SD Public Utilities

Biennial Receiving Waters Monitoring and Assessment Report for the Point Loma and South Bay Ocean Outfalls

2016–2017

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

The City of
SAN DIEGO
Public Utilities Department
Environmental Monitoring & Technical Services Division

June 30, 2018

Mr. David W. Gibson, Executive Officer
California Regional Water Quality Control Board
San Diego Region
2375 Northside Drive, Suite 100
San Diego, CA 92108

Attention: POTW Compliance Unit

Dear Mr. Gibson:

Enclosed is the 2016-2017 Biennial Receiving Waters Monitoring and Assessment Report for the Point Loma and South Bay Ocean Outfalls as per requirements set forth in Order No. R9-2017-0007 for the City of San Diego's Point Loma Wastewater Treatment Plant (NPDES No. CA0107409), Order No. R9-2013-0006 as amended by Order Nos. R9-2014-0071 and R9-2017-0023 for the City's South Bay Water Reclamation Plant (NPDES No. CA0109045), and Order R9-2014-0009 as amended by Order Nos. R9-2014-0094 and R9-2017-0024 for the United States Section of the International Boundary and Water Commission's South Bay International Wastewater Treatment Plant (NPDES No. CA0108928).

This combined report for the Point Loma and South Bay outfall regions contains data summaries, analyses, and assessments for all portions of the ocean monitoring program conducted during calendar years 2016 and 2017. Included are the following main sections: (1) Executive Summary; (2) General Introduction; (3) Coastal Oceanographic Conditions; (4) Water Quality Compliance and Plume Dispersion; (5) Sediment Quality; (6) Macrobenthic Communities; (7) San Diego Regional Benthic Condition Assessment; (8) Demersal Fish and Megabenthic Invertebrate Communities; (9) Contaminants in Marine Fishes; (10) Appendices. Additional data in support of this report will be submitted in separate addenda that will be available online by July 1, 2018.

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.

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If you have questions regarding this report, please call Dr. Timothy Stebbins, the City's Senior Marine Biologist at (619) 758-2329.

Sincerely,

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

TS/akl

cc: U.S. Environmental Protection Agency, Region 9
International Boundary and Water Commission, U.S. Section

SD Public Utilities

Biennial Receiving Waters Monitoring and Assessment Report for the Point Loma and South Bay Ocean Outfalls

2016–2017

Point Loma Wastewater Treatment Plant
(Order No. R9-2017-0007; NPDES No. CA0107409)

South Bay Water Reclamation Plant
(Order No. R9-2013-0006 as amended; NPDES No. CA0109045)

South Bay International Wastewater Treatment Plant
(Order No. R9-2014-0009 as amended; NPDES No. CA0108928)

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

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June 2018

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https://www.sandiego.gov/mwwd/environment/oceanmonitor/reports

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Collage highlighting City of San Diego ocean monitoring activities (clockwise from upper left): City scientists retrieving large trawl catch of mostly pelagic red crabs (*Pleuroncodes planipes*) off San Diego; double Van Veen grab sampler being brought on board ship; Pacific sanddabs (*Citharichthys sordidus*) caught by hook and line for analysis of contaminant accumulation in liver tissues; *Ophiura luetkeni*, a common trawl-caught brittle star off Point Loma; City research vessel *Oceanus* at sea off San Diego; carousel rosette sampler fitted with Sea-Bird CTD and Niskin bottles on deck of *Oceanus* during transport between monitoring stations. Photos taken by City Marine Biology and Ocean Operations staff.

Acknowledgments:
We are grateful to the personnel of the City's Marine Biology, Marine Microbiology, and Environmental Chemistry Services Laboratories for their assistance in the collection and/or processing of all samples, and for discussions of the results. The completion of this report would not have been possible without their continued efforts and contributions. Complete staff listings for the above labs and additional details concerning relevant QA/QC activities for the receiving waters monitoring data reported herein are available online in the 2017 Annual Receiving Waters Monitoring & Toxicity Testing Quality Assurance Report (www.sandiego.gov/mwwd/environment/reports.shtml).

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Acronyms and Abbreviations

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

Acronyms and Abbreviations

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

Acronyms and Abbreviations

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

Executive Summary

Executive Summary

The City of San Diego (City) conducts an extensive ocean monitoring program to evaluate potential environmental effects associated with the discharge of treated wastewater to the Pacific Ocean via the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively). The data collected are used to determine compliance with receiving water conditions as specified in NPDES permits and orders issued by the San Diego Regional Water Quality Control Board (San Diego Water Board) and the U.S. Environmental Protection Agency (USEPA) for the City's Point Loma Wastewater Treatment Plant (PLWTP) and South Bay Water Reclamation Plant (SBWRP), as well as the South Bay International Wastewater Treatment Plant (SBIWTP) operated by the U.S. Section of the International Boundary and Water Commission. Since treated effluent from both the SBWRP and SBIWTP commingle before discharge to the ocean via the SBOO, a single monitoring and reporting program approved by the San Diego Water Board and USEPA is conducted to comply with these two permits.

The principal objectives of the combined ocean monitoring efforts for both the PLOO and SBOO regions include:

- Measure and document compliance with NPDES permit requirements and California Ocean Plan (Ocean Plan) water quality objectives and standards.
- Assess any impact of wastewater discharge or other anthropogenic inputs on the local marine ecosystem, including effects on coastal water quality, seafloor sediments, and marine life.
- Monitor natural spatial and temporal fluctuations of key oceanographic parameters, and evaluate the overall health and status of the San Diego marine environment.

Overall, the state of San Diego's coastal ocean waters remains in good condition based on the comprehensive scientific assessment of the Point Loma and South Bay outfall monitoring regions. Although governed by three separate NPDES permits as described above, this combined biennial report approved by the San Diego Water Board and USEPA summarizes the purpose, scope, methods and findings of all ocean monitoring activities conducted in both regions during calendar years 2016 and 2017.

Regular (core) monitoring was conducted on a weekly, quarterly, semiannual or annual basis at a total of 142 discrete sites that are arranged in grids surrounding the two ocean outfalls. The PLOO terminates at a discharge depth of about 100 m located approximately 7.2 km west of the PLWTP on the Point Loma peninsula, whereas the SBOO terminates at a discharge depth of about 27 m located approximately 5.6 km offshore of southern San Diego just north of the USA/Mexico border. Core monitoring in the PLOO region extends from Mission Beach southward to the tip of Point Loma along the shore, and in nearshore to offshore waters overlying the continental shelf at depths of about 9 to 116 m. Core monitoring of shore staions in the SBOO region extends from Coronado, San Diego southward to Playa Blanca in northern Baja California, while offshore monitoring occurs in waters overlying the continental shelf at depths of about 9 to 55 m. In addition to monitoring at the permanent core stations, an annual survey of benthic conditions (sediment quality, macrobenthic communities) is typically conducted each year at 40 randomly selected "regional" stations that range from northern San Diego County southward to near the international border and that extend further offshore to continental slope depths as deep as 500 m. These broader geographic surveys are useful for evaluating patterns over the entire San Diego coastal region and provide information important for distinguishing reference areas from those impacted by human activities. Additional information on background conditions for San Diego's coastal marine environment is also available from pre-discharge baseline studies conducted by the City for the PLOO region (1991–1994) and SBOO region (1995–1998).

Details of the results of all receiving waters monitoring activities conducted for the PLOO and SBOO programs from January 1, 2016 through December 31, 2017 are presented in the following eight chapters, while supplemental analyses for Chapters 2–8 are included in Appendices B–H. Additionally, visual observations and raw data for 2017 are included in Addenda 1–8, while similar data for 2016 were submitted previously with the *2016 Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall and South Bay Ocean Outfall* and are available online. Chapter 1 represents a general introduction and overview of the combined ocean monitoring program for the PLOO and SBOO regions, while chapters 2–8 include results of the main monitoring components conducted at the core and regional stations. In Chapter 2, data characterizing oceanographic conditions and water mass transport for the region are evaluated. Chapter 3 presents the results of shoreline and offshore water quality monitoring, including measurements of fecal indicator bacteria and oceanographic data to evaluate potential movement and dispersal of the PLOO and SBOO waste fields (plumes) and to assess compliance with water contact standards defined in the Ocean Plan. Assessments of benthic sediment quality (physical properties, sediment chemistry, and sediment toxicity) and the status of macrobenthic invertebrate communities are presented in Chapters 4, 5, and 6. Chapter 7 presents the results of trawling activities designed to monitor communities of bottom dwelling (demersal) fishes and large (megabenthic) surface dwelling invertebrates. Bioaccumulation assessments to measure contaminant loads in the tissues of local marine fishes are presented in Chapter 8. In addition to the above activities, the City supports other projects relevant to assessing the quality and movement of ocean waters in the region. One such project involves satellite imaging of the San Diego/Tijuana coastal region, of which the 2016–2017 results are discussed in Chapters 2 and 3. Another major project represents an ongoing long-term assessment of the health and status of San Diego's kelp forest ecosystems conducted by the Scripps Institution of Oceanography and funded by the City, of which the most recent annual report is included herein as Appendix A. Summaries of the main findings for each of the main ocean monitoring components conducted by the City are included below.

Coastal Ocean Conditions

Oceanographic conditions off San Diego in 2016–2017 in terms of water temperatures, salinity, dissolved oxygen concentrations, pH, natural light levels (transmissivity or water clarity), and concentrations of chlorophyll *a* were generally within historical ranges reported for the PLOO and SBOO monitoring regions. As is characteristic for these waters, conditions typically indicative of coastal upwelling were most evident during the spring, while maximum stratification or layering of the water column occurred during mid-summer, after which the local waters became more mixed in the winter. Reductions in water clarity or transmissivity tended to be associated with terrestrial runoff or outflows from rivers and bays, re-suspension of bottom sediments in nearshore waters due to waves or storm activity, or the presence of phytoplankton blooms. Overall, ocean conditions during the past two years were consistent with well documented patterns for southern California and northern Baja California. These findings suggest that natural factors such as upwelling of deep ocean waters and changes due to climatic events such as El Niño/La Niña oscillations continue to explain most of the temporal and spatial variability observed in the coastal waters off San Diego.

Water Quality and Plume Dispersion

Ocean water quality was excellent in both the PLOO and SBOO regions during 2016 and 2017. Compliance was very high with all Ocean Plan water quality objectives for water contact areas, including objectives for natural light, pH, and dissolved oxygen in coastal waters off San Diego where the wastewater plumes are likely to occur. Additionally, overall compliance with the Ocean Plan single sample maximum (SSM) and geometric mean standards for fecal indicator bacteria (i.e., total coliforms, fecal coliforms, *Enterococcus*) was 98% for all shore, kelp bed and other offshore stations located within California State waters. Compliance with these standards was typically a little higher at the PLOO stations than at the SBOO stations, and tended to be higher at the nearshore kelp bed and other offshore stations compared to along the shore. Reduced compliance with the various water contact standards occurred mostly during the wet season (i.e., October–April). This relatively common pattern of higher contamination during or following storm events, especially at some of the shore stations located near the mouth of the Tijuana River, is likely due to coastal runoff from both point and non-point sources.

There was no evidence that wastewater discharged to the ocean via either the PLOO or SBOO reached recreational waters along the shore or in the nearshore kelp beds in 2016 and 2017. Results of water quality monitoring over the past 27 years off Point Loma and 23 years in the South Bay outfall region are consistent with observations from remote sensing studies (i.e., satellite imagery) that show a lack of shoreward transport of wastewater plumes from either outfall, and with previous studies that have indicated the PLOO plume typically remains submerged in deep offshore waters. Monitoring results specifically for the shallower SBOO region are also consistent with past studies that indicated other sources such as terrestrial runoff or outflows from rivers and creeks were more likely to impact coastal water quality than wastewater discharge from the outfall, especially during and immediately after significant rain events. Further, the general relationship between higher rainfall levels and elevated bacteria counts in the SBOO region existed before wastewater discharge began in 1999.

Regional Benthic Conditions

Benthic habitats and associated biological communities found on the continental shelf and upper slope off San Diego were in good condition during the 2016–2017 reporting period. The results of comprehensive assessments of benthic condition at 129 different monitoring sites indicated that the physical composition of the sediments, sediment quality, and the ecological status of the resident macrofaunal communities remain stable in areas surrounding the two outfalls and show little evidence of environmental impact off San Diego. Particle size composition varied throughout the region, but generally followed the typical pattern of sediments becoming finer with increasing depth. Sediment quality was generally good in terms of both presence and concentrations of key chemical contaminants, as well as from the results of recently initiated sediment toxicity studies. For example, although concentrations of various organic loading indicators (e.g., total organic carbon, total nitrogen, and sulfides), trace metals, pesticides (e.g., DDT), PCBs, and PAHs varied widely in sediments throughout both outfall regions, there was no evidence of degraded benthic habitats based on distribution patterns of these contaminants that could be associated with wastewater discharge. The only evidence of possible organic enrichment was slightly higher sulfide and BOD concentrations at a few stations located within 200 m of the PLOO discharge zone. In addition, the results of sediment toxicity studies conducted in the summers of 2016 and 2017 revealed no toxicity at any of the core or regional stations tested during these two years.

Benthic macrofaunal communities off San Diego also appeared healthy in 2016 and 2017, with most of the different types of assemblages remaining similar to those observed in the region from 1991 through 2015, as well as from similar habitats throughout southern California and northern Baja California. Although these communities varied across depth and sediment gradients, there was no evidence of disturbance or significant environmental degradation during these two years that could be attributed to anthropogenic factors such as wastewater discharge via the PLOO or SBOO or from other point sources. Instead, these communities segregated by habitat characteristics such as depth and sediment particle size, often corresponding with the "patchy" habitats reported to occur naturally in southern California's offshore coastal waters. These assemblages were typically characterized by expected abundances of pollution sensitive species of brittle stars (e.g., *Amphiodia urtica*) and amphipods (e.g., *Ampelisca* spp and *Rhepoxynius* spp). In contrast, abundances of pollution-tolerant species such as the polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa* were relatively low. Comparison of the results for other major benthic community metrics such as species richness, macrofaunal abundance, diversity, evenness, and dominance also showed no evidence of wastewater impact or significant habitat degradation. Finally, benthic response index (BRI) results also revealed little evidence of disturbance off San Diego, with < 2% of all BRI values showing evidence of likely disturbance. This result is similar to findings from other studies that have reported that at least 98% of the entire mainland shelf of the Southern California Bight is in good condition based on BRI data.

Demersal Fishes & Megabenthic Invertebrates

Results for the demersal fish and megabenthic invertebrate communities trawled off San Diego in 2016 and 2017 were difficult to compare to previous years due to the presence of exceptionally large populations of pelagic red crabs (*Pleuroncodes planipes*) that had invaded the region and impacted trawling operations at many stations. The impact was most pronounced off Point Loma where total trawling time had to be reduced from 10 minutes to ≤3 minutes at most stations in order to limit the red crab catch so that the trawl net could be safely brought onboard ship for processing. Consequently, it was not possible to determine if observed differences or changes in trawl-caught fish and invertebrate populations off San Diego during the past two years were due to unequal trawling times, direct impacts caused by pelagic red crabs, or other factors. In spite of these limitations, some patterns could still be identified. For example, although trawl-caught populations were reduced in total numbers, Pacific Sanddabs continued to dominate demersal fish assemblages surrounding the PLOO. In contrast, SBOO fish assemblages were dominated by species such as the California Lizardfish and Speckled Sanddab that are more common at shallower depths. The dominant trawl-caught invertebrate at the SBOO stations in 2016–2017 was the shrimp *Sicyonia penicillata*, while pelagic red crabs described above accounted for about 99% of the invertebrate catch at the PLOO stations. Where comparisons could be made to previous years, the findings indicated that demersal fish and megabenthic invertebrate communities in both the PLOO and SBOO regions remain unaffected by wastewater discharge. Although highly variable, spatial patterns in the abundance and distribution of individual species were similar at stations located near the two outfalls and farther away. Finally, external examinations of fish captured during these two years indicated that fish populations remained healthy off San Diego, with less than 1% of all fish having external parasites or showing any evidence of disease or other abnormalities.

Contaminants in Fishes

The accumulation of chemical contaminants in San Diego marine fishes was assessed by analyzing liver tissues from flatfish collected from trawl zones and muscle tissues from rockfish collected at rig fishing zones. Results from both analyses indicated no evidence that contaminant loads in fishes collected from the PLOO or SBOO regions were affected by wastewater discharge in 2016–2017. Although several different trace metals, pesticides, and PCB congeners were detected in both liver and muscle tissues, these contaminants occurred in fishes distributed throughout both regions with no patterns that could be attributed to wastewater discharge via the outfalls. While most of the rockfish muscle samples exceeded international standards for arsenic and selenium, all samples were within state and federal action limits. Furthermore, concentrations of all contaminants were generally within ranges reported previously for southern California fishes. Consequently, the occurrence of some metals and chlorinated hydrocarbons in some local fishes off San Diego is likely due or related to other factors such as the widespread distribution of many contaminants in southern California sediments, differences in the physiology and life history traits of various species of fish, different exposure pathways, and differences in the migration habits of various species. For example, an individual fish may be exposed to contaminants at a polluted site but then migrate to an area that is less contaminated. This is of particular concern for fishes collected in the vicinity of the PLOO and SBOO, as there are many other nearby potential point and non-point sources of contamination.

Conclusions

The findings and conclusions for the ocean monitoring efforts conducted for the Point Loma and South Bay ocean outfall monitoring regions during calendar years 2016 and 2017 were consistent with previous years. There were few changes to local receiving waters, benthic sediments, and marine invertebrate and fish communities that could be attributed to wastewater discharge or other human activities. Coastal water quality conditions and compliance with Ocean Plan standards were excellent, and there was no evidence that wastewater plumes from the two outfalls were transported shoreward into nearshore recreational waters. There were also no clear outfall related patterns in sediment contaminant distributions or differences between invertebrate and fish assemblages at the different monitoring sites. Additionally, benthic habitats surrounding both outfalls and throughout the entire San Diego region remained in good overall condition similar to reference conditions for much of the Southern California Bight. Finally, the low level of contaminant accumulation and general lack of physical anomalies or other symptoms of disease or stress in local fishes was also indicative of a healthy marine environment off San Diego.

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Chapter 1
General Introduction

Chapter 1. General Introduction

Program Requirements & Objectives

Ocean monitoring within the Point Loma and South Bay outfall regions is conducted by the City of San Diego (City) in accordance with requirements set forth in National Pollution Discharge Elimination System (NPDES) permits and associated orders for the City's Point Loma Wastewater Treatment Plant (PLWTP) and South Bay Water Reclamation Plant (SBWRP), as well as the South Bay International Wastewater Treatment Plant (SBIWTP) that is owned and operated by the U.S. Section of the International Boundary and Water Commission (see Table 1.1). These documents specify the terms and conditions that allow treated effluent to be discharged to the Pacific Ocean via the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO). In addition, the Monitoring and Reporting Program (MRP) included within each of these orders defines the requirements for monitoring ocean (receiving) waters surrounding the two outfalls, including sampling design, frequency of sampling, field operations and equipment, regulatory compliance criteria, types of laboratory tests and analyses, data management and analysis, statistical methods and procedures, environmental assessment, and reporting guidelines.

Overall, the combined ocean monitoring program for these regions is designed to assess the impact of wastewater discharged through the PLOO and SBOO on the coastal marine environment off San Diego. The main objectives of the program are to: (1) provide data that satisfy NPDES requirements; (2) demonstrate compliance with water-contact standards specified in the California Ocean Plan (Ocean Plan); (3) track movement and dispersion of the wastewater plumes discharged via the outfalls; and (4) identify any biological, chemical or physical changes that may be associated with the outfalls and wastewater discharge. These data are then used to evaluate and document any effects of wastewater discharge, other man-made influences (e.g., storm water discharge, urban runoff), or natural factors (e.g., seasonality, climate change) on coastal water quality, seafloor sediment conditions, and local marine organisms.

Background

Point Loma Ocean Outfall

The City began operation of the PLWTP and original PLOO off Point Loma in 1963, at which time treated effluent was discharged at a depth of about 60 m located approximately 3.9 km west of the Point Loma peninsula. The PLWTP operated as a primary treatment facility from 1963 to 1985, after which it was upgraded to advanced primary treatment between mid-1985 and July 1986. This improvement involved the addition of chemical coagulation to the treatment process, which resulted in an increase in removal of total suspended solids (TSS) to about 75%. Since then, the treatment process has continued to be improved with the addition of more sedimentation basins, expanded aerated grit removal, and refinements in chemical treatment, which together further reduced mass emissions from the plant. For example, TSS removals are now consistently greater than the 80% required by the NPDES permit.

The structure of the PLOO was significantly modified in the early 1990s when it was extended about 3.3 km farther offshore in order to prevent intrusion of the waste field into nearshore waters and to increase compliance with Ocean Plan standards for water-contact sports areas. Discharge from the original 60-m terminus was discontinued in November 1993 following completion of the outfall extension. The present deeper water PLOO extends approximately 7.2 km west of the PLWTP to a depth of about 94 m, where the main outfall

Table 1.1

NPDES permits and associated orders issued by the San Diego Water Board for the Point Loma Wastewater Treatment Plant (PLWTP), South Bay Water Reclamation Plant (SBWRP), and South Bay International Wastewater Treatment Plant (SBIWTP) discharges to the Pacific Ocean via the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO).

Facility	Outfall	NPDES Permit No.	Order No.	Effective Dates
PLWTP	PLOO	CA0107409	R9-2017-0007	October 1, 2017–September 30, 2022
SBWRP	SBOO	CA0109045	R9-2013-0006 [a]	April 4, 2013–April 3, 2018
SBIWTP	SBOO	CA0108928	R9-2014-0009 [b]	August 1, 2014–July 31, 2019

[a] Order R9-2013-0006 amended by Order R9-2014-0071 and R9-2017-0023

[b] Order R9-2014-0009 amended by Order R9-2014-0094 and R9-2017-0024

pipe splits into a Y-shaped (wye) multiport diffuser system. The two diffuser legs extend an additional 762 m to the north and south, each terminating at a depth of about 98 m. The average discharge of effluent through the PLOO in 2016–2017 was about 137.7 mgd (million gallons per day).

South Bay Ocean Outfall

The SBOO is located just north of the international border between the United States and Mexico where it terminates approximately 5.6 km offshore and west of Imperial Beach at a depth of about 27 m. Unlike other southern California ocean outfalls that lie on the surface of the seafloor, the SBOO pipeline begins as a tunnel on land that extends from the SBWRP and SBIWTP facilities to the coastline, after which it continues beneath the seabed to a distance of about 4.3 km offshore. From there the outfall pipe connects to a vertical riser assembly that conveys effluent to a pipeline buried just beneath the surface of the seafloor. This subsurface pipeline then splits into a Y-shaped (wye) multiport diffuser system with the two diffuser legs each extending an additional 0.6 km to the north or south. The SBOO was originally designed to discharge wastewater through 165 diffuser ports and risers, which included one riser at the center of the wye and 82 risers spaced along each diffuser leg. Since discharge began, however, low flow rates have required closure of all ports along the northern diffuser leg and many along the southern diffuser leg in order for the outfall to operate effectively. Consequently, wastewater discharge is restricted primarily to the distal end of the southern diffuser leg and to a few intermediate points at or near the center of the wye. The average discharge of effluent through the SBOO in 2016–2017 was about 28.4 mgd, including about 3.4 mgd of tertiary treated effluent from the SBWRP and 25 mgd of secondary treated effluent from the SBIWTP.

Receiving Waters Monitoring

The combined monitoring area for the PLOO and SBOO programs covers about 881 km^2 (~340 mi^2) of coastal marine waters from Northern San Diego County into Northern Baja California. Core monitoring for the Point Loma region is conducted at 82 different stations located from the shore seaward to a depth of about 116 m, while core monitoring for the South Bay region is conducted at a total of 53 stations ranging from along the shore to offshore depths of about 61 m (Figure 1.1). Each of the core monitoring stations is sampled for specific parameters as specified in their respective MRPs. A summary of the results for all quality assurance procedures performed during calendar years 2016 and 2017 in support of these requirements can be found in City of San Diego (2017a, 2018a). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the California Regional Water Quality Control Board, San Diego Region (San Diego Water Board) and the U.S. Environmental Protection Agency (USEPA), Region IX during these two years are available online at: www.sandiego.gov/mwwd/environment/oceanmonitor.shtml

Prior to 1994, the City conducted an extensive ocean monitoring program off Point Loma surrounding

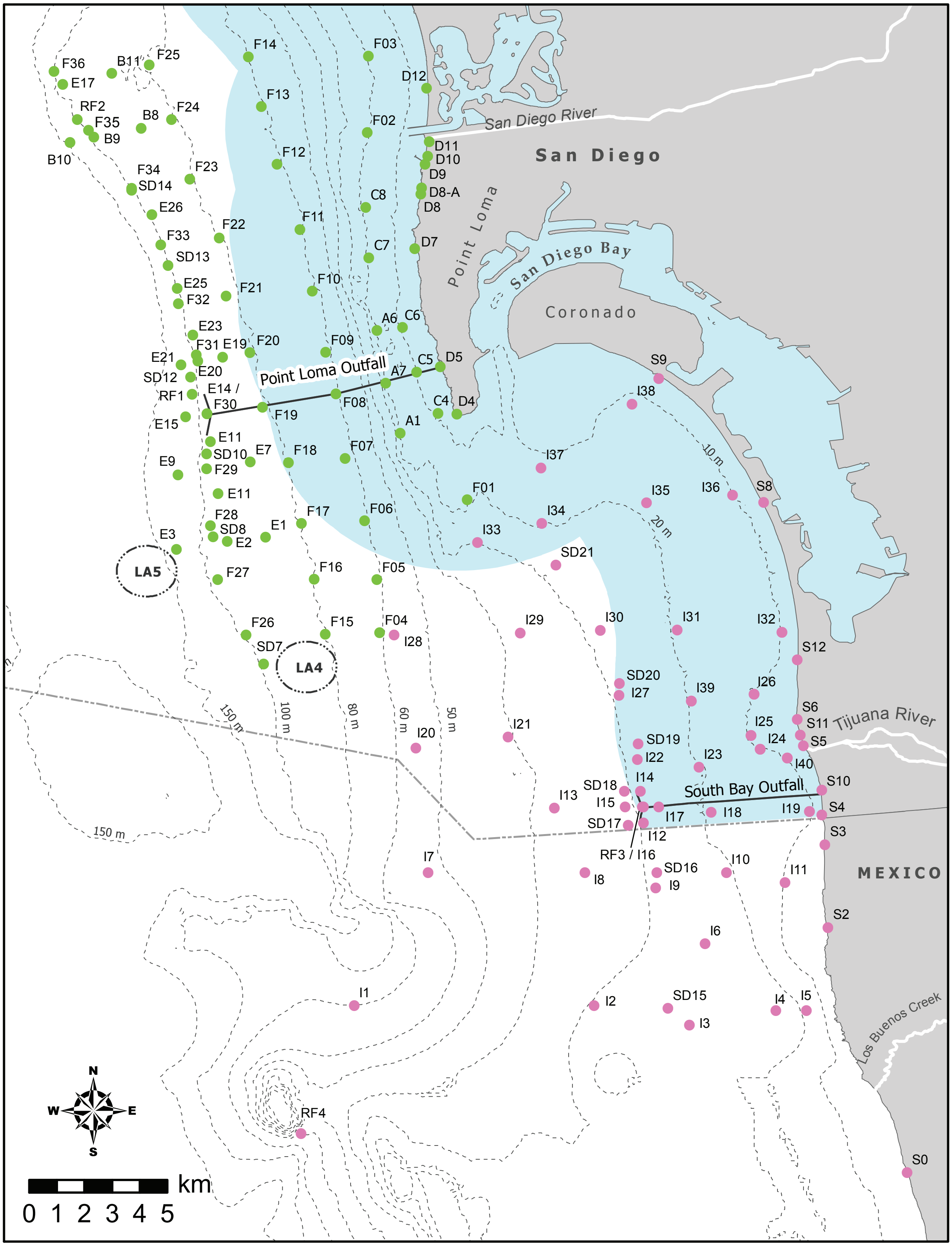

Figure 1.1

Core receiving waters monitoring stations for the Point Loma Ocean Outfall (green) and South Bay Ocean Outfall (pink) as part of the City of San Diego's Ocean Monitoring Program. Light blue shading represents State jurisdictional waters.

the original 60-m discharge site. This program was subsequently expanded with the construction and operation of the deeper outfall as discussed previously. Data from the last year of regular monitoring near the original PLOO discharge site are presented in City of San Diego (1995b), while the results of a 3-year "recovery study" are summarized in City of San Diego (1998). Additionally, a more detailed assessment of spatial and temporal patterns surrounding the original discharge site is available in Zmarzly et al. (1994). From 1991 through 1993, the City also conducted "pre-discharge" monitoring for the new PLOO discharge site in order to collect baseline data prior to wastewater discharge into these deeper waters (City of San Diego 1995a,b). All permit mandated monitoring for the South Bay region has also been performed by the City since wastewater discharge through the SBOO began in 1999, which included pre-discharge monitoring for 3½ years (July 1995–December 1998) in order to provide background information against which post-discharge conditions could be compared (City of San Diego 2000). Results of NPDES mandated monitoring for the extended PLOO from 1994 to 2015 and the SBOO from 1999 to 2015 are available in previous annual receiving waters monitoring reports (e.g., City of San Diego 2016a,b), while a combined report for both regions was first produced for CY 2016 (City of San Diego 2017b). Finally, additional detailed assessments of the PLOO region have been completed as part of past modified NPDES permit renewal applications for the PLWTP submitted by the City and subsequent technical decisions issued by the USEPA (e.g., City of San Diego 2015a, USEPA 2017).

In addition to the above, the City has conducted annual region-wide surveys off the coast of San Diego since 1994 either as part of core receiving waters monitoring requirements (e.g., City of San Diego 1999, 2016b) or as part of larger, multi-agency surveys of the entire Southern California Bight (SCB). The latter include the 1994 Southern California Bight Pilot Project (Allen et al. 1998, Bergen et al. 1998, 2001, Schiff and Gossett 1998) and subsequent Bight'98, Bight'03, Bight'08 and Bight'13 programs in 1998, 2003, 2008 and 2013 respectively (Allen et al. 2002, 2007, 2011, Noblet et al. 2002, Ranasinghe et al. 2003, 2007, 2012, Schiff et al. 2006, 2011, Dodder et al. 2016, Gillett et al. 2017, Walther et al. 2017). These large-scale surveys are useful for characterizing the ecological health of diverse coastal areas and in distinguishing reference sites from those impacted by wastewater or storm water discharges, urban runoff, or other sources of contamination. In addition to the above activities, the City participates as a member of the Region Nine Kelp Survey Consortium to fund aerial surveys of all the major kelp beds in San Diego and Orange Counties (e.g., MBC Applied Environmental Sciences 2017).

Special Studies & Enhanced Monitoring

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

- Real-Time Observing Systems for the Point Loma and South Bay Ocean Outfalls: This project addresses the primary recommendation of previous studies of the fate and behavior of wastewater discharged to the ocean via the SBOO (Terrill et al. 2009) and PLOO (Rogowski et al. 2012a,b, 2013). The study involves installation of a new real-time ocean observing system that will span both outfall regions. The project began in late 2015 with initial deployment of the SBOO mooring in December 2016 and the PLOO mooring in March 2018. This project is being conducted in partnership between the City and the Ocean Time Series Group of SIO who presently operates a similar mooring system off Del Mar. The project is expected to significantly enhance the City's environmental monitoring capabilities in order to address current and emerging issues relevant to the health of San Diego's coastal waters, including plume dispersion, subsurface current patterns, ocean acidification, hypoxia, nutrient sources, and coastal upwelling. Additional details are available in the approved Plume Tracking Monitoring Plan for the project (City of San Diego 2018b).

- Sediment Toxicity Monitoring of the San Diego Ocean Outfall Regions: This project represents a 3-year pilot study implemented as a new joint regulatory requirement for the Point Loma and South Bay outfall regions in 2015. Preliminary results for project years one and two conducted during the summers of 2016 and 2017 are discussed in Chapter 6 of this report, while findings for the entire pilot study will be presented in a final project report following completion of the year three survey scheduled for summer 2018 (see City of San Diego 2015b).

- San Diego Regional Benthic Condition Assessment Project: This multi-phase study represents an ongoing, long-term project designed to assess the condition of continental shelf and slope habitats throughout the entire San Diego region. A preliminary summary of the deeper slope (>200 m) results for data collected between 2003–2013 was included in Appendix C.5 of City of San Diego (2015a), while several publications covering the remainder of the project are planned for completion in late 2018 or 2019.

- Remote Sensing of the San Diego / Tijuana Coastal Region: This project represents a long-term effort funded by the City and the International Boundary and Water Commission since 2002 to utilize satellite and aerial imagery to better understand regional water quality conditions off San Diego. The project is conducted by Ocean Imaging (Littleton, CO), and is focused on detecting and tracking the dispersion of wastewater plumes from local ocean outfalls and nearshore sediment plumes caused by stormwater runoff or outflows from local bays and rivers. Results from this project for calendar years 2016–2017 are available in Svejkovsky (2017) and Hess (2018) and are included herein in Appendix B.

- San Diego Kelp Forest Ecosystem Monitoring Project: This project represents continuation of a long-term commitment by the City to support this important research conducted by SIO. Overall, this work is essential to assessing the health of San Diego's kelp forests and to monitoring the effects of wastewater discharge on the local coastal ecosystem relative to other factors. The final project report for the most recent 4-year agreement (2010–2014) with SIO is available in Parnell et al. (2014), while results for calendar years 2016–2017 are summarized in Appendix A of this report.

Report Components & Organization

This report presents a comprehensive biennial assessment of the results of all receiving waters monitoring activities conducted during calendar years 2016–2017 for both the Point Loma and South Bay outfall regions, including detailed comparisons of long-term spatial and temporal changes and trends. Included herein are results from all regular core stations that comprise the fixed-site monitoring grids surrounding the two outfalls (Figures 1.1), as well as results from the two corresponding summer benthic surveys of randomly selected sites that range from near the USA/Mexico border to northern San Diego County (Figure 1.2). The main components of the combined monitoring program are covered in the following sections or chapters: Executive Summary; General Introduction (Chapter 1); Coastal Oceanographic Conditions (Chapter 2); Water Quality Compliance and Plume Dispersion (Chapter 3); Sediment Quality (Chapter 4); Macrobenthic Communities (Chapter 5); San Diego Regional Benthic Condition Assessment (Chapter 6); Demersal Fish and Megabenthic Invertebrate Communities (Chapter 7); Contaminants in Marine

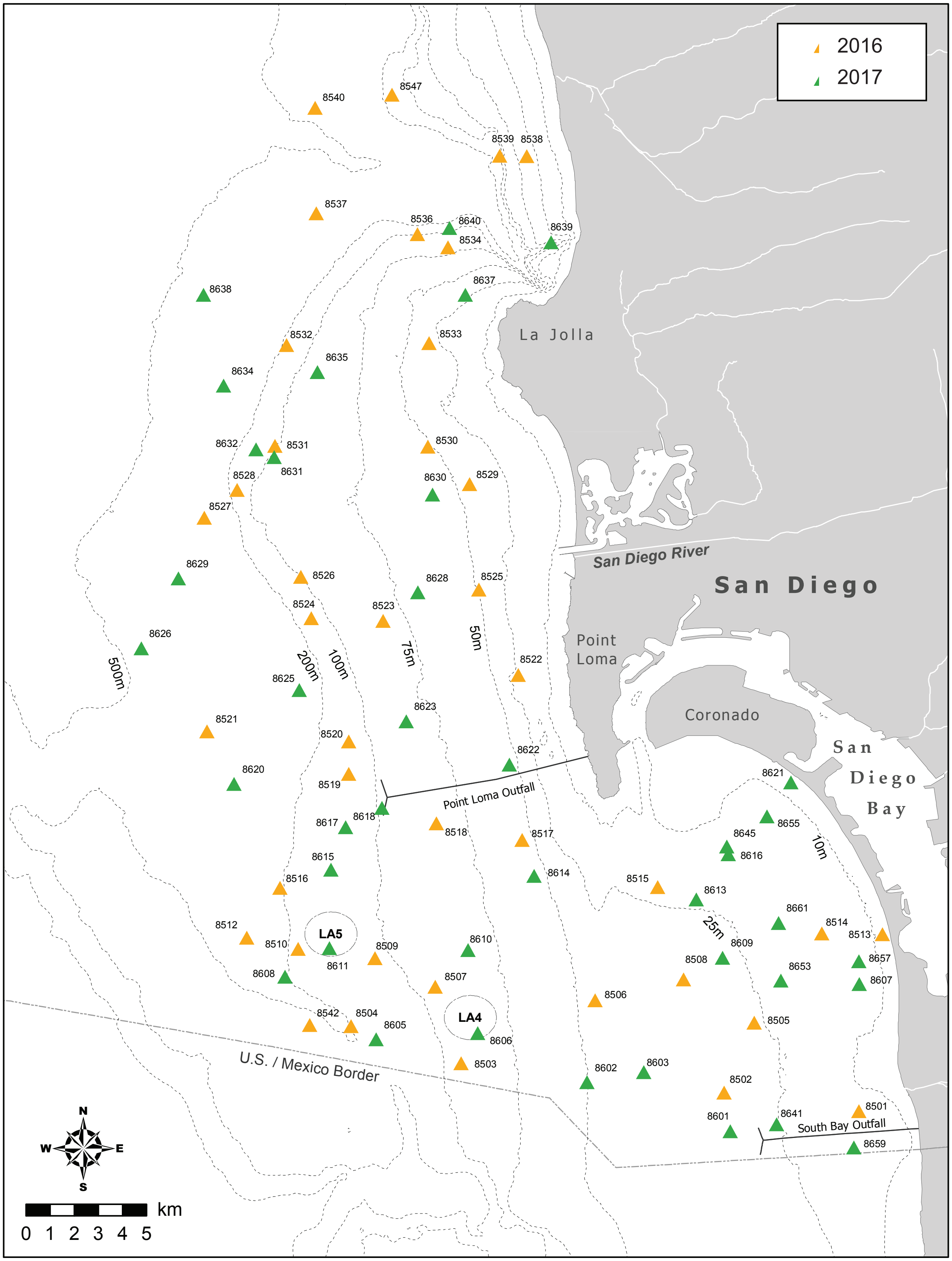

Figure 1.2
Regional randomly selected benthic survey stations sampled during July 2016 and July 2017 as part of the City of San Diego's Ocean Monitoring Program.

Fishes (Chapter 8). Supplemental analyses for Chapters 2–9 are included in Appendices B–H, while visual observations for 2016 and 2017 and raw data for 2017 samples are included in Addenda 1–8. Raw data for calendar year 2016 were submitted with the 2016 Annual Receiving Waters Monitoring Report (City of San Diego 2017b) and are available online: www.sandiego.gov/mwwd/environment/oceanmonitor.shtml

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Chapter 2
Coastal Oceanographic Conditions

Chapter 2. Coastal Oceanographic Conditions

Introduction

The City of San Diego collects a comprehensive suite of oceanographic data from coastal waters surrounding the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO) in order to characterize regional conditions and to identify possible impacts of wastewater discharge and other factors on the marine environment. These data include measurements of ocean temperatures, salinity, light transmittance (transmissivity), dissolved oxygen, pH, and chlorophyll *a* throughout the water column, all of which are considered important indicators of physical and biological processes that can impact marine life (e.g., Skirrow 1975, Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into the ocean is determined by multiple factors (e.g., outfall geometry, rate of effluent discharge, water column mixing, ocean currents), evaluations of physical parameters that influence the mixing potential of the water column are important components of many ocean monitoring programs (Bowden 1975, Pickard and Emery 1990).

In the nearshore coastal waters of the Southern California Bight (SCB) including the PLOO and SBOO monitoring areas, ocean conditions are influenced by multiple factors. These include: (1) large scale climate processes such as the El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and North Pacific Gyre Oscillation (NPGO) that can affect long-term trends (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, NOAA/NWS 2018); (2) the California Current System coupled with local gyres that transport distinct water masses into and out of the SCB (Lynn and Simpson 1987, Leising et al. 2014); (3) seasonal changes in local weather patterns (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). For example, seasonality is responsible for the main patterns in water column stratification typically observed off San Diego and in coastal waters throughout the rest of southern California (Terrill et al. 2009, Rogowski et al. 2012a,b, 2013). These patterns include relatively warm and more stratified waters typically during the dry season from May through September, and cooler more weakly stratified and well mixed waters during the wet season from October through April (e.g., City of San Diego 2015a, Svejkovsky 2017, Hess 2018).

Understanding changes in oceanographic conditions due to natural processes such as seasonal patterns as described above is important since they can affect the transport and distribution of wastewater, storm water, and other types of nearshore plumes. In the PLOO and SBOO monitoring regions, these include sediment or turbidity plumes associated with outflows from local bays, major rivers, lagoons and estuaries, discharges from storm drains or other point sources, surface runoff from local watersheds, seasonal upwelling, and variable ocean currents or eddies. For example, outflows from the San Diego River, San Diego Bay, and the Tijuana River can contribute significantly to patterns of nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009, Svejkovsky 2010, 2017, Hess 2018).

This chapter presents analysis and interpretation of the oceanographic monitoring data collected during calendar years 2016 and 2017 for the coastal waters surrounding the PLOO and SBOO. The primary goals are to: (1) summarize coastal oceanographic conditions in these regions; (2) identify natural and anthropogenic sources of variability; (3) evaluate local ocean conditions off San Diego within the context of regional climate processes. Data from static current meter and temperature sensor (thermistor) strings are included to examine the dynamics and strength of the thermocline and ocean currents in the area (see Storms et al. 2006, Dayton et al. 2009, Parnell and Rasmussen 2010, Rogowski et al. 2012a,b, 2013). Additionally, results of remote sensing observations (e.g., satellite imagery) are combined with measurements of physical oceanographic parameters to provide further insight on the horizontal transport of surface waters off San Diego (Pickard and Emery 1990, Svejkovsky 2010, 2017, Hess 2018). The results reported herein are also referred to in subsequent chapters to explain patterns of fecal indicator bacteria distributions and plume dispersion (see Chapter 3) or other changes in the local marine environment (see Chapters 5–7).

Materials and Methods

Field Sampling

A total of 69 offshore water quality monitoring stations were sampled quarterly to assess coastal oceanographic conditions in the two outfall regions (Figure 2.1). These include 36 stations surrounding the PLOO and 33 stations surrounding the SBOO. The PLOO stations are designated F1–F36 and are located along or adjacent to the 18, 60, 80, and 100-m depth contours. The SBOO stations are designated I1–II8, I20–I23, I27–I31, and I33–I38 and are located along the 9, 19, 28, 38 and 55-m depth contours, respectively. All 69 stations were monitored during winter (February), spring (May), summer (August), and fall (November) in 2016 and 2017. The 36 PLOO stations were sampled over four consecutive days during each survey, while the 33 SBOO stations were sampled over three consecutive days (Appendix B.1). Sampling at an additional eight kelp bed stations off Point Loma (i.e., stations A1, A6, A7, C4–C8) and seven kelp/nearshore stations in the South Bay region (i.e., stations I19, I24–I26, I32, I39, I40) was conducted 4 to 5 times per month to meet bacterial monitoring requirements (see Chapter 3). However, only data collected at these 15 "kelp" stations within one week of the quarterly offshore stations are analyzed in this chapter (see Appendix B.1).

Oceanographic data were collected using a SeaBird SBE 25 conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, conductivity (used to calculate salinity), pressure (used to calculate depth), dissolved oxygen (DO), pH, transmissivity (a proxy for water clarity), chlorophyll *a* fluorescence (a proxy for phytoplankton), and colored dissolved organic material (CDOM). Vertical profiles of each parameter were constructed for each station per survey by averaging the data values recorded within each 1-m depth bin. This level of data reduction ensures that physical measurements used in subsequent analyses will correspond to discrete sampling depths required for bacterial monitoring (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast. These observations were previously reported in monthly receiving waters monitoring reports submitted to the San Diego Regional Water Quality Control Board (see City of San Diego 2016–2018a,b).

Moored Instrument Data Collection

Moored instruments, including current meters (ADCPs: Acoustic Doppler Current Profilers) and vertical arrays of temperature sensors (thermistors) were deployed at two primary locations off San Diego in order to provide nearly continuous measurements of ocean currents and water temperatures for the area. These included one site near the present PLOO discharge zone at a depth of about 100 m and one site near the SBOO discharge zone at a depth of about 36 m (Figure 2.1).

Ocean current data were collected from 2015 through 2017 using one ADCP moored at each of the above sites (i.e., 100-m PLOO site, 36-m SBOO site). The ADCP data were collected every five minutes and then averaged into depth bits of 4 m. For the 100-m ADCP, this resulted in 25 bins that ranged in depth from 5 to 95 m. Data from this ADCP were unavailable during several time periods, including January 1–March 15, 2015, June 6–September 30, 2015, and December 8, 2016–June 29, 2017. For the 36-m ADCP, nine bins were created that ranged in depth from 5 to 32 m. Data from this ADCP were unavailable January 1–May 17, 2015,

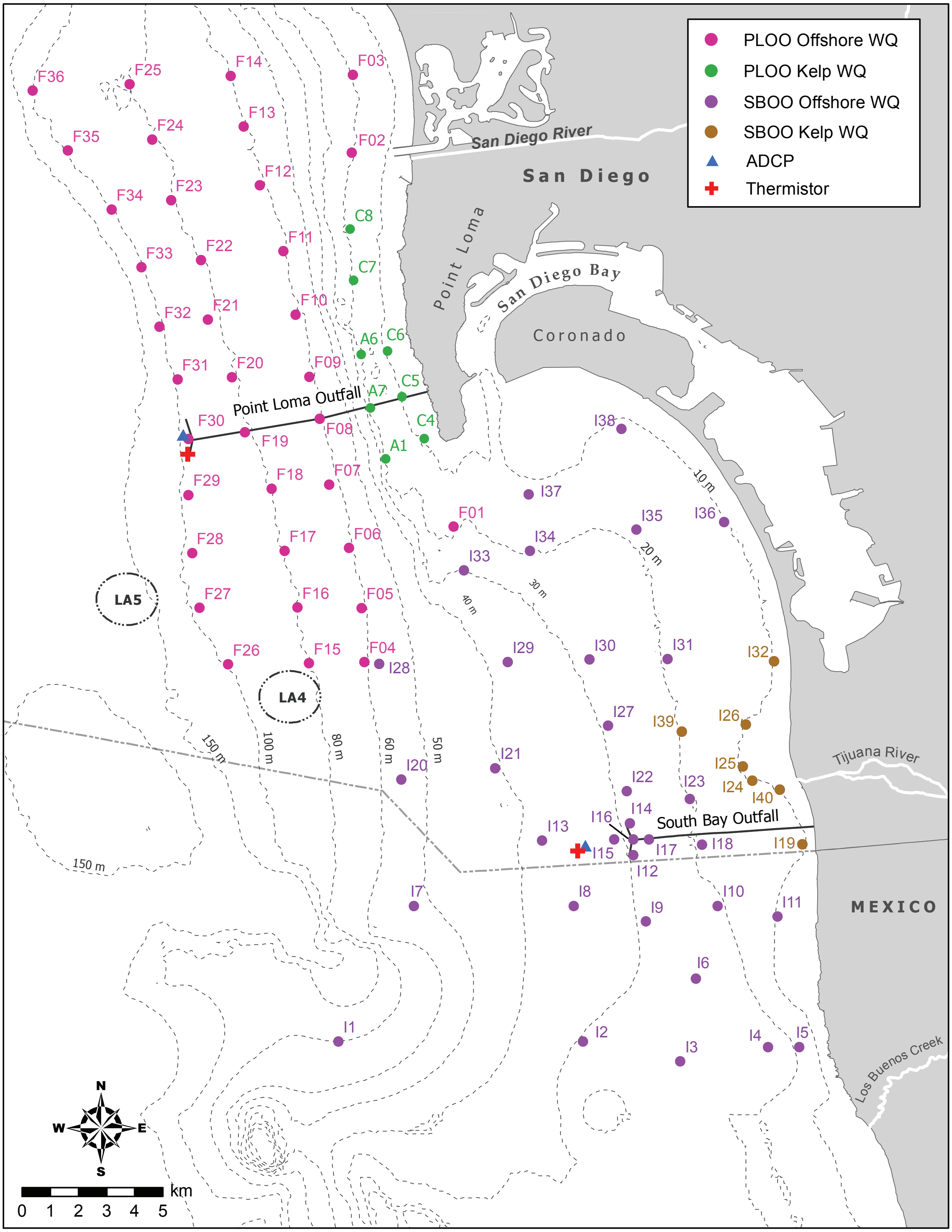

Figure 2.1
Locations of water quality (WQ) monitoring stations where CTD casts are taken around the Point Loma and South Bay Ocean Outfalls as part of the City of San Diego's Ocean Monitoring Program.

July 1–September 28, 2016, and April 8–September 5, 2017. Data were not available during these periods either due to servicing at the factory or equipment failure. Additional details for processing and analyzing the ADCP data are presented below under 'Data Analysis'.

Temperature data were collected every 10 minutes from 2015 through 2017 from duplicate thermistor strings located at the 100-m PLOO and 36-m SBOO sites. The individual thermistors (Onset Tidbit temperature loggers) were deployed on two mooring lines at each site starting at 2 m off the seafloor and extending in series every 4 m to within 6 m of the surface. Occasional gaps exist in the time series where individual thermistors were lost at sea or failed to record data properly. Additional details on specific methodology are available in Storms et al. (2006).

Remote Sensing

Coastal monitoring of the Point Loma and South Bay outfall regions during 2016–2017 included remote imaging analyses performed by Ocean Imaging based out of Littleton, CO. All satellite imaging data acquired during each year were made available for review and download from Ocean Imaging's website (Ocean Imaging 2018), while separate reports summarizing the results for each year were also produced (i.e., Svejkovsky 2017, Hess 2018). Several different types of satellite imagery were analyzed, including Moderate Resolution Imaging Spectroradiometer (MODIS), Thematic Mapper TM7 color/thermal, and high resolution RapidEye and Sentinel-2A Multispectral Instrument images. While these technologies differ in terms of capability and resolution, all are generally useful for revealing patterns in surface coastal waters to as deep as 12 m.

Data Analysis

CTD data collected at the PLOO and SBOO stations in 2017 are summarized in Addenda 2-1 and 2-2, while data collected in 2016 were reported previously (City of San Diego 2017) and are available online (City of San Diego 2018). Water column parameters were summarized as quarterly means pooled over all stations by the following depth layers: 1–20 m, 21–60 m, 61–80 m, 81–100 m. The top layer is herein referred to as surface water while the subsurface layers account for mid and bottom waters. Unless otherwise noted, analyses were performed using R (R Development Core Team, 2016) and various functions within the Hmisc, mixOmics, oce, Rmisc, RODBC, reshape2, and tidyverse packages (Hope 2013, Le Cao et al. 2016, Harrell et al. 2015, Kelley and Richards 2015, Ripley and Lapsley 2017, Wickham 2007, 2017).

Vertical density profiles were constructed to depict the pycnocline (i.e., depth layer where the density gradient was greatest) for each survey and to illustrate seasonal changes in water column stratification. Data for these density profiles were limited to stations located along the 100-m depth contour off Point Loma (i.e., stations F26–F36) and the 28-m depth contour in the SBOO region (i.e., stations I2, I3, I6, I9, I12, I14, I15, I16, I17, I22, I27, I30, I33) in order to prevent masking trends that occur when data from multiple depth contours are combined. Buoyancy frequency (BF), a measure of the static stability of the water column, was used to quantify the magnitude of stratification for each station per survey and was calculated as follows:

$$BF = \sqrt{(g/\rho * (d\rho/dz))}$$

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

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

Summary statistics for seasonal ocean current data were generated for each depth bin, while prevailing current variability was examined using two-dimensional histograms of frequency distributions. The top three PLOO depth bins and two SBOO depth bins were excluded from all analyses due to surface backscatter interference. Since ocean currents in southern California typically vary seasonally (Winant and Bratkovich 1981), ADCP data were subset into the following seasonal periods prior to subsequent analyses: winter (January–February); spring (March–May); summer (June–August); fall (September–December). In addition, since tidal currents are not likely to result in net water mass transport (Rogowski et al. 2012a), tidal values were removed prior to analyses using the PL33 filter (Alessi et al. 1984).

Results and Discussion

Oceanographic Conditions in 2016–2017

Water Temperature and Density

Ocean temperatures recorded during the 2016–2017 quarterly surveys followed expected seasonal patterns throughout the PLOO and SBOO regions, ranging from 9.7 to 16.0°C in winter, 9.6 to 19.3°C in spring, 10.1 to 24.0°C in summer, and 10.3 to 19.5°C in fall (Addenda 2-1, 2-2, City of San Diego 2017). The warmest water temperatures ranging from 22.9 to 24.0°C were recorded in the surface waters of both regions during the summer surveys (Figures 2.2, 2.3). These temperatures were up to 1.9°C warmer than maximum temperatures recorded during the previous year (City of San Diego 2016a,b). Cold water was apparent at sub-surface depths of the 60–100 m PLOO stations and the 28–55 m SBOO stations during most surveys over the past two years, although the coldest water temperatures (< 10°C) were recorded during the spring surveys. Shoaling of these cold waters into shallower depths may be indicative of spring upwelling. Continuous temperature data collected at both the PLOO 100-m and SBOO 36-m thermistor sites since 2015 also suggested that upwelling events may have occurred from early winter through fall (Figure 2.4). Additionally, these data depict warm surface temperatures > 16°C extending down to bottom depths in the SBOO region, and to depths greater than 60 m in the PLOO region, over several weeks in 2015 prior to the current reporting period. However, downwelling events like these were not observed in 2016 or 2017. Overall, these results are consistent with El Niño conditions present throughout the southern California Current region from fall 2014 through spring 2016 (Wells et al. 2017, NOAA/NWS 2018).

In shallow coastal waters of southern California and elsewhere, density is primarily influenced by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, seasonal changes in thermal stratification over the past two years were mirrored by density stratification of the water column during each survey (Figures 2.2, 2.3, 2.5, Appendices B.2, B.3). The water column ranged from minimally stratified in both regions during the winter surveys when maximum BF ranged from 3 to 6 cycles/min, to stratified in the spring and summer when maximum BF ranged from 9 to 17 cycles/min, and then to moderately stratified in fall when maximum BF ranged from 7 to 10 cycles/min (Figure 2.5). As expected, the depth of the pycnocline also varied by season, with shallower pycnocline depths (≤ 14 m) in spring and summer corresponding to greater stratification.

Salinity

Salinity also followed expected seasonal patterns throughout the PLOO and SBOO regions during 2016–2017, ranging from 32.72 to 33.90 ppt in winter, 33.20 to 34.20 ppt in spring, 33.21 to 34.02 ppt in summer, and 33.16 to 33.72 ppt in fall (Addenda 2-1, 2-2, City of San Diego 2017). Relatively high salinity values were recorded in near-bottom waters of both regions during most surveys, with the highest values occurring during the spring, which corresponded with the coldest temperatures as described above (Figures 2.2, 2.3, Appendices B.4, B.5). Taken together, these results further support the observation that local coastal upwelling appears to be strongest during the spring months (Jackson 1986). This is consistent with

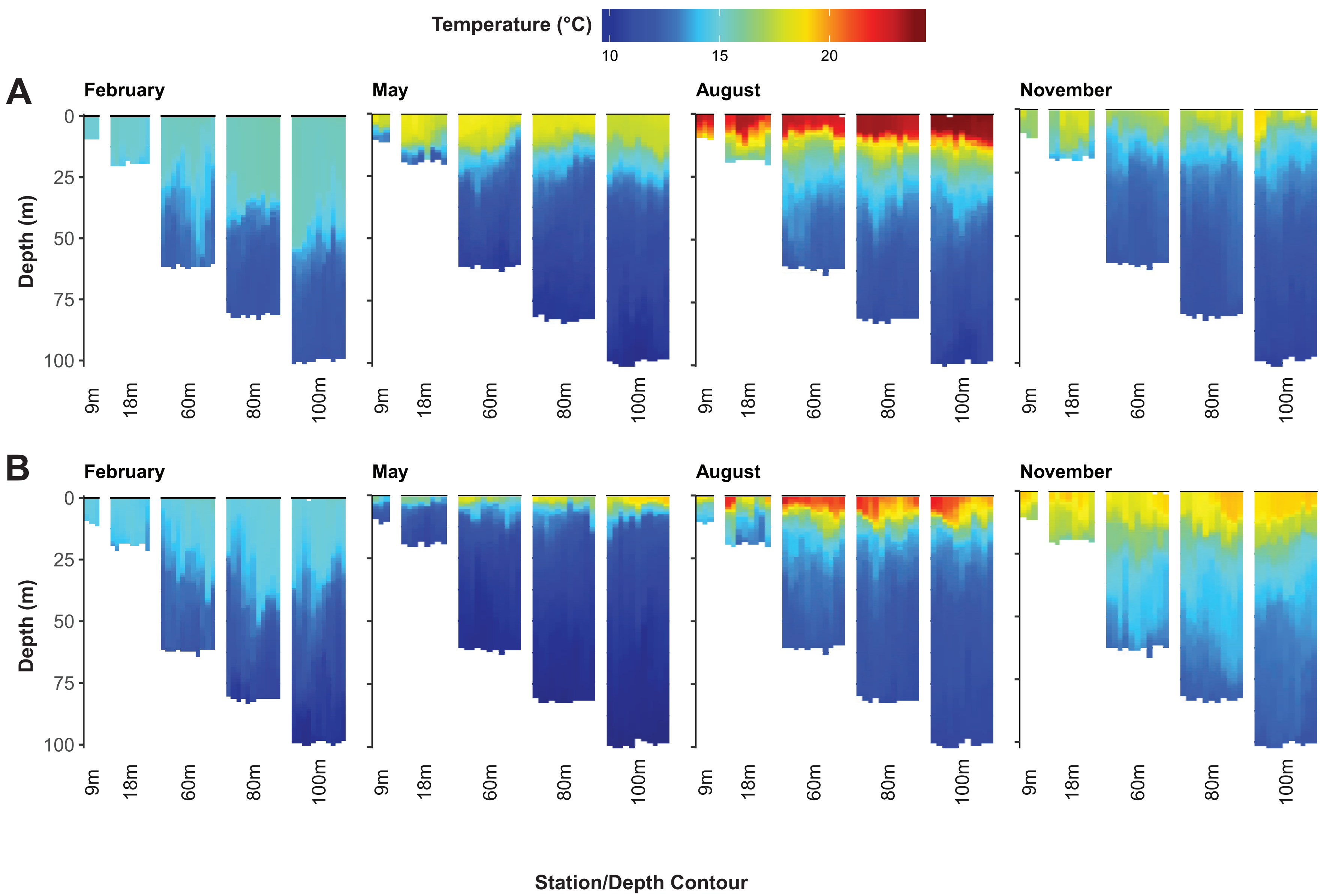

Figure 2.2
Temperature recorded in the PLOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over four days during each quarterly survey. Stations are depicted from north to south along each depth contour.

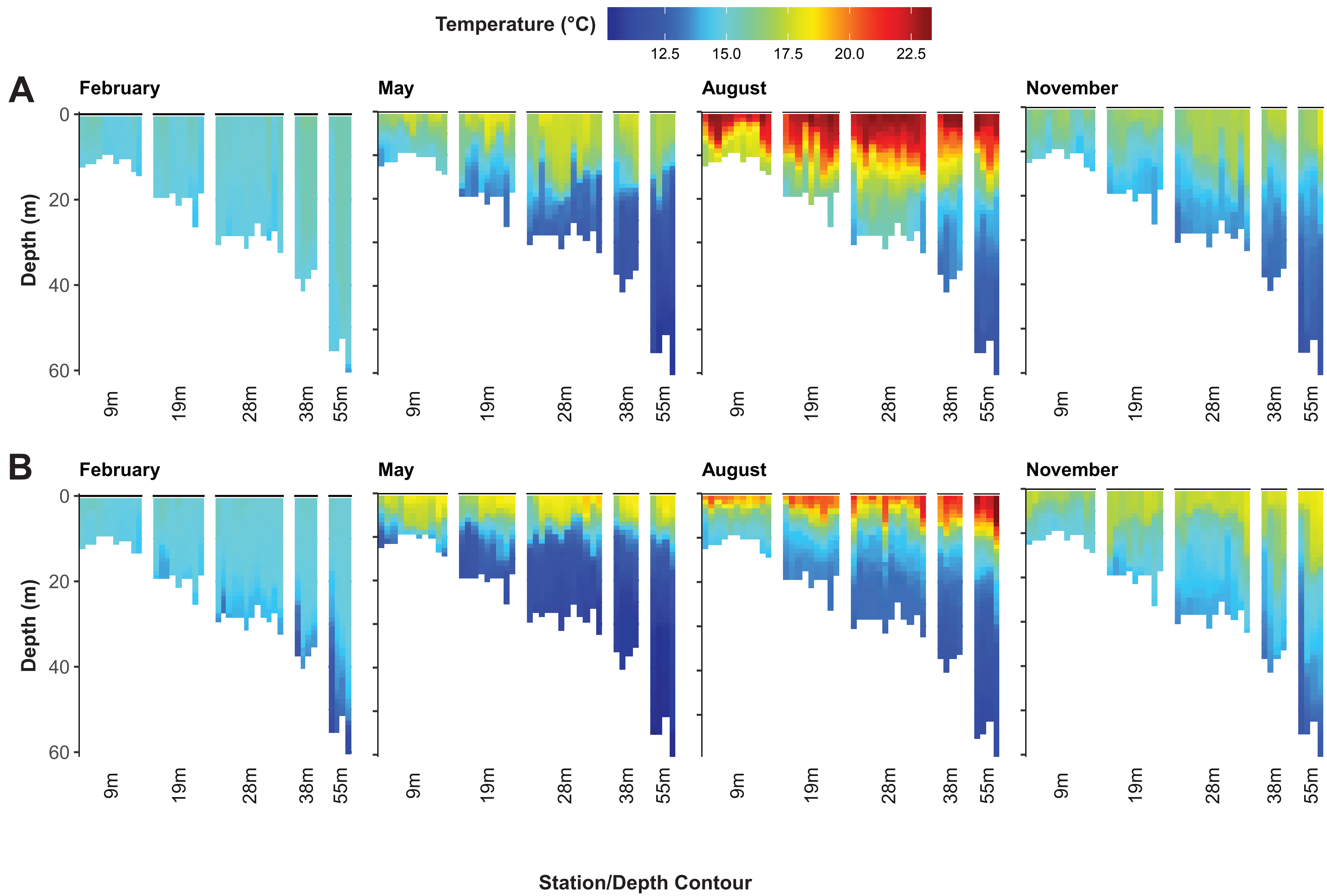

Figure 2.3
Temperature recorded in the SBOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over three days during each quarterly survey. Stations are depicted from north to south along each depth contour.

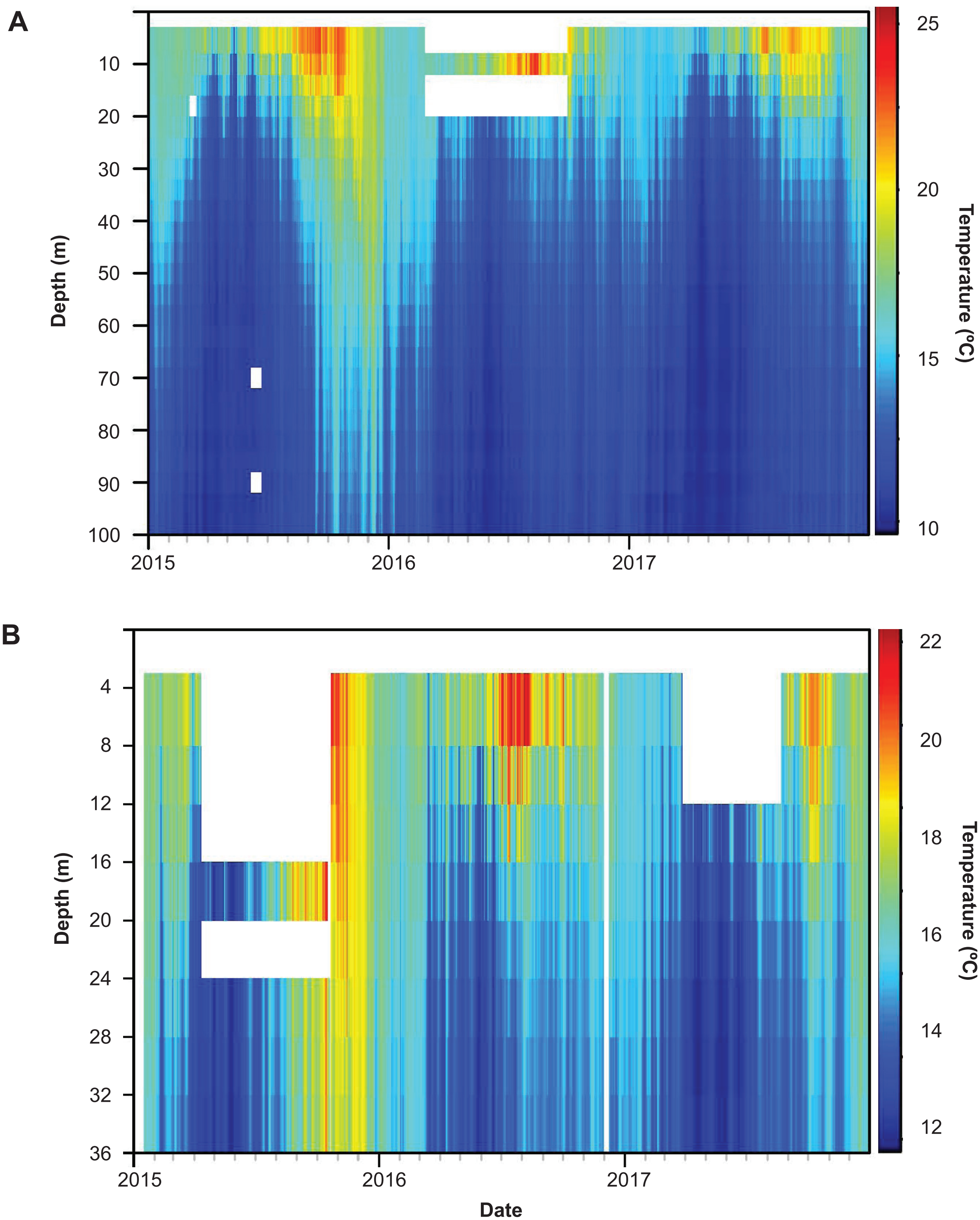

Figure 2.4
Temperature data collected from January 2015 through December 2017 at (A) the PLOO 100-m thermistor site and (B) the SBOO 36-m thermistor site. Data were collected every 10 minutes. Missing data due to instrument failure or loss shown as white spaces.

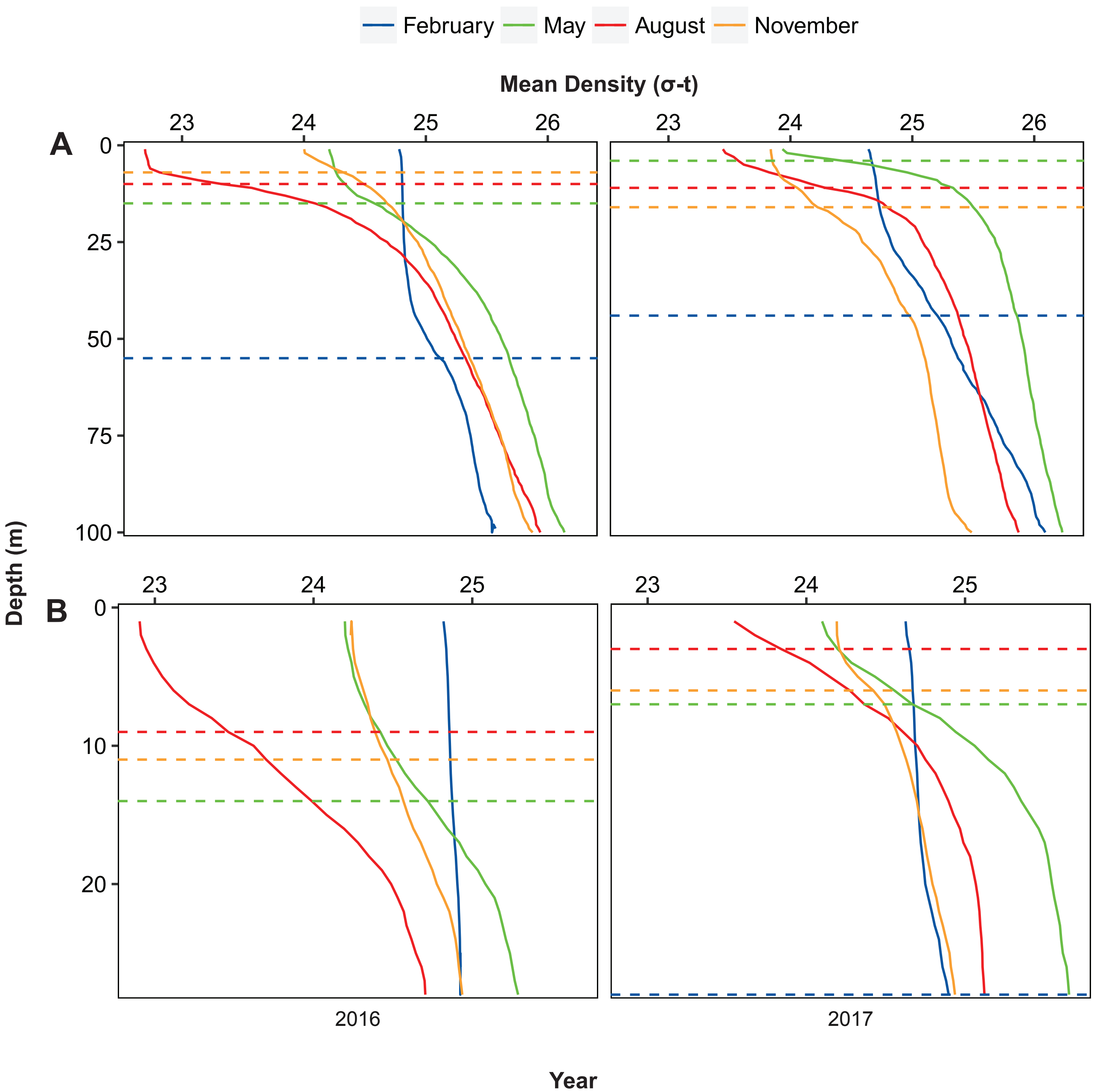

Figure 2.5

Mean density for each survey conducted during 2016 and 2017 at (A) PLOO depth stations (n = 11) and (B) SBOO depth stations (n = 13). Horizontal dashed lines indicate depth of maximum buoyancy frequency. Dashed line not shown for buoyancy frequencies less than 5.5 cycles/minute indicating a well mixed water column.

previous reports for the San Diego region and other areas of the Southern California Bight in recent years (e.g., City of San Diego 2016a,b, OCSD 2018). The lowest salinity values observed in 2016 and 2017 were reported during the winter surveys in surface waters at shallow, nearshore stations near the mouth of the Tijuana River and other sources of freshwater input that corresponded to rain events (Hess 2018, NWS 2018).

As in previous years, a layer of relatively low salinity water was evident at subsurface depths across the PLOO region during February, May and August of 2016, and again during May, August and November of 2017 (Appendix B.4). This subsurface salinity minimum layer (SSML) was most apparent at offshore PLOO stations along the 60, 80, and 100-m depth contours. The SSML was not evident within the SBOO region at all during the 2016–2017 reporting period (Appendix B.5), although it has been observed in this area previously (e.g., City of San Diego 2016b). It is unlikely that the SSML present in 2016–2017 was related to wastewater discharge via the PLOO. First, a recently published study of the PLOO effluent plume demonstrated that the plume disperses in only one direction at any given time and has a very weak salinity signature (Rogowski et al. 2012a,b, 2013). Second, similar SSMLs have been reported previously off San Diego and elsewhere in southern California, suggesting that this phenomenon is related to larger-scale oceanographic processes (e.g., City of San Diego 2011–2014a,b, 2015b,c, 2016a,b, LACSD 2016). Finally, other potential indicators of wastewater, such as elevated levels of fecal indicator bacteria or colored dissolved organic matter (CDOM), did not correspond to the SSML (see Chapter 3). Instead, the SSML may be partially due to a slight increase in salinity near the surface due to evaporation caused by seasonal atmospheric warming (Jones et al. 2002).

Dissolved Oxygen and pH

Dissolved oxygen (DO) concentrations within the PLOO and SBOO regions in 2016 and 2017 ranged from 3.5 to 8.9 mg/L in winter, 2.8 to 12.0 mg/L in spring, 3.5 to 14.0 mg/L in summer, and 4.2 to 10.0 mg/L in fall, while pH ranged from 7.7 to 8.2 in winter, 7.7 to 8.4 in spring, 7.6 to 8.4 in summer, and 7.8 to 8.4 in fall (Appendices B.6–B.9, Addenda 2-1, 2-2) (City of San Diego 2017). Changes in DO and pH were closely linked since both parameters reflect fluctuations in dissolved carbon dioxide associated with biological activity in coastal waters (Skirrow 1975). These ranges for both DO and pH were within historical values for the San Diego region (City of San Diego 2015a,b,c, 2016a,b).

Distributions of DO and pH in the coastal waters off San Diego followed expected patterns that generally corresponded to seasonal fluctuations in water column stratification and phytoplankton productivity. For example, high DO and pH values were recorded in near-bottom waters of both the PLOO and SBOO regions during most surveys conducted in 2016 and 2017 (Appendices B.6–B.9). The highest values for both parameters occurred during the spring, which was likely due to upwelling of cold, saline, oxygen-poor water moving inshore similar to the pattern described above for temperature and salinity. Conversely, higher DO and pH concentrations were often associated with phytoplankton blooms as evident from relatively high chlorophyll *a* concentrations (see below). Such dense accumulations of phytoplankton just below the thermocline can cause the waters to become supersaturated with oxygen. This relationship was most evident at the 60–100 m PLOO and 28–55 m SBOO stations in May 2017 (Appendices B.6, B.7, B.12, B.13).

Transmissivity

Although water clarity (transmissivity) ranged widely from <1 to 94% throughout the PLOO and SBOO regions, values were generally quite high, exceeding 80% during most of 2016 and 2017 (Addenda 2-1, 2-2, City of San Diego 2017). The lowest transmissivity values (<25%) were observed during November 2016 and February 2017 at the nearshore 9-m depth PLOO stations, and during February and May of both years at the nearshore 9-m SBOO stations (Appendices B.10, B.11, Addenda 2-1, 2-2). Low transmissivity was most often observed at shallow monitoring stations located close to shore where the influence of waves, currents, and land-based turbidity plumes was most acute. For example, reduced water clarity in February 2017 at the 9-m PLOO and SBOO stations coincided with increased turbidity along the coast that was likely due to recent rain activity and large waves (Figure 2.6, CDIP 2018, Hess 2018). Other patches of low transmissivity during spring and summer surveys were associated with high concentrations of chlorophyll *a,* indicative of dense accumulations of phytoplankton cells (see below). Finally, low transmissivity values were also occasionally observed near the bottom at stations located along all depth contours indicating a possible resuspension of soft sediments caused by the CTD approaching or hitting the seafloor.

Chlorophyll a

Concentrations of chlorophyll *a* ranged from <0.1 to 59 µg/L across the PLOO and SBOO regions in 2016 and 2017 (Addenda 2-1, 2-2, City of San Diego 2017). Elevated chlorophyll *a* levels were recorded at depths from ~15 to 30 m along all depth contours in both outfall regions during May 2017, corresponding to the strongest indicators of local upwelling, and to depths associated with (or just below) the mixed layer (Appendices B.12, B.13). These results reflect the tendency for phytoplankton to accumulate along isopycnals near the thermocline where deeper water nutrients are available and light is not yet limiting (Lalli and Parsons 1993). While no surface phytoplankton blooms were observed during the quarterly CTD surveys conducted during the past two years, satellite imagery taken during this period showed evidence of surface algal blooms during February and November 2016, and February, May and November 2017 (Svejkovsky 2017, Hess 2018).

Summary of Ocean Currents in 2015–2017

Ocean currents in the San Diego region varied by season and depth in the PLOO and SBOO regions during the 2016–2017 reporting period as well as throughout 2015. Current velocity off Point Loma, averaged by 1-m depth bin over these three years for each season, ranged from 57 to 152 mm/s during winter, 43 to 205 mm/s during spring, 48 to 132 mm/s during summer, and 57 to 140 mm/s during fall at the 100-m PLOO ADCP site (Appendices B.14, B.15). Current velocity at the 36-m SBOO ADCP site ranged from 60 to 120 mm/s during winter, 50 to 108 mm/s during spring, 50 to 109 mm/s during summer, and 57 to 104 mm/s during fall. The highest mean speeds occurred in surface waters, and then decreased with depth during all seasons for both locations. Additionally, most observations of current direction fell along a northwest/southeast axis of variation regardless of season or outfall region (Figures 2.7, 2.8). These results are consistent with previous studies off San Diego demonstrating that local ocean currents tend to travel along-coast (i.e., Winant and Bratkovich 1981, Rogowski et al. 2012a).

Historical Assessment of Oceanographic Conditions

A review of temperature, salinity, and DO data from all outfall depth stations sampled from 1991 through 2017 indicates how the PLOO and SBOO regions have responded to long-term climate-related changes in the SCB (Figure 2.9). Overall, these

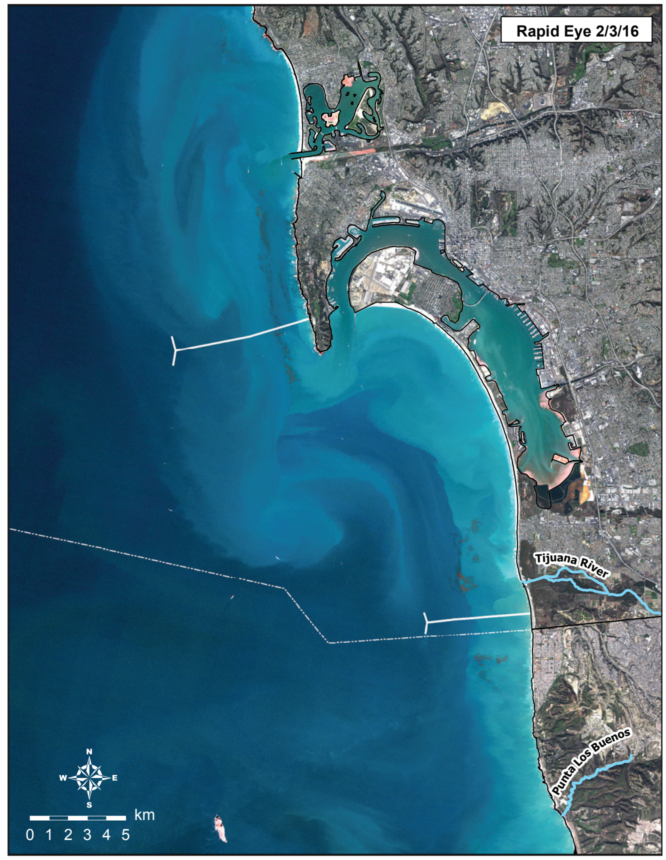

Figure 2.6
Rapid Eye satellite image of the San Diego region acquired February 3, 2016 (Ocean Imaging 2018) depicting increased turbidity along the coast.

results are consistent with large-scale temporal patterns in the California Current System (CCS) associated with ENSO, PDO and NPGO events (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, Leising et al. 2014, 2015, NOAA/NWS 2018). For example, nine major events have affected SCB coastal waters during the last two decades: (1) the colossal El Niño of 1997–1998; (2) a shift to cold ocean conditions reflected in ENSO and PDO indices from 1999 to 2002; (3) a subtle but persistent return to warm ocean conditions in the CCS that began in October 2002 and lasted through 2006; (4) the intrusion of subarctic waters into the CCS that resulted in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña in 2007 that coincided with a PDO cooling event and a return to positive NPGO values indicating an increased flow of cold, nutrient-rich water from the north; (6) development of another La Niña starting in May 2010; (7) a region-wide warming, beginning in

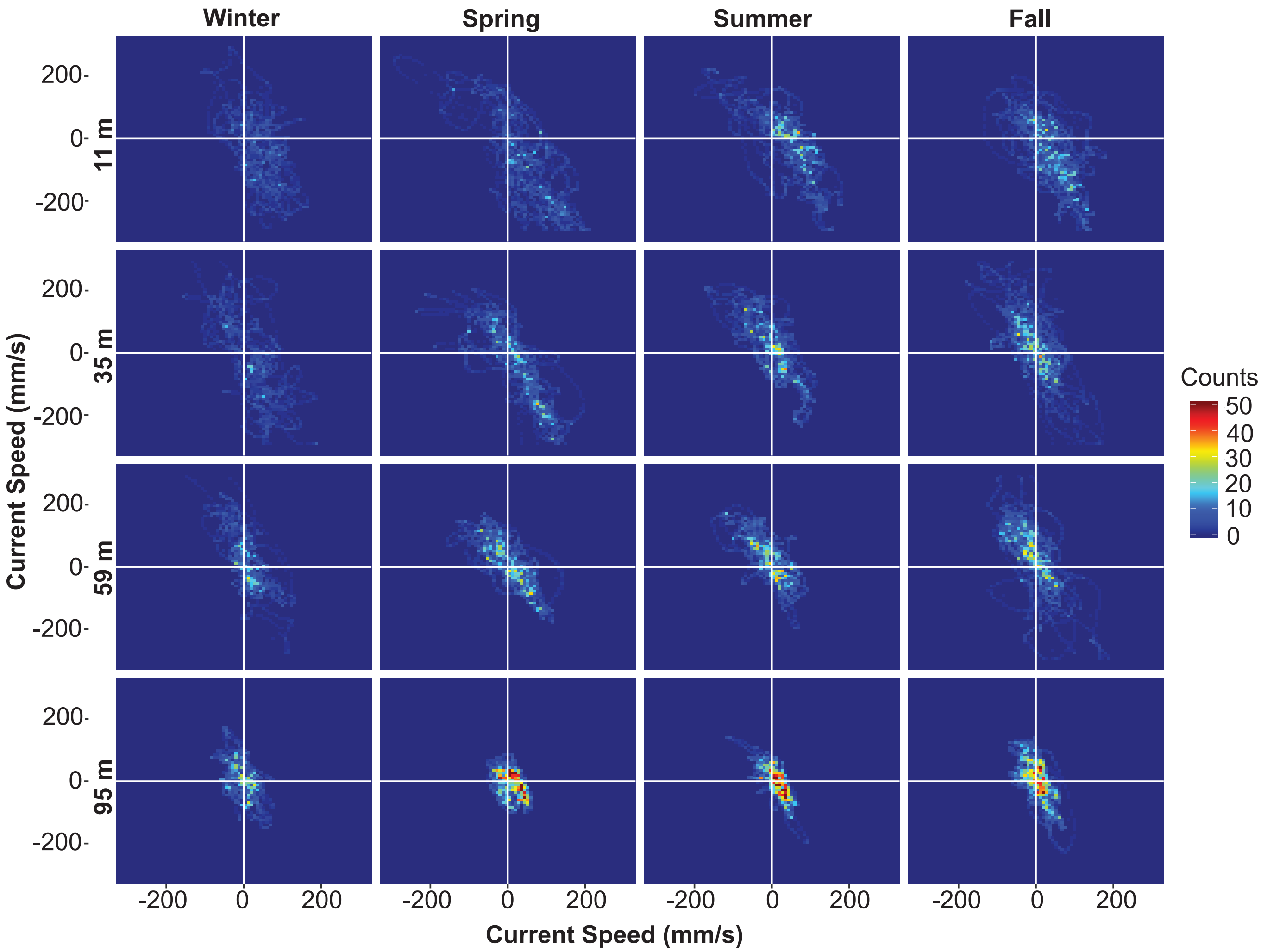

Figure 2.7

Frequency distribution by season of current speed (mm/s) and direction from 2015 through 2017 at the PLOO ADCP mooring location at representative depth bins. On the x-axis, positive values indicate an eastward direction while negative values indicate a westward direction. On the y-axis, positive values indicate a northward direction while negative values indicate a southward direction.

the winter of 2013/2014, when the PDO, NPGO and MEI (Multivariate ENSO Index) all changed phase; (8) the colossal El Niño of 2015; (9) a weak La Niña in mid to late 2016. Temperature and salinity data for the entire San Diego region are generally consistent with all but a third of these CCS events. For example, while the CCS was experiencing a warming trend through 2006, the PLOO region experienced cooler than normal conditions during much of 2005 and 2006. Additionally, conditions in San Diego waters during 2005–2006 were more consistent with observations from northern Baja California where water temperatures were well below the decadal mean (Peterson et al. 2006). Ocean temperatures were also warmer than the long-term average during February, May, and August 2016. These results corresponded to El Niño conditions that lasted until spring 2016 before switching to being relatively cool in November 2016, a pattern that corresponded well with a La Niña that lasted from summer 2016 through winter 2017. Subsequent deviations from the long-term average have been minor, reflecting the ENSO neutral conditions that have endured most of 2017 (NOAA/NWS 2018).

Historical trends in local DO concentrations reflect several periods during which lower than normal DO has aligned with low water temperatures and high salinity (Figure 2.9). The alignment of these anomalies is consistent with cold, saline, and

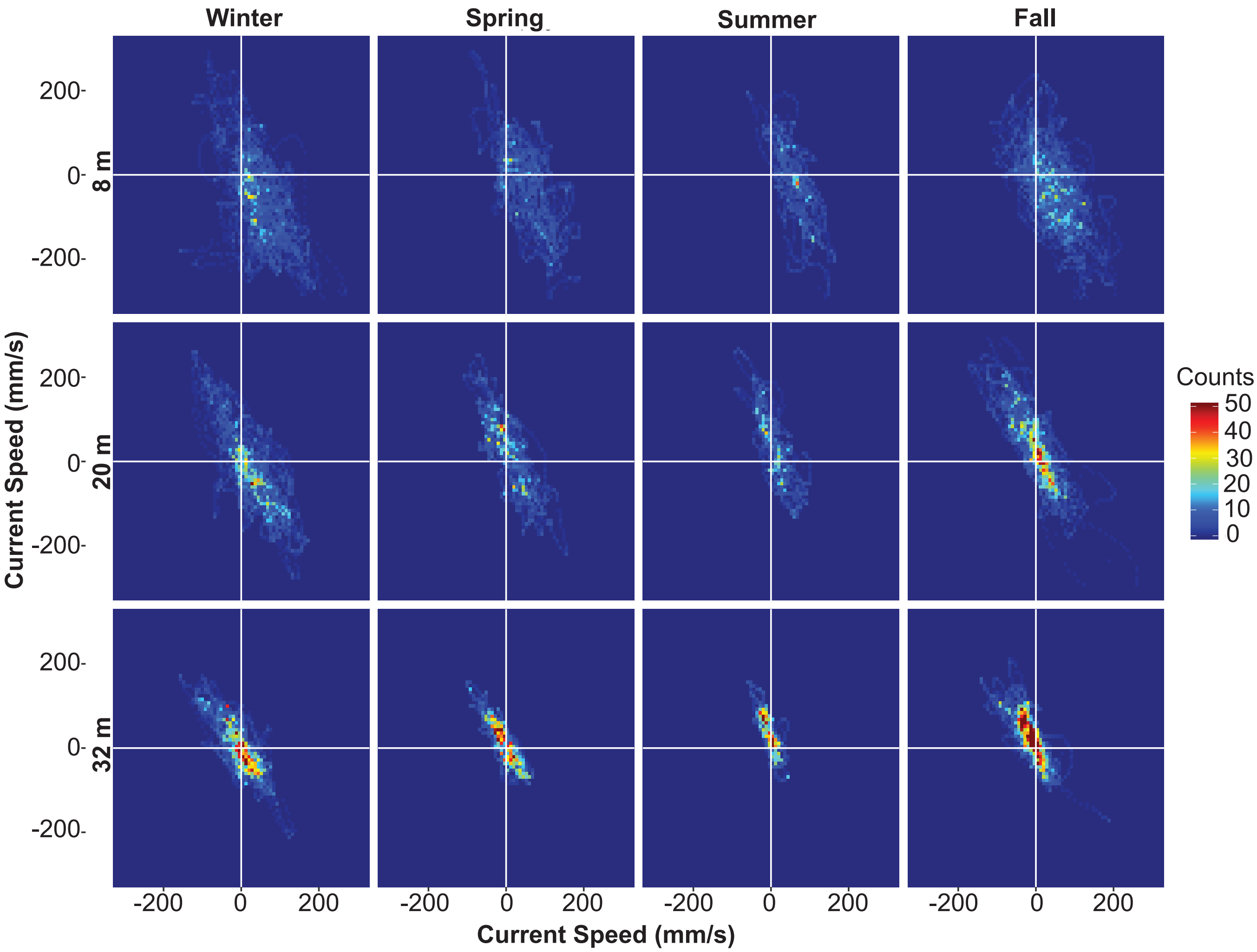

Figure 2.8
Frequency distribution by season of current speed (mm/s) and direction from 2015 through 2017 at the SBOO ADCP mooring location at representative depth bins. On the x-axis, positive values indicate an eastward direction while negative values indicate a westward direction. On the y-axis, positive values indicate a northward direction while negative values indicate a southward direction.

oxygen-poor ocean waters due to strong local coastal upwelling (e.g., 2002, 2005–2012). The overall decrease in DO in the PLOO and SBOO regions over the past decade has been observed throughout the entire CCS and may be linked to changing ocean climate (Bjorkstedt et al. 2012). However, these large negative anomalies have been absent since mid-2013 and conditions were again near neutral during most of 2016 and 2017.

Summary

Oceanographic conditions in the PLOO and SBOO regions during 2016 and 2017 followed typical seasonal patterns for the coastal waters off San Diego. For example, maximum water column stratification occurred during mid-summer, while well-mixed waters were present during the winter. Ocean conditions indicative of local coastal upwelling, such as relatively cold, dense waters with low DO and pH at subsurface depths, were most evident during the spring of both years. Phytoplankton blooms, indicated by high chlorophyll *a* concentrations, were evident at subsurface depths during May 2017, while other bloom events visible in satellite images occurred throughout 2016 and 2017 (Svejkovsky 2017, Hess 2018). These results are similar to findings reported previously for the San Diego region (City of San Diego 2015a,b,c, 2016a,b) and are consistent

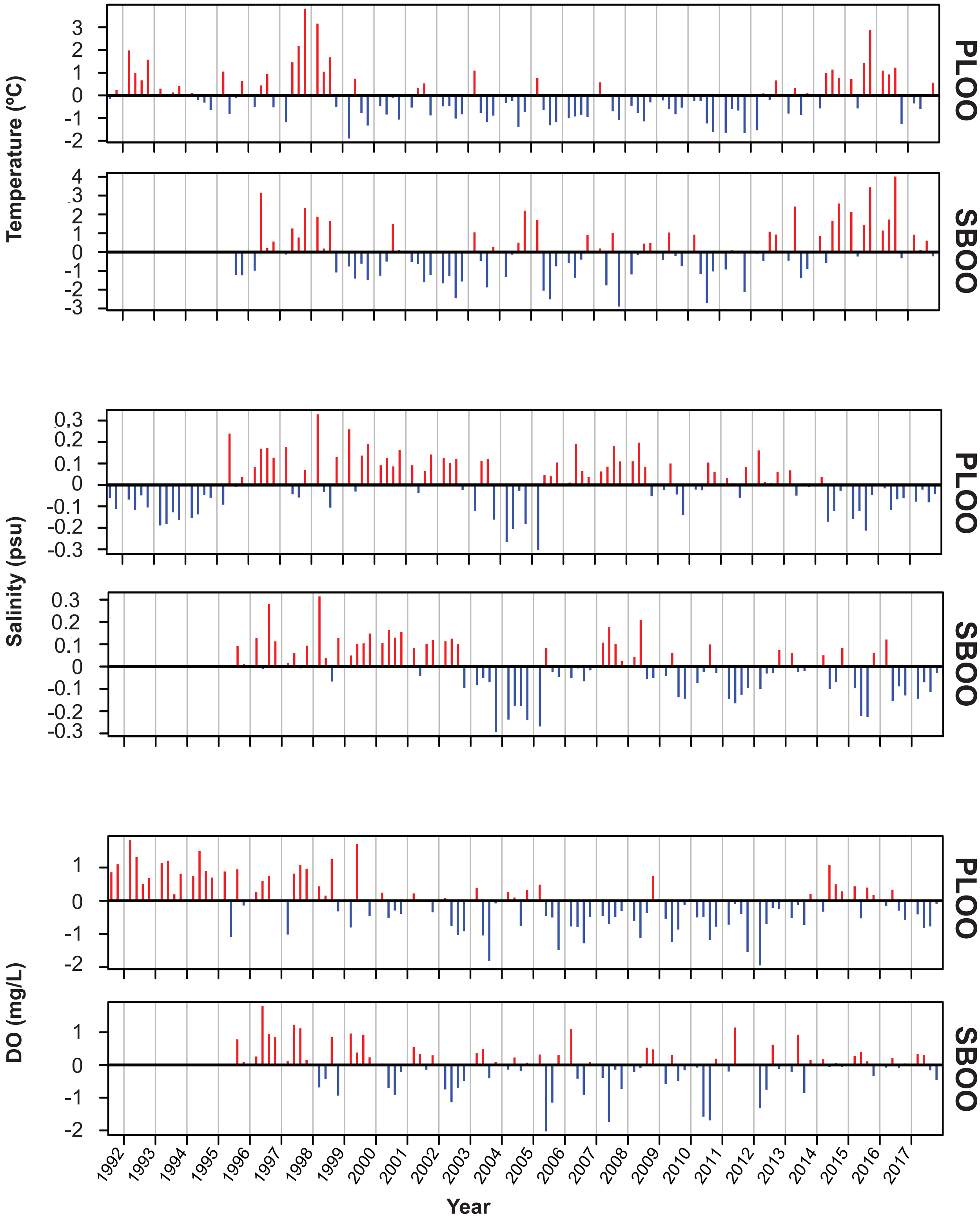

Figure 2.9
Time series of temperature, salinity, and dissolved oxygen (DO) anomalies from 1991 through 2017 at Point Loma outfall depth stations (n = 11) and South Bay outfall depth stations (n = 13), all depths combined. Monitoring at the SBOO stations began in 1995.

with long-term trends in the SCB (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, Leising et al. 2014, 2015, NOAA/NWS 2018) and with conditions in northern Baja California waters (Peterson et al. 2006). These observations suggest that most of the temporal and spatial variability observed in oceanographic parameters off San Diego is explained by a combination of local (e.g., coastal upwelling, rain-related runoff) and large-scale oceanographic processes (e.g., ENSO, PDO, NPGO).

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Chapter 3
Water Quality Compliance & Plume Dispersion

Chapter 3. Water Quality Compliance and Plume Dispersion

Introduction

The City of San Diego conducts extensive monitoring along the shoreline (beaches), nearshore (e.g., kelp forests), and other offshore coastal waters surrounding the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively) to characterize regional water quality conditions and to identify possible impacts of wastewater discharge or other contaminant sources on the marine environment. Densities of fecal indicator bacteria, including total coliforms, fecal coliforms, and *Enterococcus*, are measured and evaluated in context with various oceanographic parameters (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged into the Pacific Ocean through these two outfalls. Evaluation of these data may also help to identify other sources of bacterial contamination off San Diego. In addition, the City's water quality monitoring efforts are designed to assess compliance with the bacterial water contact standards and other physical and chemical water quality objectives specified in the California Ocean Plan (Ocean Plan) (SWRCB 2012) that are intended to help protect the beneficial uses of State ocean waters.

Multiple sources of bacterial contamination exist in the Point Loma and South Bay outfall monitoring regions, and being able to separate any impact that may be associated with wastewater discharge from other point or non-point sources of contamination is often challenging. Examples of other possible contaminant sources include outflows from the San Diego River, 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 terrestrial runoff from local watersheds during storms or other wet weather events can also flush sediments and contaminants into nearshore coastal waters (Noble et al. 2003, Reeves et al. 2004, Sercu et al. 2009, Griffith et al. 2010). Moreover, decaying kelp and seagrass (beach wrack), sediments and sludge accumulating in storm drains, and sandy beach sediments themselves can serve as reservoirs for bacteria until release into coastal waters by returning tides, rain events, or other disturbances (Gruber et al. 2005, Martin and Gruber 2005, Noble et al. 2006, Yamahara et al. 2007, Phillips et al. 2011). Further, the presence of shore birds and their droppings has been associated with high bacterial counts that may impact nearshore water quality (Grant et al. 2001, Griffith et al. 2010).

In order to better understand potential impacts of a wastewater plume on ocean conditions, analytical tools using natural chemical tracers can be leveraged to detect and distinguish an outfall's effluent signal from other non-point sources. For example, colored dissolved organic material (CDOM) has proved useful in identifying wastewater plumes from the PLOO and SBOO in the San Diego region (Terrill et al. 2009, Rogowski et al. 2012a,b, 2013). The reliability of plume detection can be improved by combining measurements of CDOM with additional metrics (e.g., low chlorophyll *a* concentrations), thus facilitating quantification of possible wastewater impacts on coastal waters.

This chapter presents an analysis and assessment of bacterial distribution patterns, ocean chemistry, and other oceanographic data collected during calendar years 2016 and 2017 at more than 100 permanent water quality monitoring stations surrounding the PLOO and SBOO. The primary goals are to: (1) document overall water quality conditions off San Diego; (2) distinguish the PLOO and SBOO wastewater plumes from other possible sources of contamination; (3) evaluate potential movement and dispersal of the PLOO and SBOO plumes; (4) assess compliance with Ocean Plan water contact standards. Results of remote sensing observations (i.e., satellite imagery) for the San Diego and Tijuana regions are also evaluated to provide insight into the transport and dispersal of wastewater and other types of surface water plumes during the study period.

Materials and Methods

Field Sampling

Shore stations

Seawater samples were collected weekly at 19 shoreline stations to monitor concentrations of fecal indicator bacteria (FIB) in waters adjacent to public beaches (Figure 3.1). Sixteen of these stations are located in California State waters and are therefore subject to Ocean Plan water contact standards (Box 3.1, SWRCB 2012). These include eight PLOO stations (D4, D5, D7, D8/D8-A, D9, D10, D11, D12) located from Mission Beach southward to the tip of Point Loma and eight SBOO stations (S4, S5, S6, S8, S9, S10, S11, S12) located between the USA/Mexico border and Coronado. The other three SBOO shoreline stations (S0, S2, S3) are located south of the border and are not subject to Ocean Plan requirements.

Seawater samples were collected from the surf zone at each of the above stations in sterile 250-mL bottles, after which they were transported on blue ice to the City's Marine Microbiology Laboratory and analyzed to determine concentrations of three types of FIB (i.e., total coliform, fecal coliform, and *Enterococcus* bacteria). In addition, weather conditions and visual observations of water color, surf height, and human or animal activity were recorded at the time of collection. These observations were previously reported in monthly receiving waters monitoring reports submitted to the San Diego Regional Water Quality Control Board and USEPA (see City of San Diego 2016–2018a,b).

Kelp and offshore stations

Fifteen stations located in relatively shallow waters within or near the Point Loma or Imperial Beach kelp beds (i.e., referred to as "kelp" stations herein) were monitored four to five times each month to assess water quality conditions and Ocean Plan compliance in nearshore areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking (Figure 3.1). These included PLOO stations C4, C5, and C6 located along the 9-m depth contour near the inner edge of the Point Loma kelp forest, PLOO stations A1, A6, A7, C7, and C8 located along the 18-m depth contour near the outer edge of the Point Loma kelp forest, SBOO stations I25, I26, and I39 located at depths of 9–18 m contiguous to the Imperial Beach kelp bed, and SBOO stations I19, I24, I32, and I40 located in other nearshore waters along the 9-m depth contour.

An additional 69 offshore stations were sampled quarterly to monitor water quality conditions and to estimate dispersion of the PLOO and SBOO wastewater plumes. These stations were monitored during February, May, August, and November in both 2016 and 2017, with the 36 PLOO and 33 SBOO stations sampled over four and three consecutive days, respectively, during each survey (Appendix C.1). Stations F1–F36 are arranged in a grid surrounding the PLOO along or adjacent to the 18, 60, 80, and 100-m depth contours, while stations I1–I40 are arranged in a grid surrounding the SBOO along the 9, 19, 28, 38, and 55-m depth contours (Figure 3.1). Of these, 15 of the PLOO stations (i.e., F01–F03, F06–F14, F18–F20) and 15 of the SBOO stations (i.e., I12, I14, I16–I18, I22–I23, I27, I31, I33–I38) are located within State jurisdictional waters (i.e., within 3 nautical miles of shore) and therefore subject to the Ocean Plan compliance standards.

Seawater samples for FIB analyses were collected from 3–5 discrete depths at the kelp and offshore stations as indicated in Table 3.1. These samples were typically collected using a rosette sampler fitted with Niskin bottles surrounding a central CTD, although replacement samples due to misfires or other causes may have been collected from a separate follow-up cast using stand-alone Van Dorn bottles if necessary. All weekly kelp/nearshore samples and quarterly offshore

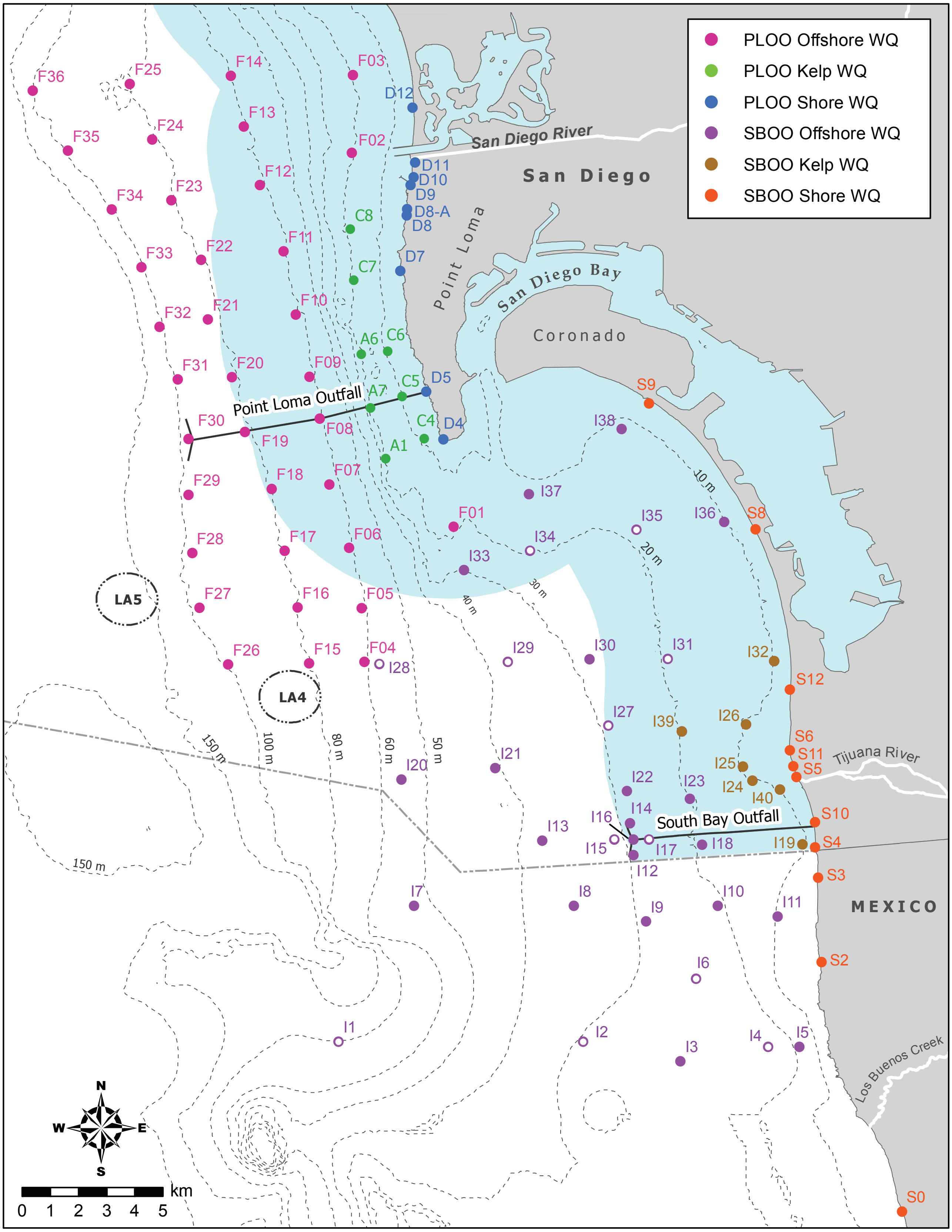

Figure 3.1

Water quality (WQ) monitoring station locations sampled around the Point Loma and South Bay Ocean Outfalls as part of the City of San Diego's Ocean Monitoring Program. Open circles are sampled by CTD only. Light blue shading represents State jurisdictional waters.

Box 3.1

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

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

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

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

B. Physical Characteristics

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

C. Chemical Characteristics

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

SBOO samples were analyzed for all three types of FIB, while the quarterly offshore PLOO samples were only analyzed for *Enterococcus* per permit requirements. All FIB samples were refrigerated at sea and then transported on blue ice to the City's Marine Microbiology Lab for processing and analysis. Oceanographic data were collected simultaneously with the water samples at each station using the central CTD to measure temperature, conductivity (salinity), pressure (depth), chlorophyll *a*, CDOM, dissolved oxygen (DO), pH, and transmissivity (see Chapter 2). Visual observations of weather, sea conditions, and human and/or animal activity were also recorded at the time of sampling. These latter observations were also reported previously in monthly receiving waters monitoring reports submitted to the San Diego Regional Water Quality Control Board and USEPA (see City of San Diego 2016–2018a,b).

Additional seawater aliquots were collected for analysis of ammonium at a subset of the PLOO stations, as well as for total suspended solids (TSS) and oil and grease (O&G) at a subset of the SBOO stations during the quarterly sampling surveys. However, the requirement for monitoring these parameters was discontinued for the PLOO stations effective October 1, 2017 and for the SBOO stations effective December 13, 2017. Because of these regulatory changes and since the results for these analyses have been reported previously in various monthly receiving waters monitoring reports (City of San Diego 2016–2018a,b), these parameters are not discussed further herein.

Laboratory Analyses

The City's Marine Microbiology Laboratory follows guidelines issued by the USEPA Water

Table 3.1

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

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

Station Contour	SBOO Sample Depth (m)							
	2	6	9/11	12	18	27	37	55
Kelp Bed								
9-m	x	x	x[a]					
18-m	x			x	x			
Offshore								
9-m	x	x	x[a]					
18-m	x			x	x			
28-m	x				x	x		
38-m	x				x		x	
55-m	x				x			x

[a] Stations I25, I26, I32, and I40 sampled at 9 m; stations I11, I19, I24, I36, I37, and I38 sampled at 11 m

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

FIB densities were determined and validated in accordance with USEPA and APHA guidelines (Bordner et al. 1978, APHA 2005, USEPA 2006). Plates with FIB counts above or below the ideal counting range were given greater than (>), greater than or equal to (≥), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values when calculating means and in determining compliance with Ocean Plan standards.

Quality assurance tests were performed routinely on bacterial samples to ensure that analyses and sampling variability did not exceed acceptable limits. Laboratory and field duplicate bacteriological samples were processed according to method requirements to measure analyst precision and variability between samples, respectively. Results of these procedures were reported under separate cover (City of San Diego 2017b, 2018a).

Data Analyses

Bacteriology

Compliance with Ocean Plan water contact standards was summarized as the number of times per sampling period that each shore, kelp, and offshore station within State waters exceeded geometric mean or single sample maximum (SSM) standards for total coliforms, fecal coliforms, and *Enterococcus* (Box 3.1, SWRCB 2012). Data for individual exceedances of these standards at the PLOO and SBOO stations sampled during 2017 are listed in Addenda 3-1 and 3-2. Data collected during 2016 were reported previously (City of San Diego 2017a) and are available online (City of San Diego 2018b). These analyses were performed using R (R Core Team, 2016) and various functions within the gtools, Hmisc, psych, reshape2, RODBC, and tidyverse packages (Wickham 2007, 2017, Harrell et al. 2015, Warnes et al. 2015, Revelle 2015, Ripley and Lapsley 2017).

Wastewater Plume Detection and Out-of-Range Calculations

Presence or absence of the wastewater plume at the PLOO and SBOO offshore stations was estimated by evaluation of a combination of oceanographic parameters (i.e., detection criteria). All stations along the 9-m depth contour were excluded from analyses due to the potential for coastal runoff or sediment resuspension in shallow nearshore waters to confound any CDOM signal that could be associated with plume dispersion from the outfalls (Appendices C.1, C.2). Previous monitoring results have consistently shown that the PLOO plume remains trapped below the pycnocline with no evidence of surfacing throughout the year (City of San Diego 2010a–2014a, 2015b, 2016a, Rogowski et al. 2012a,b, 2013). In contrast, the SBOO plume stays trapped below the pycnocline during seasonal periods of water column stratification, but may rise to the surface when waters become more mixed and stratification breaks down (City of San Diego 2010b–2014b, 2015c, 2016b, Terrill et al. 2009). Water column stratification and pycnocline depth were quantified using buoyancy frequency (BF, cycles/min) calculations for each quarterly survey. This measure of the water column's static stability was used to quantify the magnitude of stratification for each survey and was calculated as follows:

$$BF = \sqrt{g/\rho * (d\rho/dz)}$$

where g is the acceleration due to gravity, ρ is the seawater density, and dρ/dz is the density gradient (Mann and Lazier 1991). The depth of maximum BF was used as a proxy for the depth at which stratification was the greatest. If the water column was determined to be stratified (i.e., maximum BF > 5.5 cycles/min), subsequent analyses were limited to depths below the pycnocline.

Identification of potential plume signal at each monitoring station was based on a combination of CDOM, chlorophyll *a*, and salinity levels, as well as a visual review of the overall water column profile. Detection thresholds for the PLOO and SBOO stations were set adaptively for each quarter according to the criteria described in City of San Diego (2016a,b). It should be noted that these thresholds are based on observations of ocean properties specific to the distinct PLOO and SBOO monitoring regions, and are thus constrained to use within those regions. Finally, water column profiles were visually interpreted to remove stations with spurious signals (e.g., CDOM signals near the seafloor that were likely caused by sediment resuspension). All analyses were performed using R (R Core Team, 2016) and the various functions within the oce, reshape2, Rmisc, RODBC and tidy verse packages (Wickham 2007, 2017, Hope 2013, Kelley and Richards 2015, Ripley and Lapsley 2017).

The effect of any potential "plume detection" on local water quality was evaluated by comparing mean values of DO, pH, and transmissivity within the possible plume boundaries to thresholds calculated for the same depths from reference stations. Stations with CDOM values below the 85th percentile were considered "reference" (Appendix C.3). Individual non-reference stations were then determined to be out-of-range (OOR) compared to the reference stations if values for the above parameters exceeded narrative water quality standards defined in the Ocean Plan (see Box 3.1). For example, the Ocean Plan defines OOR thresholds for DO as a 10% reduction from that which occurs naturally, for pH as a 0.2 pH unit change, and for transmissivity as below the lower 95% confidence interval from the mean. For purposes of this report, "naturally" is defined for DO as the mean concentration minus one standard deviation (see Nezlin et al. 2016).

Results and Discussion

Bacteriological Compliance and Distribution

Shore stations

Overall compliance with the Ocean Plan water contact standards specified in Box 3.1 was high at the PLOO shore stations in 2016–2017. Seawater samples collected from these eight stations were 100% compliant with the 30-day total coliform and fecal coliform geometric mean standards, while compliance with the 30-day *Enterococcus* geometric mean standard was 60–100% (Figure 3.2). Compliance with the single sample maximum (SSM) standards at these sites was 88–100% for total coliforms, 90–100% for fecal coliforms,

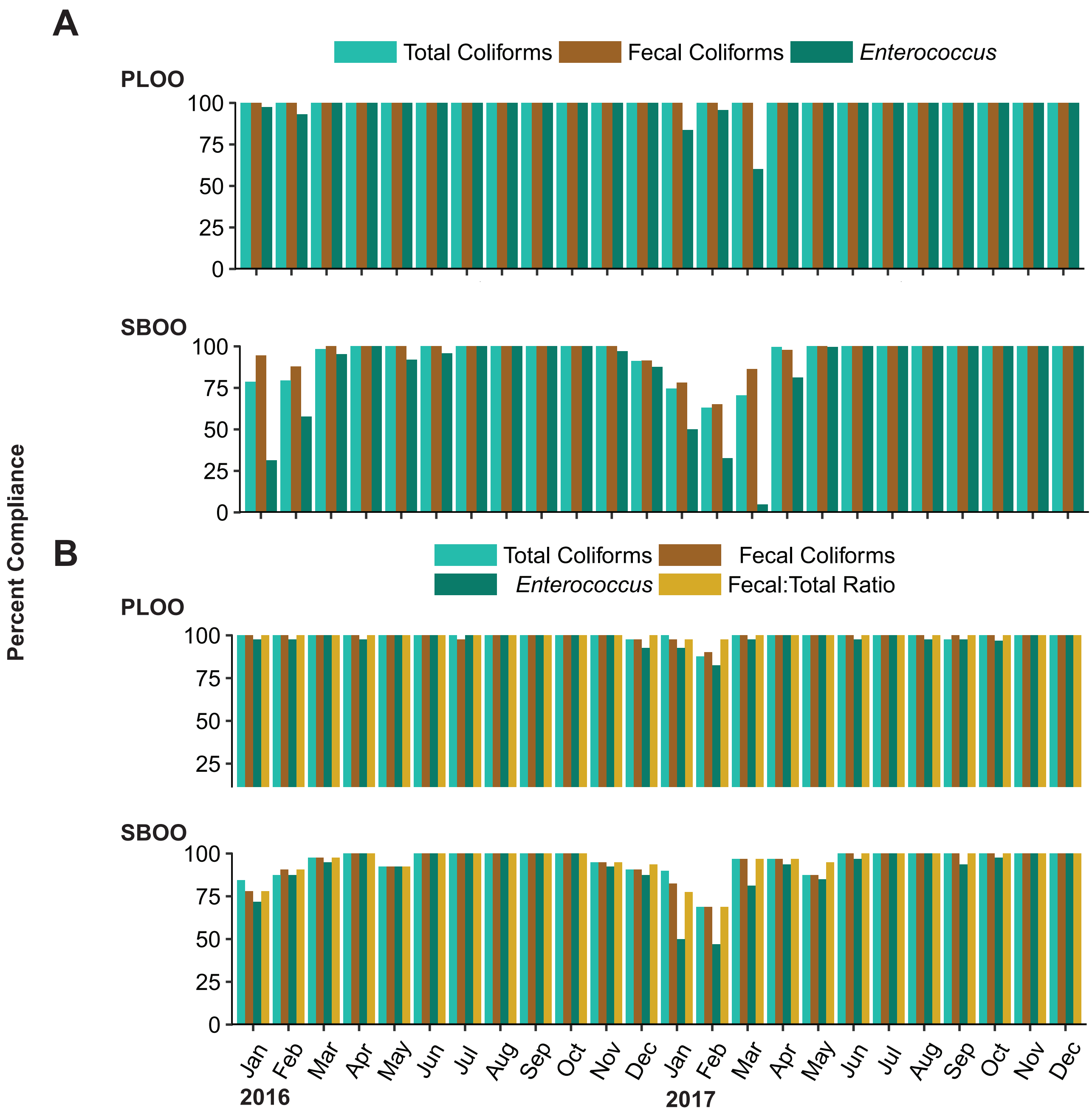

Figure 3.2
Compliance rates for (A) the three geometric mean and (B) the four single sample maximum water contact standards from shore stations during 2016 and 2017.

83–100% for *Enterococcus*, and 98–100% for the fecal:total coliform ratio (FTR) criterion. In contrast, compliance rates were more variable during these two years at the eight SBOO shore stations located in California waters. For example, compliance with the 30-day geometric mean standards at these SBOO stations was 63–100% for total coliforms, 65–100% for fecal coliforms, and 5–100% for *Enterococcus*, while compliance with the SSM standards was 69–100% for total coliforms, fecal coliforms, and the FTR criteria, and 47–100% for *Enterococcus*. However, six of these eight stations (S4, S5, S6, S10, S11, S12) are located near or within areas listed as impaired waters and are not expected to be in compliance with State water contact standards (State of California 2010). Thus, when these stations are excluded, overall SSM compliance at the remaining SBOO shore stations was 95%.

Table 3.2

Number of samples with elevated FIB (eFIB) densities collected from shore stations during wet and dry seasons in 2016 and 2017. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

	Seasons		
Station	Wet	Dry	% Wet
PLOO			
D12	3	0	100
D11	6	1	86
D10	3	0	100
D9	1	1	50
D8-A	1	1	50
D8	2	0	100
D7	2	0	100
D5	1	0	100
D4	0	1	0
SBOO			
S9	5	0	100
S8	5	0	100
S12	5	0	100
S6	7	2	78
S11	7	2	78
S5	19	4	83
S10	13	2	87
S4	8	2	80
S3	13	4	76
S2	8	3	73
S0	37	16	70
Rain (in)	16.38	1.78	90
Total eFIB	146	39	79
Total Samples	1211	879	58

Of the 2090 sea water samples collected at the PLOO and SBOO shore stations in 2016–2017 (not including resamples), about 9% (n=185) had elevated FIB counts (Table 3.2, Addenda 3-1, 3-2). A large majority (79%) of the shore samples with elevated FIB were collected during the wet seasons when rainfall totaled 16.4 inches over both years (Table 3.2). This general relationship between rainfall and elevated bacterial levels at the shore stations has been evident since water quality monitoring began in both regions. For example, historical analysis indicates that the occurrence of a sample with elevated FIB is significantly more likely to occur along the San Diego shoreline during the wet season than during the dry season (15% versus 4%, respectively; n=23,064, $\chi2=1386.7$, $p<<0.0001$). These analyses also indicated that elevated FIB occurred most often in the wet season at the SBOO shore stations (see below and Figure 3.3).

During 2016 and 2017, elevated FIB were detected most often at shore stations S4, S5, S10, and S11 located close to the mouth of the Tijuana River, as well as in northern Baja California waters at stations S0, S2, and S3 (Table 3.2, Addenda 3-1, 3-2). Additionally, storm drain runoff and sewage-like odors were often observed at all three of the Mexican stations (City of San Diego 2016–2018b). Results from historical analyses also indicated that elevated FIB densities occur more frequently at stations near the Tijuana River and south of the border near Los Buenos Creek than at other shore stations, especially during the wet seasons (Figure 3.3). Over the past several years for example, high FIB counts at these stations have consistently corresponded to outflows from the Tijuana River and Los Buenos Creek, typically following rain events (City of San Diego 2009–2014b, 2015c), although several sanitary sewer overflows in Tijuana also impacted the Tijuana River Valley during 2016–2017 (e.g., IBWC 2017).

Kelp bed stations

Overall compliance with Ocean Plan water contact standards was also high at the eight PLOO kelp stations in 2016–2017. Seawater samples from these stations were 100% compliant with each of the geometric mean standards and with the SSM standards for fecal coliform and FTR criteria, while compliance was 97–100% with the total coliform SSM and 93–100% with the *Enterococcus* SSM (Figure 3.4). Similar to the SBOO shore stations, compliance rates were more variable at the seven kelp bed or nearshores stations in the SBOO region. For example, compliance with the 30-day geometric mean standards was 56–100% for total coliform, 72–100% for fecal coliform, and 28–100% for

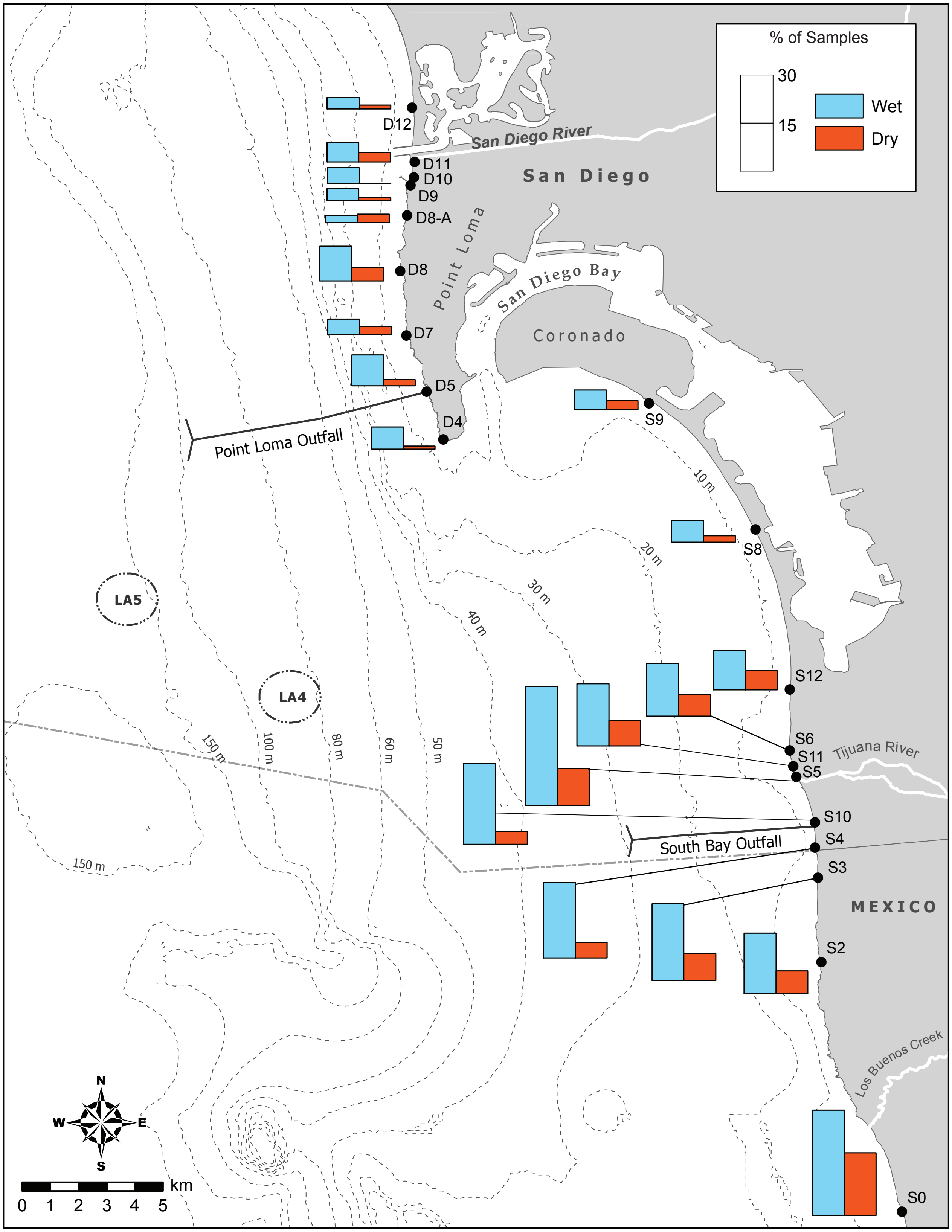

Figure 3.3
Percentage of samples with elevated FIB densities in wet versus dry seasons at shore stations from 1991 through 2017. Shore sampling in the SBOO region began in 1995.

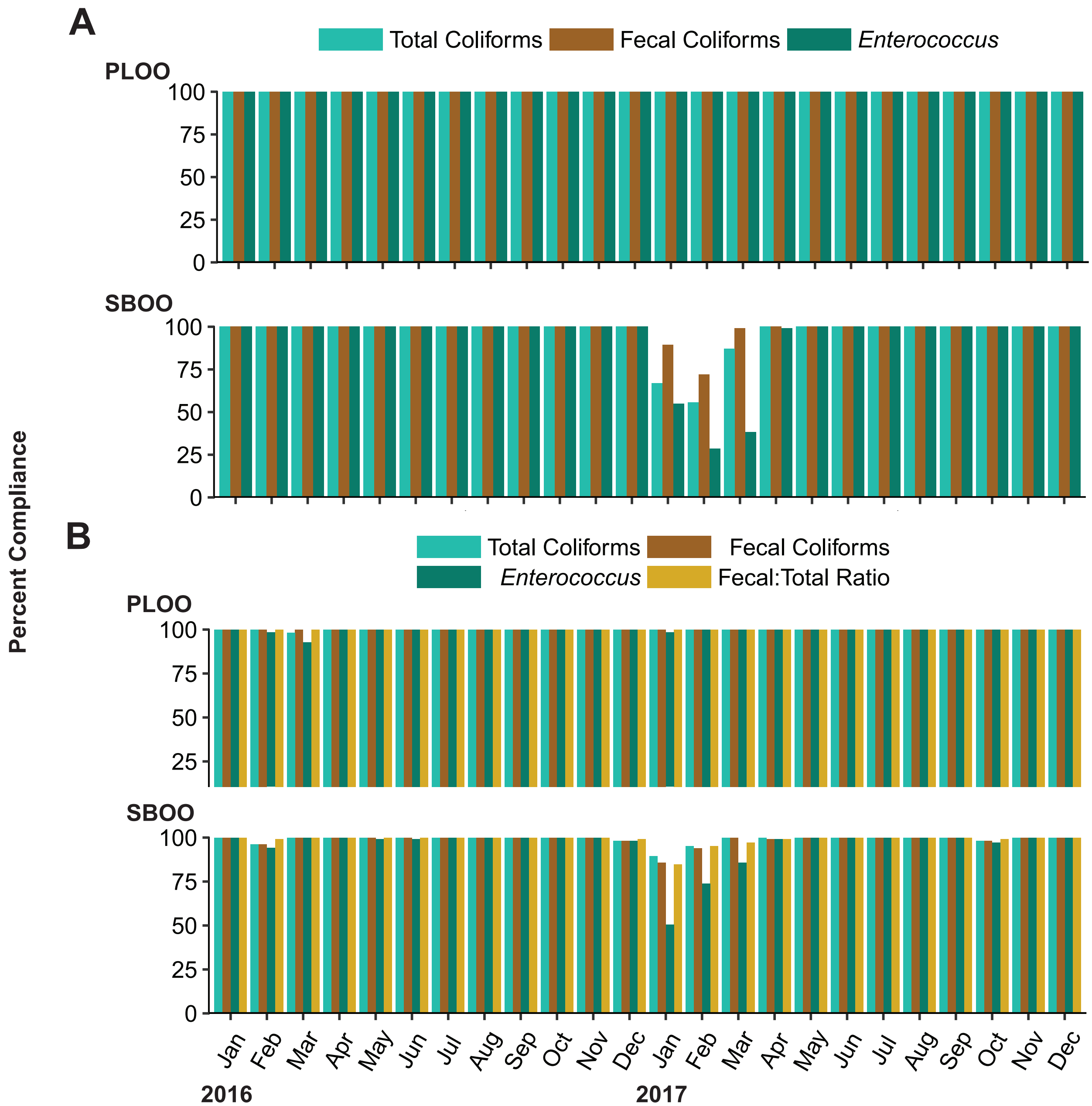

Figure 3.4
Compliance rates for (A) the three geometric mean and (B) the four single sample maximum water contact standards from kelp stations during 2016 and 2017.

Enterococcus, while compliance with the SSM standards was 90–100% for total coliform, 86–100% for fecal coliform, 50–100% for *Enterococcus*, and 85–100% for the FTR criteria. Nothing of sewage origin was observed at any of the 15 kelp stations over the past two years.

Of the 5178 samples collected at the PLOO and SBOO kelp stations in 2016–2017 (not including resamples), a total of 120 (~2.3%) had elevated FIB (Addenda 3-1, 3-2, City of San Diego 2017a), of which 98% occurred during the wet season (Table 3.3). However, historical water quality monitoring data (Figure 3.5) indicate that the relationship between rainfall and elevated FIBs has been negligible at the PLOO kelp stations over the years (~3% in either season; n=48,143, $\chi2=290.99$, $p<0.0001$). Instead, the likelihood of encountering elevated FIB at these stations was significantly higher before the PLOO was extended

Table 3.3

Number of samples with elevated FIB (eFIB) densities collected at kelp stations during wet and dry seasons in 2016 and 2017. Within each contour stations are listed from north to south. Rain data are shown in Table 3.2.

	Seasons		
PLOO	**Wet**	**Dry**	**% Wet**
9-m Depth Contour			
C6	0	0	—
C5	0	0	—
C4	0	0	—
18-m Depth Contour			
C8	1	0	100
C7	0	0	—
A7	4	0	100
A6	3	0	100
A1	4	0	100
SBOO			
9-m Depth Contour			
I32	7	0	100
I26	8	0	100
I25	20	0	100
I24	20	1	95
I40	26	0	100
I19	19	1	95
18-m Depth Contour			
I39	6	0	100
Total eFIB	118	2	98
Total Samples	2928	2250	56

to its present discharge site in late 1993 (13% versus < 1%; n = 48,143, $\chi2 = 211.99$, $p < 0.0001$). The influence of rainfall on FIB levels has been much more pronounced in the SBOO region over the past 23 years, with elevated FIB significantly more likely to occur at these stations during the wet season than during the dry season (8% versus 1%, respectively; n = 15,329, $\chi2 = 783.05$, $p << 0.0001$). As at the shore stations, high FIB counts at the SBOO kelp stations have historically corresponded to outflows from the Tijuana River and Los Buenos Creek, following rain events in the area (City of San Diego 2009–2015). Such rain-driven turbidity plumes originating from the Tijuana River and overlapping SBOO kelp stations with elevated FID counts have often been observed in satellite images of the region (e.g., Figure 3.6). Additionally, the higher incidence of elevated FIBs at the SBOO kelp bed stations during the wet season of 2017 compared to previous years was likely related to a series of large sewage spills that originated in Tijuana before spreading through the Tijuana River Valley and eventually reaching ocean waters and moving offshore (e.g., see IBWC 2017).

Offshore stations

Water quality was extremely high at all of the non-kelp offshore stations that were sampled quarterly in the PLOO and SBOO regions in 2016–2017. Of the 1632 samples collected at these stations over the past two years, only 57 (3%) had elevated FIBs (Table 4.3, Addenda 3-1, 3-2) (City of San Diego 2017a). This translates into ≥90% compliance with the SSM standard for *Enterococcus* at the 25 offshore stations (15 PLOO, 10 SBOO) located within State of California jurisdictional waters where Ocean Plan standards apply (Figure 3.7). Additionally, the above 10 SBOO stations were 100% compliant with the SSM standards for total coliforms, fecal coliforms, and the FTR; only *Enterococcus* is required to be measured at the PLOO offshore stations.

Most of the offshore samples with elevated FIBs (n = 8) in 2016–2017 occurred in the PLOO region (Table 3.4). However, 96% of these high counts were from depths of 60 m or deeper at stations located along the 80 or 100-m depth contours. In addition, a total of 14 of these samples (~29%) were from stations F29, F30, and F31 located within 1000 m of the PLOO discharge site (i.e., nearfield stations). These results suggest that the wastewater plume from the PLOO continues to be restricted to relatively deep, offshore waters throughout the year. Additionally, there were no signs of wastewater at any of the 36 offshore PLOO stations based on visual observations of the surface (City of San Diego 2016-2018a). This conclusion is consistent with remote sensing observations that provided no evidence of the PLOO plume reaching surface waters in 2016 or 2017 (Svejkovsky 2017, Hess 2018).

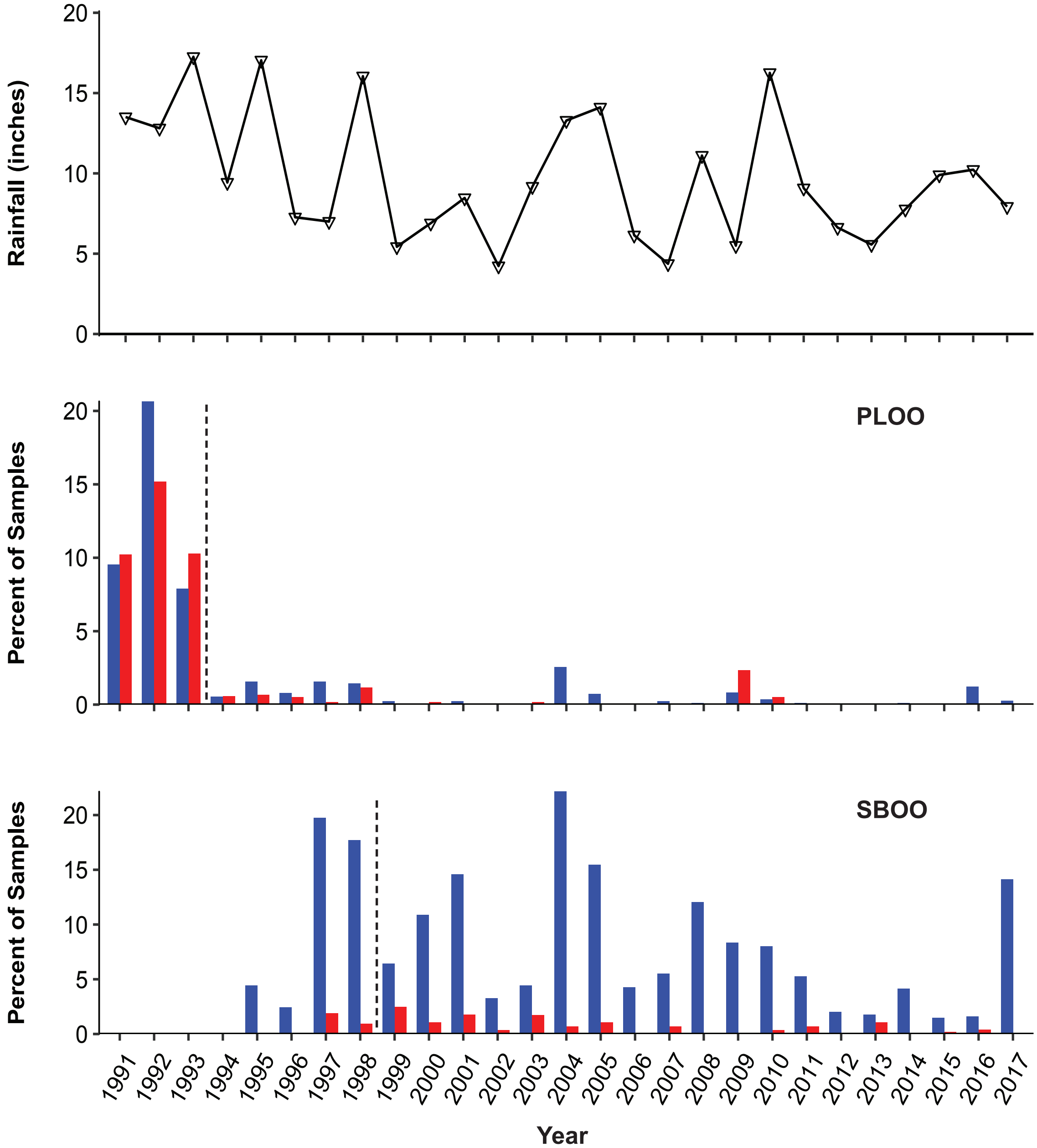

Figure 3.5
Comparison of annual rainfall (inches) to the percent of samples with elevated FIB densities in wet versus dry seasons at PLOO and SBOO kelp stations from 1991 through 2017. Rain data are from Lindbergh Field, San Diego, CA. Vertical dashed lines indicate onset of wastewater discharge at each outfall. Monitoring at the South Bay stations began in July 1995.

The above findings are also consistent with historical results, which revealed that $<4\%$ of samples collected from 1991 through 2015 from depths ≤ 25 m at the PLOO stations located along the 100-m discharge depth contour had elevated levels of *Enterococcus* (Figure 3.8A). Over this time period, detection of elevated *Enterococcus* was significantly more likely at the three nearfield stations described above than at any other 100-m site (21% versus 8%, respectively; $n = 5900$, $\chi^2 = 34.773$, $p < 0.0001$) (Figure 3.8B). In addition, following initiation of partial chlorination at the Point Loma Wastewater Treatment Plant in 2008 (City of San Diego 2009), the number of samples with elevated *Enterococcus* also decreases significantly at these three stations (i.e., 26% before versus 9% after, $n = 1961$, $\chi^2 = 527.32$, $p < 0.0001$), as well as at the other

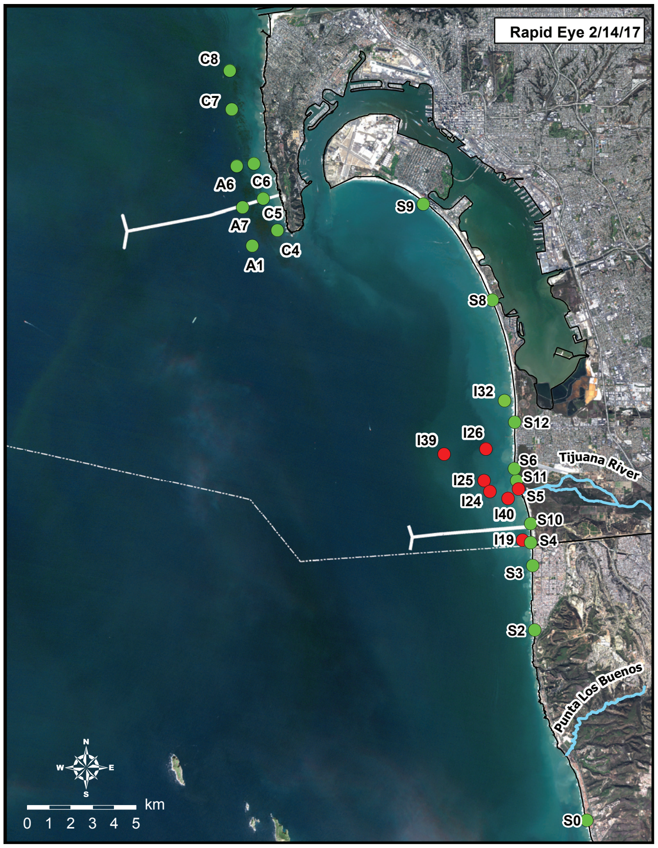

Figure 3.6
Rapid Eye satellite image showing stations throughout the region on February 14, 2017 (Ocean Imaging 2018) combined with bacteria levels sampled at shore and kelp stations on February 14, 2017. Turbid waters from the Tijuana River, San Diego Bay and Los Buenos Creek, can be seen overlapping stations with elevated FIB (red circles).

100-m stations (11% before versus 3% after; n = 3939, $\chi^2 = 322.67$, $p < 0.0001$) (Figure 3.8C).

In contrast to the PLOO region, only nine of all the samples with elevated FIBs in 2016–2017 were from the SBOO region (Table 3.4), of which six (~55%) occurred at station I5 located in northern Baja California waters just north of Los Buenos Creek. The three remaining samples with elevated FIBs were all collected on February 13, 2017 in surface waters at nearfield stations I12 and I16, and station I18 located inshore of these sites just south of the outfall pipe, even though satellite imagery for that day did not reveal any evidence of plume presence (see Figure 3.9). However, it is possible that these few elevated FIB counts were associated with a large 143 million gallon sewage spill that began on February 6 and lasted for two weeks (e.g., IBWC 2017).

Historically, elevated bacterial levels been recorded more often at the three nearfield stations when compared to other stations along the 28-m depth contour (11% versus 3%; n = 5705, $\chi^2 = 14.002$, $p < 0.0002$). These samples were predominately collected at a depth of 18 m (Figure 3.10). With the exception of 2017, the number of samples with elevated FIB collected from nearfield stations has decreased to ≤2 samples per year since secondary treatment was initiated at the SBIWTP in January 2011. These results demonstrate improved water quality near the outfall compared to previous years.

Plume Dispersion and Effects

PLOO Region

The dispersion of the wastewater plume from the PLOO and its effects on natural light (% transmissivity), dissolved oxygen (DO), and pH levels were assessed by evaluating the results of 288 CTD profile casts performed in 2016 and 2017. Based on the criteria described previously (City of San Diego 2016a), potential evidence of a plume signal was detected a total of 61 times during the year from 29 different stations, while 5–23 stations were identified as reference sites during each quarterly survey (Table 3.5, Figure 3.11, Appendix C.3). About 23% of possible plume detections (n = 14) occurred at the three stations located closest to the outfall (F29, F30, F31), equating to a detection rate of 58% at these nearfield sites over the year. Another 64% of the possible detections (n = 39) occurred at stations along the 80 and/or 100-m depth contours located up to 13 km to the north or 8 km to the south of the outfall. The remaining potential plume signals may be spurious due to their distance from the outfall and/or proximity to other known sources of organic matter. For example, stations along the 60-m depth contour in May 2017 may have been influenced by the decay from a significant phytoplankton bloom (see Chapter 2), such that additional organic matter was detected (e.g., Rochelle-Newall and Fisher 2002, Romera-Castillo et al. 2010). Overall, the variation in plume

Table 3.4

Number of samples with elevated FIB (eFIB) densities collected at PLOO and SBOO offshore stations during wet and dry seasons in 2016 and 2017. Within each contour stations are listed from north to south. See Table 3.1 for rain data. Stations not listed had no samples with elevated FIB concentrations during this time period.

	Seasons		
	Wet	**Dry**	**% Wet**
PLOO			
60-m Depth Contour			
F06	0	1	0
F05	0	1	0
80-m Depth Contour			
F21	1	1	50
F20	1	2	33
F19	0	2	0
F18	0	2	0
F17	0	1	0
F16	0	1	0
F15	0	1	0
100-m Depth Contour			
F36	0	2	0
F35	1	2	33
F34	1	2	33
F33	2	1	67
F32	1	3	25
F31*	3	0	100
F30*	3	5	38
F29*	1	2	33
F28	1	1	50
F27	0	1	0
F26	0	2	0
SBOO			
9-m Depth Contour			
I5	5	1	83
18-m Depth Contour			
I18	1	0	100
28-m Depth Contour			
I12*	1	0	100
I16*	1	0	100
Total eFIB	23	34	40
Total Samples	816	816	50

* Nearfield station

dispersion observed off Point Loma in 2016 and 2017 was similar to flow-mediated dispersal patterns reported previously for the region (Rogowski et al. 2012a,b, 2013).

The width and rise height of potential PLOO plume detections varied between stations throughout the year (Appendix C.4). Despite fluctuations in depth of the pycnocline, the plume remained below 43 m even during periods of weak water column stratification. This finding is in agreement with satellite imagery observations that showed no visual evidence of the plume surfacing during 2016 or 2017 (Svejkovsky 2017, Hess 2018). About 57% (n = 35) of the potential plume detections corresponded with elevated *Enterococcus* densities, with all but one collected at depths ≥60 m; the exception was collected at 25 m depth from station F36 located 13 km to the north of the PLOO discharge site (see Addendum 3-1).

The effects of the PLOO plume on the natural light, DO, and pH water quality indicators were calculated for each station and depth where a plume signal was indicated. For each of these detections, mean values for each indicator within the estimated plume were compared to thresholds within similar depths from non-plume reference stations (Appendix C.4). Of the 61 potential plume signals that occurred during the reporting period, a total of 45 out-of-range (OOR) events were identified, which consisted of 30 OOR events for natural light at various stations throughout the year, and 15 OOR events for DO (Table 3.5, Appendix C.4). Representative quarterly profiles from station F30 are shown in Appendices C.6–C.13. There were no OOR events for pH. Overall, 12 (40%) of the natural light OOR events and eight (53%) of the OOR events for DO occurred at stations located within State jurisdictional waters where Ocean Plan compliance standards apply (i.e., stations F06, F08–F12, F14, F18, F19).

SBOO Region

The dispersion of the SBOO plume and its effects on natural light, DO, and pH levels were assessed by evaluating the results of 224 CTD profile casts

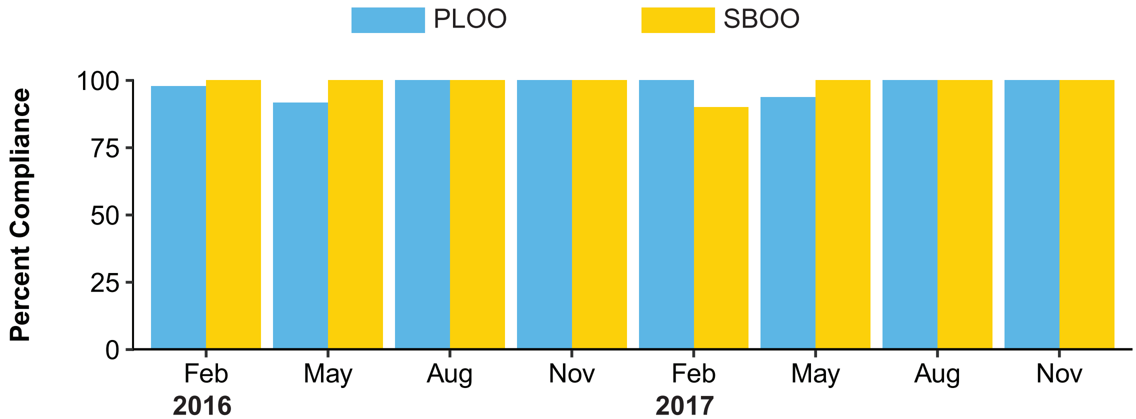

Figure 3.7
Compliance rates for the *Enterococcus* single sample maximum water contact standard at offshore stations during 2016 and 2017. Compliance rates for the Fecal coliform, Total coliform and Fecal:Total coliform ratio criteria were 100%. See text for details.

performed in 2016–2017. Potential evidence of a plume signal was detected a total of 29 times during the year from 17 different stations, while 10–20 stations were identified as reference sites during each quarterly survey (Table 3.5, Figure 3.11, Appendix C.3). Thirteen of the possible detections (~45%) occurred at nearfield stations located near the outfall wye (i.e., I12, I14, I15, I16), while the remaining potential plume signals may be spurious due to their distance from the outfall and/or proximity to other known sources of organic matter. None of these plume detections were associated with elevated FIB counts (Addendum 3-2, City of San Diego 2017a). Other potential plume signals may be due to their proximity to other known sources of organic matter. For example, station I34 is located within the possible influence of San Diego Bay tidal pumping, while stations I23 and I39 are located within the possible influence of Tijuana River outflows.

The effects of the SBOO wastewater plume on the three physical water quality indicators described above were calculated for each station and depth where a plume signal was detected. For each of these detections, mean values for natural light, DO, and pH within the estimated plume were compared to thresholds within similar depths from non-plume reference stations (Table 3.5, Appendix C.5). Representative profiles from station I15 are shown in Appendices C.14–C.21. Of the 29 potential plume signals that occurred during the reporting period, a total of 14 OOR events were identified for transmissivity, while four OOR events occurred for DO. There were no OOR events for pH. Twelve of the above 18 OOR events occurred at stations within State jurisdictional waters where Ocean Plan compliance standards apply.

Summary

The detection of the PLOO and SBOO wastewater plumes and their effects on various water quality indicators such as natural light levels, dissolved oxygen concentrations, and pH were low during 2016 and 2017. Additionally, water quality conditions were excellent throughout both outfall monitoring regions during these years. For example, overall compliance with Ocean Plan water contact standards was 98%, which was similar to that observed during recent years (City of San Diego 2010–2015b). Compliance with both the SSM and geometric mean standards was typically higher at the PLOO and SBOO kelp bed and other offshore stations compared to the shore stations, and also tended to be higher at PLOO stations than at the SBOO stations. Reduced compliance in both regions tended to occur during the wet season. In addition, there was no evidence that wastewater discharged into the ocean via either outfall reached nearshore waters. Historically, elevated FIB counts

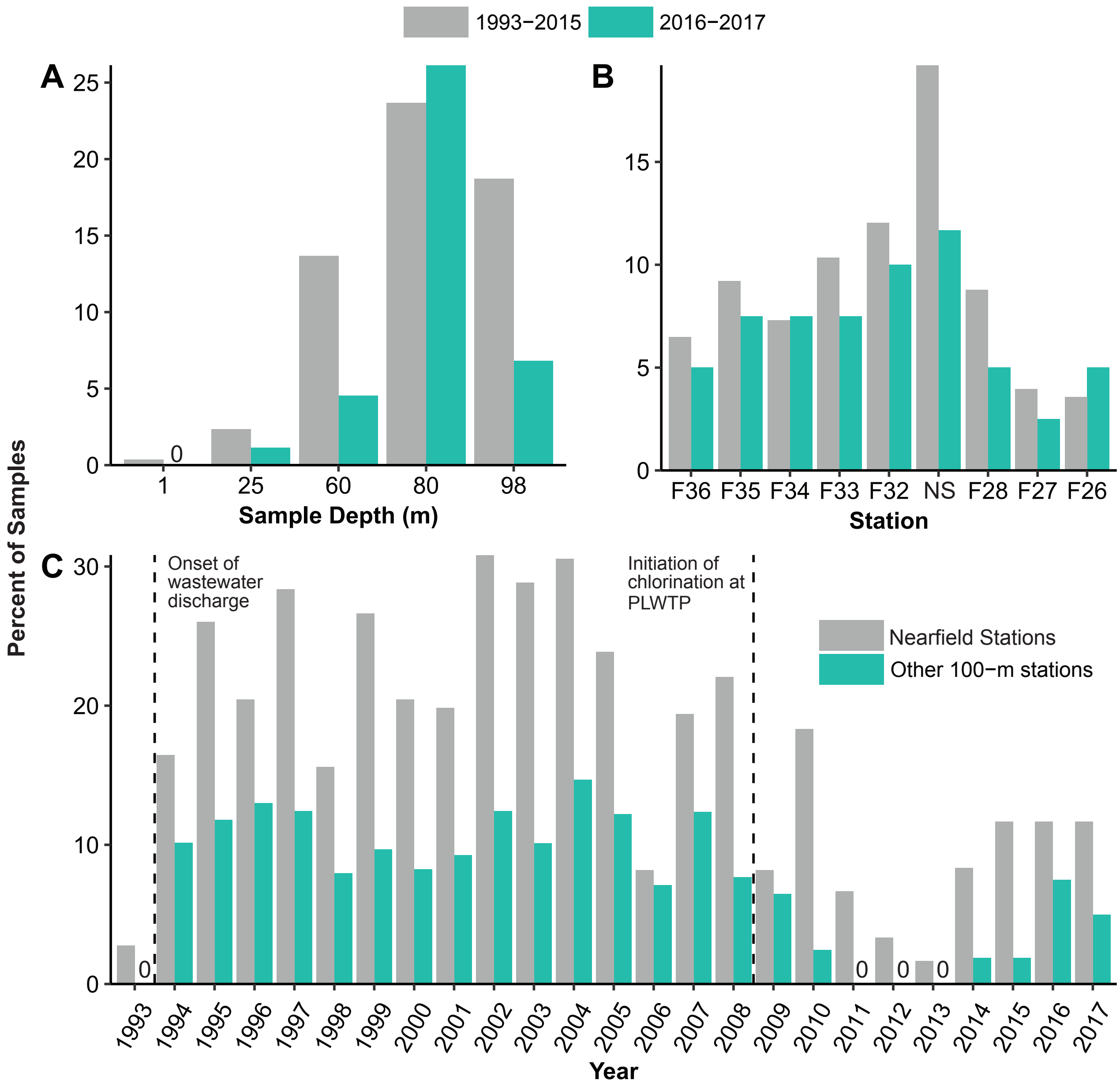

Figure 3.8

Percent of samples collected from PLOO 100-m offshore stations with elevated bacteria densities. Samples from 2016 and 2017 are compared to those collected from 1993 through 2015 by (A) sampling depth, (B) station listed north to south from left to right, and (C) year. NS = nearfield stations (F31, F30, F29).

along the shore or at the kelp bed stations have typically been associated with storm activity (rain), heavy recreational use, the presence of seabirds, and decaying kelp or surfgrass (e.g., City of San Diego 2009–2015b). Exceptions to the above patterns have occurred over the years due to specific events. For example, the elevated bacteria that occurred at the PLOO shore and kelp stations during a few months back in 1992 followed a catastrophic rupture of the outfall that occurred within the Point Loma kelp forest (e.g., Tegner et al. 1995). An additional source of more frequent contamination in the SBOO region has been cross-border transportation of sewage that originate from spills in Tijuana, Mexico such as the 143 million gallon spill that occurred in February 2017 (e.g., IBWC 2017).

The above results are also consistent with observations from remote sensing studies (i.e., satellite imagery) over several years that show a lack of shoreward

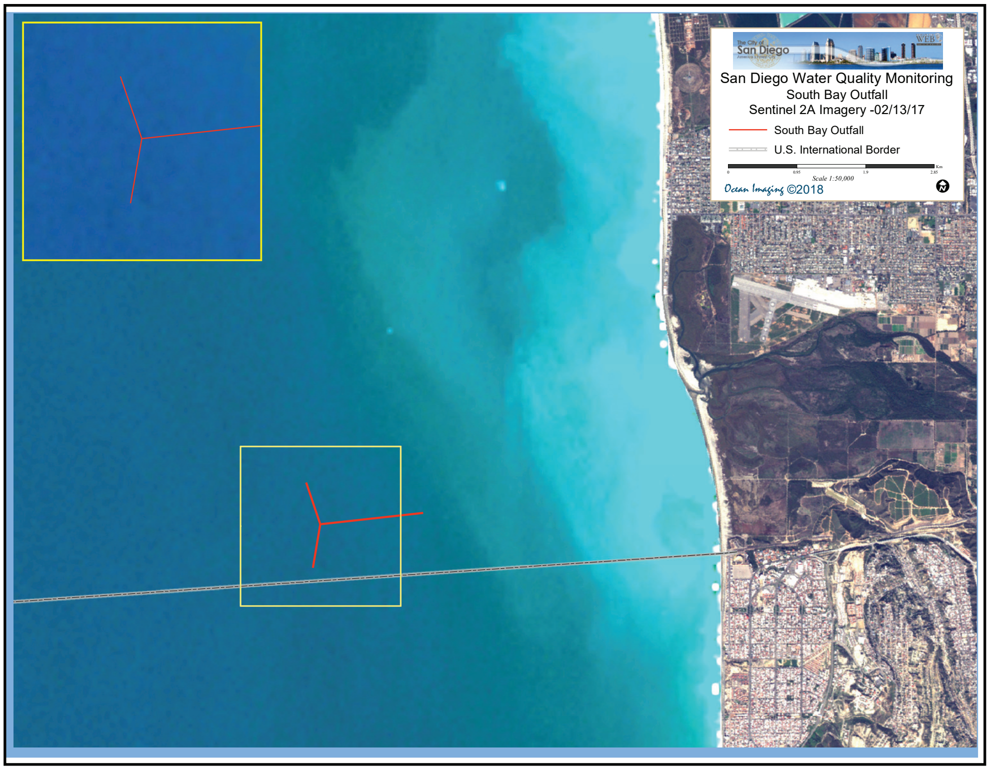

Figure 3.9
Sentinel 2A satellite image of the SBOO region on February 13, 2017 (Ocean Imaging 2018). Turbidity plume corresponds to 143 million gallon raw sewage spill that started February 6, 2017 and lasted for two weeks (IBWC 2017). Inset shows that the SBOO effluent plume is not evident in surfaces waters on this date.

transport of wastewater plumes from either the PLOO or SBOO (e.g., Svejkovsky 2010, 2017, Hess 2018), and with previous studies that have indicated the PLOO wastefield typically remains submerged in deep offshore waters (e.g., City of San Diego 2007–2015a, Rogowski et al. 2012a,b, 2013). The approximately 100-m depth of the PLOO discharge site may be the dominant factor that inhibits the wastewater plume from reaching surface waters. For example, wastewater released into these deep, cold, and dense waters does not appear to mix with the upper 25 m of the water column (Rogowski et al. 2012a,b, 2013).

Within the shallower SBOO region, past studies have shown that other sources such as coastal runoff from rivers and creeks were more likely to impact coastal water quality than wastewater discharge from the outfall, especially during and immediately after significant rain events. For example, the shore stations located near the mouths of the Tijuana River and in Mexican waters near Los Buenos Creek have historically had higher numbers of elevated FIB samples than stations located farther to the north (City of San Diego 2009–2016b). It is also well established that sewage-laden discharges from the Tijuana River and Los Buenos Creek are likely sources of bacteria during or after 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 levels and elevated FIB counts in the SBOO region existed before wastewater discharge began in 1999 (see also City of San Diego 2000). The low number of elevated FIB samples near the outfall during recent years is likely related to chlorination of South Bay International Water Treatment Plant effluent (November–April) and the initiation of full secondary treatment that began in January 2011.

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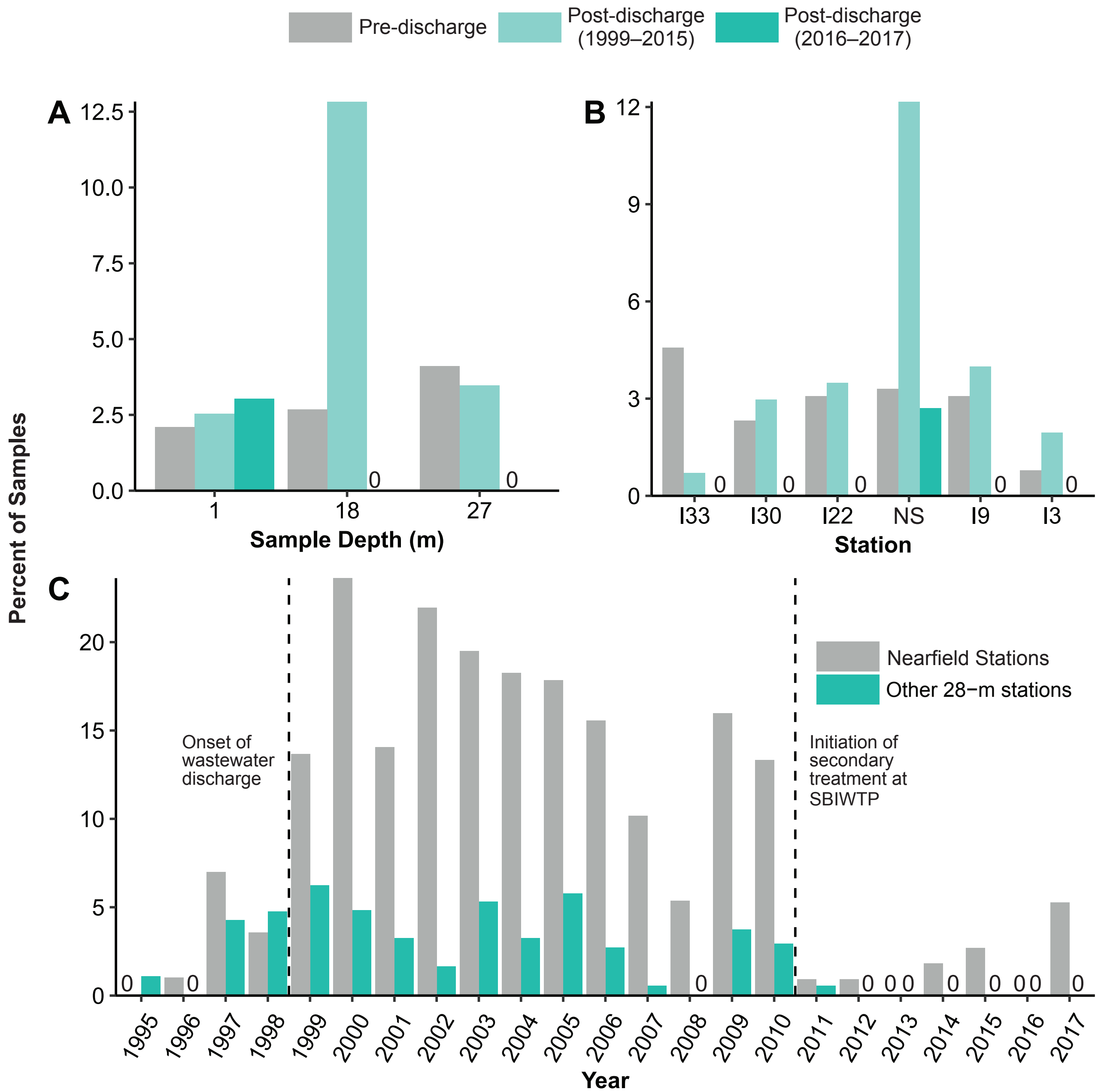

Figure 3.10
Percent of samples collected from SBOO 28-m offshore stations with elevated bacteria densities. Samples from 2016 and 2017 are compared to those collected from 1995 through 2015 by (A) sampling depth, (B) station listed north to south from left to right, and (C) year. NS = nearfield stations (I12, I14, I16).

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Table 3.5

Summary of potential wastewater plume detections and out-of-range values at offshore stations during 2016 and 2017. See text for additional station restrictions. Stations within State jurisdictional waters are in bold. DO = dissolved oxygen; XMS = transmissivity.

	Potential Plume Detections	PLOO Out of Range DO	pH	XMS	Stations
2016					
Feb	9	0	0	1	**F19**, **F20**, F21, F22, F23, F29, F30[a], F31, F34
May	12	5	0	8	**F06**[a], F15[ab], F16[ab], F17[ab], **F18**[a], **F19**[ab], F23[ab], F26, F27, F28, F29, F30[a]
Aug	3	1	0	0	F31, F32[b], F33
Nov	6	0	0	1	F30[a], F31, F33, F34, F35,F36
2017					
Feb	8	0	0	7	**F10**[a], **F14**[a], F21[a], F22[a], F23[a], F30[a], F31[a], F32[a]
May	11	9	0	10	**F08**[ab], **F09**[ab], **F10**[ab], **F11**[ab], **F12**[ab], F17[a], **F18**[ab], **F19**[ab], **F20**, F29[ab], F30[ab]
Aug	8	0	0	3	F24, F25, F30, F32[a], F33[a], F34, F35[a], F36
Nov	4	0	0	0	F27, F28, F30, F32
Detection Rate (%)	21	5	0	10	
Total Count	61	15	0	30	
Total Samples	288	288	288	288	

	Potential Plume Detections	SBOO Out of Range DO	pH	XMS	Stations
2016					
Feb	5	0	0	5	**I12**[a], **I14**[a], I15[a], **I16**[a], **I27**[a]
May	2	0	0	0	**I12**, I15
Aug	4	2	0	1	I15, **I27**, **I34**[ab], **I39**[b]
Nov	3	0	0	3	**I12**[a], I15[a], **I16**[a]
2017					
Feb	4	0	0	1	I2, I8, **I17**, **I23**[a]
May	7	2	0	3	I15, **I18**[a], **I23**, I28, I29[a], I30[b], **I34**[ab]
Aug	1	0	0	1	I7[a]
Nov	3	0	0	0	I6, **I12**, I15
Detection Rate (%)	13	2	0	6	
Total Count	29	4	0	14	
Total Samples	224	224	224	224	

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

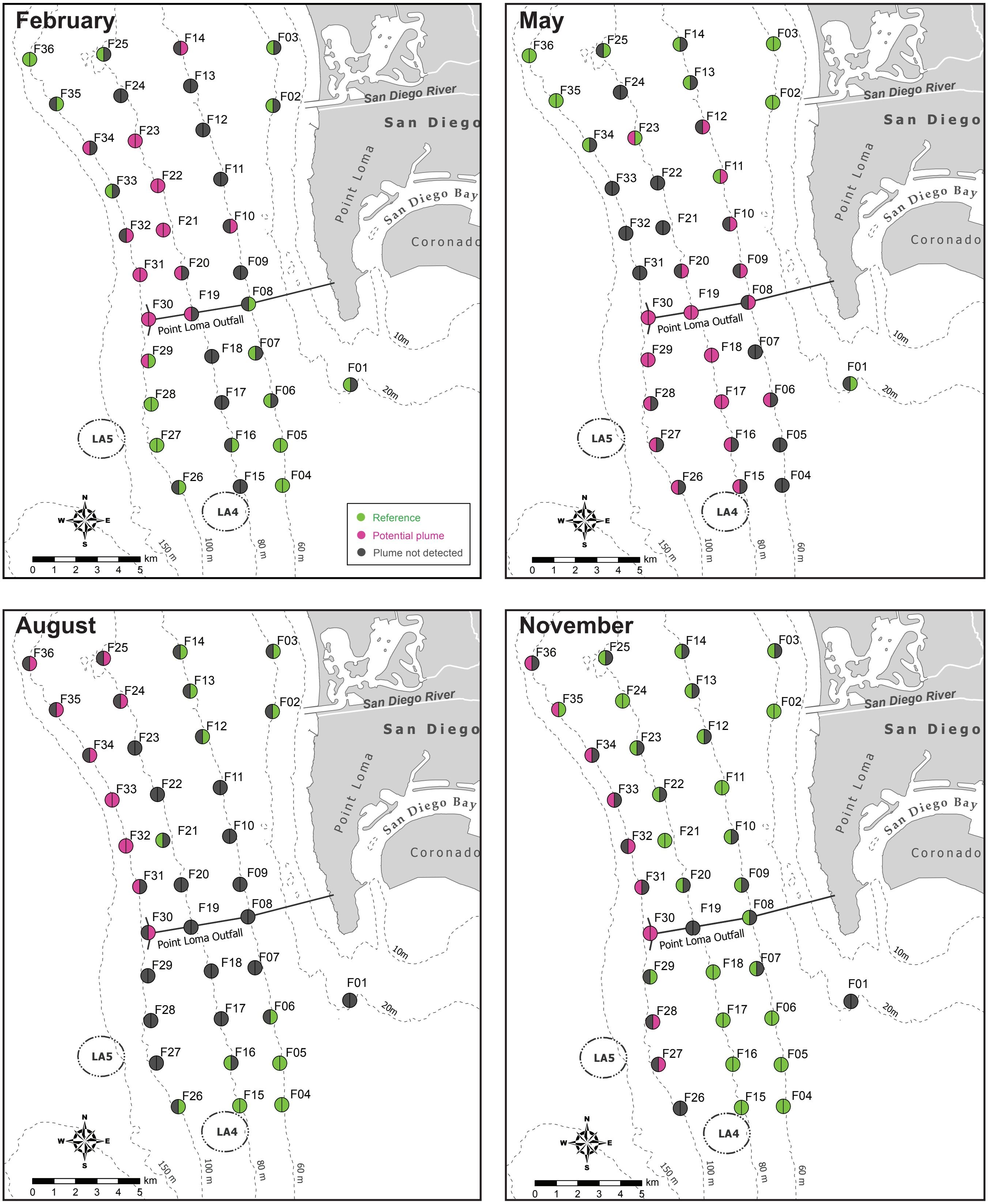

Figure 3.11

Distribution of stations meeting potential plume criteria (pink) and those used as reference stations (green) near the PLOO (this page) and SBOO (facing page) during quarterly surveys in 2016 (left half of pie) and 2017 (right half).

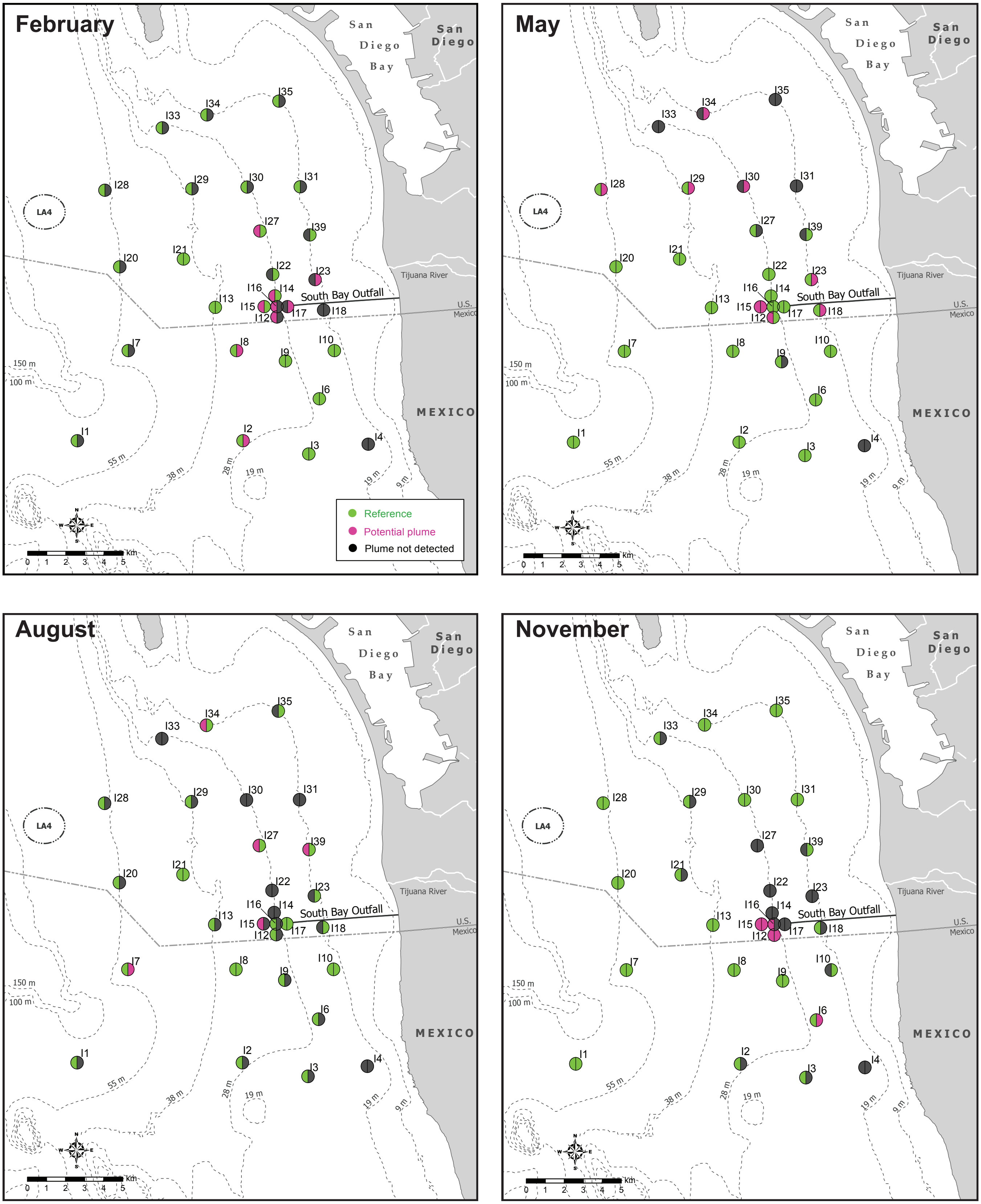

Figure 3.11 *continued*

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Chapter 4
Sediment Quality

Chapter 4. Sediment Quality

Introduction

Ocean sediment samples are analyzed as part of the City of San Diego's Ocean Monitoring Program to examine the effects of wastewater discharge from the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO), as well as other anthropogenic inputs, on the marine benthic environment. Analyses of various sediment contaminants are conducted because anthropogenic inputs to the marine ecosystem, including municipal wastewater, can lead to increased concentrations of pollutants within the local environment. The relative percentages of sand, silt, clay, and other particle size parameters are examined because concentrations of some compounds are known to be directly linked to sediment composition (Emery 1960, Eganhouse and Venkatesan 1993). Physical and chemical sediment characteristics are also analyzed because together they define the primary microhabitats for benthic macroinvertebrates (macrofauna) that live within or on the seafloor, and therefore influence the distribution and presence of various species. For example, differences in sediment composition and organic loading impact the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Many demersal fish species are also associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Understanding the differences in sediment conditions and quality over time and space is therefore crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 7, respectively).

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

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

This chapter presents analysis and interpretation of sediment particle size and chemistry data collected at NPDES permit designated core benthic monitoring stations surrounding the PLOO and SBOO during 2016 and 2017. The three primary goals of the chapter are to: (1) document sediment conditions at these core monitoring stations; (2) identify possible effects of wastewater discharge on sediment quality in these areas; (3) identify other potential natural or anthropogenic sources of sediment contaminants to the local marine environment. Finally, a broader regional assessment of benthic condition throughout the entire San Diego region based on a subset of the data reported in this chapter combined with a suite of randomly selected stations sampled during the summers of 2016 and 2017 is presented in Chapter 6.

Materials and Methods

Field Sampling

The benthic samples analyzed in this chapter were collected at a total of 49 core monitoring stations located at inner shelf (≤30 m) to middle shelf (>30–120 m) depths surrounding the Point Loma and South Bay Ocean Outfalls during January (winter) and July (summer) of 2016 and 2017 in order to monitor sediment quality conditions off San Diego (Figure 4.1). The PLOO monitoring sites include 12 primary core stations located along the 98-m discharge depth contour and 10 secondary core stations located along or adjacent to the 88-m or 116-m depth contours. The SBOO monitoring sites include 12 primary core stations located along the 28-m discharge depth contour and 15 secondary core stations located along or adjacent the 19, 38, or 55-m depth contours. The four stations located within 1000 m of the zone of initial dilution (ZID) for each outfall are considered to represent near-ZID conditions. These include PLOO stations E11, E14, E15, and E17, and SBOO stations I12, I14, I15, and I16.

Each sediment sample was collected from one side of a double 0.1-m^2 Van Veen grab, while the other grab sample from the cast was used for macrofaunal community analysis (see Chapters 5 and 6). Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Environmental Chemistry Services Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2018a). Briefly, sediment sub-samples were analyzed on a dry weight basis to determine concentrations of various indicators of organic loading (i.e., biochemical oxygen demand, total organic carbon, total nitrogen, total sulfides, and total volatile solids), 18 trace metals, nine chlorinated pesticides, 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs). These data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix D.1). However, concentrations below MDLs were included as estimated values if presence of the specific constituent was verified by mass-spectrometry. Additionally, a variety of laboratory technical issues resulted in a significant amount of non-reportable sediment chemistry data for the 2016 and 2017 benthic surveys as follows: (1) mercury results were not reportable for 40 of 138 samples analyzed in 2016; (2) results for the pesticide HCB were not reportable for 83 of 135 samples analyzed in 2016; (3) Pesticides, PCBs, PAHs, and total volatile solids were not analyzed for samples collected at PLOO station E21 and regional station 8517 in July 2016; (4) all pesticide results (including HCB) were not reportable for one sample analyzed from PLOO station E17 in 2016; (5) BOD results were not reportable for one sample analyzed from PLOO station E1 in 2016; (6) all pesticide results were not reportable for 69 of 138 samples analyzed in 2017; (7) PCB results were not reportable for 59 of 138 samples analyzed in 2017; (8) PAH results were not reportable for 51 of 138 samples analyzed in 2017; Details for the above non-reportable results for 2016 are available in City of San Diego (2017), while results for 2017 are available in Addenda 4-7, 4-8, and 6-4 of this report.

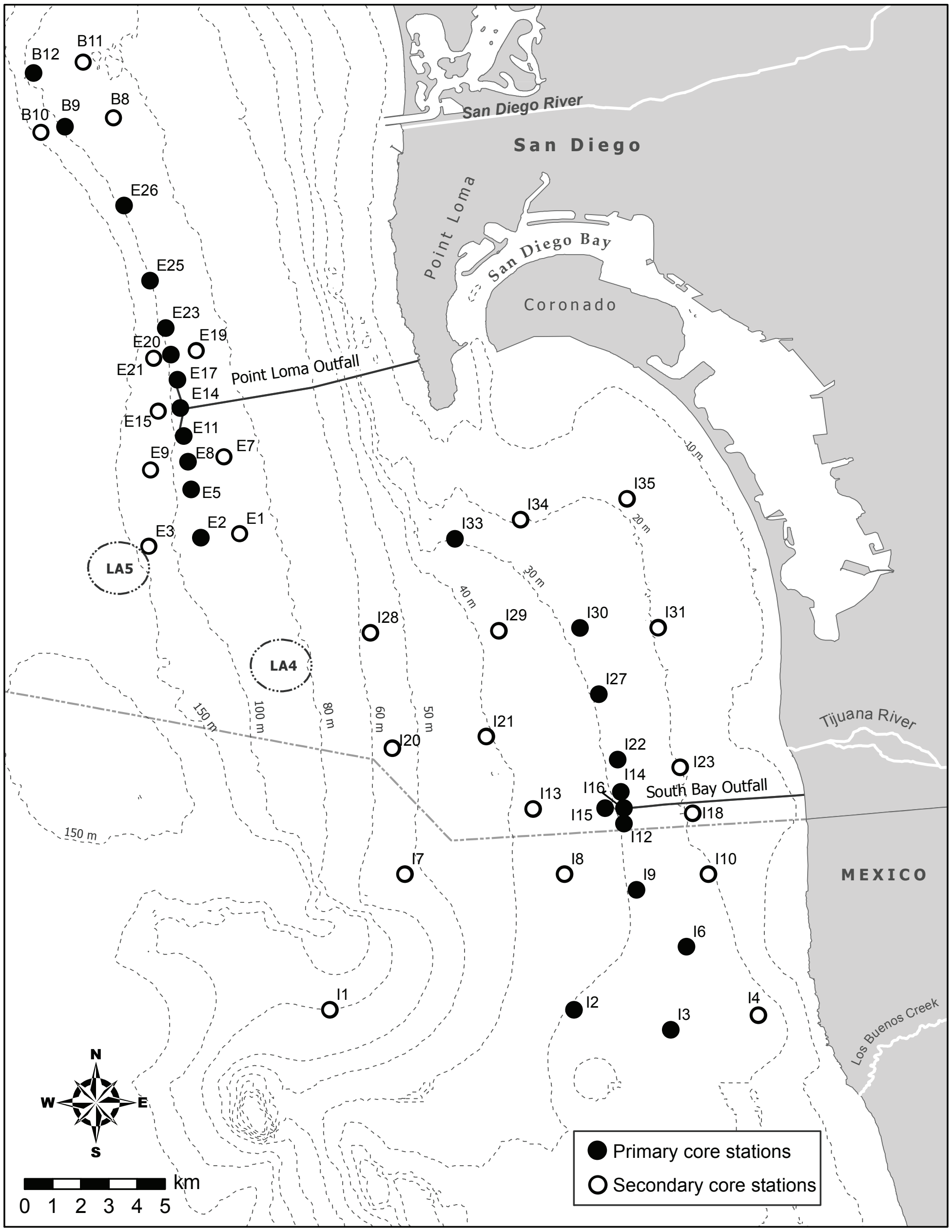


Figure 4.1

Benthic station locations sampled around the Point Loma and South Bay Ocean Outfalls as part of the City of San Diego's Ocean Monitoring Program.

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

Data Analyses

Data for each sediment parameter collected from the core PLOO and SBOO stations sampled during calendar year 2017 are listed in Addenda 4-1 through 4-10, while data collected during 2016 were reported previously and are available online (see City of San Diego 2017, 2018b). Data summaries for the various sediment parameters included detection rate, mean, minimum and maximum values for all samples combined by outfall region (i.e., PLOO, SBOO). All means were calculated using detected values only with no substitutions made for non-detects (i.e., analyte concentrations <MDL). Total DDT (tDDT), total hexachlorocyclohexane (tHCH), total chlordane, total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values for individual constituents (see above and Addenda 4-9, 4-10, City of San Diego 2017). 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. ERLs represent chemical concentrations below which adverse biological effects are rarely observed, while values above ERLs but below ERMs represent levels at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these may not always be validated by toxicity testing results (Schiff and Gossett 1998). Analyses were performed using R (R Core Team 2016) and various functions within the dplyr, plyr, reshape2, tidyr, and zoo packages (Zeileis and Grothendieck 2005, Wickham 2007, 2011, Wickham and Henry 2017, Wickham et al. 2017).

Results

Particle Size Distribution

Ocean sediments sampled at the core PLOO stations in 2016 and 2017 were composed primarily of fine silts and clays (percent fines) plus fine sands. Percent fines ranged from about 12% to 66% per sample, fine sands from about 33% to 78%, medium-coarse sands from <1% to 30%, and coarse particles from 0 to about 21% (Table 4.1). Coarser particles often included shell hash, rock, black sand, and/or gravel (Addendum 4-1, City of San Diego 2017). Overall, there were no significant spatial patterns in sediment composition relative to the PLOO discharge site during the past two years (Figure 4.2, Appendix D.3). However, near-ZID station E14 stood out from other nearby stations by averaging the third largest proportion of coarse particles and the fourth smallest proportion of percent fines. Other PLOO stations that had comparatively large proportions of medium-coarse sands and/or coarse particles included northern stations B11 and B12, as well as the southern stations E1, E2, E3 and E9. There was no evidence that the amount of percent fines has increased at any of the PLOO primary core stations since wastewater discharge began at the current discharge site in late 1993 (Figure 4.3). Instead, sediment composition at the sites mentioned above has demonstrated some temporal variability in terms of the sand and coarse fractions (City of San Diego 2014a). This variability has corresponded to occasional patches of coarse sands (e.g., black sand) or larger particles (e.g., gravel, shell hash). For example, coarse black sands were observed at station E14 during all four surveys of 2016 and 2017 (Addendum 4-1, City of San Diego 2017), possibly due in part to the presence of ballast or bedding material near the outfall (City of San Diego 2015).

In contrast to the PLOO region, seafloor sediments were much more diverse at the SBOO monitoring sites during 2016 and 2017. Percent fines ranged from 0 to about 39% per sample at these stations, fine sands from about 2% to 92%, medium-coarse sands from <1% to about 91%, and coarse particles from 0 to about 57% (Table 4.2). Coarser particles at the SBOO stations were often comprised of red relict sands, black sands, and/or shell hash (Addendum 4-2, City of San Diego 2017). There were no spatial patterns in sediment composition relative to the SBOO discharge site during the 2016 and 2017

Table 4.1

Summary of particle sizes and chemistry concentrations in sediments from PLOO benthic stations sampled historically (1991–2015) and during the current reporting period (2016–2017). Data include the total number of samples analyzed (n), detection rate (DR), minimum, maximum, and mean values for the entire survey area during each time period. Minimum and maximum values were calculated based on all samples, whereas means were calculated on detected values only; nd = not detected.

	Historical (1991–2015)					Current (2016–2017)				
Parameter	**n**	**DR**	**min**	**max**	**mean**	**n**	**DR**	**min**	**max**	**mean**
Particle Size (%)										
Coarse Particles	576	23	0.0	64.2	4.3	88	27	nd	20.5	5.5
Med-Coarse Sands	576	95	0.0	64.5	3.5	88	100	0.1	30.4	4.9
Fine Sands	576	100	11.7	85.6	55.5	88	100	32.8	77.8	54.9
Fine Particles	576	100	10.8	55.2	40.3	88	100	12.1	65.6	38.7
Organic Indicators										
BOD (ppm)	574	90	nd	980	303	86	100	146	598	314
Sulfides (ppm)	588	96	nd	89.50	5.55	88	100	1.67	50.90	8.29
TN (% weight)	588	92	nd	0.192	0.051	88	100	0.023	0.090	0.051
TOC (% weight)	588	94	0.00	4.85	0.68	88	100	0.13	2.46	0.49
TVS (% weight)	588	100	0.00	5.42	2.37	87	100	0.20	3.90	2.02
Metals (ppm)										
Aluminum	528	100	3130	22,800	9619	88	100	3470	12,600	7629
Antimony	577	39	nd	13.0	1.8	88	95	nd	1.8	0.9
Arsenic	588	100	1.27	7.81	3.12	88	100	0.76	5.95	2.16
Barium	312	100	10.30	155.00	37.72	88	100	12.40	61.30	33.55
Beryllium	588	48	nd	3.06	0.44	88	2	nd	0.03	0.03
Cadmium	588	52	nd	5.70	0.61	88	7	nd	0.09	0.08
Chromium	588	100	7.0	40.6	17.1	88	100	12.2	34.1	19.1
Copper	588	100	1.3	82.4	7.7	88	99	nd	14.2	5.8
Iron	552	100	4840	27,200	13084	88	100	7090	21,300	11,631
Lead	588	61	nd	15.5	5.3	88	100	1.9	107.0	5.1
Manganese	480	100	31.5	317.0	104.9	88	100	31.6	136.0	87.6
Mercury	588	64	nd	0.093	0.029	75	99	nd	0.093	0.024
Nickel	588	96	nd	29.0	7.5	88	100	2.5	9.7	5.6
Selenium	588	47	nd	0.90	0.27	88	49	nd	0.82	0.31
Silver	588	16	nd	5.84	1.16	88	1	nd	3.15	3.15
Thallium	588	10	nd	113.0	10.6	88	0	—	—	—
Tin	480	62	nd	42.0	1.5	88	94	nd	3.2	0.7
Zinc	588	100	12.4	176.0	29.0	88	100	18.0	42.3	27.5
Pesticides (ppt)										
Total Chlordane	588	<1	nd	2000	767	64	34	nd	985	117
Total DDT	588	58	nd	44,830	1284	64	100	204	1300	513
Dieldrin	588	<1	nd	270	270	64	0	—	—	—
Endrin aldehyde	588	<1	nd	970	970	64	0	—	—	—
Beta-endosulfan	588	0	—	—	—	64	2	0	11	11
Hexachlorobenzene	504	8	nd	3300	543	45	84	nd	1650	251
Total HCH	588	<1	nd	370	370	64	23	nd	191	64
Mirex	588	0	—	—	—	64	2	nd	66	66
Total PCB (ppt)	420	14	nd	22,690	1438	64	88	nd	18,226	1439
Total PAH (ppb)	586	29	nd	3063	116	72	83	nd	400	39

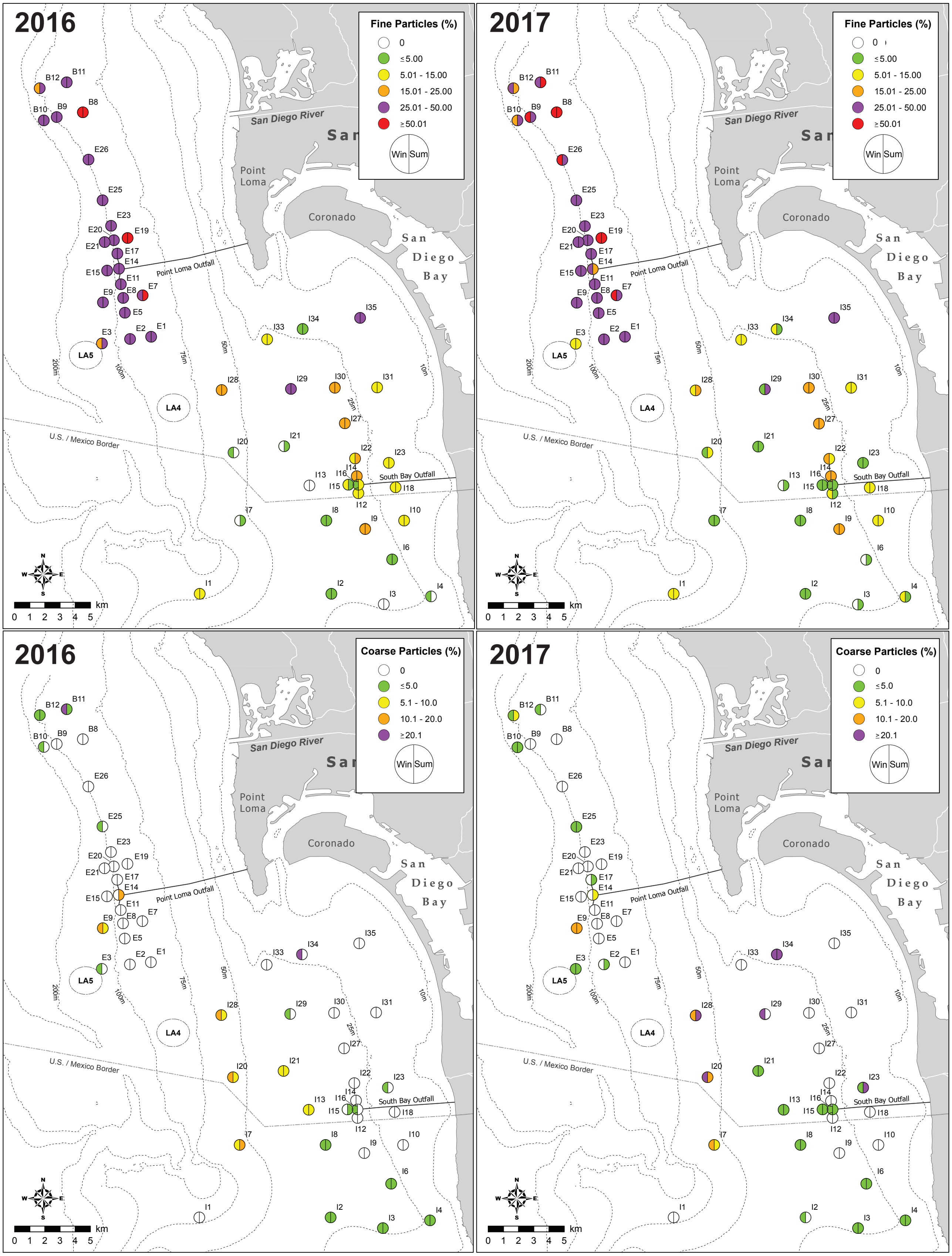


Figure 4.2

Distribution of fine particles and coarse particles in sediments from the PLOO and SBOO regions during winter and summer surveys of 2016 and 2017.

reporting period (Figure 4.2, Appendix D.4). Sediments from SBOO near-ZID stations I12 and I14 averaged 9–18% fines with no coarse particles present, which was generally similar to sediments found at the 28-m stations located to the north. In contrast, sediments from near-ZID stations I15 and I16 averaged only 3% fines and 0.3-0.4% coarse particles per sample, more closely resembling sediments from stations I2, I3, I6, I7, and I8 located west and south of the outfall. Previous analysis of particle size data revealed considerable temporal variability at some SBOO stations and relative stability at others, with no clear patterns evident relative to depth, proximity to the outfall, or other sources of nearshore sediment plumes such as San Diego Bay and the Tijuana River (City of San Diego 2014b).

Indicators of Organic Loading

Detection rates and concentrations of the various indicators of organic loading in benthic sediments surrounding the Point Loma and South Bay outfalls varied both within and between regions during the 2016 to 2017 reporting period (Tables 4.1, 4.2, Addenda 4-3, 4-4, City of San Diego 2017). Only total volatile solids (TVS) was detected in all sediment samples from both regions. In contrast, sulfides, total organic carbon (TOC), and total nitrogen (TN) were also detected in 100% of the PLOO sediment samples but in only 69 to 97% of the SBOO samples. Although not a required parameter for any of the PLOO or SBOO permits, biochemical oxygen demand (BOD) has long been measured voluntarily by the City at the PLOO benthic stations where it was detected in all samples during 2016 and 2017. Overall, results for all five indicators are consistent with historical detection rates of 86% or more since monitoring began (see Tables 4.1 and 4.2).

Sediments off Point Loma in 2016 and 2017 had concentrations of BOD ranging from 146 to 598 ppm, sulfide concentrations ranging from 1.7 to 50.9 ppm, TOC concentrations ranging from 0.13 to 2.46% weight, TN concentrations ranging from 0.02 to 0.90% weight, and TVS concentrations ranging from 0.2 to 3.9% weight per sample (Table 4.1). Concentrations of TOC, TN and TVS were consistently highest in sediments from the northern 'B' stations located at least 10 km north of the PLOO (Figure 4.2, Appendix D.5). In contrast, BOD and sulfide distributions were more variable over this period. For example, the four highest concentrations of BOD (≥531 ppm) occurred in one sample from southern farfield station E7, one sample from northern farfield station B8, and two samples from near-ZID station E14. Additionally, the highest concentrations of sulfides (≥43.2 ppm) occurred in one sample from northern farfield station E19 and one sample from near-ZID station E15 (Figure 4.2, Addendum 4-3, City of San Diego 2017). In general, only sulfide and BOD concentrations near the PLOO have shown any changes that appear consistent with possible organic enrichment (Figure 4.3; see also City of San Diego 2015).

Sediments surrounding the SBOO in 2016 and 2017 had sulfide concentrations ≤48.2 ppm, TOC concentrations were ≤0.85% weight, TN concentrations ≤0.061% weight, and TVS concentrations ranging from 0.2 to 8.2% weight (Table 4.2). There was little evidence of any significant organic enrichment near the SBOO discharge site during these two years, with the highest concentrations of the various organic loading indicators being widely distributed throughout the region (Figure 4.4, Appendix D.6). For TOC, TN, and TVS, variable concentrations may be linked to regional differences in sediment particle composition since these parameters tend to co-vary with the amount of percent fines (see Chapter 6 and City of San Diego 2014b). In contrast to the overall survey area, concentrations of these organic indicators have been less variable at the SBOO primary core stations, with no patterns indicative of organic enrichment being evident since wastewater discharge began in early 1999 (Figure 4.3).

Trace Metals

Nine of the 18 trace metals analyzed were detected in all sediment samples collected at the PLOO and SBOO core benthic stations during 2016 and 2017, including aluminum, arsenic, barium,

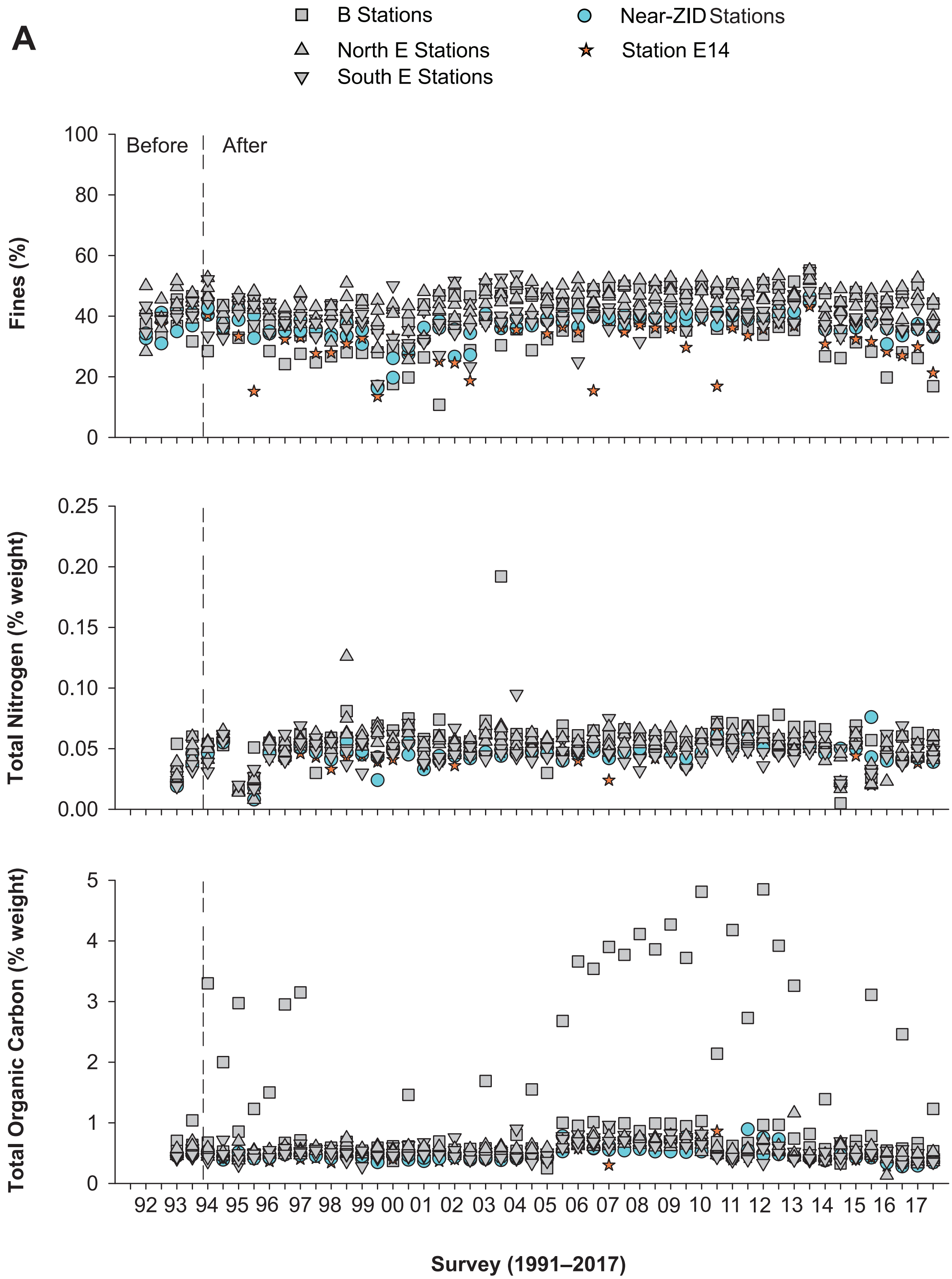


Figure 4.3

Percent fines and concentrations of organic indicators in sediments sampled during winter and summer surveys at PLOO primary core stations from 1991 through 2017 (A,C) and at SBOO primary core stations from 1995 through 2017 (B,D). Data represent detected values from each station, n≤12 samples per survey. Dashed lines indicate onset of discharge from the PLOO or SBOO.

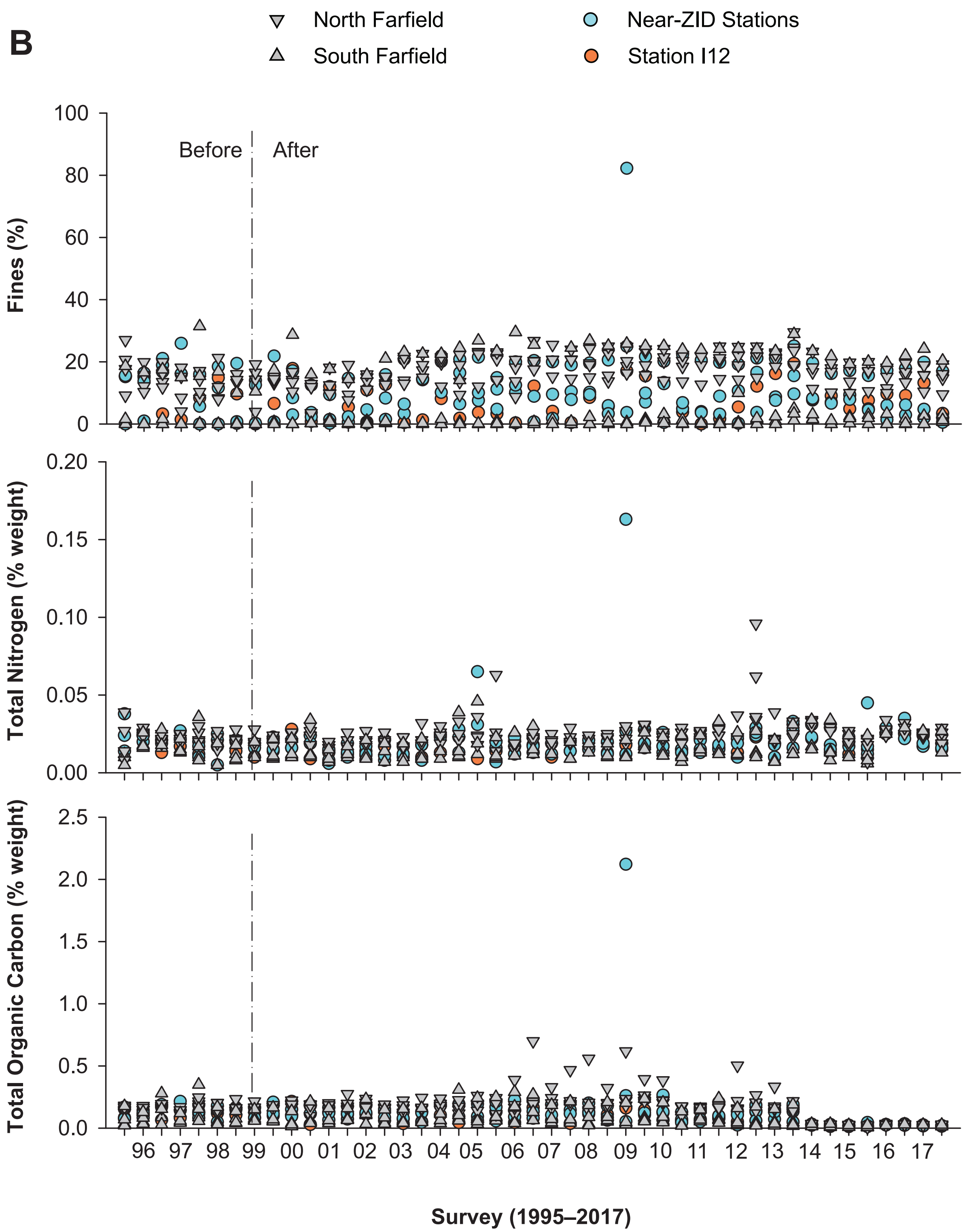


Figure 4.3 *continued*

chromium, iron, lead, manganese, nickel, and zinc (Tables 4.1, 4.2, Addenda 4-5, 4-6, City of San Diego 2017). In contrast, detection rates (DR) for antimony, copper, mercury, and tin were much higher in the PLOO region (i.e., 94–99%) than in the SBOO region (i.e., 16–67%). Detection rates for selenium also varied considerably between the regions, ranging from 49% at the PLOO stations to

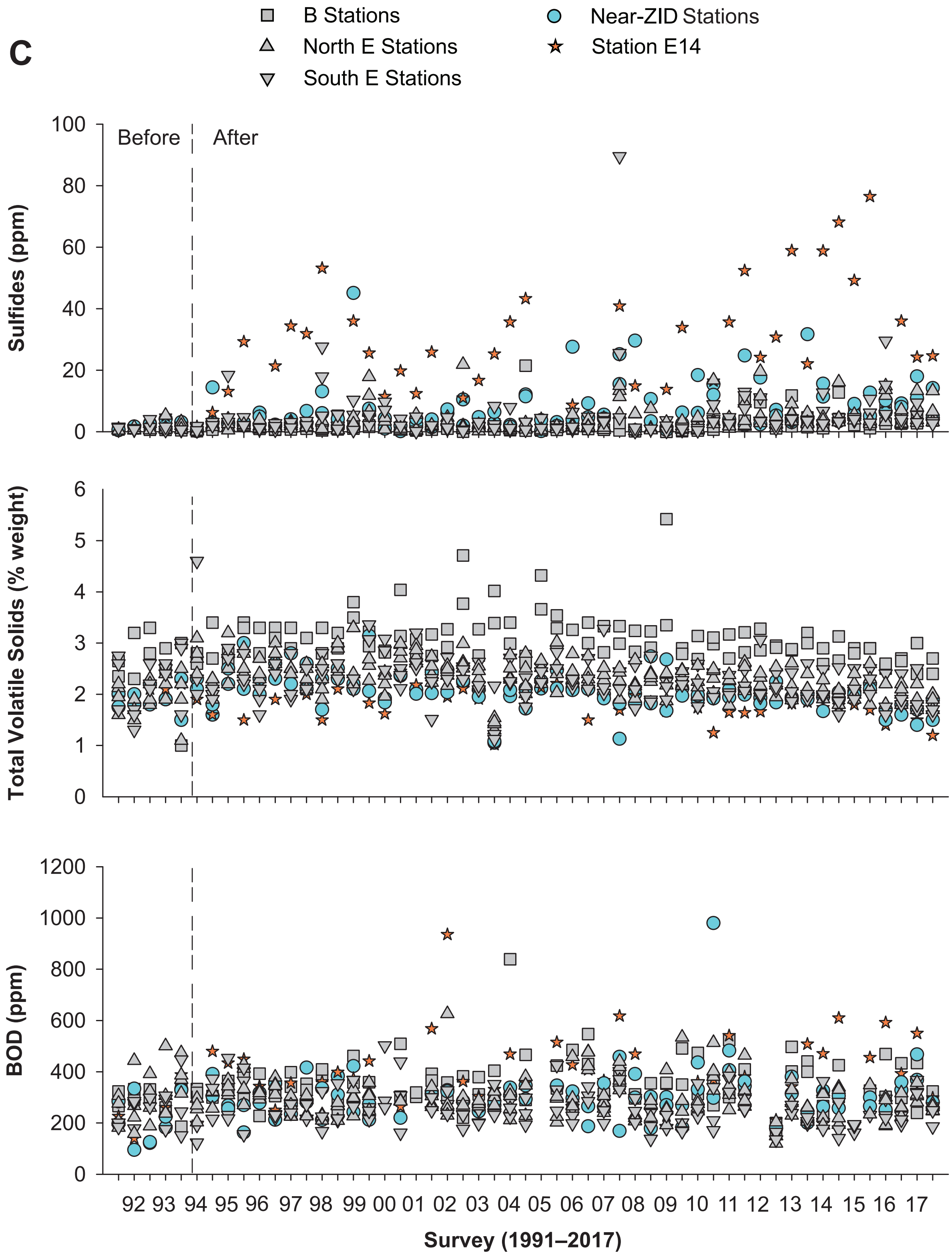
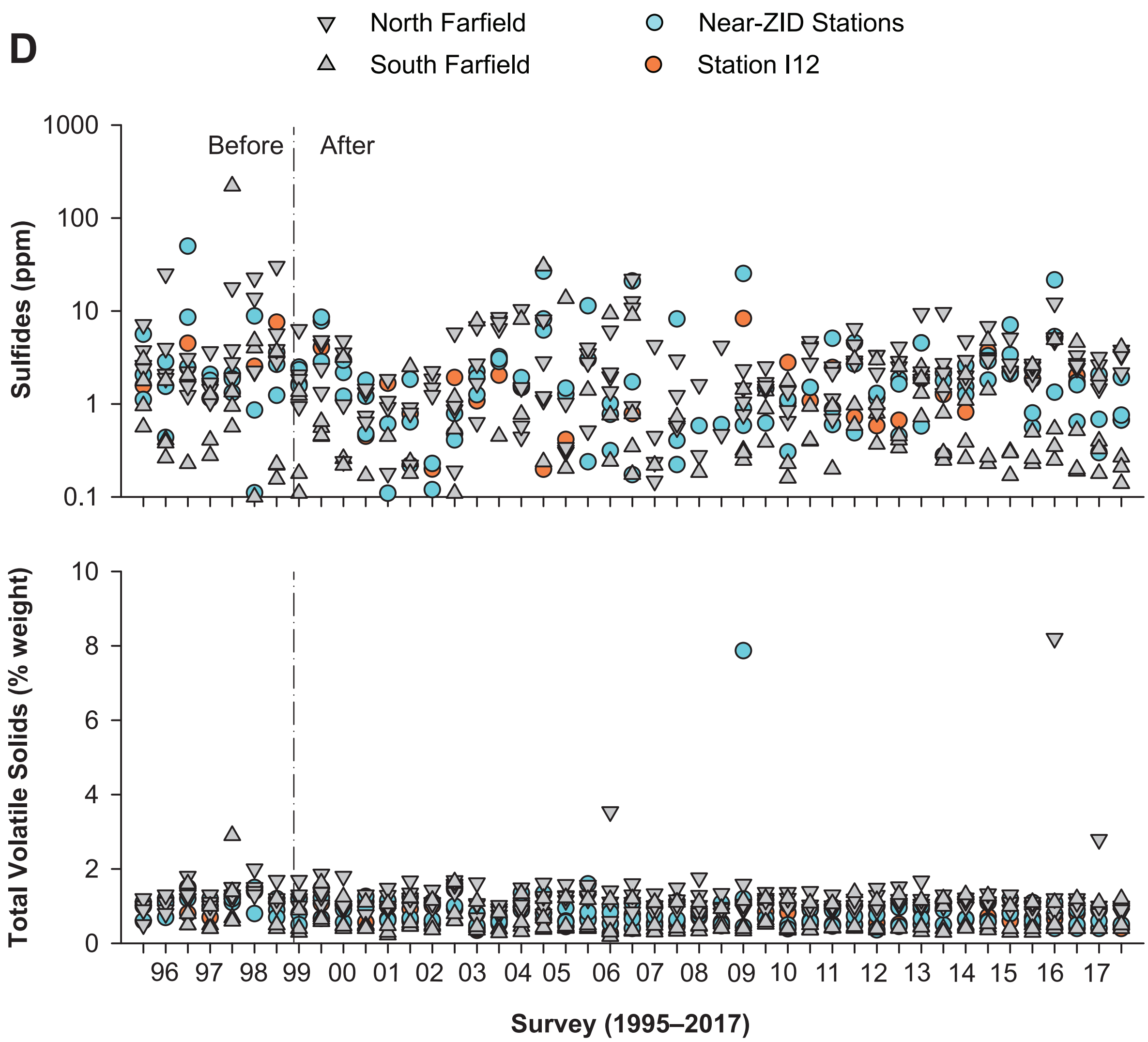


Figure 4.3 *continued*

only 4% at the SBOO stations. Cadmium and silver were also detected in both regions but at very low rates. For example, cadmium was detected in 7% of both the PLOO and SBOO samples, while silver was detected in only 1% of the PLOO samples and 3% of the SBOO samples. Beryllium was detected in only 2% of PLOO sediments and not at all at the SBOO stations. Thallium was not detected in any samples collected during the 2-year reporting period. Three of nine metals with published ERLs



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and ERMs in Long et al. (1995) were reported at levels above these thresholds during 2016 and 2017 (Table 4.3, Addenda 4-5, 4-6, City of San Diego 2017). These included: (1) arsenic, which exceeded its ERL at SBOO station I21 during both the winter and summer surveys of 2016; (2) lead, which exceeded its ERL at PLOO station E1 during the 2016 summer survey; (3) silver, which exceeded its ERL at PLOO near-ZID station E11, also during the 2016 summer survey. In addition to low overall values, metal concentrations varied in sediments from throughout the two regions, with no discernible patterns relative to either outfall. Within the PLOO region for example, the highest concentrations for metals such as antimony, arsenic, barium, beryllium, chromium, copper, iron, lead, mercury, selenium, tin, and zinc were typically found in sediments from one or more of the northern 'B' stations or southern 'E' stations (Figure 4.5, Appendix D.7). In contrast, the highest concentrations of aluminum, barium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc in the SBOO region all occurred in sediments from farfield station I35 (Appendix D.8); sediments from this station also had the largest proportion of percent fines in the SBOO region over the past two years.

Detection rates have been relatively high for a number of different metals ever since monitoring

Table 4.2

Summary of particle sizes and chemistry concentrations in sediments from SBOO benthic stations sampled historically (1995–2015) and during the current reporting period (2016–2017). Data include the total number of samples analyzed (n), detection rate (DR), minimum, maximum, and mean values for the entire survey area during each time period. Minimum and maxium values were calculated based on all samples, whereas means were calculated on detected values only; nd = not detected.

	Historical (1995–2015)					Current (2016–2017)				
Parameter	n	DR	min	max	mean	n	DR	min	max	mean
Particle Size (%)										
Coarse Particles	489	34	0.0	12.3	2.8	108	49	nd	56.8	8.3
Med-Coarse Sands	489	99	0.0	99.8	31.3	108	100	0.5	91.3	36.8
Fine Sands	489	100	0.0	96.1	56.8	108	100	1.6	91.5	49.7
Fine Particles	489	90	0.0	82.3	12.6	108	90	nd	39.1	10.5
Organic Indicators										
Sulfides (ppm)	490	86	nd	222.00	3.27	108	97	nd	48.20	2.69
TN (% weight)	491	94	nd	0.163	0.020	108	69	nd	0.061	0.027
TOC (% weight)	491	99	nd	2.12	0.15	108	82	nd	0.85	0.16
TVS (% weight)	477	100	0.19	7.87	0.91	108	100	0.20	8.20	0.81
Metals (ppm)										
Aluminum	491	100	495	30100	5380	108	100	564	12,000	3438
Antimony	491	30	nd	5.6	0.8	108	34	nd	1.5	0.6
Arsenic	491	99	nd	9.18	1.82	108	100	0.56	10.50	2.27
Barium	312	100	0.86	177.00	23.28	108	100	1.24	56.40	17.29
Beryllium	491	38	nd	2.10	0.18	108	0	nd	nd	NA
Cadmium	491	31	nd	1.00	0.15	108	7	nd	0.28	0.10
Chromium	491	100	nd	38.2	9.8	108	100	2.8	28.7	9.9
Copper	491	84	nd	37.6	3.6	108	67	nd	9.2	2.2
Iron	491	100	559	29,300	6069	108	100	1200	16,900	5501
Lead	491	57	nd	20.0	2.3	108	100	0.7	5.8	1.9
Manganese	479	100	5.2	473.0	68.9	108	100	5.4	134.0	46.8
Mercury	491	30	nd	0.135	0.009	81	36	nd	0.026	0.009
Nickel	491	74	nd	22.8	3.3	108	100	0.3	9.3	2.2
Selenium	491	15	nd	0.56	0.22	108	4	nd	0.24	0.14
Silver	491	15	nd	4.59	0.74	108	3	nd	0.29	0.18
Thallium	491	7	nd	11.0	2.0	108	0	—	—	—
Tin	479	53	nd	4.5	1.0	108	16	nd	1.3	0.7
Zinc	491	90	nd	126.0	15.4	108	100	2.0	40.9	11.1
Pesticides (ppt)										
Aldrin	491	<1	nd	500	500	65	0	—	—	—
Total Chlordane	491	<1	nd	1620	592	65	8	nd	86	40
Total DDT	491	18	nd	9400	596	65	78	nd	3020	215
Endrin	491	0	—	—	—	65	2	nd	133	133
Beta-endosulfan	491	<1	nd	820	820	65	0	—	—	—
Hexachlorobenzene	360	13	nd	2700	374	39	67	nd	6200	553
Total HCH	491	<1	nd	3880	1690	65	8	nd	134	60
Mirex	491	0	—	—	—	65	2	nd	17	17
Total PCB (ppt)	420	7	nd	11320	884	71	61	nd	3607	273
Total PAH (ppb)	490	22	nd	752	119	97	22	nd	468	42

began at the PLOO stations in 1991 and the SBOO stations in 1995. For example, aluminum, arsenic, barium, chromium, copper, iron, manganese, and zinc have been detected in ≥84% of the sediment samples collected in these areas over the past 23 to 27 years (Tables 4.1, 4.2). Concentrations of chromium, lead, and mercury have remained below their ERLs during this time, while exceedances for arsenic, cadmium, copper, nickel, and silver have also been rare (i.e., historical detection rates ≤8% within each region; Table 4.3). Concentrations of the remaining metals have been extremely variable with most being detected within ranges reported elsewhere in the Southern California Bight (Dodder 2016). While high metal concentrations have been occasionally recorded in sediments collected from both PLOO and SBOO near-ZID stations, no discernible long-term patterns have been identified that could be associated with proximity to either outfall or to the onset of wastewater discharge (Figure 4.6, Appendix D.9). Instead, concentrations of several metals tend to co-vary mostly with the level of percent fines present in local sediments (see Chapter 6 and City of San Diego 2014b).

Pesticides, PCBs, PAHs

Based on reportable results (see Material & Methods: Laboratory Analyses), sediments sampled at the core benthic monitoring stations in 2016 and 2017 varied between regions in terms of detection rates and concentrations of the various chlorinate pesticides, PCBs, and PAHs (Tables 4.1 and 4.2). For example, most of these parameters were detected more often and at higher concentrations in PLOO sediments versus SBOO sediments.

A total of seven chlorinated pesticides were detected in benthic sediments off San Diego during the current reporting period, including chlordane, DDT, endosulfan, endrin, HCB, HCH, and mirex (Tables 4.1, 4.2). DDT was the most common of these pesticides detected in 100% of the PLOO samples and 78% of the SBOO samples at total DDT concentrations averaging 513 ppt and 215 ppt per region, respectively. HCB was the second most common pesticide detected in 84% of PLOO samples and 67% of SBOO samples at average concentrations of 251 ppt and 553 ppt, respectively. Chlordane and HCH were the next most common pesticides detected in 34% and 23% of the PLOO samples, respectively, but each in only 8% of the SBOO samples. Each of the other three pesticides were detected in no more than 2% of the samples for either region. Of the above pesticide results, only a single total DDT value for SBOO station I28 sampled in July 2017 exceeded its ERL threshold of 1580 ppt (see Addendum 4-8). Six additional samples from region stations 8504, 8519, 8537, 8540, 8614, and 8657 had DDT above this threshold (Addenda 6-4, City of San Diego 2017).

PCBs and PAHs were also detected more often in the PLOO region than in the SBOO region during the 2016 and 2017 reporting period (Tables 4.1, 4.2). For example, PCBs were measured in 88% of the PLOO samples compared to 61% of the SBOO samples at total PCB concentrations up to 18,226 ppt and 3607 ppt, respectively. In contrast, PAHs were detected in 83% of the PLOO samples but in only 22% of the SBOO samples during the reporting period, However, there was little difference between average (i.e., 39–42 ppb) or maximum (i.e., 400–468 ppb) total PAH concentrations for these two regions. Additionally, the maximum total PAH concentration of 468 ppb was well below the ERL threshold of 4022 ppb.

Although historical comparisons of pesticide, PCB, and PAH results indicate considerably higher detection rates in 2016–2017 versus previous years (Tables 4.1, 4.2), these apparent recent increases should be viewed with caution since they are most likely due to improved methods that increase the likelihood of detecting these parameters (e.g., lower MDLs). In addition, pesticide, PCB and, PAH concentrations have been consistently low, with total DDT exceeding its ERL in just 9% of the samples collected in the PLOO region and 1% of the samples in the SBOO region over the past 22 to 26 years (Table 4.3). Total DDT has also never exceeded its ERM, while total PAH has never exceeded either its ERL or ERM. These thresholds do not exist for PCBs measured as congeners. Finally, changes in DDT, PCB, and PAH demonstrated no discernible

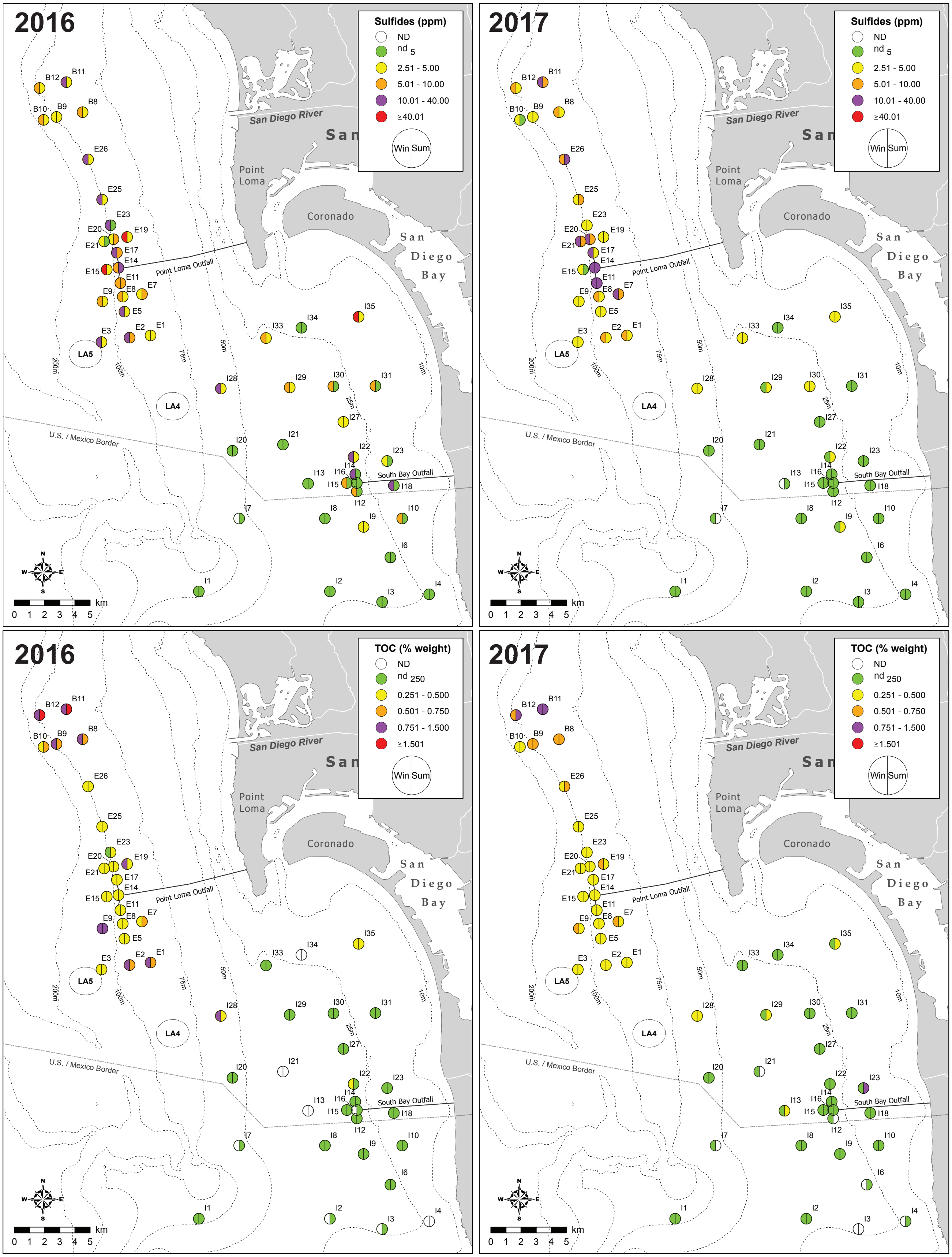


Figure 4.4

Distribution of select organic loading indicators in sediments from the PLOO and SBOO regions during winter and summer surveys of 2016 and 2017; nd = not detected.

Table 4.3

Summary of samples with chemistry concentrations that exceeded Effects Range Low (ERL) and Effects Range Median (ERM) thresholds (see Long et al 1995) in sediments from PLOO and SBOO benthic stations sampled historically (1991–2015) and during the current reporting period (2016–2017). Data include the percent of samples that exceeded the ERL (%ERL) and ERM (%ERM) threholds during each time period. See Tables 4.1 and 4.2 for total number of samples analyzed.

			PLOO				SBOO			
	Thresholds		1991–2015		2016–2017		1995–2015		2016–2107	
Parameter	ERL	ERM	%ERL	%ERM	%ERL	%ERM	%ERL	%ERM	%ERL	%ERM
Metals										
Arsenic	8.2	70	0	0	0	0	0.2	0	1.9	0
Cadmium	1.2	9.6	7.7	0	0	0	0	0	0	0
Chromium	81	370	0	0	0	0	0	0	0	0
Copper	34	270	0.2	0	0	0	0.2	0	0	0
Lead	46.7	218	0	0	1.1	0	0	0	0	0
Mercury	0.15	0.71	0	0	0	0	0	0	0	0
Nickel	20.9	51.6	0.2	0	0	0	0.2	0	0	0
Silver	1	3.7	6.1	0.6	1.1	0	3.7	0.4	0	0
Zinc	150	410	0.2	0	0	0	0	0	0	0
Pesticides										
tDDT	1580	461000	9.1	0	0	0	1.0	0	1.5	0
tPAH	4022	44792	0	0	0	0	0	0	0	0

long-term patterns that can be associated with wastewater discharge via either outfall (Figure 4.7).

Discussion

Particle size composition at the PLOO and SBOO stations was similar during the current reporting period (2016–2017) to that seen historically (e.g., Emery 1960, MBC-ES 1988, City of San Diego 2016a, b). Within the PLOO region, percent fines (silt and clay) and fine sands comprised the largest proportion of sediments. In contrast, sands comprised the largest proportion of sediments in the SBOO region, with the relative amounts of coarser and finer particles varying among sites. No spatial relationship was evident between sediment particle size composition and proximity to the SBOO discharge site, while only minor deviations were found near the PLOO. Further, there has not been any substantial increase in the amount of percent fines at any of near-ZID stations or elsewhere since wastewater discharge began at the current PLOO discharge site in late 1993 or the SBOO discharge site in early 1999. Instead, the diversity of sediment types in these areas reflect multiple geologic origins and complex patterns of transport and deposition. In particular, variability in the composition of Point Loma sediments is likely affected by both anthropogenic and natural influences, including outfall construction or ballast materials, offshore disposal of dredged materials, and recent deposition of sediment and detrital materials (Emery 1960, Parnell et al. 2008, City of San Diego 2015). For example, the PLOO lies within the Mission Bay littoral cell (Patsch and Griggs 2007), which has natural sources of sediments, such as outflows from Mission Bay, the San Diego River, and San Diego Bay. However, fine particles may also travel in suspension across littoral cell borders up and down the coast (e.g., Farnsworth and Warrick 2007, Svejkovsky 2013), thus widening the range of potential sediment sources to the region. Additionally, the presence of relict red sands at some stations in the SBOO region is indicative of minimal sediment deposition in recent years. Several SBOO stations are also located within or near an accretion

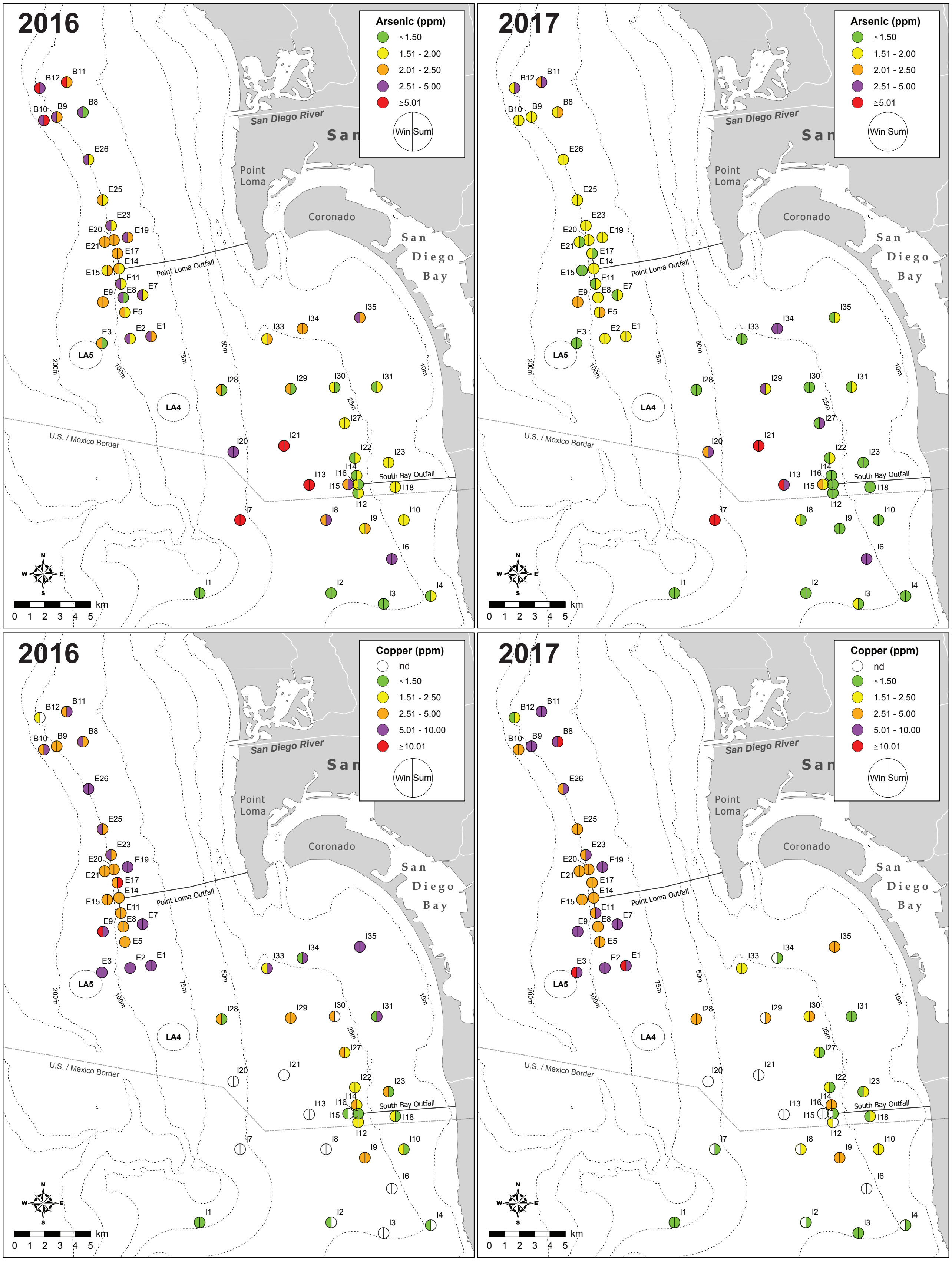
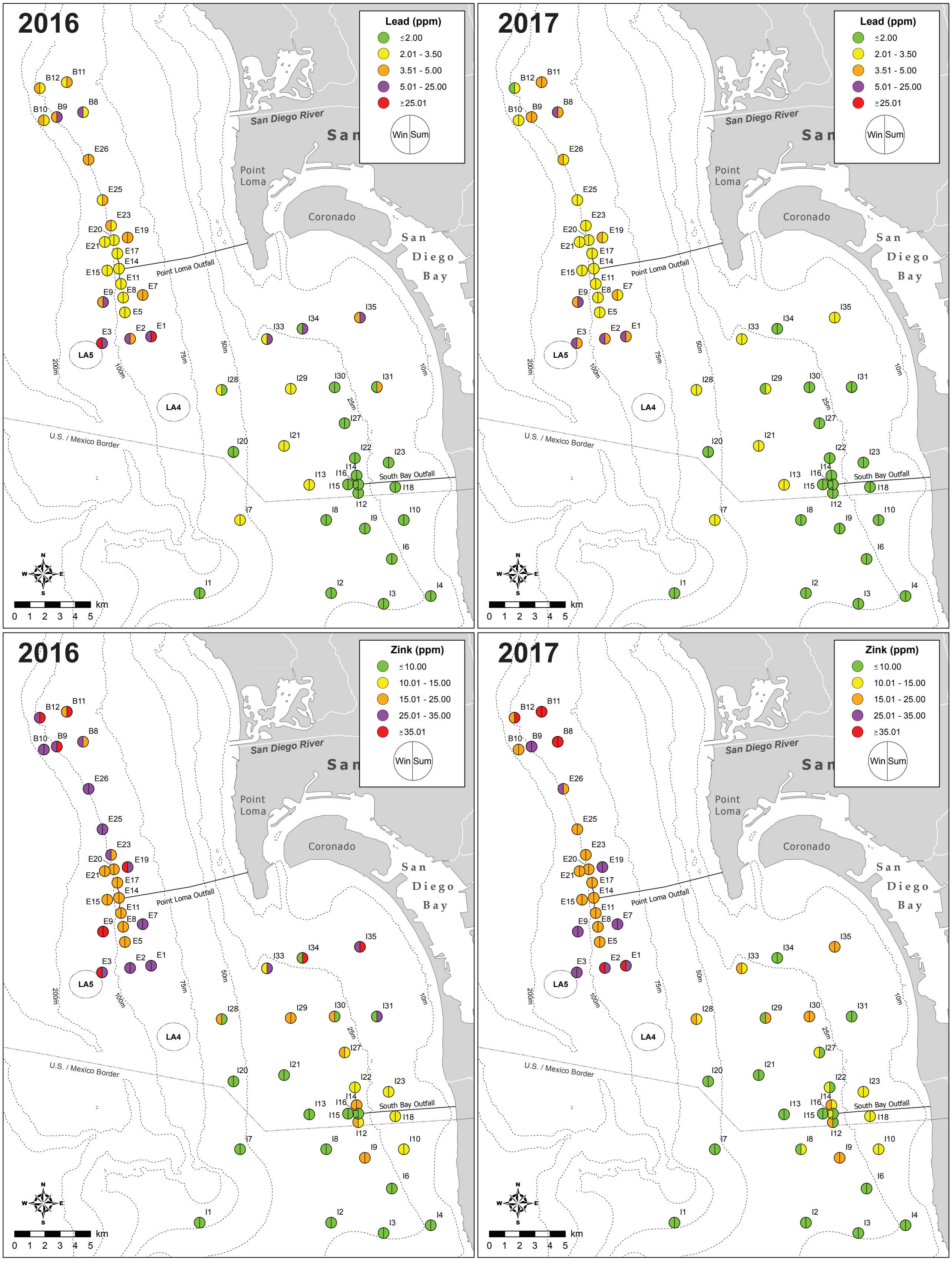


Figure 4.5

Distribution of select metals in sediments from the PLOO and SBOO regions during winter and summer surveys of 2016 and 2017; nd = not detected.



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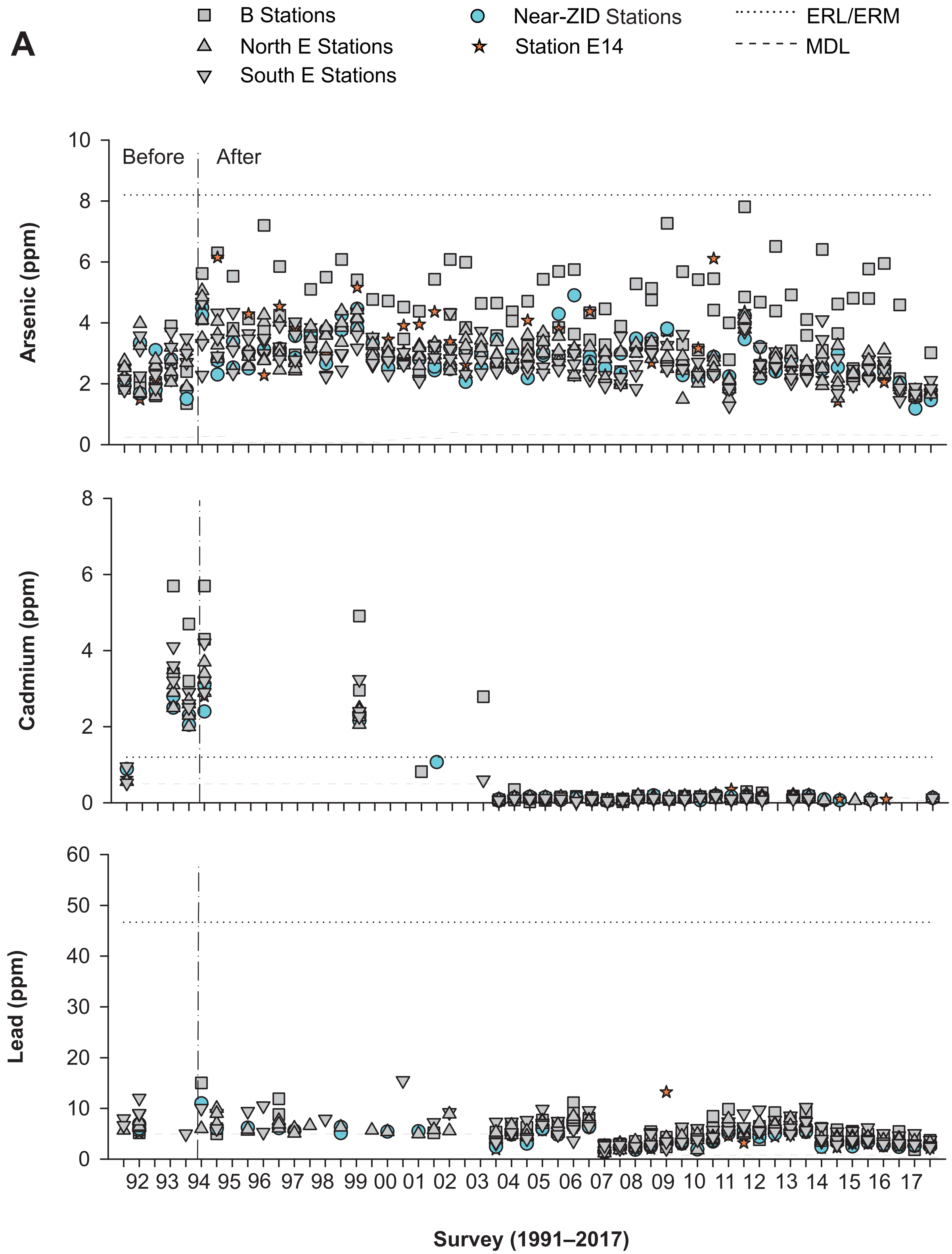


Figure 4.6

Concentrations of select metals in sediments sampled during winter and summer surveys at PLOO primary core stations from 1991 through 2017 (A,C) and at SBOO primary core stations from 1995 through 2017 (B,D). Data represent detected values from each station, n ≤ 12 samples per survey. Dashed lines indicate onset of discharge from the PLOO or SBOO. See Table 4.3 for values of ERLs and ERMs.

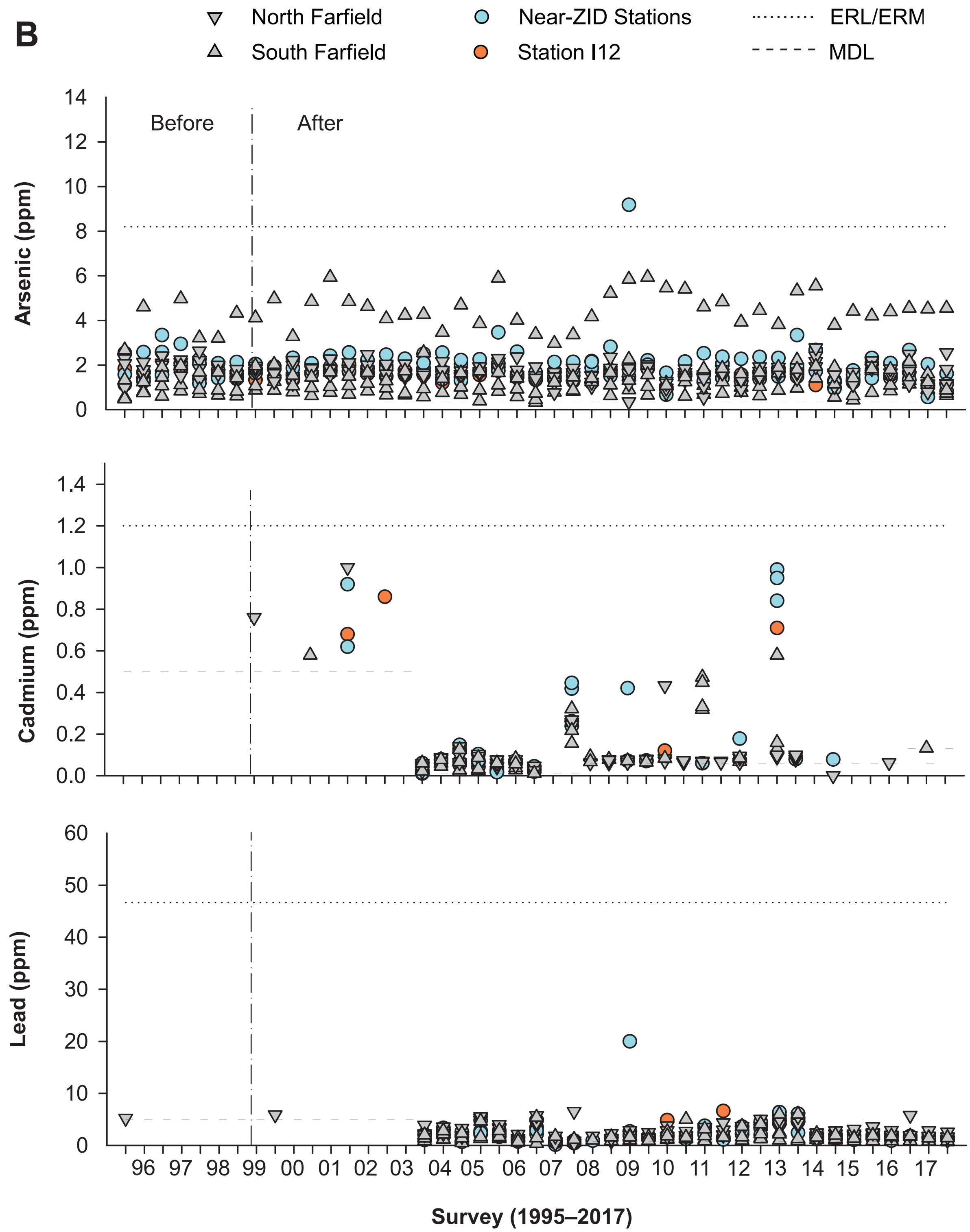
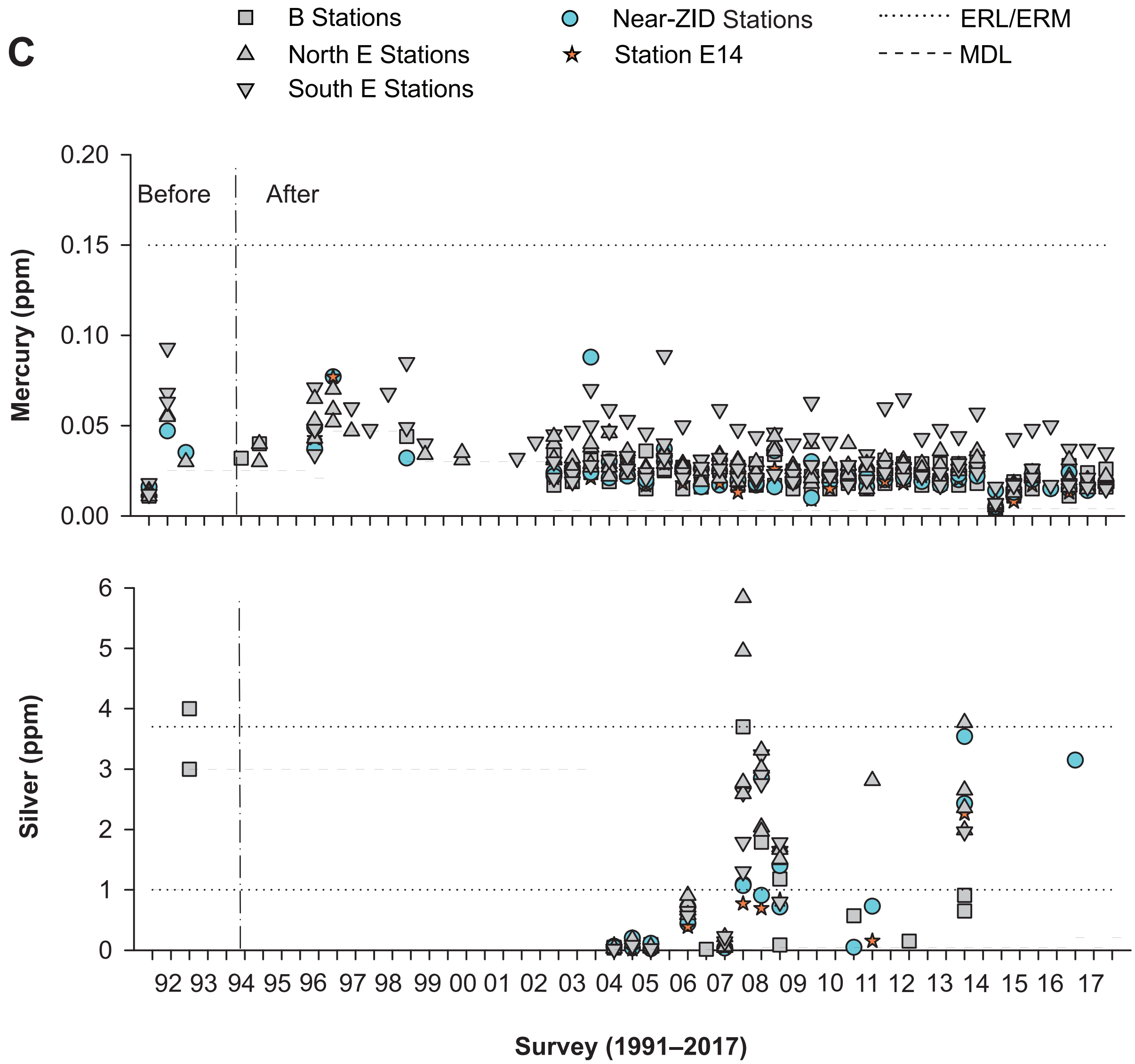


Figure 4.6 *continued*

zone for sediments moving within the Silver Strand littoral cell (MBC-ES 1988, Patsch and Griggs 2007). Therefore, higher proportions of fine sands, silts, and clays at these sites are also 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).

Various organic loading indicators, trace metals, pesticides, PCBs, and PAHs were detected in



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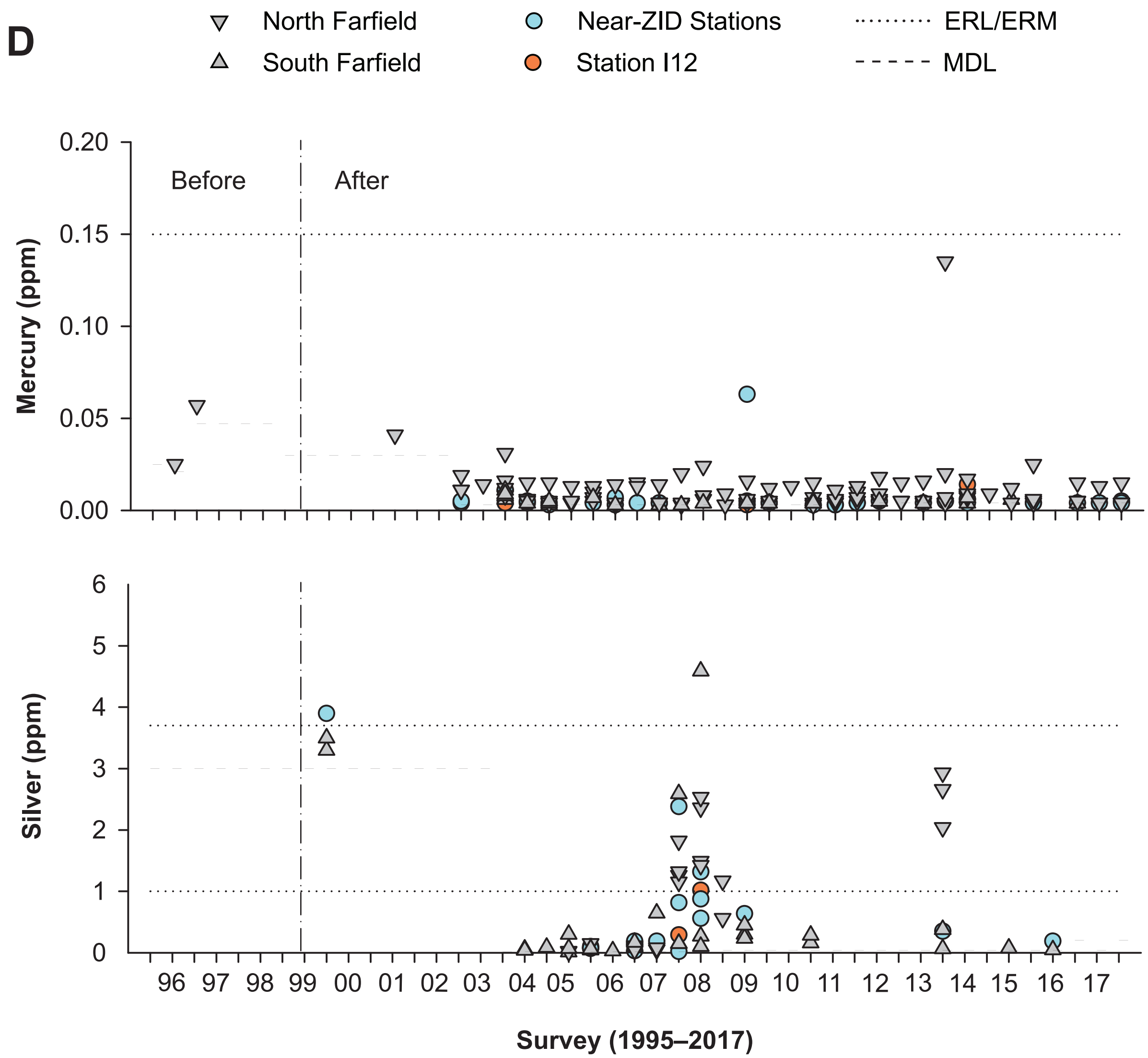
sediment samples collected throughout the PLOO and SBOO regions in 2016 and 2017. However, concentrations of these parameters were below ERM thresholds, mostly below ERL thresholds, and typically within historical ranges (City of San Diego 2014a, b, 2016a, b). Additionally, values for most sediment parameters remained within ranges typical for other areas of the southern California continental shelf (see Schiff and Gossett 1998, City of San Diego 2000, 2015, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009, Dodder et al. 2016).

There have been few if any clear spatial patterns consistent with outfall discharge effects on sediment chemistry values over the past several years, with concentrations of most contaminants at near-ZID sites falling within the range of values observed at farfield stations. The only exceptions off San Diego have been slightly higher sulfide and BOD levels measured in sediments near the PLOO discharge site (see also City of San Diego 2014a, 2015). Instead, the highest concentrations of several organic indicators, trace metals, pesticides, PCBs, and PAHs have historically occurred in sediments from southern and/or northern farfield stations. The cause behind elevated contaminants at the northern PLOO stations is unknown, while sediments from the southern PLOO stations are known to be impacted by the dumping of dredged materials



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destined originally for the LA-5 dredged disposal dumpsite (Anderson et al. 1993, Steinberger et al. 2003, Parnell et al. 2008). In the SBOO region, relatively high values of most parameters could be found distributed throughout the region, and several organic indicators and metals co-occurred in samples characterized by finer sediments. This association is expected due to the known correlation between particle size and concentrations of these chemical parameters (Eganhouse and Venkatesan 1993).

The broad distribution of various contaminants in sediments throughout the PLOO and SBOO regions is likely derived from several sources. Mearns et al. (1991) described the distribution of contaminants such as arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB, while Brown et al. (1986) concluded that there may be no coastal areas in southern California that are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent surveys of SCB continental shelf habitats (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Dodder et al. 2016). The lack of contaminant-free reference areas clearly pertains to the PLOO and SBOO regions as demonstrated by the presence of many contaminants in sediments prior to wastewater discharge (see City of San Diego 2000, 2015).

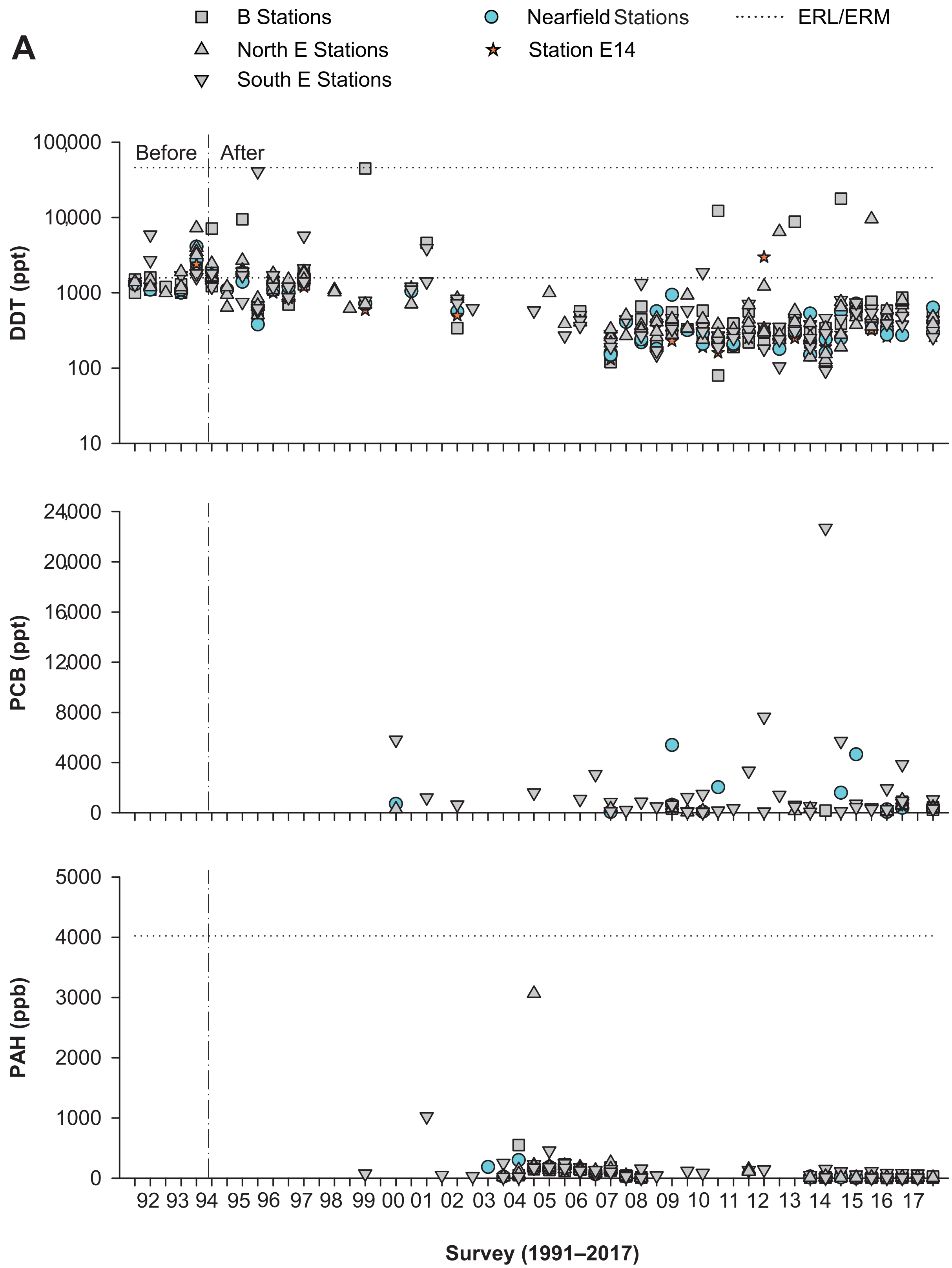
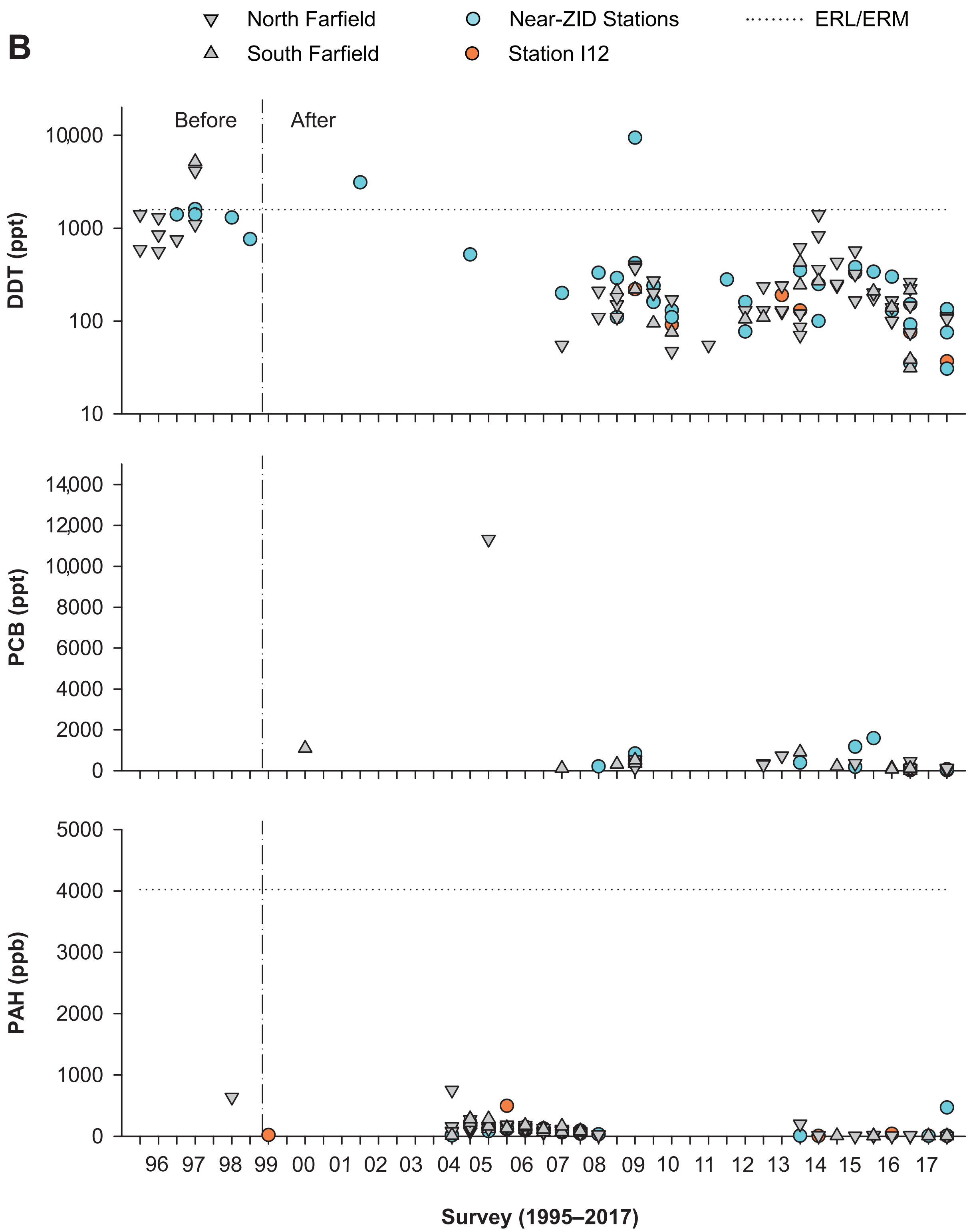


Figure 4.7

Concentrations of total DDT, total PCB, and total PAH in sediments sampled during winter and summer surveys at PLOO primary core stations from 1991 through 2017 (A) and at SBOO primary core stations from 1995 through 2017 (B). Data represent detected values from each station, n ≤ 12 samples per survey. Dashed lines indicate onset of discharge from the PLOO or SBOO. See Table 4.3 for values of ERLs and ERMs.



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In addition, historical assessments of benthic sediments off the coast of Los Angeles have shown that as wastewater treatment improved, sediment conditions were more likely affected by other factors (Stein and Cadien 2009). Such factors may include bioturbative re-exposure of buried legacy sediments (Niedoroda et al. 1996, Stull et al. 1996), large storms that assist redistribution of legacy contaminants (Sherwood et al. 2002), and stormwater discharges (Schiff et al. 2006, Nezlin et al. 2007). Possible non-outfall sources and pathways of contaminant dispersal off San Diego include transport of contaminated sediments from San Diego Bay via tidal exchange, offshore disposal of dredged sediments, nearshore turbidity plumes emanating from the Tijuana River, and surface runoff from local watersheds (Parnell et al. 2008).

In conclusion, there was no evidence of fine-particle loading related to wastewater discharge via the PLOO or SBOO during the current reporting period or since the discharge originally began through either outfall in the 1990s. Likewise, contaminant concentrations at near-ZID stations were generally within the range of variability observed throughout both outfall regions and do not appear to reflect any significant organic enrichment. The only sustained effects have been restricted to a few sites located within about 200 m of the PLOO (i.e., near-ZID stations E11, E14 and E17). These minor effects include small increases in sulfide and BOD concentrations (City of San Diego 2015). Finally, the quality of PLOO and SBOO sediments in 2016 and 2017 was similar to previous years with overall contaminant concentrations remaining relatively low compared to available thresholds or other southern California coastal areas (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009). Finally, there is presently no evidence to suggest that wastewater discharge via the PLOO or SBOO is affecting the quality of benthic sediments off San Diego to the point that it may degrade resident marine biological communities (e.g., see Chapters 5–7).

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Chapter 5
Macrobenthic Communities

Chapter 5. Macrobenthic Communities

Introduction

The City of San Diego conducts extensive monitoring of soft-bottom marine macrobenthic communities at permanent (core) monitoring sites surrounding the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO), as well as at randomly selected (regional) stations distributed throughout the broader San Diego coastal region in order to characterize the status of the local marine ecosystem and to identify any possible effects of waste water discharge or other anthropogenic or natural influences. Benthic macrofauna (e.g., worms, crabs, clams, brittle stars, other small invertebrates) are targeted for monitoring seafloor habitats because such organisms play important ecological roles in coastal marine ecosystems off southern California and throughout the world (e.g., Fauchald and Jones 1979, Thompson et al. 1993a, Snelgrove et al. 1997). Additionally, because many macrobenthic species live relatively long and stationary lives, they may integrate the effects of pollution or other disturbances over time (Hartley 1982, Bilyard 1987). The response of many of these species to environmental stressors is also well documented, and therefore monitoring changes in discrete populations or more complex communities can help identify locations impacted by anthropogenic inputs (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). For example, pollution-tolerant species are often opportunistic, successfully colonizing impacted areas, and can therefore displace more sensitive species. In contrast, populations of pollution-sensitive species will typically decrease in numbers in response to contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation (Gray 1979). For these reasons, the assessment of benthic community structure has become a major component of many ocean monitoring programs.

The City relies on a suite of ecological indices to evaluate potential changes in local marine macrobenthic communities. Biological indices such as the benthic response index (BRI), Shannon diversity index (H'), and Swartz dominance index are used as important metrics of community structure (e.g., Smith et al. 2001). The use of multiple measures of community health also provides better resolution than the evaluation of single parameters, some of which include established benchmarks for determining environmental impacts caused by anthropogenic influences. Collectively, these data are used to evaluate whether macrobenthic assemblages from habitats with comparable depth and sediment particle size are similar, or whether impacts from local ocean outfalls or other sources may be occurring. For example, minor organic enrichment due to wastewater discharge should be evident through increases in species richness and abundance in macrofaunal assemblages, whereas more severe impacts should result in decreases in the overall number of species coupled with dominance by a few pollution-tolerant species (Pearson and Rosenberg 1978).

This chapter presents analysis and interpretation of macrofaunal data collected at NPDES permit designated core benthic monitoring stations surrounding the Point Loma and South Bay Ocean Outfalls during calendar years 2016 and 2017. Included are descriptions of the different macrobenthic communities present in these two regions, along with comparisons of spatial patterns and long-term changes over time. The three primary goals of the chapter are to: (1) characterize and document the benthic assemblages present during the reporting period; (2) determine the presence or absence of biological impacts on these assemblages that may be associated with wastewater discharge from the two outfalls; (3) identify other potential natural or anthropogenic sources of variability in the San Diego coastal marine ecosystem. Finally, a broader regional assessment of benthic conditions throughout the entire San Diego region based on a subset of data reported in this chapter combined with a suite of randomly selected stations sampled during the summers of 2016 and 2017 is presented in Chapter 6.

Materials and Methods

Field Sampling

The benthic samples analyzed in this chapter were collected at a total of 49 core monitoring stations located at inner shelf (≤30 m) to middle shelf (>30–120 m) depths surrounding the Point Loma and South Bay Ocean Putfalls during January (winter) and July (summer) of 2016 and 2017 (Figure 5.1). The PLOO sites include 12 primary core stations located along the 98-m discharge depth contour and 10 secondary core stations located along or adjacent to the 88-m or 116-m depth contours. The SBOO sites include 12 primary core stations located along the 28-m discharge depth contour and 15 secondary core stations located along or adjacent to the 19, 38, or 55-m depth contours. The four stations located within 1000 m of the zone of initial dilution (ZID) for each outfall are considered to represent near-ZID conditions. These include PLOO stations E11, E14, E15, and E17, and SBOO stations I12, I14, I15, and I16.

Samples for benthic analyses were collected using a double 0.1-m^2 Van Veen grab, with one grab per cast used for sediment quality analysis (see Chapter 4) and one grab per cast used for benthic community analysis. Criteria established by the U.S. Environmental Protection Agency (USEPA) to ensure consistency of these types of samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). All samples for infauna analysis were brought aboard ship, the sediments and benthic organisms transferred to a wash table and rinsed with seawater, and then sieved through a 1.0-mm mesh screen in order to remove as much sediment debris as possible. The macroinvertebrates (macrofauna or infauna) retained on the screen were transferred to sample jars, relaxed for 30 minutes in a magnesium sulfate solution, and then fixed with buffered formalin. The preserved samples were then transferred back to the City's Marine Biology Laboratory where after a minimum of 72 hours in formalin, each sample was thoroughly rinsed with fresh water and transferred to 70% ethanol for final preservation. All organisms were separated from the raw material (e.g., sediment grunge, shell hash, debris) and sorted into the following six taxonomic groups by an external contract lab: Annelids (e.g., polychaete and oligochaete worms), Arthropods (e.g., crustaceans and pycnogonids), Molluscs (e.g., clams, snails, and scaphopods), non-ophiuroid Echinoderms (e.g., sea urchins, sea stars, and sea cucumbers), Ophiuroids (i.e., brittle stars), and miscellaneous other phyla (e.g., flatworms, nemerteans, and cnidarians). The sorted macrofaunal samples were then returned to the City's Marine Biology Laboratory where all animals were identified to species or to the lowest taxon possible by staff marine biologists. All identifications followed nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT 2014).

Data Analyses

Macrofaunal data for each PLOO and SBOO core station sampled in 2017 are listed in Addenda 5-1 and 5-2, while data collected during 2016 were reported previously (City of San Diego 2017) and are available online (City of San Diego 2018). The following community metrics were determined for each station and expressed per 0.1-m^2 grab: species richness (number of species or distinct taxa), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance index (see Swartz et al. 1986, Ferraro et al. 1994), and benthic response index (BRI) (see Smith et al. 2001). Unless otherwise noted, the above analyses were performed using R (R Core Team 2016) and various functions within the reshape2, Rmisc, RODBC, tidyverse, and vegan packages (Wickham 2007, 2017, Hope 2013, Oksanen et al. 2017, Ripley and Lapsley 2017).

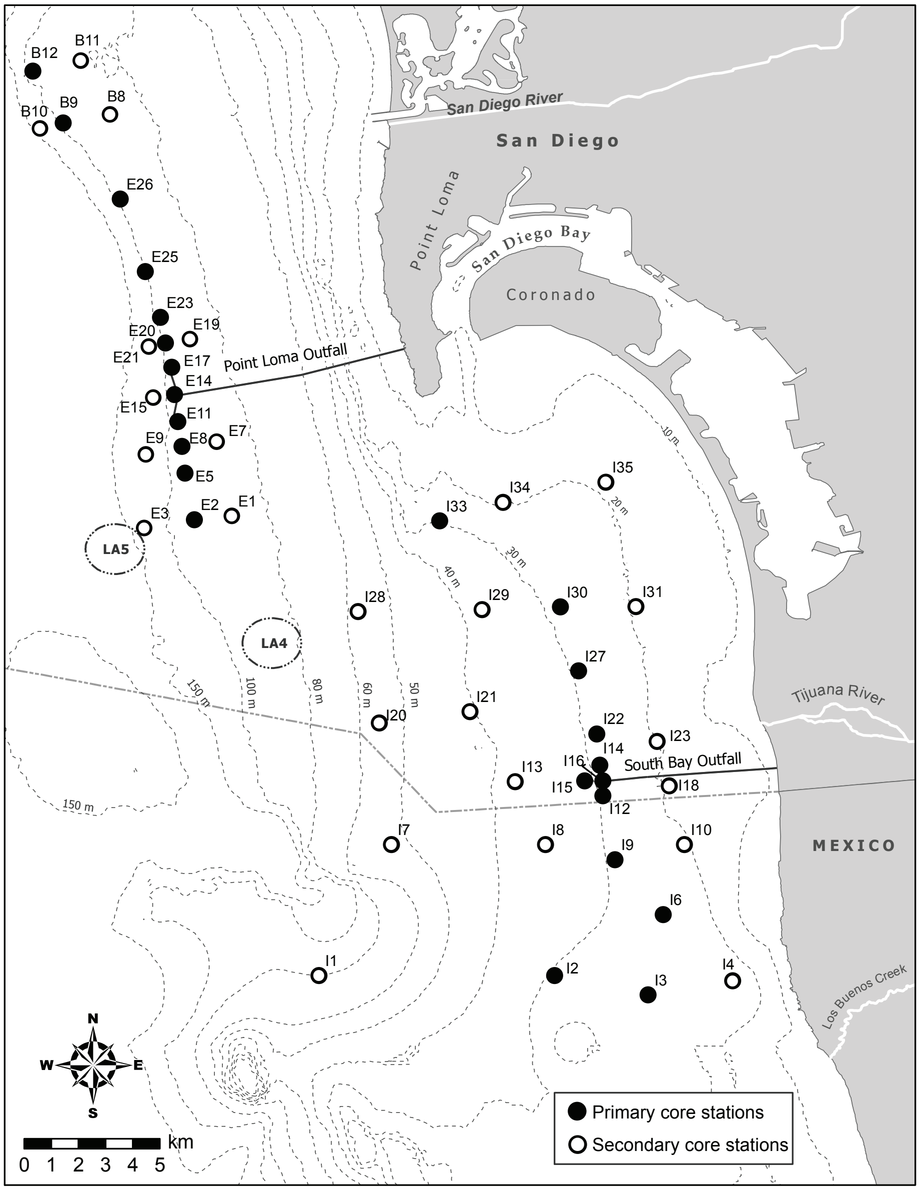

Figure 5.1

Benthic station locations sampled around the Point Loma and South Bay Ocean Outfalls as part of the City of San Diego's Ocean Monitoring Program.

Results and Discussion

Community Parameters

Species richness

A total of 861 different taxa were identified from the 196 grabs samples collected semiannually at the 22 core PLOO stations and 27 core SBOO stations during 2016 and 2017. About 81% (n = 695) of these taxa were fully identified to species, while the remainder could only be identified to genus or higher taxonomic levels. In the somewhat deeper (88–116 m) mid-shelf waters off Point Loma, 486 taxa were identified during this period, of which at least 391 (~80%) were distinct species. In contrast, 714 taxa were identified from the shallower (19–55 m) inner to mid-shelf waters in the South Bay outfall region. Of these, 569 (~80%) were distinct species. Most taxa occurred at multiple stations, although about 30% of the PLOO taxa and 26% of the SBOO taxa were recorded only once. Four new taxa were reported that had not already been recorded by the City's Ocean Monitoring Program, including the polychaetes *Paramphinome* sp and *Goniadopsis* sp, both new genera to the SCB, as well as a small, damaged specimen of the axiid shrimp *Calocarides* sp that could not be identified to species, and a new provisional species of nemertean named *Heteronemertea* sp SD3.

Species richness averaged 40–111 taxa per grab at the PLOO stations and 24–96 taxa per grab at the SBOO stations during 2016 and 2017 (Tables 5.1 and 5.2, respectively). Additionally, species richness values for individual samples (see Addenda 5-1, 5-2, City of San Diego 2017) were within the historical range of 13–192 taxa per grab for these sites reported from 1991 through 2015 (Appendix E.1). Long-term comparisons did not reveal any clear spatial patterns that could be attributed to the onset of wastewater discharge at either the current PLOO discharge site in late 1993 or the SBOO discharge site in early 1999. However, the number of taxa encountered at the PLOO stations appeared depressed in 2016 and 2017 compared to the previous post-discharge period (1994–2015), while there has not appeared to be a similar change at the SBOO stations (Figure 5.2).

Macrofaunal abundance

A total of 44,580 macrofaunal animals were recorded for all the core PLOO and SBOO stations samples collected in 2016 and 2017. Abundance per grab averaged from 134 animals at station E21 to 398 animals at station B11 in the PLOO region (Table 5.1) while in the SBOO region mean abundance ranged from 103 animals per grab at station I7 to 401 per grab at station I33 (Table 5.2). As with species richness, there were no clear patterns relative to distance from either outfall, depth, or sediment type (see Figure 5.2 and Chapter 4). Abundance values during the current reporting period (Addenda 5-1, 5-2, City of San Diego 2017) were also within the range of 21–2843 organisms per grab reported from 1991 to 2015 (Appendix E.1). Similar to the pattern described above for species richness, historical comparisons indicate that macrofaunal abundances in the PLOO region were lower in 2016–2017 than during the previous 25 years regardless of proximity to the outfall (Figure 5.2). In contrast, abundances across the SBOO region have shown little change over time. This recent depression in macrofaunal species richness and abundances off Point Loma may be partly due to the impact of unusually large populations of the pelagic galatheid red crab *Pleuroncodes planipes* that were present in this region during these two years (see Chapter 7).

Species diversity, evenness, and dominance

Shannon diversity (H') values averaged from 3.0 to 4.1 per grab at the PLOO stations and from 1.5 to 3.9 per grab at the SBOO stations during 2016 and 2017 (Tables 5.1, 5.2). Pielou's evenness (J') values averaged from 0.77 to 0.91 and from 0.45 to 0.90 in the PLOO and SBOO regions, respectively. The lowest diversity and evenness occurred at stations E19 and I2 in their respective programs, while the highest respective values for these indices occurred at stations B11 and E3 off Point Loma and stations I20 and I28 in the South Bay outfall region. Overall, these results indicate that the PLOO and SBOO benthic communities remain characterized by relatively diverse assemblages of evenly distributed species. Swartz dominance values averaged from 14 to 41 taxa per grab at the PLOO stations, with the highest dominance (lowest index value) occurring at near-ZID station E14 and the lowest dominance (highest index value) occurring at northern reference station B11 (Table 5.1). In contrast, dominance averaged from 4 to 34 taxa per grab taxa at stations I2 and I28, respectively in the SBOO region. Values for all three of the above parameters in 2016 and 2017 (Addenda 5-1, 5-2) (City of San Diego 2017) were within historical ranges (see Appendix E.1), and there remain no patterns that appear relevant to wastewater discharge, depth, or sediment particle size in either region (see Figure 5.2 and Chapter 4).

Benthic response index

The benthic response index (BRI) is an important tool for evaluating anthropogenic impact in coastal seafloor habitats off southern California. For example, BRI values less than 25 are considered indicative of reference conditions, values between 25 and 34 represent possible minor deviation from reference condition, and values greater than 34 represent increasing levels

Table 5.1

Summary of macrofaunal community parameters for PLOO benthic stations sampled during 2016 and 2017. Data for each station are expressed as biennial means (n = 4). SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = Pielou's evenness; Dom = Swartz dominance; BRI = benthic response index. Stations are listed north to south from top to bottom for each depth contour.

	Station	SR	Abun	H'	J'	Dom	BRI
88-m Depth Contour	B11	111	398	4.1	0.89	41	10
	B8	54	198	3.1	0.78	16	8
	E19	53	218	3.0	0.77	16	11
	E7	54	207	3.3	0.84	18	12
	E1	68	277	3.5	0.84	21	9
98-m Depth Contour	B12	85	266	3.9	0.88	32	11
	B9	70	249	3.6	0.86	25	6
	E26	56	189	3.4	0.86	20	9
	E25	56	240	3.4	0.85	18	7
	E23	51	188	3.4	0.87	20	10
	E20	54	180	3.5	0.88	22	9
	E17 [a]	53	198	3.3	0.85	17	14
	E14 [a]	47	190	3.2	0.84	14	34
	E11 [a]	60	196	3.6	0.87	22	16
	E8	58	185	3.6	0.88	22	9
	E5	54	180	3.4	0.86	20	6
	E2	68	234	3.6	0.86	24	8
116-m Depth Contour	B10	79	300	3.7	0.84	24	15
	E21	40	134	3.2	0.86	15	10
	E15 [a]	54	240	3.2	0.79	15	12
	E9	80	298	3.8	0.87	28	10
	E3	74	181	3.9	0.91	32	11
All Grabs	Mean	63	225	3.5	0.85	22	11
	95% CI	4	18	0.1	0.01	2	1
	Min	28	56	2.5	0.71	9	3
	Max	149	625	4.4	0.94	48	37

[a] Near-ZID station

of disturbance or degradation (Smith et al. 2001). About 86% (n = 169) of all individual benthic samples collected in the combined PLOO and SBOO regions during 2016 and 2017 were characteristic of reference conditions (see Addenda 5-1, 5-2, City of San Diego 2017), and only 1% (n = 2) could be considered indicative of disturbance.

More than 95% of the individual samples in the PLOO region had BRI values indicative of reference conditions. Only near-ZID station E14 with individual BRI scores of 37 for both the winter and summer surveys in 2017 appeared to show evidence of environmental disturbance. The other three PLOO near-ZID stations all had BRI values only slightly higher than most other sites located farther away. Station E14 is distinguished from the other primary core "E" stations located along the 98-m PLOO discharge depth contour in having a higher proportion of coarse sediment particles and

Table 5.2

Summary of macrofaunal community parameters for SBOO benthic stations sampled during 2016 and 2017. Data for each station are expressed as biennial means (n=4 grabs). SR=species richness; Abun=abundance; H'=Shannon diversity index; J'=Pielou's evenness; Dom=Swartz dominance; BRI=benthic response index. Stations are listed north to south from top to bottom for each depth contour.

	Station	SR	Abun	H'	J'	Dom	BRI
19-m Stations	I35	70	239	3.7	0.88	25	28
	I34	36	288	2.6	0.75	9	13
	I31	49	213	2.7	0.70	13	19
	I23	48	131	3.1	0.83	20	20
	I18	50	184	3.0	0.77	18	20
	I10	56	144	3.3	0.83	24	20
	I4	24	118	2.4	0.79	8	2
28-m Stations	I33	84	401	3.1	0.72	22	23
	I30	72	259	3.2	0.76	22	26
	I27	54	184	3.0	0.76	19	25
	I22	81	354	3.2	0.73	22	24
	I14 [a]	82	374	3.1	0.71	21	26
	I16 [a]	51	201	2.8	0.72	16	19
	I15 [a]	37	290	2.0	0.57	5	17
	I12 [a]	63	349	2.7	0.68	13	21
	I9	80	294	3.5	0.81	26	25
	I6	38	132	2.6	0.72	12	11
	I2	30	350	1.5	0.45	4	14
	I3	30	263	1.9	0.57	5	14
38-m Stations	I29	82	274	3.7	0.85	28	20
	I21	37	108	2.8	0.78	14	11
	I13	40	119	3.0	0.82	15	14
	I8	33	188	2.5	0.72	8	25
55-m Stations	I28	96	312	3.9	0.86	34	16
	I20	48	138	3.3	0.90	19	9
	I7	41	103	3.3	0.89	18	9
	I1	54	190	3.2	0.80	18	16
All Grabs	Mean	54	230	2.9	0.75	17	18
	95% CI	5	30	0.1	0.03	2	1
	Minimum	15	27	0.6	0.18	1	-4
	Maximum	114	866	4.1	0.97	40	30

[a] Near-ZID station

lower proportion of very fine particles compared with the other "E" stations (see Chapter 4). This difference in habitat may contribute to the elevated BRI score at station E14 since it may also affect presence of pollution-sensitive species (e.g., the brittle star *Amphiodia urtica*) that are known to prefer finer sediments (Bergen 1995). No other spatial patterns relative to depth or sediments were observed (Figure 5.3, Tables 5.1, 5.2).

In contrast to the PLOO region, BRI values ranged from -4 to 30 at the SBOO stations in 2016–2017, with about 79% of these being characteristic of reference condition and 21% demonstrating a possible minor deviation from reference condition (see Table 5.2). No SBOO samples had BRI values >34 that would indicate any significant environmental disturbance. BRI values corresponding to possible minor deviation from

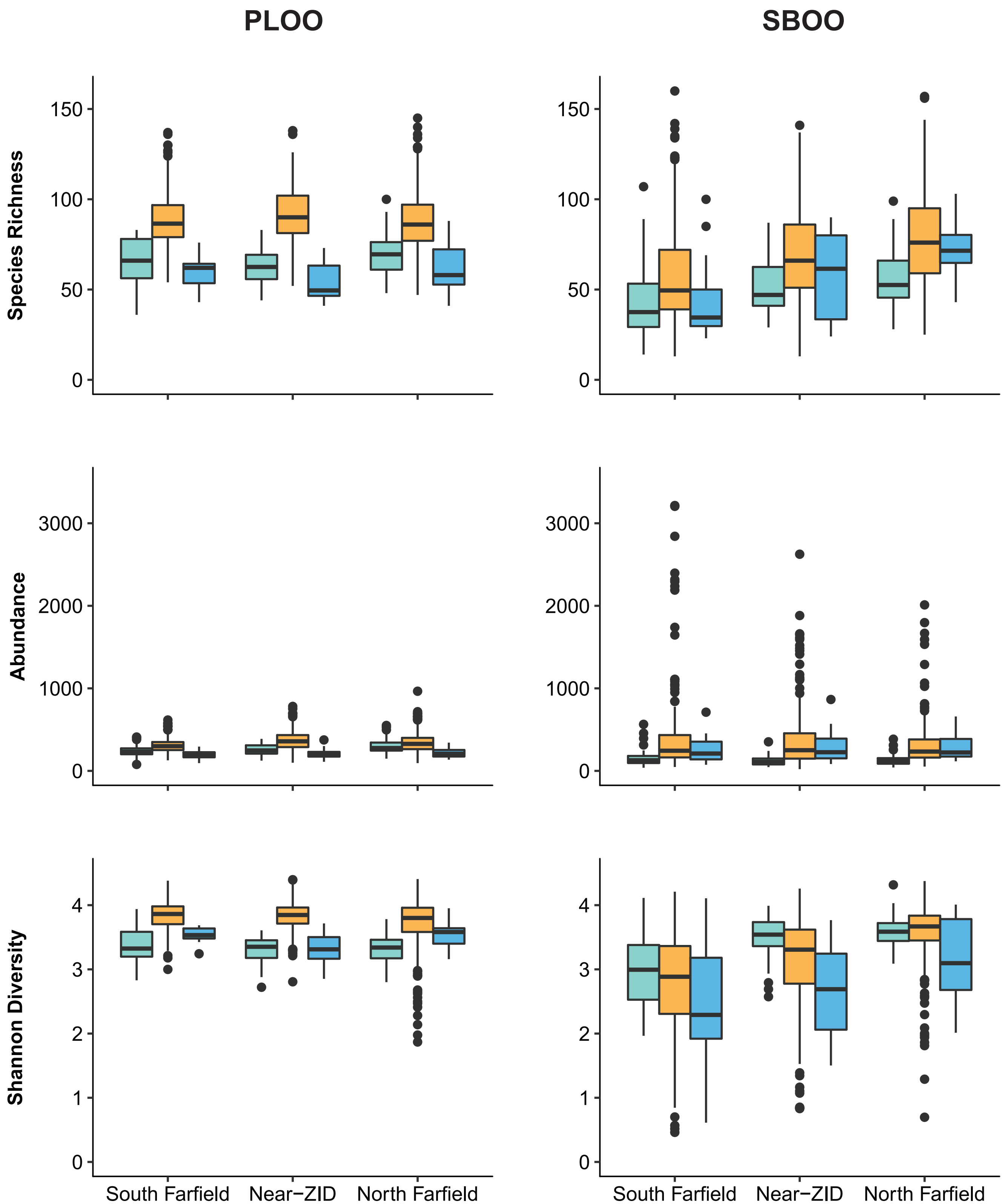

Figure 5.2
Species richness, abundance, and diversity (H') of benthic infauna collected from PLOO and SBOO near-ZID, north farfield, and south farfield primary core stations during pre-discharge (green), historical post-discharge (orange), and current post-discharge (blue); Boxes = median, upper, and lower quantiles; whiskers = 1.5x interquantile range; circles = outliers; see text for description of pre- versus post-discharge periods for the two outfalls.

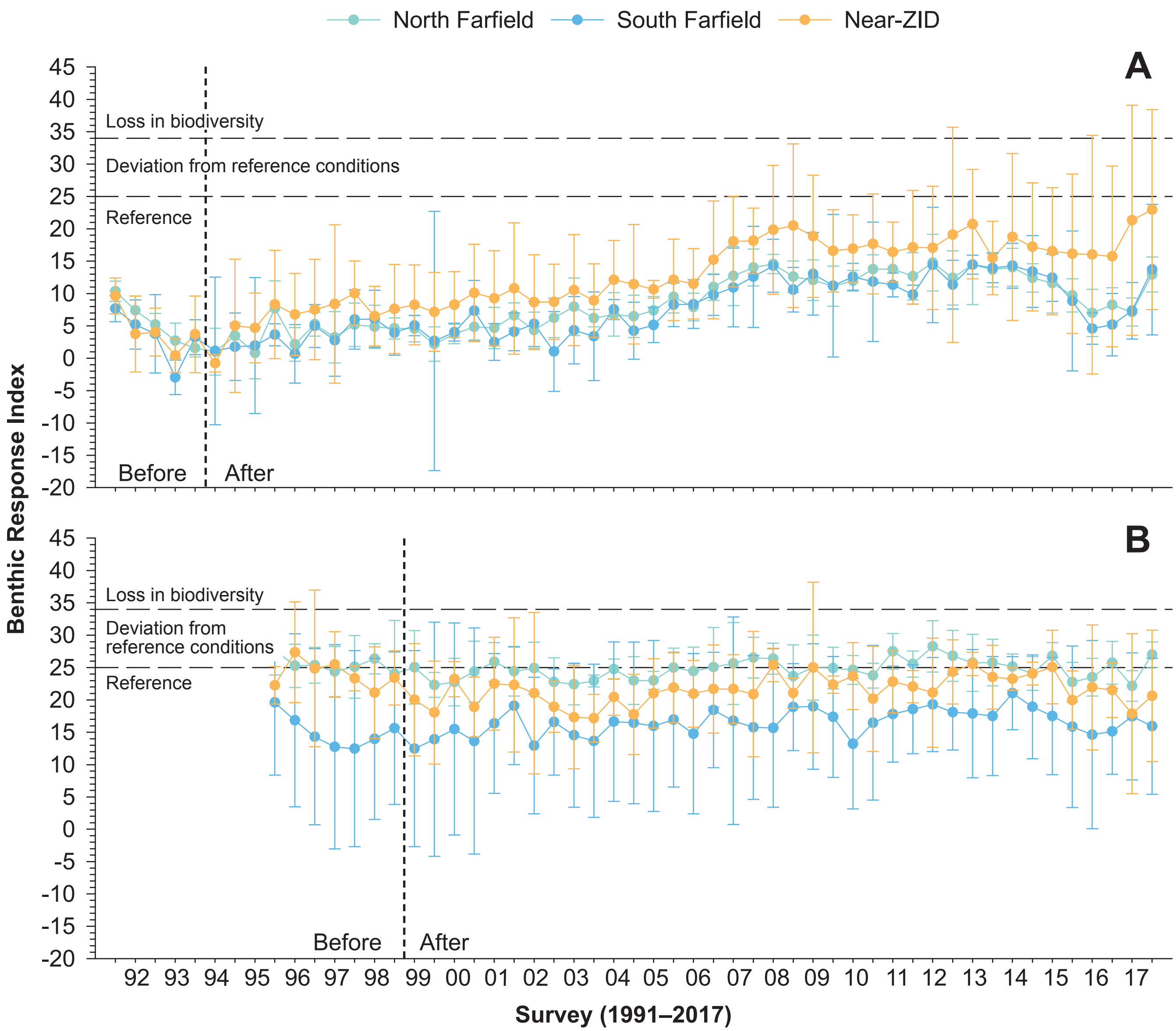

Figure 5.3
Benthic Response Index at PLOO (A) and SBOO (B) near-ZID, north farfield, and south farfield primary core stations sampled from 1991 through 2017. Data for each station group are expressed as means ±95% confidence intervals per grab (n≤8). Vertical dashed lines indicate onset of wastewater discharge.

reference condition occurred at a total of six stations as follows: Station I35 had a mean BRI of 28 and is located along the 19-m depth contour about 10.4 km north of the SBOO; stations I9, I14, I27, and I30 had mean BRI values of 25–26 and are located along the 28-m outfall discharge depth contour between about 2.3 km south to 10.3 km north of the outfall; station I8 had a mean BRI of 25 and is located along the 38-m depth contour about 2.5 km southeast of the outfall. The slightly higher BRI values at these somewhat shallower stations in the SBOO region are not unexpected because of naturally higher levels of organic matter that may occur at depths <30 m (Smith et al. 2001). Historically, BRI values at the nearfield SBOO stations have been similar to values at the northern farfield SBOO stations, while BRI has been consistently lower at the southern farfield SBOO stations (Figure 5.3).

Species of Interest

Dominant taxa

Polychaete worms were the dominant taxonomic group found in both the PLOO and SBOO regions during 2016 and 2017, accounting for 52% and 47% of all taxa collected, respectively (Table 5.3).

Table 5.3

Percent composition and abundance of major taxonomic groups in PLOO and SBOO benthic grabs sampled during 2016 and 2017.

Phyla	PLOO		SBOO	
	Species (%)	Abundance (%)	Species (%)	Abundance (%)
Annelida (Polychaeta)	52	59	47	71
Arthropoda (Crustacea)	17	7	18	10
Mollusca	17	20	19	9
Echinodermata	5	12	4	3
Other Phyla	9	2	12	7

Crustaceans accounted for 17–18% of the taxa per region, molluscs for 17–19%, echinoderms 4–5%, and all other taxa combined 9–12%. Polychaetes were also the most abundant organisms, accounting for 59% and 71% of all macrofauna in the PLOO and SBOO regions, respectively. Crustaceans, molluscs, echinoderms, and all other taxa combined each contributed to ≤20% of the total abundance in each region. Overall, the percentage of taxa that occurred within each of the above major taxa and their relative abundances have shown little change since monitoring began (City of San Diego 2000, 2015) and are similar to the rest of the Southern California Bight (see Ranasinghe et al. 2012, Gillet et al. 2017).

The 10 most abundant taxa in the PLOO region during 2016–2017 included six species of polychaetes, three species of bivalve molluscs, and one ophiuroid (Table 5.4). Together, these species accounted for about 42% of all invertebrates identified during this period. The numerically dominant polychaetes included the spionids *Spiophanes duplex* and *Prionospio (Prionospio) dubia,* the cirratulid *Chaetozone hartmanae*, the ampharetid *Eclysippe trilobata*, the maldanid *Praxillella pacifica* and the sternaspid *Sternaspis affinis*. The dominant bivalves included *Nuculana* sp A, *Axinopsida serricata*, and *Tellina carpenteri* while the brittle star *Amphiodia urtica* was the dominant ophiuroid. *Amphiodia urtica* was also the most abundant species during the current reporting period, accounting for ~8% of all invertebrates collected in the region, and occurring in 88% of grabs with a mean abundance of ~19 individuals per grab. This ophiuroid remains the most abundant benthic invertebrate in the Point Loma outfall region after 24 years of outfall operation at the present discharge site (Figure 5.4). Historically, the polychaetes *Proclea* sp A and *Spiophanes duplex* have also been numerically dominant. The other top two historically dominant species, the oweniid *Myriochele striolata* and the ostracod *Euphilomedes producta*, were not as abundant during this past 2-year reporting period. *Proclea* sp A and *M. striolata* have also not been abundant in the region since 2005 while *E. producta* showed a steep decline in numbers in 2016, perhaps due to the impact of unusually large populations of the pelagic red crab *Pleuroncodes planipes* (See Chapter 7, Appendix E.2).

The 10 most abundant taxa in the SBOO region during 2016–2017 included eight polychaetes, one bivalve, and one echinoderm. The dominant polychaetes were the spionids *Spiophanes norrisi* and *Spiophanes duplex*, the terebellid *Pista wui*, the capitellids *Mediomastus* sp and *Notomastus latericeus*, the lumbrinerid *Lumbrinerides platypygos,* the ampharetid *Ampharete labrops,* and the pisionid *Pisione* sp. The dominant bivalve was *Simomactra falcata,* while the most abundant echinoderm was the sand dollar *Dendraster terminalis*. *Spiophanes norrisi* was by far the most abundant of these species during these two years, accounting for 30% of invertebrates collected in the area and

Table 5.4

The 10 most abundant macroinvertebrate taxa collected from PLOO benthic stations during 2016 and 2017. Data are expressed as percent abundance (number of individuals per species/total abundance of all species), frequency of occurrence (percentage of grabs in which a species occurred), and abundance per grab (mean number of individuals per grab, n = 88).

Species	Taxonomic Classification	Percent Abundance	Frequency of Occurrence	Abundance per Grab
Amphiodia urtica	Echinodermata: Ophiuroidea	8	88	19
Spiophanes duplex	Polychaeta: Spionidae	6	89	14
Nuculana sp A	Mollusca: Bivalvia	6	99	13
Axinopsida serricata	Mollusca: Bivalvia	5	89	10
Eclysippe trilobata	Polychaeta: Ampharetidae	4	92	10
Tellina carpenteri	Mollusca: Bivalvia	3	86	8
Chaetozone hartmanae	Polychaeta: Cirratulidae	3	94	7
Prionospio (Prionospio) dubia	Polychaeta: Spionidae	3	93	6
Praxillella pacifica	Polychaeta: Maldanidae	2	90	5
Sternaspis affinis	Polychaeta: Sternaspidae	2	94	5

occurring in 95% of all grabs. Although not as numerous as in previous surveys, *S. norrisi* has remained the most abundant species recorded in the SBOO region since 2007 (e.g., Figure 5.5), with up to 3009 individuals found in a single grab from station I6 during the summer of 2010 (City of San Diego 2011). All other species averaged fewer than 10 individuals per grab. Three other numerically dominant species also occurred in ≥55% of the samples, including *Spiophanes duplex, Mediomastus* sp, and *Ampharete labrops* (Table 5.5). The remaining six of the top 10 taxa occurred in 9–46% of the samples. Historically, *S. norrisi*, *Mediomastus* sp, *S. duplex, Monticellina siblina* and the maldanid polychaete Euclymeninae sp A/B species complex were the most numerically dominant species (Figure 5.5, Appendix E.3).

Indicator species

Several species known to be useful indicators of environmental change that occur in the region include the capitellid polychaete *Capitella teleta*, amphipods in the genera *Ampelisca* and *Rhepoxynius*, the bivalve *Solemya pervernicosa*, the terebellid polychaete *Proclea* sp A, and the brittle star *Amphiodia urtica*. For example, increased abundances of pollution-tolerant species such as *C. teleta* and *S. pervernicosa* and decreased abundances of pollution-sensitive taxa such as *A. urtica*, *Proclea* sp A, *Ampelisca* spp, and *Rhepoxynius* spp are often indicative of organic enrichment and may indicate habitats impacted by human activity (Barnard and Ziesenhenne 1961, Anderson et al. 1998, Linton and Taghon 2000, Smith et al. 2001, Kennedy et al. 2009, McLeod and Wing 2009). During 2016 and 2017, a total of only 42 individuals of *C. teleta* were found across the entire region distributed between eight different sites (i.e., stations B11, B12, E11, E14, E15, E17, I28, and I29), while a total of 72 individuals of *S. pervernicosa* were identified in samples from nine different sites (i.e., stations E11, E14, E17, I1, I14, I22, I27, I29, and I31). Despite occasionally exceeding regional tolerance intervals of 0–1 animals per grab (see City of San Diego 2015), abundances of *C. telata* and *S. pervernicosa* remained characteristic of relatively undisturbed habitats. For example, *C. teleta* commonly reaches densities as high as 500 individuals per 0.1-m^2 grab in polluted sediments (Reish 1957, Swartz et al. 1986). Changes in abundances of *Ampelisca* and *Rhepoxynius* amphipod species continued to vary at all discharge depth stations regardless of proximity to either outfall, which may also represent influence

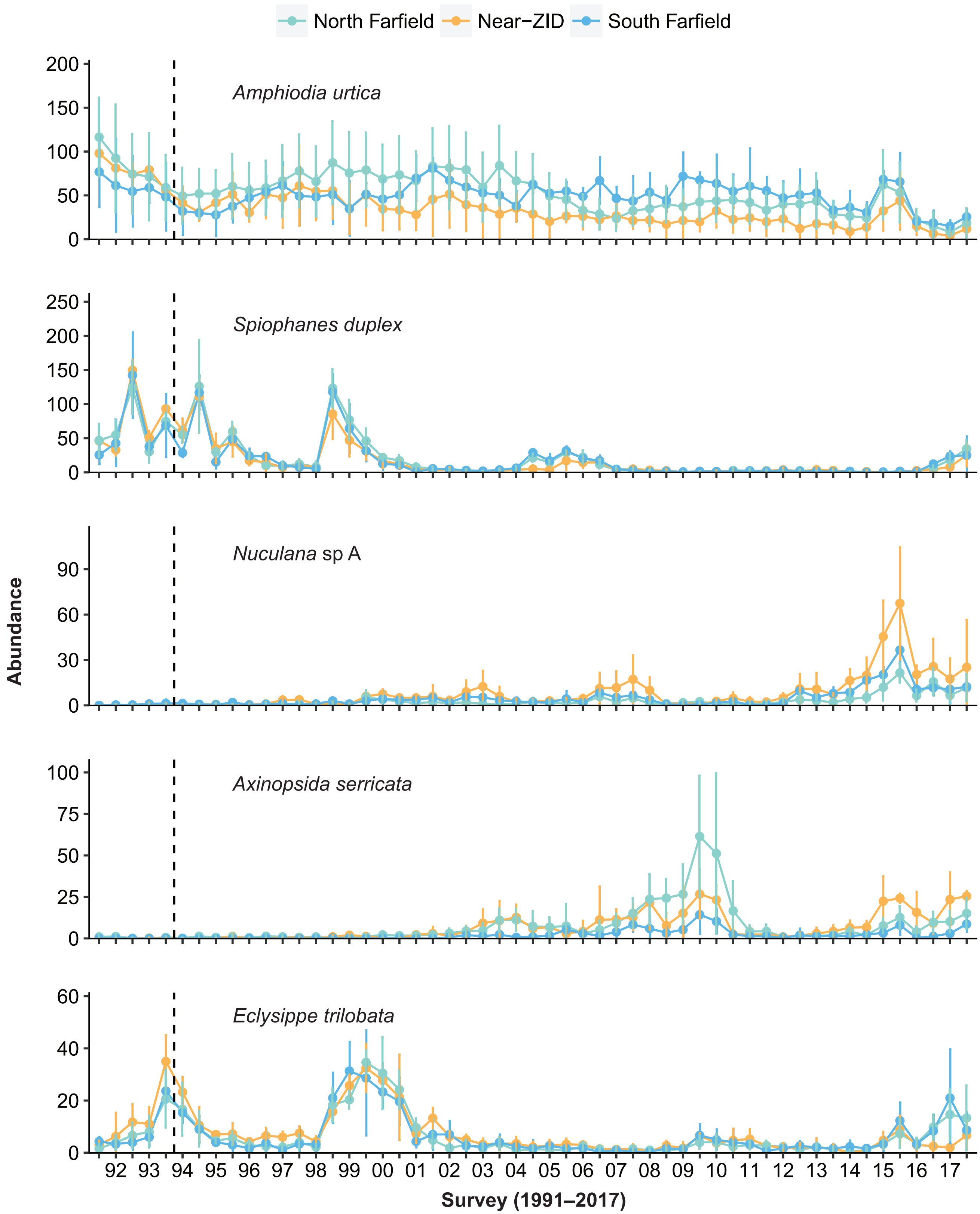

Figure 5.4
Abundances of the five most numerically dominant species recorded during 2016 and 2017 (presented in order) at PLOO north farfield, near-ZID, and south farfield primary core stations from 1991 through 2017. Data for each station group are expressed as means per survey ± 95% confidence intervals (n ≤ 8). Dashed lines indicate onset of wastewater discharge at the PLOO extension.

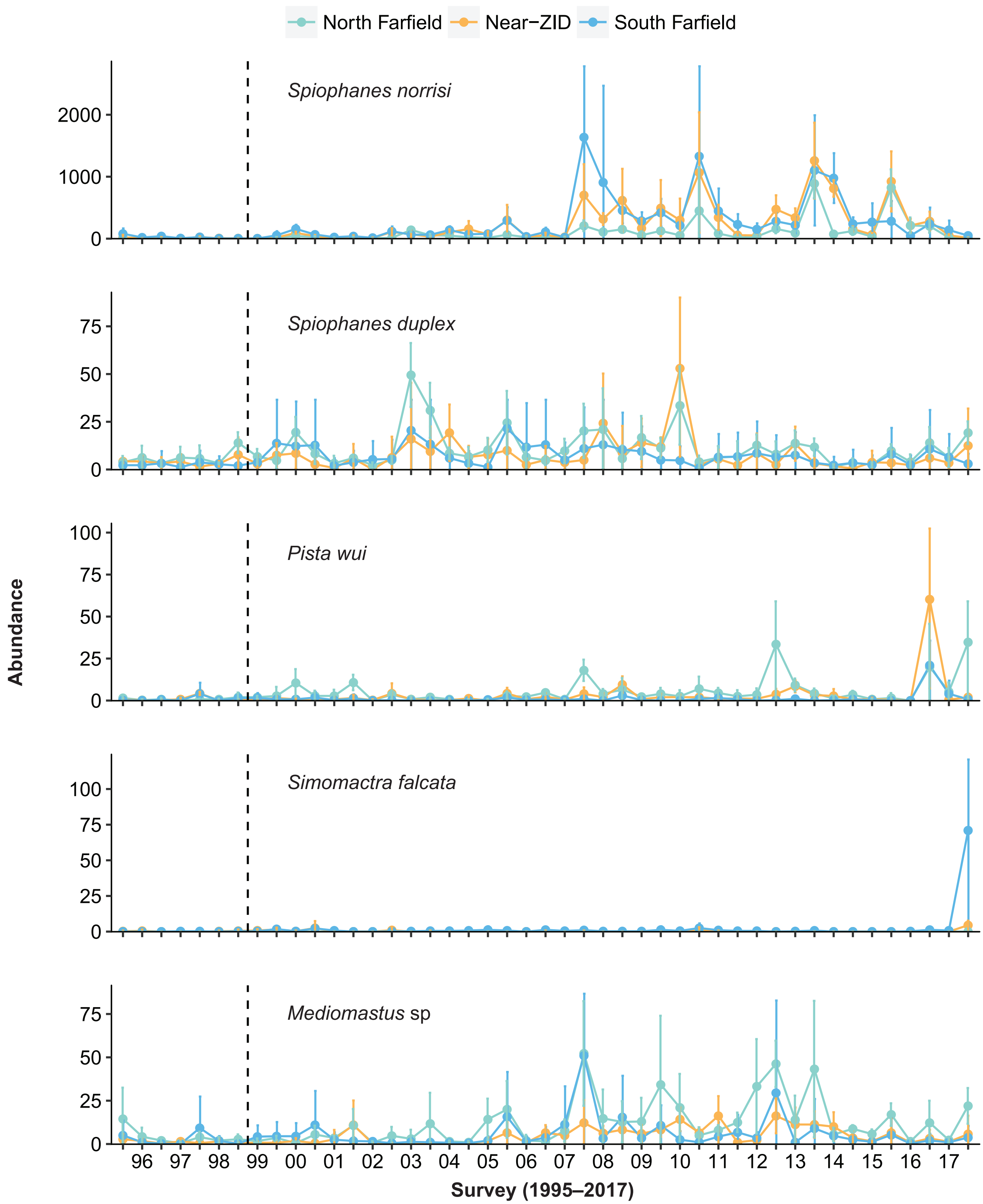

Figure 5.5
Abundances of the five most numerically dominant species (presented in order) recorded during 2016 and 2017 at SBOO north farfield, near-ZID, and south farfield primary core stations from 1995 through 2017. Data for each station group are expressed as means ±95% confidence intervals per survey (n≤8). Dashed lines indicate onset of wastewater discharge.

Table 5.5

The 10 most abundant macroinvertebrate taxa collected from SBOO benthic stations during 2016 and 2017. Data are expressed as percent abundance (number of individuals per species/total abundance of all species), frequency of occurrence (percentage of grabs in which a species occurred) and abundance per grab (mean number of individuals per grab, n = 108).

Species	Taxonomic Classification	Percent Abundance	Frequency of Occurrence	Abundance per Grab
Spiophanes norrisi	Polychaeta: Spionidae	30	95	69
Spiophanes duplex	Polychaeta: Spionidae	4	72	9
Pista wui	Polychaeta: Terebellidae	3	44	7
Simomactra falcata	Mollusca: Bivalvia	2	26	3
Mediomastus sp	Polychaeta: Capitellidae	1	55	3
Lumbrinerides platypygos	Polychaeta: Lumbrineridae	1	40	3
Ampharete labrops	Polychaeta: Ampharetidae	1	60	3
Pisione sp	Polychaeta: Pisionidae	1	9	3
Dendraster terminalis	Echinodermata: Echinoidea	1	31	3
Notomastus latericeus	Polychaeta: Capitellidae	1	46	2

by the invasion of large populations of pelagic red crabs during these past two years (see Chapter 7, Figures 5.6, 5.7).

Summary

Analyses of the macrofaunal data for the 2016–2017 reporting period demonstrate that wastewater discharged through the Point Loma and South Bay outfalls has not negatively impacted macrobenthic communities in the coastal waters off San Diego, with the values for most community parameters being similar at stations located both near and far away from the discharge areas. Major community metrics such as species richness, abundance, diversity, evenness, and dominance were generally within historical ranges reported for the San Diego region (e.g., City of San Diego 2000, 2015), and were representative of those characteristic of similar Southern California Bight (SCB) benthic habitats (Barnard and Ziesenhenne 1961, Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993b, Zmarzly et al. 1994, Diener and Fuller 1995, Bergen et al. 1998, 2000, 2001, Ranasinghe et al. 2003, 2007, 2010, 2012, Mikel et al. 2007, Gillett et al. 2017). Benthic response index (BRI) values for about 95% of the PLOO sites and 79% of the SBOO sites were considered characteristic of undisturbed habitats, while most of the remaining samples (~13%) had values suggestive of only a possible minor deviation from reference conditions. Only two samples from PLOO near-ZID station E14 sampled in 2017 could be considered characteristic of disturbed conditions. Additionally, BRI values at the slightly shallower 28-m depth stations in the SBOO region have typically been higher than BRI values for deeper water sites since monitoring began. However, this pattern is not unexpected since naturally higher levels of organic matter often occur closer to shore (Smith et al. 2001). A similar phenomenon has been reported across the SCB where Smith et al. (2001) found a pattern of lower BRI values at mid-depth stations (25–130 m) versus shallower (10–35 m) or deeper (110–324 m) sites.

Changes in populations of pollution-sensitive and pollution-tolerant species or other indicators of benthic condition provide little or no evidence of habitat degradation in either outfall region. For instance, the brittle star *Amphiodia urtica* is a well-known dominant species of mid-shelf, primarily fine sediment habitats in the SCB that is sensitive to changes near wastewater outfalls. Abundances of *A. urtica* off Point Loma remain

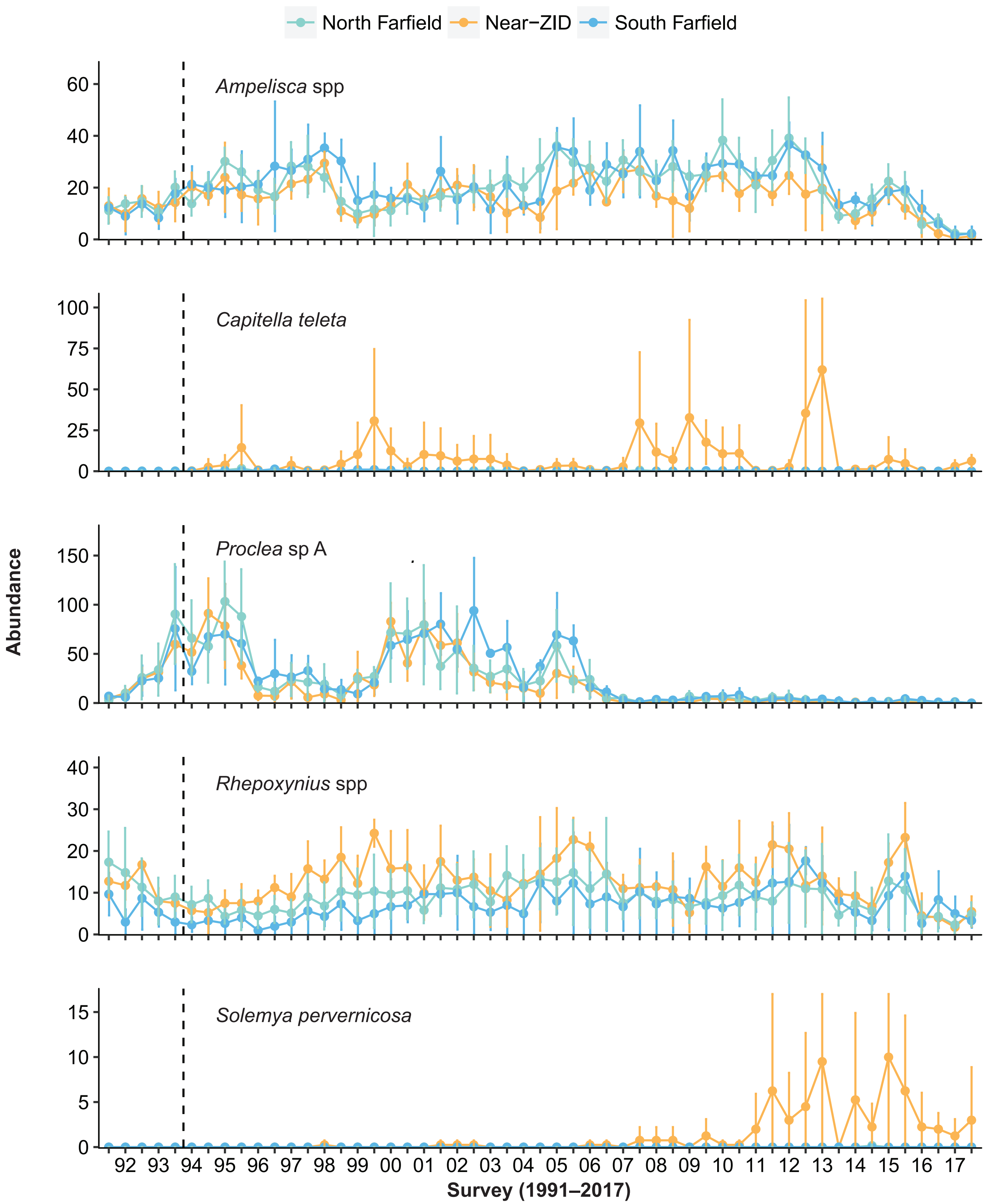

Figure 5.6
Abundances of representative ecologically important indicator taxa collected at PLOO north farfield, near-ZID, and south farfield primary core stations from 1991 through 2017. Data for each station group are expressed as means ±95% confidence intervals per survey (n≤8). Dashed lines indicate onset of wastewater discharge.

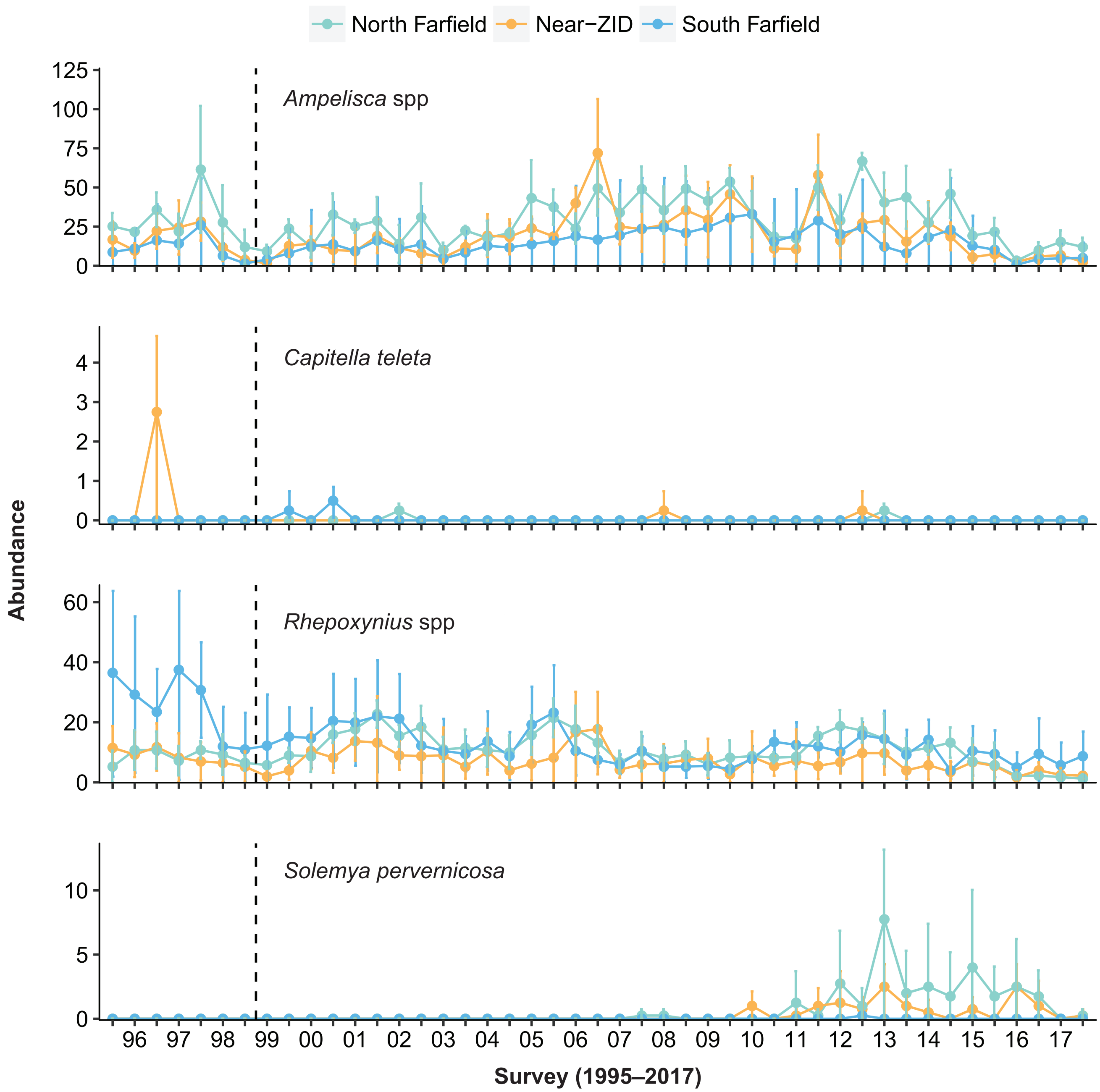

Figure 5.7

Abundances of representative ecologically important indicator taxa collected at SBOO north farfield, near-ZID, and south farfield primary core stations from 1995 through 2017. Data for each station group are expressed as means ±95% confidence intervals per survey (n ≤ 8). Dashed lines indicate onset of wastewater discharge.

within the range of natural variation in SCB populations (i.e., Gillett et al 2017). Further, populations of opportunistic species such as the polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa* were low during 2016 and 2017, while populations of pollution-sensitive amphipods in the genera *Ampelisca* and *Rhepoxynius* have generally co-varied between nearfield and farfield stations. Additionally, although spionid polychaetes are often abundant in other coastal areas of the world that possess high levels of organic matter (Díaz-Jaramillo et al. 2008), in the SCB these worms are known to be a stable, dominant component of many healthy environments with normal levels of organic inputs (Rodríguez-Villanueva et al. 2003). Thus, the presence of large populations of *Spiophanes norrisi* observed at many SBOO stations since 2007 is not considered to be indicative of habitat degradation related to wastewater discharge. Instead, population fluctuations of this spionid in recent years may instead correspond to natural changes in large-scale oceanographic conditions. Further support for this hypothesis is shown by the decrease in *S. norrisi* abundances at all station groups during 2016 and 2017 (Figure 5.5).

In conclusion, benthic macrofaunal communities appear to be in overall good condition throughout the PLOO and SBOO regions, remain similar to those observed prior to outfall operations, and are representative of natural indigenous communities from similar habitats on the southern California continental shelf. About 86% of all benthic sites surveyed for the combined region in 2016 and 2017 were classified in reference condition based on assessments using the BRI, while the few slightly elevated BRI values that were found along and inshore of the outfall discharge depth contours generally fit historical patterns that have existed since before operation of either outfall began. More moderate indicators of increasing disturbance at PLOO near-ZID station E14 remain highly localized and below the threshold of community degradation. Thus, no significant effects of wastewater discharge on the local macrobenthic communities off San Diego could be identified during this past 2-year reporting period.

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Chapter 6
San Diego Regional Benthic Condition Assessment

Chapter 6. San Diego Regional Benthic Condition Assessment

Introduction

The City of San Diego has conducted annual surveys of randomly selected (regional) benthic stations off the coast of San Diego since 1994 (see Chapter 1). The primary objectives of these regional surveys, which typically range from offshore of Del Mar in northern San Diego County southward to the USA/Mexico border, are to: (1) describe the overall condition and quality of the diverse benthic habitats that occur in the offshore coastal waters off San Diego; (2) characterize both sediment quality and the health of the soft-bottom marine benthos in the region; (3) gain a better understanding of regional variation in order to distinguish between the effects of anthropogenic and natural factors; (4) put into context the results of more frequent sampling at permanent (core) monitoring sites surrounding the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively). These regional 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. However, beginning in 2009, the survey area was expanded to include deeper habitats along the upper continental slope (i.e., 200–500 m). No separate San Diego regional survey was conducted in 2004 due to sampling for a special sediment mapping project (Stebbins et al. 2004), while the 1994, 1998, 2003, 2008, and 2013 regional surveys were conducted as part of the larger Southern California Bight (SCB) Regional Monitoring Program (Bergen et al. 1998, 2001, Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009, Ranasinghe et al. 2003, 2007, 2010, 2012, Dodder et al. 2016, Gillett et al. 2017). In total more than 800 samples from 764 different regional stations have been collected off San Diego over the past 24 years (1994–2017).

This chapter presents an overall assessment of regional benthic conditions on the continental shelf and upper slope off San Diego during 2016 and 2017. Included are analyses of particle size, sediment chemistry, sediment toxicity, and macrofaunal community data collected from a total of 129 regional or core benthic stations sampled during the summers of 2016 and 2017 in order to provide a snapshot of the region's sediment quality and benthic community structure across the major depth strata defined by the SCB regional monitoring programs (e.g., Dodder et al. 2016, Gillett et al. 2017). Additional analysis of spatial patterns, winter versus summer differences, and long-term changes over time at the core PLOO and SBOO stations are presented in Chapters 4 and 5.

Materials and Methods

Collection and Processing of Samples

The benthic samples analyzed in this chapter were collected during the summers of 2016 and 2017 at a total of 129 stations that ranged from Del Mar southward to below the USA/Mexico border (Figure 6.1). A total of 80 of these stations (40/year) were selected using a probability-based random stratified sampling design as described in Bergen (1996), Stevens (1997), and Stevens and Olsen (2004). These "regional" stations were sampled at depths ranging from 5 to 469 m spanning four distinct depth strata off southern California. These included 19 regional stations along the inner shelf (5–30 m), 35 regional stations along the mid-shelf (30–120 m), 14 regional stations along the outer shelf (120–200 m), and 12 regional stations on the upper slope (200–500 m). In addition to the above, the results of the summer sampling at the 49 core PLOO and SBOO monitoring stations

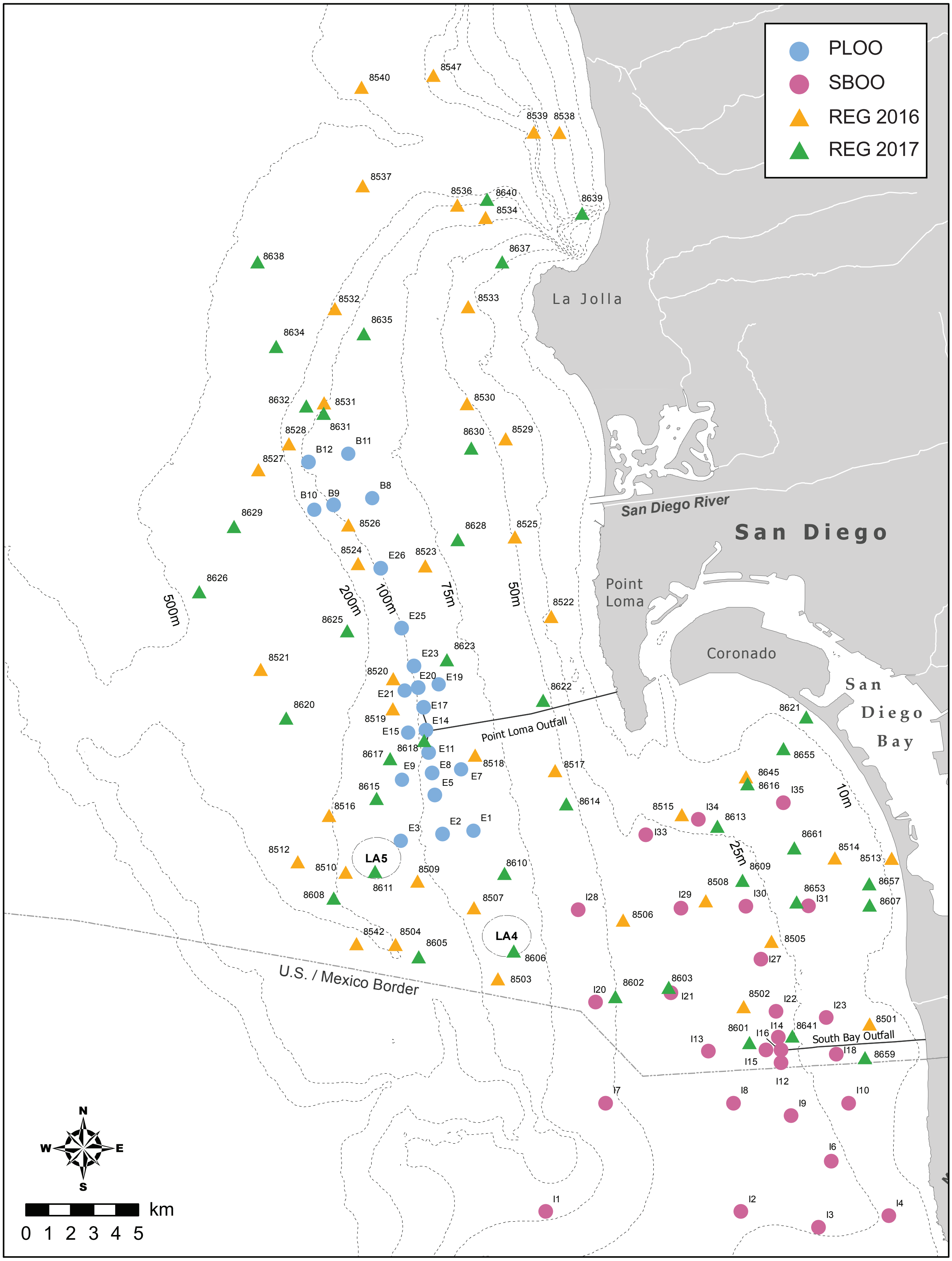


Figure 6.1
Distribution of 80 regional (REG) and 49 core (PLOO/SBOO) benthic stations sampled off San Diego and northern Baja California during the 2016 and 2017 summer surveys. See text for additional details.

located at inner to mid-shelf depths as described in Chapters 4 and 5 are also analyzed in this chapter. Finally, stations located within 1000 m of the boundary of the zone of initial dilution (ZID) for either outfall are considered to represent near-ZID conditions. These include PLOO stations E11, E14, E15, and E17, SBOO stations I12, I14, I15, and I16, and regional stations 8601 and 8641 near the SBOO, and 8618 near the PLOO.

Samples for benthic analyses were collected using a double 0.1-m^2 Van Veen grab, with one grab per cast used for sediment quality analysis and one grab per cast used for benthic community analysis. Criteria established by the U.S. Environmental Protection Agency (USEPA) to ensure consistency of these types of samples were followed with regard to sample disturbance and depth of penetration (USEPA 1987). Sub-samples for particle size and sediment chemistry analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines (USEPA 1987, SCCWRP 2013). Samples for infauna analysis were transferred to a wash table aboard ship, rinsed with seawater, and then sieved through a 1.0-mm mesh screen in order to remove as much sediment as possible. The macroinvertebrates (macrofauna or infauna) and other debris retained on the screen were transferred to individual sample jars, relaxed for 30 minutes in a magnesium sulfate solution, and then fixed with buffered formalin. The preserved samples were then transferred back to the City's Marine Biology Laboratory where after a minimum of 72 hours in formalin, each sample was thoroughly rinsed with fresh water and transferred to 70% ethanol for final preservation. All organisms were separated from the remaining raw material (e.g., sediment grunge, shell hash, debris) and sorted into the following six taxonomic groups by an external contract lab: Annelids (e.g., polychaete and oligochaete worms), Arthropods (e.g., crustaceans and pycnogonids), Molluscs (e.g., clams, snails, and scaphopods), non-ophiuroid Echinoderms (e.g., sea urchins, sea stars, and sea cucumbers), Ophiuroids (i.e., brittle stars), and miscellaneous other phyla (e.g., flatworms, nemerteans, and cnidarians). The sorted macrofaunal samples were then returned to the City's Marine Biology Laboratory where all animals were identified to species or to the lowest taxon possible by staff marine biologists. All identifications followed nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (e.g., SCAMIT 2014).

In addition to the above, additional sediment grabs were collected at a subset of the above sites during the summer surveys of 2016 and 2017 as part of a 3-year sediment toxicity pilot study. For year one (July 2016) these included the eight near-ZID stations for the PLOO and SBOO plus 20 of the other randomly selected regional stations. For year two (July 2017) only the eight PLOO and SBOO near-ZID stations were repeated; the specific stations tested for sediment toxicity each year are listed in Nautilus Environmental (2016, 2017). Details of the protocols for collecting, processing, and testing sediment toxicity samples are not included in this report, but follow the general guidelines specified in the City's Toxicology Laboratory Quality Assurance Manual (City of San Diego 2017b), the Sediment Toxicity Monitoring Plan for this pilot study (City of San Diego 2015c), and the most recently completed Sediment Toxicity report for the Southern California Bight Regional Monitoring Program (Bay et al. 2015). All methods and analyses for the City's pilot study will be fully documented in the final project report expected to be completed by the end of 2018.

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Environmental Chemistry Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2018a). Briefly, sediment sub-samples were analyzed on a dry weight basis to determine concentrations of various indictors of organic loading (i.e., total organic carbon, total nitrogen, total sulfides, total volatile solids), 18 trace metals, nine chlorinated pesticides (e.g., DDT), 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs). These data were generally limited to values above the method detection limit (MDL) for each parameter (see Appendix D.1). However, concentrations below MDLs were included as estimated values if presence of a specific constituent was verified by mass-spectrometry. Additionally, a variety of laboratory technical issues resulted in a significant amount of non-reportable sediment chemistry data for the 2016 and 2017 benthic surveys (see Chapter 4), prohibiting the inclusion of pesticides, PCBs, and PAHs in the regional assessment presented in this chapter.

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

Data Analyses

Sediment Chemistry

Data for each sediment parameter collected from the San Diego regional benthic stations sampled during 2017 are listed in Addenda 6-1 through 6-5, while data collected from PLOO and SBOO core stations during 2017 are listed in Addenda 4-1 through 4-10 (see Chapter 4). Data collected during 2016 were reported previously (City of San Diego 2017a) and are available online (City of San Diego 2018b). Data summaries for the various sediment parameters included detection rate, mean, minimum, and maximum values. All means were calculated using detected values only; no substitutions were made for non-detects in the data (i.e., analyte concentrations < MDL). 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). Unless stated otherwise, analyses were performed using R (R Core Team 2016) and various functions within the dplyr, plyr, reshape2, tidyr, and zoo packages (Zeileis and Grothendieck 2005, Wickham 2007, 2011, Wickham and Henry 2017, Wickham et al. 2017).

Spearman rank correlations were calculated to assess if values for the various parameters co-varied in the sediments. This non-parametric analysis accounts for non-detects in the data without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in rank-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.

Macrobenthic Assemblages

The following community metrics were determined for each station and expressed per 0.1-m^2 grab: species richness (number of species or distinct taxa), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance index (see Swartz et al. 1986, Ferraro et al. 1994), and benthic response index (BRI) (see Smith et al. 2001). These values are listed for each San Diego regional station sampled during 2017 in Addendum 6-6, while community parameter values from PLOO and SBOO core stations sampled during 2017 are listed in Addenda 5-1 and 5-2 (see Chapter 5). Data collected during 2016 were reported previously (City of San Diego 2017a) and are available online (City of San Diego 2018b). Unless otherwise noted, analyses were performed using R (R Core Team 2016) and various functions within the reshape2, Rmisc, RODBC, tidyverse, and vegan packages (Wickham 2007, 2017, Hope 2013, Oksanen et al. 2017, Ripley and Lapsley 2017).

Multivariate Analyses

Multivariate analyses were performed using PRIMER v7 software to examine spatial and temporal patterns in particle size, sediment chemistry, and macrofaunal data collected at the 129 regional and core stations sampled during 2016 and 2017 (Clarke et al. 2008, Clarke et al. 2014). These included ordination and hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrograms. Prior to these analyses, proportions of silt and clay sub-fractions were combined as percent fines to accommodate sieved samples, while sediment chemistry data were normalized after non-detects (see above) were converted to "0" and macrofaunal abundance data were square-root transformed to lessen the influence of overly abundant species and increase the importance (or presence) of rare species. Measures of similarity used as the basis for clustering included Euclidean distance for particle size and sediment chemistry data, and the Bray-Curtis measure of similarity for macrofaunal data. Major ecologically-relevant clusters receiving SIMPROF support were retained, and similarity percentages analysis (SIMPER) was used to determine which sub-fractions, chemical parameter, or species were responsible for the greatest contributions to within-group similarity (i.e., characteristic species) and between-group dissimilarity for retained clusters.

To determine whether sediment particle size sub-fractions, sediment chemistry concentrations, and macrofaunal assemblages varied by winter versus summer season for the PLOO and SBOO core stations, a one-way analysis of similarity (ANOSIM) was conducted (maximum number of permutations = 9999) on each set of data using data collected during both the January and July surveys of 2016 and 2017. The randomly selected regional stations were excluded from this analysis since they were sampled only during the summer each year. No significant differences were found between these two seasons for particle size composition ($\rho = -0.008$, $p = 0.998$), the levels of contaminants present ($\rho = 0.009$, $p = 0.092$), or the type of assemblages ($\rho = 0.019$, $p = 0.026$) (Appendix F.1). Therefore, all subsequent analyses were limited to just the 49 core PLOO and SBOO stations and the 80 randomly selected regional stations sampled during the summers of 2016 and 2017.

BEST tests using the BVSTEP procedure were conducted to determine which subset of sediment sub-fractions, chemical parameters, or species best described patterns within the dendrograms resulting from each of the above cluster analyses. Additional BEST tests using the BIO-ENV procedure were conducted to (a) determine which subsets of sediment sub-fractions were the best explanatory variables for the similarity between the particle size and sediment chemistry resemblance matrices and (b) determine which subsets of sediment sub-fractions were the best explanatory variables for similarity between the particle size and macrofaunal resemblance matrices. To determine whether sediment chemistry concentrations or macrofaunal communities varied by sediment particle size sub-fractions, a RELATE test was used to compare patterns in the matrices with patterns in the particle size Euclidean distance matrix.

Results

Regional Sediment Quality

Particle Size Composition

Ocean sediments were diverse at the 129 benthic stations sampled during the 2016 and 2017 summer surveys. The proportion of fine silt and clay particles (i.e., referred to as percent fines) ranged from 0 to 87% per sample, while fine sands ranged from 2 to 92%, medium-coarse sands ranged from <1 to 94%, and coarse particles ranged from 0 to 36% (Table 6.1). Overall, sediment composition varied by depth and region as expected. For example,

Table 6.1

Summary of particle sizes and chemistry concentrations in sediments from San Diego regional (Reg) and core benthic stations sampled during the summer surveys of 2016 and 2017. Data include detection rate (DR; %), minimum, maximum, and mean values for the entire survey area, as well as mean value by depth stratum. Minimum and maximum values were calculated using all samples, whereas means were calculated on detected values only; n = number of samples; nd = not detected.

					Depth Strata						
					Inner Shelf		Mid-Shelf			Outer Shelf	Upper Slope
	2016–2017 Survey Area				SBOO	Reg	PLOO	SBOO	Reg	Reg	Reg
Parameters	DR	Min	Max	Mean	n=34	n=19	n=44	n=20	n=35	n=14	n=12
Particle Size (%)											
Coarse particles	30	0.0	35.6	1.8	6.4	8.0	5.2	7.9	5.5	2.4	0.0
Med-coarse sands	100	0.1	94.3	18.0	28.9	13.9	5.3	55.4	18.1	6.1	0.2
Fine sands	100	1.8	91.5	51.9	59.2	73.2	54.7	30.0	48.0	48.5	29.2
Fines	98	0.0	87.3	28.3	10.5	11.7	38.6	10.0	32.2	44.9	70.6
Organic Indicators											
Sulfides (ppm)	99	nd	149.00	5.70	1.93	3.44	5.74	1.02	9.22	8.07	14.22
TN (% weight)	87	nd	0.239	0.056	0.026	0.028	0.052	0.029	0.052	0.076	0.177
TOC (% weight)	93	nd	5.07	0.58	0.16	0.35	0.54	0.18	0.63	1.09	1.86
TVS (% weight)	100	0.20	9.20	1.83	0.76	0.74	2.04	0.64	1.83	2.96	6.46
Trace Metals (ppm)											
Aluminum	100	564	27,500	6838	4279	4306	7530	2168	7580	10,546	16,858
Antimony	58	nd	4.1	1.3	1.0	0.6	1.0	nd	1.3	1.6	2.1
Arsenic	100	0.64	10.50	2.12	1.75	1.57	2.02	3.22	2.43	1.62	2.24
Barium	100	1.28	129.00	32.50	22.36	23.51	32.71	8.19	36.50	48.19	85.28
Beryllium	1	nd	0.31	0.17	nd	nd	0.03	nd	nd	0.31	nd
Cadmium	17	nd	0.60	0.17	nd	nd	0.07	nd	nd	0.34	0.23
Chromium	100	2.8	69.6	18.4	11.1	9.4	20.9	9.0	19.8	26.6	46.6
Copper	86	nd	31.8	6.2	2.5	1.5	5.9	1.6	6.1	10.8	20.0
Iron	100	1200	28,100	9927	5988	5584	11,532	5096	11,585	14,560	19,892
Lead	100	0.7	107.0	3.8	2.0	1.9	5.8	2.0	3.6	6.3	5.7
Manganese	100	5.4	218.0	77.7	55.1	61.3	85.7	29.3	91.4	103.6	148.8
Mercury	75	nd	0.226	0.026	0.008	0.006	0.023	0.013	0.024	0.051	0.058
Nickel	100	0.3	20.5	4.8	2.6	2.0	5.4	1.4	4.8	7.9	15.8
Selenium	27	nd	1.18	0.40	0.09	0.08	0.35	0.15	0.32	0.54	0.61
Silver	1	nd	3.15	2.43	nd	nd	3.15	nd	nd	1.70	nd
Thallium	0	—	—	—	nd	nd	nd	nd	nd	nd	nd
Tin	62	nd	81.8	1.5	0.8	0.5	0.6	0.7	0.7	6.7	1.2
Zinc	100	2.0	83.5	23.8	13.2	13.4	27.3	7.5	28.0	36.9	56.8

the amount of percent fines increased with depth, averaging about 10.5% per sample along the inner shelf, 31% along the middle shelf, 45% along the outer shelf, and 71% along the upper slope (Appendix F.2). Correlation analysis confirmed that percent fines tended to increase with depth throughout the San Diego region (Figure 6.2).

Classification (cluster) analysis of the sediment particle data described above discriminated eight main particle size cluster groups (Figures 6.3, 6.4, Table 6.2). According to BEST BVSTEP results ($\rho = 0.959$, $p = 0.001$), these eight clusters were primarily distinguished by proportions of coarse sand (e.g., particle size cluster groups 1, 2, 3, 6), very

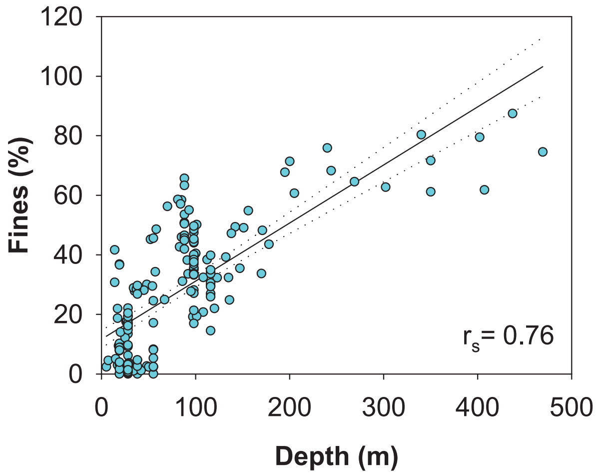


Figure 6.2
Scatterplot of concentrations of fine particles (Fines) versus depth for sediments collected from San Diego regional and core benthic stations during the summer surveys of 2016 and 2017.

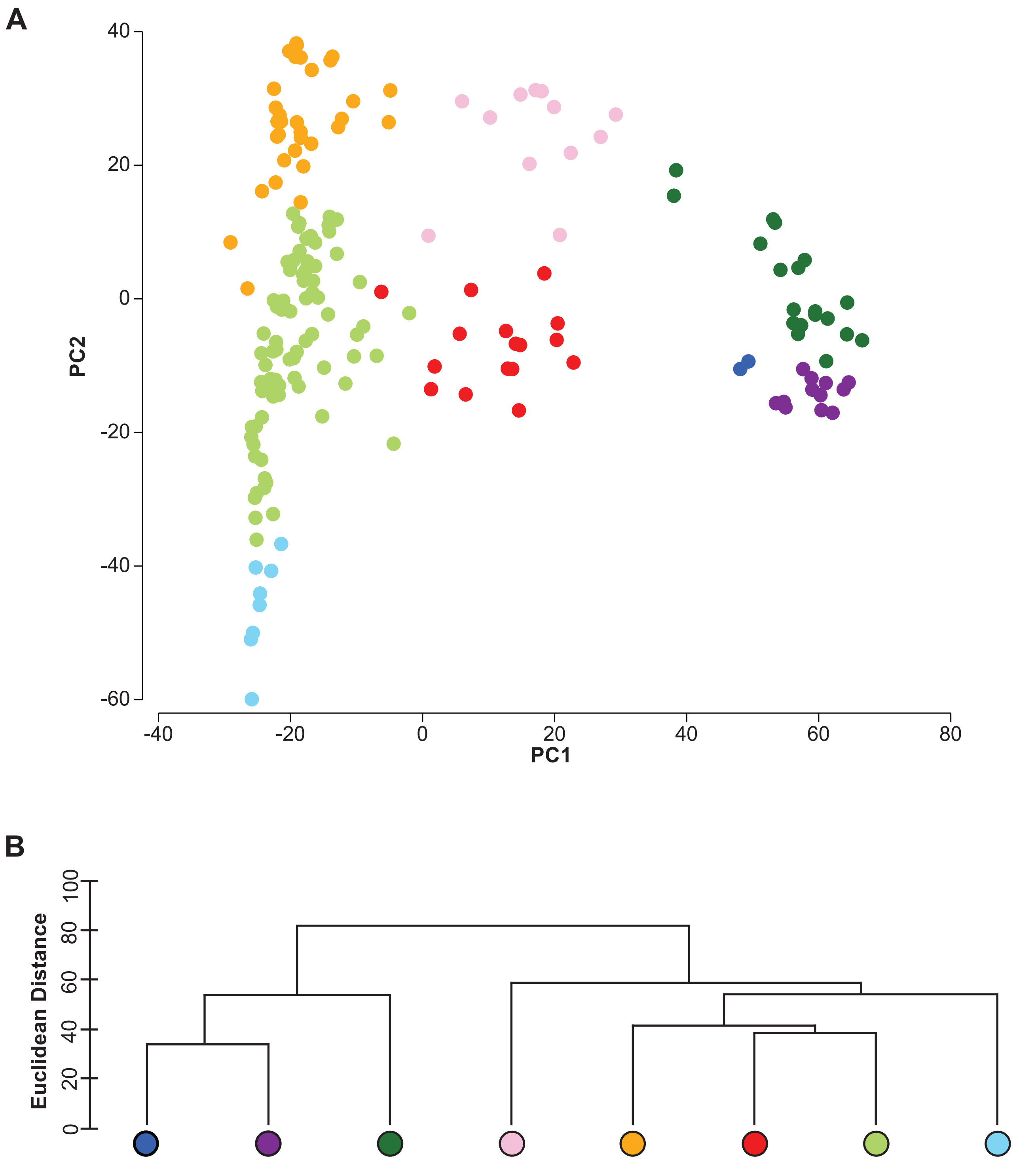
fine sand (e.g., particle size groups 4, 5, 7), and fine particles (e.g., particle size group 8). Additionally, these groups were distributed to some degree by depth strata, with cluster groups 1–4 representing inner and mid-shelf stations and particle size group 8 representing outer shelf and upper slope stations. In contrast, samples represented by particle size cluster groups 5–7 were collected from stations located across >2 strata each at depths ranging from 17 to 407 m. Four of the nine samples collected nearest the PLOO discharge site (i.e., at near-ZID stations E11, E14, E15, E17, and regional station 8618) had coarser sediments than other surrounding mid-shelf stations (i.e., groups 5–6 versus group 7), while the nine samples collected nearest the SBOO discharge site (i.e., at near-ZID stations I12, I14, I15, I16, and regional station 8641) fell into three different clusters (i.e., groups 3–5) that were characterized by varying proportions of fine particles and sand. The main characteristics and distribution of each of the eight particle size cluster groups are described below.

Particle size cluster group 1 comprised a total of two samples collected from SBOO farfield stations I23 and I34 along the inner shelf (19–21 m) during the summer of 2017 (Figures 6.3, 6.4). These sediments had the largest proportions of granules (15%) and very coarse sand (18%), as well as the second largest proportion of coarse sand (30%) (Table 6.2). This cluster group also averaged 2% fines (silt and clay), 2% very fine sand, 4% fine sand, and 28% medium sand.

Particle size cluster group 2 comprised 12 samples collected from nine stations located at inner to mid-shelf depths of 18–55 m. These included eight stations in the SBOO monitoring region (i.e., stations I4, I7, I13, I20, I21, 8601, 8602, 8603), and station 8522 located on the inner shelf off Point Loma (Figures 6.3, 6.4). Sediments represented by this cluster group had the highest proportion of coarse sand (55%), second largest proportion of medium sand (30%), and also the second highest proportion of very coarse sand (8%) (Table 6.2). Sediments at these sites were distinguished from group 1 sediments by averaging <1% granules per sample, but had otherwise similar low levels of percent fines (2%), very fine sand (1%), and fine sand (4%).

Particle size cluster group 3 comprised 19 sediment samples from 14 inner to mid-shelf stations that ranged in depth from 5 to 48 m. These included three SBOO near-ZID stations (I12, I15, I16), six SBOO farfield stations located to the west and south of the outfall (I2, I3, I6, I8, I13, I21), SBOO farfield station I34 and regional station 8506 located to the north of the outfall, regional station 8513 located in shallow South Bay waters (5 m) just off Silver Strand Beach (Coronado Island), and regional stations 8533 and 8637 located much farther to the north off Point La Jolla (Figures 6.3, 6.4). Sediments from these widespread locations had the largest proportion of medium sand (53%), the second largest proportion of fine sand (26%), and the third largest proportion of coarse sand (15%) (Table 6.2). Relative to particle size groups 1 and 2, group 3 sediments had low levels of very coarse sand (1%), but similar low levels of percent fines (2%) and very fine sand (3.5%).

Particle size cluster group 4 was also widely distributed off San Diego, comprising 12 samples from 11 different stations ranging in depth from 7 m along the inner shelf to 116 m along the mid-shelf. These included PLOO farfield station E3 located near the edge of the EPA-designated LA-5 dumpsite for dredged materials, SBOO near-ZID stations



Cluster:	1	2	3	4	5	6	7	8
n	2	12	19	12	33	16	76	8
Depth (m)	20 (19-21)	40 (18-55)	30 (5-48)	38 (7-116)	39 (17-136)	109 (55-170)	105 (14-407)	329 (195-469)

Figure 6.3
Results of (A) two-dimensional principal components (PC) analysis ordination and (B) cluster analysis of particle size sub-fraction data from San Diego regional and core benthic stations sampled during the summer surveys of 2016 and 2017. Depth presented as means (ranges) is calculated over all stations within a cluster group (n).

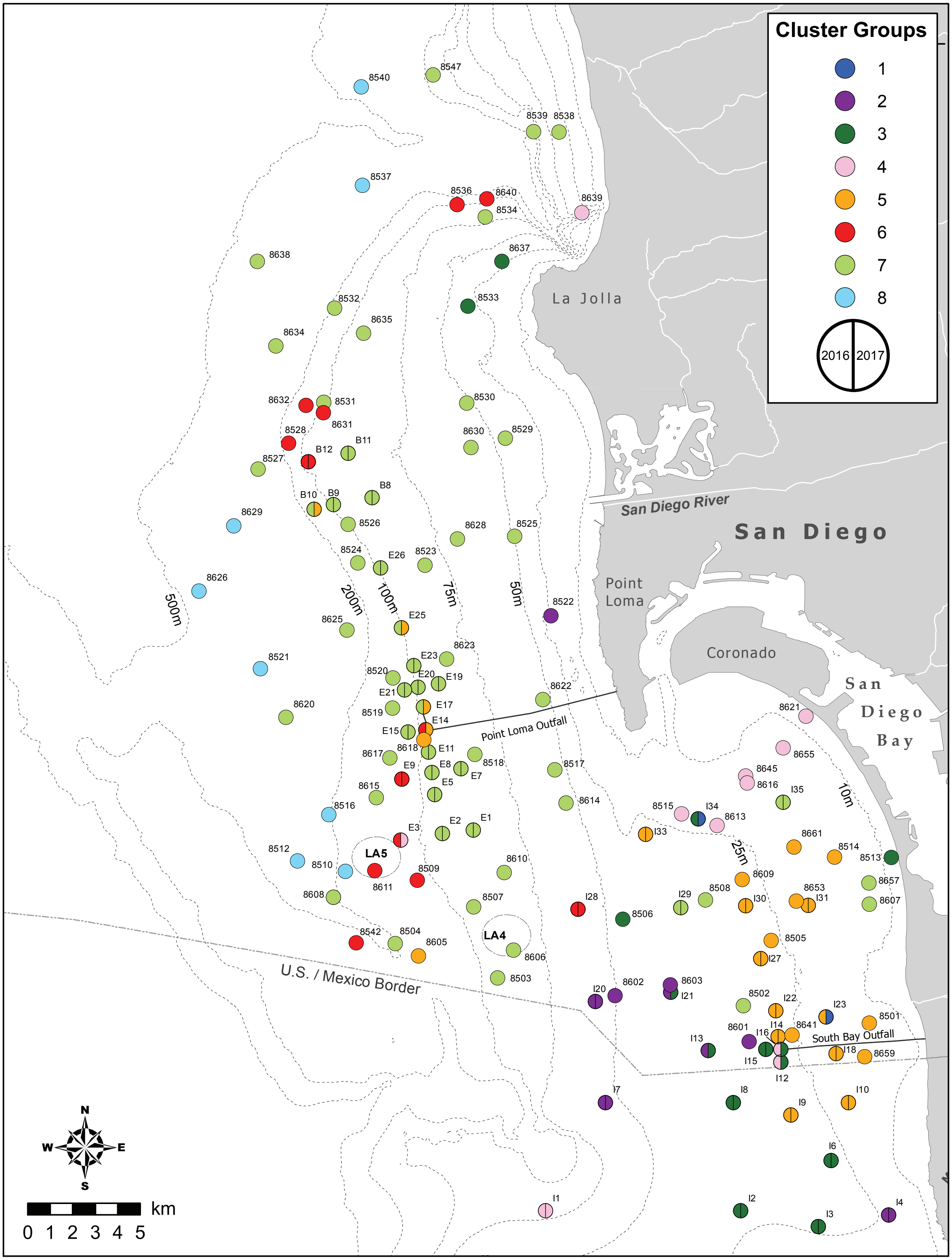


Figure 6.4
Spatial distribution of particle size cluster groups 1–8 defined in Figure 6.3.

Table 6.2

Particle size (%) summary for each cluster group 1–8 (defined in Figure 6.3). Data are presented as means (ranges) calculated over all stations within a cluster group (n). VF = very fine; F = fine; M = medium; C = coarse; VC = very coarse.

	Particle Size Cluster Group							
	1	2	3	4	5	6	7	8
n	2	12	19	12	33	16	76	8
Depth (m)	20 (19-21)	40 (18-55)	30 (5-48)	38 (7-116)	39 (17-136)	109 (55-170)	105 (14-407)	329 (195-469)
Fines	2.4 (1.6-3.3)	1.9 (0-5.2)	2.1 (0-4.7)	7.7 (2.1-24.9)	16.6 (7.8-38.3)	26.9 (16.9-35.4)	43.4 (26.8-68.2)	76.0 (67.6-87.3)
VFSand	2.0 (0.3-3.6)	0.9 (0-3.3)	3.5 (0.4-15)	25.9 (12.8-37.1)	64.4 (47.8-73.4)	23.0 (13.3-40.2)	40.7 (21.5-55.0)	18.3 (9.7-23.3)
FSand	4.4 (2.3-6.6)	3.9 (1.6-8.1)	25.7 (8.1-55.0)	52.6 (37.9-70.1)	17.2 (1.3-36.1)	16.5 (3.4-32.6)	14.0 (5.3-28.2)	5.4 (2.9-9.2)
MSand	27.5 (25.9-29.2)	29.8 (15.8-42.5)	52.5 (29.5-67.1)	12.5 (5.4-21.7)	1.4 (0.2-4.2)	14.3 (2.6-25.9)	1.6 (0.1-9.6)	0.4 (0.1-1.4)
CSand	30.3 (30.0-30.6)	54.6 (42.6-72.4)	15.0 (1.6-35.0)	1.1 (0-7.2)	0.1 (0-3.1)	13.2 (0.6-27.3)	0.2 (0-5.8)	0 (0-0)
VCSand	18 (17.7-18.3)	8.2 (1.0-15.6)	1.2 (0-10.5)	0.2 (0-2.5)	0.2 (0-6.4)	4.8 (0-13.7)	0.1 (0-4.7)	0 (0-0)
Granules	15.4 (13.4-17.3)	0.7 (0-7.0)	0 (0-0.3)	0.1 (0-0.6)	0.1 (0-1.4)	1.3 (0-7.4)	0.1 (0-8.3)	0 (0-0)

I12 and I16, SBOO farfield station I1 located far southwest of the SBOO, regional stations 8515, 8613, 8616, 8621, 8645. and 8655 located south of the entrance to San Diego Bay off Silver Strand Beach, and regional station 8639 located to the north off La Jolla on the edge of the Scripps submarine canyon (Figures 6.3, 6.4). Sediments represented by this cluster group had the highest proportion of fine sand (53%) and third highest proportion of very find sand (26%) (Table 6.2). These sediments also averaged 8% fines, 12% medium sand, 1% coarse sand, and < 1% very coarse sand and granules.

Particle size cluster group 5 was the second largest group, comprising 33 samples from 24 stations, 18 of which were located at inner shelf depths of 17–30 m within the SBOO monitoring region. These stations included near-ZID station I14, farfield stations I9, I10, I18, I22, I23, I27, I30, I31 and, I33, and regional stations 8501, 8505, 8514, 8609, 8641, 8653, 8659, and 8661 (Figures 6.3, 6.4). The remaining six stations were located at mid to outer shelf depths of 97–136 m within the PLOO region, and included near-ZID stations E14 and E17, farfield stations B10 and E25, and regional stations 8605 and 8618. The sediments associated with this cluster group were distinguished by having the largest proportion of very fine sands (64%) (Table 6.2). Sediments at these sites also averaged 17% fines, 17% fine sand, 1% medium sand, and < 1% coarse sand, very coarse sand and granules.

Particle size cluster group 6 comprised 16 samples from 13 widely distributed stations ranged in depth from 55 m on the mid-shelf to 170 m on the outer shelf. These included SBOO farfield station I28 located northwest of the outfall, regional station 8542 located far offshore on the Coronado Bank, PLOO farfield station E3 and regional stations 8509 and 8611 located within or near the LA-5 dredge spoils dumpsite, PLOO farfield station E9 located between LA-5 and the PLOO, PLOO near-ZID station E14, PLOO farfield station B12, and regional stations 8528, 8631, and 8632 located offshore of Mission Beach in an area well known for shell hash (see Chapter 4), and regional stations 8536 and 8640 located far to the north along the outer edge of the La Jolla submarine canyon

(Figures 6.3, 6.4). Sediments represented by this cluster group were distinguished in having the third largest proportion of percent fines (27%) and fourth largest proportion of very fine and fine sand (23% and 16%, respectively), but also containing relatively large amounts of medium sand (14%), coarse sand (13%), very coarse sand (5%), and granules (1%) (Table 6.2).

Particle size cluster group 7 was the largest group, comprising 76 sediment samples from 59 widely distributed stations ranging in depth from 14 m on the inner shelf to 407 m on the upper slope (Figures 6.3, 6.4). Forty-three percent of these samples were collected from stations located within the PLOO region, including near-ZID stations E11, E15, and E17, while ~10% were collected from core SBOO and regional stations located within the SBOO monitoring region. The remaining 46% of the sediment samples in this cluster group were collected from other regional stations located on the inner shelf, middle shelf, outer shelf, and upper slope from Del Mar southward to the US/Mexico border. The sediments in this group were composed almost entirely of percent fines (43%) and very fine sand (41%), with the remainder composed of 14% fine sand, and ≤2% medium sand, coarse sand, very coarse sand, and granules (Table 6.2).

Particle size cluster group 8 comprised sediment samples from only eight regional stations located on the outer shelf and upper slope at depths of 195–469 m (Figures 6.3, 6.4). Sediments in this group were comprised of predominately fine particles (i.e., 76% fines), with just 18% very fine sand, 5% fine sand, and <1% medium sand (Table 6.2). Larger coarse sands and granules were absent from these sediments.

Sediment Chemistry

Overall, the different organic indictors and metals analyzed in this chapter for sediments collected throughout the San Diego region during the summers of 2016 and 2017 were detected at concentrations generally below ERL or ERM thresholds and/or within historical ranges (Table 6.1; see also Chapter 4). For example, only 3% of all sediment samples collected during these surveys had metal concentrations that exceeded ERLs (Long et al. 1995). These included arsenic at stations I21 and 8603 located northwest of the SBOO region, lead at station E1 located south of the PLOO, mercury at station 8516 located southwest of the PLOO, and silver at PLOO near-ZID station E11 and station 8542 located far offshore just north of the US/Mexico border (Addenda 4-5, 4-6, 6-3, City of San Diego 2017a). As in previous surveys, several analytes tended to co-vary with percent fines, including total nitrogen, total volatile solids, aluminum, antimony, barium, chromium, copper, iron, manganese, mercury, nickel, and zinc (Appendix F.4). Since percent fines tended to co-vary with depth (Figure 6.2), several parameters also had increasing concentrations across depth strata (Table 6.1, Appendix F.4). For example, aluminum averaged 4279–4306 ppm per sample at inner shelf core SBOO and regional stations, 7530–7580 ppm at mid-shelf core PLOO and regional stations, 10,546 ppm at outer shelf regional stations, and 16,858 ppm at upper slope regional stations. In contrast, mid-shelf stations in the SBOO region did not fit well within this pattern since these sites generally have coarser sediments (i.e., higher proportions of sand) than other stations at similar depths.

Cluster analysis of the organic indicator and metals data described above discriminated seven main sediment chemistry clusters (i.e., sediment chemistry groups A–G; Figures 6.5, 6.6, 6.7). According to BEST BVSTEP results ($\rho = 0.961$, $p = 0.001$), these seven groups were primarily distinguished by aluminum, arsenic, cadmium, chromium, lead, nickel, silver, sulfides, zinc, and total organic carbon (e.g., Figure 6.7), and according to RELATE results ($\rho = 0.367$, $p = 0.001$), overall patterns in combined sediment chemistry concentrations were weakly linked to sediment particle size composition. Percent fines and very coarse sand were the particle size sub-fractions most highly correlated to the distribution of organic loading indicators and metals (BEST BIOENV, $\rho = 0.563$, $p = 0.001$). This weak association is due to the combination of organic loading indicators and trace metals that co-vary with percent fines, and those that do not,

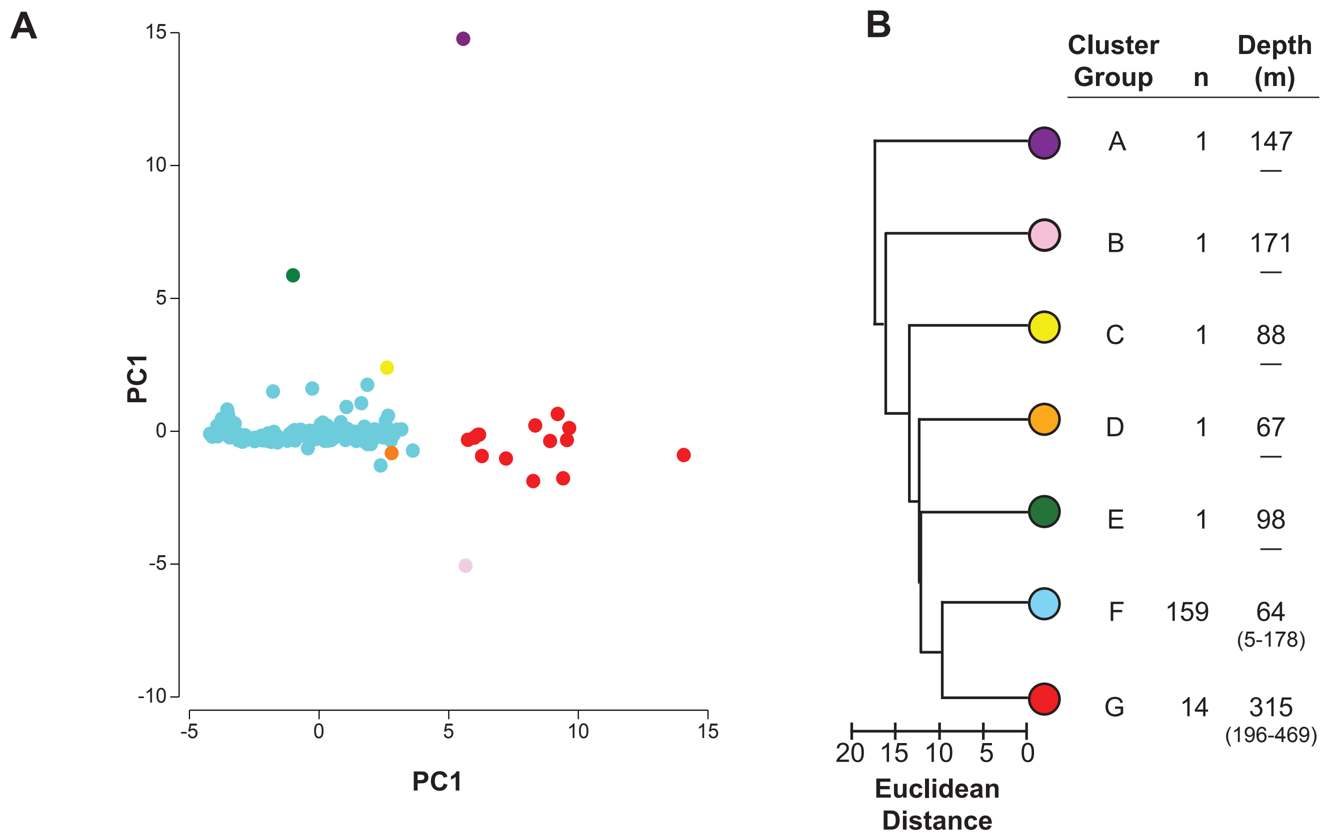


Figure 6.5
Results of (A) two-dimensional principal components (PC) analysis ordination and (B) cluster analysis of sediment chemistry data from San Diego regional and core benthic stations sampled during the summer surveys of 2016 and 2017. Depths are presented as means (ranges) calculated over all stations within a cluster group (n).

such as sulfides, total organic carbon, and arsenic (Appendices F.2, F.4). This also explains why the sediment chemistry cluster groups did not fall out by depth strata. Instead, 89% of all samples, including all but one of the 18 sediment samples collected from stations located near the PLOO and SBOO discharge sites, occurred within the same sediment chemistry cluster group indicative of background conditions off San Diego (see group F). The distribution and main characteristics of each cluster group are described below.

Sediment chemistry group F represented by far the largest cluster, which included 159 of the 178 (89%) samples analyzed for the 2016 and 2017 summers surveys (Figures 6.5, 6.6). These samples were collected from a wide range of inner to outer shelf stations that spanned the entire San Diego region at depths ranging from 5 to 178 m. Included in this group were 15 of 16 samples collected from the near-ZID PLOO and SBOO sites as well as two other near-ZID regional stations. According to SIMPER results, a wide range of analytes accounted for 47% of the within-group similarity for group F, including sulfides, total organic carbon, total nitrogen, aluminum, barium, beryllium, cadmium, chromium, copper, lead, mercury, nickel, silver, thallium, and tin (e.g., Figure 6.7). It is likely that this cluster group represents background conditions for continental shelf habitats in the San Diego region.

Sediment chemistry cluster group G included 14 stations located on the outer shelf and upper slope at depths from 196 to 469 m (Figures 6.5, 6.6). This group of stations had the highest proportion of percent fines (i.e., 61–87% per station) and was characterized by relatively high concentrations of parameters such as total nitrogen, aluminum, antimony, barium, chromium, copper, iron,

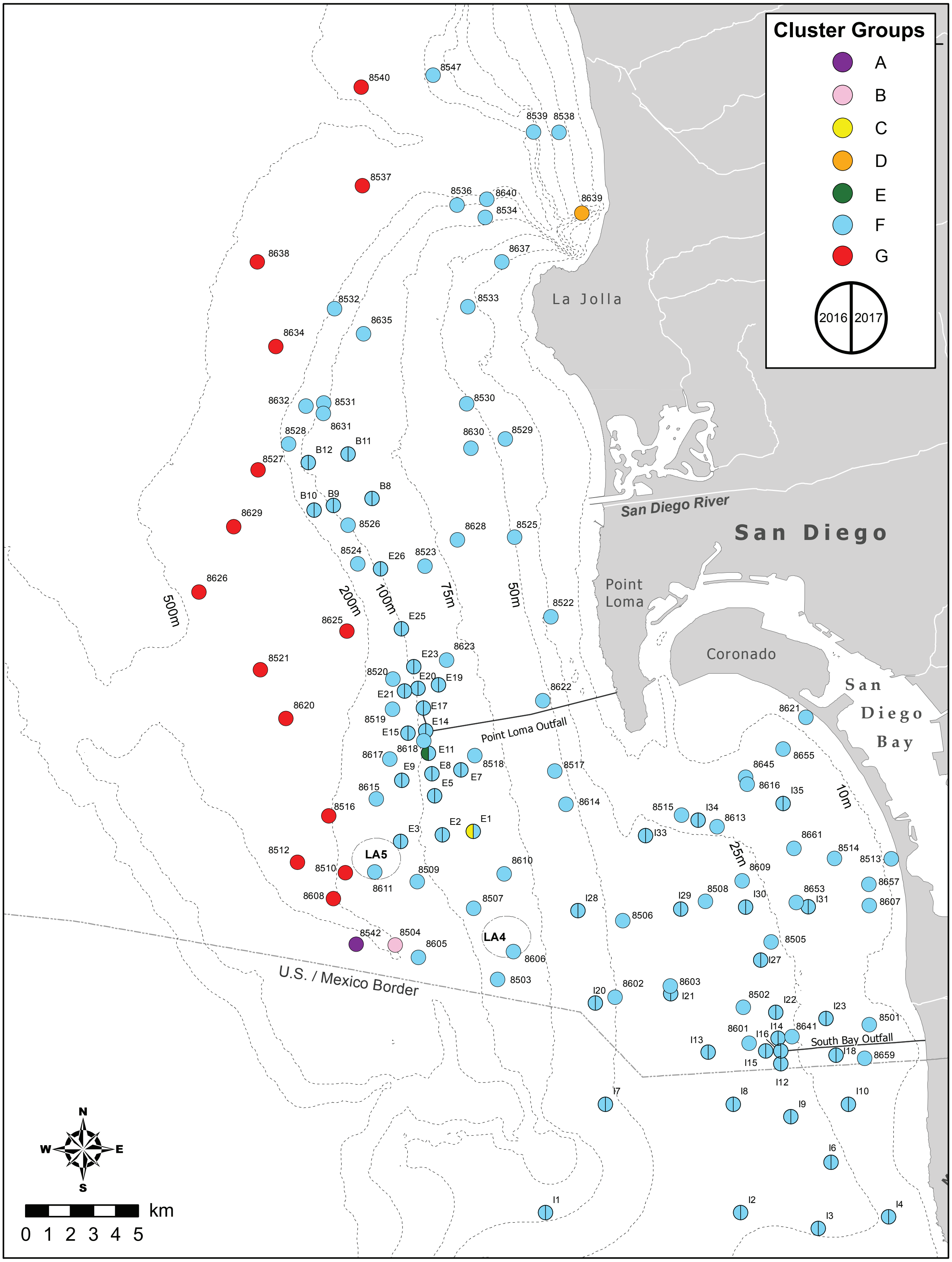


Figure 6.6
Spatial distribution of sediment chemistry cluster groups A–G defined in Figure 6.5.

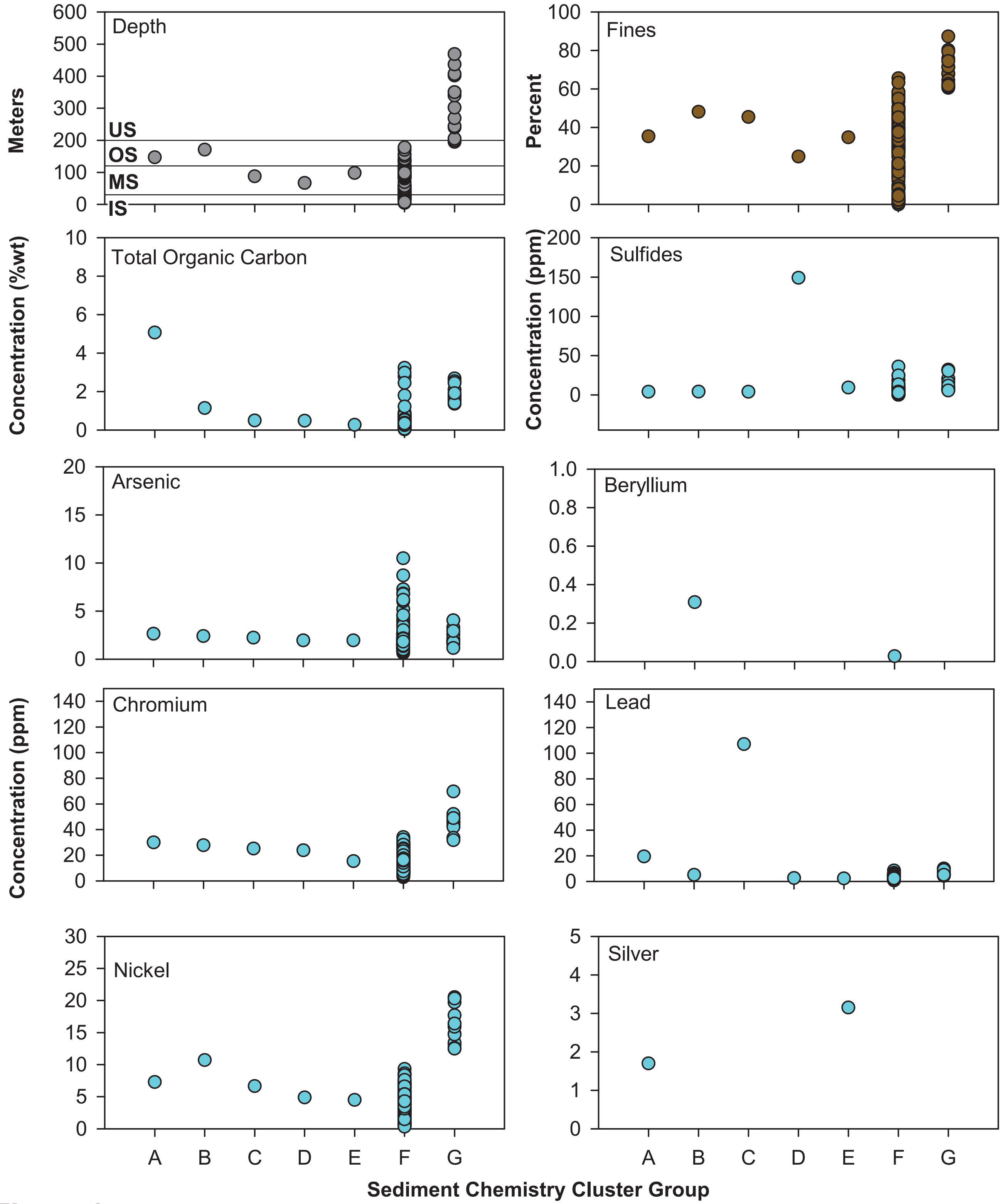


Figure 6.7
Depth, percent fines, and select sediment chemistry parameters that contributed to sediment chemistry cluster group dissimilarities. Each data point represents a single sample. IS=inner shelf; MS=mid-shelf; OS=outer shelf; US=upper slope.

manganese, mercury, nickel, and zinc that were found to co-vary with percent fines (e.g., Figure 6.7; see Appendix F.3 for correlation results). Each of the five remaining sediment chemistry cluster groups represented a single "outlier" station that differed from major groups F and G primarily by having higher values of a few select contaminants (Figures 6.5, 6.6, 6.7). For example, station 8542 (sediment chemistry group A) had the highest concentrations of total organic carbon, antimony, iron, and tin. This station was located on the eastern edge of the Coronado Bank just north of the US/Mexico border at a depth of 147 m. Station 8504 (sediment chemistry group B), located at a depth of 171 m just east of station 8542, was characterized by the highest concentrations of beryllium, cadmium, and selenium. The July 2016 sample from PLOO station E1 located south of the outfall and inshore of the LA-5 dumpsite comprised sediment chemistry group C. The sediments at this site had the highest lead value of any other sample by an order of magnitude. Station 8639 (sediment chemistry group D) was located at a depth of 67 m along the edge of the Scripps Submarine Canyon. The sediments at this site had the highest concentration of sulfides of all sites, also by an order of magnitude. Finally, sediment chemistry group E represented the July 2016 sample collected from near-ZID PLOO station E11. These sediments had the highest silver concentration measured during these surveys.

Sediment Toxicity

Results of all sediment toxicity testing conducted during the summers of 2016 and 2017 as part of a 3-year pilot study for the Point Loma and South Bay ocean outfall regions indicated no evidence of toxicity at any of the monitoring sites. The details of these toxicity tests and results are not included in this report but are available in Nautilus Environmental (2016, 2017). Additionally, these results, along with results for the upcoming summer 2018 survey, will be fully reported in a separate final project report expected to be completed by the end of calendar year 2018.

Regional Macrobenthic Communities

A total of 40,578 macrobenthic invertebrates were identified from the 178 grabs collected during the summer 2016 and 2017 surveys at depths ranging from 5 to 469 m off San Diego. Of the 910 taxa recorded, about 80% (n = 724) were identified to species, while the rest could only be identified to higher taxonomic levels. Macrofaunal community structure varied across both the continental shelf and slope, with species richness ranging from 14 to 149 taxa per grab, macrofaunal abundance ranging from 27 to 866 individuals per grab, Shannon diversity (H') ranging from 0.6 to 4.3 per grab, Pielou's evenness (J') ranging from 0.18 to 0.97 per grab, and Swartz dominance ranging from 1 to 51 per grab (Table 6.3). Reported values and the variation observed between strata for each parameter generally correspond to findings reported previously for the San Diego region (e.g., City of San Diego 2015a,b). For example, species richness and abundance values were lowest at upper slope stations. As has also been reported previously, benthic response index (BRI) values off San Diego have generally been indicative of reference or non-impacted conditions (i.e., BRI < 25; Smith et al. 2001). This remained true for the summer 2016 and 2017 surveys with 141 of 164 samples (~86%) collected from BRI-validated depths having BRI values indicative of reference condition. A total of 20 samples (~12%) had slightly elevated BRI values between 25–34 that indicate a possible minor deviation from reference condition; these samples were collected at near-ZID stations E14 and I14, farfield stations I8, I9, I22, I27, I30, I33, and I35, and regional stations 8609, 8613, 8653, 8655, 8657, and 8661. Only three stations sampled in 2017 had BRI values > 34 that represent increasing levels of disturbance or environmental degradation. These included PLOO near-ZID station E14, regional station 8618, also located near the PLOO ZID, and station 8639 located far to the north near the edge of the La Jolla Submarine Canyon (see Appendix F.5).

Cluster analysis of the macrofaunal data described above resulted in 14 ecologically-relevant SIMPROF-supported groups or types of assemblages (Figures 6.8, 6.9, 6.10, Appendices F.6, F.7). These assemblages (referred to herein as macrofauna cluster groups A–N) represented between 1–84 grab samples each. Composition of each cluster group varied in terms of the specific taxa present, as well as their relative abundances, and occurred at sites separated by different depth and/or sediment microhabitats. For example, the macrofaunal assemblages represented by the six

Table 6.3

Macrofaunal community summary statistics calculated for San Diego regional and core benthic stations sampled during the summer surveys of 2016 and 2017. Data are presented as means (ranges) by stratum; n = number of grabs; SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = Pielou's evenness; Dom = Swartz dominance; BRI = benthic response index.

Stratum		n	SR	Abun	H'	J'	Dom	BRI [a]
Inner Shelf								
	SBOO	34	60 (15-103)	267 (27-866)	3.0 (1.6-4.0)	0.76 (0.46-0.93)	18 (3-36)	20 (0-30)
	Regional	19	41 (14-76)	164 (55-341)	2.7 (1.9-3.4)	0.75 (0.52-0.86)	12 (3-19)	22 (-3-31)
	All Inner Shelf	53	53	230	2.9	0.76	16	21
Middle Shelf								
	PLOO	44	66 (43-149)	249 (125-625)	3.5 (2.9-4.3)	0.84 (0.73-0.93)	22 (12-48)	13 (3-37)
	SBOO	20	47 (24-105)	200 (37-712)	2.9 (0.6-4.0)	0.76 (0.18-0.97)	16 (1-36)	16 (3-28)
	Regional	35	68 (19-133)	276 (47-830)	3.4 (2.4-4.3)	0.82 (0.67-0.93)	22 (7-51)	16 (3-42)
	All Middle Shelf	99	63	249	3.3	0.82	21	14
Outer Shelf								
	Regional	14	58 (29-79)	220 (63-428)	3.4 (3.0-4.0)	0.84 (0.75-0.92)	19 (13-39)	16 (7-23)
Upper Slope								
	Regional	12	30 (18-47)	57 (31-102)	3.1 (2.3-3.6)	0.91 (0.81-0.96)	16 (7-23)	—
	All Stations	178	57 (14-149)	228 (27-866)	3.2 (0.6-4.3)	0.81 (0.18-0.97)	19 (1-51)	17 (-3-42)

[a]BRI statistic not calculated for stations located at depths < 10 m or > 200 m

stations (samples) comprising cluster groups A, B, and C occurred along the inner shelf at depths of 5–22 m, with all but one sample (i.e. from station 8522) located within the SBOO monitoring region. Assemblages represented by cluster groups D, E, F, G, H, I, and J were from a total of 74 samples collected along the inner and middle shelf at depths between 14–67 m. Stations located near the main SBOO discharge zone fell into either group G (n = 41) or group E (n = 19). Macrofaunal assemblages associated with cluster group K, the largest group (n = 84), spanned a significant portion of the middle and outer shelf off San Diego. Group K also included all samples collected at stations located near the PLOO discharge site. Assemblages associated with cluster groups L, M, and N represented a total of 14 samples that occurred along outer shelf and upper slope at depths of 195–469 m. Additionally, similar patterns of variation occurred in the macrofaunal and sediment similarity/dissimilarity matrices used to generate cluster dendrograms (RELATE $\rho = 0.67$, $p = 0.001$). The sediment sub-fractions that were most highly correlated with the macrofaunal communities included granules, coarse sand, medium sand, and fine particles (BEST BIOENV $\rho = 0.689$, $p = 0.001$).

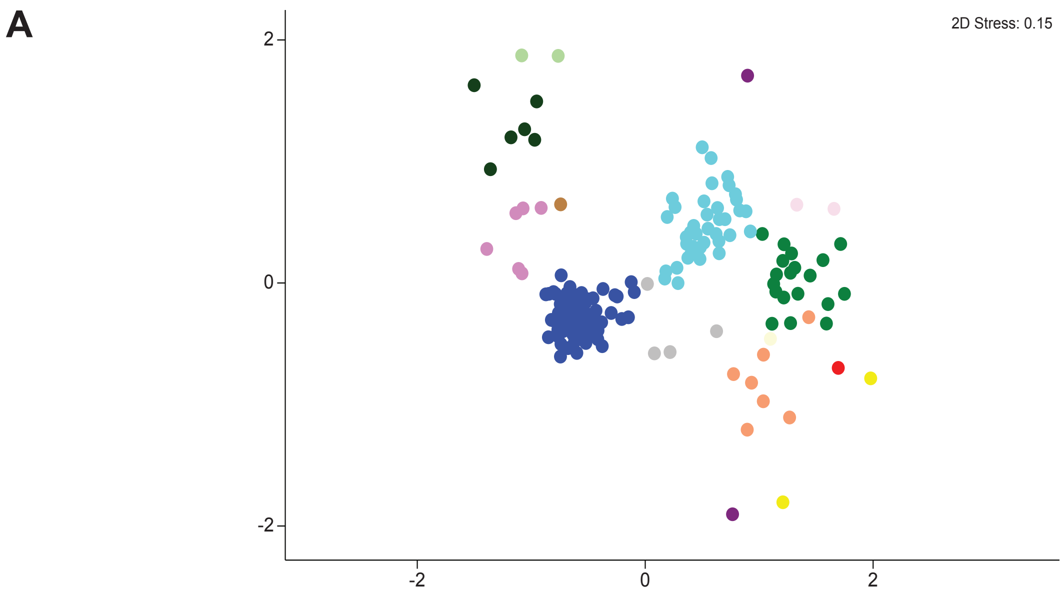
Species richness averaged from 16 to 68 taxa per grab for the different cluster groups or assemblages, while mean abundance ranged from 46 to 289 individuals per grab (Figure 6.8). According to BEST BVSTEP ($\rho = 0.817$, $p = 0.001$), just eight species best described the overall pattern (gradient) of the cluster dendrogram, including the polychaetes *Anobothrus gracilis*, *Chaetozone hartmanae*, *Lysippe* sp B and *Cossura candida*, the ophiuroid *Amphiodia urtica*, and the bivalves *Axinopsida serricata*, *Nuculana* sp A and *Tellina* sp B. All of these species occurred primarily in assemblages represented by cluster group K (see below and Appendix F.6). The main characteristics and distribution of each cluster group are described below.

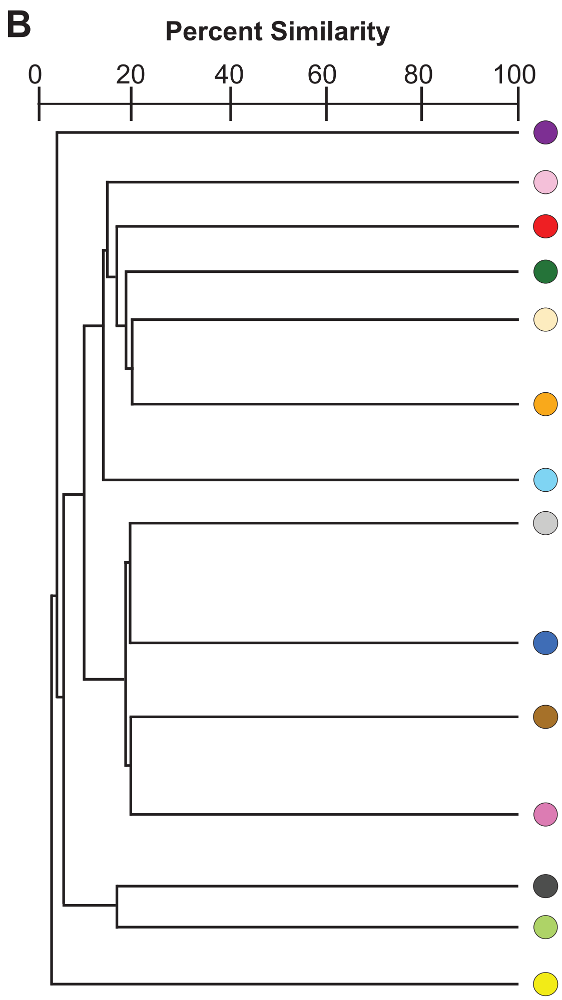
Macrofauna cluster group A represented inner shelf assemblages present at station 8513 in 2016 and station 8621 in 2017 (Figures 6.8, 6.9). Both sites were located in very shallow waters (7–9 m) along the Coronado "Silver Strand" beach. These assemblages averaged 16 taxa and 76 individuals per grab. According to SIMPER, the five most characteristic species for cluster group A were the echinoid *Dendraster excentricus* (18/grab), the amphipod *Rhepoxynius menziesi* (15/grab), the polychaete *Apoprionospio pygmaea* (9/grab), the bivalve *Tellina bodegensis* (3/grab), and the amphipod *Gibberosus myersi* (e.g., Figure 6.10, Appendix F.7). This was the highest number of *R. menziesi* and *A. pygmaea* and the second highest number of *D. excentricus*. The sediments associated with this cluster group were characterized by 3% fines, 13% very fine sand, 58% fine sand, 23% medium sand, 2% coarse sand, and the absence of any very coarse sand or granules (Appendix F.8). The 58% fine sands represented the largest proportion of this particle size sub-fraction compared to all other groups.

Macrofauna cluster group B represented two inner shelf assemblages present in 2017 stations I23 and I34 located at depths of 19–21 m in the SBOO region (Figures 6.8, 6.9). These two assemblages averaged 46 taxa and 289 individuals per grab. The five most characteristic taxa for cluster group B were the polychaetes *Pisione* sp (41/grab), *Pareurythoe californica* (26/grab) and *Protodorvillea gracilis* (21/grab), unidentified nematodes (7/grab), and the sipunculid *Apionsoma misakianum* (10/grab) (e.g., Figure 6.10, Appendix F.7). This was the highest number of these species found across all cluster groups. The sediments associated with cluster group B were characterized by 2% fine particles, 2% very fine sand, 4% fine sand, 28% medium sand, 30% coarse sand, 18% very coarse sand, and 15% granules (Appendix F.8). Overall, this was the largest proportion of very coarse sand and granules compared to all other cluster groups.

Macrofauna cluster group C represented inner shelf assemblages from stations 8522 and I4, sampled in 2016 at depths of 18 and 22 m, respectively (Figures 6.8, 6.9). These two stations are located far apart, with station 8522 located off Point Loma and station I4 located south of the US/Mexico border (southern-most edge of sampling region). These two assemblages averaged 19 taxa and 117 individuals per grab. The five most characteristic taxa for cluster group C were the gastropods *Micranellum crebricinctum* (33/grab) and *Halistylus pupoideus* (31/grab), the isopod *Eurydice caudata* (2/grab), unidentified nematodes (1/grab), and the chordate *Branchiostoma californiense* (1/grab) (e.g., Figure 6.10, Appendix F.7). These assemblages had the highest numbers of *M. crebricinctum* and *H. pupoideus* compared to all other cluster groups. The sediments associated with group C were characterized by 1% fine particles, <1% very fine sand, 3% fine sand, 32% medium sand, 51% coarse sand, 10% very coarse sand, and 3.5% granules (Appendix F.8). Compared to all other groups, these sediments averaged the lowest concentrations of percent fines, very fine sand, and fine sand, as well as the third highest concentrations of coarse sand and very coarse sand, and the second highest concentration of granules.

Macrofauna cluster group D represented a unique shallow mid-shelf assemblage present in 2016 at station 8533 located west of La Jolla at a depth of 36 m (Figures 6.8, 6.9). A total of 23 taxa and 67 individuals were found in this single grab sample. The five most abundant taxa were the ophiuroid *Ophiuroconis bispinosa* (n = 22), the polychaetes *Spiophanes norrisi* (n = 9), *Lumbrinerides platypygos* (n = 8) and *Diopatra ornata* (n = 3), and the scaphopod *Polyschides quadrifissatus* (n = 3) (e.g., Figure 6.10, Appendix F.7). Sediments associated with this sample were 2% fine particles, 1% very fine sand, 15% fine sand, 45% medium sand, 26% coarse sand, and 10% very coarse sand,





Cluster Group	n	Depth Range (m)	Community Metric	
			SR	Abun
A	2	5–7	16	76
B	2	19–21	46	289
D	1	36	23	67
E	19	18–38	37	208
F	1	41	33	130
I	7	41–55	29	58
G	41	14–38	66	279
H	4	37–60	46	126
K	84	45–178	68	264
J	1	67	19	66
L	6	195–269	40	87
M	6	302–407	28	49
N	2	437–469	21	46

Figure 6.8
Results of (A) non-metric multi-dimensional scaling ordination and (B) cluster analysis of macrofauna data from San Diego regional and core benthic stations sampled during the summer surveys of 2016 and 2017. Data are presented as mean values over all stations in each group (n); SR = species richness; Abun = abundance. Cluster groups have been re-ordered so they correspond to increasing mean depth.

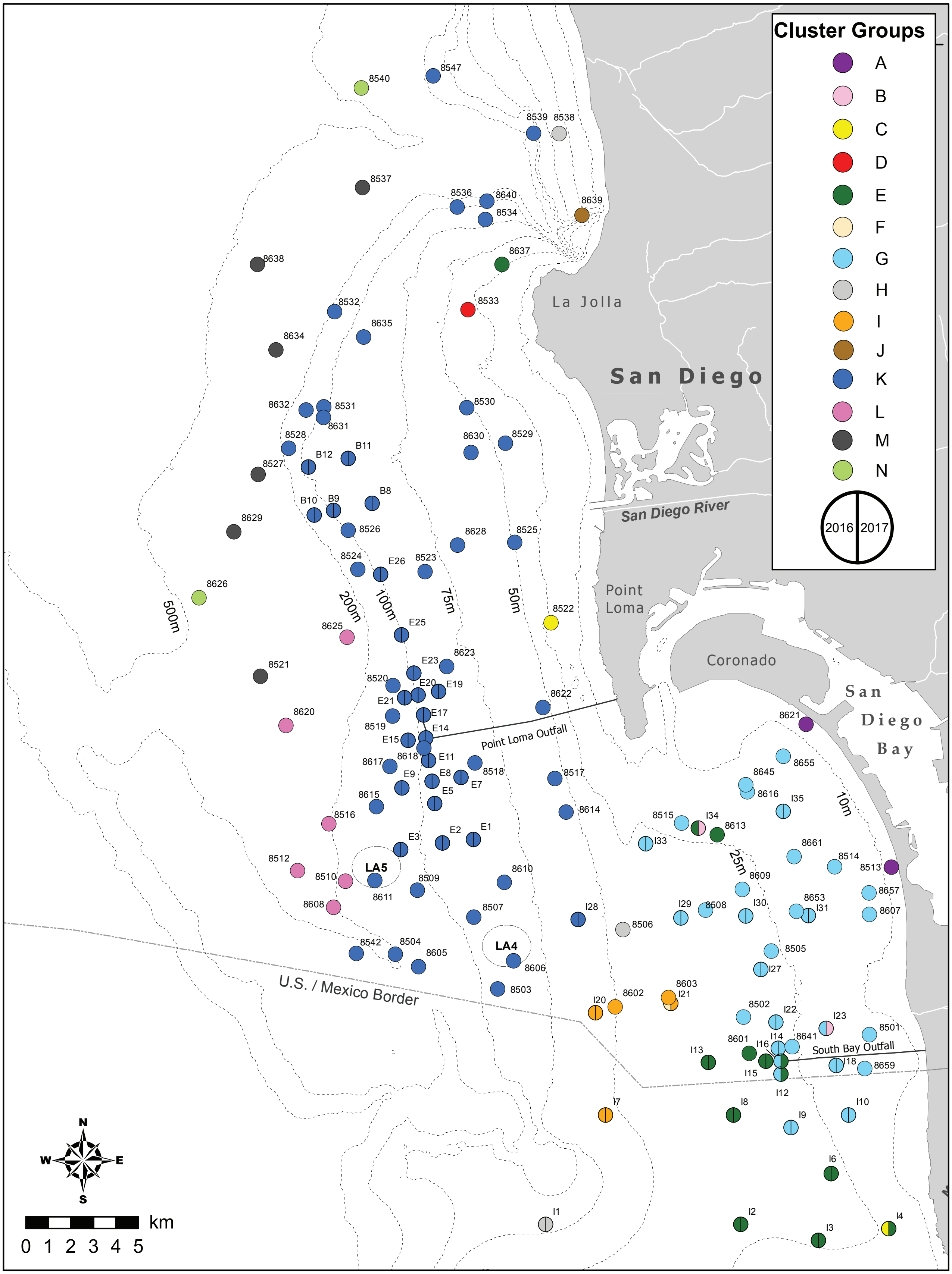


Figure 6.9
Spatial distribution of macrofauna cluster groups A–N defined in Figure 6.8.

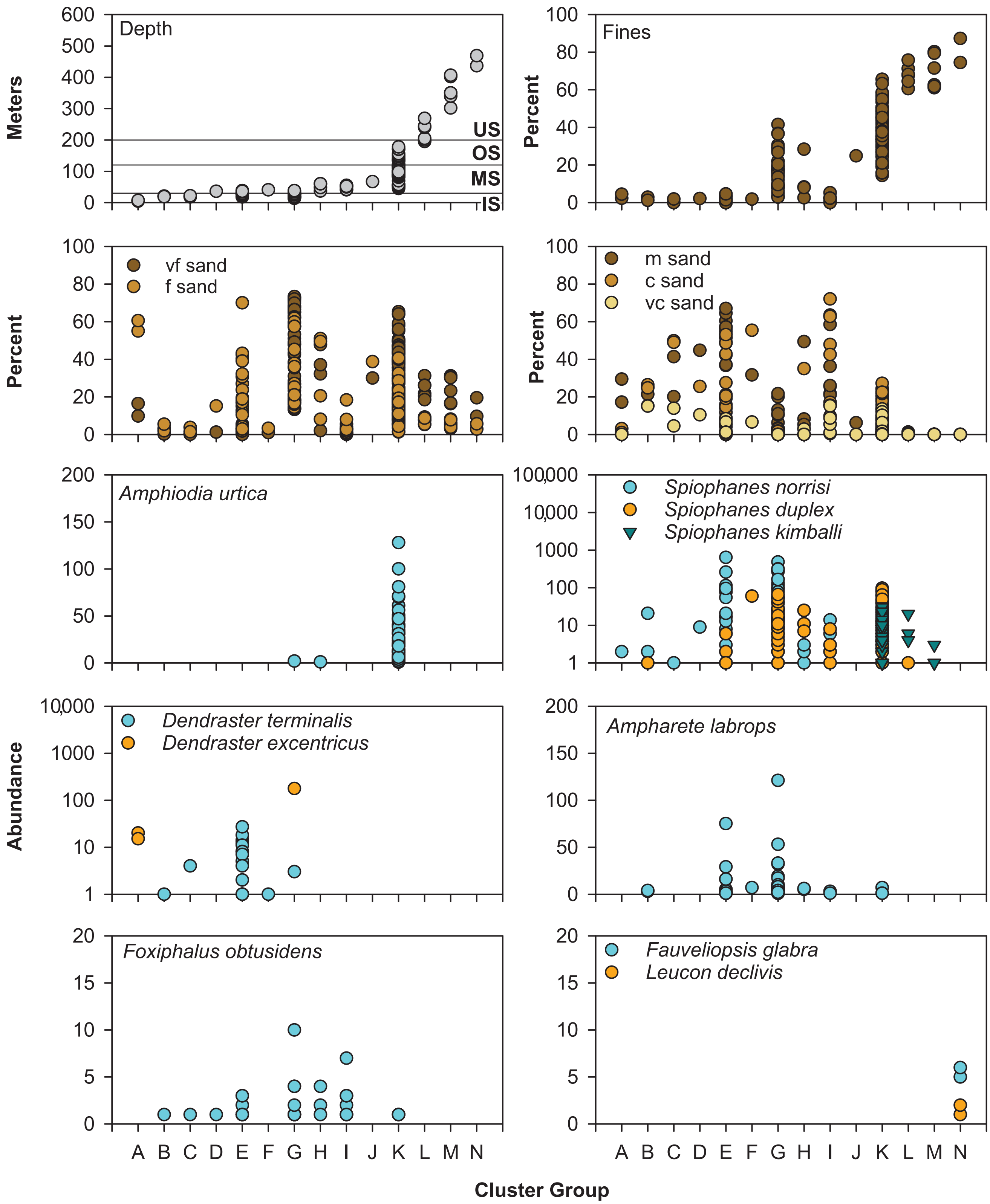


Figure 6.10

Depth, sediment composition, and abundances of select species that contributed to macrofauna cluster group dissimilarities during 2016 and 2017 (see Figure 6.8). Each data point represents a single sediment or grab sample; IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope; vf = very fine; f = fine; m = medium; c = coarse; vc = very coarse.

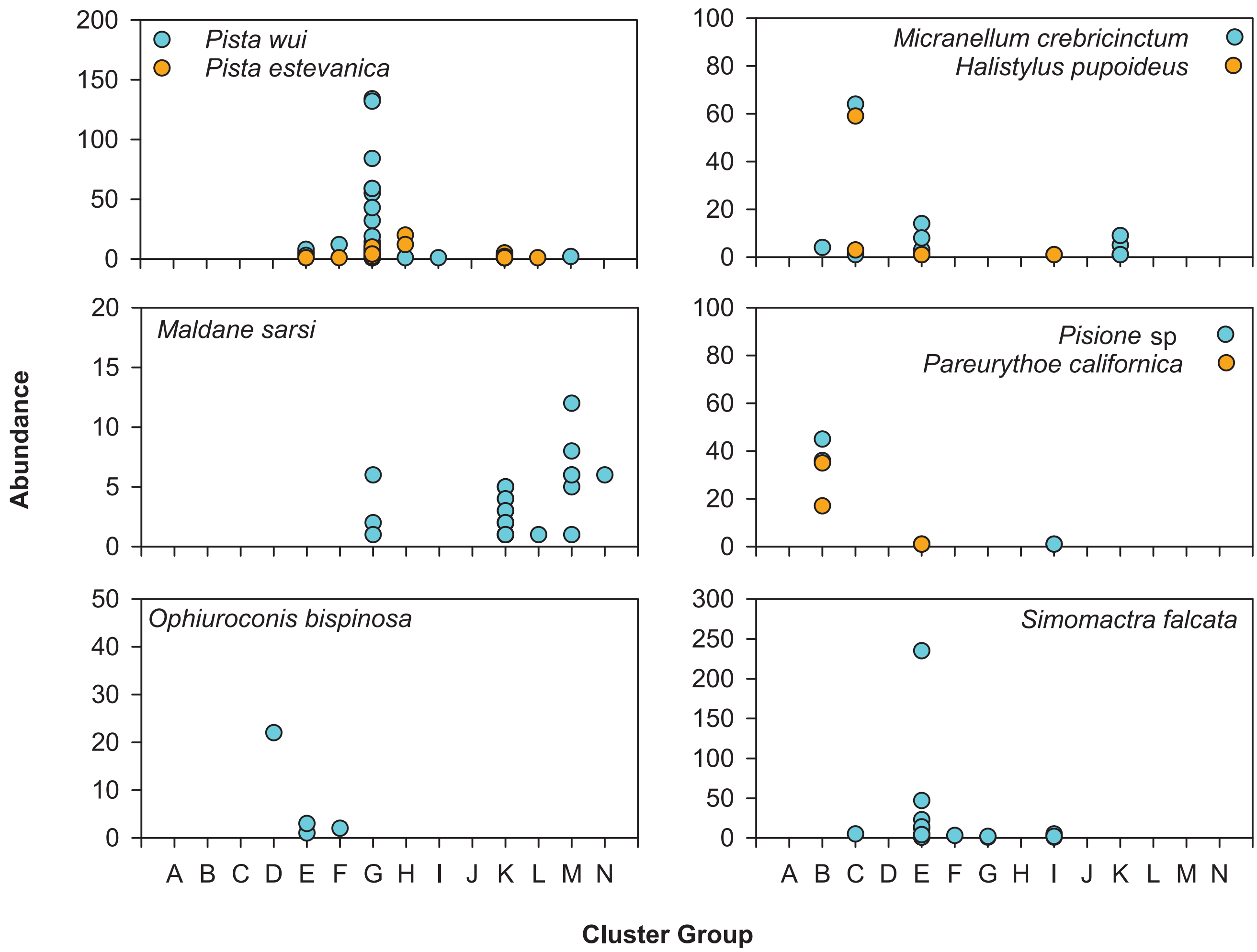


Figure 6.10 *continued*

with no granules present (Appendix F.8). These sediments had the second highest concentrations of medium sand and very coarse sand compared to the other groups.

Macrofauna cluster group E represented assemblages from 19 grabs from 13 different stations sampled at inner to mid-shelf depths 18–38 m, including four stations located near the SBOO ZID (i.e., I12, I15, I16, and 8601), eight other stations in the SBOO region (i.e., I2, I3, I4, I6, I8, I13, I34, and 8613), and station 8637 located far north off La Jolla (Figures 6.8, 6.9). These assemblages averaged 37 taxa and 208 individuals per grab. The five most characteristic taxa for cluster group E were the polychaete *Spiophanes norrisi* (86/grab), the bivalve *Simomactra falcata* (19/grab), a second polychaete *Ampharete labrops* (9/grab), the echinoid *Dendraster terminalis* (7/grab), and a third polychaete *Lumbrinerides platypygos* (7/grab) (e.g., Figure 6.10, Appendix F.7). These assemblages had the highest numbers of *S. norrisi*, *S. falcata*, and *D. terminalis* found across all cluster groups. The sediments associated with this cluster group were characterized by 2% fine particles, 4% very fine sand, 25% fine sand, 50% medium sand, 18% coarse sand, 1% very coarse sand, and <1% granules (Appendix F.8). Compared to all other groups, these sediments had the highest concentration of medium sand.

Macrofauna cluster group F represented a unique mid-shelf assemblage restricted to SBOO station I21 (Figures 6.8, 6.9). This assemblage comprised 33 taxa and 130 individuals. The most abundant taxa were the polychaetes *Spiophanes duplex* (n=60), *Pista wui* (n=12), *Ampharete labrops* (n=7) and *Onuphis* sp A (n=4), the enteropneust *Balanoglossus* sp (n=4), and the isopod *Eurydice caudata* (n=4) (e.g., Figure 6.10, Appendix F.7). These represented the highest numbers of *S. duplex, Onuphis* sp A and *Balanoglossus* sp, and the second highest number of *P. wui.* The sediments associated with the cluster group F assemblages were 2% fine particles, 1% very fine sand, 3% fine sand, 32% medium sand, 55% coarse sand, and 7% very coarse sand, with no granules present (Appendix F.8). These sediments had the highest concentration of coarse sand.

Macrofauna cluster group G was the second largest group (n=41), representing assemblages from inner to mid shelf depths of 14–38 m located around and to the north of the SBOO (Figures 6.8, 6.9). These included assemblages present in four of eight grabs collected over the past two years from near-ZID stations I12, I14, and I16. These assemblages averaged 66 taxa and 279 individuals per grab, and were characterized by the highest numbers of the polychaetes *Pista wui* (17/grab), *Ampharete labrops* (10/grab), and *Mediomastus* sp (11/grab), the second highest number of the polychaete *Spiophanes norrisi* (74/grab), and the third highest number of *Spiophanes duplex* (19/grab) (e.g., Figure 6.10, Appendix F.7). The sediments associated with cluster group G were characterized by 16% fines, 56% very fine sand, 24% fine sand, 3% medium sand, <1% coarse sand, with no very coarse sand or granules present (Appendix F.8). These sediments had the highest concentrations of very fine sand compared to all other cluster groups, and the highest concentration of percent fines relative to other shallow (≤41 m) assemblages at depths ≤41 m within the SBOO region (i.e., cluster groups A, B, C, E, F).

Macrofauna cluster group H represented assemblages from four grabs collected at three mid-shelf stations, including regional station 8538 sampled off Del Mar in 2016 at a depth 37 m, station 8506 sampled northwest and offshore of the SBOO in 2016 at a depth of 48 m, and SBOO station I1 sampled in both 2016 and 2017 at a depth of about 60 m (Figures 6.8, 6.9). These assemblages averaged 46 taxa and 126 individuals per grab, and were characterized by the polychaetes *Spiophanes duplex* (17/grab), *Prionospio (Prionospio) jubata* (5/grab), *Spiophanes norrisi* (4/grab), *Sthenelanella uniformis* (2/grab), plus unidentified species of Euclyeminae (5/grab) (e.g., Figure 6.10, Appendix F.7). The sediments associated with this cluster group were characterized by 12% fines, 30% very fine sand, 32% fine sand, 16% medium sand, 9% coarse sand, and <1% very coarse sand, with no granules present (Appendix F.8). These sediments averaged the third highest proportion of fine sand.

Macrofauna cluster group I represented assemblages from seven grabs collected from five mid-shelf stations sampled at depths between 41–55 m directly offshore and a little to the north or south of the SBOO (Figures 6.8, 6.9). This group included stations stations I7, I20, I21, 8603, and 8602. These assemblages averaged 29 taxa and 58 individuals per grab, and were characterized by the polychaete *Eusyllis* sp SD2 (3/grab), the amphipod *Foxiphalus obtusidens* (3/grab), the polychaete *Polycirrus* sp A (2/grab), the sipunculid *Thysanocardia nigra* (3/grab), and the polychaete *Lumbrinerides platypygos* (2/grab) (e.g., Figure 6.10, Appendix F.7). The sediments associated with this cluster group were characterized by 2% fine particles, 1% very fine sand, 6% fine sand, 29% medium sand, 53% coarse sand, 8% very coarse sand, and <1% granules (Appendix F.8). These sediments had very low concentrations of fine particles similar to cluster groups A–F (i.e., all ≤3% fines), and very low concentrations of very fine sand similar to groups B–F (i.e., all ≤4% very fine sand). These sites also had the second highest concentration of coarse sand.

Cluster group J represented another unique assemblage restricted to station 8639 sampled at a depth of 67 m along the edge of the Scripps submarine canyon (Figures 6.8, 6.9). This assemblage comprised 19 taxa and 66 individuals. The five most abundant taxa were the bivalves *Axinopsida serricata* (n=19), *Macoma carlottensis* (n=11) and *Tellina* sp B (n=6), and the polychaetes *Nephtys caecoides* (n=4) and *Mediomastus* sp (n=6) (e.g., Figure 6.10, Appendix F.7). This assemblage also had the highest number of *A. serricata*, *M. carlottensis*, and *N. caecoides* of all samples. The sediments associated with group J were 25% fines, 30% very fine sand, 39% fine sand, and 6% medium sand, with no coarse sand, very coarse sand, or granules present (Appendix F.8). This was the second highest concentration of fine sand relative to the other cluster groups. This station also had very high levels of sulfides in the sediment (i.e., 149 ppm; see previous section).

Macrofauna cluster group K was the largest group (n = 84), representing assemblages from most of the middle to outer shelf sites at depths ranging from 45 to 178 m, and including all of the near-ZID and farfield PLOO stations sampled during both 2016 and 2017 (Figures 6.8, 6.9). Overall, these assemblages were typical of the ophiuroid-dominated community that occurs along much of the mainland shelf off southern California (see Mikel et al. 2007, City of San Diego 2015a). This group averaged 68 taxa and 264 individuals per grab. This cluster group was primarily characterized and dominated by the ophiuroid *Amphiodia urtica* (20/grab), which was relatively unique compared to the other cluster groups. In addition to *A. urtica*, the remaining four of the top five most characteristic species for group K included the polychaete *Spiophanes duplex* (23/grab), the bivalves *Axinopsida serricata* (14/grab) and *Nuculana* sp A (13/ grab), and another polychaete *Eclysippe trilobata* (11/grab) (Figure 6.10, Appendix F.7). This cluster group had the highest numbers of *A. urtica*, *Nuculana* sp A, and *E. trilobata*, and the second highest numbers of *S. duplex* and *A. serricata* (see Figure 6.13 and Appendix F.5) of all groups. The sediments associated with this cluster group were characterized by 39% fines, 39% very fine sand, 14% fine sand, 4% medium sand, 3% coarse sand, 1% very coarse sand, and < 1% granules (Appendix F.8). These sediments had the second highest concentration of very fine sand.

Macrofauna cluster group L represented assemblages from six sites sampled on the outer shelf and upper slope at depths between 195 and 269 m, including stations 8510, 8516, 8608, 8512, 8625, and 8620 (Figures 6.8, 6.9). These assemblages averaged 40 taxa and 87 individuals per grab, and were characterized by *Axinopsida serricata* (5/grab), *Mediomastus* sp (4/grab), the bivalves *Tellina carpenteri* (4/grab) and *Thyasira flexuosa* (3/grab), and the polychaete *Paraprionospio alata* (2/grab) (e.g., Appendix F.7). The sediments associated with this cluster group were characterized by 68% fine particles, 24% very fine sand, 7% fine sand, and < 1% medium sand, with no coarse sand, very coarse sand, or granules present (Appendix F.8). These sediments had the third highest concentration of fine particles.

Macrofauna cluster group M represented deep water assemblages sampled at six upper slope sites at depths of 302–407 m, including stations 8521, 8527, 8537, 8629, 8634, and 8638 (Figures 6.8, 6.9). These assemblages averaged 28 taxa and 49 individuals per grab, and were characterized by the polychaetes *Maldane sarsi* (6/grab), *Aphelochaeta monilaris* (2/grab) and *Leitoscoloplos* sp A (1/grab), the bivalve *Nuculana conceptionis* (2/grab), and the scaphopod *Cadulus californicus* (1/grab) (e.g., Figure 6.10, Appendix F.7). The sediments associated with this cluster group were characterized by 70% fines, 25% very fine sand, 6% fine sand, and < 1% medium sand, with no coarse sand, very coarse sand, or granules present (Appendix F.8). These sediments had the second highest proportion of fine particles.

Macrofauna cluster group N represented another deep water community sampled at two upper slope sites at depths of 437 and 469 m (Figures 6.8, 6.9). These assemblages averaged 21 taxa and 46 individuals per grab, and were characterized by the polychaete *Fauveliopsis glabra* (6/grab), the scaphopod *Cadulus californicus* (2/grab), the cumacean *Leucon declivis* (2/grab), the polychaete *Leitoscoloplos* sp A (1/grab), and the bivalve *Yoldiella nana* (1/grab) (Appendix F.7). This cluster group had the highest number of *F. glabra* and *L. declivis* (see Figure 6.10). The sediments associated with these two upper slope stations had the highest percent fines (81%), 15% very fine sand, 4% fine sand, and < 1% medium sand, with no coarse sand, very coarse sand, or granules present (Appendix F.8).

Discussion and Summary

Benthic habitats and associated macrofaunal communities found on the continental shelf and upper slope off San Diego remained in good condition during the 2016–2017 reporting period. Overall, this regional assessment is consistent with the findings from the more extensive sampling of the core PLOO and SBOO stations reported in Chapter 4 for sediment quality and Chapter 5 for macrofaunal communities.

The physical composition of the sediments at the regional and core benthic stations sampled during the summer survey in each of these two years was typical for this portion of the southern California coast (Emery 1960) and consistent with results of previous surveys off San Diego (e.g., City of San Diego 2008–2014, 2015a,b, 2016). Overall, particle size composition varied as expected by outfall region and depth stratum. For example, stations sampled along the inner and middle shelf within the SBOO monitoring area tended to be composed predominantly of different types of sands, whereas stations sampled along the middle and outer shelf within the PLOO region were typically characterized by much finer sediments (see Chapter 4). Much of the variability in particle size distributions off San Diego is probably related to the complexities of local seafloor geology, topography and current patterns, all of which can significantly affect sediment transport and deposition (Emery 1960, Patsch and Griggs 2007).

Sediment quality was generally good throughout the entire San Diego region in 2016 and 2017. For example, there was no evidence of degraded benthic habitats in terms of the chemical properties of the sediments or spatial patterns in the distribution of the different types of contaminants that may accumulate over time (e.g., organic indicators, trace metals). In addition, preliminary results of a pilot study to monitor sediment toxicity in offshore San Diego waters revealed no toxicity at any of the near-ZID or regional stations tested during these two years (Nautilus Environmental 2016, 2017). Similar to the observations described for particle size composition, sediment contamination patterns during the current reporting period were similar to those seen in previous years. Although a number of different indicators of organic loading and trace metals were detected in sediment samples throughout the San Diego region, almost all occurred at concentrations below critical ERL and ERM thresholds similar to that observed in previous years (City of San Diego 2008–2014, 2015a,b, 2016). Further, examination of spatial patterns revealed no evidence of sediment contamination that could be attributed to local wastewater discharges via the PLOO or SBOO. Instead, concentrations of total nitrogen and several trace metals were found to increase with increasing amounts of fine silt and clay sediments (percent fines). Since percent fines generally increase with depth across the region, many chemical contaminants also tended to be detected at higher concentrations in deeper strata compared to the shallower mid-shelf and inner shelf regions. For example, the highest concentrations of most contaminants occurred at stations 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 concentrations of organics and trace metals (Eganhouse and Venkatesan 1993). Finally, concentrations of these contaminants in San Diego waters remained relatively low compared too 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, Dodder et al. 2016).

Macrofaunal communities in the San Diego region also appeared healthy in 2016 and 2017, with most of the different types of assemblages remaining similar to those observed during previous regional surveys conducted from 1994 to 2015 (City of San Diego 2010–2014, 2015a,b, 2016). These assemblages were typically characterized by expected abundances of pollution sensitive species such as the brittle star *Amphiodia urtica* and the amphipods *Ampelisca* spp and *Rhepoxynius* spp. In contrast, abundances of pollution tolerant species such as the polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa* were relatively low. Comparison of the results for the other major benthic community metrics (e.g. species richness, macrofaunal abundance, diversity, evenness, and dominance) also showed no evidence of wastewater impact or significant habitat degradation during the 2016 and 2017 surveys. For example, most values for these different parameters remain within or near the range of tolerance intervals calculated for their specific habitats (see City of San Diego 2015a). Benthic response index (BRI) results also revealed little evidence of disturbance off San Diego, with about 86% of all calculated BRI values being indicative of reference conditions and another 12% being characteristic of a possible minor deviation. Only three stations sampled near the ZID of the PLOO or the edge of the La Jolla Submarine Canyon had slightly higher values > 34 that may indicate an environmental impact.

Most of the macrofaunal assemblages identified in 2016–2017 are segregated by habitat characteristics such as depth and sediment particle size, often corresponding with the "patchy" habitats reported to occur naturally across the SCB (Fauchald and Jones 1979, Jones 1969, Bergen et al. 2001, Mikel et al. 2007). Several of the inner to mid-shelf assemblages (i.e., cluster groups E and G) described in this chapter were similar to those found in other shallow habitats across southern California (Barnard 1963, Jones 1969, Thompson et al. 1987, 1993, MBC-ES 1988, Mikel et al. 2007). These assemblages occurred in sandy sediments and were characterized by several species of polychaetes, including the spionids *Spiophanes norrisi* and *Spiophanes duplex*, and the capitellid *Mediomastus* sp. However, differences between these two groups were probably driven by minor variations in sediment type (e.g., shell hash, relict red sand) or depth that differentially affected populations of the resident species. The middle to outer shelf strata off San Diego were overwhelmingly dominated by macrofauna cluster group K, which represented assemblages from about 48% of the samples analyzed for the 2016–2017 surveys. These assemblages occurred in sediments with nearly evenly balanced proportions of percent fines and very fine sand, which were often dominated by the brittle star *Amphiodia urtica*. Benthic communities dominated by brittle stars and polychaete worms such as *A. urtica* and *S. duplex* have long been common off Point Loma and in similar other seafloor habitats in southern California (Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993a,b, Zmarzly et al. 1994, Diener and Fuller 1995, Bergen et al. 1998, 2000, 2001, Mikel et al. 2007, City of San Diego 2015b). The relatively fine sediment upper slope stations sampled off San Diego in 2016–2017 were typically characterized by macrofaunal assemblages with much lower total abundances and fewer species than at most shelf stations. This pattern is similar to results reported previously for the region since regular monitoring of these deeper slope habitats began (e.g., City of San Diego 2010–2014, 2015a,b, 2016)

Although benthic habitats and their associated macrofaunal communities continue to vary across depth and sediment gradients throughout the San Diego region, there was no evidence of disturbance or environmental degradation in 2016 and 2017 that could be attributed to anthropogenic factors such as wastewater discharge via the Point Loma or South Bay Ocean Outfalls or other point sources. Macrobenthic communities appeared to be in good condition overall, with only 2% of the sites surveyed showing evidence consistent with environmental disturbance. This result is similar to findings in Gillett et al. (2017) who reported that at least 98% of the entire SCB mainland shelf is in good condition based on BRI data from bight-wide regional monitoring program.

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Chapter 7
Demersal Fishes and Megabenthic Invertebrates

Chapter 7. Demersal Fishes and Megabenthic Invertebrates

Introduction

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

In healthy coastal marine ecosystems, demersal fish and invertebrate communities are known to be inherently variable and influenced by many natural factors. For example, prey availability, bottom topography, sediment composition, and changes in water temperatures associated with large scale oceanographic events such as El Niño can affect migration patterns or the recruitment of different species fish (Cross et al. 1985, Helvey and Smith 1985, Karinen et al. 1985, Murawski 1993, Stein and Cadien 2009). Population fluctuations may also be due to the mobile nature of many species (e.g., fish schools, urchin aggregations). Therefore, an understanding of natural background conditions is essential to determining whether observed differences or changes in community structure may be related to anthropogenic activities. Pre-discharge and regional monitoring efforts by the City and others since 1991 provide baseline information on the variability of demersal fish and megabenthic invertebrate communities in the San Diego region critical for such comparative analyses (e.g., Allen et al. 1998, 2002, 2007, 2011, City of San Diego 1995, 1998, 2000, Walther et al. 2017).

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

This chapter presents analysis and interpretation of demersal fish and megabenthic invertebrate data collected at NPDES permit designated monitoring stations surrounding the Point Loma and South Bay ocean outfalls during calendar years 2016 and 2017. Included are descriptions of the different fish and invertebrate communities present in these two regions, along

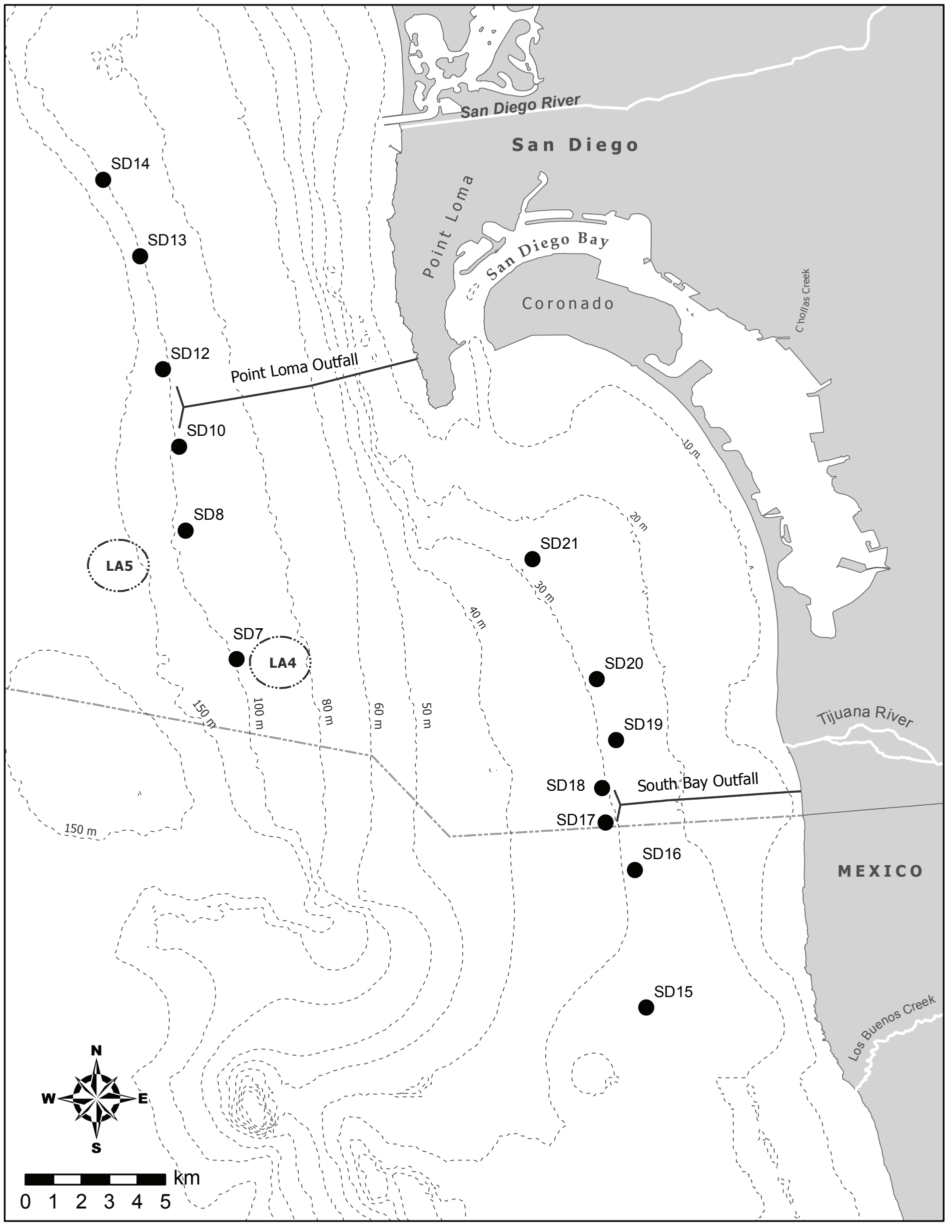


Figure 7.1
Trawl station locations sampled around the Point Loma and South Bay Ocean Outfalls as part of the City of San Diego's Ocean Monitoring Program.

with comparisons of spatial patterns and long-term changes over time. The primary goals are to: (1) characterize and document the demersal fish and megabenthic invertebrate assemblages present during the current reporting period; (2) determine the presence or absence of biological impacts on these assemblages that may be associated with wastewater discharge from the two outfalls; (3) identify other potential natural or anthropogenic sources of variability in the San Diego coastal marine ecosystem.

Materials and Methods

Field Sampling

Trawls were conducted at 13 stations to monitor demersal fishes and megabenthic invertebrates during winter and summer of 2016 and 2017 (Figure 7.1). These included six PLOO stations located along the 100-m depth contour (i.e., PLOO discharge depth) ranging from 9 km south to 8 km north of the PLOO, and seven SBOO stations located along the 28-m depth contour (i.e., SBOO discharge depth) ranging from 7 km south to 8.5 km north of the SBOO. The two PLOO stations (i.e., SD10, SD12) and two SBOO stations (i.e., SD17, SD18) located within 1000 m of the outfall structures are considered to represent nearfield conditions.

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. Although standard procedures require towing the net for a total of 10 minutes bottom time per trawl at a speed of about 2 knots, this was not possible at many of the PLOO stations during the current reporting period when exceptionally large hauls of the pelagic red crab *Pleuroncodes planipes* proved too heavy to be brought onboard ship. In these cases, only one to three minute trawls were able to be successfully conducted (see Appendix G.1). The catch from each successful trawl was sorted and inspected aboard ship. All individual fish and invertebrates captured were identified to species or to the lowest taxon possible based on accepted taxonomic protocols for the region (i.e., Eschmeyer and Herald 1998, Page et al. 2013, SCAMIT 2014). If an animal could not be accurately identified to species in the field, it was returned to the laboratory for further identification. The total number of individuals and total biomass (kg, wet weight) were recorded for each species of fish. Additionally, each fish was inspected for the presence of physical abnormalities (e.g., tumors, lesions, fin erosion, discoloration) or external parasites (e.g., copepods, cymothoid isopods, leeches). The length of each individual fish was measured to the nearest centimeter to determine size class distributions; total length (TL) was measured for cartilaginous fishes and standard length (SL) was measured for bony fishes (SCCWRP 2013). For trawl-caught invertebrates, only the total number of individuals was recorded for each species.

Data Analyses

Demersal fish and megabenthic invertebrate data for each trawl conducted during 2017 are listed in Addendum 7-1 through 7-6. Data collected during 2016 were reported previously and are available online (City of San Diego 2017, 2018). Population characteristics of fish and invertebrate species were summarized as percent abundance (number of individuals per species/total abundance of all species), frequency of occurrence (percentage of stations at which a species was collected), mean abundance per haul (number of individuals per species/total number of sites sampled), and mean abundance per occurrence (number of individuals per species/number of sites at which the species was collected). Additionally, the following community structure parameters were calculated per trawl for both fishes and invertebrates: species richness (number of species), total abundance (number of individuals), and Shannon diversity index (H'). Total biomass was also calculated for each fish species captured. These analyses were performed using R (R Core Team 2016) and various functions within the gtools, plyr, reshape2, RODBC, sqldf, and vegan packages (Wickham 2007, 2011, Grothendieck 2014, Oksanen et al. 2015, Ripley and Lapsley 2015, Warnes et al. 2015, Revelle 2017, Wickham et al. 2017).

Multivariate analyses were performed in PRIMER v7 software using demersal fish and megabenthic invertebrate data collected from 10-minute trawls conducted in the PLOO and SBOO regions from 1991 through 2017 (see Clarke 1993, Warwick 1993, Clarke et al. 2014). Prior to these analyses, all data were limited to summer surveys only to reduce statistical noise from natural seasonal variations evident in previous studies (e.g., City of San Diego 1997, 2013). Analyses included ordination (non-metric multidimensional scaling; nMDS), as well as hierarchical agglomerative clustering (cluster analysis) with group-average linking and similarity profile analysis (SIMPROF) to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008). The Bray-Curtis measure of similarity was used as the basis for the cluster analysis, and abundance data were square-root transformed to lessen the influence of the most abundant species and increase the importance of rare species. Major ecologically-relevant clusters

Table 7.1

Demersal fish species collected from 24 trawls[a] conducted in the PLOO region during 2016 and 2017. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
Pacific Sanddab	50	96	45	47	Basketweave Cusk-eel	<1	4	<1	2
Dover Sole	10	62	9	15	California Skate	<1	4	<1	2
Stripetail Rockfish	9	83	8	10	Longfin Sanddab	<1	4	<1	2
Plainfin Midshipman	9	29	8	28	Pacific Argentine	<1	4	<1	2
Longspine Combfish	6	50	5	11	Smooth Stargazer	<1	4	<1	2
Pink Seaperch	3	54	2	4	Specklefin Midshipman	<1	8	<1	1
California Lizardfish	3	54	2	4	Bigfin Eelpout	<1	4	<1	1
Halfbanded Rockfish	2	46	2	5	Blacktip Poacher	<1	4	<1	1
Yellowchin Sculpin	2	17	2	9	Brown Rockfish	<1	4	<1	1
Shortspine Combfish	1	42	1	3	Curlfin Sole	<1	4	<1	1
Slender Sole	1	21	1	3	Flag Rockfish	<1	4	<1	1
Spotted Cusk-eel	1	17	1	3	Greenblotched Rockfish	<1	4	<1	1
English Sole	1	17	<1	3	Greenstriped Rockfish	<1	4	<1	1
California Scorpionfish	<1	17	<1	2	Rosy Rockfish	<1	4	<1	1
California Tonguefish	<1	8	<1	2	Roughback Sculpin	<1	4	<1	1
Hornyhead Turbot	<1	12	<1	2	Spotted Ratfish	<1	4	<1	1
Bigmouth Sole	<1	12	<1	1	Undentified Rockfish	<1	8	<1	1
Vermilion Rockfish	<1	4	<1	3	White Croaker	<1	4	<1	1

[a] these included 19 trawls with durations ≤3 minutes

receiving SIMPROF support were retained, and similarity percentages analysis (SIMPER) was used to determine which species were responsible for the greatest contributions to within-group similarity (i.e., characteristic species). A BEST test using the BVSTEP procedure was conducted to determine which subset of species best described patterns within the resulting cluster dendrograms. To determine whether demersal fish and megabenthic invertebrate communities varied by region, a one-way analysis of similarity (ANOSIM) was conducted (maximum number of permutations = 9999).

Results and Discussion

Demersal Fishes

Community Parameters

A total of 9718 fishes were captured from the 52 trawls conducted within the PLOO and SBOO monitoring regions in 2016–2017, representing at least 58 different species from 28 families (Tables 7.1, 7.2, Appendix G.2, G.3). The total catch of 928 fishes in 2016 and 1197 fishes in 2017 at the PLOO stations represented about 82% and 77% fewer fish than reported for the same number of trawls at the same sites in 2015 (see City of San Diego 2016a). However, this large reduction in fish catch off Point Loma was related to significantly less total trawling time over the past two years compared to 2015 (i.e., 120 minutes in 2015, 39 minutes in 2016, 39 minutes in 2017; see Appendix G.1), which was caused by the necessity to limit bottom time to ≤3 minutes for most PLOO trawls due to the presence of massive populations of the pelagic red crab *Pleuroncodes planipes* (see Materials & Methods). Despite this reduction in total numbers of fish, Pacific Sanddabs continued to dominate PLOO demersal fish assemblages during the current reporting period, occurring in almost every haul and accounting for ~50% of the fishes

Table 7.2

Demersal fish species collected from 28 trawls conducted in the SBOO region during 2016 and 2017. 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	46	100	126	126	Ocean Whitefish	<1	11	<1	1
California Lizardfish	27	96	72	75	California Scorpionfish	<1	11	<1	1
Longfin Sanddab	13	82	36	44	Pygmy Poacher	<1	7	<1	2
California Tonguefish	5	96	13	14	Salema	<1	4	<1	3
Hornyhead Turbot	2	93	6	6	Shovelnose Guitarfish	<1	11	<1	1
White Croaker	1	21	3	14	Threadfin Sculpin	<1	4	<1	3
Yellowchin Sculpin	1	29	3	10	Vermilion Rockfish	<1	7	<1	2
Queenfish	1	4	2	47	Curlfin Sole	<1	7	<1	1
Longspine Combfish	1	32	2	5	Pacific Seahorse	<1	7	<1	1
Fantail Sole	1	61	1	2	Round Stingray	<1	7	<1	1
Plainfin Midshipman	<1	43	1	2	Stripetail Rockfish	<1	7	<1	1
California Halibut	<1	50	1	2	Blacksmith	<1	4	<1	1
Unidentified Pipefish	<1	50	1	2	Diamond Turbot	<1	4	<1	1
Roughback Sculpin	<1	25	1	3	Giant Kelpfish	<1	4	<1	1
English Sole	<1	32	1	2	Gulf Sanddab	<1	4	<1	1
Specklefin Midshipman	<1	29	<1	2	Halfbanded Rockfish	<1	4	<1	1
Spotted Turbot	<1	25	<1	2	Horn Shark	<1	4	<1	1
Pacific Sanddab	<1	11	<1	2	Pacific Pompano	<1	4	<1	1
Basketweave Cusk-eel	<1	7	<1	2	Petrale Sole	<1	4	<1	1
California Skate	<1	18	<1	1	Sarcastic Fringehead	<1	4	<1	1
Unidentified Sanddab	<1	7	<1	2	Spotted Cusk-eel	<1	4	<1	1

collected (Table 7.1). Other species of fish collected in at least 50% of the trawls, but in relatively low numbers (≤9 fish per haul), included Dover Sole, Stripetail Rockfish, Longspine Combfish, Pink Seaperch, and California Lizardfish.

In contrast to the pattern described for PLOO fishes, the total catches of 4356 fishes in 2016 and 3237 fishes in 2017 at the SBOO stations were about 127% and 69% larger than the total catch reported for 2015 (City of San Diego 2016b). As in most recent years, SBOO fish assemblages were dominated by Speckled Sanddabs and California Lizardfish, each of which occurred in at least 96% of the hauls, and with sanddabs accounting for ~46% (n = 3517) and lizardfish ~27% (n = 2026) of the fishes collected from this outfall region (Table 7.2). Other species collected in at least 50% of the trawls, but in relatively low numbers (≤36 fish per haul), included Longfin Sanddab, California Tonguefish, Hornyhead Turbot, Fantail Sole, California Halibut, and various pipefish species.

More than 99% of the fishes collected in the PLOO and SBOO monitoring regions were <30 cm in length. Larger fishes with mean lengths ≥30 cm included five species of cartilaginous fish and two species of bony fish (Appendices G.2, G.3). The cartilaginous fishes included seven California Skate individuals averaging 35 cm total length, three Shovelnose Guitarfish individuals averaging 50 cm total length, two Round Stingray individual averaging 35 cm total length, one Horn Shark measuring 56 cm total length, and one Spotted Ratfish measuring 34 cm standard length. The large bony fishes included 25 specimens of California

Table 7.3

Summary of demersal fish community parameters for PLOO and SBOO trawl stations sampled during 2016 and 2017. Data are included for species richness, abundance, diversity (H'), and biomass (kg, wet weight).

		Species Richness				*Abundance*			
		2016		2017		2016		2017	
	Station[a]	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
PLOO	SD7	11	15	2	5	157	277	17	36
	SD8	16	9	6	15	275	65	21	575
	SD10	5	8	8	2	21	42	22	2
	SD12	4	7	8	4	7	31	27	19
	SD13	5	6	4	7	14	25	16	25
	SD14	1	6	5	15	1	13	20	417
SBOO	SD15	4	10	7	10	61	478	82	416
	SD16	8	10	8	9	59	409	175	323
	SD17	11	12	9	12	104	545	151	231
	SD18	10	13	12	9	68	710	136	278
	SD19	7	9	10	9	132	490	159	329
	SD20	11	13	12	17	94	480	216	371
	SD21	15	13	10	8	177	549	153	217

		Diversity				*Biomass*			
		2016		2017		2016		2017	
	Station[a]	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
PLOO	SD7	1.4	1.5	0.6	0.7	4.6	6.0	0.2	1.0
	SD8	1.9	1.5	1.4	1.6	6.7	1.4	0.6	8.1
	SD10	1.1	1.1	1.8	0.7	0.7	1.0	0.8	0.2
	SD12	1.2	1.4	1.9	1.0	0.4	0.8	0.9	0.4
	SD13	1.3	1.3	1.1	1.7	0.6	0.8	0.6	1.3
	SD14	0.0	1.7	1.4	1.0	0.1	0.6	0.6	17.0
SBOO	SD15	0.6	0.9	1.1	0.8	0.6	5.1	0.9	5.3
	SD16	1.4	1.0	1.1	0.8	1.4	4.5	2.2	7.0
	SD17	1.5	1.4	1.5	1.4	1.8	15.1	2.3	10.9
	SD18	1.4	1.3	1.5	1.2	2.2	5.7	4.4	7.7
	SD19	1.4	1.4	1.4	1.1	1.2	4.7	2.9	5.6
	SD20	1.5	1.3	1.4	1.4	1.9	9.2	3.3	9.9
	SD21	1.7	1.4	1.6	1.4	8.8	6.9	2.0	3.4

[a] Shaded value indicates trawl duration ≤ 3 minutes

Halibut averaging 33 cm standard length and one Petrale Sole that measured 36 cm standard length.

As indicated above for total trawl catch, species richness, abundance, diversity (H') and biomass values for the demersal fish assemblages sampled off Point Loma in 2016 and 2017 were not fully comparable to each other because of the differences in trawling time (i.e., 10-minute vs. ≤ 3-minute trawls) and therefore area of coverage at the different PLOO trawl stations. Consequently, the results presented in Table 7.3 are summarized separately below for the regular and reduced PLOO trawls. The five 10-minute trawls conducted at station SD7

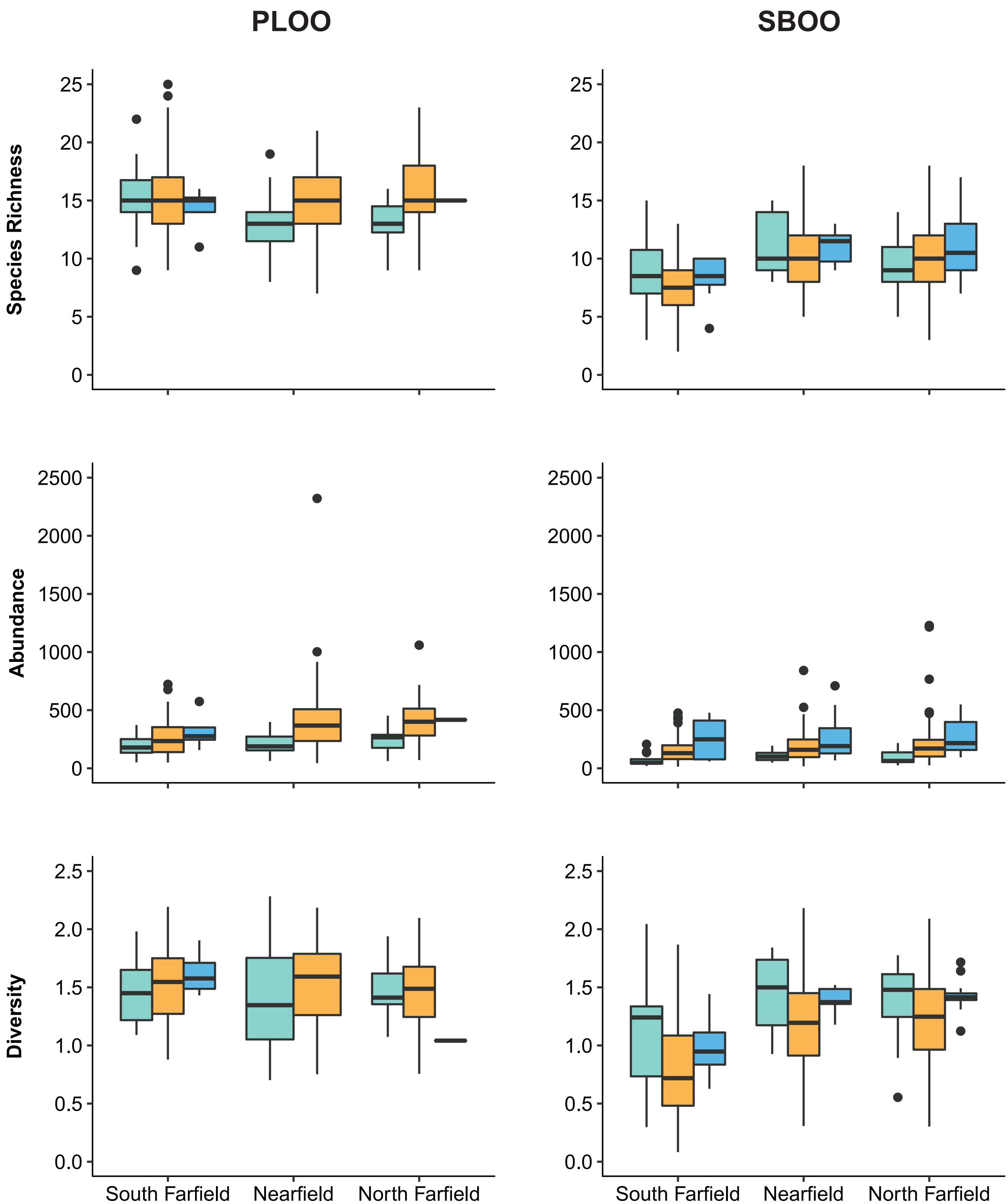


Figure 7.2
Species richness, abundance, and diversity (H') of demersal fishes collected from PLOO and SBOO nearfield, north farfield, and south farfield during pre-discharge (green), historical post-discharge (orange), and current post-discharge (blue) periods. Data limited to 10-minute trawls; Boxes = median, upper, and lower quantiles; whiskers = 1.5x interquantile range; circles = outliers; see text for description of pre- versus post-discharge periods for the two outfalls.

during both winter and summer of 2016, station SD8 in winter 2016 and summer 2017, and SD14 in summer 2017 had species richness values ranging from 11 to 16 species per haul, total fish abundance ranging from 157 to 575 individuals per haul, H' ranging from 1.0 to 1.9, and total fish biomass ranging from 4.6 to 17.0 kg per haul. In contrast, the remaining 19 reduced trawls (≤3 minutes) had species richness values ranging from 1 to 9 species per haul, fish abundance ranging from 1 to 65 individuals per haul, H' ranging from 0 to 1.9, and total biomass ranging from 0.1 to 1.4 kg per haul. Overall, there were no discernible spatial patterns in the demersal fish community metrics relative to the PLOO discharge site. Additionally, results from the regular 10-minute trawls were generally consistent with previous findings for the region (Figure 7.2; see also City of San Diego 2016a) and elsewhere in the SCB (Walther et al. 2017).

In contrast to the PLOO surveys, all 28 of the SBOO trawls were conducted for 10 minutes bottom time and are therefore directly comparable to each other as well as to historical values. Species richness and diversity were consistently low across all stations during the 2016–2017 reporting period (i.e., SR ≤17 species; H' ≤1.7) as is typical for the region (e.g., City of San Diego 2000). In contrast, fish abundance and biomass were more variable among stations and between surveys over these two years, with abundance ranging from 59–710 fish/trawl and biomass ranging from 0.6–15.1 kg/trawl. The largest hauls of ≥478 fishes occurred during summer 2016 at all SBOO stations except SD16, which reflected large numbers of California Lizardfish, Speckled Sanddab, and/or Longfin Sanddab (City of San Diego 2017). The heaviest hauls with ≥8.8 kg of fishes occurred during winter 2016 at station SD21 due to the collection of a large Shovelnose Guitarfish, and at stations SD17 and SD20 during the summers of 2016 and 2017 deu to large numbers of smaller fishes such as sanddabs and lizardfish. Overall, these results are consistent with the findings from elsewhere in the SCB (Walther et al. 2017). There were no spatial patterns in the demersal fish community metrics relative to proximity to the SBOO discharge site or to the onset of wastewater discharge that began in 1999 (Figure 7.2).

Historical comparisons indicate that demersal fish assemblages have demonstrated large variations off San Diego that primarily reflect population fluctuations of a few dominant species (Figures 7.3, 7.4; see also next section). For example, differences in overall fish abundances (trawl catches) tend to track changes in Pacific Sanddab populations at the PLOO stations and Speckled Sanddab populations at the SBOO stations over time since these two species have been numerically dominant in these regions since monitoring began 23–27 years ago. In addition, occasional spikes in fish abundances within the PLOO region have been due to large hauls of other common species such as Yellowchin Sculpin, Halfbanded Rockfish, Longspine Combfish, Dover Sole, California Lizardfish, Stripetail Rockfish, Plainfin Midshipman, Longfin Sanddab, and Shortspine Combfish (Figure 7.3). In contrast, spikes within the SBOO region have been due to large hauls of California Lizardfish, White Croaker, Longfin Sanddab, Yellowchin Sculpin, Hornyhead Turbot, California Tonguefish, Roughback Sculpin, Longspine Combfish, and English Sole (Figure 7.4). Overall, none of the observed changes described baove appear to be associated with wastewater discharge from either of the outfalls.

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the PLOO and SBOO regions in 2016–2017. There were no incidences of fin rot or skin lesions on any fish sampled during the year, while other recorded abnormalities were limited to a) one tumor on a Dover Sole specimen collected at PLOO station SD8 during summer 2017, and b) two instances of ambicoloration, one on a Spotted Turbot and one on a Speckled Sanddab, collected at SBOO nearfield station SD17 during summer 2016 (Appendix G.4).

Evidence of parasitism was also very low (0.21%) for trawl-caught fishes from both outfall regions over the past two years (Appendix G.4). Incidences included: (1) the copepod eye parasite *Phrixocephalus cincinnatus* that infested four

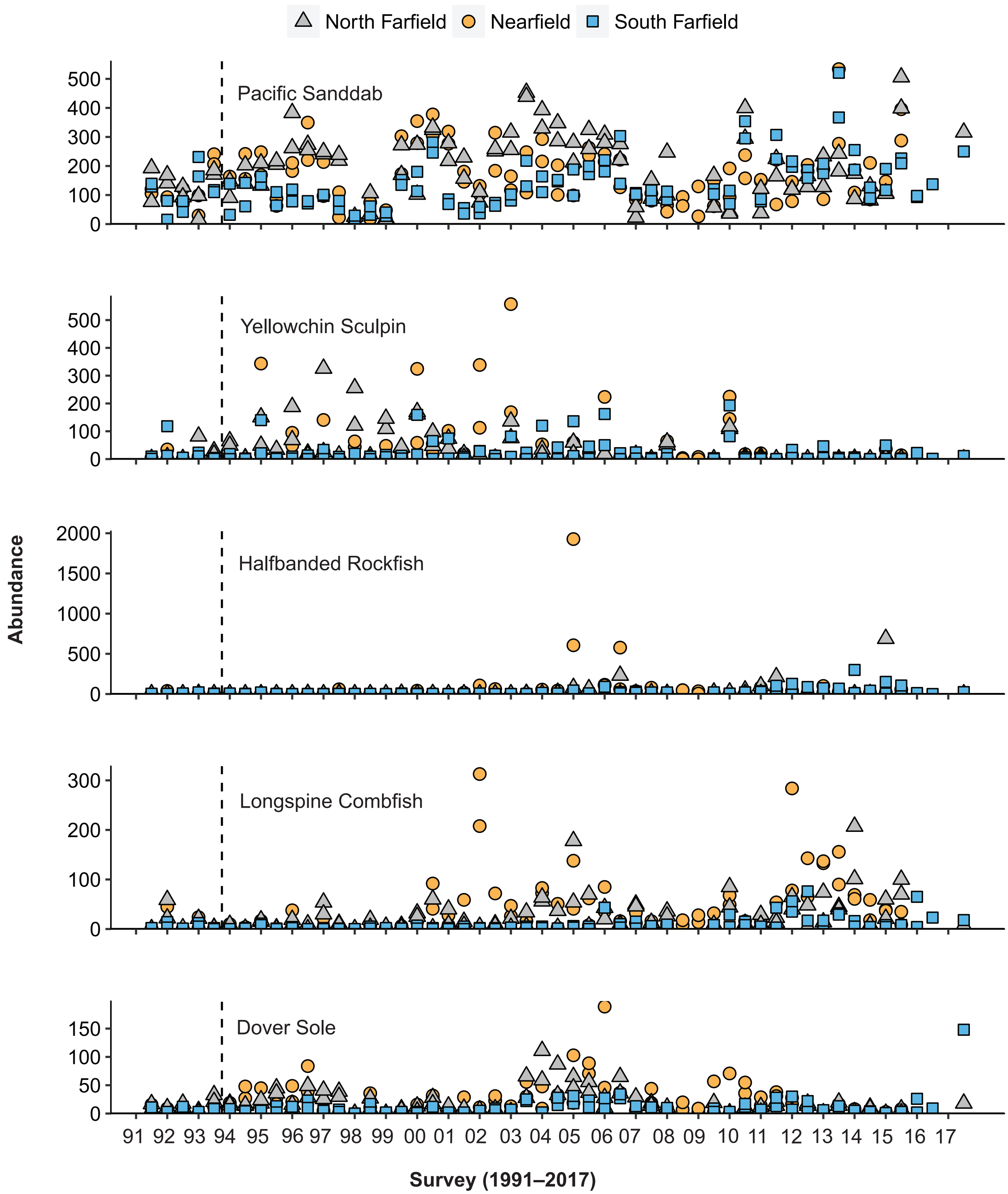


Figure 7.3
The ten most abundant demersal fish species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2017. Data are limited to 10-minute trawls and are total values per haul. Dashed lines indicate onset of wastewater discharge.

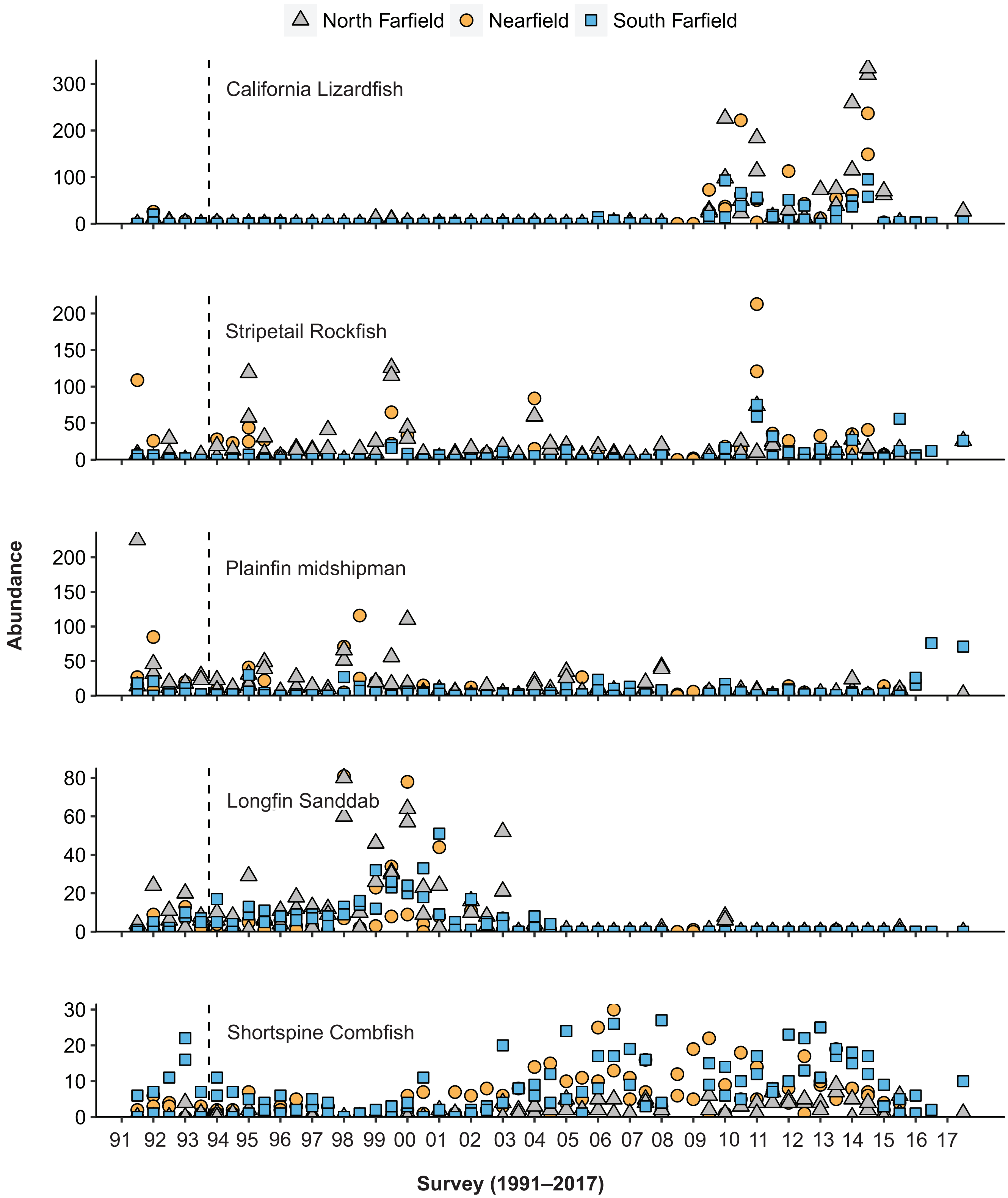


Figure 7.3 *continued*

Pacific Sanddabs from PLOO farfield station SD8, one Pacific Sanddab from PLOO farfield station SD14, and one Longfin Sanddab from SBOO nearfield station SD18; (2) unidentified species of leech found on a single Hornyhead Turbot from SBOO nearfield station SD17 during winter 2016, and on a single California Skate from SBOO farfield station SD19 during summer 2017; (3) several unidentified worms that were found on a Fantail Sole from SBOO farfield station SD19 during summer 2017; (4) an unidentified copepod that was found on a California Skate from SBOO farfield station SD20 during summer 2017; (5) ten specimens of the cymothoid isopod *Elthusa vulgaris* (a gill parasite of fishes) that were reported on Pacific Sanddabs and Speckled Sanddabs from multiple stations. Another 190 individuals of *E. vulgaris* were identified as part of the trawl invertebrate catches during the year. Since *E. vulgaris* often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these isopods. However, *E. vulgaris* is known to be especially common on Sanddab and California Lizardfish in southern California waters where it may reach infestation rates of 3% and 80%, respectively (see Brusca 1978, 1981).

Classification of Demersal Fish Assemblages

Multivariate analyses were used to discriminate between demersal fish assemblages from a total of 310 10-minute trawls conducted during summer surveys only from 1991 through 2017 at 13 PLOO and SBOO stations. These fish assemblages were found to be significantly different (one-way ANOSIM, $\rho = 0.992$, $p = 0.0001$). Classification (cluster) and ordination analyses further demonstrated a distinct separation of the PLOO and SBOO regions at about the 88% dissimilarity level (Figure 7.5). Seven species had comparatively strong (i.e., Pearson correlation > 0.65) explanatory power for the patterns in the 2-D ordination of trawl samples. These included Pacific Sanddab, Dover Sole, Shortspine Combfish and Pink Seaperch that helped distinguish PLOO stations, and Speckled Sanddab, California Lizardfish and Hornyhead Turbot that helped distinguish SBOO stations. A BEST BVSTEP ($\rho = 0.96$, $p = 0.001$) test also implicated California Lizardfish, Pacific Sanddab, and Speckled Sanddab, as well as Longfin Sanddab, Longspine Combfish, and Yellowchin Sculpin as being influential to the overall pattern (gradient) of the cluster dendrogram (not shown). Based on these results, subsequent multivariate analyses were performed separately on data from each outfall region.

<u>*PLOO Region*</u>

Cluster and ordination analyses discriminated between four ecologically-relevant SIMPROF-supported groups or types of fish assemblages in the PLOO region over the past 27 years (cluster groups A–D; Figure 7.6, Appendix G.5). These included two groups each comprised of one "outlier" trawl (groups A, B) and two larger groups with 35 and 112 hauls each, representing 23% and 75% of all trawls, respectively (groups C, D). A BEST BVSTEP ($\rho = 0.954$, $p = 0.001$) test implicated Bay Goby, California Lizardfish, Dover Sole, English Sole, Halfbanded Rockfish, Longfin Sanddab, Longspine Combfish, Pacific Sanddab, Pink Seaperch, Plainfin Midshipman, Shortspine Combfish, Slender Sole, Spotfin Sculpin, Stripetail Rockfish, and Yellowchin Sculpin as being influential to the overall pattern (gradient) of the cluster dendrogram. There were only three 10-minute trawls from 2016 and 2017 that could be included in these analyses, which included the haul from station SD7 in the summer of 2016 that grouped with cluster group C, and the hauls from stations SD8 and SD14 in the summer of 2017 that grouped with cluster group D (see group descriptions below). Overall, there were no discernible patterns in the demersal fish assemblages associated with proximity to the PLOO discharge site (Figure 7.6). Instead, assemblages appear influenced by the distribution of the more abundant species or unique characteristics of specific station locations (e.g., habitat differences). For example, assemblages from stations SD7 and SD8 located south of the outfall often grouped apart from the remaining stations between 1993 and 2002 (see group C). Assemblages represented by this cluster group also occasionally occurred at stations around the outfall and to the north during summers with relatively warm ocean waters associated with El Niño events (e.g., 1991/1992, 1995, 1998) (NOAA/

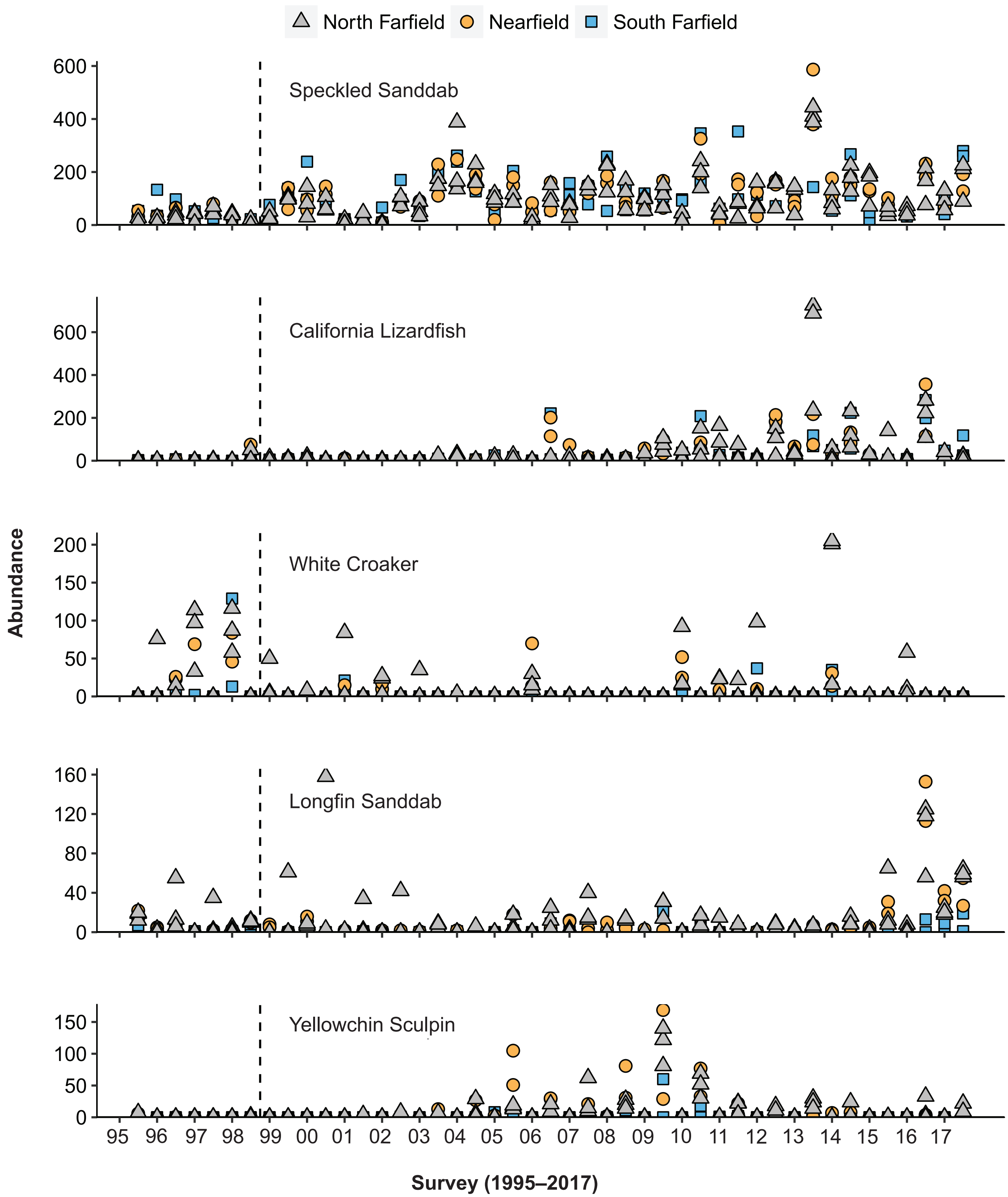


Figure 7.4
The ten most abundant demersal fish species (presented in order) collected from SBOO trawl stations sampled from 1995 through 2017. Data are limited to 10-minute trawls and are total values per haul. Dashed lines indicate onset of wastewater discharge.

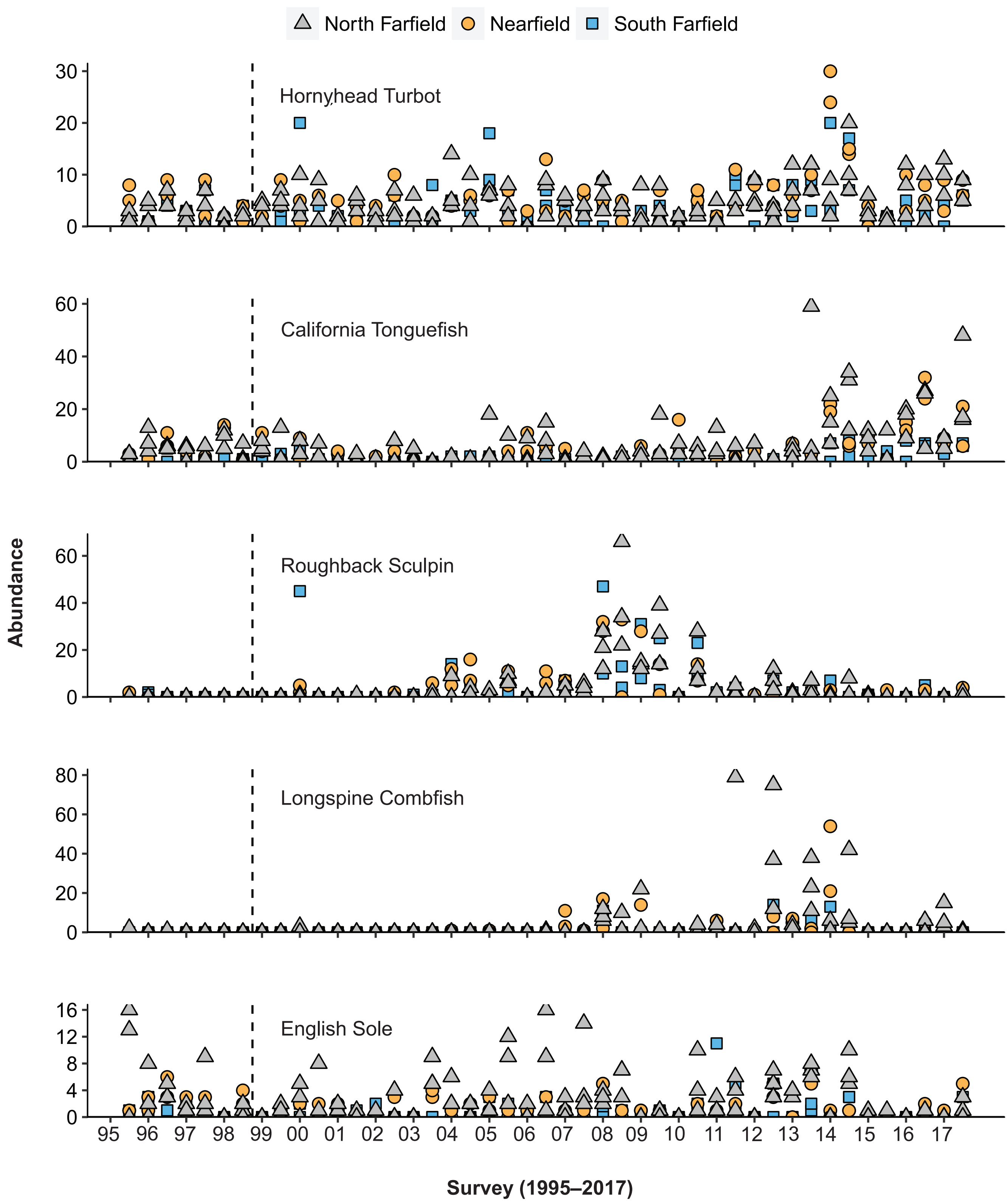


Figure 7.4 *continued*

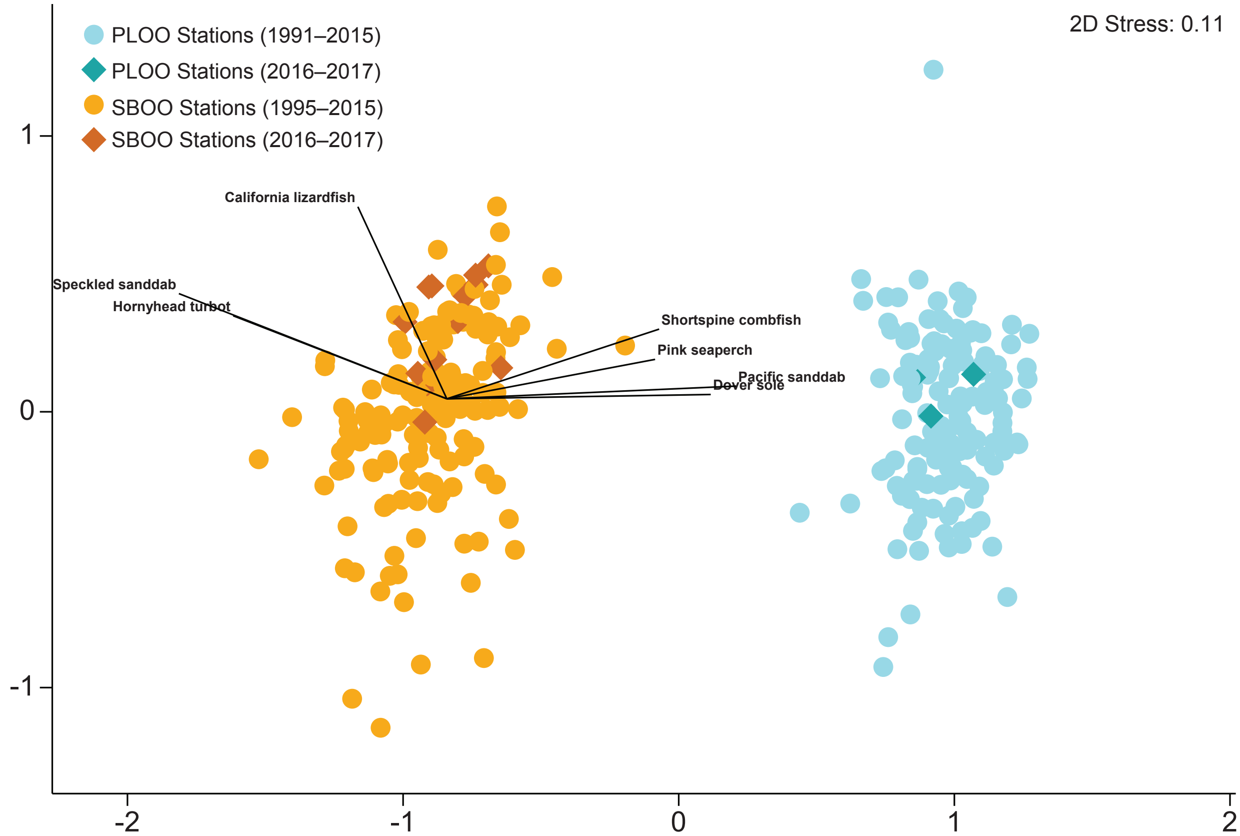


Figure 7.5
Results of non-metric multidimensional scaling oridnation of demersal fish assemblages from PLOO and SBOO trawl stations sampled from 1991 through 2017. Species abundance vectors overlaid, and limited to species with the strongest correlations (> 0.5) to the ordination pattern. Data are limited to 10 minute trawls from summer surveys.

NWS 2018). The species composition and main descriptive characteristics of each of the four cluster groups are included below.

PLOO fish cluster groups A and B each represented a unique assemblage sampled at a single nearfield trawl station. The assemblage represented by cluster group A occurred at station SD10 in 1997 and was characterized by the lowest species richness (7 species), lowest total abundance (44 fish), and lowest number of Pacific Sanddabs of any cluster group (23 fish) (Figure 7.6, Appendix G.5). The assemblage represented by cluster group B occurred at station SD12 in 1998 and had 16 species and 261 individuals, including the highest numbers of Plainfin Midshipman (116 fish), Dover Sole (36 fish), and Gulf Sanddab (5 fish) of any cluster.

PLOO fish cluster group C was the second largest group, representing assemblages from a total of 35 hauls that included 21 (88%) of the trawls conducted at south farfield stations SD7 and SD8 from 1991–2002 (Figure 7.6). This cluster group also included all of the trawls from stations SD10, SD12, SD13 and SD14 sampled in 1991 and 1992, the trawls from stations SD10 and SD12 sampled in 1995, the trawls from stations SD10 and SD14 sampled in 1998, and the trawls from station SD7 sampled in 2007 and 2016. These assemblages averaged 13 species of fish, 155 individuals, and 93 Pacific Sanddab per haul (Figure 7.6, Appendix G.5). Along with Pacific Sanddabs, Plainfin Midshipman (15/haul), Dover Sole (9/haul), Longfin Sanddab (6/haul), and California Tonguefish (3/haul) were the other three most characteristic species of these assemblages based on SIMPER results.

PLOO fish cluster group D was the largest cluster group, representing assemblages from a total of 112

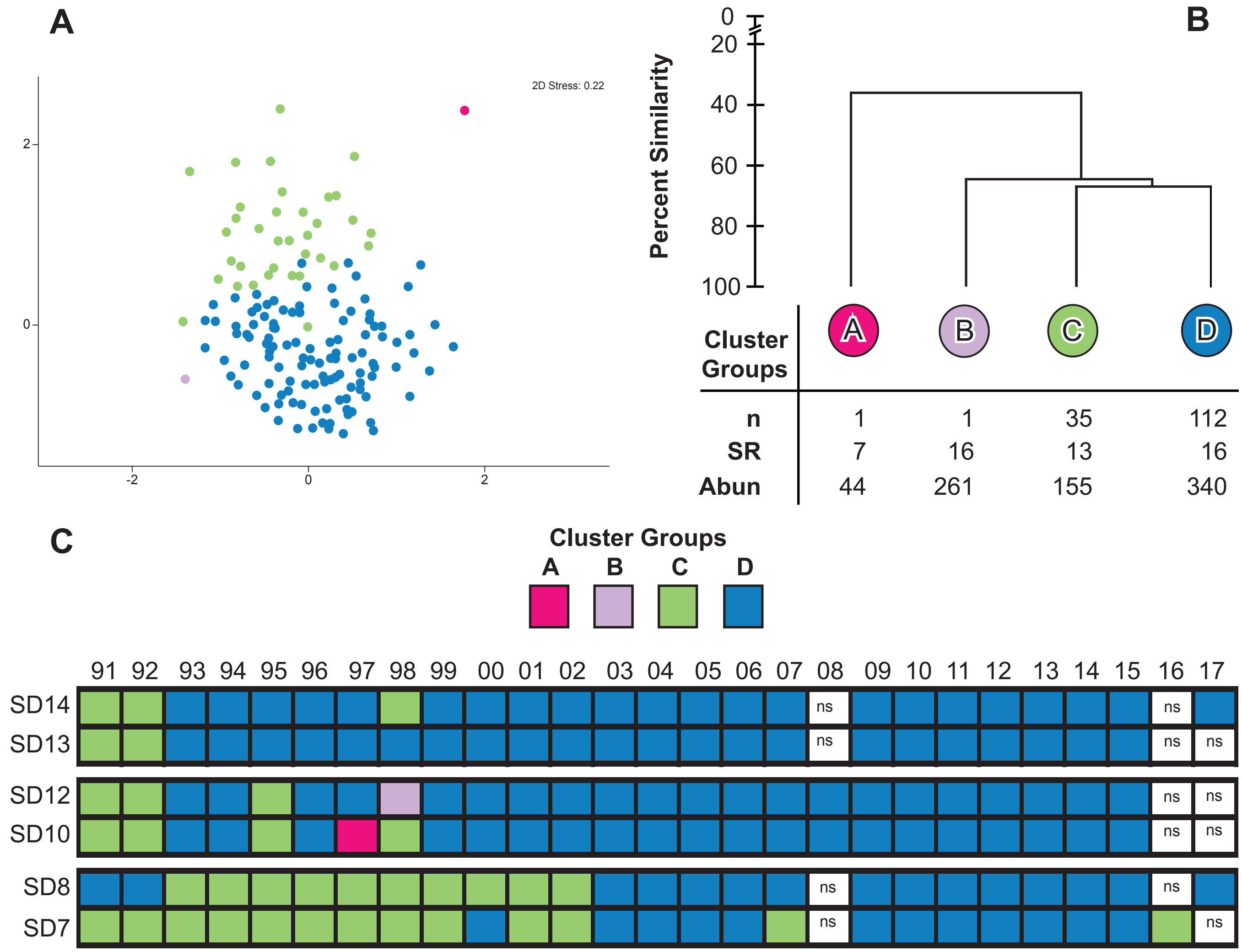


Figure 7.6
Results of ordination and cluster analysis of demersal fish assemblages from PLOO trawl station sampled from 1991 through 2017. Data are limited to 10-minute trawls from summer surveys and presented as (A) non-metric multi-dimensional scaling ordination; (B) a dendrogram of main cluster groups; (C) a matrix showing distribution of cluster groups over time; n = number of hauls; SR = mean species richness; Abun = mean abundance; ns = no sample.

hauls that included 37 (51%) of the trawls conducted from 1991 through 2002, and 75 (97%) of the trawls conducted from 2003 through 2017 (Figure 7.6). Assemblages represented by this cluster group averaged 16 species and 340 individuals per haul. The most characteristic species of cluster group D were Pacific Sanddab (219/haul), Dover Sole (24/haul), Halfbanded Rockfish (24/haul), Longspine Combfish (20/haul), and Shortspine Combfish (6/haul) (Appendix G.5).

SBOO Region

Cluster and ordination analyses discriminated between six ecologically-relevant SIMPROF-supported groups or types of fish assemblages in the South Bay outfall region over the past 23 years (cluster groups A–F; Figure 7.7, Appendix G.6). These assemblages represented from 1 to 77 hauls each, and varied in terms of species present, as well as the relative abundances of individual species. A BEST BVSTEP ($\rho = 0.95$, $p = 0.001$) test implicated California Lizardfish, California Tonguefish, English Sole, Hornyhead Turbot, Longfin Sanddab, Roughback Sculpin, Speckled Sanddab, and Yellowchin Sculpin as being influential to the overall pattern (gradient) of the cluster dendrogram. With exception of the haul from SD21 in 2017, SBOO fish assemblages sampled during 2016–2017 were distributed within the

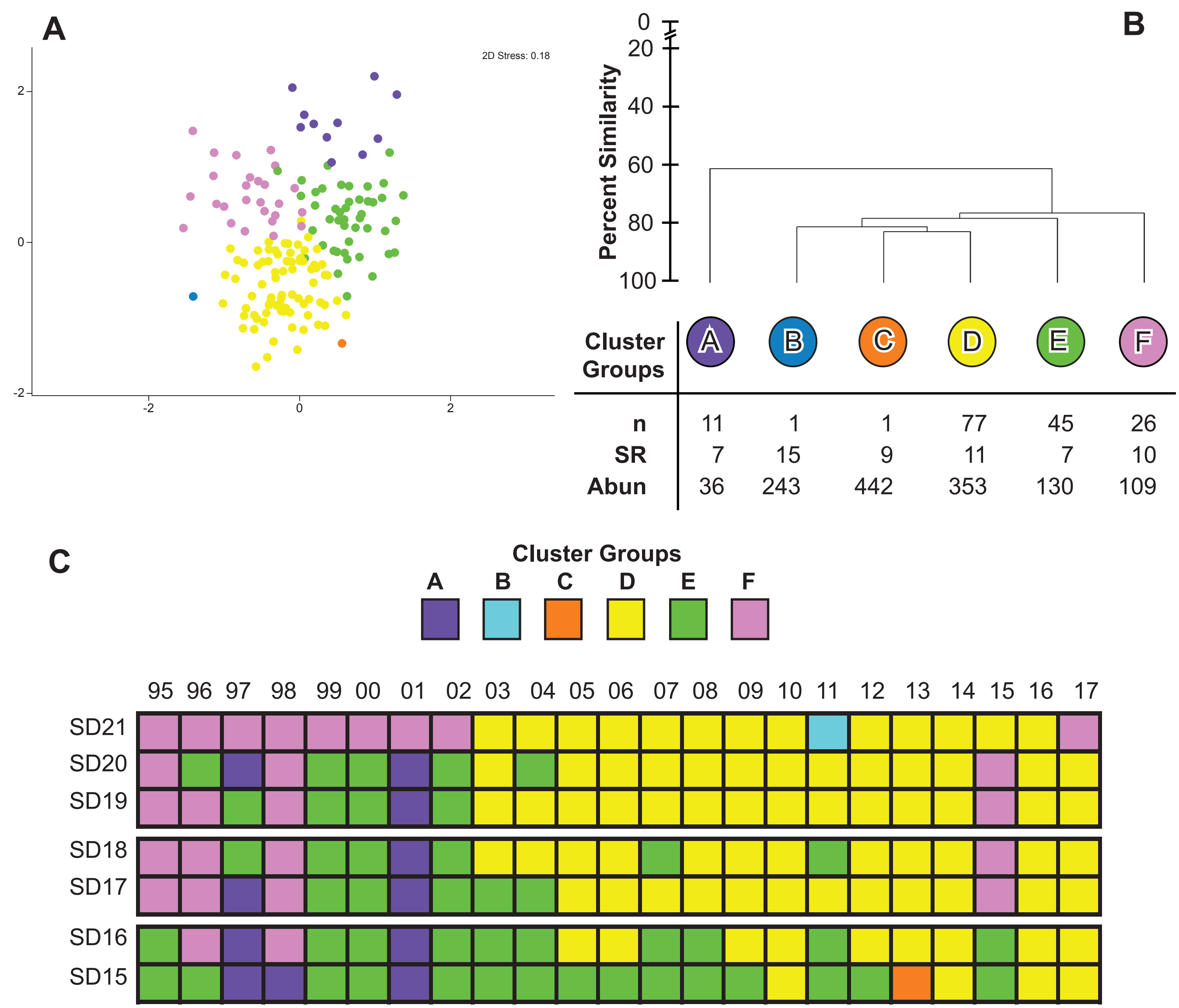


Figure 7.7

Results of ordination and cluster analysis of demersal fish assemblages from SBOO trawl station sampled from 1995 through 2017. Data are limited to 10-minute trawls from summer surveys and presented as (A) non-metric multi-dimensional scaling ordination; (B) a dendrogram of main cluster groups; (C) a matrix showing distribution of cluster groups over time; n = number of hauls; SR = mean species richness; Abun = mean abundance.

largest cluster group (i.e., cluster group D). Overall, there were no discernible patterns associated with proximity to the SBOO discharge site (Figure 7.7). Instead, SBOO fish assemblages also appear to be influenced by the distribution of the more abundant species or the unique characteristics of a specific station location. For example, cluster groups A and F were distinguished by comparatively low numbers of Speckled Sanddab (≤48 fish/haul) that generally coincided with or followed warm water El Niño events in 1994/1995, 1997/1998 and 2014/2015 (NOAA/NWS 2018). Additionally, station SD15 located farthest south of the SBOO in northern Baja California waters often grouped apart from the remaining stations (see cluster group E), possibly due to habitat differences such as sandier sediments (see Chapter 4). The species composition and main descriptive characteristics of each of the six cluster groups are included below.

SBOO fish cluster group A represented assemblages from 11 trawls that included stations

SD15, SD16, SD17 and SD20 sampled in 1997, station SD15 sampled in 1998, and stations SD15–SD20 sampled in 2001 (Figure 7.7). This cluster group averaged the lowest species richness (7 species/haul) and the lowest abundance (36 fish/haul). SIMPER results indicated that the most characteristic species for cluster group A were Speckled Sanddab (23/haul), Hornyhead Turbot (3/haul), California Lizardfish (2/haul), California Scorpionfish (2/haul), and Spotted Turbot (2/haul) (Appendix G.6).

SBOO fish cluster group B represented a unique demersal fish assemblage sampled during 2011 at station SD21 (Figure 7.7, Appendix G.6). This assemblage had the highest species richness (15 species), the third highest abundance (243 fish), the largest number of Longspine Combfish (79 fish) and White Croaker (22 fish), the third largest number of California Lizardfish (75 fish), and the second lowest number of Speckled Sanddabs (26 fish).

SBOO fish cluster group C represented a unique demersal fish assemblage sampled during 2013 at station SD15 (Figure 7.7, Appendix G.6). This assemblage had the third lowest species richness (9 species), the highest abundance (442 fish), the largest numbers of Pacific Sanddab (153 fish), California Lizardfish (118 fish), Curlfin Sole (15 fish) and Hornyhead Turbot (9 fish), and the second largest number of Speckled Sanddab (143 fish).

SBOO fish cluster group D was the largest group, representing the assemblages from a total of 77 trawls, including 64 (85%) of the trawls conducted at stations SD17–SD21 and 13 (43%) of the trawls conducted at stations SD15 and SD16 from 2003 through 2017 (Figure 7.7). Assemblages represented by cluster group D had the second highest average species richness (11 species/haul) and the second highest average abundance (353 fish/haul). The five most characteristic species for this group were Speckled Sanddabs (179/haul), California Lizardfish (98/haul), Yellowchin Sculpin (24/haul), Longfin Sanddab (18/haul), and Hornyhead Turbot (6/haul) (Appendix G.6).

SBOO fish cluster group E comprised 45 hauls, including 15 (65%) of the trawls from station SD15 and 10 (43%) of the trawls from station SD16 over the past 23 years (Figure 7.7). This cluster group also included all 12 hauls from stations SD17–SD20 conducted in 1999, 2000, and 2002. The remaining eight hauls from group E occurred sporadically at stations SD17–SD20 in 1996–1997, 2003–2004, 2007 and 2011. This type of fish assemblage never occurred at station SD21. The assemblages represented by cluster group E averaged 7 species and 130 fish per haul. These assemblages had the third highest average numbers of Speckled Sanddab (112/haul) (Appendix G.6). In addition to Speckled Sanddab, the remaining four of the five most characteristic species for this clsuter group were California Lizardfish (5/haul), Hornyhead Turbot (4/haul), Spotted Turbot (1/haul), and California Tonguefish (< 1 per haul).

SBOO fish cluster group F comprised 26 hauls, including nine trawls from station SD21 in 1995–2002 and in 2017, four trawls from stations SD17−SD20 in 1995, four trawls from stations SD16–SD19 in 1996, five trawls from station SD16–SD20 in 1998, and four trawls from SD17–SD20 in 2015 (Figure 7.7). Assemblages represented by clsuter group F had the third highest average species richness (10 species/haul), the second lowest average abundance (109 fish/haul), and the highest average numbers of Longfin Sanddabs (27/haul) (Figure 7.7, Appendix G.6). The remaining four of the five most characteristic species for this cluster group were Speckled Sanddab (48/haul), California Lizardfish (10/haul), California Tonguefish (5/haul), and Hornyhead Turbot (4/haul).

Megabenthic Invertebrates

Community Parameters

A total of 306,298 invertebrates, representing at least 72 species from five different phyla (i.e., Arthropoda, Echinodermata, Mollusca, Cnidaria, and Silicea), were captured during the 52 trawls conducted within the PLOO and SBOO monitoring regions in 2016–2017 (Tables 7.4, 7.5, Appendices G.7, G.8). This total catch for these two years comprised

304,080 trawled invertebrates collected from PLOO stations, 99% of which were the pelagic red crab *Pleuroncodes planipes.* These large red crab hauls resulted in total catch increases of about 373% in 2016 and 1335% in 2017 compared to 2015 despite the significantly less total trawling time during these last two years (i.e., 120 minutes in 2015 vs. 39 minutes in both 2016 and 2017; see Appendix G.1). Other species of megabenthic invertebrates collected in at least 50% of the PLOO trawls, but in relatively low numbers (≤77 individuals per haul), included the sea urchin *Lytechinus pictus* and the shrimp *Sicyonia ingentis*. In contrast, the total SBOO trawl catches of 1243 invertebrates in 2016 and 975 invertebrates in 2017 were about 28% and 43% smaller than the catch for 2015 (City of San Diego 2016b). Two invertebrates dominated the SBOO trawls over these two years. The shrimp *Sicyonia penicillata* accounted for 31% of the total invertebrate catch at these stations and occurred in 82% of the hauls, while the opisthobranch *Philine auriformis* accounted for 25% of the total catch from just 36% of the hauls. Other invertebrates collected in at least 50% of the SBOO trawls, but in relatively low numbers (≤7 individuals per haul), included the isopod *Elthusa vulgaris*, the shrimp *Crangon nigromaculata*, the sea star *Astropecten californicus*, the octopus *Octopus rubescens*, and the snail *Kelletia kelletii*.

As described for demersal fishes, species richness, abundance, diversity (H') and biomass values for the trawl-caught invertebrates at the PLOO stations in 2016–2017 were not comparable to each other or previosu years because of the reduced trawling times required at most sites due to the presence of large populations of pelagic red crabs. Consequently, the results presented in Table 7.6 are summarized below for the few regular 10-minute trawls and separately for reduced trawls (≤3 minutes). The five 10-minute trawls conducted at station SD7 during winter and summer 2016, station SD8 in winter 2016 and summer 2017, and station SD14 in summer 2017 had species richness values ranging from 4 to 7 species per haul, abundances ranging from 75 to 1260 individuals per haul, and H' ranging from 0.78 to 1.17 per haul. In contrast, the 19 short trawls had species richness ranging from 1 to 6 species per haul, abundance ranging from 989 to 39,417 individuals per haul, and very low diversity (H') ranging from 0 to 0.27 per haul. These short trawls were almost entirely dominated by *P. planipes*. Overall, there were no discernible spatial patterns in the megabenthic invertebrate community metrics relative to the PLOO discharge site, and these results are consistent with the findings from elsewhere in the SCB (Walther et al. 2017). Additionally, long-term comparisons using results from the regular 10-minute trawls did not reveal any clear spatial patterns that could be attributed to the onset of wastewater discharge at the current PLOO discharge site in late 1993 (Figure 7.8).

Megabenthic invertebrate community structure varied among stations and between surveys for

Table 7.4

Megabenthic invertebrate species collected from 24 trawls[a] conducted in the PLOO region during 2016 and 2017. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO
Pleuroncodes planipes	99	100	12,579	12,579
Lytechinus pictus	1	88	77	88
Sicyonia ingentis	<1	71	10	14
Strongylocentrotus fragilis	<1	4	2	41
Parastichopus californicus	<1	29	1	2
Astropecten californicus	<1	25	<1	2
Elthusa vulgaris	<1	21	<1	2
Octopus rubescens	<1	12	<1	3
Hinea insculpta	<1	4	<1	7
Luidia foliolata	<1	17	<1	1
Platymera gaudichaudii	<1	8	<1	2
Paguristes bakeri	<1	8	<1	1
Suberites latus	<1	8	<1	1
Cancellaria cooperii	<1	4	<1	1
Luidia asthenosoma	<1	4	<1	1
Paguristes turgidus	<1	4	<1	1
Solenocera mutator	<1	4	<1	1
Spatangus californicus	<1	4	<1	1

[a] these included 19 trawls with durations ≤3 minutes

Table 7.5

Megabenthic invertebrate species collected from 28 trawls conducted in the SBOO region during 2016 and 2017. 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
Sicyonia penicillata	31	82	25	30	*Heptacarpus stimpsoni*	<1	11	<1	1
Philine auriformis	25	36	20	56	*Metacarcinus gracilis*	<1	11	<1	1
Portunus xantusii	8	46	7	14	*Pagurus spilocarpus*	<1	11	<1	1
Elthusa vulgaris	8	82	6	8	*Randallia ornata*	<1	7	<1	2
Pleuroncodes planipes	7	43	5	12	Cancridae	<1	4	<1	2
Crangon nigromaculata	6	54	4	8	*Crangon alba*	<1	7	<1	1
Astropecten californicus	2	50	2	3	*Ophiura luetkenii*	<1	4	<1	2
Octopus rubescens	2	61	1	2	*Pteropurpura festiva*	<1	7	<1	1
Kelletia kelletii	2	50	1	3	*Rossia pacifica*	<1	7	<1	1
Dendraster terminalis	1	11	1	10	*Thesea* sp B	<1	7	<1	1
Crossata ventricosa	1	36	1	2	Actiniaria	<1	4	<1	1
Acanthodoris brunnea	1	11	<1	5	*Alpheus clamator*	<1	4	<1	1
Hemisquilla californiensis	1	21	<1	2	*Calliostoma tricolor*	<1	4	<1	1
Lytechinus pictus	<1	11	<1	3	*Crassispira semiinflata*	<1	4	<1	1
Pyromaia tuberculata	<1	25	<1	1	*Doryteuthis opalescens*	<1	4	<1	1
Acanthoptilum sp	<1	4	<1	7	*Epitonium bellastriatum*	<1	4	<1	1
Farfantepenaeus californiensis	<1	11	<1	2	*Glebocarcinus amphioetus*	<1	4	<1	1
Ophiothrix spiculata	<1	14	<1	2	*Heptacarpus palpator*	<1	4	<1	1
Platymera gaudichaudii	<1	14	<1	2	*Leptopecten latiauratus*	<1	4	<1	1
Ericerodes hemphillii	<1	7	<1	2	*Luidia armata*	<1	4	<1	1
Metacarcinus anthonyi	<1	11	<1	2	*Megasurcula carpenteriana*	<1	4	<1	1
Ophiopteris papillosa	<1	4	<1	5	*Paguristes bakeri*	<1	4	<1	1
Dendronotus iris	<1	14	<1	1	*Philine alba*	<1	4	<1	1
Lovenia cordiformis	<1	11	<1	1	*Pleurobranchaea californica*	<1	4	<1	1
Loxorhynchus grandis	<1	11	<1	1	*Pteropurpura vokesae*	<1	4	<1	1
Stylatula elongata	<1	14	<1	1	*Pugettia dalli*	<1	4	<1	1
Acanthodoris rhodoceras	<1	7	<1	2	*Pugettia producta*	<1	4	<1	1
Aglaja ocelligera	<1	11	<1	1	*Romaleon antennarium*	<1	4	<1	1
Armina californica	<1	7	<1	2	*Sicyonia ingentis*	<1	4	<1	1
Astropecten ornatissimus	<1	4	<1	3	*Sinum scopulosum*	<1	4	<1	1
Euspira lewisii	<1	7	<1	2	*Suberites* sp	<1	4	<1	1

the 28 10-minute trawls conducted within the SBOO region during the current reporting period (Table 7.6). For each haul, species richness ranged from 4 to 16 species, total abundance ranged from 10 to 400 individuals, and H' ranged from 0.58 to 2.20. Over the past two years, the highest species richness values (≥12 species) were recorded at stations SD15, SD16, SD18, and SD21 during the summer of 2016 and/or the winter of 2017. The largest hauls (≥166 individuals) were recorded at stations SD19, SD20, and SD21 during the winter of 2016, reflecting relatively large numbers of

Table 7.6

Summary of megabenthic invertebrate community parameters for PLOO and SBOO trawl stations sampled during 2016 and 2017. Data are included for species richness, abundance, diversity (H'), and biomass (kg, wet weight).

		2016		2017		2016		2017	
	Station[a]	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
		Species Richness				*Abundance*			
PLOO	SD7	4	7	5	4	242	192	26532	1499
	SD8	7	5	4	7	310	17461	39417	1260
	SD10	3	6	4	3	3151	13156	32956	989
	SD12	1	4	5	4	3360	18641	51143	9787
	SD13	2	4	2	4	3722	6167	22741	14271
	SD14	1	5	3	6	2389	6550	28069	75
SBOO	SD15	8	13	5	11	21	57	10	25
	SD16	7	6	12	9	68	74	49	29
	SD17	8	11	10	10	74	62	400	15
	SD18	10	10	14	9	68	57	55	19
	SD19	8	6	11	9	167	111	78	44
	SD20	6	4	9	6	166	32	28	26
	SD21	10	8	16	11	228	58	175	22

		2016		2017	
	Station[a]	Winter	Summer	Winter	Summer
		Diversity			
PLOO	SD7	0.82	0.94	0.01	0.27
	SD8	0.89	0.06	0.01	0.78
	SD10	0.07	0.04	0.02	0.07
	SD12	0.00	0.01	0.04	0.01
	SD13	0.01	0.03	0.00	0.01
	SD14	0.00	0.03	0.00	1.17
SBOO	SD15	1.65	2.02	1.36	2.09
	SD16	1.19	0.99	1.64	1.78
	SD17	1.24	1.89	0.58	2.15
	SD18	1.26	1.65	1.71	1.98
	SD19	0.89	1.16	1.27	1.81
	SD20	0.61	1.02	1.98	1.49
	SD21	1.27	0.92	1.39	2.20

[a] Shaded value indicates trawl duration ≤ 3 minutes

Sicyonia pencillata and *Crangon nigromaculata*, and/or the crab *Portunus xantussi*, (City of San Diego 2017) and at stations SD17 and SD21 during the winter of 2017, reflecting relatively large numbers of *Philine auriformis* and *S. penicillata*. The large hauls described above from stations SD17, SD19, and SD20 corresponded with the lowest H' values recorded during the current reporting period. Overall, these results are consistent with the findings from elsewhere in the SCB (Walther et al. 2017). There were no spatial patterns in the megabenthic invertebrate community metrics relative to the SBOO discharge site, while long-term comparisons did not reveal any clear spatial patterns that could

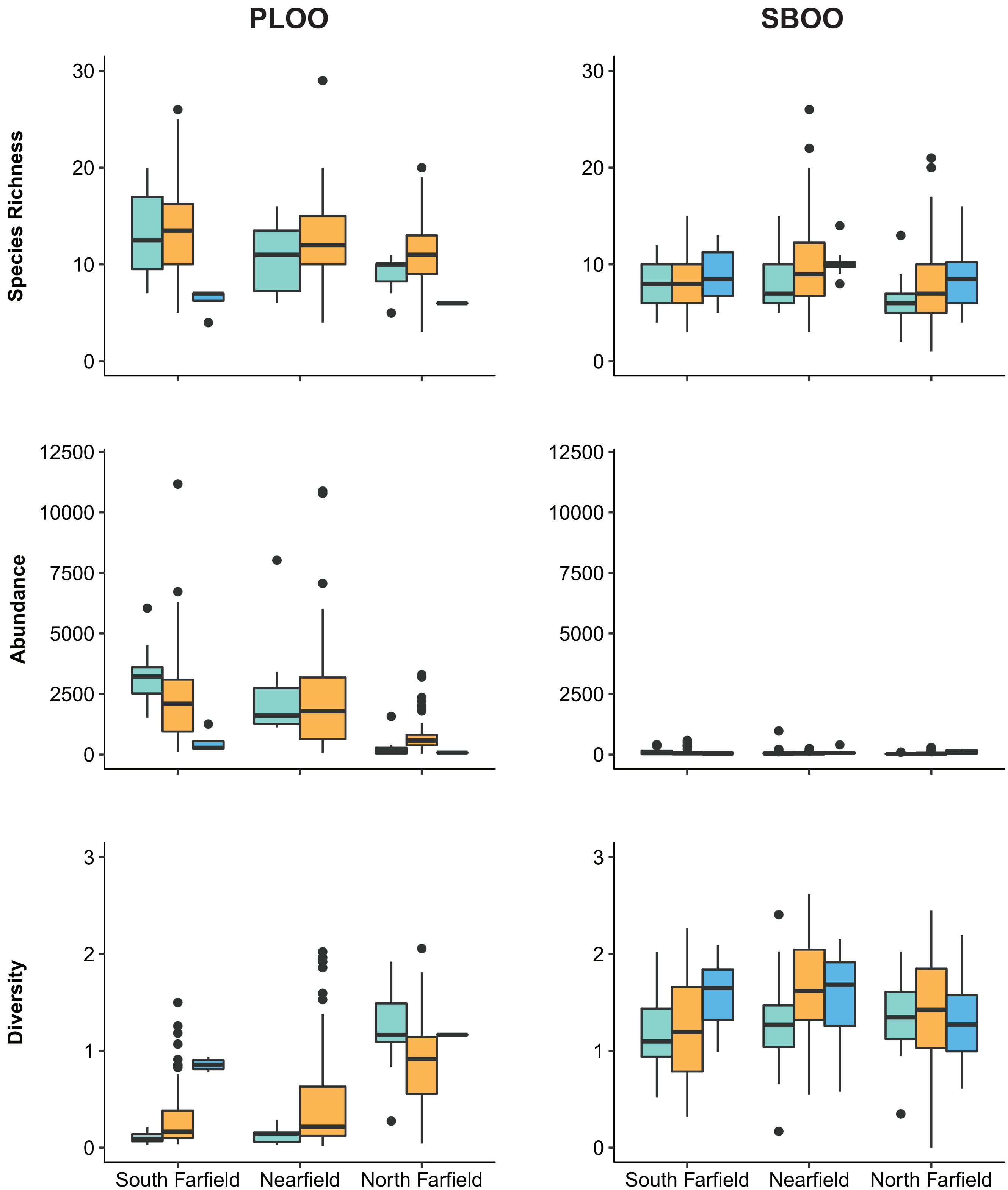


Figure 7.8
Species richness, abundance, and diversity (H') of megabenthic invertebrates collected from PLOO and SBOO nearfield, north farfield, and south farfield trawl stations during pre-discharge (green), historical post-discharge (orange) and current post-discharge (blue) periods. Data are limited to 10-minute trawls; Boxes = median, upper, and lower quantiles; whiskers = 1.5x interquantile range; circles = outliers; see text for description of pre- versus post-discharge periods for the two outfalls.

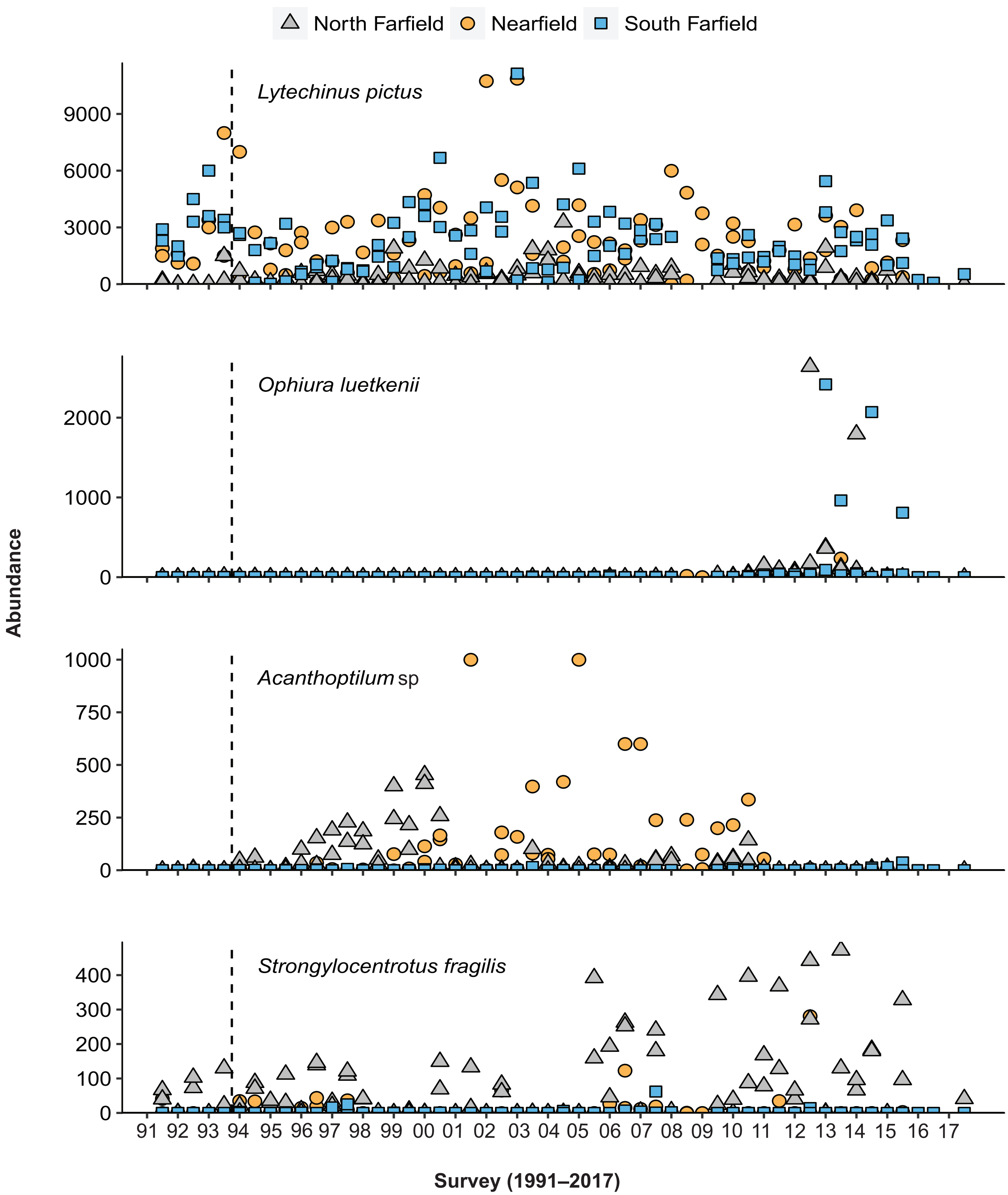
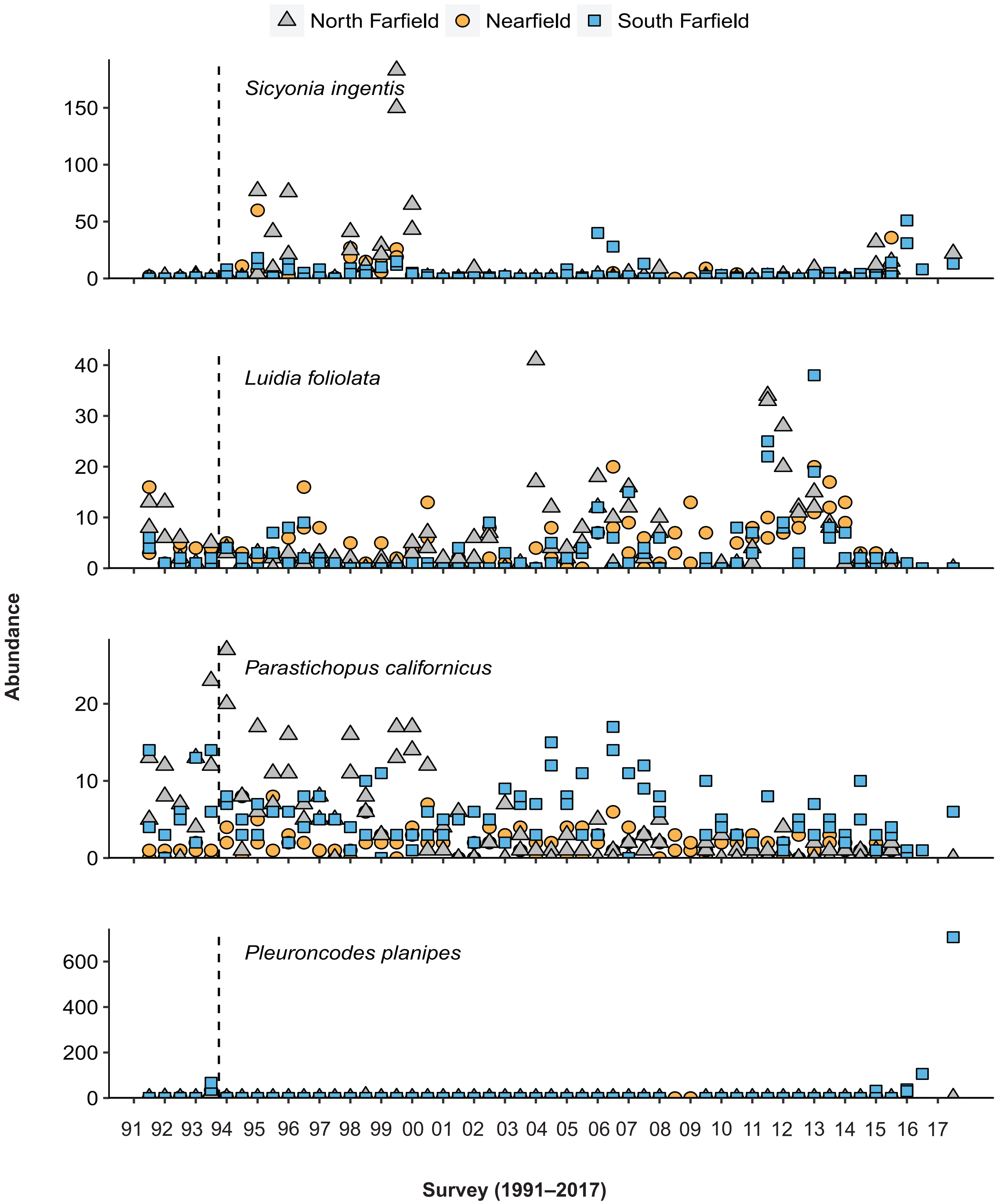


Figure 7.9

The eight most abundant megabenthic invertebrate species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2017. Data are limited to 10-minute trawls and are total values per haul. Dashed lines indicate onset of wastewater discharge.



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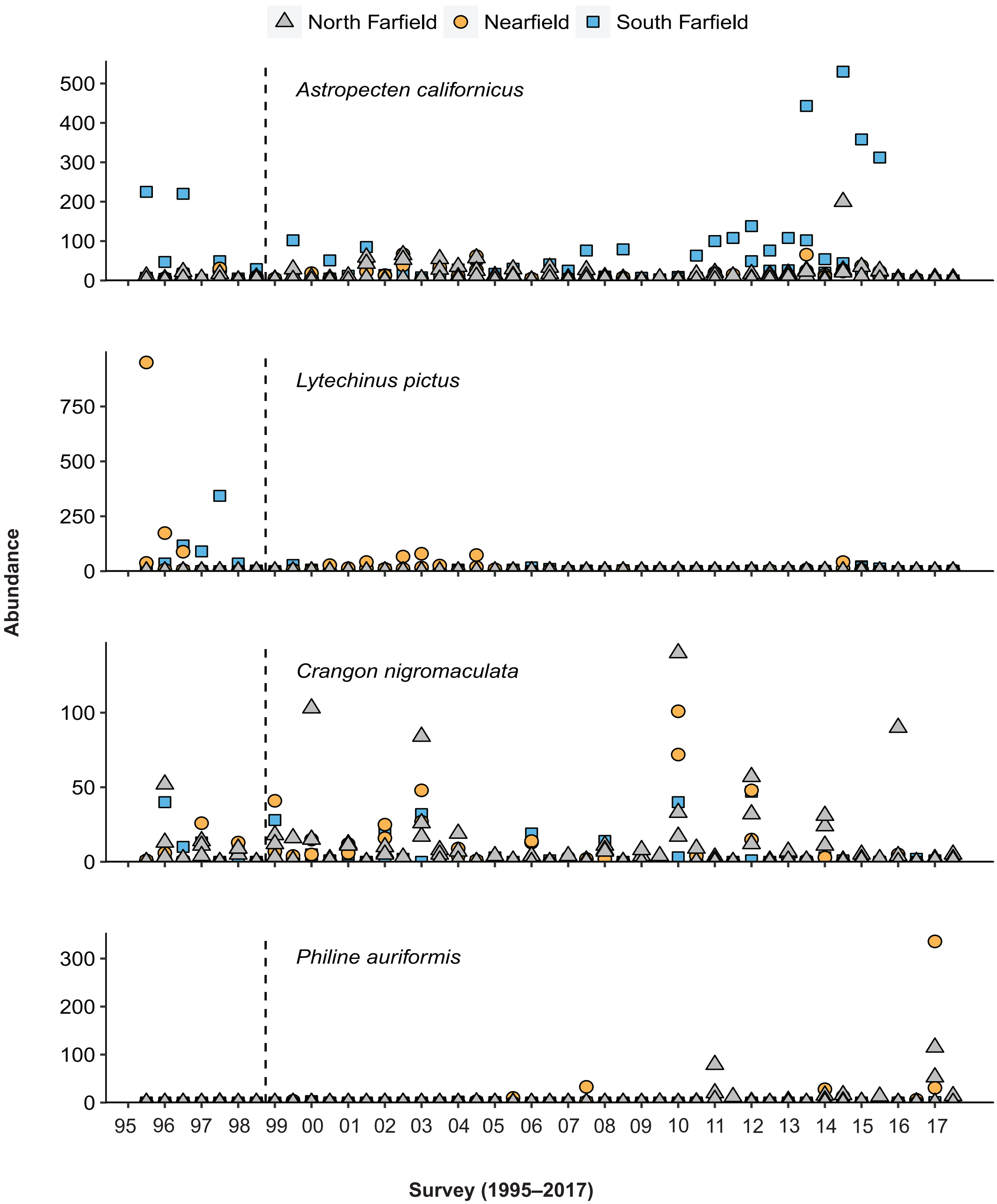

Figure 7.10
The eight most abundant megabenthic invertebrate species (presented in order) collected from SBOO trawl stations sampled from 1995 through 2017. Data are limited to 10-minute trawls and are total values per haul. Dashed lines indicate onset of wastewater discharge.

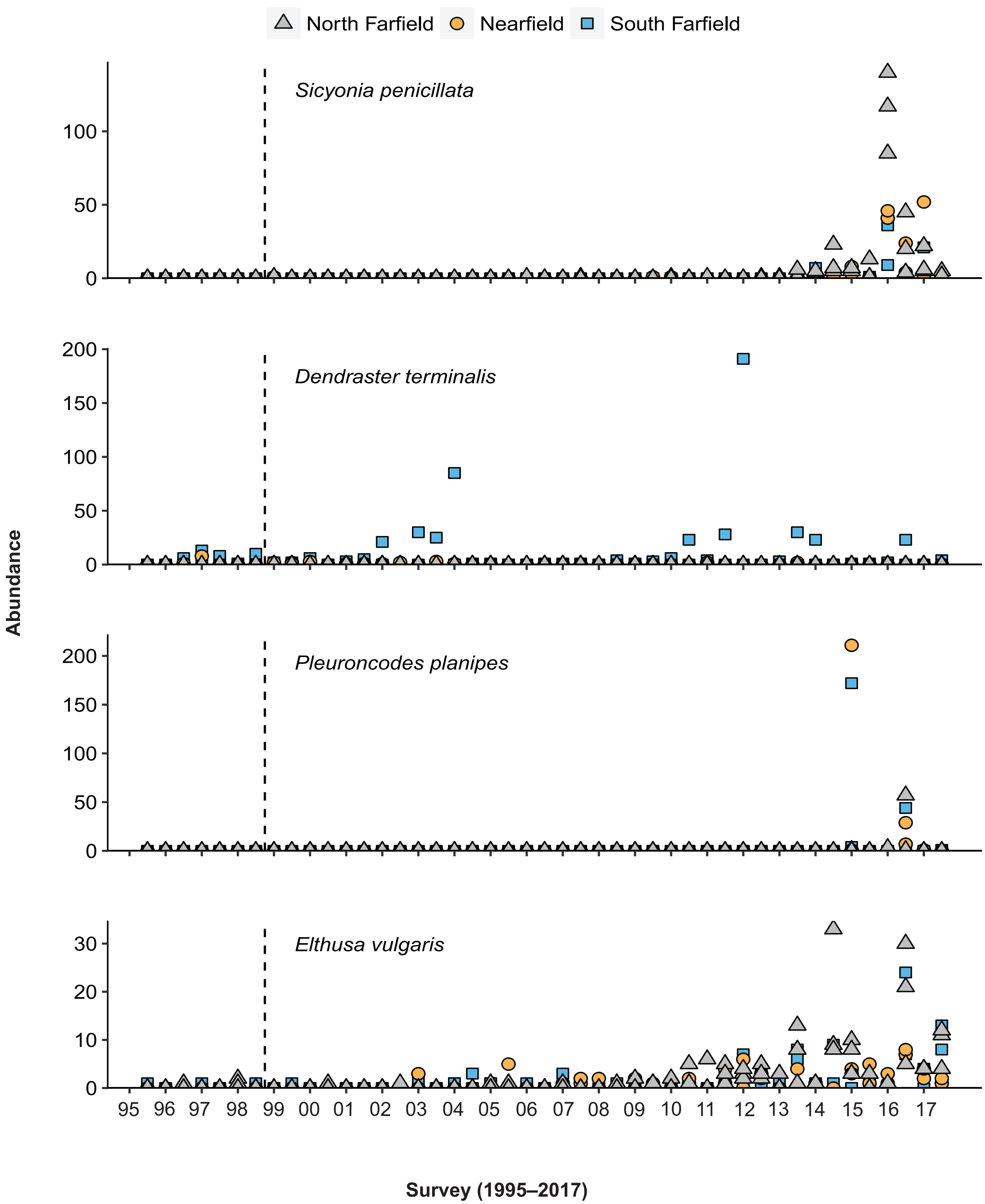

Figure 7.10 *continued*

be attributed to the onset of wastewater discharge from the SBOO in early 1999 (Figure 7.8).

Similar to the patterns described above for demersal fish assemblages, trawl-caught invertebrates off San Diego have demonstrated large spatial and temporal variations over the past 27 years that mostly reflect population fluctuations of a few numerically dominant species (Figures 7.9, 7.10; see also next section). For example, differences in overall megabenthic invertebrate abundances at the PLOO stations tended to track population changes of the pelagic red crab *Pleuroncodes planipes*, the sea urchins *Lytechinus pictus* and *Strongylocentrotus fragilis*, the brittle star *Ophiura luetkenii*, the sea star *Luidia foliolata*, the sea pen *Acanthoptilum* sp, the sea cucumber *Parastichopus californicus*, and the shrimp *Sicyonia ingentis* (Figure 7.9). Differences in overall abundances at SBOO stations also tended to track population changes of *P. planipes* and *L. pictus*, as well as *Astropecten californicus*, *Crangon nigromaculata*, *Sicyonia penicillata*, *Philine auriformis*, *Elthusa vulgaris*, and the sand dollar *Dendraster terminalis* (Figure 7.10). Overall, none of the observed changes appear to be associated with wastewater discharge from either outfall.

Classification Analysis of Invertebrate Assemblages

Multivariate analyses were used to discriminate between invertebrate assemblages from a total of 310 10-minute trawls conducted during summer surveys only from 1991 through 2017 at 13 PLOO and SBOO stations. These invertebrate assemblages were found to be significantly different (one-way ANOSIM, $\rho = 0.623$, $p = 0.001$). Classification (cluster) and ordination analyses further demonstrated a distinct split between the two outfall regions at about the 91.5% dissimilarity level (Figure 7.11). Six species had comparatively strong (i.e., Pearson correlation > 0.5) explanatory power for the patterns in the 2-D ordination of trawl samples. These included the sea urchins *Lytechinus pictus* and *Stronglyocentrotus fragilis*, the sea star *Luidia foliolata*, and the sea cucumber *Parastichopus californicus* that helped distinguish PLOO stations, and the isopod *Elthusa vulgaris* and the sea star *Pisaster brevispinus* that helped distinguish SBOO stations. A BEST BVSTEP ($\rho = 0.96$, $p = 0.001$) test also implicated *L. pictus*, *S. fragilis*, and *E. vulgaris*, as well as the sea star *Astropecten californicus*, the elbow crab *Latulambrus occidentalis*, the octopus *Octopus rubescens*, the brittle star *Ophiura luetkenii*, and the pear crab *Pyromaia tuberculata* as being influential to the overall pattern (gradient) of the cluster dendrogram (not shown). Based on these results, subsequent analyses were performed separately on data from each region.

<u>*PLOO Region*</u>

Cluster and ordination analyses discriminated between five ecologically-relevant SIMPROF-supported groups or types of megabenthic invertebrate assemblages in the PLOO region over the past 27 years (cluster groups A–E; Figure 7.12, Appendix G.9). These assemblages represented from 1 to 93 hauls each, and varied in terms of species present, as well as the relative abundances of individual species. A BEST BVSTEP ($\rho = 0.951$, $p = 0.001$) test implicated *Lytechinus pictus*, *Stronglyocentrotus fragilis*, *Ophiura luetkenii*, and the sea pen *Acanthoptilum* sp as being influential to the overall pattern (gradient) of the cluster dendrogram. There were only three 10-minute trawls from the 2016–2017 reporting period that could be included in these analyses; the haul from station SD7 in the summer of 2016, and the haul from station SD8 in the summer of 2017 grouped by themselves due to the influence of pelagic red crab *Pleuroncodes planipes*, while the haul from station SD14 in the summer of 2017 grouped with cluster group A (see group descriptions below). Overall, there were no discernible patterns associated with proximity to the PLOO discharge site (Figure 7.12). Instead, assemblages appear influenced by the distribution of the more abundant species or the unique characteristics of specific station locations. For example, stations SD13 and SD14 located north of the PLOO often grouped apart from the remaining stations (i.e., cluster group E). The species composition and main descriptive characteristics of each of the five cluster groups are included below.

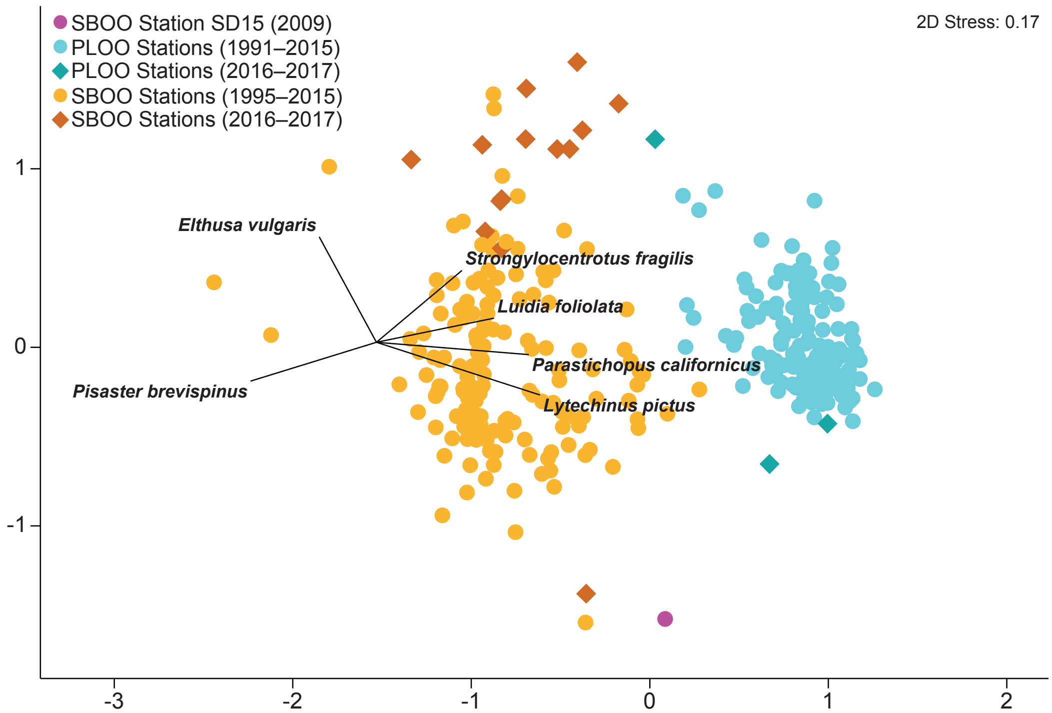

Figure 7.11

Results of non-metric multidimensional scaling oridnation of megabenthic invertebrate data from PLOO and SBOO trawl stations sampled from 1991 through 2017. Species abundance vectors overlaid, and limited to species with the strongest correlations (> 0.4) to the ordination pattern. Data are limited to 10-minute trawls from summer surveys.

PLOO invertebrate cluster group A comprised five hauls, including those from station SD12 in 1998, 2007, and 2009, and from station SD14 in 1998 and 2017 (Figure 7.12). Assemblages represented by this cluster group averaged 12 species per haul, and had the lowest total abundance (152 individuals/haul), the highest number of *Acanthoptilum* sp (97/haul) and the lowest number of *Lytechinus pictus* (8/haul) (Figure 7.12, Appendix G.9). *Acanthoptilum* sp, along with *Strongylocentrotus fragilis* (13/haul), the shrimp *Sicyonia ingentis* (12/haul), *Astropecten californicus* (4/haul), and *Ophiura luetkenii* (2/haul), were the five most characteristic species of these assemblages according to SIMPER results.

PLOO invertebrate cluster group B represented a unique megabenthic invertebrate assemblage that occurred at station SD14 in 2012 (Figure 7.12). This assemblage had the second lowest species richness (10 species), the highest abundance (3205 individuals), the highest numbers of *Ophiura luetkenii* (2640 individuals) and *Strongylocentrotus fragilis* (442 individuals), and the second lowest number of *Lytechinus pictus* (102 individuals) of any cluster group (Figure 7.12, Appendix G.9). Two other characteristic species for this group were the sea stars *Luidia foliolata* (11 individuals) and *Astropecten ornatissimus* (5 individuals).

PLOO invertebrate cluster group C comprised only two hauls, including one from station SD7 in 2016 and one from station SD8 in 2017 (Figure 7.12). Assemblages represented by this cluster group averaged the lowest species richness (7 species/haul), the third highest total abundance (756/haul), and the highest number of *Pleuroncodes planipes* (407/haul) (Figure 7.12, Appendix G.9). In addition to *P. planipes*, the other most characteristic species for these assemblages were *Lytechinus pictus* (302/haul), *Sicyonia ingentis* (11/haul), *Parastichopus californicus* (4/haul), and *Astropecten californicus* (2/haul).

PLOO invertebrate cluster group D was the largest group, representing assemblages from a total of 93

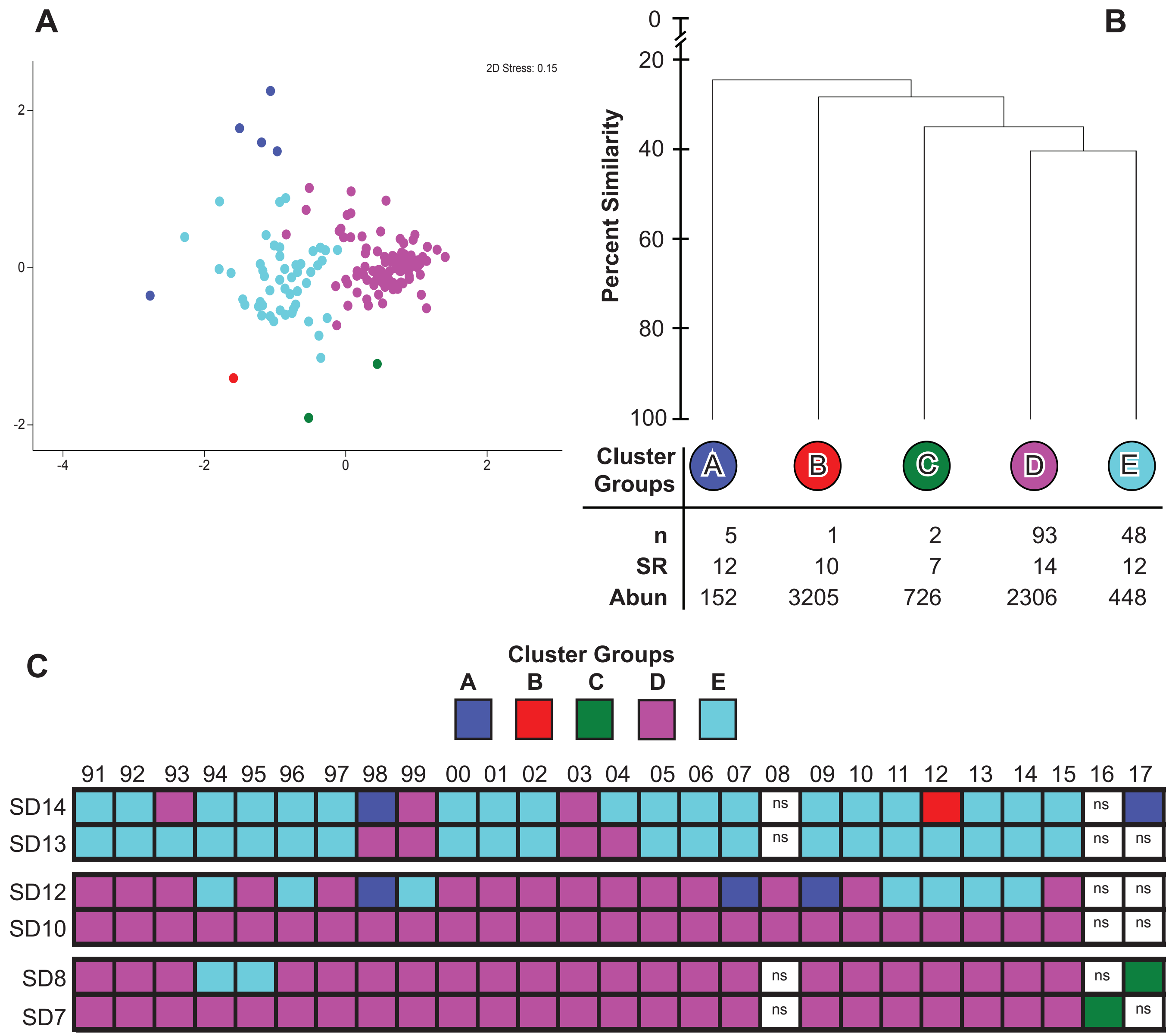

Figure 7.12

Results of ordination and cluster analysis of megabenthic invertebrate assemblages from PLOO trawl station sampled from 1991 through 2017. Data are limited to 10-minute trawls from summer surveys and presented as (A) non-metric multi-dimensional scaling ordination; (B) a dendrogram of main cluster groups; (C) a matrix showing distribution of cluster groups over time; n = number of hauls; SR = mean species richness; Abun = mean abundance; ns=no sample.

hauls, including 46 (96%) of the trawls from south farfield stations SD7 and SD8 and 40 (80%) of the trawls from nearfield stations SD10 and SD12, but only 7 (15%) of the trawls from north farfield stations SD13 and SD14 conducted from 1991 through 2015 (Figure 7.12). These assemblages averaged the highest species richness (14 species/haul), the second highest total abundance (2306 individuals/haul), and the highest number of *Lytechinus pictus* (2161/haul) (Figure 7.12, Appendix G.9). Along with *L. pictus*, the remaining most characteristic species of the group D assemblages were *Ophiura luetkenii* (49/haul), *Acanthoptilum* sp (47/haul), *Astropecten californicus* (5/haul), and *Parastichopus californicus* (5/haul).

PLOO invertebrate cluster group E was the second largest group, representing assemblages from a total of 48 hauls that included 39 (80%) of the trawls conducted at north farfield stations SD13

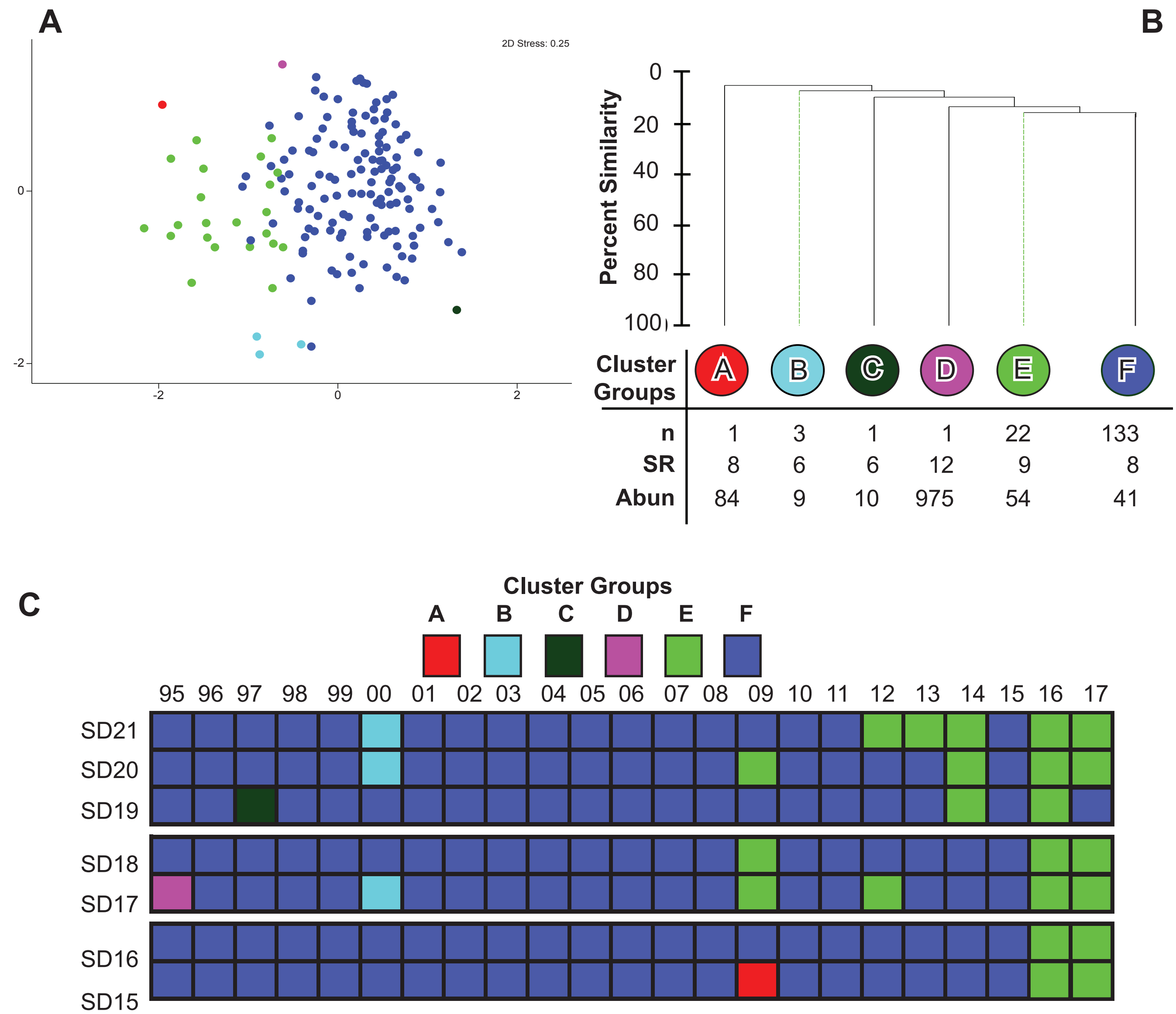

Figure 7.13

Results of ordination and cluster analysis of megabenthic invertebrate assemblages from SBOO trawl station sampled from 1995 through 2017. Data are limited to 10-minute trawls from summer surveys and presented as (A) non-metric multi-dimensional scaling ordination; (B) a dendrogram of main cluster groups; (C) a matrix showing distribution of cluster groups over time; n = number of hauls; SR = mean species richness; Abun = mean abundance.

and SD14 over the past 27 years, as well as the trawls from south farfield station SD8 in 1994 and 1995, and from nearfield station SD12 in 1994, 1996, 1999, and 2011–2014 (Figure 7.12). These group E assemblages averaged 12 species and 448 individuals per haul. The five most characteristic species of group E were *Lytechinus pictus* (236/haul), *Strongylocentrotus fragilis* (138/haul), *Acanthoptilum* sp (29/haul), *Ophiura luetkenii* (17/haul), and *Luidia foliolata* (5/haul) (Appendix G.9)

SBOO Region

Cluster and ordination analyses discriminated between six ecologically-relevant SIMPROF-supported groups or types of megabenthic invertebrate assemblages in the SBOO region over the past 23 years (cluster groups A–F; Figure 7.13, Appendix G.10). These assemblages represented from 1 to 133 hauls each, and varied in terms of species present, as well as the relative abundances of individual species. A BEST BVSTEP ($\rho = 0.952$, p = 0.001) test implicated the sea urchin *Lytechinus pictus*, brittle star *Ophiothrix spiculata*, the cepahlopod *Octopus rubescens*, the isopod *Elthusa vulgaris*, the sea stars *Astropecten californicus*, *Luidia armata*, and *Pisaster brevispinus*, the sand dollar *Dendraster terminalis*, the snail *Kelletia kelletii*, the opisthobranchs *Philine auriformis* and *Acanthodoris brunnea*, the crabs *Pyromaia tuberculata*, *Latulambrus occidentalis*, *Metacarcinus gracilis*, and the shrimps *Sicyonia penicillata* and *Crangon nigromaculata* as being influential to the overall pattern (gradient) of the cluster dendrogram. During 2016 and 2017, trawled invertebrate assemblages were distributed into two of the largest cluster groups (see descriptions of groups E and F below). Overall, there were no discernible patterns associated with proximity to the SBOO (Figure 7.13). Instead, assemblages appear influenced by the distribution of the more abundant species during specific time periods (groups B and E) versus background conditions (group F). The species composition and main descriptive characteristics of each of the six cluster groups are included below.

SBOO invertebrate cluster groups A, C, and D each represented a unique megabenthic invertebrate assemblage that occurred at a single trawl station in different years. The cluster group A assemblage occurred at station SD15 in 2009 and had 8 species and 84 individuals, and included the highest number of *Ophiura luetkenii* (72 individuals) of any SBOO invertebrate cluster group (Figure 7.13, Appendix G.10). The cluster group C assemblage occurred at station SD19 in 1997 and had 10 individuals comprised of six species, including four individuals of the sea star *Astropecten ornatissimus*. The cluster group D assemblage occurred at station SD17 in 1995 and had the highest species richness (12 species) and abundance (975 individuals) of all SBOO invertebrate cluster groups, of which 951 individuals were *Lytechinus pictus*.

SBOO invertebrate cluster group B represented assemblages that occurred at stations SD17, SD20 and SD21 in 2000 (Figure 7.13). These assemblages averaged six species and nine individuals per haul, and were characterized by an unidentified species of leech (i.e. Hirudinea; 1/haul), *Crangon nigromaculata* (1/haul), the crab *Loxorhynchus grandis* (1/haul), and the snail *Caesia perpinguis* (1/haul) (Appendix G.10).

SBOO invertebrate cluster group E represented assemblages from a total of 22 hauls, including the trawls from stations SD17, SD18, and SD20 in 2009, stations SD17 and SD21 in 2012, station SD21 in 2013, stations SD19–SD21 in 2014, and all but one trawl from stations SD15–SD21 in 2016 and 2017 (Figure 7.13). This group averaged nine species and 54 individuals per haul. The most characteristic species for the cluster group E assemblages were *Astropecten californicus* (13/haul), *Elthusa vulgaris* (9/haul), *Sicyonia penicillata* (7/haul), *Kellatia kelletii* (2/haul), and *Octopus rubescens* (2/haul) (Appendix G.10).

SBOO invertebrate cluster group F comprised 133 trawls, and was found at all stations a majority of the time between 1995 and 2017, likely reflecting background conditions within the region (Figure 7.13). Assemblages represented by cluster group F averaged 8 species and 41 individuals per haul, and were characterized by *Astropecten californicus* (35/haul), *Lytechinus pictus* (8/haul), *Latulambrus occidentalis* (2/haul), *Kellatia kelletii* (1/haul), and *Pisaster brevispinus* (1/haul).

Summary

Analyses of the demersal fish and megabenthic invertebrate data collected in 2016–2017 demonstrate that wastewater discharged through the Point Loma and South Bay outfalls has not negatively impacted these communities in the coastal waters off San Diego, with the values for most community parameters being similar at stations located both near and far away from the outfall discharge sites. Major community metrics such as species richness, abundance, and diversity were generally within historical ranges reported for the San Diego region (City of San Diego 1995, 1998, 2000, 2016a, b), and were representative of those characteristic of similar habitats throughout the SCB (e.g., Allen et al. 1998, 2002, 2007, 2011, Walther et al. 2017).

Multivariate analyses demonstrated that the demersal fish and megabenthic invertebrate assemblages differed between the PLOO and SBOO regions. The total catch of fishes at the PLOO stations during 2016–2017 represented ≥77% fewer fish than reported for the same number of trawls at the same sites in 2015 (City of San Diego 2016a), reflecting the significantly reduced total trawling time over the past two years caused by the necessity to limit bottom time due to the presence of excessive populations of pelagic red crabs. In contrast, the SBOO total fish catches were ≥69% larger than the catch reported for 2015 (City of San Diego 2016b). Over the past two years, Pacific Sanddab dominated fish assemblages surrounding the PLOO and Speckled Sanddab dominated fish assemblages surrounding the SBOO, as they have since monitoring within each region began. California Lizardfish were also prevalent within the SBOO region during 2016–2017, as they have been in seven of the past eight years. Other commonly captured, but less abundant fishes, collected from the PLOO and SBOO regions included Dover Sole, Stripetail Rockfish, Longspine Combfish, Pink Seaperch, Longfin Sanddab, California Tonguefish, Hornyhead Turbot, Fantail Sole, California Halibut, and various pipefish species. Almost all fishes collected were <30 cm in length.

Of the 306,298 megabenthic invertebrates encountered during 2016 and 2017, 99% were the pelagic red crab *Pleuroncodes planipes*, collected almost exclusively at PLOO trawl stations. The invasion of red crabs over the past two years translated into huge increases of 373% in 2016 and a 1335% in 2017 for megabenthic invertebrates at the PLOO stations compared to 2015. In contrast, the total SBOO invertebrate catches in 2016 and 2017 were about 28–43% smaller than during the previous year (City of San Diego 2016b).

Overall, there is no evidence that wastewater discharged through the PLOO or SBOO affected demersal fish or megabenthic invertebrate communities in 2016 or 2017. Although highly variable, patterns in the abundance and distribution of species were similar at stations located near the outfalls and farther away. Instead, the high degree of variability in these assemblages during the this reporting period was similar to that observed in previous years, including before wastewater discharge began through either outfall (City of San Diego 2000, 2005–2016a,b). Further, this sort of variability has also been observed in similar habitats elsewhere off southern California (Allen et al. 1998, 2002, 2007, 2011, Walther 2017). Consequently, changes in local community structure of these fishes and invertebrates are more likely due to natural factors such as changes in ocean temperatures associated with El Niño or other large-scale oceanographic events, and to the mobile nature of many resident species. Finally, the absence of disease indicators or other physical abnormalities in local fishes suggests that populations in the Point Loma and South Bay outfall regions continue to be healthy.

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Chapter 8
Contaminants in Marine Fishes

Chapter 8. Contaminants in Marine Fishes

Introduction

Bottom dwelling (i.e., demersal) fishes are collected as part of the City of San Diego's (City) Ocean Monitoring Program to evaluate if contaminants present in wastewater discharged from the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO) may be accumulating in their tissues. Anthropogenic inputs to coastal waters can result in increased concentrations of pollutants within the local marine environment, and subsequently in the tissues of fishes and their prey. Such accumulation occurs through the biological uptake and retention of chemicals derived via various exposure pathways, including 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 types of fishes throughout the Southern California Bight (SCB) are often related to those found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

This portion of the City's ocean monitoring program consists of two components: (1) analyzing liver tissues from mostly trawl-caught fishes; (2) analyzing muscle tissues from fishes collected by hook and line (rig fishing). Species targeted by trawling activities (see Chapter 7) are considered representative of the general demersal fish community off San Diego. The chemical analysis of liver tissues in target species of these fishes is important for assessing population effects because this is the organ where contaminants typically bioaccumulate. In contrast, species targeted for capture by rig fishing represent fish that are more characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance and more directly relevant to human health concerns. Consequently, muscle samples are analyzed from these fishes because this is the tissue most often consumed by humans. All liver and muscle tissue samples collected from San Diego fishes during the year are analyzed for contaminants as specified in the NPDES discharge permits that govern monitoring requirements for the PLOO and SBOO regions (see Chapter 1). Most of these contaminants are also sampled for the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program, which was initiated to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants of environmental concern (Lauenstein and Cantillo 1993).

This chapter presents analysis and interpretation of all chemical analyses performed on the tissues of fishes collected in the Point Loma and South Bay outfall regions during 2016 and 2017. The primary goals of the chapter are to: (1) document levels of contaminant loading in local demersal fishes; (2) identify whether any contaminant bioaccumulation detected in local fishes may be related to wastewater discharge via the outfalls; (3) identify other potential natural and anthropogenic sources of pollutants to the San Diego coastal marine environment.

Materials and Methods

Fishes were collected in October 2016 and October 2017 from a total of nine trawl zones (TZ1–TZ9) and four rig fishing zones (RF1–RF4) that span the PLOO and SBOO discharge sites and monitoring regions (Figure 8.1). Each trawl zone represents an area centered on one or two trawl stations as specified in Chapter 7. Trawl Zone 1 includes the

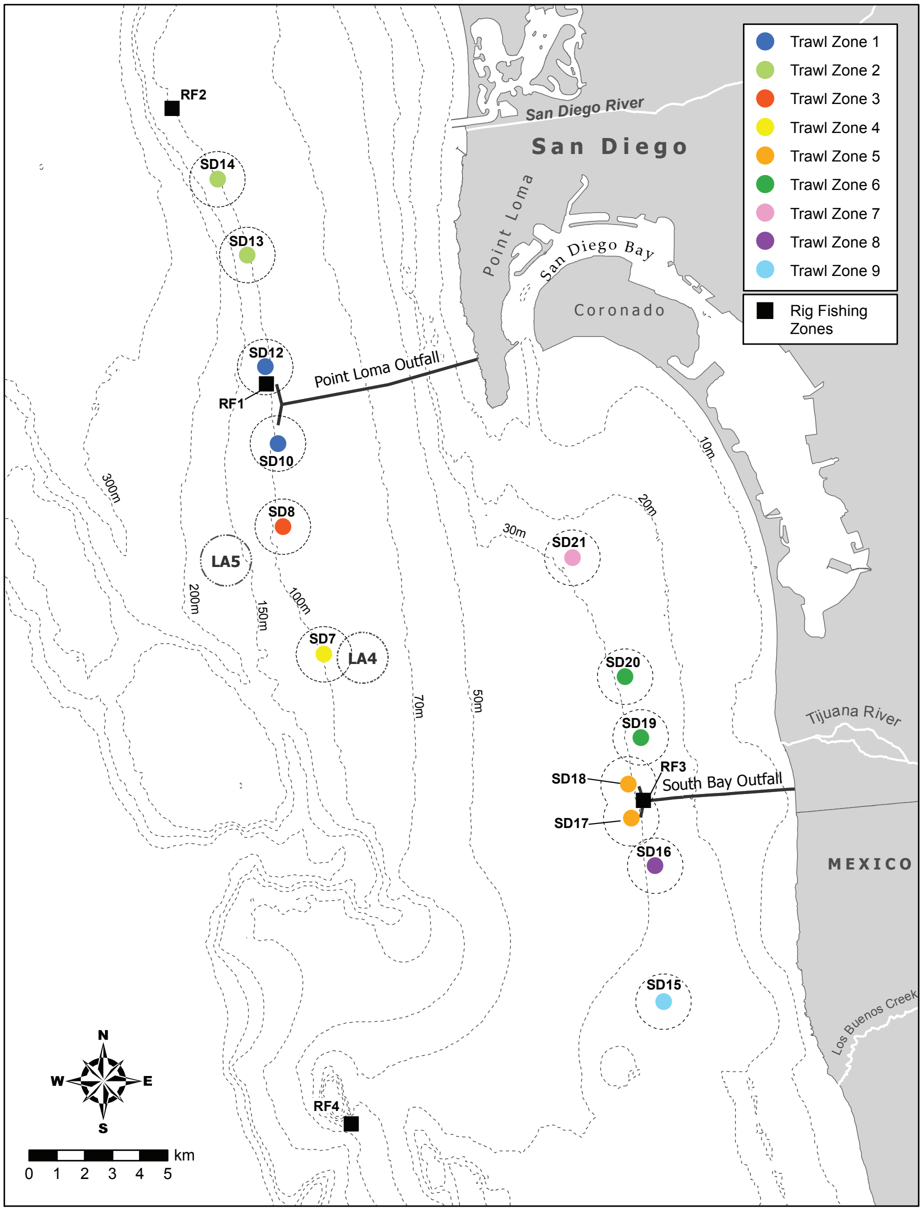

Figure 8.1

Trawl and rig fishing zone locations sampled around the Point Loma and South Bay Ocean Outfalls as part of the City of San Diego's Ocean Monitoring Program.

"nearfield" area within a 1-km radius of PLOO stations SD10 and SD12 located just south and north of the outfall discharge site, respectively. Trawl Zone 2 includes the area within a 1-km radius surrounding northern "farfield" PLOO stations SD13 and SD14. Trawl Zone 3 represents the area within a 1-km radius surrounding "farfield" PLOO station SD8, which is located south of the outfall near the LA-5 dredged material disposal site. Trawl Zone 4 is the area within a 1-km radius surrounding "farfield" PLOO station SD7 located several kilometers south of the outfall. Trawl Zone 5 includes the area located within a 1-km radius of SBOO stations SD17 and SD18 located just south and north of the outfall discharge site, respectively. Trawl Zone 6 includes the area within 1-km radius surrounding northern SBOO stations SD19 and SD20, while Trawl Zone 7 includes the area within a 1-km radius of northern SBOO station SD21. Trawl Zone 8 represents the area within a 1-km radius surrounding southern SBOO station SD16, while Trawl Zone 9 represents the area within a 1-km radius surrounding southern SBOO station SD15. Rig Fishing Zones 1–4 represent the areas within a

Table 8.1

Species of fish collected from each PLOO and SBOO trawl and rig fishing zone during 2016 and 2017.

	Zone	Composite 1	Composite 2	Composite 3
PLOO				
2016	Rig Fishing Zone 1 (RF1)	Vermilion Rockfish	Vermilion Rockfish	Mixed Rockfish [a]
	Rig Fishing Zone 2 (RF2)	Speckled Rockfish	Mixed Rockfish [b]	Mixed Rockfish [c]
	Trawl Zone 1 (TZ1)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
	Trawl Zone 2 (TZ2)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
	Trawl Zone 3 (TZ3)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
	Trawl Zone 4 (TZ4)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2017	Rig Fishing Zone 1 (RF1)	Vermilion Rockfish	Vermilion Rockfish	Vermilion Rockfish
	Rig Fishing Zone 2 (RF2)	Vermilion Rockfish	Vermilion Rockfish	Mixed Rockfish [d]
	Trawl Zone 1 (TZ1)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
	Trawl Zone 2 (TZ2)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
	Trawl Zone 3 (TZ3)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
	Trawl Zone 4 (TZ4)	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
SBOO				
2016	Rig Fishing Zone 3 (RF3)	California Scorpionfish	Mixed Rockfish [e]	Mixed Rockfish [f]
	Rig Fishing Zone 4 (RF4)	Treefish	Treefish	Starry Rockfish
	Trawl Zone 5 (TZ5)	Fantail Sole	Hornyhead Turbot	Longfin Sanddab
	Trawl Zone 6 (TZ6)	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
	Trawl Zone 7 (TZ7)	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
	Trawl Zone 8 (TZ8)	Longfin Sanddab	Longfin Sanddab	Fantail Sole
	Trawl Zone 9 (TZ9)	Fantail Sole	Spotted Turbot	Hornyhead Turbot
2017	Rig Fishing Zone 3 (RF3)	California Scorpionfish	California Scorpionfish	California Scorpionfish
	Rig Fishing Zone 4 (RF4)	Gopher Rockfish	Treefish	Mixed Rockfish [g]
	Trawl Zone 5 (TZ5)	Fantail Sole	Hornyhead Turbot	Hornyhead Turbot
	Trawl Zone 6 (TZ6)	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
	Trawl Zone 7 (TZ7)	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
	Trawl Zone 8 (TZ8)	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
	Trawl Zone 9 (TZ9)	Fantail Sole	Hornyhead Turbot	Spotted Turbot

[a] Includes Copper and Rosy Rockfish; [b] includes Greenstriped and Starry Rockfish; [c] includes Vermilion, Flag, and Copper Rockfish; [d] includes Starry and Copper Rockfish; [e] includes Olive and Brown Rockfish; [f] includes Vermilion and Olive Rockfish; [g] includes Starry and Rosy Rockfish

1-km radius of the nominal coordinates for stations RF1, RF2, RF3, and RF4. Stations RF1 and RF3 are located within 1 km of the PLOO and SBOO discharge sites, respectively, and are considered the "nearfield" rig fishing sites. In contrast, station RF2 is located about 11 km northwest of the PLOO, while station RF4 is located about 13.2 km southeast of the SBOO. These two sites are considered "farfield" or reference stations for the analyses herein.

A total of 17 species of fish were collected for analysis of liver and muscle tissues during the 2016 and 2017 October surveys (Table 8.1). Five different species of flatfish were collected from the nine trawl zones for analysis of liver tissues, including Pacific Sanddab (*Citharichthys sordidus*), Fantail Sole (*Xystreurys liolepis*), Hornyhead Turbot (*Pleuronichthys verticalis*), Longfin Sanddab (*Citharichthys xanthostigma*), and Spotted Turbot (*Pleuronichthys ritteri*). These flatfish were captured from regular trawls at the SBOO stations and by alternative hook and line methods at the PLOO stations. In contrast, 12 different species of rockfish were collected for analysis of muscle tissues at the rig fishing stations using standard hook and line fishing techniques. These species included California Scorpionfish (*Scorpaena guttata*), Brown Rockfish (*Sebastes auriculatus*), Copper Rockfish (*Sebastes caurinus*), Flag Rockfish (*Sebastes rubrivinctus*), Gopher Rockfish (*Sebastes carnatus*), Greenstriped Rockfish (*Sebastes elongatus*), Olive Rockfish (*Sebastes serranoides*), Rosy Rockfish (*Sebastes rosaceus*), Speckled Rockfish (*Sebastes ovalis*), Starry Rockfish (*Sebastes constellatus*), Treefish (*Sebastes serriceps*), and Vermilion Rockfish (*Sebastes miniatus*).

Only fishes with standard lengths ≥12 cm were retained in order to facilitate collection of sufficient tissue for analysis. These fishes were sorted into three composite samples per station, with a minimum of three individuals in each composite. All fishes were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were stored at -20°C prior to dissection and tissue processing.

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis. A brief summary follows, but see City of San Diego (in prep) for additional details. Prior to dissection, each fish was partially defrosted, cleaned with a paper towel to remove loose scales and excess mucus, and the standard length (cm) and weight (g) were recorded (Addenda 8-1, 8-2, City of San Diego 2017). Dissections were carried out on Teflon® pads that were cleaned between samples. The liver or muscle tissues from each fish were removed and placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses.

All tissue analyses were performed at the City of San Diego's Environmental Chemistry Laboratory. A detailed description of the analytical protocols can be found in City of San Diego (2018a). Briefly, all fish tissue samples were analyzed on a wet weight basis to determine the concentrations of 18 different trace metals, nine chlorinated pesticides, 40 polychlorinated biphenyl compound congeners (PCBs), and 24 polycyclic aromatic hydrocarbons (PAHs). While PAHs have always been a requirement for samples from the SBOO region, PAH analyses were added as a new requirement for the PLOO stations with renewal of the NPDES permit for the Point Loma Wastewater Treatment Plant in 2017. Data were generally limited to values above the method detection limit (MDL) for each parameter (Appendices H.1, H.2). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. Additionally, a variety of laboratory technical issues resulted in a significant amount of non-reportable fish tissue chemistry data for 2016 and 2017 as follows: (1) hexachlorobenzene results were not reportable for 17 of 39 samples analyzed in 2016; (2) thallium was not recorded for any of the 39 fish tissue samples analyzed in 2017; (3) mercury results were not reportable for 2 of 39 samples analyzed in 2017; (4) pesticide and PCB results were not reportable for 1 of 39 samples analyzed in 2017; (5) naphthalene results were not reportable for 2 of 39 samples analyzed 2017. Details for the above non-reportable results for 2016 are available in City of San Diego (2017), while results for 2017 are available in Addenda 8-3, 8-4, 8-5, and 8-6 of this report.

Data Analyses

Data for each chemical parameter analyzed in PLOO and SBOO fish tissues sampled during October 2017 are listed in Addenda 8-3 through 8-7, while data collected in October 2016 were reported previously and are available online (see City of San Diego 2017, 2018b). Data summaries for each parameter included detection rate, mean, minimum and maximum values for all samples combined by species for each outfall region. All means were calculated using detected values only with no substitutions made for non-detects (i.e., analyte concentrations <MDL). Total DDT (tDDT), total hexachlorocyclohexane (tHCH), total chlordane, total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values for individual constituents (see above and Addendum 8-7, City of San Diego 2017). For comparative historical analyses, data were limited as follows: (1) October surveys only; (2) data collected after 1994; (3) specific species feeding guilds (e.g., mixed sanddabs, mixed rockfish; see Allen et al. 2002) or the most frequently collected species (see Appendices H.3, H.4). Data collected from the PLOO region prior to 1995 were excluded due to incompatible methods used by the external contract lab at the time (see City of San Diego 2015). Barred Sand Bass were also included in the historical analyses because it was the only species collected at SBOO station RF3 in 1995. Data analyses were performed using SAS software v9.3, or R (R Core Team 2016) using various functions within the dplyr, ggplot2, plyr, reshape2, and tidyr packages (Zeileis and Grothendieck 2005, Wickham 2007, 2011, 2017, Wickham and Francios 2017).

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

Results

Contaminants in Fish Liver Tissues

Trace Metals

A total of eight of the 17 trace metals analyzed for during 2016 and 2017 were detected in all fish liver tissue samples collected at the four PLOO trawl zones and five SBOO trawl zones, including arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc (Table 8.2, Addendum 8-3, City of San Diego 2017). Detection rates per outfall region were also relatively high for tin at 73–100% and chromium at 83–87%, while antimony, barium, lead, nickel, and silver were detected at rates ≤30% per region. The remaining two metals, aluminum and beryllium, were detected at rates ≤4% in liver tissues from the PLOO region, but were undetected in fish captured at the SBOO trawl zones. Intra-species comparisons between nearfield and farfield trawl zones revealed no clear patterns or relationship in terms of proximity to either the PLOO or SBOO discharge sites, with tissue concentrations of most metals being highly variable across the different zones (Figure 8.2).

Historical comparisons indicate that detection rates have been relatively high for a number of different metals in the liver tissues of fishes captured at the trawl stations since 1995 (Table 8.3). For example, cadmium, copper, iron, manganese, mercury, selenium, and zinc have been detected in ≥86% of all liver samples analyzed from the PLOO and SBOO trawl zones over the past 23 years. Metal concentrations have also been highly variable during this time, with most being detected within ranges reported elsewhere in the SCB (e.g., Mearns et al. 1991, CLA 2015, OCSD 2018). While high values of various metals have been occasionally recorded in liver tissues from fishes captured at nearfield zones, there were no discernible intra-species patterns that could be associated with proximity to either outfall (Figure 8.3, Appendix H.5).

Pesticides

A total of six chlorinated pesticides were detected in fish liver tissue samples collected from the PLOO

Table 8.2

Summary of metals (ppm) in liver tissues of fishes collected from PLOO and SBOO trawl zones during 2016 and 2017. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations for each species, and the total number of samples, detection rate, and maximum value for all species within each region; nd = not detected.

		Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Sn	Zn
PLOO	Pacific Sanddab																	
	n	1	3	24	2	1	24	20	24	24	6	24	24	4	24	1	24	24
	Min	nd	nd	3.3	nd	nd	0.80	nd	2.0	27.0	nd	0.5	0.028	nd	0.49	nd	0.400	13.10
	Max	5.0	0.400	12.0	15.20	0.184	11.00	1.3	8.3	143.0	0.2	1.3	0.377	0.6	1.83	2.20	1.000	38.00
	Mean	5.0	0.299	6.1	7.85	0.184	2.40	0.4	4.1	57.4	0.1	0.7	0.078	0.3	0.98	2.20	0.726	21.14
	Total Samples	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
	Detection Rate (%)	4	13	100	8	4	100	83	100	100	25	100	100	17	100	4	100	100
	Max	5.0	0.4	12.0	15.00	0.184	11.00	1.3	8.3	143.0	0.2	1.3	0.377	0.6	1.83	2.20	1.000	38.00
SBOO	Fantail Sole																	
	n	0	0	5	1	0	5	4	5	5	0	5	5	2	5	0	2	5
	Min	—	—	15.5	nd	—	2.10	nd	8.9	87.0	—	1.1	0.066	nd	0.68	—	nd	39.90
	Max	—	—	39.4	0.24	—	4.00	0.5	27.4	205.0	—	2.6	0.197	0.1	1.30	—	0.400	74.40
	Mean	—	—	28.8	0.24	—	3.09	0.2	16.3	157.8	—	1.7	0.111	0.1	0.94	—	0.400	60.66
	Hornyhead Turbot																	
	n	0	0	6	0	0	6	6	6	6	0	6	5	2	6	2	2	6
	Min	—	—	4.0	—	—	1.40	0.1	2.3	48.0	—	0.8	0.059	nd	1.00	nd	nd	38.30
	Max	—	—	15.7	—	—	5.90	0.5	8.3	113.0	—	1.3	0.237	0.1	1.77	0.20	0.500	76.00
	Mean	—	—	8.0	—	—	3.10	0.2	5.3	70.7	—	1.0	0.101	0.1	1.33	0.15	0.450	52.18
	Longfin Sanddab																	
	n	0	2	17	0	0	17	15	17	17	0	17	17	5	17	1	17	17
	Min	—	nd	5.8	—	—	0.91	nd	4.2	59.0	—	0.8	0.050	nd	0.70	nd	0.500	19.00
	Max	—	0.220	12.1	—	—	2.08	0.7	7.6	111.0	—	1.7	0.110	0.3	1.60	0.11	0.948	28.00
	Mean	—	0.207	8.7	—	—	1.39	0.3	5.9	76.9	—	1.1	0.075	0.1	1.18	0.11	0.674	23.96
	Spotted Turbot																	
	n	0	0	2	0	0	2	1	2	2	1	2	1	0	2	1	1	2
	Min	—	—	4.4	—	—	0.97	nd	2.3	64.0	nd	0.8	0.094	—	1.30	nd	nd	22.00
	Max	—	—	10.7	—	—	3.50	0.1	28.9	96.0	0.2	2.1	0.094	—	1.57	0.20	0.700	43.20
	Mean	—	—	7.5	—	—	2.23	0.1	15.6	80.0	0.2	1.4	0.094	—	1.43	0.20	0.700	32.60
	Total Samples	30	30	30	30	30	30	30	30	30	30	30	28	30	30	30	30	30
	Detection Rate (%)	0	7	100	3	0	100	87	100	100	3	100	100	30	100	13	73	100
	Max	—	0.220	39.8	0.236	—	5.9	0.7	28.9	205.0	0.2	2.6	0.237	0.3	1.77	0.20	0.948	76.0

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

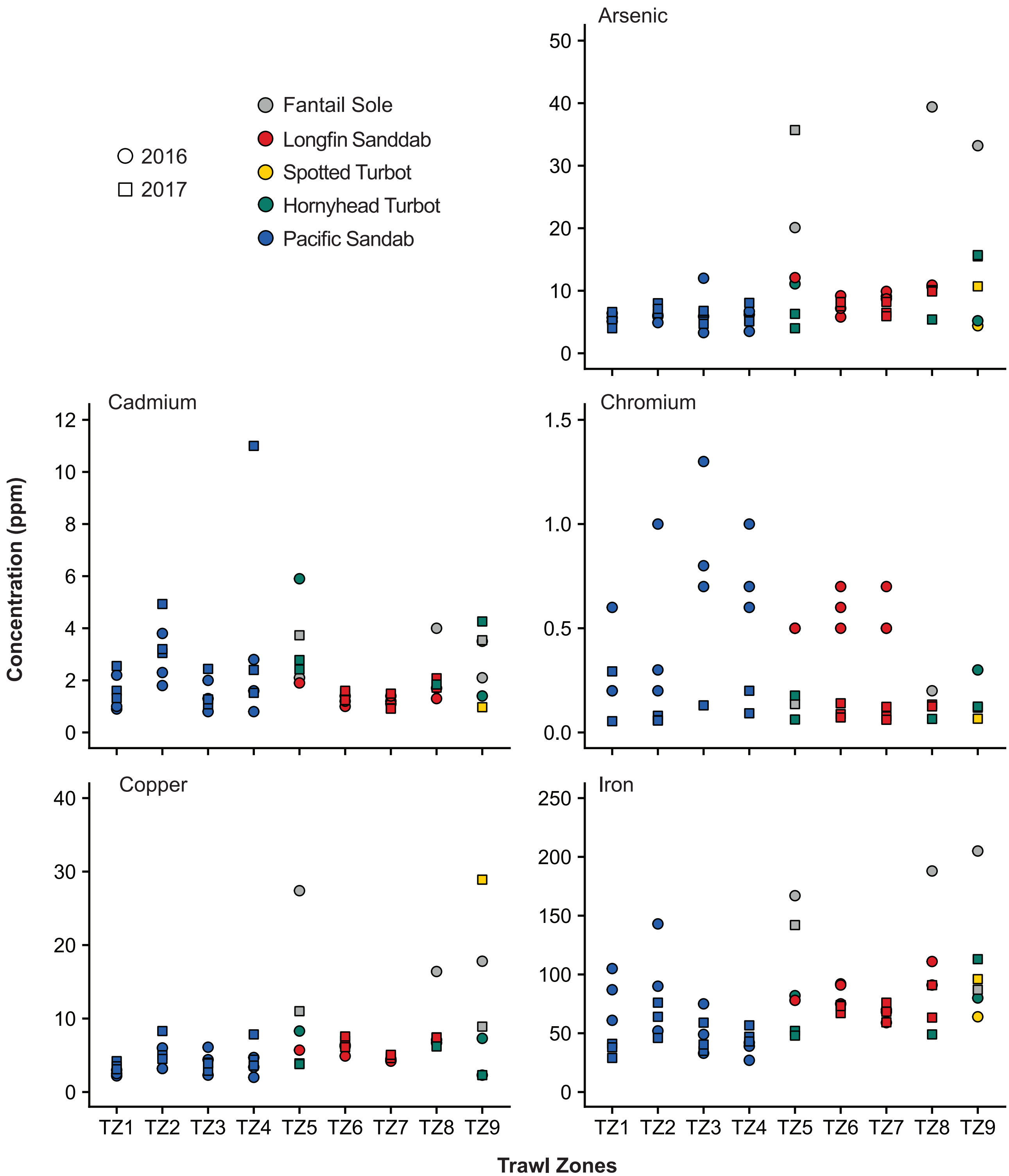

Figure 8.2
Concentrations of metals with detection rates ≥20% in liver tissues of fishes collected from each PLOO and SBOO trawl zone during 2016 and 2017. Zones TZ1 and TZ5 are considered nearfield stations.

and SBOO trawl zones in 2016 and 2017 (Table 8.4, Addenda 8-4, 8-7, City of San Diego 2017). DDT (primarily p,p-DDE) and HCB were the two most prevalent pesticides, occurring in all samples, while detection rates for each region were 73–100% for total HCH (primarily alpha- and beta-HCH), 61–63% for chlordane (primarily trans-nonachlor), 22–23% for mirex, and 0–7% for endosulfan sulfate. The pesticides (or pesticide constituents) aldrin, alpha-endosulfan, beta-endosulfan, dieldrin, endrin,

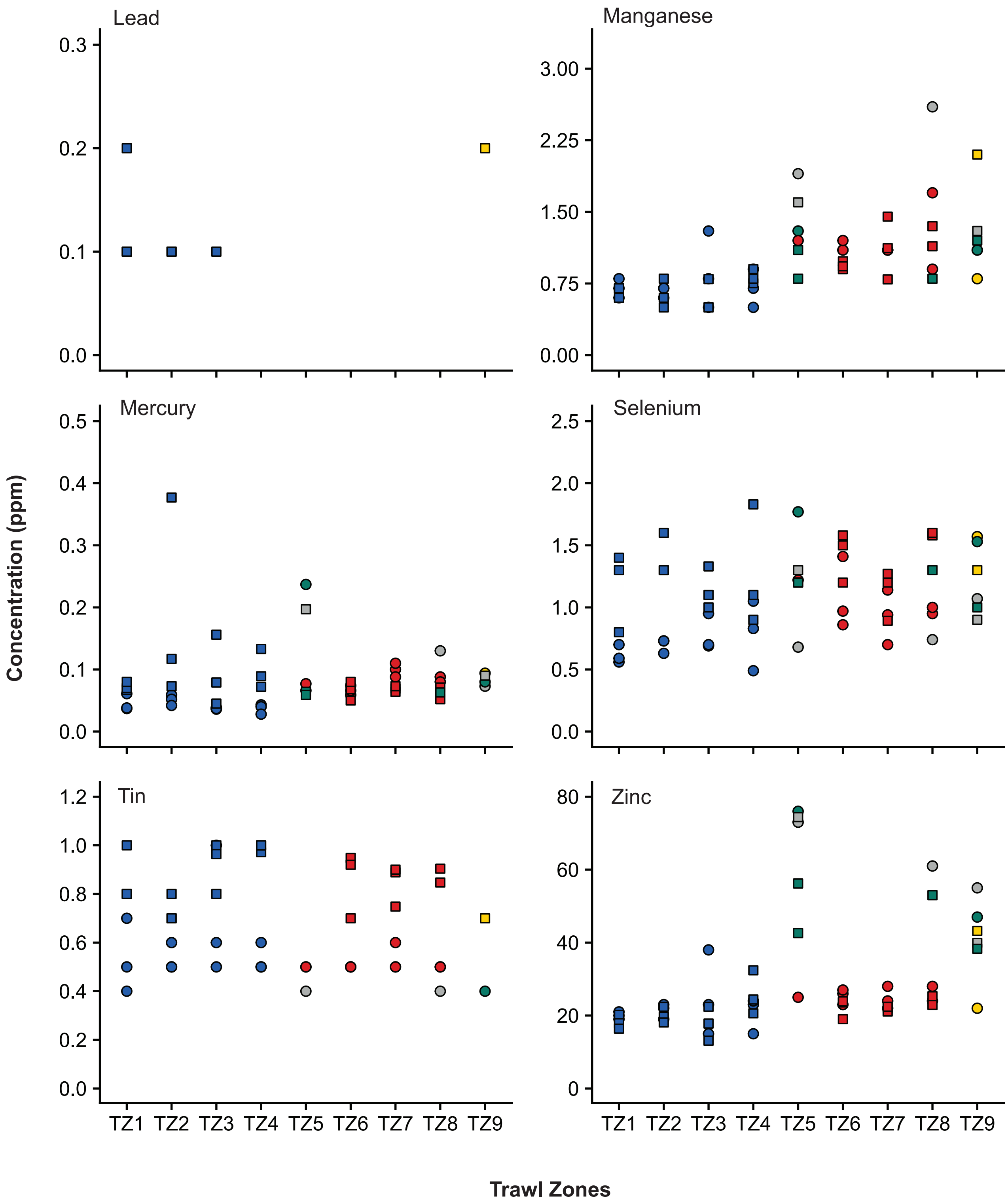

Figure 8.2 *continued*

and endrin aldehyde were not detected in any liver samples from fishes collected during the 2016–2017 surveys. As with metals, intra-species comparisons of frequently occurring pesticides at the nearfield and farfield trawl zones did not illustrate any clear relationships with proximity to the outfall discharge sites, with pesticide concentrations being highly variable across all zones (Figure 8.4).

Only three of the above pesticides have been frequently detected in liver tissues from trawl zone fishes since 1995 (Table 8.5). For example,

Table 8.3

Summary of metals (ppm) in liver tissues of fishes collected from PLOO and SBOO trawl zones from 1995 through 2017. Data include the total number of samples (n), detection rate (DR%), minimum, maximum, and mean[a] detected concentrations for each guild or species; nd = not detected.

		Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
PLOO	Mixed Sanddabs																		
	n	295	295	295	186	295	295	295	295	295	295	295	297	295	296	295	283	295	295
	DR%	66	17	90	66	13	93	66	100	100	18	98	89	19	100	27	27	51	100
	min	nd	nd	nd	nd	nd	nd	nd	0.9	27.0	nd	nd	nd	nd	nd	nd	nd	nd	9
	max	44.6	9.7	123.0	15.20	0.184	19.2	22.8	28.7	233.0	8.8	5.5	0.579	18.9	4.37	2.2	6.4	277.0	74
	mean	12.0	1.4	5.1	0.26	0.018	4.3	0.6	5.4	98.4	0.9	0.8	0.093	0.7	1.15	0.2	1.6	3.9	24
SBOO	California Scorpionfish																		
	n	103	103	103	41	103	103	103	103	103	103	103	105	103	105	103	103	103	103
	DR%	88	12	44	98	10	94	55	100	100	15	87	94	25	100	42	15	26	100
	min	nd	nd	nd	nd	nd	nd	nd	4.1	29.6	nd	nd	nd	nd	0.42	nd	nd	nd	21
	max	59.8	1.7	8.10	0.58	0.057	6.9	5.3	81.1	481.0	8.1	2.5	0.695	2.7	2.82	1.2	5.3	3.4	207
	mean	13.6	0.9	2.3	0.09	0.010	2.6	0.9	22.9	179.2	1.4	0.6	0.175	0.4	0.88	0.3	4.2	1.3	97
	Hornyhead Turbot																		
	n	128	128	128	108	128	128	128	128	128	128	128	128	128	129	128	124	128	128
	DR%	66	9	91	57	5	99	80	100	100	16	99	98	16	99	78	20	60	100
	min	nd	nd	nd	nd	nd	nd	nd	2.3	19.4	nd	nd	nd	nd	nd	nd	nd	nd	23
	max	27.8	1.8	25.0	0.29	0.018	12.0	7.7	24.9	250.0	3.3	2.2	0.407	4.6	3.01	1.3	3.8	88.2	163
	mean	7.0	1.1	4.0	0.06	0.005	3.9	0.4	7.6	53.6	0.6	1.1	0.109	0.5	0.81	0.2	1.7	2.1	61
	Longfin Sanddab																		
	n	150	150	150	103	150	150	150	150	150	150	150	150	150	151	150	142	150	150
	DR%	66	17	84	54	5	91	67	100	100	14	97	86	22	100	45	32	61	100
	min	nd	nd	nd	nd	nd	nd	nd	1.4	33.0	nd	nd	nd	nd	0.27	nd	nd	nd	10
	max	49.0	2.4	12.1	0.54	0.043	9.3	3.6	23.2	449.0	14.3	2.0	0.438	1.6	1.77	1.6	2.7	4.6	109
	mean	12.6	0.9	5.4	0.15	0.015	2.0	0.4	6.2	75.8	1.1	1.0	0.089	0.4	0.88	0.2	0.9	1.4	24

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

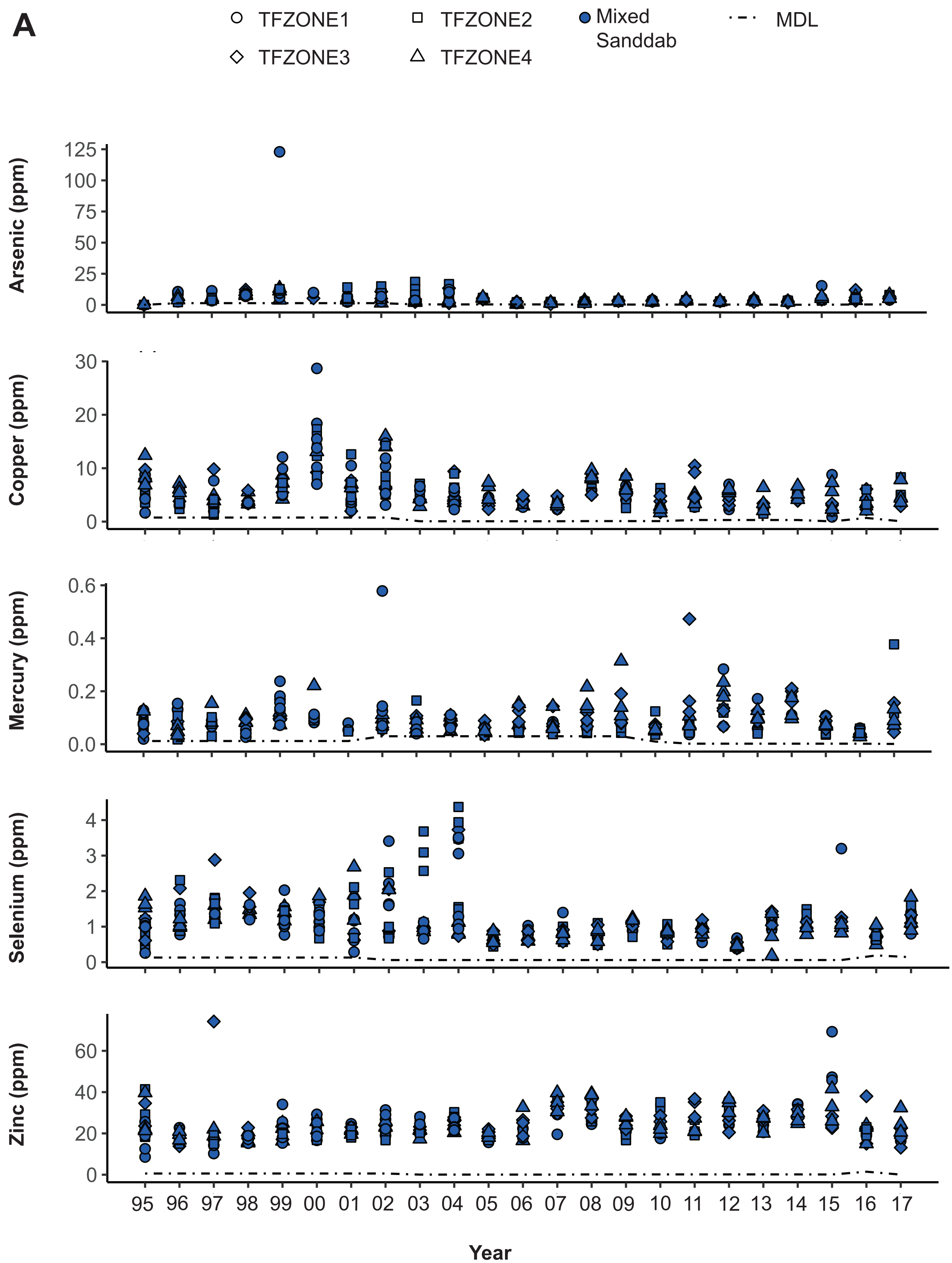

Figure 8.3
Concentrations of select metals in liver tissues of fishes collected from PLOO (A) and SBOO (B) trawl zones from 1995 through 2017. Zones TZ1 and TZ5 are considered nearfield.

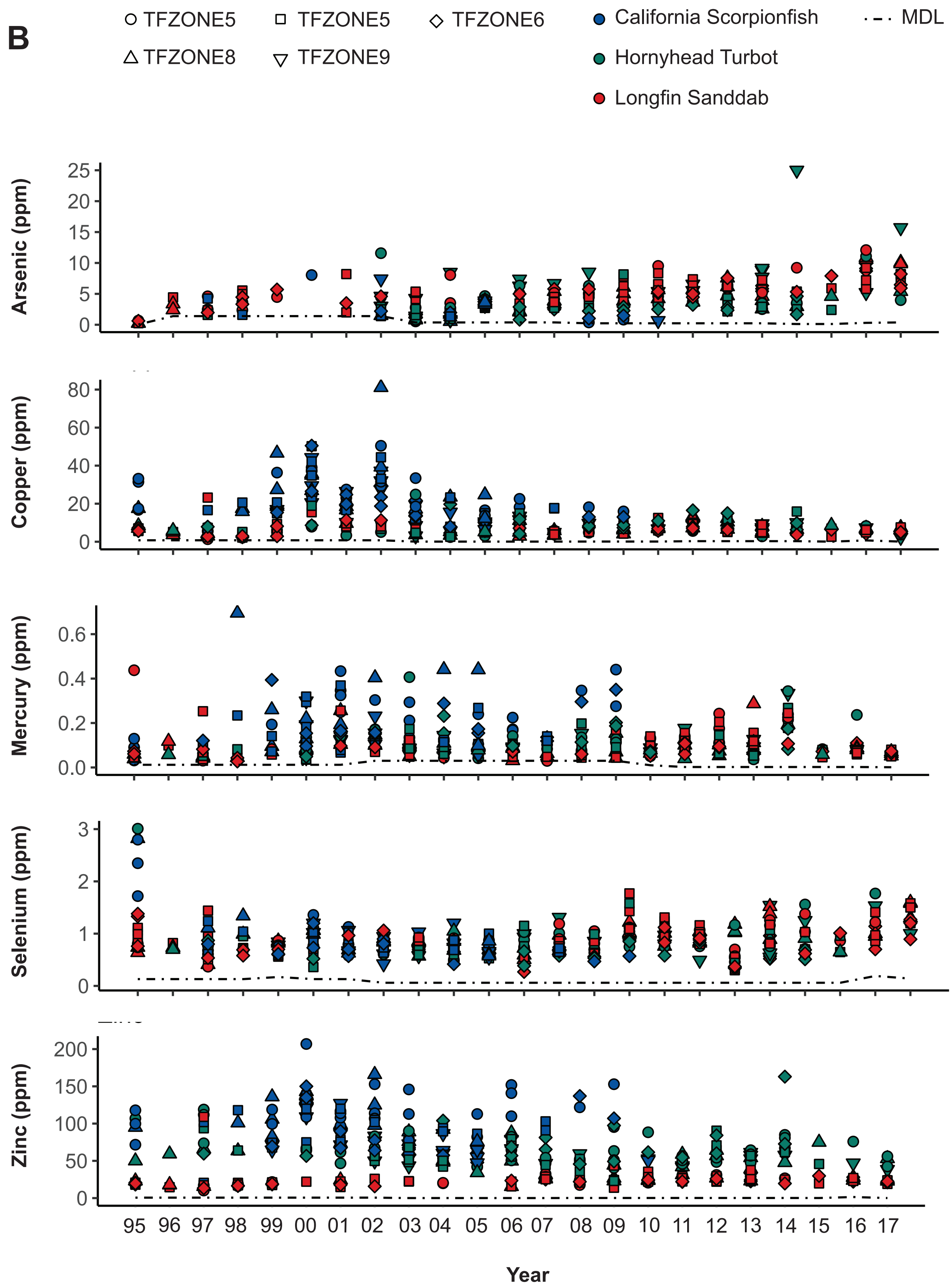

Figure 8.3 *continued*

Table 8.4

Summary of pesticides (ppb), total PCB (ppb), total PAH (ppb), and lipids (% weight) in liver tissues of fishes collected from PLOO and SBOO trawl zones during 2016 and 2017. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations for each species, and the total number of samples, detection rate and maximum value for all species; nd = not detected; EndSul = endosulfan sulfate. See Addendum 8-7 and City of San Diego 2017 for values of individual constituents summed for total chlordane (tChlor), tDDT, tHCH, tPCB, and tPAH.

		Pesticides								
		tChlor	tDDT	EndSul	HCB	tHCH	Mirex	tPCB	tPAH	Lipids
PLOO	Pacific Sanddab									
	n	14	23	0	13	23	5	24	10	24
	Min	nd	275.9	—	7.7	2.00	nd	127.7	nd	32.8
	Max	11.48	693.0	—	120.0	5.33	1.88	705.3	375.5	58.0
	Mean	4.81	430.3	—	21.2	3.39	0.93	315.9	142.9	45.8
	Total Samples	23	23	23	13	23	23	24	12	24
	Detection Rate (%)	61	100	0	100	100	22	100	83	100
	Max	11.48	693.0	—	120	5.33	1.88	705.3	375.5	58.0
SBOO	Fantail Sole									
	n	2	5	0	4	1	0	5	0	5
	Min	nd	14.7	—	0.3	nd	—	9.0	—	1.4
	Max	4.23	50.7	—	215.0	2.12	—	46.1	—	9.9
	Mean	2.36	33.0	—	6.4	2.12	—	26.4	—	5.0
	Hornyhead Turbot									
	n	1	6	0	5	3	0	6	1	6
	Min	nd	25.7	—	0.4	nd	—	12.9	nd	3.8
	Max	0.15	53.5	—	36.1	0.89	—	28.1	330.5	17.2
	Mean	0.15	37.1	—	9.8	0.86	—	18.2	330.5	9.1
	Longfin Sanddab									
	n	14	17	2	13	17	7	16	0	17
	Min	nd	312.4	nd	0.3	0.83	nd	239.6	—	28.8
	Max	9.76	931.8	0.19	20.6	4.85	1.19	564.8	—	48.6
	Mean	4.42	542.2	0.14	8.0	2.49	1.03	406.7	—	39.0
	Spotted Turbot									
	n	2	2	0	1	1	0	2	1	2
	Min	0.08	8.9	—	nd	nd	—	17.6	nd	2.2
	Max	0.67	11.1	—	3.8	0.84	—	22.5	40.8	3.4
	Mean	0.38	10.0	—	3.8	0.84	—	20.0	40.8	2.8
	Total Samples	30	30	30	23	30	30	29	30	30
	Detection Rate (%)	63	100	7	100	73	23	100	7	100
	Max	9.76	931.8	0.19	36.1	4.85	1.19	564.8	330.5	48.6

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

historical detection rates were 99–100% per species for DDT, 50–71% for HCB, and 7–66% for total chlordane over these past 23 years. In contrast, long-term detection rates were 3–12% for total HCH, ≤7% for mirex, ≤3% for endosulfan sulfate and ≤2% for dieldrin, aldrin, endrin, and alpha-endosulfan. Endrin aldehyde and beta-endosulfan have never been detected in any liver tissue samples collected at the PLOO or SBOO stations. As with metals, pesticide

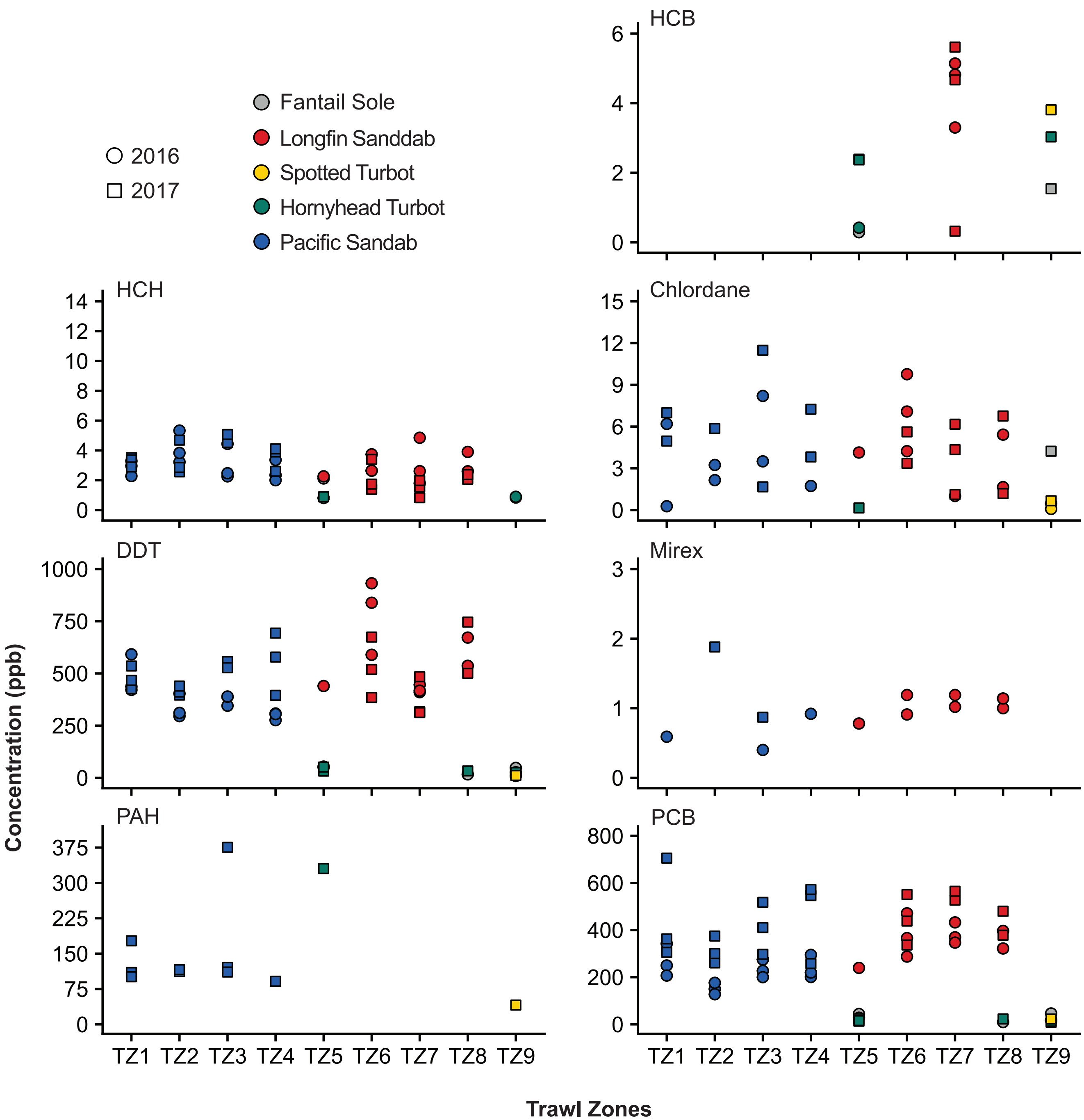

Figure 8.4
Concentrations of pesticides, total PCB and total PAH in liver tissues of fishes collected from each PLOO and SBOO trawl zone during 2016 and 2017. Zones TZ1 and TZ5 are considered nearfield stations.

concentrations have been highly variable over time, with most being detected at levels within ranges reported elsewhere in the SCB (e.g., Allen et al. 1998, 2002, Mearns et al. 1991, LACSD 2016). While high values of various pesticides have been occasionally recorded in liver tissues from nearfield zones, there were no discernible intra-species patterns that could be associated with proximity to either outfall (Figure 8.5, Appendix H.7).

PCBs
PCBs were detected in all liver tissue samples analyzed from flatfishes collected in 2016–2017 (Table 8.4, Addenda 8-4, 8-7, City of San Diego 2017).

Table 8.5

Summary of pesticides (ppb), total PCB (ppb), total PAH (ppb), and lipids (% weight) in liver tissues of fishes collected from PLOO and SBOO trawl zones from 1995 through 2017. Data include total number of samples (n), detection rate (DR%), minimum, maximum, and mean[a] detected concentrations per guild or species; nd = not detected; tChlor = total chlordane; Dield = dieldrin; A-Endo = lpha-endosulfan ; E-Sul = endosulfan sulfate.

		Pesticides												
		Aldrin	tChlor	tDDT	Dield	Endrin	A-Endo	E-Sul	HCB	tHCH	Mirex	tPCB	tPAH	Lipids
PLOO	Mixed Sanddab													
	n	293	304	304	281	281	293	148	294	304	304	305	130	301
	DR%	0	61	99	1	0	0	0	68	10	5	100	9	100
	min	—	nd	nd	nd	—	—	—	nd	nd	nd	35.2	nd	6.9
	max	—	128.00	3800.0	15.8	—	—	—	120.0	22.00	48.00	2978.0	1353.0	69.6
	mean	—	18.78	742.5	14.9	—	—	—	6.4	5.01	5.02	469.6	315.2	37.8
SBOO	California Scorpionfish													
	n	93	93	93	93	93	93	39	93	93	93	107	72	105
	DR%	2	66	100	2	2	2	0	57	3	0	95	0	100
	min	nd	nd	2.6	nd	nd	nd	—	nd	nd	—	nd	—	6.4
	max	19.0	215.80	15,503.0	63.0	66.0	9.6	—	37.3	278.00	—	2187.9	—	45.4
	mean	12.1	20.13	1237.4	38.5	55.0	9.0	—	3.2	142.00	—	362.8	—	19.7
	Hornyhead Turbot													
	n	131	134	134	129	129	131	49	133	134	134	136	119	133
	DR%	0	7	100	0	0	0	0	50	4	0	89	4	100
	min	—	nd	3.5	—	—	—	—	nd	nd	—	nd	nd	0.1
	max	—	32.04	2802.0	—	—	—	—	41.0	5.90	—	841.9	330.5	32.2
	mean	—	9.51	134.7	—	—	—	—	2.9	1.94	—	49.2	156.7	9.6
	Longfin Sanddab													
	n	144	147	147	135	135	144	75	143	147	147	151	123	150
	DR%	0	35	99	0	0	0	3	71	12	7	99	4	100
	min	—	nd	nd	—	—	—	nd	nd	nd	nd	nd	nd	6.2
	max	—	120.00	3600.0	—	—	—	0.2	51.3	4.85	2.00	6781.9	43,167.0	62.4
	mean	—	10.78	695.6	—	—	—	0.1	4.2	2.49	1.25	614.9	8678.3	35.7

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

Total PCB concentrations were highly variable with detected values ranging from 9 to 705 ppb. There were no discernible intra-species patterns that could be associated with proximity to either the PLOO or the SBOO (Figure 8.4). Instead, several of the highest PCB concentrations occurred in Pacific or Longfin Sanddabs from PLOO farfield trawl zones TZ3 and TZ4 and SBOO farfield trawl zones TZ6 and TZ7. Historically, PCBs have been detected in 89–100% of the liver tissue samples analyzed for trawled fishes since 1995, with total PCB concentrations being highly variable but generally within ranges reported elsewhere in the Southern California Bight (e.g., Allen et al. 1998, Mearns et al. 1991, LACSD 2016). There were no discernible intra-species patterns that could be associated with proximity to either outfall over the past 23 years (Table 8.5, Figure 8.5).

PAHs

Detection rates of PAHs were much higher in liver tissue samples from PLOO trawl zones during 2017 (83%) than those from SBOO trawl zones in 2016 and 2017 (7%; Table 8.4, Addenda 8-4, 8-7, City of San Diego 2017). As noted previously, PAHs were not a required parameter for PLOO fishes prior to 2017. Fishes from both outfall regions had total PAH concentrations up 376 ppb. No discernible intra-species patterns in terms of PAHs could be associated with proximity to the PLOO (Figure 8.4). Over the past 23 years, PAHs have been detected in 4–9% of the liver tissue samples from trawled fishes in the SBOO region at highly variable concentrations within ranges reported elsewhere in the SCB (e.g., Allen et al. 1998, Mearns et al. 1991, LACSD 2016), and with no discernible intra-species patterns that could be associated with proximity to the SBOO (Table 8.5, Appendix H.6).

Lipids

Because hydrophobic compounds, including organochlorines like chlorinated pesticides and PCBs, demonstrate high affinity for lipids, differences in the lipid content of tissues between species may be the primary reason for differential organochlorine accumulation (see Groce 2002 and references therein). During 2016 and 2017, lipid levels in liver tissues of Pacific Sanddabs collected from the PLOO region ranged from 33 to 58% weight (Table 8.4). Within the SBOO region, liver lipid levels ranged from 1 to 10% weight for Fantail Sole, from 2 to 3% for Spotted Turbot, from 4 to 17% for Hornyhead Turbot, and from 29 to 49% for Longfin Sanddab. Historically, liver lipid levels ranged from 6 to 70% weight in Longfin and Pacific Sanddabs (also Mixed Sanddabs), 6 to 45% weight in California Scorpionfish, and <1 to 32% weight in Hornyhead Turbot (Table 8.5). The high variability in liver lipid levels likely explains much of the differences within and among species in pesticide and PCB concentrations during the 2016–2017 reporting period as well as over the past 23 years.

Contaminants in Fish Muscle Tissues

Metals

Only three trace metals were detected in all muscle tissue samples from rockfishes collected at PLOO and SBOO rig fishing zones in 2016–2017, including arsenic, mercury, and zinc (Table 8.6, 8.7, Addendum 8-5, City of San Diego 2017). Detection rates per region for other relatively common metals were 92–100% for selenium, and between 17–75% for chromium, cadmium, iron, manganese, and tin. Antimony and barium were detected at rates ≤25% in the muscle tissues of fishes from PLOO rig fishing zones and were undetected in all fishes collected from the SBOO rig fishing zones. In contrast, copper and nickel were detected at rates ≤25% in the muscle tissues of SBOO rockfishes, but were undetected in PLOO rockfishes. Finally, aluminum, beryllium, lead, and silver were not detected in any muscle tissue samples collected during 2016 and 2017. Overall, metal concentrations were highly variable throughout both outfall regions (see Figure 8.6 for select examples), possibly reflecting differences in weight, length, and/or life history of the different species of fish analyzed. Arsenic and selenium exceeded their median international standards in 11 of 12 muscle tissue samples analyzed during the 2016–2017 reporting period.

The results of historical comparisons indicate that detection rates have been relatively high for a number of different metals in muscle tissues from all rig fishing zones since 1995 (Table 8.8). For example, arsenic, copper, iron, mercury, selenium, and zinc have been detected in ≥58% of the samples collected from California Scorpionfish and mixed rockfish samples. Metal concentrations in muscle tissues of San Diego fishes have been highly variable but consistently lower than in liver tissues and within ranges reported elsewhere in the SCB (Mearns et al. 1991, CLA 2015, LACSD 2016, OCSD 2018). Cadmium, copper, lead, tin, and zinc were never found at concentrations above their median international standards. In contrast, 58% of all muscle tissue samples from both outfall regions exceeded the median international standard for arsenic, 51% exceeded the standard for selenium, and 1% exceeded the standard for chromium. None of these samples exceeded the OEHHA fish contaminant goal for selenium. Over the past 23 years, only 17% of the samples exceeded the OEHHA goal for mercury, and only one sample (0.4%) exceeded the mercury USFDA action limit. While relatively high values of various metals have been occasionally recorded in muscle tissues from nearfield zones off San Diego,

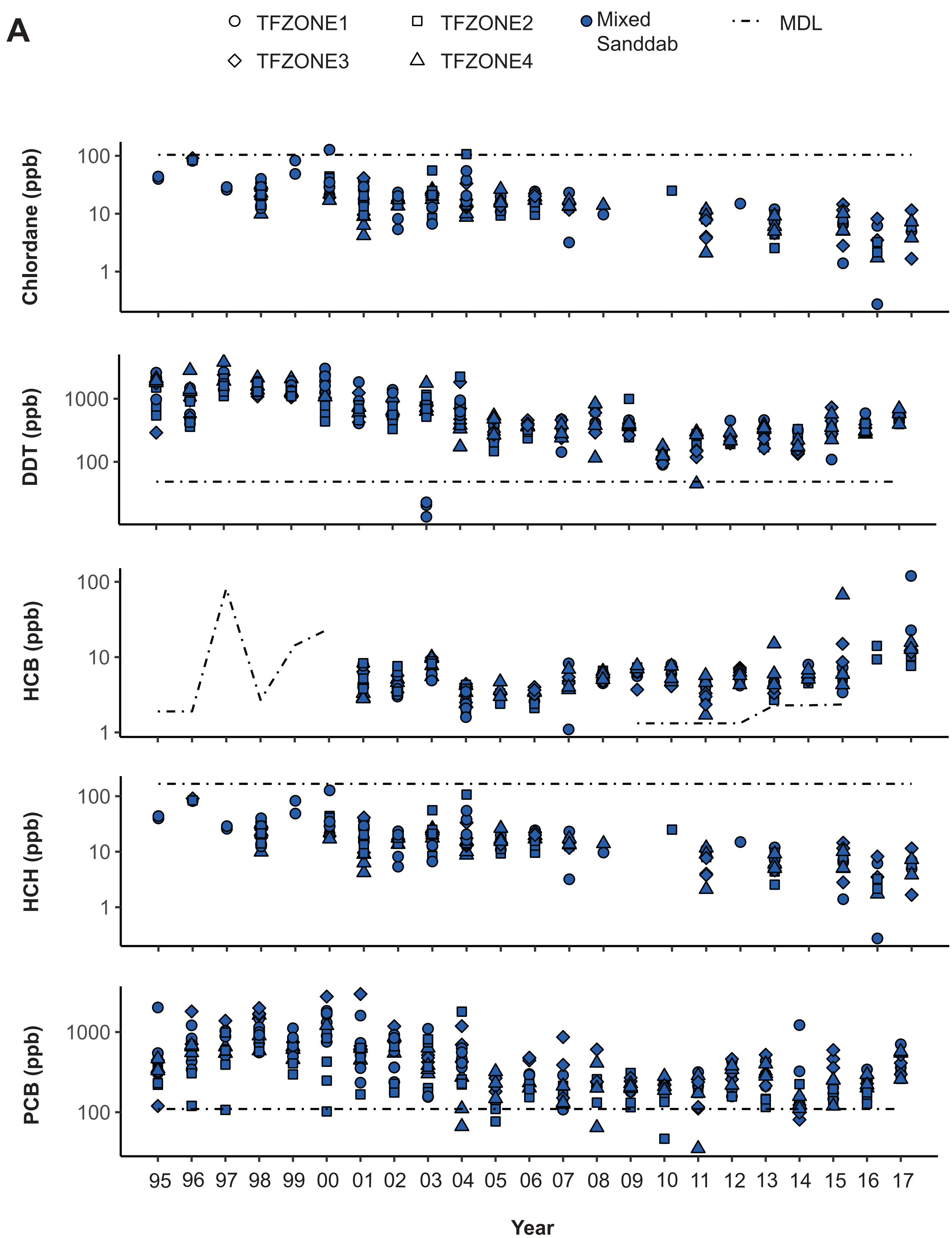

Figure 8.5
Concentrations of pesticides and total PCB in liver tissues of fishes collected from PLOO (A) and SBOO (B) trawl zones from 1995 through 2017. Zones TZ1 and TZ5 are considered nearfield.

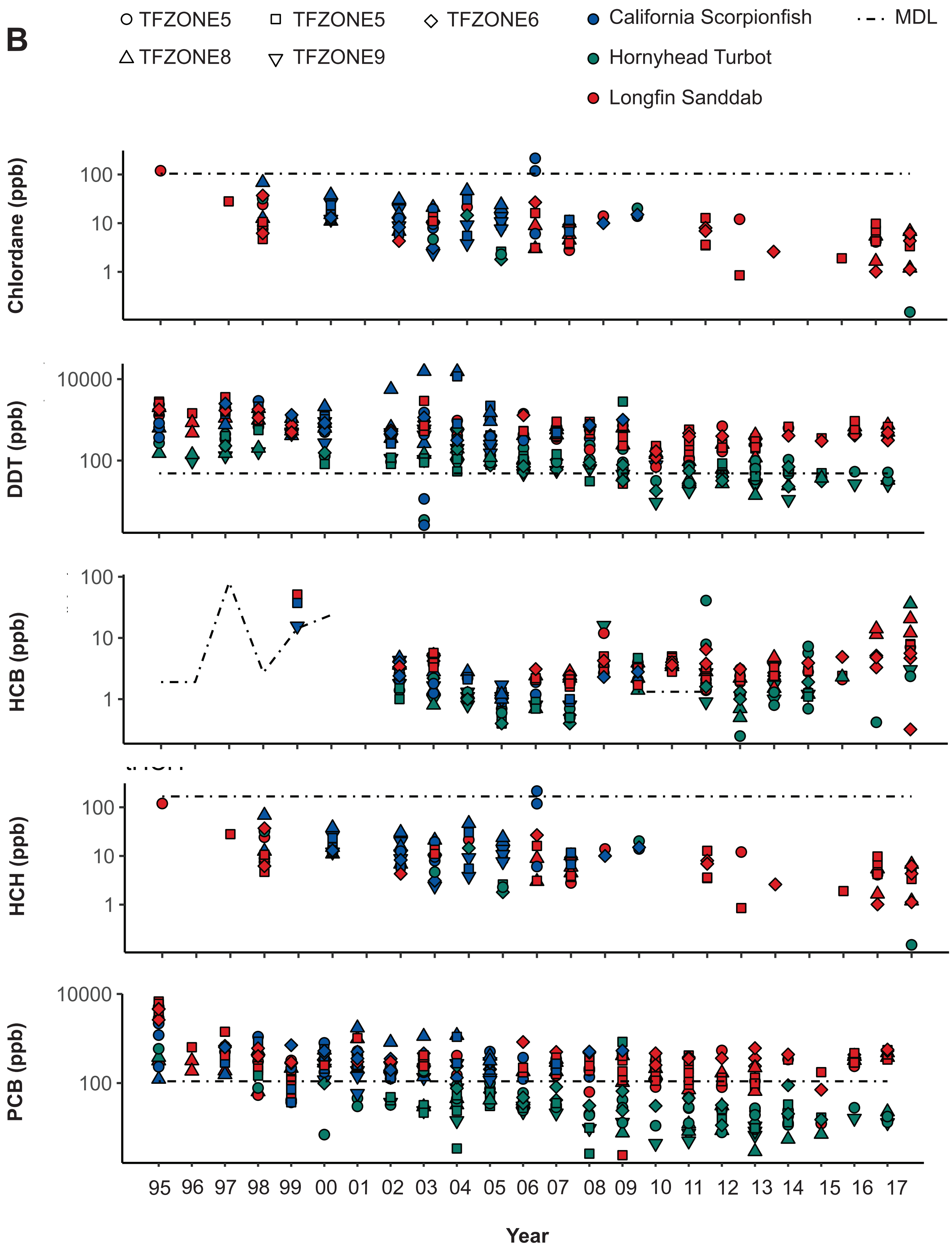

Figure 8.5 *continued*

Table 8.6

Summary of metals (ppm) in muscle tissues of fishes collected from PLOO rig fishing zones during 2016 and 2017. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species and the total number of samples, detection rate, and maximum value for all species; na = not available; nd = not detected; IS = international standard.

	Sb	As	Ba	Cd	Cr	Fe	Mn	Hg	Se	Sn	Zn
Vermilion Rockfish											
n	1	7	1	5	4	4	2	5	7	2	7
Min	nd	3.5	nd	nd	nd	nd	nd	0.027	0.3	nd	3
Max	0.4	9.1	0.14	0.10	0.30	38.0	5.3	0.048	0.7	0.4	4
Mean	0.4	6.7	0.14	0.07	0.12	14.6	3.7	0.043	0.5	0.4	3
Mixed Rockfish											
n	0	4	2	1	1	4	3	4	4	3	4
Min	—	3.0	nd	nd	nd	3.0	nd	0.060	0.4	nd	3
Max	—	5.3	0.11	0.03	0.05	20.0	4.0	0.137	0.7	0.4	4
Mean	—	3.7	0.10	0.03	0.05	13.0	3.8	0.110	0.5	0.4	4
Speckled Rockfish											
n	0	1	0	0	1	1	1	1	1	1	1
Value	—	2.9	—	—	0.30	13.0	4.2	0.136	0.5	0.4	4
Total Samples	12	12	12	12	12	12	12	10	12	12	12
Detection rate(%)	8	100	25	50	50	75	50	100	100	50	100
Max	0.4	9.1	0.14	0.10	0.30	38.0	5.3	0.137	0.7	0.4	4.0
OEHHA[b]	na	na	na	na	na	na	na	0.22	7.4	na	na
USFDA Action Limit[c]	na	na	na	na	na	na	na	1.00	na	na	na
Median IS[c]	na	1.4	na	1.0	1.0	na	na	0.50	0.3	175	70

[a] Minimum and maximum values were based on all samples, whereas means were calculated from detected values only; [b] From the California OEHHA (Klasing and Brodberg 2008); [c] from Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish

there were no discernible patterns at the rig fishing zones that could be associated with proximity to either the PLOO or the SBOO (Figure 8.7, Appendix H.6).

Pesticides

Only DDT (primarily p,p-DDE) was detected in all muscle tissue samples from fishes collected at PLOO and SBOO rig fishing zones in 2016–2017 (Table 8.9, 8.10, Addenda 8-6, 8-7, City of San Diego 2017). Detection rates for total chlordane (alpha (cis) chlordane and/or oxychlordane), HCB, and total HCH (primarily beta-HCH), ranged from 25 to 83% per region. The pesticides (or pesticide constituents) aldrin, alpha-endosulfan, beta-endosulfan, dieldrin, endosulfan sulfate, endrin, endrin aldehyde, and mirex were not detected in any muscle samples from fishes collected during these two years. Additionally, concentrations of DDT, chlordane, HCB, and HCH in muscle tissue samples were variable, substantially lower than in liver tissues, well below available thresholds, and demonstrated no discernible patterns with proximity to either outfall (Figure 8.8).

Historically, only four pesticides have been found in muscle tissues from Barred Sand Bass, California Scorpionfish, and mixed rockfish samples from the PLOO or SBOO rig fishing zones (Table 8.11). Detection rates for DDT ranged from 50 to 95% per species, while rates were 0–58% for HCB, 0–18% for total chlordane, and 0–10% for total HCH. Other pesticides such as aldrin, dieldrin, endrin, endrin aldehyde, alpha-endosulfan, beta-endosulfan, endosulfan sulfate, and mirex have never been

Table 8.7

Summary of metals (ppm) in muscle tissues of fishes collected from SBOO rig fishing zones during 2016 and 2017. Data include the number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the total number of samples, detection rate and maximum value for all species; na = not available; nd = not detected; IS = international standard.

	As	Cd	Cr	Cu	Fe	Mn	Hg	Ni	Se	Sn	Zn
California Scorpionfish											
n	4	3	1	3	4	1	4	1	3	1	4
Min	2.9	nd	nd	0.9	3.0	nd	0.092	nd	nd	nd	3
Max	5.4	0.06	0.09	1.7	6.5	1.9	0.216	0.1	0.5	0.4	4
Mean	4.0	0.05	0.09	1.2	4.8	1.9	0.127	0.1	0.4	0.4	3
Mixed Rockfish											
n	3	1	1	0	2	1	3	0	3	2	3
Min	2.3	nd	nd	—	nd	nd	0.044	—	0.4	nd	3
Max	6.0	0.07	0.05	—	9.5	2.6	0.160	—	0.6	0.5	4
Mean	4.7	0.07	0.05	—	6.8	2.6	0.091	—	0.5	0.5	4
Treefish											
n	3	0	2	0	2	0	3	0	3	2	3
Min	1.3	—	nd	—	nd	—	0.141	—	0.5	nd	3
Max	2.0	—	0.45	—	4.5	—	0.213	—	0.6	0.6	4
Mean	1.7	—	0.43	—	3.8	—	0.173	—	0.6	0.5	4
Gopher Rockfish											
n	1	1	1	0	0	0	1	0	1	0	1
Value	2.9	0.04	0.06	—	—	—	0.088	—	0.5	—	4
Starry Rockfish											
n	1	0	1	0	1	0	1	0	1	1	1
Value	1.6	—	0.70	–	4.5	—	0.152	—	0.6	0.4	3
Total Samples	12	12	12	12	12	12	12	12	12	12	12
Detection Rate (%)	100	42	50	25	75	17	100	8	92	50	100
Max	6.0	0.07	0.7	1.7	9.5	2.6	0.216	0.1	0.6	0.6	4
OEHHA[b]	na	na	na	na	na	na	0.22	na	7.4	na	na
USFDA Action Limit[c]	na	na	na	na	na	na	1.00	na	na	na	na
Median IS[c]	1.4	1.0	1.0	20	na	na	0.50	na	0.3	175	70

[a] Minimum and maximum values were based on all samples, whereas means were calculated from detected values only; [b] From the California OEHHA (Klasing and Brodberg 2008); [c] from Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish

detected in muscle tissues from these species collected in the PLOO or SBOO regions since 1995. During this time, pesticides also typically occurred in lower concentrations in muscle tissues compared to liver tissue, and most were detected at levels within ranges reported elsewhere in the SCB (e.g., Allen et al. 1998, 2002, Mearns et al. 1991, CLA 2015). Additionally, there were no discernible patterns that could be associated with proximity to either outfall over the past 23 years (Figure 8.9, Appendix H.7). DDT concentrations greater than OEHHA fish contaminant goals were limited to 13% of the muscle tissue samples from the PLOO region. All samples from the SBOO region were below this threshold for DDT, and all samples from both regions were below USFDA action limits. Chlordane never exceeded its OEHHA contaminant goal or USFDA action limit in either region.

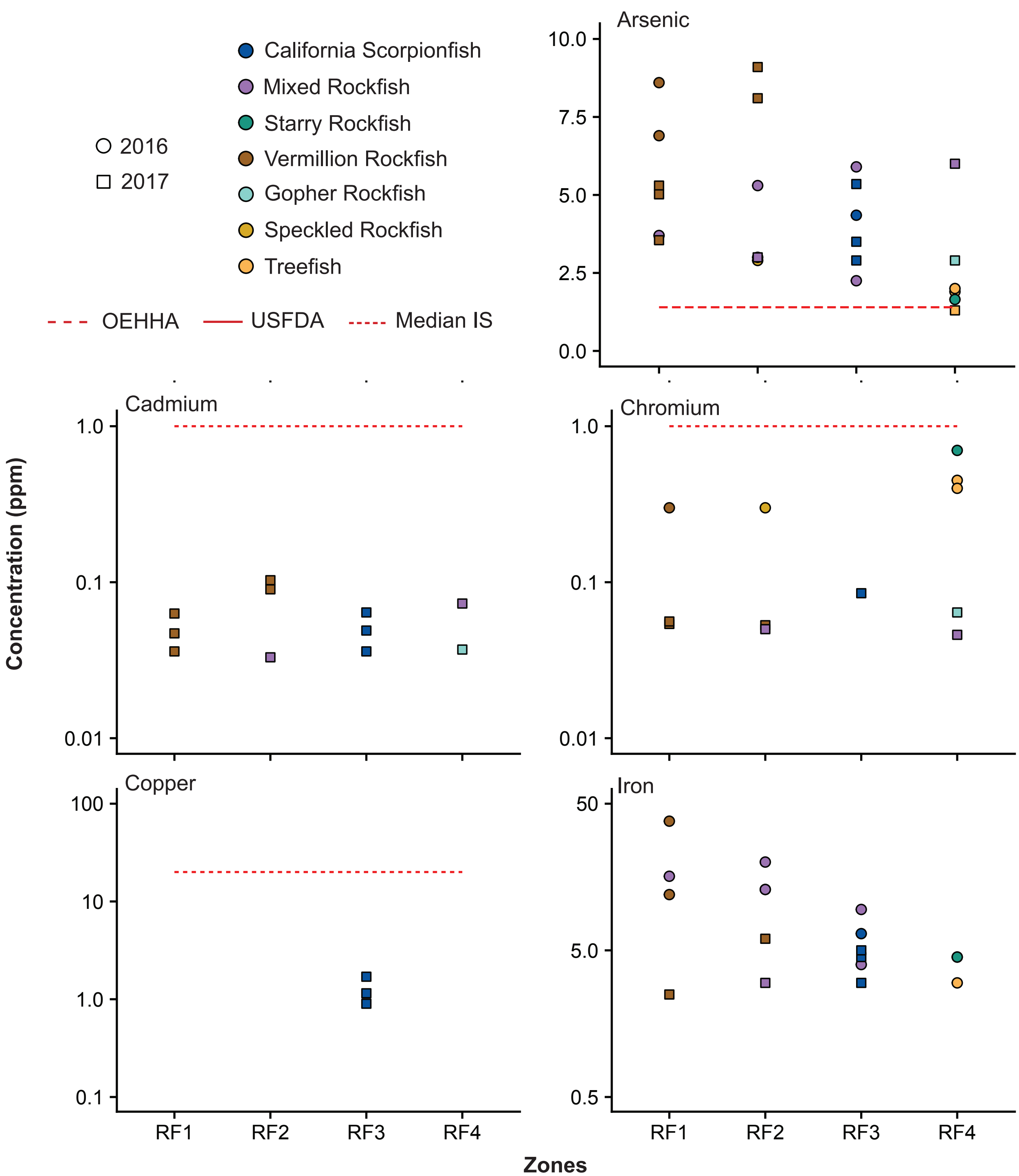

Figure 8.6
Concentrations of metals with detection rates ≥20% in muscle tissues of fishes collected from each rig fishing zone during 2016 and 2017. See Table 8.3 for thresholds. Zones RF1 and RF3 are considered nearfield.

PCBs
PCBs were detected in all muscle tissue samples from fishes collected at PLOO and SBOO rig fishing zones in 2016–2017 (Table 8.9, 8.10, Addenda 8-6, 8-7, City of San Diego 2017). Total PCB concentrations were low overall, falling below the OEHHA threshold of 3.6 ppb, and varied across all four rig fishing zones with no discernible patterns that could be associated with proximity to either the PLOO or the SBOO (Figure 8.8). Historically, PCB muscle tissue detection rates were 72–77% per species, with highly variable concentrations

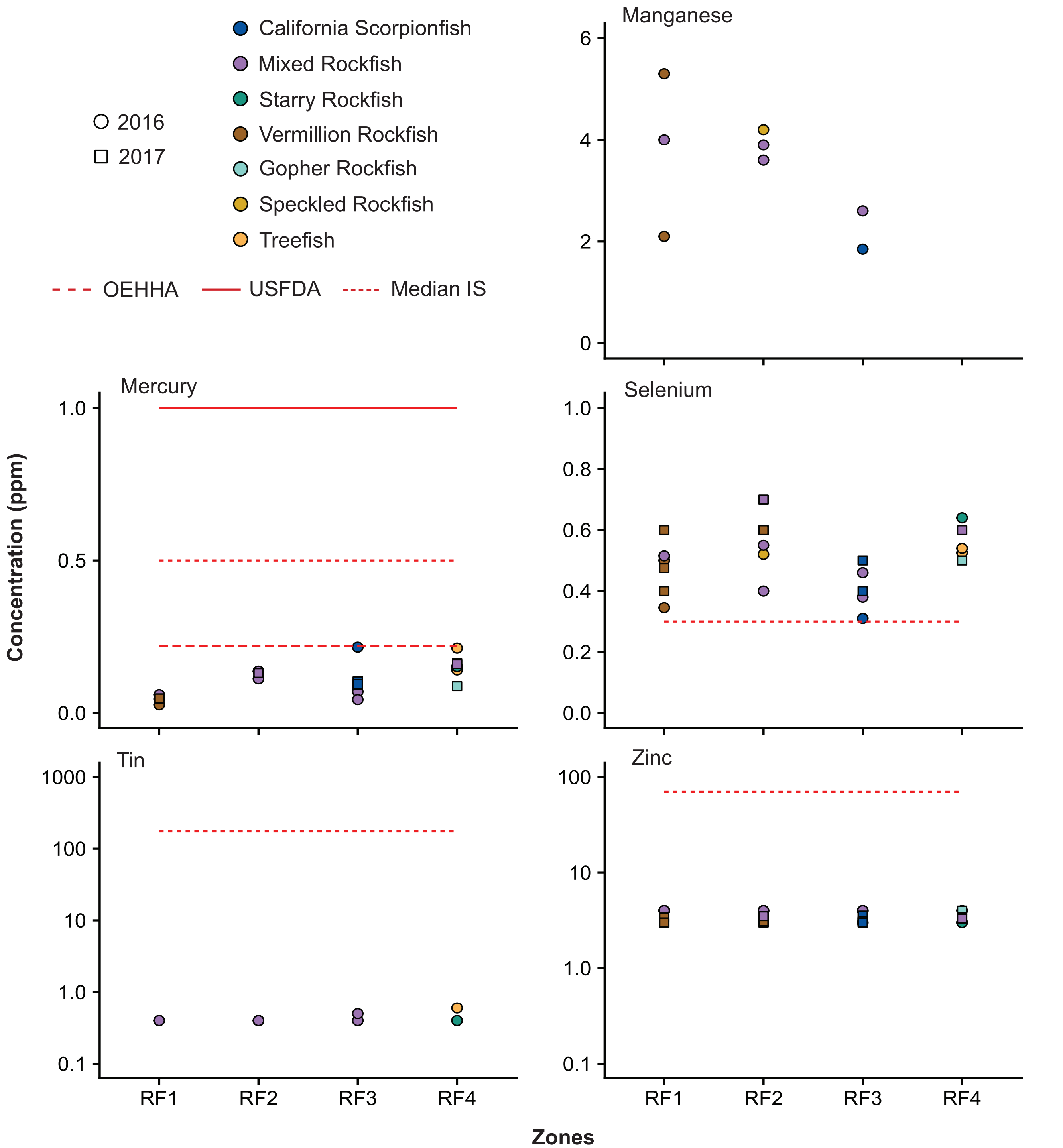

Figure 8.6 *continued*

falling within ranges reported elsewhere in the SCB (e.g., Allen et al. 2002, Mearns et al. 1991, LACSD 2016, OCSD 2018) and with no discernible patterns that could be associated with proximity to either outfall (Table 8.11, Figure 8.9). Of the 274 muscle tissues samples analyzed for PCBs over the past 23 years, only 22% exceeded the OEHHA fish contaminant goal for total PCB.

PAHs

PAHs were detected in 50% of the muscle tissue samples collected from the PLOO rig fishing zones in 2017 at concentrations up to 360 ppb (Table 8.9, 8.10, Addenda 8-6, 8-7, City of San Diego 2017). In contrast, PAH detection rates and concentrations were lower in muscle tissues from the SBOO rig fishing zones, occurring in 25% of the samples at

Table 8.8

Summary of metals (ppm) in muscle tissues of fishes collected from PLOO and SBOO rig fishing zones from 1995 through 2017. Data include the total number of samples (n), detection rate (DR%), minimum, maximum, and mean[a] detected concentrations for each guild or species; nd = not detected; AL = USFDA action limits; MIS = median international standard.

		Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
PLOO	Mixed Rockfish																		
	n	124	124	124	85	124	124	124	124	124	124	124	122	124	124	124	118	124	124
	DR%	40	10	83	51	2	20	54	58	75	3	40	96	10	99	6	15	39	99
	min	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	max	22.1	1.1	13.5	0.19	0.042	0.18	1.78	9.0	38.0	0.4	5.3	0.790	0.4	0.7	0.50	2.9	2.1	6
	mean	6.4	0.6	2.6	0.06	0.016	0.07	0.27	1.1	5.1	0.3	0.6	0.162	0.2	0.4	0.12	1.3	1.0	4
SBOO	Barred Sand Bass																		
	n	4	4	4	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	DR%	0	0	0	—	0	0	0	0	100	0	0	100	0	75	0	0	0	75
	min	—	—	—	—	—	—	—	—	3.2	—	—	0.230	—	nd	—	—	—	nd
	max	—	—	—	—	—	—	—	—	6.7	—	—	0.362	—	0.7	—	—	—	5
	mean	—	—	—	—	—	—	—	—	4.6	—	—	0.294	—	0.7	—	—	—	4
	California Scorpionfish																		
	n	71	71	71	38	71	71	71	71	71	71	71	71	71	71	71	68	71	71
	DR%	44	1	69	47	6	14	44	65	77	6	28.2	96	6	93	4	21	27	100
	min	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	2
	max	19.4	0.2	5.4	0.15	0.025	0.08	2.21	5.1	21.2	0.4	1.9	1.540	0.2	0.6	0.11	2.7	2.0	7
	mean	6.5	0.2	2.4	0.06	0.013	0.05	0.29	1.2	5.6	0.3	0.2	0.200	0.1	0.3	0.09	1.1	0.9	4
	Mixed Rockfish																		
	n	56	56	56	47	56	56	56	56	56	56	56	56	56	56	56	54	56	56
	DR%	36	16	91	55	0	21	79	71	70	4	54	95	16	100	4	26	54	100
	min	nd	nd	nd	nd	—	nd	nd	nd	nd	nd	nd	nd	nd	0.1	nd	nd	nd	1
	max	16.1	1.6	11.2	0.20	—	0.20	0.81	3.8	9.5	0.4	2.6	0.330	0.7	0.7	0.07	2.9	2.4	6
	mean	5.6	0.8	2.3	0.06	—	0.11	0.27	0.7	3.67	0.4	0.2	0.099	0.2	0.3	0.07	1.1	1.0	4
OEHHA[b]		na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
AL[c]		na	na	na	na	na	na	na	na	na	na	na	1	na	na	na	na	na	na
MIS[c]		na	na	1.4	na	na	1.0	1.0	20	na	2	na	0.50	na	0.3	na	na	175	70

[a]Minimum and maximum values were based on all samples, whereas means were calculated from detected values only; [b]From the California OEHHA (Klasing and Brodberg 2008) ;[c]from Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish

concentrations up to 22.7 ppb. The highest PAH values were recorded in two samples from PLOO farfield zone RF2 (Figure 8.8). Historically, PAHs were detected in ≤6% of the muscle tissue samples from Barred Sand Bass, California Scorpionfish, and mixed rockfish collected since 1995. Concentrations of PAHs have been highly variable and within ranges reported elsewhere in the SCB (e.g., Mearns et al. 1991), with no discernible patterns that could be associated with proximity to either outfall (Table 8.11, Figure 8.9).

Lipids

During 2016 and 2017, lipid levels in fish muscle tissue samples from PLOO and SBOO rig fishing zones were generally much lower than levels found in liver tissues during the same period, which is similar to historical patterns observed since 1995 (Tables 8.4, 8.9, 8.10, 8.11). Speckled Rockfish had the lowest lipid content during the 2016–2017 reporting period at just 0.17% weight for one sample collected from the PLOO region. Lipid content was also ≤0.9% weight in samples of California Scorpionfish, Gopher Rockfish, Mixed Rockfish, and Starry Rockfish from PLOO and/or SBOO regions. Only Treefish and Vermilion Rockfish had lipid levels at ~1% (1.02 and 1.04% weight, respectively). These low lipid concentrations indicate that these species do not store fat in their muscle tissues, which likely explains some of the generally lower levels of contaminants found in these tissues.

Discussion

Several trace metals, pesticides, PCBs, and PAHs were detected in liver tissues from various fish species collected in the Point Loma and South Bay outfall regions in 2016–2017. Many of the same metals, pesticides, PCBs and PAHs were also detected in California Scorpionfish and rockfish muscle tissues during the current reporting period, although generally less frequently and/or in lower concentrations. Although tissue contaminant concentrations varied among different species of fish and between stations, most values were within ranges reported previously for southern California fishes (e.g., Mearns et al. 1991, Allen et al. 1998, 2002, CLA 2015, LACSD 2016, OCSD 2018). Over the past two annual surveys, arsenic and selenium were found to exceed their median international standards for human consumption in 92% of the muscle tissue samples from sport fish collected in the PLOO and SBOO regions. In contrast, all muscle tissue samples of local San Diego fishes had concentrations of mercury, total chlordane, and total DDT below USFDA action limits. Historically, elevated levels of such contaminants have remained uncommon in sport fish captured in both survey areas.

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

Other factors that affect contaminant loading in fish tissues include the physiology and life history of different species (see Groce 2002 and references therein). Exposure to contaminants can also vary greatly between different species of fish and among individuals of the same species depending on migration habits (Otway 1991). Fishes may be exposed to contaminants in a highly polluted area and then move into an area that is not. For example, California Scorpionfish tagged in Santa Monica Bay have been recaptured as far south as the Coronado Islands (Hartmann 1987, Love et al. 1987). This is of particular concern for fishes collected in the vicinity of the PLOO and the SBOO, as there are many point and non-point sources that may contribute to local contamination in the region, including the San Diego River,

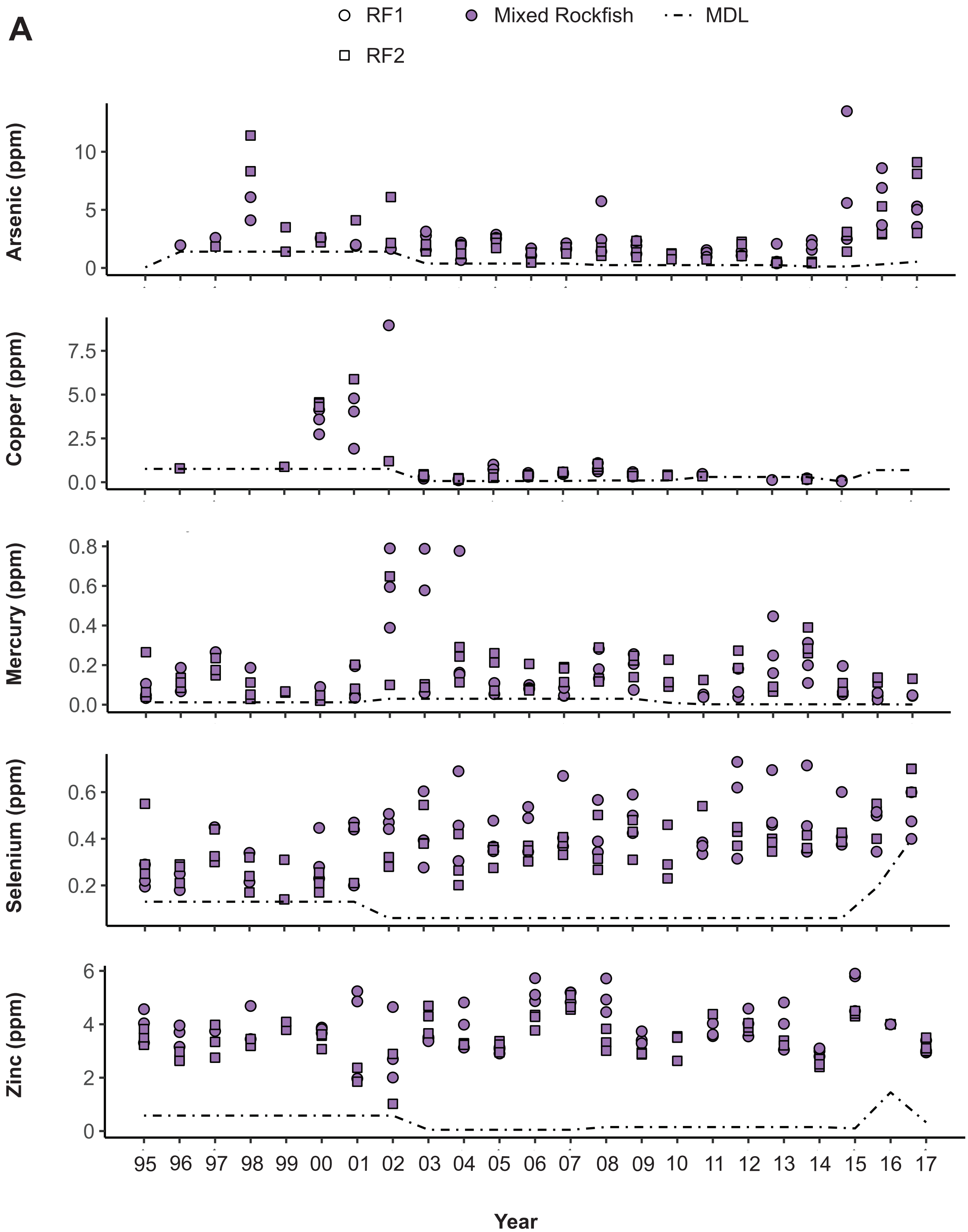

Figure 8.7
Concentrations of select metals with detection rates in muscle tissues of fishes collected from PLOO (A) and SBOO (B) rig fishing zones from 1995 through 2017. Zones RF1 and RF3 are considered nearfield.

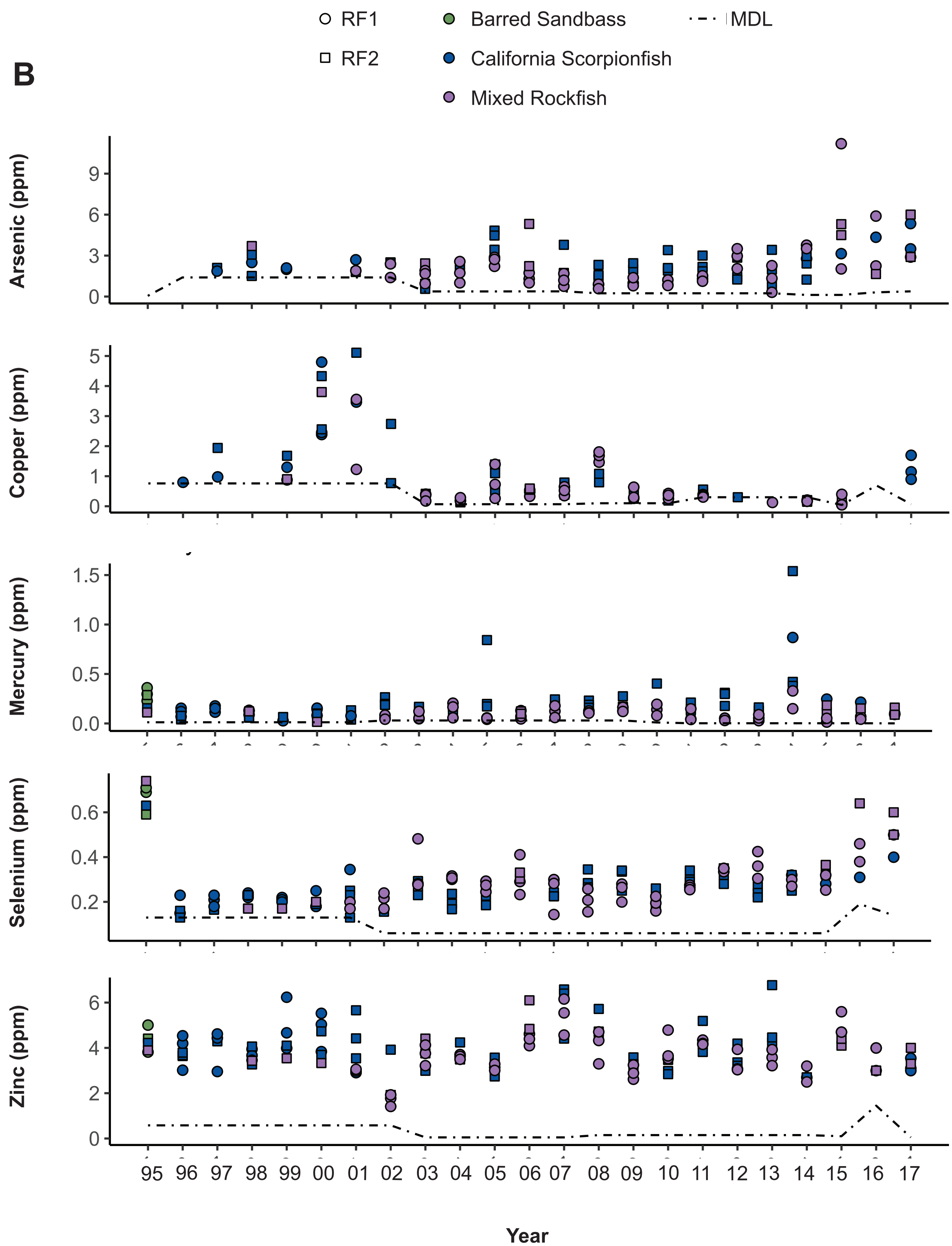

Figure 8.7 *continued*

Table 8.9

Summary of pesticides (ppb), total PCB (ppb), total PAH (ppb), and lipids (% weight) in muscle tissues of fishes collected from PLOO rig fishing stations during 2016 and 2017. Data include number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the total number of samples, detection rate and maximum value for all species; nd = not detected; na = not available; IS = international standard.

	Pesticides						
	tChlor	tDDT	HCB	tHCH	tPCB	tPAH	Lipids
Vermilion Rockfish							
n	3	7	4	7	7	2	7
Min	nd	0.3	nd	0.08	0.3	nd	0.3
Max	0.14	5.6	1.0	0.15	2.5	168.3	1.0
Mean	0.06	2.5	0.6	0.10	1.4	91.3	0.4
Mixed Rockfish							
n	0	4	1	2	4	1	4
Min	—	0.7	nd	nd	0.6	nd	0.3
Max	—	5.3	0.8	0.19	3.0	360.1	0.7
Mean	—	2.1	0.8	0.14	1.3	360.1	0.5
Speckled Rockfish							
n	0	1	0	1	1	0	1
Value	—	0.3	—	0.04	0.2	—	0.2
Total Samples	12	12	6	12	12	6	12
Detection Rate (%)	25	100	83	83	100	50	100
Max	0.06	5.6	1.0	0.19	3.0	360.1	1.0
OEHHA[b]	5.6	21	na	na	3.6	na	—
USFDA Action Limit[c]	300	5000	na	na	na	na	—
Median IS[c]	100	5000	na	na	na	na	—

[a] Minimum and maximum values were based on all samples, whereas means were calculated from detected values only; [b] From the California OEHHA (Klasing and Brodberg 2008) ;[c] from Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish

San Diego Bay, Tijuana River, and offshore dredged material disposal sites (see Chapters 2–4 and Parnell et al. 2008). In contrast, assessments of contaminant loading in San Diego offshore sediments have revealed no evidence to indicate that the PLOO or SBOO are major sources of pollutants in the region (see Chapters 4, 6, and Parnell et al. 2008).

Overall, there was no evidence of contaminant accumulation in PLOO or SBOO fishes during the 2016–2017 reporting period that could be associated with wastewater discharge from either outfall, which is consistent with historical findings. Concentrations of most contaminants were generally similar across trawl or rig fishing zones, and no relationships relevant to the PLOO or SBOO were evident. These results are consistent with findings of other assessments of bioaccumulation in fishes off San Diego (City of San Diego 2007, 2015, Parnell et al. 2008). Finally, there were no other indications of poor fish health in the region, such as the presence of fin rot or other indicators of disease (see Chapter 7).

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Table 8.10

Summary of pesticides (ppb), total PCB (ppb), total PAH (ppb), and lipids (% weight) in muscle tissues of fishes collected from SBOO rig fishing stations during 2016 and 2017. Data include number of detected values (n), minimum, maximum, and mean[a] detected concentrations per species, and the total number of samples, detection rate and maximum value for all species; nd = not detected; na = not available; IS = international standard.

	Pesticides						
	tChlor	tDDT	HCB	tHCH	tPCB	tPAH	Lipids
California Scorpionfish							
n	1	4	2	1	4	1	4
Min	nd	1.5	nd	nd	1.6	nd	0.3
Max	0.01	3.4	0.3	0.02	2.7	22.7	0.7
Mean	0.01	2.6	0.3	0.02	2.1	22.7	0.6
Mixed Rockfish							
n	2	3	1	2	3	1	3
Min	nd	0.3	nd	nd	0.2	nd	0.3
Max	0.07	3.0	0.1	0.07	2.9	15.2	0.9
Mean	0.07	1.3	0.1	0.06	1.2	15.2	0.5
Treefish							
n	0	3	0	2	3	1	3
Min	—	0.4	—	nd	0.2	nd	0.3
Max	—	6.5	—	0.10	2.7	15.0	1.0
Mean	—	2.6	—	0.07	1.1	15.0	0.6
Gopher Rockfish							
n	0	1	0	1	1	0	1
Value	—	1.6	—	0.06	1.1	—	0.8
Starry Rockfish							
n	0	1	0	1	1	0	1
Value	—	0.5	—	0.14	0.2	—	0.2
Total Samples	12	12	6	12	12	12	12
Detection Rate (%)	25	100	50	58	100	25	100
Max	0.07	6.5	0.3	0.14	2.9	22.7	1.0
OEHHA[b]	5.6	21	na	na	3.6	na	—
USFDA Action Limit[c]	na	5000	300	na	na	na	—
Median IS[c]	100	5000	100	na	na	na	—

[a] Minimum and maximum values were based on all samples, whereas means were calculated from detected values only; [b] From the California OEHHA (Klasing and Brodberg 2008); [c] from Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish

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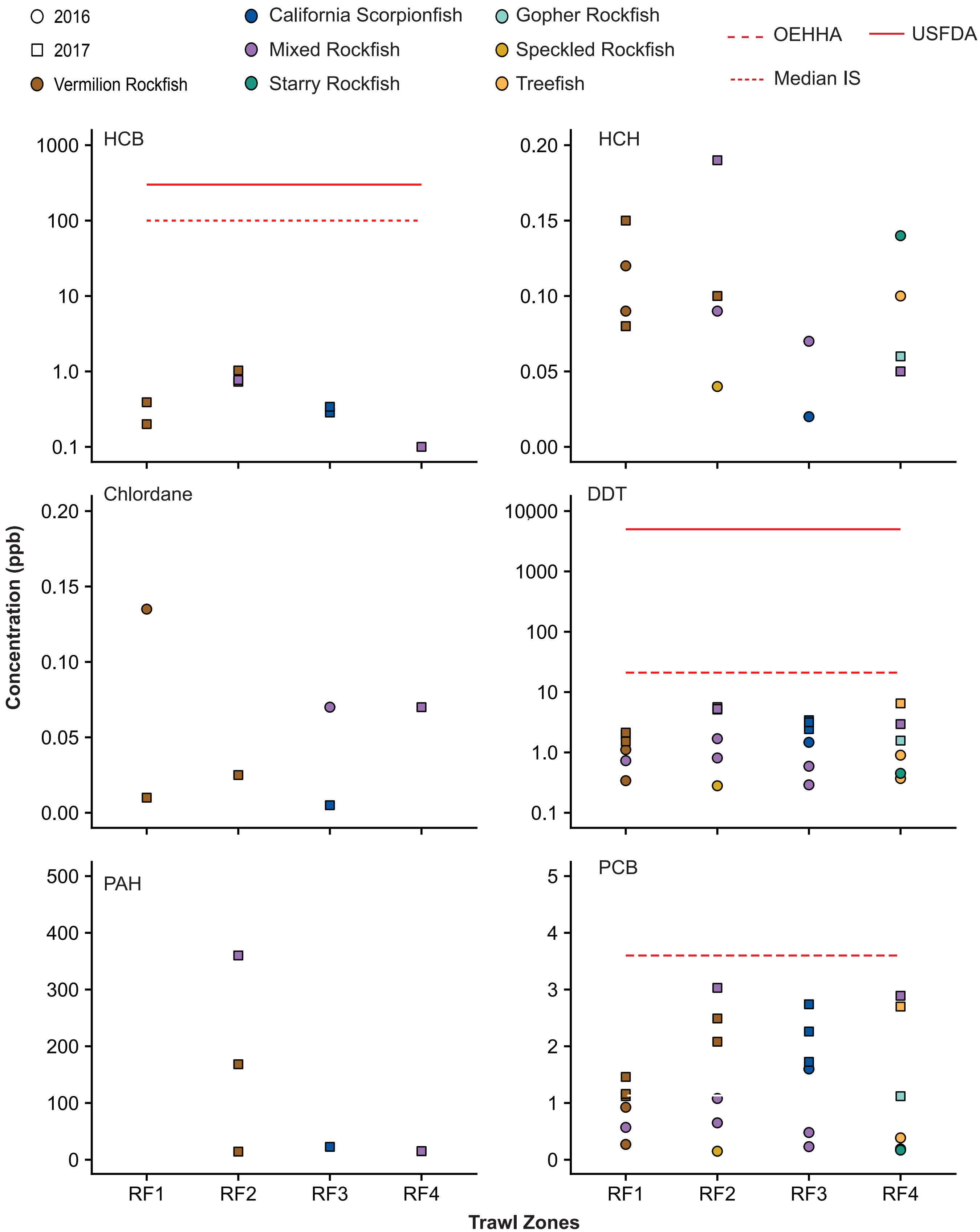

Figure 8.8
Concentrations of pesticides, total PCB and total PAH in muscle tissues of fishes collected from each PLOO and SBOO trawl zone during 2016 and 2017. Zones RF1 and RF3 are considered nearfield.

Table 8.11

Summary of pesticides (ppb), total PCB (ppb), total PAH (ppb), and lipids (% weight) in muscle tissues of fishes collected from PLOO and SBOO rig fishing zones from 1995 through 2017. Data include total number of samples (n), detection rate (DR%), minimum, maximum, and mean[a] detected concentrations per species; nd = not detected; na = not available; IS = international standard.

		Pesticides						
		tChlor	tDDT	HCB	tHCH	tPCB	tPAH	Lipids
PLOO	Mixed Rockfish							
	n	124	124	118	124	124	51	124
	DR (%)	18	95	58	10	75	6	99
	min	nd	nd	nd	nd	nd	nd	nd
	max	4.30	217.3	15.0	13.40	76.8	360.1	4.4
	mean	1.02	14.0	0.5	1.25	7.4	180.9	0.9
SBOO	Barred Sand Bass							
	n	4	4	4	4	4	4	4
	DR (%)	0	50	0	0	75	0	100
	min	—	nd	nd	nd	nd	—	0.7
	max	—	13.0	nd	nd	32.0	—	1.4
	mean	—	9.6	nd	nd	20.0	—	1.0
	California Scorpionfish							
	n	67	67	66	67	71	50	71
	DR (%)	3	94	20	3	72	2	100
	min	nd	nd	nd	nd	nd	nd	0.1
	max	1.00	195.7	0.4	0.02	49.3	22.7	2.6
	mean	0.50	18.3	0.2	0.02	4.6	22.7	0.7
	Mixed Rockfish							
	n	54	54	51	54	56	52	56
	DR (%)	7	83	43	7	77	4	100
	min	nd	nd	nd	nd	nd	nd	0.1
	max	0.20	15.1	7.2	0.90	5.6	35.0	3.0
	mean	0.14	3.5	0.5	0.35	1.2	25.1	0.6
OEHHA[b]		na	21	na	na	3.6	na	—
USFDA Action Limits[c]		300	5000	300	na	na	na	—
Median IS[c]		100	5000	100	na	na	na	—

[a] Minimum and maximum values were based on all samples, whereas means were calculated from detected values only; [b] From the California OEHHA (Klasing and Brodberg 2008); [c] from Mearns et al. 1991. USFDA action limits for mercury and all international standards are for shellfish, but are often applied to fish

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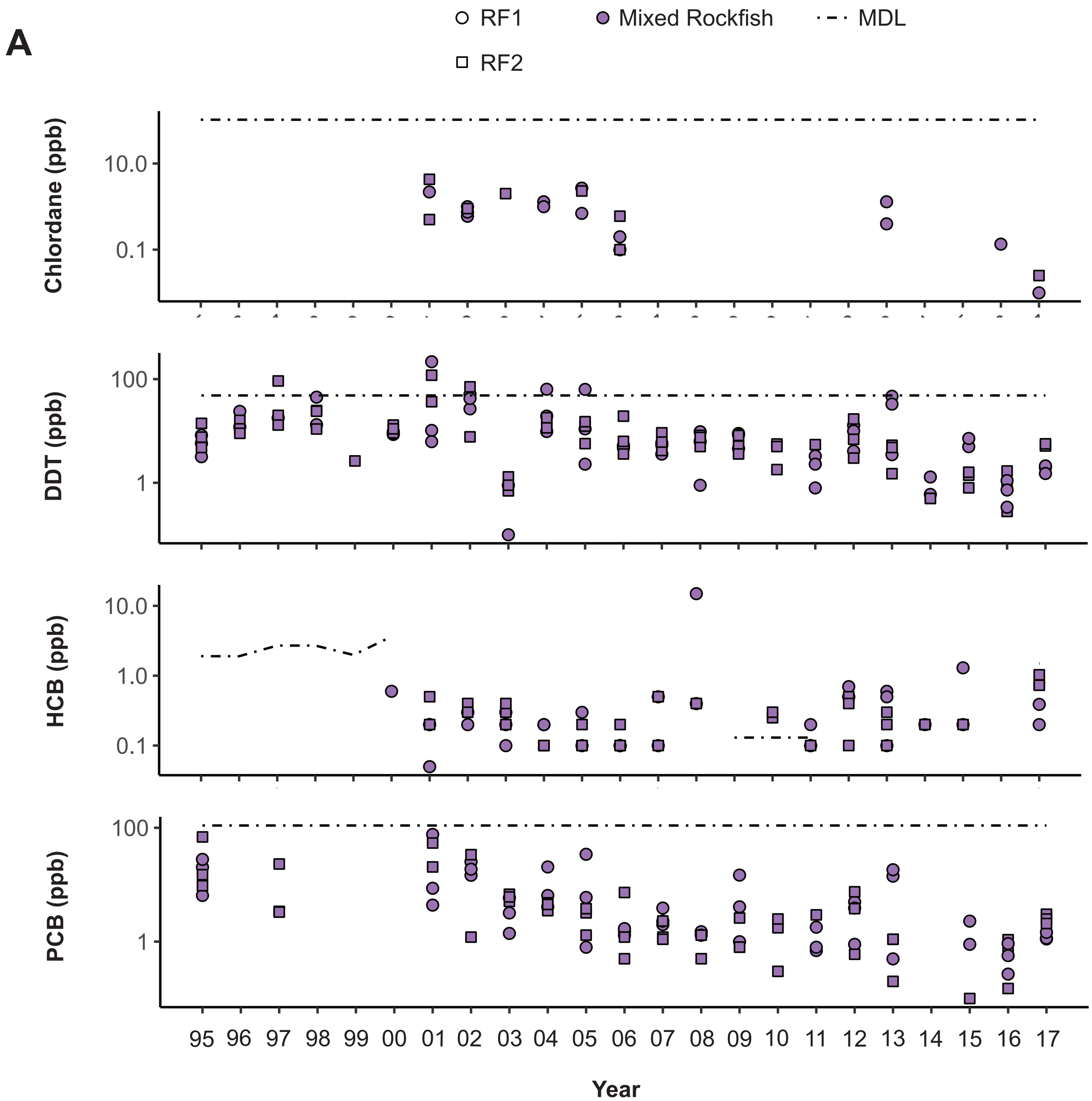

Figure 8.9
Concentrations of pesticides and total PCB in muscle tissues of fishes collected from PLOO (A) and SBOO (B) rig fishing zones from 1995 through 2017. Zones RF1 and RF3 are considered nearfield.

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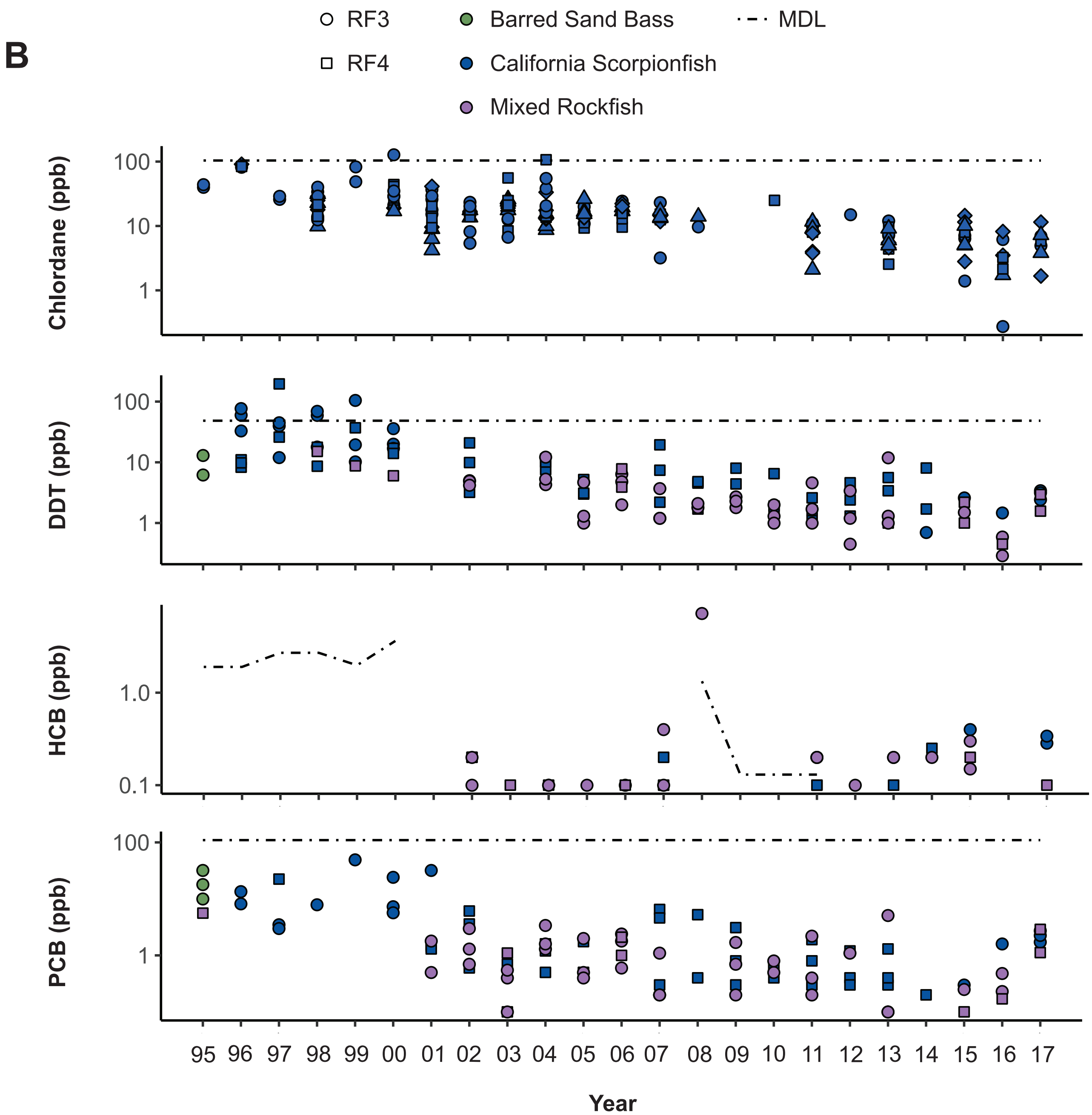

Figure 8.9 *continued*

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Appendices

Appendix A

Status and Trends of San Diego Kelp Forests

2016 – 2017

Status and Trends of San Diego Kelp Forests, 2016-2017

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Submitted to City of San Diego
Public Utilities Department
Contract No. H146233

March 29, 2018

Executive Summary

The kelp forests off La Jolla and Point Loma are the largest contiguous kelp forests off the western coast of the United States. They host complex marine communities supported by their eponymous species, the giant kelp *Macrocystis pyrifera*, which provides structure and food for hundreds of species of marine fishes and invertebrates. Kelp forests off southern California are subjected to both natural and human-induced stress. For example, the El Niño Southern Oscillation (ENSO) represents the primary ocean climate mode that affects the abundance, growth, and reproduction of kelp along the western Americas. Positive ENSO events known as El Niños are associated with warm water, depressed concentrations of nitrate (the principal nutrient limiting giant kelp), and a more energetic storm environment off southern California. The opposite conditions occur during negative ENSO events (La Niñas). Together, these two modes drive the greatest amount of annual variability in surface canopy cover of *M. pyrifera*. El Niño periodicity is variable, typically occurring at 3–5 year intervals and persisting for <1 year. Kelp forests wax and wane over these cycles, experiencing high mortality during El Niños with recovery periods afterwards. Rates of kelp recovery depend on growth conditions after each El Niño ebbs. The kelp forests off San Diego have been studied by researchers at the Scripps Institution of Oceanography (SIO) since the 1970s, and are currently being monitored at twenty permanent study sites located among the Point Loma, La Jolla, and North County kelp forests as part of a long-term project presently funded by the City of San Diego Public Utilities Department in order to enhance its ocean monitoring efforts for the Point Loma and South Bay ocean outfall regions. This report summarizes the findings from the last several years of the SIO kelp forest monitoring project with an emphasis on calendar years 2016 and 2017.

California kelp forests have been subjected to severe temperature and nutrient stress that began in late 2013 and persisted until the spring of 2017. This lengthened period of stress was due to the combination of two consecutive ocean climate events. First, an anomalous warm pool of surface ocean waters extended across much of the NE Pacific from 2013–2015. This warm pool, unique in the climate record of the NE Pacific, was coined the BLOB and resulted from completely different forcing events than ENSO. Second, a strong El Niño occurred just after the BLOB dissipated, and together these consecutive warm periods resulted in the longest and warmest period ever observed in the >100 year ocean temperature time series data collected at the SIO pier.

The consecutive warm events described above and associated low nutrient conditions decimated populations of *M. pyrifera* and cohabiting algal species off San Diego. Pooled across 20 kelp forest sites off San Diego, densities of adult *M. pyrifera* were reduced >90%. Unlike previous warm water events attributed to El Niño, the BLOB resulted in warming and low nutrient exposure of understory kelp species as well for prolonged periods of time leading to dramatic reductions in those species. The BLOB persisted longer than a typical El Niño and kelps did not recover after the warm pool dissipated because of the stress induced by the following El Niño of 2016. Since these two events affected kelps at the study sites differently, the classic pattern of a real synchronized mortality and recovery has been disrupted. More recently, growth conditions returned to normal with the onset of mild La Niña conditions in the spring of 2017. Rates of giant kelp recovery since that

time have been variable among study sites and are now either slower than previous recovery periods or near zero. Additionally, surface canopy cover has been precluded by increases in understory species in some areas. Some of these areas are likely to remain devoid of giant kelp canopy for years since understory species are long-lived and competitively interfere with giant kelp recruitment.

Diseases in many invertebrates, including sea urchins (echinoids) and predatory seastars (asteroids), are common during warm events. Mass mortality of red sea urchins (*Mesocentrotus franciscanus*), purple sea urchins (*Strongylocentrotus purpuratus*), and seastars in the genus *Pisaster* began off San Diego in 2014 and extended through 2017. This resulted in the disappearance or near-disappearance of these species from our study sites and from the kelp forests generally. Further, little to no recruitment of sea urchins has been observed until recently in the fall of 2017. Sea urchins are primary herbivores of giant kelp and can overgraze giant kelp and associated algal species given the right conditions. They are capable of precluding kelp recovery and overgrazed areas known as barrens that can persist in some areas for decades. Kelp forest recovery in the coming year (2018) is not likely to be affected by sea urchin overgrazing given their recent die-off. However, overgrazing may occur in some areas by the following year (2019) as recruits grow large enough to migrate out of juvenile refuge habitats.

Present La Niña conditions are predicted to shift to ENSO neutral conditions by the spring of 2018, and if so, this will occur during the season of maximal nutrient delivery up onto the nearshore coastal shelf off San Diego. Conditions for giant kelp recovery may therefore become less favorable at a critical time for their growth and reproduction and could potentially further slow the rates of giant kelp forest recovery off San Diego. Another source of stress is the gradual colonization of an invasive algal species, *Sargassum horneri*, first observed in the kelp forests off San Diego in 2014. This species has become established at several study sites. *Sargassum horneri* can outcompete *M. pyrifera* for space and may further slow the recovery of kelp forest canopies off San Diego, perhaps precluding recovery in some areas altogether.

Introduction

Kelp forests are one of the most charismatic marine communities off southern California. They are highly productive, characterized by the rapid growth of their structural species, *Macrocystis pyrifera* (commonly referred to as giant kelp), whose areal rate of primary production can exceed that of tropical rain forests (Towle and Pearse 1973). Giant kelp forests provide food and shelter for a host of marine fishes and invertebrates as well as many cohabiting species of understory algae. These forests occupy the inner margins of the continental shelf and offshore islands extending from the outer edge of tidepools to depths as great as 30 meters off southern California. Kelp forests also host a range of economically and aesthetically important consumptive and non-consumptive human activities including boating, recreational fishing, spearfishing, SCUBA diving, and the commercial harvest of finfishes, invertebrates, and algae. For example, the Point Loma and La Jolla are the most important fishing grounds for the commercial red sea urchin (*Mesocentrotus franciscanus*) and spiny lobster (*Panulirus interruptus*) fisheries off California.

Kelp forests are susceptible to human disturbances because of their proximity to urbanized coasts exposing them to polluted stormwater runoff and wastewater disposal. Perhaps the largest effect is that due to increased turbidity in coastal waters that limits light penetration for kelps to grow, germinate, and reproduce (Clendenning and North 1960). Dramatic reductions in kelp forest canopy cover off Palos Verdes have been attributed to the combined effects of wastewater disposal and an energetic El Niño in the late 1950's (Grigg 1978). However, nearshore turbidity due to wastewater discharge has long been mitigated by increasing the offshore distances and depths of discharge sites and improved outfall design (Roberts 1991). The Point Loma Ocean Outfall (PLOO), for example, was extended and deepened effective in late 1993, presently discharging treated wastewater ~7.3 km offshore in waters ~98 m deep. The current location of the PLOO discharge is ~5 km offshore of the western edge of the Point Loma kelp forest. Beach replenishment can also negatively impact kelp forests via sedimentation and burial. This has been observed at kelp forests off northern San Diego County as the replenished sediments erode from beaches and partially bury low relief hard bottom habitat as eroded sediments redistribute offshore.

Kelp forests in southern California are also disturbed naturally by ocean climate variability that occurs at interannual (e.g., El Niño Southern Oscillation - ENSO) and decadal (e.g., Pacific Decadal Oscillation - PDO) periods. Positive phases of both ocean climate modes are associated with a deepened thermocline limiting nutrient delivery to the inner shelf necessary for kelp growth. These modes are also associated with increased storm energy, which can cause giant kelp mortality via plant detachment and abrasion (Seymour et al. 1989). The northeastern Pacific experienced a profound regime shift in the late 1970s in which the main ocean thermocline deepened, resulting in a step reduction in nitrate concentrations that still persists (see Figure 1, Parnell et al. 2010). Concentrations of nitrate, the main limiting nutrient for kelp growth in southern California, switched from being conducive for kelp growth most years, with the exception of the most intense El Niños, to being less adequate most of the time (Parnell et al. 2010) with the exception of strong negative ENSO phases known as La Niñas. The ecology of kelp forests off San Diego has changed fundamentally due to the increased frequency of natural disturbance resulting in a demographic shift towards younger and smaller *M. pyrifera* individuals (Parnell et al. 2010).

Sea urchin overgrazing is another form of natural disturbance within kelp forests (Leighton et al. 1966). Forests are susceptible to overgrazing when sea urchin densities increase or when sea urchins aggregate into overgrazing fronts. Overgrazing can lead to areas denuded of most or all algae and are known as sea urchin barrens. Such barrens and forested modes can be semi-permanent or resilient in some areas such as in the southern Point Loma kelp forest (Parnell 2015) or the two modes can alternate due to external forcing such as reductions in kelp standing stock as a result of El Niño, sea urchin disease epidemics, and indirectly from human activities including the harvest of important sea urchin predators (Steneck et al. 2002).

Another source of natural disturbance is the increasing establishment of an invasive alga, *Sargassum horneri*, throughout southern California. This species competes with *M. pyrifera* for space and light, and is now seasonally dominant in some areas previously dominated by *M. pyrifera*. The most impacted areas include the protected low energy habitats in the lee of islands such as the northern Channel Islands and Santa Catalina Island (Miller et al. 2011). *Sargassum horneri* is now establishing itself in less protected areas along the mainland including San Diego County.

Researchers at the Scripps Institution of Oceanography (SIO) have partnered with the City of San Diego Ocean Monitoring Program to conduct regular surveys of the kelp forests off San Diego County including the kelp forests off Point Loma, La Jolla and North County. These surveys represent a continuation of ecological studies that began at SIO in the Point Loma Kelp Forest (PLKF) and La Jolla Kelp Forest (LJKF) and continue at several of the sites established in the 1970s and 1980s (Dayton and Tegner 1984). Additional study sites have been established more recently in both kelp forests and in kelp forests off northern San Diego County (NCKF). PLKF and LJKF are the largest contiguous kelp forests off the western United States coast and together historically represent one of the most studied kelp forest ecosystems in the world.

Materials and Methods

A variety of marine algae and invertebrates and bottom temperatures are monitored at 20 permanently established study sites in the kelp forest off San Diego (Figure 2). Algae and invertebrates are monitored along four replicate parallel permanent band transects oriented perpendicular to shore (25 x 4 m bands

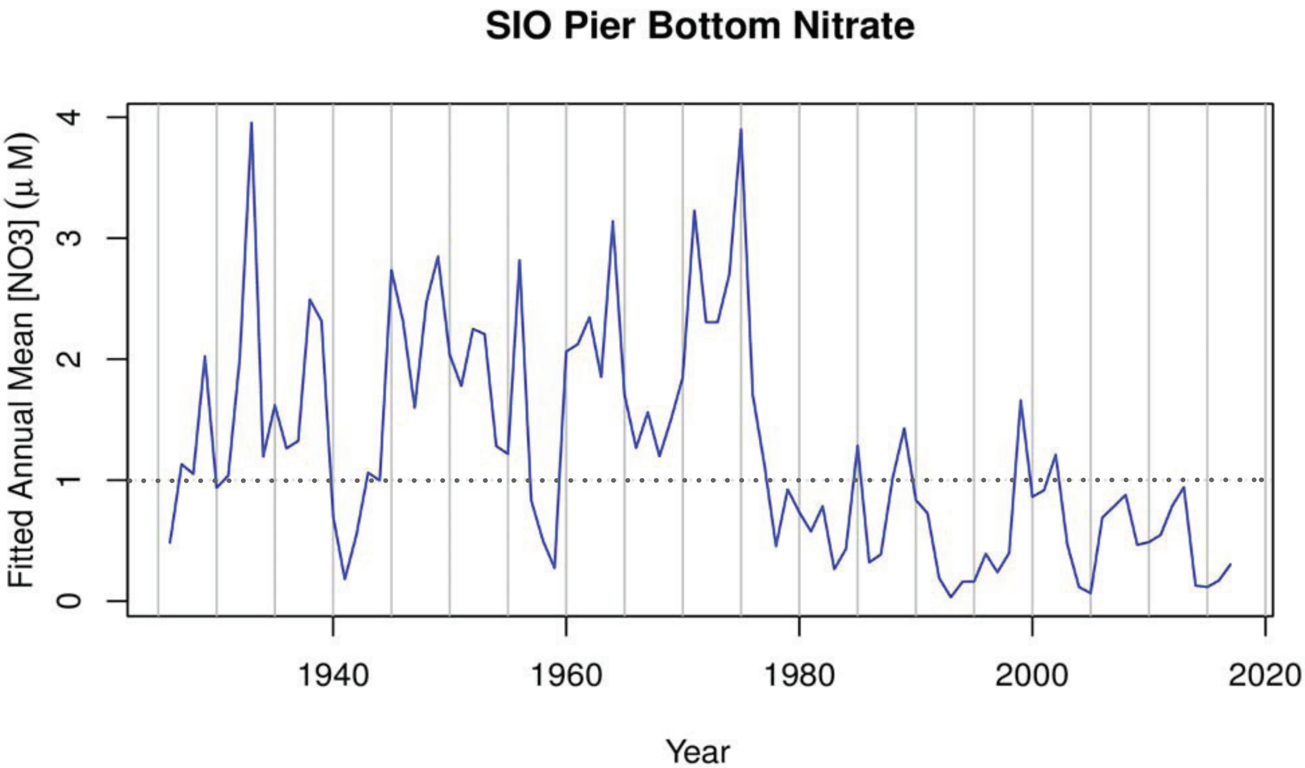


Figure 1
Time series of annual mean nitrate concentrations estimated from daily temperature and salinity data at the base of the Scripps Institution of Oceanography Pier (see Parnell et al. 2010 for details). Dotted gray line indicates the minimum nitrate threshold for growth of *Macrocystis pyrifera*.

separated 3–5 m apart) except at the Del Mar (DM) study site where two sets of band transects are located ~1300 m apart due to the small size and fragmented shape of that forest. The main components of the kelp forest monitoring program include assessments of (1) algal density, growth, reproductive condition and recruitment; (2) invertebrate densities; (3) sea urchin demography (size distributions to monitor for episodic recruitment); and (4) bottom temperature (which is a proxy of ocean nutrient status). The types of data collected and the frequency of collection are listed in Table 1.

Conspicuous macroalgal species/groups are enumerated or percent cover is estimated within 5 x 2 m (10 m^2) continuous quadrats along the band transect lines at all sites. Reproduction and growth of giant kelp *Macroscystis pyrifera*, and the understory kelps *Pterygophora californica* and *Laminaria farlowii,* are measured on permanently tagged plants along the central PLKF study sites. All conspicuous sessile and mobile invertebrates are enumerated annually within the 10 m^2 quadrats during spring. Size frequencies of red sea urchins (RSU - *Mesocentrotus franciscanus*) and purple sea urchins (PSU - *Strongylocentrotus purpuratus*) are recorded for >100 individuals of each species located near all of the study sites except within the NCKF where there are not adequate densities of sea urchins. Sedimentation is monitored along the NCKF sites by measuring the height of permanently established spikes at replicate locations within each of those forests. Bottom temperature is recorded at 10 minute intervals using ONSET Tidbit recorders (accuracy and precision = 0.2˚C and 0.3˚C, respectively). All field work was conducted using SCUBA.

Growth of *M. pyrifera* is monitored by counting the number of stipes on each tagged plant one meter above the substratum. Reproductive state is represented by the size of the sporophyll bundle (germ tissue) at the base of each plant. Sporophyll volume is calculated as a cylinder based on the

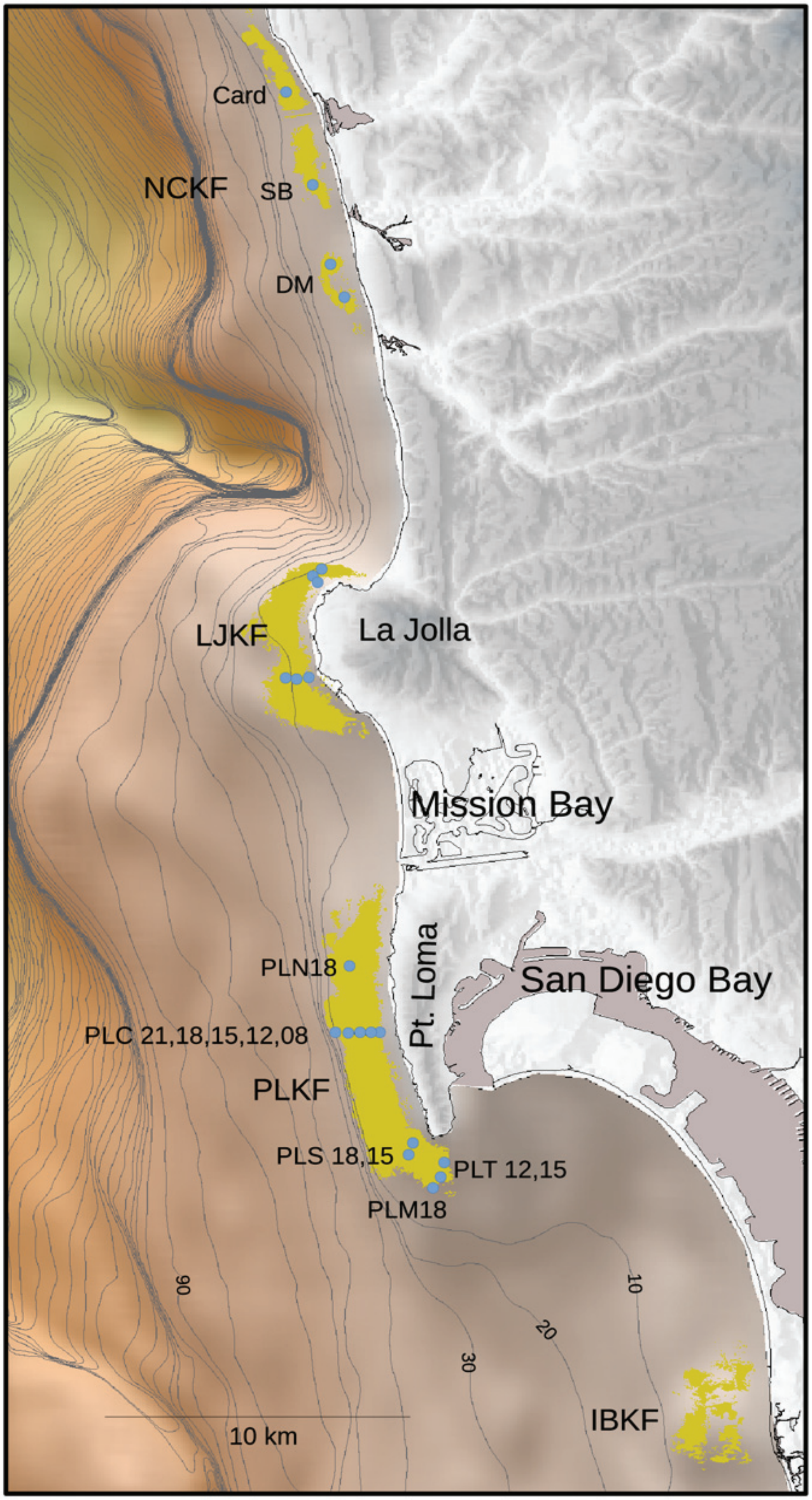


Figure 2

Map of the San Diego marine shelf showing locations of the Point Loma (PLKF), La Jolla (LJKF), North County (NCKF), and Imperial Beach (IBKF) kelp forests. Permanent study sites are indicated with blue circles with study site names clustered with site clusters. Depth contour units are meters.

Table 1

List of study sites including year of establishment and work conducted at each site. ABT = algal band transects, USF = sea urchin size frequency, Inv = Invertebrate censuses, AR = algal reproduction and growth measurements, and BT = bottom temperature. Frequencies are noted in parenthesis: a = annual, sa = semi-annual, q = quarterly, m = monthly.

Study Site	Depth (m)	Year Established	Work Conducted (frequency)
Card	17	2006	ABT(q), Inv(a), BT(10min), Sed(q)
SB	16	2006	ABT(q), Inv(a), BT(10min), Sed(q)
DM	16	2007	ABT(q), Inv(a), BT(10min), Sed(q)
LJN18	18	2004	ABT(q), Inv(a), USF(sa), BT(10 min)
LJN15	15	2004	ABT(q), USF(sa), Inv(a), BT(10 min)
LJN12	12	2004	ABT(q), USF(sa), Inv(a), BT(10 min)
LJS18	18	2004	ABT(q), USF(sa), Inv(a), BT(10 min)
LJS15	15	1992	ABT(q), USF(sa), Inv(a), BT(10 min)
LJS12	12	2004	ABT(q), USF(sa), Inv(a), BT(10 min)
PLN18	18	1983	ABT(q), USF(sa), Inv(a), BT(10 min)
PLC21	21	1995	ABT(q), USF(sa), Inv(a), AR(m), BT(10 min)
PLC18	18	1983	ABT(q), USF(sa), Inv(a), AR(m), BT(10 min)
PLC15	15	1983	ABT(q), USF(sa), Inv(a), AR(m), BT(10 min)
PLC12	12	1983	ABT(q), USF(sa), Inv(a), AR(m), BT(10 min)
PLC08	8	1997	ABT(q), USF(sa), Inv(a), AR(m), BT(10 min)
PLS18	18	1983	ABT(q), USF(sa), Inv(a), BT(10 min)
PLS15	15	1992	ABT(q), USF(sa), Inv(a), BT(10 min)
PLT12	12	1997	ABT(q), USF(sa), Inv(a), BT(10 min)
PLT15	15	1997	ABT(q), USF(sa), Inv(a), BT(10 min)
PLM18	18	1996	ABT(q), USF(sa), Inv(a), BT(10 min)

height and diameter of each bundle. This is an indirect measure of reproductive effort, and Reed (1987) has shown that sporophyll biomass is closely related to zoospore production. Reproductive capacity, a derived parameter that represents the relative reproductive potential among plants by coupling sporophyll volume and reproductive state, is calculated as the product of sporophyll volume and squared reproductive state. Reproductive capacity is then standardized by division of each value by the maximal value observed among all sites. Reproductive state for each plant is ranked according to the following ordinal scale:

0 = No sporophylls present.

1 = Sporophylls present but no sori (sites of active reproduction) development.

2 = Sporophylls with sori only at the base of sporophylls.

3 = Sporophylls with sori over most of the sporophylls surface.

4 = Sporophylls with sori over all of the sporophylls surface.

5 = Sporophylls with sori over all of the sporophylls surface releasing zoospores.

Growth of *Pterygophora californica* was determined by the method of DeWreede (1984). A 6 mm diameter hole is punched in the midrib of the terminal blade ~30 mm from the base of the blade, and another hole is punched monthly at the same location. The distance between the two holes represents the linear growth of each blade.

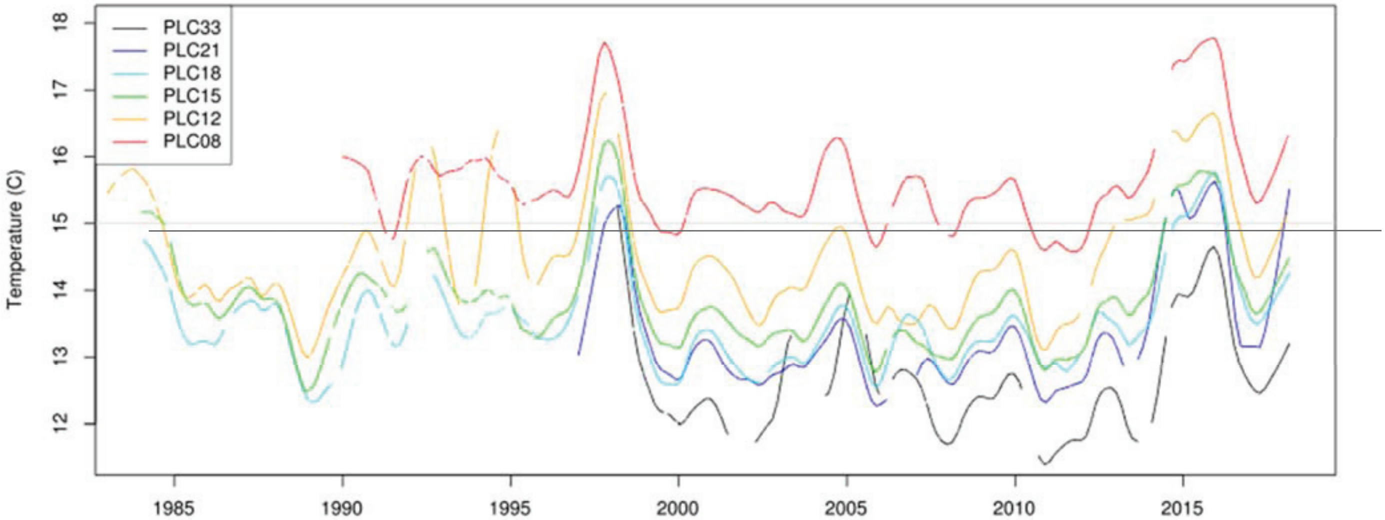


Figure 3
Sea bottom temperature trends at the central Point Loma study sites. The horizontal gray line indicates the temperature above which nitrate concentrations are typically limiting for giant kelp growth. Gaps indicate missing data due to instrument loss/malfunction.

Reproductive effort for *P. californica* is evaluated by a count of the total number of sporophyll blades on each plant and the number with sori.

Growth of *Laminaria farlowii* is determined in a similar manner to *P. californica*. A 13 mm diameter hole is punched 100 mm from the base of each blade, which is repeated each visit. The distance between the two holes represents the linear growth of each blade. The reproductive status of *L. farlowii* is evaluated as the percent of each blade covered by sori.

Sea urchin recruitment is sampled semi-annually (spring and fall) at all of the PLKF and LJKF study sites. Sea urchins are exhaustively collected in haphazardly placed 1-m^2 quadrats in suitable substrate within 50 m of each study site. Suitable substrate includes ledges and rocks which can be fully searched for sea urchins as small as 2 mm. Sea urchins are measured using calipers and then placed back where they were collected.

The distribution of algal species among all permanent sites was calculated using factor analysis in R (R Core Team 2018). Factor analysis (Lawley and Maxwell 1971) was used to reduce the multi-dimensional algal data. Thirteen algal groups and derived bare space were analyzed among 20 sites. Relative bare space was derived by ranking the sum of rankings for individual algal groups among sampling units. Sampling units (individual 10-m^2 quadrats) with the least amount of total algae (density or percent cover) were ranked highest for bare space.

Results and Discussion

Bottom Temperature

The bottom temperature record at the central PLKF study sites extends back to 1983 when the strong 1982/1983 El Niño was ebbing. The largest temperature signals in the time series include the 1997–98 El Niño and the extended warm period (2013–2015) associated with the large scale anomalous NE Pacific warm event (DiLorenzo and Mantua 2016) termed the BLOB and was immediately followed by a strong El Niño (Figure 3). Relatively less pronounced warm periods have occurred between the 1997–98 and 2016–17 El Niños. Most notable was the 2005/2006 El Niño when much of the giant kelp canopy disappeared at the surface but plants still grew below the thermocline where nutrients were more abundant. Because bottom temperatures decrease with depth, nutrient stress during warming events decreases with depth. This physical forcing is a fundamental mechanism that controls space competition between the understory and canopy kelps. Strong El Niños such as the 1997/98 El Niño and the 2014-2017 BLOB/El Niño penetrate to the bottom for extended periods even at the offshore edge of the forest stressing all kelps. By contrast, milder El Niños do not typically penetrate to the bottom of the forests for extended periods (e.g., >1 month) and therefore primarily stress only the surface canopy kelps (mainly *M. pyrifera*) more than the understory kelps where temperatures are cooler. Repeated cycles of mild El Niños over many years in the absence of large storm waves leads to increasing understory domination at the expense of giant kelp canopy cover. The bottom temperature climate off San Diego during the present reporting period encompasses the end of the unprecedented warm event of 2013–2017, and bottom temperatures have since cooled but appear to be increasing again. Currently, unseasonably warm winter sea surface temperatures with anomalies as great as 2ºC are being observed at the SIO pier despite this period being categorized as a La Niña (Climate Prediction Center, NOAA).

The ENSO index is based on equatorial sea surface temperatures in the Pacific Ocean. ENSO warming and cooling of western American coasts propagates poleward from the tropics, and each El Niño/La Niña events penetrate higher latitudes differently. Present sea surface temperature anomalies off San Diego during the current La Niña indicate that dynamic forcing of the temperature and nutrient climates off southern California may have changed over the observational time period of available temperature records in the region. The NOAA Climate Prediction Center forecasts a return to neutral ENSO conditions from the present La Niña by spring. This portends a less favorable growth climate for the kelp forests off San Diego, potentially interrupting the recent improvement in kelp growth conditions present at the end of 2017 (Figure 1).

Kelps and Algal Reproduction

The effects of the 2014–2017 warm period on the kelp forests off San Diego were clearly negative. Densities of adult *M. pyrifera* (Figure 4) and giant kelp stipes decreased dramatically at all study sites. *Macroscystis pyrifera* was entirely lost from several study sites and has not yet recovered at many of the study sites, especially the deeper sites including PLC21, PLS18, PLM18, and LJN18. Giant kelp surface canopy was nearly entirely lost off most of San Diego, Orange, and Los Angeles counties during 2016 (MBC Applied Environmental Sciences 2017). These losses are set against an overall declining trend of *M. pyrifera* density observed at the long term study sites off central Point Loma.

The primary abundance pattern for *M. pyrifera* since the 1980's includes rapid declines associated with El Niño's followed by step increases as giant kelp recovers afterward (e.g., Figure 4a). Densities then typically slowly decrease from post El Niño recoveries. The most recent declines observed between 2015 and 2017 contrast with this primary pattern. Whereas previous losses associated with El Niño have been nearly simultaneous among sites, the most recent die-off affected giant kelp differently among sites because they were previously impacted by the BLOB. Densities at some sites such as PLC08 declined quickly and began recovery with two episodes of moderate recruitment (Figure 5). Other sites, such as PLC18, PLC15, and PLC12 experienced at least one bout of *M. pyrifera* recruitment between the ebbing of the BLOB and the onset of the 2016 El Niño (Figure 5). The fates of these cohorts differed among sites with the greatest recovery observed at PLC08 and LJN15. Generally, giant kelp at the deepest sites off Point Loma and La Jolla has decreased to zero or near zero with little recovery despite cooler temperatures. These areas have also experienced diminished cover of competing understory algae (Figures 6 and 7) suggesting that the lack of recovery at the deeper sites is likely due to decreased reproductive capacity of *M. pyrifera* (Figure 8) prior to the mass mortality of giant kelp during the El Niño of 2016. Limited recovery at the deeper sites during this period could also be partly due to decreased light levels reducing rates of kelp germination. Light penetration data are not available. Reproductive capacities of giant kelp at all of the central Point Loma sites are presently at historic lows suggesting that recoveries from the two warm events between 2014–2017 are less

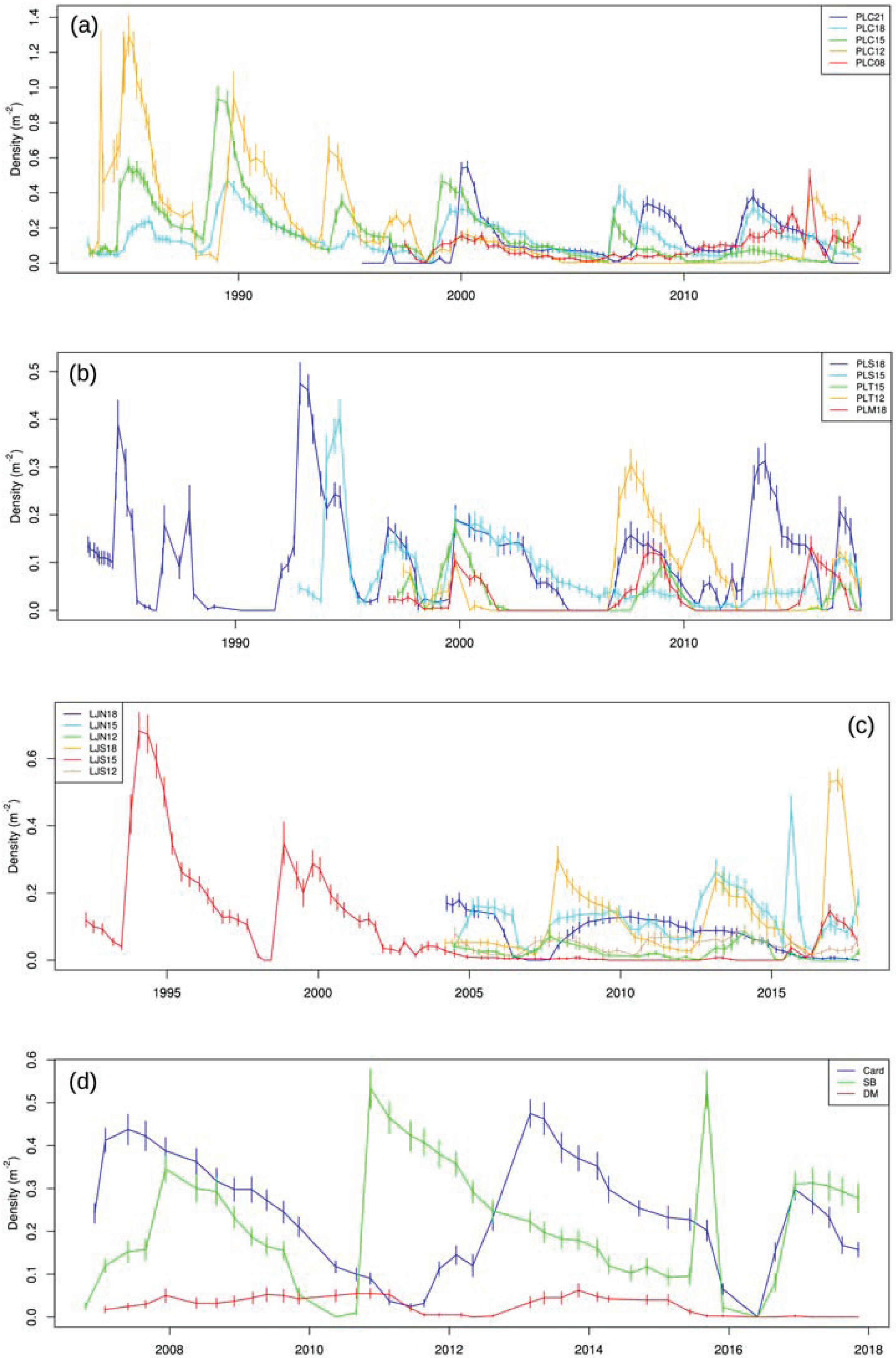


Figure 4

Mean densities of adult *Macrocystis pyrifera* among study site groups: (a) central Point Loma, (b) south Point Loma, (c) La Jolla, and (d) North County. Error bars indicate standard errors.

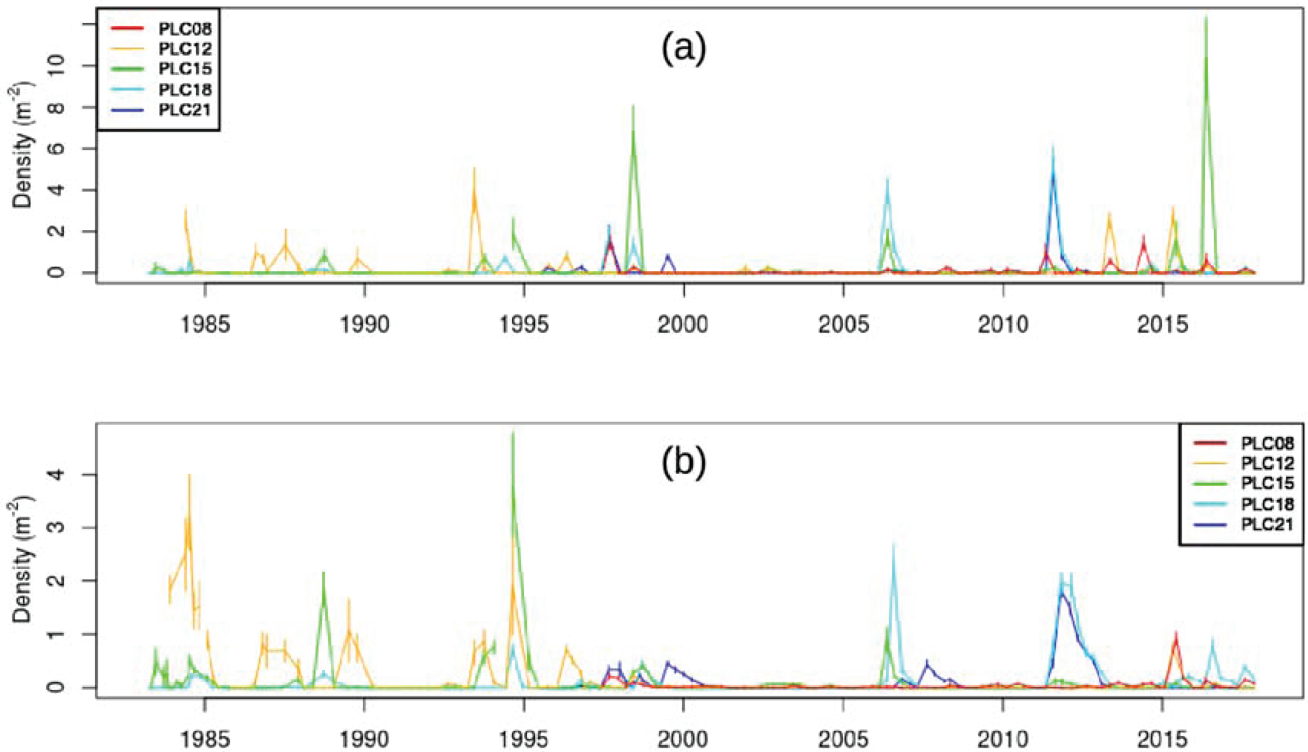


Figure 5
Mean densities of *Macrocystis pyrifera* recruit stages: (a) pre-bifurcate stage, (b) bifurcate stage. Error bars indicate standard errors.

supported by reproductive output than at any other time since the 1980's. Therefore, rapid increases in giant kelp density will likely be muted this spring (2018) and may not follow the rapid post-El Niño patterns observed in the past.

Understory Kelps

Understory kelps, *Pterygophora californica* and *Laminaria farlowii*, were affected differentially by the consecutive warm periods. The main effects of the warm periods on *P. californica* were exemplified by two groups of sites (Figure 6). The first group included sites where densities decreased dramatically with the BLOB and remained low during and after the 2016 El Niño (i.e., PLC21, PLC18, PLC12, PLC08, LJN15, LJN12, LJS12). Densities of *P. californica* at the second set of sites decreased during the BLOB then increased rapidly through the 2016 El Niño (i.e., PLC15, LJS18, LJS15). Densities of *P. californica* at the North County sites have been persistently low and remain low at present. The response of *L. farlowii* to the warm periods was more variable among sites. Three types of responses were observed. First, previously high fractional cover at many sites quickly decreased during the BLOB with subsequent increases during the 2016 El Niño (e.g., PLC15, LJS18, and LJS15). Relatively high fractional cover at other sites decreased due to the BLOB and remained reduced through the 2016 El Niño to the present. These mainly include the sites in La Jolla and Del Mar. The third response occurred at PLS15 where fractional cover was increasing prior to the BLOB when it decreased slightly followed by a rapid increase during and after the 2016 El Niño.

The complex trajectories of understory kelps during and after the consecutive warm periods appear to have switched states. These states can be defined by three canopy/understory modes and are forced by the shading effects of *M. pyrifera* surface canopy. The three modes include (1) lush to moderate surface canopy with low understory; (2) lush understory with low surface canopy; and (3) lush to moderate canopy with low fractional cover of understory. A fourth ephemeral mode

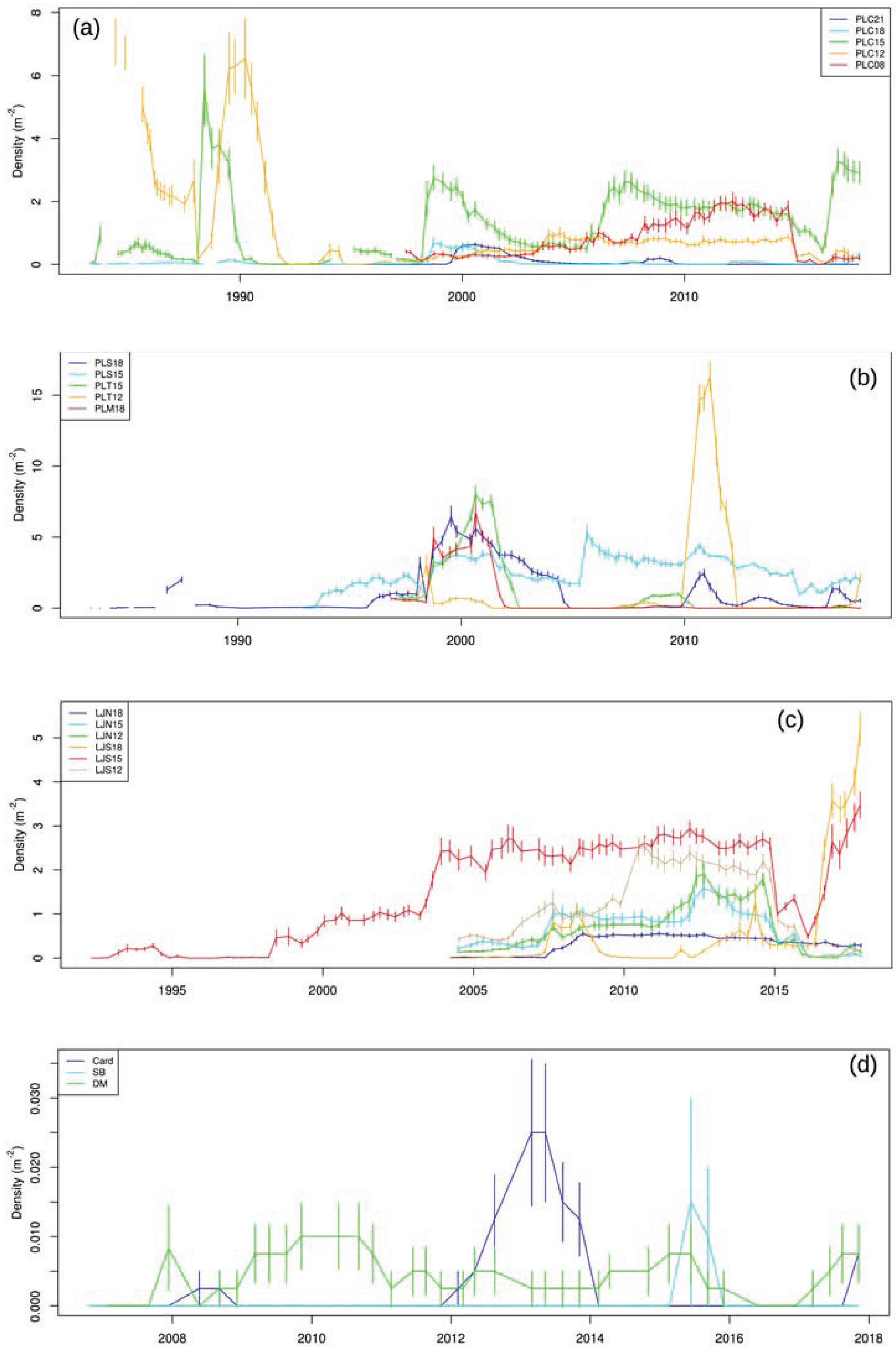


Figure 6

Mean densities of the understory kelp *Pteryogophora californica*: (a) central Pt. Loma, (b) south Pt. Loma, (c) La Jolla, and (d) North County. Error bars indicate standard errors.

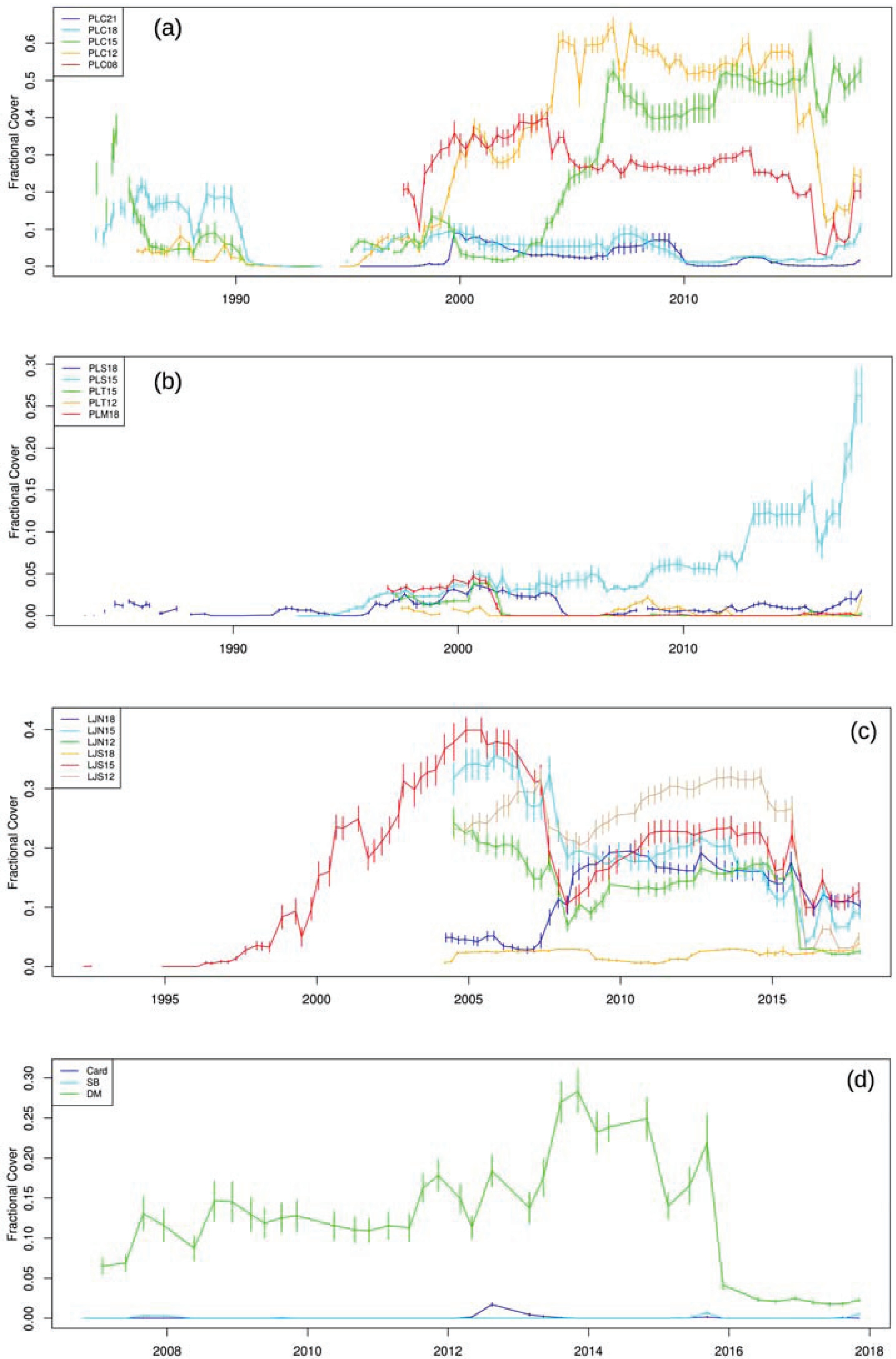


Figure 7

Mean fractional cover of the understory kelp *Laminaria farlowii*: (a) central Point Loma, (b) south Point Loma, (c) La Jolla, and (d) North County. Error bars indicate standard errors.

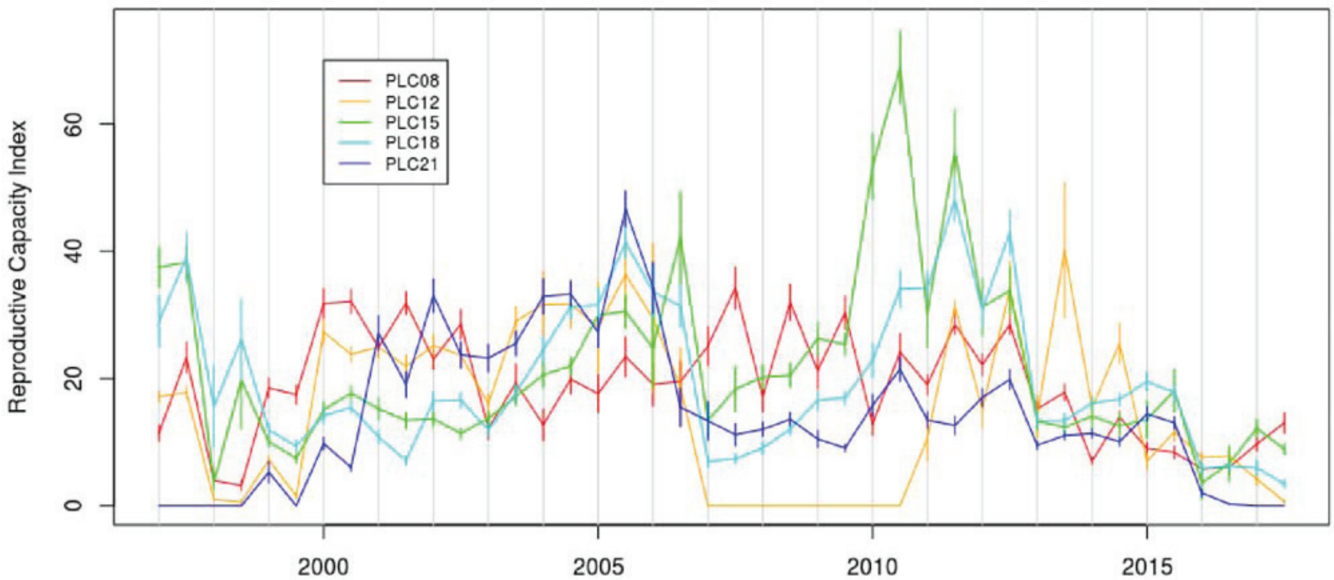


Figure 8
Mean reproductive capacity (see text for derivation details) of *Macrocystis pyrifera* at the central Point Loma study sites.

was also observed during the consecutive warm periods with sparse canopy and understory forced by the unprecedented duration of nutrient stress during the combined warm periods. In contrast to previous warming events when the shading effect of giant kelp on understory decreases due to thinning of the surface canopy, warm temperatures during the BLOB penetrated to the bottom for an extended period of time (Figure 3). This resulted in long periods of nutrient stress for these lower canopy species, and effectively limited their recovery even when light limitation decreased during periods of low surface canopy.

Growth and reproductive states of understory kelps was reduced during the BLOB and increased afterward, though both growth and reproduction of *P. californica* is still depressed at the deeper central Point Loma sites (Figures 9 and 10). Decreased reproductive output by both species can delay understory recovery after El Niño disturbances (Dayton et al. 1984), and may contribute to the persistence of switched canopy/understory states that we currently observe. Such forcing can lead to a hysteresis that can persist for several years until the occurrence of a new major disturbance.

Algal states among all of the study sites for 2016 and 2017 are shown in Figures 11 and 12, respectively. The first two factors resulting from the factor analysis of all algal data represent >82% of the overall variance and therefore are a good representation of the data. Factor 1 indicates a continuum of understory and turf states from bare ground to lush turf algae with understory canopy species such as *P. californica*, *Eisenia arborea*, *L. farlowii*, and *Agarum fimbriatum* in between these two extremes. Factor 2 indicates the condition of *M. pyrifera*, whether sites are dominated by adults and abundant stipes or young recruits and pre-adults (<4 stipes). The increase in giant kelp between 2016 and 2017 is indicated by increases in factor 2 for many sites including LJS18, SB, PLN18, and PLC08. There is also a shift away from bare space between the two years towards more abundant understory canopy and turf species. For example, *Desmerestia ligulata* is an early colonizing species that competes with both giant kelp and understory species after disturbances for up to several months (Dayton et al. 1992). The fractional cover of this species increased sharply in 2016 at PLT15, PLT12, Cardiff, and Del Mar. *Agarum fimbriatum* was still abundant at PLT15 in 2017. Fractional cover of *A. fimbriatum* increased after the El Niño of 2016 at PLC21 and PLC18, but was rare at these study sites after the BLOB. This species had the clearest competitive effects on surface and canopy kelp recovery at Cardiff, Del Mar, PLT15, and PLT12.

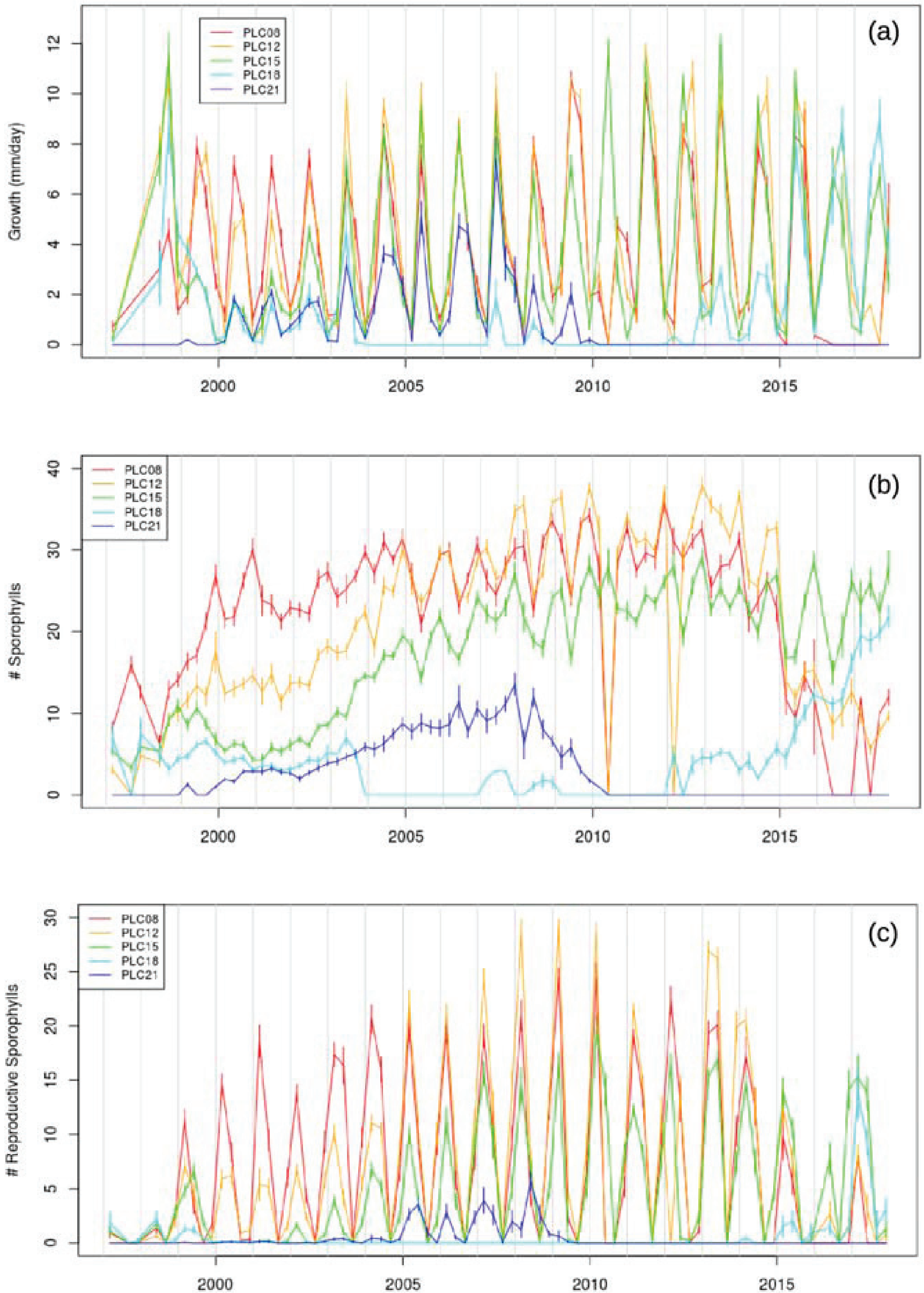


Figure 9

Time series of (a) mean growth, (b) mean sporophyll count, and (c) mean count of reproductive sporophylls for the understory kelp *Pterygophora californica*. Error bars indicate standard errors.

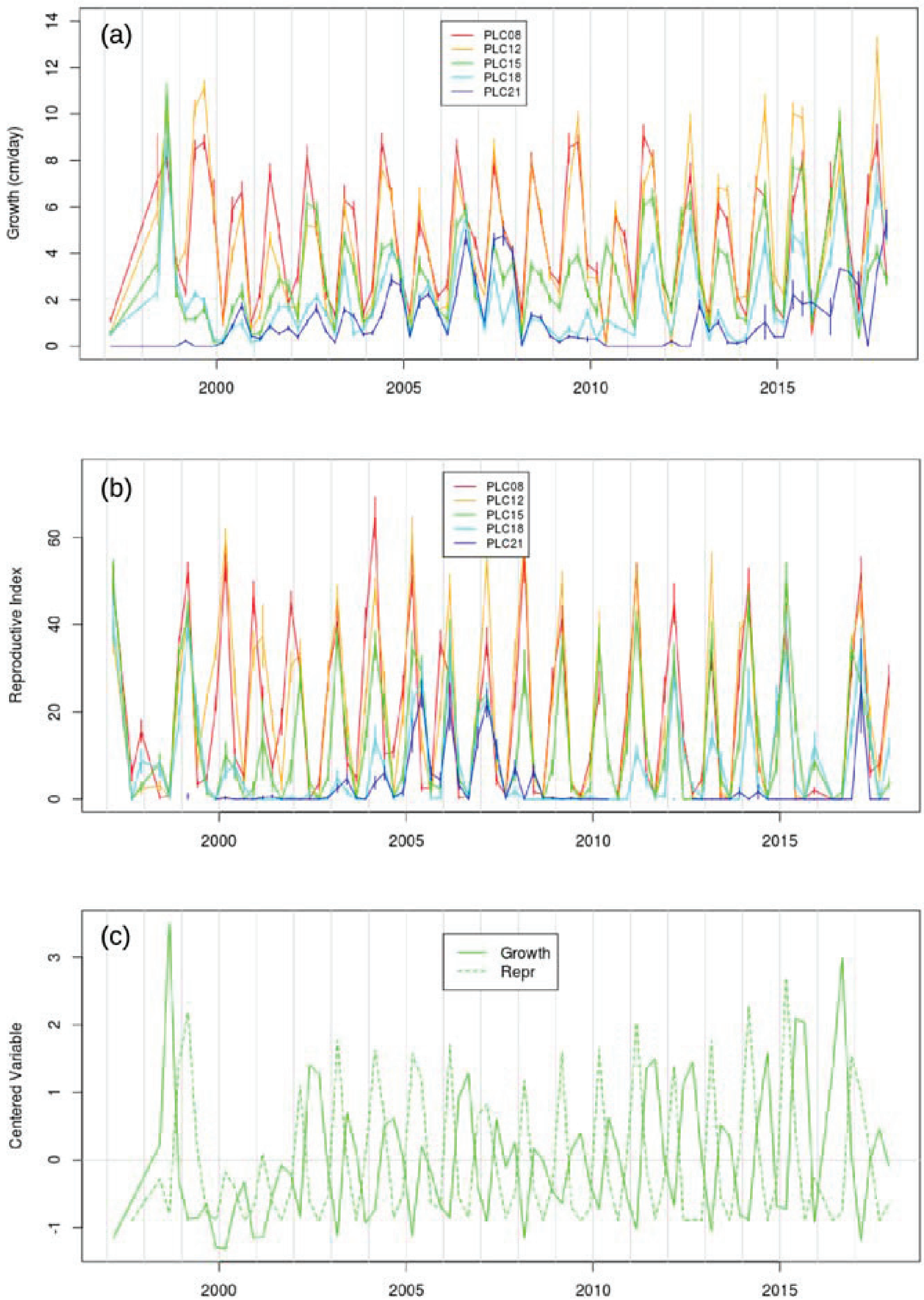


Figure 10

Mean growth (a) and reproductive index (b) of *Laminaria farlowii*, and (c) centered growth and reproduction of *L. farlowii* at the PLC15 study site showing relative seasonal phasing of growth and reproduction.

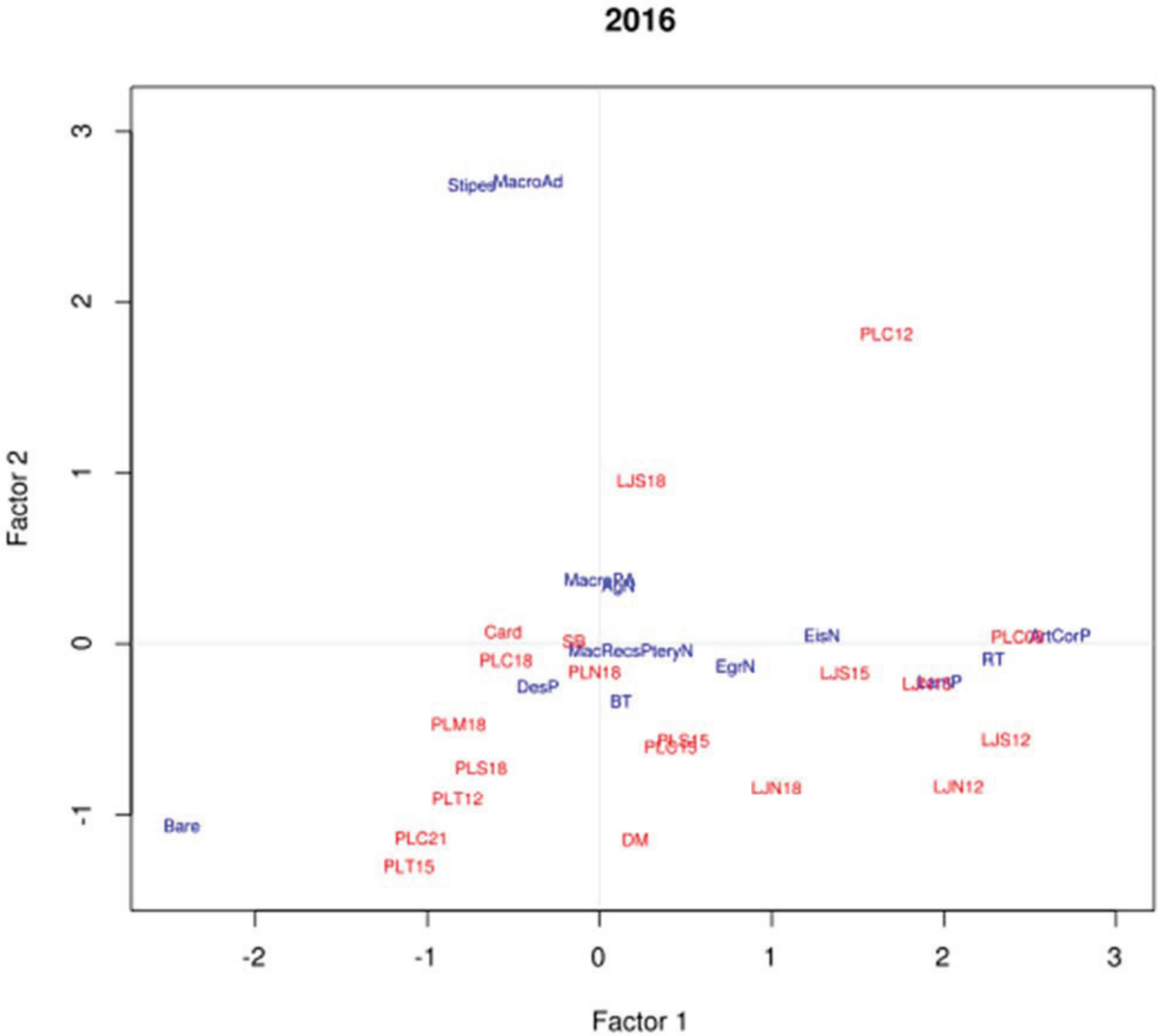


Figure 11

Plot of first two factors resulting from the factor analysis of algal groups among the 20 permanent study sites in 2016. Algal group definitions: Bare = derived bare space, MacRecs = *M. pyrifera* recruit stage (pre-bifurcates + bifurcates), MacroAd = *M. pyrifera* adult density, Stipes = *M. pyrifera* stipe density, MarcroPA = *M. pyrifera* pre-adults (<4 stipes), PteryN = *Pteryogophora californica* density, LamP = *Laminaria farlowii* percent cover, EisN = *Eisenia arborea* density, EgrN = *Egregia menziesii* density, AgN = *Agarum fimbriatum* density, DesP = *Desmerestia ligulata* percent cover, ArtCorP = articulated coralline algae percent cover, RT = foliose red algal percent cover, BT = brown algal turf percent cover.

Sargassum horneri is an invasive alga that invaded southern California in 2006 when it was reported from Long Beach Harbor (Miller et al. 2007). Since that time it has gradually spread along the coast and was observed in Mission Bay by 2008. *Sargassum horneri* dominates some areas formerly dominated by *M. pyrifera* including areas off Santa Catalina Island and the Northern Channel Islands off Santa Barbara. This species was first observed in the kelp forests off San Diego in 2014 and has spread slowly, first observed near study sites and subsequently established onto the permanent band transects at several of the study sites. The greatest percent cover observed thus far was at LJN18 in the fall of 2017 when mean percent cover approached 30%. This species has also been observed on the permanent transects at (in order of decreasing percent cover) PLC18, PLC08, LJS12, LJN15, and PLN18.

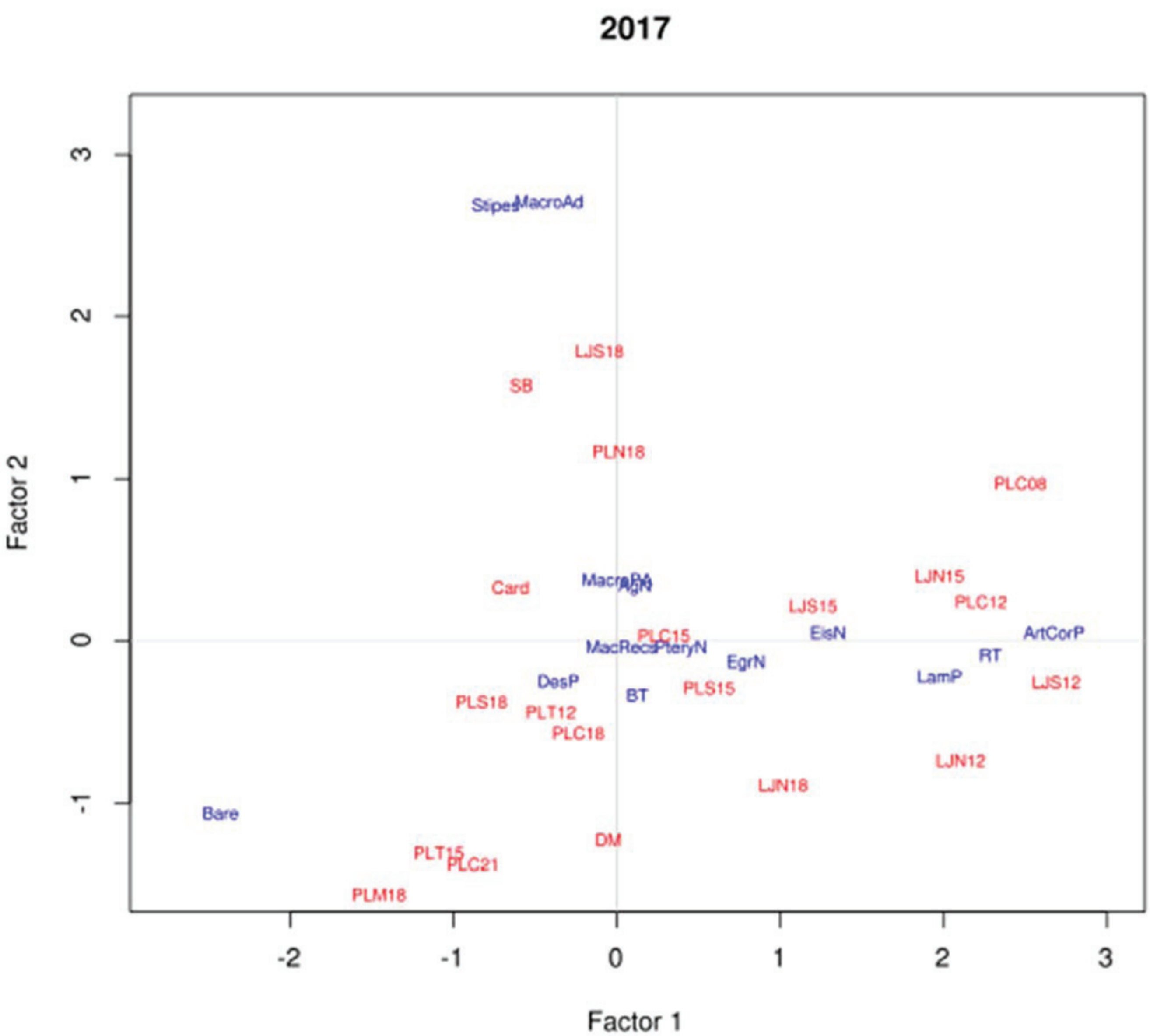


Figure 12
Plot of first two factors resulting from the factor analysis of algal groups among the 20 permanent study sites in 2017. See Fig. 11 caption for definitions of algal groups.

Sargassum horneri clearly poses a risk to *M. pyrifera* and many other algal species due to its rapid seasonal growth rates. It is not implausible for it to take over some areas of San Diego kelp forests especially after a future major disturbance that reduces the densities and cover of native algal species.

Invertebrates

Densities of both red and purple sea urchins (RSU and PSU, respectively) either crashed in response to the consecutive warm periods or were already at or near zero. Sea urchin densities are shown in Figures 13 and 14 for the sites where these species were most abundant prior to 2013. Decimation of sea urchin populations off San Diego was a direct result of disease mortality and included the 'dark-blotch' disease. Disease epidemics commonly occur in echinoids (sea urchins - Lafferty 2004) and asteroids ('sea star wasting disease' - Eckert et al. 2000) during periods of warm water stress. Presently, there are very few sea urchins of either species at any of the study sites, even off south Point Loma where sea urchin overgrazing has been historically resilient (Parnell 2015). Additionally, sea urchin recruitment was absent or extremely limited at all

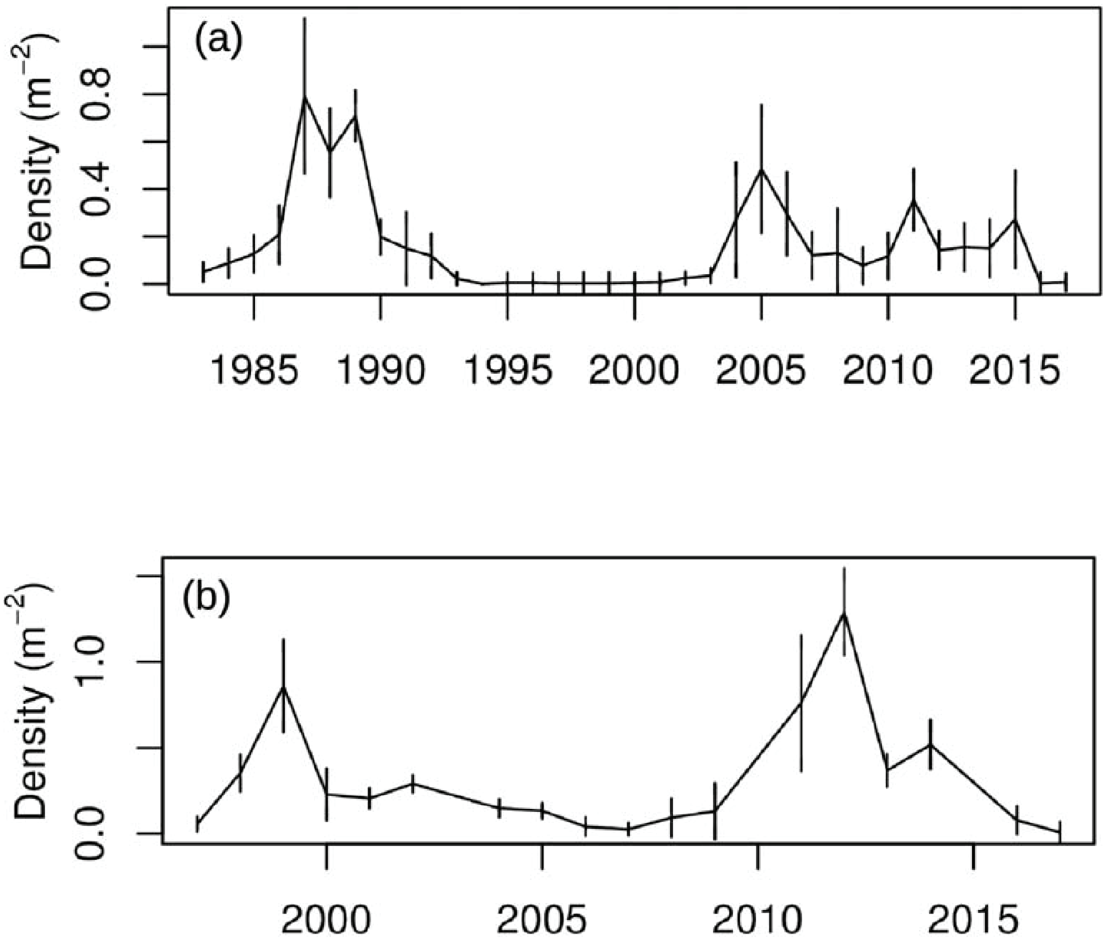
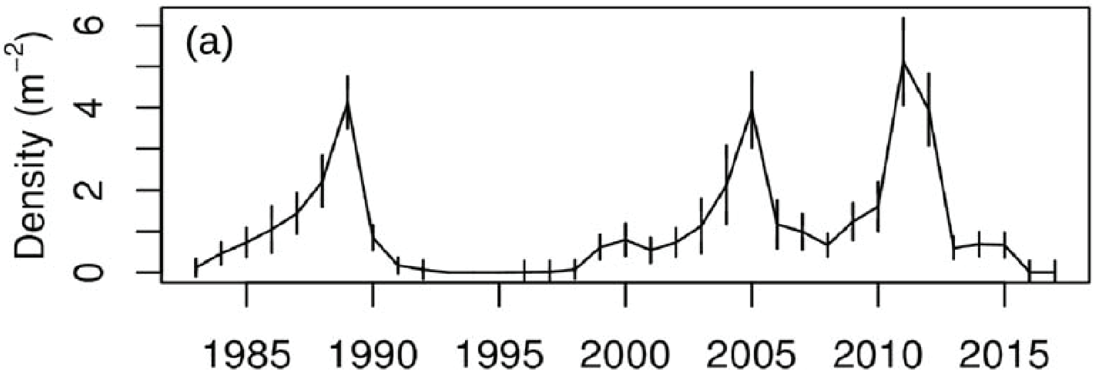


Figure 13
Time series of red sea urchin (*Mesocentrotus franciscanus*) densities at the (a) PLS18, and (b) PLT12 study sites. Error bars indicate standard errors.

sites until the fall of 2017 (based on semi-annual size frequency sampling). Sea urchin recruitment (percent in the first year age class at a site) for both species increased at several sites (Table 2). The largest increases were observed mainly at the southern Point Loma sites, and all sites off La Jolla with the exception of LJS18. Recruitment of RSU was strong at the outer central Point Loma stations (PLC18 and PLC21). Sea urchins are not likely to have any significant effects on kelp recovery in 2018 due to their reduced abundance and delayed recruitment. However, the fall 2017 recruit cohort may result in overgrazing at some sites as they mature and migrate away from sheltering juvenile habitat and actively forage over larger areas. Sea urchin overgrazing may occur at some sites by 2019 as the fall 2017 cohort matures and begins to actively forage over broader areas.

Diseases affecting echinoderms has also caused mass mortality of several asteroid species throughout the southern California Bight during the consecutive warm periods (Hewson et al. 2014). Species that suffered the greatest mortality at our study sites included *Pisaster giganteus* and *P. brevispinus* (Figure 15) where densities were reduced to zero for both species, even at sites where they were previously abundant. Disease induced mass mortality events of asteroids and echinoids are commonly followed by recovery at differing rates. Juvenile *P. giganteus* were observed recruiting onto giant kelp plants off Point Loma as early as 2017, thus heralding their recovery. However, disease has also decimated *Pycnopodia helianthodes*, an important sea urchin predator (Moitoza et al. 1979). This species has not been observed anywhere off Point Loma since 2014 even in areas where they



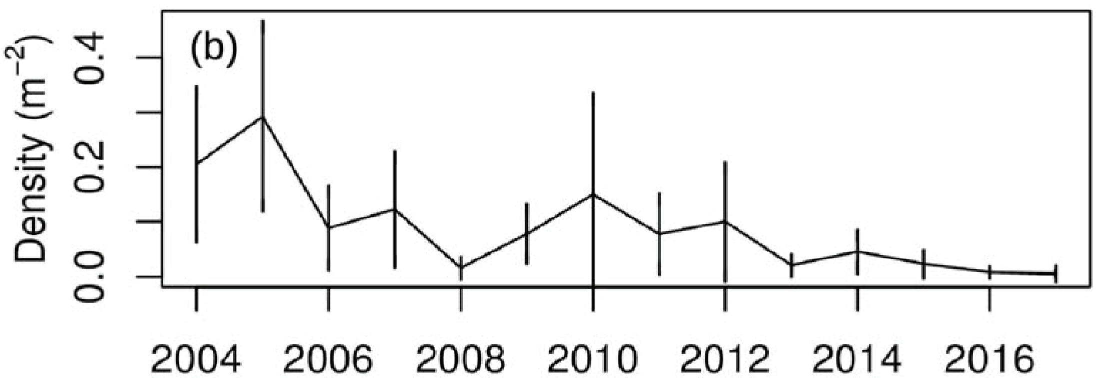


Figure 14
Time series of purple sea urchins (*Strongylocentrotus purpuratus*) at (a) PLS18, (b) LJN12, and (c) Cardiff study sites. Error bars indicate standard errors.

were once common. *P. helianthodes* was in gradual decline even prior to the BLOB event.

Abalones are marine mollusks and once supported an economically important commercial fishery throughout California until the 1980's. Their primary food in southern California is giant kelp. Therefore, when kelp populations are reduced, abalones become stressed both by the lack of food as well as diseases associated with warm water events (Vilchis et al. 2005). Historically, seven species of abalone have been common off San Diego. Two species, *Haliotis cracherodii* and *H. sorenseni*, are now on the federal endangered species list. Another species, *H. rufescens*, has been in decline off southern California since the 1970's, and populations off Point Loma crashed in the 1980's (Tegner and Dayton 1987). However, *H. rufescens* persisted in low numbers near PLS18 and LJS18. Those few individuals were lost during the recent prolonged warm periods. At the same time, densities of pink abalone (*H. corrugata*) have been steadily increasing at PLC08 since 2012 (mean density in 2017 = 0.12 m^2), exhibiting steady population increases throughout the warm period.

Sedimentation among North County Kelp Forests

Sediments at the NCKF sites have been relatively stable since 2008. Sediment horizons have varied less than 10 cm since 2008 when the sediment time series began. This period included the significant replenishment of beaches inshore of the study sites in 2012. North County beaches are presently undergoing a larger sand replenishment project that is slated to last four years. The grain size of sediments used for

Table 2

Recruitment rates for red and purple sea urchins (*M. franciscanus* and *S. purpuratus*, respectively) during the fall of 2017. Recruit percent is the fraction of ~1 year old individuals sampled within quadrats. Size thresholds for RSU and PSU recruits are <35 and <25 mm, respectively. "*" refers to sites where too few sea urchins were available for measurement (<75).

Site	***Mesocentrotus franciscanus***	***Strongylocentrotus purpuratus***
LJN18	17.31	15.84
LJN15	33.32	54.84
LJN12	64.7	91.49
LJS18	4.85	1.94
LJS15	17.65	14.17
LJS12	50.00	15.38
PLN18	15.84	7.94
PLC21	28.92	8.99
PLC18	32.69	9.57
PLC15	6.19	4
PLC12	*	19.42
PLC08	*	45.35
PLS18	48.25	37.9
PLS15	18.75	16.49
PLM18	2.73	8.89
PLT12	57.14	57.43
PLT15	69.33	71.60

beach replenishment is an important determinant of beach stability. The 2012 replenishment event utilized coarser sediments than previous replenishment efforts, and therefore erosion of those beaches did not appear to affect NCKF reefs. The source of sediments for the present beach replenishment effort is San Elijo Lagoon, as part of an effort to restore the estuary to more marine conditions. The grain size composition of these sediments is not clearly defined and therefore the potential impact of this most recent replenishment project on North County reefs is presently uncertain.

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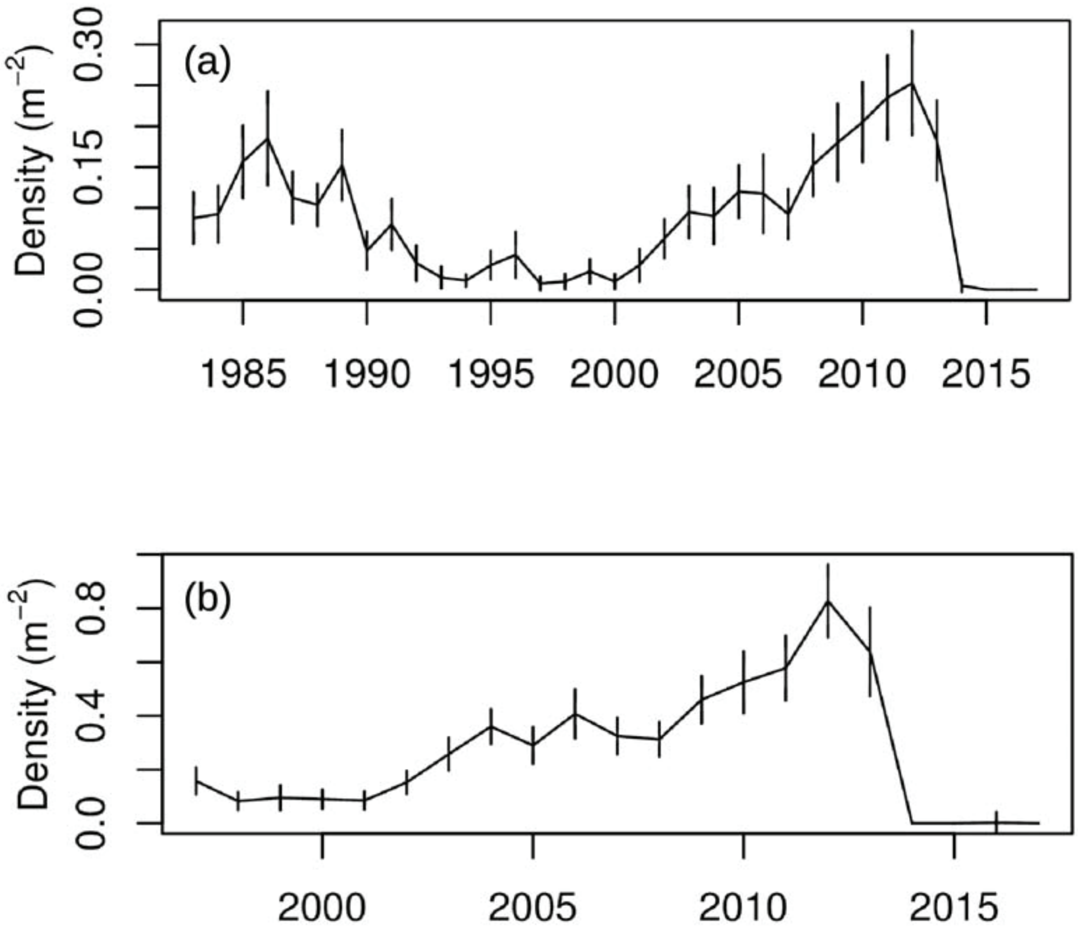

Figure 15
Time series of seastar density (*Pisaster giganteus* and *P. brevispinus* combined) at (a) PLS18 and (b) PLT15 study sites. Error bars indicate standard errors.

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Appendix B

Coastal Oceanographic Conditions

2016 – 2017 Supplemental Analyses

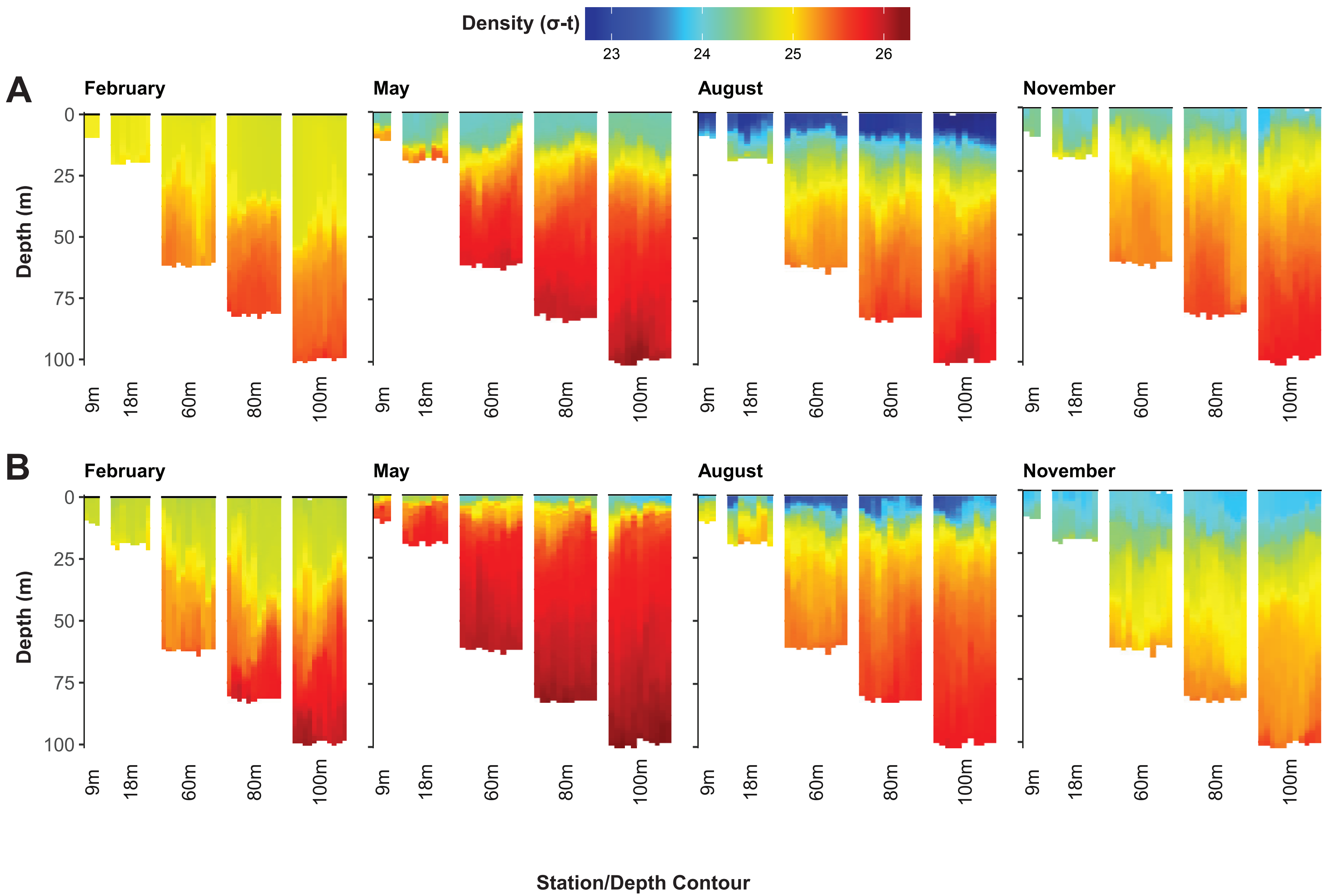
PLOO and SBOO Stations

Appendix B.1

Sample dates for quarterly oceanographic surveys conducted during 2016 and 2017. All stations in each station group were sampled on a single day (see Figure 2.1 for stations and locations).

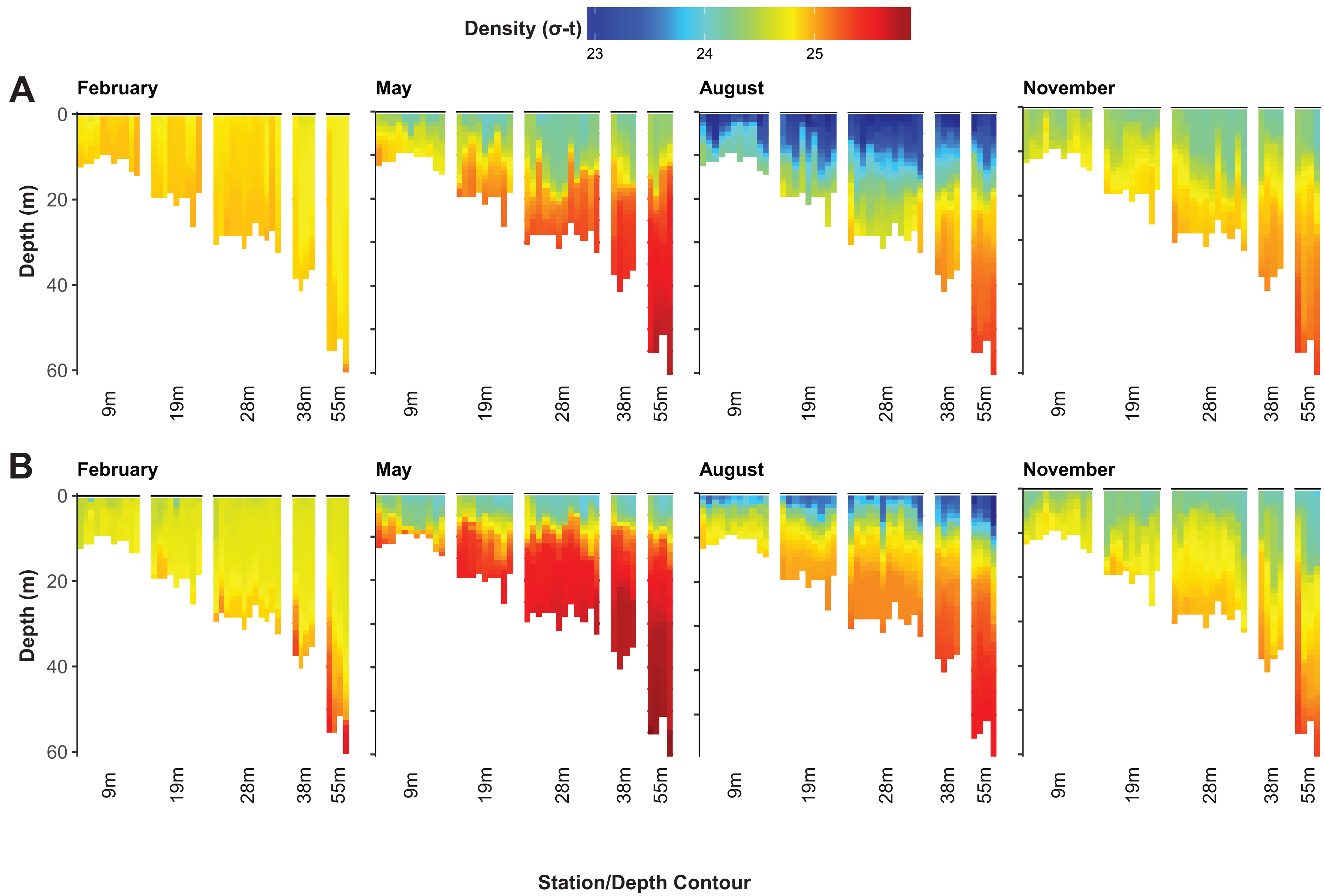
	Sampling Dates in 2016				Sampling Dates in 2017			
	Feb	**May**	**Aug**	**Nov**	**Feb**	**May**	**Aug**	**Nov**
PLOO Station Group								
Kelp WQ	4	5	11	10	4	25	10	Oct 30
18 & 60-m WQ	3	3	8	8	1	24	7	1
80-m WQ	2	4	9	9	2	23	8	2
100-m WQ	5	2	10	7	3	22	9	3
SBOO Station Group								
North WQ	11	11	3	3	9	2	3	8
Mid WQ[a]	10	10	4	1	8	3	2	7
South WQ	9	9	2	2	7	4	1	6

[a] Includes kelp stations



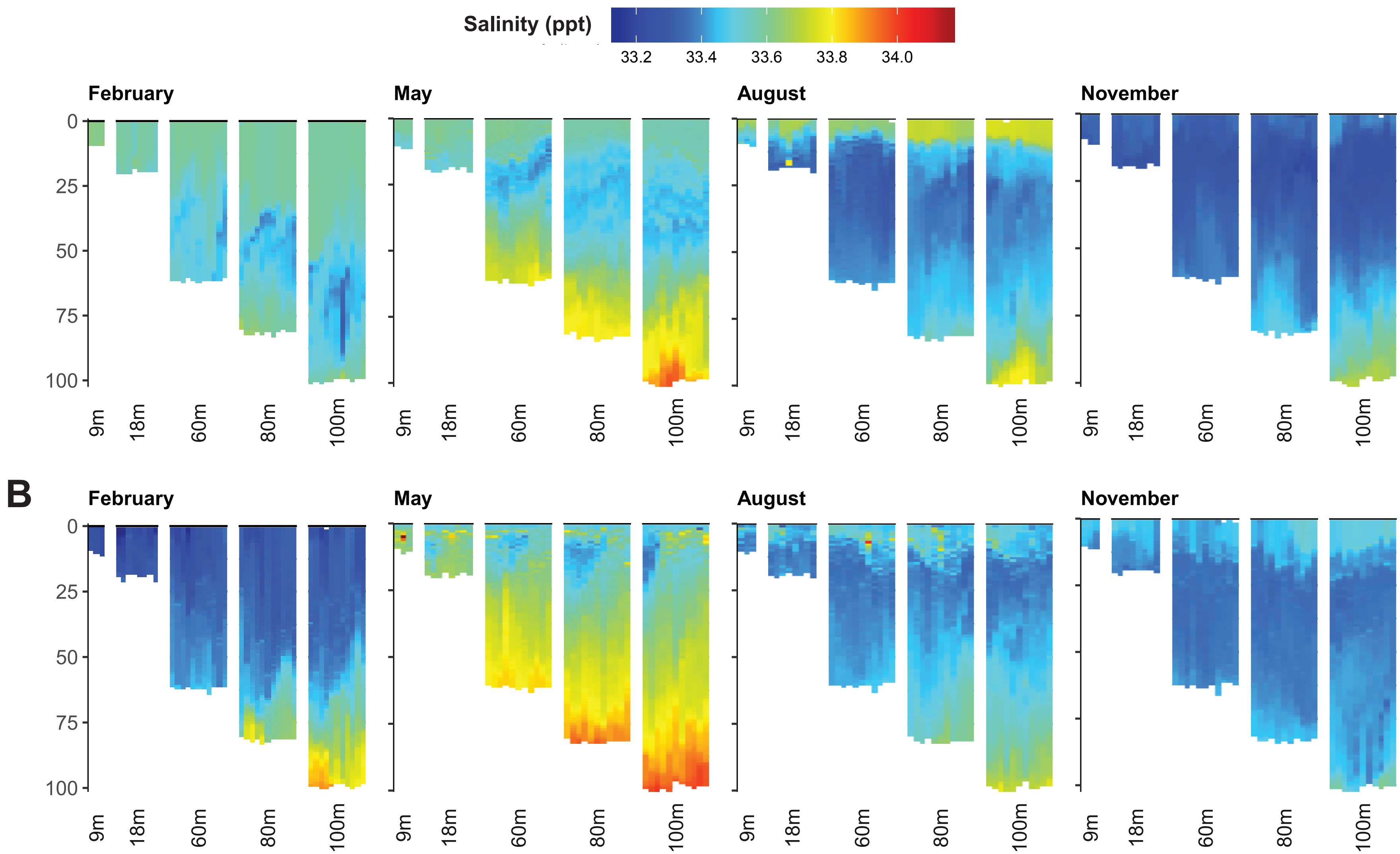
Appendix B.2

Density recorded in the PLOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over four days during each quarterly survey. Stations are depicted from north to south along each depth contour.

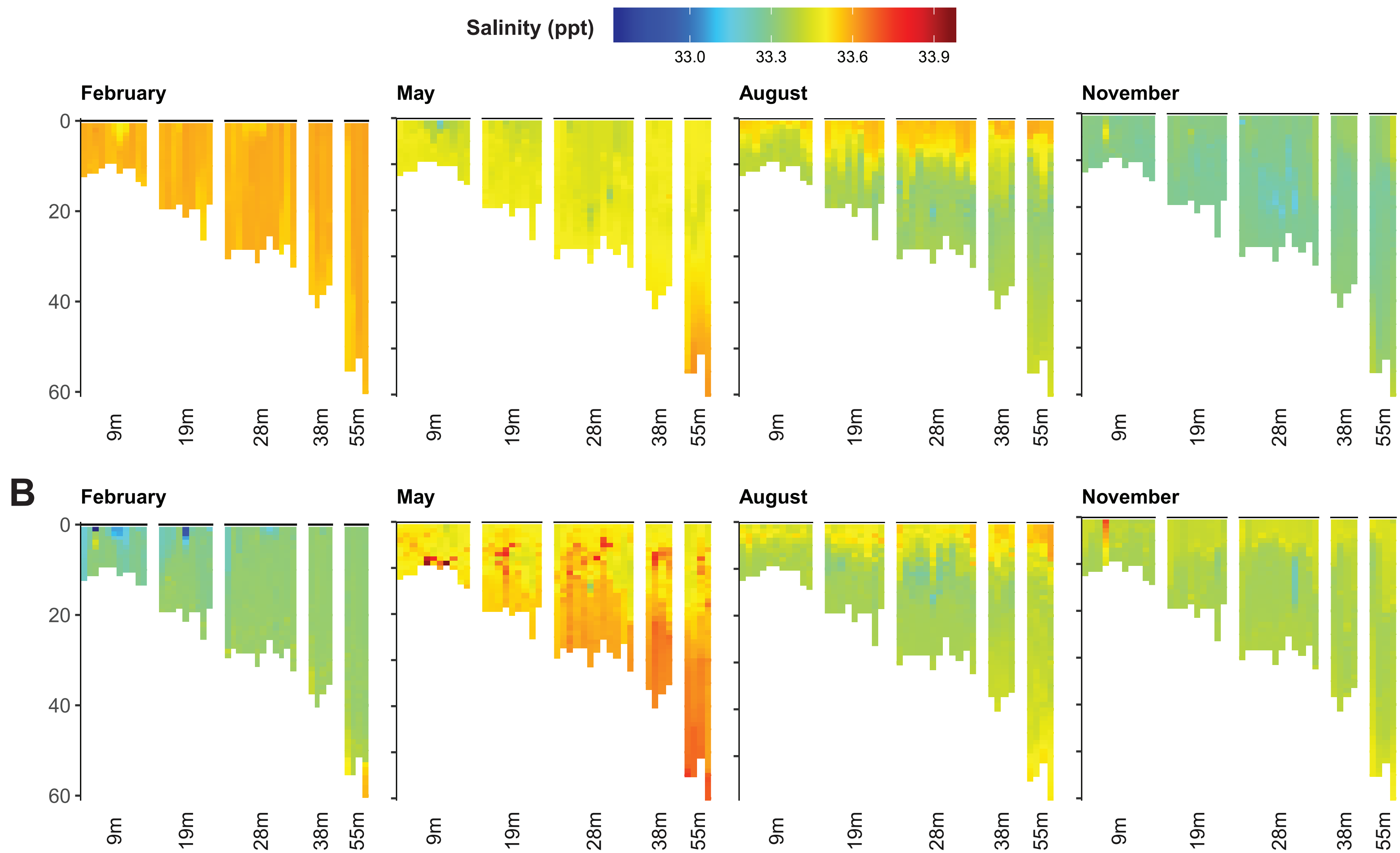


Appendix B.3

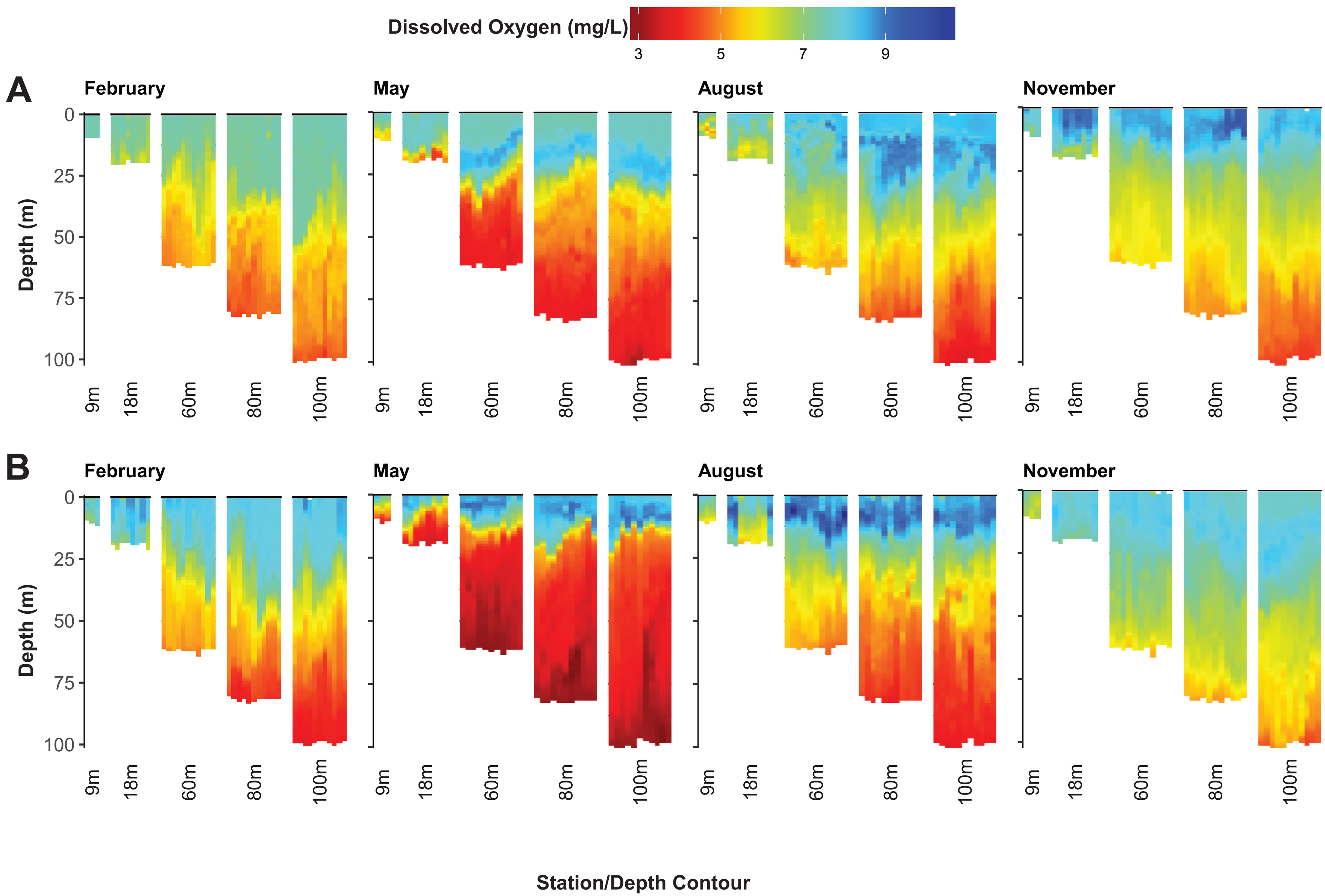
Density recorded in the SBOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over three days during each quarterly survey. Stations are depicted from north to south along each depth contour.



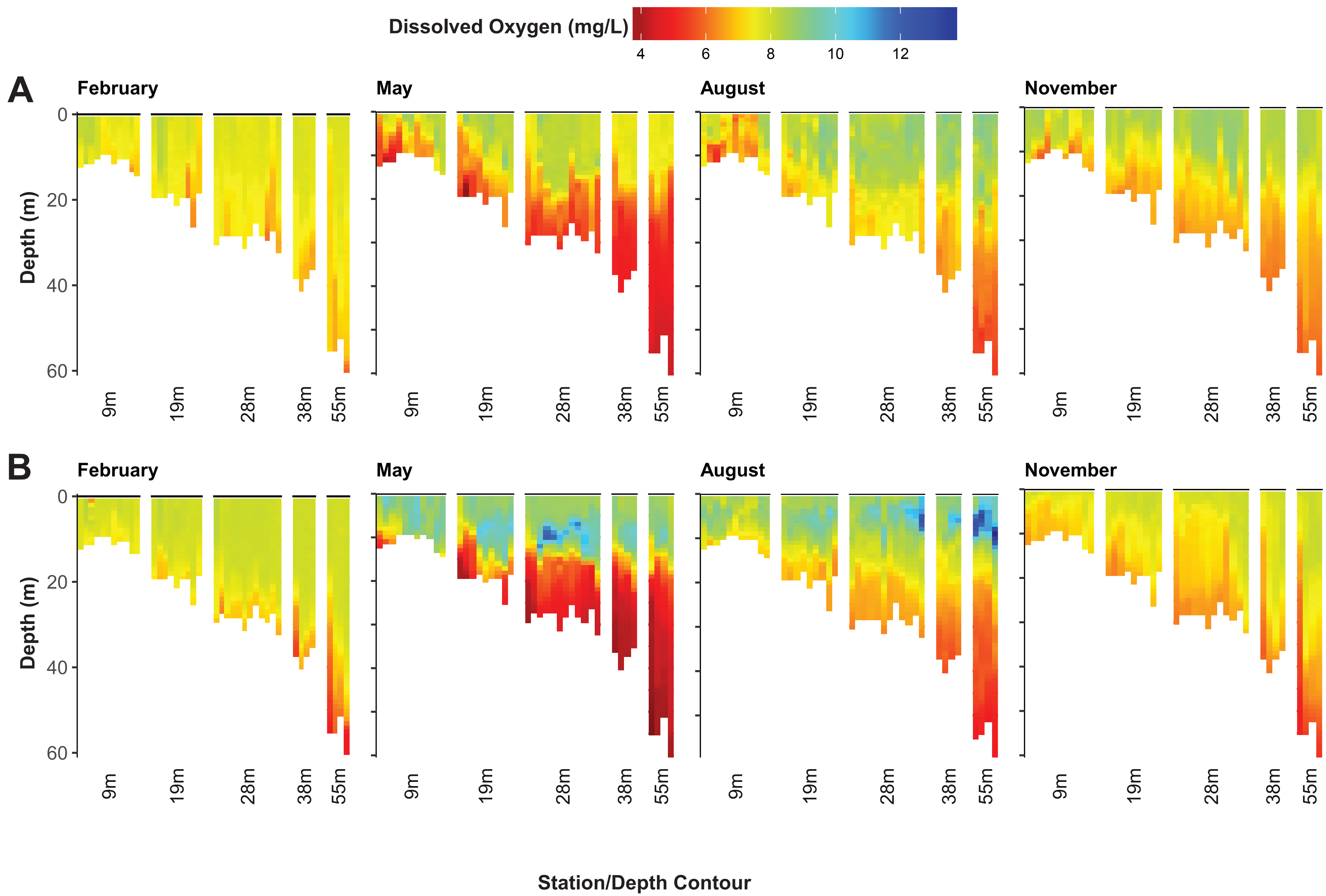
Appendix B.4
Salinity recorded in the PLOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over four days during each quarterly survey. Stations are depicted from north to south along each depth contour.



Appendix B.5
Salinity recorded in the SBOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over three days during each quarterly survey. Stations are depicted from north to south along each depth contour.

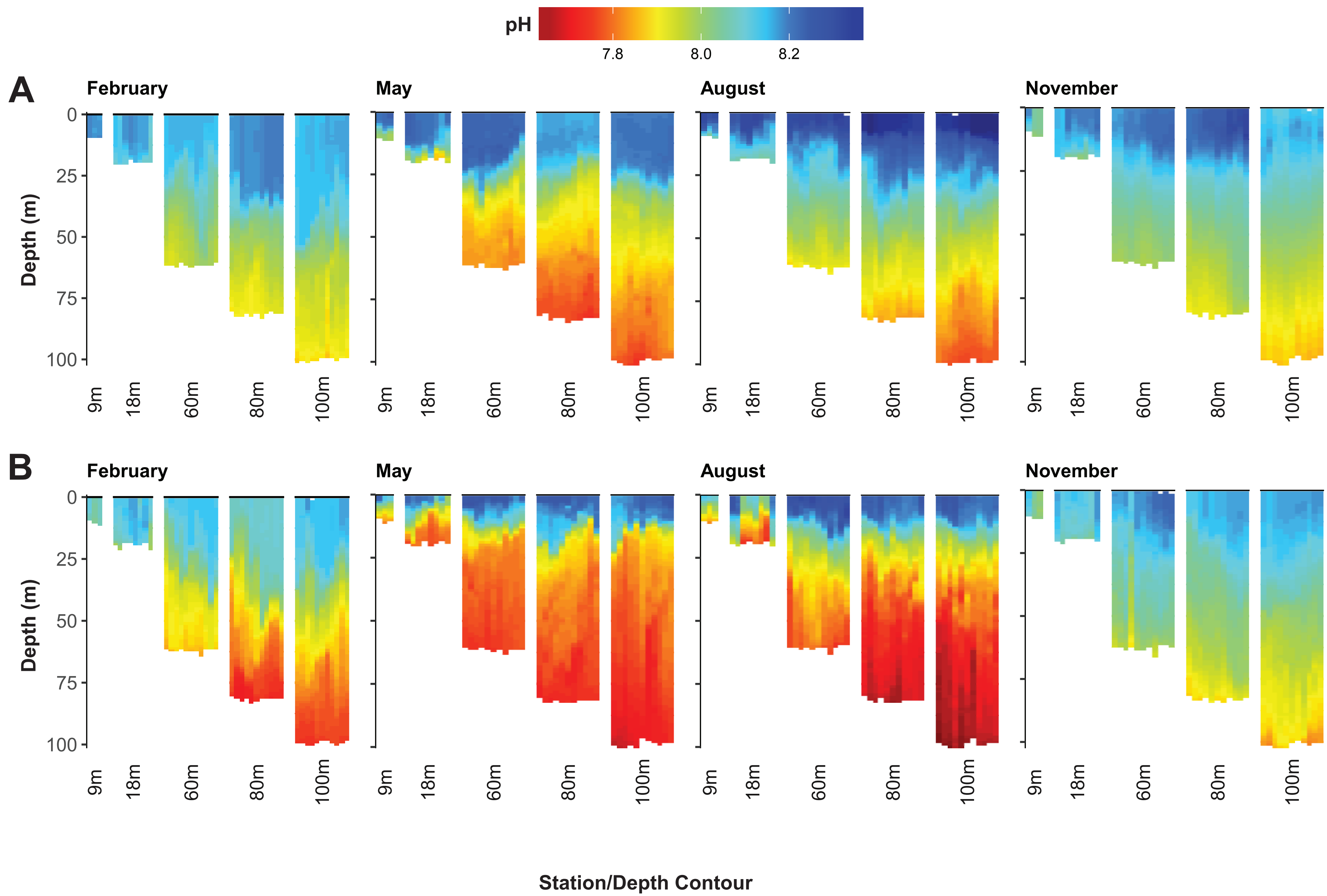


Appendix B.6
Dissolved oxygen recorded in the PLOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over four days during each quarterly survey. Stations are depicted from north to south along each depth contour.



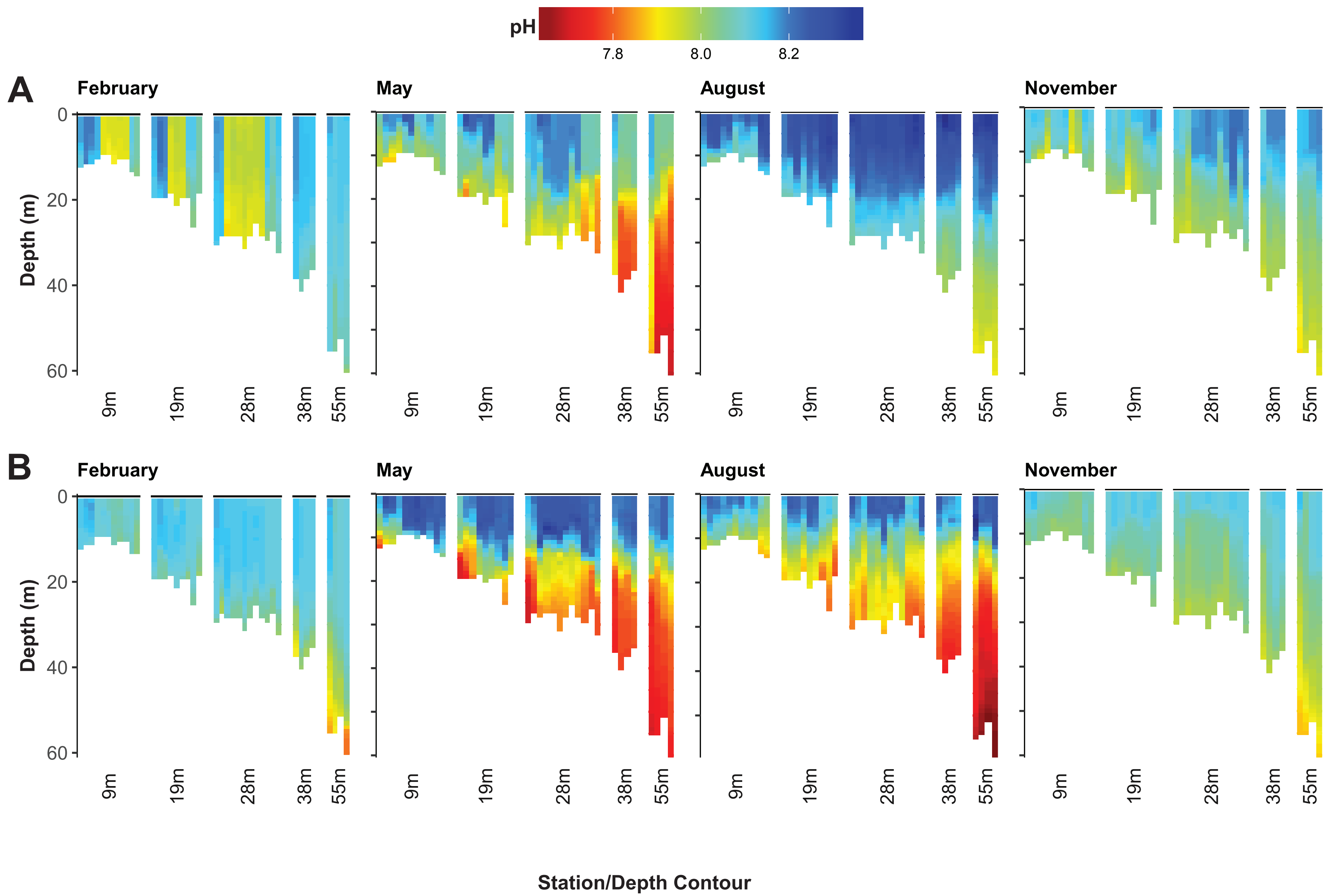
Appendix B.7

Dissolved oxygen recorded in the SBOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over three days during each quarterly survey. Stations are depicted from north to south along each depth contour.



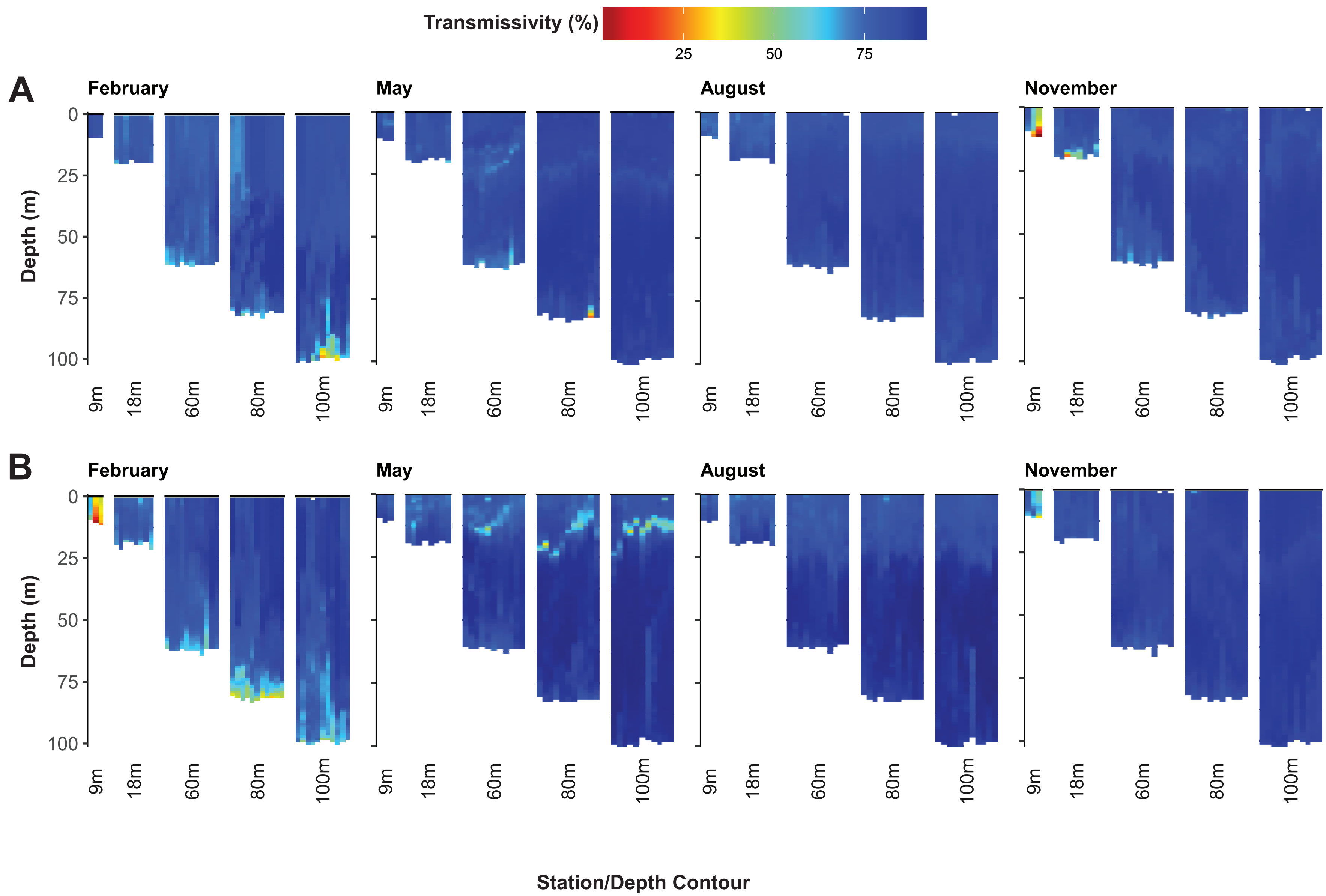
Appendix B.8

Values of pH recorded in the PLOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over four days during each quarterly survey. Stations are depicted from north to south along each depth contour.



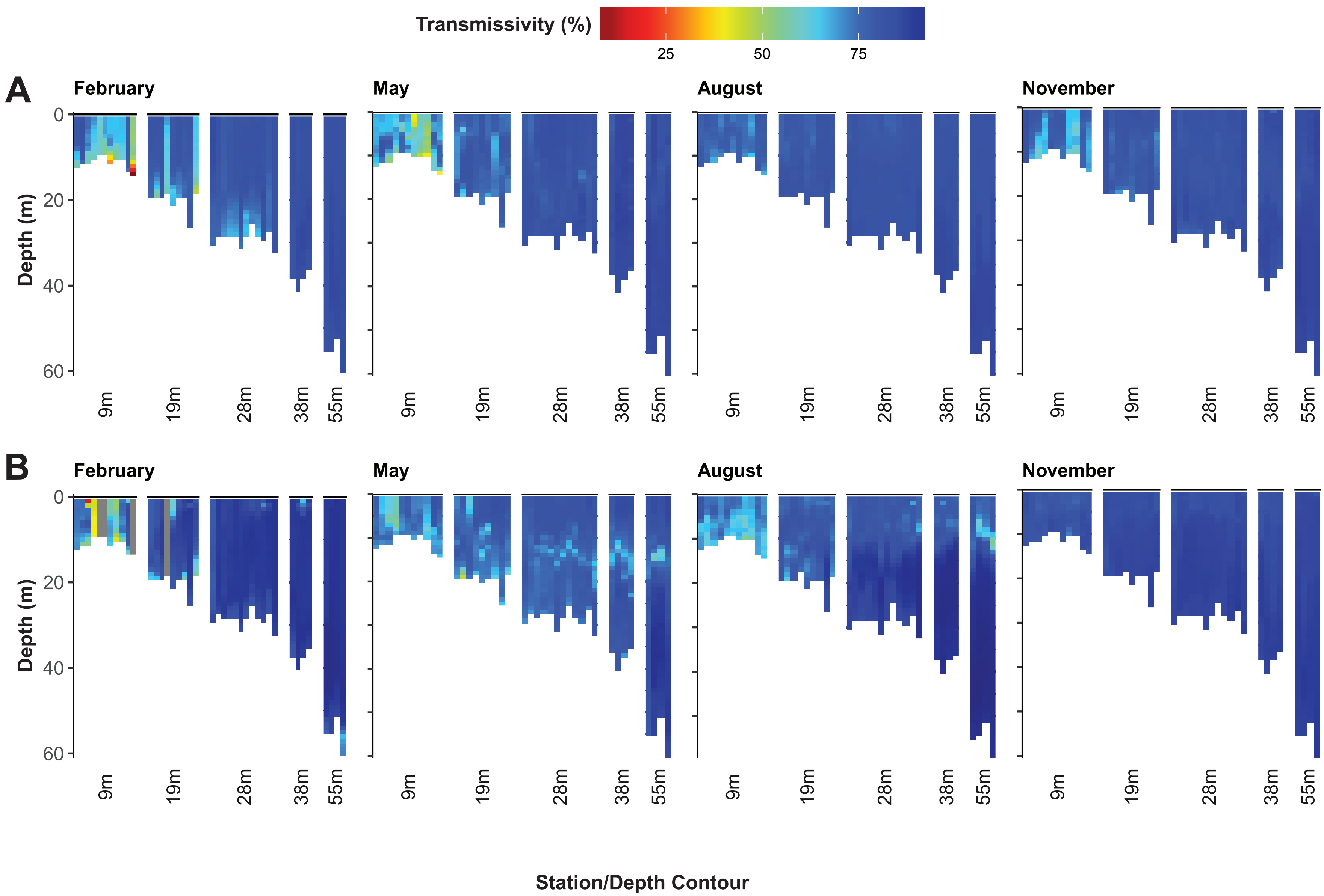
Appendix B.9

Values of pH recorded in the SBOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over three days during each quarterly survey. Stations are depicted from north to south along each depth contour.



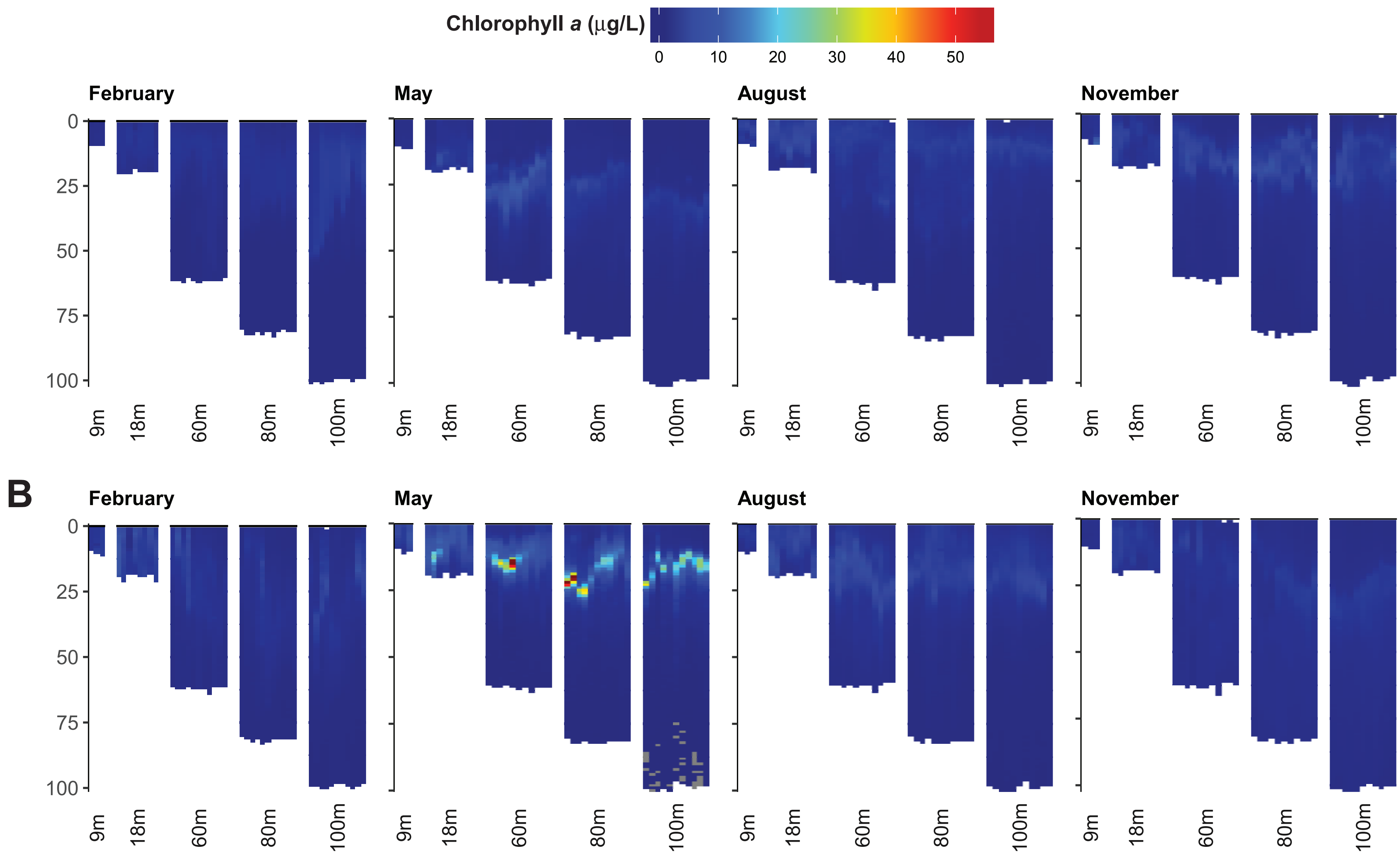
Appendix B.10

Transmissivity recorded in the PLOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over four days during each quarterly survey. Stations are depicted from north to south along each depth contour.



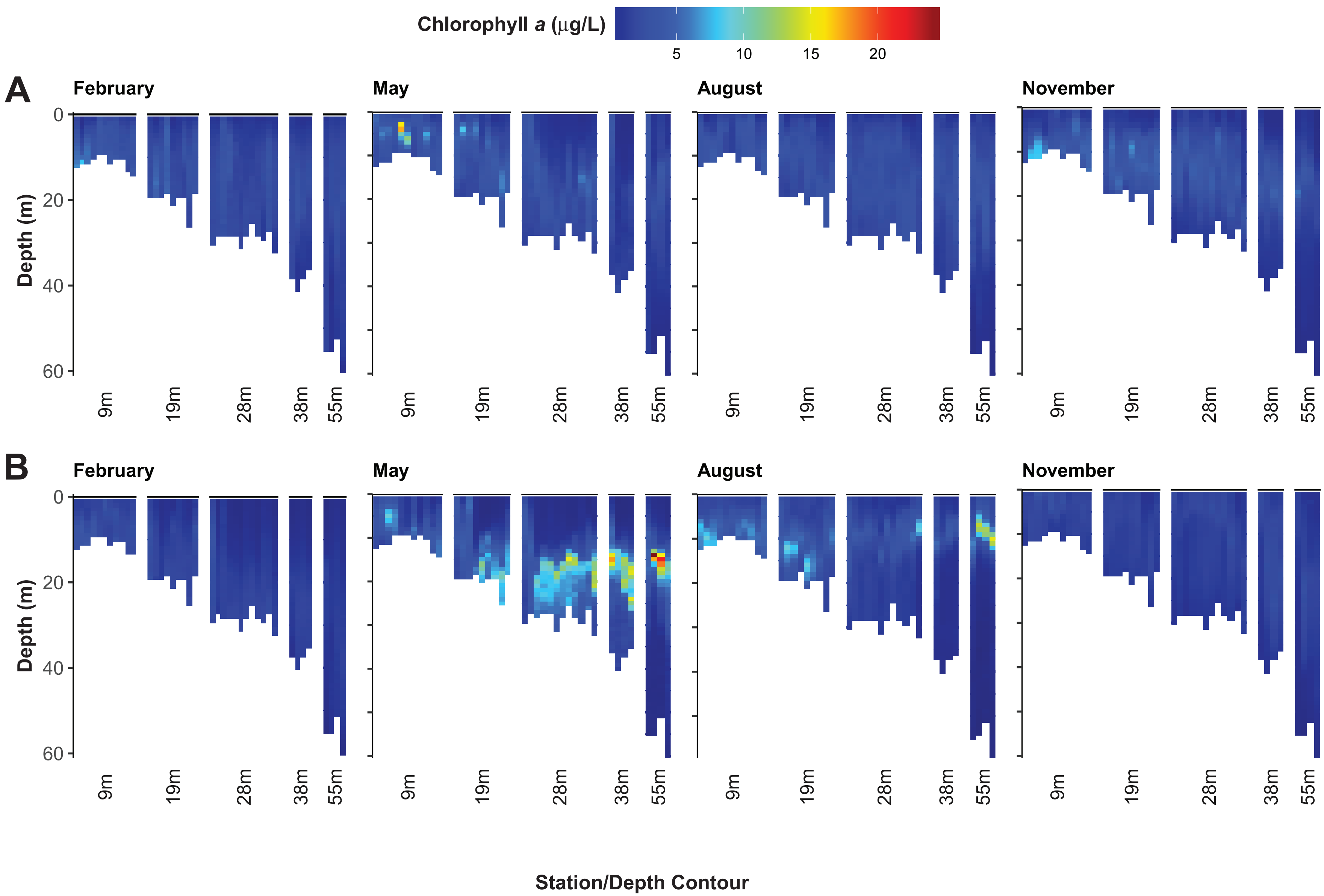
Appendix B.11

Transmissivity recorded in the SBOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over three days during each quarterly survey. Stations are depicted from north to south along each depth contour.



Appendix B.12

Chlorophyll *a* recorded in the PLOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over four days during each quarterly survey. Stations are depicted from north to south along each depth contour.



Appendix B.13
Chlorophyll *a* recorded in the SBOO region during (A) 2016 and (B) 2017. Data are 1-m binned values per depth for each station and were collected over three days during each quarterly survey. Stations are depicted from north to south along each depth contour.

Appendix B.14

Summary of current velocity magnitude and direction from the 100-m ADCP off Point Loma from 2015 to 2017. Data are presented as seasonal means with 95% confidence intervals. Minimum and maximum angles of velocity are not shown due to the circular nature of the measurement.

100-m ADCP		Magnitude (mm/s)				Angle (°)	
	Depth (m)	Min	Max	Mean	95% CI	Mean	95% CI
Winter	11	3	302	114	3	148	37
	15	3	394	152	4	164	36
	19	6	390	151	3	159	36
	23	2	394	150	3	155	36
	27	5	384	147	3	152	36
	31	3	385	143	3	151	36
	35	2	387	139	3	149	36
	39	1	391	134	3	142	36
	43	2	400	128	3	129	37
	47	3	404	120	3	111	37
	51	1	406	109	3	85	38
	55	1	398	98	3	55	38
	59	2	376	89	3	35	38
	63	1	342	84	2	24	37
	67	2	311	81	2	18	36
	71	1	286	78	2	13	36
	75	1	266	76	2	12	37
	79	2	258	75	2	11	39
	83	1	245	72	2	12	39
	87	1	237	69	2	15	38
	91	2	214	64	2	20	38
	95	0	179	57	1	349	39

Appendix B.14 *continued*

100-m ADCP

		Magnitude (mm/s)				Angle (°)	
	Depth (m)	**Min**	**Max**	**Mean**	**95% CI**	**Mean**	**95% CI**
Spring	11	1	502	183	4	167	40
	15	3	557	205	4	172	41
	19	2	534	188	4	171	41
	23	3	498	169	4	171	41
	27	2	478	152	3	171	41
	31	4	463	137	3	169	42
	35	2	451	125	3	166	43
	39	1	424	115	2	162	45
	43	1	390	106	2	157	45
	47	2	361	97	2	148	46
	51	2	305	90	2	121	47
	55	2	248	84	1	62	48
	59	2	211	78	1	24	48
	63	2	193	74	1	6	49
	67	0	185	70	1	357	49
	71	1	175	65	1	354	50
	75	1	168	60	1	356	50
	79	1	153	56	1	6	48
	83	1	140	52	1	27	46
	87	0	130	50	1	66	44
	91	3	118	48	1	111	44
	95	1	110	43	1	146	46

Appendix B.14 *continued*

100-m ADCP

	Depth (m)	Magnitude (mm/s) Min	Max	Mean	95% CI	Angle (°) Mean	95% CI
Summer	11	3	330	110	2	128	46
	15	1	412	132	3	170	43
	19	2	448	125	3	172	43
	23	0	411	115	2	165	43
	27	1	319	106	2	38	42
	31	1	287	98	2	15	42
	35	2	271	91	2	11	42
	39	2	253	86	2	10	43
	43	3	238	83	2	10	44
	47	0	230	80	2	11	45
	51	2	225	78	2	10	45
	55	0	221	76	2	5	45
	59	1	220	75	2	357	46
	63	1	224	72	2	347	46
	67	1	227	70	2	339	46
	71	1	238	68	1	336	45
	75	2	254	66	1	337	44
	79	0	266	63	1	344	42
	83	1	266	60	1	359	41
	87	0	260	57	1	33	40
	91	2	247	55	1	86	40
	95	1	215	48	1	121	42

Appendix B.14 *continued*

100-m ADCP

	Depth (m)	Magnitude (mm/s) Min	Max	Mean	95% CI	Angle (°) Mean	95% CI
Fall	11	0	326	110	2	154	42
	15	1	471	140	3	172	40
	19	2	389	125	2	170	40
	23	1	425	113	2	166	40
	27	1	428	105	2	134	40
	31	1	410	98	2	13	39
	35	1	394	96	2	9	40
	39	1	391	94	2	10	40
	43	2	384	94	2	12	40
	47	0	379	95	2	12	39
	51	0	372	96	2	10	39
	55	1	367	97	2	9	39
	59	1	361	98	2	5	39
	63	1	343	98	2	360	40
	67	0	316	96	2	354	40
	71	1	305	92	2	351	40
	75	1	287	88	2	351	39
	79	1	298	84	2	354	38
	83	1	305	78	1	1	37
	87	0	298	73	1	15	36
	91	0	273	67	1	44	36
	95	0	238	57	1	102	38

Appendix B.15

Summary of current velocity magnitude and direction from the SBOO 36-m ADCP from 2015 to 2017. Data are presented as seasonal means with 95% confidence intervals. Minimum and maximum angles of velocity are not shown due to the circular nature of the measurement.

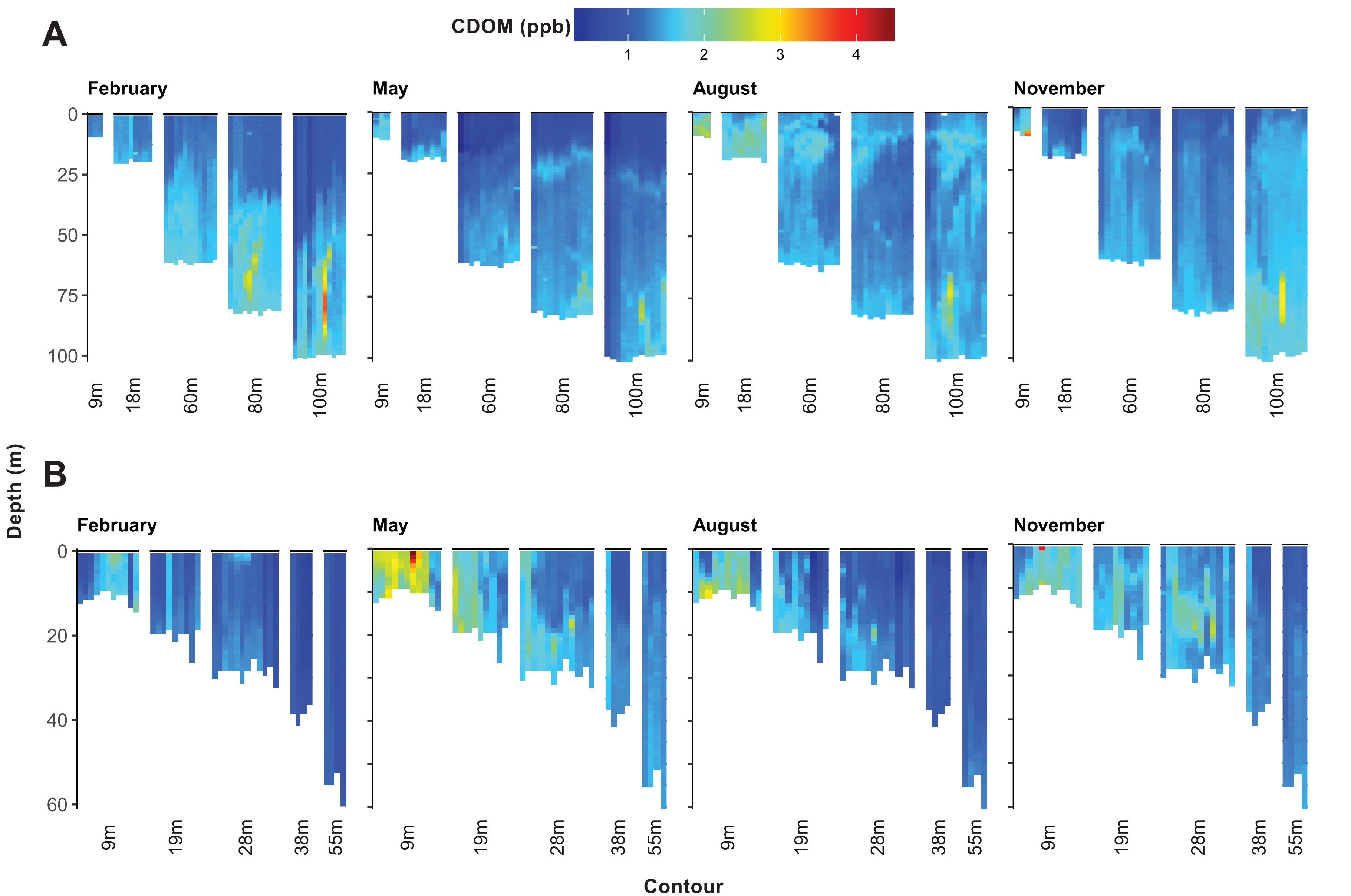
		Magnitude (mm/s)				Angle (°)	
	Depth (m)	Min	Max	Mean	95% CI	Mean	95% CI
Winter	8	0	390	120	2	153	42
	12	1	326	106	2	158	42
	16	1	325	102	2	148	43
	20	1	315	97	2	141	45
	24	0	304	88	2	138	45
	28	1	287	75	1	140	46
	32	0	246	60	1	311	49
Spring	8	3	328	108	2	129	42
	12	1	343	98	2	139	40
	16	2	307	93	2	69	41
	20	0	268	87	2	37	41
	24	2	248	77	2	16	41
	28	1	226	66	1	1	42
	32	2	184	50	1	351	46
Summer	8	7	341	109	2	125	36
	12	7	289	100	2	102	36
	16	3	282	90	2	54	36
	20	1	278	82	2	29	36
	24	5	260	73	2	20	36
	28	2	203	62	2	15	34
	32	2	166	50	1	6	36
Fall	8	2	382	104	2	141	44
	12	2	379	96	2	119	45
	16	1	393	91	2	36	44
	20	1	393	86	2	12	44
	24	1	361	78	2	1	44
	28	0	314	68	1	354	44
	32	0	254	57	1	345	45

Appendix C

Water Quality Compliance and Plume Dispersion

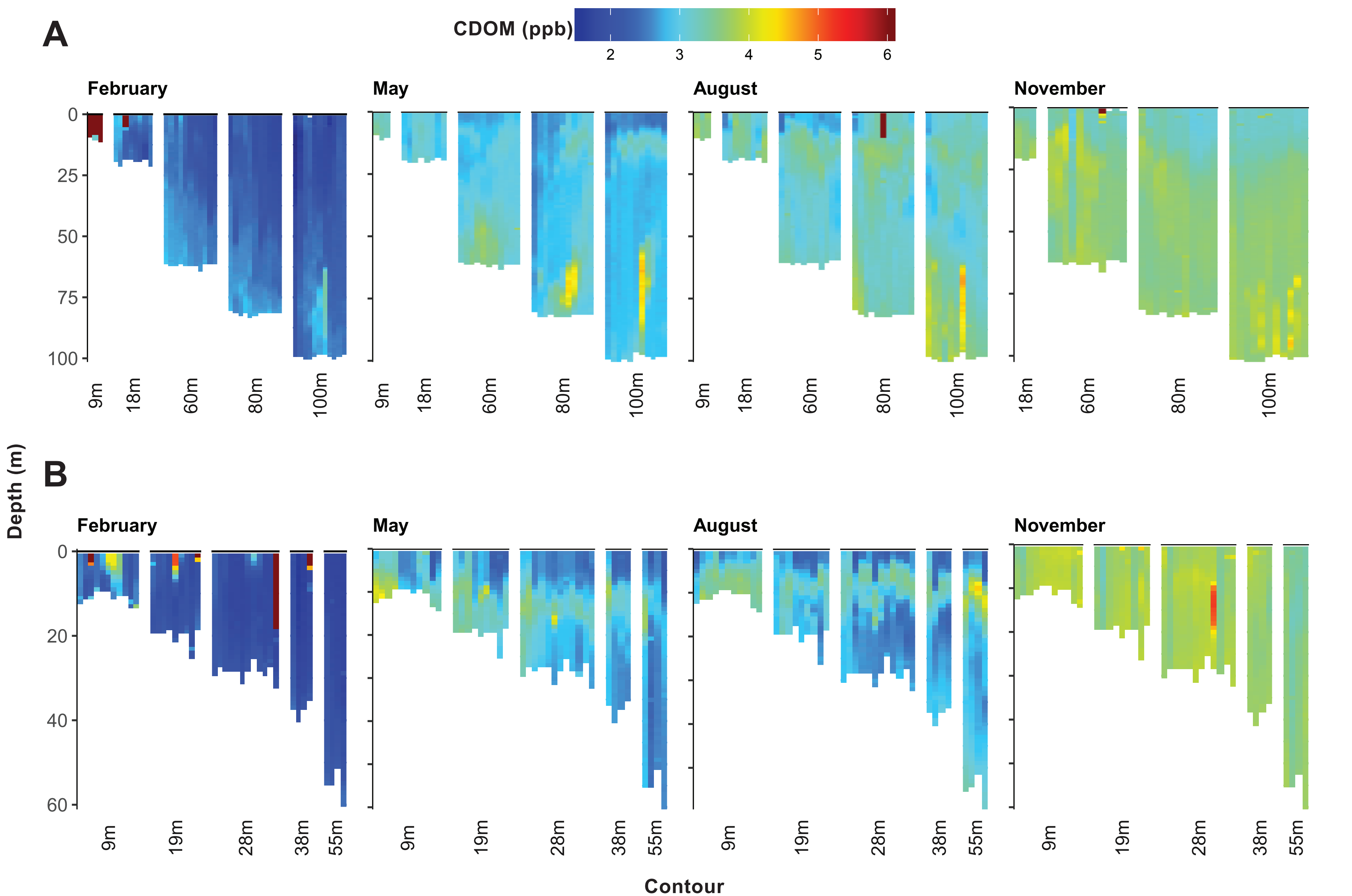
2016 – 2017 Supplemental Analyses

PLOO and SBOO Stations



Appendix C.1

Concentrations of CDOM recorded in the (A) PLOO and (B) SBOO regions during 2016. Data are 1-m binned values per depth for each station during each quarterly survey. Stations depicted from north to south along each depth contour. See Chapter 2 for additional sampling details.



Appendix C.2

Concentrations of CDOM recorded in the (A) PLOO and (B) SBOO regions during 2017. Data are 1-m binned values per depth for each station during each quarterly survey. Stations depicted from north to south along each depth contour. See Chapter 2 for additional sampling details.

Appendix C.3

Summary of PLOO and SBOO reference stations used during 2016 and 2017 to calculate out-of-range thresholds (see text for details).

2016	Stations
February	
PLOO	F01, F02, F03, F04, F05, F06, F07, F25, F27, F28, F33, F36
SBOO	I1, I2, I3, I6, I7, I8, I9, I10, I13, I20, I21, I28, I29, I30, I31, I33, I34, I35
May	
PLOO	F02, F03, F11, F13, F14, F34, F35, F36
SBOO	I1, I2, I3, I6, I7, I8, I9, I10, I13, I14, I16, I17, I18, I20, I21, I22, I23, I27, I28, I29
August	
PLOO	F04, F05, F15, F16, F21
SBOO	I1, I2, I3, I6, I7, I8, I9, I10, I12, I13, I16, I17, I20, I21, I28, I29
November	
PLOO	F02, F03, F04, F05, F06, F07, F08, F09, F10, F11, F12, F13, F14, F15, F16, F17, F18, F20, F21, F22, F23, F24, F25
SBOO	I1, I2, I3, I6, I7, I8, I9, I13, I18, I20, I21, I28, I29, I30, I31, I33, I34, I35

2017	Stations
February	
PLOO	F04, F05, F08, F16, F26, F27, F28, F29, F35, F36
SBOO	I3, I6, I9, I10, I13, I14, I15, I21, I22, I27, I39
May	
PLOO	F01, F02, F03, F23, F25, F35, F36
SBOO	I1, I2, I3, I6, I7, I8, I10, I12, I13, I14, I16, I17, I20, I21, I22, I39
August	
PLOO	F02, F03, F04, F05, F06, F12, F13, F14, F15, F26
SBOO	I8, I10, I17, I18, I21, I23, I27, I34, I35, I39
November	
PLOO	F02, F04, F05, F06, F11, F15, F16, F17, F18, F21, F24, F29, F35
SBOO	I1, I7, I8, I9, I10, I13, I20, I28, I30, I31, I34, I35, I39

Appendix C.4

Summary of oceanographic data within potential detected plume at PLOO offshore stations and corresponding reference values during 2016 and 2017. Plume depth is the minimum depth at which CDOM exceeds the 95th percentile while plume width is the number of meters across which that exceedance occurs. Out-of-range values are indicated with an asterisk. DO = dissolved oxygen; XMS = transmissivity; SD = standard deviation; CI = confidence interval.

		Potential Plume					Reference		
Station	Date	Depth (m)	Width (m)	Mean DO	Mean pH	Mean XMS	DO (Mean - SD)	pH (Mean)	XMS (Mean - 95% CI)
F19[a]	2-Feb-16	50	8	5.1	8.0	87	5.2	8.0	78
F20[a]	2-Feb-16	53	14	4.8	7.9	86	5.2	8.0	81
F21	2-Feb-16	44	23	4.7	7.9	84	5.1	8.0	83
F22	2-Feb-16	48	19	4.8	8.0	84	5.1	8.0	80
F23	2-Feb-16	54	2	5.0	8.0	85	5.2	8.0	78
F29	5-Feb-16	55	8	5.2	8.0	81	5.3	8.0	80
F30	5-Feb-16	60	37	4.8	7.9	70*	4.9	7.9	80
F31	5-Feb-16	63	11	5.1	7.9	80	5.0	8.0	80
F34	5-Feb-16	94	5	4.7	7.9	83	4.7	7.9	61
F26	2-May-16	68	28	4.2	7.8	89	4.1	7.8	89
F27	2-May-16	93	3	3.9	7.8	89	4.0	7.8	87
F28	2-May-16	94	3	3.9	7.8	88	3.9	7.8	87
F29	2-May-16	84	13	3.8	7.8	89	3.9	7.8	88
F30	2-May-16	75	13	3.8	7.8	88*	4.1	7.8	89
F06[a]	3-May-16	48	4	3.5	7.8	77*	3.8	7.9	86
F15	4-May-16	71	9	3.8*	7.8	87*	4.3	7.8	90
F16	4-May-16	65	15	3.8*	7.8	82*	4.4	7.9	90
F17	4-May-16	70	10	3.8*	7.8	88*	4.3	7.8	90
F18[a]	4-May-16	76	5	3.8	7.8	88*	4.2	7.8	90
F19[a]	4-May-16	80	1	3.7*	7.8	87*	4.1	7.8	90
F23	4-May-16	68	1	4.0*	7.8	89*	4.5	7.9	90

[a]Station located within State jurisdictional waters

Appendix C.4 *continued*

		Potential Plume					Reference		
Station	Date	Depth (m)	Width (m)	Mean DO	Mean pH	Mean XMS	DO (Mean-SD)	pH (Mean)	XMS (Mean-95% CI)
F31	10-Aug-16	73	2	4.4	7.8	86	4.7	7.9	84
F32	10-Aug-16	66	26	4.2*	7.8	85	4.8	7.9	85
F33	10-Aug-16	74	14	4.4	7.8	85	4.5	7.9	85
F30	7-Nov-16	66	23	4.7	7.9	81*	5.2	8.0	84
F31	7-Nov-16	76	6	5.0	7.9	86	5.1	7.9	82
F33	7-Nov-16	73	11	4.9	7.9	86	5.1	8.0	83
F34	7-Nov-16	66	25	4.8	7.9	84	5.2	8.0	84
F35	7-Nov-16	70	27	4.9	7.9	85	5.1	8.0	84
F36	7-Nov-16	74	20	4.9	7.9	86	5.1	7.9	83
F10[a]	1-Feb-17	55	4	5.0	7.9	66*	4.9	7.9	80
F14[a]	1-Feb-17	30	19	5.2	7.9	78*	5.3	7.9	84
F21	2-Feb-17	77	4	4.0	7.7	59*	4.3	7.8	72
F22	2-Feb-17	75	4	4.1	7.7	54*	4.3	7.8	72
F23	2-Feb-17	70	4	4.2	7.7	57*	4.5	7.8	80
F30	3-Feb-17	63	33	4.1	7.8	67*	4.3	7.8	74
F31	3-Feb-17	72	20	4.1	7.8	70*	4.2	7.8	72
F32	3-Feb-17	80	15	4.1	7.8	77	4.0	7.8	69
F29	22-May-17	65	7	3.1*	7.7	89*	3.5	7.8	91
F30	22-May-17	55	36	3.0*	7.7	86*	3.5	7.8	89
F17	23-May-17	61	3	3.2	7.8	90*	3.5	7.8	91
F18[a]	23-May-17	60	17	2.9*	7.7	88*	3.5	7.8	90
F19[a]	23-May-17	62	18	2.9*	7.7	88*	3.4	7.7	89
F20[a]	23-May-17	72	7	3.0	7.7	90	3.3	7.7	87

[a] Station located within State jurisdictional waters

Appendix C.4 *continued*

		Potential Plume					Reference		
Station	Date	Depth (m)	Width (m)	Mean DO	Mean pH	Mean XMS	DO (Mean - SD)	pH (Mean)	XMS (Mean - 95% CI)
F08[a]	24-May-17	52	5	3.1*	7.8	86*	3.7	7.8	92
F09[a]	24-May-17	48	5	3.1*	7.8	83*	3.7	7.8	92
F10[a]	24-May-17	45	14	3.0*	7.7	89*	3.8	7.8	92
F11[a]	24-May-17	46	9	3.1*	7.8	87*	3.9	7.8	92
F12[a]	24-May-17	57	2	3.1*	7.8	89*	3.6	7.8	92
F24	8-Aug-17	75	4	4.2	7.7	90	4.2	7.7	72
F25	8-Aug-17	65	11	4.6	7.7	89	4.2	7.7	77
F30	9-Aug-17	62	32	4.0	7.6	85	4.2	7.7	83
F32	9-Aug-17	82	7	3.9	7.6	91*	4.0	7.7	92
F33	9-Aug-17	86	4	4.0	7.7	90*	4.0	7.7	93
F34	9-Aug-17	78	4	3.9	7.6	92	4.2	7.7	81
F35	9-Aug-17	61	18	4.1	7.7	91*	4.2	7.7	92
F36	9-Aug-17	64	32	4.1	7.6	92	4.2	7.7	83
F27	3-Nov-17	68	15	5.3	7.9	88	5.8	8.0	88
F28	3-Nov-17	73	23	5.2	7.9	88	5.5	7.9	87
F30	3-Nov-17	80	17	5.5	7.9	88	5.3	7.9	85
F32	3-Nov-17	72	18	5.5	7.9	89	5.5	7.9	87

[a]Station located within State jurisdictional waters

Appendix C.5

Summary of oceanographic data within potential detected plume at SBOO offshore stations and corresponding reference values during 2016 and 2017. Plume depth is the minimum depth at which CDOM exceeds the 95[th] percentile while plume width is the number of meters across which that exceedance occurs. Out-of-range values are indicated with an asterisk. DO = dissolved oxygen; XMS = transmissivity; SD = standard deviation; CI = confidence interval.

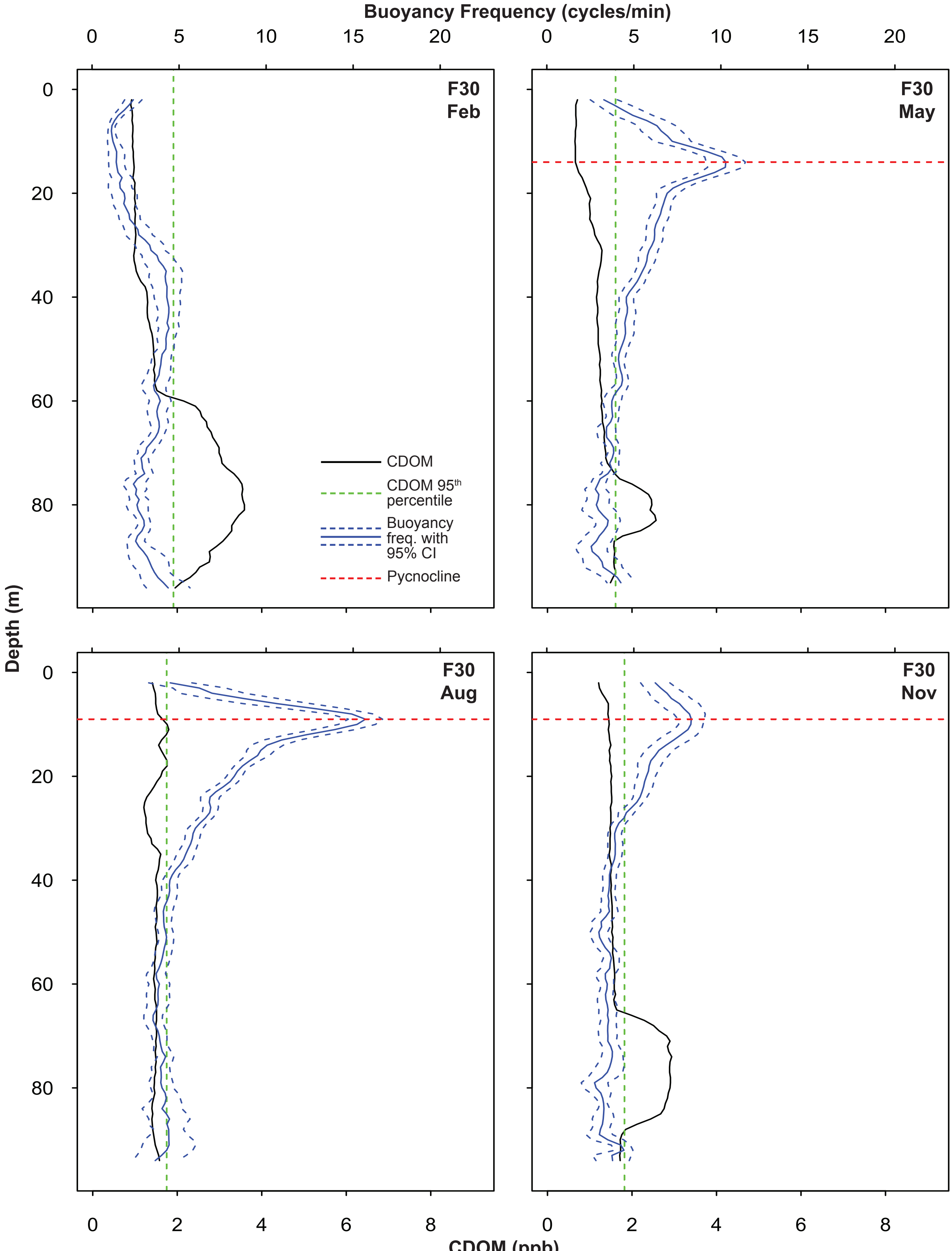
		Potential Plume					Reference		
Station	Date	Depth (m)	Width (m)	Mean DO	Mean pH	Mean XMS	DO (Mean - SD)	pH (Mean)	XMS (Mean - 95% CI)
I12[a]	10-Feb-16	3	23	7.4	7.9	73*	7.0	8.1	80
I14[a]	10-Feb-16	8	2	7.4	7.9	75*	7.1	8.1	81
I15	10-Feb-16	2	2	7.5	8.0	79*	7.5	8.2	83
I16[a]	10-Feb-16	3	2	7.4	7.9	74*	7.3	8.1	82
I27[a]	10-Feb-16	3	23	7.0	7.9	74*	7.0	8.1	80
I12	10-May-16	18	1	5.9	8.0	83	5.9	8.0	81
I15	10-May-16	2	22	6.0	8.0	83	5.4	7.9	82
I34[a]	3-Aug-16	7	10	7.1*	8.2	81*	8.1	8.2	82
I15	4-Aug-16	3	19	7.6	8.2	83	7.1	8.2	83
I27[a]	4-Aug-16	2	19	7.4	8.2	83	7.2	8.2	83
I39[a]	4-Aug-16	5	11	7.2*	8.1	82	8.2	8.2	82
I12[a]	1-Nov-16	4	18	7.1	8.0	82*	6.8	8.1	83
I15	1-Nov-16	2	18	7.2	8.1	82*	7.0	8.1	83
I16[a]	1-Nov-16	2	21	7.1	8.0	82*	6.7	8.1	84
I2	7-Feb-17	17	2	8.0	8.1	91	8.0	8.1	88
I8	7-Feb-17	4	2	8.0	8.1	89	8.0	8.1	85
I17[a]	8-Feb-17	2	2	8.1	8.1	85	8.0	8.1	82
I23[a]	8-Feb-17	6	2	8.1	8.1	70*	8.0	8.1	86

[a]Station located within State jurisdictional waters

Appendix C.5 *continued*

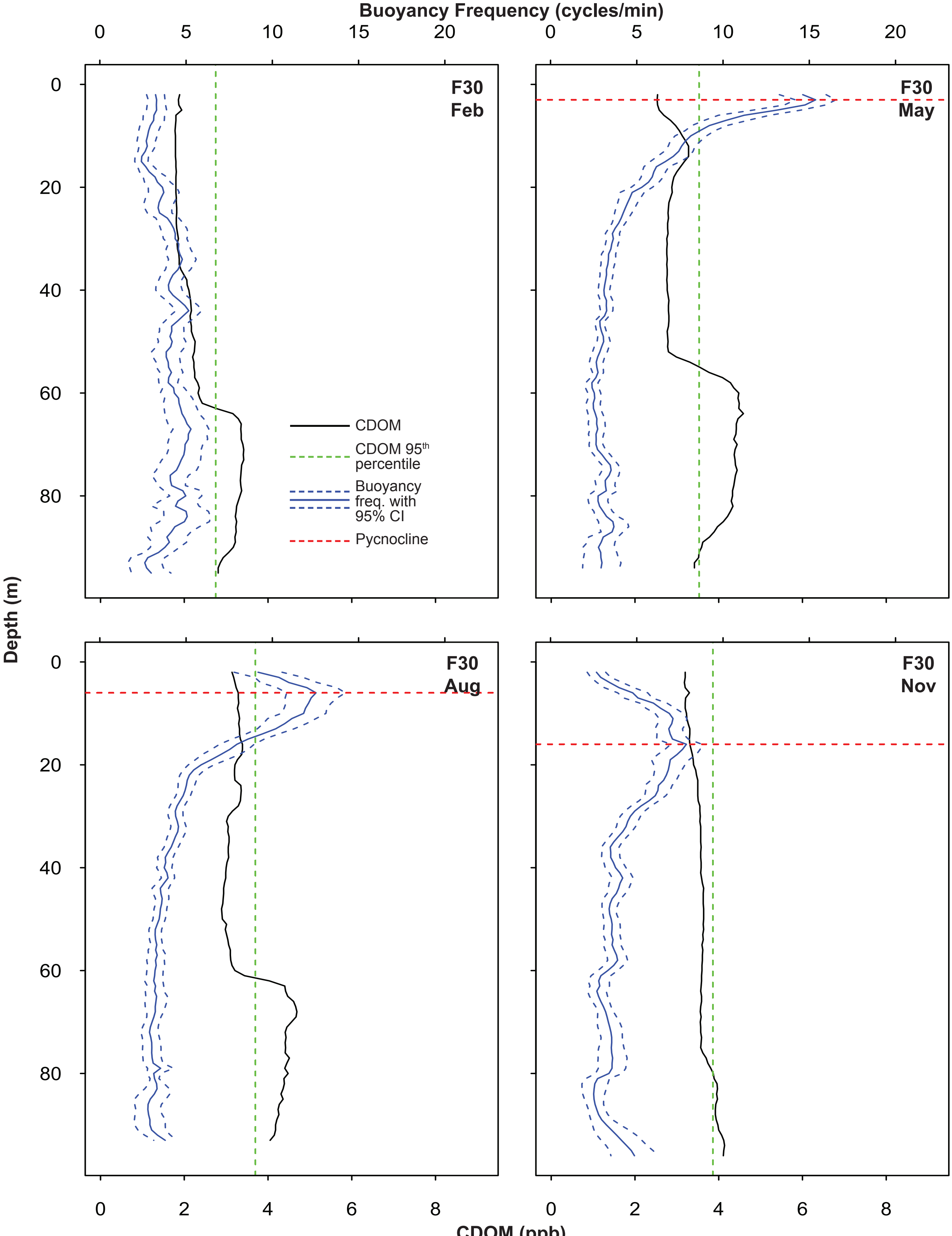
		Potential Plume					Reference		
Station	Date	Depth (m)	Width (m)	Mean DO	Mean pH	Mean XMS	DO (Mean-SD)	pH (Mean)	XMS (Mean-95% CI)
I28	2-May-17	6	13	7.2	8.0	74	6.3	8.0	71
I29	2-May-17	4	8	8.2	8.1	75*	9.0	8.2	77
I30	2-May-17	4	10	7.2*	8.0	75	8.2	8.1	73
I34[a]	2-May-17	2	10	7.3*	8.0	74*	8.9	8.2	75
I15	3-May-17	3	15	5.9	7.9	72	5.8	8.0	72
I18[a]	3-May-17	2	9	9.4	8.2	73*	9.1	8.2	77
I23[a]	3-May-17	2	11	9.6	8.2	74	8.6	8.1	73
I7	1-Aug-17	7	7	9.7	8.1	75*	8.1	8.0	79
I6	6-Nov-17	6	8	7.8	8.1	87	7.2	8.1	86
I12[a]	7-Nov-17	15	9	6.7	8.0	88	6.9	8.1	87
I15	7-Nov-17	3	7	7.3	8.1	88	7.5	8.1	86

[a]Station located within State jurisdictional waters



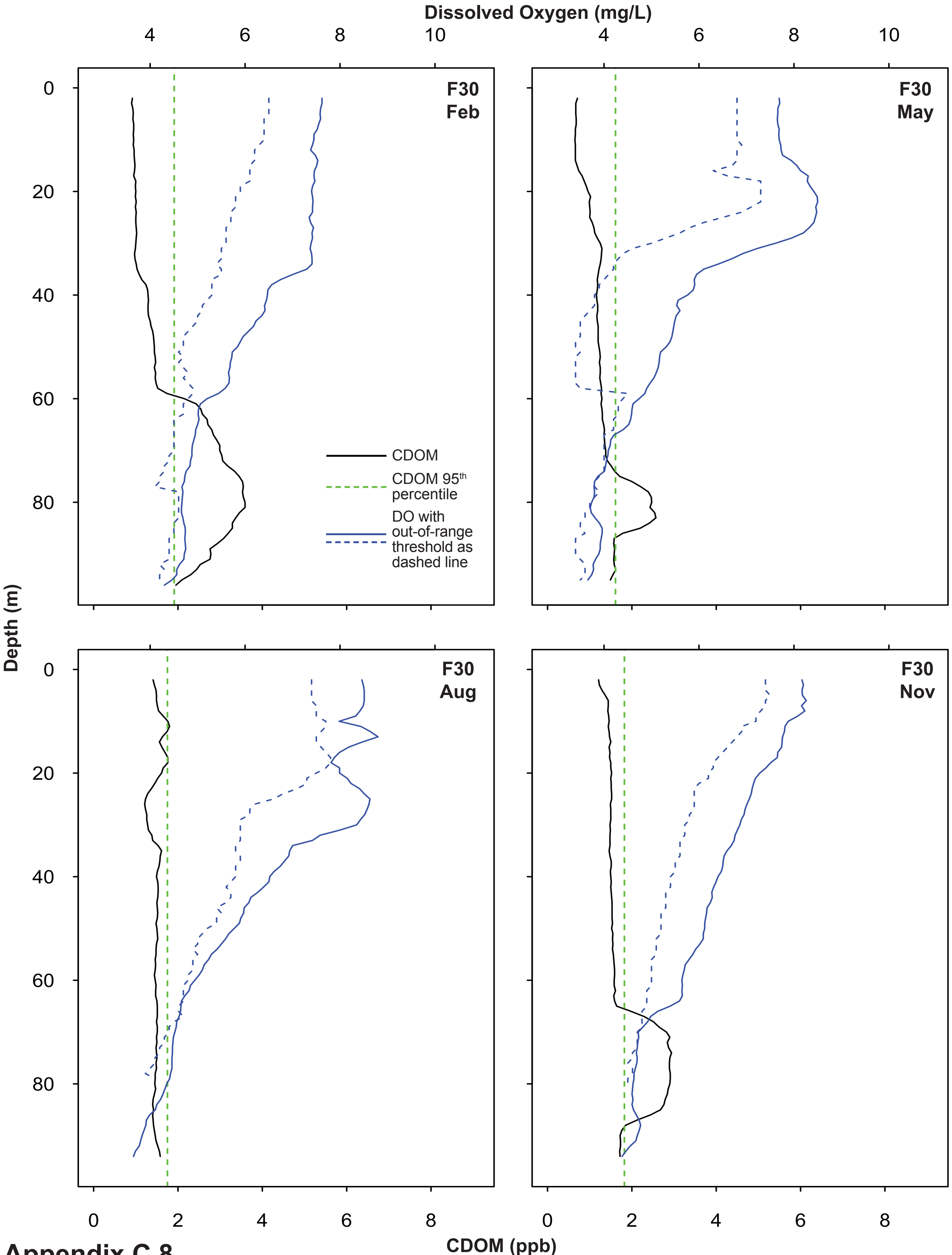
Appendix C.6

Representative vertical profiles of CDOM and buoyancy frequency from PLOO nearfield station F30 during 2016.



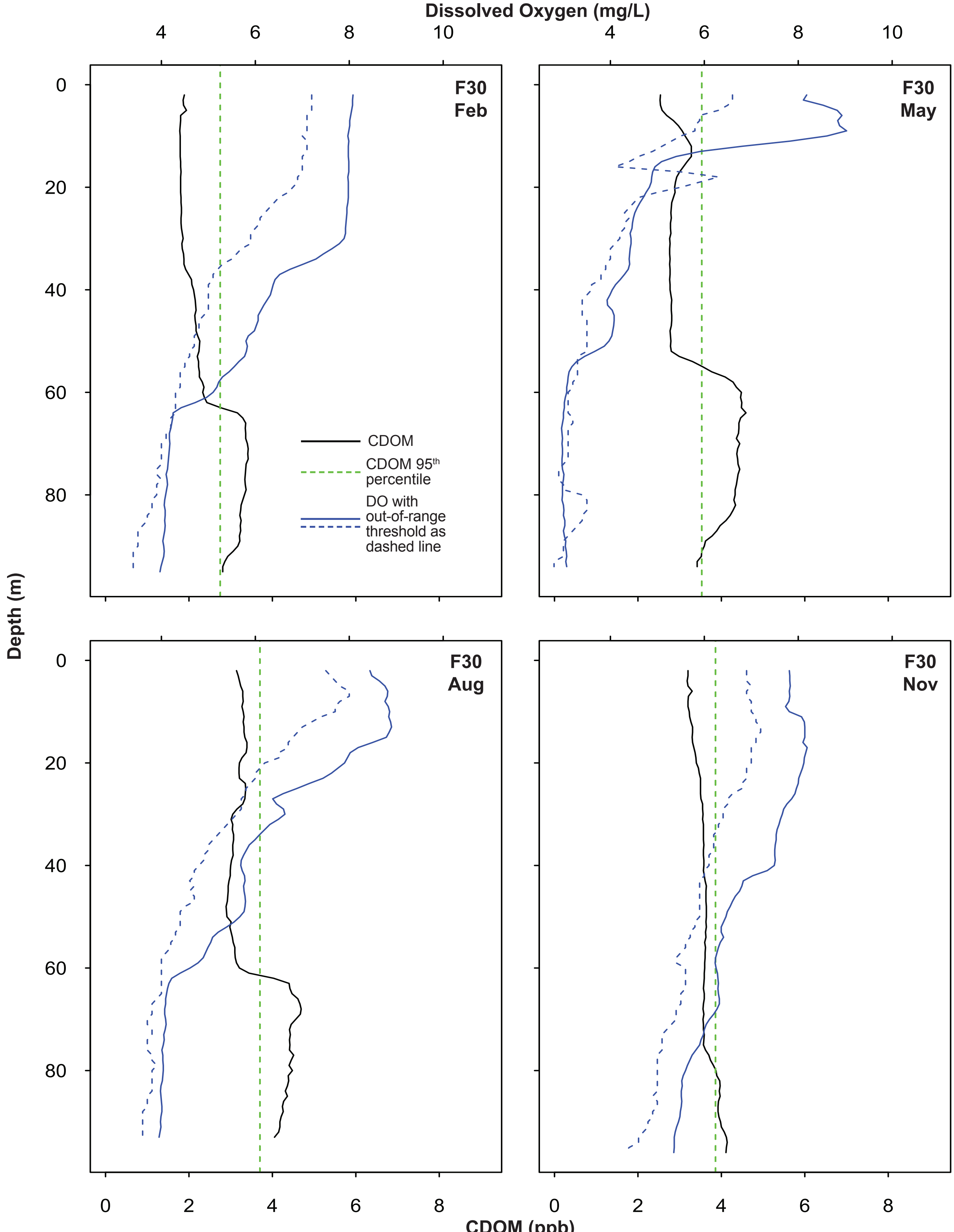
Appendix C.7

Representative vertical profiles of CDOM and buoyancy frequency from PLOO nearfield station F30 during 2017.



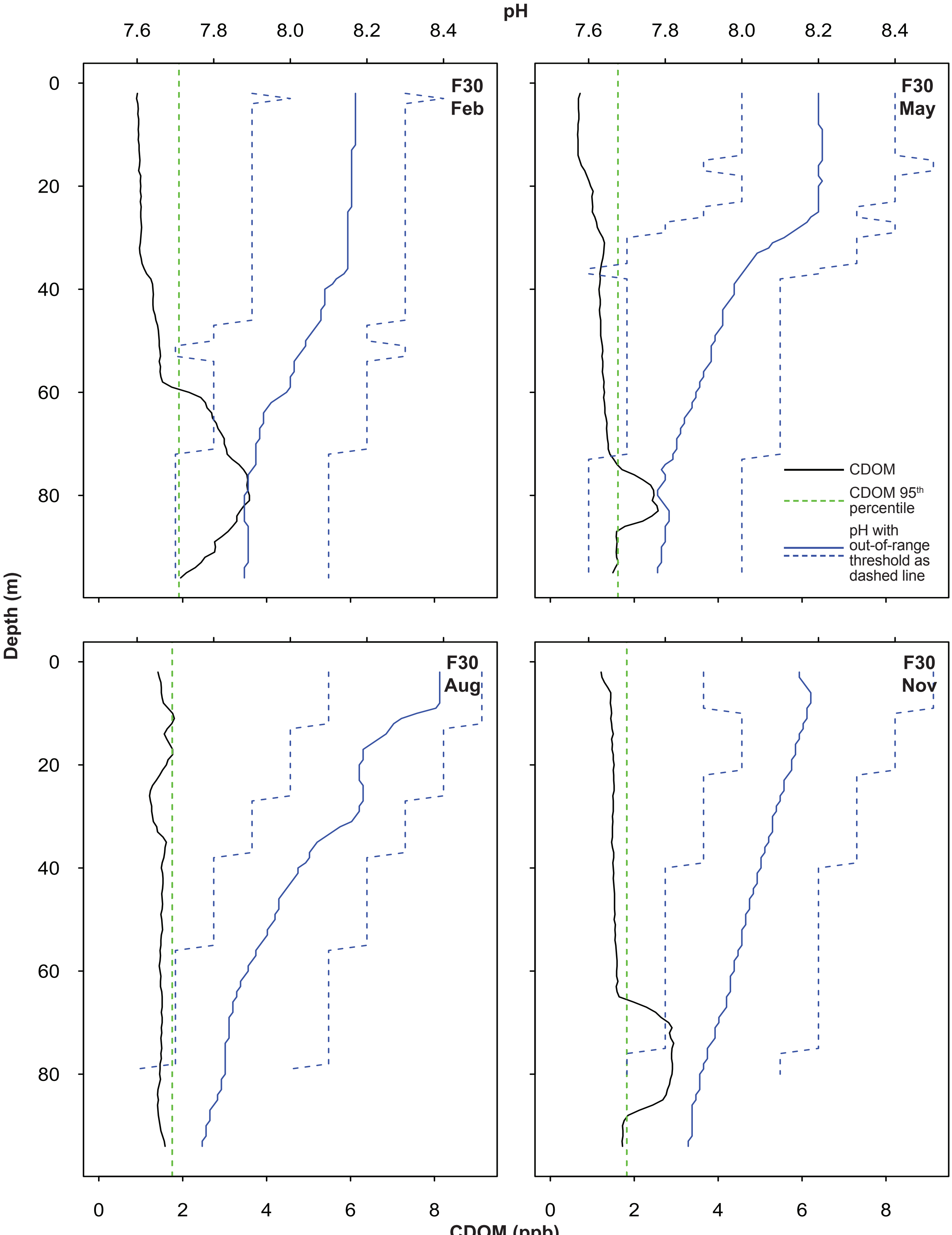
Appendix C.8

Representative vertical profiles of CDOM and dissolved oxygen (DO) from PLOO nearfield station F30 during 2016.

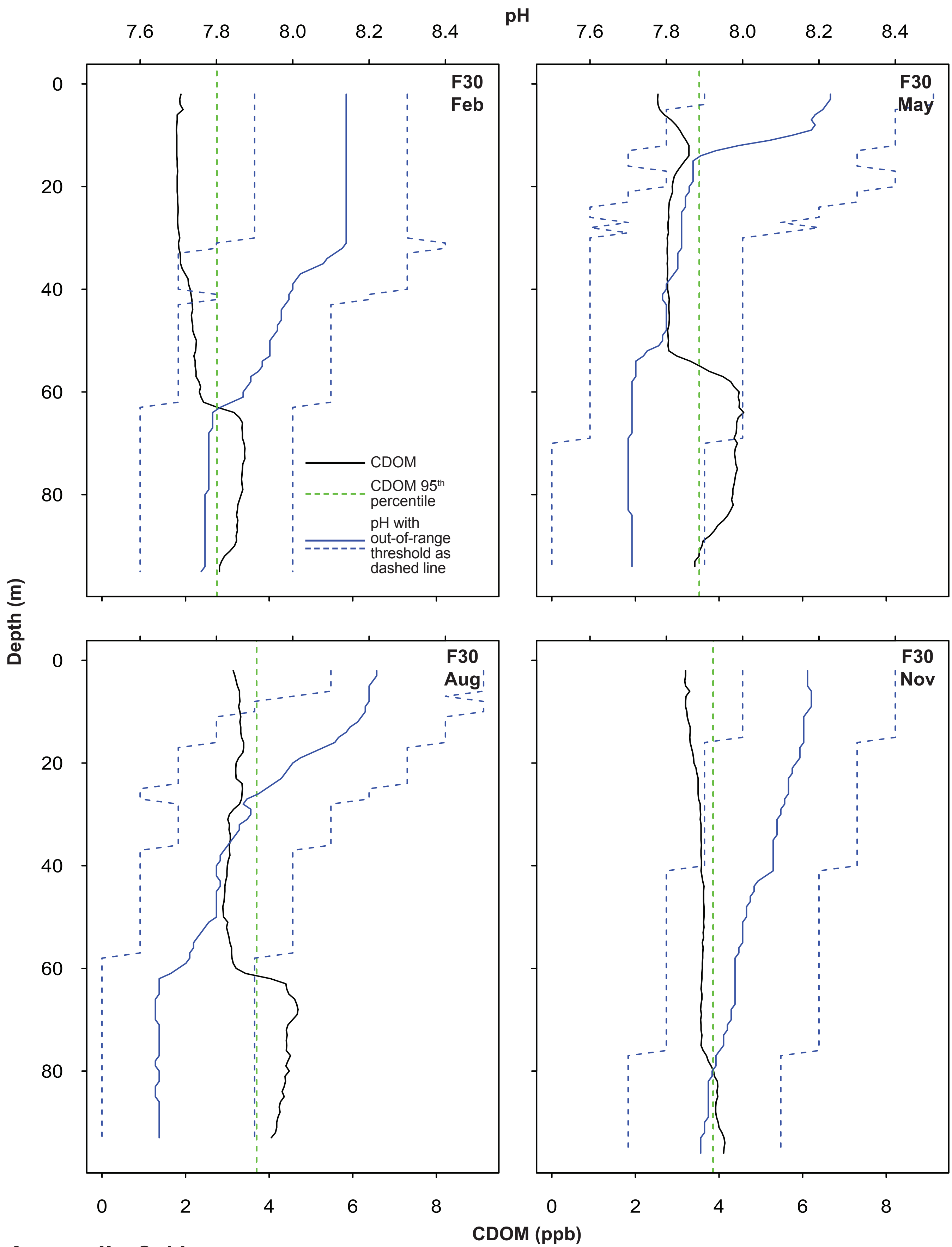


Appendix C.9

Representative vertical profiles of CDOM and dissolved oxygen (DO) from PLOO nearfield station F30 during 2017.

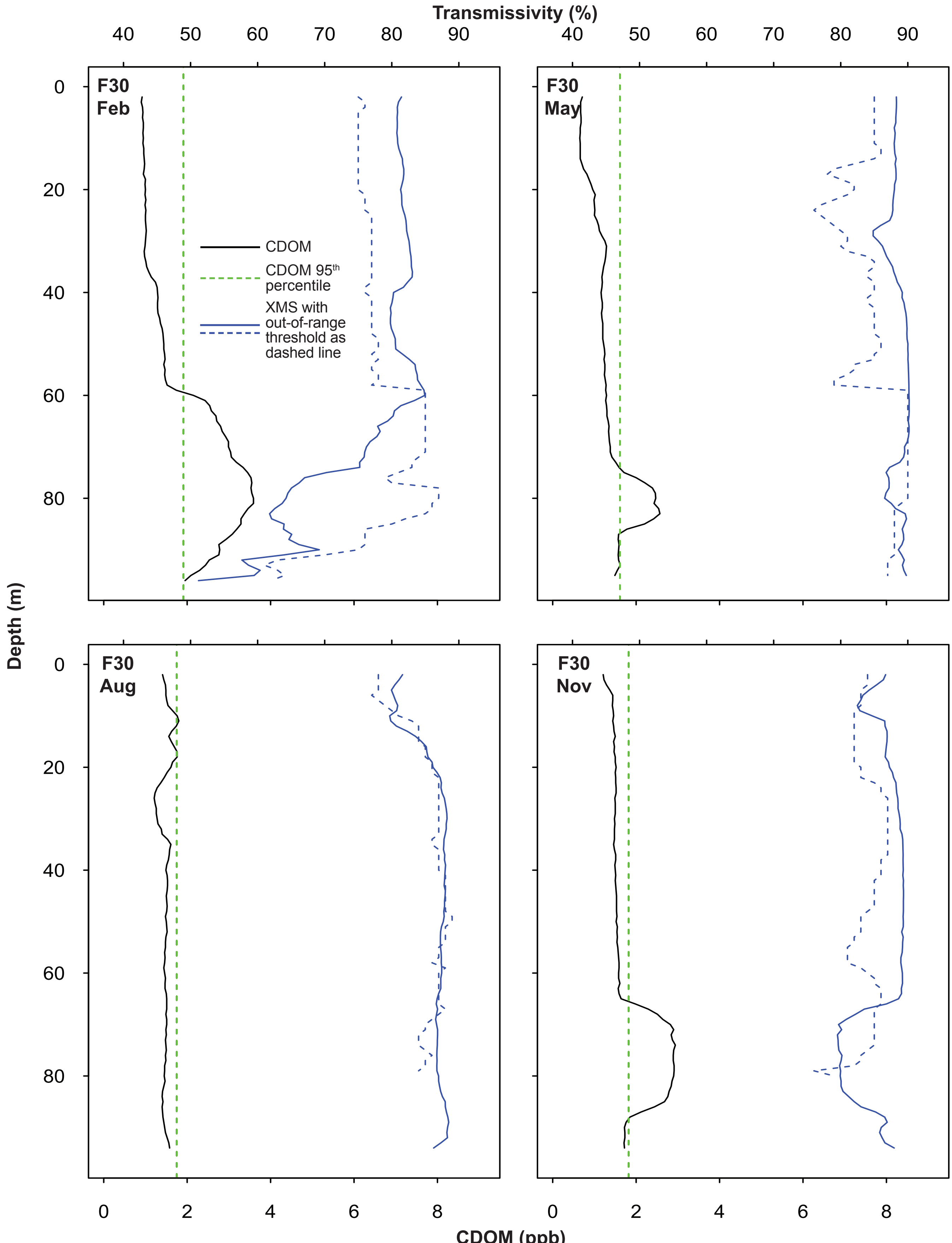


Appendix C.10
Representative vertical profiles of CDOM and pH from PLOO nearfield station F30 during 2016.



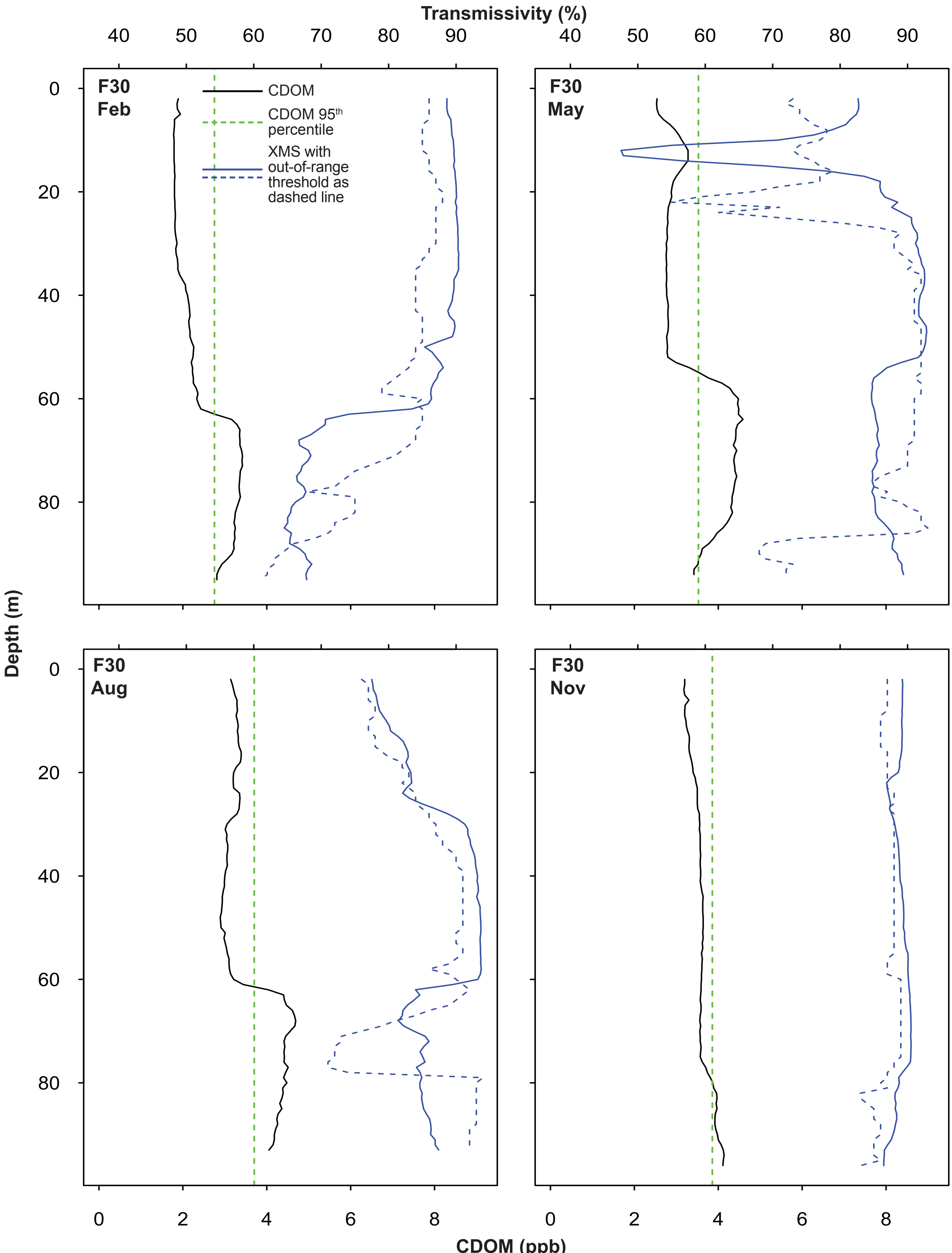
Appendix C.11

Representative vertical profiles of CDOM and pH from PLOO nearfield station F30 during 2017.



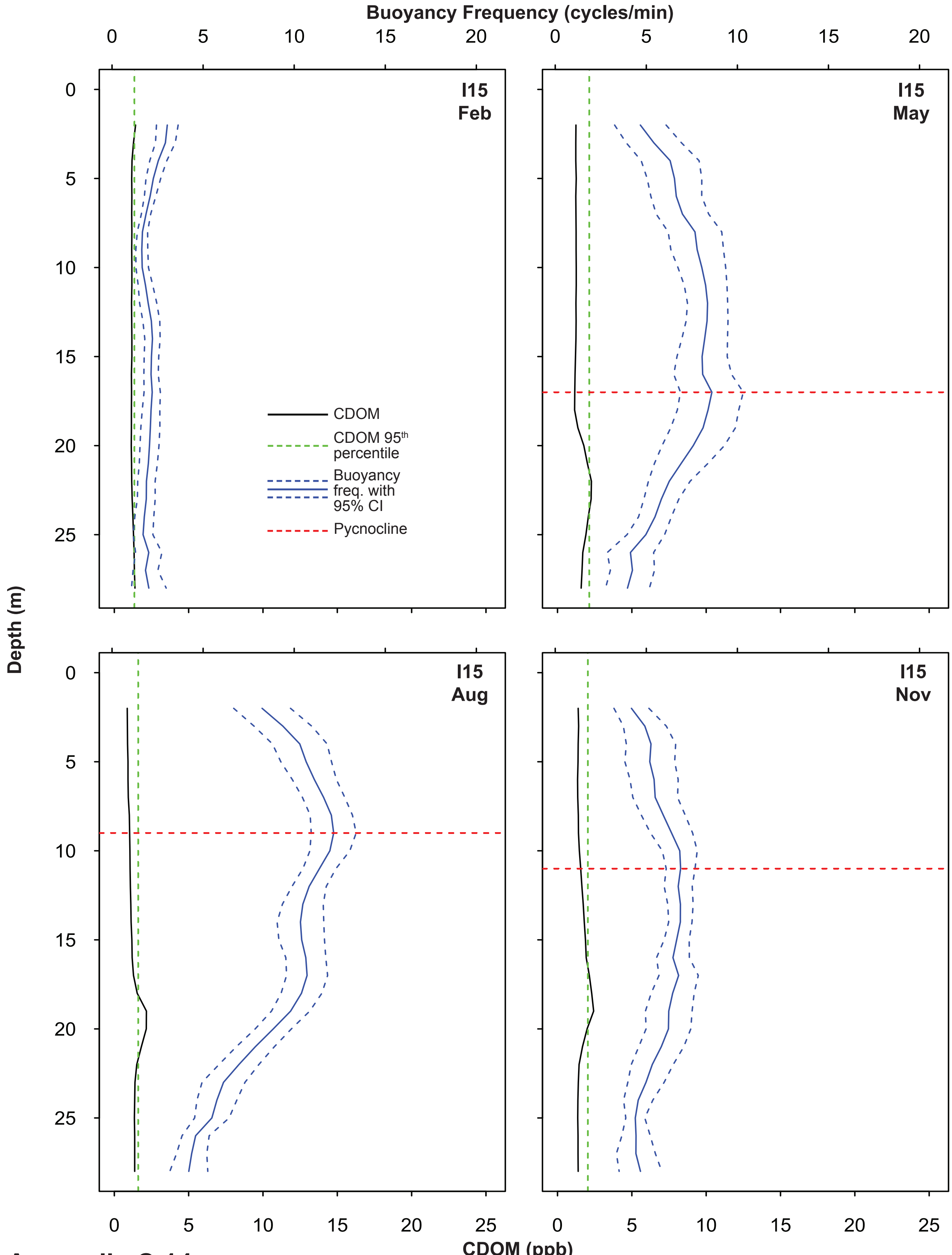
Appendix C.12

Representative vertical profiles of CDOM and transmissivity (XMS) from PLOO nearfield station F30 during 2016.

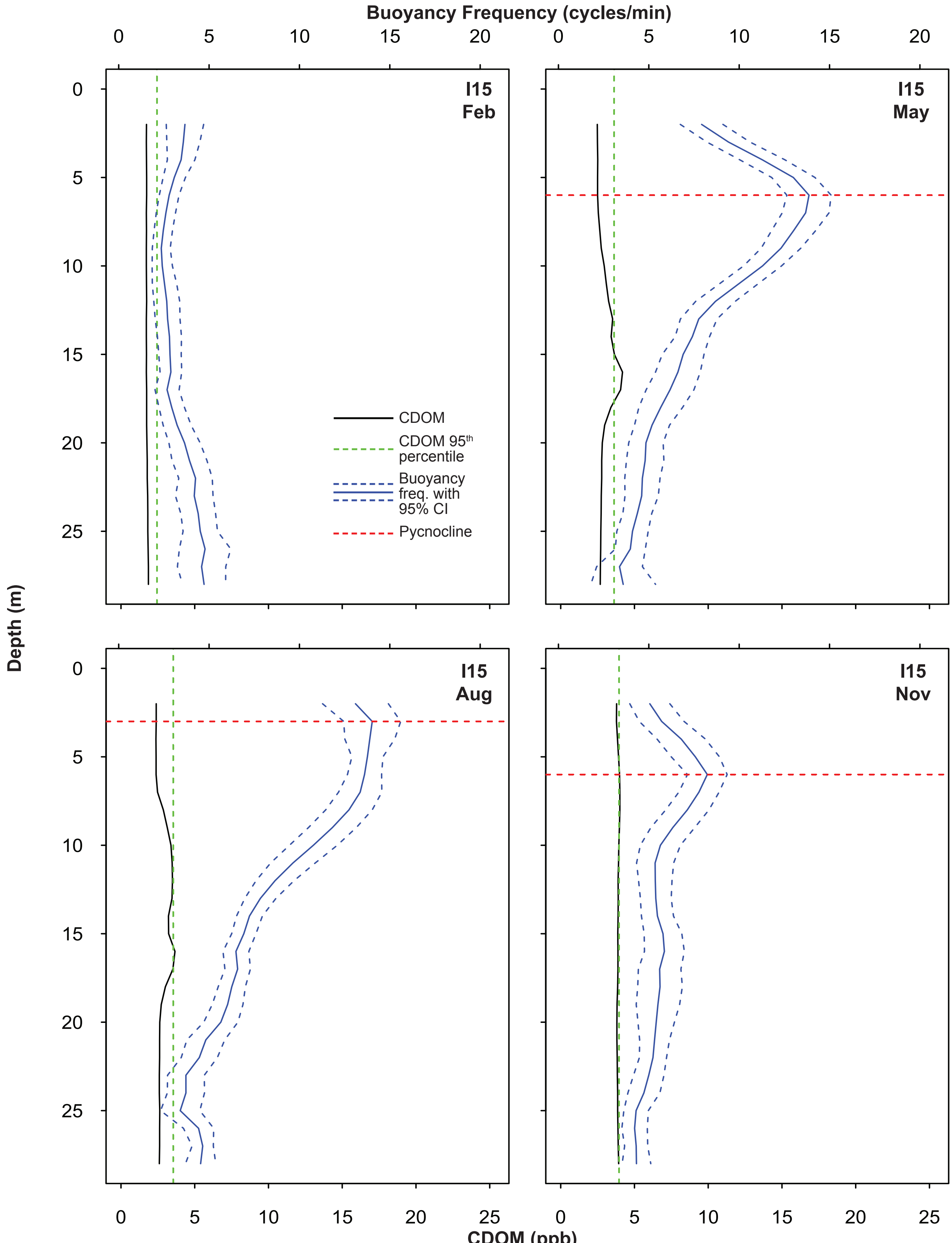


Appendix C.13

Representative vertical profiles of CDOM and transmissivity (XMS) from PLOO nearfield station F30 during 2017.

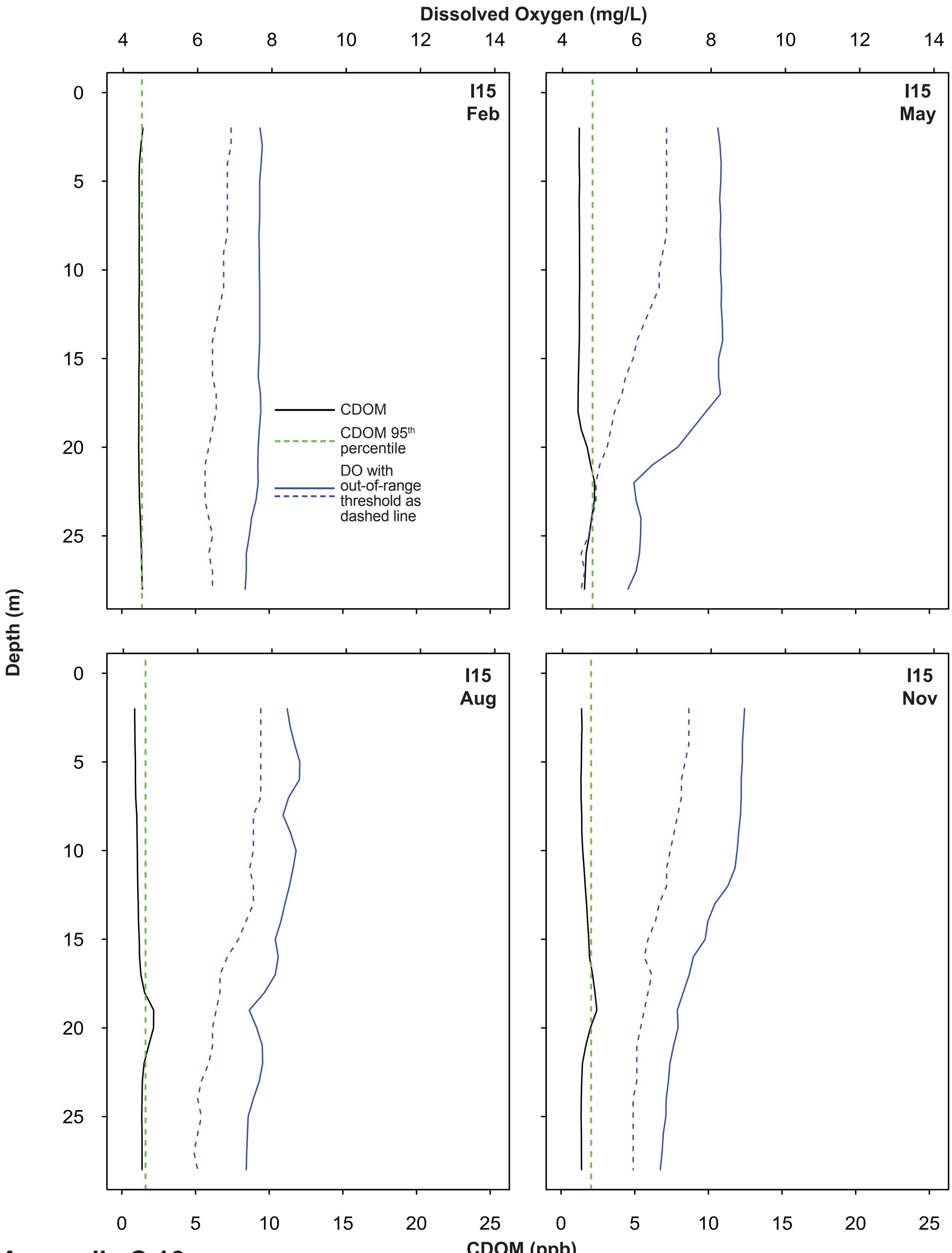


Appendix C.14
Representative vertical profiles of CDOM and buoyancy frequency from SBOO nearfield station I15 during 2016.

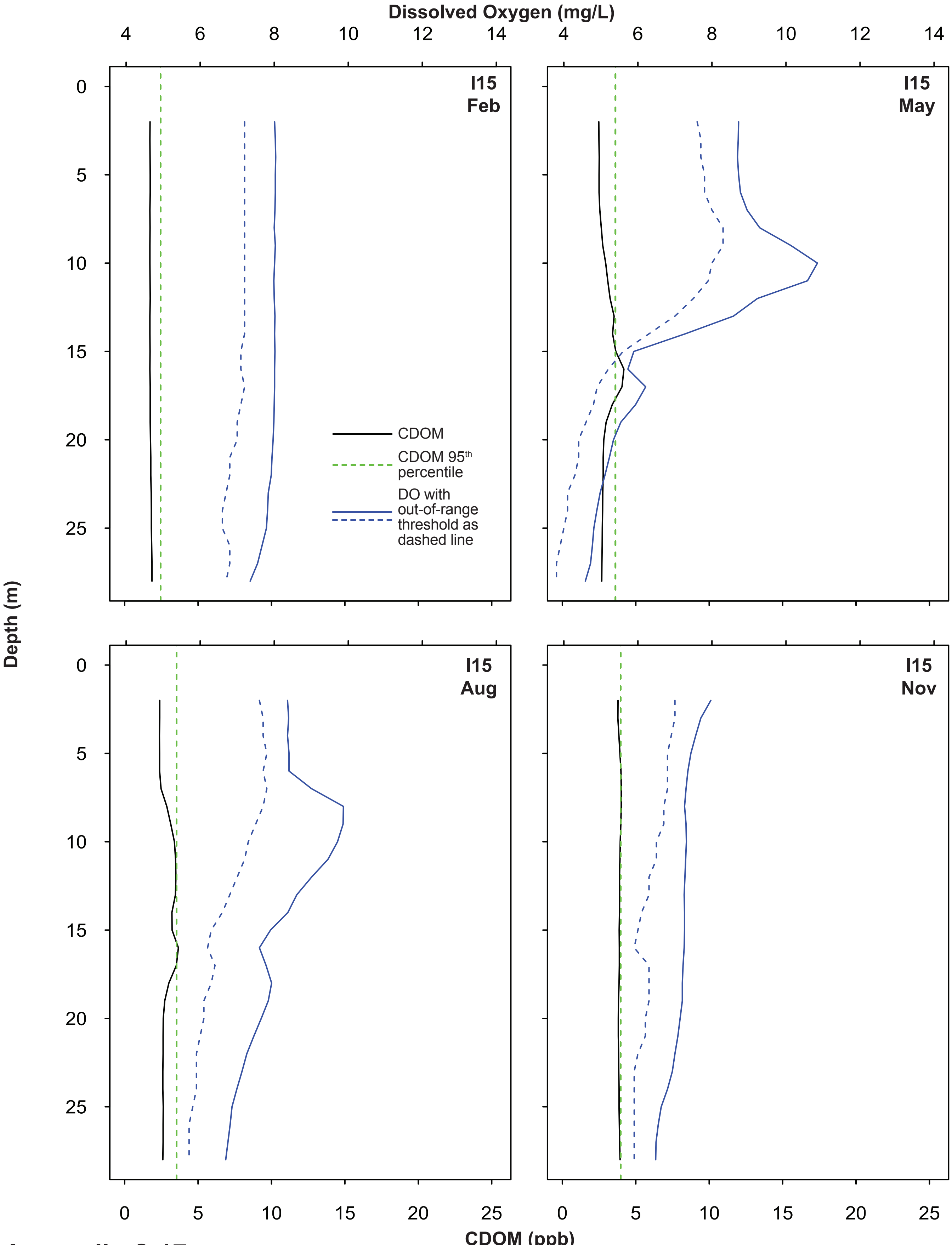


Appendix C.15

Representative vertical profiles of CDOM and buoyancy frequency from SBOO nearfield station I15 during 2017.

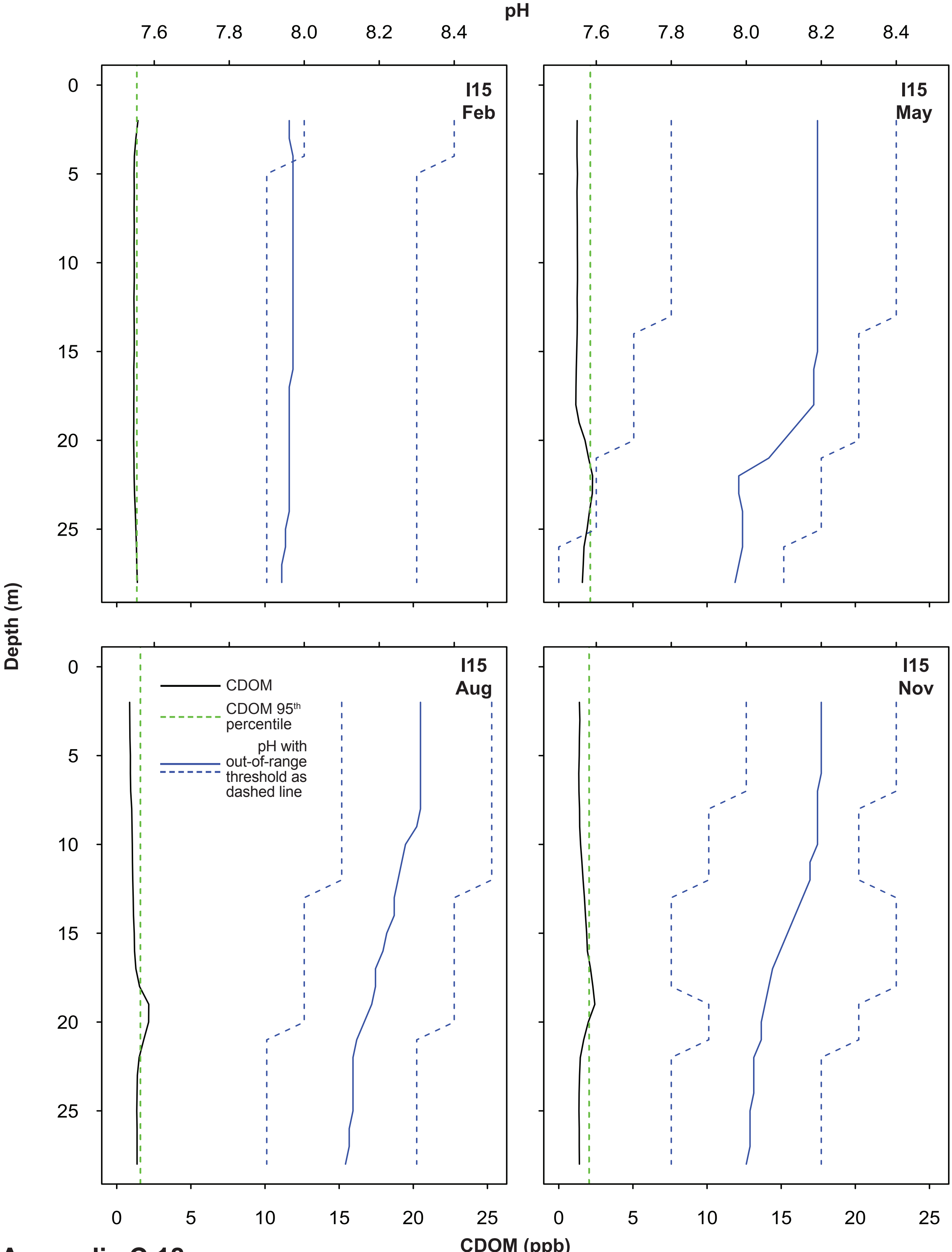


Appendix C.16
Representative vertical profiles of CDOM and dissolved oxygen (DO) from SBOO nearfield station I15 during 2016.



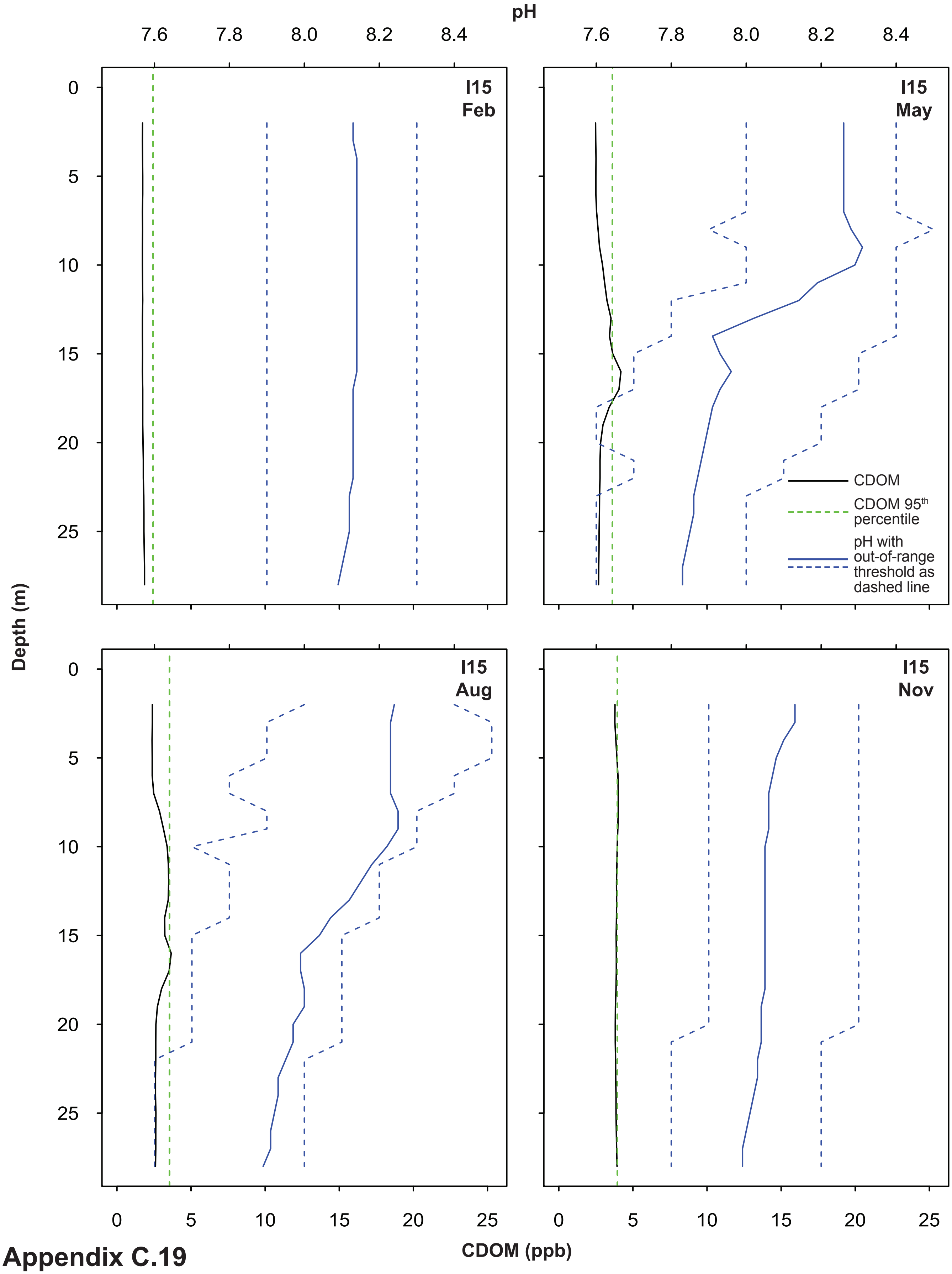
Appendix C.17

Representative vertical profiles of CDOM and dissolved oxygen (DO) from SBOO nearfield station I15 during 2017.



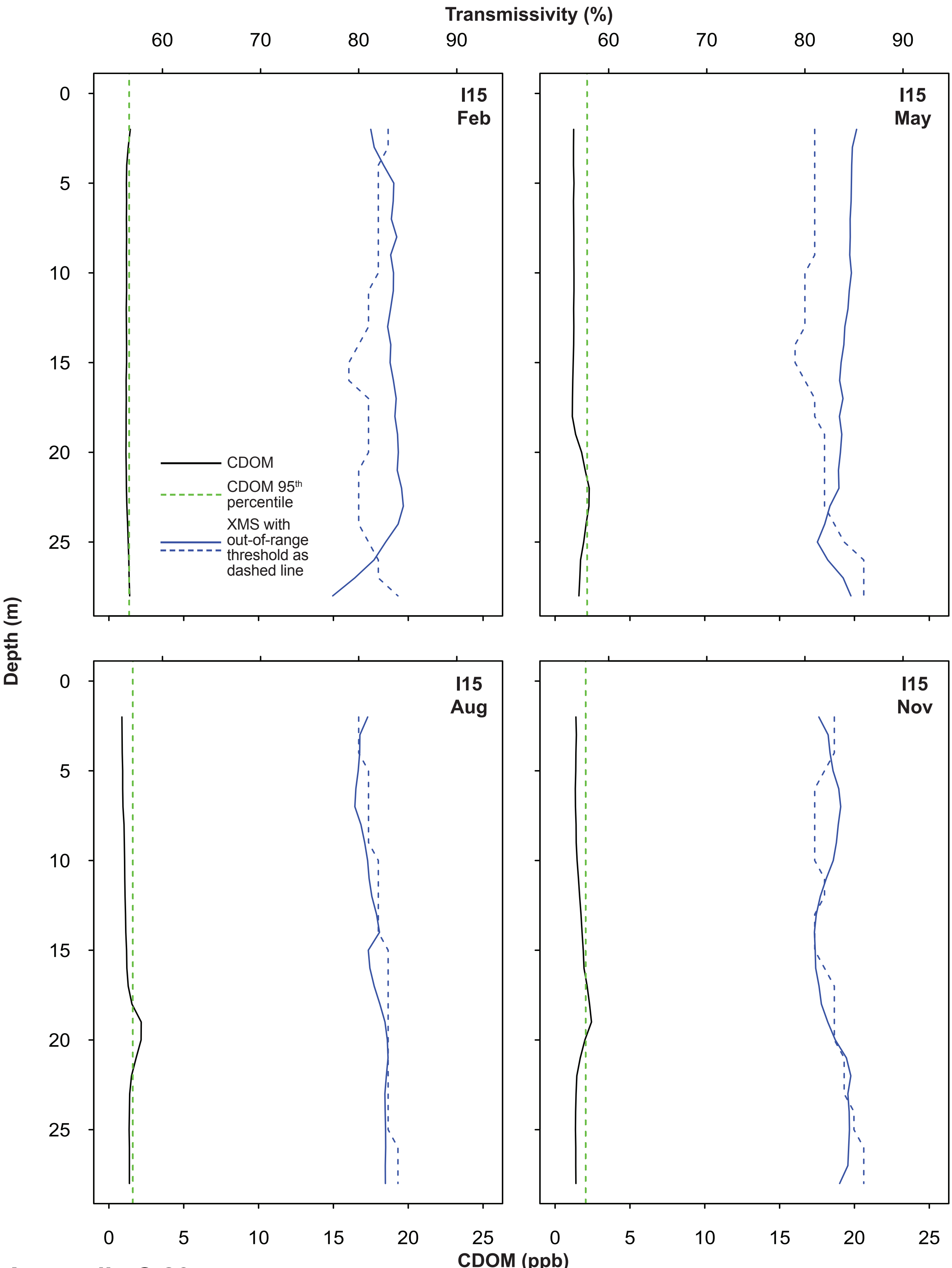
Appendix C.18

Representative vertical profiles of CDOM and pH from SBOO nearfield station I15 during 2016.

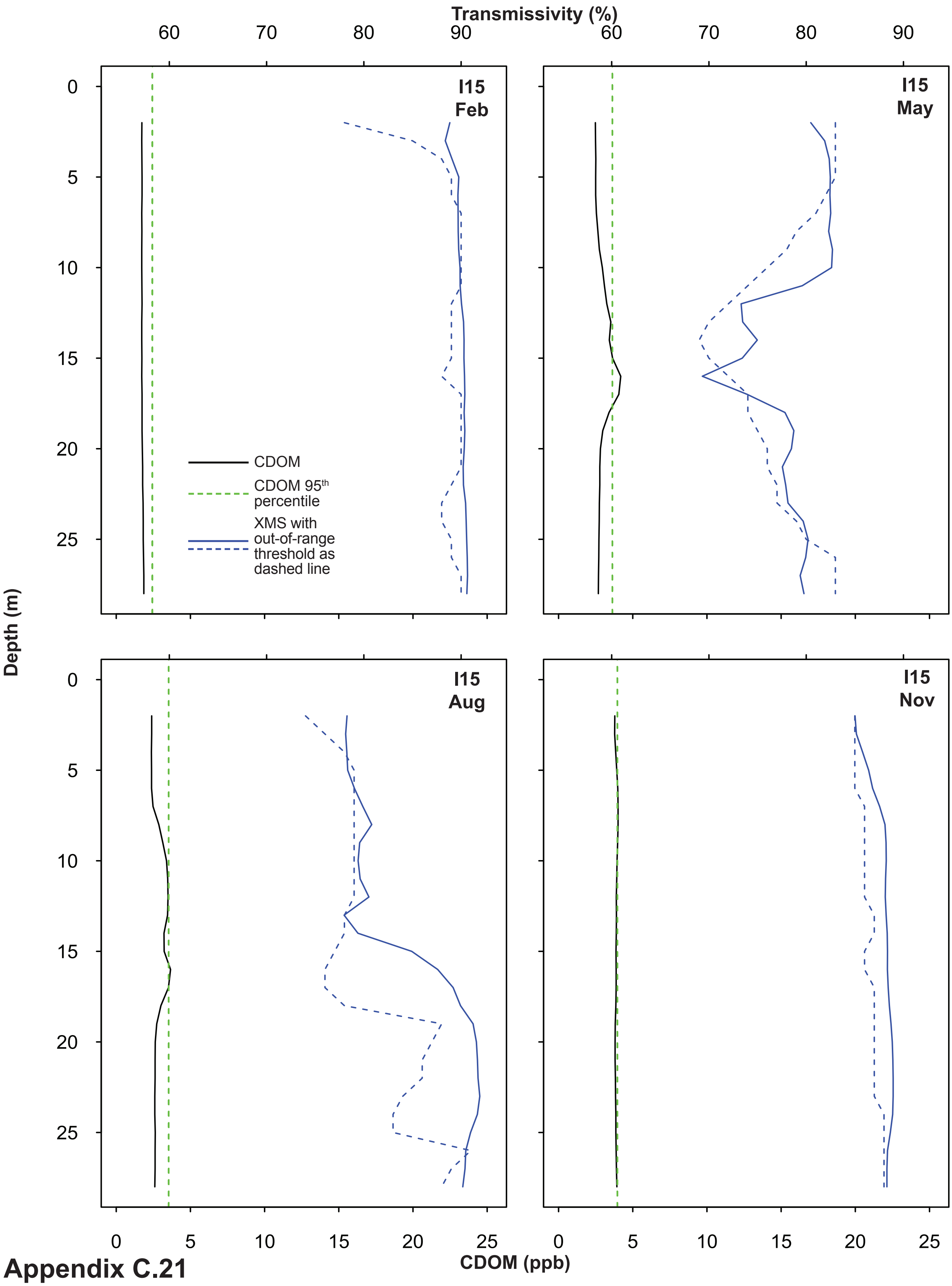


Appendix C.19

Representative vertical profiles of CDOM and pH from SBOO nearfield station I15 during 2017.



Appendix C.20
Representative vertical profiles of CDOM and transmissivity (XMS) from SBOO nearfield station I15 during 2016.



Appendix C.21

Representative vertical profiles of CDOM and transmissivity (XMS) from SBOO nearfield station I15 during 2017.

Appendix D

Sediment Quality

2016 – 2017 Supplemental Analyses

PLOO and SBOO Stations

Appendix D.1

Constituents and method detection limits used for the analysis of sediments during 2016 and 2017.

Parameter	Method Detection Limit 2016	Method Detection Limit 2017	Parameter	Method Detection Limit 2016	Method Detection Limit 2017
Organic Indicators					
BOD (ppm	2	2	Sulfides (ppm)	0.14	0.14
TN (% wt)	0.01	0.012	TVS (% wt.)	0.11	0.11
TOC (% wt.)	0.04	0.063			
Metals (ppm)					
Aluminum (Al)[a]	2, 2.4	2, 2.4	Lead (Pb)[a]	0.8, 0.3	0.8, 0.3
Antimony (Sb)[a]	0.3, 0.79	0.3, 0.79	Manganese (Mn)[a]	0.08, 0.19	0.08, 0.19
Arsenic (As)[a]	0.33, 0.308	0.308, 0.409	Mercury (Hg)	0.004	0.004
Barium (Ba)[a]	0.02, 0.08	0.02, 0.08	Nickel (Ni)[a]	0.1,0.3	0.1,0.3
Beryllium (Be)[a]	0.01, 0.02	0.01, 0.02	Selenium (Se)[a]	0.24	0.24, 0.14-0.463
Cadmium (Cd)[a]	0.06, 0.13	0.06, 0.13	Silver (Ag)[a]	0.04, 0.206	0.04, 0.206
Chromium (Cr)[a]	0.1, 0.136	0.1, 0.136	Thallium (Tl)[a]	0.5, 0.43	0.5, 0.43
Copper (Cu)[a]	0.2, 0.695	0.2, 0.695	Tin (Sn)[a]	0.3, 0.409	0.3, 0.409-2.46
Iron (Fe)[a]	9, 2.88	9, 2.88	Zinc (Zn)[a]	0.25, 1.45	0.25, 1.45
Chlorinated Pesticides (ppt)					
Total Chlordane					
Alpha (cis) Chlordane[a]	170, 49.7	96.8	Heptachlor epoxide[a]	76, 29.6	74.1
Cis Nonachlor[a]	210, 81.9	126	Methoxychlor[a]	250, 66	77.1
Gamma (trans) Chlordane[a]	61, 52.2	103	Oxychlordane[a]	210, 78.2	99.6
Heptachlor[a]	76, 29.6	65.3	Trans Nonachlor[a]	150, 25.3	118
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD[a]	90, 31.2	34.5	p,p-DDE[a]	90, 31.4	60.5
o,p-DDE[a]	110, 31.8	43.9	p,p-DDMU[a]	46, 15.4	35.9
o,p-DDT[a]	73, 43.3	42.6	p,p-DDT[a]	52, 47.7	74.3
p,p-DDD[a]	120, 53.3	49.6			
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer[a]	730, 62.7	45.2	HCH, Delta isomer[a]	160, 47.1	66.8
HCH, Beta isomer[a]	50, 52.7	85.6	HCH, Gamma isomer[a]	500, 40.1	66.6
Miscellaneous Pesticides					
Aldrin[a]	300, 41.6	61.7	Alpha Endosulfan[a]	380, 53.6	103
Dieldrin[a]	370, 103	282	Beta Endosulfan[a]	230, 138	103
Endrin[a]	1000, 128	128	Endosulfan Sulfate[a]	570, 75.5	104
Endrin aldehyde[a]	1800, 72.9	107	Hexachlorobenzene (HCB)[a]	64, 90.7	254
			Mirex[a]	61, 25.8	25.5

[a] MDL differed between winter and summer samples for this parameter

Appendix D.1 *continued*

Parameter	Method Detection Limit 2016	Method Detection Limit 2017	Parameter	Method Detection Limit 2016	Method Detection Limit 2017
Polychlorinated Biphenyl Congeners (PCBs) (ppt)					
PCB 18 [a]	90, 53.8	33.3	PCB 126 [a]	98, 25.5	45.6
PCB 28 [a]	96, 40.3	27.8	PCB 128 [a]	110, 34.3	38.9
PCB 37 [a]	47, 16.9	36.3	PCB 138 [a]	39, 45.5	57.5
PCB 44 [a]	37, 38.8	38.3	PCB 149 [a]	54, 59.6	50.8
PCB 49 [a]	32, 34.4	31.1	PCB 151 [a]	81, 56.2	40.8
PCB 52 [a]	37, 36.6	40.8	PCB 153/168 [a]	100, 104	91.3
PCB 66 [a]	72, 16.5	33.6	PCB 156 [a]	57, 28.6	59.4
PCB 70 [a]	58, 21.8	41.9	PCB 157 [a]	62, 23.0	45.1
PCB 74 [a]	51, 17.9	36.6	PCB 158 [a]	57, 26.7	46.0
PCB 77 [a]	110, 23.9	38.4	PCB 167 [a]	37, 23.2	50.2
PCB 81 [a]	18, 22.3	42.8	PCB 169 [a]	58, 17.3	44.7
PCB 87 [a]	44, 30.7	42.7	PCB 170 [a]	72, 44.2	64.1
PCB 99 [a]	80, 31.0	52.8	PCB 177 [a]	37, 25.8	43.8
PCB 101 [a]	50, 30.0	31.4	PCB 180 [a]	100, 56.7	32.8
PCB 105 [a]	37, 23.4	41.7	PCB 183 [a]	55, 28.5	59.5
PCB 110 [a]	48, 53.6	37.6	PCB 187 [a]	96, 36.6	41.6
PCB 114 [a]	78, 33.0	58.0	PCB 189 [a]	26, 17.8	42.1
PCB 118 [a]	110, 30.8	49.3	PCB 194 [a]	110, 31.0	56.8
PCB 119 [a]	59, 27.3	45.7	PCB 201 [a]	51, 21.4	23.7
PCB 123 [a]	79, 31.3	34.1	PCB 206 [a]	68, 26.1	54.7
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
1-methylnaphthalene [a]	20, 14.1	14.1	Benzo[G,H,I]perylene [a]	20, 16.4	16.4
1-methylphenanthrene [a]	20, 22.5	22.5	Benzo[K]fluoranthene [a]	20, 13.9	13.9
2,3,5-trimethylnaphthalene [a]	20, 23.2	23.2	Biphenyl [a]	30, 21.3	21.3
2,6-dimethylnaphthalene [a]	20, 17.7	17.7	Chrysene [a]	40, 14.8	14.8
2-methylnaphthalene [a]	20, 20.2	20.2	Dibenzo(A,H)anthracene [a]	20, 12.0	12.0
3,4-benzo(B)fluoranthene [a]	20, 9.93	9.93	Fluoranthene [a]	20, 13.6	13.6
Acenaphthene [a]	20, 17.6	17.6	Fluorene [a]	20, 17.9	17.9
Acenaphthylene [a]	30, 15.7	15.7	Indeno(1,2,3-CD)pyrene [a]	20, 11.7	11.7
Anthracene [a]	20, 16.2	16.2	Naphthalene [a]	30, 32.9	32.9
Benzo[A]anthracene [a]	20, 13.5	13.5	Perylene [a]	30, 14.6	14.8
Benzo[A]pyrene [a]	20, 12.5	12.5	Phenanthrene [a]	30, 14.3	14.3
Benzo[e]pyrene [a]	20, 11.4	11.4	Pyrene [a]	20, 15.4	15.4

[a] MDL differed between winter and summer samples for this parameter

Appendix D.2

Particle size classification schemes (based on Folk 1980) used in the analysis of sediments during 2016 and 2017. Included is a subset of the Wentworth scale presented as "phi" categories with corresponding Horiba channels, sieve sizes, and size fractions.

Wentworth Scale

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

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

Appendix D.3

Summary of particle size fractions (%) in sediments from PLOO stations sampled during 2016 and 2017. Data are means (range) for each station.

	Fine Particles	Fine Sands	Med-Coarse Sands	Coarse Particles
88-m Depth Contour				
B11	43.4 (33.2-50.7)	40.3 (34.6-46.4)	8.9 (2.9-13.5)	9.8 (0-20.5)
B8	63.8 (61.8-65.6)	36 (34.2-38.1)	0.1 (0.1-0.1)	0 (0-0)
E19	52.8 (50.3-53.8)	47.1 (46.1-49.5)	0.1 (0.1-0.2)	0 (0-0)
E7	48.8 (44.9-50.8)	50.8 (48.7-54.6)	0.4 (0.2-0.5)	0 (0-0)
E1	44.0 (41.8-45.5)	49.8 (46.9-52.2)	6.2 (5.2-8.2)	0 (0-0)
98-m Depth Contour				
B12	22.8 (16.9-28.1)	46.4 (42.8-53.8)	27.7 (24.8-30.4)	3.1 (0.5-7.6)
B9	46.7 (44.2-50.4)	51.8 (48.2-54.3)	1.4 (1.3-1.6)	0 (0-0)
E26	49.2 (45.2-52.5)	50.7 (47.4-54.5)	0.2 (0.2-0.2)	0 (0-0)
E25	42.2 (36.6-48.5)	56.9 (50.9-62.6)	0.6 (0.6-0.7)	0.4 (0-0.6)
E23	43.3 (40.0-45.1)	56.2 (54.3-59.6)	0.5 (0.2-0.6)	0 (0-0)
E20	41.5 (38.8-47.1)	58 (52.5-60.6)	0.5 (0.2-0.6)	0 (0-0)
E17[a]	33.4 (30.8-35.7)	65.9 (63.7-68.4)	0.6 (0.4-0.7)	0.3 (0-0.3)
E14[a]	26.6 (21.3-29.9)	64.5 (50.8-70.9)	4.4 (0.7-11.9)	9 (0-10.3)
E11[a]	35.3 (33.1-37.4)	63.5 (61.3-65.4)	1.2 (0.8-1.5)	0 (0-0)
E8	36.2 (35.6-37.6)	62.3 (61-63.1)	1.4 (1.3-1.5)	0 (0-0)
E5	35.6 (33.4-37.5)	62.8 (61.3-64.9)	1.6 (1.2-1.7)	0 (0-0)
E2	41.5 (36.8-44.8)	52.7 (50.6-54.3)	5.3 (3.1-10.3)	2.3 (0-2.3)
116-m Depth Contour				
B10	24.3 (18.8-26.9)	72.8 (70.5-77.8)	2.0 (1.3-2.6)	1.3 (0-1.9)
E21	34.6 (34.1-35.3)	64.8 (64.2-65.4)	0.6 (0.6-0.6)	0 (0-0)
E15	33.6 (30.5-39.8)	65.5 (59.4-68.2)	1.0 (0.8-1.4)	0 (0-0)
E9	31.9 (29.3-34.2)	33.9 (32.8-35)	2.01 (18.0-22.9)	13.3 (10-14.9)
E3	19.1 (12.1-29.6)	55.9 (44.5-61.9)	22.4 (19.0-26.0)	3.5 (0-4.6)

[a] Near-ZID station

Appendix D.4

Summary of particle size fractions (%) in sediments from SBOO stations sampled during 2016 and 2017. Data are means (range) for each station.

	Fine Particles	Fine Sands	Med-Coarse Sands	Coarse Particles
19-m Depth Contour				
I35	37.7 (36.6-39.1)	60.3 (58.9-61.5)	2.0 (1.6-2.6)	0 (0-0)
I34	2.1 (0.1-5.7)	16.2 (5.1-45.5)	48.2 (32.5-55.9)	44.8 (0-56.8)
I31	7.7 (7.3-8)	91.5 (91.4-91.5)	0.8 (0.6-1.2)	0 (0-0)
I23	7.5 (3.3-11.4)	66.8 (5.9-90)	17.7 (1.4-59.8)	10.7 (0-31.1)
I18	10.0 (8.8-13.2)	88.9 (85.1-90.6)	1.1 (0.5-1.7)	0 (0-0)
I10	8.4 (7.9-8.8)	89.7 (89.1-90.4)	1.9 (1.7-2.1)	0 (0-0)
I4	3.1 (0-5.1)	7.4 (4.2-9.9)	87.8 (85.7-91.3)	2.5 (0.8-4.5)
28-m Depth Contour				
I33	10.9 (9.6-13.5)	86.1 (83.3-87.9)	3.0 (2.0-3.3)	0 (0-0)
I30	19.0 (18.2-19.5)	80.5 (79.9-81.2)	0.6 (0.6-0.7)	0 (0-0)
I27	16.0 (15.2-16.8)	83.4 (82.4-84.1)	0.6 (0.6-0.7)	0 (0-0)
I22	14.5 (11.6-15.8)	78.8 (73.5-82.5)	6.7 (2.7-14.9)	0 (0-0)
I14[a]	18 (17.0-19.9)	80.5 (79.1-81.6)	1.6 (1.0-2.1)	0 (0-0)
I16[a]	3.2 (0.6-6.2)	53.1 (19.9-75.9)	43.4 (19.3-77.8)	0.3 (0-0.8)
I15[a]	3.2 (1.9-6.0)	31.6 (20.2-48.5)	64.8 (45.5-76.3)	0.4 (0-0.5)
I12[a]	8.9 (3.4-13.3)	65.3 (55.3-70.3)	25.8 (19.9-41.2)	0 (0-0)
I9	21.6 (19.7-24.2)	77.5 (75-79.6)	0.9 (0.7-1.5)	0 (0-0)
I6	1.6 (0-3.3)	11.7 (9.0-13.6)	86.0 (82.9-88.8)	1.1 (0.2-2.2)
I2	1.9 (0.1-3.1)	33.6 (28.6-42.7)	64.3 (54.3-69.7)	0.2 (0-0.4)
I3	0.7 (0-0.7)	23.3 (10.6-34.3)	75.7 (64.9-86.7)	0.8 (0-2.6)

[a] Near-ZID station

Appendix D.4 *continued*

	Fine Particles	Fine Sands	Med-Coarse Sands	Coarse Particles
38-m Depth Contour				
I29	22.4 (4.7-29.6)	51.5 (8.4-70.3)	13.7 (1.6-36.4)	25.3 (0-50.4)
I21	1.7 (0-2.5)	10.4 (4.4-21.3)	84.9 (75.6-89.6)	3.4 (0.5-6.6)
I13	4.6 (0-4.6)	8.8 (3-20.6)	86.2 (73.9-91.2)	4.2 (1-6.7)
I8	2.2 (0.9-4.7)	21.5 (19-25.9)	75.4 (71.9-78.9)	0.9 (0.4-1.2)
55-m Depth Contour				
I28	19.5 (14.3-24.5)	28.5 (22.7-33.4)	37.2 (35.6-39.8)	14.8 (7.7-20.4)
I20	3.3 (0-5.2)	5.1 (3.4-6.3)	75.7 (67-83.9)	16.6 (9.8-22.9)
I7	2.1 (0-2.4)	6.0 (1.6-9.9)	81.1 (76.3-90.6)	11.2 (7.8-15.3)
I1	8.9 (8.0-11.0)	84.6 (81.4-87)	6.5 (4.7-8.4)	0 (0-0)

Appendix D.5

Summary of organic indicators in sediments from PLOO stations sampled during 2016 and 2017. Data are means (range) for each station. Minimum and maximum values were based on all samples (n≤4), whereas means were calculated on detected values only.

	BOD (ppm)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
88-m Depth Contour					
B11	480 (476-484)	9.70 (3.02-16.10)	0.082 (0.073-0.09)	1.01 (0.65-1.80)	3.6 (3.1-3.9)
B8	420 (311-531)	5.33 (2.94-9.23)	0.075 (0.07-0.078)	0.69 (0.65-0.71)	2.9 (2.6-3.0)
E19	346 (264-390)	15.25 (2.97-50.90)	0.055 (0.05-0.06)	0.49 (0.45-0.57)	2.2 (2.1-2.3)
E7	436 (261-598)	9.24 (3.43-20.30)	0.055 (0.048-0.059)	0.48 (0.43-0.50)	2.0 (1.9-2.1)
E1	258 (240-283)	4.64 (3.28-8.14)	0.056 (0.052-0.059)	0.50 (0.47-0.53)	1.9 (1.7-2.1)
98-m Depth Contour					
B12	415 (323-469)	5.32 (3.66-7.23)	0.056 (0.052-0.06)	1.22 (0.51-2.46)	2.7 (2.5-3.0)
B9	280 (240-302)	3.04 (2.69-3.95)	0.06 (0.058-0.063)	0.55 (0.53-0.57)	2.5 (2.4-2.6)
E26	307 (264-358)	9.46 (2.80-13.70)	0.057 (0.054-0.06)	0.5 (0.49-0.52)	2.1 (1.9-2.2)
E25	254 (193-312)	7.15 (3.08-14.90)	0.05 (0.043-0.06)	0.41 (0.37-0.46)	2.0 (1.8-2.2)
E23	286 (264-306)	5.13 (2.47-11.80)	0.04 (0.023-0.049)	0.31 (0.13-0.42)	2 (1.8-2.2)
E20	236 (189-281)	7.22 (3.29-13.40)	0.046 (0.041-0.05)	0.38 (0.35-0.41)	1.8 (1.7-1.8)
E17 [a]	315 (252-368)	10.20 (4.55-180)	0.041 (0.039-0.042)	0.33 (0.29-0.34)	1.5 (1.4-1.6)
E14 [a]	458 (298-592)	23.59 (9.34-36.00)	0.04 (0.038-0.042)	0.32 (0.29-0.34)	1.4 (1.2-1.7)
E11 [a]	324 (246-468)	10.19 (6.45-14.20)	0.043 (0.039-0.045)	0.33 (0.28-0.37)	1.8 (1.7-1.9)
E8	249 (213-316)	5.47 (2.66-9.41)	0.041 (0.037-0.044)	0.35 (0.31-0.37)	1.8 (1.6-1.9)
E5	232 (186-320)	6.15 (3.00-15.20)	0.046 (0.044-0.05)	0.38 (0.37-0.39)	1.7 (1.6-1.8)
E2	288 (228-367)	10.70 (2.87-29.50)	0.059 (0.049-0.069)	0.50 (0.42-0.56)	2.3 (1.8-2.5)
116-m Depth Contour					
B10	291 (200-372)	3.93 (2.11-7.66)	0.044 (0.04-0.051)	0.44 (0.34-0.59)	2.1 (2-2.2)
E21	268 (235-305)	5.80 (2.27-10.10)	0.044 (0.042-0.047)	0.36 (0.34-0.39)	1.5 (1.4-1.6)
E15	264 (226-325)	13.13 (1.67-43.2)	0.042 (0.039-0.043)	0.32 (0.29-0.35)	1.3 (0.2-1.9)
E9	246 (202-289)	4.58 (3.4-6.83)	0.055 (0.05-0.058)	0.61 (0.44-0.91)	1.9 (1.7-2.0)
E3	222 (146-290)	7.13 (2.68-18.8)	0.046 (0.034-0.051)	0.4 (0.28-0.47)	1.4 (1.0-1.8)

[a] Near-ZID station

Appendix D.6

Summary of organic indicators in sediments from SBOO stations sampled during 2016 and 2017. Data are means (range) for each station. Minimum and maximum values were based on all samples (n ≤ 4), whereas means were calculated on detected values only; nd = not detected.

	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
19-m Depth Contour				
I35	15.09 (3.58-48.20)	0.034 (0.026-0.042)	0.26 (0.18-0.31)	1.2 (1.0-1.4)
I34	0.76 (0.69-0.80)	0.021 (nd-0.022)	0.13 (nd-0.20)	0.6 (0.4-0.9)
I31	2.45 (1.00-5.55)	0.02 (nd-0.02)	0.10 (0.07-0.13)	0.7 (0.6-0.7)
I23	2.42 (1.54-3.86)	0.026 (0.021-0.032)	0.29 (0.08-0.84)	0.9 (0.8-1.0)
I18	4.12 (1.69-10.60)	0.017 (nd-0.018)	0.09 (0.07-0.11)	0.7 (0.6-0.7)
I10	2.93 (1.47-7.19)	0.017 (nd-0.021)	0.10 (0.09-0.12)	0.8 (0.7-0.8)
I4	0.25 (0.05-0.38)	0.028 (nd-0.028)	0.17 (nd-0.17)	0.3 (0.2-0.4)
28-m Depth Contour				
I33	3.58 (2.61-5.09)	0.027 (0.024-0.029)	0.16 (0.13-0.19)	1.5 (0.9-2.8)
I30	3.52 (2.43-5.19)	0.027 (0.024-0.029)	0.17 (0.15-0.19)	1.0 (0.8-1.2)
I27	2.83 (1.65-4.78)	0.023 (0.019-0.025)	0.13 (0.12-0.15)	2.7 (0.8-8.2)
I22	5.07 (1.46-12.20)	0.028 (0.022-0.034)	0.20 (0.15-0.30)	0.8 (0.7-0.9)
I14[a]	6.83 (1.72-21.60)	0.027 (0.019-0.035)	0.17 (0.14-0.20)	1.0 (0.9-1.1)
I16[a]	1.1 (0.68-1.61)	0.018 (nd-0.019)	0.09 (nd-0.10)	0.5 (0.4-0.6)
I15[a]	1.73 (0.30-5.30)	0.020 (0.015-0.025)	0.1 (0.08-0.11)	0.5 (0.4-0.8)
I12[a]	2.46 (0.67-5.10)	0.024 (nd-0.025)	0.13 (nd-0.16)	0.7 (0.4-0.9)
I9	3.92 (2.01-4.95)	0.027 (0.025-0.029)	0.17 (0.14-0.22)	1.2 (1.1-1.2)
I6	0.22 (0.14-0.35)	0.013 (nd-0.013)	0.06 (nd-0.07)	0.4 (0.4-0.5)
I2	0.43 (0.27-0.54)	0.024 (nd-0.028)	0.08 (nd-0.09)	0.4 (0.4-0.5)
I3	0.24 (0.19-0.33)	nd	0.04 (nd-0.04)	0.4 (0.4-0.4)

[a] Near-ZID station

Appendix D.6 *continued*

	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
38-m Depth Contour				
I29	3.00 (0.66-5.84)	0.031 (0.03-0.034)	0.22 (0.20-0.25)	1.2 (0.6-1.5)
I21	0.22 (0.19-0.23)	0.020 (nd-0.020)	0.09 (nd-0.09)	0.5 (0.4-0.5)
I13	0.33 (nd-0.56)	0.055 (nd-0.055)	0.19 (nd-0.31)	0.4 (0.3-0.6)
I8	0.60 (0.27-0.92)	0.021 (nd-0.024)	0.10 (0.07-0.13)	0.4 (0.4-0.5)
55-m Depth Contour				
I28	5.29 (3.26-10.3)	0.057 (0.054-0.061)	0.50 (0.46-0.56)	1.3 (1.2-1.5)
I20	0.32 (0.27-0.42)	0.025 (nd-0.032)	0.13 (0.08-0.23)	0.4 (0.2-0.6)
I7	0.18 (nd-0.18)	0.019 (nd-0.025)	0.10 (nd-0.12)	0.4 (0.4-0.5)
I1	1.03 (0.55-1.84)	0.027 (0.021-0.031)	0.14 (0.13-0.14)	0.9 (0.85-0.9)

Appendix D.7

Summary of metals (ppm) in sediments from PLOO stations sampled during 2016 and 2017. Data are means (range) for each station. Minimum and maximum values were based on all samples (n ≤ 4), whereas means were calculated on detected values only; nd = not detected.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe
88-m Depth Contour									
B11	8710 (6730-9860)	1.3 (0.5-1.8)	3.27 (2.34-5.55)	35.4 (23.8-41.5)	nd	nd	26.3 (17.4-33.3)	5.6 (3.5-7.0)	17,725 (12,700-20,900)
B8	9362 (6420-10,900)	1.2 (nd-1.4)	2.17 (1.02-3.52)	45.9 (32.0-53.6)	nd	nd	23.4 (13.6-34.1)	7.7 (2.6-11.5)	12,698 (7090-14,800)
E19	10,048 (8390-12,600)	1.1 (0.8-1.2)	2.12 (1.7-2.60)	46.1 (40.7-56.5)	nd	nd	23.0 (20.6-27)	6.9 (6.0-8.2)	12,725 (11,700-14,400)
E7	8710 (7470-10,200)	0.9 (0.6-1.1)	1.97 (1.43-3.00)	40.6 (37.6-44.0)	nd	nd	19.8 (16.7-22.9)	6.5 (5.6-7.1)	11,100 (10,600-11,800)
E1	9350 (7830-10,600)	1.1 (0.6-1.3)	2.26 (1.72-3.17)	45.8 (37.5-49.6)	nd	nd	20.8 (17.0-25.1)	9.8 (7.3-14.2)	12,400 (11,000-13,400)
98-m Depth Contour									
B12	5800 (3470-7050)	1.3 (0.8-1.7)	3.84 (1.79-5.95)	18.0 (12.4-21.0)	0.03 (nd-0.03)	nd	24.6 (14.1-29.0)	1.8 (nd-2.5)	18,825 (12,300-21,300)
B9	8312 (7740-9750)	1.3 (0.8-1.7)	2.00 (1.59-2.59)	50.2 (41.2-61.3)	nd	nd	26.3 (20.4-32.1)	5.2 (4.8-6.0)	15,500 (14,200-17,600)
E26	8112 (6980-9600)	0.9 (0.7-1.2)	2.17 (1.62-3.11)	33.8 (30.3-36.2)	nd	nd	18.1 (16.2-19.9)	5.3 (4.6-6.0)	10,958 (9930-11,800)
E25	7722 (6110-9010)	0.7 (0.4-1.0)	1.92 (1.66-2.32)	31.7 (27.3-36.6)	nd	nd	17.7 (15.1-23.0)	4.5 (3.6-5.1)	10,335 (9390-11,400)
E23	7768 (6500-9610)	0.7 (0.4-1.0)	2.01 (1.72-2.61)	33.0 (29.2-37.4)	nd	nd	18.1 (16.2-21.6)	5.0 (4.3-5.9)	10,368 (9310-11,500)
E20	7400 (6500-8660)	0.9 (0.6-1.0)	1.94 (1.56-2.29)	29.9 (27.3-32.0)	nd	nd	16.7 (14.5-19.4)	4.6 (4.2-4.8)	9840 (9010-10,600)
E17 [a]	6562 (5520-7320)	0.8 (0.6-0.9)	1.86 (1.46-2.39)	25.6 (24.6-27.6)	nd	nd	15.3 (12.7-18.2)	5.9 (3.7-11.0)	8865 (8450-9280)
E14 [a]	5460 (4760-6270)	0.6 (0.4-0.8)	1.80 (1.63-2.05)	21.3 (20.4-22.9)	nd	0.09 (nd-0.09)	13.4 (12.2-14.7)	4.6 (4.3-4.7)	7795 (7690-8010)
E11 [a]	6495 (5560-7360)	0.7 (nd-0.9)	1.82 (1.18-2.54)	25.1 (22.7-28.1)	nd	nd	15.0 (13.1-17.2)	4.2 (3.2-5.5)	9002 (8400-9450)
E8	6840 (5800-8140)	0.8 (0.6-1.0)	1.93 (1.45-2.75)	26.9 (24.9-28.6)	nd	nd	15.6 (13.8-17.5)	4.3 (4-4.6)	9408 (9010-10,100)
E5	6710 (5880-8130)	0.9 (0.7-1.2)	2.08 (1.86-2.48)	28.6 (26.9-30.7)	nd	nd	15.5 (13.7-17.3)	4.5 (4.0-5.0)	9532 (8820-10,000)
E2	9985 (8450-11,500)	1.2 (0.8-1.6)	1.91 (1.61-2.63)	50.4 (44.9-54.1)	nd	nd	23.0 (18.5-25.2)	9.1 (7.5-10)	13,550 (12,200-14,500)
116-m Depth Contour									
B10	6605 (5140-9050)	0.8 (nd-1.1)	3.00 (1.67-5.21)	25.8 (20.6-39.0)	nd	0.07 (nd-0.07)	19.7 (17.1-23.9)	4.3 (2.7-7.4)	13,825 (11,000-20,200)
E21	6565 (5390-7560)	0.6 (0.4-0.9)	1.92 (1.46-2.43)	25.3 (23.6-27.8)	nd	nd	15.3 (13.3-18.4)	4.0 (3.3-4.4)	8952 (8210-9690)
E15	6130 (5350-6960)	0.7 (0.5-0.9)	1.69 (1.37-2.23)	21.9 (20.1-23.7)	nd	nd	14.8 (12.8-17.5)	4.1 (3.6-4.9)	8670 (8040-9460)
E9	7172 (6690-7610)	1.1 (0.7-1.4)	2.31 (2.2-2.48)	28.4 (26.3-31.4)	nd	nd	20.7 (17.6-22.7)	9.0 (6.6-11.8)	12,400 (11,700-13,600)
E3	8018 (6340-9450)	1.0 (0.7-1.2)	1.44 (0.76-2.45)	48.5 (40.9-55.2)	nd	nd	17.2 (13.3-22.1)	10.0 (9.9-10.1)	11,402 (9510-13,400)

[a] Near-ZID station

Appendix D.7 *continued*

	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour									
B11	4.1 (3.1-4.6)	101.3 (75.5-118.0)	0.034 (0.027-0.048)	6.5 (4.9-7.6)	0.49 (nd-0.82)	nd	nd	0.7 (0.5-0.9)	36.6 (24.9-41.9)
B8	4.7 (2.2-6.7)	107.3 (69.4-127.0)	0.032 (nd-0.033)	7.3 (3.1-9.7)	0.38 (0.24-0.55)	nd	nd	1.7 (nd-3.2)	31 (18.0-36.4)
E19	4.1 (3.1-4.9)	113.2 (101.0-136.0)	0.028 (0.026-0.031)	7.4 (6.4-9.1)	0.32 (nd-0.43)	nd	nd	0.8 (0.6-0.8)	30.8 (28.0-35.4)
E7	3.8 (3.4-4.1)	99.5 (89.8-114.0)	0.027 (0.024-0.031)	6.6 (5.7-7.3)	0.26 (nd-0.30)	nd	nd	0.7 (0.6-0.8)	27.7 (26.0-28.9)
E1	31.9 (4.9-107.0)	101.0 (86.8-115.0)	0.055 (0.035-0.093)	6.1 (5.2-7.1)	0.25 (nd-0.25)	nd	nd	1.0 (0.8-1.1)	32.1 (25.8-38.7)
98-m Depth Contour									
B12	3 (1.9-3.9)	56.1 (31.6-76.5)	0.014 (0.011-0.016)	4.2 (2.5-5.4)	0.40 (nd-0.43)	nd	nd	0.6 (nd-0.6)	31.3 (19.5-38.9)
B9	4.4 (3.7-5.5)	100.1 (94.6-113.0)	0.026 (0.024-0.028)	6.8 (5.9-7.6)	0.28 (0.10-0.53)	nd	nd	0.7 (0.6-0.9)	34.1 (30.7-39.2)
E26	3.6 (3.2-3.9)	92.9 (82.5-108.0)	0.024 (0.02-0.031)	6.2 (5.4-7.0)	0.25 (nd-0.28)	nd	nd	0.7 (0.6-0.7)	26.1 (23.5-28.7)
E25	3.4 (3.0-4.1)	87.8 (74.1-102.0)	0.018 (0.015-0.020)	5.7 (4.8-6.5)	0.29 (nd-0.37)	nd	nd	0.6 (0.5-0.6)	24.4 (22.3-27.2)
E23	3.4 (3.0-3.8)	89.7 (76.6-107.0)	0.02 (0.019-0.022)	5.9 (4.9-7.1)	0.28 (nd-0.32)	nd	nd	0.6 (0.5-0.7)	24.6 (22.1-27.4)
E20	3.1 (2.8-3.4)	85.4 (76.9-96.9)	0.018 (0.016-0.020)	5.7 (4.8-6.5)	0.37 (nd-0.37)	nd	nd	0.5 (0.4-0.5)	23.3 (21.8-24.5)
E17 [a]	2.8 (2.5-2.9)	79.8 (67.1-91.4)	0.019 (0.015-0.024)	5.1 (4.7-5.5)	nd	nd	nd	0.5 (0.4-0.5)	21.2 (20.6-21.9)
E14 [a]	2.4 (2.1-2.5)	69.8 (59.2-76.3)	0.016 (0.013-0.018)	4.7 (4.4-5.2)	0.25 (nd-0.25)	nd	nd	0.5 (0.5-0.5)	20.8 (19.9-21.3)
E11 [a]	2.6 (2.4-2.7)	74.8 (66.1-84.1)	0.015 (0.014-0.017)	4.7 (4.5-5.3)	0.41 (nd-0.41)	3.15 (nd-3.15)	nd	0.5 (nd-0.6)	21.6 (20.2-23.1)
E8	2.8 (2.4-3.1)	79.3 (69.7-92.3)	0.016 (0.015-0.017)	5.0 (4.3-5.7)	0.26 (nd-0.26)	nd	nd	0.5 (0.4-0.6)	22.4 (21.2-23.5)
E5	3.0 (2.7-3.4)	77.1 (66.5-91.0)	0.026 (0.016-0.050)	4.9 (4.3-5.7)	0.26 (nd-0.27)	nd	nd	0.5 (0.5-0.6)	22.5 (20.0-23.7)
E2	4.6 (3.7-5.0)	111.7 (98.7-126.0)	0.036 (0.035-0.037)	6.5 (5.4-7.5)	0.21 (nd-0.27)	nd	nd	0.8 (0.7-0.9)	33.5 (28.8-37.6)
116-m Depth Contour									
B10	3.3 (2.6-4.8)	77.0 (61.1-111.0)	0.015 (0.013-0.017)	4.8 (3.7-6.9)	0.35 (nd-0.42)	nd	nd	0.6 (nd-0.7)	28.4 (23.6-33.9)
E21	2.9 (2.6-3.1)	76.1 (64.3-85.1)	0.016 (0.013-0.018)	5.1 (4.5-5.8)	nd	nd	nd	0.5 (nd-0.5)	20.9 (19.5-22.3)
E15	2.7 (2.4-2.9)	70.3 (62.1-79.1)	0.016 (0.014-0.018)	4.6 (3.9-5.1)	nd	nd	nd	0.4 (0.4-0.5)	20.6 (19.3-21.3)
E9	4.7 (3.7-5.2)	77.9 (73.4-85.8)	0.021 (0.017-0.026)	5.4 (4.3-5.8)	0.29 (nd-0.4)	nd	nd	0.7 (0.6-0.7)	37.2 (32.4-42.3)
E3	10.5 (4.5-26.0)	98.5 (79.3-119.0)	0.036 (0.029-0.043)	4.4 (3.4-5.3)	0.20 (nd-0.20)	nd	nd	0.6 (0.6-0.7)	33.3 (27.4-36.1)

[a] Near-ZID station

Appendix D.8

Summary of metals (ppm) in sediments from SBOO stations sampled during 2016 and 2017. Data are means (range) for each station. Minimum and maximum values were based on all samples (n ≤ 4), whereas means were calculated on detected values only; nd = not detected.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe
19-m Depth Contour									
I35	8810 (6410-12,000)	1.0 (0.8-1.5)	1.96 (1.37-2.63)	45.9 (33.6-56.4)	nd	0.07 (nd-0.07)	19.7 (14.2-28.7)	6.2 (4.3-9.2)	11,418 (7940-16,900)
I34	3258 (1040-9520)	1.3 (nd-1.3)	2.68 (2.07-3.47)	16.5 (3.55-51.6)	nd	nd	8.7 (2.8-25.9)	2.4 (nd-5.8)	6555 (3000-16,600)
I31	4220 (1390-9060)	0.8 (nd-1.0)	1.37 (0.87-1.82)	21.4 (2.9-49.5)	nd	0.07 (nd-0.07)	10.5 (5.1-21.1)	2.1 (0.7-5.9)	5655 (3070-12,100)
I23	4730 (4230-5600)	0.6 (nd-0.6)	1.37 (0.99-1.60)	28.6 (24.9-31.5)	nd	nd	10.5 (8.8-12.7)	1.9 (1.3-2.6)	5465 (5010-5920)
I18	4628 (4540-4740)	0.6 (nd-0.8)	1.31 (0.97-1.73)	39.4 (33.5-48.9)	nd	nd	13.9 (11.2-15.9)	1.5 (1.3-1.7)	6838 (6410-7290)
I10	4932 (4790-4990)	0.5 (nd-0.5)	1.33 (1.04-1.52)	28.1 (25.5-29.5)	nd	nd	11.1 (9.2-12.9)	1.8 (1.5-2.1)	6178 (5990-6400)
I4	830 (564-1380)	nd	1.38 (1.03-1.77)	2.8 (1.3-5.9)	nd	0.28 (nd-0.28)	4.2 (3.7-5.1)	0.5 (nd-0.7)	1730 (1520-2260)
28-m Depth Contour									
I33	5468 (4020-9360)	0.8 (nd-1.1)	1.56 (0.79-2.48)	27.7 (18.6-47.5)	nd	nd	12.3 (8.1-22.1)	3.4 (2.1-6.9)	7702 (5810-13,200)
I30	4810 (1690-6140)	0.7 (nd-0.9)	1.27 (1.13-1.64)	24.0 (6.7-33.4)	nd	0.06 (nd-0.06)	10.6 (4.8-13.8)	2.5 (nd-2.7)	5630 (3820-6520)
I27	4508 (1450-6020)	0.7 (nd-0.8)	1.77 (1.15-2.55)	22.5 (7.3-32.3)	nd	nd	9 (4.5-11.1)	1.9 (0.7-2.8)	5282 (3240-6360)
I22	3830 (1450-5150)	0.3 (nd-0.3)	1.42 (0.90-1.80)	18.9 (3.9-29.8)	nd	nd	9.7 (7.8-12.4)	1.6 (0.7-2.1)	4928 (3600-6000)
I14[a]	6285 (5730-6750)	0.8 (nd-0.9)	1.34 (0.83-1.98)	34.7 (32.2-39.0)	nd	nd	13.0 (10.6-15.2)	2.7 (2.3-3.2)	6995 (6480-7380)
I16[a]	2570 (1720-3080)	0.9 (nd-0.9)	1.15 (0.56-1.56)	11.0 (5.8-14.9)	nd	nd	8.2 (3.8-13.7)	0.5 (nd-0.8)	4240 (3080-5590)
I15[a]	2052 (1760-2290)	0.5 (nd-0.5)	2.10 (1.61-2.67)	7.5 (5.8-9.0)	nd	nd	9.2 (7.9-10.3)	0.3 (nd-0.3)	4300 (3970-4670)
I12[a]	4222 (2410-5310)	0.5 (nd-0.5)	1.32 (1.03-1.67)	25.7 (11.1-35.4)	nd	nd	9.5 (7.8-12.1)	1.9 (nd-2)	5552 (3800-6640)
I9	7015 (6670-7530)	0.6 (nd-0.8)	1.52 (0.88-2.16)	39.9 (36.1-44.0)	nd	nd	13.9 (11.7-17.4)	3.2 (2.7-3.8)	7808 (7570-8040)
I6	901 (854-966)	0.4 (nd-0.4)	4.50 (4.39-4.55)	2.3 (1.8-3.2)	nd	nd	8.1 (7.5-8.6)	nd	3702 (3550-3920)
I2	1069 (957-1160)	0.3 (nd-0.3)	0.89 (0.64-1.15)	2.4 (2.1-3.0)	nd	nd	5.7 (5.3-5.9)	0.5 (nd-0.7)	1300 (1200-1410)
I3	796 (671-934)	nd	1.19 (0.75-1.61)	1.4 (1.2-1.6)	nd	0.13 (nd-0.13)	6.1 (5.4-7.0)	1.1 (nd-1.5)	1262 (1220-1290)

[a] Near-ZID station

Appendix D.8 *continued*

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe
38-m Depth Contour									
I29	4210 (1370-5610)	0.5 (nd-0.5)	1.97 (1.37-2.80)	19.1 (4.3-27.8)	nd	0.08 (nd-0.08)	10.4 (6.1-13.8)	2.8 (nd-2.9)	6442 (5150-6940)
I21	1140 (900-1370)	0.5 (nd-0.5)	8.00 (6.03-10.50)	2.1 (1.8-2.3)	nd	nd	12.3 (10.7-13.5)	nd	8045 (7510-8620)
I13	986 (873-1120)	0.4 (nd-0.4)	6.01 (3.96-7.27)	2.3 (1.7-2.9)	nd	nd	10.1 (9.0-11.0)	nd	5622 (5040-5930)
I8	2300 (1540-4380)	0.4 (nd-0.4)	1.94 (1.09-2.60)	8.8 (3.4-23.4)	nd	nd	9.4 (8.0-11.4)	1.6 (nd-1.6)	4155 (3810-5020)
55-m Depth Contour									
I28	4458 (3710-5240)	0.5 (nd-0.5)	1.45 (0.79-2.16)	21.2 (17.8-25.2)	nd	0.05 (nd-0.05)	9.8 (8.6-10.8)	2.8 (1.2-4.2)	5960 (4310-7100)
I20	1250 (1160-1350)	0.3 (nd-0.3)	2.75 (2.22-3.48)	2.7 (2.0-3.4)	nd	nd	5.4 (5-5.8)	nd	4860 (4420-5290)
I7	1136 (875-1370)	0.5 (nd-0.5)	6.79 (6.56-7.00)	2.3 (1.8-2.8)	nd	nd	9.5 (8.6-10.9)	0.7 (nd-0.7)	7408 (7140-7770)
I1	2405 (2290-2510)	0.4 (nd-0.4)	0.95 (0.67-1.28)	7.8 (6.6-8.4)	nd	0.06 (nd-0.06)	7.1 (6.3-7.7)	0.9 (0.8-1.0)	3490 (3330-3640)

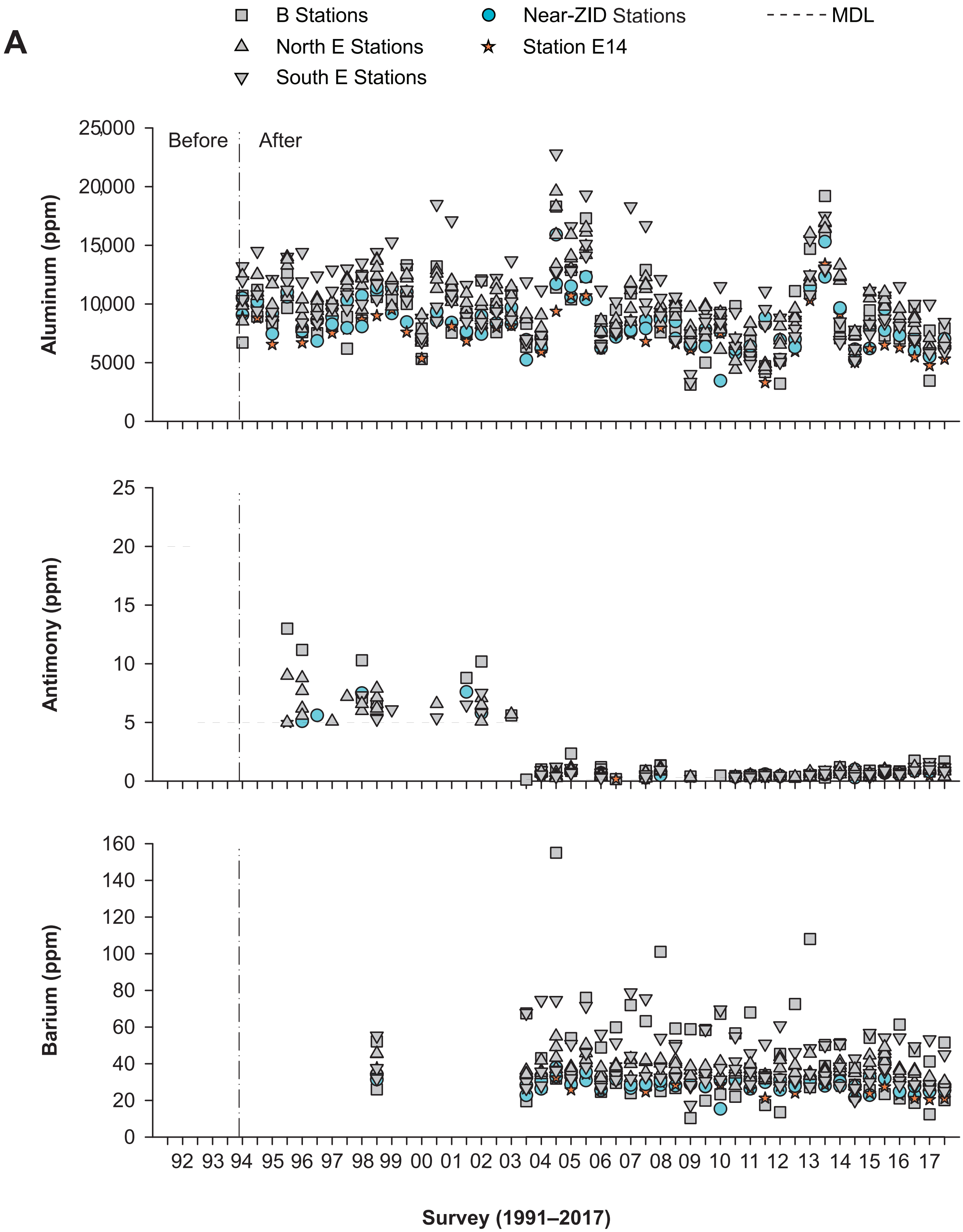
Appendix D.8 *continued*

	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Depth Contour									
I35	3.9 (2.6-5.8)	112.0 (89.6-134.0)	0.014 (0.011-0.017)	5.8 (3.2-9.3)	nd	nd	nd	0.7 (0.5-1.1)	29.6 (21.8-40.9)
I34	2.4 (1.3-5.3)	50.8 (23.4-125.0)	0.005 (nd-0.005)	2.2 (0.6-6.3)	nd	nd	nd	1.0 (nd-1.0)	13.7 (5.5-37.7)
I31	1.9 (1.1-3.9)	62.5 (17.2-121.0)	nd	2.3 (0.5-5.1)	nd	nd	nd	0.7 (nd-0.7)	14 (5.6-33.5)
I23	1.7 (1.4-1.9)	64.5 (55.6-69.5)	0.005 (nd-0.005)	2.5 (1.9-3)	nd	nd	nd	nd	12.7 (10.9-14.3)
I18	1.7 (1.5-1.9)	76.6 (66.1-87.4)	nd	2.7 (2.2-3.3)	nd	nd	nd	nd	12.7 (10.7-14.5)
I10	1.6 (1.4-1.7)	68.8 (63.5-73.5)	nd	2.7 (2.4-3.1)	nd	nd	nd	nd	13.5 (11.6-14.6)
I4	1.1 (1.0-1.3)	14.8 (11.3-21.6)	nd	0.9 (0.5-1.3)	nd	nd	nd	nd	4.1 (2.2-5.6)
28-m Depth Contour									
I33	3.5 (2.6-5.8)	81.0 (66.7-114.0)	0.014 (0.013-0.015)	3.4 (1.8-6.6)	nd	nd	nd	0.7 (nd-1.1)	19.3 (14.4-33.2)
I30	1.8 (1.6-2.0)	56.2 (31.9-68.5)	0.004 (0.004-0.005)	2.5 (0.7-4.0)	nd	nd	nd	nd	13.6 (6.2-17.4)
I27	1.6 (1.5-1.8)	54.6 (27.4-68.9)	0.004 (nd-0.004)	2.6 (0.6-4.0)	nd	nd	nd	nd	12.9 (6.6-16.8)
I22	1.5 (1.0-1.8)	49.0 (18.3-70.0)	0.005 (nd-0.005)	2.5 (0.7-3.2)	nd	nd	nd	nd	11.1 (6.2-14.2)
I14[a]	1.7 (1.5-2.0)	75.6 (67.3-83.7)	0.004 (0.004-0.005)	3.6 (3.1-4.4)	nd	nd	nd	0.3 (nd-0.3)	17.1 (15-19.8)
I16[a]	1.3 (0.9-1.5)	57.5 (29.2-123.0)	0.004 (nd-0.004)	1.4 (1.2-2.0)	nd	0.19 (nd-0.19)	nd	nd	9.1 (7.4-11.8)
I15[a]	1.7 (1.6-1.9)	26.1 (20.6-32.2)	nd	1.3 (0.9-1.8)	nd	nd	nd	1.3 (nd-1.3)	7.8 (6.9-8.9)
I12[a]	1.4 (1.2-1.6)	59.0 (34.7-73.2)	nd	2.4 (1.0-3.3)	nd	nd	nd	nd	13.1 (6.8-16.8)
I9	1.6 (1.4-1.8)	82.5 (78.0-90.0)	nd	4.3 (3.7-4.8)	0.09 (nd-0.09)	nd	nd	0.8 (nd-0.8)	19.6 (16.9-22.2)
I6	1.6 (1.5-1.7)	10.9 (9.4-13.3)	nd	0.7 (0.4-1.0)	nd	nd	nd	nd	3.7 (2.7-4.4)
I2	0.9 (0.7-1.0)	10.4 (9.6-11.1)	0.004 (nd-0.004)	0.9 (0.7-1.1)	nd	0.05 (nd-0.05)	nd	nd	3.3 (2.4-4.7)
I3	0.9 (0.8-1.0)	6.7 (5.3-8.4)	nd	0.8 (0.6-1.0)	nd	nd	nd	nd	3.5 (2.0-5.7)

[a] Near-ZID station

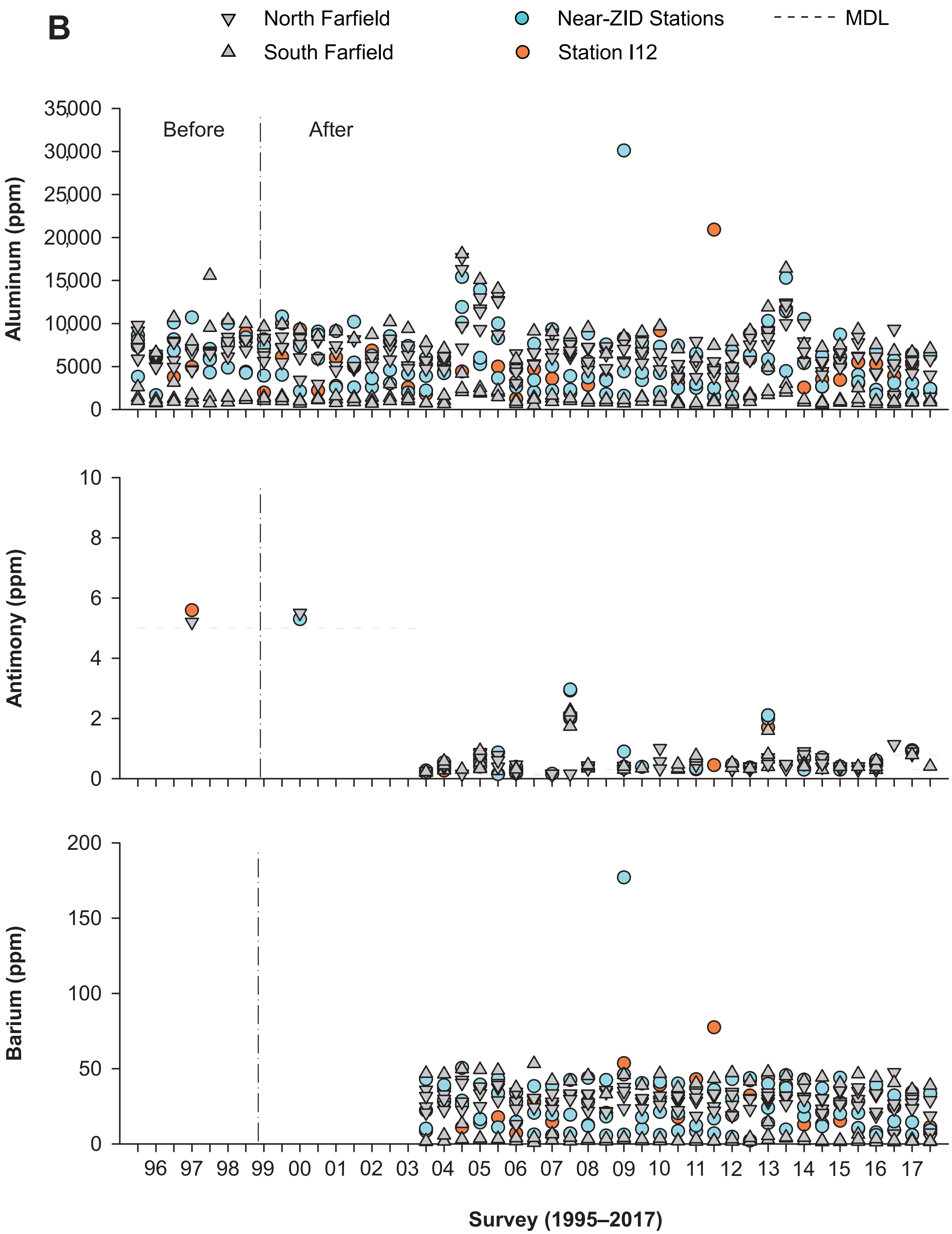
Appendix D.8 *continued*

	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
38-m Depth Contour									
I29	2.4 (1.6-3.4)	55.1 (19.9-76.3)	0.013 (0.004-0.026)	2.7 (0.7-4.4)	nd	nd	nd	0.5 (nd-0.5)	13.6 (6.1-17.4)
I21	3.2 (2.9-3.5)	14.1 (13.7-14.8)	nd	0.9 (0.4-1.3)	nd	nd	nd	nd	6.5 (5.5-7.0)
I13	2.3 (2.2-2.5)	15.5 (14.4-16.1)	nd	0.8 (0.5-1.1)	nd	nd	nd	nd	5.1 (4.5-5.7)
I8	1.3 (1.2-1.4)	30.3 (19.8-60.5)	nd	1.5 (1.0-2.2)	nd	nd	nd	nd	8.3 (6.7-11.1)
55-m Depth Contour									
I28	2.4 (1.5-3.4)	53.7 (41.3-60.5)	0.015 (0.013-0.020)	3.7 (1.7-5.7)	nd	0.29 (nd-0.29)	nd	0.5 (nd-0.5)	13.3 (9.7-15.9)
I20	1.6 (1.5-1.9)	17.2 (14.8-19.9)	nd	0.8 (0.5-1.2)	0.14 (nd-0.14)	nd	nd	nd	6.0 (5.3-6.6)
I7	2.6 (2.5-2.8)	18.7 (13.3-23.5)	nd	0.7 (0.3-1.2)	nd	nd	nd	nd	6.1 (5.8-6.7)
I1	1.5 (1.4-1.6)	39.3 (35-45)	0.007 (0.004-0.012)	2.4 (2.1-2.8)	0.15 (nd-0.24)	nd	nd	nd	7.5 (6.2-9)



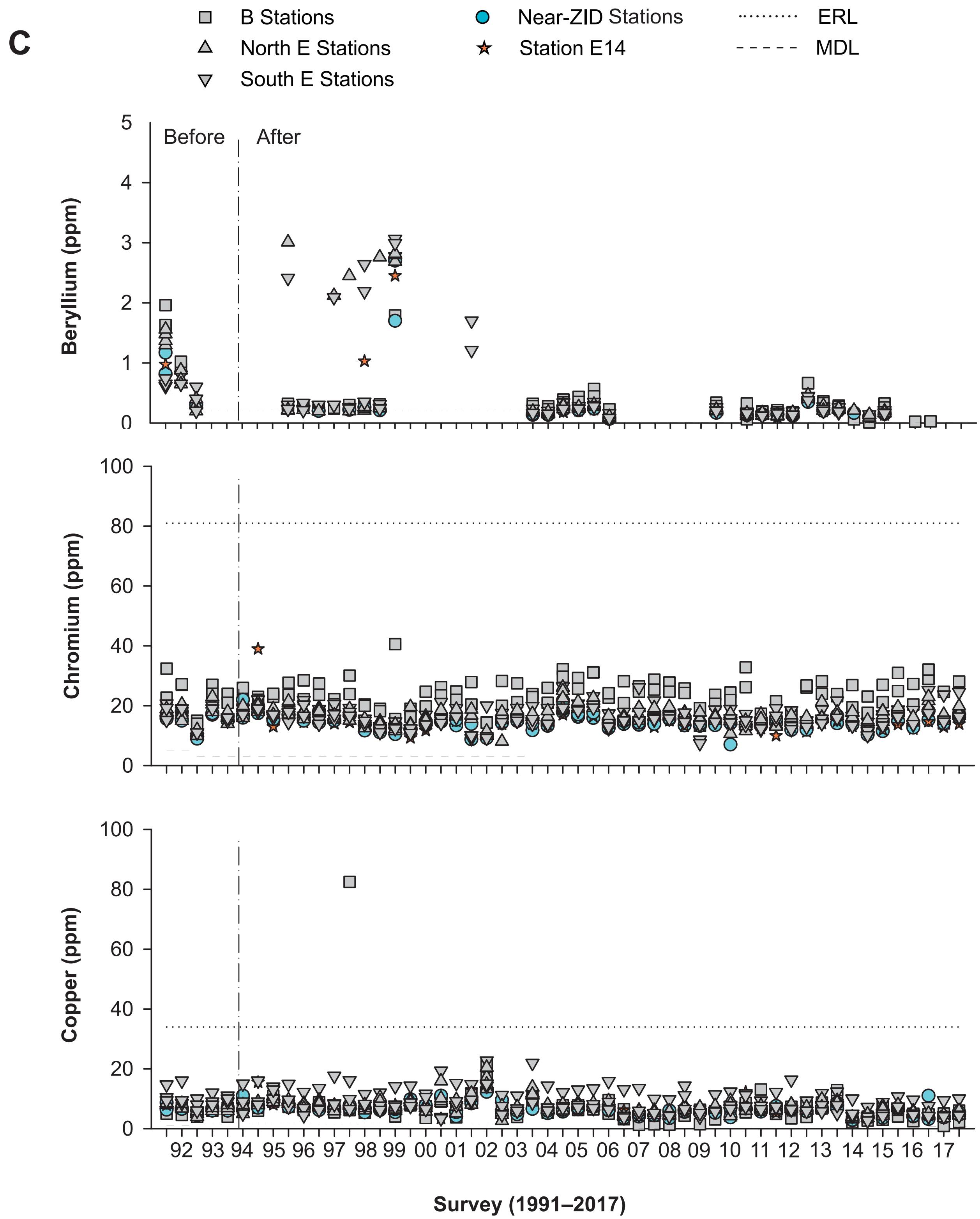
Appendix D.9

Concentrations of select metals in sediments sampled during winter and summer surveys at PLOO primary core stations from 1991 through 2017 (A, C, E, G, I) and SBOO primary core stations from 1995 through 2017 (B, D, F, H, J). Data represent detected values from each station, n≤12 samples per survey. Verticle dashed lines indicate onset of discharge from the PLOO or SBOO.



Appendix D.9 *continued*

C



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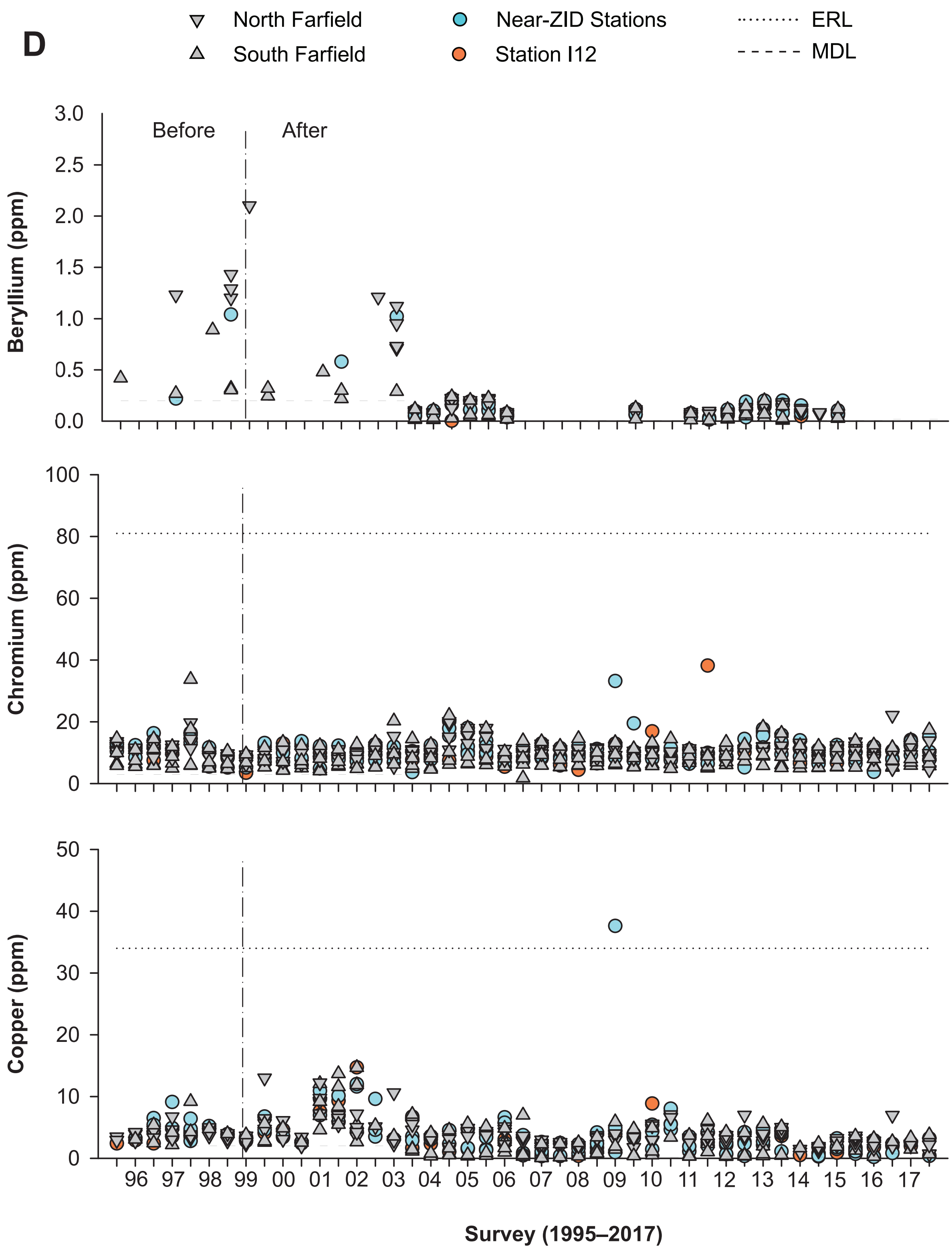

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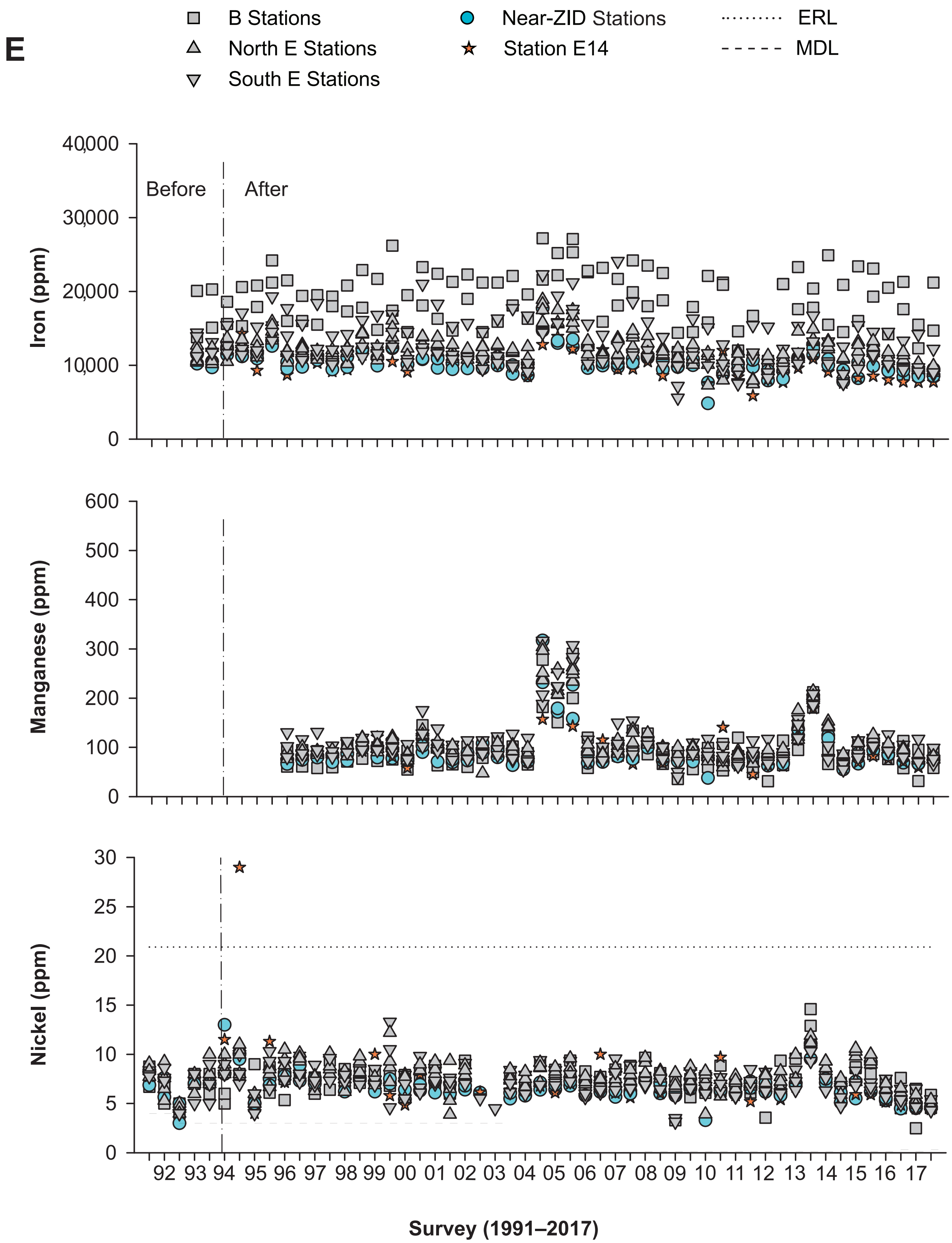

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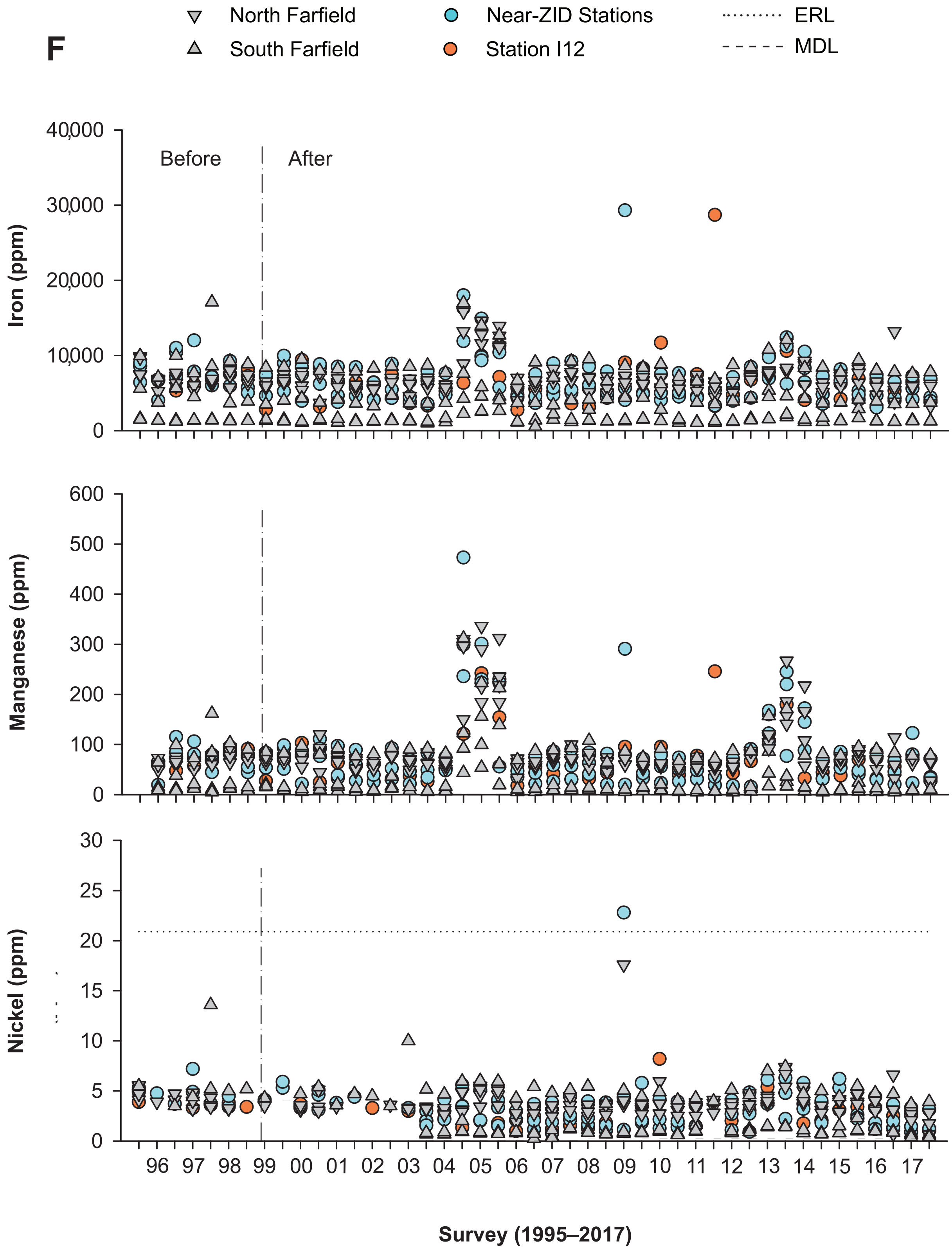
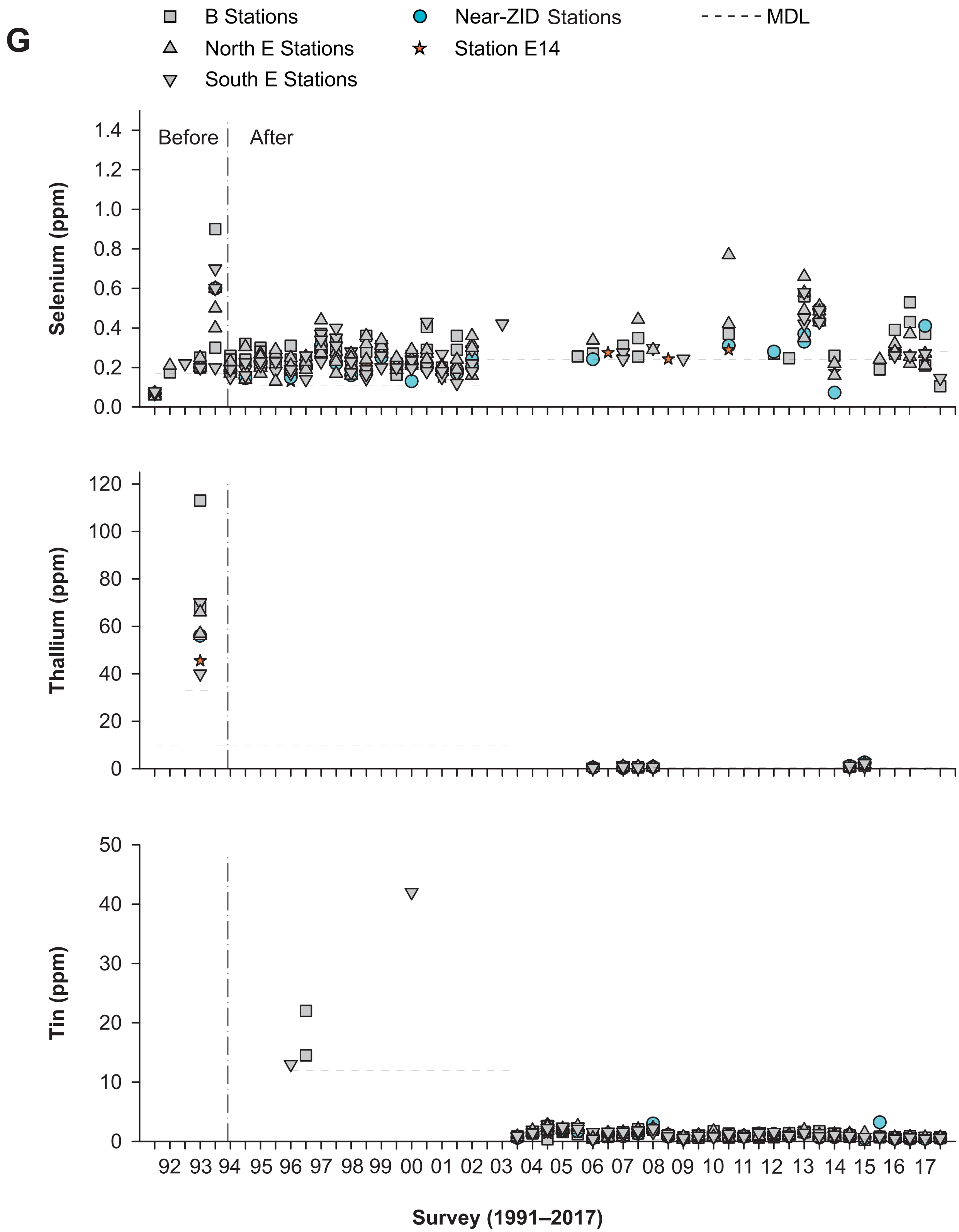


Appendix D.9 *continued*



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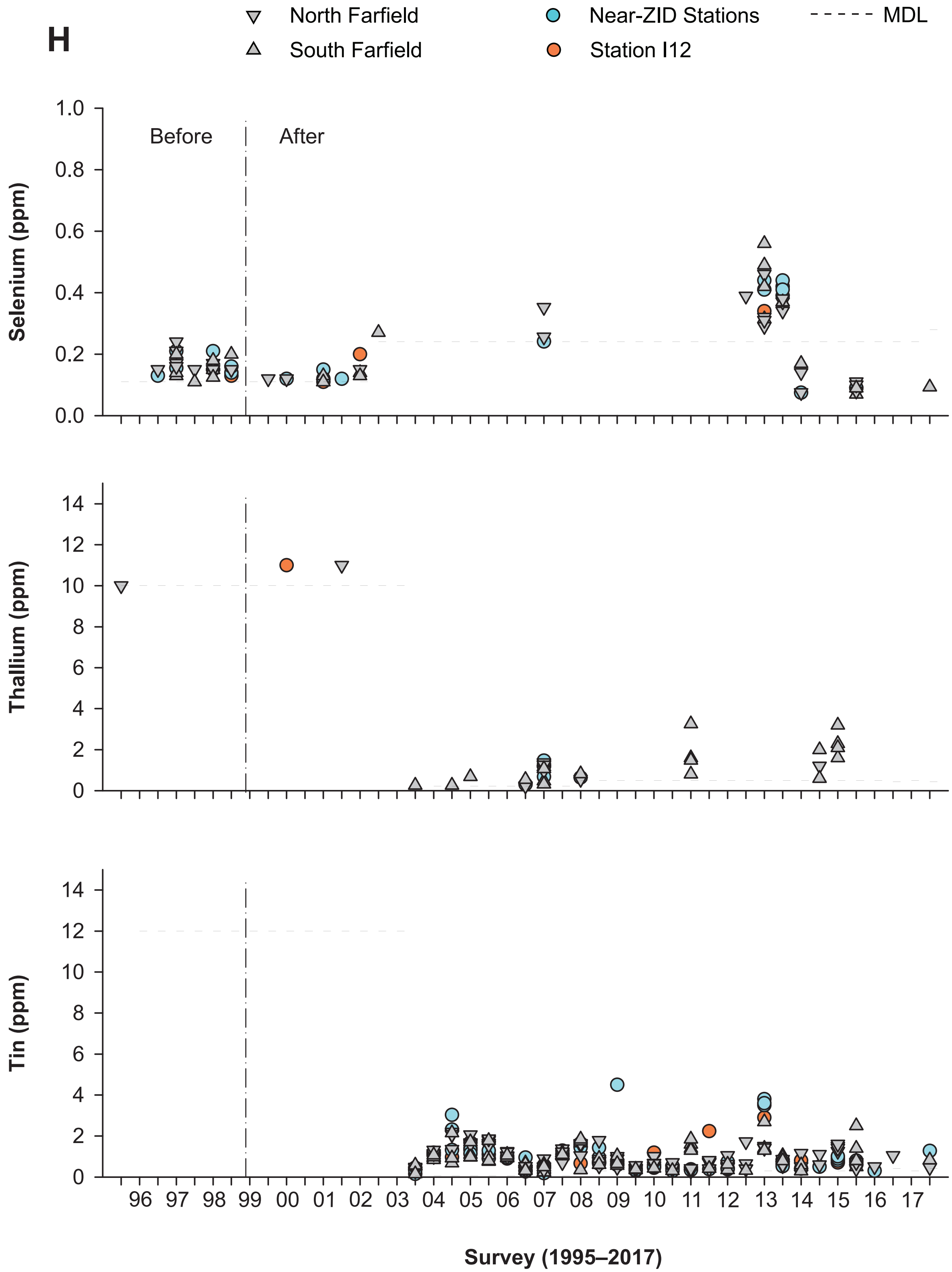
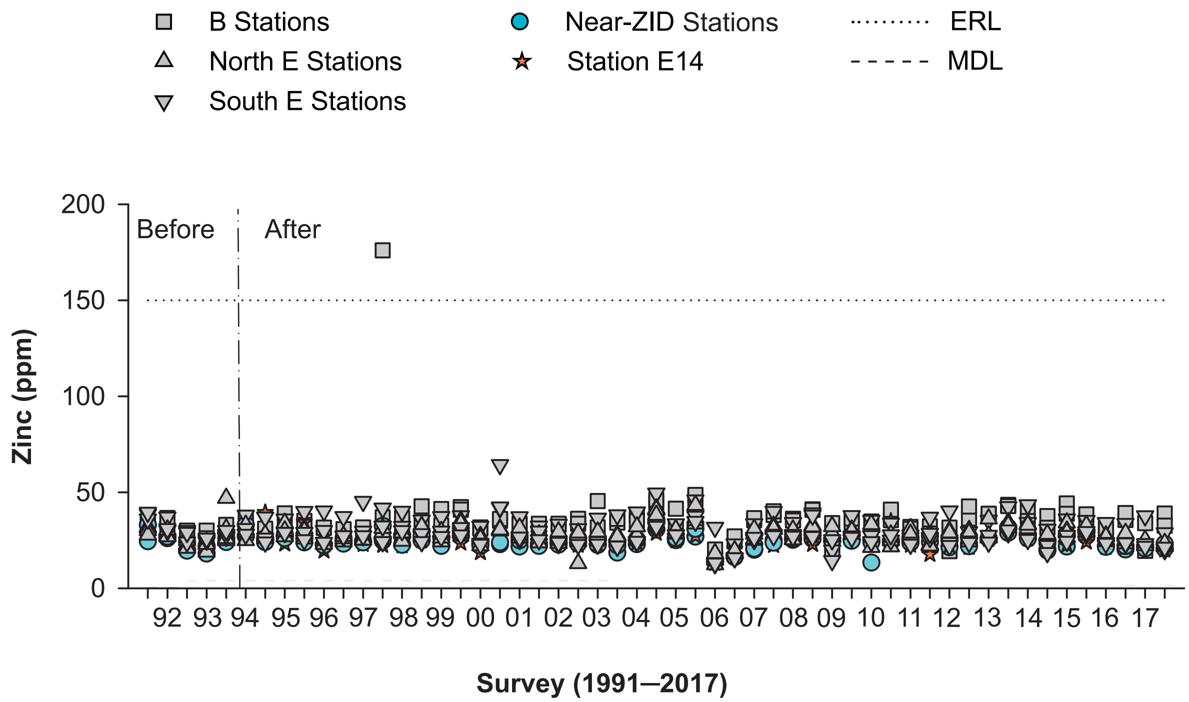
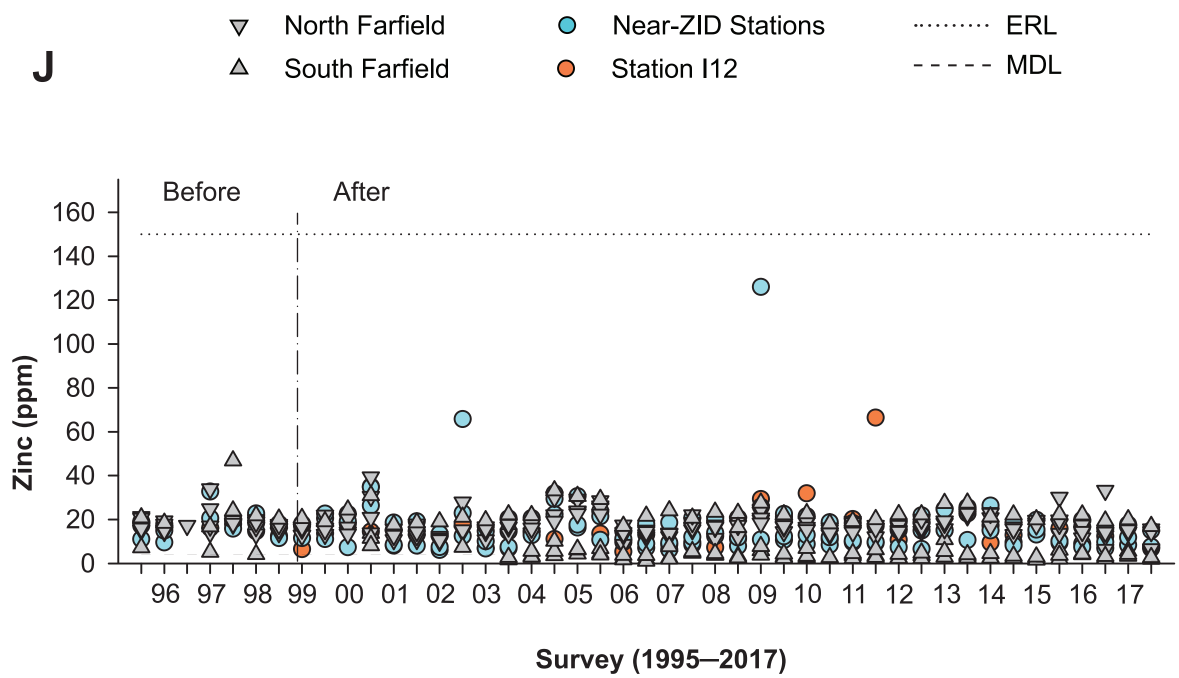


Appendix D.9 *continued*

I



Appendix D.9 *continued*



Appendix D.9 *continued*

Appendix D.10

Summary of pesticides (ppt), total PCB (ppt), and total PAH (ppb) in sediments from PLOO stations sampled during 2016 and 2017. Data are means (range) for each station. Minimum and maximum values were based on all samples with reportable results ($n \leq 4$; see Methods), whereas means were calculated on detected values only; nd = not detected.

	Total Chlordane	Total DDT	Beta-Endosulfan	HCB	Total HCH	Mirex	Total PCB	Total PAH
88-m Depth Contour								
B11	115 (nd-211)	764 (454-1189)	nd	24 (nd-24)	11 (nd-11)	nd	527 (104-1102)	20 (nd-25)
B8	24 (nd-24)	687 (213-1275)	nd	30 (29-31)	14 (nd-14)	nd	574 (26-1228)	20 (7-36)
E19	45 (nd-77)	619 (470-869)	nd	830 (10-1650)	nd	nd	799 (464-1179)	19 (nd-28)
E7	nd	490 (360-556)	nd	643 (86-1200)	34 (nd-34)	nd	1591 (888-2809)	29 (17-39)
E1	136 (nd-210)	816 (446-1300)	nd	286 (60-511)	nd	nd	2903 (1620-5007)	183 (149-249)
98-m Depth Contour								
B12	45 (nd-70)	513 (345-793)	nd	45 (9-82)	29 (nd-29)	nd	383 (nd-517)	8 (nd-9)
B9	17 (nd-17)	676 (580-864)	nd	809 (17-1600)	13 (nd-13)	nd	650 (nd-871)	13 (3-18)
E26	nd	528 (386-799)	nd	136 (92-180)	nd	nd	684 (nd-1010)	17 (14-19)
E25	nd	607 (476-754)	nd	19 (nd-19)	nd	nd	502 (nd-633)	10 (nd-12)
E23	nd	538 (443-690)	nd	90 (79-101)	nd	nd	409 (134-700)	11 (9-18)
E20	6 (nd-6)	502 (450-578)	nd	47 (5-88)	27 (nd-27)	nd	364 (79-584)	8 (nd-9)
E17 [a]	27 (nd-27)	458 (280-636)	nd	1100 (nd-1100)	11 (nd-11)	nd	341 (261-421)	8 (nd-8)
E14 [a]	34 (nd-34)	333 (260-476)	11 (nd-11)	114 (110-118)	112 (nd-112)	66 (nd-66)	461 (nd-529)	10 (nd-11)
E11 [a]	36 (nd-36)	297 (275-320)	nd	168 (135-200)	45 (nd-45)	nd	289 (64-410)	9 (7-10)
E8	nd	379 (257-491)	nd	232 (35-430)	nd	nd	616 (nd-921)	9 (nd-9)
E5	nd	359 (310-390)	nd	54 (54-55)	nd	nd	465 (261-762)	8 (7-10)
E2	116 (nd-116)	514 (434-624)	nd	514 (28-1000)	159 (nd-159)	nd	2277 (1055-3849)	78 (75-80)
116-m Depth Contour								
B10	62 (nd-89)	565 (441-682)	nd	4 (nd-4)	30 (nd-30)	nd	526 (nd-700)	33 (nd-79)
E21	nd	363 (300-426)	nd	70 (62-77)	44 (nd-44)	nd	683 (nd-683)	6 (nd-6)
E15	91 (nd-91)	298 (250-330)	nd	21 (nd-21)	191 (nd-191)	nd	334 (47-590)	8 (nd-8)
E9	24 (nd-24)	328 (204-429)	nd	21 (nd-21)	58 (nd-58)	nd	2247 (1001-4477)	33 (22-54)
E3	464 (69-985)	576 (227-850)	nd	107 (nd-126)	179 (nd-179)	nd	11070 (2470-18,226)	253 (107-400)

[a] Near-ZID station

Appendix D.11

Summary of pesticides (ppt), total PCB (ppt), and total PAH (ppb) in sediments from SBOO stations sampled during 2016 and 2017. Data are means (range) for each station. Minimum and maximum values were based on all samples with reportable results (n ≤ 4; see Methods), whereas means were calculated on detected values only; nd = not detected.

	Total Chlordane	Total DDT	Endrin	HCB	Total HCH	Mirex	Total PCB	Total PAH
19-m Depth Contour								
I35	nd	229 (170-288)	nd	360 (360-360)	nd	nd	220 (48-384)	33 (nd-33)
I34	nd	nd	nd	82 (82-82)	nd	nd	10 (nd-10)	nd
I31	nd	50 (nd-66)	nd	85 (9-160)	nd	nd	118 (nd-118)	nd
I23	nd	87 (30-130)	nd	3 (nd-3)	nd	nd	160 (nd-317)	nd
I18	34 (nd-34)	63 (36-80)	nd	326 (1-650)	nd	17 (nd-17)	71 (nd-122)	4 (nd-4)
I10	nd	71 (69-73)	nd	nd	134 (nd-134)	nd	57 (nd-57)	nd
I4	nd	17 (nd-17)	nd	nd	nd	nd	3607 (nd-3607)	nd
28-m Depth Contour								
I33	nd	87 (75-100)	nd	35 (35-35)	nd	nd	126 (nd-126)	13 (nd-13)
I30	nd	143 (140-146)	nd	nd	nd	nd	96 (nd-109)	7 (nd-8)
I27	38 (nd-38)	177 (106-261)	nd	75 (6-144)	24 (nd-35)	nd	246 (nd-445)	4 (nd-4)
I22	nd	144 (99-223)	nd	nd	nd	nd	53 (nd-55)	7 (nd-7)
I14[a]	nd	195 (134-300)	nd	nd	nd	nd	34 (nd-34)	237 (nd-468)
I16[a]	24 (nd-24)	61 (nd-92)	nd	45 (8-82)	nd	nd	107 (nd-147)	nd
I15[a]	nd	80 (35-130)	nd	10 (nd-10)	nd	nd	40 (nd-40)	8 (nd-8)
I12[a]	nd	56 (nd-76)	nd	37 (nd-37)	nd	nd	16 (nd-17)	31 (nd-56)
I9	15 (nd-15)	178 (140-216)	nd	650 (650-650)	nd	nd	116 (nd-116)	6 (nd-7)
I6	nd	39 (nd-39)	nd	6200 (6200-6200)	nd	nd	nd	nd
I2	nd	31 (nd-31)	nd	120 (120-120)	nd	nd	131 (130-132)	nd
I3	nd	nd	nd	75 (75-75)	nd	nd	44 (18-70)	nd

[a] Near-ZID station

Appendix D.11 *continued*

	Total Chlordane	Total DDT	Endrin	HCB	Total HCH	Mirex	Total PCB	Total PAH
38-m Depth Contour								
I29	nd	925 (530-1320)	nd	nd	nd	nd	329 (nd-444)	6 (nd-6)
I21	nd	57 (38-76)	nd	nd	nd	nd	17 (nd-17)	nd
I13	nd	nd	nd	2800 (nd-2800)	nd	nd	7 (nd-7)	nd
I8	nd	61 (nd-61)	nd	55 (nd-55)	nd	nd	59 (nd-59)	nd
55-m Depth Contour								
I28	nd	1480 (570-3020)	nd	575 (51-1100)	nd	nd	890 (485-1256)	18 (nd-34)
I20	86 (nd-86)	64 (32-118)	133 (nd-133)	550 (1-1100)	95 (nd-95)	nd	61 (nd-78)	71 (nd-71)
I7	nd	29 (nd-29)	nd	110 (110-110)	nd	nd	16 (nd-16)	nd
I1	nd	94 (56-133)	nd	521 (nd-521)	21 (nd-21)	nd	716 (100-1333)	121 (nd-121)

Appendix E

Macrobenthic Communities

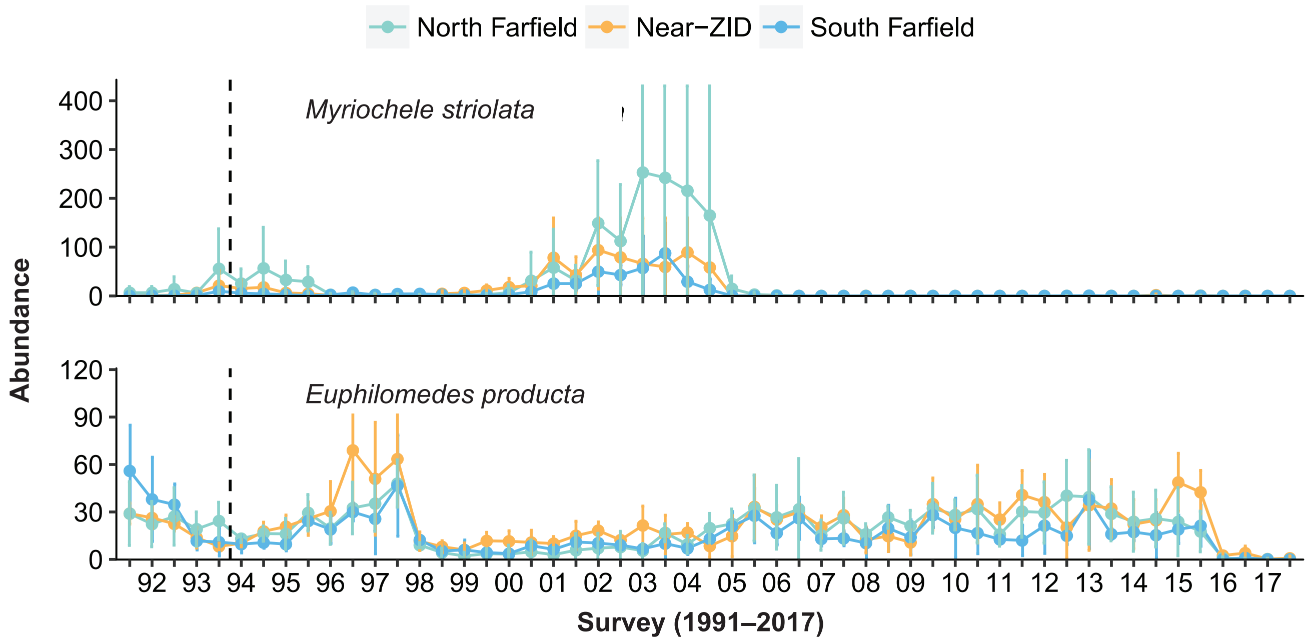
2016 – 2017 Supplemental Analyses

PLOO and SBOO Stations

Appendix E.1

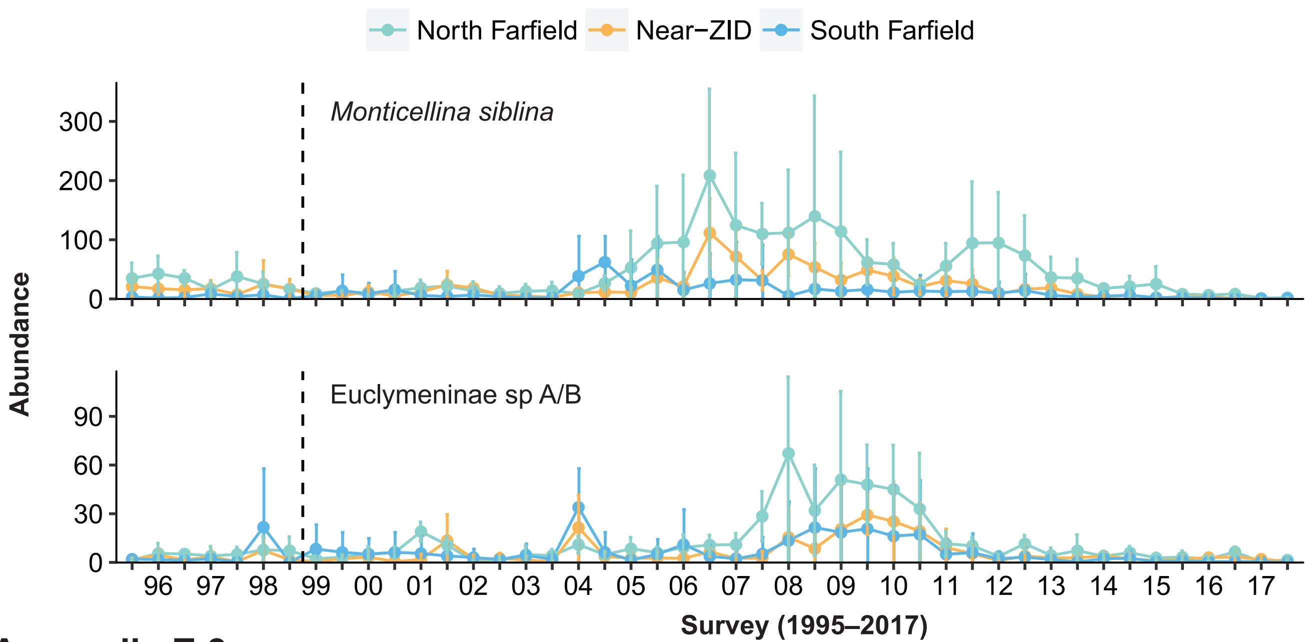
Comparison of benthic infauna species richness (SR), abundance (Abun), diversity (H'), evenness (J'), dominance (Dom), and BRI values for the PLOO and SBOO surveys conducted between 1991 and 2015. PLOO and SBOO data were limited to winter and summer surveys, grab one only, but included all stations. Data are expressed as means with ranges in parentheses. For the PLOO region, pre-discharge = 1991–1993; for the SBOO region, pre-discharge = 1995–1998.

Stratum	Period	n	SR	Abun	H'	J'	Dom	BRI
Inner Shelf								
SBOO	Pre-Discharge	118	47 (14-107)	131 (21-737)	3.4 (0.6-4.3)	0.89 (0.20-0.99)	21 (1-47)	19 (-7-32)
SBOO	Post-Discharge	578	67 (13-161)	363 (21-2843)	3.2 (0.3-4.4)	0.77 (0.08-0.96)	20 (1-48)	20 (-6-37)
Mid-Shelf								
PLOO	Pre-Discharge	105	67 (33-122)	276 (124-566)	3.3 (2.0-4.0)	0.78 (0.56-0.90)	18 (6-33)	5 (-4-14)
PLOO	Post-Discharge	909	91 (40-174)	343 (88-1024)	3.8 (1.5-4.7)	0.84 (0.32-0.95)	30 (1-69)	9 (-6-30)
SBOO	Pre-Discharge	70	63 (23-160)	203 (55-597)	3.5 (2.5-4.5)	0.87 (0.69-0.96)	24 (8-58)	15 (2-32)
SBOO	Post-Discharge	340	71 (17-192)	326 (27-2626)	3.3 (0.8-4.7)	0.78 (0.21-0.97)	22 (1-67)	14 (-5-31)



Appendix E.2

Two of the five historically most abundant species recorded from 1991 through 2017 at PLOO north farfield, near-ZID, and south farfield primary core stations from 1991 through 2017. *Amphiodia urtica, Proclea* sp A*,* and *Spiophanes duplex* are shown in Figures 5.3 and 5.5. Data for each station group are expressed as means per survey ±95% confidence intervals (n≤8). Dashed lines indicate onset of wastewater discharge.



Appendix E.3

Two of the five historically most abundant species recorded from 1995 through 2017 at SBOO north farfield, near-ZID, and south farfield primary core stations. *Spiophanes norrisi, Spiophanes duplex,* and *Mediomastus* sp are shown in Figures 5.4 and 5.6. Data for each station group are expressed as means per survey ± 95% confidence intervals (n ≤ 8). Dashed lines indicate onset of wastewater discharge.

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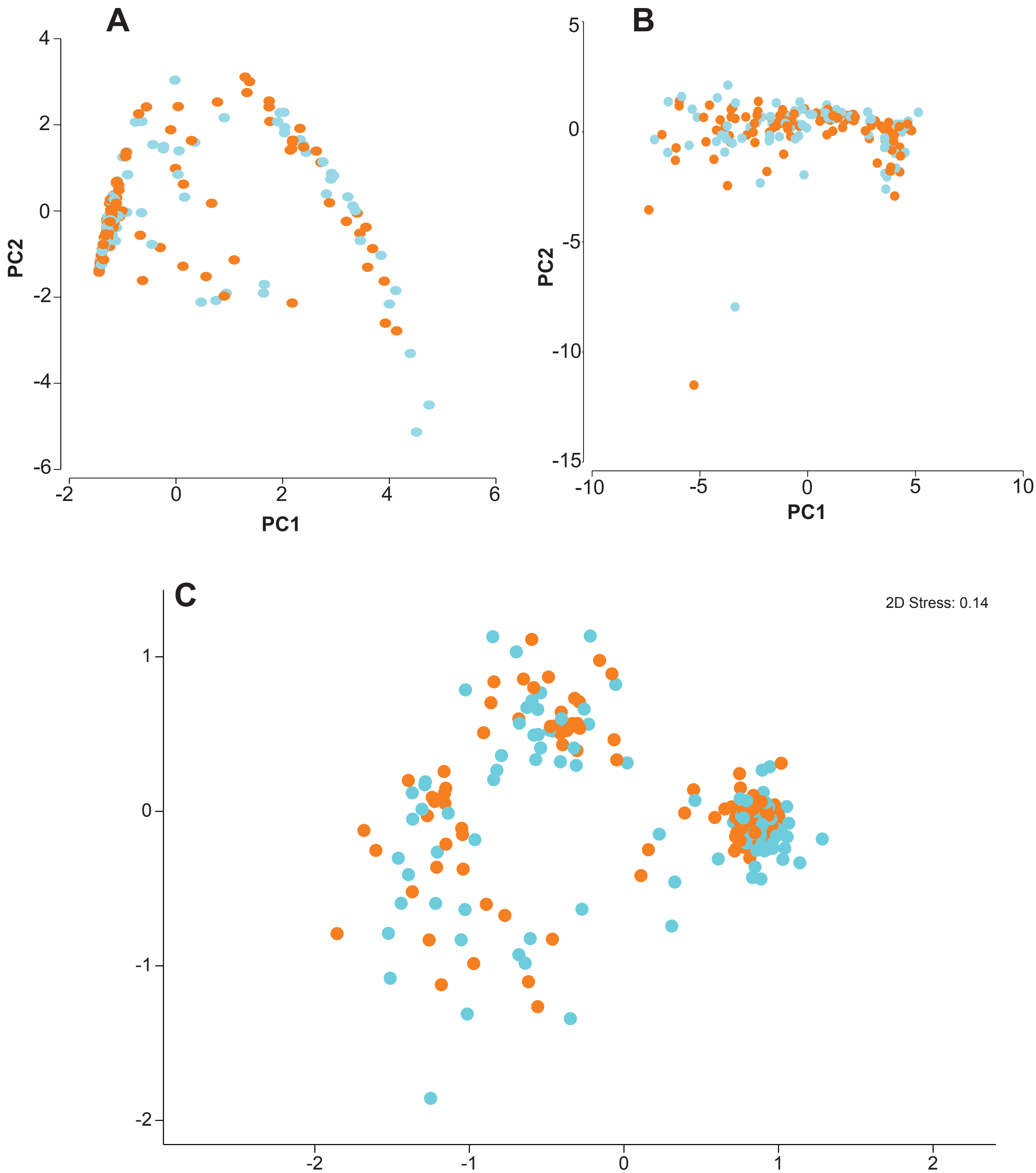
Appendix F

San Diego Regional Benthic Condition Assessment

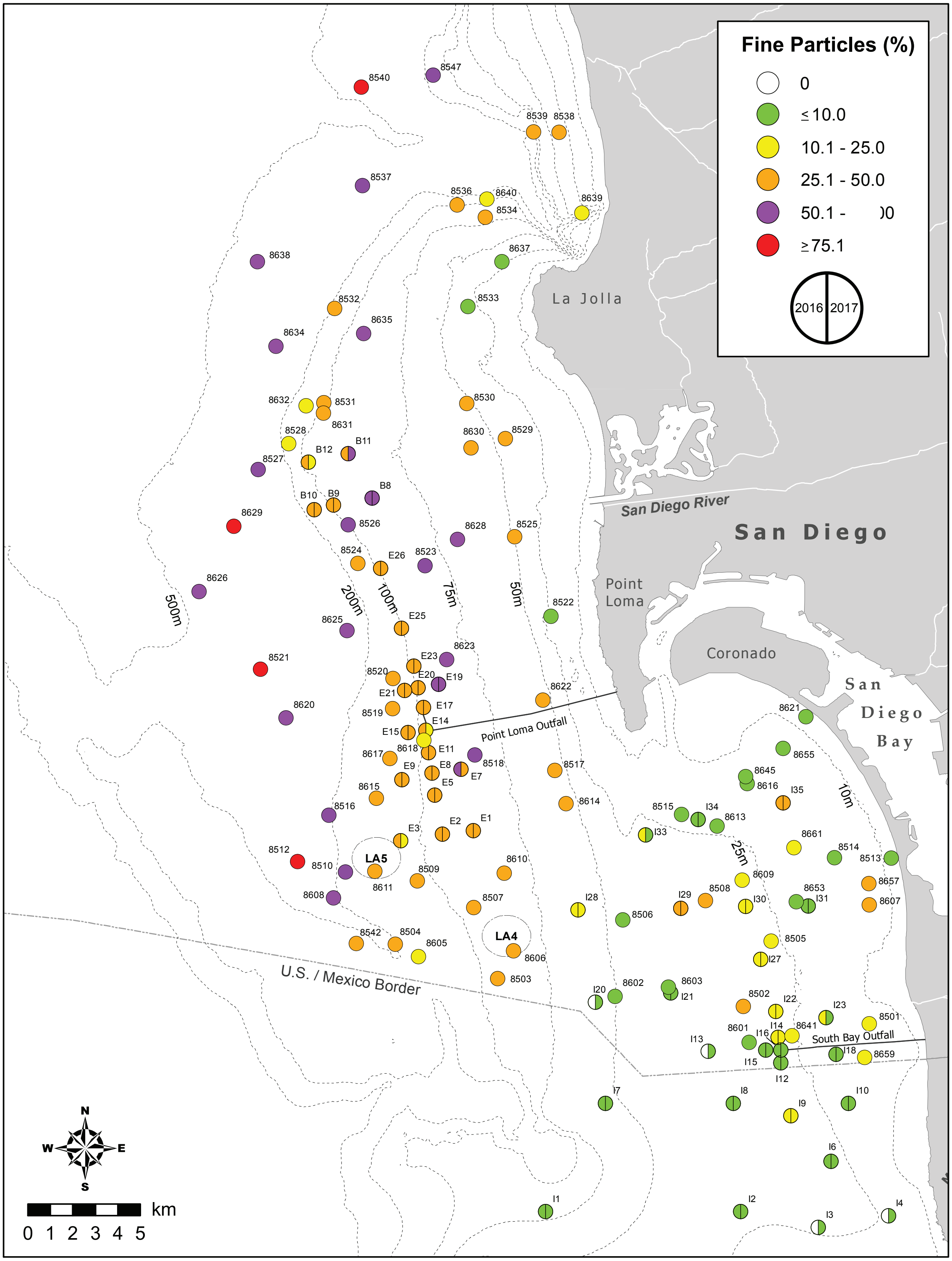
2016 – 2017 Supplemental Analyses

Core and San Diego Regional Stations



Appendix F.1

Ordination analyses of (A) particle size sub-fraction, (B) sediment chemistry, and (C) macrofaunal data from PLOO and SBOO core benthic stations sampled during the winters (turquoise) and summers (orange) of 2016 and 2017. Particle size and sediment chemistry data were analyzed using Principal Components (PC) ordination, while macrofaunal data were analyzed using non-metric multi-dimensional scaling ordination.



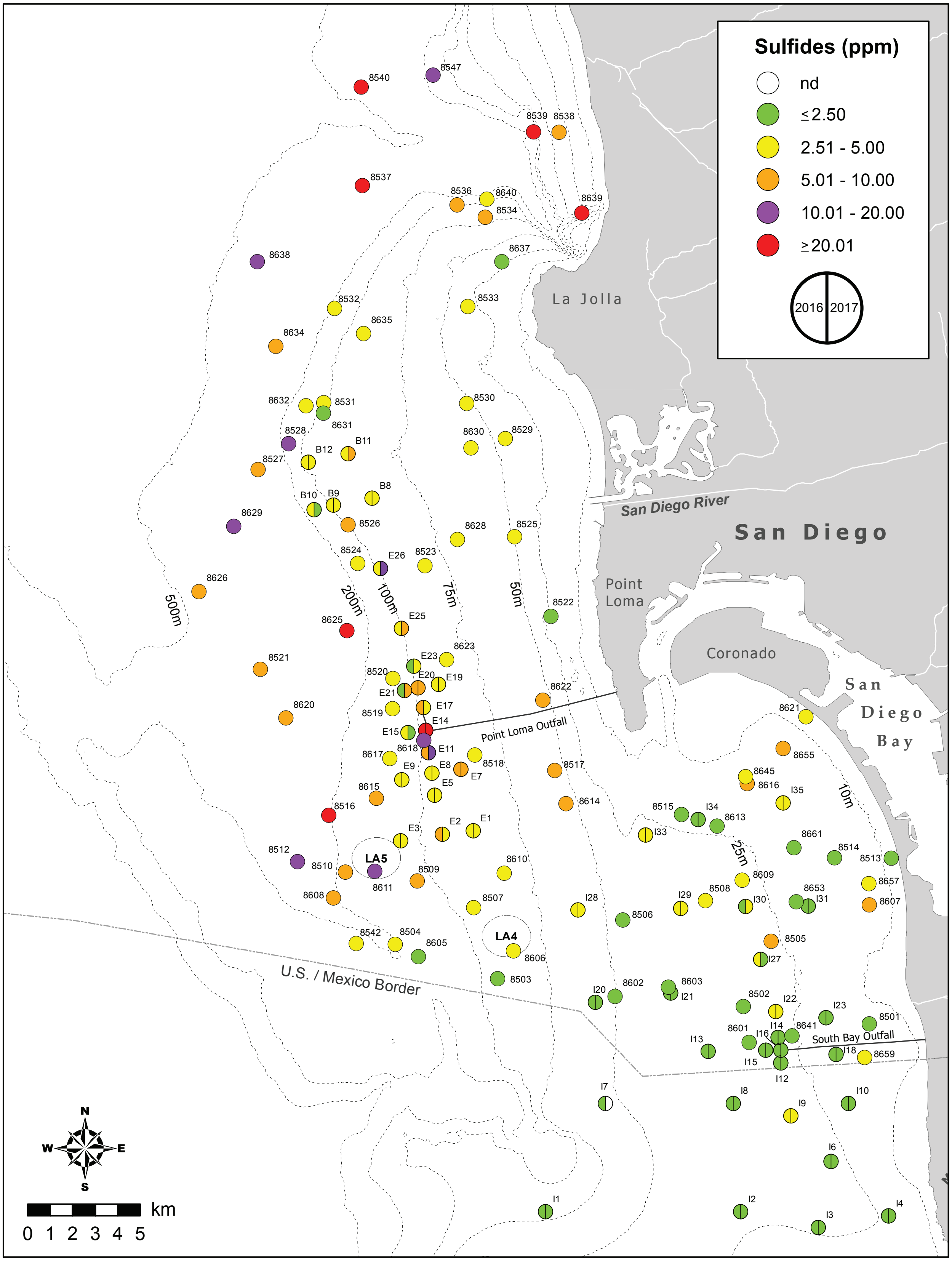
Appendix F.2

Distribution of fine particles in sediments from San Diego regional and core benthic stations sampled during the summers of 2016 and 2017.

Appendix F.3

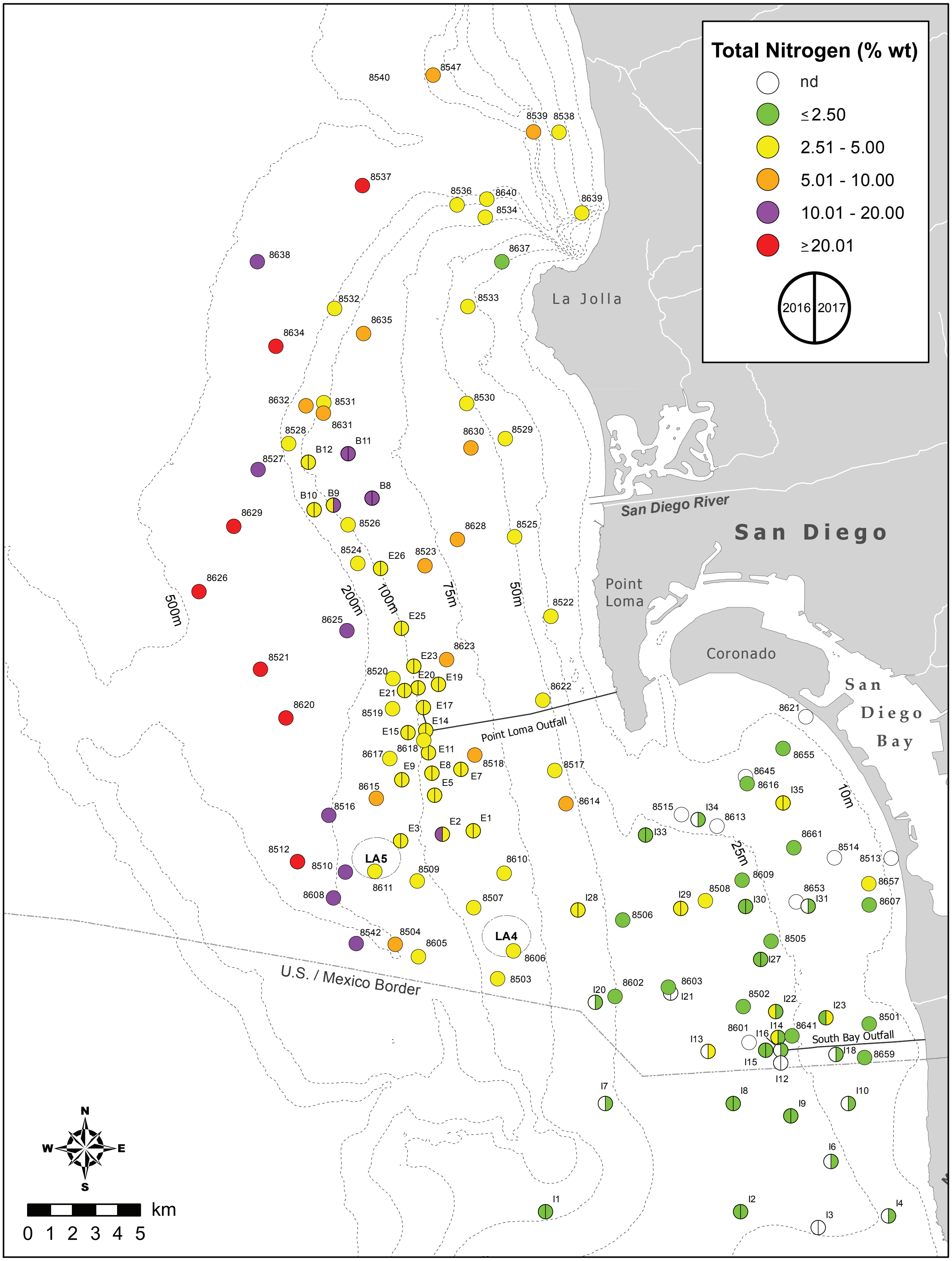
Results of Spearman rank correlation analyses of various sediment parameters from San Diego regional and core benthic stations sampled during the summer surveys of 2016 and 2017. Data include the correlation coefficient (r_s) for all parameters with detection rates ≥50% (see Table 6.1). Correlation coefficients $r_s \geq 0.70$ are highlighted.

	Fines	Sulfides	TN	TOC	TVS	Al	Sb	As	Ba	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Ag	Sn
Sulfides	0.23																	
TN	0.84	0.28																
TOC	0.51	0.17	0.72															
TVS	0.85	0.26	0.96	0.72														
Al	0.88	0.31	0.86	0.57	0.88													
Sb	0.77	0.27	0.77	0.72	0.81	0.85												
As	-0.13	-0.05	0.01	0.14	0.02	-0.12	0.03											
Ba	0.80	0.35	0.83	0.58	0.83	0.95	0.79	-0.12										
Cr	0.85	0.30	0.87	0.64	0.91	0.93	0.86	0.02	0.88									
Cu	0.81	0.32	0.85	0.53	0.85	0.89	0.75	-0.09	0.86	0.90								
Fe	0.77	0.26	0.78	0.67	0.83	0.87	0.91	0.16	0.81	0.91	0.75							
Pb	0.22	0.03	0.18	0.18	0.18	0.24	0.25	0.03	0.24	0.23	0.20	0.25						
Mn	0.83	0.35	0.74	0.46	0.75	0.95	0.78	-0.16	0.94	0.86	0.81	0.82	0.23					
Hg	0.72	0.25	0.72	0.48	0.74	0.76	0.65	-0.07	0.69	0.74	0.82	0.66	0.22	0.66				
Ni	0.88	0.28	0.93	0.62	0.94	0.96	0.83	-0.06	0.91	0.93	0.90	0.84	0.21	0.86	0.76			
Ag	0.03	0.01	0.04	0.21	0.06	0.00	0.09	0.01	0.01	0.02	-0.02	0.05	0.06	-0.03	-0.01	0.02		
Sn	0.08	0.01	0.16	0.52	0.17	0.10	0.38	0.03	0.15	0.14	0.07	0.21	0.17	0.03	0.06	0.11	0.47	
Zn	0.85	0.32	0.85	0.64	0.88	0.96	0.90	-0.02	0.92	0.94	0.87	0.94	0.24	0.92	0.74	0.92	0.01	0.13



Appendix F.4

Distribution of select parameters in sediments from San Diego regional and core benthic stations sampled during the summers of 2016 and 2017; nd = not detected.



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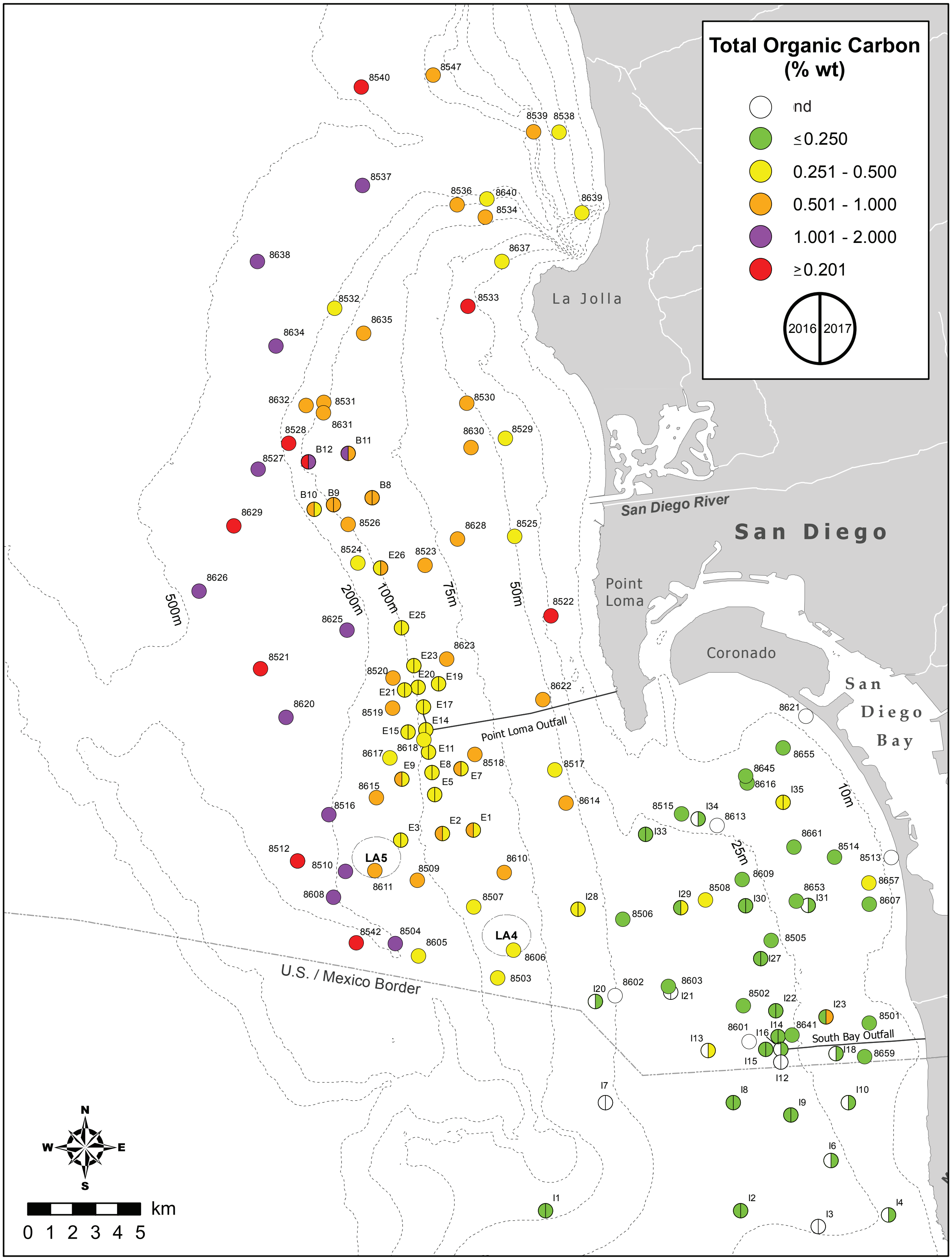

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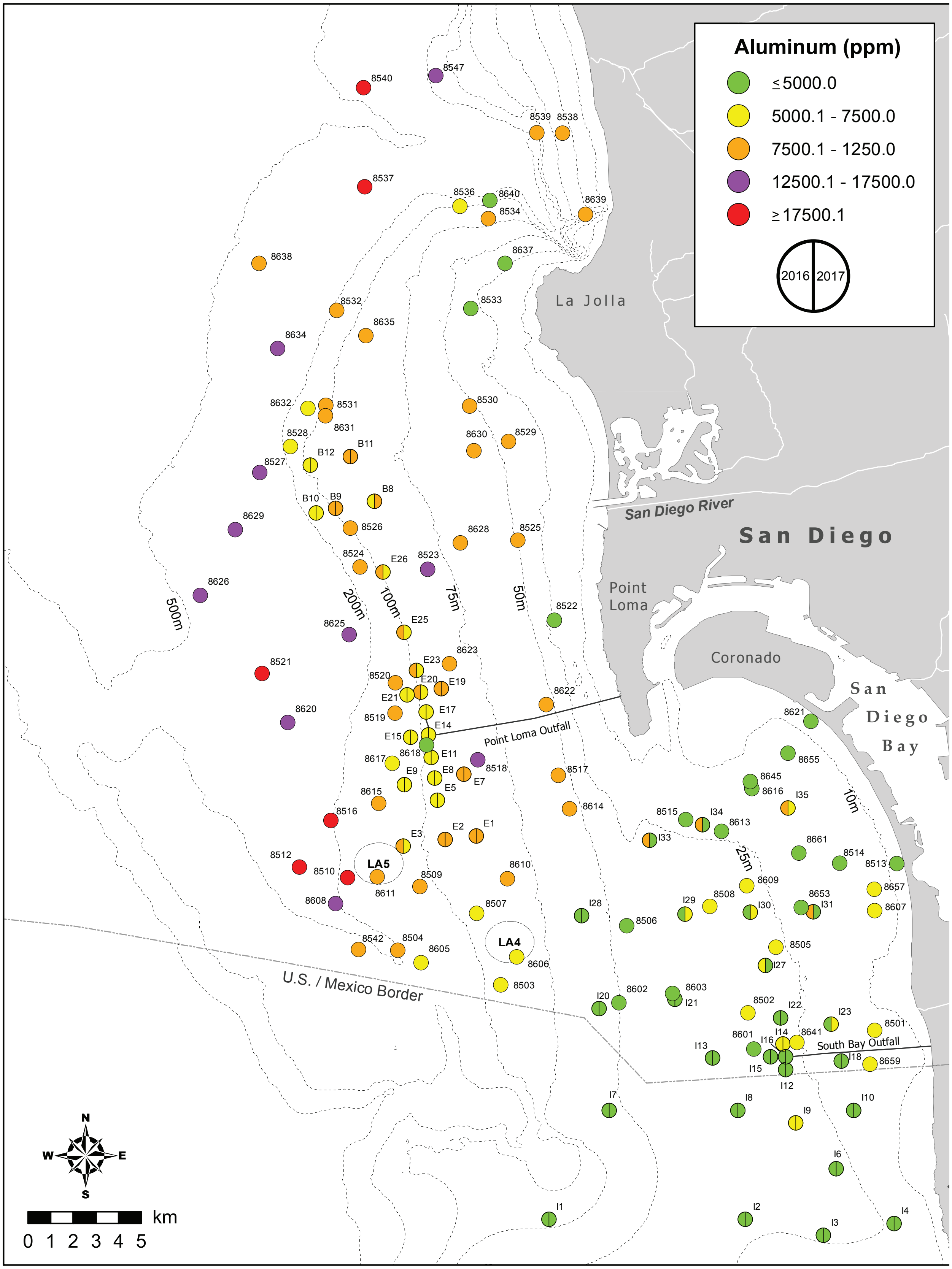
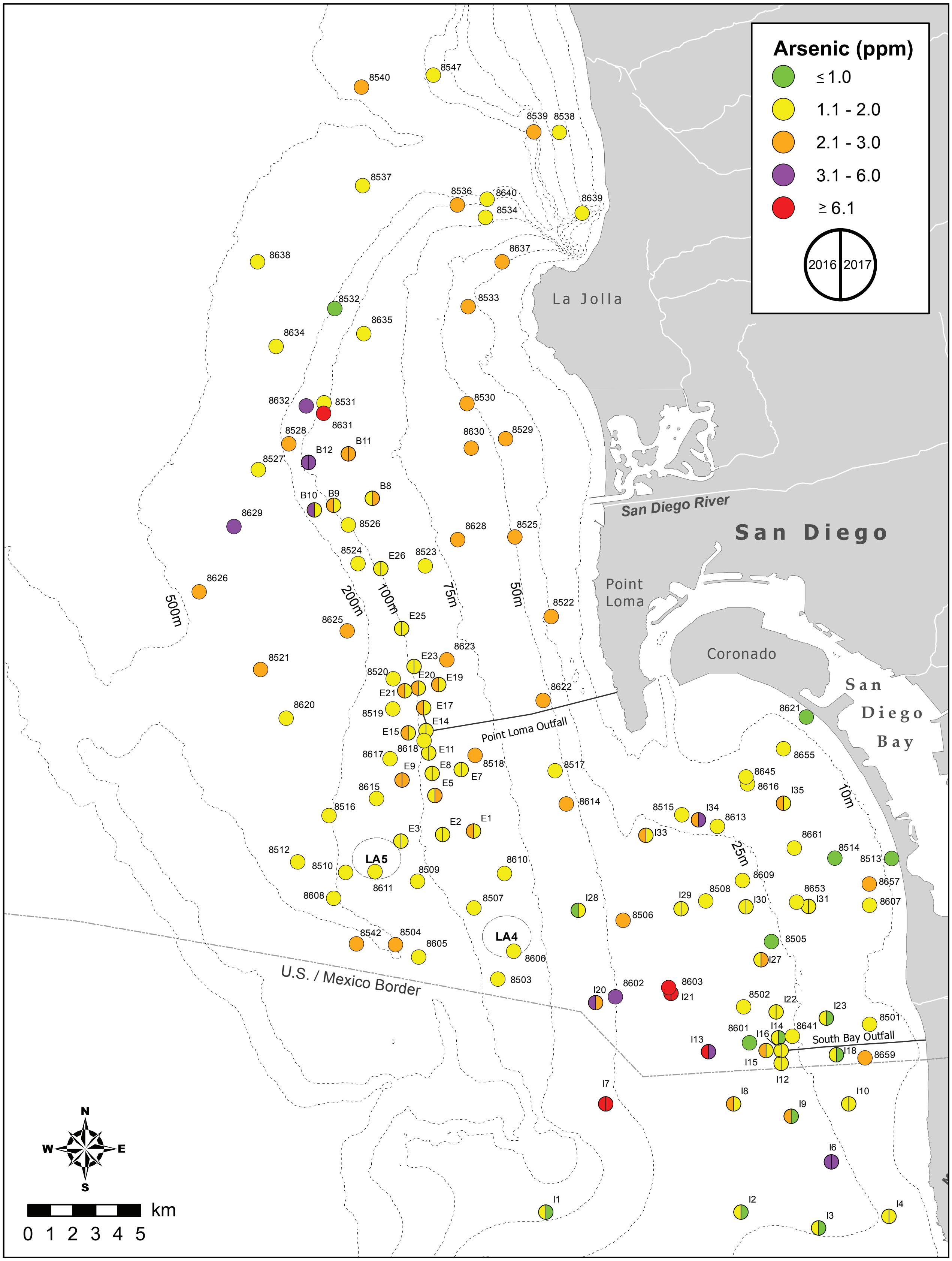


Appendix F.4 *continued*



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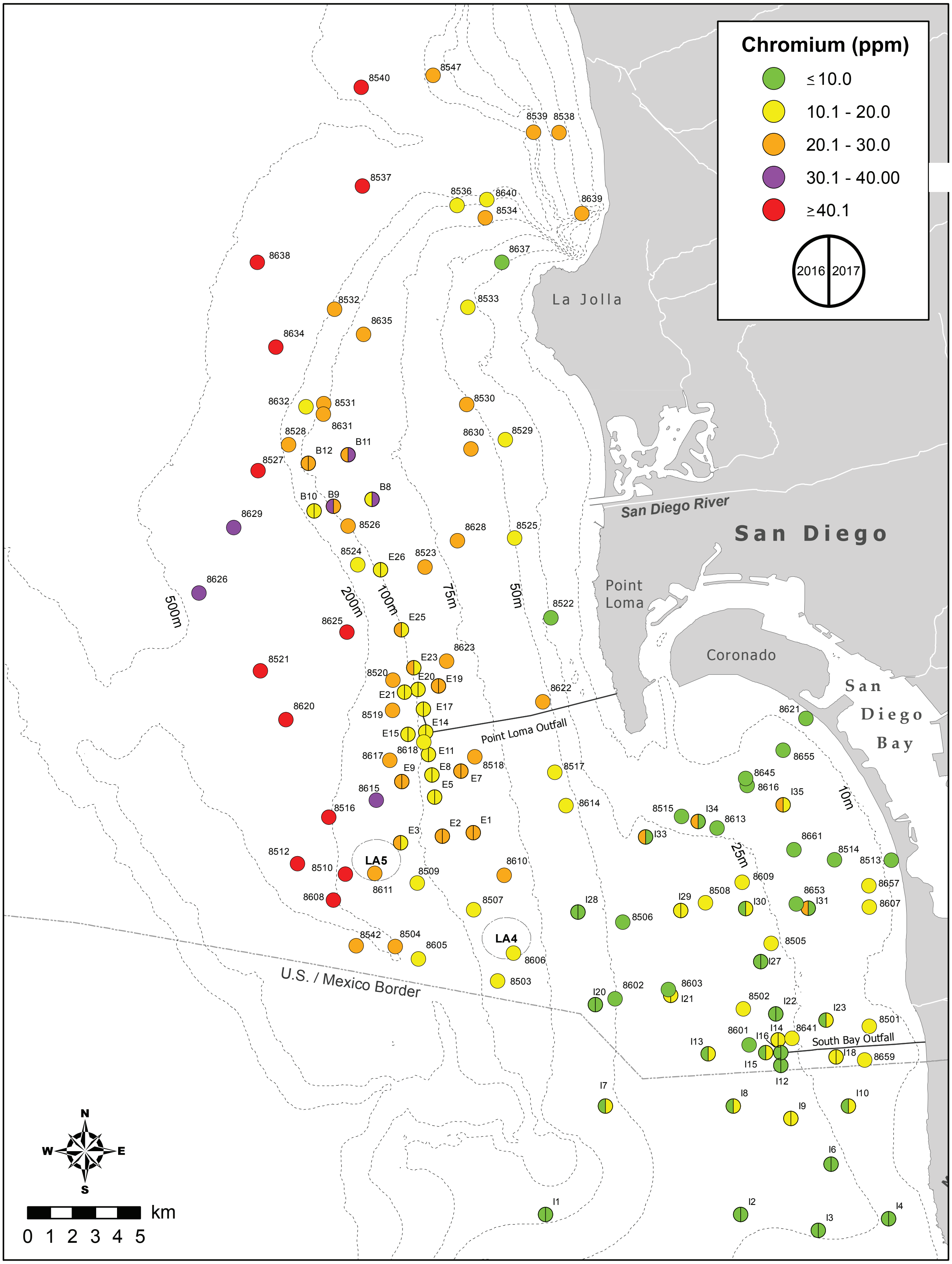

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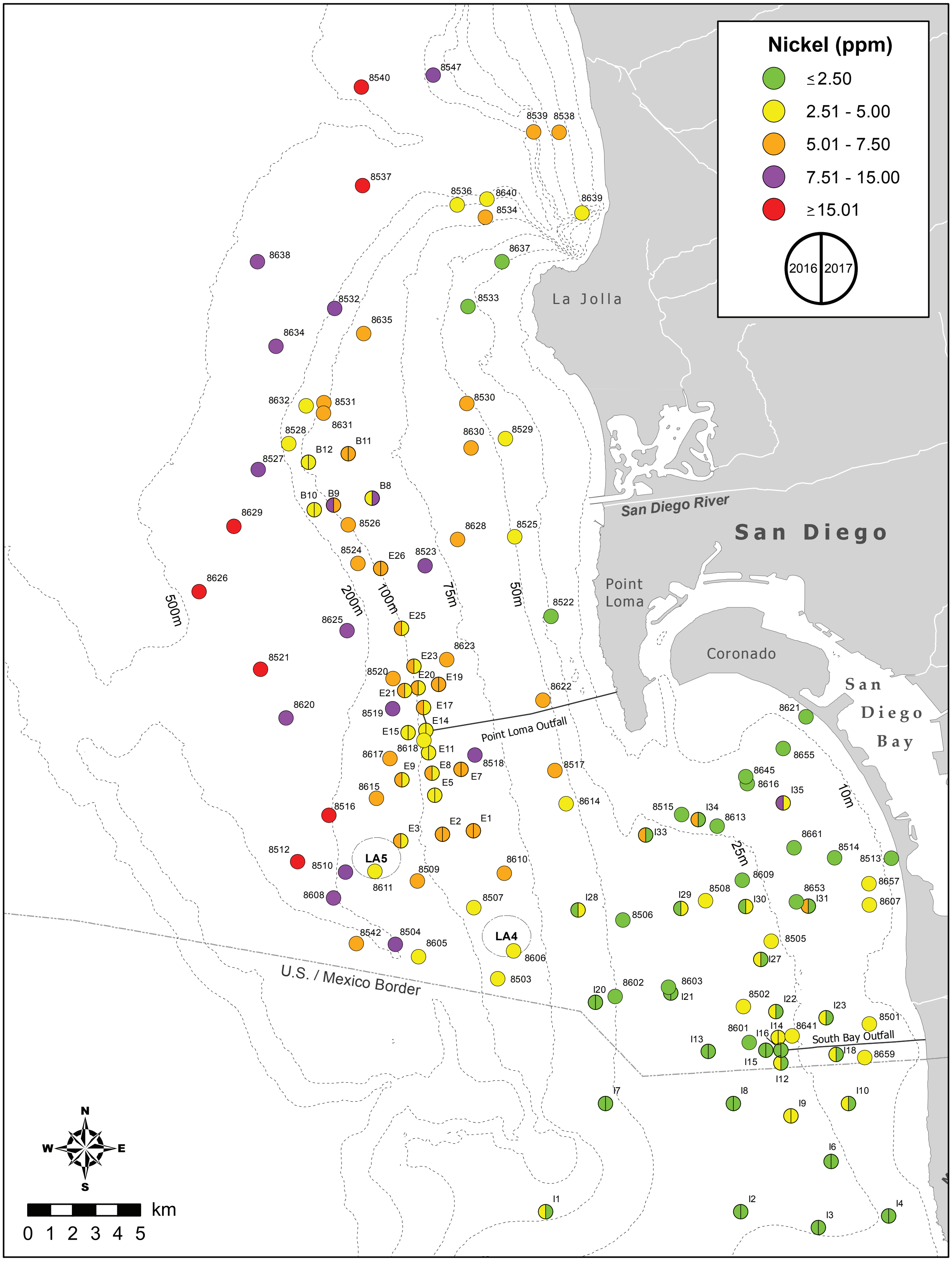

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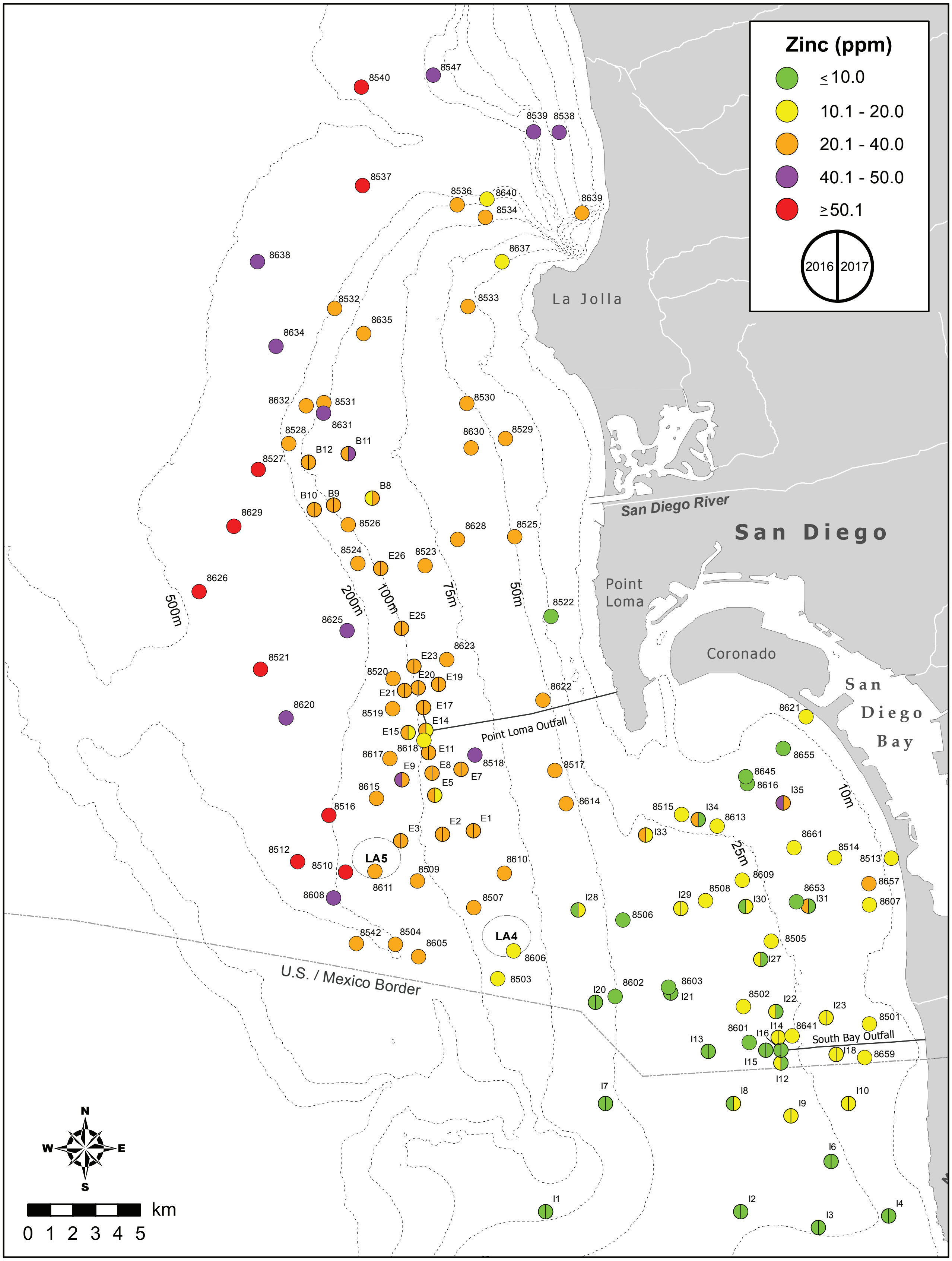

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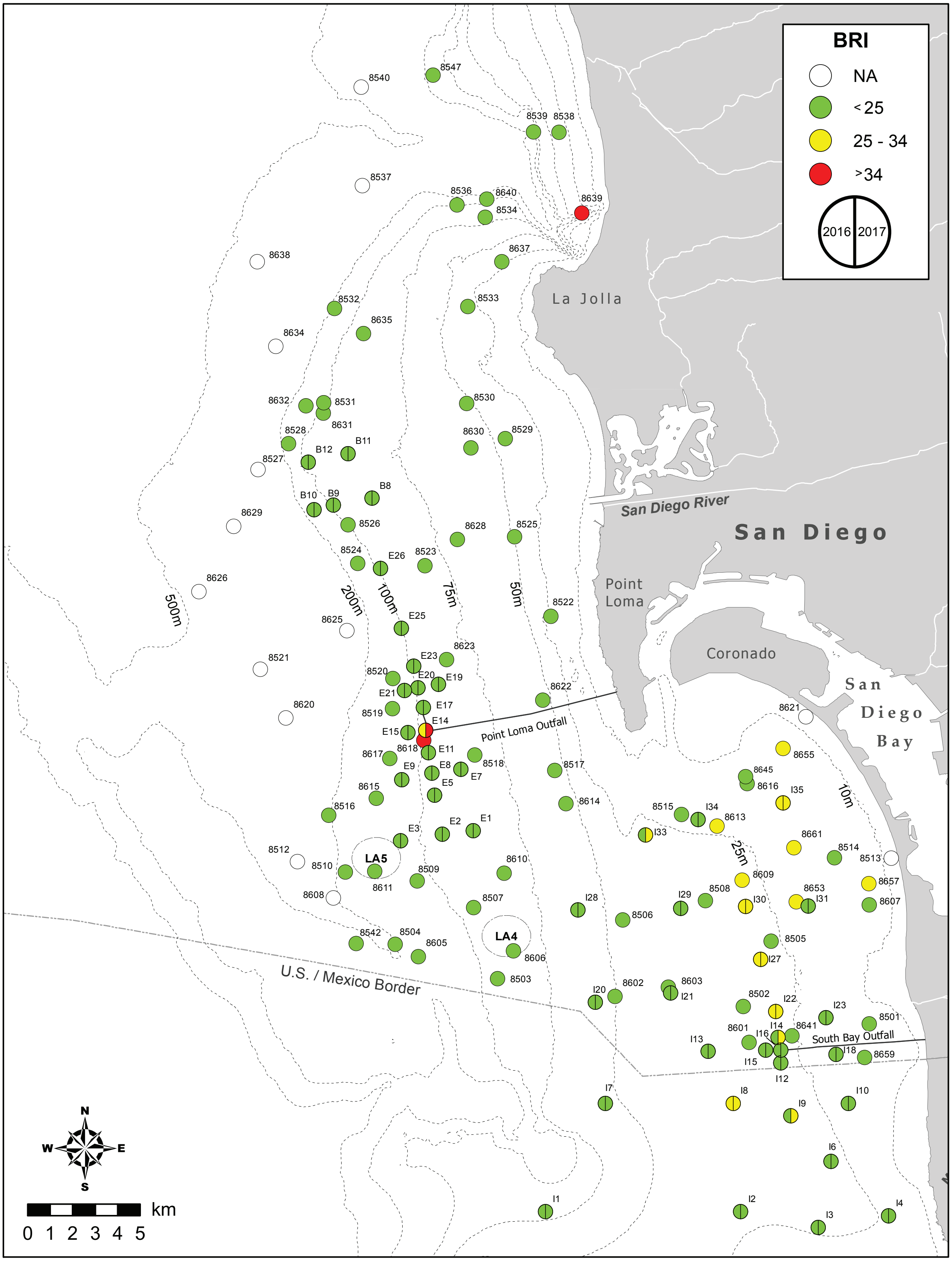
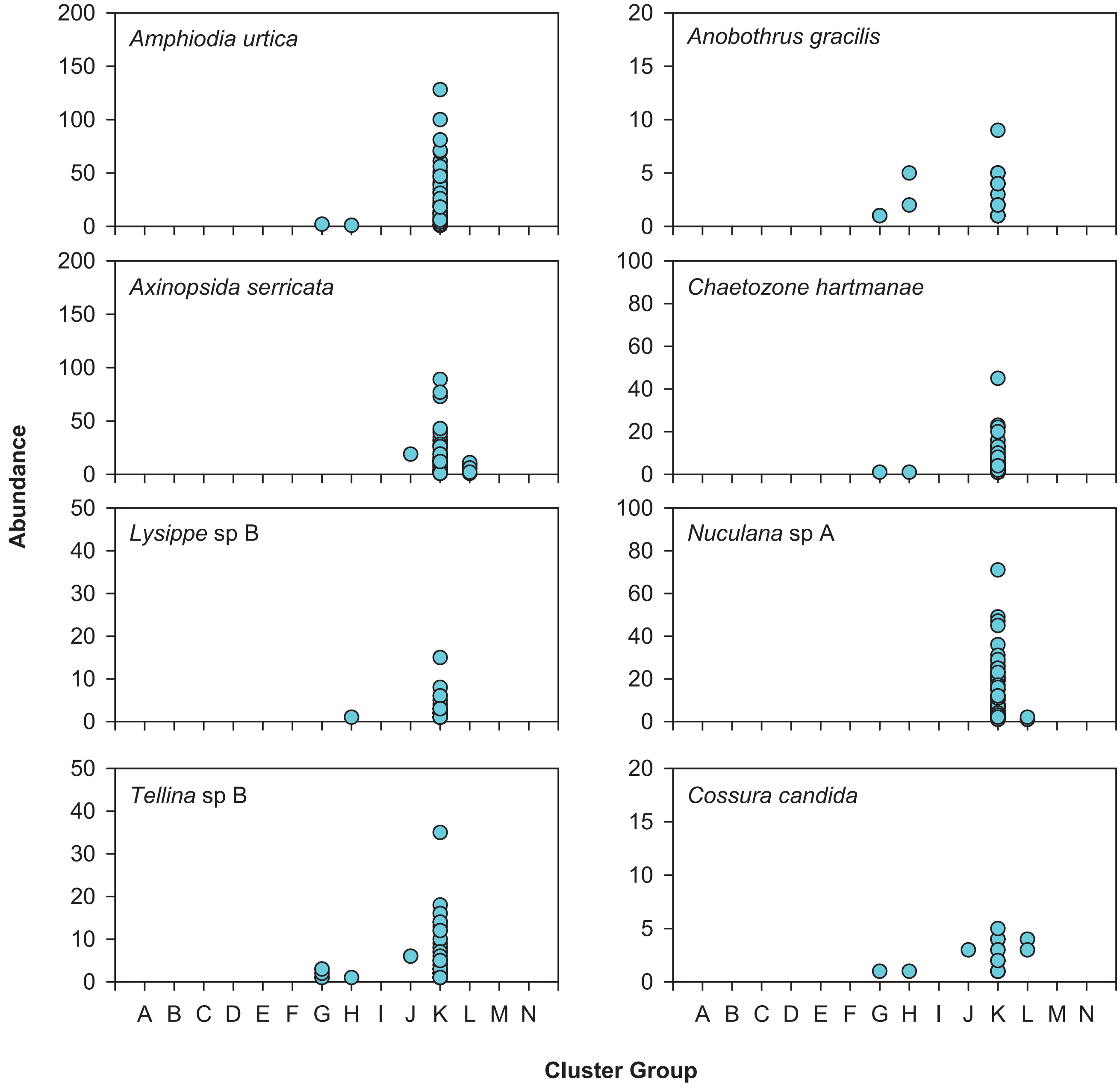


Appendix F.5

Distribution of BRI values from San Diego regional and core benthic stations sampled during the summers of 2016 and 2017; NA = not applicable.



Appendix F.6

The eight species accounting for 82% of the variability in cluster analysis results according to the BEST BVSTEP test (see Figure 6.8).

Appendix F.7

Mean abundance of the characteristic species found in each macrofauna cluster group A–N (defined in Figure 6.8). Highlighted values indicate the top five most characteristic species according to SIMPER analysis.

	Cluster Group													
Taxa	**A**	**B**	**C**	**D** [a]	**E**	**F** [a]	**G**	**H**	**I**	**J** [a]	**K**	**L**	**M**	**N**
Dendraster excentricus	18	0	0	0	0	0	4	0	0	0	0	0	0	0
Rhepoxynius menziesi	15	0	0	0	1	0	1	0	0	0	0	0	0	0
Apoprionospio pygmaea	9	0	0	0	0	0	2	0	0	0	0	0	0	0
Tellina bodegensis	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Gibberosus myersi	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Pisione sp	0	41	0	0	0	0	0	0	0	0	0	0	0	0
Pareurythoe californica	0	26	0	0	0	0	0	0	0	0	0	0	0	0
Protodorvillea gracilis	0	21	0	2	4	0	0	0	1	0	0	0	0	0
NEMATODA	0	7	1	0	1	0	1	1	0	0	0	0	0	0
Apionsoma misakianum	0	10	0	0	1	0	0	0	3	0	0	0	0	0
Micranellum crebricinctum	0	2	33	0	1	0	0	0	0	0	0	0	0	0
Halistylus pupoideus	0	0	31	0	0	0	0	0	0	0	0	0	0	0
Eurydice caudata	0	1	2	2	1	4	0	1	1	0	0	0	0	0
Branchiostoma californiense	0	4	1	0	0	0	0	0	0	0	0	0	0	0
Ophiuroconis bispinosa	0	0	0	22	0	2	0	0	0	0	0	0	0	0
Spiophanes norrisi	1	12	1	9	86	0	74	4	3	0	0	0	0	0
Lumbrinerides platypygos	0	2	0	8	7	0	0	1	2	0	0	0	0	0
Diopatra ornata	0	0	0	3	0	0	1	0	0	0	0	0	0	0
Polyschides quadrifissatus	0	0	0	3	0	0	0	0	2	0	1	0	0	0
Simomactra falcata	0	0	3	0	19	3	0	0	1	0	0	0	0	0
Ampharete labrops	0	4	0	0	9	7	10	3	1	0	0	0	0	0
Dendraster terminalis	0	1	2	0	7	1	0	0	0	0	0	0	0	0
Spiophanes duplex	0	1	0	0	1	60	19	17	2	0	23	0	0	0
Pista wui	0	0	0	0	1	12	17	0	0	0	0	0	0	0
Onuphis sp A	0	0	0	0	0	4	2	2	0	0	0	1	0	0
Balanoglossus sp	0	0	0	0	0	4	0	0	0	0	0	0	0	0

[a] SIMPER analyses not conducted on cluster groups that contain only one grab. For these groups, shading indicates five most abundant taxa.

Appendix F.7 *continued*

	Cluster Group													
Taxa	**A**	**B**	**C**	**D[a]**	**E**	**F[a]**	**G**	**H**	**I**	**J[a]**	**K**	**L**	**M**	**N**
Mediomastus sp	0	1	0	0	0	0	11	3	0	6	4	4	0	0
Euclymeninae	0	0	0	0	0	0	1	5	0	0	3	2	0	0
Prionospio (Prionospio) jubata	0	0	0	0	0	0	1	5	0	1	5	0	0	0
Sthenelanella uniformis	0	0	0	0	0	0	1	2	0	0	2	0	0	0
Eusyllis sp SD2	0	0	0	0	0	2	0	0	3	0	0	0	0	0
Foxiphalus obtusidens	0	1	1	1	1	0	1	2	3	0	0	0	0	0
Polycirrus sp A	0	0	0	0	5	0	0	1	2	0	1	0	0	0
Thysanocardia nigra	0	1	0	0	0	0	0	0	3	0	0	0	0	0
Axinopsida serricata	0	0	0	0	0	0	0	0	0	19	14	5	0	0
Macoma carlottensis	0	0	0	0	0	0	0	1	0	11	1	1	0	0
Tellina sp B	0	0	0	0	0	0	0	0	0	6	3	0	0	0
Nephtys caecoides	0	0	0	0	0	0	1	2	0	4	0	0	0	0
Amphiodia urtica	0	0	0	0	0	0	0	0	0	0	20	0	0	0
Nuculana sp A	0	0	0	0	0	0	0	0	0	0	13	1	0	0
Eclysippe trilobata	0	0	0	0	0	0	0	0	0	1	11	0	2	1
Tellina carpenteri	0	0	0	0	0	0	0	3	0	0	9	4	0	0
Thyasira flexuosa	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Paraprionospio alata	0	1	0	0	0	0	3	0	0	2	1	2	1	1
Maldane sarsi	0	0	0	0	0	0	0	0	0	0	1	0	6	3
Aphelochaeta monilaris	1	0	0	0	0	0	1	0	0	0	1	1	2	0
Nuculana conceptionis	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Cadulus californicus	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Leitoscoloplos sp A	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Fauveliopsis glabra	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Leucon declivis	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***2***
Yoldiella nana	0	0	0	0	0	0	0	0	0	0	0	0	0	1

[a] SIMPER analyses not conducted on cluster groups that contain only one grab. For these groups shading indicates five most abundant taxa.

Appendix F.8

Particle size summary for each macrofauna cluster group A–N (defined in Figure 6.8). Data are presented as means (ranges) calculated over all stations within a cluster group. VF = very fine; Med = medium; VC = very coarse.

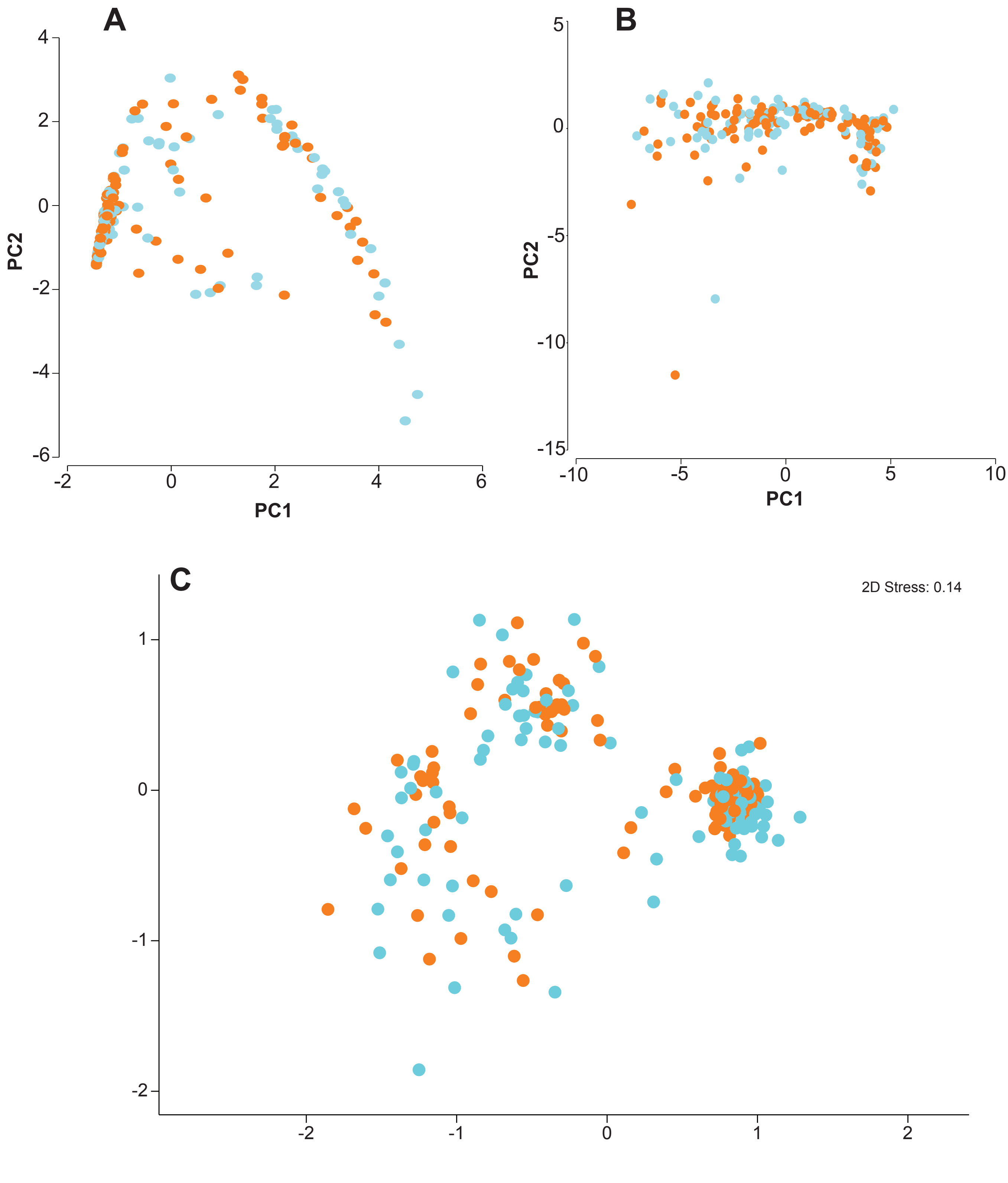
Macrofauna	Sediments (%)						
Cluster Group	Fines	VF Sand	Fine Sand	Med Sand	Coarse Sand	VC Sand	Granules
A	3.4 (2.4-4.5)	13.2 (9.9-16.5)	57.8 (55-60.6)	23.4 (17.3-29.5)	2.1 (1.1-3.1)	0 (0-0)	0 (0-0)
B	2.4 (1.6-3.3)	2.0 (0.3-3.6)	4.4 (2.3-6.6)	27.5 (25.9-29.2)	30.3 (30.0-30.6)	18.0 (17.7-18.3)	15.4 (13.4-17.3)
C	1.1 (0-2.1)	0.3 (0.2-0.4)	2.7 (1.6-3.8)	31.5 (21.6-41.4)	51.3 (49.9-52.7)	9.8 (4.5-15.0)	3.5 (0-7.0)
D	2.2	1.3	15.2	44.8	25.6	10.5	0
E	2.0 (0-4.7)	3.5 (0-15.0)	24.9 (2.9-70.1)	49.7 (13.9-67.1)	18.5 (0.9-53.1)	1.3 (0-8.5)	0.1 (0-0.8)
F	1.9	1.0	3.4	31.7	55.4	6.6	0
G	16.4 (2.9-41.6)	56.0 (25.1-73.4)	24.2 (13.4-61.9)	3.3 (0.2-21.7)	0.1 (0-1.9)	0 (0-0)	0 (0-0)
H	11.8 (2.6-28.4)	29.8 (2.0-47.8)	32.3 (8.1-51)	16.5 (3.1-49.4)	8.8 (0-35.0)	0.7 (0-2.8)	0 (0-0)
I	2.3 (0-5.2)	1.1 (0.1-2.9)	6.4 (2.7-18.4)	29.3 (15.8-58.5)	52.7 (17.1-72.4)	8.1 (0.5-15.6)	0.1 (0-0.3)
J	24.9	30.0	38.8	6.3	0	0	0
K	38.6 (14.5-65.6)	38.7 (13.3-66.1)	14.2 (1.3-40.9)	4.2 (0.1-25.9)	2.8 (0-27.3)	1.1 (0-13.7)	0.4 (0-8.3)
L	68.0 (60.6-75.8)	24.1 (18.5-31.3)	7.4 (5.4-9.2)	0.5 (0.1-1.4)	0 (0-0)	0 (0-0)	0 (0-0)
M	69.5 (61.1-80.2)	24.7 (16.4-31.2)	5.7 (3.3-8.2)	0.1 (0.1-0.2)	0 (0-0)	0 (0-0)	0 (0-0)
N	80.9 (74.5-87.3)	14.6 (9.7-19.6)	4.3 (2.9-5.8)	0.1 (0.1-0.1)	0 (0-0)	0 (0-0)	0 (0-0)

Appendix F

San Diego Regional Benthic Condition Assessment

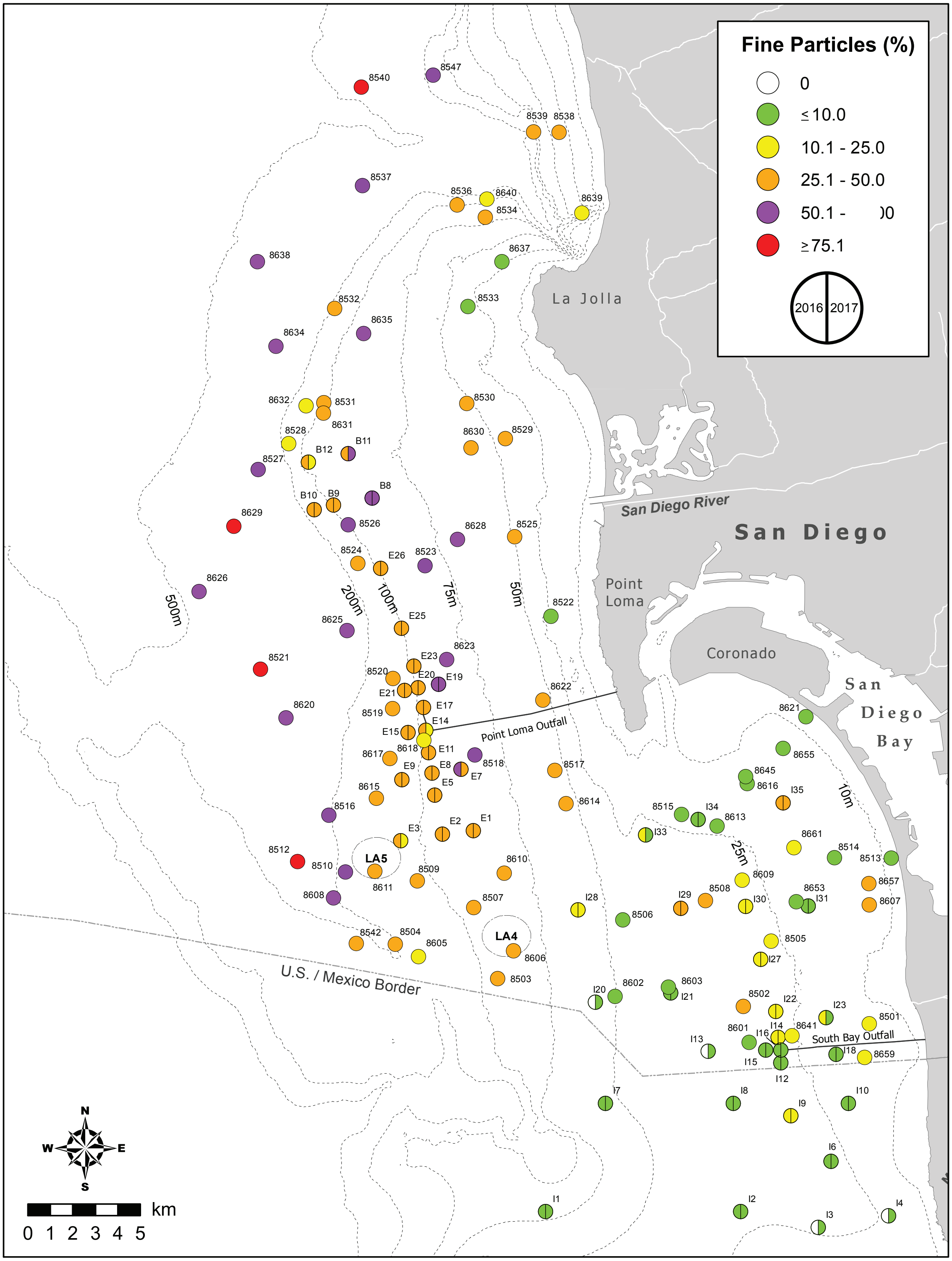
2016 – 2017 Supplemental Analyses

Core and San Diego Regional Stations



Appendix F.1

Ordination analyses of (A) particle size sub-fraction, (B) sediment chemistry, and (C) macrofaunal data from PLOO and SBOO core benthic stations sampled during the winters (turquoise) and summers (orange) of 2016 and 2017. Particle size and sediment chemistry data were analyzed using Principal Components (PC) ordination, while macrofaunal data were analyzed using non-metric multi-dimensional scaling ordination.



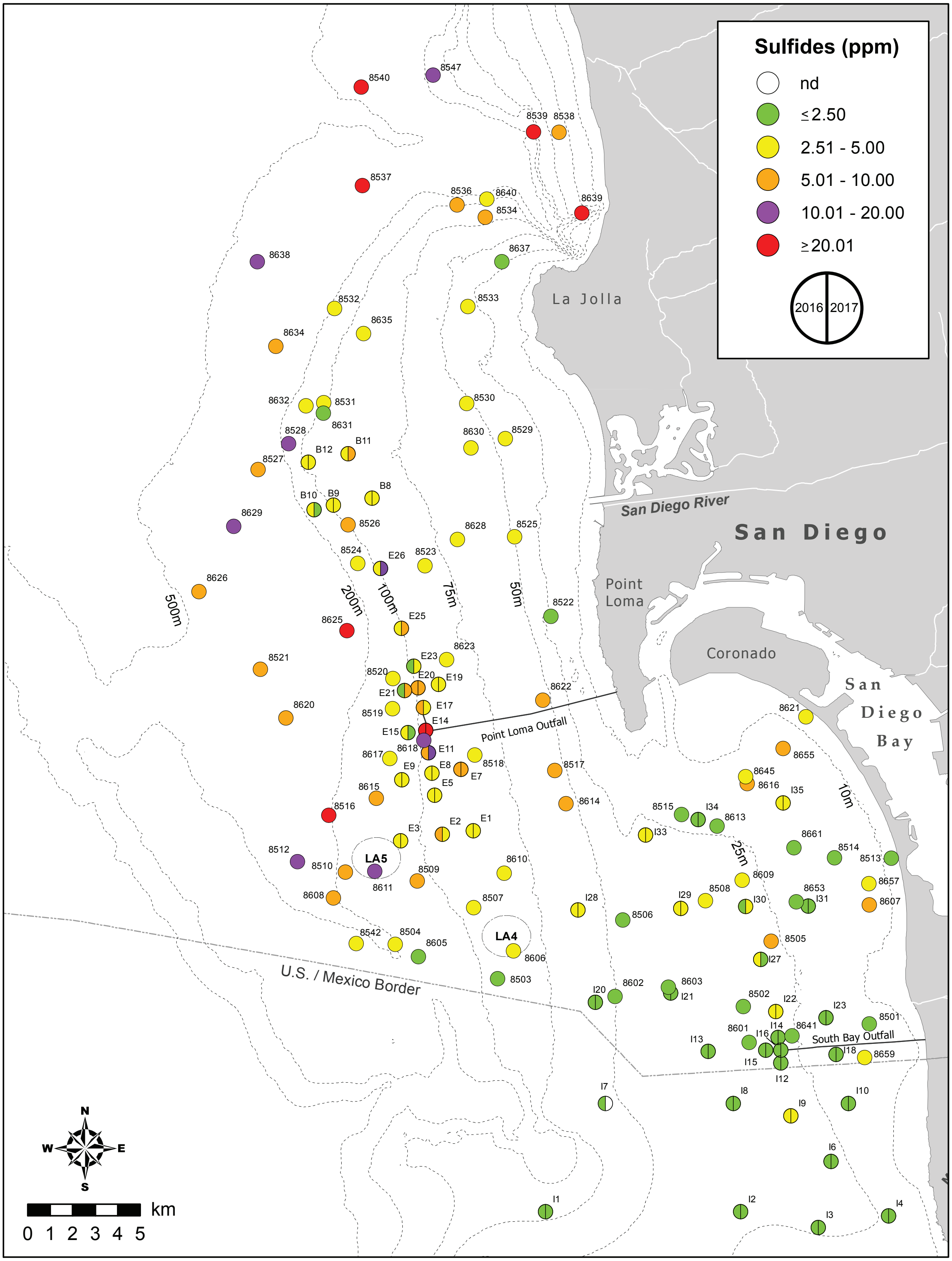
Appendix F.2

Distribution of fine particles in sediments from San Diego regional and core benthic stations sampled during the summers of 2016 and 2017.

Appendix F.3

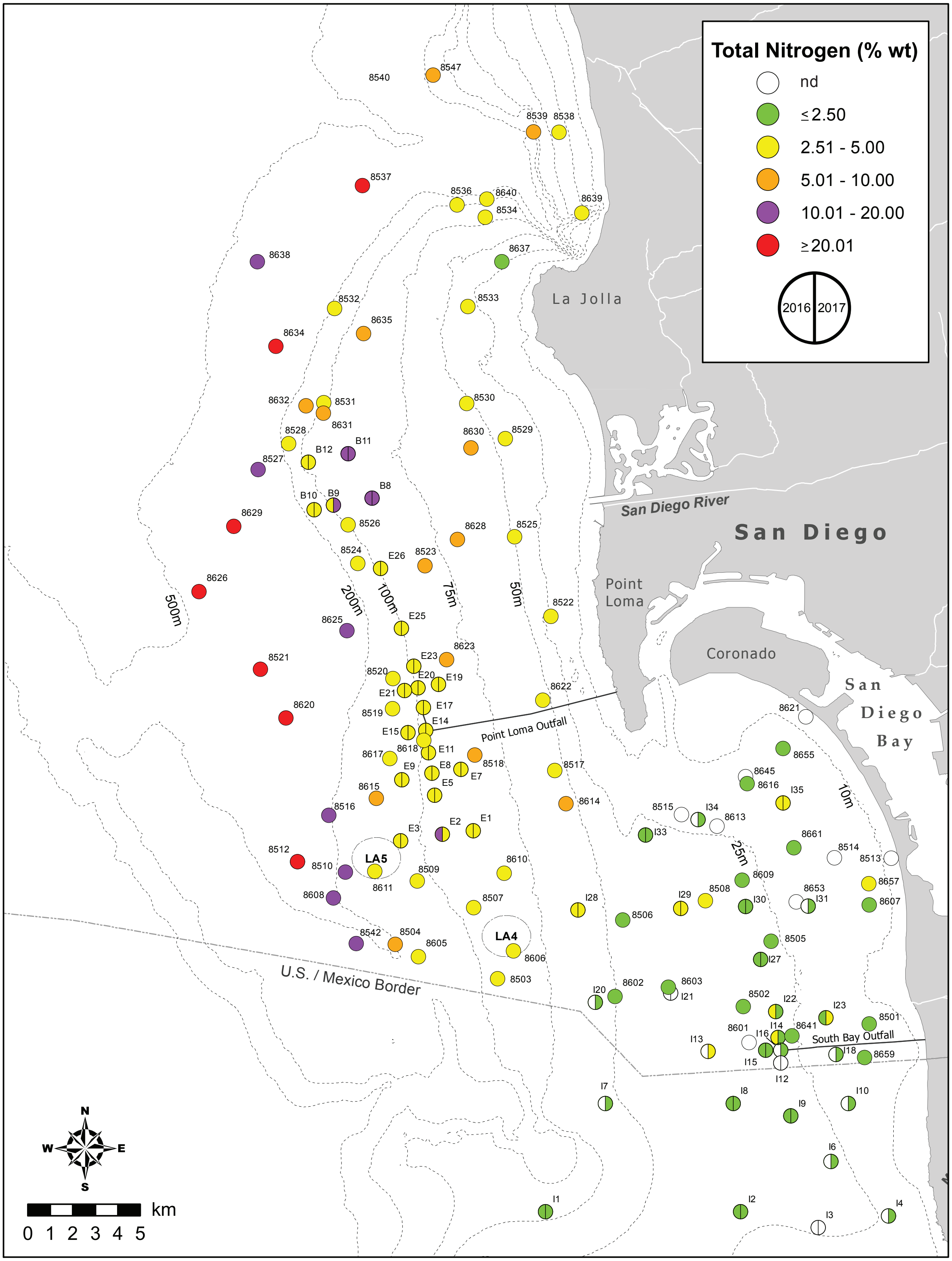
Results of Spearman rank correlation analyses of various sediment parameters from San Diego regional and core benthic stations sampled during the summer surveys of 2016 and 2017. Data include the correlation coefficient (r_s) for all parameters with detection rates ≥50% (see Table 6.1). Correlation coefficients $r_s \geq 0.70$ are highlighted.

	Fines	Sulfides	TN	TOC	TVS	Al	Sb	As	Ba	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Ag	Sn
Sulfides	0.23																	
TN	0.84	0.28																
TOC	0.51	0.17	0.72															
TVS	0.85	0.26	0.96	0.72														
Al	0.88	0.31	0.86	0.57	0.88													
Sb	0.77	0.27	0.77	0.72	0.81	0.85												
As	-0.13	-0.05	0.01	0.14	0.02	-0.12	0.03											
Ba	0.80	0.35	0.83	0.58	0.83	0.95	0.79	-0.12										
Cr	0.85	0.30	0.87	0.64	0.91	0.93	0.86	0.02	0.88									
Cu	0.81	0.32	0.85	0.53	0.85	0.89	0.75	-0.09	0.86	0.90								
Fe	0.77	0.26	0.78	0.67	0.83	0.87	0.91	0.16	0.81	0.91	0.75							
Pb	0.22	0.03	0.18	0.18	0.18	0.24	0.25	0.03	0.24	0.23	0.20	0.25						
Mn	0.83	0.35	0.74	0.46	0.75	0.95	0.78	-0.16	0.94	0.86	0.81	0.82	0.23					
Hg	0.72	0.25	0.72	0.48	0.74	0.76	0.65	-0.07	0.69	0.74	0.82	0.66	0.22	0.66				
Ni	0.88	0.28	0.93	0.62	0.94	0.96	0.83	-0.06	0.91	0.93	0.90	0.84	0.21	0.86	0.76			
Ag	0.03	0.01	0.04	0.21	0.06	0.00	0.09	0.01	0.01	0.02	-0.02	0.05	0.06	-0.03	-0.01	0.02		
Sn	0.08	0.01	0.16	0.52	0.17	0.10	0.38	0.03	0.15	0.14	0.07	0.21	0.17	0.03	0.06	0.11	0.47	
Zn	0.85	0.32	0.85	0.64	0.88	0.96	0.90	-0.02	0.92	0.94	0.87	0.94	0.24	0.92	0.74	0.92	0.01	0.13

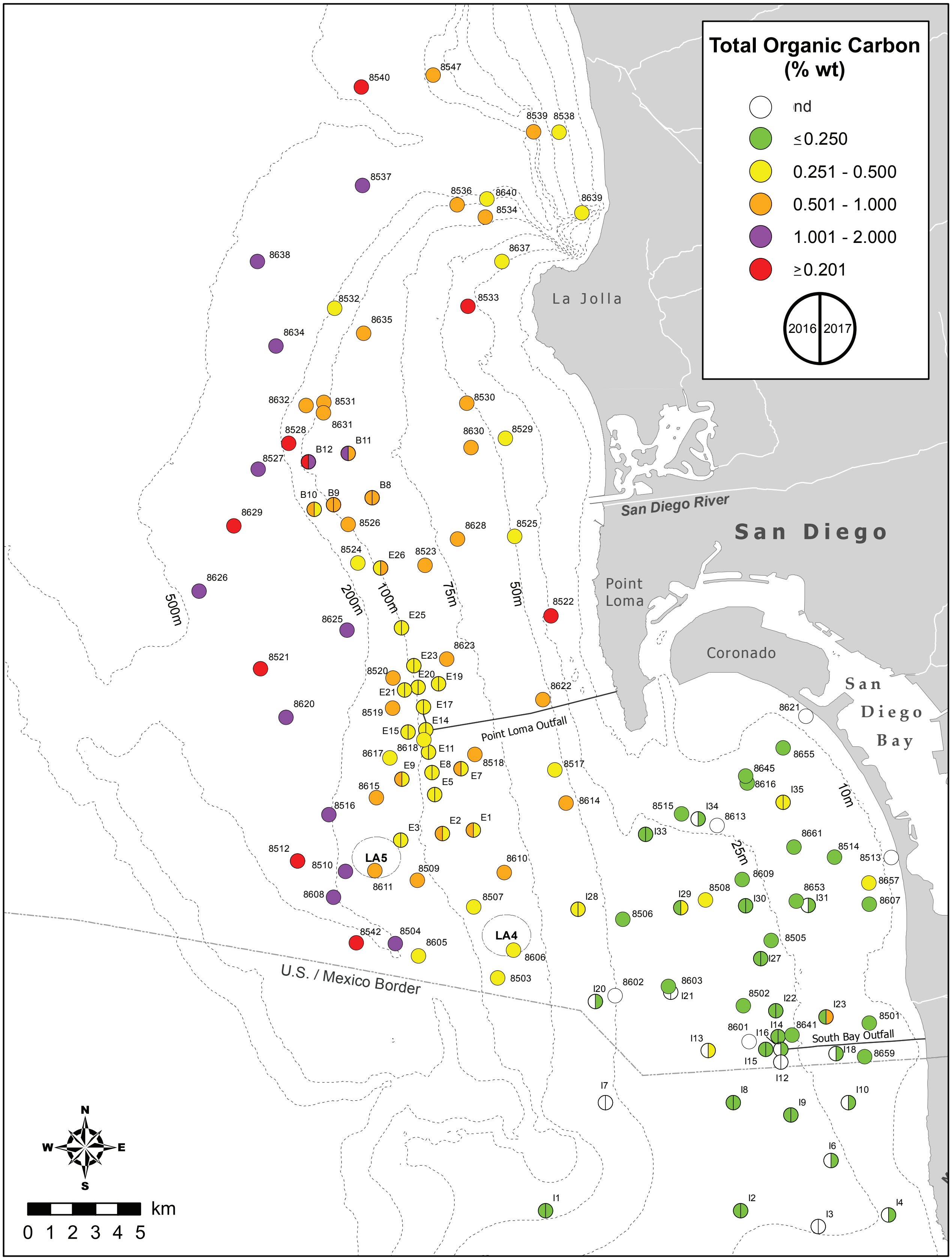


Appendix F.4

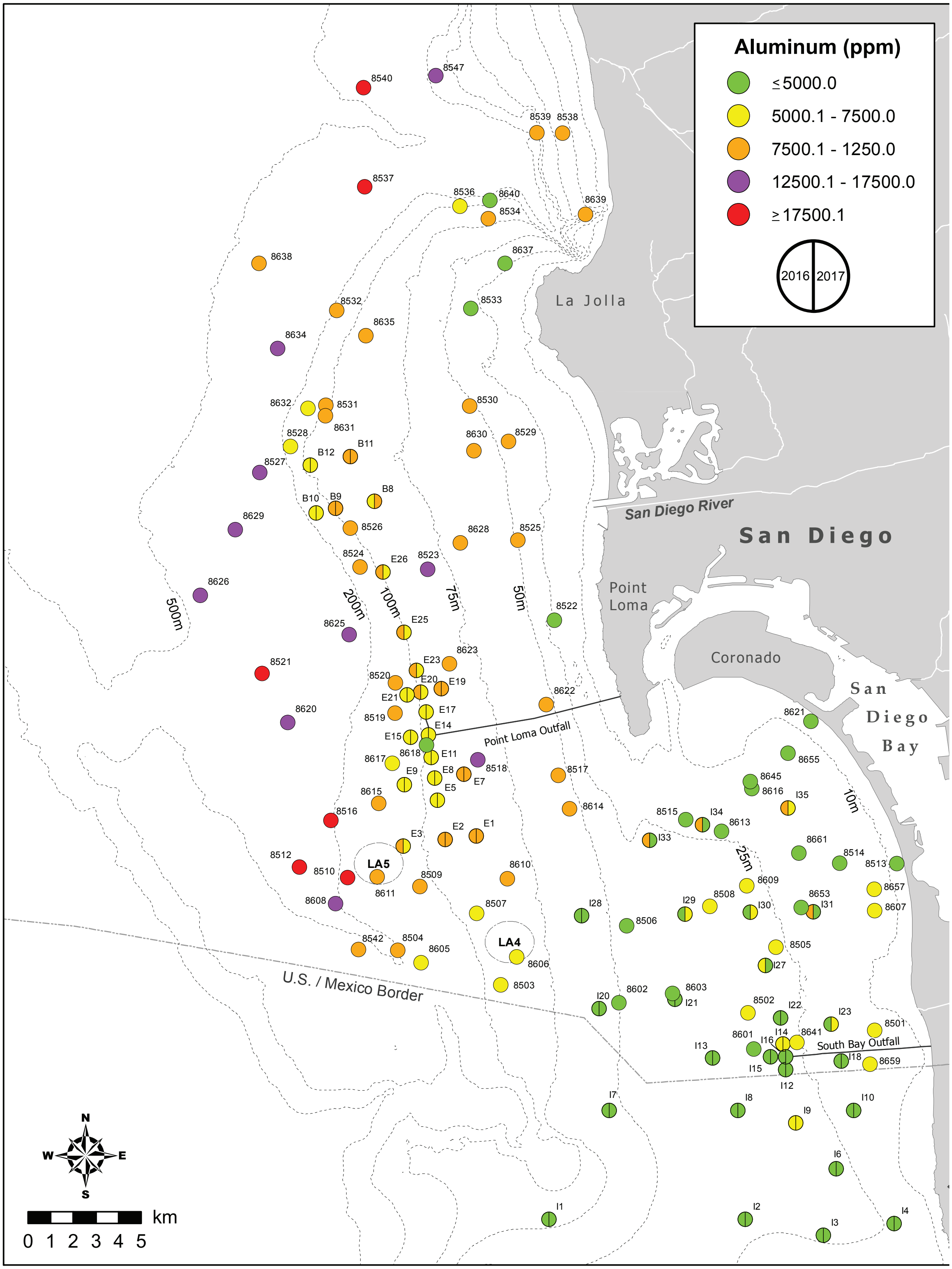
Distribution of select parameters in sediments from San Diego regional and core benthic stations sampled during the summers of 2016 and 2017; nd = not detected.



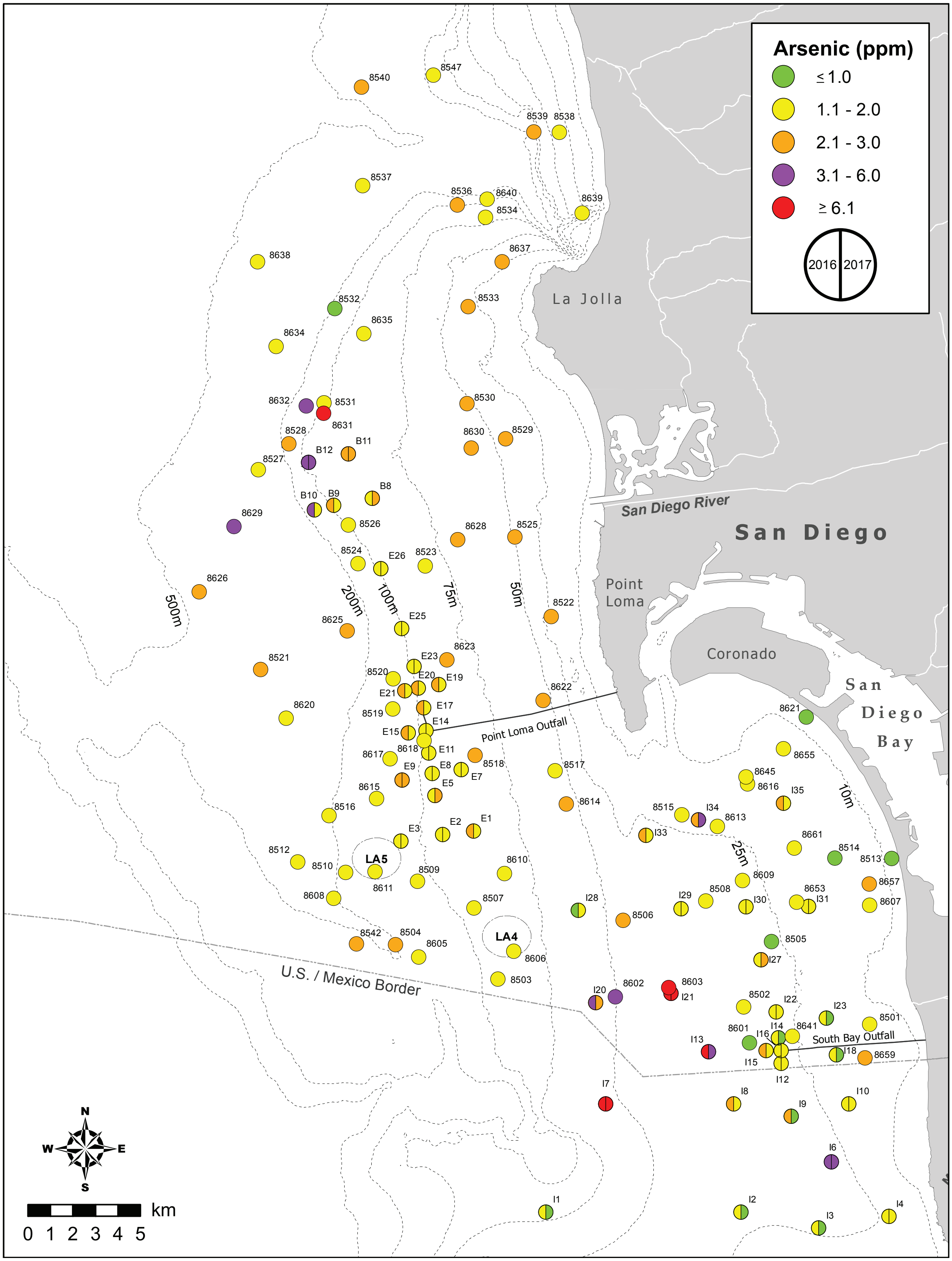
Appendix F.4 *continued*



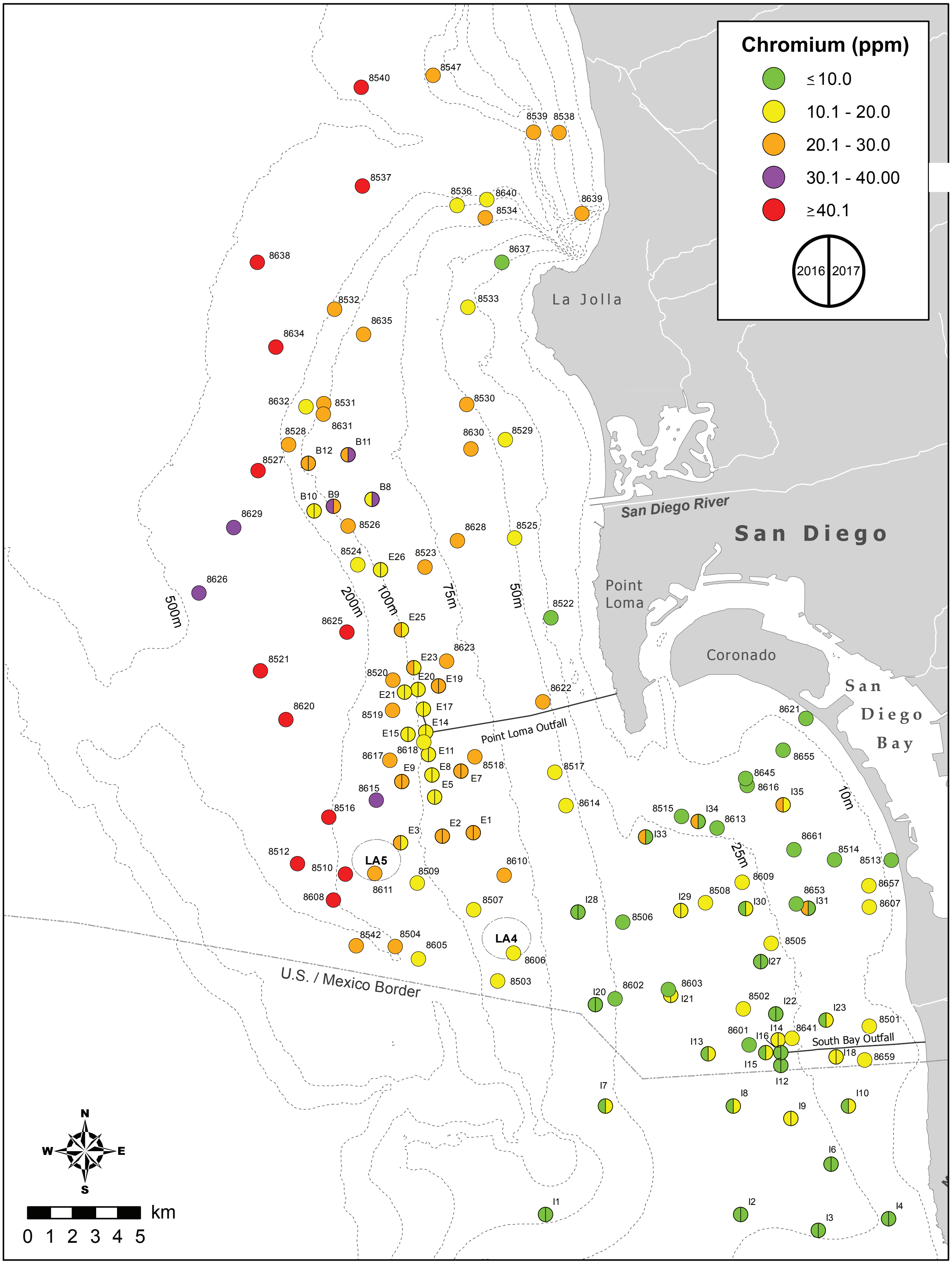
Appendix F.4 *continued*



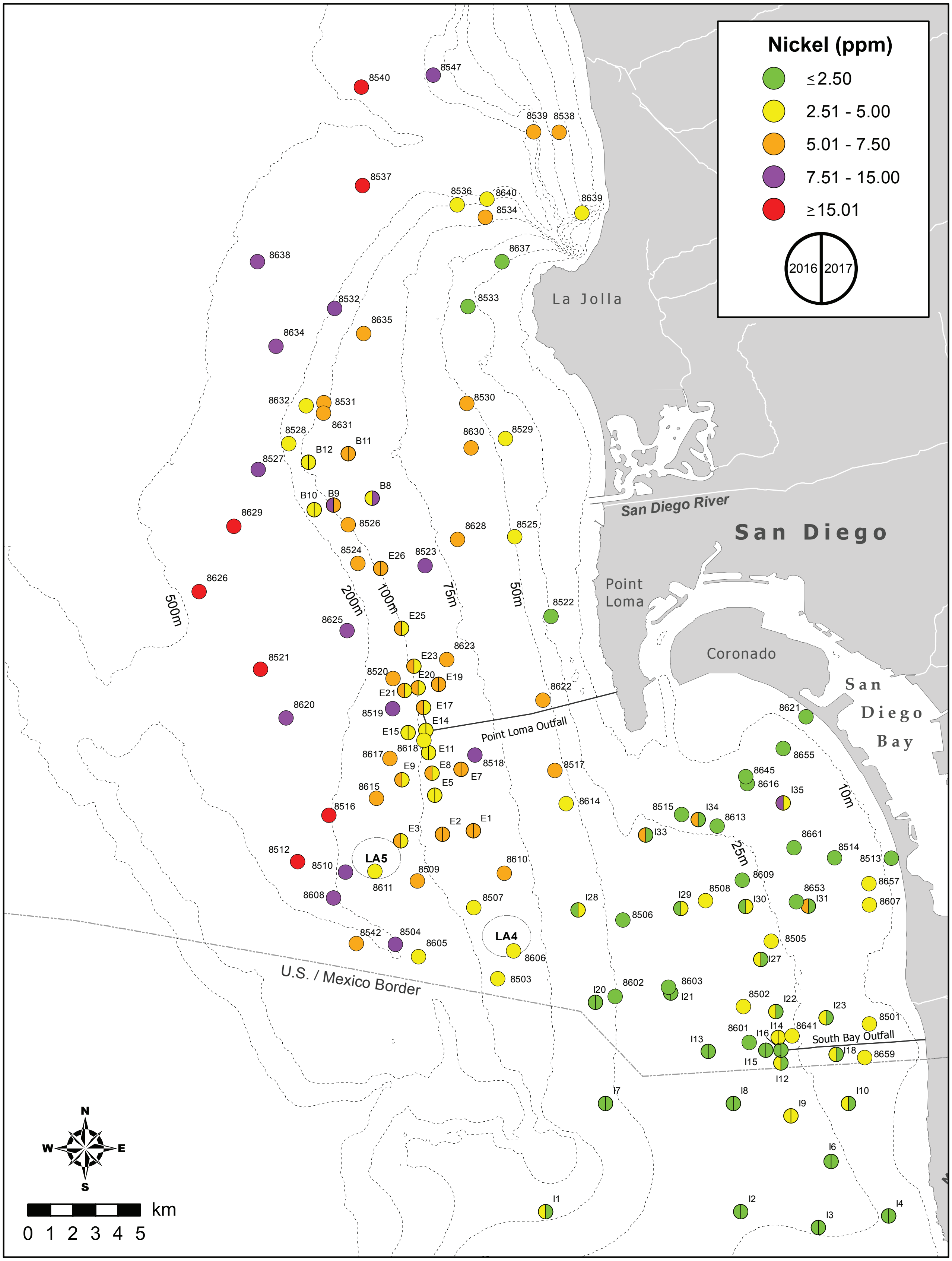
Appendix F.4 *continued*



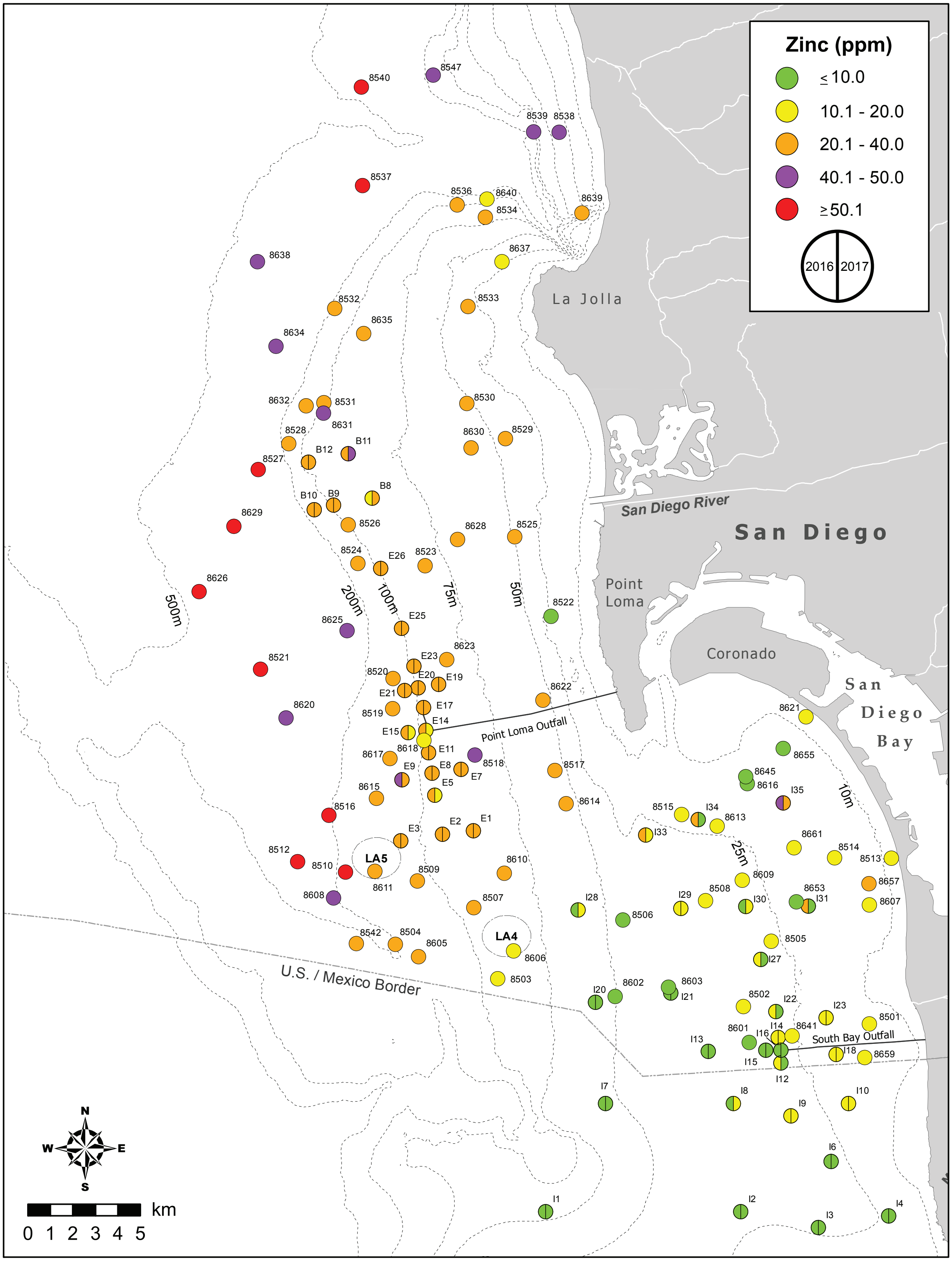
Appendix F.4 *continued*



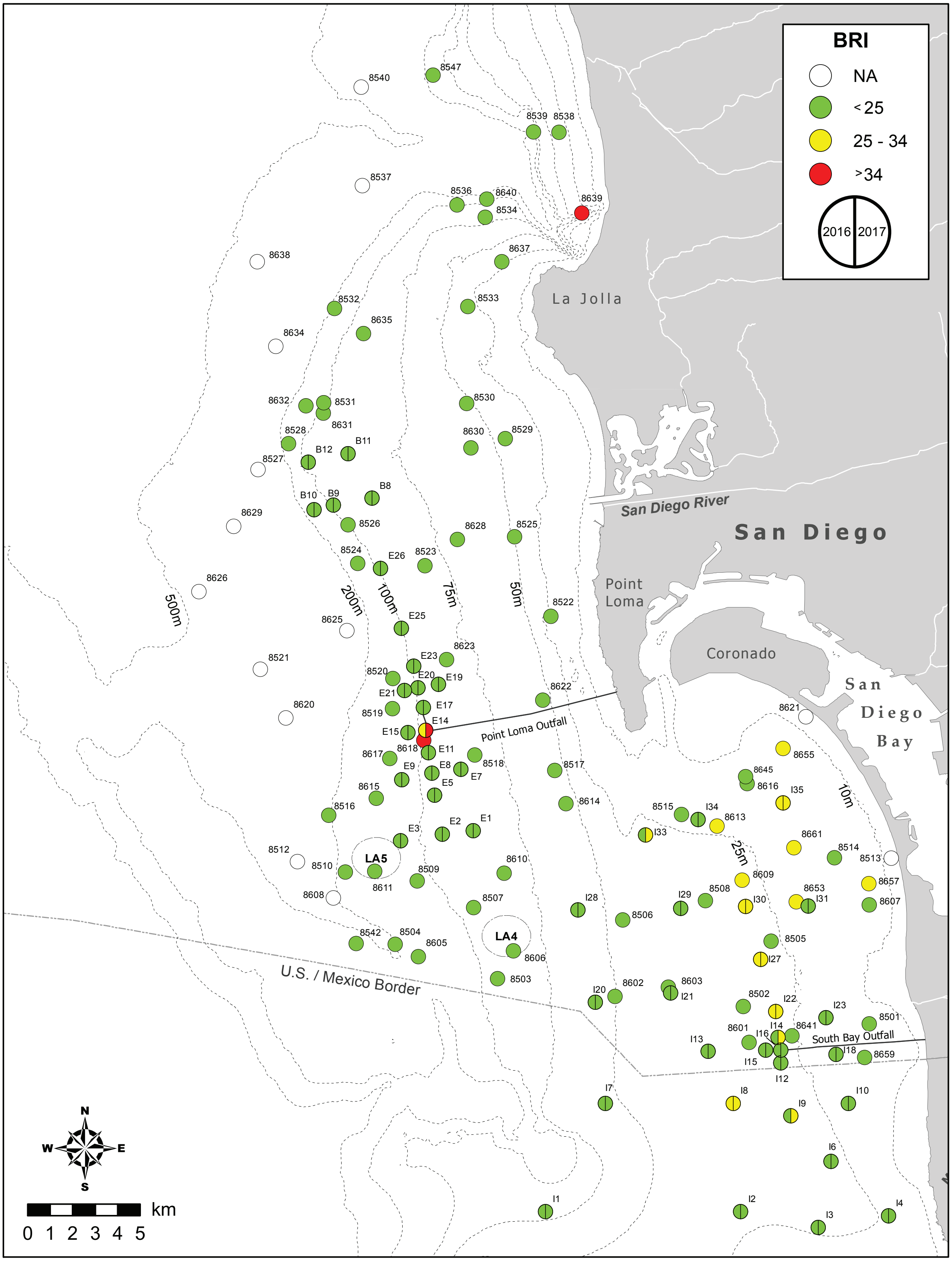
Appendix F.4 *continued*



Appendix F.4 *continued*

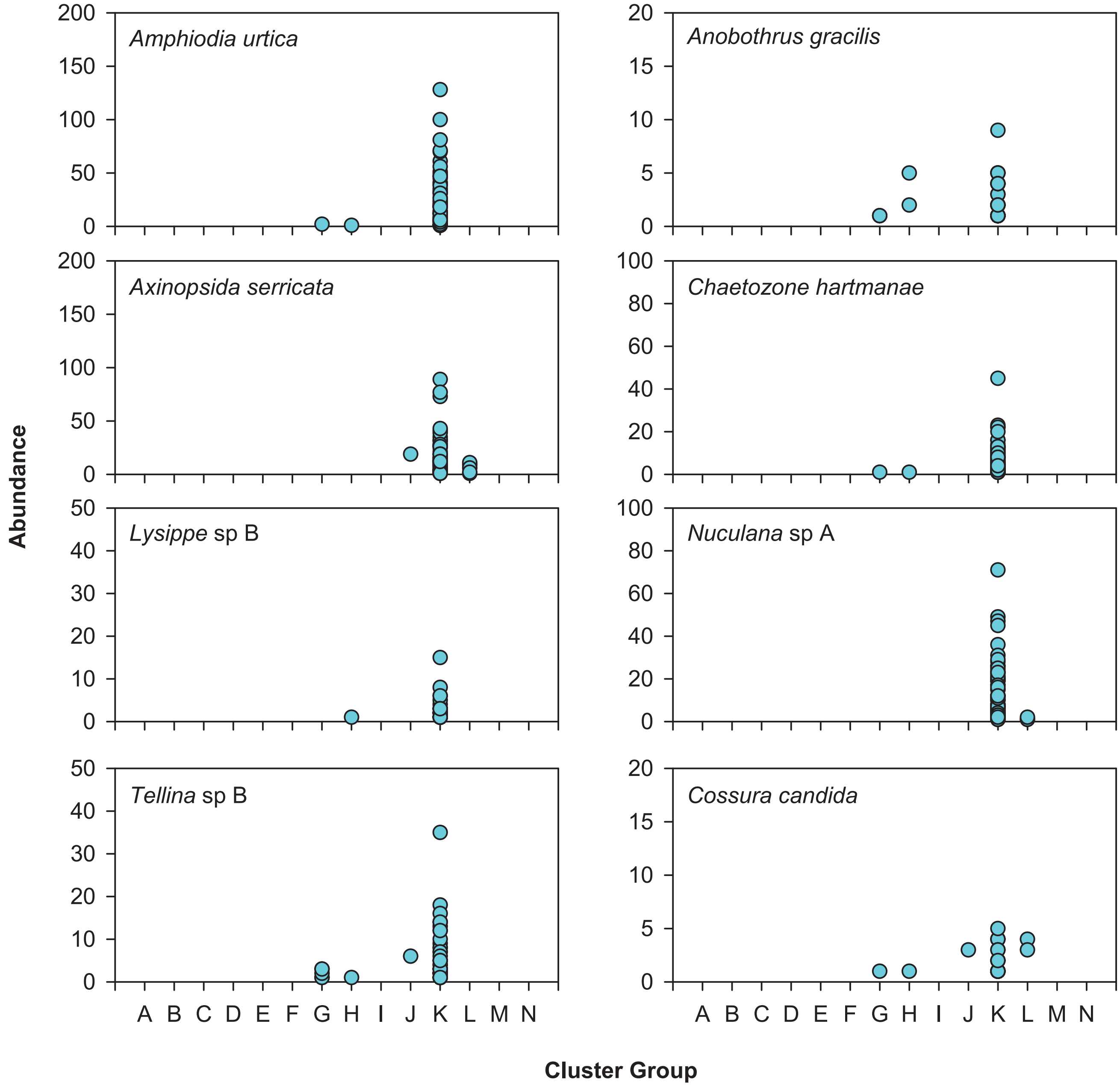


Appendix F.4 *continued*



Appendix F.5

Distribution of BRI values from San Diego regional and core benthic stations sampled during the summers of 2016 and 2017; NA = not applicable.



Appendix F.6

The eight species accounting for 82% of the variability in cluster analysis results according to the BEST BVSTEP test (see Figure 6.8).

Appendix F.7

Mean abundance of the characteristic species found in each macrofauna cluster group A–N (defined in Figure 6.8). Highlighted values indicate the top five most characteristic species according to SIMPER analysis.

	Cluster Group													
Taxa	A	B	C	D [a]	E	F [a]	G	H	I	J [a]	K	L	M	N
Dendraster excentricus	18	0	0	0	0	0	4	0	0	0	0	0	0	0
Rhepoxynius menziesi	15	0	0	0	1	0	1	0	0	0	0	0	0	0
Apoprionospio pygmaea	9	0	0	0	0	0	2	0	0	0	0	0	0	0
Tellina bodegensis	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Gibberosus myersi	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Pisione sp	0	41	0	0	0	0	0	0	0	0	0	0	0	0
Pareurythoe californica	0	26	0	0	0	0	0	0	0	0	0	0	0	0
Protodorvillea gracilis	0	21	0	2	4	0	0	0	1	0	0	0	0	0
NEMATODA	0	7	1	0	1	0	1	1	0	0	0	0	0	0
Apionsoma misakianum	0	10	0	0	1	0	0	0	3	0	0	0	0	0
Micranellum crebricinctum	0	2	33	0	1	0	0	0	0	0	0	0	0	0
Halistylus pupoideus	0	0	31	0	0	0	0	0	0	0	0	0	0	0
Eurydice caudata	0	1	2	2	1	4	0	1	1	0	0	0	0	0
Branchiostoma californiense	0	4	1	0	0	0	0	0	0	0	0	0	0	0
Ophiuroconis bispinosa	0	0	0	22	0	2	0	0	0	0	0	0	0	0
Spiophanes norrisi	1	12	1	9	86	0	74	4	3	0	0	0	0	0
Lumbrinerides platypygos	0	2	0	8	7	0	0	1	2	0	0	0	0	0
Diopatra ornata	0	0	0	3	0	0	1	0	0	0	0	0	0	0
Polyschides quadrifissatus	0	0	0	3	0	0	0	0	2	0	1	0	0	0
Simomactra falcata	0	0	3	0	19	3	0	0	1	0	0	0	0	0
Ampharete labrops	0	4	0	0	9	7	10	3	1	0	0	0	0	0
Dendraster terminalis	0	1	2	0	7	1	0	0	0	0	0	0	0	0
Spiophanes duplex	0	1	0	0	1	60	19	17	2	0	23	0	0	0
Pista wui	0	0	0	0	1	12	17	0	0	0	0	0	0	0
Onuphis sp A	0	0	0	0	0	4	2	2	0	0	0	1	0	0
Balanoglossus sp	0	0	0	0	0	4	0	0	0	0	0	0	0	0

[a] SIMPER analyses not conducted on cluster groups that contain only one grab. For these groups, shading indicates five most abundant taxa.

Appendix F.7 *continued*

Taxa	Cluster Group													
	A	B	C	D [a]	E	F [a]	G	H	I	J [a]	K	L	M	N
Mediomastus sp	0	1	0	0	0	0	11	3	0	6	4	4	0	0
Euclymeninae	0	0	0	0	0	0	1	5	0	0	3	2	0	0
Prionospio (Prionospio) jubata	0	0	0	0	0	0	1	5	0	1	5	0	0	0
Sthenelanella uniformis	0	0	0	0	0	0	1	2	0	0	2	0	0	0
Eusyllis sp SD2	0	0	0	0	0	2	0	0	3	0	0	0	0	0
Foxiphalus obtusidens	0	1	1	1	1	0	1	2	3	0	0	0	0	0
Polycirrus sp A	0	0	0	0	5	0	0	1	2	0	1	0	0	0
Thysanocardia nigra	0	1	0	0	0	0	0	0	3	0	0	0	0	0
Axinopsida serricata	0	0	0	0	0	0	0	0	0	19	14	5	0	0
Macoma carlottensis	0	0	0	0	0	0	0	1	0	11	1	1	0	0
Tellina sp B	0	0	0	0	0	0	0	0	0	6	3	0	0	0
Nephtys caecoides	0	0	0	0	0	0	1	2	0	4	0	0	0	0
Amphiodia urtica	0	0	0	0	0	0	0	0	0	0	20	0	0	0
Nuculana sp A	0	0	0	0	0	0	0	0	0	0	13	1	0	0
Eclysippe trilobata	0	0	0	0	0	0	0	0	0	1	11	0	2	1
Tellina carpenteri	0	0	0	0	0	0	0	3	0	0	9	4	0	0
Thyasira flexuosa	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Paraprionospio alata	0	1	0	0	0	0	3	0	0	2	1	2	1	1
Maldane sarsi	0	0	0	0	0	0	0	0	0	0	1	0	6	3
Aphelochaeta monilaris	1	0	0	0	0	0	1	0	0	0	1	1	2	0
Nuculana conceptionis	0	0	0	0	0	0	0	0	0	0	0	0	2	1
Cadulus californicus	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Leitoscoloplos sp A	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Fauveliopsis glabra	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Leucon declivis	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***2***
Yoldiella nana	0	0	0	0	0	0	0	0	0	0	0	0	0	1

[a] SIMPER analyses not conducted on cluster groups that contain only one grab. For these groups shading indicates five most abundant taxa.

Appendix F.8

Particle size summary for each macrofauna cluster group A–N (defined in Figure 6.8). Data are presented as means (ranges) calculated over all stations within a cluster group. VF = very fine; Med = medium; VC = very coarse.

Macrofauna	Sediments (%)						
Cluster Group	Fines	VF Sand	Fine Sand	Med Sand	Coarse Sand	VC Sand	Granules
A	3.4 (2.4-4.5)	13.2 (9.9-16.5)	57.8 (55-60.6)	23.4 (17.3-29.5)	2.1 (1.1-3.1)	0 (0-0)	0 (0-0)
B	2.4 (1.6-3.3)	2.0 (0.3-3.6)	4.4 (2.3-6.6)	27.5 (25.9-29.2)	30.3 (30.0-30.6)	18.0 (17.7-18.3)	15.4 (13.4-17.3)
C	1.1 (0-2.1)	0.3 (0.2-0.4)	2.7 (1.6-3.8)	31.5 (21.6-41.4)	51.3 (49.9-52.7)	9.8 (4.5-15.0)	3.5 (0-7.0)
D	2.2	1.3	15.2	44.8	25.6	10.5	0
E	2.0 (0-4.7)	3.5 (0-15.0)	24.9 (2.9-70.1)	49.7 (13.9-67.1)	18.5 (0.9-53.1)	1.3 (0-8.5)	0.1 (0-0.8)
F	1.9	1.0	3.4	31.7	55.4	6.6	0
G	16.4 (2.9-41.6)	56.0 (25.1-73.4)	24.2 (13.4-61.9)	3.3 (0.2-21.7)	0.1 (0-1.9)	0 (0-0)	0 (0-0)
H	11.8 (2.6-28.4)	29.8 (2.0-47.8)	32.3 (8.1-51)	16.5 (3.1-49.4)	8.8 (0-35.0)	0.7 (0-2.8)	0 (0-0)
I	2.3 (0-5.2)	1.1 (0.1-2.9)	6.4 (2.7-18.4)	29.3 (15.8-58.5)	52.7 (17.1-72.4)	8.1 (0.5-15.6)	0.1 (0-0.3)
J	24.9	30.0	38.8	6.3	0	0	0
K	38.6 (14.5-65.6)	38.7 (13.3-66.1)	14.2 (1.3-40.9)	4.2 (0.1-25.9)	2.8 (0-27.3)	1.1 (0-13.7)	0.4 (0-8.3)
L	68.0 (60.6-75.8)	24.1 (18.5-31.3)	7.4 (5.4-9.2)	0.5 (0.1-1.4)	0 (0-0)	0 (0-0)	0 (0-0)
M	69.5 (61.1-80.2)	24.7 (16.4-31.2)	5.7 (3.3-8.2)	0.1 (0.1-0.2)	0 (0-0)	0 (0-0)	0 (0-0)
N	80.9 (74.5-87.3)	14.6 (9.7-19.6)	4.3 (2.9-5.8)	0.1 (0.1-0.1)	0 (0-0)	0 (0-0)	0 (0-0)

Appendix G

Demersal Fishes and Megabenthic Invertebrates

2016 – 2017 Supplemental Analyses

PLOO and SBOO Stations

Appendix G.1

Sample dates and duration for trawls conducted in the PLOO and SBOO regions during 2016 and 2017.

		2016		2017	
Station	Survey	Sample Date	Duration	Sample Date	Duration
PLOO Region					
SD7	Winter	21-Mar-2016	10 minute	05-Jan-2017	1 minute
	Summer	14-Jul-2016	10 minute	26-Jul-2017	2 minute
SD8	Winter	21-Mar-2016	10 minute	17-Jan-2017	2 minute
	Summer	27-Sep-2016	1 minute	26-Jul-2017	10 minute
SD10	Winter	21-Mar-2016	1 minute	17-Jan-2017	2 minute
	Summer	27-Sep-2016	1 minute	01-Aug-2017	1 minute
SD12	Winter	21-Mar-2016	1 minute	17-Jan-2017	3 minute
	Summer	27-Sep-2016	1 minute	01-Aug-2017	1 minute
SD13	Winter	21-Mar-2016	1 minute	17-Jan-2017	3 minute
	Summer	27-Sep-2016	1 minute	01-Aug-2017	1 minute
SD14	Winter	28-Mar-2016	1 minute	17-Jan-2017	3 minute
	Summer	27-Sep-2016	1 minute	01-Aug-2017	10 minute
SBOO Region					
SD15	Winter	25-Jan-2016	10 minute	04-Jan-2017	10 minute
	Summer	25-Aug-2016	10 minute	25-Jul-2017	10 minute
SD16	Winter	25-Jan-2016	10 minute	04-Jan-2017	10 minute
	Summer	8-Jul-2016	10 minute	25-Jul-2017	10 minute
SD17	Winter	25-Jan-2016	10 minute	04-Jan-2017	10minute
	Summer	8-Jul-2016	10 minute	25-Jul-2017	10 minute
SD18	Winter	25-Jan-2016	10 minute	04-Jan-2017	10 minute
	Summer	12-Jul-2016	10 minute	25-Jul-2017	10 minute
SD19	Winter	26-Jan-2016	10 minute	04-Jan-2017	10 minute
	Summer	12-Jul-2016	10 minute	25-Jul-2017	10 minute
SD20	Winter	26-Jan-2016	10 minute	05-Jan-2017	10 minute
	Summer	25-Aug-2016	10 minute	26-Jul-2017	10 minute
SD21	Winter	20-Jan-2016	10 minute	05-Jan-2017	10 minute
	Summer	12-Jul-2016	10 minute	26-Jul-2017	10 minute

Appendix G.2

Taxonomic listing of demersal fish species captured at PLOO trawl stations[a] during 2016 and 2017. Data are total number of fish (n), biomass (BM, wet weight, kg), minimum, maximum, and mean length (standard length, cm). Taxonomic arrangement and scientific names are of Eschmeyer and Herald (1998) and Page et al. (2013).

				Length (cm)		
Taxon/Species	**Common Name**	**n**	**BM**	**Min**	**Max**	**Mean**
CHIMAERIFORMES						
Chimaeridae						
Hydrolagus colliei	Spotted Ratfish	1	0.2	34	34	34
RAJIFORMES						
Rajidae						
Raja inornata	California Skate	2	0.8	34	38	36
ARGENTINIFORMES						
Argentinidae						
Argentina sialis	Pacific Argentine	2	0.1	5	7	6
AULOPIFORMES						
Synodontidae						
Synodus lucioceps	California Lizardfish	55	4.1	10	25	20
OPHIDIIFORMES						
Ophidiidae						
Chilara taylori	Spotted Cusk-eel	13	0.4	11	16	13
Ophidion scrippsae	Basketweave Cusk-eel	2	0.1	16	18	17
BATRACHOIDIFORMES						
Batrachoididae						
Porichthys myriaster	Specklefin Midshipman	2	0.2	11	17	14
Porichthys notatus	Plainfin Midshipman	193	2.8	8	17	11
SCORPAENIFORMES						
Scorpaenidae						
Scorpaena guttata	California Scorpionfish	7	1.3	13	21	17
Sebastidae						
Sebastes spp	Unidentified Rockfish	2	0.4	4	8	6
Sebastes auriculatus	Brown Rockfish	1	0.1	7	7	7
Sebastes elongatus	Greenstriped Rockfish	1	0.1	7	7	7
Sebastes miniatus	Vermilion Rockfish	3	0.1	10	11	10
Sebastes rosaceus	Rosy Rockfish	1	0.1	8	8	8
Sebastes rosenblatti	Greenblotched Rockfish	1	0.1	8	8	8
Sebastes rubrivinctus	Flag Rockfish	1	0.1	7	7	7
Sebastes saxicola	Stripetail Rockfish	194	2.8	5	10	8
Sebastes semicinctus	Halfbanded Rockfish	53	1.5	6	13	10
Hexagrammidae						
Zaniolepis frenata	Shortspine Combfish	26	1	9	17	13
Zaniolepis latipinnis	Longspine Combfish	128	2.8	8	16	12
Cottidae						
Chitonotus pugetensis	Roughback Sculpin	1	0.1	9	9	9
Icelinus quadriseriatus	Yellowchin Sculpin	36	0.4	6	9	8
Agonidae						
Xeneretmus latifrons	Blacktip Poacher	1	0.1	13	13	13
PERCIFORMES						
Sciaenidae						
Genyonemus lineatus	White Croaker	1	0.1	17	17	17
Embiotocidae						
Zalembius rosaceus	Pink Seaperch	56	1.3	5	12	8

[a] these included 19 trawls with durations ≤ 3 minutes

Appendix G.2 *continued*

Taxon/Species	Common Name	n	BM	Length (cm) Min	Max	Mean
Zoarcidae						
Lycodes cortezianus	Bigfin Eelpout	1	0.1	19	19	19
Uranoscopidae						
Kathetostoma averruncus	Smooth Stargazer	2	0.1	11	12	12
PLEURONECTIFORMES						
Paralichthyidae						
Citharichthys sordidus	Pacific Sanddab	1072	27.5	4	27	10
Citharichthys xanthostigma	Longfin Sanddab	2	0.1	12	13	12
Hippoglossina stomata	Bigmouth Sole	4	0.3	17	24	19
Pleuronectidae						
Lyopsetta exilis	Slender Sole	16	0.6	5	19	14
Microstomus pacificus	Dover Sole	223	3.9	5	20	10
Parophrys vetulus	English Sole	11	1.2	14	24	18
Pleuronichthys decurrens	Curlfin Sole	1	0.2	20	20	20
Pleuronichthys verticalis	Hornyhead Turbot	5	0.3	10	14	13
Cynoglossidae						
Symphurus atricaudus	California Tonguefish	5	0.2	11	14	13

Appendix G.3

Taxonomic listing of demersal fish species captured at SBOO trawl stations during 2016 and 2017. Data are total number of fish (n), biomass (BM, wet weight, kg), minimum, maximum, and mean length (standard length, cm). Taxonomic arrangement and scientific names are of Eschmeyer and Herald (1998) and Page et al. (2013).

				Length (cm)		
Taxon/Species	**Common Name**	**n**	**BM**	**Min**	**Max**	**Mean**
HETERODONTIFORMES						
Heterodontidae						
Heterodontus francisci	Horn Shark	1	1.4	56	56	56
RAJIFORMES						
Rhinobatidae						
Rhinobatos productus	Shovelnose Guitarfish	3	2.4	37	74	50
Rajidae						
Raja inornata	California Skate	5	2.2	23	54	34
MYLIOBATIFORNES						
Urolophidae						
Urobatis halleri	Round Stingray	2	1.0	34	36	35
AULOPIFORMES						
Synodontidae						
Synodus lucioceps	California Lizardfish	2026	24.2	7	29	14
OPHIDIIFORMES						
Ophidiidae						
Chilara taylori	Spotted Cusk-eel	1	0.1	14	14	14
Ophidion scrippsae	Basketweave Cusk-eel	5	0.2	10	14	12
BATRACHOIDIFORMES						
Batrachoididae						
Porichthys myriaster	Specklefin Midshipman	14	0.8	10	24	14
Porichthys notatus	Plainfin Midshipman	27	1.2	4	22	11
GASTEROSTEIFORMES						
Syngnathidae						
Syngnathus spp	Unidentified Pipefish	21	1.4	12	30	20
Hippocampus ingens	Pacific Seahorse	2	0.2	11	13	12
SCORPAENIFORMES						
Scorpaenidae						
Scorpaena guttata	California Scorpionfish	3	0.4	15	18	17
Sebastidae						
Sebastes miniatus	Vermilion Rockfish	3	0.2	3	7	5
Sebastes saxicola	Stripetail Rockfish	2	0.2	5	12	9
Sebastes semicinctus	Halfbanded Rockfish	1	0.1	6	6	6
Hexagrammidae						
Zaniolepis latipinnis	Longspine Combfish	42	1.0	11	14	13
Cottidae						
Chitonotus pugetensis	Roughback Sculpin	19	0.7	3	10	8
Icelinus filamentosus	Threadfin Sculpin	3	0.1	10	11	11
Icelinus quadriseriatus	Yellowchin Sculpin	79	0.8	3	8	7
Agonidae						
Odontopyxis trispinosa	Pygmy Poacher	3	0.2	8	13	11

Appendix G.3 *continued*

Taxon/Species	Common Name	n	BM	Length (cm) Min	Max	Mean
PERCIFORMES						
Malacanthidae						
Caulolatilus princeps	Ocean Whitefish	4	0.3	5	6	6
Haemulidae						
Haemulon californiensis	Salema	3	0.1	6	7	7
Sciaenidae						
Genyonemus lineatus	White Croaker	83	2.8	7	20	13
Seriphus politus	Queenfish	47	0.3	6	19	11
Pomacentridae						
Chromis punctipinnis	Blacksmith	1	0.1	7	7	7
Clinidae						
Heterostichus rostratus	Giant Kelpfish	1	0.1	14	14	14
Labrisomidae						
Neoclinus blanchardi	Sarcastic Fringehead	1	0.1	9	9	9
Stromateidae						
Peprilus simillimus	Pacific Pompano	1	0.1	14	14	14
PLEURONECTIFORMES						
Paralichthyidae						
Citharichthys spp	Unidentified Sanddab	4	0.2	3	4	4
Citharichthys fragilis	Gulf Sanddab	1	0.1	9	9	9
Citharichthys sordidus	Pacific Sanddab	6	0.3	6	12	10
Citharichthys stigmaeus	Speckled Sanddab	3517	28.7	3	13	8
Citharichthys xanthostigma	Longfin Sanddab	1020	21.5	3	20	11
Paralichthys californicus	California Halibut	25	15.7	21	49	33
Xystreurys liolepis	Fantail Sole	41	11.3	6	33	21
Pleuronectidae						
Eopsetta jordani	Petrale Sole	1	0.1	36	36	36
Parophrys vetulus	English Sole	18	3.3	10	28	20
Pleuronichthys decurrens	Curlfin Sole	2	0.2	4	18	11
Pleuronichthys guttulatus	Diamond Turbot	1	0.1	15	15	15
Pleuronichthys ritteri	Spotted Turbot	14	1.2	10	20	16
Pleuronichthys verticalis	Hornyhead Turbot	164	7.9	4	20	12
Cynoglossidae						
Symphurus atricaudus	California Tonguefish	376	3.6	5	17	11

Appendix G.4

Summary of demersal fish abnormalities and parasites at PLOO and SBOO trawl stations during 2016 and 2017.

Region/Year	Survey	Station	Species	Abnormalities/Parasite	n
PLOO Region					
2016	Winter	SD8	Pacific Sanddab	*Phrixocephalus cincinnatus*	2
2017	Winter	SD8	Pacific Sanddab	*Phrixocephalus cincinnatus*	1
	Summer	SD8	Dover Sole	Tumor, ventral side	1
	Summer	SD8	Pacific Sanddab	*Phrixocephalus cincinnatus*	1
	Summer	SD14	Pacific Sanddab	*Phrixocephalus cincinnatus*	1
	Summer	SD14	Pacific Sanddab	*Elthusa vulgaris*	1
SBOO Region					
2016	Winter	SD17	Hornyhead Turbot	Hirundinea	1
	Winter	SD18	Speckled Sanddab	*Elthusa vulgaris*	1
	Summer	SD15	Pacific Sanddab	*Elthusa vulgaris*	2
	Summer	SD17	Spotted Turbot	Ambicoloration	1
	Summer	SD17	Speckled Sanddab	Ambicoloration	1
	Summer	SD18	Longfin Sanddab	*Phrixocephalus cincinnatus*	1
	Summer	SD18	Pacific Sanddab	*Elthusa vulgaris*	1
2017	Summer	SD16	Speckled Sanddab	*Elthusa vulgaris*	2
	Summer	SD19	Speckled Sanddab	*Elthusa vulgaris*	2
	Summer	SD19	Fantail Sole	Worms (unidentified)	1
	Summer	SD19	California Skate	Hirudinea	1
	Summer	SD19	California Skate	Copepod (unidentified)	1
	Summer	SD20	Speckled Sanddab	*Elthusa vulgaris*	1

Appendix G.5

Description of PLOO demersal fish cluster groups A–D defined in Figure 7.6. Data are mean abundance of the characteristic species. Highlighted values indicate the top five most characteristic species according to SIMPER analysis.

	Cluster Groups			
Species	**A** [a]	**B** [a]	**C**	**D** [a]
Pacific Sanddab	23.0	75.0	92.7	219.4
Halfbanded Rockfish	16.0	0.0	1.5	24.1
Greenspotted Rockfish	1.0	0.0	0.3	0.3
Gulf Sanddab	1.0	5.0	0.3	0.3
Longfin Sanddab	1.0	0.0	6.1	2.7
Pink Seaperch	1.0	4.0	0.9	4.3
Spotfin Sculpin	1.0	0.0	1.9	0.6
Plainfin Midshipman	0.0	116.0	14.8	6.1
Dover Sole	0.0	36.0	9.2	24.2
Longspine Combfish	0.0	7.0	1.5	20.3
Shortspine Combfish	0.0	0.0	1.8	6.0
California Tonguefish	0.0	0.0	3.1	0.9

[a] SIMPER analysis only conducted on cluster groups that contain more than one haul. For these groups shading indicates five most abundant species.

Appendix G.6

Description of SBOO demersal fish cluster groups A–F defined in Figure 7.7. Data are mean abundance of the characteristic species. Highlighted values indicate the top five most characteristic species according to SIMPER analysis.

	Cluster Groups					
Species	**A**	**B**[a]	**C**[a]	**D**	**E**	**F**
Speckled Sanddab	23	26	143	179	112	48
Hornyhead Turbot	3	3	9	6	4	4
California Lizardfish	2	75	118	98	5	10
California Scorpionfish	2	2	0	<1	<1	<1
Spotted Turbot	2	0	0	<1	1	1
Longspine Combfish	0	79	1	4	0	<1
White Croaker	0	22	0	0	0	3
Longfin Sanddab	<1	8	0	18	<1	27
Pacific Sanddab	0	0	153	1	<1	<1
Curlfin Sole	<1	0	15	<1	<1	0
Yellowchin Sculpin	0	5	0	24	<1	2
California Tonguefish	<1	6	0	6	<1	5

[a] SIMPER analysis only conducted on cluster groups that contain more than one haul. For these groups shading indicates five most abundant species

Appendix G.7

Summary taxonomic listing of megabenthic invertebrate taxa captured at all PLOO trawl stations[a] during 2016 and 2017. Data are total number of individuals (n). Taxonomic arrangement from SCAMIT (2014).

Taxon/Species				n
SILICEA				
	Demospongiae	Suberitidae	*Suberites latus*	2
MOLLUSCA				
	Gastropoda	Nassariidae	*Hinea insculpta*	7
		Cancellariidae	*Cancellaria cooperii*	1
	Cephalopoda	Octopodidae	*Octopus rubescens*	8
ARTHROPODA				
	Malacostraca	Cymothoidae	*Elthusa vulgaris*	10
		Solenoceridae	*Solenocera mutator*	1
		Sicyoniidae	*Sicyonia ingentis*	239
		Diogenidae	*Paguristes bakeri*	2
			Paguristes turgidus	1
		Munididae	*Pleuroncodes planipes*	301,887
		Calappidae	*Platymera gaudichaudii*	3
ECHINODERMATA				
	Asteroidea	Luidiidae	*Luidia asthenosoma*	1
			Luidia foliolata	5
		Astropectinidae	*Astropecten californicus*	10
	Echinoidea	Toxopneustidae	*Lytechinus pictus*	1847
		Strongylocentrotidae	*Strongylocentrotus fragilis*	41
		Spatangidae	*Spatangus californicus*	1
	Holothuroidea	Stichopodidae	*Parastichopus californicus*	14

[a] these included 19 trawls with durations ≤ 3 minutes

Appendix G.8

Summary taxonomic listing of megabenthic invertebrate taxa captured at all SBOO trawl stations during 2016 and 2017. Data are total number of individuals (n). Taxonomic arrangement from SCAMIT (2014).

Taxon/Species				n
SILICEA				
	Demospongiae	Suberitidae	*Suberites* sp	1
CNIDARIA				
	Anthozoa	Plexauridae	*Thesea* sp B	2
		Virgulariidae	*Acanthoptilum* sp	7
			Stylatula elongata	4
		Actiniaria[a]		1
MOLLUSCA				
	Gastropoda	Calliostomatidae	*Calliostoma tricolor*	1
		Naticidae	*Euspira lewisii*	3
			Sinum scopulosum	1
		Bursidae	*Crossata ventricosa*	18
		Epitoniidae	*Epitonium bellastriatum*	1
		Buccinidae	*Kelletia kelletii*	38
		Muricidae	*Pteropurpura festiva*	2
			Pteropurpura vokesae	1
		Pseudomelatomidae	*Crassispira semiinflata*	1
			Megasurcula carpenteriana	1
		Philinidae	*Philine alba*	1
			Philine auriformis	559
		Aglajidae	*Aglaja ocelligera*	3
		Pleurobranchidae	*Pleurobranchaea californica*	1
		Onchidorididae	*Acanthodoris brunnea*	14
			Acanthodoris rhodoceras	3
		Arminidae	*Armina californica*	3
		Dendronotidae	*Dendronotus iris*	4
	Bivalvia	Pectinidae	*Leptopecten latiauratus*	1
	Cephalopoda	Sepiolidae	*Rossia pacifica*	2
		Loliginidae	*Doryteuthis opalescens*	1
		Octopodidae	*Octopus rubescens*	39
ARTHROPODA				
	Malacostraca	Hemisquillidae	*Hemisquilla californiensis*	13
		Cymothoidae	*Elthusa vulgaris*	180
		Penaeidae	*Farfantepenaeus californiensis*	6
		Sicyoniidae	*Sicyonia ingentis*	1
			Sicyonia penicillata	689
		Alpheidae	*Alpheus clamator*	1
		Hippolytidae	*Heptacarpus palpator*	1
			Heptacarpus stimpsoni	3
		Crangonidae	*Crangon alba*	2
			Crangon nigromaculata	125
		Diogenidae	*Paguristes bakeri*	1
		Paguridae	*Pagurus spilocarpus*	3
		Munididae	*Pleuroncodes planipes*	149

[a]Order; family unknown

Appendix G.8 *continued*

Taxon/Species				n
		Calappidae	*Platymera gaudichaudii*	6
		Leucosiidae	*Randallia ornata*	3
		Epialtidae	*Pugettia dalli*	1
			Pugettia producta	1
			Loxorhynchus grandis	4
		Inachidae	*Ericerodes hemphillii*	5
		Inachoididae	*Pyromaia tuberculata*	8
		Cancridae	Cancridae	2
			Glebocarcinus amphioetus	1
			Metacarcinus anthonyi	5
			Metacarcinus gracilis	3
			Romaleon antennarium	1
		Portunidae	*Portunus xantusii*	187
ECHINODERMATA				
	Asteroidea	Luidiidae	*Luidia armata*	1
		Astropectinidae	*Astropecten californicus*	46
			Astropecten ornatissimus	3
	Ophiuroidea	Ophiuridae	*Ophiura luetkenii*	2
		Ophiotricidae	*Ophiothrix spiculata*	6
		Ophiocomidae	*Ophiopteris papillosa*	5
	Echinoidea	Toxopneustidae	*Lytechinus pictus*	8
		Dendrasteridae	*Dendraster terminalis*	29
		Loveniidae	*Lovenia cordiformis*	4

Appendix G.9

Description of PLOO megabenthic invertebrate cluster groups A–E defined in Figure 7.12. Data are mean abundance of the characteristic species. Highlighted values indicate top five most characteristic species according to SIMPER analysis.

	Cluster Groups				
Species	**A**	**B** [a]	**C**	**D**	**E**
Acanthoptilum sp	97	0	0	47	29
Strongylocentrotus fragilis	13	442	0	5	138
Sicyonia ingentis	12	0	11	6	2
Astropecten californicus	4	1	2	5	4
Ophiura luetkenii	2	2640	0	49	17
Lytechinus pictus	8	102	302	2161	236
Luidia foliolata	0	11	0	4	5
Astropecten ornatissimus	0	5	0	0	0
Pleuroncodes planipes	2	0	407	2	1
Parastichopus californicus	3	0	4	5	3

[a] SIMPER analysis only conducted on cluster groups that contain more than one haul. For these groups shading indicates five most abundant species.

Appendix G.10

Description of SBOO megabenthic invertebrate cluster groups A–F defined in Figure 7.13. Data are mean abundance of the characteristic species. Highlighted values indicate the top five most characteristic species according to SIMPER analysis.

	Cluster Groups					
Species	**A[a]**	**B**	**C[a]**	**D[a]**	**E**	**F**
Ophiura luetkenii	72	0	0	0	<1	<1
Dendraster terminalis	3	0	0	0	1	1
Ophiothrix spiculata	3	0	0	4	0	1
Crangon alba	2	0	0	1	<1	<1
Megastraea turbanica	1	0	0	0	0	0
Octopus rubescens	1	0	0	0	2	<1
Pagurus spilocarpus	1	<1	0	0	<1	<1
Pyromaia tuberculata	1	1	0	4	1	1
Hirudinea	0	1	0	0	0	<1
Crangon nigromaculata	0	1	0	1	1	1
Loxorhynchus grandis	0	1	0	0	<1	<1
Caesia perpinguis	0	1	0	0	<1	<1
Astropecten ornatissimus	0	0	4	0	<1	<1
Pisaster brevispinus	0	0	2	2	0	1
Latulambrus occidentalis	0	<1	1	0	1	2
Flabellina iodinea	0	0	1	0	0	<1
Heptacarpus stimpsoni	0	0	1	0	<1	<1
Luidia armata	0	0	1	0	<1	<1
Lytechinus pictus	0	1	0	951	1	8
Astropecten californicus	0	0	0	6	13	35
Halosydna latior	0	0	0	1	0	<1
Pisaster giganteus capitatus	0	0	0	1	0	0
Romaleon jordani	0	0	0	1	0	0
Elthusa vulgaris	0	<1	0	0	9	1
Sicyonia penicillata	0	0	0	0	7	<1
Kelletia kelletii	0	0	0	0	2	1

[a] SIMPER analysis only conducted on cluster groups that contain more than one haul. For these groups shading indicates five most abundant species.

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Appendix H

Contaminants in Marine Fishes

2016 – 2017 Supplemental Analyses

PLOO and SBOO Stations

Appendix H.1

Constituents and method detection limits (MDL) used for the analysis of liver and muscle tissues of fishes collected during 2016; na = not applicable.

	MDL			MDL	
Parameter	**Liver**	**Muscle**	**Parameter**	**Liver**	**Muscle**
Metals (ppm)					
Aluminum (Al)	2.4	2.4	Lead (Pb)	0.326	0.326
Antimony (Sb)	0.79	0.79	Manganese (Mn)	0.19	0.19
Arsenic (As)	0.308	0.308	Mercury (Hg)	0.002	0.002
Barium (Ba)	0.08	0.08	Nickel (Ni)	0.3	0.3
Beryllium (Be)	0.02	0.02	Selenium (Se)	0.19	0.19
Cadmium (Cd)	0.13	0.13	Silver (Ag)	0.206	0.206
Chromium (Cr)	0.136	0.136	Thallium (Tl)	0.43	0.43
Copper (Cu)	0.69	0.69	Tin (Sn)	0.33	0.33
Iron (Fe)	2.88	2.88	Zinc (Zn)	1.45	1.45
Chlorinated Pesticides (ppb)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	1.58	0.16	HCH, Delta isomer	3.47	0.34
HCH, Beta isomer	4.5	0.45	HCH, Gamma isomer	3.68	0.37
Total Chlordane					
Alpha (cis) chlordane	5.89	0.59	Heptachlor epoxide	2.97	0.29
Cis nonachlor	6.06	0.61	Methoxychlor	13.10	na
Gamma (trans) chlordane	3.84	0.38	Oxychlordane	2.81	0.28
Heptachlor	1.86	0.19	Trans nonachlor	5.12	0.51
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	2.03	0.21	p,p-DDD	2.62	0.26
o,p-DDE	3.16	0.31	p,p-DDE	1.75	0.18
o,p-DDT	2.92	0.29	p,p-DDT	2.66	0.27
p,-p-DDMU	3.44	0.34			
Miscellaneous Pesticides					
Aldrin	2.98	0.30	Beta endosulfan	na	na
Dieldrin	na	na	Endosulfan sulfate	2.31	0.23
Endrin	na	na	Hexachlorobenzene (HCB)	26.80	2.68
Endrin aldehyde	na	na	Mirex	1.99	0.20
Alpha endosulfan	1.77	0.17			

Appendix H.1 *continued*

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Polychlorinated Biphenyls Congeners (PCBs) (ppb)					
PCB 18	1.21	0.12	PCB 126	1.34	0.13
PCB 28	1.65	0.16	PCB 128	1.43	0.14
PCB 37	1.43	0.14	PCB 138	2.51	0.25
PCB 44	1.16	0.12	PCB 149	1.79	0.18
PCB 49	0.97	0.10	PCB 151	1.31	0.14
PCB 52	1.27	0.12	PCB 153/168	2.79	0.28
PCB 66	1.16	0.12	PCB 156	1.86	0.19
PCB 70	1.40	0.14	PCB 157	3.20	0.32
PCB 74	1.09	0.11	PCB 158	1.45	0.14
PCB 77	1.81	0.18	PCB 167	1.59	0.16
PCB 81	1.63	0.16	PCB 169	2.72	0.27
PCB 87	1.39	0.14	PCB 170	2.02	0.21
PCB 99	1.25	0.12	PCB 177	2.31	0.23
PCB 101	1.49	0.15	PCB 180	2.54	0.26
PCB 105	1.83	0.19	PCB 183	1.14	0.11
PCB 110	1.42	0.14	PCB 187	1.16	0.12
PCB 114	1.31	0.13	PCB 189	1.44	0.14
PCB 118	2.38	0.24	PCB 194	1.76	0.18
PCB 119	1.96	0.20	PCB 201	1.68	0.17
PCB 123	1.94	0.19	PCB 206	1.31	nr
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
1-methylnaphthalene	27.9	26.4	Benzo[G,H,I]perylene	27.2	59.5
1-methylphenanthrene	17.4	23.3	Benzo[K]fluoranthene	32.0	37.3
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[e]pyrene	41.8	40.6	Pyrene	9.1	16.6

Appendix H.2

Constituents and method detection limits (MDL) used for the analysis of liver and muscle tissues of fishes collected during 2017; nr = not reportable.

	MDL			MDL	
Parameter	**Liver**	**Muscle**	**Parameter**	**Liver**	**Muscle**
		Metals (ppm)			
Aluminum (Al)[a]	0.58, 6.42	0.58, 6.42	Lead (Pb)[a]	0.099, 0.03	0.099, 0.03
Antimony (Sb)[a]	0.167, 0.48	0.167, 0.48	Manganese (Mn)[a]	0.007, 0.129	0.007, 0.129
Arsenic (As)[a]	0.38, 0.531	0.38, 0.531	Mercury (Hg)	0.001	0.001
Barium (Ba)[a]	0.007, 0.186	0.007, 0.186	Nickel (Ni)[a]	0.042, 0.094	0.042, 0.094
Beryllium (Be)[a]	0.003, 0.039	0.003, 0.039	Selenium (Se)[a]	0.14, 0.398	0.14, 0.398
Cadmium (Cd)[a]	0.029, 0.032	0.029, 0.032	Silver (Ag)[a]	0.057, 0.105	0.057, 0.105
Chromium (Cr)[a]	0.045, 0.08	0.045, 0.08	Tin (Sn)	0.24, 0.575	0.24, 0.575
Copper (Cu)[a]	0.068, 0.693	0.068, 0.693	Zinc (Zn)[a]	0.049, 0.326	0.049, 0.326
Iron (Fe)[a]	0.096 – 2.12	0.096 – 2.12			
		Chlorinated Pesticides (ppb)			
		Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	2.75	0.28	HCH, Delta isomer	2.43	0.24
HCH, Beta isomer	2.01	0.20	HCH, Gamma isomer	2.68	0.27
		Total Chlordane			
Alpha (cis) chlordane	2.40	0.24	Heptachlor epoxide	2.06	0.21
Cis nonachlor	22.10	2.21	Methoxychlor	21.4	2.14
Gamma (trans) chlordane	2.58	0.26	Oxychlordane	3.70	0.37
Heptachlor	4.21	0.42	Trans nonachlor	2.78	0.28
		Total Dichlorodiphenyltrichloroethane (DDT)			
o,p-DDD	2.20	0.22	p,p-DDD	4.64	0.46
o,p-DDE	1.60	0.16	p,p-DDE	1.90	0.19
o,p-DDT	2.67	0.27	p,p-DDT	1.84	0.18
p,-p-DDMU	1.41	0.14			
		Miscellaneous Pesticides			
Aldrin	5.73	0.57	Beta endosulfan	18.1	1.81
Dieldrin	15.9	1.59	Endosulfan sulfate	12.4	1.24
Endrin	26.30	2.63	Hexachlorobenzene (HCB)	15.00	1.50
Endrin aldehyde	11.20	1.12	Mirex	2.16	0.22
Alpha endosulfan	7.37	0.74			

[a]MDL differed within the survey for this parameter.

Appendix H.2 *continued*

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Polychlorinated Biphenyls Congeners (PCBs) (ppb)					
PCB 18	2.29	0.23	PCB 126	1.71	0.17
PCB 28	0.92	0.09	PCB 128	2.46	0.25
PCB 37	1.32	0.13	PCB 138	1.79	0.18
PCB 44	1.12	0.11	PCB 149	1.58	0.16
PCB 49	1.35	0.14	PCB 151	2.72	0.27
PCB 52	1.64	0.16	PCB 153/168	3.85	0.39
PCB 66	1.77	0.18	PCB 156	2.41	0.24
PCB 70	1.54	0.15	PCB 157	2.48	0.25
PCB 74	1.40	0.14	PCB 158	1.66	0.17
PCB 77	1.82	0.18	PCB 167	1.71	0.17
PCB 81	2.10	0.21	PCB 169	1.85	0.19
PCB 87	1.08	0.11	PCB 170	2.35	0.24
PCB 99	1.79	0.18	PCB 177	1.47	0.15
PCB 101	1.30	0.13	PCB 180	2.30	0.23
PCB 105	1.43	0.14	PCB 183	1.53	0.15
PCB 110	1.78	0.18	PCB 187	1.36	0.14
PCB 114	1.79	0.18	PCB 189	1.24	0.12
PCB 118	2.91	0.29	PCB 194	1.61	0.16
PCB 119	2.26	0.23	PCB 201	1.44	0.14
PCB 123	2.52	0.25	PCB 206	1.66	nr
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
1-methylnaphthalene	27.9	26.4	Benzo[G,H,I]perylene	27.2	59.5
1-methylphenanthrene	17.4	23.3	Benzo[K]fluoranthene	32	37.3
2,3,5-trimethylnaphthalene	21.7	21.6	Biphenyl	38	19.9
2,6-dimethylnaphthalene	21.7	19.5	Chrysene	18.1	23
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	nr
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[e]pyrene	41.8	40.6	Pyrene	9.1	16.6

Appendix H.3

Species of fish collected from each PLOO trawl and rig fishing zone during October surveys from 1995 through 2015.[a]

Year	Zone	Station	Composite 1	Composite 2	Composite 3
1995	RF1	RF1	Copper Rockfish	Vermilion Rockfish	Vermilion Rockfish
1995	RF2	RF2	Mixed Rockfish	Mixed Rockfish	Canary Rockfish
1995	TZ1	SD10	Longfin Sanddab	Longfin Sanddab	Dover Sole
1995	TZ1	SD11	English Sole	English Sole	English Sole
1995	TZ1	SD12	Pacific Sanddab	California Scorpionfish	California Scorpionfish
1995	TZ1	SD9	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1995	TZ2	SD13	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1995	TZ2	SD14	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
1995	TZ3	SD8	Longfin Sanddab	Longfin Sanddab	Pacific Sanddab
1995	TZ4	SD7	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1996	RF1	RF1	Copper Rockfish	Vermilion Rockfish	Mixed Rockfish
1996	RF2	RF2	Speckled Rockfish	Speckled Rockfish	Mixed Rockfish
1996	TZ1	SD10	Longfin Sanddab	Longfin Sanddab	English Sole
1996	TZ1	SD11	English Sole	English Sole	Pacific Sanddab
1996	TZ1	SD12	English Sole	English Sole	Greenblotched Rockfish
1996	TZ1	SD9	Longfin Sanddab	Longfin Sanddab	Pacific Sanddab
1996	TZ2	SD13	English Sole	Pacific Sanddab	Longfin Sanddab
1996	TZ2	SD14	Longfin Sanddab	Pacific Sanddab	Pacific Sanddab
1996	TZ3	SD8	Pacific Sanddab	Longfin Sanddab	Mixed Rockfish
1996	TZ4	SD7	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1997	RF1	RF1	California Scorpionfish	California Scorpionfish	Mixed Rockfish
1997	RF2	RF2	Starry Rockfish	Squarespot Rockfish	Speckled Rockfish
1997	TZ1	SD10	Longfin Sanddab	Longfin Sanddab	California Scorpionfish
1997	TZ1	SD11	Longfin Sanddab	California Scorpionfish	California Scorpionfish
1997	TZ1	SD12	Longfin Sanddab	California Scorpionfish	California Scorpionfish
1997	TZ1	SD9	California Scorpionfish	Longfin Sanddab	Longfin Sanddab
1997	TZ2	SD13	California Scorpionfish	Longfin Sanddab	Longfin Sanddab
1997	TZ2	SD14	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1997	TZ3	SD8	Longfin Sanddab	Halfbanded Rockfish	Halfbanded Rockfish
1997	TZ4	SD7	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
1998	RF1	RF1	Mixed Rockfish	California Scorpionfish	Copper Rockfish
1998	RF2	RF2	Starry Rockfish	Vermilion Rockfish	Vermilion Rockfish
1998	TZ1	SD10	Longfin Sanddab	Longfin Sanddab	California Scorpionfish
1998	TZ1	SD11	Longfin Sanddab	California Scorpionfish	California Scorpionfish
1998	TZ1	SD12	California Scorpionfish	California Scorpionfish	Longfin Sanddab
1998	TZ1	SD9	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1998	TZ2	SD13	Longfin Sanddab	California Scorpionfish	California Scorpionfish
1998	TZ2	SD14	Longfin Sanddab	Longfin Sanddab	California Scorpionfish
1998	TZ3	SD8	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1998	TZ4	SD7	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1999	RF1	RF1	California Scorpionfish	California Scorpionfish	California Scorpionfish

Appendix H.3 *continued*

Year	Zone	Station	Composite 1	Composite 2	Composite 3
1999	RF2	RF2	Speckled Rockfish	Vermilion Rockfish	California Scorpionfish
1999	TZ1	SD10	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1999	TZ1	SD11	Longfin Sanddab	California Scorpionfish	California Scorpionfish
1999	TZ1	SD12	California Scorpionfish	California Scorpionfish	California Scorpionfish
1999	TZ1	SD9	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1999	TZ2	SD13	Longfin Sanddab	California Scorpionfish	California Scorpionfish
1999	TZ2	SD14	Longfin Sanddab	California Scorpionfish	California Scorpionfish
1999	TZ3	SD8	Longfin Sanddab	Flag Rockfish	Flag Rockfish
1999	TZ4	SD7	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2000	RF1	RF1	Vermilion Rockfish	Vermilion Rockfish	Mixed Rockfish
2000	RF2	RF2	Vermilion Rockfish	Mixed Rockfish	Vermilion Rockfish
2000	TZ1	SD10	Longfin Sanddab	Longfin Sanddab	California Scorpionfish
2000	TZ1	SD11	California Scorpionfish	California Scorpionfish	Longfin Sanddab
2000	TZ1	SD12	California Scorpionfish	California Scorpionfish	California Scorpionfish
2000	TZ1	SD9	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2000	TZ2	SD13	Longfin Sanddab	Pacific Sanddab	English Sole
2000	TZ2	SD14	Pacific Sanddab	Longfin Sanddab	Longfin Sanddab
2000	TZ3	SD8	Longfin Sanddab	Mixed Rockfish	California Scorpionfish
2000	TZ4	SD7	Longfin Sanddab	Hornyhead Turbot	California Scorpionfish
2001	RF1	RF1	Vermilion Rockfish	Vermilion Rockfish	Copper Rockfish
2001	RF2	RF2	Starry Rockfish	Mixed Rockfish	no sample
2001	TZ1	SD10	English Sole	English Sole	Pacific Sanddab
2001	TZ1	SD11	Pacific Sanddab	Longfin Sanddab	California Scorpionfish
2001	TZ1	SD12	Longfin Sanddab	Greenblotched Rockfish	California Scorpionfish
2001	TZ1	SD9	Longfin Sanddab	California Scorpionfish	Longfin Sanddab
2001	TZ2	SD13	Longfin Sanddab	California Scorpionfish	Greenspotted Rockfish
2001	TZ2	SD14	Longfin Sanddab	Pacific Sanddab	California Scorpionfish
2001	TZ3	SD8	Pacific Sanddab	Pacific Sanddab	Greenspotted Rockfish
2001	TZ4	SD7	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2002	RF1	RF1	Copper Rockfish	Copper Rockfish	Mixed Rockfish
2002	RF2	RF2	Flag Rockfish	Vermilion Rockfish	no sample
2002	TZ1	SD10	Longfin Sanddab	Pacific Sanddab	California Scorpionfish
2002	TZ1	SD11	Longfin Sanddab	California Scorpionfish	California Scorpionfish
2002	TZ1	SD12	California Scorpionfish	Dover Sole	Pacific Sanddab
2002	TZ1	SD9	Longfin Sanddab	Longfin Sanddab	English Sole
2002	TZ2	SD13	Longfin Sanddab	California Scorpionfish	California Scorpionfish
2002	TZ2	SD14	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2002	TZ3	SD8	California Scorpionfish	Longfin Sanddab	Pacific Sanddab
2002	TZ4	SD7	Longfin Sanddab	Dover Sole	Longfin Sanddab
2003	RF1	RF1	Copper Rockfish	Mixed Rockfish	Vermilion Rockfish
2003	RF2	RF2	Vermilion Rockfish	Vermilion Rockfish	Vermilion Rockfish
2003	TZ1	TZ1	English Sole	English Sole	English Sole
2003	TZ2	TZ2	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab

Appendix H.3 *continued*

Year	Zone	Station	Composite 1	Composite 2	Composite 3
2003	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2003	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2004	RF1	RF1	Copper Rockfish	Copper Rockfish	Mixed Rockfish
2004	RF2	RF2	Greenspotted Rockfish	Mixed Rockfish	Mixed Rockfish
2004	TZ1	TZ1	English Sole	English Sole	English Sole
2004	TZ2	TZ2	English Sole	English Sole	English Sole
2004	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2004	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2005	RF1	RF1	Rosethorn Rockfish	Mixed Rockfish	Mixed Rockfish
2005	RF2	RF2	Squarespot Rockfish	Squarespot Rockfish	Speckled Rockfish
2005	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2005	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2005	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2005	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2006	RF1	RF1	Copper Rockfish	Copper Rockfish	Copper Rockfish
2006	RF2	RF2	Starry Rockfish	Yellowtail Rockfish	Yellowtail Rockfish
2006	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2006	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2006	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2006	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	English Sole
2007	RF1	RF1	Vermilion Rockfish	Vermilion Rockfish	Copper Rockfish
2007	RF2	RF2	Greenblotched Rockfish	Greenblotched Rockfish	Mixed Rockfish
2007	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	English Sole
2007	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2007	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2007	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2008	RF1	RF1	Copper Rockfish	Mixed Rockfish	Greenblotched Rockfish
2008	RF2	RF2	Vermilion Rockfish	Vermilion Rockfish	Mixed Rockfish
2008	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	English Sole
2008	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2008	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2008	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2009	RF1	RF1	Copper Rockfish	Vermilion Rockfish	Mixed Rockfish
2009	RF2	RF2	Vermilion Rockfish	Vermilion Rockfish	Mixed Rockfish
2009	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2009	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2009	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2009	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2010	RF1	RF1	California Scorpionfish	California Scorpionfish	California Scorpionfish
2010	RF2	RF2	Vermilion Rockfish	Mixed Rockfish	Mixed Rockfish
2010	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2010	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2010	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab

Appendix H.3 *continued*

Year	Zone	Station	Composite 1	Composite 2	Composite 3
2010	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2011	RF1	RF1	Vermilion Rockfish	Vermilion Rockfish	Vermilion Rockfish
2011	RF2	RF2	Chilipepper	Chilipepper	Flag Rockfish
2011	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2011	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2011	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2011	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2012	RF1	RF1	Vermilion Rockfish	Copper Rockfish	Mixed Rockfish
2012	RF2	RF2	Starry Rockfish	Greenspotted Rockfish	Mixed Rockfish
2012	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2012	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2012	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2012	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2013	RF1	RF1	Mixed Rockfish	Mixed Rockfish	Starry Rockfish
2013	RF2	RF2	Speckled Rockfish	Speckled Rockfish	Speckled Rockfish
2013	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2013	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2013	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2013	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2014	RF1	RF1	Vermilion Rockfish	Vermilion Rockfish	Copper Rockfish
2014	RF2	RF2	Speckled Rockfish	Speckled Rockfish	Speckled Rockfish
2014	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2014	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2014	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2014	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2015	RF1	RF1	Vermilion Rockfish	Copper Rockfish	Mixed Rockfish
2015	RF2	RF2	Speckled Rockfish	Speckled Rockfish	Speckled Rockfish
2015	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2015	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	English Sole
2015	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2015	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab

[a] During 2003 and 2004, extra composite samples were collected from PLOO Trawl Zones TZ1 – TZ4. Species from these samples included: Pacific Sanddab (2003: TZ1 composites 4–6, TZ2 composites 7–9; 2004: TZ1 composites 4–6, TZ2 composites 4–6), Longfin Sanddab (2003: TZ4 composite 5; 2004: TZ1 composites 7–9, TZ2 composites 7–9, TZ3 composite 6), English Sole (2003: TZ2 composites 4–6; 2004: TZ3 composites 4–5), Hornyhead Turbot (2003: TZ1 composites 7–8), Bigmouth Sole (2003: TZ4, composite 4)

Appendix H.4

Species of fish collected from each SBOO trawl and rig fishing zone during October surveys from 1995 through 2015.

Year	Zone	Station	Composite 1	Composite 2	Composite 3
1995	RF3	RF3	Barred Sand Bass	Barred Sand Bass	Barred Sand Bass
1995	RF4	RF4	Mixed Rockfish	Barred Sand Bass	California Scorpionfish
1995	TZ5	SD17	Hornyhead Turbot	California Scorpionfish	California Scorpionfish
1995	TZ5	SD18	Longfin Sanddab	Longfin Sanddab	California Scorpionfish
1995	TZ6	SD19	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1995	TZ6	SD20	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1995	TZ7	SD21	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1995	TZ8	SD16	Longfin Sanddab	Hornyhead Turbot	California Scorpionfish
1996	RF3	RF3	California Scorpionfish	California Scorpionfish	California Scorpionfish
1996	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
1996	TZ6	SD19	White Croaker	White Croaker	White Croaker
1996	TZ6	SD20	Longfin Sanddab	White Croaker	White Croaker
1996	TZ7	SD21	White Croaker	White Croaker	White Croaker
1996	TZ8	SD16	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
1996	TZ9	SD15	Hornyhead Turbot	no sample	no sample
1997	RF3	RF3	California Scorpionfish	California Scorpionfish	California Scorpionfish
1997	RF4	RF4	Treefish	California Scorpionfish	California Scorpionfish
1997	TZ5	SD17	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
1997	TZ5	SD18	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
1997	TZ6	SD19	Longfin Sanddab	Hornyhead Turbot	California Scorpionfish
1997	TZ6	SD20	California Scorpionfish	Longfin Sanddab	Longfin Sanddab
1997	TZ7	SD21	Longfin Sanddab	Hornyhead Turbot	California Scorpionfish
1997	TZ8	SD16	Longfin Sanddab	Hornyhead Turbot	California Scorpionfish
1997	TZ9	SD15	Hornyhead Turbot	no sample	no sample
1998	RF3	RF3	California Scorpionfish	California Scorpionfish	California Scorpionfish
1998	RF4	RF4	California Scorpionfish	California Scorpionfish	Mixed Rockfish
1998	TZ5	SD17	California Scorpionfish	Longfin Sanddab	no sample
1998	TZ5	SD18	Longfin Sanddab	Hornyhead Turbot	Longfin Sanddab
1998	TZ6	SD19	Longfin Sanddab	California Scorpionfish	Longfin Sanddab
1998	TZ6	SD20	Longfin Sanddab	Hornyhead Turbot	California Scorpionfish
1998	TZ7	SD21	Longfin Sanddab	Longfin Sanddab	White Croaker
1998	TZ8	SD16	California Scorpionfish	Hornyhead Turbot	California Scorpionfish
1998	TZ9	SD15	Hornyhead Turbot	no sample	no sample
1999	RF3	RF3	California Scorpionfish	California Scorpionfish	California Scorpionfish
1999	RF4	RF4	Starry Rockfish	Treefish	California Scorpionfish
1999	TZ5	SD17	Longfin Sanddab	California Scorpionfish	California Scorpionfish
1999	TZ5	SD18	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1999	TZ6	SD19	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
1999	TZ6	SD20	Longfin Sanddab	California Scorpionfish	California Scorpionfish
1999	TZ7	SD21	Longfin Sanddab	Longfin Sanddab	California Scorpionfish
1999	TZ8	SD16	California Scorpionfish	California Scorpionfish	California Scorpionfish

Appendix H.4 *continued*

Year	Zone	Station	Composite 1	Composite 2	Composite 3
1999	TZ9	SD15	California Scorpionfish	California Scorpionfish	no sample
2000	RF3	RF3	California Scorpionfish	California Scorpionfish	California Scorpionfish
2000	RF4	RF4	California Scorpionfish	California Scorpionfish	Mixed Rockfish
2000	TZ5	SD17	California Scorpionfish	California Scorpionfish	California Scorpionfish
2000	TZ5	SD18	California Scorpionfish	Hornyhead Turbot	Hornyhead Turbot
2000	TZ6	SD19	California Scorpionfish	California Scorpionfish	Longfin Sanddab
2000	TZ6	SD20	California Scorpionfish	California Scorpionfish	Hornyhead Turbot
2000	TZ7	SD21	California Scorpionfish	California Scorpionfish	Hornyhead Turbot
2000	TZ8	SD16	California Scorpionfish	California Scorpionfish	California Scorpionfish
2000	TZ9	SD15	California Scorpionfish	California Scorpionfish	California Scorpionfish
2001	RF3	RF3	Vermilion Rockfish	Vermilion Rockfish	California Scorpionfish
2001	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2001	TZ5	SD17	Hornyhead Turbot	California Scorpionfish	California Scorpionfish
2001	TZ5	SD18	Hornyhead Turbot	California Scorpionfish	California Scorpionfish
2001	TZ6	SD19	Longfin Sanddab	Longfin Sanddab	California Scorpionfish
2001	TZ6	SD20	Longfin Sanddab	California Scorpionfish	California Scorpionfish
2001	TZ7	SD21	Longfin Sanddab	California Scorpionfish	California Scorpionfish
2001	TZ8	SD16	Longfin Sanddab	California Scorpionfish	California Scorpionfish
2001	TZ9	SD15	California Scorpionfish	California Scorpionfish	California Scorpionfish
2002	RF3	RF3	Vermilion Rockfish	Brown Rockfish	Vermilion Rockfish
2002	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2002	TZ5	SD17	California Scorpionfish	California Scorpionfish	California Scorpionfish
2002	TZ5	SD18	Hornyhead Turbot	Hornyhead Turbot	no sample
2002	TZ6	SD19	Hornyhead Turbot	California Scorpionfish	no sample
2002	TZ6	SD20	Hornyhead Turbot	Longfin Sanddab	California Scorpionfish
2002	TZ7	SD21	California Scorpionfish	Longfin Sanddab	California Scorpionfish
2002	TZ8	SD16	California Scorpionfish	California Scorpionfish	California Scorpionfish
2002	TZ9	SD15	California Scorpionfish	California Scorpionfish	California Scorpionfish
2003	RF3	RF3	Vermilion Rockfish	Vermilion Rockfish	Brown Rockfish
2003	RF4	RF4	Mixed Rockfish	California Scorpionfish	California Scorpionfish
2003	TZ5	SD17	California Scorpionfish	California Scorpionfish	California Scorpionfish
2003	TZ5	SD18	California Scorpionfish	Hornyhead Turbot	California Scorpionfish
2003	TZ6	SD19	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
2003	TZ6	SD20	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2003	TZ7	SD21	California Scorpionfish	California Scorpionfish	California Scorpionfish
2003	TZ8	SD16	California Scorpionfish	California Scorpionfish	Hornyhead Turbot
2003	TZ9	SD15	California Scorpionfish	California Scorpionfish	Hornyhead Turbot
2004	RF3	RF3	Brown Rockfish	Brown Rockfish	Vermilion Rockfish
2004	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2004	TZ5	SD17	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2004	TZ5	SD18	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2004	TZ6	SD19	Hornyhead Turbot	Hornyhead Turbot	no sample
2004	TZ6	SD20	Hornyhead Turbot	California Scorpionfish	California Scorpionfish

Appendix H.4 *continued*

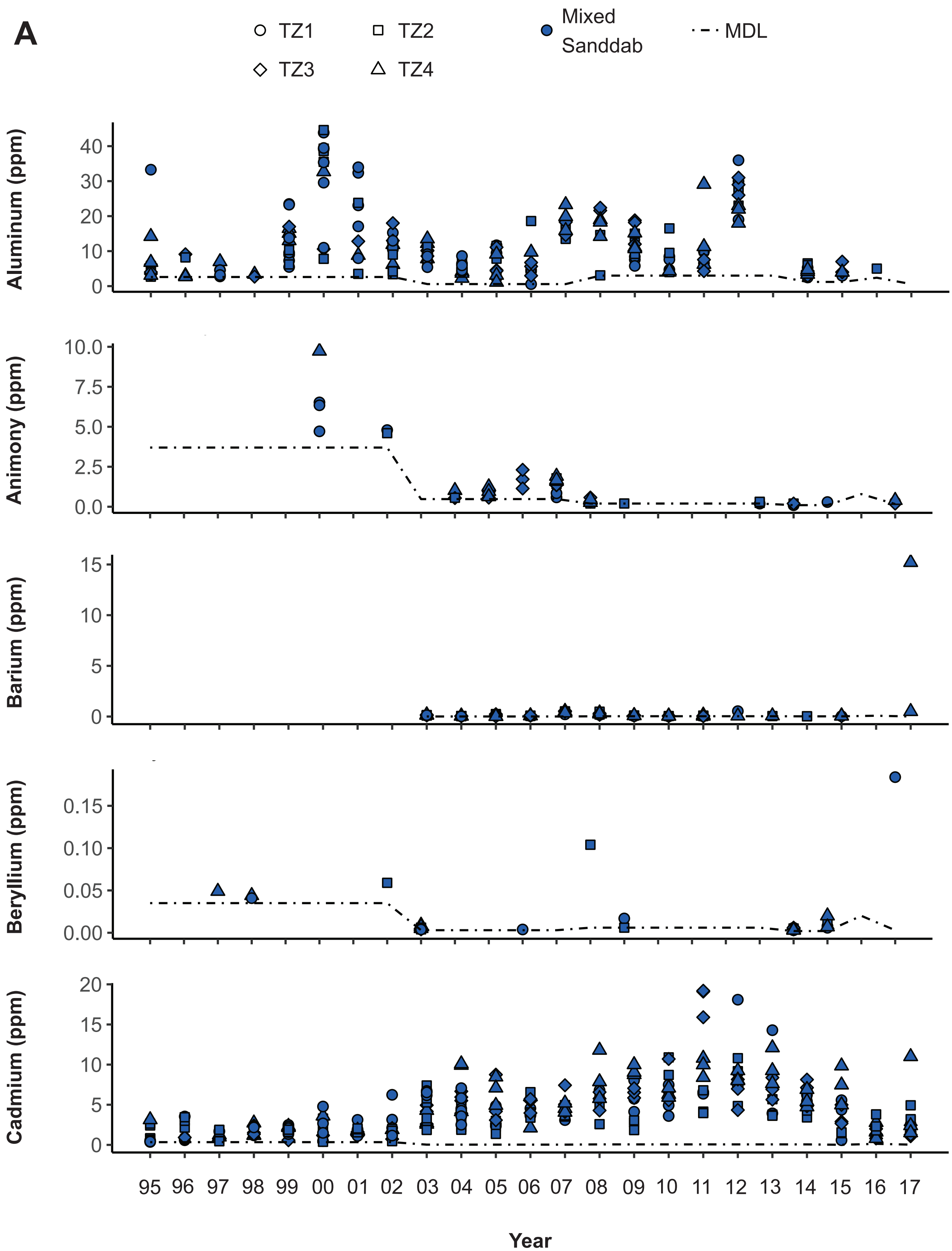
Year	Zone	Station	Composite 1	Composite 2	Composite 3
2004	TZ7	SD21	Hornyhead Turbot	California Scorpionfish	Hornyhead Turbot
2004	TZ8	SD16	Hornyhead Turbot	Hornyhead Turbot	California Scorpionfish
2004	TZ9	SD15	Hornyhead Turbot	California Scorpionfish	California Scorpionfish
2005	RF3	RF3	Brown Rockfish	Vermilion Rockfish	Vermilion Rockfish
2005	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2005	TZ5	SD17	Hornyhead Turbot	Hornyhead Turbot	California Scorpionfish
2005	TZ5	SD18	Hornyhead Turbot	California Scorpionfish	California Scorpionfish
2005	TZ6	SD19	California Scorpionfish	Hornyhead Turbot	California Scorpionfish
2005	TZ6	SD20	Hornyhead Turbot	Hornyhead Turbot	Hornyhead Turbot
2005	TZ7	SD21	Hornyhead Turbot	California Scorpionfish	California Scorpionfish
2005	TZ8	SD16	Hornyhead Turbot	California Scorpionfish	California Scorpionfish
2005	TZ9	SD15	California Scorpionfish	California Scorpionfish	California Scorpionfish
2006	RF3	RF3	Mixed Rockfish	Mixed Rockfish	Brown Rockfish
2006	RF4	RF4	Mixed Rockfish	Honeycomb Rockfish	Treefish
2006	TZ5	SD17	California Scorpionfish	California Scorpionfish	Hornyhead Turbot
2006	TZ5	SD18	California Scorpionfish	Hornyhead Turbot	Hornyhead Turbot
2006	TZ6	SD19	Hornyhead Turbot	Hornyhead Turbot	Longfin Sanddab
2006	TZ6	SD20	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2006	TZ7	SD21	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2006	TZ8	SD16	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2006	TZ9	SD15	Hornyhead Turbot	Pacific Sanddab	Hornyhead Turbot
2007	RF3	RF3	Brown Rockfish	Vermilion Rockfish	Mixed Rockfish
2007	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2007	TZ5	SD17	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
2007	TZ5	SD18	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
2007	TZ6	SD19	Longfin Sanddab	Hornyhead Turbot	Longfin Sanddab
2007	TZ6	SD20	Longfin Sanddab	California Scorpionfish	California Scorpionfish
2007	TZ7	SD21	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2007	TZ8	SD16	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2007	TZ9	SD15	Hornyhead Turbot	no sample	no sample
2008	RF3	RF3	Brown Rockfish	Brown Rockfish	Brown Rockfish
2008	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2008	TZ5	SD17	Hornyhead Turbot	Longfin Sanddab	California Scorpionfish
2008	TZ5	SD18	Hornyhead Turbot	Longfin Sanddab	Longfin Sanddab
2008	TZ6	SD19	Hornyhead Turbot	Longfin Sanddab	Longfin Sanddab
2008	TZ6	SD20	Hornyhead Turbot	Longfin Sanddab	Longfin Sanddab
2008	TZ7	SD21	Longfin Sanddab	Hornyhead Turbot	California Scorpionfish
2008	TZ9	SD15	Hornyhead Turbot	no sample	no sample
2009	RF3	RF3	Brown Rockfish	Brown Rockfish	Mixed Rockfish
2009	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2009	TZ5	SD17	Hornyhead Turbot	California Scorpionfish	Hornyhead Turbot
2009	TZ5	SD18	Hornyhead Turbot	Hornyhead Turbot	California Scorpionfish
2009	TZ6	SD19	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab

Appendix H.4 *continued*

Year	Zone	Station	Composite 1	Composite 2	Composite 3
2009	TZ6	SD20	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
2009	TZ7	SD21	Hornyhead Turbot	Hornyhead Turbot	California Scorpionfish
2009	TZ8	SD16	Hornyhead Turbot	Longfin Sanddab	Longfin Sanddab
2009	TZ9	SD15	Hornyhead Turbot	no sample	no sample
2010	RF3	RF3	Brown Rockfish	Brown Rockfish	Brown Rockfish
2010	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2010	TZ5	SD17	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
2010	TZ5	SD18	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2010	TZ6	SD19	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2010	TZ6	SD20	Longfin Sanddab	Longfin Sanddab	no sample
2010	TZ7	SD21	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
2010	TZ8	SD16	Longfin Sanddab	English Sole	Longfin Sanddab
2010	TZ9	SD15	Hornyhead Turbot	English Sole	California Scorpionfish
2011	RF3	RF3	Brown Rockfish	Vermilion Rockfish	Mixed Rockfish
2011	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2011	TZ5	SD17	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2011	TZ5	SD18	Hornyhead Turbot	Hornyhead Turbot	Hornyhead Turbot
2011	TZ6	SD19	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2011	TZ6	SD20	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2011	TZ7	SD21	Hornyhead Turbot	Longfin Sanddab	Longfin Sanddab
2011	TZ8	SD16	Hornyhead Turbot	Hornyhead Turbot	Longfin Sanddab
2011	TZ9	SD15	Hornyhead Turbot	Hornyhead Turbot	Pacific Sanddab
2012	RF3	RF3	Vermilion Rockfish	Vermilion Rockfish	Vermilion Rockfish
2012	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2012	TZ5	SD17	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2012	TZ5	SD18	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2012	TZ6	SD19	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2012	TZ6	SD20	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
2012	TZ7	SD21	Hornyhead Turbot	Hornyhead Turbot	Longfin Sanddab
2012	TZ8	SD16	Longfin Sanddab	Hornyhead Turbot	Hornyhead Turbot
2012	TZ9	SD15	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2013	RF3	RF3	Vermilion Rockfish	Mixed Rockfish	Mixed Rockfish
2013	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2013	TZ5	SD17	Hornyhead Turbot	Hornyhead Turbot	Hornyhead Turbot
2013	TZ5	SD18	Hornyhead Turbot	Hornyhead Turbot	Longfin Sanddab
2013	TZ6	SD19	Hornyhead Turbot	Longfin Sanddab	Longfin Sanddab
2013	TZ6	SD20	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2013	TZ7	SD21	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2013	TZ8	SD16	Longfin Sanddab	Hornyhead Turbot	Longfin Sanddab
2013	TZ9	SD15	Hornyhead Turbot	Hornyhead Turbot	Hornyhead Turbot
2014	RF3	RF3	Vermilion Rockfish	Vermilion Rockfish	California Scorpionfish
2014	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2014	TZ5	SD17	Hornyhead Turbot	Hornyhead Turbot	no sample

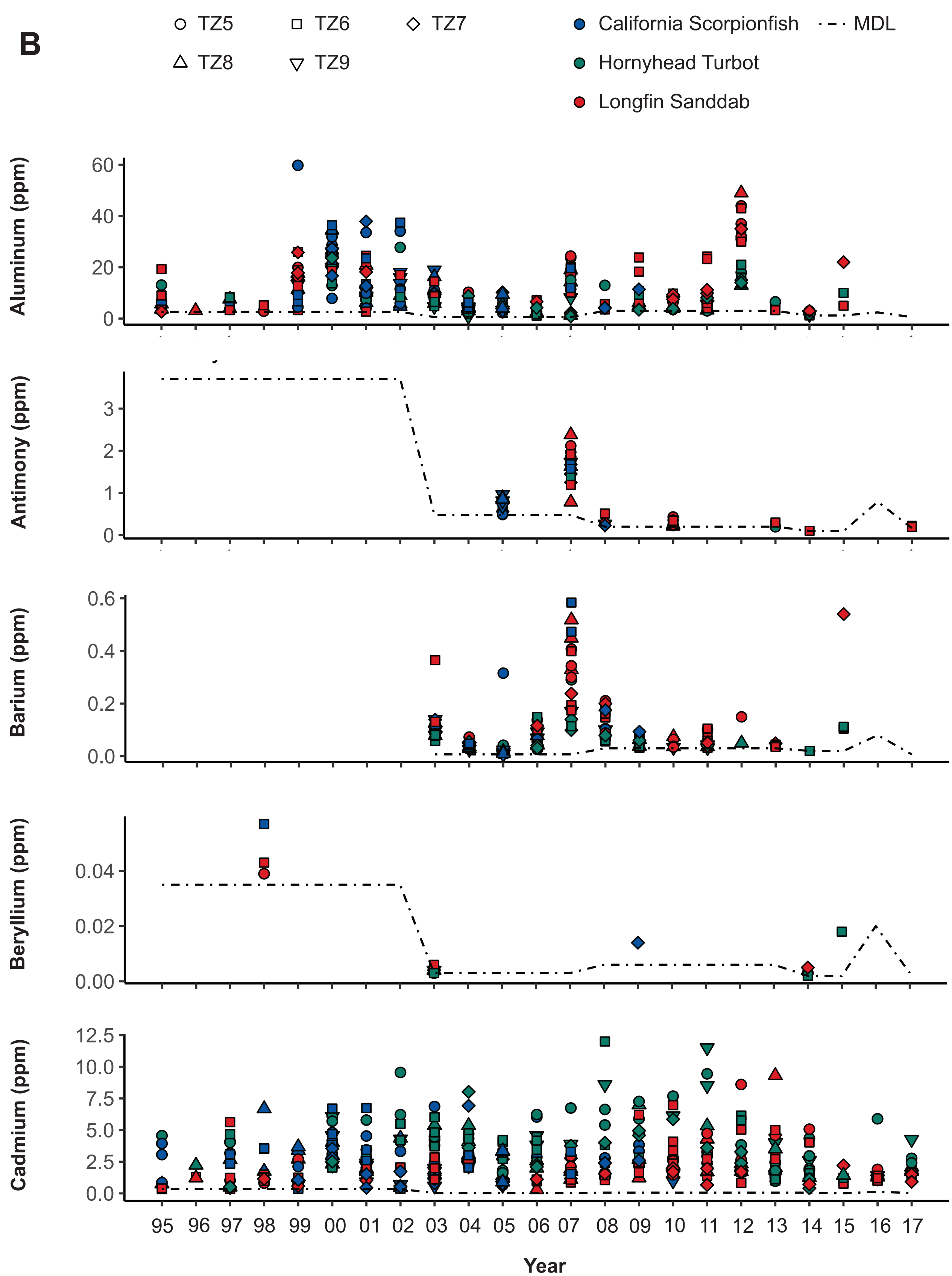
Appendix H.4 *continued*

Year	Zone	Station	Composite 1	Composite 2	Composite 3
2014	TZ5	SD18	Hornyhead Turbot	Hornyhead Turbot	Longfin Sanddab
2014	TZ6	SD19	Hornyhead Turbot	no sample	no sample
2014	TZ6	SD20	Longfin Sanddab	Hornyhead Turbot	no sample
2014	TZ7	SD21	Hornyhead Turbot	Hornyhead Turbot	Longfin Sanddab
2014	TZ8	SD16	Hornyhead Turbot	no sample	no sample
2014	TZ9	SD15	Hornyhead Turbot	no sample	no sample
2015	RF3	RF3	Squarespot Rockfish	California Scorpionfish	Mixed Rockfish
2015	RF4	RF4	Treefish	Gopher Rockfish	Gopher Rockfish
2015	TZ5	TZ5	Longfin Sanddab	Fantail Sole	no sample
2015	TZ6	TZ6	Longfin Sanddab	Fantail Sole	Hornyhead Turbot
2015	TZ7	TZ7	Fantail Sole	Hornyhead Turbot	Longfin Sanddab
2015	TZ8	TZ8	Fantail Sole	Fantail Sole	Hornyhead Turbot



Appendix H.5

Concentrations of select metals in liver tissues of fishes collected from PLOO (A,C,E) and SBOO (B,D,F) trawl zones from 1995 through 2017. Zones TZ1 and TZ5 are considered nearfield stations.



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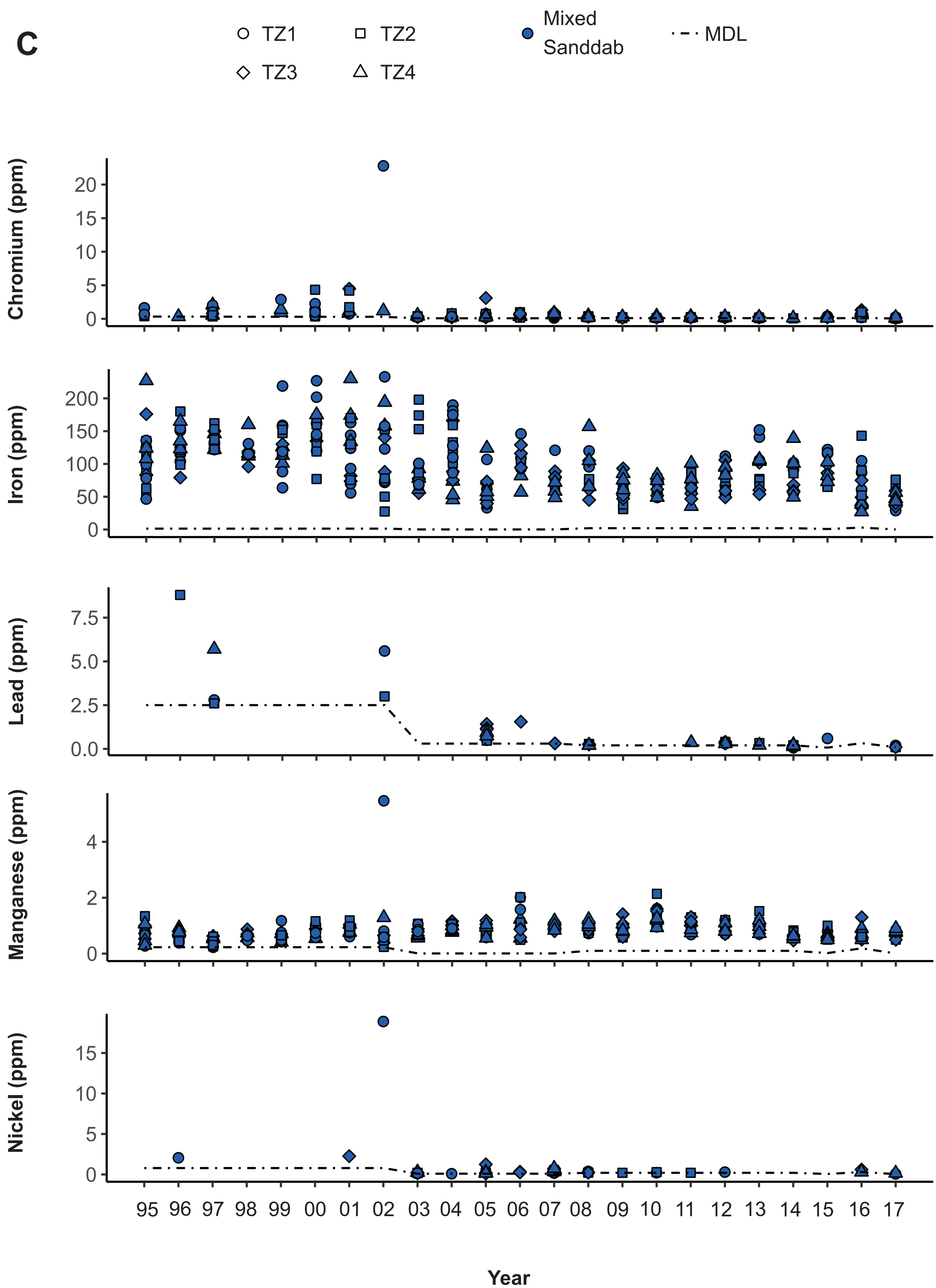

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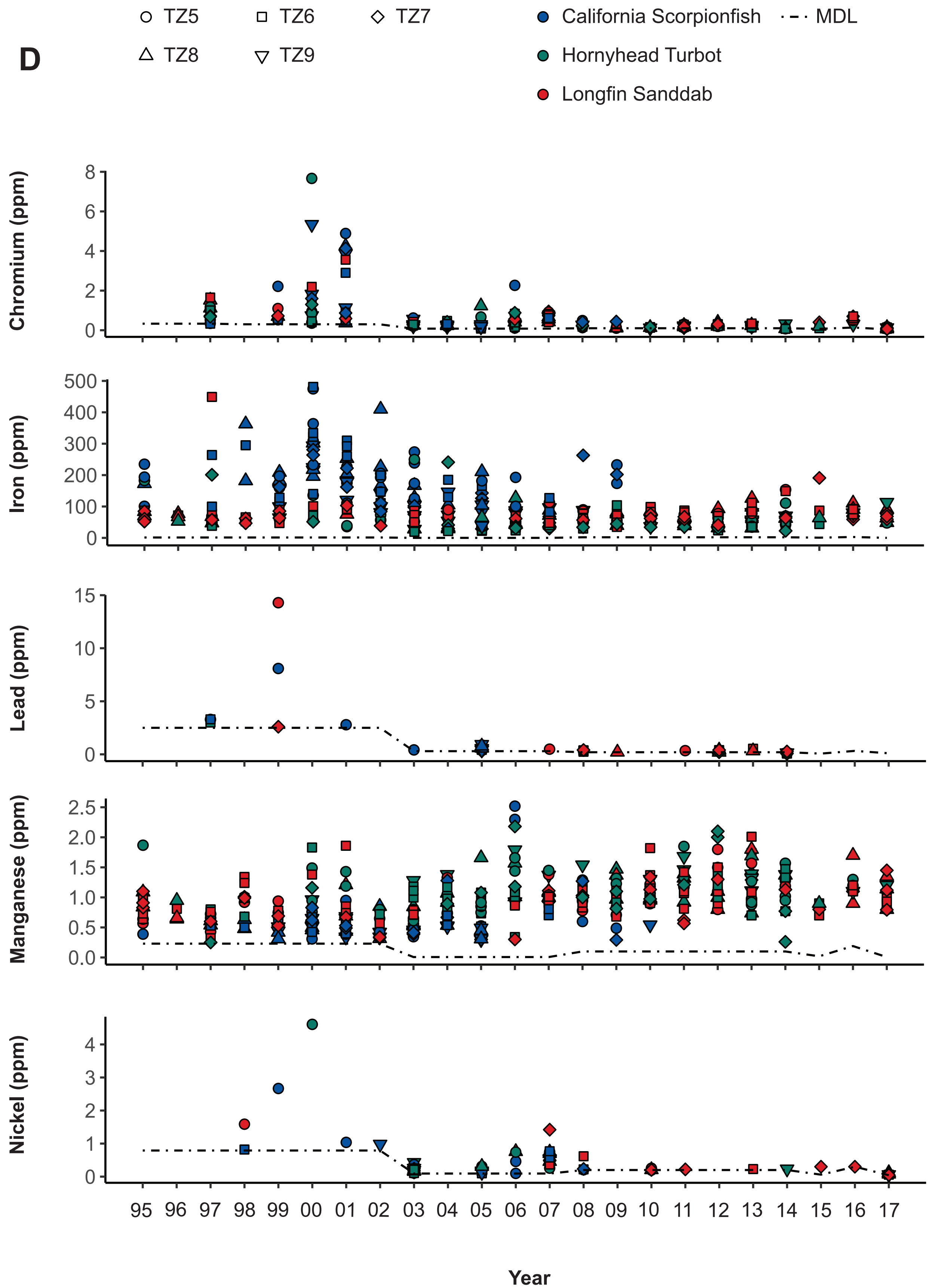

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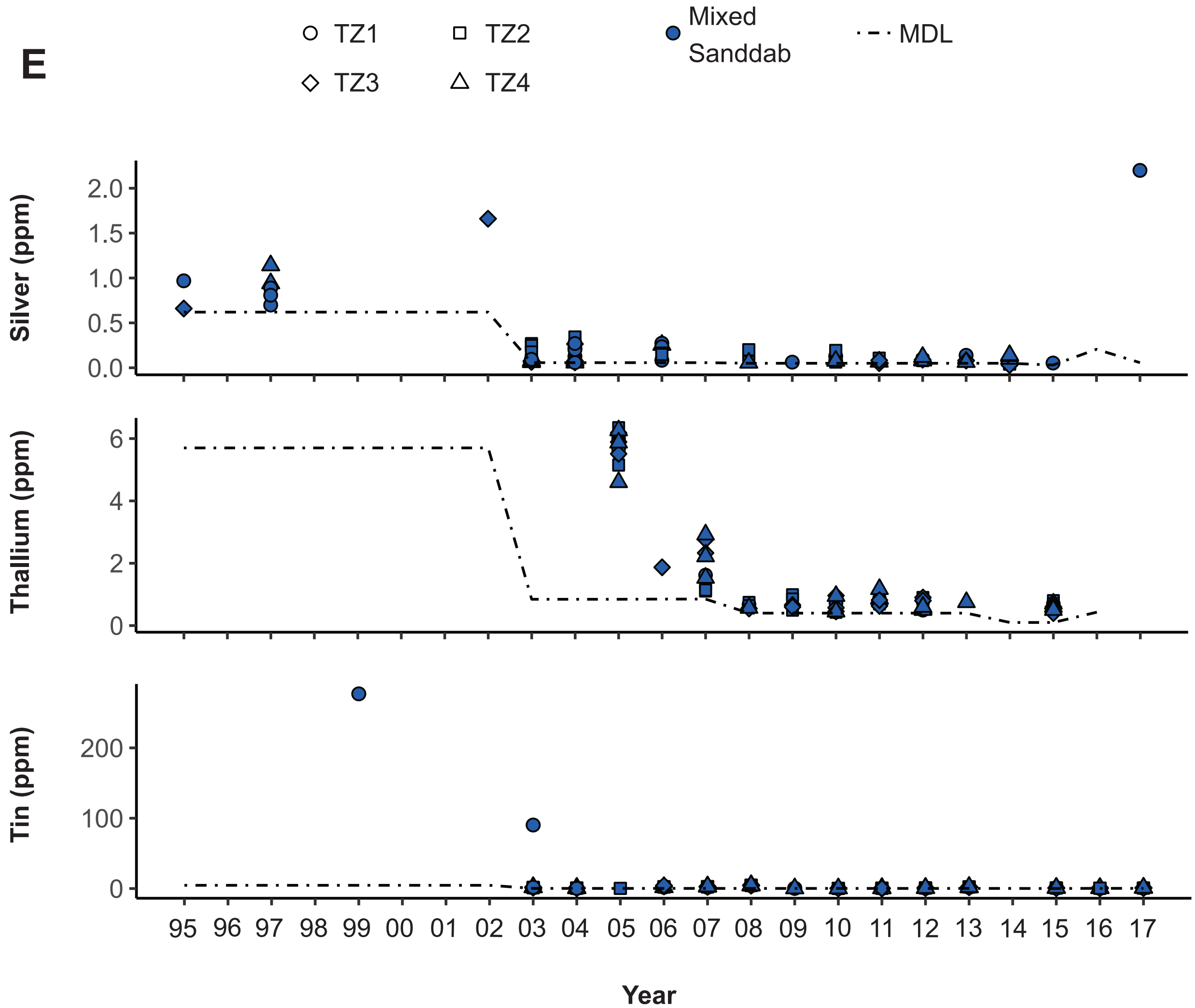

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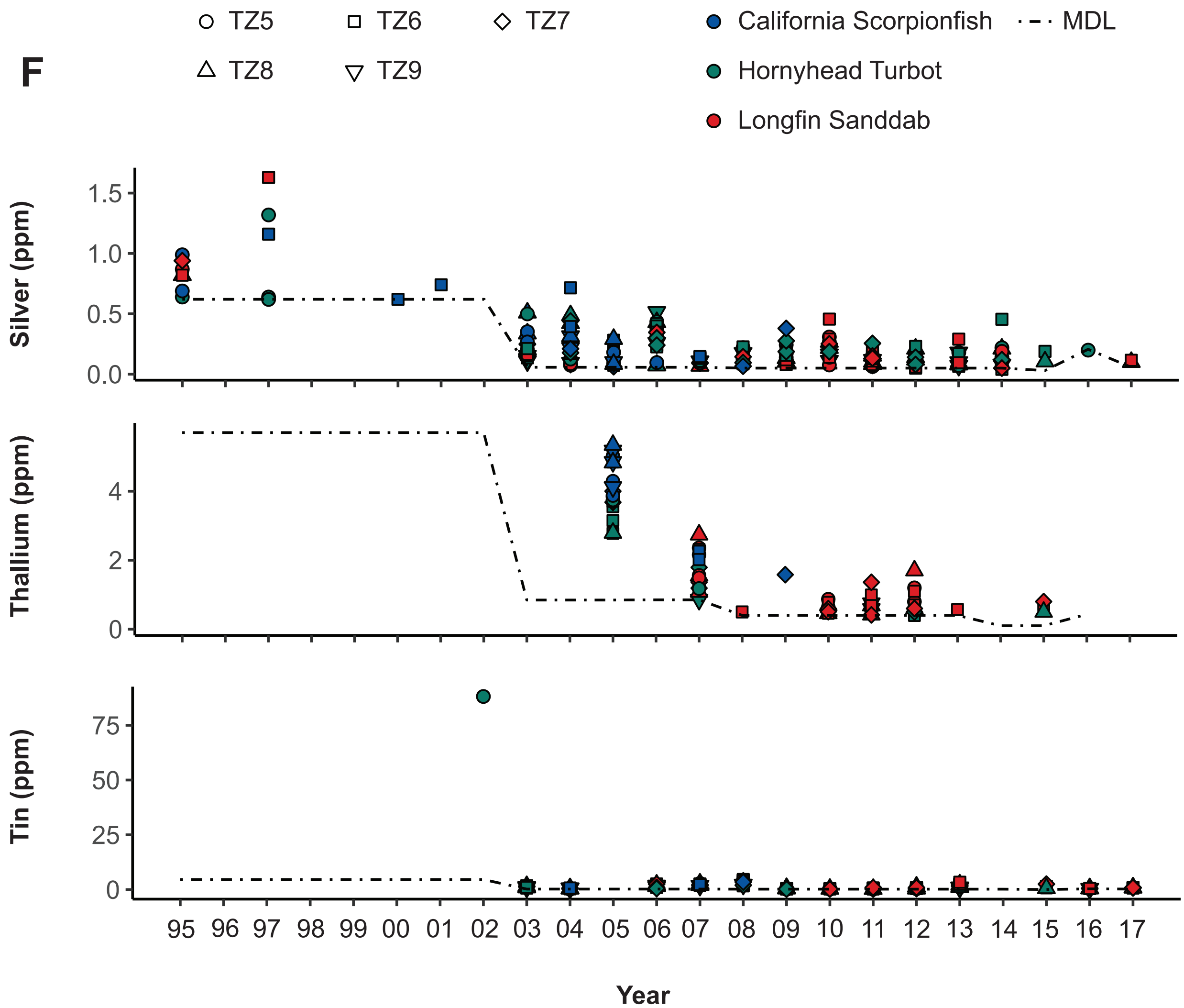

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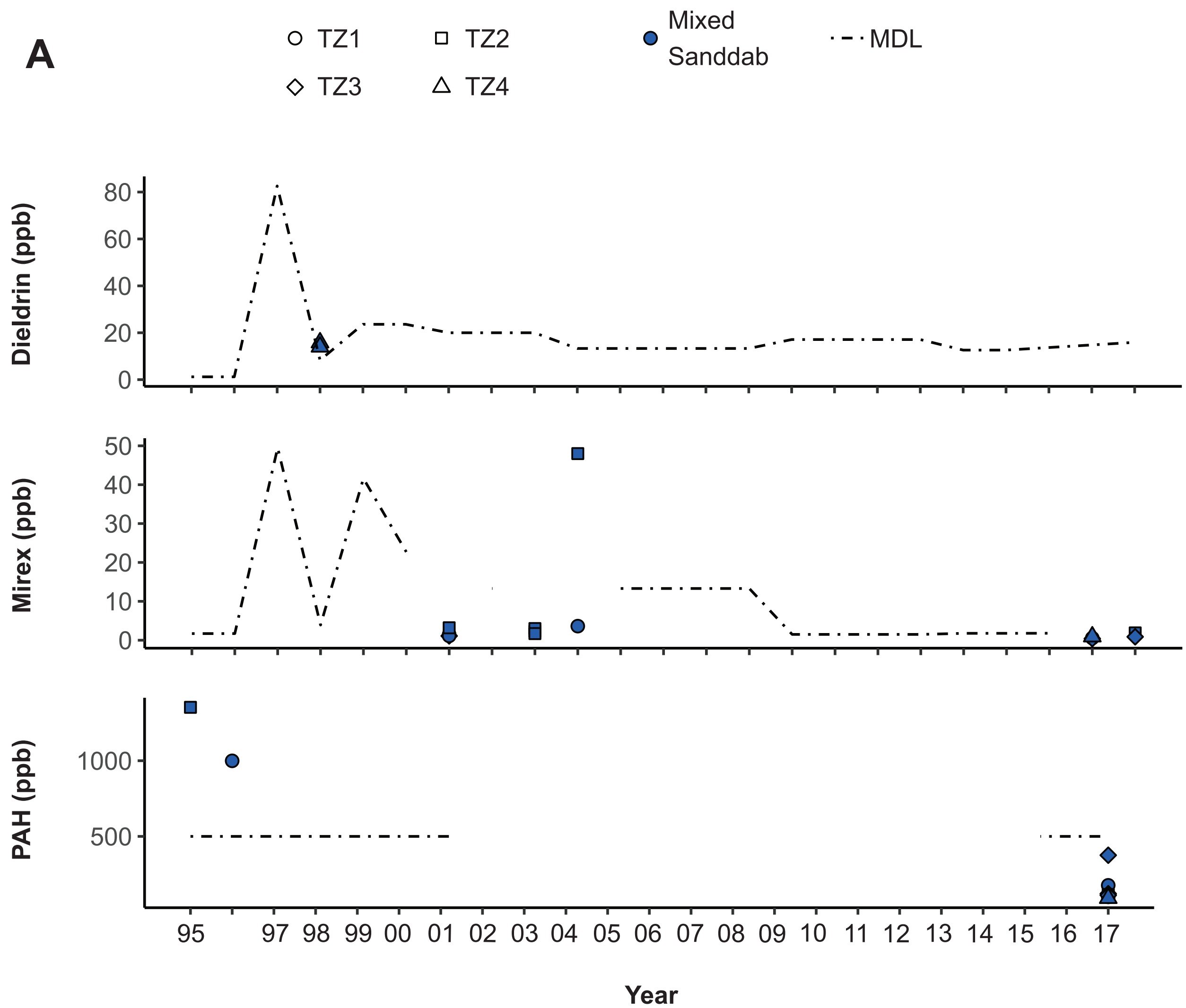
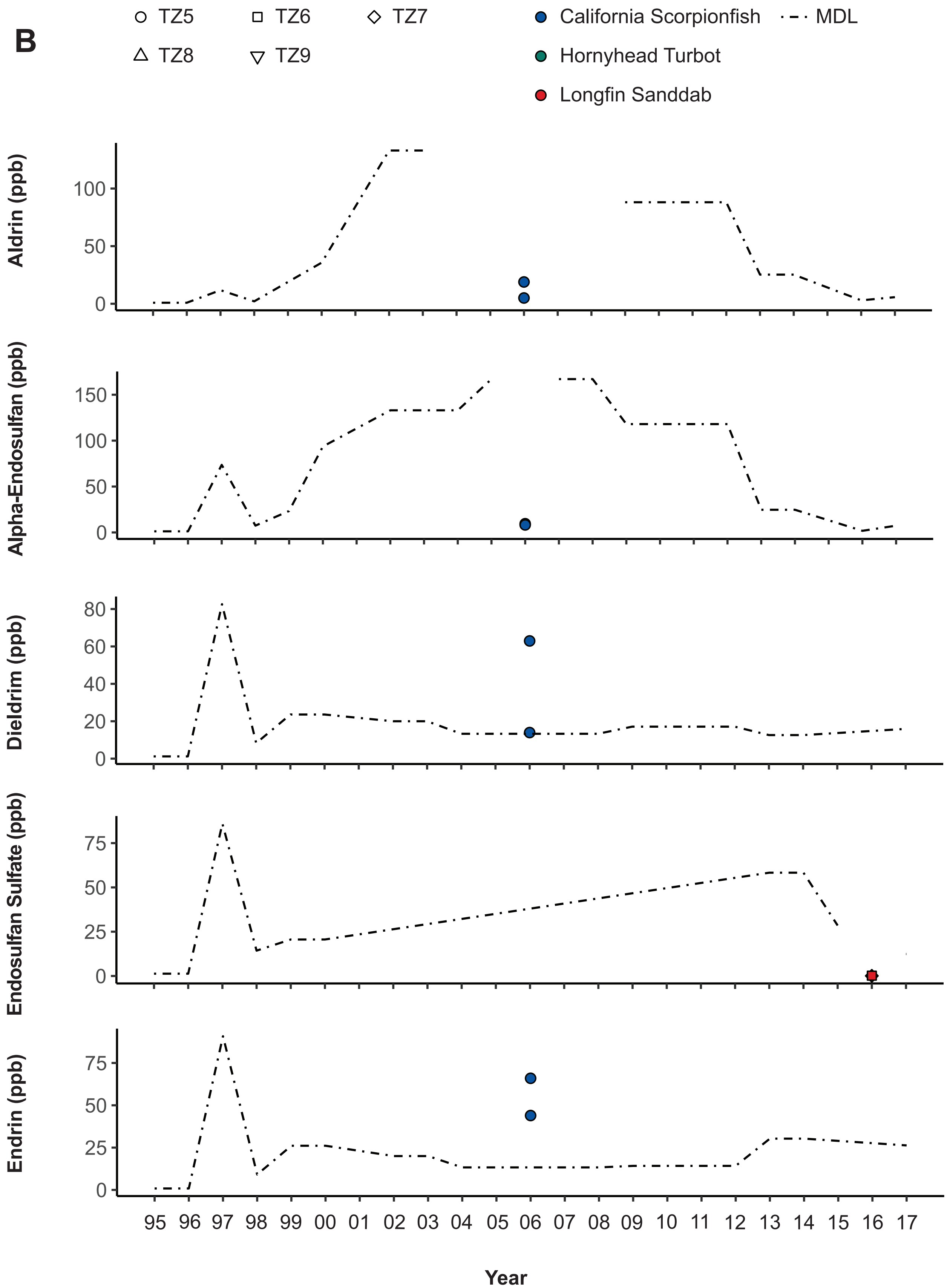
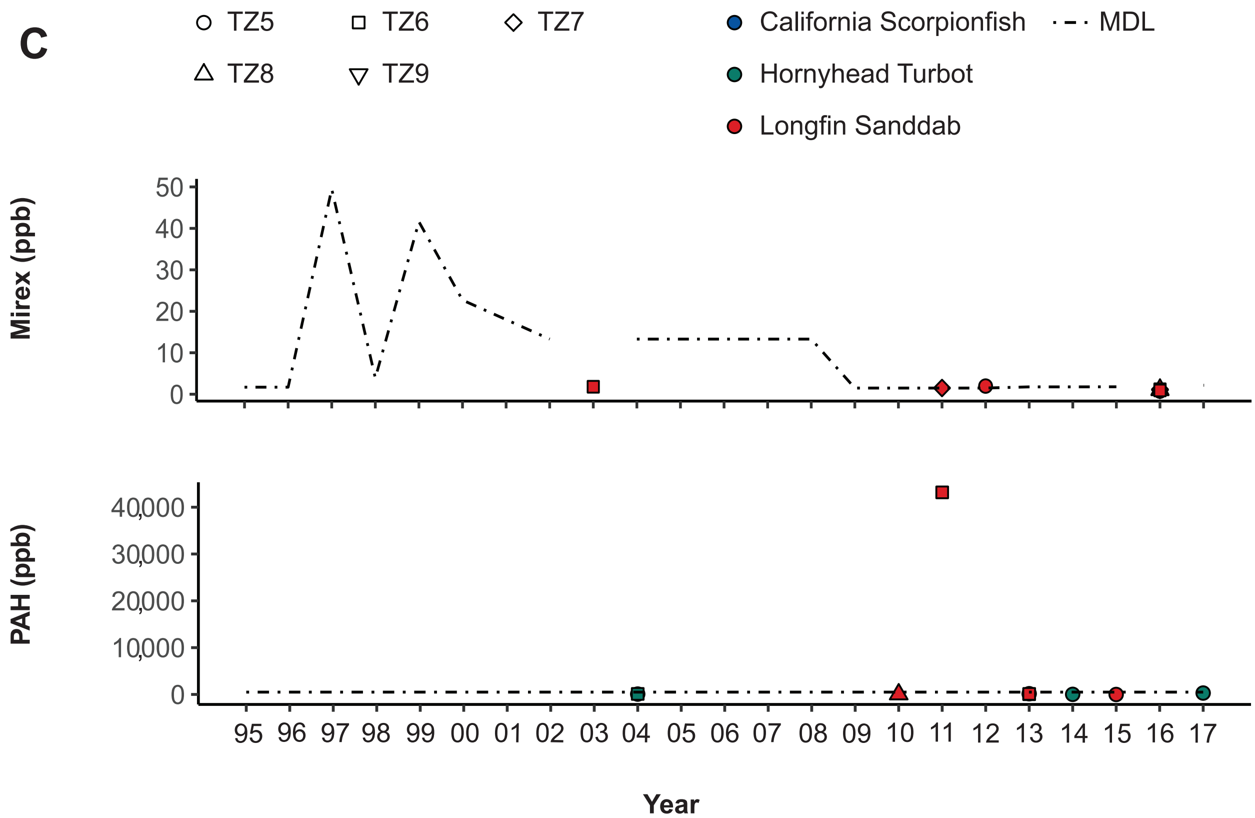


Appendix H.6

Concentrations of pesticides and total PAH in liver tissues of fishes collected from PLOO (A) and SBOO (B, C) trawl zones from 1995 through 2017. Zones TZ1 and TZ5 are considered nearfield stations. PAHs were not analyzed for samples from PLOO zones between 2003 and 2016.



Appendix H.6 *continued*



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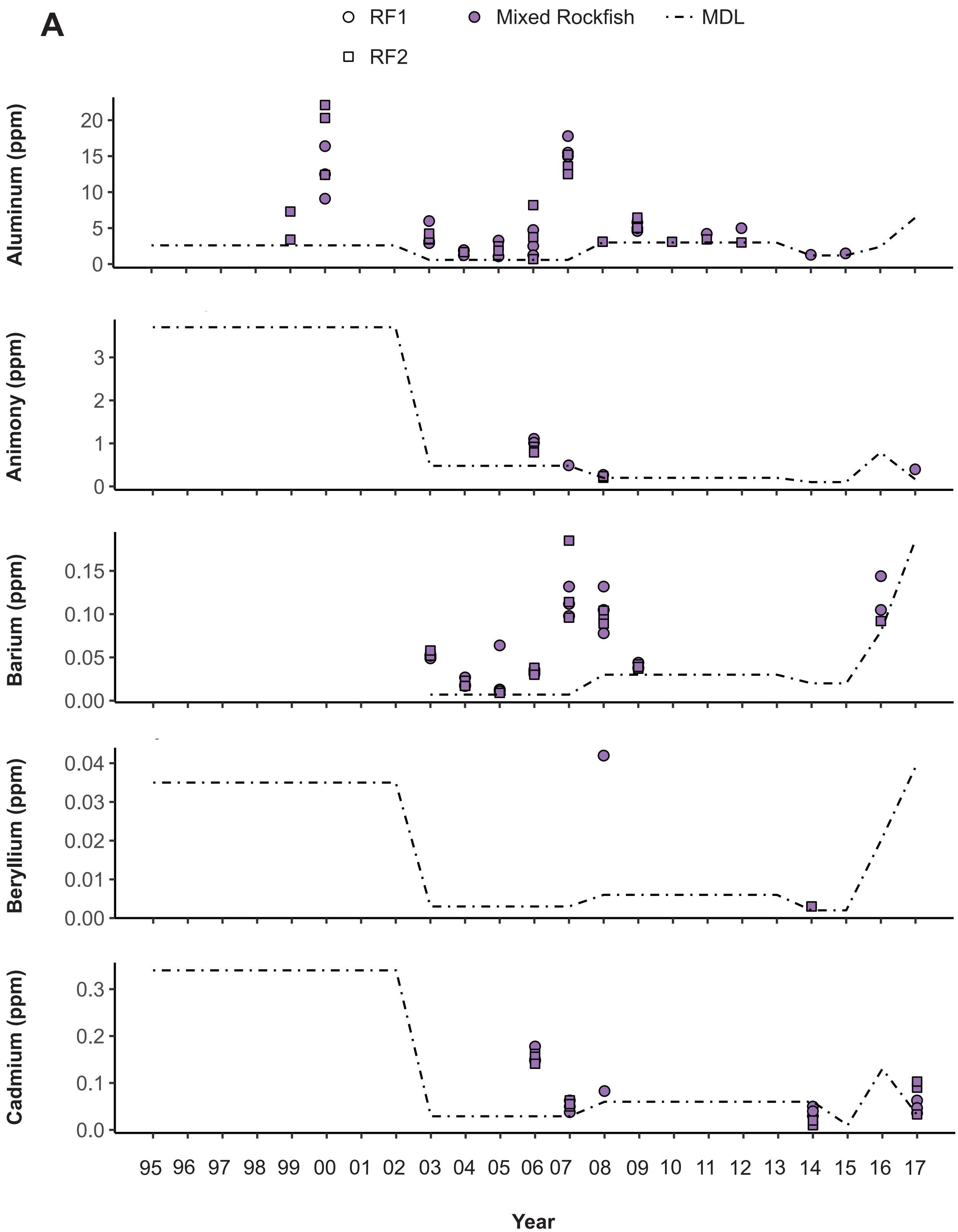
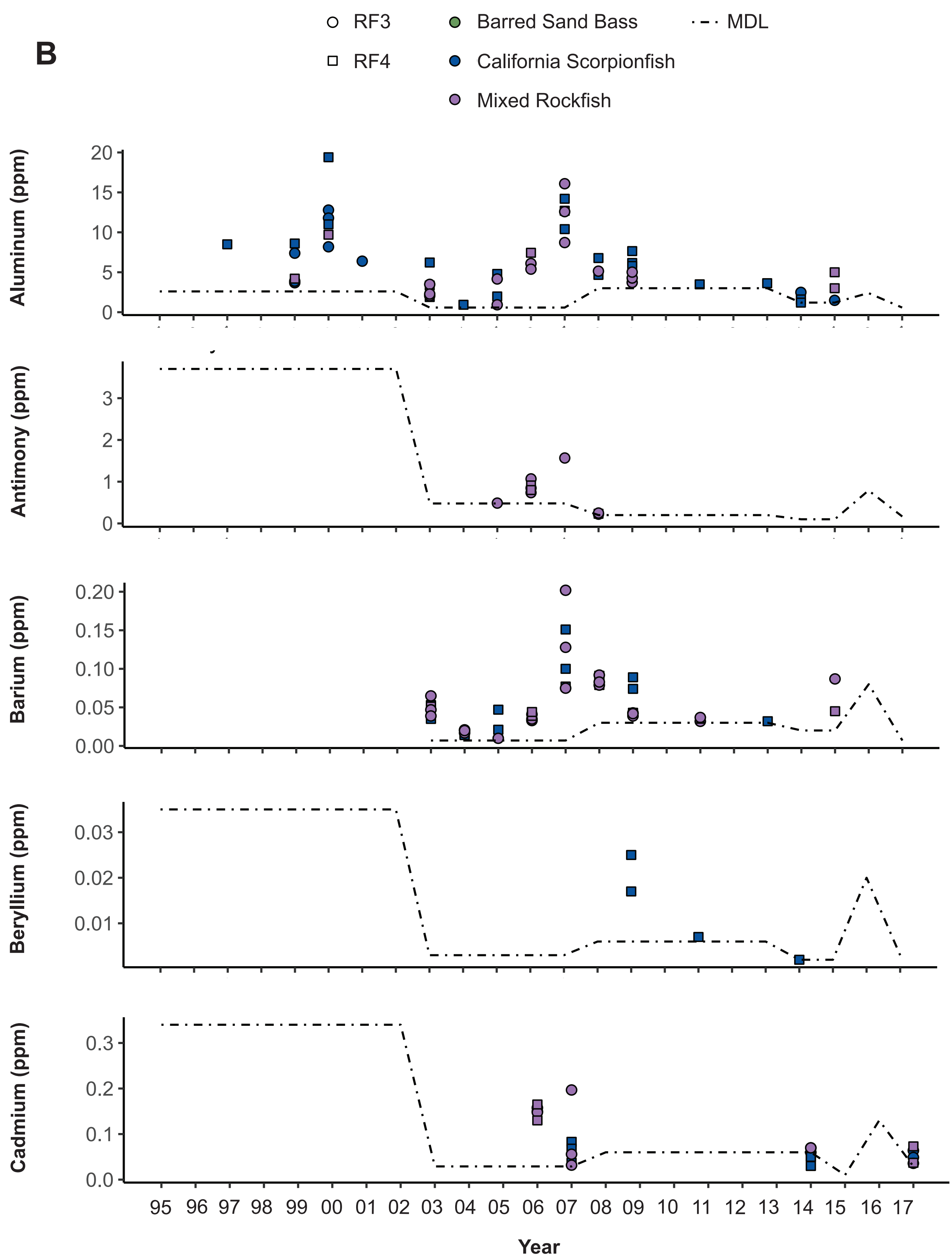


Appendix H.7

Concentrations of select metals in muscle tissues of fishes collected from PLOO (A,C,E) and SBOO (B,D,F) rig fishing zones from 1995 through 2017. Zones RF1 and RF3 are considered nearfield stations.



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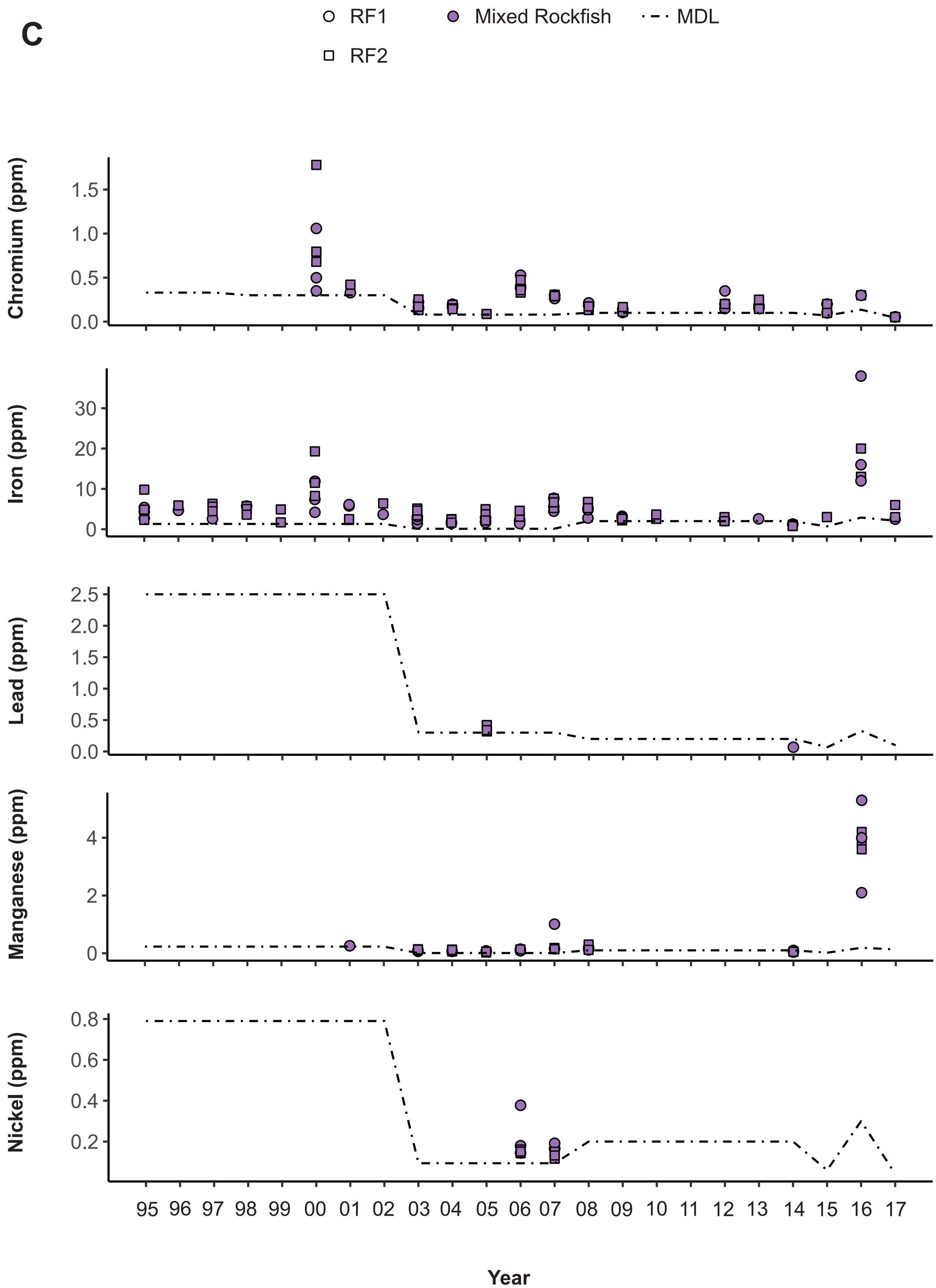
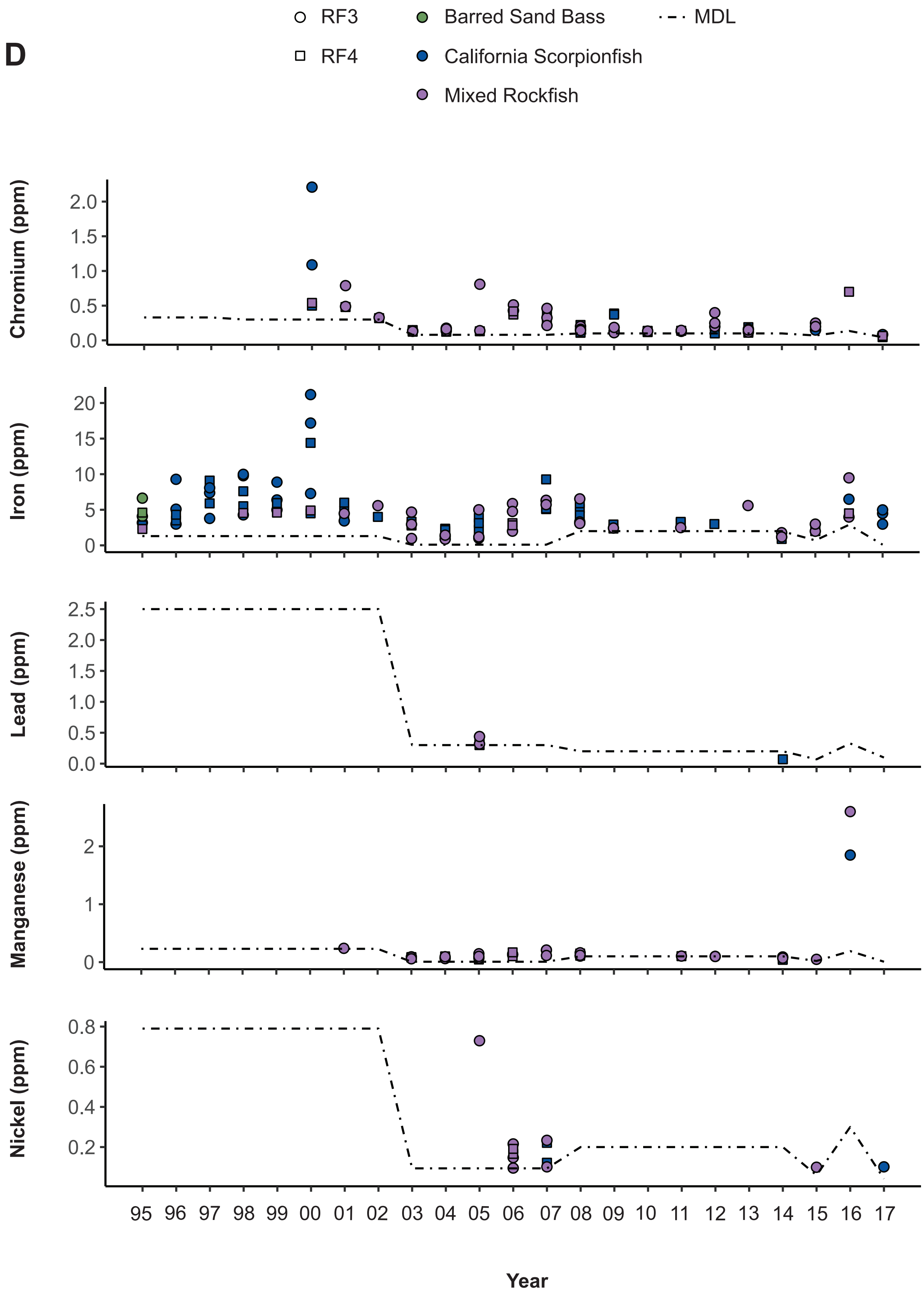


Appendix H.7 *continued*

D



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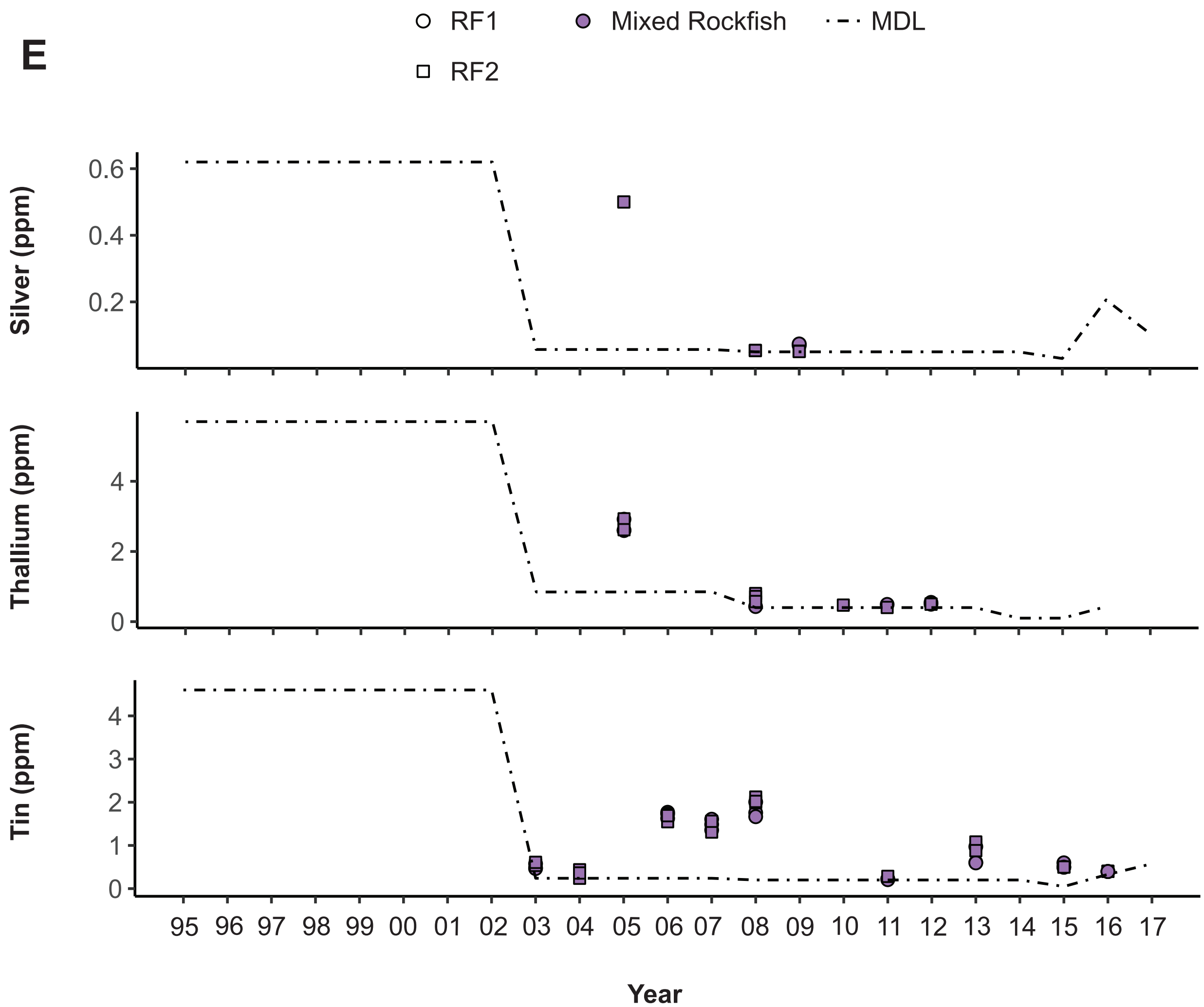

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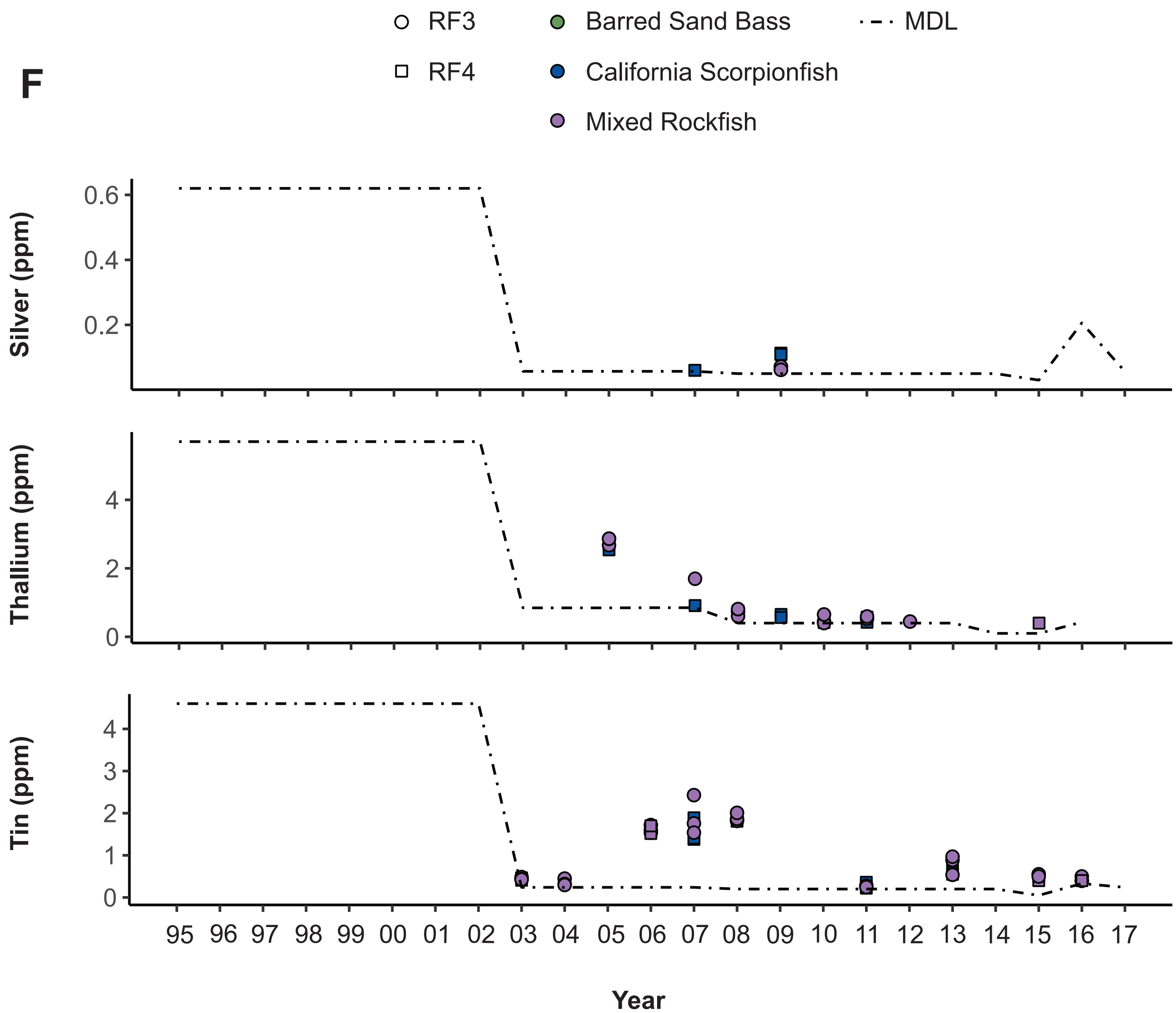

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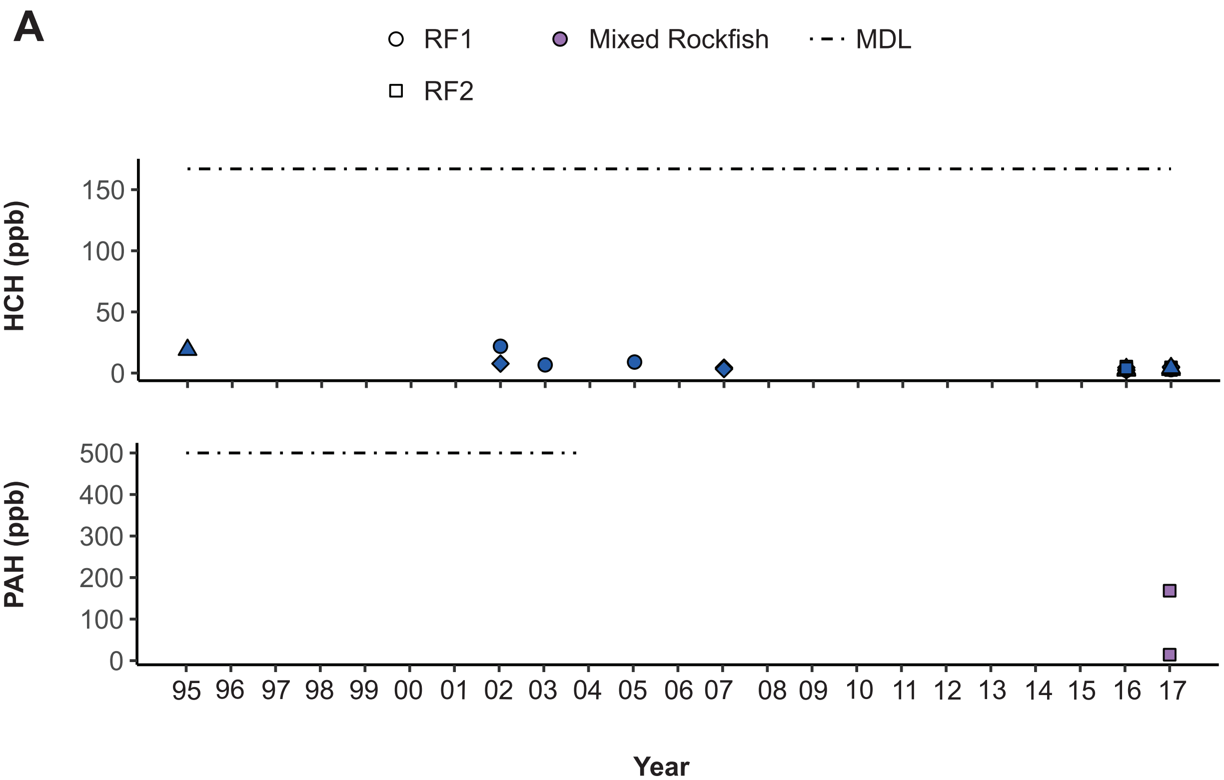
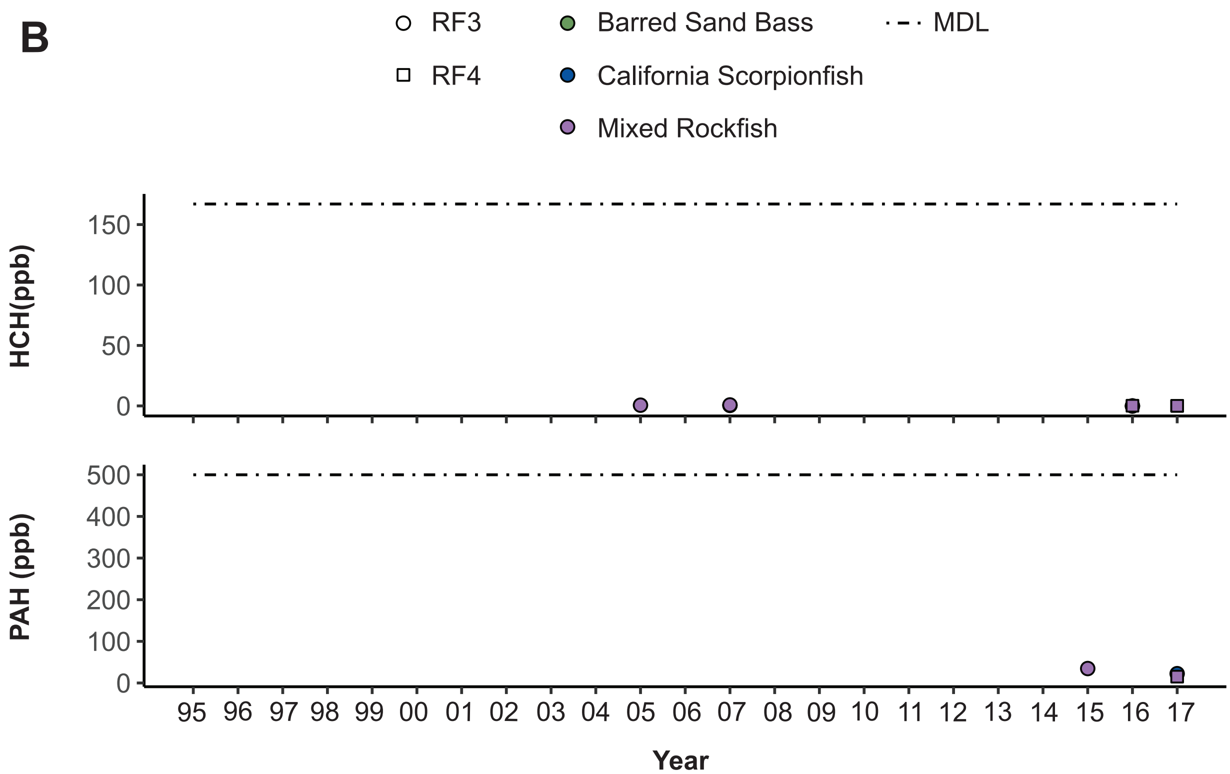


Appendix H.8

Concentrations of total HCH and total PAH in muscle tissues of fishes collected from PLOO (A) and SBOO (B) rig fishing zones from 1995 through 2017. Zones RF1 and RF3 are considered nearfield stations. PAHs were not analyzed for samples from PLOO zones between 2003 and 2016.



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