75** |
| S0 | 8 Feb 2011 | **>16,000** | 400 | **3600** | 0.02 |
| S5 | 22 Feb 2011 | 7800 | 130 | **110** | 0.02 |
| S11 | 22 Feb 2011 | 1600 | 100 | **110** | 0.06 |
| S5 | 1 Mar 2011 | **>16,000** | **>12,000** | **120** | **0.75** |
| S0 | 8 Mar 2011 | 5800 | **1100** | **700** | **0.19** |
| S3 | 8 Mar 2011 | 2200 | 200 | **200** | 0.09 |
| S4 | 8 Mar 2011 | **>16,000** | **2200** | 100 | **0.14** |
| S10 | 8 Mar 2011 | **>16,000** | **5000** | **320** | **0.31** |
| S3 | 15 Mar 2011 | 6400 | **540** | 36 | 0.08 |
| S4 | 15 Mar 2011 | **13,000** | **800** | 60 | 0.06 |
| S10 | 15 Mar 2011 | **>16,000** | **2600** | **240** | **0.16** |
| S0 | 22 Mar 2011 | 420 | 36 | **180** | 0.09 |
| S4 | 22 Mar 2011 | 2400 | 110 | **130** | 0.05 |
| S5 | 22 Mar 2011 | **>16,000** | **>12,000** | **>12,000** | **0.75** |
| S6 | 22 Mar 2011 | **>16,000** | **3000** | **1000** | **0.19** |
| S8 | 22 Mar 2011 | **13,000** | **760** | **440** | 0.06 |
| S9 | 22 Mar 2011 | 8800 | **640** | **260** | 0.07 |
| S10 | 22 Mar 2011 | 4200 | 160 | **220** | 0.04 |
| S11 | 22 Mar 2011 | **>16,000** | **4400** | **2200** | **0.28** |
| S12 | 22 Mar 2011 | **>16,000** | **1000** | **800** | 0.06 |
| S0 | 5 Apr 2011 | 800 | 120 | **420** | 0.15 |
| S5 | 12 Apr 2011 | **>16,000** | **>12,000** | **>12,000** | **0.75** |
| S10 | 12 Apr 2011 | **>16,000** | **7600** | **1800** | **0.48** |
| S11 | 12 Apr 2011 | **>16,000** | **720** | 100 | 0.04 |
| S0 | 19 Apr 2011 | 540 | 160 | **260** | 0.3 |
| S2 | 19 Apr 2011 | 4 | 2 | **180** | 0.5 |
| S12 | 19 Apr 2011 | 6000 | **960** | 34 | **0.16** |
| S3 | 26 Apr 2011 | **>16,000** | **1200** | 2 | 0.08 |

## Appendix B.1 *continued*

| Station | Date | Total | Fecal | Entero | F:T |
|---|---|---|---|---|---|
| S4 | 26 Apr 2011 | **>16,000** | 200 | 2 | 0.01 |
| S5 | 26 Apr 2011 | **>16,000** | **>12,000** | **1000** | **0.75** |
| S10 | 26 Apr 2011 | **>16,000** | **1200** | 2 | 0.08 |
| S0 | 3 May 2011 | 1000 | 100 | **180** | 0.1 |
| S5 | 24 May 2011 | **>16,000** | **6000** | **820** | **0.38** |
| S0 | 31 May 2011 | 2600 | **500** | **420** | **0.19** |
| S5 | 31 May 2011 | 620 | **480** | 8 | 0.77 |
| S0 | 14 Jun 2011 | 4600 | **440** | **300** | 0.1 |
| S2 | 28 Jun 2011 | 5000 | 80 | **110** | 0.02 |
| S3 | 28 Jun 2011 | **15,000** | **540** | **800** | 0.04 |
| S0 | 26 Jul 2011 | 2800 | 100 | **260** | 0.04 |
| S3 | 27 Sep 2011 | 20 | 44 | **140** | 2.2 |
| S3 | 25 Oct 2011 | 160 | 60 | **200** | 0.38 |
| S5 | 8 Nov 2011 | **>16,000** | **>12,000** | **6000** | **0.75** |
| S8 | 15 Nov 2011 | **7200** | **420** | 26 | 0.06 |
| S10 | 15 Nov 2011 | **11000** | **460** | **160** | 0.04 |
| S0 | 22 Nov 2011 | 860 | 100 | **110** | 0.12 |
| S2 | 22 Nov 2011 | **13,000** | **460** | **160** | 0.04 |
| S3 | 22 Nov 2011 | **>16,000** | **580** | **220** | 0.04 |
| S4 | 22 Nov 2011 | **>16,000** | **7200** | **280** | **0.45** |
| S5 | 22 Nov 2011 | **>16,000** | **>12,000** | **9000** | **0.75** |
| S10 | 22 Nov 2011 | **>16,000** | **8600** | **860** | **0.54** |
| S11 | 22 Nov 2011 | **13,000** | **1300** | 38 | 0.1 |
| S0 | 29 Nov 2011 | 2200 | 300 | 22 | **0.14** |
| S0 | 13 Dec 2011 | **>16,000** | **2600** | **>12,000** | **0.16** |
| S2 | 13 Dec 2011 | 3000 | 120 | **240** | 0.04 |
| S3 | 13 Dec 2011 | **>16,000** | **1800** | **1400** | **0.11** |
| S4 | 13 Dec 2011 | 3000 | 320 | **300** | **0.11** |
| S5 | 13 Dec 2011 | 7800 | 360 | **>12,000** | 0.05 |
| S6 | 13 Dec 2011 | **>16,000** | **4200** | **>12,000** | **0.26** |
| S10 | 13 Dec 2011 | 3400 | 200 | **240** | 0.06 |
| S11 | 13 Dec 2011 | **12,000** | 320 | **760** | 0.03 |
| S0 | 20 Dec 2011 | **>16,000** | **720** | **340** | 0.04 |
| S4 | 20 Dec 2011 | 3000 | 240 | **180** | 0.08 |
| S10 | 20 Dec 2011 | **>16,000** | **500** | **220** | 0.03 |
| S0 | 27 Dec 2011 | **>16,000** | **10,000** | **4600** | **0.62** |

## Appendix B.2

Summary of elevated bacteria densities in samples collected at SBOO kelp bed stations during 2011. 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 |
|---|---|---|---|---|---|---|
| I25 | 18 Jan 2011 | 2 | 1400 | 240 | **110** | **0.17** |
| I26 | 18 Jan 2011 | 2 | 2400 | 360 | 98 | **0.15** |
| I26 | 18 Jan 2011 | 6 | 1400 | 180 | 46 | **0.13** |
| I26 | 31 Jan 2011 | 9 | 20 | 2 | **220** | 0.1 |
| I39 | 12 Mar 2011 | 18 | 200 | 18 | **340** | 0.09 |
| I26 | 22 Mar 2011 | 6 | **13,000** | 300 | **130** | 0.02 |
| I26 | 22 Mar 2011 | 9 | **>16,000** | 300 | **240** | 0.02 |
| I26 | 19 May 2011 | 6 | 1200 | 180 | 24 | **0.15** |
| I26 | 19 May 2011 | 9 | **12,000** | **1300** | 60 | **0.11** |
| I25 | 15 Dec 2011 | 2 | 9000 | **580** | 52 | 0.06 |
| I25 | 15 Dec 2011 | 6 | 5000 | 320 | **160** | 0.06 |
| I25 | 15 Dec 2011 | 9 | 4800 | 180 | **400** | 0.04 |
| I26 | 15 Dec 2011 | 6 | 4400 | 140 | **220** | 0.03 |
| I26 | 15 Dec 2011 | 9 | 3800 | 260 | **140** | 0.07 |
| I26 | 18 Dec 2011 | 2 | 2200 | 260 | 48 | **0.12** |

# Appendix B.3

Summary of elevated bacteria densities in samples collected at SBOO non-kelp bed offshore stations during 2011. 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 |
|---|---|---|---|---|---|---|
| I32 | 3 Jan 2011 | 6 | 3800 | 54 | **130** | 0.01 |
| I19 | 4 Jan 2011 | 2 | 5600 | 280 | **110** | 0.05 |
| I19 | 4 Jan 2011 | 6 | 8200 | 300 | **130** | 0.04 |
| I19 | 4 Jan 2011 | 11 | 280 | 54 | **140** | 0.19 |
| I24 | 1 Feb 2011 | 6 | 3800 | **580** | 100 | **0.15** |
| I19 | 2 Mar 2011 | 2 | 9200 | **560** | 2 | 0.06 |
| I19 | 2 Mar 2011 | 11 | **13,000** | **600** | 46 | 0.05 |
| I10 | 3 Mar 2011 | 12 | **17,000** | **1700** | **400** | 0.1 |
| I11 | 3 Mar 2011 | 6 | 2400 | 74 | **220** | 0.03 |
| I40 | 6 Apr 2011 | 2 | **>16,000** | **420** | **120** | 0.03 |
| I12 | 10 May 2011 | 18 | 1600 | **740** | 100 | **0.46** |
| I22 | 6 Jul 2011 | 18 | 2000 | 240 | 86 | **0.12** |

## Appendix B.4

Summary of samples with elevated FIB densities at SBOO shore stations during wet and dry seasons bewteen 1995–2011. Wet = January–April and October–December; Dry = May–September; *n* = total number of samples. Shore station sampling began in October 1995. Rain totals from 1995 include only October–December. Rain was measured at Lindbergh Field, San Diego, CA. Stations are listed north to south from left to right.

| Year | Season | S9 | S8 | S12 | S6 | S11 | S5 | S10 | S4 | S3 | S2 | S0 | Rain(in) | Total | *n* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | Wet | 1 | 0 | ns | 0 | ns | 0 | ns | 0 | 0 | 0 | ns | 14.76 | 1 | 43 |
| | Dry | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| 1996 | Wet | 2 | 0 | 5 | 3 | 3 | 3 | 1 | 10 | 6 | 8 | ns | 7.13 | 41 | 291 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | ns | 0.14 | 3 | 131 |
| 1997 | Wet | 3 | 3 | 5 | 6 | 7 | 21 | 13 | 15 | 9 | 8 | ns | 6.15 | 90 | 595 |
| | Dry | 1 | 0 | 3 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | ns | 0.85 | 11 | 422 |
| 1998 | Wet | 4 | 2 | 8 | 12 | 13 | 36 | 17 | 15 | 16 | 11 | ns | 15.08 | 134 | 537 |
| | Dry | 0 | 1 | 12 | 13 | 13 | 22 | 3 | 5 | 8 | 4 | ns | 0.97 | 81 | 416 |
| 1999 | Wet | 0 | 4 | 4 | 6 | 8 | 19 | 11 | 10 | 6 | 4 | ns | 5.31 | 80 | 431 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 2 | 1 | ns | 0.12 | 5 | 220 |
| 2000 | Wet | 2 | 4 | 7 | 9 | 8 | 14 | 6 | 5 | 5 | 9 | ns | 6.89 | 69 | 322 |
| | Dry | 3 | 0 | 2 | 2 | 1 | 1 | 3 | 4 | 3 | 3 | ns | 0.01 | 22 | 224 |
| 2001 | Wet | 7 | 6 | 8 | 11 | 11 | 19 | 11 | 14 | 16 | 7 | ns | 8.46 | 110 | 340 |
| | Dry | 3 | 0 | 2 | 1 | 1 | 0 | 1 | 3 | 1 | 2 | ns | 0.01 | 14 | 218 |
| 2002 | Wet | 1 | 1 | 1 | 1 | 4 | 10 | 9 | 9 | 5 | 5 | 2 | 3.92 | 48 | 340 |
| | Dry | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 0 | 0.31 | 6 | 219 |
| 2003 | Wet | 1 | 3 | 5 | 9 | 10 | 19 | 12 | 12 | 7 | 5 | 12 | 8.88 | 95 | 360 |
| | Dry | 1 | 0 | 2 | 1 | 2 | 3 | 2 | 2 | 4 | 4 | 3 | 0.30 | 24 | 243 |
| 2004 | Wet | 3 | 2 | 9 | 13 | 13 | 18 | 11 | 11 | 8 | 4 | 8 | 13.29 | 100 | 336 |
| | Dry | 1 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0.00 | 6 | 241 |
| 2005 | Wet | 4 | 5 | 9 | 13 | 19 | 30 | 14 | 13 | 10 | 5 | 7 | 13.86 | 129 | 376 |
| | Dry | 0 | 1 | 1 | 4 | 3 | 4 | 2 | 2 | 2 | 2 | 7 | 0.25 | 28 | 248 |
| 2006 | Wet | 1 | 1 | 4 | 5 | 7 | 10 | 7 | 7 | 5 | 4 | 7 | 5.33 | 58 | 328 |
| | Dry | 0 | 1 | 3 | 2 | 3 | 4 | 2 | 1 | 2 | 0 | 6 | 0.82 | 24 | 241 |
| 2007 | Wet | 0 | 0 | 1 | 2 | 1 | 5 | 7 | 6 | 4 | 4 | 6 | 4.32 | 36 | 330 |
| | Dry | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4 | 0.05 | 8 | 242 |
| 2008 | Wet | 3 | 4 | 5 | 8 | 10 | 13 | 10 | 6 | 12 | 6 | 8 | 10.86 | 85 | 352 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 3 | 0.25 | 6 | 230 |
| 2009 | Wet | 0 | 3 | 4 | 6 | 5 | 11 | 10 | 9 | 9 | 7 | 12 | 5.43 | 76 | 330 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.07 | 1 | 242 |
| 2010 | Wet | 2 | 2 | 4 | 7 | 6 | 15 | 13 | 9 | 11 | 7 | 14 | 16.20 | 90 | 301 |
| | Dry | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 2 | 11 | 0.08 | 16 | 239 |
| 2011 | Wet | 1 | 2 | 2 | 2 | 5 | 9 | 12 | 9 | 7 | 8 | 12 | 8.56 | 69 | 330 |
| | Dry | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 1 | 4 | 0.52 | 9 | 242 |
| **Total** | **Wet** | **35** | **42** | **81** | **113** | **131** | **256** | **166** | **161** | **136** | **102** | **88** | **162.97** | **1311** | **5942** |
| | **Dry** | **10** | **7** | **26** | **25** | **26** | **42** | **14** | **21** | **29** | **23** | **41** | **5.27** | **264** | **4018** |

ns = not sampled

## Appendix B.5

Summary of samples with elevated FIB densities at SBOO kelp bed stations during wet and dry seasons between 1995–2011. Wet = January–April and October–December; Dry = May–September; *n* = total number of samples. Kelp bed station sampling began in July 1995. Rain totals from 1995 include only July–December. Rain was measured at Lindbergh Field, San Diego, CA.

| | Depth Contour: | 9-m | | 19-m | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Season** | **I25** | **I26** | **I39** | **Rain(in)** | **Total** | ***n*** |
| 1995 | Wet | 0 | 0 | ns | 14.76 | 0 | 18 |
| | Dry | 0 | 0 | ns | 0.05 | 0 | 18 |
| 1996 | Wet | 0 | 0 | 0 | 7.13 | 0 | 51 |
| | Dry | 0 | 0 | 0 | 0.14 | 0 | 39 |
| 1997 | Wet | 4 | 3 | 2 | 6.15 | 9 | 63 |
| | Dry | 1 | 0 | 0 | 0.85 | 1 | 45 |
| 1998 | Wet | 6 | 3 | 1 | 15.08 | 10 | 63 |
| | Dry | 0 | 0 | 1 | 0.97 | 1 | 45 |
| 1999 | Wet | 6 | 3 | 9 | 5.31 | 18 | 306 |
| | Dry | 0 | 1 | 6 | 0.12 | 7 | 225 |
| 2000 | Wet | 16 | 11 | 10 | 6.89 | 37 | 330 |
| | Dry | 0 | 0 | 3 | 0.01 | 3 | 224 |
| 2001 | Wet | 25 | 22 | 2 | 8.46 | 49 | 339 |
| | Dry | 2 | 0 | 3 | 0.01 | 5 | 226 |
| 2002 | Wet | 3 | 6 | 2 | 3.92 | 11 | 297 |
| | Dry | 0 | 0 | 1 | 0.31 | 1 | 212 |
| 2003 | Wet | 9 | 4 | 3 | 8.88 | 16 | 315 |
| | Dry | 4 | 0 | 1 | 0.30 | 5 | 227 |
| 2004 | Wet | 21 | 27 | 18 | 13.29 | 66 | 322 |
| | Dry | 0 | 1 | 1 | 0.00 | 2 | 224 |
| 2005 | Wet | 19 | 16 | 8 | 13.86 | 43 | 322 |
| | Dry | 0 | 0 | 2 | 0.25 | 2 | 225 |
| 2006 | Wet | 1 | 2 | 1 | 5.33 | 4 | 315 |
| | Dry | 0 | 0 | 0 | 0.82 | 0 | 225 |
| 2007 | Wet | 6 | 1 | 2 | 4.32 | 9 | 315 |
| | Dry | 1 | 0 | 1 | 0.05 | 2 | 225 |
| 2008 | Wet | 18 | 13 | 4 | 10.86 | 35 | 315 |
| | Dry | 0 | 0 | 0 | 0.25 | 0 | 225 |
| 2009 | Wet | 11 | 6 | 2 | 5.43 | 19 | 315 |
| | Dry | 0 | 0 | 0 | 0.07 | 0 | 225 |
| 2010 | Wet | 11 | 10 | 5 | 16.20 | 26 | 315 |
| | Dry | 0 | 0 | 1 | 0.08 | 1 | 225 |
| 2011 | Wet | 4 | 8 | 1 | 8.56 | 13 | 315 |
| | Dry | 0 | 2 | 0 | 0.52 | 2 | 225 |
| **Total** | **Wet** | **160** | **135** | **70** | **162.97** | **365** | **4316** |
| | **Dry** | **8** | **4** | **20** | **5.27** | **32** | **3060** |

ns = not sampled

## Appendix B.6

Summary of compliance with the 2005 California Ocean Plan water contact standards for SBOO shore and kelp bed stations during 2011. The values reflect the number of times per month that each station exceeded various total coliform, fecal coliform, and enterococcus bacterial standards (see Chapter 3; Box 3.1). Shore stations are listed north to south from left to right.

**30 day Geometric Mean Standards**

| | Shore Stations | | | | | | | | Kelp Bed Stations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **S9** | **S8** | **S12** | **S6** | **S11** | **S5** | **S10** | **S4** | **I25** | **I26** | **I39** |
| ***Total Coliform*** | | | | | | | | | | | |
| January | 0 | 0 | 0 | 0 | 7 | 31 | 31 | 28 | 0 | 0 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 7 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 5 | 27 | 17 | 5 | 0 | 0 | 0 |
| April | 0 | 0 | 0 | 5 | 9 | 25 | 30 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 16 | 11 | 0 | 0 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 14 | 7 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 | 0 | 10 | 11 | 0 | 0 | 0 | 0 |
| **Percent Compliance** | **100%** | **100%** | **100%** | **99%** | **94%** | **66%** | **63%** | **89%** | **100%** | **100%** | **100%** |
| ***Fecal Coliform*** | | | | | | | | | | | |
| January | 0 | 0 | 0 | 0 | 10 | 26 | 31 | 29 | 0 | 0 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 2 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 4 | 7 | 15 | 0 | 0 | 0 | 0 |
| April | 0 | 0 | 0 | 0 | 9 | 17 | 17 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 13 | 7 | 0 | 0 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 18 | 6 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 | 0 | 10 | 5 | 0 | 0 | 0 | 0 |
| **Percent Compliance** | **100%** | **100%** | **100%** | **100%** | **94%** | **75%** | **73%** | **92%** | **100%** | **100%** | **100%** |
| ***Enterococcus*** | | | | | | | | | | | |
| January | 19 | 19 | 24 | 24 | 25 | 31 | 31 | 31 | 26 | 31 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 4 | 19 | 5 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 8 | 8 | 29 | 15 | 0 | 0 | 0 | 0 |
| April | 0 | 0 | 0 | 20 | 22 | 30 | 16 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 21 | 9 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 19 | 0 | 22 | 26 | 10 | 0 | 0 | 0 |
| **Percent Compliance** | **95%** | **95%** | **93%** | **81%** | **85%** | **59%** | **68%** | **87%** | **93%** | **92%** | **100%** |

## Appendix B.6 *continued*

**Single Sample Maximum Standards**

| | Shore Stations | | | | | | | | Kelp Bed Stations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **S9** | **S8** | **S12** | **S6** | **S11** | **S5** | **S10** | **S4** | **I25** | **I26** | **I39** |
| ***Total Coliform*** | | | | | | | | | | | |
| January | 0 | 0 | 0 | 0 | 0 | 3 | 7 | 2 | 0 | 0 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 |
| March | 0 | 1 | 1 | 3 | 3 | 5 | 3 | 2 | 0 | 1 | 0 |
| April | 0 | 0 | 0 | 0 | 1 | 6 | 5 | 1 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 1 | 6 | 3 | 2 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| **Total** | **0** | **1** | **1** | **4** | **6** | **22** | **21** | **8** | **0** | **2** | **0** |
| ***Fecal Coliform*** | | | | | | | | | | | |
| January | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 2 | 0 | 0 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 |
| March | 1 | 1 | 1 | 3 | 3 | 5 | 4 | 2 | 0 | 0 | 0 |
| April | 0 | 0 | 1 | 0 | 1 | 4 | 5 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 1 | 0 | 0 | 1 | 6 | 3 | 2 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| **Total** | **1** | **2** | **2** | **4** | **5** | **20** | **20** | **7** | **1** | **1** | **0** |
| ***Enterococcus*** | | | | | | | | | | | |
| January | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 3 | 2 | 3 | 0 |
| February | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 1 | 0 | 0 | 0 |
| March | 1 | 1 | 1 | 3 | 3 | 6 | 4 | 1 | 0 | 1 | 1 |
| April | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 6 | 3 | 2 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 0 |
| **Total** | **1** | **1** | **1** | **5** | **7** | **24** | **17** | **9** | **4** | **5** | **1** |

## Appendix B.6 *continued*

**Single Sample Maximum Standards**

| | Shore Stations | | | | | | | | Kelp Bed Stations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **S9** | **S8** | **S12** | **S6** | **S11** | **S5** | **S10** | **S4** | **I25** | **I26** | **I39** |
| ***Fecal/Total Coliform Ratio (F:T)*** | | | | | | | | | | | |
| January | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 1 | 1 | 1 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 3 | 3 | 5 | 3 | 1 | 0 | 0 | 0 |
| April | 0 | 0 | 1 | 0 | 0 | 4 | 2 | 0 | 0 | 0 | 0 |
| May | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| June | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| September | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 5 | 2 | 2 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| **Total** | **0** | **0** | **1** | **4** | **3** | **18** | **12** | **6** | **1** | **3** | **0** |

# Appendix C

# Supporting Data

# 2011 SBOO Stations

# Sediment Conditions

## Appendix C.1

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

**Wentworth Scale**

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

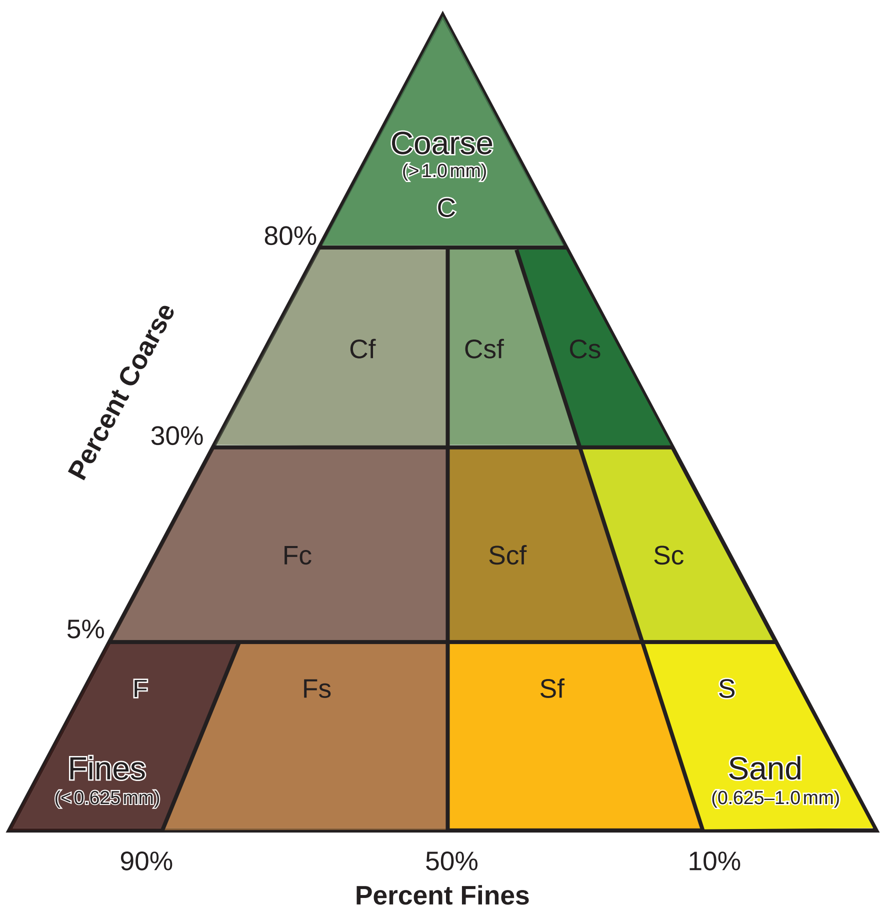
**Sorting Coefficient**

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

## Appendix C.2

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

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



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## Appendix C.3

Constituents and method detection limits (MDL) used for the analysis of sediments collected from the SBOO region between 2007–2011.

| Parameter | MDL 2007–2010 | MDL 2011 | Parameter | MDL 2007–2010 | MDL 2011 |
|---|---|---|---|---|---|
| **Organic Indicators** | | | | | |
| Total Nitrogen (TN, % wt.) | 0.005 | 0.005 | Total Sulfides (ppm) | 0.14 | 0.14 |
| Total Organic Carbon (TOC, % wt.) | 0.01 | 0.01 | Total Volatile Solids (TVS, % wt.) | 0.11 | 0.11 |
| **Metals (ppm)** | | | | | |
| Aluminum (Al) | 1.2–2 | 2 | Lead (Pb) | 0.142–0.8 | 0.8 |
| Antimony (Sb) | 0.13–0.3 | 0.3 | Manganese (Mn) | 0.0037–0.08 | 0.08 |
| Arsenic (As) | 0.33 | 0.33 | Mercury (Hg) | 0.003 | 0.003, 0.004[a] |
| Barium (Ba) | 0.0018–0.02 | 0.02 | Nickel (Ni) | 0.036–0.1 | 0.1 |
| Beryllium (Be) | 0.0012–0.01 | 0.01 | Selenium (Se) | 0.24 | 0.24 |
| Cadmium (Cd) | 0.01–0.06 | 0.06 | Silver (Ag) | 0.013–0.04 | 0.04 |
| Chromium (Cr) | 0.016–0.1 | 0.1 | Thallium (Ti) | 0.22–0.5 | 0.5 |
| Copper (Cu) | 0.028–0.2 | 0.2 | Tin (Sn) | 0.059–0.3 | 0.3 |
| Iron (Fe) | 0.76–9 | 9 | Zinc (Zn) | 0.052–0.25 | 0.25 |
| **Chlorinated Pesticides (ppt)** | | | | | |
| *Hexachlorocyclohexane (HCH)* | | | | | |
| HCH, Alpha isomer | e | 150 | HCH, Delta isomer | e | 700 |
| HCH, Beta isomer | e | 310 | HCH, Gamma isomer | e | 260 |
| *Total Chlordane* | | | | | |
| Alpha (cis) Chlordane | e | 240 | Heptachlor epoxide | e | 120 |
| Cis Nonachlor | e | 240 | Methoxychlor | e | 1100 |
| Gamma (trans) Chlordane | e | 350 | Oxychlordane | e | 240 |
| Heptachlor | e | 1200 | Trans Nonachlor | e | 250 |
| *Total Dichlorodiphenyltrichloroethane (DDT)* | | | | | |
| o,p-DDD | e | 830 | p,p-DDE | e | 260 |
| o,p-DDE | e | 720 | p,-p-DDMU[b] | e | — |
| o,p-DDT | e | 800 | p,p-DDT | e | 800 |
| p,p-DDD | e | 470 | | | |
| *Miscellaneous Pesticides* | | | | | |
| Aldrin | e | 430 | Endrin | e | 830 |
| Alpha Endosulfan | e | 240 | Endrin aldehyde | e | 830 |
| Beta Endosulfan | e | 350 | Hexachlorobenzene | e | 470 |
| Dieldrin | e | 310 | Mirex | e | 500 |
| Endosulfan Sulfate | e | 260 | | | |

[a] methods changed between Jan & Jul; [b] No MDL available for this parameter; e = values estimated regardless of MDL

## Appendix C.3 *continued*

| Parameter | MDL 2007–2010 | MDL 2011 | Parameter | MDL 2007–2010 | MDL 2011 |
|---|---|---|---|---|---|
| **Polychlorinated Biphenyl Congeners (PCBs) (ppt)** | | | | | |
| PCB 18 | e | 540 | PCB 126 | e | 720 |
| PCB 28 | e | 700 | PCB 128 | e | 570 |
| PCB 37 | e | 700 | PCB 138 | e | 590 |
| PCB 44 | e | 700 | PCB 149 | e | 500 |
| PCB 49 | e | 700 | PCB 151 | e | 640 |
| PCB 52 | e | 700 | PCB 153/168 | e | 600 |
| PCB 66 | e | 700 | PCB 156 | e | 620 |
| PCB 70 | e | 700 | PCB 157 | e | 700 |
| PCB 74 | e | 700 | PCB 158 | e | 510 |
| PCB 77 | e | 700 | PCB 167 | e | 620 |
| PCB 81 | e | 700 | PCB 169 | e | 610 |
| PCB 87 | e | 700 | PCB 170 | e | 570 |
| PCB 99 | e | 700 | PCB 177 | e | 650 |
| PCB 101 | e | 430 | PCB 180 | e | 530 |
| PCB 105 | e | 720 | PCB 183 | e | 530 |
| PCB 110 | e | 640 | PCB 187 | e | 470 |
| PCB 114 | e | 700 | PCB 189 | e | 620 |
| PCB 118 | e | 830 | PCB 194 | e | 420 |
| PCB 119 | e | 560 | PCB 201 | e | 530 |
| PCB 123 | e | 660 | PCB 206 | e | 510 |
| **Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)** | | | | | |
| 1-methylnaphthalene | e | 20 | Benzo[G,H,I]perylene | e | 20 |
| 1-methylphenanthrene | e | 20 | Benzo[K]fluoranthene | e | 20 |
| 2,3,5-trimethylnaphthalene | e | 20 | Biphenyl | e | 30 |
| 2,6-dimethylnaphthalene | e | 20 | Chrysene | e | 40 |
| 2-methylnaphthalene | e | 20 | Dibenzo(A,H)anthracene | e | 20 |
| 3,4-benzo(B)fluoranthene | e | 20 | Fluoranthene | e | 20 |
| Acenaphthene | e | 20 | Fluorene | e | 20 |
| Acenaphthylene | e | 30 | Indeno(1,2,3-CD)pyrene | e | 20 |
| Anthracene | e | 20 | Naphthalene | e | 30 |
| Benzo[A]anthracene | e | 20 | Perylene | e | 30 |
| Benzo[A]pyrene | e | 20 | Phenanthrene | e | 30 |
| Benzo[e]pyrene | e | 20 | Pyrene | e | 20 |

e = values estimated regardless of MDL

# Appendix C.4

Summary of the constituents that make up total DDT and total PCB in sediments collected from the SBOO region in 2011.

| Station | Class | Constituent | January | July | Units |
|---|---|---|---|---|---|
| I7 | DDT | p,p-DDE | 130 | nd | ppt |
| I14 | DDT | p,p-DDE | nd | 280 | ppt |
| I28 | DDT | p,p-DDE | 730 | 690 | ppt |
| I29 | DDT | p,p-DDE | 2700 | 340 | ppt |
| I29 | DDT | p,-p-DDMU | 870 | nd | ppt |
| I29 | DDT | p,p-DDT | 1700 | nd | ppt |
| I29 | PCB | PCB 105 | 200 | nd | ppt |
| I29 | PCB | PCB 110 | 260 | nd | ppt |
| I29 | PCB | PCB 118 | 210 | nd | ppt |
| I29 | PCB | PCB 149 | 230 | nd | ppt |
| I29 | PCB | PCB 153/168 | 320 | nd | ppt |
| I35 | DDT | p,p-DDE | 240 | 350 | ppt |

nd = not detected

## Appendix C.5

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

| | Mean (µm) | Mean (phi) | SD (phi) | Median (phi) | Coarse (%) | Sand (%) | Silt (%) | Clay (%) | Fines (%) | Sediment Type | Visual Observations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *19-m Stations* | | | | | | | | | | | |
| I35[c] | 130 | 3.8 | 1.4 | 3.7 | 1.4 | 66.4 | 31.3 | 1.0 | 32.3 | Sand w/ fines | organic debris (worm tubes) |
| I34 | 243 | 2.2 | 0.7 | 2.2 | 0.0 | 98.2 | 1.8 | 0.0 | 1.8 | Sand | worm tubes/organic debris/shell hash |
| I31 | 114 | 3.4 | 0.9 | 3.3 | 0.0 | 90.2 | 9.6 | 0.2 | 9.8 | Sand | — |
| I23[s] | 754 | 0.9 | 1.2 | 1.0 | 31.9 | 66.6 | — | — | 1.5 | Coarse w/ sand | shell hash |
| I18 | 115 | 3.3 | 0.9 | 3.3 | 0.0 | 90.3 | 9.4 | 0.2 | 9.7 | Sand | — |
| I10 | 120 | 3.3 | 0.9 | 3.3 | 0.0 | 91.3 | 8.6 | 0.1 | 8.7 | Sand | — |
| I4 | 290 | 2.2 | 1.2 | 2.3 | 1.9 | 94.7 | 3.4 | 0.0 | 3.4 | Sand | worm tubes/shell hash |
| *28-m Stations* | | | | | | | | | | | |
| I33 | 131 | 3.2 | 1.1 | 3.0 | 0.0 | 89.8 | 9.8 | 0.4 | 10.2 | Sand w/ fines | organic debris (worm tubes) |
| I30 | 100 | 3.6 | 1.0 | 3.5 | 0.0 | 85.9 | 13.8 | 0.4 | 14.2 | Sand w/ fines | organic debris (worm tubes) |
| I27 | 103 | 3.6 | 1.0 | 3.5 | 0.0 | 85.3 | 14.3 | 0.5 | 14.8 | Sand w/ fines | organic debris (worm tubes) |
| I22 | 120 | 3.4 | 1.1 | 3.3 | 0.0 | 86.1 | 13.3 | 0.5 | 13.9 | Sand w/ fines | organic debris (worm tubes) |
| I14[a] | 107 | 3.5 | 1.1 | 3.3 | 0.0 | 85.9 | 13.6 | 0.6 | 14.2 | Sand w/ fines | organic debris (worm tubes) |
| I16[a] | 331 | 1.9 | 1.1 | 1.7 | 2.1 | 94.8 | 3.2 | 0.0 | 3.2 | Sand | organic debris (worm tubes) |
| I15[a] | 382 | 1.7 | 1.1 | 1.6 | 3.4 | 93.3 | 3.3 | 0.0 | 3.3 | Sand | organic debris (worm tubes) |
| I12[a] | 553 | 1.0 | 0.7 | 1.0 | 7.3 | 92.8 | 0.0 | 0.0 | 0.0 | Sand w/ coarse | organic debris (worm tubes) |
| I9 | 101 | 3.6 | 1.0 | 3.5 | 0.0 | 84.4 | 15.2 | 0.4 | 15.7 | Sand w/ fines | organic debris (worm tubes) |
| I6 | 526 | 1.1 | 0.8 | 1.0 | 7.4 | 92.5 | 0.1 | 0.0 | 0.1 | Sand w/ coarse | red relict sand/shell hash |
| I2 | 410 | 1.5 | 0.8 | 1.6 | 4.7 | 95.0 | 0.4 | 0.0 | 0.4 | Sand | — |
| I3 | 424 | 1.5 | 0.8 | 1.5 | 5.0 | 95.0 | 0.0 | 0.0 | 0.0 | Sand w/ coarse | — |
| *38-m Stations* | | | | | | | | | | | |
| I29 | 92 | 3.9 | 1.4 | 3.7 | 0.0 | 70.6 | 27.9 | 1.5 | 29.4 | Sand w/ fines | organic debris (worm tubes) |
| I21 | 143 | 3.1 | 1.1 | 3.0 | 0.0 | 89.2 | 10.4 | 0.4 | 10.8 | Sand w/ fines | red relict sand |
| I13 | 533 | 1.1 | 0.7 | 1.0 | 6.9 | 93.2 | 0.0 | 0.0 | 0.0 | Sand w/ coarse | worm tubes/organic debris/shell hash |
| I8 | 289 | 2.1 | 1.1 | 1.7 | 0.0 | 95.2 | 4.8 | 0.0 | 4.8 | Sand | worm tubes |
| *55-m Stations* | | | | | | | | | | | |
| I28[s] | 403 | 2.2 | 1.6 | 2.0 | 16.6 | 62.0 | — | — | 21.3 | Sand w/ coarse and fines | coarse black sand/pea gravel |
| I20 | 375 | 1.8 | 1.4 | 1.5 | 0.7 | 92.0 | 6.9 | 0.4 | 7.3 | Sand | — |
| I7 | 625 | 0.9 | 1.0 | 0.8 | 12.3 | 86.1 | 1.6 | 0.0 | 1.6 | Sand w/ coarse | red relict sand/shell hash |
| I1 | 150 | 3.0 | 1.2 | 2.7 | 0.0 | 90.3 | 9.3 | 0.4 | 9.7 | Sand | — |

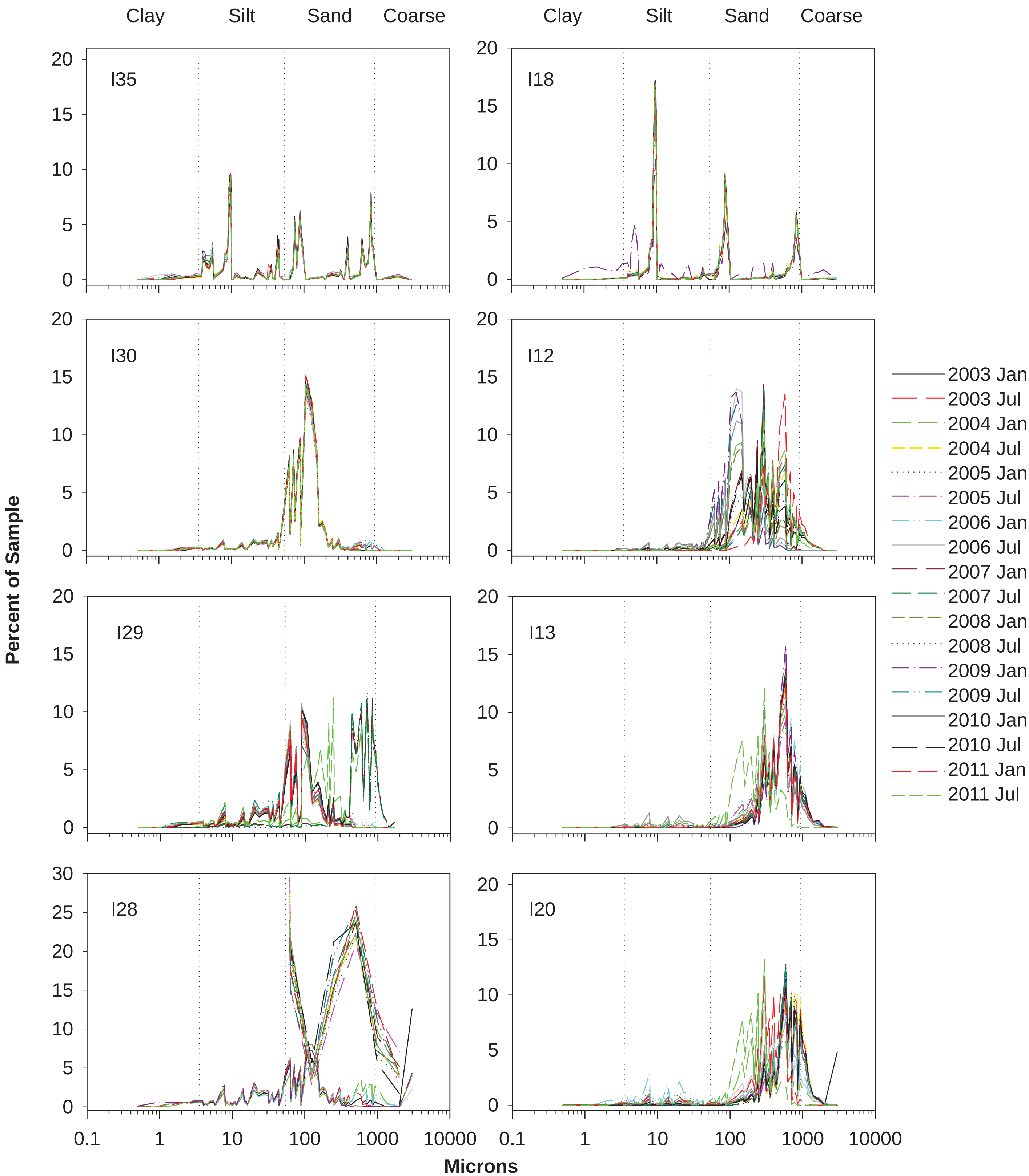
[a] nearfield stations; [s] measured by sieve (not Horiba); [c] contains fraction > 2000 microns measured by sieve (not Horiba)

## Appendix C.5 *continued*

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

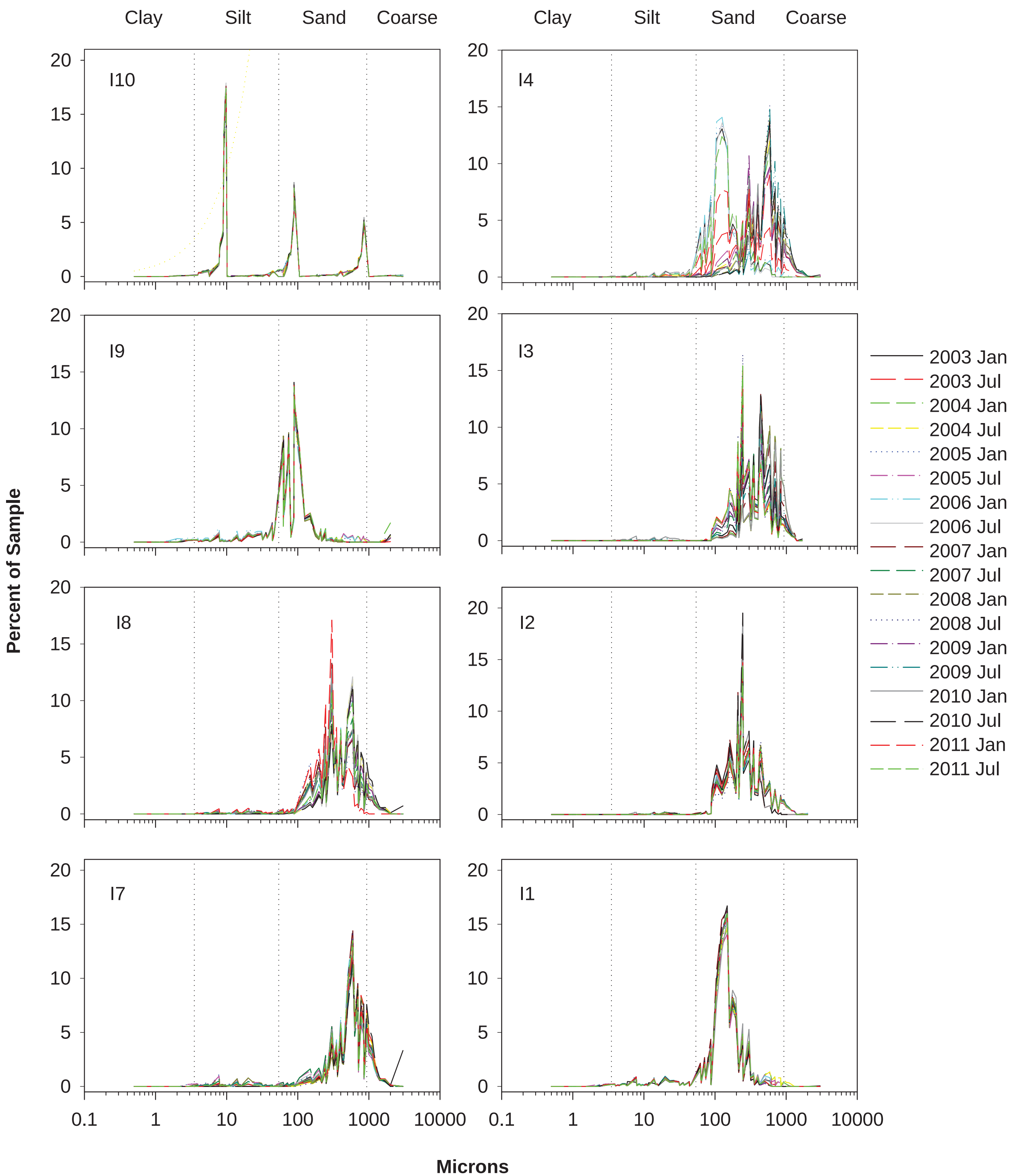
| | Mean (µm) | Mean (phi) | SD (phi) | Median (phi) | Coarse (%) | Sand (%) | Silt (%) | Clay (%) | Fines (%) | Sediment Type | Visual Observations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *19-m Stations* | | | | | | | | | | | |
| I35 | 91 | 3.94 | 1.37 | 3.65 | 0.0 | 66.3 | 32.4 | 1.4 | 33.7 | Sand w/ fines | organic debris (worm tubes) |
| I34 [s] | 744 | 0.97 | 1.30 | 1.00 | 38.5 | 61.0 | — | — | 0.5 | Coarse w/ sand | red relict sand/gravel/shell hash |
| I31 | 114 | 3.33 | 0.88 | 3.25 | 0.0 | 91.8 | 8.1 | 0.1 | 8.2 | Sand | organic debris (worm tubes) |
| I23 | 119 | 3.31 | 0.96 | 3.25 | 0.0 | 90.7 | 9.2 | 0.1 | 9.3 | Sand | shell hash/organic debris (worm tubes) |
| I18 | 115 | 3.33 | 0.87 | 3.25 | 0.0 | 91.3 | 8.6 | 0.1 | 8.7 | Sand | — |
| I10 | 120 | 3.27 | 0.87 | 3.25 | 0.0 | 92.1 | 7.9 | 0.0 | 7.9 | Sand | organic debris (worm tubes) |
| I4 | 171 | 2.83 | 0.97 | 2.75 | 0.0 | 94.5 | 5.4 | 0.0 | 5.4 | Sand | shell hash |
| *28-m Stations* | | | | | | | | | | | |
| I33 | 125 | 3.31 | 1.19 | 3.00 | 0.0 | 88.0 | 11.4 | 0.6 | 12.0 | Sand w/ fines | organic debris (worm tubes) |
| I30 | 96 | 3.67 | 1.09 | 3.51 | 0.0 | 82.8 | 16.5 | 0.8 | 17.3 | Sand w/ fines | organic debris (worm tubes) |
| I27 | 101 | 3.55 | 1.00 | 3.47 | 0.0 | 86.0 | 13.5 | 0.5 | 14.0 | Sand w/ fines | organic debris (worm tubes) |
| I22 | 125 | 3.39 | 1.27 | 3.25 | 0.0 | 84.5 | 14.8 | 0.8 | 15.6 | Sand w/ fines | organic debris (worm tubes) |
| I14 [a] | 108 | 3.48 | 1.02 | 3.25 | 0.0 | 86.7 | 12.9 | 0.4 | 13.3 | Sand w/ fines | organic debris (worm tubes) |
| I16 [a] | 187 | 2.74 | 1.11 | 2.64 | 0.0 | 93.0 | 6.9 | 0.1 | 7.0 | Sand | organic debris (worm tubes) |
| I15 [a] | 416 | 1.57 | 1.07 | 1.51 | 4.6 | 92.7 | 2.7 | 0.0 | 2.7 | Sand | — |
| I12 [a] | 444 | 1.43 | 0.92 | 1.32 | 4.9 | 93.9 | 1.2 | 0.0 | 1.2 | Sand | large shell hash/few rock pebbles |
| I9 | 101 | 3.59 | 1.04 | 3.51 | 0.0 | 84.0 | 15.4 | 0.6 | 16.0 | Sand w/ fines | organic debris (worm tubes) |
| I6 | 531 | 1.08 | 0.71 | 1.00 | 6.7 | 93.3 | 0.0 | 0.0 | 0.0 | Sand w/ coarse | red relict sand/shell hash |
| I2 | 401 | 1.58 | 0.90 | 1.64 | 4.6 | 94.6 | 0.8 | 0.0 | 0.8 | Sand | — |
| I3 | 423 | 1.45 | 0.76 | 1.51 | 4.7 | 95.3 | 0.0 | 0.0 | 0.0 | Sand w/ coarse | organic debris (worm tubes) |
| *38-m Stations* | | | | | | | | | | | |
| I29 | 162 | 3.35 | 1.84 | 2.64 | 0.0 | 74.4 | 23.6 | 1.9 | 25.6 | Sand w/ fines | red relict sand/gravel |
| I21 | 621 | 0.99 | 1.25 | 0.76 | 12.2 | 84.1 | 3.7 | 0.0 | 3.7 | Sand w/ coarse | red relict sand/shell hash |
| I13 | 246 | 2.43 | 1.35 | 2.20 | 0.0 | 92.1 | 7.5 | 0.4 | 7.9 | Sand | organic debris (worm tubes) |
| I8 | 475 | 1.35 | 1.05 | 1.32 | 5.9 | 92.0 | 2.2 | 0.0 | 2.2 | Sand w/ coarse | — |
| *55-m Stations* | | | | | | | | | | | |
| I28 [s] | 374 | 2.33 | 1.63 | 2.00 | 14.1 | 62.8 | — | — | 23.3 | Sand w/ coarse and fines | coarse black sand/gravel |
| I20 | 227 | 2.53 | 1.38 | 2.25 | 0.0 | 91.2 | 8.3 | 0.5 | 8.8 | Sand | coarse black sand/worm tubes |
| I7 | 601 | 1.00 | 1.12 | 0.76 | 10.4 | 87.3 | 2.4 | 0.0 | 2.4 | Sand w/ coarse | red relict sand |
| I1 | 154 | 2.99 | 1.12 | 2.75 | 0.0 | 91.3 | 8.3 | 0.3 | 8.6 | Sand | — |

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




## Appendix C.6

Select plots illustrating historical grain size distributions in sediments collected from the SBOO region between 2003–2011.




**Appendix C.6** *continued*

## Appendix C.7

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

| | January | | | | July | | | |
|---|---|---|---|---|---|---|---|---|
| | Sulfides (ppm) | TN (% wt) | TOC (% wt) | TVS (% wt) | Sulfides (ppm) | TN (% wt) | TOC (% wt) | TVS (% wt) |
| *19-m Stations* | | | | | | | | |
| I35 | **9.09** | 0.036 | 0.24 | 1.23 | **5.18** | 0.035 | 0.23 | 1.58 |
| I34 | 1.12 | 0.011 | 0.03 | 0.51 | 1.43 | 0.014 | 0.36 | 0.73 |
| I31 | 1.32 | 0.017 | 0.09 | 0.65 | 2.16 | 0.022 | 0.12 | 0.62 |
| I23 | 3.06 | 0.014 | **1.92** | 1.02 | 0.65 | 0.021 | 0.13 | 0.74 |
| I18 | 0.90 | 0.018 | 0.10 | 0.64 | 2.17 | 0.018 | 0.10 | 0.73 |
| I10 | 0.64 | 0.020 | 0.11 | 0.92 | 1.94 | 0.021 | 0.13 | 0.86 |
| I4 | 1.29 | 0.013 | 0.05 | 0.53 | 2.84 | 0.017 | 0.09 | 0.62 |
| *28-m Stations* | | | | | | | | |
| I33 | 2.18 | 0.027 | 0.16 | 1.30 | **6.49** | 0.028 | 0.17 | 1.19 |
| I30 | 0.69 | 0.026 | 0.17 | 1.01 | 2.73 | 0.029 | 0.18 | 1.02 |
| I27 | 1.14 | 0.023 | 0.14 | 0.93 | 4.34 | 0.024 | 0.16 | 1.02 |
| I22 | 2.51 | 0.025 | 0.17 | 0.89 | 2.91 | 0.024 | 0.16 | 0.88 |
| I14 [a] | 5.10 | 0.021 | 0.15 | 0.88 | 4.58 | 0.030 | 0.21 | 1.02 |
| I16 [a] | 0.88 | 0.013 | 0.05 | 0.46 | 2.70 | 0.018 | 0.10 | 0.73 |
| I15 [a] | 0.60 | 0.015 | 0.07 | 0.50 | 0.49 | 0.015 | 0.08 | 0.50 |
| I12 [a] | 2.47 | 0.023 | 0.14 | 0.99 | 0.72 | 0.016 | 0.08 | 0.50 |
| I9 | 0.95 | 0.024 | 0.15 | 1.07 | 3.03 | 0.033 | 0.24 | 1.37 |
| I6 | nd | 0.015 | 0.07 | 0.43 | 0.59 | 0.012 | 0.04 | 0.46 |
| I2 | 0.20 | 0.014 | 0.07 | 0.42 | nd | 0.014 | 0.07 | 0.42 |
| I3 | nd | 0.013 | 0.05 | 0.42 | 0.98 | 0.014 | 0.06 | 0.41 |
| *38-m Stations* | | | | | | | | |
| I29 | 2.50 | **0.049** | 0.40 | **1.64** | 1.29 | 0.012 | 0.04 | 0.45 |
| I21 | 0.38 | 0.013 | 0.12 | 0.49 | 0.19 | 0.017 | 0.09 | 0.62 |
| I13 | nd | 0.015 | 0.06 | 0.52 | 4.92 | 0.018 | 0.10 | 0.68 |
| I8 | 0.33 | 0.013 | 0.06 | 0.51 | 3.84 | 0.016 | 0.07 | 0.55 |
| *55-m Stations* | | | | | | | | |
| I28 | 2.07 | **0.050** | 0.39 | **1.60** | 3.25 | **0.051** | 0.40 | **1.89** |
| I20 | nd | 0.013 | 0.05 | 0.48 | 1.04 | 0.023 | 0.12 | 0.71 |
| I7 | nd | 0.013 | 0.06 | 0.45 | 1.25 | 0.015 | 0.06 | 0.57 |
| I1 | 0.23 | 0.025 | 0.18 | 0.96 | 1.15 | 0.025 | 0.17 | 1.06 |
| Detection Rate (%) | 81 | 100 | 100 | 100 | 96 | 100 | 100 | 100 |
| 95th Percentile | 5.15 | 0.041 | 0.40 | 1.59 | 5.15 | 0.041 | 0.40 | 1.59 |

[a] nearfield stations; nd = not detected

# Appendix C.8

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

| | Al | Sb | As | Ba | Be | Cd | Cr | Cu | Fe | Pb | Mn | Hg | Ni | Se | Ag | Tl | Sn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *19-m Stations* | | | | | | | | | | | | | | | | | | |
| I35 | 7300 | 0.46 | 1.5 | 42.4 | 0.095 | 0.11 | 12.6 | 4.8 | 8930 | **5.20** | **89.6** | 0.012 | 4.60 | nd | nd | nd | 0.51 | **26.4** |
| I34 | 1870 | nd | 0.9 | 9.9 | 0.011 | nd | 4.3 | 1.1 | 3290 | 2.26 | 26.9 | 0.004 | 1.06 | nd | nd | nd | nd | 7.4 |
| I31 | 3350 | nd | nd | 16.8 | 0.033 | nd | 7.0 | 1.3 | 3230 | 1.93 | 33.5 | 0.003 | 1.79 | nd | nd | nd | nd | 8.0 |
| I23 | 857 | nd | 2.4 | 4.4 | 0.033 | nd | 3.6 | 0.6 | 3460 | 2.47 | 21.5 | nd | 0.69 | nd | nd | nd | nd | 6.8 |
| I18 | 5810 | nd | 1.6 | 38.6 | 0.058 | nd | 12.4 | 2.5 | 7220 | 3.33 | 79.7 | nd | 2.81 | nd | nd | nd | 0.36 | 15.0 |
| I10 | 3990 | 0.63 | 1.4 | 24.3 | 0.043 | 0.39 | 7.7 | 2.1 | 4350 | 2.16 | 47.7 | nd | 2.89 | nd | nd | 1.15 | 1.63 | 12.3 |
| I4 | 1760 | 0.55 | 1.3 | 11.5 | 0.020 | 0.31 | 6.0 | 1.1 | 2480 | 1.92 | 24.5 | nd | 2.07 | nd | nd | 1.71 | 1.27 | 6.9 |
| *28-m Stations* | | | | | | | | | | | | | | | | | | |
| I33 | 3730 | nd | 1.4 | 18.5 | 0.048 | 0.07 | 7.2 | 2.8 | 5260 | 3.45 | 53.5 | 0.011 | 2.49 | nd | nd | nd | 0.41 | 14.1 |
| I30 | 5750 | nd | 1.0 | 30.6 | 0.067 | 0.07 | 10.6 | 3.2 | 6240 | 3.26 | 58.0 | 0.006 | 3.40 | nd | nd | nd | nd | 18.4 |
| I27 | **7930** | 0.46 | 0.5 | 34.0 | 0.085 | nd | 11.3 | 3.3 | 7390 | 3.47 | 74.7 | 0.005 | 3.82 | nd | nd | nd | 0.31 | 19.0 |
| I22 | 5170 | nd | 1.6 | 28.5 | 0.063 | nd | 9.9 | 3.1 | 6340 | 3.34 | 51.7 | 0.004 | 3.20 | nd | nd | nd | 0.30 | 15.1 |
| I14[a] | 6480 | 0.34 | 1.3 | 37.2 | 0.076 | 0.06 | 10.8 | 3.5 | 6570 | 3.75 | 71.4 | nd | 3.68 | nd | nd | nd | 0.34 | 18.3 |
| I16[a] | 2970 | nd | 1.6 | 12.2 | 0.041 | nd | 6.4 | 1.9 | 4330 | 2.06 | 48.4 | nd | 1.44 | nd | nd | nd | nd | 10.3 |
| I15[a] | 2510 | nd | 2.5 | 8.4 | 0.042 | nd | 9.1 | 1.1 | 4570 | 2.51 | 31.1 | 0.003 | 1.49 | nd | nd | nd | nd | 9.6 |
| I12[a] | 6260 | 0.31 | 1.6 | 42.9 | 0.075 | 0.06 | 10.9 | 3.3 | 7490 | 3.39 | 77.7 | 0.003 | 3.57 | nd | nd | nd | 0.37 | 20.2 |
| I9 | 5980 | 0.77 | 1.8 | 40.3 | 0.076 | **0.45** | 11.1 | 3.7 | 6560 | 3.19 | 73.0 | nd | 4.29 | nd | nd | 0.81 | **1.85** | 19.2 |
| I6 | 779 | 0.68 | 4.6 | 3.2 | 0.013 | 0.33 | 8.9 | 0.3 | 3750 | 1.87 | 9.7 | nd | 1.04 | nd | nd | 1.48 | 1.30 | 4.6 |
| I2 | 642 | 0.69 | 0.7 | 2.3 | nd | **0.47** | 7.7 | 0.5 | 1140 | 1.18 | 6.7 | nd | 1.63 | nd | nd | **3.26** | 1.60 | 3.7 |
| I3 | 503 | 0.59 | 1.1 | 1.7 | nd | 0.32 | 6.8 | 0.3 | 1080 | 0.87 | 5.3 | nd | 0.96 | nd | nd | 1.60 | 1.40 | 2.3 |
| *38-m Stations* | | | | | | | | | | | | | | | | | | |
| I29 | **19,200** | 0.84 | 2.2 | **76.0** | **0.222** | 0.19 | **27.4** | **11.1** | **19,000** | **10.40** | **169.0** | 0.012 | **10.10** | nd | nd | nd | 1.20 | **45.5** |
| I21 | 1370 | 0.42 | **9.5** | 5.5 | 0.034 | 0.10 | 12.0 | 0.8 | 8650 | 3.77 | 16.3 | nd | 1.05 | nd | nd | nd | nd | 7.6 |
| I13 | 1240 | 0.37 | 5.0 | 3.0 | 0.019 | 0.06 | 10.9 | 0.8 | 5910 | 2.87 | 18.7 | nd | 0.90 | nd | nd | nd | nd | 6.5 |
| I8 | 1620 | 0.66 | 2.6 | 4.7 | 0.031 | 0.37 | 9.9 | 0.6 | 3940 | 1.54 | 19.9 | nd | 1.55 | nd | nd | 1.36 | 1.38 | 7.9 |
| *55-m Stations* | | | | | | | | | | | | | | | | | | |
| I28 | 6950 | 0.35 | 2.8 | 28.2 | 0.096 | 0.09 | 11.2 | 5.2 | 8500 | 5.18 | 63.9 | 0.018 | 5.58 | 0.30 | nd | nd | 0.58 | 20.8 |
| I20 | 902 | nd | 2.1 | 2.0 | 0.048 | nd | 5.4 | 0.5 | 5440 | 1.66 | 14.2 | nd | 0.83 | nd | nd | nd | nd | 5.4 |
| I7 | 1030 | **0.85** | **5.9** | 2.6 | 0.024 | 0.41 | 9.3 | 0.2 | 6460 | 2.39 | 14.8 | 0.017 | 1.35 | nd | nd | 0.99 | 1.41 | 6.5 |
| I1 | 1600 | 0.56 | 1.2 | 7.2 | 0.033 | 0.32 | 6.0 | 1.4 | 2540 | 2.18 | 24.4 | 0.022 | 2.80 | nd | nd | 2.32 | 1.14 | 7.5 |
| Detection Rate (%) | 100 | 63 | 96 | 100 | 93 | 67 | 100 | 100 | 100 | 100 | 100 | 48 | 100 | 4 | 0 | 33 | 67 | 100 |
| 95th Percentile | 7618 | 0.84 | 5.6 | 43.7 | 0.106 | 0.45 | 13.4 | 6.0 | 9196 | 5.19 | 88.4 | 0.023 | 5.64 | — | — | 2.88 | 1.72 | 25.8 |

[a]nearfield stations; nd=not detected; na=not available

## Appendix C.8 *continued*

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

| | Al | Sb | As | Ba | Be | Cd | Cr | Cu | Fe | Pb | Mn | Hg | Ni | Se | Ag | Tl | Sn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *19-m Stations* | | | | | | | | | | | | | | | | | | |
| I35 | 7250 | 0.33 | 2.5 | **44.3** | **0.118** | 0.10 | 12.3 | 5.9 | **9690** | 4.78 | 87.8 | **0.023** | 4.96 | nd | nd | nd | 0.93 | 25.5 |
| I34 | 972 | nd | 2.7 | 6.0 | 0.027 | nd | 2.5 | 3.0 | 2200 | 1.47 | 25.2 | nd | 1.12 | nd | nd | nd | nd | 5.6 |
| I31 | 2990 | nd | 1.3 | 16.6 | 0.053 | nd | 6.4 | 2.5 | 2930 | 1.61 | 30.6 | nd | 1.74 | nd | nd | nd | 0.34 | 7.6 |
| I23 | 3830 | nd | 1.5 | 32.4 | 0.040 | nd | 7.8 | 3.0 | 4110 | 0.89 | 41.0 | 0.007 | 4.19 | nd | nd | nd | 0.68 | 11.6 |
| I18 | 3380 | nd | 1.5 | 37.4 | 0.020 | nd | 6.8 | 1.6 | 3500 | 1.00 | 40.6 | nd | nd | nd | nd | nd | 0.31 | 10.4 |
| I10 | 5150 | nd | 1.6 | 31.5 | nd | nd | 6.3 | 1.7 | 4930 | 0.81 | 52.5 | nd | nd | nd | nd | nd | 0.43 | 12.7 |
| I4 | 2990 | nd | 1.3 | 19.1 | nd | nd | 6.0 | 2.5 | 3380 | 1.35 | 32.3 | nd | nd | nd | nd | nd | 0.40 | 8.1 |
| *28-m Stations* | | | | | | | | | | | | | | | | | | |
| I33 | 4560 | nd | 1.6 | 21.9 | 0.070 | 0.06 | 8.1 | 3.6 | 5990 | 4.35 | 61.0 | 0.013 | 2.80 | nd | nd | nd | 0.81 | 15.9 |
| I30 | 5570 | nd | 1.8 | 33.2 | 0.096 | 0.07 | 10.4 | 4.6 | 6510 | 2.94 | 59.4 | 0.007 | 4.07 | nd | nd | nd | 0.74 | 17.2 |
| I27 | 4810 | nd | 1.5 | 31.9 | 0.079 | nd | 8.9 | 3.4 | 5320 | 2.05 | 53.8 | 0.005 | 3.77 | nd | nd | nd | 0.40 | 16.1 |
| I22 | 3790 | nd | 1.5 | 24.8 | 0.074 | nd | 8.5 | 2.4 | 4430 | 1.96 | 40.8 | 0.010 | 3.39 | nd | nd | nd | 0.69 | 12.0 |
| I14[a] | 4820 | nd | 2.1 | 35.8 | 0.014 | nd | 9.9 | 4.2 | 5400 | 1.25 | 61.7 | 0.004 | nd | nd | nd | nd | 0.38 | 17.0 |
| I16[a] | 2490 | nd | 1.4 | 16.8 | 0.020 | nd | 6.4 | 2.0 | 3350 | 1.15 | 35.3 | nd | nd | nd | nd | nd | nd | 9.6 |
| I15[a] | 1480 | nd | 2.4 | 6.8 | 0.032 | nd | 8.2 | 2.6 | 3270 | 1.58 | 18.9 | 0.004 | nd | nd | nd | nd | nd | 9.3 |
| I12[a] | **20,900** | 0.45 | 1.4 | **77.4** | nd | nd | **38.2** | 4.1 | **28,700** | **6.60** | **246.0** | nd | nd | nd | nd | nd | **2.23** | **66.4** |
| I9 | 7450 | nd | 1.8 | 43.3 | 0.010 | nd | 8.9 | 3.6 | 6840 | nd | 71.9 | nd | 3.97 | nd | nd | nd | 0.42 | 20.1 |
| I6 | 900 | nd | 4.8 | 2.0 | nd | nd | 9.2 | **6.1** | 3560 | 1.60 | 6.8 | nd | nd | nd | nd | nd | nd | 6.3 |
| I2 | 1090 | nd | 0.7 | 2.1 | nd | nd | 5.0 | 2.4 | 1120 | nd | 7.8 | nd | nd | nd | nd | nd | nd | 3.6 |
| I3 | 1000 | nd | 1.3 | 1.7 | nd | nd | 5.6 | 1.0 | 1320 | nd | 6.2 | nd | nd | nd | nd | nd | nd | 2.9 |
| *38-m Stations* | | | | | | | | | | | | | | | | | | |
| I29 | 1200 | nd | 3.3 | 3.7 | 0.052 | nd | 5.7 | 1.4 | 5840 | 2.03 | 12.1 | 0.008 | 1.16 | nd | nd | nd | nd | 8.0 |
| I21 | 834 | nd | **8.6** | 2.4 | 0.052 | nd | 11.1 | nd | 6740 | 4.14 | 12.4 | nd | nd | nd | nd | nd | nd | 6.0 |
| I13 | 993 | nd | 2.7 | 4.8 | 0.023 | nd | 9.0 | 0.7 | 3250 | 2.07 | 13.7 | 0.007 | nd | nd | nd | nd | nd | 5.4 |
| I8 | 2070 | nd | 2.3 | 4.9 | nd | nd | 7.1 | 1.2 | 4190 | 1.15 | 20.1 | nd | nd | nd | nd | nd | nd | 8.2 |
| *55-m Stations* | | | | | | | | | | | | | | | | | | |
| I28 | 4570 | nd | 2.3 | 29.0 | **0.108** | 0.10 | 9.7 | 6.0 | 6760 | 4.10 | 52.6 | **0.024** | **5.98** | nd | nd | nd | 0.89 | 18.2 |
| I20 | 1420 | nd | 2.4 | 5.8 | 0.042 | nd | 5.9 | 1.0 | 3260 | 1.77 | 15.4 | 0.006 | nd | nd | nd | nd | nd | 7.4 |
| I7 | 1260 | nd | 5.3 | 2.7 | 0.015 | nd | **15.0** | **15.8** | 5900 | 2.63 | 15.5 | nd | nd | nd | nd | nd | nd | 13.3 |
| I1 | 2460 | nd | 1.2 | 10.2 | nd | nd | 4.8 | 1.3 | 3000 | 1.45 | 28.2 | 0.007 | nd | nd | nd | nd | 0.36 | 7.4 |
| Detection Rate (%) | 100 | 7 | 100 | 100 | 70 | 15 | 100 | 96 | 100 | 89 | 100 | 48 | 41 | 0 | 0 | 0 | 56 | 100 |
| 95th Percentile | 7618 | 0.84 | 5.6 | 43.7 | 0.106 | 0.45 | 13.4 | 6.0 | 9196 | 5.19 | 88.4 | 0.023 | 5.64 | — | — | 2.88 | 1.72 | 25.8 |

[a]nearfield stations; nd=not detected; na=not available

## Appendix C.9

Concentrations of total DDT, HCB, and total PCB detected in sediments from SBOO stations sampled during January and July 2011. Values that exceed thresholds are highlighted (see Table 4.1).

| | January | | | July | | |
|---|---|---|---|---|---|---|
| | tDDT (ppt) | HCB (ppt) | tPCB (ppt) | tDDT (ppt) | HCB (ppt) | tPCB (ppt) |
| *19-m Stations* | | | | | | |
| I35 | 240 | nd | nd | 350 | nd | nd |
| I34 | nd | nd | nd | nd | nd | nd |
| I31 | nd | nd | nd | nd | nd | nd |
| I23 | nd | nd | nd | nd | nd | nd |
| I18 | nd | nd | nd | nd | nd | nd |
| I10 | nd | nd | nd | nd | nd | nd |
| I4 | nd | nd | nd | nd | nd | nd |
| *28-m Stations* | | | | | | |
| I33 | nd | nd | nd | nd | nd | nd |
| I30 | nd | nd | nd | nd | 2700 | nd |
| I27 | nd | nd | nd | nd | nd | nd |
| I22 | nd | nd | nd | nd | nd | nd |
| I14[a] | nd | nd | nd | 280 | nd | nd |
| I16[a] | nd | nd | nd | nd | nd | nd |
| I15[a] | nd | nd | nd | nd | nd | nd |
| I12[a] | nd | nd | nd | nd | nd | nd |
| I9 | nd | nd | nd | nd | nd | nd |
| I6 | nd | nd | nd | nd | nd | nd |
| I2 | nd | nd | nd | nd | nd | nd |
| I3 | nd | nd | nd | nd | nd | nd |
| *38-m Stations* | | | | | | |
| I29 | 5270 | nd | 1220 | 340 | nd | nd |
| I21 | nd | nd | nd | nd | nd | nd |
| I13 | nd | nd | nd | nd | nd | nd |
| I8 | nd | nd | nd | nd | 490 | nd |
| *55-m Stations* | | | | | | |
| I28 | 730 | nd | nd | 690 | nd | nd |
| I20 | nd | nd | nd | nd | nd | nd |
| I7 | 130 | nd | nd | nd | nd | nd |
| I1 | nd | nd | nd | nd | nd | nd |
| Detection Rate (%) | 15 | 0 | 4 | 15 | 7 | 0 |

[a]nearfield station; nd=not detected; na=not available

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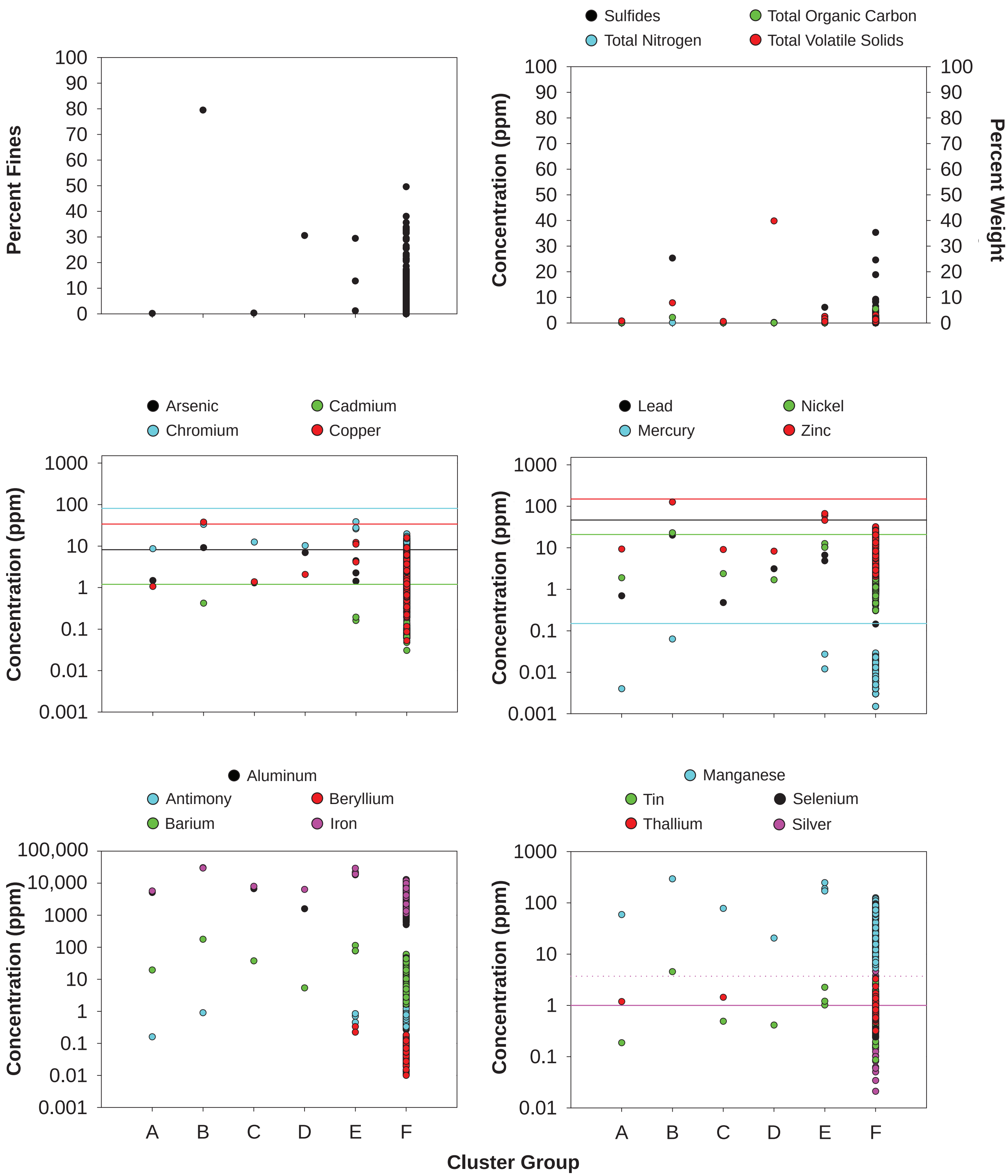
## Appendix C.10

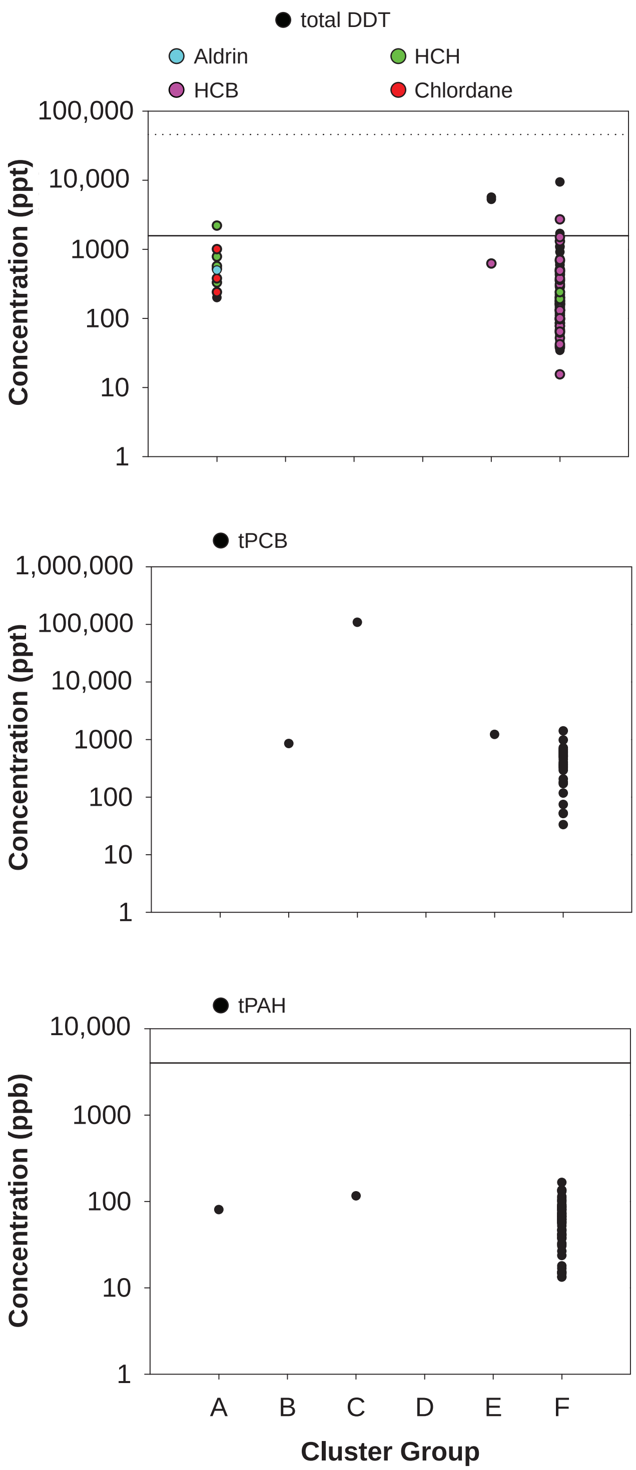
Description of cluster groups A−F (as defined in Figure 4.5). Data are expressed as the average percent or concentration of each parameter for each cluster group. For groups containing more than one sample, bold indicates parameters that were considered most defining for each group according to SIMPER analysis. The range of values found in cluster group F is also provided.

| | Cluster Group | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F: Avg | F: Min | F: Max |
| *Organic Indicators* | | | | | | | | |
| Sulfides (*ppm*) | 0 | 25.30 | 0.21 | 0.20 | 3.10 | 1.28 | 0 | 35.30 |
| TN *(% weight*) | 0.012 | 0.163 | 0.012 | 0.012 | **0.051** | 0.018 | 0 | 0.058 |
| TOC (*% weight*) | 0.10 | 2.12 | 0.11 | 0.06 | 0.51 | 0.21 | 0 | 5.460 |
| TVS (*% weight*) | 0.73 | 7.87 | 0.57 | 39.80 | 1.56 | 0.82 | 0.25 | 3.05 |
| *Trace Metals (ppm)* | | | | | | | | |
| Aluminum | 5050 | 30,100 | 6670 | 1580 | 19,400 | 3940 | 503 | 11,200 |
| Antimony | 0.16 | 0.90 | 0 | 0 | 0.66 | **0.30** | 0 | 2.96 |
| Arsenic | 1.5 | 9.2 | 1.3 | 6.9 | 2.7 | 2.3 | 0 | 11.9 |
| Barium | 19.3 | 177.0 | 37.4 | 5.3 | 88.8 | 19.2 | 1.7 | 59.5 |
| Beryllium | 0 | 0 | 0 | 0 | **0.184** | 0.015 | 0 | 0.180 |
| Cadmium | 0 | 0.42 | 0 | 0 | 0.12 | 0.06 | 0 | 0.47 |
| Chromium | 8.6 | 33.2 | 12.4 | 10.2 | 30.5 | 9.1 | 2.5 | 19.5 |
| Copper | 1.1 | 37.6 | 1.4 | 2.0 | 9.1 | 2.4 | 0 | 15.8 |
| Iron | 5690 | 29,300 | 7890 | 6370 | 23,200 | 5580 | 1070 | 12,800 |
| Lead | 0.69 | 20.00 | 0.48 | 3.11 | 7.27 | 1.72 | 0 | 6.52 |
| Manganese | 58.6 | 291.0 | 77.4 | 20.4 | 201.0 | 44.8 | 5.3 | 125 |
| Mercury | 0.004 | 0.063 | 0 | 0 | **0.013** | 0.004 | 0 | 0.029 |
| Nickel | 1.88 | 22.80 | 2.37 | 1.68 | **7.53** | 2.38 | 0 | 17.6 |
| Selenium | 0 | 0 | 0 | 0 | 0 | **0.01** | 0 | 0.35 |
| Silver | 0 | 0 | 0 | 0 | 0 | **0.30** | 0 | 4.61 |
| Thallium | 1.18 | 0 | 1.43 | 0 | 0 | **0.17** | 0 | 3.26 |
| Tin | 0.19 | 4.50 | 0.49 | 0.41 | 1.48 | 0.64 | 0 | 2.82 |
| Zinc | 9.3 | 126.0 | 9.0 | 8.2 | 57.2 | 12.3 | 2.03 | 31.9 |
| *Chlorinated Pesticides (ppt)* | | | | | | | | |
| Aldrin | 500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HCH, alpha isomer | 780 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HCH, beta isomer | 2200 | 0 | 0 | 0 | 0 | 1 | 0 | 190 |
| HCH, delta isomer | 330 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HCH, gamma isomer | 570 | 0 | 0 | 0 | 0 | 1 | 0 | 240 |
| Gamma (trans) chlordane | 380 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Heptachlor | 1000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Heptachlor epoxide | 240 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HCB | 520 | 0 | 0 | 0 | 207 | **61** | 0 | 2700 |
| Total DDT | 200 | 0 | 0 | 0 | **3360** | 126 | 0 | 9400 |
| *Total PCB (ppt)* | 0 | 840.0 | 108,790.0 | 0 | 407.0 | 57.7 | 0 | 1392 |
| *Total PAH (ppb)* | 80 | 0 | 115 | 0 | 0 | 15 | 0 | 166 |




## Appendix C.11

Particle size and sediment chemistry parameters by cluster group (see Figure 4.5). Solid lines are ERLs, dashed lines are ERMs (see text).




**Appendix C.11** *continued*

# Appendix D

## Supporting Data

## 2011 SBOO Stations

## Macrobenthic Communities

## Appendix D.1

SBOO two-way crossed ANOSIM results for benthic infauna (A = sediment type, B = depth stratum).

**Global Test: Factor A**

*Tests for differences between depth strata  (across all sediment types)*

| | |
|---|---|
| Sample statistic (Global R): | 0.616 |
| Significance level of sample statistic: | 0.01% |
| Number of permutations: | 9999 |
| Number of permuted statistics greater than or equal to Global R: | 0 |

**Pairwise Tests: Factor A**

*Tests for pairwise differences between individual depths across all sediment types: r values (p values)*

| | Sand with coarse | Sand with fines | Coarse with sand | Sand with coarse and fines |
|---|---|---|---|---|
| **Sand** | 0.305 (0.002) | 0.433 (0.0001) | 0.955 (0.01) | 0.376 (0.015) |
| **Sand with coarse** | | 0.755 (0.0001) | 0.836 (0.048) | 0.964 (0.048) |
| **Sand with fines** | | | 1 (0.008) | 0.167 (0.300) |
| **Coarse with sand** | | | | no test |

**Global Test: Factor B**

*Tests for differences between sediment types (across all depth strata)*

| | |
|---|---|
| Sample statistic (Global R): | 0.539 |
| Significance level of sample statistic: | 0.01% |
| Number of permutations: | 9999 |
| Number of permuted statistics greater than or equal to Global R: | 0 |

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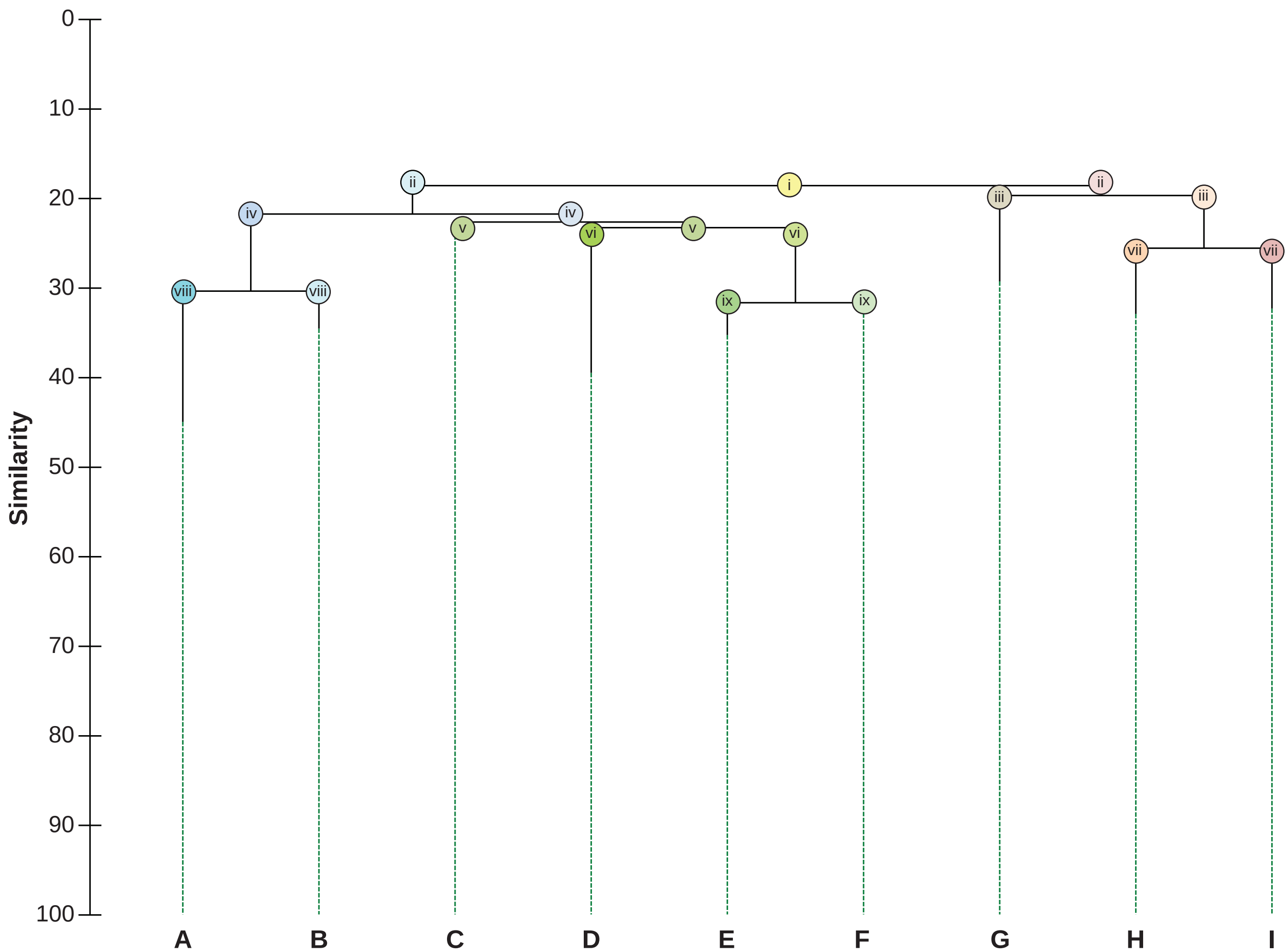
## Appendix D.2

Delineation of cluster groups (see Figure 5.4) by species exclusivity (i.e., species that occur solely in each supported clade versus species that occur in multiple non-related clades). Roman numerals and colored circles in dendrogram (below) correspond to numbers and colors delineating each SIMPROF-supported split featured in the appendix (following pages). Inner = inner shelf (5–30 m), mid = mid-shelf (30–120 m). S = sand, Sc = sand with coarse, Sf = sand with fines, Scf = sand with coarse and fines, Cs = coarse with sand. CG = cluster group.

| | # grabs (*n*) | | | | Depth | | | | Fines | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CG** | **invert** | **sed.** | **nearfield** | **stratum** | **mean** | **min** | **max** | **Sed.** | **mean** | **min** | **max** | **depth/sediment exceptions** |
| **A** | 4 | 2 | 0 | mid | 55 | 55 | 55 | Scf | 22.3 | 21.3 | 23.3 | — |
| **B** | 5 | 3 | 0 | mid | 59 | 55 | 60 | S | 9.0 | 8.6 | 9.7 | — |
| **C** | 4 | 2 | 0 | inner | 20 | 19 | 21 | S | 9.0 | 8.8 | 9.3 | — |
| **D** | 2 | 1 | 0 | inner | 18 | 18 | 18 | S | 5.4 | 5.4 | 5.4 | — |
| **E** | 35 | 16 | 11 | inner | 30 | 28 | 38 | Sf | 13.5 | 0.0 | 29.4 | Sf/mid = 1, S/inner = 1, S/mid = 1, Sc/inner = 1 |
| **F** | 15 | 7 | 0 | inner | 19 | 19 | 21 | S | 15.8 | 7.9 | 33.8 | Sf = 2 |
| **G** | 3 | 3 | 0 | inner | 26 | 19 | 38 | Cs | 9.2 | 0.5 | 25.6 | Sf/mid = 1 |
| **H** | 14 | 6 | 0 | mid | 47 | 38 | 55 | Sc | 4.3 | 0.0 | 10.8 | Sf = 1, S = 2 |
| **I** | 26 | 12 | 5 | inner | 28 | 18 | 36 | varied | 1.7 | 0.0 | 4.8 | S/mid = 4, Sc/inner = 4, S/inner = 2, Sc/mid = 1, Cs/inner = 1 |



## **Appendix D.2** *continued*

**(i.)** Species occurring in all cluster groups

| **Cluster groups** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
|---|---|---|---|---|---|---|---|---|---|
| *Aricidea* (*Acmira*) *catherinae* | 3.3 | 1.4 | 0.3 | 0.5 | 2.9 | 0.5 | 0.3 | 0.07 | 0.04 |
| *Leptochelia dubia* | 9.8 | 2.6 | 0.8 | 1.0 | 1.9 | 0.6 | 1.0 | 3.5 | 0.27 |
| Lineidae | 2.5 | 1.6 | 0.8 | 0.5 | 2.5 | 1.5 | 1.3 | 0.79 | 1.58 |
| *Lumbrineris lingulata* | 8.3 | 4.0 | 0.3 | 0.5 | 0.5 | 0.5 | 11.3 | 1 | 0.38 |
| *Paranemertes californica* | 0.5 | 0.2 | 0.5 | 0.5 | 1.0 | 0.8 | 1.0 | 0.57 | 0.04 |
| *Prionospio* (*Prionospio*) *jubata* | 15.5 | 5.0 | 2.0 | 1.5 | 13.0 | 2.3 | 2.3 | 2 | 3.08 |
| *Scoloplos armiger* Cmplx | 1.0 | 7.8 | 0.5 | 3.0 | 4.0 | 1.1 | 0.7 | 1.29 | 5.69 |
| *Spiophanes berkeleyorum* | 2.5 | 0.2 | 0.3 | 1.0 | 4.1 | 1.3 | 0.3 | 0.29 | 0.31 |
| *Spiophanes norrisi* | 57.0 | 14.2 | 1.3 | 11.0 | 43.7 | 21.9 | 61.7 | 42.64 | 196.27 |
| *Tiron biocellata* | 1.0 | 0.2 | 1.3 | 2.0 | 0.6 | 0.3 | 0.3 | 0.14 | 0.04 |

**(ii.)** Species delineating the separation of cluster groups A, B, C, D, E, and F from cluster groups G, H, and I (18.57% similarity)

| **Cluster groups** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
|---|---|---|---|---|---|---|---|---|---|
| *Typosyllis* sp SD1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.3 | 4.43 | 0.27 |
| *Micranellum crebricinctum* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.7 | 0.29 | 0.38 |
| *Cnemidocarpa rhizopus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 2 | 0.38 |
| *Sipunculus nudus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.07 | 0.19 |

**(iii.)** Species delineating the separation of cluster group G from cluster groups H and I (19.67% similarity)

| **Cluster groups** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
|---|---|---|---|---|---|---|---|---|---|
| *Aricidea* (*Acmira*) *cerrutii* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.79 | 0.15 |
| *Clymenella* sp A | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.36 | 0.31 |
| *Aphelochaeta* sp SD5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.29 | 0.42 |
| *Clymenella complanata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.29 | 0.08 |
| additional 5 taxa (<0.15) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | x | x |
| *Saccocirrus* sp | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 76.0 | 0.0 | 0.0 |
| *Pareurythoe californica* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 27.7 | 0.0 | 0.0 |
| *Eulalia* sp SD1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.0 | 0.0 | 0.0 |
| Leptoplanidae | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 | 0.0 | 0.0 |
| *Typosyllis* sp SD6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 0.0 | 0.0 |
| *Dorvillea* (*Schistomeringos*) sp | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 |
| *Microphthalmus* sp | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 |
| *Polygordius* sp | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 |
| Rhabdocoela sp A | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 |
| additional 11 taxa (<0.68) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | x | 0.0 | 0.0 |

**(iv.)** Species delineating the separation of cluster groups A and B from cluster groups C, D, E, and F (21.73% similarity)

| **Cluster groups** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
|---|---|---|---|---|---|---|---|---|---|
| *Aphelochaeta williamsae* | 5.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Euchone incolor* | 2.8 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Aphelochaeta* sp SD13 | 2.3 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Proclea* sp A | 2.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Eclysippe trilobata* | 0.5 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Eusyllis habei* | 0.5 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Chiridota* sp | 0.5 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| additional 5 taxa (<0.25) | x | x | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Neotrypaea* sp | 0.0 | 0.0 | 0.3 | 2.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |

## Appendix D.2 *continued*

**(v.)** Species delineating the separation of cluster group C from cluster groups D, E, and F (22.64% similarity)

| **Cluster groups** | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| *Travisia gigas* | 0.0 | 0.0 | 0.0 | 0.5 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Nassariidae | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Naticidae | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Rutiderma rostratum* | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| additional 7 taxa (<0.25) | 0.0 | 0.0 | x | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**(vi.)** Species delineating the separation of cluster group D from cluster groups E and F (23.26% similarity)

| **Cluster groups** | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| *Lamprops quadriplicatus* | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Terebra pedroana* | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Ampelisca cristata microdentata* | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 0.6 | 0.0 | 0.0 | 0.0 |
| *Monticellina tesselata* | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 0.1 | 0.0 | 0.0 | 0.0 |
| *Neosabellaria cementarium* | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 0.1 | 0.0 | 0.0 | 0.0 |
| *Metasychis disparidentatus* | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 1.2 | 0.0 | 0.0 | 0.0 |
| *Chaetozone corona* | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.5 | 0.0 | 0.0 | 0.0 |
| *Glycera macrobranchia* | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.6 | 0.0 | 0.0 | 0.0 |
| *Typosyllis farallonensis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.5 | 0.0 | 0.0 | 0.0 |
| *Hamatoscalpellum californicum* | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.1 | 0.0 | 0.0 | 0.0 |
| *Naineris uncinata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.3 | 0.0 | 0.0 | 0.0 |
| additional 27 taxa (<0.25) | 0.0 | 0.0 | 0.0 | 0.0 | x | x | 0.0 | 0.0 | 0.0 |

**(vii.)** Species delineating the separation of cluster groups H and I (25.55% similarity)

| **Cluster groups** | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| *Lirobarleeia kelseyi* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.79 | 0.0 |
| *Lytechinus pictus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.64 | 0.0 |
| Megaluropidae sp A | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.64 | 0.0 |
| *Cirrophorus branchiatus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.36 | 0.0 |
| *Cyclocardia ventricosa* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.36 | 0.0 |
| *Entodesma navicula* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.36 | 0.0 |
| *Solariella peramabilis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.36 | 0.0 |
| *Flabelligera infundibularis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.29 | 0.0 |
| *Laticorophium baconi* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.29 | 0.0 |
| additional 26 taxa (<0.22) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | x | 0.0 |
| *Blepharipoda occidentalis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.42 |
| *Modiolus neglectus* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.38 |
| Aoridae | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.27 |
| additional 35 taxa (<0.20) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | x |

## Appendix D.2 *continued*

**(viii.)** Species delineating the separation of cluster groups A and B (30.35% similarity)

| **Cluster groups** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
|---|---|---|---|---|---|---|---|---|---|
| *Aphelochaeta tigrina* | 4.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Clymenura gracilis* | 4.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Streblosoma* sp SD1 | 3.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Nuculana hamata* | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Gymnonereis crosslandi* | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Photis bifurcata* | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Cardiomya pectinata* | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Cirratulus* sp | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Dougaloplus* sp A | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Eulalia californiensis* | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Thyasira flexuosa* | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| additional 39 taxa (≤0.75) | x | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Aricidea* (*Allia*) *antennata* | 0.0 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Polycirrus* sp SD3 | 0.0 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Tritella pilimana* | 0.0 | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| additional 21 taxa (≤0.80) | 0.0 | x | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**(ix.)** Species delineating the separation of cluster groups E and F (31.66% similarity)

| **Cluster groups** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
|---|---|---|---|---|---|---|---|---|---|
| *Caprella penantis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| additional 74 taxa (<0.25) | 0.0 | 0.0 | 0.0 | 0.0 | x | 0.0 | 0.0 | 0.0 | 0.0 |
| *Astyris gausapata* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| additional 14 taxa (<0.25) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | x | 0.0 | 0.0 | 0.0 |

# Appendix E

# Supporting Data

# 2011 SBOO Stations

# Demersal Fishes and Megabenthic Invertebrates

## Appendix E.1

Summary of demersal fish species captured during 2011 at SBOO 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).

| Taxon/Species | | | Common Name | *n* | BM | Length Min | Length Max | Length Mean |
|---|---|---|---|---|---|---|---|---|
| RAJIFORMES [a] | | | | | | | | |
| | Rajidae | | | | | | | |
| | | *Raja inornata* | California skate | 4 | 5.6 | 36 | 53 | 44 |
| MYLIOBATIFROMES [a] | | | | | | | | |
| | Urolophidae | | | | | | | |
| | | *Urobatis halleri* | round stingray | 3 | 1.7 | 32 | 38 | 36 |
| AULOPIFORMES | | | | | | | | |
| | Synodontidae | | | | | | | |
| | | *Synodus lucioceps* | California lizardfish | 625 | 15.1 | 8 | 29 | 14 |
| OPHIDIIFORMES | | | | | | | | |
| | Ophidiidae | | | | | | | |
| | | *Chilara taylori* | spotted cusk-eel | 12 | 0.9 | 8 | 20 | 16 |
| | | *Ophidion scrippsae* | basketweave cusk-eel | 1 | 0.1 | 16 | 16 | 16 |
| BATRACHOIDIFORMES | | | | | | | | |
| | Batrachoididae | | | | | | | |
| | | *Porichthys notatus* | plainfin midshipman | 22 | 1.9 | 5 | 27 | 14 |
| SYNGNATHIFORMIES | | | | | | | | |
| | Syngnathidae | | | | | | | |
| | | *Syngnathus californiensis* | kelp pipefish | 5 | 0.4 | 13 | 25 | 21 |
| SCORPAENIFORMES | | | | | | | | |
| | Scorpaenidae | | | | | | | |
| | | *Scorpaena guttata* | California scorpionfish | 9 | 2.4 | 14 | 19 | 17 |
| | | *Seabastes carntinus* | copper rockfish | 2 | 0.1 | 5 | 5 | 5 |
| | | *Sebastes elongatus* | greenstriped rockfish | 1 | 0.1 | 4 | 4 | 4 |
| | | *Sebastes miniatus* | vermilion rockfish | 1 | 0.1 | 8 | 8 | 8 |
| | Hexagrammidae | | | | | | | |
| | | *Zaniolepis latipinnis* | longspine combfish | 158 | 4.1 | 7 | 18 | 13 |
| | Cottidae | | | | | | | |
| | | *Chitonotus pugetensis* | roughback sculpin | 117 | 3.5 | 5 | 12 | 10 |
| | | *Icelinus quadriseriatus* | yellowchin sculpin | 158 | 2.0 | 3 | 10 | 7 |
| | | *Icelinus tenuis* | spotfin sculpin | 2 | 0.1 | 7 | 7 | 7 |
| | | *Leptocottus amatus* | Pacific staghorn sculpin | 2 | 0.3 | 15 | 16 | 16 |
| | Agonidae | | | | | | | |
| | | *Odontopyxis trispinosa* | pygmy poacher | 14 | 0.8 | 5 | 9 | 7 |
| PERCIFORMES | | | | | | | | |
| | Sciaenidae | | | | | | | |
| | | *Genyonemus lineatus* | white croaker | 82 | 4.1 | 8 | 22 | 12 |
| | Embiotocidae | | | | | | | |
| | | *Cymatogaster aggregata* | shiner perch | 20 | 0.8 | 7 | 10 | 9 |
| | Bathymasteridae | | | | | | | |
| | | *Rathbunella hypoplecta* | bluebanded ronquil | 1 | 0.1 | 11 | 11 | 11 |
| | Stromateidae | | | | | | | |
| | | *Peprilus simillimus* | Pacific pompano | 2 | 0.2 | 8 | 11 | 10 |

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

## Appendix E.1 *continued*

| Taxon/Species | Common Name | *n* | BM | Length Min | Length Max | Length Mean |
|---|---|---|---|---|---|---|
| PLEURONECTIFORMES | | | | | | |
| Paralichthyidae | | | | | | |
| *Citharichthys sordidus* | Pacific sanddab | 5 | 2.5 | 4 | 21 | 9 |
| *Citharichthys stigmaeus* | speckled sanddab | 3319 | 37.5 | 3 | 14 | 8 |
| *Citharichthys xanthostigma* | longfin sanddab | 97 | 9.9 | 9 | 20 | 14 |
| *Hippoglossina stomata* | bigmouth sole | 1 | 0.2 | 21 | 21 | 21 |
| *Paralichthys californicus* | California halibut | 8 | 13.1 | 30 | 67 | 40 |
| *Xystreurys liolepis* | fantail sole | 8 | 1.5 | 6 | 30 | 15 |
| Pleuronectidae | | | | | | |
| *Parophrys vetulus* | English sole | 90 | 5.6 | 1 | 26 | 13 |
| *Pleuronichthys decurrens* | curlfin sole | 23 | 2.4 | 6 | 19 | 15 |
| *Pleuronichthys ritteri* | spotted turbot | 13 | 2.1 | 7 | 23 | 15 |
| *Pleuronichthys verticalis* | hornyhead turbot | 148 | 9.4 | 3 | 25 | 12 |
| Cynoglossidae | | | | | | |
| *Symphurus atricaudus* | California tonguefish | 102 | 2.3 | 5 | 15 | 13 |

## Appendix E.2

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

| | January 2011 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Name | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | Species Abundance by Survey |
| California lizardfish | 4 | 27 | | 18 | 164 | 86 | 18 | 317 |
| Speckled sanddab | 62 | 12 | 18 | 6 | 45 | 71 | 40 | 254 |
| White croaker | | | 4 | 9 | 24 | 23 | | 60 |
| California tonguefish | | | 2 | | 3 | 4 | 13 | 22 |
| Shiner perch | | 1 | 3 | 2 | 10 | 4 | | 20 |
| English sole | | 11 | | 1 | 1 | 3 | 1 | 17 |
| Hornyhead turbot | 1 | 2 | 2 | 1 | 5 | 5 | 1 | 17 |
| Longfin sanddab | | | | | | | 15 | 15 |
| Longspine combfish | | 1 | 1 | 6 | 2 | 1 | 4 | 15 |
| Roughback sculpin | 2 | 2 | 1 | 1 | | 2 | 2 | 10 |
| Kelp pipefish | 1 | 1 | | | 2 | 1 | | 5 |
| California halibut | | 1 | | 2 | 1 | | | 4 |
| Plainfin midshipman | 1 | | | | | 2 | 1 | 4 |
| Fantail sole | | | | 1 | 1 | | | 2 |
| Pacific pompano | | | 1 | | 1 | | | 2 |
| Pygmy poacher | | | 1 | | | 1 | | 2 |
| Yellowchin sculpin | 1 | | | | | | 1 | 2 |
| Basketweave cusk-eel | | | | | | 1 | | 1 |
| California skate | | | | | 1 | | | 1 |
| Curlfin sole | 1 | | | | | | | 1 |
| Quarter Total | 73 | 58 | 33 | 47 | 260 | 204 | 96 | 771 |

## Appendix E.2 *continued*

| Name | April 2011 | | | | | | | Species Abundance by Survey |
|---|---|---|---|---|---|---|---|---|
| | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | |
| Speckled sanddab | 252 | 63 | 175 | 165 | 108 | 146 | 89 | 998 |
| California lizardfish | | 34 | 22 | 6 | 21 | 6 | 1 | 90 |
| Roughback sculpin | 5 | 10 | 15 | 2 | 2 | 29 | 3 | 66 |
| Longspine combfish | 2 | 5 | 1 | 1 | 10 | 30 | 3 | 52 |
| Yellowchin sculpin | | 1 | 11 | 8 | 11 | 3 | 6 | 40 |
| Hornyhead turbot | 2 | 9 | 3 | 4 | 3 | 5 | 7 | 33 |
| California tonguefish | | 1 | 2 | 3 | 3 | 3 | 14 | 26 |
| English sole | 2 | 3 | 5 | 4 | | 3 | | 17 |
| Longfin sanddab | | | 6 | 4 | 1 | 2 | 2 | 15 |
| Plainfin midshipman | | 1 | 1 | 3 | | | | 5 |
| Spotted cusk-eel | | 1 | | 1 | 3 | | | 5 |
| Curlfin sole | 3 | 1 | | | | | | 4 |
| Round stingray | | | | | | | 3 | 3 |
| California halibut | | | 1 | 1 | | | | 2 |
| Fantail sole | | | | 2 | | | | 2 |
| Bluebanded ronquil | | | 1 | | | | | 1 |
| California scorpionfish | | | 1 | | | | | 1 |
| California skate | | | | | | | 1 | 1 |
| Greenstriped rockfish | 1 | | | | | | | 1 |
| Pygmy poacher | | | | 1 | | | | 1 |
| Quarter Total | 267 | 129 | 244 | 205 | 162 | 227 | 129 | 1363 |

## Appendix E.2 *continued*

| Name | July 2011 | | | | | | | Species Abundance by Survey |
|---|---|---|---|---|---|---|---|---|
| | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | |
| Speckled sanddab | 353 | 97 | 173 | 153 | 81 | 87 | 26 | 970 |
| California lizardfish | 15 | 9 | 10 | 10 | 12 | 6 | 75 | 137 |
| Yellowchin sculpin | | 2 | 22 | 4 | 23 | 22 | 5 | 78 |
| Longspine combfish | | | | | | | 79 | 79 |
| Hornyhead turbot | 8 | 10 | 4 | 11 | 5 | 5 | 3 | 46 |
| English sole | 1 | 5 | 2 | | 1 | 4 | 6 | 19 |
| White croaker | | | | | | | 22 | 22 |
| Longfin sanddab | | 4 | 1 | | 3 | 1 | 8 | 17 |
| Roughback sculpin | 4 | | | | 2 | 1 | 5 | 12 |
| California tonguefish | 2 | | | 2 | 1 | | 6 | 11 |
| Curlfin sole | 2 | 1 | 5 | 2 | | | | 10 |
| California scorpionfish | | | 1 | 3 | | 1 | 2 | 7 |
| Pacific sanddab | 5 | | | | | | | 5 |
| Spotted cusk-eel | 2 | | | | | 1 | 1 | 4 |
| Pygmy poacher | | | | | | | 3 | 3 |
| Spotted turbot | | 2 | | 1 | | | | 3 |
| Spotfin sculpin | | | | | 2 | | | 2 |
| California halibut | | 1 | | | | | | 1 |
| California skate | | | | 1 | | | | 1 |
| Vermilion rockfish | | | | | | | 1 | 1 |
| Plainfin midshipman | | | | | | | 1 | 1 |
| Quarter Total | 392 | 131 | 218 | 187 | 130 | 128 | 243 | 1429 |

## Appendix E.2 *continued*

| NAME | October 2011 SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | Species Abundance by Survey |
|---|---|---|---|---|---|---|---|---|
| Speckled sanddab | 269 | 173 | 160 | 144 | 116 | 125 | 110 | 1097 |
| California lizardfish | 4 | 13 | 13 | 15 | 12 | 10 | 14 | 81 |
| Hornyhead turbot | 5 | 11 | 9 | 10 | 7 | 4 | 6 | 52 |
| Longfin sanddab | | 2 | 22 | 3 | 12 | 4 | 7 | 50 |
| California tonguefish | 2 | 5 | 3 | 6 | 9 | 5 | 13 | 43 |
| Yellowchin sculpin | 3 | 10 | 18 | | | | 7 | 38 |
| English sole | | 5 | | 1 | 11 | 13 | 7 | 37 |
| Roughback sculpin | 3 | 6 | 1 | | 3 | 7 | 9 | 29 |
| Longspine combfish | | 3 | | | 7 | 1 | 1 | 12 |
| Plainfin midshipman | | 2 | | | 1 | 2 | 7 | 12 |
| Spotted turbot | 5 | | | 2 | | | 3 | 10 |
| Curlfin sole | | | 2 | 5 | | 1 | | 8 |
| Pygmy poacher | | 2 | 2 | 2 | | | 2 | 8 |
| Fantail sole | | 2 | 1 | 1 | | | | 4 |
| Spotted cusk-eel | | 1 | | | 1 | | 1 | 3 |
| Copper rockfish | | | | | | | 2 | 2 |
| Pacific staghorn sculpin | 1 | | | | | 1 | | 2 |
| Bigmouth sole | | | 1 | | | | | 1 |
| California halibut | | | | | | | 1 | 1 |
| California scorpionfish | | | | | 1 | | | 1 |
| California skate | 1 | | | | | | | 1 |
| Quarter Total | 293 | 235 | 232 | 189 | 180 | 173 | 190 | 1492 |
| **Annual Total** | **1025** | **553** | **727** | **628** | **732** | **732** | **633** | **5055** |

## Appendix E.3

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

| | January 2011 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Name | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | Species Biomass by Survey |
| California halibut | | 2.0 | | 8.0 | 0.4 | | | 10.4 |
| California lizardfish | 0.2 | 0.5 | | 0.3 | 2.9 | 1.2 | 0.2 | 5.3 |
| Speckled sanddab | 0.6 | 0.3 | 0.4 | 0.1 | 0.7 | 0.6 | 0.4 | 3.1 |
| White croaker | | | 0.2 | 0.4 | 1.0 | 0.5 | | 2.1 |
| Hornyhead turbot | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.4 | 0.1 | 1.2 |
| California skate | | | | | 1.1 | | | 1.1 |
| English sole | | 0.2 | | 0.1 | 0.3 | 0.1 | 0.1 | 0.8 |
| Longspine combfish | | 0.1 | 0.1 | 0.3 | 0.1 | 0.1 | 0.1 | 0.8 |
| Shiner perch | | 0.1 | 0.1 | 0.1 | 0.4 | 0.1 | | 0.8 |
| Fantail sole | | | | 0.6 | 0.1 | | | 0.7 |
| Longfin sanddab | | | | | | | 0.6 | 0.6 |
| Roughback sculpin | 0.1 | 0.1 | 0.1 | 0.1 | | 0.1 | 0.1 | 0.6 |
| California tonguefish | | | 0.1 | | 0.1 | 0.1 | 0.1 | 0.4 |
| Kelp pipefish | 0.1 | 0.1 | | | 0.1 | 0.1 | | 0.4 |
| Plainfin midshipman | 0.1 | | | | | 0.1 | 0.1 | 0.3 |
| Pacific pompano | | | 0.1 | | 0.1 | | | 0.2 |
| Pygmy poacher | | | 0.1 | | | 0.1 | | 0.2 |
| Yellowchin sculpin | 0.1 | | | | | | 0.1 | 0.2 |
| Basketweave cusk-eel | | | | | | 0.1 | | 0.1 |
| Curlfin sole | 0.1 | | | | | | | 0.1 |
| Quarter Total | 1.5 | 3.5 | 1.3 | 10.1 | 7.5 | 3.6 | 1.9 | 29.4 |

## Appendix E.3 *continued*

| Name | April 2011 | | | | | | | Species Biomass by Survey |
|---|---|---|---|---|---|---|---|---|
| | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | |
| Speckled sanddab | 1.7 | 0.9 | 2.5 | 2.5 | 0.8 | 1.8 | 0.7 | 10.9 |
| Longfin sanddab | | | 2.5 | 0.3 | 0.1 | 0.2 | 0.1 | 3.2 |
| Round stingray | | | | | | | 1.7 | 1.7 |
| English sole | 0.2 | 0.1 | 1.0 | 0.2 | | 0.1 | | 1.6 |
| Roughback sculpin | 0.1 | 0.2 | 0.5 | 0.1 | 0.1 | 0.5 | 0.1 | 1.6 |
| California lizardfish | | 0.5 | 0.3 | 0.1 | 0.2 | 0.4 | 0.1 | 1.6 |
| California halibut | | | 1.0 | 0.4 | | | | 1.4 |
| Hornyhead turbot | 0.1 | 0.4 | 0.1 | 0.2 | 0.1 | 0.2 | 0.3 | 1.4 |
| Longspine combfish | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.8 |
| California tonguefish | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.6 |
| Yellowchin sculpin | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.6 |
| California skate | | | | | | | 0.4 | 0.4 |
| Plainfin midshipman | | 0.1 | 0.1 | 0.1 | | | | 0.3 |
| Spotted cusk-eel | | 0.1 | | 0.1 | 0.1 | | | 0.3 |
| Curlfin sole | 0.1 | 0.1 | | | | | | 0.2 |
| Bluebanded ronquil | | | 0.1 | | | | | 0.1 |
| California scorpionfish | | | 0.1 | | | | | 0.1 |
| Fantail sole | | | | 0.1 | | | | 0.1 |
| Greenstriped rockfish | 0.1 | | | | | | | 0.1 |
| Pygmy poacher | | | | 0.1 | | | | 0.1 |
| Quarter Total | 2.4 | 2.7 | 8.5 | 4.5 | 1.8 | 3.5 | 3.7 | 27.1 |

## Appendix E.3 *continued*

| Name | July 2011 | | | | | | | Species Biomass by Survey |
|---|---|---|---|---|---|---|---|---|
| | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | |
| Speckled sanddab | 5.6 | 2.0 | 1.3 | 1.5 | 1.3 | 1.2 | 0.3 | 13.2 |
| California lizardfish | 0.4 | 0.3 | 0.1 | 0.3 | 0.2 | 0.3 | 2.8 | 4.4 |
| Hornyhead turbot | 0.4 | 0.7 | 0.2 | 0.4 | 0.4 | 0.7 | 0.1 | 2.9 |
| Longspine combfish | | | | | | | 2.0 | 2.0 |
| White croaker | | | | | | | 2.0 | 2.0 |
| California scorpionfish | | | 0.1 | 0.8 | | 0.2 | 0.8 | 1.9 |
| English sole | 0.1 | 0.5 | 0.1 | | 0.1 | 0.2 | 0.6 | 1.6 |
| Longfin sanddab | | 0.4 | 0.1 | | 0.3 | 0.1 | 0.3 | 1.2 |
| Curlfin sole | 0.1 | 0.1 | 0.5 | 0.3 | | | | 1.0 |
| Pacific sanddab | 0.7 | | | | | | | 0.7 |
| Yellowchin sculpin | | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.7 |
| Spotted turbot | | 0.5 | | 0.1 | | | | 0.6 |
| California skate | | | | 0.6 | | | | 0.6 |
| California halibut | | 0.4 | | | | | | 0.4 |
| California tonguefish | 0.1 | | | 0.1 | 0.1 | | 0.1 | 0.4 |
| Roughback sculpin | 0.1 | | | | 0.1 | 0.1 | 0.1 | 0.4 |
| Spotted cusk-eel | 0.1 | | | | | 0.1 | 0.1 | 0.3 |
| Plainfin midshipman | | | | | | | 0.1 | 0.1 |
| Pygmy poacher | | | | | | | 0.1 | 0.1 |
| Spotfin sculpin | | | | | 0.1 | | | 0.1 |
| Vermilion rockfish | | | | | | | 0.1 | 0.1 |
| Quarter Total | 7.6 | 5.0 | 2.5 | 4.2 | 2.8 | 3.0 | 9.6 | 34.7 |

## Appendix E.3 *continued*

| Name | October 2011 | | | | | | | Species Biomass by Survey |
|---|---|---|---|---|---|---|---|---|
| | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | |
| Speckled sanddab | 2.5 | 2.1 | 2.2 | 1.5 | 1.4 | 1.4 | 1 | 12.1 |
| Longfin sanddab | | 0.1 | 2.5 | 0.5 | 0.8 | 0.5 | 0.5 | 4.9 |
| Hornyhead turbot | 0.4 | 0.5 | 1 | 0.6 | 0.6 | 0.3 | 0.5 | 3.9 |
| California lizardfish | 0.3 | 0.6 | 0.7 | 0.8 | 0.6 | 0.3 | 0.5 | 3.8 |
| California skate | 3.5 | | | | | | | 3.5 |
| English sole | | 0.4 | | 0.1 | 0.4 | 0.4 | 0.3 | 1.6 |
| Spotted turbot | 0.5 | | | 0.6 | | | 0.4 | 1.5 |
| Plainfin midshipman | | 0.4 | | | 0.1 | 0.1 | 0.6 | 1.2 |
| Curlfin sole | | | 0.4 | 0.5 | | 0.2 | | 1.1 |
| California tonguefish | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 | 0.2 | 0.9 |
| Roughback sculpin | 0.1 | 0.2 | 0.1 | | 0.1 | 0.2 | 0.2 | 0.9 |
| California halibut | | | | | | | 0.9 | 0.9 |
| Fantail sole | | 0.5 | 0.1 | 0.1 | | | | 0.7 |
| Longspine combfish | | 0.2 | | | 0.1 | 0.1 | 0.1 | 0.5 |
| Yellowchin sculpin | 0.1 | 0.1 | 0.2 | | | | 0.1 | 0.5 |
| California scorpionfish | | | | | 0.4 | | | 0.4 |
| Pygmy poacher | | 0.1 | 0.1 | 0.1 | | | 0.1 | 0.4 |
| Pacific staghorn sculpin | 0.1 | | | | | 0.2 | | 0.3 |
| Spotted cusk-eel | | 0.1 | | | 0.1 | | 0.1 | 0.3 |
| Bigmouth sole | | | 0.2 | | | | | 0.2 |
| Copper rockfish | | | | | | | 0.1 | 0.1 |
| Quarter Total | 7.6 | 5.4 | 7.6 | 4.9 | 4.8 | 3.8 | 5.6 | 39.7 |
| **Annual total** | **19.1** | **16.6** | **19.9** | **23.7** | **16.9** | **13.9** | **20.8** | **130.9** |

## Appendix E.4

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

**Global Test: Factor A**

*Tests for differences between stations (across all years)*

| | |
|---|---|
| Sample statistic (Rho): | 0.422 |
| Significance level of sample statistic: | 0.01% |
| Number of permutations: | 9999 |
| Number of permuted statistics greater than or equal to Rho: | 0 |

**Global Test: Factor B**

*Tests for differences between years (across all stations)*

| | |
|---|---|
| Sample statistic (Rho): | 0.473 |
| Significance level of sample statistic: | 0.01% |
| Number of permutations: | 9999 |
| Number of permuted statistics greater than or equal to Rho: | 0 |

## Appendix E.5

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

| Taxon/ Species | | | | | *n* |
|---|---|---|---|---|---|
| CNIDARIA | | | | | |
| | ANTHOZOA | | | | |
| | | PENNATULACEA | | | |
| | | | Virgulariidae | | |
| | | | | *Stylatula elongata* | 1 |
| MOLLUSCA | | | | | |
| | GASTROPODA | | | | |
| | | | Calliostomatidae | | |
| | | | | *Calliostoma canaliculatum* | 2 |
| | | | | *Calliostoma tricolor* | 2 |
| | | | Turbinidae | | |
| | | | | *Megastraea undosa* | 1 |
| | | HYPSOGASTROPODA | | | |
| | | | Naticidae | | |
| | | | | *Euspira lewisii* | 2 |
| | | | | *Sinum scopulosum* | 1 |
| | | | Bursidae | | |
| | | | | *Crossata californica* | 4 |
| | | | Buccinidae | | |
| | | | | *Kelletia kelletii* | 16 |
| | | | Nassariidae | | |
| | | | | *Caesia perpinguis* | 17 |
| | | | Muricidae | | |
| | | | | *Pteropurpura festiva* | 1 |
| | | | Turridae | | |
| | | | | *Megasurcula carpenteriana* | 1 |
| | | OPISTHOBRANCHIA | | | |
| | | | Philinidae | | |
| | | | | *Philine auriformis* | 194 |
| | | | Aglajidae | | |
| | | | | *Aglaja ocelligera* | 1 |
| | | | Pleurobranchidae | | |
| | | | | *Pleurobranchaea californica* | 33 |
| | | | Onchidorididae | | |
| | | | | *Acanthodoris brunnea* | 53 |
| | | | | *Acanthodoris rhodoceras* | 1 |
| | | | Arminidae | | |
| | | | | *Armina californica* | 1 |
| | | | Dendronotidae | | |
| | | | | *Dendronotus iris* | 4 |
| | | | Flabellinidae | | |
| | | | | *Flabellina iodinea* | 7 |
| | CEPHALOPODA | | | | |
| | | TEUTHIDA | | | |
| | | | Loliginidae | | |
| | | | | *Doryteuthis opalescens* | 3 |

**Appendix E.5** *continued*

| Taxon/ Species | | | | *n* |
|---|---|---|---|---|
| | OCTOPODA | | | |
| | | Octopodidae | | |
| | | | *Octopus rubescens* | 30 |
| ANNELIDA | | | | |
| POLYCHAETA | | | | |
| | ACICULATA | | | |
| | | Aphroditidae | | |
| | | | *Aphrodita armifera* | 1 |
| | | | *Aphrodita refulgida* | 1 |
| | | | *Aphrodita* sp | 1 |
| | | Polynoidae | | |
| | | | *Halosydna latior* | 3 |
| ARTHROPODA | | | | |
| MAXILLOPODA | | | | |
| | PEDUNCULATA | | | |
| | | Scalpellidae | | |
| | | | *Hamatoscalpellum californicum* | 16 |
| MALACOSTRACA | | | | |
| | STOMATOPODA | | | |
| | | Hemisquillidae | | |
| | | | *Hemisquilla californiensis* | 14 |
| | ISOPODA | | | |
| | | Cymothoidae | | |
| | | | *Elthusa vulgaris* | 58 |
| | DECAPODA | | | |
| | | Penaeidae | | |
| | | | *Farfantepenaeus californiensis* | 1 |
| | | Sicyoniidae | | |
| | | | *Sicyonia ingentis* | 9 |
| | | | *Sicyonia penicillata* | 1 |
| | | Hippolytidae | | |
| | | | *Heptacarpus palpator* | 3 |
| | | | *Heptacarpus stimpsoni* | 12 |
| | | | *Spirontocaris prionota* | 1 |
| | | Pandalidae | | |
| | | | *Pandalus danae* | 1 |
| | | | *Pandalus platyceros* | 1 |
| | | Crangonidae | | |
| | | | *Crangon alba* | 9 |
| | | | *Crangon nigromaculata* | 5 |
| | | Diogenidae | | |
| | | | *Paguristes bakeri* | 1 |
| | | | *Paguristes ulreyi* | 2 |
| | | Paguridae | | |
| | | | *Pagurus armatus* | 1 |
| | | | *Pagurus spilocarpus* | 2 |
| | | Calappidae | | |
| | | | *Platymera gaudichaudii* | 7 |

## Appendix E.5 *continued*

| Taxon/ Species | | | | | *n* |
|---|---|---|---|---|---|
| | | | Leucosiidae | | |
| | | | | *Randallia ornata* | 4 |
| | | | Epialtidae | | |
| | | | | *Pugettia producta* | 1 |
| | | | Pisinae | | |
| | | | | *Loxorhynchus crispatus* | 7 |
| | | | | *Loxorhynchus grandis* | 2 |
| | | | Inachidae | | |
| | | | | *Podochela hemphillii* | 3 |
| | | | Inachoididae | | |
| | | | | *Pyromaia tuberculata* | 33 |
| | | | Parthenopidae | | |
| | | | | *Heterocrypta occidentalis* | 37 |
| | | | Cancridae | | |
| | | | | *Metacarcinus anthonyi* | 1 |
| | | | | *Metacarcinus gracilis* | 104 |
| ECHINODERMATA | | | | | |
| | ASTEROIDEA | | | | |
| | | PAXILLOSIDA | | | |
| | | | Luidiidae | | |
| | | | | *Luidia armata* | 6 |
| | | | | *Luidia foliolata* | 29 |
| | | | Astropectinidae | | |
| | | | | *Astropecten californicus* | 626 |
| | | FORCIPULATIDA | | | |
| | | | Asteriidae | | |
| | | | | *Pisaster brevispinus* | 9 |
| | OPHIUROIDEA | | | | |
| | | OPHIURIDA | | | |
| | | | Ophiotricidae | | |
| | | | | *Ophiothrix spiculata* | 16 |
| | | | Ophiuridae | | |
| | | | | *Ophiura luetkenii* | 275 |
| | ECHINOIDEA | | | | |
| | | CAMARODONTA | | | |
| | | | Toxopneustidae | | |
| | | | | *Lytechinus pictus* | 7 |
| | | | Strongylocentrotidae | | |
| | | | | *Strongylocentrotus purpuratus* | 1 |
| | | CLYPEASTEROIDA | | | |
| | | | Dendrasteridae | | |
| | | | | *Dendraster terminalis* | 125 |

## Appendix E.6

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

| | January 2011 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Name | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | Species Abundance by Survey |
| *Astropecten californicus* | 100 | 6 | 20 | 13 | 20 | 12 | 1 | 172 |
| *Philine auriformis* | | | | 1 | 20 | 6 | 79 | 106 |
| *Metacarcinus gracilis* | | | 24 | | 1 | 6 | 2 | 33 |
| *Acanthodoris brunnea* | | 3 | 1 | 2 | 7 | 1 | 1 | 15 |
| *Dendraster terminalis* | 4 | | 2 | | | | | 6 |
| *Elthusa vulgaris* | | | | | 6 | | | 6 |
| *Octopus rubescens* | | 2 | 1 | 1 | 1 | 1 | | 6 |
| *Ophiura luetkenii* | | | 1 | 5 | | | | 6 |
| *Crangon nigromaculata* | | | | | 3 | 1 | | 4 |
| *Doryteuthis opalescens* | | | | | | 3 | | 3 |
| *Kelletia kelletii* | | | 1 | 2 | | | | 3 |
| *Ophiothrix spiculata* | | 1 | 2 | | | | | 3 |
| *Pleurobranchaea californica* | | | | | 1 | 1 | 1 | 3 |
| *Hemisquilla californiensis* | | 1 | | | | 1 | | 2 |
| *Luidia armata* | | 1 | | 1 | | | | 2 |
| *Lytechinus pictus* | | 1 | 1 | | | | | 2 |
| *Aphrodita armifera* | | | | | 1 | | | 1 |
| *Aphrodita refulgida* | | | | | 1 | | | 1 |
| *Aphrodita* sp | | | | | | 1 | | 1 |
| *Crangon alba* | 1 | | | | | | | 1 |
| *Crossata californica* | 1 | | | | | | | 1 |
| *Farfantepenaeus californiensis* | | | 1 | | | | | 1 |
| *Flabellina iodinea* | | 1 | | | | | | 1 |
| *Halosydna latior* | | | 1 | | | | | 1 |
| *Pisaster brevispinus* | | | | | | | 1 | 1 |
| *Pyromaia tuberculata* | 1 | | | | | | | 1 |
| *Sicyonia ingentis* | | | | | | | 1 | 1 |
| *Sicyonia penicillata* | | | | | | | 1 | 1 |
| Quarter Total | 107 | 16 | 55 | 25 | 61 | 33 | 87 | 384 |

## Appendix E.6 *continued*

| Name | April 2011 | | | | | | | Species Abundance by Survey |
|---|---|---|---|---|---|---|---|---|
| | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | |
| *Ophiura luetkenii* | | | 150 | 50 | 2 | | | 202 |
| *Astropecten californicus* | 30 | 15 | 37 | 7 | 11 | 27 | 5 | 132 |
| *Dendraster terminalis* | 89 | | | | | | | 89 |
| *Philine auriformis* | | | 2 | 6 | 28 | 1 | 32 | 69 |
| *Metacarcinus gracilis* | | 5 | 2 | 4 | 1 | 1 | 6 | 19 |
| *Pleurobranchaea californica* | | | | 8 | 1 | 5 | 5 | 19 |
| *Luidia foliolata* | | | 12 | 4 | 1 | | | 17 |
| *Elthusa vulgaris* | 1 | | 1 | 1 | 4 | 5 | 2 | 14 |
| *Hemisquilla californiensis* | | 4 | 1 | 2 | 1 | 2 | 1 | 11 |
| *Acanthodoris brunnea* | | | 6 | 3 | | | 1 | 10 |
| *Pyromaia tuberculata* | 8 | | | | 1 | | 1 | 10 |
| *Crangon alba* | 4 | | | | | | 2 | 6 |
| *Dendronotus iris* | | | 1 | | | 3 | | 4 |
| *Flabellina iodinea* | | | 3 | | | 1 | | 4 |
| *Octopus rubescens* | 2 | 1 | | | | | 1 | 4 |
| *Sicyonia ingentis* | | | | | | | 4 | 4 |
| *Kelletia kelletii* | | 1 | | | | 1 | 1 | 3 |
| *Euspira lewisii* | | | | | | | 2 | 2 |
| *Halosydna latior* | | | | 1 | | 1 | | 2 |
| *Platymera gaudichaudii* | | | 1 | | 1 | | | 2 |
| *Aglaja ocelligera* | | | 1 | | | | | 1 |
| *Armina californica* | | | 1 | | | | | 1 |
| *Calliostoma canaliculatum* | 1 | | | | | | | 1 |
| *Crossata californica* | 1 | | | | | | | 1 |
| *Luidia armata* | | | | 1 | | | | 1 |
| *Paguristes bakeri* | | | | 1 | | | | 1 |
| *Pagurus spilocarpus* | | | 1 | | | | | 1 |
| *Pandalus danae* | | | | | | 1 | | 1 |
| *Pisaster brevispinus* | 1 | | | | | | | 1 |
| *Podochela hemphillii* | 1 | | | | | | | 1 |
| *Randallia ornata* | | 1 | | | | | | 1 |
| *Sinum scopulosum* | 1 | | | | | | | 1 |
| *Strongylocentrotus purpuratus* | | | | 1 | | | | 1 |
| Quarter Total | 139 | 27 | 219 | 89 | 51 | 48 | 63 | 636 |

## Appendix E.6 *continued*

| Name | July 2011 | | | | | | | Species Abundance by Survey |
|---|---|---|---|---|---|---|---|---|
| | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | |
| *Astropecten californicus* | 108 | 10 | 15 | 4 | 7 | 8 | 11 | 163 |
| *Dendraster terminalis* | 28 | | | | | | | 28 |
| *Heterocrypta occidentalis* | | | 2 | 10 | 7 | 3 | | 22 |
| *Elthusa vulgaris* | 4 | 1 | 1 | 4 | 5 | 1 | 3 | 19 |
| *Philine auriformis* | | | 3 | 3 | | | 12 | 18 |
| *Acanthodoris brunnea* | | | 11 | 6 | | | | 17 |
| *Hamatoscalpellum californicum* | | | 13 | 3 | | | | 16 |
| *Metacarcinus gracilis* | | 14 | 1 | | | 1 | | 16 |
| *Pyromaia tuberculata* | | | 6 | 6 | 2 | | 2 | 16 |
| *Ophiura luetkenii* | | | 3 | 11 | | | 1 | 15 |
| *Heptacarpus stimpsoni* | | | | | | | 12 | 12 |
| *Luidia foliolata* | | 1 | 1 | 1 | | | 8 | 11 |
| *Loxorhynchus crispatus* | 1 | 1 | 1 | 1 | 1 | 2 | | 7 |
| *Ophiothrix spiculata* | | | 1 | 4 | | | 2 | 7 |
| *Pleurobranchaea californica* | | 1 | 1 | 1 | 1 | | 1 | 5 |
| *Octopus rubescens* | | 2 | | | | 1 | 1 | 4 |
| *Kelletia kelletii* | | 1 | | | | 2 | | 3 |
| *Calliostoma tricolor* | | | | | | | 2 | 2 |
| *Crangon alba* | 2 | | | | | | | 2 |
| *Heptacarpus palpator* | | | | | | | 2 | 2 |
| *Platymera gaudichaudii* | 1 | | | | 1 | | | 2 |
| *Podochela hemphillii* | | | 2 | | | | | 2 |
| *Randallia ornata* | | 1 | | | | 1 | | 2 |
| *Caesia perpinguis* | | | | 1 | | | | 1 |
| *Calliostoma canaliculatum* | | | | | | | 1 | 1 |
| *Flabellina iodinea* | | | 1 | | | | | 1 |
| *Loxorhynchus grandis* | | | | | | | 1 | 1 |
| *Luidia armata* | | 1 | | | | | | 1 |
| *Megasurcula carpenteriana* | | | | | | | 1 | 1 |
| *Paguristes ulreyi* | | 1 | | | | | | 1 |
| *Pagurus armatus* | | | 1 | | | | | 1 |
| *Pandalus platyceros* | | | | | | | 1 | 1 |
| *Pisaster brevispinus* | | | | | | 1 | | 1 |
| *Sicyonia ingentis* | | | | | | | 1 | 1 |
| *Stylatula elongata* | | | | 1 | | | | 1 |
| Quarter Total | 144 | 34 | 63 | 56 | 24 | 20 | 62 | 403 |

## Appendix E.6 *continued*

| Name | October 2011 | | | | | | | Species Abundance by Survey |
|---|---|---|---|---|---|---|---|---|
| | SD15 | SD16 | SD17 | SD18 | SD19 | SD20 | SD21 | |
| *Astropecten californicus* | 111 | 27 | 4 | | 2 | 10 | 5 | 159 |
| *Ophiura luetkenii* | | | 23 | 24 | 5 | | | 52 |
| *Metacarcinus gracilis* | 1 | 6 | 14 | | | 9 | 6 | 36 |
| *Elthusa vulgaris* | 2 | 1 | 2 | 3 | 5 | 5 | 1 | 19 |
| *Caesia perpinguis* | 1 | | | 14 | 1 | | | 16 |
| *Octopus rubescens* | | | | | 6 | 4 | 6 | 16 |
| *Heterocrypta occidentalis* | | 1 | | 6 | | | 8 | 15 |
| *Acanthodoris brunnea* | | | 5 | 4 | 1 | | 1 | 11 |
| *Kelletia kelletii* | | 1 | 1 | 2 | | 2 | 1 | 7 |
| *Ophiothrix spiculata* | 1 | 1 | | | 2 | | 2 | 6 |
| *Pisaster brevispinus* | 4 | | 1 | | 1 | | | 6 |
| *Pleurobranchaea californica* | | | | | 4 | 2 | | 6 |
| *Pyromaia tuberculata* | | 1 | | 4 | | 1 | | 6 |
| *Lytechinus pictus* | 1 | | | 4 | | | | 5 |
| *Platymera gaudichaudii* | | 1 | 1 | 1 | | | | 3 |
| *Sicyonia ingentis* | | | | | | | 3 | 3 |
| *Crossata californica* | | 1 | | 1 | | | | 2 |
| *Dendraster terminalis* | 2 | | | | | | | 2 |
| *Luidia armata* | | 2 | | | | | | 2 |
| *Acanthodoris rhodoceras* | | | | | | 1 | | 1 |
| *Crangon nigromaculata* | | 1 | | | | | | 1 |
| *Flabellina iodinea* | | | 1 | | | | | 1 |
| *Hemisquilla californiensis* | | 1 | | | | | | 1 |
| *Heptacarpus palpator* | | | | | | | 1 | 1 |
| *Loxorhynchus grandis* | | | | 1 | | | | 1 |
| *Luidia foliolata* | | 1 | | | | | | 1 |
| *Megastraea undosa* | | 1 | | | | | | 1 |
| *Metacarcinus anthonyi* | | | 1 | | | | | 1 |
| *Paguristes ulreyi* | | 1 | | | | | | 1 |
| *Pagurus spilocarpus* | | | | | 1 | | | 1 |
| *Philine auriformis* | | | 1 | | | | | 1 |
| *Pteropurpura festiva* | | | | | | | 1 | 1 |
| *Pugettia producta* | | | | | | 1 | | 1 |
| *Randallia ornata* | | 1 | | | | | | 1 |
| *Spirontocaris prionota* | | | | | | | 1 | 1 |
| Quarter Total | 123 | 48 | 54 | 64 | 28 | 35 | 36 | 388 |
| **Annaul Total** | **513** | **125** | **391** | **234** | **164** | **136** | **248** | **1811** |

# Appendix F

## Supporting Data

## 2011 SBOO Stations

## Bioaccumulation of Contaminants in Fish Tissues

## Appendix F.1

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

| | | | | Length (cm, size class) | | | Weight (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Station** | **Comp** | **Species** | ***n*** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** |
| *April 2011* | | | | | | | | | |
| RF3 | 1 | Brown rockfish | 3 | 22 | 27 | 24 | 264 | 630 | 418 |
| RF3 | 2 | Brown rockfish | 3 | 23 | 29 | 26 | 407 | 655 | 552 |
| RF3 | 3 | Vermillion rockfish | 3 | 20 | 25 | 22 | 198 | 440 | 289 |
| RF4 | 1 | California scorpionfish | 3 | 24 | 26 | 25 | 492 | 612 | 570 |
| RF4 | 2 | California scorpionfish | 3 | 25 | 30 | 28 | 530 | 1084 | 787 |
| RF4 | 3 | California scorpionfish | 3 | 25 | 30 | 27 | 540 | 861 | 676 |
| SD15 | 1 | Hornyhead turbot | 3 | 10 | 19 | 15 | 21 | 151 | 98 |
| SD15 | 2 | English sole | 4 | 15 | 20 | 18 | 46 | 120 | 88 |
| SD15 | 3 | (no sample) | — | — | — | — | — | — | — |
| SD16 | 1 | Hornyhead turbot | 4 | 19 | 20 | 19 | 170 | 235 | 199 |
| SD16 | 2 | Longfin sanddab | 7 | 13 | 17 | 15 | 44 | 134 | 85 |
| SD16 | 3 | (no sample) | — | — | — | — | — | — | — |
| SD17 | 1 | Longfin sanddab | 6 | 16 | 20 | 18 | 110 | 153 | 130 |
| SD17 | 2 | English sole | 6 | 13 | 25 | 21 | 31 | 275 | 158 |
| SD17 | 3 | Hornyhead turbot | 8 | 12 | 22 | 16 | 41 | 241 | 105 |
| SD18 | 1 | Longfin sanddab | 9 | 15 | 17 | 16 | 71 | 100 | 86 |
| SD18 | 2 | Hornyhead turbot | 11 | 11 | 17 | 14 | 40 | 109 | 69 |
| SD18 | 3 | English sole | 6 | 17 | 24 | 21 | 74 | 215 | 130 |
| SD19 | 1 | Longfin sanddab | 10 | 13 | 19 | 15 | 45 | 134 | 72 |
| SD19 | 2 | English sole | 3 | 18 | 25 | 22 | 70 | 224 | 152 |
| SD19 | 3 | Hornyhead turbot | 4 | 13 | 22 | 17 | 53 | 265 | 127 |
| SD20 | 1 | English sole | 4 | 22 | 25 | 24 | 160 | 189 | 177 |
| SD20 | 2 | Longfin sanddab | 6 | 14 | 18 | 17 | 50 | 137 | 98 |
| SD20 | 3 | Longfin sanddab | 11 | 13 | 18 | 14 | 39 | 105 | 63 |
| SD21 | 1 | Longfin sanddab | 5 | 12 | 18 | 15 | 40 | 133 | 73 |
| SD21 | 2 | Hornyhead turbot | 4 | 11 | 21 | 16 | 36 | 271 | 143 |
| SD21 | 3 | (no sample) | — | — | — | — | — | — | — |

## Appendix F.1 *continued*

| Station | Comp | Species | *n* | Length (cm, size class) Min | Length (cm, size class) Max | Length (cm, size class) Mean | Weight (g) Min | Weight (g) Max | Weight (g) Mean |
|---|---|---|---|---|---|---|---|---|---|
| *October 2011* | | | | | | | | | |
| RF3 | 1 | Brown rockfish | 3 | 15 | 31 | 22 | 78 | 701 | 331 |
| RF3 | 2 | Vermillion rockfish | 3 | 20 | 25 | 22 | 227 | 475 | 341 |
| RF3 | 3 | Mixed rockfish | 3 | 16 | 33 | 23 | 124 | 615 | 301 |
| RF4 | 1 | California scorpionfish | 3 | 25 | 27 | 26 | 494 | 609 | 560 |
| RF4 | 2 | California scorpionfish | 3 | 26 | 29 | 27 | 543 | 920 | 708 |
| RF4 | 3 | California scorpionfish | 3 | 23 | 27 | 25 | 463 | 685 | 601 |
| SD15 | 1 | Hornyhead turbot | 4 | 13 | 20 | 16 | 51 | 240 | 135 |
| SD15 | 2 | Hornyhead turbot | 7 | 12 | 18 | 14 | 43 | 160 | 76 |
| SD15 | 3 | Pacific sanddab | 5 | 16 | 16 | 16 | 60 | 78 | 68 |
| SD16 | 1 | Hornyhead turbot | 3 | 20 | 22 | 21 | 249 | 341 | 294 |
| SD16 | 2 | Hornyhead turbot | 12 | 12 | 20 | 14 | 48 | 222 | 81 |
| SD16 | 3 | Longfin sanddab | 3 | 17 | 20 | 18 | 124 | 189 | 146 |
| SD17 | 1 | Longfin sanddab | 4 | 17 | 19 | 18 | 121 | 158 | 140 |
| SD17 | 2 | Longfin sanddab | 3 | 16 | 20 | 18 | 103 | 192 | 142 |
| SD17 | 3 | Longfin sanddab | 4 | 17 | 19 | 18 | 106 | 143 | 126 |
| SD18 | 1 | Hornyhead turbot | 8 | 13 | 19 | 16 | 60 | 179 | 112 |
| SD18 | 2 | Hornyhead turbot | 4 | 16 | 20 | 18 | 133 | 224 | 184 |
| SD18 | 3 | Hornyhead turbot | 7 | 13 | 21 | 16 | 49 | 272 | 117 |
| SD19 | 1 | Longfin sanddab | 4 | 14 | 19 | 17 | 66 | 157 | 116 |
| SD19 | 2 | Longfin sanddab | 3 | 18 | 19 | 18 | 133 | 146 | 138 |
| SD19 | 3 | Longfin sanddab | 8 | 13 | 17 | 14 | 46 | 111 | 63 |
| SD20 | 1 | Longfin sanddab | 9 | 13 | 17 | 14 | 48 | 115 | 64 |
| SD20 | 2 | Longfin sanddab | 6 | 13 | 17 | 15 | 55 | 108 | 81 |
| SD20 | 3 | Longfin sanddab | 7 | 14 | 19 | 15 | 52 | 144 | 69 |
| SD21 | 1 | Hornyhead turbot | 7 | 12 | 19 | 14 | 45 | 213 | 88 |
| SD21 | 2 | Longfin sanddab | 12 | 12 | 14 | 13 | 35 | 58 | 45 |
| SD21 | 3 | Longfin sanddab | 9 | 12 | 16 | 13 | 38 | 81 | 54 |

## Appendix F.2

Constituents and method detection limits (MDL) used for the analysis of liver and muscle tissues of fishes collected from the SBOO region between 2009–2011.

| Parameter | MDL Liver | MDL Muscle | Parameter | MDL Liver | MDL Muscle |
|---|---|---|---|---|---|
| **Metals (ppm)** | | | | | |
| Aluminum (Al) | 3.0 | 3.0 | Lead (Pb) | 0.2 | 0.2 |
| Antimony (Sb) | 0.2 | 0.2 | Manganese (Mn) | 0.1 | 0.1 |
| Arsenic (As) | 0.24 | 0.24 | Mercury (Hg) | 0.002 | 0.002 |
| Barium (Ba) | 0.03 | 0.03 | Nickel (Ni) | 0.2 | 0.2 |
| Beryllium (Be) | 0.006 | 0.006 | Selenium (Se) | 0.06 | 0.06 |
| Cadmium (Cd) | 0.06 | 0.06 | Silver (Ag) | 0.05 | 0.05 |
| Chromium (Cr) | 0.1 | 0.1 | Thallium (Tl) | 0.4 | 0.4 |
| Copper (Cu) | 0.1 | 0.1 | Tin (Sn) | 0.2 | 0.2 |
| Iron (Fe) | 2.0 | 2.0 | Zinc (Zn) | 0.15 | 0.15 |
| **Chlorinated Pesticides (ppb)** | | | | | |
| *Hexachlorocyclohexane (HCH)* | | | | | |
| HCH, Alpha isomer | 24.70 | 2.47 | HCH, Delta isomer | 4.53 | 0.45 |
| HCH, Beta isomer | 4.68 | 0.47 | HCH, Gamma isomer | 63.40 | 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 | 88.1 | 8.81 | Hexachlorobenzene (HCB) | 1.32 | 0.13 |
| Alpha endosulfan | 118.0 | 11.8 | Mirex | 1.49 | 0.15 |
| Dieldrin | 17.1 | 1.71 | Toxaphene | 342.0 | 34.20 |
| Endrin | 14.2 | 1.42 | | | |

## Appendix F.2 *continued*

| Parameter | MDL Liver | MDL Muscle | Parameter | MDL Liver | MDL Muscle |
|---|---|---|---|---|---|
| **Polychlorinated Biphenyls 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 | 2.5 | 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 |
| **Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)** | | | | | |
| 1-methylnaphthalene | 17.4 | 23.3 | Benzo[K]fluoranthene | 32 | 37.3 |
| 1-methylphenanthrene | 27.9 | 26.4 | Benzo[e]pyrene | 41.8 | 40.6 |
| 2,3,5-trimethylnaphthalene | 21.7 | 21.6 | Biphenyl | 38.0 | 19.9 |
| 2,6-dimethylnaphthalene | 21.7 | 19.5 | Chrysene | 18.1 | 23.0 |
| 2-methylnaphthalene | 35.8 | 13.2 | Dibenzo(A,H)anthracene | 37.6 | 40.3 |
| 3,4-benzo(B)fluoranthene | 30.2 | 26.8 | Fluoranthene | 19.9 | 12.9 |
| Acenaphthene | 28.9 | 11.3 | Fluorene | 27.3 | 11.4 |
| Acenaphthylene | 24.7 | 9.1 | Indeno(1,2,3-CD)pyrene | 25.6 | 46.5 |
| Anthracene | 25.3 | 8.4 | Naphthalene | 34.2 | 17.4 |
| Benzo[A]anthracene | 47.3 | 15.9 | Perylene | 18.5 | 50.9 |
| Benzo[A]pyrene | 42.9 | 18.3 | Phenanthrene | 11.6 | 12.9 |
| Benzo[G,H,I]perylene | 27.2 | 59.5 | Pyrene | 9.1 | 16.6 |

## Appendix F.3

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

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 101 | 0.3 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 118 | 0.4 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 138 | 0.3 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 149 | 0.2 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 153/168 | 0.7 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 180 | 0.3 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 187 | 0.2 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 194 | 0.1 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 99 | 0.2 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | DDT | o,p-DDE | 0.2 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | DDT | p,-p-DDMU | 0.4 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | DDT | p,p-DDD | 0.3 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | DDT | p,p-DDE | 2.7 | ppb |
| 2011-2 | RF3 | 1 | Brown rockfish | Muscle | DDT | p,p-DDT | 0.2 | ppb |
| | | | | | | | | |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 101 | 0.3 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 110 | 0.1 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 118 | 0.3 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 138 | 0.4 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 149 | 0.2 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 153/168 | 0.7 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 180 | 0.3 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 187 | 0.2 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 194 | 0.1 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | PCB | PCB 99 | 0.3 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | DDT | o,p-DDE | 0.3 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | DDT | p,-p-DDMU | 0.4 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | DDT | p,p-DDD | 0.3 | ppb |
| 2011-2 | RF3 | 2 | Brown rockfish | Muscle | DDT | p,p-DDE | 2.7 | ppb |
| | | | | | | | | |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | PCB | PCB 101 | 0.3 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | PCB | PCB 110 | 0.2 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | PCB | PCB 118 | 0.3 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | PCB | PCB 138 | 0.2 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | PCB | PCB 149 | 0.2 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | PCB | PCB 153/168 | 0.5 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | PCB | PCB 180 | 0.2 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | PCB | PCB 187 | 0.2 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | DDT | o,p-DDE | 0.1 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | DDT | p,-p-DDMU | 0.3 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | DDT | p,p-DDD | 0.2 | ppb |
| 2011-2 | RF3 | 3 | Vermilion rockfish | Muscle | DDT | p,p-DDE | 1.8 | ppb |
| | | | | | | | | |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 101 | 0.2 | ppb |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 118 | 0.3 | ppb |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 128 | 0.1 | ppb |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 138 | 0.3 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 153/168 | 0.7 | ppb |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 180 | 0.3 | ppb |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 187 | 0.3 | ppb |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 194 | 0.1 | ppb |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 99 | 0.3 | ppb |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | DDT | p,p-DDE | 2.3 | ppb |
| 2011-2 | RF4 | 1 | California scorpionfish | Muscle | DDT | p,p-DDT | 0.6 | ppb |
| 2011-2 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 118 | 0.3 | ppb |
| 2011-2 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 138 | 0.4 | ppb |
| 2011-2 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 153/168 | 0.6 | ppb |
| 2011-2 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 183 | 0.1 | ppb |
| 2011-2 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 187 | 0.2 | ppb |
| 2011-2 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 194 | 0.1 | ppb |
| 2011-2 | RF4 | 2 | California scorpionfish | Muscle | DDT | p,p-DDE | 1.2 | ppb |
| 2011-2 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 118 | 0.3 | ppb |
| 2011-2 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 138 | 0.4 | ppb |
| 2011-2 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 153/168 | 0.6 | ppb |
| 2011-2 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 180 | 0.2 | ppb |
| 2011-2 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 183 | 0.1 | ppb |
| 2011-2 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 187 | 0.2 | ppb |
| 2011-2 | RF4 | 3 | California scorpionfish | Muscle | DDT | p,p-DDE | 0.7 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 118 | 1.9 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 138 | 2.5 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 149 | 1.3 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 5.1 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 180 | 1.9 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 187 | 2.3 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 194 | 0.7 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDD | 2.2 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDE | 14.0 | ppb |
| 2011-2 | SD15 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDT | 1.4 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 101 | 5.0 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 105 | 1.5 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 110 | 2.8 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 118 | 6.4 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 138 | 8.4 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 149 | 4.7 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 151 | 1.5 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 153/168 | 17.0 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 170 | 2.2 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 177 | 1.8 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 180 | 8.7 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 183 | 2.9 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 187 | 9.9 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 194 | 3.3 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 201 | 3.8 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 206 | 1.9 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | PCB | PCB 99 | 4.7 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | DDT | o,p-DDE | 3.1 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | DDT | p,-p-DDMU | 2.7 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | DDT | p,p-DDD | 2.3 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | DDT | p,p-DDE | 34 | ppb |
| 2011-2 | SD15 | 2 | English sole | Liver | DDT | p,p-DDT | 1.7 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 118 | 1.4 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 138 | 2.2 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 3.6 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 180 | 1.8 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 187 | 1.8 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 28 | 1.2 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 44 | 2.5 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 49 | 1.9 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 52 | 2.7 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 66 | 1.8 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 70 | 2.4 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 74 | 1.3 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 99 | 1.8 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | DDT | p,-p-DDMU | 1.5 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDD | 1.8 | ppb |
| 2011-2 | SD16 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDE | 12.0 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 101 | 3.2 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 105 | 1.8 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 110 | 2.4 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 118 | 6.9 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 138 | 7.8 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 149 | 1.6 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 151 | 1.0 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 153/168 | 16 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 170 | 2.6 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 180 | 7.9 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 183 | 2.5 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 187 | 7.1 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 194 | 3.0 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 201 | 2.4 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 28 | 1.5 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 44 | 3.7 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 49 | 2.9 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 52 | 5.1 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 66 | 2.5 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 70 | 3.2 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 74 | 1.7 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | PCB | PCB 99 | 3.8 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | DDT | o,p-DDE | 2.3 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 2.4 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | DDT | p,p-DDD | 1.8 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | DDT | p,p-DDE | 39.0 | ppb |
| 2011-2 | SD16 | 2 | Longfin sanddab | Liver | DDT | p,p-DDT | 2.1 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 101 | 3.8 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 105 | 1.7 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 118 | 9.2 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 138 | 8.9 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 149 | 2.6 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 151 | 1.7 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 153/168 | 19 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 170 | 2.5 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 180 | 8.6 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 183 | 2.4 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 187 | 6.3 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 194 | 2.3 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 201 | 2.2 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 66 | 1.3 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 99 | 5.0 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | DDT | o,p-DDE | 3.4 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 6.6 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | DDT | p,p-DDD | 3.2 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | DDT | p,p-DDE | 82 | ppb |
| 2011-2 | SD17 | 1 | Longfin sanddab | Liver | DDT | p,p-DDT | 2.6 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 101 | 5.4 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 105 | 1.5 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 110 | 3.2 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 118 | 5.8 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 138 | 6.1 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 149 | 3.9 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 151 | 1.1 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 153/168 | 9.7 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 180 | 4.3 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 183 | 1.6 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 187 | 4.6 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 66 | 1.3 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | PCB | PCB 99 | 3.8 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | DDT | o,p-DDE | 10.0 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | DDT | p,-p-DDMU | 20.0 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | DDT | p,p-DDD | 4.5 | ppb |
| 2011-2 | SD17 | 2 | English sole | Liver | DDT | p,p-DDE | 60.0 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | PCB | PCB 138 | 3.4 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | PCB | PCB 149 | 1.2 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 6.4 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | PCB | PCB 180 | 2.9 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | PCB | PCB 183 | 1.0 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | PCB | PCB 187 | 2.7 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | PCB | PCB 194 | 1.1 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | DDT | p,-p-DDMU | 2.3 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | DDT | p,p-DDD | 2.7 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | DDT | p,p-DDE | 22.0 | ppb |
| 2011-2 | SD17 | 3 | Hornyhead turbot | Liver | DDT | p,p-DDT | 1.8 | ppb |
| | | | | | | | | |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 101 | 7.1 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 105 | 4.3 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 110 | 5.0 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 118 | 18.5 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 128 | 4.4 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 138 | 26.0 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 149 | 5.9 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 151 | 4.2 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 153/168 | 50.0 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 156 | 2.2 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 170 | 7.6 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 177 | 3.7 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 180 | 21.0 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 183 | 6.1 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 187 | 2.03 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 194 | 6.6 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 201 | 6.7 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 206 | 2.8 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | PCB | PCB 99 | 10.5 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | DDT | o,p-DDE | 5.2 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 10.5 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | DDT | p,p-DDD | 6.6 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | DDT | p,p-DDE | 130.0 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | DDT | p,p-DDT | 5.8 | ppb |
| | | | | | | | | |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 118 | 3.5 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 138 | 4.8 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 149 | 1.3 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 8.4 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 170 | 1.3 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 180 | 4.8 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 183 | 1.3 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 187 | 3.8 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 194 | 2.0 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 99 | 2.2 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | DDT | o,p-DDE | 2.1 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | DDT | p,-p-DDMU | 3.7 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | DDT | p,p-DDD | 4.2 | ppb |
| 2011-2 | SD18 | 2 | Hornyhead turbot | Liver | DDT | p,p-DDE | 29.0 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 101 | 9.9 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 105 | 3.4 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 110 | 6.7 | ppb |
| 2010-2 | SD19 | 2 | English sole | Liver | PCB | PCB 118 | 5.4 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 118 | 11.0 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 138 | 7.2 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 149 | 3.6 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 151 | 1.9 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 153/168 | 13.0 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 170 | 2.0 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 180 | 4.9 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 183 | 1.5 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 187 | 4.8 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 194 | 1.6 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 44 | 1.4 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 49 | 3.0 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 52 | 3.7 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 66 | 4.4 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 70 | 3.6 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 74 | 2.7 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 87 | 3.3 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | PCB | PCB 99 | 5.7 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | DDT | o,p-DDE | 67.0 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | DDT | p,-p-DDMU | 140.0 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | DDT | p,p-DDD | 21.0 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | DDT | p,p-DDE | 260.0 | ppb |
| 2011-2 | SD18 | 3 | English sole | Liver | DDT | p,p-DDT | 2.8 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 101 | 6.5 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 105 | 3.7 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 110 | 3.1 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 118 | 15.0 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 128 | 4.8 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 138 | 25.0 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 149 | 5.1 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 151 | 4.3 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 153/168 | 44.0 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 156 | 2.2 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 158 | 1.9 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 167 | 1.4 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 170 | 7.6 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 177 | 3.1 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 180 | 19.0 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 183 | 5.3 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 187 | 16.0 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 194 | 5.8 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 201 | 5.5 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 206 | 2.7 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 49 | 1.2 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 52 | 3.0 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 66 | 1.7 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 74 | 1.2 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 99 | 12.0 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | DDT | o,p-DDE | 8.3 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 6.7 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | DDT | p,p-DDD | 7.0 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | DDT | p,p-DDE | 140.0 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | DDT | p,p-DDT | 4.0 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 101 | 4.2 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 110 | 2.9 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 118 | 4.1 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 138 | 3.0 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 149 | 1.8 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 153/168 | 6.6 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 18 | 2.8 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 180 | 1.9 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 187 | 2.9 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 194 | 1.2 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 28 | 1.5 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 44 | 3.9 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 49 | 3.3 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 52 | 5.2 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 66 | 3.5 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 70 | 5.1 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 74 | 2.4 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | PCB | PCB 99 | 2.7 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | DDT | o,p-DDE | 3.4 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | DDT | p,-p-DDMU | 2.5 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | DDT | p,p-DDE | 19.0 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | DDT | p,p-DDT | 5.5 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 138 | 2.1 | ppb |
| 2010-2 | SD21 | 2 | Hornyhead turbot | Liver | DDT | p,p-DDE | 48.0 | ppb |
| 2010-2 | SD21 | 2 | Hornyhead turbot | Liver | DDT | p,-p-DDMU | 1.9 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 3.3 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 180 | 1.8 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 183 | 1.2 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 187 | 1.8 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 28 | 1.9 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 44 | 4.0 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 49 | 2.6 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 52 | 5.1 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 66 | 1.6 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | PCB | PCB 70 | 2.3 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | DDT | p,-p-DDMU | 1.5 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | DDT | p,p-DDE | 13.0 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | DDT | p,p-DDT | 20.0 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 101 | 10.0 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 105 | 2.6 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 110 | 7.4 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 118 | 9.6 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 138 | 6.8 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 149 | 3.8 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 153/168 | 8.4 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 180 | 1.8 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 187 | 1.9 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 49 | 2.4 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 52 | 4.3 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 66 | 1.5 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 70 | 2.8 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | PCB | PCB 99 | 6.0 | ppb |
| 2011-2 | SD20 | 1 | English sole | Liver | DDT | p,p-DDE | 12.0 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 101 | 2.4 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 105 | 1.7 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 110 | 1.6 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 118 | 7.4 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 138 | 13.0 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 149 | 1.9 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 151 | 1.8 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 153/168 | 24.0 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 170 | 3.5 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 177 | 1.6 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 180 | 10.0 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 99 | 4.6 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | DDT | o,p-DDE | 2.8 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 5.3 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | DDT | p,p-DDD | 3.5 | ppb |
| 2011-2 | SD20 | 2 | Longfin sanddab | Liver | DDT | p,p-DDE | 61.0 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 101 | 5.5 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 105 | 4.5 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 110 | 5.4 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 118 | 19.0 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 128 | 4.8 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 138 | 30.0 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 149 | 5.9 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 151 | 4.2 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 153/168 | 46.0 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 156 | 2.5 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 170 | 6.7 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 177 | 3.7 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 180 | 19.5 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 183 | 6.0 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 187 | 19.5 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 194 | 6.0 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 201 | 6.4 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 206 | 3.0 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 99 | 13.5 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | DDT | o,p-DDE | 4.3 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 8.5 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | DDT | p,p-DDD | 4.0 | ppb |
| 2011-2 | SD20 | 3 | Longfin sanddab | Liver | DDT | p,p-DDE | 107.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 101 | 4.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 105 | 2.9 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 110 | 3.1 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 118 | 13.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 128 | 4.2 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 138 | 22.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 149 | 4.2 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 151 | 3.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 153/168 | 36.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 156 | 1.7 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 158 | 1.7 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 170 | 4.9 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 177 | 3.1 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 180 | 13.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 183 | 3.9 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 187 | 15.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 194 | 3.9 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 201 | 4.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 52 | 2.1 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 66 | 1.4 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | PCB | PCB 99 | 9.9 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | DDT | o,p-DDE | 3.3 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 5.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | DDT | p,p-DDD | 2.5 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | DDT | p,p-DDE | 61.0 | ppb |
| 2011-2 | SD21 | 1 | Longfin sanddab | Liver | DDT | p,p-DDT | 3.2 | ppb |
| 2011-2 | SD21 | 2 | Hornyhead turbot | Liver | PCB | PCB 138 | 3.2 | ppb |
| 2011-2 | SD21 | 2 | Hornyhead turbot | Liver | PCB | PCB 149 | 1.6 | ppb |
| 2011-2 | SD21 | 2 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 4.5 | ppb |
| 2011-2 | SD21 | 2 | Hornyhead turbot | Liver | PCB | PCB 180 | 1.7 | ppb |
| 2011-2 | SD21 | 2 | Hornyhead turbot | Liver | PCB | PCB 187 | 1.8 | ppb |
| 2011-2 | SD21 | 2 | Hornyhead turbot | Liver | PCB | PCB 99 | 1.9 | ppb |
| 2011-2 | SD21 | 2 | Hornyhead turbot | Liver | DDT | p,p-DDE | 8.1 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 138 | 0.2 | ppb |
| 2011-4 | RF3 | 1 | Brown rockfish | Muscle | PCB | PCB 153/168 | 0.3 | ppb |
| 2011-4 | RF3 | 1 | Brown rockfish | Muscle | DDT | p,p-DDE | 1.7 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | PCB | PCB 101 | 0.4 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | PCB | PCB 110 | 0.3 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | PCB | PCB 118 | 0.2 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | PCB | PCB 138 | 0.3 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | PCB | PCB 149 | 0.2 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | PCB | PCB 153/168 | 0.5 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | PCB | PCB 180 | 0.3 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | PCB | PCB 187 | 0.3 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | PCB | PCB 99 | 0.3 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | DDT | p,p-DDD | 0.3 | ppb |
| 2011-4 | RF3 | 2 | Vermilion rockfish | Muscle | DDT | p,p-DDE | 4.4 | ppb |
| 2011-4 | RF3 | 3 | Mixed rockfish | Muscle | PCB | PCB 153/168 | 0.3 | ppb |
| 2011-4 | RF3 | 3 | Mixed rockfish | Muscle | DDT | p,p-DDE | 1.0 | ppb |
| 2011-4 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 153/168 | 0.3 | ppb |
| 2011-4 | RF4 | 1 | California scorpionfish | Muscle | PCB | PCB 187 | 0.3 | ppb |
| 2011-4 | RF4 | 1 | California scorpionfish | Muscle | DDT | p,p-DDE | 1.1 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 118 | 0.2 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 138 | 0.2 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 153/168 | 0.4 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 156 | 0.1 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 167 | 0.2 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 170 | 0.2 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 180 | 0.3 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 187 | 0.3 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 189 | 0.2 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | PCB | PCB 201 | 0.3 | ppb |
| 2011-4 | RF4 | 2 | California scorpionfish | Muscle | DDT | p,p-DDE | 1.6 | ppb |
| 2011-4 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 118 | 0.2 | ppb |
| 2011-4 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 138 | 0.2 | ppb |
| 2011-4 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 153/168 | 0.3 | ppb |
| 2011-4 | RF4 | 3 | California scorpionfish | Muscle | PCB | PCB 180 | 0.3 | ppb |
| 2011-4 | RF4 | 3 | California scorpionfish | Muscle | DDT | p,p-DDE | 2.6 | ppb |
| 2011-4 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 4.1 | ppb |
| 2011-4 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 180 | 2.6 | ppb |
| 2011-4 | SD15 | 1 | Hornyhead turbot | Liver | PCB | PCB 187 | 2.5 | ppb |
| 2011-4 | SD15 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDE | 20.0 | ppb |
| 2011-4 | SD15 | 2 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 3.0 | ppb |
| 2011-4 | SD15 | 2 | Hornyhead turbot | Liver | PCB | PCB 180 | 2.6 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD15 | 2 | Hornyhead turbot | Liver | PCB | PCB 187 | 2.5 | ppb |
| 2011-4 | SD15 | 2 | Hornyhead turbot | Liver | DDT | p,p-DDE | 18.0 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 101 | 4.3 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 105 | 2.3 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 110 | 2.5 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 118 | 4.9 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 128 | 1.2 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 138 | 6.7 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 149 | 3.1 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 151 | 2.0 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 153/168 | 15.0 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 170 | 1.9 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 180 | 5.6 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 183 | 1.6 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 187 | 5.3 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 66 | 2.8 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | PCB | PCB 99 | 3.1 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | DDT | p,-p-DDMU | 3.3 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | DDT | p,p-DDE | 76.0 | ppb |
| 2011-4 | SD15 | 3 | Pacific sanddab | Liver | DDT | p,p-DDT | 2.7 | ppb |
| 2011-4 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 138 | 2.6 | ppb |
| 2011-4 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 5.6 | ppb |
| 2011-4 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 180 | 2.6 | ppb |
| 2011-4 | SD16 | 1 | Hornyhead turbot | Liver | PCB | PCB 187 | 2.5 | ppb |
| 2011-4 | SD16 | 1 | Hornyhead turbot | Liver | DDT | p,-p-DDMU | 4.0 | ppb |
| 2011-4 | SD16 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDE | 30.0 | ppb |
| 2011-4 | SD16 | 2 | Hornyhead turbot | Liver | PCB | PCB 138 | 1.8 | ppb |
| 2011-4 | SD16 | 2 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 3.5 | ppb |
| 2011-4 | SD16 | 2 | Hornyhead turbot | Liver | PCB | PCB 180 | 2.6 | ppb |
| 2011-4 | SD16 | 2 | Hornyhead turbot | Liver | PCB | PCB 187 | 2.5 | ppb |
| 2011-4 | SD16 | 2 | Hornyhead turbot | Liver | DDT | p,p-DDE | 27.0 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 101 | 4.3 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 105 | 2.3 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 110 | 2.6 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 118 | 8.1 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 128 | 1.7 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 138 | 9.1 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 149 | 2.5 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 151 | 1.9 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 153/168 | 17.0 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 170 | 2.3 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 180 | 5.9 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 183 | 1.6 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 187 | 6.6 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 66 | 2.8 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | PCB | PCB 99 | 5.5 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | DDT | o,p-DDE | 2.8 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 3.8 | ppb |
| 2011-4 | SD16 | 3 | Longfin sanddab | Liver | DDT | p,p-DDE | 89.0 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 101 | 4.3 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 105 | 2.3 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 118 | 3.5 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 128 | 1.2 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 138 | 6.7 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 149 | 2.3 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 151 | 1.9 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 153/168 | 12.0 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 170 | 1.8 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 180 | 5.4 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 183 | 1.6 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 187 | 4.1 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 28 | 2.5 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 66 | 2.8 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | PCB | PCB 99 | 3.1 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | DDT | o,p-DDE | 2.8 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 3.3 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | DDT | p,p-DDD | 3.4 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | DDT | p,p-DDE | 100.0 | ppb |
| 2011-4 | SD17 | 1 | Longfin sanddab | Liver | DDT | p,p-DDT | 2.8 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 101 | 4.3 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 105 | 2.3 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 118 | 3.9 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 128 | 1.3 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 138 | 6.4 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 149 | 2.5 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 151 | 1.9 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 153/168 | 13.0 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 170 | 1.7 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 180 | 4.4 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 183 | 1.6 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 187 | 4.8 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 66 | 2.8 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | PCB | PCB 99 | 3.1 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | DDT | o,p-DDE | 2.8 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 3.4 | ppb |
| 2011-4 | SD17 | 2 | Longfin sanddab | Liver | DDT | p,p-DDE | 110.0 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | PCB | PCB 118 | 3.8 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | PCB | PCB 138 | 6.3 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | PCB | PCB 153/168 | 12.0 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | PCB | PCB 170 | 2.1 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | PCB | PCB 180 | 5.1 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | PCB | PCB 187 | 5.0 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | PCB | PCB 201 | 2.9 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | PCB | PCB 66 | 2.8 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | DDT | p,p-DDE | 94.0 | ppb |
| 2011-4 | SD17 | 3 | Longfin sanddab | Liver | DDT | p,p-DDT | 5.4 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 101 | 4.3 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 110 | 2.5 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 118 | 2.2 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 138 | 3.7 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 149 | 2.3 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 6.8 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 170 | 1.5 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 180 | 3.2 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 183 | 1.6 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 187 | 2.8 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | PCB | PCB 99 | 3.1 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | DDT | p,-p-DDMU | 3.3 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDD | 3.4 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDE | 70.0 | ppb |
| 2011-4 | SD18 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDT | 2.7 | ppb |
| 2011-2 | SD18 | 1 | Longfin sanddab | Liver | tCHLOR | Trans Nonachlor | 5.3 | ppb |
| 2011-4 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 138 | 2.7 | ppb |
| 2011-4 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 149 | 2.3 | ppb |
| 2011-4 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 3.8 | ppb |
| 2011-4 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 180 | 2.6 | ppb |
| 2011-4 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 187 | 2.5 | ppb |
| 2011-4 | SD18 | 2 | Hornyhead turbot | Liver | PCB | PCB 99 | 3.1 | ppb |
| 2011-4 | SD18 | 2 | Hornyhead turbot | Liver | DDT | p,p-DDE | 28.0 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 101 | 4.3 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 118 | 2.2 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 138 | 3.9 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 149 | 2.3 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 151 | 1.9 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 7.1 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 170 | 1.2 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 180 | 4.0 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 183 | 1.6 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 187 | 3.3 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | PCB | PCB 99 | 3.1 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | DDT | p,-p-DDMU | 3.3 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | DDT | p,p-DDD | 3.4 | ppb |
| 2011-4 | SD18 | 3 | Hornyhead turbot | Liver | DDT | p,p-DDE | 65.0 | ppb |
| | | | | | | | | |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 101 | 4.3 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 110 | 2.8 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 118 | 7.5 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 128 | 2.0 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 138 | 9.9 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 149 | 4.6 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 151 | 2.3 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 153/168 | 21.0 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 167 | 1.6 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 170 | 2.3 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 177 | 1.9 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 180 | 6.9 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 183 | 2.3 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 187 | 9.0 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 194 | 2.5 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 201 | 3.1 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 66 | 2.8 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 74 | 3.1 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | PCB | PCB 99 | 5.4 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | DDT | o,p-DDE | 3.1 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 7.5 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | DDT | p,p-DDD | 3.6 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | DDT | p,p-DDE | 150.0 | ppb |
| 2011-4 | SD19 | 1 | Longfin sanddab | Liver | DDT | p,p-DDT | 2.7 | ppb |
| 2011-2 | SD19 | 1 | Longfin sanddab | Liver | tCHLOR | Trans Nonachlor | 5.4 | ppb |
| | | | | | | | | |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 101 | 4.7 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 105 | 2.3 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 110 | 3.1 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 118 | 8.4 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 128 | 2.4 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 138 | 13.0 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 149 | 4.1 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 151 | 2.5 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 153/168 | 26.0 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 156 | 1.2 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 158 | 2.7 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 167 | 1.6 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 170 | 3.3 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 177 | 2.3 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 180 | 10.0 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 183 | 2.4 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 187 | 11.0 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 194 | 2.7 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 201 | 3.1 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 28 | 2.5 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 49 | 5.0 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 66 | 2.8 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 74 | 3.1 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | PCB | PCB 99 | 7.0 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | DDT | o,p-DDE | 4.2 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 9.9 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | DDT | p,p-DDD | 3.5 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | DDT | p,p-DDE | 210.0 | ppb |
| 2011-4 | SD19 | 2 | Longfin sanddab | Liver | DDT | p,p-DDT | 3.8 | ppb |
| 2011-2 | SD19 | 2 | English sole | Liver | tCHLOR | Heptachlor | 12.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 101 | 5.4 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 105 | 3.3 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 110 | 3.3 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 118 | 13.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 128 | 4.2 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 138 | 27.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 149 | 6.7 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 151 | 3.8 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 153/168 | 50.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 156 | 2.1 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 158 | 2.7 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 167 | 1.6 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 170 | 7.6 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 177 | 4.2 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 180 | 17.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 183 | 4.5 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 187 | 21.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 201 | 5.5 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 206 | 2.2 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 28 | 2.5 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 49 | 5.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 66 | 2.8 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 74 | 3.1 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | PCB | PCB 99 | 10.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | DDT | o,p-DDE | 6.1 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 11.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | DDT | p,p-DDD | 5.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | DDT | p,p-DDE | 410.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | DDT | p,p-DDT | 5.7 | ppb |
| 2011-2 | SD19 | 3 | Hornyhead turbot | Liver | tCHLOR | Heptachlor | 13.0 | ppb |
| 2011-4 | SD19 | 3 | Longfin sanddab | Liver | tCHLOR | Trans Nonachlor | 3.5 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 101 | 6.4 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 105 | 5.1 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 110 | 4.4 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 118 | 22.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 123 | 2.6 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 128 | 6.2 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 138 | 41.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 149 | 8.1 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 151 | 5.6 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 153/168 | 74.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 156 | 3.3 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 158 | 2.7 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 167 | 2.2 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 169 | 3.7 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 170 | 9.8 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 177 | 5.3 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 180 | 26.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 183 | 7.9 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 187 | 32.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 194 | 7.4 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 201 | 7.5 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 206 | 3.4 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 28 | 2.5 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 49 | 5.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 52 | 5.3 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 66 | 3.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 74 | 3.1 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | PCB | PCB 99 | 16.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | DDT | o,p-DDE | 5.8 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 15.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | DDT | p,p-DDD | 6.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | DDT | p,p-DDE | 410.0 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | DDT | p,p-DDT | 6.6 | ppb |
| 2011-4 | SD20 | 1 | Longfin sanddab | Liver | tCHLOR | Trans Nonachlor | 3.6 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 101 | 7.5 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 105 | 3.4 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 110 | 4.4 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 118 | 13.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 128 | 3.3 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 138 | 19.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 149 | 5.6 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 151 | 3.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 153/168 | 36.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 167 | 1.6 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 170 | 4.9 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 177 | 3.6 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 180 | 14.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 183 | 3.9 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 187 | 16.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 194 | 3.6 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 201 | 4.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 206 | 1.7 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 28 | 2.5 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 49 | 5.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 52 | 5.3 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 66 | 2.8 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 74 | 3.1 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | PCB | PCB 99 | 11.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | DDT | o,p-DDE | 5.5 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 15.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | DDT | p,p-DDD | 4.8 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | DDT | p,p-DDE | 270.0 | ppb |
| 2011-4 | SD20 | 2 | Longfin sanddab | Liver | DDT | p,p-DDT | 3.6 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 101 | 7.8 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 105 | 6.7 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 110 | 4.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 118 | 31.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 123 | 3.3 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 128 | 9.0 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 138 | 59.0 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 149 | 9.7 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 151 | 8.0 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 153/168 | 105.0 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 156 | 5.3 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 158 | 4.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 167 | 3.4 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 170 | 13.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 177 | 6.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 180 | 33.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 183 | 9.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 187 | 38.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 194 | 11.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 201 | 9.8 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 206 | 4.1 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 66 | 3.2 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 70 | 2.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 74 | 3.1 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | PCB | PCB 99 | 19.0 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | DDT | o,p-DDE | 6.1 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 18.0 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | DDT | p,p-DDD | 8.3 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | DDT | p,p-DDE | 535.0 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | DDT | p,p-DDT | 8.1 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | tCHLOR | Alpha (cis) Chlordane | 6.0 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | tCHLOR | Heptachlor | 24.5 | ppb |
| 2011-4 | SD20 | 3 | Longfin sanddab | Liver | tCHLOR | Trans Nonachlor | 5.3 | ppb |
| | | | | | | | | |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 101 | 1.7 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 118 | 4.1 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 138 | 5.9 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 149 | 2.4 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 151 | 1.1 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 153/168 | 13.0 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 170 | 1.0 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 180 | 2.9 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 183 | 1.1 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 187 | 4.6 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 194 | 1.7 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 201 | 1.0 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 49 | 0.7 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 52 | 0.8 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 66 | 1.1 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 74 | 0.5 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | PCB | PCB 99 | 2.3 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | DDT | o,p-DDE | 1.0 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | DDT | p,-p-DDMU | 4.6 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDD | 2.0 | ppb |
| 2011-4 | SD21 | 1 | Hornyhead turbot | Liver | DDT | p,p-DDE | 48.0 | ppb |
| | | | | | | | | |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 101 | 9.7 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 105 | 8.7 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 110 | 7.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 118 | 29.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 119 | 0.9 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 123 | 4.1 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 128 | 17.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 138 | 44.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 149 | 13.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 151 | 7.2 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 153/168 | 84.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 156 | 11.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 157 | 3.9 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 158 | 4.1 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 167 | 4.9 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 170 | 8.1 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 177 | 6.3 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 180 | 22.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 183 | 6.4 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 187 | 30.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 194 | 7.2 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 201 | 4.8 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 206 | 4.2 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 28 | 2.5 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 44 | 0.5 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 49 | 2.3 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 52 | 4.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 66 | 5.8 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 70 | 2.1 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 74 | 3.4 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 87 | 1.8 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | PCB | PCB 99 | 20.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | DDT | o,p-DDD | 1.1 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | DDT | o,p-DDE | 6.5 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 30.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | DDT | p,p-DDD | 7.1 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | DDT | p,p-DDE | 420.0 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | DDT | p,p-DDT | 5.1 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | tCHLOR | Alpha (cis) Chlordane | 2.6 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | tCHLOR | Cis Nonachlor | 1.8 | ppb |
| 2011-4 | SD21 | 2 | Longfin sanddab | Liver | tCHLOR | Trans Nonachlor | 3.6 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 101 | 7.9 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 105 | 7.2 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 110 | 6.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 118 | 25.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 119 | 0.6 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 123 | 3.7 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 128 | 18.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 138 | 41.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 149 | 12.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 151 | 6.4 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 153/168 | 77.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 156 | 9.7 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 157 | 4.5 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 158 | 3.5 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 167 | 5.5 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 170 | 7.7 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 177 | 6.3 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 180 | 19.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 183 | 5.6 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 187 | 27.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 189 | 4.2 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 194 | 7.2 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 201 | 4.5 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 206 | 4.8 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 28 | 3.4 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 44 | 0.6 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 49 | 2.6 | ppb |

## Appendix F.3 *continued*

| Yr-Qtr | Station | Comp | Species | Tissue | Class | Parameter | Value | Units |
|---|---|---|---|---|---|---|---|---|
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 52 | 3.9 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 66 | 5.2 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 70 | 2.2 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 74 | 3.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 87 | 1.7 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | PCB | PCB 99 | 17.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | DDT | o,p-DDD | 1.1 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | DDT | o,p-DDE | 5.8 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | DDT | p,-p-DDMU | 29.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | DDT | p,p-DDD | 6.3 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | DDT | p,p-DDE | 340.0 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | DDT | p,p-DDT | 4.5 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | tCHLOR | Alpha (cis) Chlordane | 2.3 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | tCHLOR | Cis Nonachlor | 1.5 | ppb |
| 2011-4 | SD21 | 3 | Longfin sanddab | Liver | tCHLOR | Trans Nonachlor | 3.1 | ppb |

## Appendix F.4

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

| Station | Comp | 2009-2 | 2009-4 | 2010-2 | 2010-4 | 2011-2 | 2011-4 |
|---|---|---|---|---|---|---|---|
| *(muscle tissue)* | | | | | | | |
| RF3 | 1 | Brown rockfish | Brown rockfish | Brown rockfish | Brown rockfish | Brown rockfish | Brown rockfish |
| RF3 | 2 | Brown rockfish | Brown rockfish | Brown rockfish | Brown rockfish | Brown rockfish | Vermillion rockfish |
| RF3 | 3 | Mixed rockfish | Mixed rockfish | Mixed rockfish | Brown rockfish | Vermillion rockfish | Mixed rockfish |
| RF4 | 1 | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish |
| RF4 | 2 | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish |
| RF4 | 3 | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish | Ca. scorpionfish |
| *(liver tissue)* | | | | | | | |
| SD15 | 1 | English sole | Hornyhead turbot | no sample | Hornyhead turbot | Hornyhead turbot | Hornyhead turbot |
| SD15 | 2 | Hornyhead turbot | no sample | no sample | English sole | English sole | Hornyhead turbot |
| SD15 | 3 | no sample | no sample | no sample | Ca. scorpionfish | no sample | Pacific sanddab |
| SD16 | 1 | Longfin sanddab | Hornyhead turbot | English Sole | Longfin sanddab | Hornyhead turbot | Hornyhead turbot |
| SD16 | 2 | Hornyhead turbot | Longfin sanddab | no sample | English sole | Longfin sanddab | Hornyhead turbot |
| SD16 | 3 | no sample | Longfin sanddab | no sample | Longfin sanddab | no sample | Longfin sanddab |
| SD17 | 1 | Longfin sanddab | Hornyhead turbot | English sole | Longfin sanddab | Longfin sanddab | Longfin sanddab |
| SD17 | 2 | Longfin sanddab | Ca. scorpionfish | Longfin sanddab | Longfin sanddab | English sole | Longfin sanddab |
| SD17 | 3 | Longfin sanddab | Hornyhead turbot | Hornyhead turbot | Hornyhead turbot | Hornyhead turbot | Longfin sanddab |
| SD18 | 1 | Longfin sanddab | Hornyhead turbot | English sole | Longfin sanddab | Longfin sanddab | Hornyhead turbot |
| SD18 | 2 | Longfin sanddab | Hornyhead turbot | English sole | Longfin sanddab | Hornyhead turbot | Hornyhead turbot |
| SD18 | 3 | Longfin sanddab | Ca. scorpionfish | Hornyhead turbot | Longfin sanddab | English sole | Hornyhead turbot |
| SD19 | 1 | Longfin sanddab | Longfin sanddab | Longfin sanddab | Longfin sanddab | Longfin sanddab | Longfin sanddab |
| SD19 | 2 | Hornyhead turbot | Longfin sanddab | English sole | Longfin sanddab | English sole | Longfin sanddab |
| SD19 | 3 | no sample | Longfin sanddab | Hornyhead turbot | Longfin sanddab | Hornyhead turbot | Longfin sanddab |
| SD20 | 1 | no sample | Longfin sanddab | Hornyhead turbot | Longfin sanddab | English sole | Longfin sanddab |
| SD20 | 2 | no sample | Longfin sanddab | Hornyhead turbot | Longfin sanddab | Longfin sanddab | Longfin sanddab |
| SD20 | 3 | no sample | Hornyhead turbot | English sole | no sample | Longfin sanddab | Longfin sanddab |

**Appendix F.4** *continued*

| Station | Comp | 2009-2 | 2009-4 | 2010-2 | 2010-4 | 2011-2 | 2011-4 |
|---|---|---|---|---|---|---|---|
| SD21 | 1 | Longfin sanddab | Hornyhead turbot | Hornyhead turbot | Longfin sanddab | Longfin sanddab | Hornyhead turbot |
| SD21 | 2 | Longfin sanddab | Hornyhead turbot | Hornyhead turbot | Longfin sanddab | Hornyhead turbot | Longfin sanddab |
| SD21 | 3 | Hornyhead turbot | Ca. scorpionfish | English sole | Hornyhead turbot | no sample | Longfin sanddab |

# Appendix F.5

SBOO three-way PERMANOVA results for liver tissue. df = degrees of freedom, SS = sums of squares, MS = mean squares, P(perm) = permutation p-value.

*Pairwise tests: r values (p values)*

| | df | SS | MS | Pseudo-F | P(perm) | Unique perms |
|---|---|---|---|---|---|---|
| Survey | 2 | 79.881 | 39.941 | 2.7460 | 0.0022 | 9921 |
| Species | 1 | 25.189 | 25.189 | 1.7318 | 0.1428 | 9951 |
| Lipid content | 1 | 44.940 | 44.940 | 3.0898 | 0.0042 | 9939 |
| Survey x species [a] | 6 | 102.590 | 17.098 | 1.1756 | 0.2753 | 9893 |
| Survey x lipid content [a] | 7 | 83.459 | 11.923 | 0.8197 | 0.6559 | 9910 |
| Species x lipid content [a] | 3 | 48.723 | 16.241 | 1.1166 | 0.3486 | 9930 |
| Survey x species x lipid content [a] | 0 | 0 | | No test | | |
| Residual | 68 | 989.060 | 14.545 | | | |
| **Total** | 101 | 2525 | | | | |

[a] Term has one or more empty cells

## Appendix F.6

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

**Global Test: Factor A**

*Tests for differences between surveys across all species*

| | |
|---|---|
| Sample statistic (Global R): | 0.557 |
| Significance level of sample statistic: | 0.01% |
| Number of permutations: | 9999 |
| Number of permuted statistics greater than or equal to Global R: | 0 |

**Pairwise Tests: Factor A**

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

| | 2009-4 | 2010-2 | 2010-4 | 2011-2 | 2011-4 |
|---|---|---|---|---|---|
| **2009-2** | 0.829 (0.033) | 0.914 (0.033) | 0.911 (0.01) | 0.600 (0.033) | 0.648 (0.033) |
| **2009-4** | | 0.600 (0.033) | 0.599 (0.04) | 0.571 (0.033) | 0.480 (0.1) |
| **2010-2** | | | 0.799 (0.01) | 0.543 (0.033) | 0.456 (0.033) |
| **2010-4** | | | | 0.521 (0.01) | 0.457 (0.05) |
| **2011-2** | | | | | 0.288 (0.167) |

**Global Test: Factor B**

*Tests for differences between species across all surveys*

| | |
|---|---|
| Sample statistic (Global R): | 0.162 |
| Significance level of sample statistic: | 10.5% |
| Number of permutations: | 9999 |
| Number of permuted statistics greater than or equal to Global R: | 1051 |

**Pairwise Tests: Factor B**

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

| | Mixed rockfish | California scorpionfish | Vermilion rockfish |
|---|---|---|---|
| **Brown rockfish** | 0.333 (0.37) | 0.182 (0.062) | 0 (0.667) |
| **Mixed rockfish** | | 0.278 (0.215) | no test |
| **California scorpionfish** | | | 0 (0.625) |

# Appendix G

# Supporting Data

# 2011 Regional Stations

# Sediment Conditions

## Appendix G.1

Constituents and method detection limits (MDL) used for the analysis of sediments collected as part of the 2009–2011 regional surveys.

| Parameter | MDL 2009–2010 | MDL 2011 | Parameter | MDL 2009–2010 | MDL 2011 |
|---|---|---|---|---|---|
| **Organic Indicators** | | | | | |
| Total Nitrogen (TN, % wt.) | 0.005 | 0.005 | Total Sulfides (ppm) | 0.14 | 0.14 |
| Total Organic Carbon (TOC, % wt.) | 0.01 | 0.01 | Total Volatile Solids (TVS, % wt.) | 0.11 | 0.11 |
| **Metals (ppm)** | | | | | |
| Aluminum (Al) | 2 | 2 | Lead (Pb) | 0.8 | 0.8 |
| Antimony (Sb) | 0.3 | 0.3 | Manganese (Mn) | 0.08 | 0.08 |
| Arsenic (As) | 0.33 | 0.33 | Mercury (Hg) | 0.003 | 0.003, 0.004[a] |
| Barium (Ba) | 0.02 | 0.02 | Nickel (Ni) | 0.1 | 0.1 |
| Beryllium (Be) | 0.01 | 0.01 | Selenium (Se) | 0.24 | 0.24 |
| Cadmium (Cd) | 0.06 | 0.06 | Silver (Ag) | 0.04 | 0.04 |
| Chromium (Cr) | 0.1 | 0.1 | Thallium (Ti) | 0.5 | 0.5 |
| Copper (Cu) | 0.2 | 0.2 | Tin (Sn) | 0.3 | 0.3 |
| Iron (Fe) | 9 | 9 | Zinc (Zn) | 0.25 | 0.25 |
| **Chlorinated Pesticides (ppt)** | | | | | |
| *Hexachlorocyclohexane (HCH)* | | | | | |
| HCH, Alpha isomer | e | 150 | HCH, Delta isomer | e | 700 |
| HCH, Beta isomer | e | 310 | HCH, Gamma isomer | e | 260 |
| *Total Chlordane* | | | | | |
| Alpha (cis) Chlordane | e | 240 | Heptachlor epoxide | e | 120 |
| Cis Nonachlor | e | 240 | Methoxychlor | e | 1100 |
| Gamma (trans) Chlordane | e | 350 | Oxychlordane | e | 240 |
| Heptachlor | e | 1200 | Trans Nonachlor | e | 250 |
| *Total Dichlorodiphenyltrichloroethane (DDT)* | | | | | |
| o,p-DDD | e | 830 | p,p-DDE | e | 260 |
| o,p-DDE | e | 720 | p,-p-DDMU[b] | e | — |
| o,p-DDT | e | 800 | p,p-DDT | e | 800 |
| p,p-DDD | e | 470 | | | |
| *Miscellaneous Pesticides* | | | | | |
| Aldrin | e | 430 | Endrin | e | 830 |
| Alpha Endosulfan | e | 240 | Endrin aldehyde | e | 830 |
| Beta Endosulfan | e | 350 | Hexachlorobenzene | e | 470 |
| Dieldrin | e | 310 | Mirex | e | 500 |
| Endosulfan Sulfate | e | 260 | | | |

[a] methods changed between Jan & Jul; [b] No MDL available for this parameter; e=values estimated regardless of MDL

## Appendix G.1 *continued*

| Parameter | MDL 2009–2010 | MDL 2011 | Parameter | MDL 2009–2010 | MDL 2011 |
|---|---|---|---|---|---|
| **Polychlorinated Biphenyl Congeners (PCBs) (ppt)** | | | | | |
| PCB 18 | e | 540 | PCB 126 | e | 720 |
| PCB 28 | e | 700 | PCB 128 | e | 570 |
| PCB 37 | e | 700 | PCB 138 | e | 590 |
| PCB 44 | e | 700 | PCB 149 | e | 500 |
| PCB 49 | e | 700 | PCB 151 | e | 640 |
| PCB 52 | e | 700 | PCB 153/168 | e | 600 |
| PCB 66 | e | 700 | PCB 156 | e | 620 |
| PCB 70 | e | 700 | PCB 157 | e | 700 |
| PCB 74 | e | 700 | PCB 158 | e | 510 |
| PCB 77 | e | 700 | PCB 167 | e | 620 |
| PCB 81 | e | 700 | PCB 169 | e | 610 |
| PCB 87 | e | 700 | PCB 170 | e | 570 |
| PCB 99 | e | 700 | PCB 177 | e | 650 |
| PCB 101 | e | 430 | PCB 180 | e | 530 |
| PCB 105 | e | 720 | PCB 183 | e | 530 |
| PCB 110 | e | 640 | PCB 187 | e | 470 |
| PCB 114 | e | 700 | PCB 189 | e | 620 |
| PCB 118 | e | 830 | PCB 194 | e | 420 |
| PCB 119 | e | 560 | PCB 201 | e | 530 |
| PCB 123 | e | 660 | PCB 206 | e | 510 |
| **Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)** | | | | | |
| 1-methylnaphthalene | e | 20 | Benzo[G,H,I]perylene | e | 20 |
| 1-methylphenanthrene | e | 20 | Benzo[K]fluoranthene | e | 20 |
| 2,3,5-trimethylnaphthalene | e | 20 | Biphenyl | e | 30 |
| 2,6-dimethylnaphthalene | e | 20 | Chrysene | e | 40 |
| 2-methylnaphthalene | e | 20 | Dibenzo(A,H)anthracene | e | 20 |
| 3,4-benzo(B)fluoranthene | e | 20 | Fluoranthene | e | 20 |
| Acenaphthene | e | 20 | Fluorene | e | 20 |
| Acenaphthylene | e | 30 | Indeno(1,2,3-CD)pyrene | e | 20 |
| Anthracene | e | 20 | Naphthalene | e | 30 |
| Benzo[A]anthracene | e | 20 | Perylene | e | 30 |
| Benzo[A]pyrene | e | 20 | Phenanthrene | e | 30 |
| Benzo[e]pyrene | e | 20 | Pyrene | e | 20 |

e=values estimated regardless of MDL

## Appendix G.2

Summary of the constituents that make up total DDT, total PCB and total PAH in each sediment sample collected as part of the 2011 regional survey.

| Station | Class | Constituent | Value | Units |
|---|---|---|---|---|
| 8101 | PAH | Indeno(1,2,3-CD)pyrene | 21.2 | ppb |
| | | | | |
| 8102 | DDT | p,p-DDE | 360 | ppt |
| 8102 | PAH | Benzo[G,H,I]perylene | 33.1 | ppb |
| 8102 | PAH | Dibenzo(A,H)anthracene | 28.1 | ppb |
| 8102 | PAH | Indeno(1,2,3-CD)pyrene | 27.9 | ppb |
| | | | | |
| 8104 | DDT | p,p-DDE | 430 | ppt |
| 8104 | PAH | Benzo[G,H,I]perylene | 25.6 | ppb |
| 8104 | PAH | Indeno(1,2,3-CD)pyrene | 22.5 | ppb |
| | | | | |
| 8105 | DDT | p,p-DDE | 590 | ppt |
| 8105 | PAH | Benzo[G,H,I]perylene | 27.3 | ppb |
| 8105 | PAH | Dibenzo(A,H)anthracene | 26.1 | ppb |
| 8105 | PAH | Indeno(1,2,3-CD)pyrene | 25.3 | ppb |
| | | | | |
| 8106 | DDT | p,p-DDE | 660 | ppt |
| 8106 | PAH | Benzo[G,H,I]perylene | 27.7 | ppb |
| 8106 | PAH | Dibenzo(A,H)anthracene | 22.5 | ppb |
| 8106 | PAH | Indeno(1,2,3-CD)pyrene | 24.9 | ppb |
| | | | | |
| 8107 | DDT | p,p-DDE | 550 | ppt |
| 8107 | PAH | Benzo[G,H,I]perylene | 22.9 | ppb |
| 8107 | PAH | Indeno(1,2,3-CD)pyrene | 20.6 | ppb |
| | | | | |
| 8109 | DDT | p,p-DDE | 390 | ppt |
| | | | | |
| 8110 | DDT | p,p-DDE | 500 | ppt |
| 8110 | PAH | 2,6-dimethylnaphthalene | 32.1 | ppb |
| | | | | |
| 8112 | DDT | p,p-DDE | 640 | ppt |
| 8112 | PAH | 2,6-dimethylnaphthalene | 24.6 | ppb |
| | | | | |
| 8113 | DDT | p,p-DDE | 610 | ppt |
| 8113 | PAH | 2,6-dimethylnaphthalene | 20.5 | ppb |
| | | | | |
| 8114 | DDT | p,p-DDE | 770 | ppt |
| 8114 | PAH | 2,6-dimethylnaphthalene | 30.0 | ppb |
| | | | | |
| 8119 | DDT | p,p-DDE | 470 | ppt |
| 8119 | PAH | Anthracene | 38.5 | ppb |
| 8119 | PAH | Benzo[A]anthracene | 45.0 | ppb |
| 8119 | PAH | Benzo[A]pyrene | 80.3 | ppb |
| 8119 | PAH | Benzo[e]pyrene | 46.0 | ppb |
| 8119 | PAH | Benzo[G,H,I]perylene | 42.8 | ppb |
| 8119 | PAH | Chrysene | 135.0 | ppb |
| 8119 | PAH | Fluoranthene | 25.1 | ppb |
| 8119 | PAH | Indeno(1,2,3-CD)pyrene | 35.6 | ppb |
| 8119 | PAH | Pyrene | 25.4 | ppb |
| 8119 | PCB | PCB 101 | 840 | ppt |
| 8119 | PCB | PCB 110 | 640 | ppt |

## Appendix G.2 *continued*

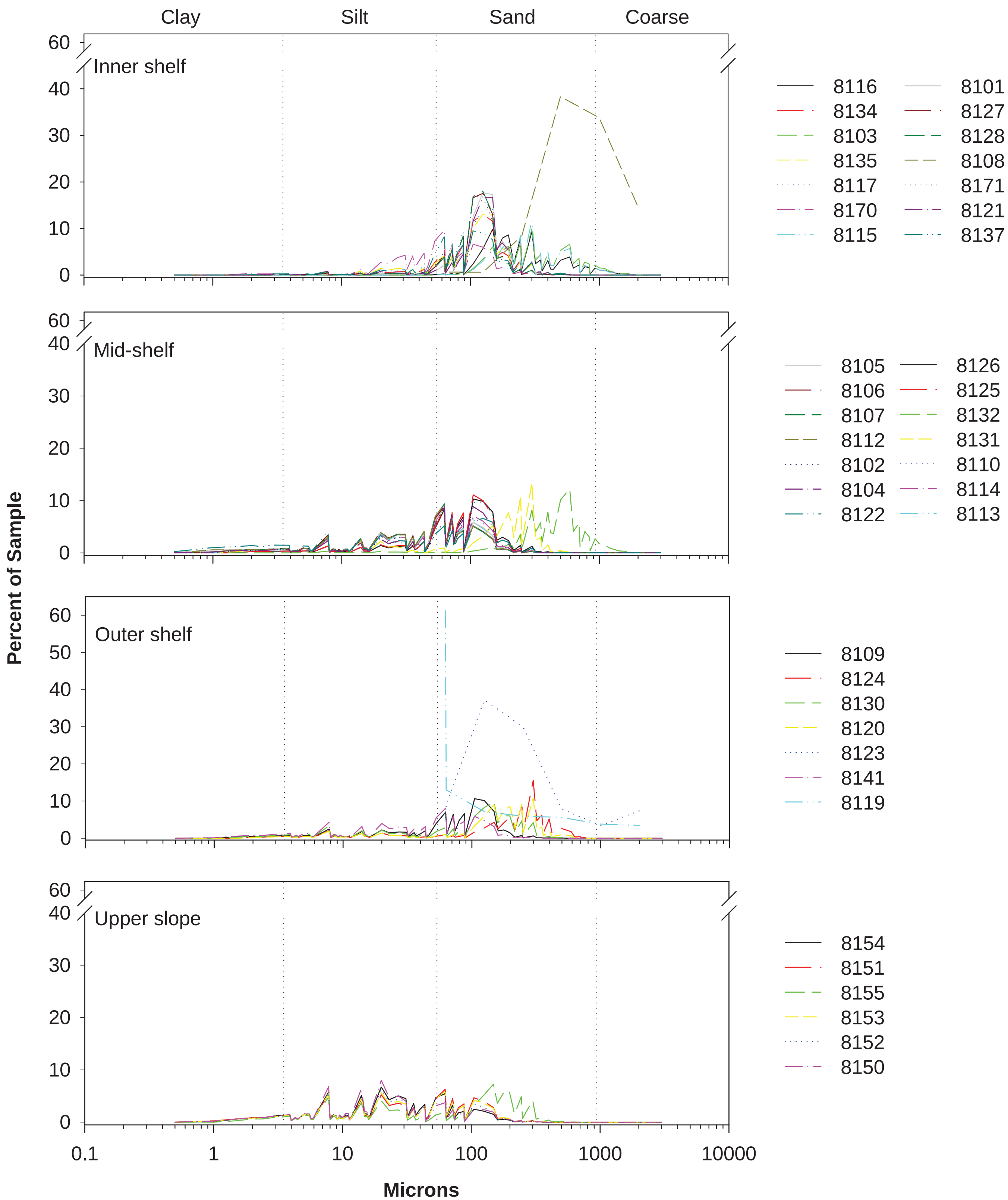
| Station | Class | Constituent | Value | Units |
|---|---|---|---|---|
| 8119 | PCB | PCB 118 | 830 | ppt |
| 8119 | PCB | PCB 138 | 590 | ppt |
| 8119 | PCB | PCB 149 | 500 | ppt |
| 8119 | PCB | PCB 153/168 | 600 | ppt |
| 8119 | PCB | PCB 180 | 530 | ppt |
| 8120 | DDT | p,p-DDE | 230 | ppt |
| 8122 | DDT | p,p-DDE | 410 | ppt |
| 8123 | DDT | p,p-DDE | 390 | ppt |
| 8125 | DDT | p,p-DDE | 380 | ppt |
| 8126 | DDT | p,p-DDE | 550 | ppt |
| 8126 | PCB | PCB 101 | 730 | ppt |
| 8126 | PCB | PCB 110 | 640 | ppt |
| 8126 | PCB | PCB 138 | 590 | ppt |
| 8126 | PCB | PCB 149 | 500 | ppt |
| 8126 | PCB | PCB 52 | 1000 | ppt |
| 8130 | DDT | p,p-DDE | 450 | ppt |
| 8134 | DDT | p,p-DDE | 635 | ppt |
| 8141 | DDT | p,p-DDE | 1500 | ppt |
| 8150 | PAH | 2,6-dimethylnaphthalene | 28.6 | ppb |
| 8151 | DDT | p,p-DDE | 1000 | ppt |
| 8153 | DDT | p,p-DDE | 1500 | ppt |
| 8154 | DDT | p,p-DDE | 690 | ppt |
| 8155 | DDT | p,p-DDE | 690 | ppt |

## Appendix G.3

Summary of sediment grain size parameters for each regional station sampled during July 2011. Silt and clay fractions are indistinguishable for samples analyzed by sieve. SD = standard deviation; ST = sediment type (F = fines; Fs = fines with sand; Fc = fines with coarse; S = sand; Sf = sand with fines; Scf = sand with coarse and fines; Sc = sand with coarse; C = coarse; Cf = coarse with fines; Csf = coarse with sand and fines; Cs = coarse with sand). Visual observations are from sieved "grunge" (i.e., particles retained on 1-mm mesh screen and preserved with infauna for benthic community analysis); abbreviations are: Sh = shell hash; Pg = pea gravel; R = rock; Wt = worm tubes; Cs = coarse sand; Cbs = coarse black sand.

| | Station | Depth (m) | Mean (µm) | Mean (phi) | SD (phi) | Median (phi) | Coarse (%) | Sand (%) | Silt (%) | Clay (%) | Fines (%) | ST | Visual Observations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inner Shelf | 8116 | 10 | 333 | 1.9 | 0.9 | 2.0 | 4.0 | 95.9 | 0.1 | 0.0 | 0.1 | S | Sh |
| | 8134 | 10 | 127 | 3.3 | 1.0 | 3.3 | 0.0 | 87.0 | 12.7 | 0.2 | 12.9 | Sf | — |
| | 8103 | 12 | 407 | 1.6 | 0.9 | 1.7 | 5.2 | 94.8 | 0.0 | 0.0 | 0.0 | Sc | Sh |
| | 8135 | 13 | 123 | 3.4 | 1.2 | 3.0 | 0.0 | 81.4 | 18.2 | 0.4 | 18.6 | Sf | Wt |
| | 8117 | 16 | 135 | 3.2 | 1.1 | 3.0 | 0.0 | 87.9 | 11.9 | 0.2 | 12.1 | Sf | — |
| | 8170 | 16 | 74 | 4.2 | 1.2 | 4.0 | 0.0 | 54.0 | 44.7 | 1.3 | 46.0 | Sf | — |
| | 8115 | 19 | 373 | 1.7 | 0.9 | 1.7 | 3.8 | 96.2 | 0.0 | 0.0 | 0.0 | S | Sh |
| | 8101 | 20 | 143 | 3.0 | 0.9 | 3.0 | 0.0 | 94.3 | 5.6 | 0.1 | 5.7 | S | — |
| | 8127 | 20 | 117 | 3.3 | 0.9 | 3.3 | 0.0 | 91.5 | 8.4 | 0.1 | 8.5 | S | Wt, Sh |
| | 8128 | 20 | 117 | 3.3 | 0.9 | 3.3 | 0.0 | 91.4 | 8.4 | 0.2 | 8.6 | S | — |
| | 8108[s] | 24 | 848 | 0.6 | 1.1 | 1.0 | 48.5 | 48.0 | — | — | 3.5 | Cs | Pg, Sh |
| | 8171 | 25 | 111 | 3.4 | 0.9 | 3.3 | 0.0 | 91.1 | 8.8 | 0.1 | 8.9 | S | — |
| | 8121 | 29 | 139 | 3.2 | 1.2 | 3.0 | 0.0 | 90.1 | 9.4 | 0.5 | 9.9 | S | Sh |
| | 8137 | 29 | 112 | 3.6 | 1.3 | 3.5 | 0.0 | 78.2 | 21.0 | 0.8 | 21.8 | Sf | Wt |
| Mid-shelf | 8126 | 32 | 97 | 3.8 | 1.3 | 3.5 | 0.0 | 74.8 | 24.1 | 1.2 | 25.2 | Sf | Wt |
| | 8125 | 36 | 89 | 3.9 | 1.3 | 3.7 | 0.0 | 73.2 | 25.6 | 1.2 | 26.8 | Sf | — |
| | 8132 | 40 | 500 | 1.3 | 1.1 | 1.2 | 5.6 | 91.3 | 3.0 | 0.0 | 3.0 | Sc | Sh |
| | 8131 | 58 | 170 | 3.4 | 2.0 | 2.3 | 0.0 | 73.2 | 24.4 | 2.4 | 26.8 | Sf | — |
| | 8110 | 62 | 65 | 4.5 | 1.5 | 4.0 | 0.0 | 50.5 | 46.4 | 3.1 | 49.5 | Sf | — |
| | 8114 | 72 | 66 | 4.5 | 1.5 | 4.0 | 0.0 | 52.0 | 45.4 | 2.6 | 48.0 | Sf | — |
| | 8113 | 75 | 59 | 4.7 | 1.5 | 4.2 | 0.0 | 46.3 | 50.6 | 3.0 | 53.7 | Fs | — |
| | 8105 | 78 | 59 | 4.7 | 1.6 | 4.2 | 0.0 | 45.0 | 51.1 | 3.9 | 55.0 | Fs | — |
| | 8106 | 80 | 55 | 4.8 | 1.5 | 4.5 | 0.0 | 41.7 | 54.7 | 3.6 | 58.3 | Fs | — |
| | 8107 | 84 | 56 | 4.8 | 1.5 | 4.4 | 0.0 | 42.5 | 54.0 | 3.5 | 57.5 | Fs | Cbs, Pg |
| | 8112 | 84 | 56 | 4.7 | 1.5 | 4.4 | 0.0 | 42.9 | 53.2 | 3.9 | 57.1 | Fs | — |
| | 8102 | 93 | 80 | 4.3 | 1.6 | 3.8 | 0.0 | 61.6 | 35.6 | 2.8 | 38.4 | Sf | Sh |
| | 8104 | 100 | 72 | 4.3 | 1.5 | 4.0 | 0.0 | 59.4 | 37.7 | 2.9 | 40.6 | Sf | Cbs, Pg |
| | 8122 | 101 | 70 | 4.8 | 2.0 | 4.2 | 0.0 | 48.0 | 43.9 | 8.1 | 52.0 | Fs | Cs, Pg, Sh |
| Outer Shelf | 8109 | 122 | 82 | 4.2 | 1.5 | 3.8 | 0.0 | 66.2 | 31.3 | 2.5 | 33.8 | Sf | Sh |
| | 8124 | 139 | 232 | 2.8 | 1.8 | 2.0 | 0.0 | 83.1 | 15.6 | 1.4 | 16.9 | Sf | Cs, Pg, Sh |
| | 8130 | 139 | 121 | 3.8 | 1.9 | 3.0 | 0.0 | 69.3 | 27.9 | 2.8 | 30.7 | Sf | Cs, Pg, Sh |
| | 8120 | 148 | 185 | 3.0 | 1.7 | 2.5 | 0.0 | 83.5 | 15.3 | 1.2 | 16.5 | Sf | Cs, Pg, Sh |
| | 8123[s] | 161 | 350 | 2.3 | 1.3 | 3.0 | 10.8 | 83.7 | — | — | 5.6 | Sc | Cs, Pg, Sh |
| | 8141 | 165 | 56 | 4.9 | 1.6 | 4.4 | 0.0 | 43.4 | 52.4 | 4.3 | 56.6 | Fs | — |
| | 8119[s] | 193 | 203 | 3.3 | 1.3 | 4.0 | 7.2 | 31.5 | — | — | 61.3 | Fc | Cs, Pg, Sh |
| Upper Slope | 8154 | 249 | 40 | 5.4 | 1.6 | 5.2 | 0.0 | 23.2 | 72.0 | 4.9 | 76.8 | Fs | Wt |
| | 8151 | 286 | 49 | 5.1 | 1.7 | 5.0 | 0.0 | 35.0 | 60.1 | 4.9 | 65.0 | Fs | Wt |
| | 8155 | 312 | 106 | 4.3 | 2.1 | 3.7 | 0.0 | 54.5 | 42.1 | 3.4 | 45.5 | Fs | Pg, R |
| | 8153 | 339 | 48 | 5.2 | 1.7 | 5.0 | 0.0 | 32.8 | 62.5 | 4.7 | 67.2 | Fs | Wt |
| | 8152 | 393 | 42 | 5.3 | 1.6 | 5.2 | 0.0 | 28.4 | 67.1 | 4.6 | 71.6 | Fs | Wt, Sh |
| | 8150 | 427 | 38 | 5.6 | 1.6 | 5.6 | 0.0 | 20.7 | 74.4 | 4.9 | 79.3 | Fs | Wt, Sh |

[s] measured by sieve (not Horiba)




## Appendix G.4

Plots illustrating sediment grain size composition for all 2011 regional stations within each major depth stratum.

## Appendix G.5

Concentrations of chemical analytes in sediments from the 2011 regional stations. ERL=Effects Range Low threshold value; ERM=Effects Range Median threshold value; see Appendix G.1 for MDLs, parameter abbreviations, and translation of periodic table symbols. Values that exceed ERL or ERM thresholds are highlighted in yellow.

| | Station | Depth (m) | Sulfides (ppm) | TN (% weight) | TOC (% weight) | TVS (% weight) | tDDT (ppt) | tPCB (ppt) | tPAH (ppb) |
|---|---|---|---|---|---|---|---|---|---|
| Inner Shelf | 8116 | 10 | 1.89 | 0.011 | 0.03 | 0.47 | nd | nd | nd |
| | 8134 | 10 | 85.20 | 0.019 | 0.08 | 0.90 | 635 | nd | nd |
| | 8103 | 12 | 1.08 | 0.015 | 0.06 | 0.48 | nd | nd | nd |
| | 8135 | 13 | 7.91 | 0.022 | 0.12 | 1.14 | nd | nd | nd |
| | 8117 | 16 | 8.50 | 0.016 | 0.14 | 0.87 | nd | nd | nd |
| | 8170 | 16 | 9.49 | 0.043 | 0.29 | 1.48 | nd | nd | nd |
| | 8115 | 19 | 1.12 | 0.012 | 0.04 | 0.44 | nd | nd | nd |
| | 8101 | 20 | 1.67 | 0.020 | 0.11 | 0.74 | nd | nd | 21 |
| | 8127 | 20 | nd | 0.016 | 0.08 | 0.69 | nd | nd | nd |
| | 8128 | 20 | 2.37 | 0.017 | 0.09 | 0.70 | nd | nd | nd |
| | 8108 | 24 | 7.66 | 0.173 | 2.31 | 0.98 | nd | nd | nd |
| | 8171 | 25 | 2.03 | 0.024 | 0.14 | 0.86 | nd | nd | nd |
| | 8121 | 29 | 6.19 | 0.030 | 0.19 | 1.22 | nd | nd | nd |
| | 8137 | 29 | 4.39 | 0.023 | 0.21 | 0.94 | nd | nd | nd |
| Mid-shelf | 8126 | 32 | 3.03 | 0.027 | 0.20 | 1.05 | 550 | 3460 | nd |
| | 8125 | 36 | 2.89 | 0.039 | 0.31 | 1.30 | 380 | nd | nd |
| | 8132 | 40 | 1.29 | 0.017 | 0.07 | 0.67 | nd | nd | nd |
| | 8131 | 58 | 0.78 | 0.019 | 0.10 | 0.63 | nd | nd | nd |
| | 8110 | 62 | 5.37 | 0.063 | 0.68 | 2.68 | 500 | nd | 32 |
| | 8114 | 72 | 9.29 | 0.268 | 0.77 | 2.84 | 770 | nd | 30 |
| | 8113 | 75 | 10.50 | 0.238 | 0.77 | 3.11 | 610 | nd | 21 |
| | 8105 | 78 | 5.58 | 0.097 | 0.78 | 3.11 | 590 | nd | 79 |
| | 8106 | 80 | 3.01 | 0.096 | 0.83 | 3.52 | 660 | nd | 75 |
| | 8107 | 84 | 10.00 | 0.082 | 0.75 | 3.24 | 550 | nd | 44 |
| | 8112 | 84 | 18.60 | 0.192 | 0.72 | 2.93 | 640 | nd | 25 |
| | 8102 | 93 | 9.68 | 0.068 | 0.54 | 2.60 | 360 | nd | 89 |
| | 8104 | 100 | 9.08 | 0.059 | 0.48 | 2.42 | 430 | nd | 48 |
| | 8122 | 101 | 7.92 | 0.048 | 0.43 | 2.87 | 410 | nd | nd |
| Outer Shelf | 8109 | 122 | 9.51 | 0.229 | 0.63 | 2.55 | 390 | nd | nd |
| | 8124 | 139 | 1.52 | 0.045 | 1.50 | 3.02 | nd | nd | nd |
| | 8130 | 139 | 12.10 | 0.091 | 4.71 | 4.49 | 450 | nd | nd |
| | 8120 | 148 | 2.48 | 0.034 | 1.02 | 2.01 | 230 | nd | nd |
| | 8123 | 161 | 8.18 | 0.043 | 2.35 | 2.43 | 390 | nd | nd |
| | 8141 | 165 | 13.10 | 0.071 | 0.65 | 4.20 | 1500 | nd | nd |
| | 8119 | 193 | 17.30 | 0.087 | 0.78 | 4.80 | 470 | 4530 | 474 |
| Upper Slope | 8154 | 249 | 3.07 | 0.200 | 2.42 | 7.03 | 690 | nd | nd |
| | 8151 | 286 | 15.05 | 0.159 | 1.58 | 5.39 | 1000 | nd | nd |
| | 8155 | 312 | 3.21 | 0.108 | 1.90 | 3.06 | 690 | nd | nd |
| | 8153 | 339 | 51.80 | 0.188 | 2.05 | 6.25 | 1500 | nd | nd |
| | 8152 | 393 | 11.00 | 0.184 | 1.92 | 6.32 | nd | nd | nd |
| | 8150 | 427 | 444.00 | 0.142 | 1.21 | 7.15 | nd | nd | 29 |
| | | [a]**ERL:** | na | na | na | na | 1580 | na | 4022 |
| | | [a]**ERM:** | na | na | na | na | 46,100 | na | 44,792 |

nd=not detected; na=not available; [a]from Long et al. 1995

## Appendix G.5 *continued*

| | Station | Depth (m) | Metals (ppm) Al | Sb | As | Ba | Be | Cd | Cr | Cu | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Inner Shelf | 8116 | 10 | 1360 | nd | 1.4 | 7.3 | 0.034 | 0.16 | 2.8 | 1.4 | 2070 |
| | 8134 | 10 | 4190 | nd | 1.8 | 39.4 | 0.023 | nd | 7.9 | 2.3 | 5730 |
| | 8103 | 12 | 1840 | 0.39 | 2.1 | 35.9 | 0.063 | 0.45 | 5.4 | 1.4 | 3550 |
| | 8135 | 13 | 4770 | nd | 2.1 | 41.1 | 0.085 | nd | 8.8 | 4.2 | 6800 |
| | 8117 | 16 | 3420 | nd | 2.2 | 21.8 | 0.058 | nd | 6.2 | 2.6 | 4470 |
| | 8170 | 16 | 6970 | 0.50 | 4.2 | 51.3 | 0.212 | 0.13 | 22.2 | 8.6 | 12,300 |
| | 8115 | 19 | 1160 | nd | 2.1 | 6.4 | 0.021 | nd | 2.8 | 1.2 | 2170 |
| | 8101 | 20 | 3350 | 0.38 | 3.0 | 27.7 | 0.050 | 0.07 | 8.7 | 2.6 | 4870 |
| | 8127 | 20 | 3180 | nd | 1.5 | 21.3 | 0.060 | nd | 7.1 | 2.8 | 3760 |
| | 8128 | 20 | 2820 | nd | 1.3 | 19.1 | 0.055 | nd | 6.3 | 1.4 | 2890 |
| | 8108 | 24 | 2630 | nd | 5.2 | 25.5 | 0.029 | 0.08 | 6.2 | 1.8 | 5320 |
| | 8171 | 25 | 5190 | nd | 3.0 | 30.8 | 0.075 | nd | 8.4 | 2.1 | 5050 |
| | 8121 | 29 | 3260 | nd | 2.0 | 21.2 | 0.059 | nd | 5.8 | 4.1 | 4890 |
| | 8137 | 29 | 4470 | nd | 2.5 | 26.2 | 0.101 | nd | 10.2 | 3.7 | 6480 |
| Mid-shelf | 8126 | 32 | 5310 | nd | 2.3 | 35.7 | 0.104 | 0.06 | 10.5 | 5.8 | 6940 |
| | 8125 | 36 | 5430 | nd | 2.2 | 34.1 | 0.108 | 0.08 | 10.4 | 5.1 | 6660 |
| | 8132 | 40 | 791 | nd | 5.8 | 2.4 | 0.045 | nd | 10.3 | 0.2 | 5130 |
| | 8131 | 58 | 924 | nd | 2.3 | 3.2 | 0.043 | nd | 4.5 | 0.3 | 3260 |
| | 8110 | 62 | 11,400 | 0.61 | 5.7 | 56.8 | 0.187 | 0.23 | 20.2 | 9.9 | 14,100 |
| | 8114 | 72 | 7570 | 0.63 | 5.7 | 53.1 | 0.191 | 0.42 | 17.0 | 9.5 | 11,700 |
| | 8113 | 75 | 7990 | 0.53 | 5.5 | 54.1 | 0.174 | 0.19 | 18.4 | 10.2 | 12,600 |
| | 8105 | 78 | 9190 | 0.72 | 5.1 | 52.7 | 0.185 | 0.16 | 21.2 | 9.2 | 14,500 |
| | 8106 | 80 | 12,200 | 0.75 | 5.9 | 57.2 | 0.209 | 0.14 | 24.3 | 11.6 | 17,000 |
| | 8107 | 84 | 11,300 | 0.86 | 5.6 | 53.3 | 0.200 | 0.14 | 23.7 | 10.5 | 16,400 |
| | 8112 | 84 | 14,500 | 0.60 | 5.4 | 57.7 | 0.219 | 0.16 | 23.2 | 11.6 | 16,100 |
| | 8102 | 93 | 6210 | 0.48 | 4.6 | 42.2 | 0.142 | 0.22 | 14.8 | 5.9 | 10,800 |
| | 8104 | 100 | 7500 | 0.56 | 3.9 | 38.2 | 0.152 | 0.16 | 17.0 | 6.4 | 11,100 |
| | 8122 | 101 | 6720 | 0.51 | 4.5 | 83.0 | 0.237 | 0.10 | 12.5 | 10.2 | 11,000 |
| Outer Shelf | 8109 | 122 | 7030 | 0.46 | 3.6 | 29.3 | 0.143 | 0.15 | 15.7 | 6.4 | 10,100 |
| | 8124 | 139 | 2260 | 0.36 | 7.0 | 9.2 | 0.167 | 0.17 | 13.9 | 5.3 | 8430 |
| | 8130 | 139 | 4840 | 0.58 | 8.9 | 58.7 | 0.297 | 0.21 | 24.6 | 7.7 | 15,000 |
| | 8120 | 148 | 2610 | 0.41 | 5.3 | 10.6 | 0.162 | 0.11 | 14.5 | 2.5 | 7550 |
| | 8123 | 161 | 2830 | 0.46 | 4.8 | 20.0 | 0.143 | 0.15 | 13.8 | 4.1 | 8330 |
| | 8141 | 165 | 7540 | 0.58 | 4.0 | 47.0 | 0.187 | 0.17 | 19.4 | 13.0 | 12,000 |
| | 8119 | 193 | 7970 | 0.50 | 5.0 | 61.0 | 0.224 | 0.17 | 19.8 | 20.3 | 12,600 |
| Upper Slope | 8154 | 249 | 17,000 | 0.73 | 4.9 | 74.3 | 0.258 | 0.26 | 29.9 | 20.0 | 18,100 |
| | 8151 | 286 | 14,300 | 0.73 | 5.3 | 64.8 | 0.259 | 0.51 | 26.9 | 15.0 | 17,600 |
| | 8155 | 312 | 7650 | 0.43 | 5.2 | 51.2 | 0.116 | 0.09 | 12.5 | 5.0 | 9310 |
| | 8153 | 339 | 13,200 | 0.72 | 5.0 | 90.8 | 0.278 | 0.41 | 29.7 | 15.7 | 18,000 |
| | 8152 | 393 | 13,500 | 0.71 | 5.0 | 73.8 | 0.247 | 0.39 | 27.0 | 15.1 | 16,000 |
| | 8150 | 427 | 17,000 | 0.77 | 10.5 | 97.6 | 0.308 | 0.61 | 30.4 | 20.4 | 23,200 |
| | | [a]ERL: | na | na | 8.2 | na | na | 1.2 | 81 | 34 | na |
| | | [a]ERM: | na | na | 70.0 | na | na | 9.6 | 370 | 270 | na |

nd = not detected; na = not available; [a] from Long et al. 1995

## Appendix G.5 *continued*

| | Station | Depth (m) | Metals (ppm) Pb | Mn | Hg | Ni | Se | Ag | Tl | Sn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Inner Shelf | 8116 | 10 | 1.09 | 19.9 | 0.008 | 0.85 | nd | nd | nd | nd | 7.0 |
| | 8134 | 10 | 2.24 | 56.6 | 0.037 | nd | nd | nd | nd | 0.45 | 15.0 |
| | 8103 | 12 | 1.27 | 57.5 | nd | 2.33 | nd | nd | nd | 0.57 | 10.4 |
| | 8135 | 13 | 3.01 | 62.8 | 0.014 | 3.64 | nd | nd | nd | 0.58 | 18.5 |
| | 8117 | 16 | 2.65 | 42.8 | 0.009 | 2.27 | nd | nd | nd | 0.39 | 13.3 |
| | 8170 | 16 | 5.48 | 52.7 | 0.017 | 9.12 | nd | nd | nd | 0.93 | 27.4 |
| | 8115 | 19 | 1.19 | 19.8 | 0.015 | 0.83 | nd | nd | nd | nd | 5.0 |
| | 8101 | 20 | 1.91 | 56.1 | 0.006 | 3.08 | nd | nd | nd | 0.63 | 12.8 |
| | 8127 | 20 | 2.03 | 36.1 | nd | 2.04 | nd | nd | nd | 0.43 | 11.2 |
| | 8128 | 20 | 1.58 | 30.1 | nd | 1.91 | nd | nd | nd | 0.37 | 8.2 |
| | 8108 | 24 | 3.19 | 75.7 | nd | 2.50 | nd | nd | nd | 0.66 | 16.2 |
| | 8171 | 25 | 2.52 | 53.8 | nd | 2.72 | nd | nd | nd | 0.57 | 12.7 |
| | 8121 | 29 | 3.81 | 46.3 | 0.016 | 2.24 | nd | nd | nd | 0.58 | 13.6 |
| | 8137 | 29 | 3.18 | 46.3 | 0.012 | 3.42 | nd | nd | nd | 0.60 | 15.3 |
| Mid-shelf | 8126 | 32 | 3.78 | 57.8 | 0.011 | 4.43 | nd | nd | nd | 0.72 | 18.6 |
| | 8125 | 36 | 3.88 | 60.3 | 0.015 | 4.74 | nd | nd | nd | 0.61 | 18.5 |
| | 8132 | 40 | 2.91 | 10.4 | nd | nd | nd | nd | nd | nd | 6.0 |
| | 8131 | 58 | 1.49 | 13.1 | nd | nd | nd | nd | nd | nd | 5.4 |
| | 8110 | 62 | 8.68 | 128.0 | 0.051 | 9.04 | nd | nd | nd | 1.86 | 37.4 |
| | 8114 | 72 | 7.95 | 114.0 | 0.051 | 8.49 | nd | nd | nd | 1.53 | 33.7 |
| | 8113 | 75 | 8.36 | 118.0 | 0.060 | 9.09 | nd | nd | nd | 1.70 | 35.5 |
| | 8105 | 78 | 7.90 | 116.0 | 0.037 | 9.44 | nd | nd | nd | 1.59 | 35.2 |
| | 8106 | 80 | 10.10 | 132.0 | 0.048 | 11.10 | nd | nd | nd | 2.02 | 42.0 |
| | 8107 | 84 | 9.45 | 128.0 | 0.041 | 10.80 | nd | nd | nd | 1.68 | 39.9 |
| | 8112 | 84 | 10.50 | 139.0 | 0.045 | 11.30 | nd | 0.08 | nd | 1.90 | 42.4 |
| | 8102 | 93 | 5.59 | 89.1 | 0.022 | 6.43 | nd | nd | nd | 0.93 | 26.9 |
| | 8104 | 100 | 5.58 | 88.6 | 0.025 | 7.37 | nd | nd | nd | 1.58 | 26.9 |
| | 8122 | 101 | 6.46 | 86.5 | 0.045 | 6.55 | nd | nd | nd | 0.99 | 28.6 |
| Outer Shelf | 8109 | 122 | 5.44 | 73.2 | 0.028 | 7.08 | nd | nd | nd | 1.02 | 25.1 |
| | 8124 | 139 | 5.39 | 18.2 | 0.013 | 4.79 | nd | nd | nd | 0.42 | 19.8 |
| | 8130 | 139 | 6.23 | 70.0 | 0.021 | 9.27 | nd | nd | nd | 0.78 | 32.0 |
| | 8120 | 148 | 2.97 | 21.6 | 0.009 | 3.96 | nd | nd | nd | 0.37 | 14.3 |
| | 8123 | 161 | 3.42 | 40.9 | 0.014 | 4.89 | nd | nd | nd | 0.57 | 17.5 |
| | 8141 | 165 | 7.43 | 97.1 | 0.060 | 11.60 | nd | nd | nd | 1.42 | 35.6 |
| | 8119 | 193 | 10.30 | 115.0 | 0.124 | 11.60 | nd | nd | nd | 1.50 | 41.1 |
| Upper Slope | 8154 | 249 | 11.10 | 144.0 | 0.110 | 20.40 | 0.31 | nd | nd | 1.84 | 53.0 |
| | 8151 | 286 | 10.60 | 134.0 | 0.060 | 14.30 | 0.27 | nd | nd | 1.64 | 48.2 |
| | 8155 | 312 | 4.76 | 94.0 | 0.028 | 5.04 | nd | nd | nd | 0.88 | 28.0 |
| | 8153 | 339 | 9.21 | 125.0 | 0.058 | 16.50 | 0.3 | nd | nd | 1.26 | 48.5 |
| | 8152 | 393 | 8.02 | 125.0 | 0.043 | 16.40 | 0.6 | nd | nd | 1.17 | 47.1 |
| | 8150 | 427 | 12.50 | 201.0 | 0.065 | 16.20 | 0.38 | 0.05 | nd | 1.87 | 64.0 |
| | | [a]ERL: | 46.7 | na | 0.15 | 20.9 | na | 1.0 | na | na | 150 |
| | | [a]ERM: | 218 | na | 0.71 | 51.6 | na | 3.7 | na | na | 410 |

nd = not detected; na = not available; [a] from Long et al. 1995

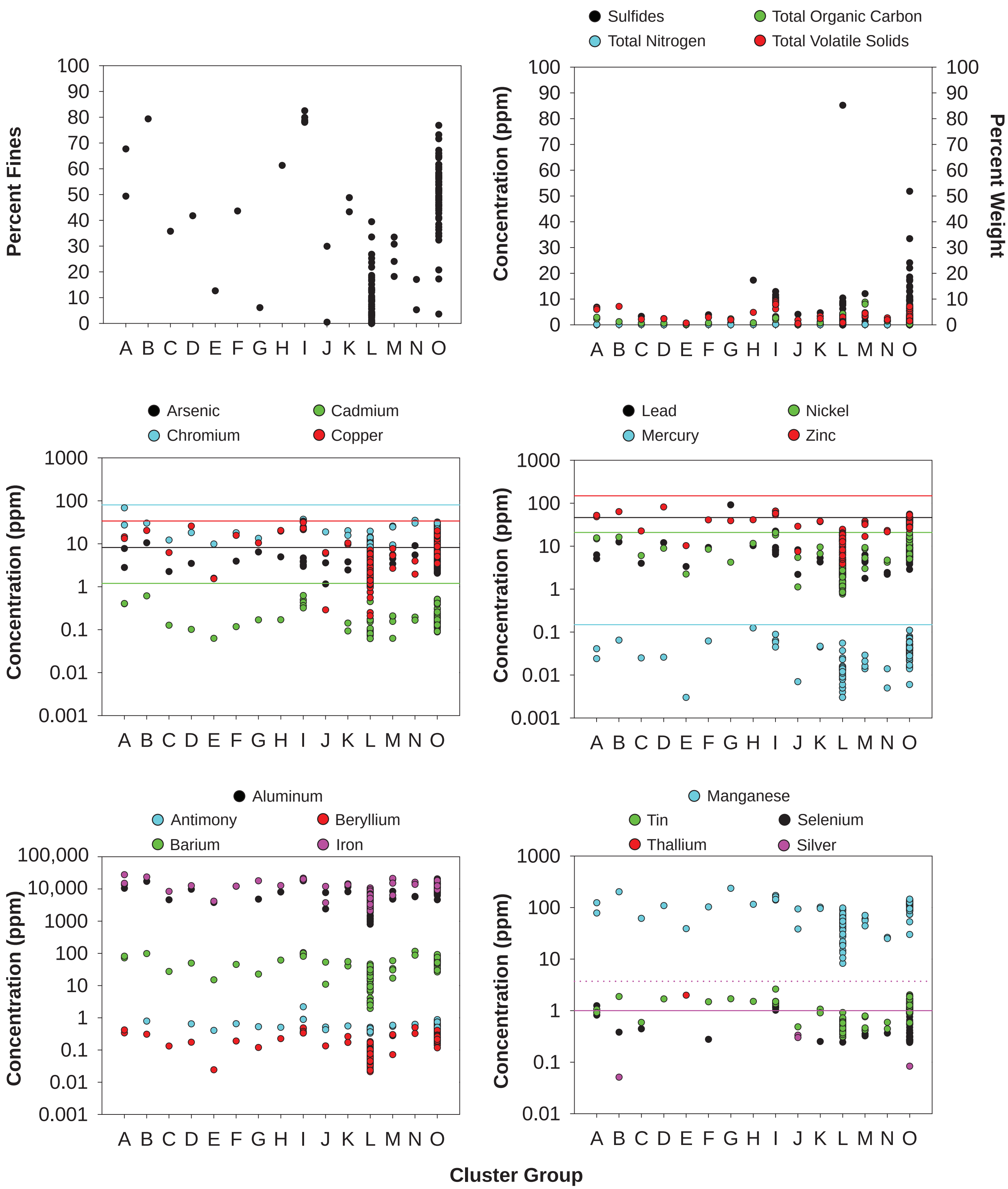
## Appendix G.6

Description of cluster groups A−O (as defined in Figure 8.5). Data are expressed as the average percent or concentration of each parameter for each cluster group. For groups containing more than one site, bold indicates parameters that were considered most defining for each group according to SIMPER analysis.

| | Cluster Groups | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| *Organic Indicators* | | | | | | | |
| Sulfides (ppm) | 3.44 | 444.00 | 3.33 | 2.43 | 0.20 | 3.91 | 0.69 |
| TN (% weight) | 0.159 | 0.142 | 0.063 | 0.052 | 0.020 | 0.077 | 0.043 |
| TOC (% weight) | 2.59 | 1.21 | 0.65 | 0.66 | 0.13 | 0.74 | 2.31 |
| TVS (% weight) | 6.24 | 7.15 | 2.15 | 2.36 | 0.69 | 2.90 | 1.98 |
| *Trace Metals (ppm)* | | | | | | | |
| Aluminum | 11,900 | 17,000 | 4560 | 9690 | 3780 | 12,000 | 4750 |
| Antimony | 0 | 0.78 | 0 | 0.64 | 0.40 | 0.65 | 0.52 |
| Arsenic | **5.28** | 10.50 | 2.24 | 3.48 | 1.58 | 3.95 | 6.41 |
| Barium | 76.3 | 97.6 | 27.2 | 49.1 | 15.0 | 44.9 | 22.5 |
| Beryllium | 0.377 | 0.308 | 0.131 | 0.173 | 0.024 | 0.188 | 0.119 |
| Cadmium | 0.402 | 0.610 | 0.126 | 0.101 | 0.063 | 0.117 | 0.169 |
| Chromium | **47.7** | 30.4 | 12.2 | 18.1 | 9.8 | 18.0 | 13.3 |
| Copper | 13.80 | 20.40 | 6.26 | 25.80 | 1.53 | 15.70 | 10.40 |
| Iron | 21,200 | 23,200 | 8310 | 12,500 | 4130 | 12,100 | 17,700 |
| Lead | 5.69 | 12.50 | 4.01 | 12.10 | 3.35 | 9.36 | 91.60 |
| Manganese | 100.0 | 201.0 | 61.3 | 108.0 | 38.8 | 102.0 | 235.0 |
| Mercury | 0.033 | 0.065 | 0.025 | 0.026 | 0.003 | 0.062 | 0 |
| Nickel | 15.20 | 16.20 | 6.05 | 8.95 | 2.24 | 8.48 | 4.22 |
| Selenium | 1.020 | 0.380 | 0.440 | 0 | 0 | 0.276 | 0 |
| Silver | 0 | 0.051 | 0 | 0 | 0 | 0 | 0 |
| Thallium | 0 | 0 | 0 | 0 | 1.97 | 0 | 0 |
| Tin | 0.980 | 1.870 | 0.585 | 1.670 | 0 | 1.470 | 1.680 |
| Zinc | 50.4 | 64.0 | 22.6 | 81.8 | 10.3 | 40.9 | 39.0 |
| *Chlorinated Pesticides (ppt)* | | | | | | | |
| Alpha (cis) chlordane | **660** | 0 | 0 | 0 | 0 | 0 | 0 |
| Gamma (trans) chlordane | 885 | 0 | 0 | 0 | 0 | 0 | 0 |
| HCH, beta isomer | **1000** | 0 | 4800 | 0 | 0 | 0 | 0 |
| HCH, delta isomer | **3300** | 0 | 3700 | 0 | 0 | 0 | 0 |
| HCH, gamma isomer | 750 | 0 | 0 | 0 | 0 | 0 | 0 |
| tDDT | 855 | 0 | 3390 | 1950 | 0 | 75,920 | 0 |
| HCB | 105 | 0 | 0 | 330 | 0 | 0 | 0 |
| *Total PCB (ppt)* | 0 | 0 | 0 | 34,730 | 0 | 5572 | 0 |
| *Total PAH (ppb)* | 0 | 28.6 | 0 | 165.0 | 0 | 101.0 | 0 |

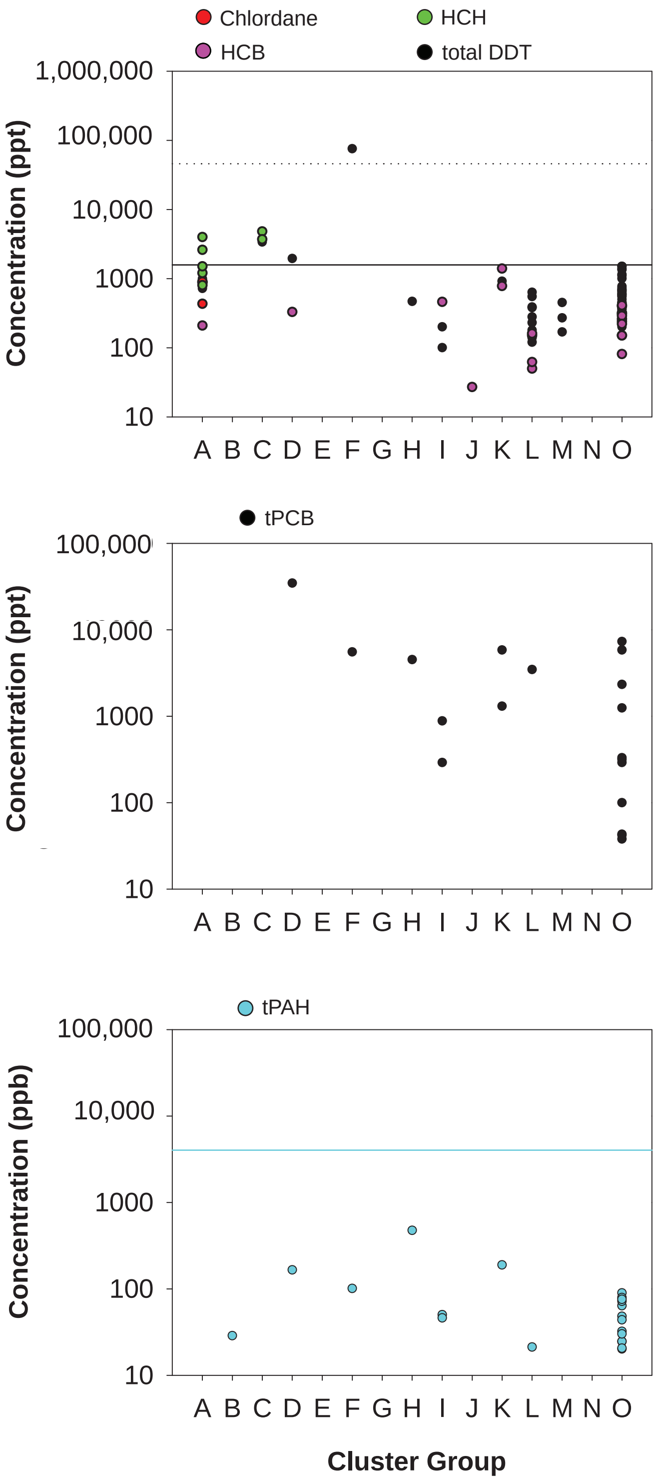
## Appendix G.6 *continued*

| | Cluster Groups | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **H** | **I** | **J** | **K** | **L** | **M** | **N** | **O** |
| *Organic Indicators* | | | | | | | | |
| Sulfides (ppm) | 17.30 | 11.00 | 2.04 | 2.57 | 4.54 | 4.16 | 1.57 | 8.20 |
| TN (% weight) | 0.087 | 0.237 | 0.032 | 0.064 | 0.027 | 0.079 | 0.038 | **0.104** |
| TOC (% weight) | 0.78 | 2.75 | 0.27 | 0.97 | **0.43** | **6.51** | 1.47 | 1.07 |
| TVS (% weight) | 4.80 | 7.91 | 1.16 | 2.88 | 1.01 | 3.87 | 2.32 | **3.52** |
| *Trace Metals (ppm)* | | | | | | | | |
| Aluminum | 7970 | 18,400 | 4990 | 9860 | 3390 | 5770 | 5730 | 10,200 |
| Antimony | 0.50 | **0.79** | 0.47 | **0.28** | **0.11** | **0.28** | 0.57 | 0.52 |
| Arsenic | 4.96 | 3.71 | **2.38** | 3.11 | **2.73** | **5.55** | **7.24** | 3.90 |
| Barium | 61.0 | 93.5 | **31.8** | 47.7 | 20.7 | 34.7 | **101.0** | 55.0 |
| Beryllium | 0.224 | 0.394 | 0.066 | **0.215** | 0.065 | **0.233** | **0.406** | 0.221 |
| Cadmium | 0.171 | **0.446** | 0 | 0.117 | **0.047** | 0.156 | 0.180 | **0.227** |
| Chromium | 19.8 | 34.3 | **12.4** | 17.9 | 8.6 | 21.1 | **32.6** | 20.6 |
| Copper | 20.30 | **24.30** | 3.27 | 10.00 | 2.82 | 5.30 | 2.95 | 10.50 |
| Iron | 12,600 | 20,000 | **7790** | 13,800 | 5650 | **15,500** | 14,800 | 14,300 |
| Lead | 10.30 | 7.88 | 5.22 | 4.79 | 2.42 | 4.23 | 2.32 | 6.31 |
| Manganese | 115.0 | 156.0 | 65.9 | 98.3 | **46.7** | 57.0 | 25.5 | 110.0 |
| Mercury | 0.124 | 0.064 | 0.004 | 0.046 | 0.008 | 0.020 | 0.010 | **0.040** |
| Nickel | 11.60 | 20.90 | 3.31 | 8.11 | 2.45 | 6.55 | 4.48 | 9.76 |
| Selenium | 0 | 1.180 | 0 | 0.125 | 0.021 | 0.269 | **0.181** | 0.209 |
| Silver | 0 | 0 | 0.314 | 0 | 0 | 0 | 0 | **0.002** |
| Thallium | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tin | 1.500 | **1.690** | 0.240 | 0.980 | 0.398 | 0.602 | 0.515 | 1.240 |
| Zinc | 41.1 | 60.4 | **18.3** | 37.7 | 12.9 | 30.3 | 22.4 | 38.0 |
| *Chlorinated Pesticides (ppt)* | | | | | | | | |
| Alpha (cis) chlordane | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gamma (trans) chlordane | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HCH, beta isomer | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HCH, delta isomer | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HCH, gamma isomer | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| tDDT | 470 | 60 | 0 | 460 | 65 | 223 | 0 | 457 |
| HCB | 0 | **92** | 14 | **1090** | 9 | 0 | 0 | 54 |
| *Total PCB (ppt)* | 4530 | 234 | 0 | **3590** | 77 | 0 | 0 | 345 |
| *Total PAH (ppb)* | 473.7 | 19.2 | 0 | **93.9** | 0.5 | 0 | 0 | 11.9 |




## Appendix G.7

Particle size and sediment chemistry parameters by cluster group (see Figure 8.5). Solid lines are ERLs, dashed lines are ERM (see text).




## Appendix G.7 *continued*

# Appendix H

## Supporting Data

## 2011 Regional Stations

## Macrobenthic Communities

## Appendix H.1

Regional three-way PERMANOVA results for benthic infauna. df = degrees of freedom, SS = sums of squares, MS = mean squares, P(perm) = permutation p-value.

| | df | SS | MS | Pseudo-F | P(perm) | Unique perms |
|---|---|---|---|---|---|---|
| Sediment type | 4 | 16,962 | 4240.4 | 1.7437 | 0.0001 | 9786 |
| Depth stratum | 2 | 20,956 | 10,478.0 | 4.3087 | 0.0001 | 9831 |
| Year | 1 | 3762 | 3761.6 | 1.5468 | 0.0205 | 9885 |
| Sediment type x depth stratum[a] | 6 | 28,059 | 4676.5 | 1.9230 | 0.0001 | 9773 |
| Sediment type x year[a] | 6 | 18,356 | 3059.3 | 1.2580 | 0.0231 | 9773 |
| Depth x year | 6 | 17,469 | 2911.6 | 1.1972 | 0.0516 | 9769 |
| Sediment type x depth x year[a] | 7 | 19,226 | 2746.6 | 1.1294 | 0.1216 | 9744 |
| Residuals | 85 | 207,000 | 2431.9 | | | |
| Total | 121 | 444,000 | | | | |

[a]Term has one or more empty cells.

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# Appendix H.2

Description of individual cluster groups A–O for regional samples collected between 2009–2011.

***Description of cluster groups***

Cluster group A consisted of two sites occurring along the 25-m isobath north of Point Loma (Figure 9.4), and was analogous to cluster group G found during analysis of SBOO fixed grid stations (see Chapter 5). These grabs housed the second highest invertebrate abundances of all cluster groups with an average of 564 individuals/grab, and possessed an average species richness of 63 taxa/grab (Table 9.5). Sediments were coarse to sandy with percent fines ranging from only 0% to 3.5% (Appendix H.3). The five most abundant taxa encountered were the polychaetes *Pareurythoe californica*, *Pisione* sp, *Polycirrus* sp, *Lumbrineris latreilli*, and *Spio maculata*. These species averaged between 30–55 individuals/grab. No other species occurred at densities > 28 individuals/grab. SIMPER revealed the five most characteristic species to be nematodes, the polychaetes *Pisione* sp, *Hesionura coineaui difficilis*, and *Protodorvillea gracilis*, and the isopod *Eurydice caudata*.

Cluster group B consisted of a single site that occurred near the mouth of La Jolla canyon (Figure 9.4). Species richness and abundance were relatively low with 33 taxa and 105 individuals/grab, respectively (Table 9.5). Sediments were coarse, possessing no fines (Appendix H.3). The most abundant species encountered were the polychaetes *Spiophanes norrisi*, individuals from the *Aphelochaeta glandaria* Cmplx, *Aphelochaeta* sp SD13, and *Chaetozone commonalis*, *Monticellina serratiseta*, the bivalve *Simomactra falcata*, and the echinoderm *Dendraster excentricus*; these species numbered between 4–31 individuals/grab. No other species exhibited > 3 individuals/grab.

Cluster group C consisted of six sites ranging from 40–60 m depths located in the SBOO monitoring region (Figure 9.4). Average species richness and mean abundance were 74 taxa and 314 individuals/grab, respectively (Table 9.5). Cluster group C was characterized by sandy sediments containing substantial quantities of red relict sand. Percent fines ranged from 0% to 26.8% (Appendix H.3). The five most abundant species encountered were the polychaetes *Spiophanes norrisi*, *Mooreonuphis* sp SD1, *Mooreonuphis* sp, *Lanassa venusta venusta*, and *Spio maculata*; these species averaged between about 12–54 individuals/grab. No other species exhibited > 8 individuals/grab. SIMPER revealed the five most characteristic species to be *S. norrisi*, *Mooreonuphis* sp, *M.* sp SD1, *L. venusta venusta*, and the isopod *Eurydice caudata*.

Cluster group D was the second largest cluster group and consisted of 14 sites occurring between 20–40-m depths in the SBOO monitoring region and north of Point Loma (Figure 9.4). Average species richness and mean abundance were 90 taxa and 356 individuals/grab, respectively (Table 9.5). Sediments were sandy with percent fines ranging from 5.7%–26.8% (Appendix H.3). The polychaetes *Spiophanes norrisi*, *Mooreonuphis nebulosa*, *Monticellina siblina*, *Mediomastus* sp, and *Spiophanes duplex* were the most abundant species encountered; these species averaged between about 10–50 individuals/grab. No other species averaged > 9 individuals per grab. The five most characteristic invertebrates found in these assemblages included the polychaetes *Spiophanes norrisi*, *Monticellina siblina*, and *Mediomastus* sp, the amphipod *Ampelisca brevisimulata*, and the bivalve *Tellina modesta*.

Cluster group E consisted of three sites located between 22–36 m depths that spanned from west of Point Loma to the SBOO (Figure 9.4). These sites possessed the highest invertebrate species richness and highest abundance of any cluster group, averaging 135 taxa and 650 individuals/grab, respectively (Table 9.5). Sediments were sandy to coarse, with percent fines ranging from 3.7% to 9.6% (Appendix H.3). *Spiophanes norrisi* dominated these sites, averaging 144 individuals per grab. Other dominant species included the polychaetes *Chaetozone* sp SD5, *Apoprionospio* *pygmaea*, and *Mediomastus* sp, and the sipunculid *Apionsoma misakianum*, which occurred at average densities between about 14–43 individuals/grab. No other species exhibited >12 individuals/grab. SIMPER revealed the five most characteristic species of the group to be the polychaetes *S. norrisi*, *Mediomastus* sp, *Ampharete labrops*, Euclymeninae sp A, and *Phyllodoce hartmanae*.

Cluster group F contained 5 sites located at the mouth of San Diego Bay (Figure 9.4). This cluster group possessed the second lowest species richness with 28 taxa/grab, and a relatively low species abundance of 147 individuals/grab (Table 9.5). Sediments were sandy with percent fines ranging from only 0% to 2.2% (Appendix H.3). The most abundant species at these sites were the arthropods *Gibberosus myersi*, *Metharpinia jonesi*, and *Anchicolurus occidentalis*, the polychaete *Apoprionospio pygmaea*, and juvenile actiniarians too small to identify to species. These taxa averaged between about 10–21 individuals/grab. No other species exhibited >6 individuals/grab. SIMPER revealed the five most characteristic species for the clade to be *G. myersi*, *M. jonesi*, *A. occidentalis*, *A. pygmaea*, and the polychaete *Spiophanes norrisi* as well as the polychaete. This cluster group is similar to cluster group C found during analysis of SBOO fixed grid stations (see Chapter 5).

Cluster group G comprised four sites that possessed sandy sediments and were located at the mouths of the San Diego River and San Diego Bay (Figure 9.4). Average species richness and mean abundance were 48 taxa and 422 individuals/grab, respectively (Table 9.5). Percent fines ranged from 0.3% to 4.2% (Appendix H.3). Sites were dominated by the oweniid polychaete *Owenia collaris*, with an average of 184 individuals/site. Other dominant species included the anthozoan *Zaolutus actius*, the polychaete *Spiophanes norrisi*, and the arthropods *Diastylopsis tenuis* and *Rhepoxynius abronius*; these species averaged between about 12–32 individuals/grab. No other taxon averaged >11 organisms/grab. The five most characteristic taxa for this clade included *O. collaris*, *Z. actius*, *S. norrisi*, the nemertean *Carinoma mutabilis*, and the bivalve *Tellina modesta*.

Cluster group H consisted of a single site located in extremely shallow water (13 m) north of the Tijuana River (Figure 9.4). Species richness and abundance were 39 taxa and 92 individuals/grab, respectively (Table 9.5). Sediments consisted of sand with percent fines equaling 18.6% (Appendix H.3). This site possessed many unique species, with the five most abundant taxa being polychaetes from the *Scoletoma tetraura* Cmplx and *Ampharete labrops*, the gastropods *Astyris gausapata* and *Rictaxis punctocaelatus*, and the arthropod *Exacanthomysis davisi*; these species numbered between 4–18 individuals/grab. No other species averaged >3 individuals/grab.

Cluster group I possessed nine sites located between 10–20-m depths in the SBOO monitoring region (Figure 9.4). Average species richness and abundance were 41 taxa and 133 individuals/grab, respectively (Table 9.5). Sediments were primarily sandy with percent fines ranging from 3.3% to 46.0% (Appendix H.3). The most abundant species at these sites were the polychaetes *Owenia collaris* (but at much lower densities than observed in cluster group G), *Spiophanes norrisi*, *Polydora cirrosa*, *S. duplex*, and *Mediomastus* sp; these species averaged between about 7–13 individuals/grab. No other species averaged >5 individuals/grab. SIMPER revealed the five most characteristic species for the clade to be *S. duplex*, *Mediomastus* sp, the bivalves *Siliqua lucida* and *Tellina modesta*, and the polychaete *Glycinde armigera*.

Cluster group J consisted of six sites with depths ranging from 286–357 m located along the upper slope (Figure 9.4). Average species richness and mean abundance were 35 taxa and 97 individuals/grab, respectively (Table 9.5). Sediments contained percent fines ranging from 65.0% to 78.8% (Appendix H.3), with a minor sandy constituent. The five most abundant species encountered were the bivalves *Macoma carlottensis*, *Nuculana conceptionis*, the scaphopod *Compressidens stearnsii*, and the polychaetes *Maldane sarsi* and other juvenile maldanids; these species averaged between about 4–14 individuals/grab. No other species averaged > 3 individuals/grab. SIMPER revealed the five most characteristic species for the clade to be *M. carlottensis*, *C. stearnsii*, *M. sarsi*, the bivalve *Ennucula tenuis*, and the polychaete *Paraprionospio alata*.

Cluster group K consisted of six sites with depths ranging from 393–433 m located along the upper slope (Figure 9.4). Average species richness and mean abundance were 27 taxa and 78 individuals/grab, respectively (Table 9.5). Sediments contained percent fines ranging from 49.9% to 82.5% (Appendix H.3), with a substantial sandy constituent. The most abundant species encountered were the bivalves *Yoldiella nana* and *Nuculana conceptionis*, and the polychaetes *Maldane sarsi*, *Eclysippe trilobata*, *Fauveliopsis glabra*, and *Myriochele gracilis*; these species averaged between about 3–12 individuals/grab. No other species averaged > 2 individuals/grab. SIMPER revealed the five most characteristic species for the clade to be *Y. nana*, *M. sarsi*, *E. trilobata*, *N. conceptionis*, and the bivalve *Ennucula tenuis*.

Cluster group L contained only one site located at a 312 m depth on the northeast side of the Coronado Bank (Figure 9.4). Species richness and abundance were 72 taxa and 247 individuals/grab (Table 9.5). Sediments consisted of sand with percent fines equaling 45.5%. The polychaete *Fauveliopsis glabra* was particularly abundant with 55 individuals recorded/grab. Other dominant species included amphiurids, the bivalve *Adontorhina cyclia*, the polychaete *Maldane sarsi*, and the sipunculid *Nephasoma diaphanes*; all of which ranged from 10–21 individuals. No other species averaged > 9 individuals/grab.

Cluster group M represented sites occurring on the Coronado Bank at depths ranging from 122–197 m. One additional site located on the outer shelf north of Point Loma also clustered together with this group (Figure 9.4). Species richness and abundance were 66 taxa and 220 individuals/grab (Table 9.5). Sediments consisted primarily of sand with percent fines ranging from 5.4% to 35.2% (Appendix H.3). The most abundant species included polychaetes from the *Aphelochaeta glandaria* Cmplx, *Chaetozone* sp SD5, and *Monticellina siblina*, the bivalves *Tellina carpenteri* and *Micranellum crebricinctum*, and the ophiuroid *Amphiodia digitata*; these species averaged between about 7–24 individuals/grab. No other taxon averaged > 6 organisms/grab. The five most characteristic taxa for this clade included *A. glandaria* Cmplx, *C.* sp SD5, *T. carpenteri*, *A. digitata*, and the bivalve *Huxleyia munita*.

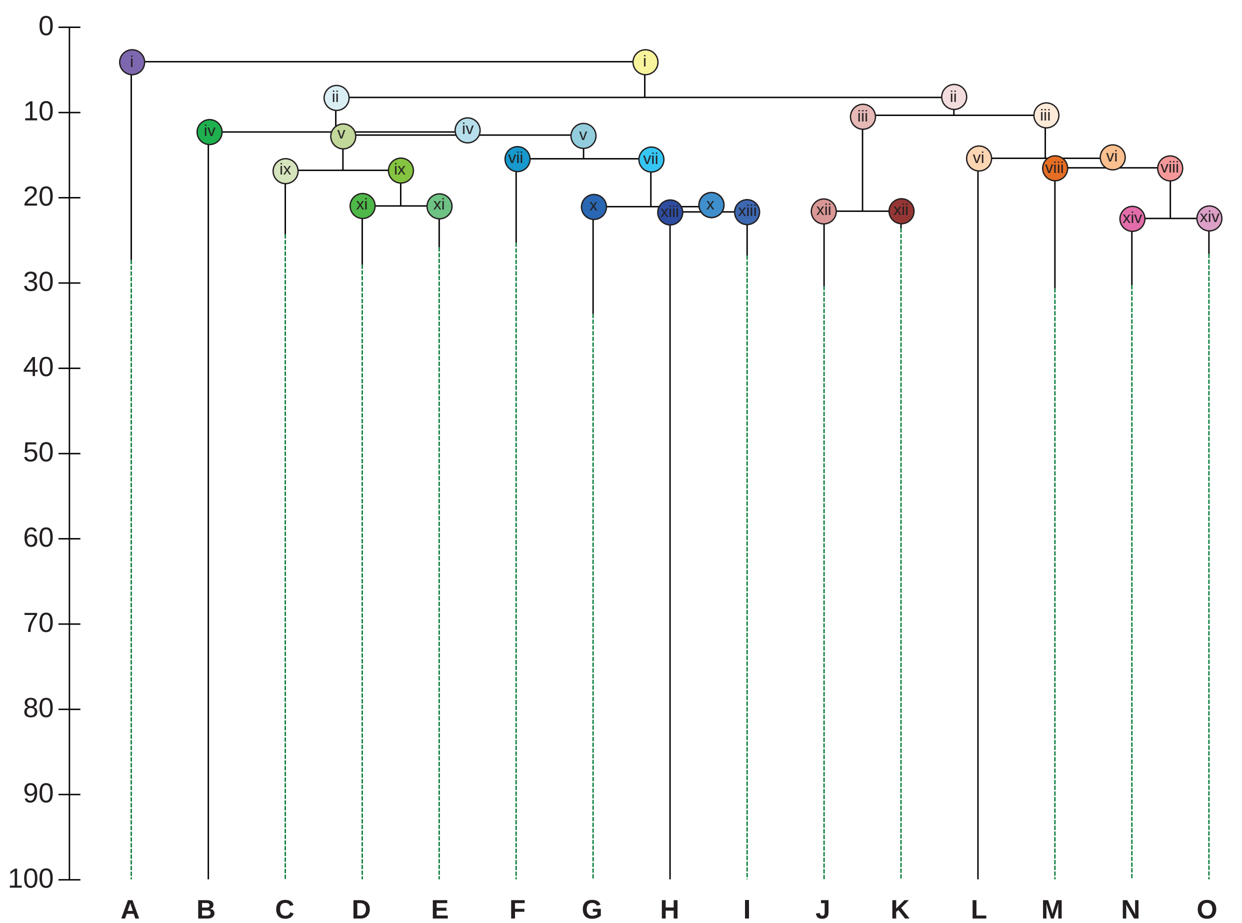
Cluster group N was the largest cluster group, containing 33% of sites surveyed. Sites were restricted to mid- and outer shelf depths and predominantly possessed sediments of sand with percent fines ranging from 3.7% to 61.7% (Figure 9.4, Appendix H.3). Sites in cluster group N were dominated by the urchin *Amphiodia urtica*, which averaged 56 individuals/grab. Other abundant species included unidentified species in the genus *Amphiodia*, the bivalves *Axinopsida serricata* and *Ennucula tenuis*, and the polychaetes *Mediomastus* sp, *Spiophanes berkeleyorum*, *Travisia brevis*, and *Prionospio* (*Prionospio*) *dubia*; these species averaged between about 3–13 individuals/grab. No other taxon averaged > 4 organisms/grab. The five most characteristic taxa for this clade included *A. urtica*, *A. serricata*, *Amphiodia* sp, *P.* (*P.*) *dubia*, and the polychaete *Sternaspis fossor*.

Cluster group O was the third largest cluster group, and possessed 13 sites located on the outer shelf west of Point Loma (Figure 9.4). Species richness and abundance were 55 taxa and 144 individuals/grab (Table 9.5). Sediments contained percent fines ranging from 48.8% to 79.9% (Appendix H.3), with a substantial sandy fraction. The five most abundant species encountered were the polychaetes *Spiophanes kimballi*, *Mediomastus* sp, and *Melinna heterodonta*, and the bivalves *Axinopsida serricata* and *Tellina carpenteri*; these species averaged between about 4–9 individuals/grab. No other taxon averaged >3 organisms/grab. SIMPER revealed the five most characteristic species for the clade to be *S. kimballi*, *T. carpenteri*, *Mediomastus* sp, *M. heterodonta*, and the polychaete *Paraprionospio alata*.

## Appendix H.3

Delineation of cluster groups (see Figure 9.4) by species exclusivity (i.e., species that occur solely in each supported clade versus species that occur in multiple non-related clades). No species occurred across all cluster groups. Inner = inner shelf, mid = mid shelf, outer = outer shelf, slope = upper slope. S = sand, Sc = sand with coarse, Sf = sand with fines, Scf = sand with coarse and fines, Fs = fines with sand, Fc = fines with coarse, Cs = coarse with sand. CG = cluster group.

| | | | Depth | | | | Fines | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **CG** | ***n*** | **stratum** | **mean** | **min** | **max** | **Sed.** | **mean** | **min** | **max** | **depth/sediment exceptions** |
| **A** | 2 | inner | 25 | 24 | 26 | Sc/Cs | 1.8 | 0.0 | 3.5 | — |
| **B** | 1 | inner | 12 | 12 | 12 | Sc | 0.0 | 0.0 | 0.0 | — |
| **C** | 6 | mid | 46 | 38 | 58 | Sc | 5.9 | 0.0 | 26.8 | Sf = 1 |
| **D** | 14 | inner | 28 | 21 | 40 | Sf | 14.5 | 5.7 | 26.8 | S/inner = 6, Sf/mid = 4 |
| **E** | 3 | mid | 30 | 22 | 36 | varied | 6.5 | 3.7 | 9.6 | Scf/inner = 1, Cs/mid = 1, Sc/mid = 1 |
| **F** | 5 | inner | 12 | 9 | 19 | S | 0.6 | 0.0 | 2.2 | Sc = 1 |
| **G** | 4 | inner | 12 | 10 | 13 | S | 2.2 | 0.3 | 4.2 | — |
| **H** | 1 | inner | 13 | 13 | 13 | Sf | 18.6 | 18.6 | 18.6 | — |
| **I** | 9 | inner | 16 | 10 | 20 | Sf | 14.8 | 3.3 | 46.0 | S = 3 |
| **J** | 6 | slope | 331 | 286 | 357 | Fs | 71.7 | 65.0 | 78.8 | — |
| **K** | 6 | slope | 415 | 393 | 433 | Fs | 70.9 | 49.4 | 82.5 | Sc = 1 |
| **L** | 1 | slope | 312 | 312 | 312 | Sf | 45.5 | 45.5 | 45.5 | — |
| **M** | 11 | outer | 150 | 122 | 197 | Sf | 20.6 | 5.4 | 35.2 | Sc = 2 |
| **N** | 40 | mid | 83 | 50 | 147 | Sf | 45.2 | 3.7 | 61.7 | Fs/mid = 13, Sc/mid = 1, Sf/outer = 4 |
| **O** | 13 | outer | 201 | 151 | 263 | Fs | 60.8 | 48.8 | 79.9 | Sf/outer = 1, Fc/outer = 1, Fs/upper = 6 |



## Appendix H.3 *continued*

**(i.)** Species delineating the separation of cluster group A from all other cluster groups (4.04% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Pareurythoe californica* | 55 | 0 | 0 | 0 | 0 | 0 |
| Rhabdocoela sp A | 21 | 0 | 0 | 0 | 0 | 0 |
| Oligochaeta | 8 | 0 | 0 | 0 | 0 | 0 |
| *Polygordius* sp SD1 | 7.5 | 0 | 0 | 0 | 0 | 0 |
| *Saccocirrus* sp | 6.5 | 0 | 0 | 0 | 0 | 0 |
| *Phyllodoce medipapillata* | 5.5 | 0 | 0 | 0 | 0 | 0 |
| Polynoinae | 3.5 | 0 | 0 | 0 | 0 | 0 |
| *Tiburonella viscana* | 3 | 0 | 0 | 0 | 0 | 0 |
| Leptoplanidae sp SD2 | 2 | 0 | 0 | 0 | 0 | 0 |
| Polycladida sp SD2 | 2 | 0 | 0 | 0 | 0 | 0 |
| *Questa caudicirra* | 2 | 0 | 0 | 0 | 0 | 0 |
| *Gyptis* sp | 1 | 0 | 0 | 0 | 0 | 0 |
| *Opisthodonta* sp SD1 | 1 | 0 | 0 | 0 | 0 | 0 |
| additional 15 taxa (<1.0) | x | 0 | 0 | 0 | 0 | 0 |

(ii.) Species delineating the separation of cluster groups B, C, D, E, F, G, H, and I from cluster groups J, K, L, M, N, and O (8.23% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Compressidens stearnsii* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Chiridota* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| *Glycera nana* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Tellina carpenteri* | 0 | 0 | 0 | 0 | 0 | 0 |

(iii.) Species delineating the separation of cluster groups J and K from cluster groups L, M, N, and O (10.33% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Nuculana conceptionis* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Chaetoderma nanulum* | 0 | 0 | 0 | 0 | 0 | 0 |

(iv.) Species delineating the separation of cluster group B from cluster groups C, D, E, F, G, H, and I (12.3% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Balcis oldroydae* | 0 | 1 | 0 | 0 | 0 | 0 |
| *Paraonella platybranchia* | 0 | 1 | 0 | 0 | 0 | 0 |
| *Stylatula elongata* | 0 | 1 | 0 | 0 | 0 | 0 |
| *Tivela stultorum* | 0 | 1 | 0 | 0 | 0 | 0 |

## Appendix H.3 *continued*

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 4.5 | 0.83 | 8 | 0.36 | 0.23 | 0.85 |
| 0 | 0 | 0 | 1 | 0.17 | 1 | 0.09 | 1.23 | 0.46 |
| 0 | 0 | 0 | 0.5 | 0.5 | 1 | 0.82 | 1.85 | 1.69 |
| 0 | 0 | 0 | 0.17 | 0.33 | 8 | 8.73 | 1.28 | 6.77 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 5.5 | 7 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0.17 | 0.17 | 0 | 0 | 0 | 0 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

(v.) Species delineating the separation of cluster groups C, D, and E from cluster groups F, G, H, and I (12.65% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Exogone dwisula* | 0 | 0 | 0.17 | 0.14 | 0.33 | 0 |

(vi.) Species delineating the separation of cluster group L from cluster groups M, N, and O (15.38% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Cadulus californicus* | 0 | 0 | 0 | 0 | 0 | 0 |
| Amphitritinae | 0 | 0 | 0 | 0 | 0 | 0 |
| *Anoplodactylus* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| *Apionsoma* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| *Dodecaceria* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| Hoplonemertea sp SD2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lysianassoidea | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pannychia moseleyi* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Paradoneis eliasoni* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Sphaerosyllis* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aricidea* (*Allia*) *antennata* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ampelisca hancocki* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Monoculodes emarginatus* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Lysippe* sp B | 0 | 0 | 0 | 0 | 0 | 0 |
| *Malmgreniella sanpedroensis* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Levinsenia gracilis* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Tanaella propinquus* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cardiomya pectinata* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cuspidaria parapodema* | 0 | 0 | 0 | 0 | 0 | 0 |

## Appendix H.3 *continued*

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.82 | 0.2 | 0.08 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.73 | 1.08 | 0.15 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.64 | 0.55 | 0.31 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.27 | 1.43 | 0.31 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.27 | 0.2 | 0.08 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.18 | 0.43 | 1.46 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.09 | 0.4 | 0.77 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.09 | 0.08 | 0.08 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.09 | 0.05 | 0.62 |

(vii.) Species delineating the separation of cluster group F from cluster groups G, H, and I (15.44% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Metamysidopsis elongata* | 0 | 0 | 0 | 0 | 0 | 3 |
| *Dendraster* sp | 0 | 0 | 0 | 0 | 0 | 2.2 |
| *Eohaustorius barnardi* | 0 | 0 | 0 | 0 | 0 | 2 |
| *Chaetozone bansei* | 0 | 0 | 0 | 0 | 0 | 1 |
| *Euphilomedes longiseta* | 0 | 0 | 0 | 0 | 0 | 0.8 |
| *Rhepoxynius lucubrans* | 0 | 0 | 0 | 0 | 0 | 0.6 |
| *Eulalia* sp | 0 | 0 | 0 | 0 | 0 | 0.2 |
| *Exosphaeroma rhomburum* | 0 | 0 | 0 | 0 | 0 | 0.2 |
| *Heteropodarke heteromorpha* | 0 | 0 | 0 | 0 | 0 | 0.2 |
| *Nereis latescens* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Rhynchospio arenincola* | 0 | 0 | 0 | 0 | 0 | 0 |

(viii.) Species delineating the separation of cluster group M from cluster groups N and O (16.49% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Mooreonuphis segmentispadix* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Urothoe elegans* Cmplx | 0 | 0 | 0 | 0 | 0 | 0 |
| *Clavopora occidentalis* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Naineris uncinata* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Caecognathia* sp SD1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Mooreonuphis exigua* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Scoloura phillipsi* | 0 | 0 | 0 | 0 | 0 | 0 |
| additional 27 taxa (<0.45) | 0 | 0 | 0 | 0 | 0 | 0 |
| *Travisia brevis* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Rhepoxynius bicuspidatus* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Heterophoxus oculatus* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nuculana* sp A | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aglaophamus verrilli* | 0 | 0 | 0 | 0 | 0 | 0 |
| additional 16 taxa (<0.95) | 0 | 0 | 0 | 0 | 0 | 0 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 3 | 0.11 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 2 | 0.11 | 0 | 0 | 0 | 0 | 0 | 0 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 2.91 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 1.27 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.82 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.64 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.55 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.45 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.45 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | x | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.7 | 0.08 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.95 | 0.31 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.73 | 0.31 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.45 | 1.23 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.95 | 0.15 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | x |

## Appendix H.3 *continued*

(ix.) Species delineating the separation of cluster group C from cluster groups D and E (16.79% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Agnezia septentrionalis* | 0 | 0 | 6.83 | 0 | 0 | 0 |
| *Laticorophium baconi* | 0 | 0 | 1.67 | 0 | 0 | 0 |
| *Polycirrus* sp I | 0 | 0 | 1.17 | 0 | 0 | 0 |
| *Aphelochaeta* sp SD5 | 0 | 0 | 0.67 | 0 | 0 | 0 |
| *Poecilochaetus* sp | 0 | 0 | 0.67 | 0 | 0 | 0 |
| *Aricidea* (*Allia*) sp SD1 | 0 | 0 | 0.5 | 0 | 0 | 0 |
| Ascidiacea | 0 | 0 | 0.5 | 0 | 0 | 0 |
| additional 20 taxa (<0.50) | 0 | 0 | x | 0 | 0 | 0 |
| *Paradoneis* sp SD1 | 0 | 0 | 0 | 1.07 | 1.67 | 0 |
| *Streblosoma* sp SF1 | 0 | 0 | 0 | 0.57 | 0.33 | 0 |
| *Euphysa* sp A | 0 | 0 | 0 | 0.36 | 1 | 0 |
| *Rochefortia grippi* | 0 | 0 | 0 | 0.14 | 0.33 | 0 |
| additional 14 taxa (<0.08) | 0 | 0 | 0 | x | x | 0 |

(x.) Species delineating the separation of cluster group G from cluster groups H and I (20.97% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Skenea coronadoensis* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aoroides intermedia* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Chone eiffelturris* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pseudopotamilla* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| *Emerita analoga* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Epitonium* (*Nitidiscala*) sp | 0 | 0 | 0 | 0 | 0 | 0 |
| *Listriella melanica* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Melanella rosa* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Onuphis elegans* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Rhepoxynius* sp A | 0 | 0 | 0 | 0 | 0 | 0 |
| *Scolelepis* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| *Thorlaksonius platypus* | 0 | 0 | 0 | 0 | 0 | 0 |
| Venerinae | 0 | 0 | 0 | 0 | 0 | 0 |
| *Yoldia cooperii* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Heptacarpus stimpsoni* | 0 | 0 | 0 | 0 | 0 | 0 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 1.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0.11 | 0 | 0 | 0 | 0 | 0 | 0 |

**(xi.)** Species delineating the separation of cluster groups D and E (21.05% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Rhepoxynius variatus* | 0 | 0 | 0 | 1.07 | 0 | 0 |
| *Anotomastus gordiodes* | 0 | 0 | 0 | 0.14 | 0 | 0 |
| *Asteropella slatteryi* | 0 | 0 | 0 | 0.14 | 0 | 0 |
| *Hima mendica* | 0 | 0 | 0 | 0.14 | 0 | 0 |
| *Magelona pitelkai* | 0 | 0 | 0 | 0.14 | 0 | 0 |
| *Marphysa* sp | 0 | 0 | 0 | 0.14 | 0 | 0 |
| *Meiodorvillea* sp SD1 | 0 | 0 | 0 | 0.14 | 0 | 0 |
| *Naineris* cf *grubei* | 0 | 0 | 0 | 0.14 | 0 | 0 |
| *Nereiphylla* sp SD1 | 0 | 0 | 0 | 0.14 | 0 | 0 |
| Pectinidae | 0 | 0 | 0 | 0.14 | 0 | 0 |
| *Polydora narica* | 0 | 0 | 0 | 0.14 | 0 | 0 |
| *Rhepoxynius fatigans* | 0 | 0 | 0 | 0.14 | 0 | 0 |
| Tellinidae | 0 | 0 | 0 | 0.14 | 0 | 0 |
| additional 33 taxa (<0.08) | 0 | 0 | 0 | x | 0 | 0 |
| *Cyathura munda* | 0 | 0 | 0 | 0 | 2.67 | 0 |
| Lumbrineridae | 0 | 0 | 0 | 0 | 2.33 | 0 |
| Phyllophoridae | 0 | 0 | 0 | 0 | 2 | 0 |
| *Idarcturus allelomorphus* | 0 | 0 | 0 | 0 | 1.67 | 0 |
| *Lepidozona scrobiculata* | 0 | 0 | 0 | 0 | 1.67 | 0 |
| *Amphipholis pugetana* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Discerceis granulosa* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Leptochiton nexus* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Ophiopsila californica* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Pettiboneia sanmatiensis* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Pherusa inflata* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Typosyllis* sp SD5 | 0 | 0 | 0 | 0 | 1 | 0 |
| additional 31 taxa (<0.68) | 0 | 0 | 0 | 0 | x | 0 |

## Appendix H.3 *continued*

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## Appendix H.3 *continued*

**(xii.)** Species delineating the separation of cluster groups J and K (21.59% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Nuculana leonina* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aglaophamus erectans* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Podarkeopsis perkinsi* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Amphioplus* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| *Brisaster townsendi* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Brissopsis* sp LA1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Calocarides quinqueseriatus* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Edwardsia profunda* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ilyarachna profunda* | 0 | 0 | 0 | 0 | 0 | 0 |

**(xiii.)** Species delineating the separation of cluster groups H and I (21.67% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Astyris gausapata* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Exacanthomysis davisi* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cirriformia* sp B | 0 | 0 | 0 | 0 | 0 | 0 |
| *Mysidopsis intii* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nereis* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| Mactridae | 0 | 0 | 0 | 0 | 0 | 0 |
| *Alia carinata* | 0 | 0 | 0 | 0 | 0 | 0 |
| Corophiida | 0 | 0 | 0 | 0 | 0 | 0 |
| *Caesia fossatus* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Crassispira semiinflata* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Schistocomus* sp | 0 | 0 | 0 | 0 | 0 | 0 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0.33 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 0 |

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 2.67 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0.22 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0.22 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0.11 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0.11 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0.11 | 0 | 0 | 0 | 0 | 0 | 0 |

## Appendix H.3 *continued*

**(xiv.)** Species delineating the separation of cluster groups N and O (22.43% similarity)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| *Foxiphalus similis* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Deflexilodes norvegicus* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Nicippe tumida* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Brada pluribranchiata* | 0 | 0 | 0 | 0 | 0 | 0 |
| additional 84 taxa (<0.31) | 0 | 0 | 0 | 0 | 0 | 0 |
| *Ilyarachna acarina* | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pherusa negligens* | 0 | 0 | 0 | 0 | 0 | 0 |
| Chaetopteridae | 0 | 0 | 0 | 0 | 0 | 0 |
| *Euchone* sp | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pardaliscella symmetrica* | 0 | 0 | 0 | 0 | 0 | 0 |
| additional 15 taxa (<0.09) | 0 | 0 | 0 | 0 | 0 | 0 |

## Appendix H.3 *continued*

| G | H | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.18 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.65 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.55 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.23 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.23 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.15 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.15 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.15 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x |