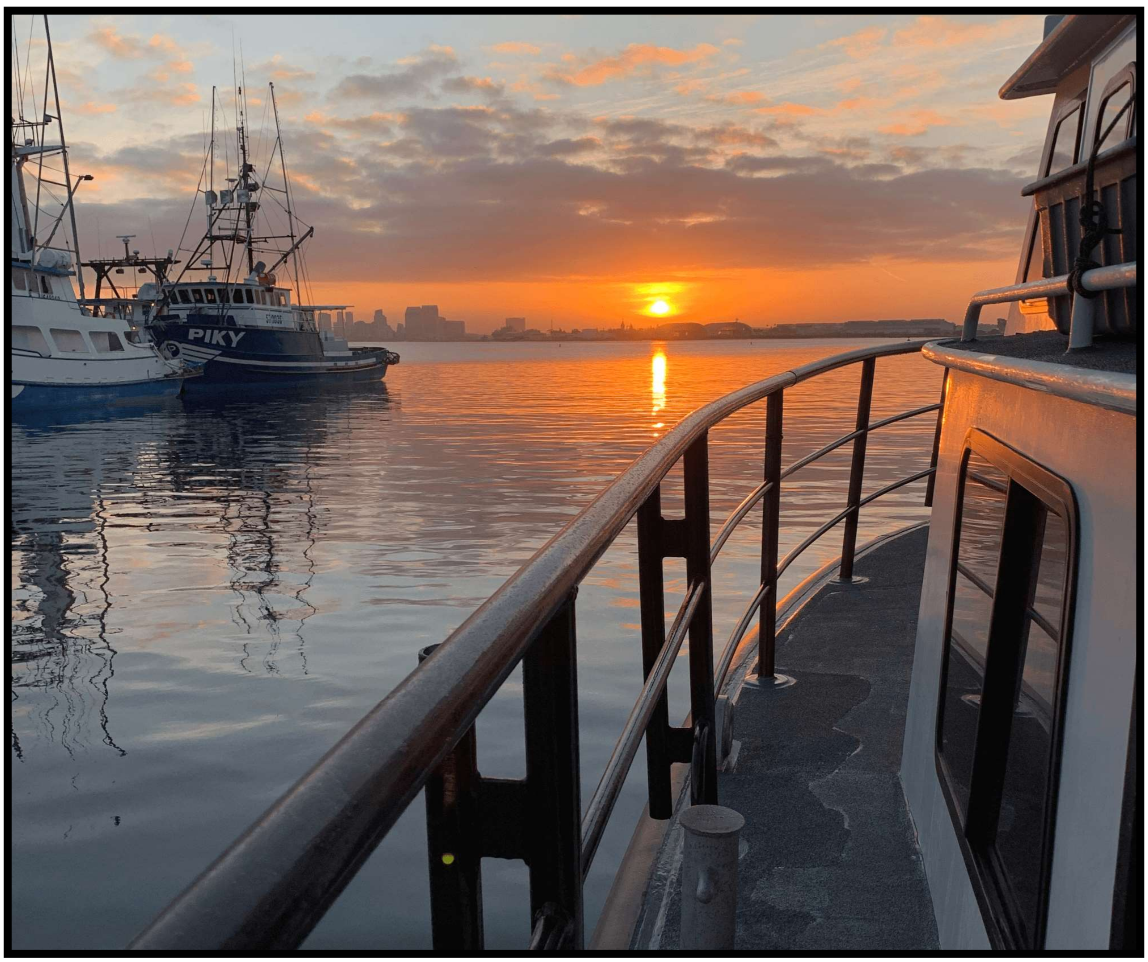
SD Public Utilities

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

2018–2019



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

March 1, 2021

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 2018-2019 Biennial Receiving Waters Monitoring and Assessment Report for the Point Loma and South Bay Ocean Outfalls, revised to address data integrity issues identified to the Board in the letter dated October 22, 2020, subject: "San Diego NPDES Shoreline Sampling Program Report." Specifically, fecal indicator data from 62 problematic sea water samples have been removed from analyses presented in *Chapter 3. Water Quality Compliance and Plume Dispersion*, its associated addendum, and the *Executive Summary*. All other sections of this report were unaffected, and therefore remain identical to the report previously submitted.

This report meets requirements set forth in the following Orders/Permits: 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) for the City's South Bay Water Reclamation Plant (NPDES No. CA0109045); Order R9-2014-0009 (as amended) for the United States Section of the International Boundary and Water Commission's South Bay International Wastewater Treatment Plant (NPDES No. CA0108928).

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.

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

Sincerely,

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

RK/akl

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

SD Public Utilities

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2018–2019

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)

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Environmental Monitoring & Technical Services Division, Public Utilities Department

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June 2020

Revised February 2021

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City research vessel *Oceanus* headed out to sea at daybreak. Photo taken by Lauren Valentino.

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 upon request.

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Acronyms and Abbreviations

Abun	Abundance
AL	USFDA Action Limits
ADCP	Acoustic Doppler Current Profiler
ANOSIM	Analysis of Similarity
APHA	American Public Health Association
BF	Buoyancy Frequency
BM	Biomass
BOD	Biochemical Oxygen Demand
BRI	Benthic Response Index
BSQPC	B'18 Sediment Quality Planning Committee
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
CI	Confidence Interval
CLA	City of Los Angeles
cm	centimeter
CSDTL	City of San Diego Toxicity Laboratory
CTD	Conductivity, Temperature, Depth instrument
DDT	Dichlorodiphenyltrichloroethane
dp/dz	density gradient
DO	dissolved Oxygen
DR	Detection Rate
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 Median
F:T	Fecal to Total coliform ratio
FIB	Fecal Indicator Bacteria
FTR	Fecal to Total coliform Ratio criterion
g	gram
H'	Shannon diversity index
HCB	Hexachlorobenzene
HCH	Hexachlorocylclohexane
in	inches
IS	International Standard
J'	Pielou's evenness index
kg	kilogram
km	kilometer
km^2	square kilometer
L	Liter

Acronyms and Abbreviations

LACSD	Los Angeles County Sanitation District
LJKF	La Jolla Kelp Forest
m	meter
m^2	square meter
MDL	Method Detection Limit
MEI	Multivariate ENSO Index
mg	milligram
mgd	millions of gallons per day
MIS	Median International Standard
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
nd	not detected
ng	nanograms
nMDS	non-metric Multidimensional Scaling
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPGO	North Pacific Gyre Oscillation
ns	not sampled
NWS	National Weather Service
OCSD	Orange County Sanitation District
OEHHA	California Office of Environmental Health Hazard Assessment
OI	Ocean Imaging
OMP	Ocean Monitoring Program
ONI	Oceanic Nino Index
OOR	Out-of-range
p	probability
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PDO	Pacific Decadal Oscillation
pH	Acidity/Alkalinity value
PLKF	Point Loma Kelp Forest
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
RF	Rig Fishing

Acronyms and Abbreviations

RTOMS	Real-Time Oceanographic Mooring System
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
SCAMIT	Southern California Association of Marine Invertebrate Taxonomists
SCB	Southern California Bight
SCBPP	Southern California Bight Pilot Project
SCCWRP	Southern California Coastal Water Research Project
SD	Standard Deviation
SDRWQCB	San Diego Regional Water Quality Control Board
SIMPER	Similarity Percentages Routine
SIMPROF	Similarity Profile Analysis
SIO	Scripps Institution of Oceanography
SL	Standard Length
sp	species (singular)
spp	species (plural)
SR	Species Richness
SSM	Single Sample Maximum
SWRCB	California State Water Resources Control Board
TL	Total Length
TN	Total Nitrogen
TOC	Total Organic Carbon
TSS	Total Suspended Solids
TVS	Total Volatile Solids
TZ	Trawl Zone
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
USGS	United States Geological Survey
USIBWC	U.S. Section of the International Boundary and Water Commission
WQ	Water Quality
wt	weight
XMS	Transmissivity
X^2	chi sq
ZID	Zone of Initial Dilution
µg	micrograms
µm	micrometer
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). Data collected are used to determine compliance with receiving water quality requirements as specified in National Pollutant Discharge Elimination System (NPDES) permits, and associated orders; These permits and orders are issued by the San Diego Regional Water Quality Control Board (SDRWQCB) and the U.S. Environmental Protection Agency (USEPA) for the City's Point Loma Wastewater Treatment Plant (PLWTP), South Bay Water Reclamation Plant (SBWRP), and the South Bay International Wastewater Treatment Plant (SBIWTP), which is operated by the U.S. Section of the International Boundary and Water Commission (USIBWC). Treated effluent from both the SBWRP and SBIWTP commingle before discharge to the ocean via the SBOO, thus a single monitoring and reporting program, approved by the SDRWQCB 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: (1) measure and document compliance with NPDES permit requirements and California Ocean Plan (Ocean Plan) water quality objectives and standards; (2) 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; (3) monitor natural spatial and temporal fluctuations of key oceanographic parameters, and evaluate the overall health and status of the San Diego marine environment.

Regular (core) monitoring was conducted on a weekly, quarterly, semiannual, and annual basis at a total of 142 discrete sites arranged in grids surrounding the PLOO and SBOO. The PLOO terminates at a discharge depth of around 100 m and is located approximately 7.2 km west of the PLWTP on the Point Loma peninsula. The SBOO terminates at a discharge depth of around 27 m and is 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 shoreline, and from the nearshore to offshore waters from depths of around 9 to 116 m. Core monitoring of shore stations in the SBOO region extends from Coronado, San Diego southward to Playa Blanca in northern Baja California, extending offshore from depths of around 9 to 55 m. In addition to monitoring at permanent core stations, an annual survey of benthic conditions (sediment quality, macrobenthic communities) is typically conducted each year at 40 randomly selected "regional" stations, which range from northern San Diego County southward to near the international border, extending offshore to depths of up to 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).

Results of all receiving waters monitoring activities conducted for the PLOO and SBOO regions, between January 1, 2018 through December 31, 2019, are presented in this report (Chapters 2–8, Appendices A–C), and supplemental analyses are included in Appendices D–J. Additionally, visual observations and raw data for 2019 are included in Addenda 1–8, while equivalent data for 2018 were submitted previously with the 2018 Interim Receiving Waters Monitoring Report for the Point Loma and South Bay Ocean Outfalls, which is 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 Coastal Oceanographic Conditions (see summary below) and water mass transport for the region are evaluated. Chapter 3 presents the results of shoreline and offshore Water Quality Compliance and Plume Dispersion, including measurements of fecal indicator bacteria and oceanographic data to evaluate potential movement and dispersal of the PLOO and SBOO wastefields (plumes), and to assess compliance with water contact standards defined in the Ocean Plan. Assessments of Regional Benthic Conditions, including 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 Megabenthic Invertebrates. Bioaccumulation assessments to measure Contaminants in Marine Fishes are presented in Chapter 8. In addition to the above activities, the City supports other projects relevant to assessing the status of receiving waters, including: (1) satellite imaging of the San Diego/Tijuana coastal region, of which the 2018–2019 results are discussed in Chapters 2 and 3; (2) ongoing long-term assessment of the health and status of San Diego's kelp forest ecosystems conducted by the Scripps Institution of Oceanography (SIO) and funded by the City, of which the most recent biennial report is included herein as Appendix A; (3) another collaboration with SIO to provide enhanced monitoring of local coastal ocean conditions and plume dispersion via Real Time Oceanographic Mooring Systems deployed at the terminal ends of the PLOO and SBOO, as described in Appendix B; (4) sediment toxicity testing conducted from 2016 through 2019 to evaluate the quality of benthic sediments off San Diego, the results of which are included as Appendix C. Summaries of the main findings for each of the core ocean monitoring components conducted by the City are included below.

Coastal Ocean Conditions

Oceanographic conditions, such as 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, resuspension 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 Compliance and Plume Dispersion

Ocean water quality was excellent in both the PLOO and SBOO regions. Compliance was very high for 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 wastewater plumes are likely to occur. Additionally, overall compliance with the Ocean Plan single sample maximum and geometric mean standards for fecal indicator bacteria (i.e., total coliforms, fecal coliforms, *Enterococcus*) was over 96% for all shore, kelp bed and other off shore stations located within California State waters. Compliance with these standards was typically a little higher at the PLOO stations than SBOO stations, and tended to be higher at the nearshore kelp bed and other offshore stations compared to those along the shoreline. 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 nearshore kelp beds. Results of water quality monitoring over the past 29 years off Point Loma, and 25 years in the South Bay, are consistent with observations from remote sensing studies (i.e., satellite imagery), which show a lack of shoreward transport of wastewater plumes from either outfall. This is further supported by previous studies, which 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, which indicate 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 found to be in good condition. The results of comprehensive assessments of benthic conditions at 89 different monitoring sites, including 49 core monitoring stations (see Chapter 4 and 5) and 40 "regional" stations sampled during the summer of 2019 (see Chapter 6), show that the physical composition of the sediments, sediment quality, and the ecological status of the resident macrofaunal communities remain stable, with little evidence of environmental impact. 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 concentration of key chemical contaminants, which is further supported by positive results from 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 2016–2019 revealed no toxicity at any of the core or regional stations tested during these four years.

Benthic macrofaunal communities off San Diego also appeared to be healthy, with most assemblages appearing to be similar to those observed in the region from 1991 through 2017, and throughout southern California and northern Baja California. Although communities varied across depth and sediment gradients, there was no evidence of disturbance or significant environmental degradation that could be attributed to anthropogenic factors, such as wastewater discharge. 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. 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, the Benthic Response Index (BRI) further confirmed no evidence of disturbance off San Diego (i.e., all stations had a BRI $\leq$34). 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 (SCB) is in good condition, based on BRI data.

Demersal Fishes and Megabenthic Invertebrates

Demersal fish and megabenthic invertebrate communities trawled off San Diego remain unaffected by wastewater discharge. Although highly variable, patterns in the abundance and distribution of individual species were similar regardless of proximity to the outfalls, and were representative of similar habitats throughout the SCB. Pacific Sanddab dominated fish assemblages surrounding the PLOO, and Speckled Sanddab dominated fish assemblages surrounding the SBOO, as they have since monitoring began in each region. Halfbanded Rockfish were also prevalent in PLOO assemblages, while California Lizardfish were prevalent in the SBOO region, as they have been in nine of the past eleven years. Other commonly captured, but less abundant fishes, collected from the PLOO and SBOO regions included California Halibut, California Tonguefish, Dover Sole, English Sole, Hornyhead Turbot, Longfin Sanddab, Longspine Combfish, Pink Seaperch, Plainfin Midshipman, Shortspine Combfish, Spotted Cusk-eel, and Stripetail Rockfish. Trawl-caught invertebrate assemblages were once again dominated by the pelagic red crab *Pleuroncodes planipes*, which accounted for 86% of the 66,194 megabenthic invertebrates recorded. These crabs were collected exclusively at PLOO trawl stations. In contrast to the PLOO region, no single species of invertebrate dominated SBOO trawls. Other commonly captured, but less abundant, trawl-caught invertebrates collected from the PLOO and SBOO regions included the sea urchin *Lytechinus pictus*, the shrimps *Sicyonia ingentis*, *S. penicillata*, *Crangon nigromaculata*, and *C. alaskensis*, the crab *Platymera gaudichaudii*, the sea cucumber *Apostichopus californicus* and the sea star *Astropecten californicus*. Finally, external examinations of fish captured indicated that fish populations remained healthy off San Diego, with less than 0.1% of all fish having external parasites or showing any evidence of disease or other abnormalities.

Contaminants in Marine 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 do not indicate any evidence to suggest that contaminant loads in fishes, collected from the PLOO or SBOO regions, were affected by wastewater discharge in either region. 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 influenced by 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 pathways 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 PLOO and SBOO monitoring regions, during 2018 and 2019, were consistent with previous years. There were few changes to local receiving waters, benthic sediments, or 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 SCB. 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 following: the Point Loma Wastewater Treatment Plant (PLWTP), the South Bay Water Reclamation Plant (SBWRP), and the South Bay International Wastewater Treatment Plant (SBIWTP), which is owned and operated by the U.S. Section of the International Boundary and Water Commission (USIBWC) (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. These requirements include 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.

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; (4) identify any biological, chemical or physical changes that may be associated with the outfalls and wastewater discharge. These data are used to evaluate and document any potential effects of wastewater discharge, or other anthropogenic inputs (e.g., storm water discharge, urban runoff), and natural influences (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 approximately 3.9 km west of the Point Loma peninsula at a depth of around 60 m. 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%, as 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. Currently, the PLOO extends approximately 7.2 km west of the PLWTP to a depth of around 94 m, where the main outfall pipe splits into a Y-shaped (wye) multiport diffuser

Table 1.1

NPDES permits and associated orders issued for the wastewater treatment plants run by the City of San Diego (PLWTP, SBWRP), and the USIBWC (SBIWTP).

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] Amended by Order Nos. R9-2014-0071 and R9-2017-0023

[b] Amended by Order Nos. R9-2014-0094, R9-2017-0024, and R9-2019-0012

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 2018–2019 was about 141 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 around 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 4.3 km offshore. 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 2018–2019 was about 28 mgd, including about 3 mgd of secondary and tertiary treated effluent from the SBWRP, and 25 mgd of secondary treated effluent from the SBIWTP.

Receiving Waters Monitoring

The total area for the PLOO and SBOO monitoring program covers approximately 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 stations, located from the shore to a depth of around 116 m. Core monitoring for the South Bay region is conducted at a total of 53 stations, ranging from the shore to depths of around 61 m (Figure 1.1). Each of the core monitoring stations is sampled for specific parameters as stated in their respective MRPs. A summary of the results for all quality assurance procedures performed during 2018 and 2019, in support of these requirements, can be found in City of San Diego (2019a, 2020a). Data files, detailed methodologies, completed reports, and other pertinent information submitted to the San Diego Regional Water Quality Control Board (SDRWQCB), and the U.S. Environmental Protection Agency (USEPA), during these two years are available online (City of San Diego 2020b).

Prior to 1994, the City conducted an extensive ocean monitoring program off Point Loma surrounding the original 60-m discharge site. This program was subsequently expanded with the construction and operation of the deeper outfall, 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

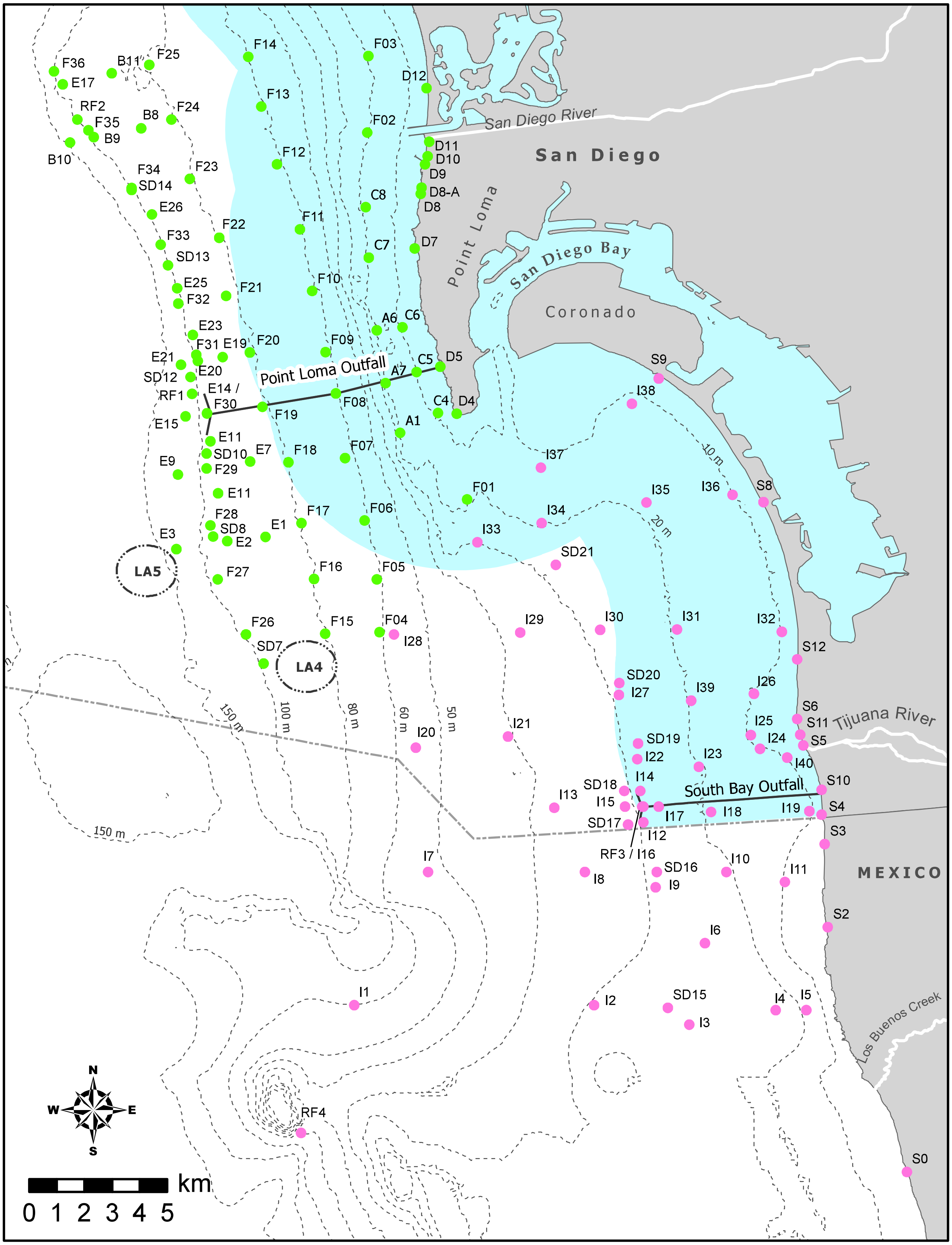

Figure 1.1
Core receiving waters monitoring stations for the PLOO (green) and SBOO (pink) as part of the City of San Diego's Ocean Monitoring Program. Light blue shading represents State jurisdictional waters.

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 ocean monitoring for the South Bay region has also been performed by the City since wastewater discharge through the SBOO began in 1999; this 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 2017, and the SBOO from 1999 to 2017, are available in previous annual receiving waters monitoring reports (e.g., City of San Diego 2018a). 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, SEPA 2017).

The City has also conducted annual region-wide surveys off the coast of San Diego since 1994, either as part of regular outfall monitoring requirements (e.g., City of San Diego 1999, 2018a), 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, Bight'13 and Bight'18 programs in 1998, 2003, 2008, 2013 and 2018 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, BSQPC 2018, SCCWRP 2018). These large-scale surveys are useful for characterizing the ecological health of diverse coastal areas to distinguish 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 2019).

Special Studies & Enhanced Monitoring

The City has actively participated in, or supported, numerous important special projects, or enhanced ocean monitoring studies, over the past 10 years or more. Many of these projects to date were identified as part of a scientific review of the City's Ocean Monitoring Program, conducted by the Scripps Institution of Oceanography (SIO) and other participating institutions (SIO 2004). This review evaluated the environmental monitoring needs of the region, and recommended special projects based on priorities identified. Examples of special projects currently underway, or being initiated include:

- <u>San Diego Kelp Forest Ecosystem Monitoring Project</u>: This project represents continuation of a long-term commitment by the City to support important research conducted on local kelp forests by SIO. This work is essential to assessing the health of San Diego's kelp forests and monitoring the effects of wastewater discharge on the local coastal ecosystem relative to other anthropogenic and natural influences (see Appendix A).
- <u>Real-Time Oceanographic Mooring Systems (RTOMS) for the Point Loma and South Bay Ocean Outfalls</u>: This project addresses recommendations that the City should improve monitoring of the fate and behavior of wastewater discharged to the ocean via the SBOO (Terrill et al. 2009) and PLOO (Rogowski et al. 2012a, 2012b, 2013). The project involves the deployment of RTOMS at the terminal ends of the PLOO and SBOO to provide real time data on ocean conditions. 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 with SIO, whom presently operate 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) and Appendix B.

- Sediment Toxicity Monitoring of the San Diego Ocean Outfall Regions: This project started with a 3-year pilot study implemented as a new joint regulatory requirement for the Point Loma and South Bay outfall regions in 2015. Findings for the 2016–2018 pilot study (City of San Diego 2015b) were summarized in a final project report (City of San Diego 2018b) that included recommendations for continued sampling through 2023. This final project report has been updated to include results from 2019 as Appendix C.
- Remote Sensing of the San Diego / Tijuana Coastal Region: This project represents a long-term effort, funded by the City and the USIBWC 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 (Hess 2019, 2020).
- 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 2020.

Report Components & Organization

This report presents a comprehensive biennial assessment of the results of all receiving waters monitoring activities conducted during 2018 and 2019 for both the Point Loma and South Bay outfall regions. Included herein are results from all regular core stations that comprise the fixed-site monitoring grids surrounding the two outfalls (Figure 1.1), as well as results from the 2019 summer benthic survey of randomly selected sites that range from near the USA/ Mexico border to northern San Diego County (Figure 1.2). Data from the 2018 SCB Regional Monitoring Program are not yet available and are therefore not included herein. 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 Fishes (Chapter 8). Supplemental analyses for Chapters 2–9 are included in Appendices D–J, while visual observations and raw data for 2019 samples are included in Addenda 1–9. Raw data for 2018 were submitted with the 2018 Interim Receiving Waters Monitoring Report (City of San Diego 2019c) and are available online (City of San Diego 2020b).

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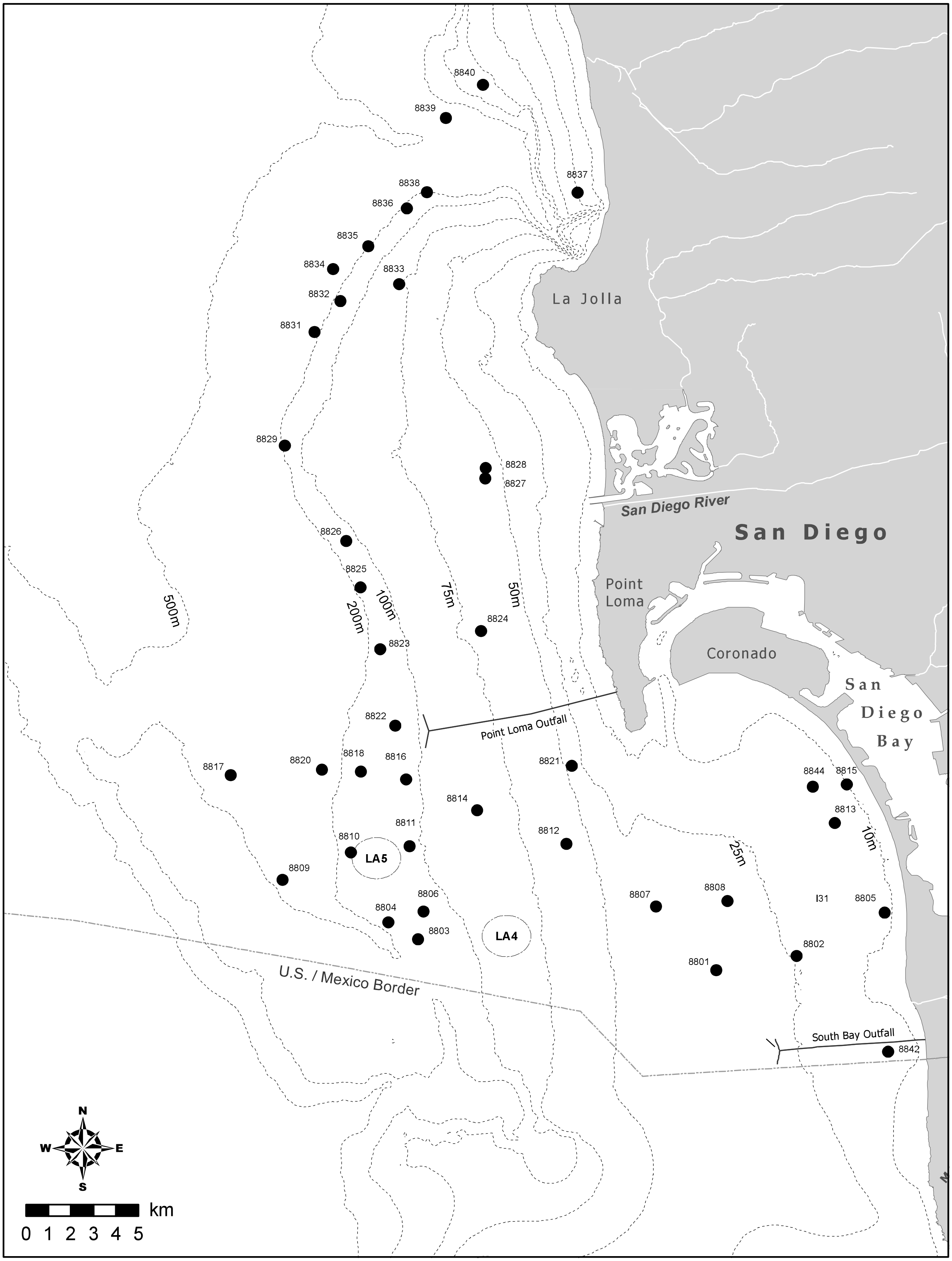

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Regional randomly selected benthic survey stations sampled during summer 2019 as part of the City of San Diego's Ocean Monitoring Program.

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Chapter 2
Coastal Oceanographic Conditions

Chapter 2. Coastal Oceanographic Conditions

Introduction

The City of San Diego (City) collects a comprehensive suite of oceanographic data from coastal waters surrounding the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO) 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 temperature, 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). As 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, tidal flows), 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 regions, ocean conditions are influenced by multiple factors. These include: (1) large-scale climatic processes, such as El Niño Southern Oscillations (ENSO), Pacific Decadal Oscillations (PDO), and North Pacific Gyre Oscillations (NPGO), which 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 2020); (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), which are a primary driver of 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 seasonal patterns include typically warmer and more stratified waters in the dry season, from May through September, and cooler, more weakly stratified and well-mixed waters, in the wet season, from October through April (e.g., City of San Diego 2015a, Hess 2019, 2020).

Understanding changes in oceanographic conditions due to natural processes, such as the seasonal patterns described above, is of utmost importance since they will likely affect the transport and distribution of wastewater, storm water, and other nearshore plumes. In the PLOO and SBOO monitoring regions, nearshore plumes 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. Outflow plumes 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, 2019, 2020).

This chapter presents analysis and interpretation of the oceanographic monitoring data collected during 2018 and 2019 for the coastal waters surrounding the PLOO and SBOO. The primary goals of this chapter are to: (1) summarize coastal oceanographic conditions in these regions; (2) identify natural and anthropogenic sources of variability; (3) evaluate local ocean conditions off the coast of San Diego within the context of regional climatic processes. In addition, 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, 2019, 2020). 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. PLOO stations are designated F1–F36 and are located along, or adjacent to, the 18, 60, 80, and 98-m depth contours. SBOO stations are designated I1–I18, 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 or March), spring (May), summer (August), and fall (November) in 2018 and 2019, and were sampled over a three to four-day period during each survey (Appendix D.1). Sampling at an additional eight kelp bed stations off Point Loma (stations A1, A6, A7, C4–C8), and seven kelp/nearshore stations in the South Bay region (stations I19, I24–I26, I32, I39, I40), was conducted four to five times per month, to meet bacterial monitoring requirements (see Chapter 3). However, only data collected at these 15 kelp bed stations within one week of the quarterly offshore stations are analyzed in this chapter (see Appendix D.1).

Oceanographic data were collected using a SeaBird SBE 25 Plus 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 2018–2020a,b).

Remote Sensing

Coastal monitoring of the PLOO and SBOO regions, during 2018–2019, 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 downloaded from Ocean Imaging's website (Ocean Imaging 2020). Separate annual reports, summarizing the results for each year, are also produced in the spring of the following year (i.e., Hess 2019, 2020). Several different types of satellite imagery were analyzed to build comprehensive comparisons to oceanographic data, 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 a depth of approximately 12 m.

Data Analysis

Data collected via CTD at PLOO and SBOO stations in 2019 are summarized in Addenda 2-1 and 2-2, while data collected in 2018 were reported

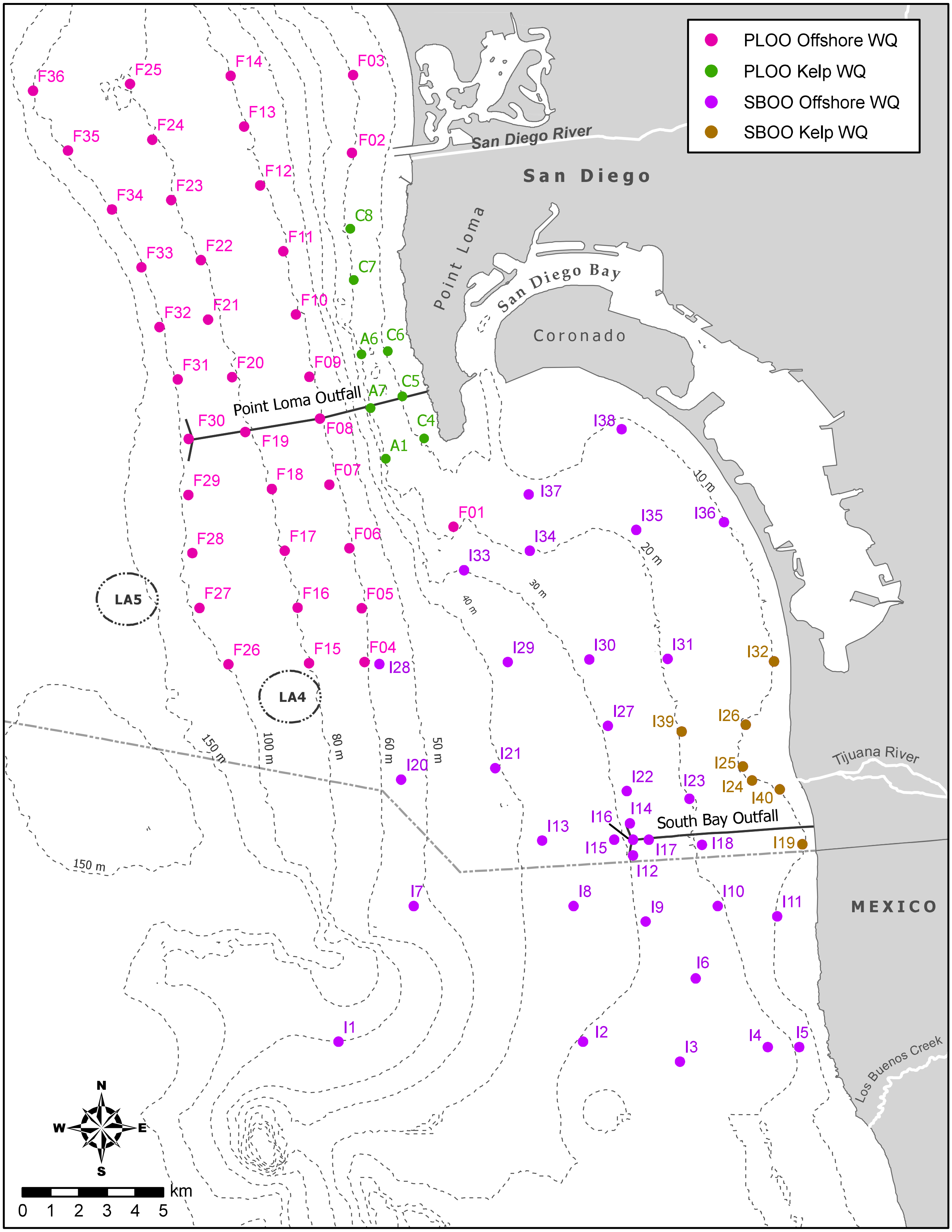

Figure 2.1

Locations of water quality (WQ) monitoring stations where CTD casts are taken around the PLOO and SBOO as part of the City of San Diego's Ocean Monitoring Program.

previously (City of San Diego 2018–2020a,b, 2019). These reports are available online (City of San Diego 2020). Water column parameters were summarized as quarterly mean values, pooled over all stations by the following depth layers: 1–20 m, 21–60 m, 61–80 m, 81–98 m (PLOO), and 1–9 m, 10–19 m, 20–28 m, 29–38 m, 39–55 m (SBOO). The top layer is herein referred to as surface water, while the subsurface layers account for mid and bottom waters. Unless otherwise noted, analyses were performed using R (R Core Team 2019) and various functions within the Hmisc, mixOmics, oce, Rmisc, RODBC, reshape2, and tidyverse packages (Hope 2013, Le Cao et al. 2017, Harrell et al. 2019, Kelley and Richards 2019, Ripley and Lapsley 2019, Wickham 2007, Wickham et al 2019).

Vertical density profiles were constructed from CTD data 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 98-m (discharge depth) stations in the PLOO region (stations F26–F36), and 28-m (discharge depth) stations in the SBOO region (stations I2, I3, I6, I9, I12, I14–I17, I22, I27, I30, I33), 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.

Time series of anomalies for water temperature, salinity, and DO were also calculated to evaluate regional oceanographic events within the context of large-scale climatic processes (i.e., ENSO events). These analyses were limited to data from the discharge depth stations for each outfall region, with all water column depths combined. Anomalies were then calculated as the difference between the quarterly historical average and quarterly means for each year.

Results and Discussion

Oceanographic Conditions in 2018–2019

Water Temperature and Density

Ocean temperatures recorded during the 2018–2019 quarterly surveys followed expected seasonal patterns throughout the PLOO and SBOO regions, ranging from a minimum of 10.1 to a maximum of 16.6°C in winter, 9.5 to 18.5°C in spring, 10.3 to 24.2°C in summer, and 11.6 to 19.6°C in fall (Figures 2.2–2.5, Addenda 2-1, 2-2, City of San Diego 2019). Regardless of the year or season, water temperature decreased throughout the water column with increasing depth. Surface waters during the summer were typically the warmest, and deeper waters during the spring were the coldest. Over the past two years, maximum water temperatures were recorded in surface waters of both regions during the summer of 2018 (PLOO: 23.9°C; SBOO: 24.2°C). Conversely, the coldest water temperatures were recorded in the deepest waters of both regions (PLOO: 81–98 m stations; SBOO: 39–55 m stations) during the spring of 2018 (PLOO: 9.5°C; SBOO: 10.5°C).

Seasonal changes in thermal stratification, over the past two years, were mirrored by density stratification of the water column during each survey (Figures 2.2–2.5). These results align with regional studies showing that density in shallow coastal waters of southern California, and elsewhere, is primarily influenced by temperature differences, since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Additionally, maximum buoyancy frequency for both regions ranged from a minimum of 4.74 to a maximum of 5.64 cycles/min during the winter, 9.48 to 13.89 cycles/min during the spring, 13.75 to 16.70 cycles/min during the summer, and 6.51 to 6.84 cycles/min during the fall (Figure 2.6, Appendix D.2). As expected, the depth of the pycnocline also varied by season. Shallower pycnocline depths (≤11 m) occurred in spring and summer, which in typically corresponded to greater stratification.

Salinity

Salinities recorded during the 2018–2019 quarterly surveys also followed expected seasonal patterns throughout the PLOO and SBOO regions, ranging from a minimum of 31.74 to a maximum of 33.97 ppt in winter, 33.47 to 34.06 ppt in spring, 33.33 to 34.02 ppt in summer, and 33.45 to 33.80 ppt in fall (Figures 2.2–2.5, Addenda 2-1, 2-2, City of San Diego 2019). Within the PLOO region, the highest salinity values (>33.8 ppt) were typically recorded at bottom depths (80 and 98-m stations) during spring 2018, 2019, and also winter 2019. Similarly, high salinities in the SBOO region (>33.7 ppt) were recorded at bottom depths (55-m stations) during spring 2018, and spring and summer 2019. However, notable in both regions were particularly high salinity values at the surface of most PLOO and SBOO stations during the summer 2018. High salinity values associated with deep waters, during the spring, in both PLOO and SBOO regions, corresponded with the coldest temperatures, as described above. Taken together, these results support the observation that local coastal upwelling appears to be strongest during the spring months (Jackson 1986).

Low salinity values in the PLOO (<33.5 ppt) and SBOO (<33.0 ppt) regions were recorded throughout the water column, across all stations, during winter 2018, but were limited to mostly surface waters in winter 2019 in the PLOO region (Figures 2.2–2.5). Similarly, during winter 2019, in the SBOO region, low salinities were also recorded at some surface depths (9 and 18-m stations), but far more sporadically than what was observed in the PLOO region. Given the proximity of these SBOO locations to the mouth of the Tijuana River, and the infrequency of the low salinity events, they may be correlated with winter rain events and the resultant influx of fresh water input into local receiving waters (Hess 2019, NOAA/NWS 2020).

Dissolved Oxygen and pH

Levels of dissolved oxygen (DO) and pH in the coastal waters off San Diego generally followed expected patterns in 2018 and 2019 that corresponded to seasonal fluctuations in water column stratification. Additionally, changes in DO and pH tended to be closely linked, since both parameters reflect fluctuations in dissolved carbon dioxide, an indicator of biological activity in coastal waters (Skirrow 1975). Concentrations of DO and pH across the PLOO and SBOO regions ranged from a minimum of 3.2 to a maximum of 9.5 mg/L in winter, 3.0 to 10.3 mg/L in spring, 3.5 to 12.0 mg/L in summer, and 4.7 to 9.6 mg/L in fall. The recorded pH ranged from a minimum of 7.8 to a maximum of 8.3 in winter, 7.7 to 8.3 in spring, 7.8 to 8.4 in summer, and 7.8 to 8.3 in fall (Figures 2.2–2.5, Addenda 2-1, 2-2, City of San Diego 2019).

Maximum DO and pH were recorded in surface waters of the PLOO region during the summer of 2019 (PLOO: 12 mg/L and 8.4) (Figures 2.2–2.5, Addenda 2-1, 2-2, City of San Diego 2019). Although the SBOO region also recorded a maximum DO in the surface waters during the summer season of 2019 (11.3 mg/L), maximum pH was recorded in the sub-surface waters during the summer of 2018 (8.4). Conversely, minimum DO and pH were recorded in the deepest waters of both regions during the spring of 2018 and 2019 (PLOO: 3.0 mg/L and 7.7; SBOO: 3.8 mg/L and 7.7), likely due to upwelling of cold, saline, oxygen-poor water moving inshore similar to the pattern described above for temperature and salinity.

Transmissivity

Although water clarity (transmissivity) ranged widely, from a minimum of 19 to a maximum of 90% throughout the PLOO and SBOO regions, values were generally quite high, exceeding 80% during most of 2018 and 2019 (Appendices D.3–D.6, Addenda 2-1, 2-2, City of San Diego 2019). During winter and fall, low transmissivity (<75%) was most often observed at shallow

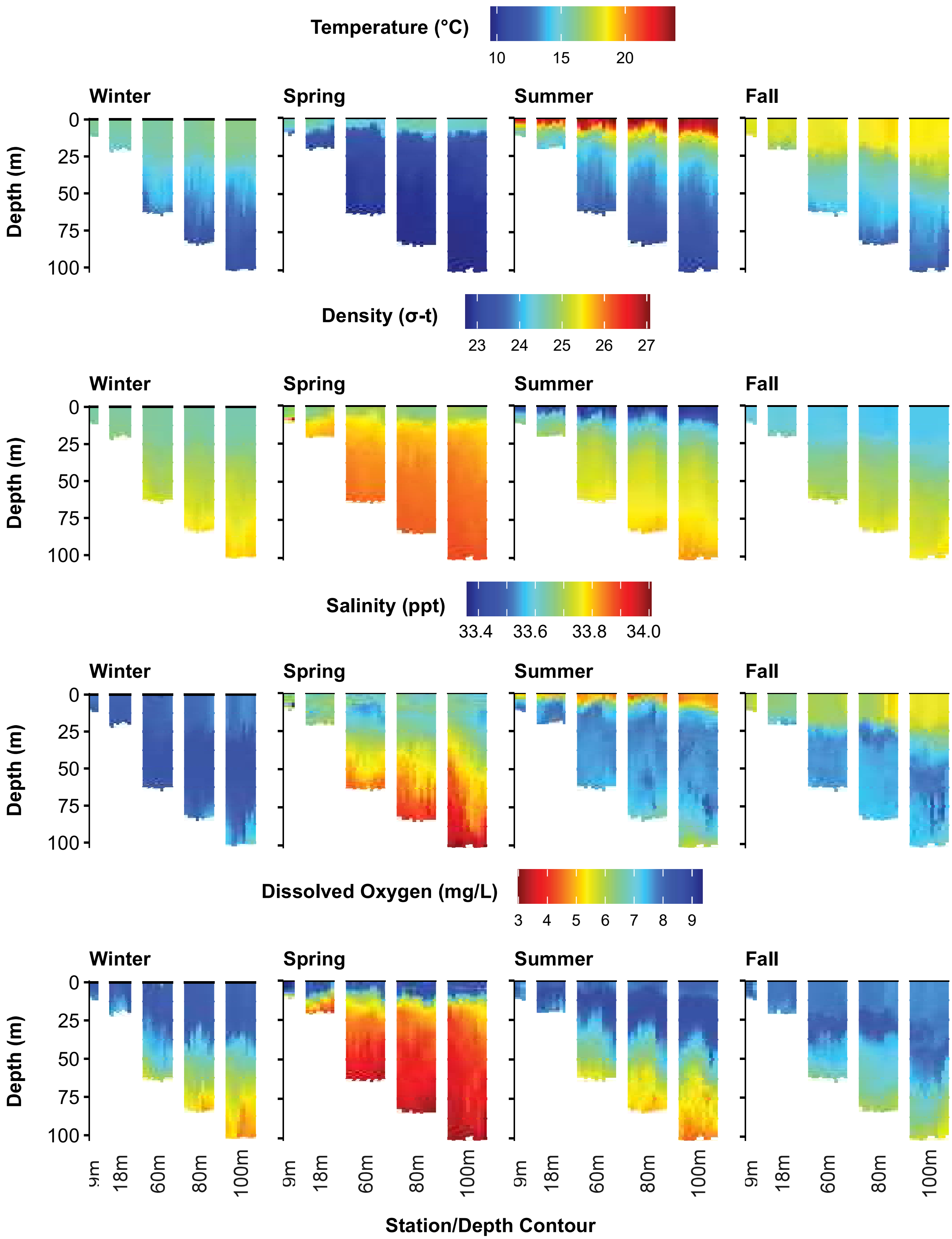

Figure 2.2
Temperature, density, salinity, and dissolved oxygen recorded in the PLOO region during 2018. Data are 1-m binned values per depth for each station and were collected over 4–5 days during each quarterly survey. Stations are depicted from north to south along each depth contour.

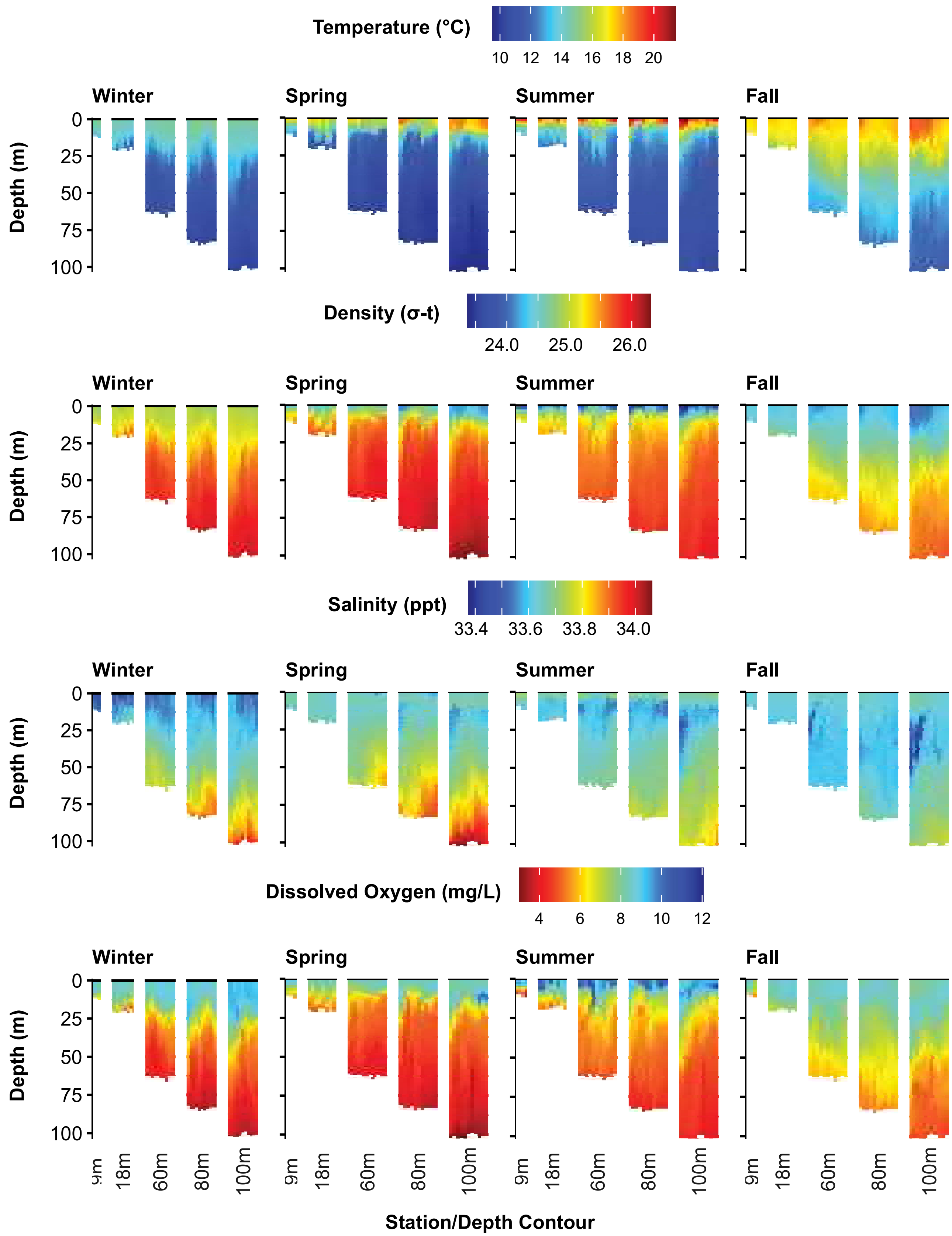

Figure 2.3
Temperature, density, salinity, and dissolved oxygen recorded in the PLOO region during 2019. Data are 1-m binned values per depth for each station and were collected over 4–5 days during each quarterly survey. Stations are depicted from north to south along each depth contour.

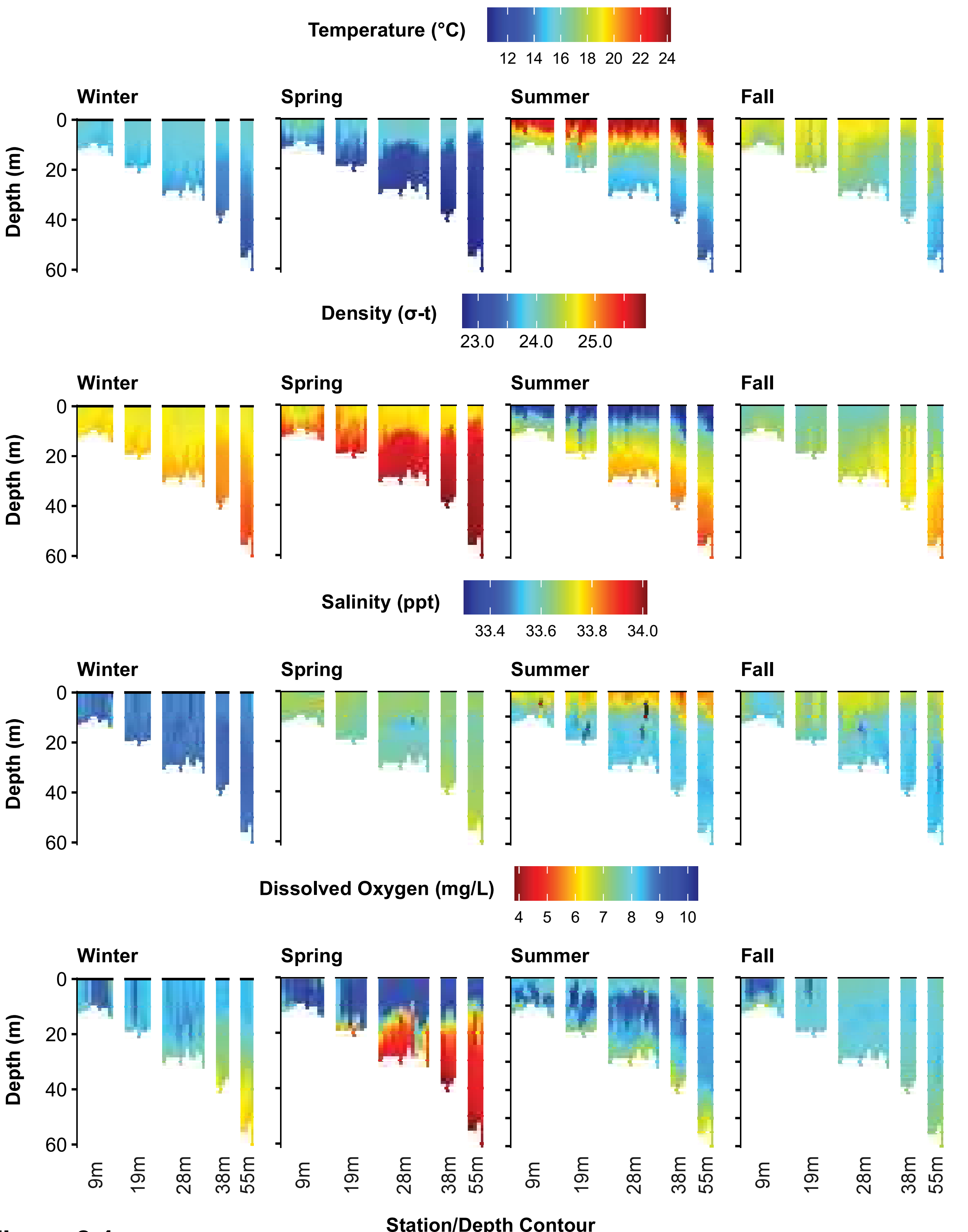

Figure 2.4
Temperature, density, salinity, and dissolved oxygen recorded in the SBOO region during 2018. Data are 1-m binned values per depth for each station and were collected over 4–5 days during each quarterly survey. Stations are depicted from north to south along each depth contour.

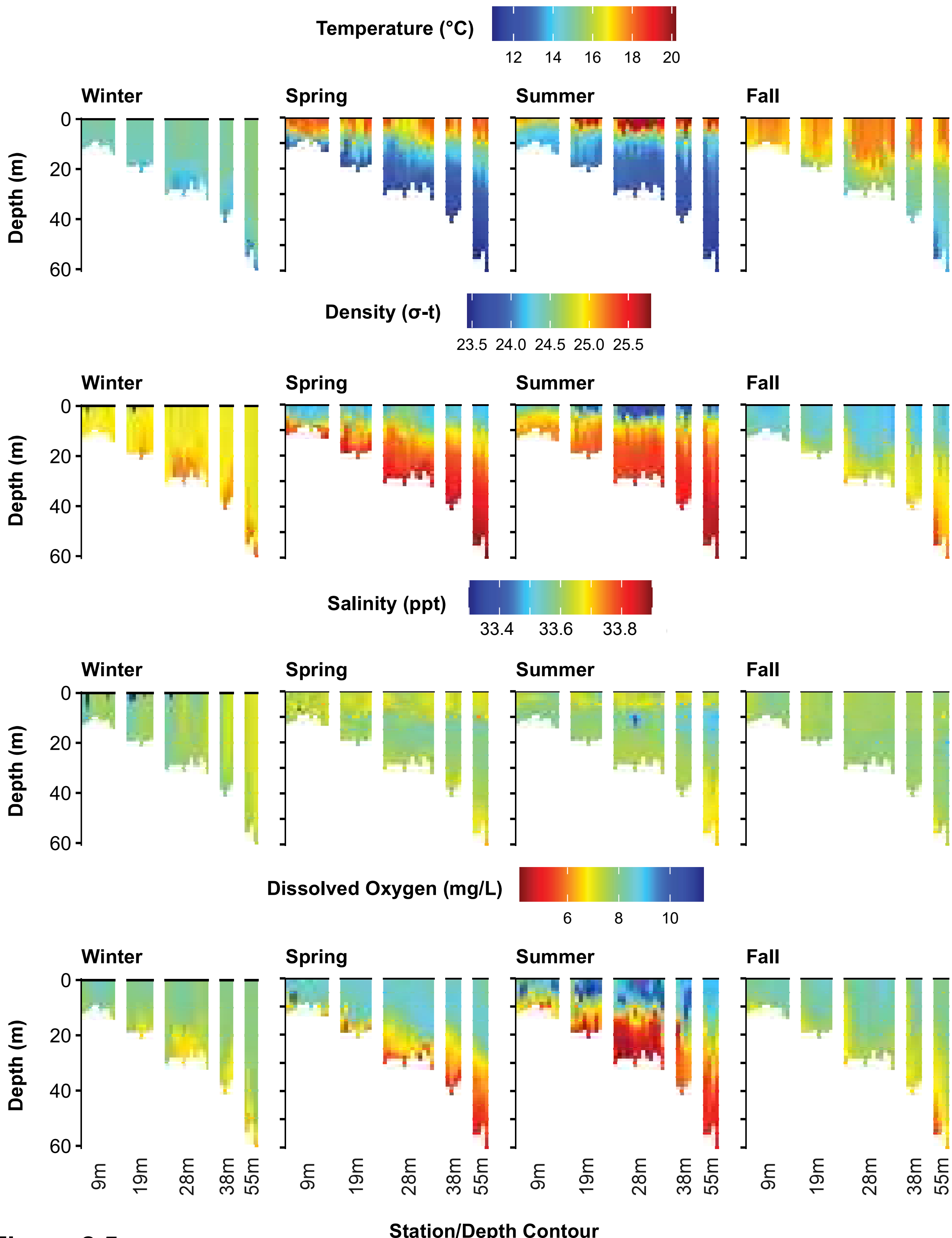

Figure 2.5
Temperature, density, salinity, and dissolved oxygen recorded in the SBOO region during 2019. Data are 1-m binned values per depth for each station and were collected over 4–5 days during each quarterly survey. Stations are depicted from north to south along each depth contour.

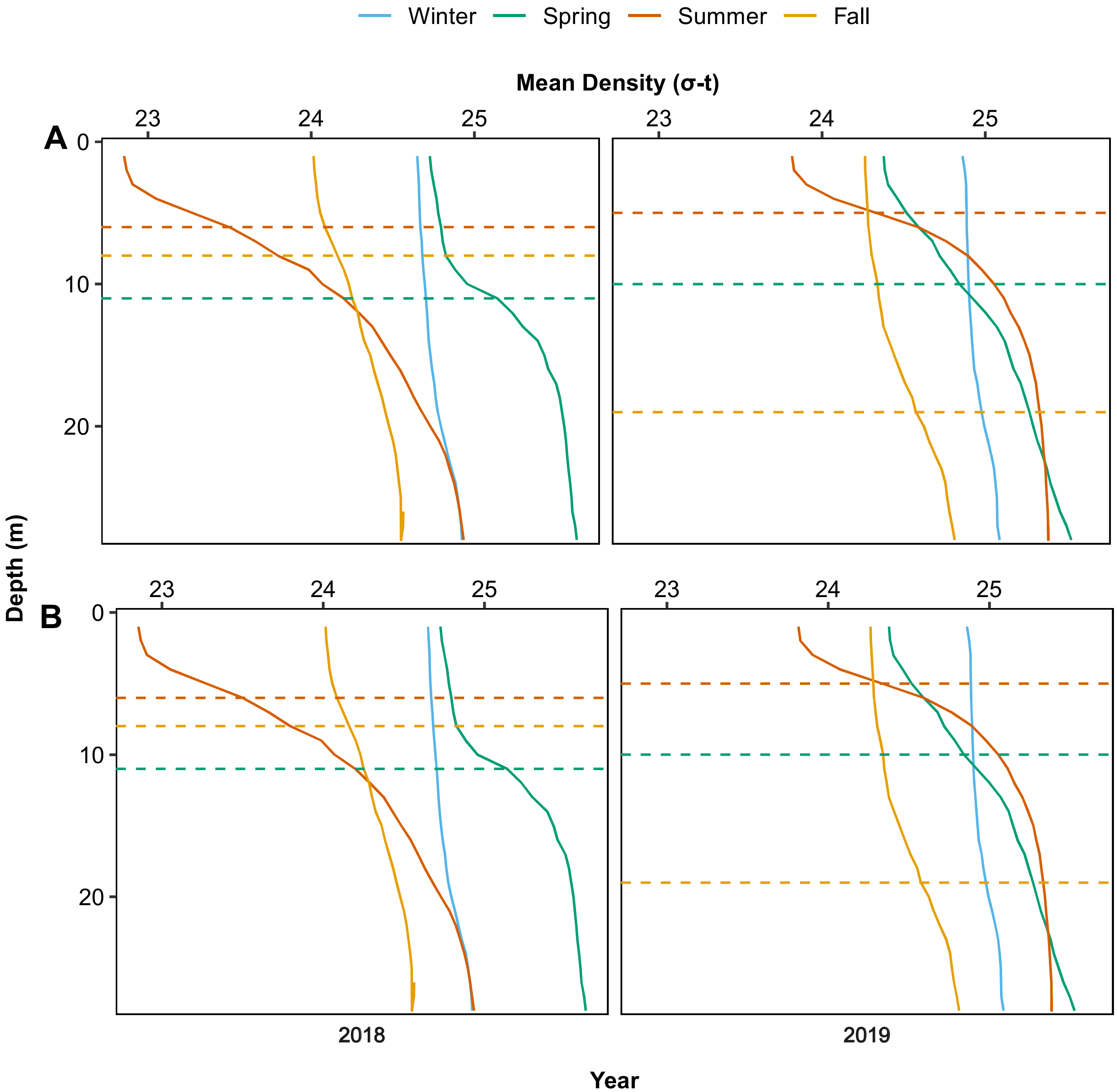

Figure 2.6

Mean density for each survey conducted during 2018 and 2019 at (A) PLOO discharge depth stations (n = 11) and (B) SBOO discharge 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.

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 winter 2019 at the 9-m SBOO stations coincided with increased turbidity along the coast that was likely due to concurrent rain activity and large waves (Figure 2.7, CDIP 2019, Ocean Imaging 2020). Other patches of low transmissivity during spring/summer surveys in both regions appeared to be somewhat associated with high concentrations of chlorophyll *a*, possibly indicative of dense accumulations of phytoplankton cells (see below). Finally, low transmissivity values were also occasionally observed in bottom waters 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 a minimum of <0.1 to a maximum of 48.0 µg/L across the PLOO and SBOO regions in 2018 and 2019 (Appendices D.3–D.6, Addenda 2-1, 2-2, City of San Diego 2019). Elevated chlorophyll *a* levels (>5 µg/L) were recorded at depths from ~5 to 25 m along all depth contours in the PLOO region during spring 2019, and to depths associated with (or just below) the mixed layer. Elevated levels were also recorded at depths from ~5 to 25 m along all depth contours in the PLOO region during summer 2019, as well as from ~10 to 25 m along the 19 through 55-m depth contours in the SBOO region during spring 2018. Elevated chlorophyll *a* levels at these depths reflect the tendency for phytoplankton to accumulate along natural barriers such as isopycnals near the thermocline, where deeper water nutrients are available and light is not yet limiting (Lalli and Parsons 1993).

Historical Assessment of Oceanographic Conditions

A review of temperature, salinity, and DO anomalies from all discharge depth stations sampled from 1991 through 2019 indicates how the PLOO and SBOO regions have responded to long-term climate-related changes in the SCB (Figure 2.8). Overall, these results are consistent with large-scale temporal patterns in the California Current System (CCS) associated with ENSO, PDO and NPGO events (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, 2012, Wells et al. 2013, Leising et al. 2014, 2015, NOAA/NWS 2020). Thirteen major events have affected SCB coastal waters during the last two decades: (1) the colossal El Niño of 1997 to 1998; (2) a shift to cold ocean conditions reflected in ENSO and PDO indices from 1998 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 from 2002 to 2004; (5) development of a moderate to strong La Niña in 2007 that coincided with a PDO cooling event and a return to positive NPGO values indicating an increased flow of cold, nutrient-rich water from the north; (6) development of another La Niña starting in May 2010; (7) a region-wide warming, beginning in the winter of 2013/2014, when the PDO, NPGO, and MEI (Multivariate ENSO Index) all changed phase; (8) an anomalous surface warm pool which extended across much of the NE Pacific from 2014–2015. This warm pool, unique in the climate record of the NE Pacific, was coined the BLOB and resulted from large scale wind patterns in the NE Pacific; (9) the colossal El Niño of 2015; (10) a weak La Niña in late 2016; (11) a second weak La Niña in late 2017 through early 2018; (12) a weak El Niño in late 2018 through mid-2019; (13) the return of a marine heat wave in mid to late 2019 in the CCS.

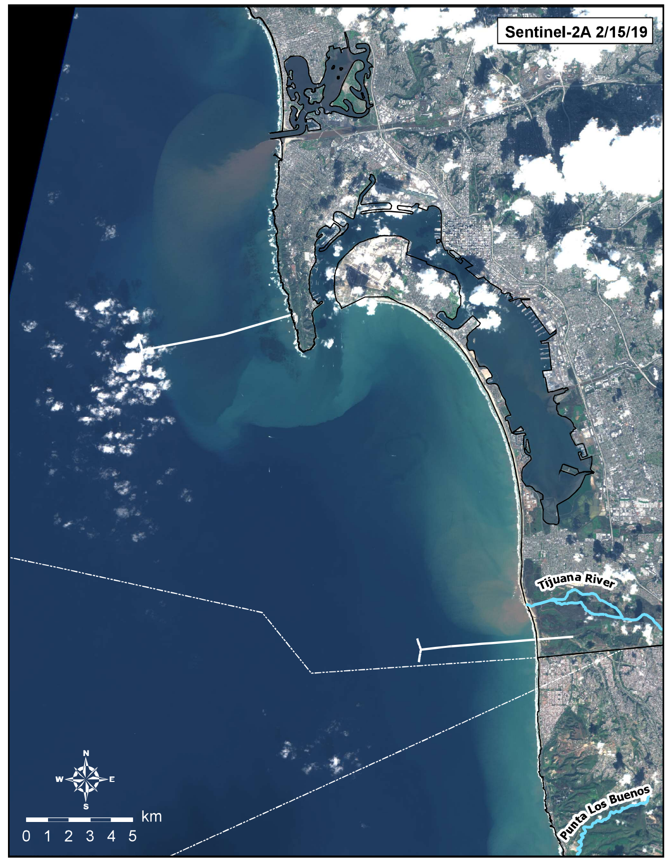

Figure 2.7
Sentinel-2A satellite image of the San Diego region acquired February 15, 2019 (Ocean Imaging 2020) depicting increased turbidity along the coast.

Temperature and salinity data for the entire San Diego region were overall consistent with the aforementioned CCS events, but there have been some notable deviations from these trends. For example, while the CCS was experiencing

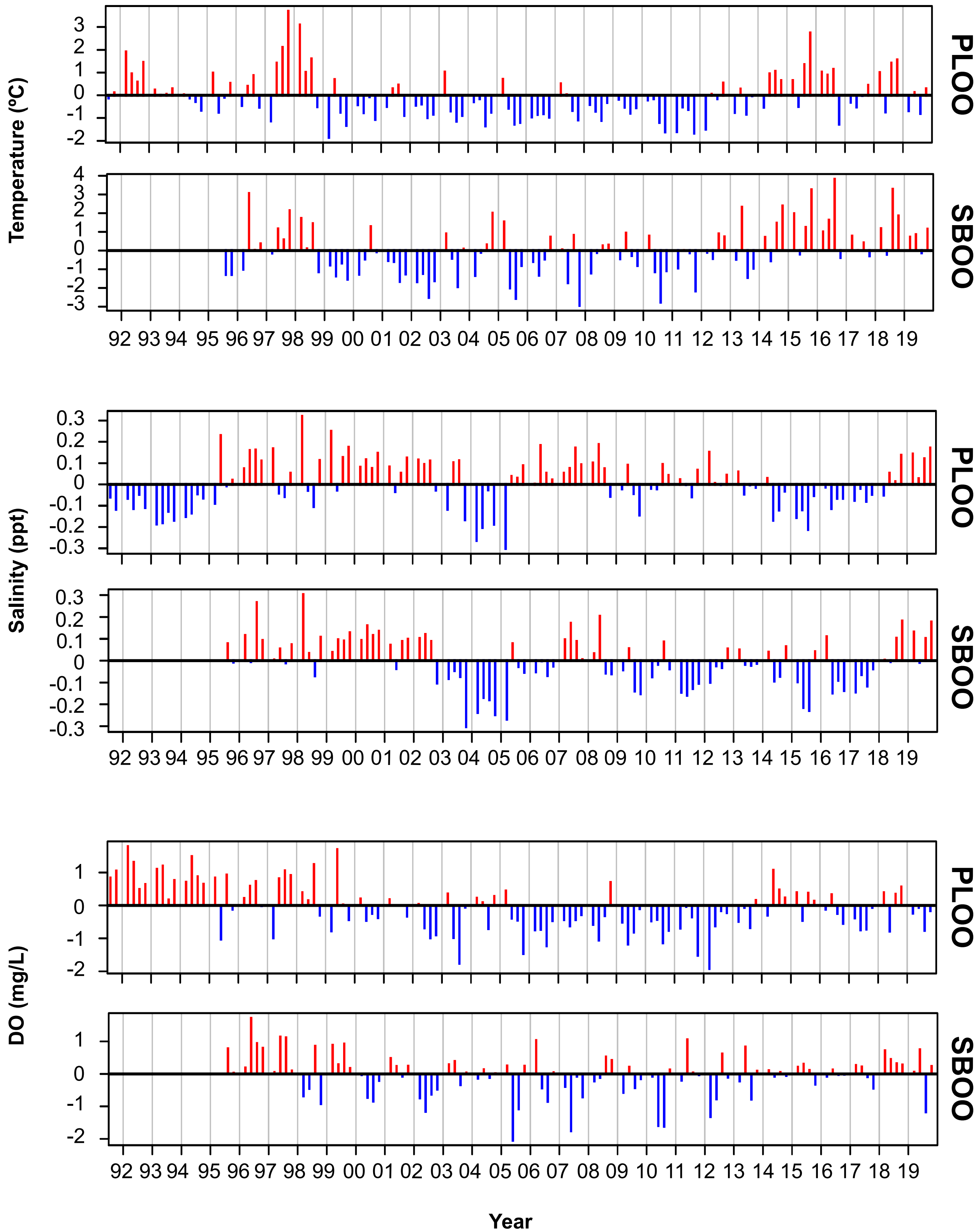

Figure 2.8
Time series of temperature, salinity, and dissolved oxygen (DO) anomalies from 1991 through 2019 at PLOO discharge depth stations (n = 11) and SBOO discharge depth stations (n = 13), all depths combined. Monitoring at the SBOO stations began in 1995.

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 these years 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 winter through summer 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 late 2016 through winter 2017. Deviations from the long-term average were minor, reflecting the ENSO neutral conditions that endured for most of 2017 (NOAA/NWS 2020). Ocean temperatures observed throughout the water column were warmer than the historical average during most of 2018, and closer to average conditions during 2019 for the PLOO region in particular. In contrast, the CCS north of Monterey Bay showed surface water temperatures far above average in summer and fall 2019, consistent with a regionwide marine heat wave, as well as positive PDO and negative NPGO phases. Above average salinity observed during 2018 and 2019 was consistent with conditions all along the west coast, shifting from lower than normal salinities during the warm period of 2014–2016. These anomalous conditions were remotely observed moving towards the SCB prior to this time period, suggesting a shifting balance of water mass source waters being responsible for these temperature and salinity anomalies (Thompson et al. 2018, 2019).

Historical trends in local DO concentrations reflect several periods during which lower than normal DO has corresponded with low water temperatures and high salinity (Figure 2.8). The alignment of these anomalies is generally consistent with cold, saline, oxygen-poor ocean waters due to strong local coastal upwelling (e.g., 2002, 2005–2012). The overall decrease observed in DO in the PLOO and SBOO regions through 2012 were also observed throughout the entire CCS and deep North Pacific and were thought to be linked to changing ocean climate (Bjorkstedt et al. 2012). However, no significant long-term trend has been shown over the last 70 years in the North Pacific shelf depths (Schmidtko et al. 2017). These large negative anomalies have been absent since mid-2013, in the PLOO and SBOO regions, and DO conditions were again near neutral during most of 2018 and 2019, with the exception of lower than average DO in summer 2019.

Summary

Oceanographic conditions in the PLOO and SBOO regions, during 2018 and 2019, 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 that are 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 months of both years. Phytoplankton blooms, indicated by high concentrations of chlorophyll *a* (>5 µg/L), were evident at subsurface depths during spring and summer 2019 in the PLOO region and spring 2018 in the SBOO region. These results are similar to findings reported previously for the San Diego region (City of San Diego 2015a,b,c, 2016a,b, 2018) and are generally consistent with conditions and 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 2020), and with conditions in northern Baja California waters (Peterson et al. 2006). These observations suggest that overall 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-climatic 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 (City) 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 (FIB), 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) that are intended to help protect the beneficial uses of State ocean waters (SWRCB 2015).

Multiple sources of bacterial contamination exist in the Point Loma and South Bay 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 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).

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 further 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 and other oceanographic data collected, during 2018 and 2019, 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 FIB in waters adjacent to public beaches (Figure 3.1). Sixteen of these stations are in California State waters and are therefore subject to Ocean Plan water contact standards (Box 3.1, SWRCB 2015). Eight PLOO stations (D4, D5, D7, D8-A/D8-B, D9, D10, D11, D12) are located from Mission Beach southward to the tip of Point Loma. Due to access issues, station D8-A replaced D8 in July 2016 and station D8-B replaced D8-A in March 2018. Eight SBOO stations (S4, S5, S6, S8, S9, S10, S11, S12) are located between the USA/Mexico border and Coronado, while the other three SBOO shoreline stations (S0, S2, S3) are located south of the border and are not subject to Ocean Plan standards. Following an internal investigation of suspicious data, conducted by the City, a total of 62 samples (including resamples) were removed from further analysis.

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, *Enterococcus* bacteria). In addition, weather conditions and visual observations of water color and clarity, surf height, and human or animal activity were recorded at the time of sample collection. Wind speed and direction were measured using a hand-held anemometer with a compass. These observations were previously reported in monthly receiving waters monitoring reports submitted to the San Diego Regional Water Quality Control Board (SDRWQCB) (see City of San Diego 2018–2020a,b). These reports are available online (City of San Diego 2020b).

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 weekly 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 over consecutive days in winter (February or March), spring (May), summer (August), and fall (November) to monitor water quality conditions and to estimate dispersion of the PLOO and SBOO wastewater plumes (Figure 3.1). These included 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 98 m depth contours. Seawater samples for FIB were collected at all of these stations (see below). The SBOO stations are designated I1–I18, I20–I23, I27–I31, and I33–I38 and are located along the 9, 19, 28, 38 and 55 m depth contours, respectively. Only a subset of SBOO sites (n = 21; I3, I5, I7, I8, I9, I10–I14, I16, I18, I20–I23, I30, I33, I36–I38), are sampled for FIB. Additionally, 15 of the PLOO stations (F01–F03, F06–F14, F18–F20) and 15 of the SBOO stations (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 to 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 Conductivity, Temperature, and Depth (CTD) instrument, although replacement samples due to

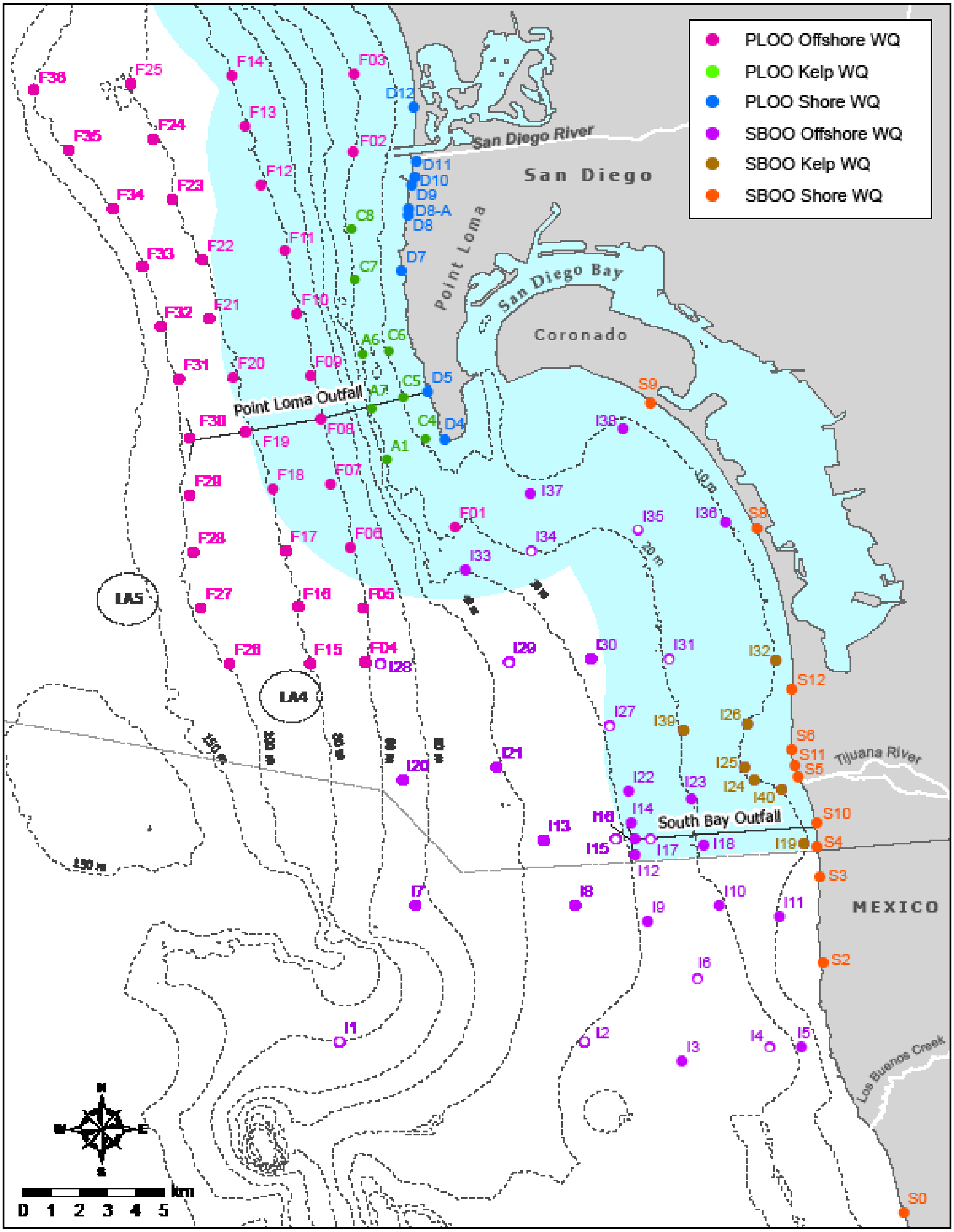

Figure 3.1
Water quality (WQ) monitoring station locations sampled around the PLOO and SBOO as part of the City of San Diego's Ocean Monitoring Program. Open circles are sampled by CTD only. Light blue shading represents State jurisdictional waters.

Box 3.1

Water quality objectives for water contact areas, California Ocean Plan (SWRCB 2015).

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.

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 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 samples were refrigerated at sea and then transported on blue ice to the City's Marine Microbiology Laboratory 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 or animal activity were also recorded at the time of sampling. These latter observations were reported previously in monthly receiving waters monitoring reports submitted to the SDRWQCB (see City of San Diego 2018–2020a,b).

Laboratory Analyses

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

FIB densities were determined and validated in accordance with USEPA and APHA guidelines (Bordner et al. 1978, APHA 2005, USEPA 2006). Plates with FIB densities above or below the ideal counting range were given greater than (>), greater than or equal to (≥), less than (<), or estimated (e) qualifiers. However, all qualifiers were dropped

Table 3.1

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

Station Contour	PLOO Sample Depth (m)									Station Contour	SBOO Sample Depth (m)							
	1	3	9	12	18	25	60	80	98		2	6	9/11	12	18	27	37	55
Kelp Bed										*Kelp Bed*								
9-m	x	x	x							9-m	x	x	x[a]					
18-m	x			x	x					18-m	x			x	x			
Offshore										*Offshore*								
18-m	x			x	x					9-m	x	x	x[a]					
60-m	x					x	x			18-m	x			x	x			
80-m	x					x	x	x		28-m	x				x	x		
98-m	x					x	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

and densities were treated as discrete values when 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 2019a, 2020a).

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 2015). Compliance calculations were limited to shore, kelp and offshore stations located within State waters. For shore stations, these calculations included resamples; no resamples are required to be collected at kelp or other offshore stations. To assess temporal and spatial trends, data were summarized as the number of samples in which FIB concentrations exceeded SSM benchmark levels. These calculations were performed for all shore, kelp and offshore stations located within and outside of State waters, but excluded resamples at shore stations. All samples collected during 2019 from PLOO and SBOO stations with elevated FIB are listed in Addenda 3-1 and 3-2. Data collected during 2018 were reported previously (City of San Diego 2018–2020a,b, City of San Diego 2019b).

Bacterial densities were compared to rainfall data from Lindbergh Field, San Diego, CA (NOAA 2018). Satellite images of the San Diego coastal region were provided by Ocean Imaging of Solana Beach, California (Ocean Imaging 2020) and used to aid in the analysis and interpretation of water quality data (see Chapter 2 for remote sensing details). All analyses were performed using R (R Core Team 2019) and various functions within the gtools, Hmisc, psych, reshape2, RODBC, tidyverse, ggpubr, quantreg, and openxlsx packages (Wickham 2007, 2017, Harrell et al. 2015, Warnes et al. 2015, Revelle 2015, Ripley and Lapsley 2017, Kassambara 2019, Koenker 2019, Schauberger and Walker 2019).

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 evaluating 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 E.1, E.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, 2015a,b, 2016a, 2018, Rogowski et al. 2012a,b, 2013, Hess 2019, 2020). 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, 2018, Terrill et al. 2009, Hess 2019, Hess 2020). 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 was determined for each quarterly survey at each monitoring station 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 thus constrained to only 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 2019) and various functions within the oce, reshape2, Rmisc, RODBC and tidyverse packages (Wickham 2007, 2017, Hope 2013, Kelley and Richards 2019, Ripley and Lapsley 2017).

The effect of any potential "plume detection" on local water quality, during each quarterly survey, 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" (Addendum 3-3, City of San Diego 2019b). Individual non-reference stations were then determined to be out-of-range (OOR) compared to the reference stations if values 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 naturally-occurring concentrations, 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 2018–2019. 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 86–100% (Figure 3.2). Compliance with the single sample maximum (SSM) standards at these sites was 93–100% for

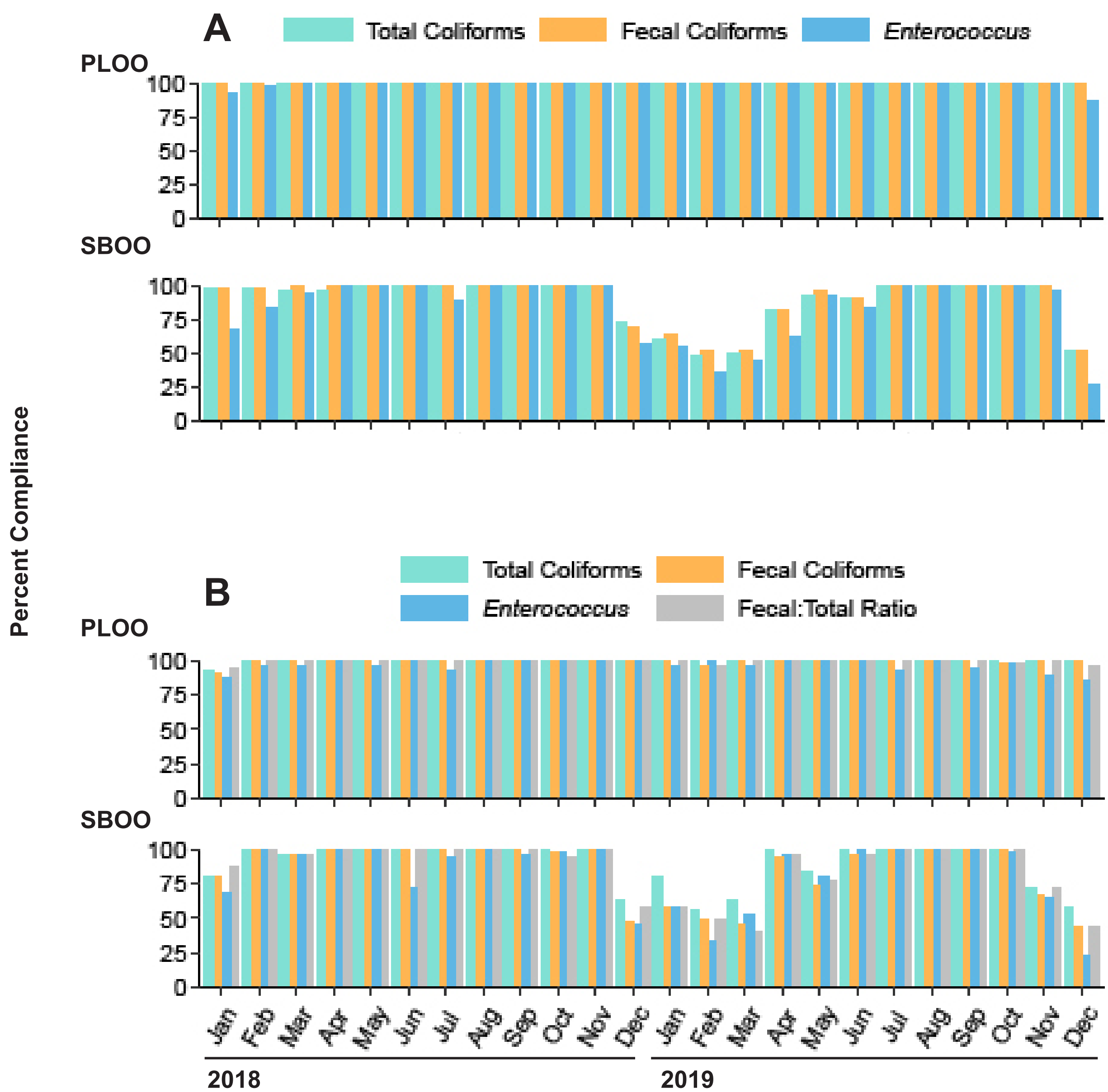

Figure 3.2
Compliance rates for (A) geometric mean and (B) single sample maximum water contact standards at shore stations during 2018 and 2019.

total coliforms, 91–100% for fecal coliforms, 87–100% for *Enterococcus*, and 95–100% for the fecal:total coliform ratio (FTR). In contrast, compliance rates were more variable during these two years at the eight SBOO shore stations located in State waters. For example, compliance with the 30 day geometric mean standards at these SBOO stations was 48–100% for total coliforms, 50–100% for fecal coliforms, and 27–100% for *Enterococcus*, while compliance with the SSM standards was 56–100% for total coliforms, 44–100% for fecal coliforms, 23–100% for *Enterococcus*, and 40–100% for the FTR criterion. 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 comply with State water contact standards (State of California 2010). Thus, when these stations are excluded, overall

Table 3.2

Number of samples with elevated FIB (eFIB) densities collected from shore stations during wet and dry seasons, and percent occuring in wet season (%wet), during 2018 and 2019. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

Station	Seasons: Wet	Seasons: Dry	% Wet
PLOO			
D12	0	1	0
D11	7	1	88
D10	1	1	50
D9	2	1	67
D8	4	2	67
D7	4	0	100
SBOO			
S9	2	4	33
S8	2	1	67
S12	8	4	67
S6	13	2	87
S11	16	1	94
S5	25	3	89
S10	19	2	91
S4	21	3	88
S3	12	3	86
S2	16	2	89
S0	35	18	66
Rain (inches)	20.09	1.06	95
Total eFIB	187	48	80
Total Samples	1091	772	59

SSM compliance at the remaining SBOO shore stations was 97%.

Of the 1863 seawater samples collected at the PLOO and SBOO shore stations in 2018–2019 (not including resamples), about 13% (n = 235) had elevated FIB (Addenda 3-1, 3-2, City of San Diego 2019b). A large majority (80%) of the shore samples with elevated FIB were collected during the wet seasons when rainfall totaled 20.09 inches over both years (Table 3.2). This general relationship between rainfall and elevated bacterial levels at shore stations has been evident since water quality monitoring began in both regions (Figure 3.3). Further analyses of data from PLOO and SBOO shore stations indicate that the occurrence of a sample with elevated FIB was significantly more likely during the wet season than during the dry season (15% versus 5%, respectively; n = 27,546, $\chi2 = 1508.5$, $p < 0.0001$).

Regionally, elevated FIB densities occurred most often at SBOO shore stations S4, S5, S10 and S11 located near the mouth of the Tijuana River, as well as in northern Baja California waters at stations S0, S2 and S3 over the past two years (Table 3.2, Addenda 3-1, 3-2, City of San Diego 2019b). Results from historical analyses also indicated that elevated FIB occurred more frequently at stations near the Tijuana River and south of the border near Los Buenos Creek, than at other PLOO or SBOO shore stations, especially during the wet seasons (Figure 3.3). Over the past several years, high FIB densities 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, 2015b–2016b, 2018). In addition, several sanitary sewer overflow events impacted the Tijuana River Valley during 2018 and 2019 (IBWC 2018–2019). Each overflow event lasted from one to 13 days, with an average length of two days, and an average overflow of 49.5 million gallons impacting the main channel of the Tijuana River.

Kelp bed stations

Overall compliance with Ocean Plan water contact standards was also high at the eight PLOO kelp stations in 2018–2019. Seawater samples from these stations were 100% compliant with each of the geometric mean standards and ≥98% compliant with the SSM standards for total coliform, fecal coliform, *Enterococcus*, and the FTR criterion (Figure 3.4). Similar to the SBOO shore stations, compliance rates were more variable at the seven kelp bed, or nearshore, stations in the SBOO region. For example, compliance with the 30-day geometric mean standards was 74–100% for total coliform, 79–100% for fecal coliform and 56–100% for *Enterococcus*, while compliance with the SSM

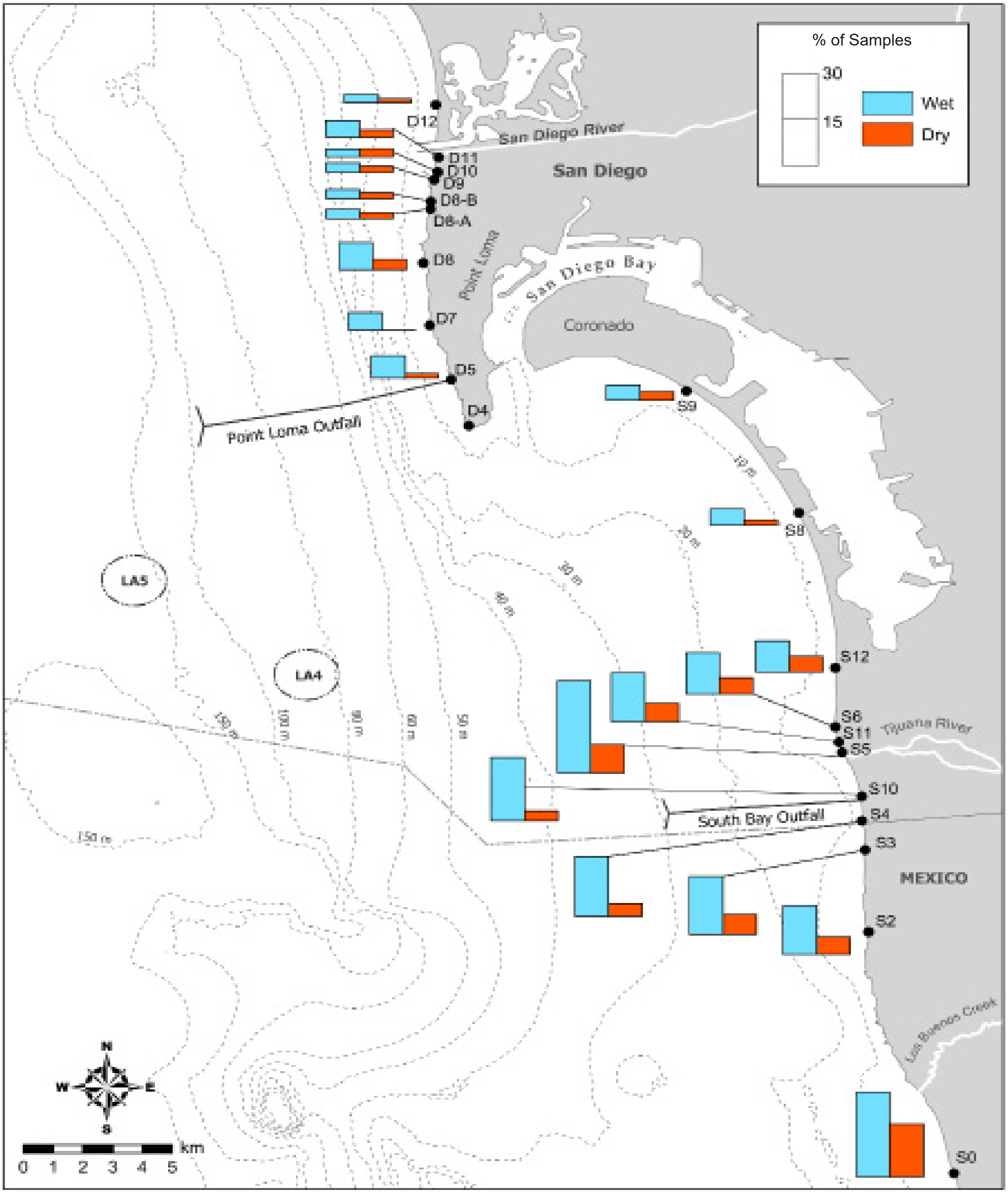

Figure 3.3
Percentage of samples with elevated FIB densities in wet versus dry seasons at shore stations from 1991 through 2019. Shore sampling in the SBOO region began in 1995.

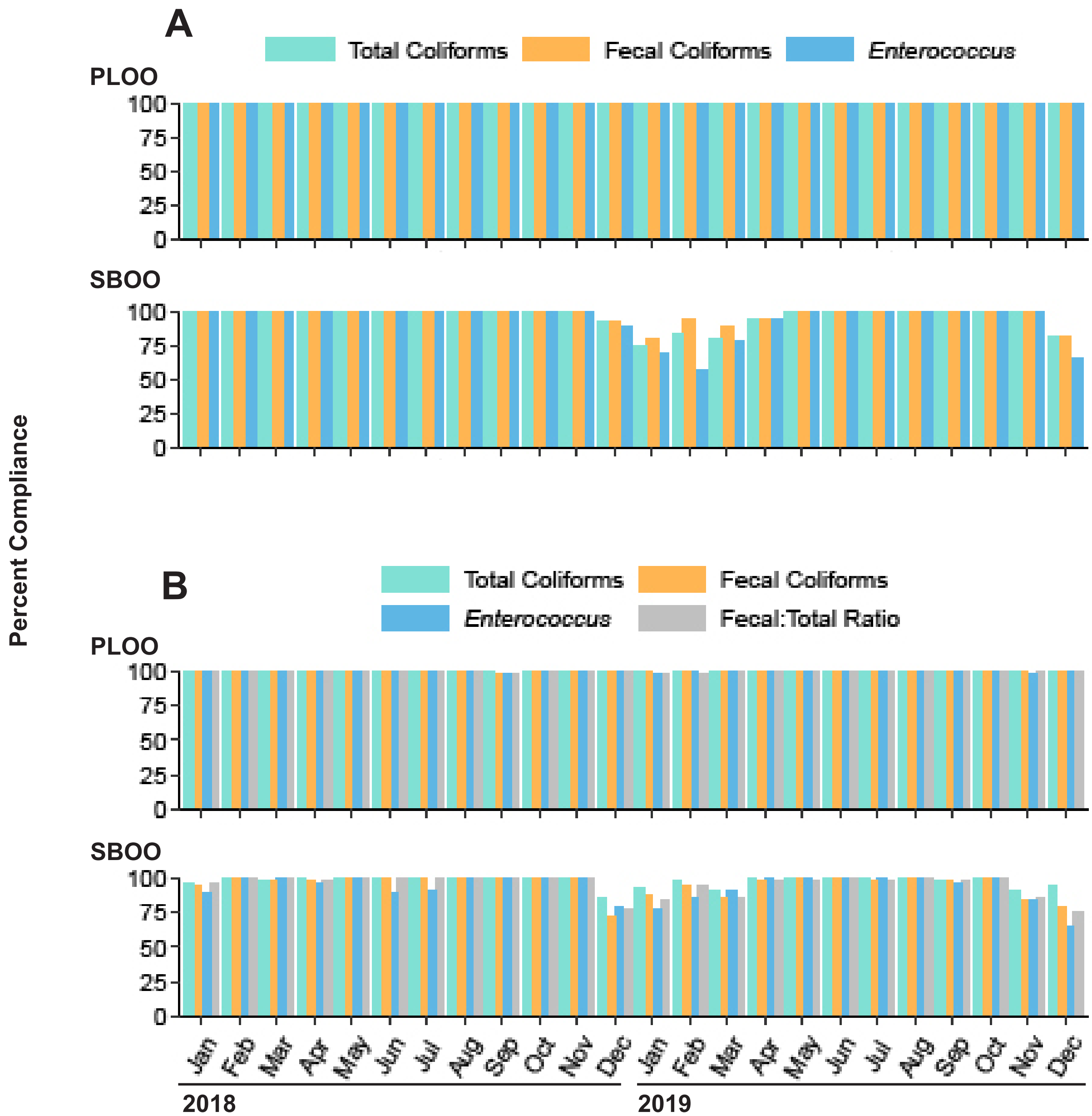

Figure 3.4
Compliance rates for (A) geometric mean and (B) single sample maximum water contact standards at kelp stations during 2018 and 2019.

standards was 86–100% for total coliform, 71–100% for fecal coliform, 64–100% for *Enterococcus*, and 75–100% for the FTR criterion.

Of the 4680 samples collected at the PLOO and SBOO kelp stations in 2018–2019, about 4% (n=184) had elevated FIB (Addenda 3-1, 3-2, City of San Diego 2019b), of which 86% occurred during the wet season (Table 3.3). However, water quality monitoring data collected at the PLOO kelp stations, since 1991, indicate that the relationship between rainfall and elevated FIB densities has been negligible over the years (~3% in either season; n=52,322, $\chi2=295.35$, $p<0.0001$). Instead, the likelihood of encountering elevated FIB at these stations was significantly higher before the PLOO was extended to its present discharge site in late 1993 (13% versus < 1%; n=52,322, $\chi2=177.21$, $p<0.0001$) (see Figure 3.5). The influence of rainfall on FIB has

Table 3.3

Number of samples with elevated FIB (eFIB) densities collected at kelp stations during wet and dry seasons, and percent occuring in wet season (%wet), during 2018 and 2019. Within each contour stations are listed from north to south. See Table 3.2 for rain data. Stations not listed had no samples with elevated FIB concentrations during this time period.

	Seasons		
	Wet	**Dry**	**% Wet**
PLOO			
18-m Depth Contour			
C7	2	0	100
A7	1	0	100
A6	1	1	50
A1	2	0	100
SBOO			
9-m Depth Contour			
I32	5	0	100
I26	12	3	80
I25	14	4	78
I24	24	4	86
I40	47	5	90
I19	43	8	84
18-m Depth Contour			
I39	8	0	100
Total eFIB	159	25	86
Total Samples	2745	1935	59

been much more pronounced in the SBOO region over the past 25 years (Figure 3.5), 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 = 18,423, $\chi 2 = 913.92$, $p < 0.0001$). As at the shore stations, high FIB densities 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 2009–2014b, 2015b–2016b, 2018). Such rain-driven turbidity plumes have often been observed in satellite images of the region overlapping SBOO kelp stations with elevated FIB counts (e.g., Figure 3.6). The higher incidence of elevated FIB at the SBOO kelp bed stations during the wet season of 2018 and 2019 was also 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 (see IBWC 2018–2019).

Offshore stations

Water quality was extremely high at all non-kelp offshore stations that were sampled quarterly in the PLOO and SBOO regions in 2018–2019. Of the 1632 samples collected at these stations over the past two years, only about 3% (n = 43) had elevated FIB, 58% of which occurred during the wet season (Table 3.4, Addenda 3-1, 3-2, City of San Diego 2019b). This translated into ≥ 80% 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 water contact standards apply (Figures 3.1, 3.7). Additionally, the above 10 SBOO stations were ≥ 87% compliant with the SSM standards for total coliforms, fecal coliforms, and the FTR criterion; only *Enterococcus* is required to be measured at the PLOO offshore stations.

Most of the offshore samples with elevated FIB (n = 34) in 2018–2019 occurred in the PLOO region (Table 3.4). These high counts were from depths of 60 m or deeper, 91% were from stations located along the 80 or 98-m depth contours, and 29% were from stations F29, F30 and F31 located within 1000 m of the PLOO discharge site (i.e., nearfield stations) (Addenda 3-1, 3-2, City of San Diego 2019b). These results suggest that the PLOO wastewater plume 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 2018–2020a). This conclusion is consistent with historical remote sensing observations that have provided no evidence of the PLOO plume reaching surface waters (Svejkovsky 2010–2017, Hess 2018–2020).

The above findings are also consistent with historical ocean monitoring results, which revealed that < 4% of samples collected at depths

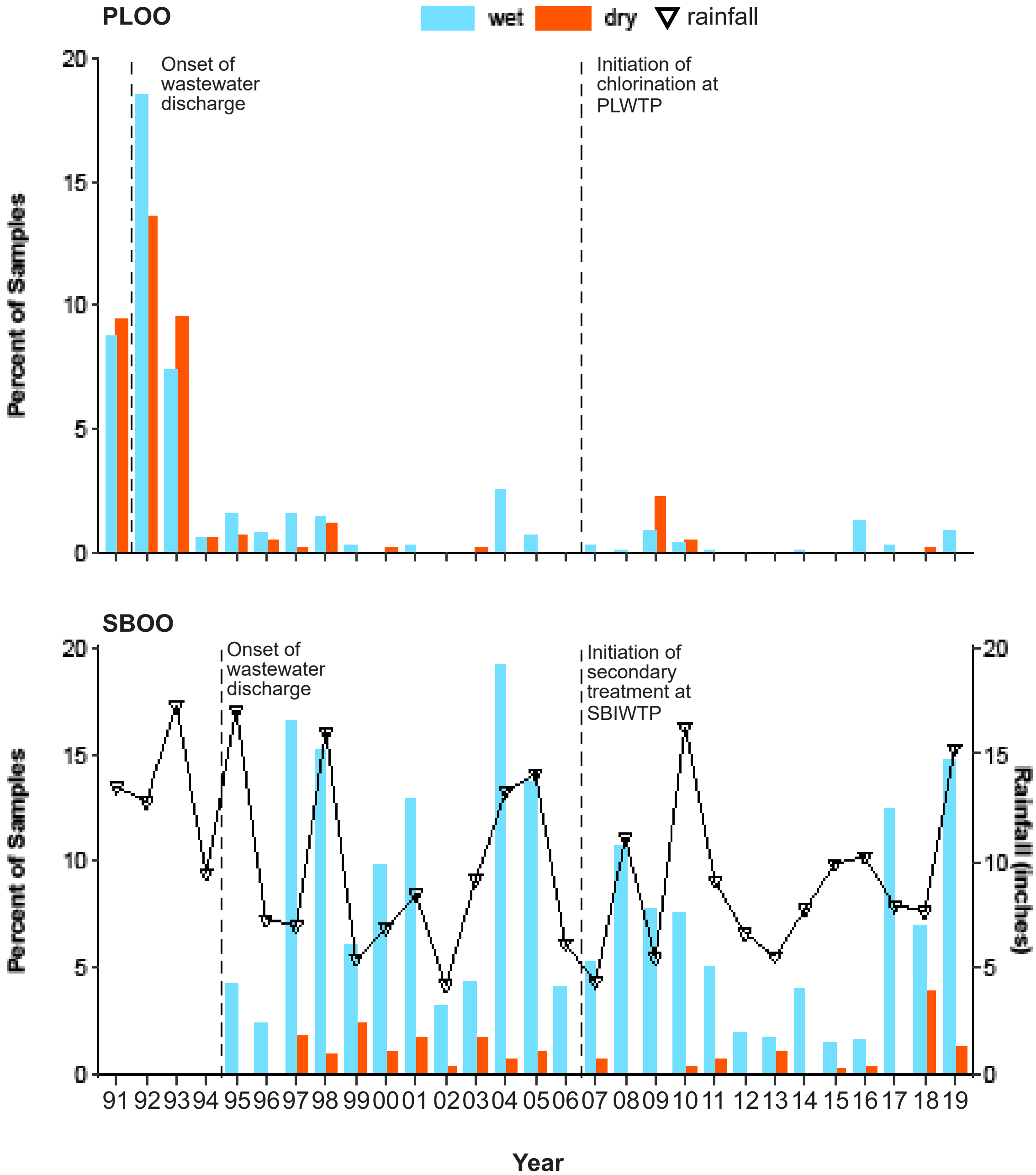

Figure 3.5
Comparison of annual rainfall to the percent of samples with elevated FIB densities in wet (blue bars) versus dry (red bars) seasons at PLOO and SBOO kelp stations from 1991 through 2019. Rain data are from Lindbergh Field, San Diego, CA. Vertical dashed lines indicate onset of wastewater discharge and changes to treatment processes at each outfall. Monitoring at the SBOO stations began in July 1995.

of ≤25 m from the PLOO 98-m (i.e., discharge depth) stations had elevated levels of *Enterococcus* during the pre-chlorination years (1993–2008). This percentage dropped to <1% at these depths following the initiation of partial chlorination at the Point Loma Wastewater Treatment Plant (PLWTP) in 2008 (City of San Diego 2009), and was zero during the current reporting period (Figure 3.8A). Overall, detection of elevated *Enterococcus* has been significantly more likely at the three nearfield stations (F29, F30, F31) than at any other 98-m site (20% versus 8%, respectively; n=7102, $\chi2=41.60$, $p<0.0001$). The addition of chlorination significantly decreased the

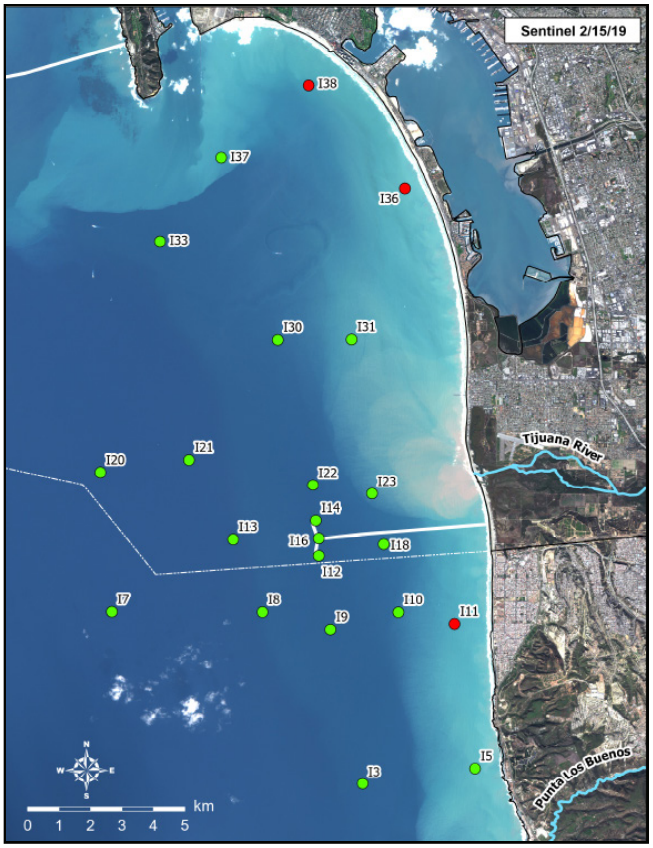

Figure 3.6
Rapid Eye satellite image showing stations throughout the region on February 7, 2019 (Ocean Imaging 2019) combined with bacteria levels sampled at shore and kelp stations on February 6 and 7, 2019, respectively. Green circles indicate FIB met and red circles indicate FIB exceeded water contact standards. Turbid waters from the Tijuana River, San Diego Bay and Los Buenos Creek, can be seen overlapping stations with elevated FIB.

number of samples with elevated *Enterococcus* at these three stations (i.e., 26% before versus 9% after, n=2503, $\chi2=425.87$, **p**<0.0001), and the other 98-m stations (11% before versus 3% after; n=4599, $\chi2=231.75$, $p<0.0001$) (Figure 3.8B).

In contrast to the PLOO region, only nine samples from the SBOO region had elevated FIB during the past two years (Table 3.4). Of these, eight occurred during the second week of February 2019 at stations I11, I30, I36, and I38, corresponding to a turbidity plume caused by a large transboundary flow into the Tijuana River that occurred from February 8 to February 12 (see Figure 3.9, IBWC 2018–2019). Only one sample with elevated FIB was collected from SBOO offshore stations during the dry season; it was taken from station I5 on August 2, 2019. Historically, elevated bacterial levels were more likely at the three nearfield stations (i.e., I12, I14, I16) when compared to other SBOO 28-m (i.e., discharge depth) stations (11% versus 3%; n=6234, $\chi2=13.44$, $p<0.0002$) (Figure 3.10). These samples were predominately collected at a depth of 18 m. Apart from 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 South Bay Wastewater Treatment Plant (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), DO, and pH levels were assessed by evaluating the results of 328 CTD profile casts performed in 2018 and 2019. Based on the criteria described previously (City of San Diego 2016a), potential evidence of a plume signal was detected a total of 66 times during the year from 26 different stations, while 8 to 20 stations were identified as reference sites during each quarterly survey (Table 3.5, Figure 3.11, Addendum 3-3, City of San Diego 2019b). About 23% of possible plume detections (n=15) occurred at the three stations located closest to the outfall (F29, F30, F31), equating to a detection rate of 63% at these nearfield sites over the past two years. Another 53% of the possible detections (n=35) occurred at stations along the 80 and/or 98-m depth contours, located up to 13 km to the north and 8 km to the south of the outfall. The remaining potential plume signals (n=16) may be spurious, due to their distance from the outfall and/or proximity to other known sources of organic matter (e.g., Rochelle-Newall and Fisher 2002, Romera-Castillo et al. 2010). Overall, the variation in plume dispersion observed off Point Loma, in 2018 and 2019, 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

Table 3.4

Number of samples with elevated FIB (eFIB) densities collected at PLOO and SBOO offshore stations during wet and dry seasons, and percent occuring in wet season (%wet), during 2018 and 2019. Within each contour stations are listed from north to south. See Table 3.2 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			
F12	1	0	100
F11	1	0	100
F10	1	0	100
80-m Depth Contour			
F25	0	1	0
F21	1	0	100
F20	0	1	0
F19	1	1	50
F18	0	2	0
F16	0	1	0
98-m Depth Contour			
F36	2	0	100
F35	1	0	100
F34	2	0	100
F33	0	1	0
F32	1	0	100
F31*	2	1	67
F30*	3	3	50
F29*	0	1	0
F28	0	2	0
F27	1	2	33
F26	0	1	0
SBOO			
9-m Depth Contour			
I38	3	0	100
I36	3	0	100
I11	1	0	100
I5	0	1	0
28-m Depth Contour			
I30	1	0	100
Total eFIB	25	18	58
Total Samples	816	816	100

* Nearfield station

year (Addendum 3-4, City of San Diego 2019b). Despite fluctuations in depth of the pycnocline, plume detections remained below 24 m even during periods of weak water column stratification. This finding is in agreement with historical satellite imagery observations that have never showed visual evidence of the plume surfacing (e.g., Svejkovsky 2010–2017, Hess 2018–2020). About 32% (n=21) of the potential plume detections corresponded with elevated Enterococcus densities, all of which were collected at depths ≥60 m (Addendum 3-1, City of San Diego 2019b).

The effects of PLOO plume on natural light, DO and pH water quality indicators were calculated for each station and depth where a potential 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 (Addendum 3-4, City of San Diego 2019b). Of the 66 potential plume signals that occurred during the reporting period, a total of 44 out-of-range (OOR) events were identified at various stations throughout the year, which consisted of 39 OOR events for natural light and 5 OOR events for DO (Table 3.5, Addendum 3-4, City of San Diego 2019b). Representative quarterly profiles from station F30 are shown in Appendices E.3–E.10. There were no OOR events for pH. Overall 46% (n=18) of the natural light OOR events and 80% (n=4) of the OOR events for DO occurred at stations located within State jurisdictional waters where Ocean Plan compliance standards apply (i.e., stations F07–F14, F18–F20).

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 232 CTD profile casts performed in 2018–2019. Potential evidence of a plume signal was detected a total of 33 times during the year from 19 different stations, while 12 to 21 stations were identified as reference sites during each quarterly survey (Table 3.5, Figure 3.11, Addendum 3-3, City of San Diego 2019b). About 27% of the possible detections (n=9) occurred at nearfield stations located near the outfall wye (i.e., I12, I14, I15, I16), while many of the remaining

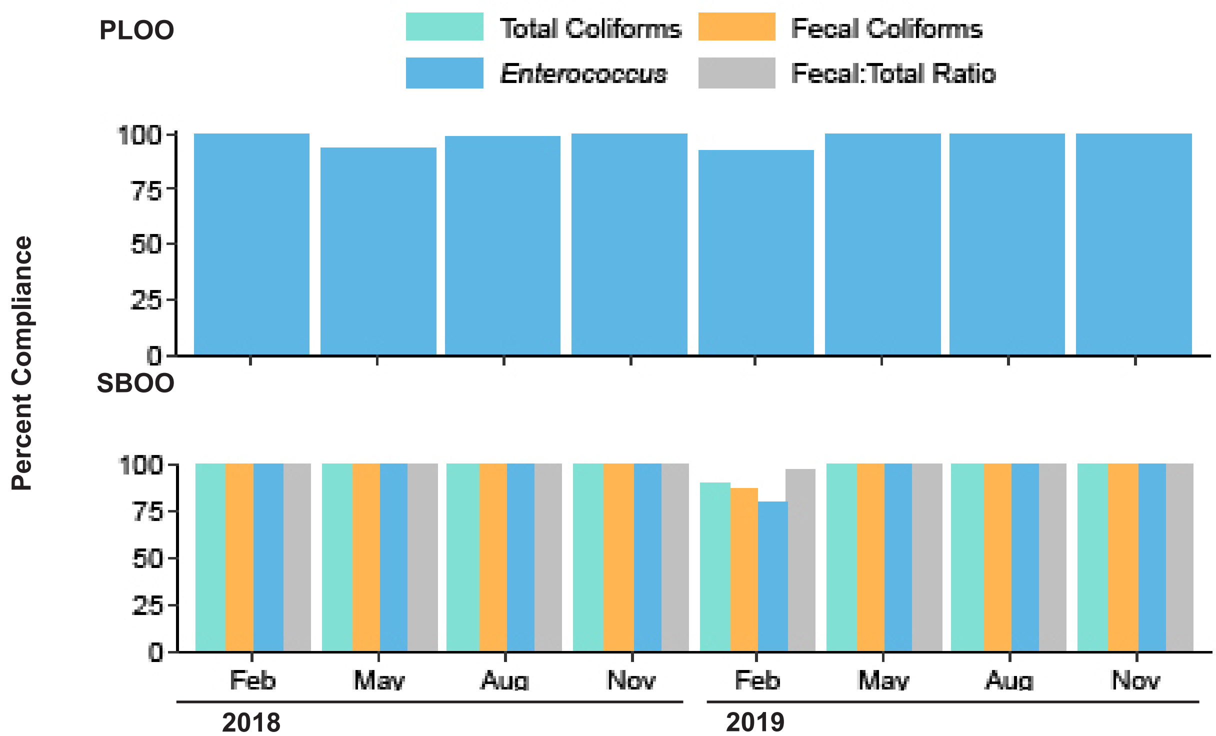

Figure 3.7
Compliance rates for the single sample maximum water contact standards at offshore stations during 2018 and 2019. Only *Enterococcus* is measured at PLOO offshore stations.

potential plume signals may be spurious due to their distance from the outfall. Only one of these plume detections, from station I30 located ~6.5 km north of the SBOO, was associated with elevated FIB (Addendum 3-2). 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 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 possible 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 reference stations (Table 3.5, Addendum 3-5, City of San Diego 2019b). Representative profiles from station I12 are shown in Appendices E.11–E.18. Of the 33 potential plume signals that occurred during the reporting period, a total of 16 OOR events were identified for transmissivity, while three OOR events occurred for DO. There were no OOR events for pH. Twelve of the 19 OOR events occurred at stations within State jurisdictional waters where Ocean Plan compliance standards apply, while five of these events occurred at nearfield stations I12, I14, I15, or I16.

Summary

Overall water quality conditions were excellent throughout both outfall monitoring regions during 2018 and 2019. For example, compliance with Ocean Plan water contact standards was over 96%, which was similar to that observed during recent years (City of San Diego 2010a–2018). Compliance with both the SSM and geometric mean standards for fecal indicator bacteria was typically higher at the PLOO and SBOO kelp beds, and other offshore stations, compared to the shore stations, and tended to be higher at PLOO stations than at the SBOO stations. Reduced compliance at shore stations, 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

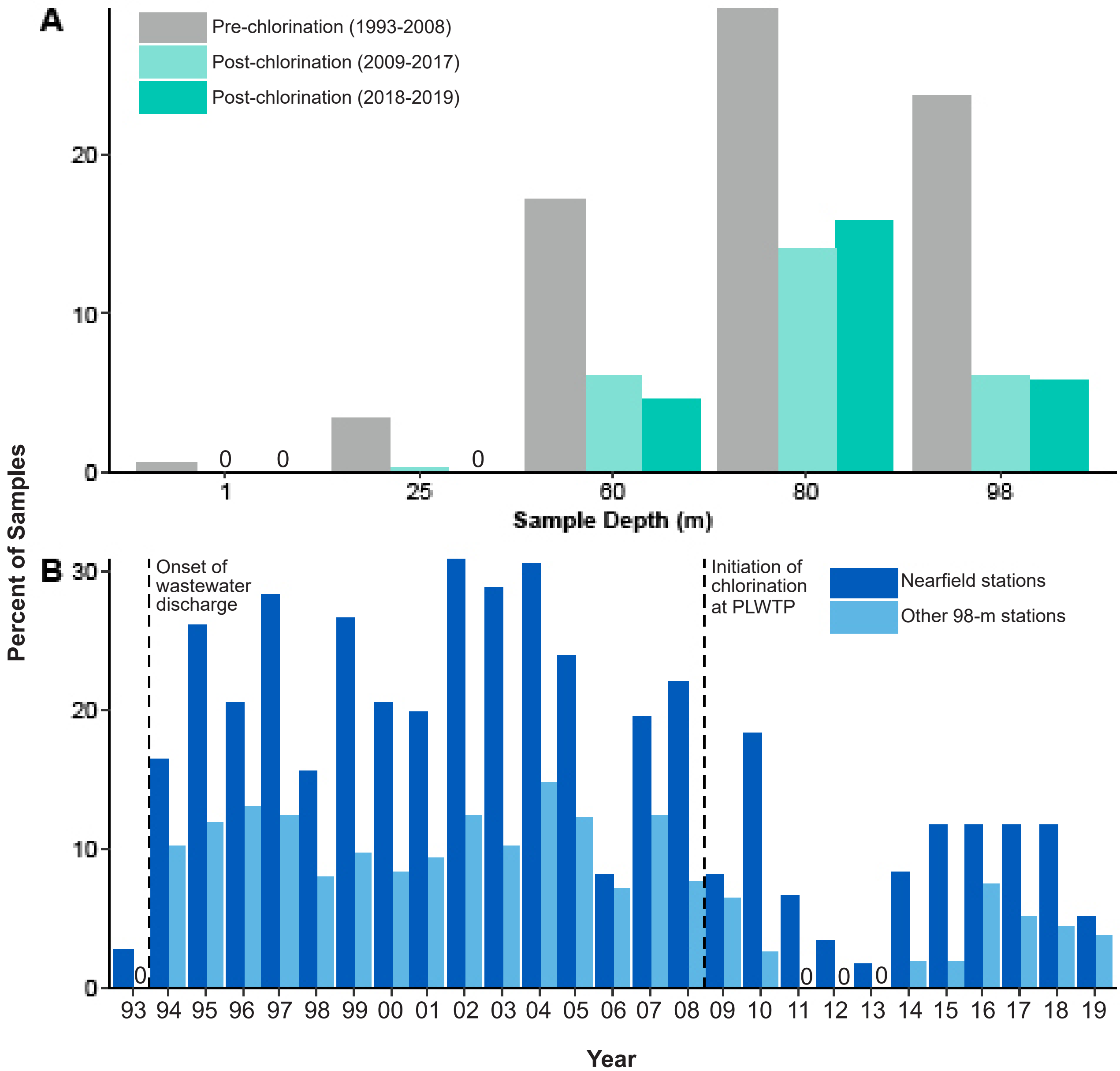

Figure 3.8
Percent of samples collected from PLOO 98-m offshore stations with elevated FIB. Samples from 2018 and 2019 are compared to those collected from 1993 through 2017 by (A) sampling depth and (B) year.

nearshore waters. Historically, elevated FIB 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 2009–2018). 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 in 1992 followed a catastrophic rupture of the outfall that occurred within the Point Loma kelp forest (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 610 million-gallon spill that occurred in January 2019 (IBWC 2018–2019).

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 transport of wastewater plumes from either the PLOO

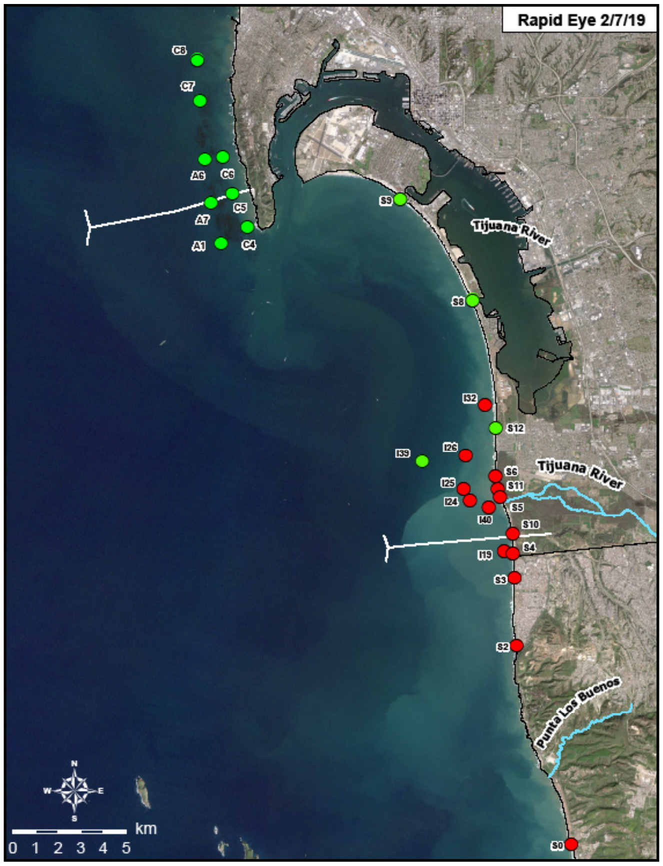

Figure 3.9
Sentinel 2A satellite image of the SBOO region on February 15, 2019 (Ocean Imaging 2019) combined with bacteria levels sampled at offshore stations on February 15, 2019. Green circles indicate FIB met and red circles indicate FIB exceeded water contact standards. Turbidity plume corresponds to a 315 million gallon raw sewage spill that started February 8, 2019 and lasted for four days (IBWC 2018-2019), and can be seen overlapping stations with elevated FIB.

or SBOO (Svejkovsky 2010-2017, Hess 2018–2020), and with previous studies that have indicated the PLOO wastefield typically remains submerged in deep offshore waters (e.g., City of San Diego 2009–2018, Rogowski et al. 2012a,b, 2013). The approximately 98-m depth of the PLOO discharge site is likely an important factor that inhibits the wastewater plume from reaching surface waters. 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 2009–2018). 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 densities in the SBOO region existed before wastewater discharge began in 1999 (see also City of San Diego 2000). The low number of samples with elevated FIB near the outfall during recent years is likely related to chlorination of SBIWTP effluent (November–April) and the initiation of full secondary treatment that began in January 2011.

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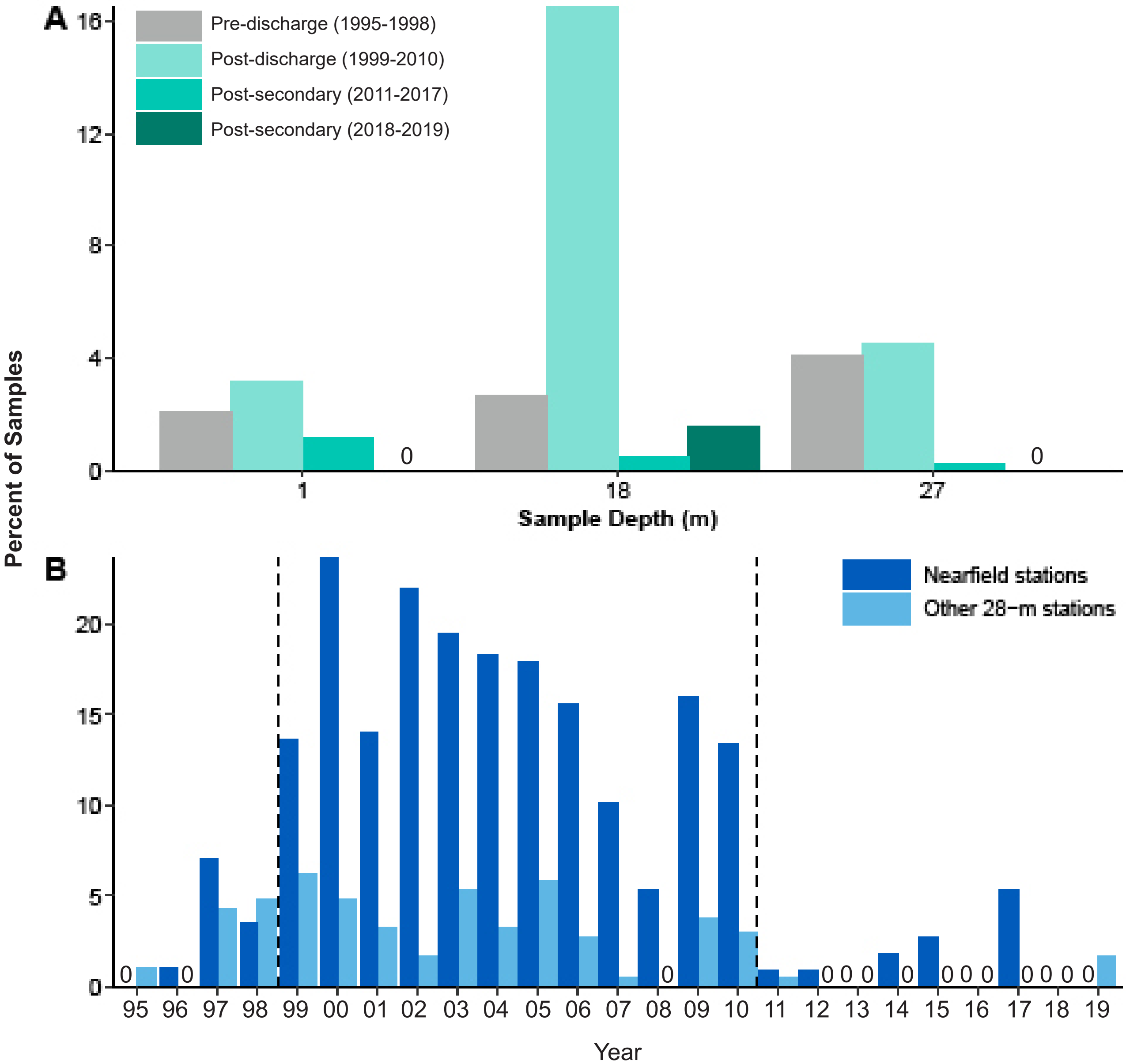

Figure 3.10
Percent of samples collected from SBOO 28-m offshore stations with elevated FIB. Samples from 2018 and 2019 are compared to those collected from 1995 through 2017 by (A) sampling depth and (B) year.

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Table 3.5

Summary of potential wastewater plume detections and out-of-range values at offshore stations during 2018 and 2019. 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
2018					
Feb	6	0	0	5	**F07**[a]**, F12**[a]**, F19**, F30[a], F31[a], F32[a]
May	8	0	0	1	F16, **F18**, **F19**, **F20**[a], F26, F27, F29, F30
Aug	11	0	0	4	**F14**[a] , **F18**[a], **F19**, **F20**, F23[a], F27, F28, F29[a], F30, F31, F33
Nov	7	1	0	7	**F11**[a], **F15**[ab], **F18**[a], F27[a], F28[a], F29[a], F30[a]
2019					
Mar	12	3	0	6	**F10**[a], **F11**[ab], **F12**[ab], **F19**[b], **F20**, F21[a], F22, F23, F30, F31[a], F32[a], F33
May	14	1	0	11	**F07**[a], **F08**[a], **F09**[a], **F10**[a], **F11**[a], **F12**[a], **F13**[a], **F14**[a], F22[a], F23[a], F30[b], F31, F32[a], F34,
Aug	2	0	0	1	F28, F30[a],
Nov	6	0	0	4	**F13**, F21, F30[a], F32[a], F34[a], F35[a]
Detection Rate (%)	20	2	0	12	
Total Count	66	5	0	39	
Total Samples	328	328	328	328	

	Potential Plume Detections	SBOO Out of Range DO	pH	XMS	Stations
2018					
Feb	4	0	0	0	I1, I2, I3, I7
May	4	1	0	0	**I12**[b], **I23**, **I31**, **I34**
Aug	2	0	0	2	**I12**[a], **I23**[a]
Nov	3	0	0	0	I1, I15, **I16**
2019					
Feb	8	0	0	5	**I12**, **I22**, **I27**, I30[a], **I31**[a]**, I34**[a]**, I35**[a]**, I39**[a]
May	4	0	0	3	I9, **I18**[a], **I27**[a], I29[a]
Aug	6	2	0	5	I3[a], **I14**[a], I15[b], **I16**[a], I29[a], I30[ab]
Nov	2	0	0	1	**I12**, **I34**[a]
Detection Rate (%)	14	1	0	7	
Total Count	33	3	0	16	
Total Samples	232	232	232	232	

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

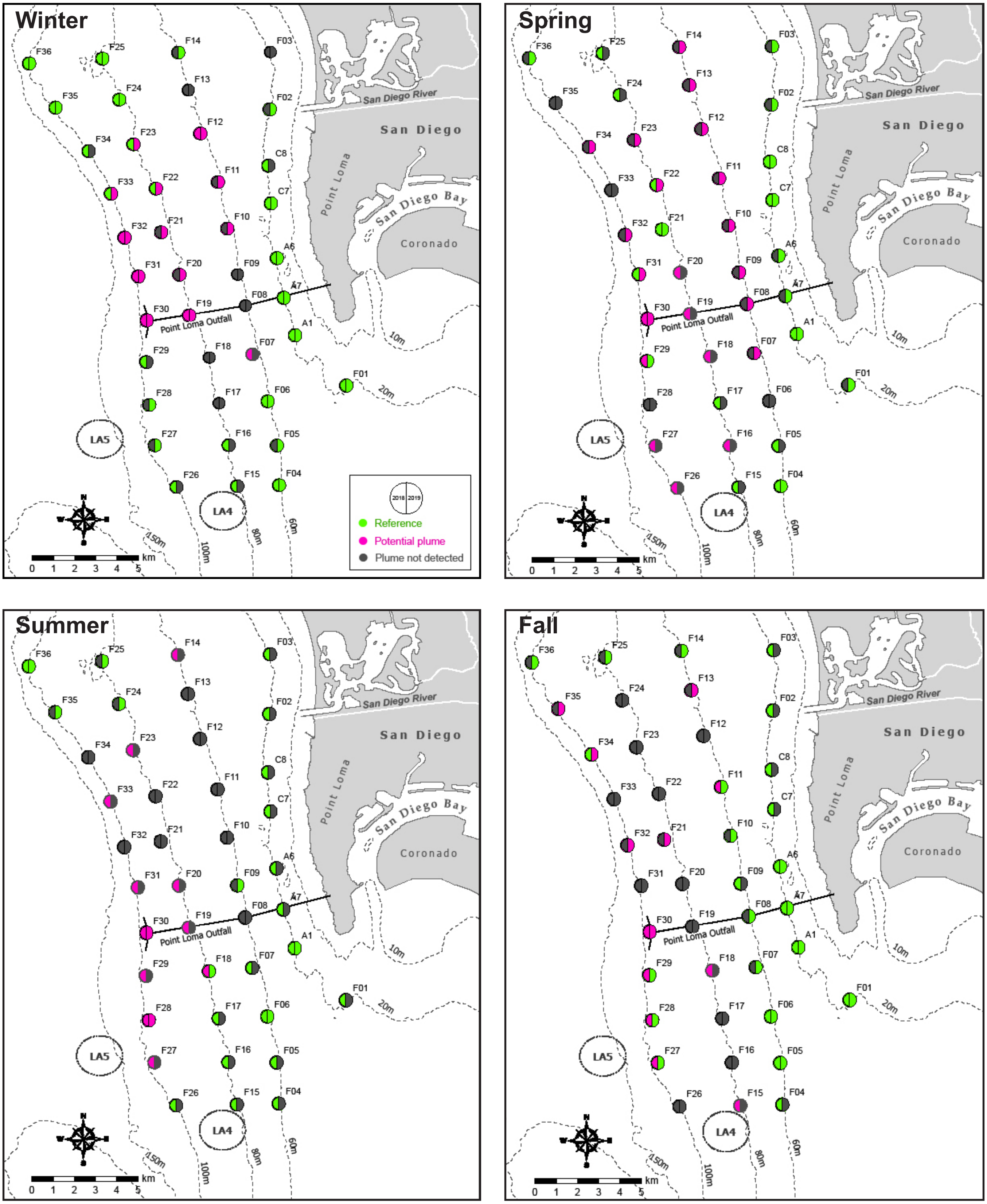

Figure 3.11
Distribution of stations meeting potential plume criteria (pink) and those used as reference stations (green) near the PLOO (this page) and SBOO (facing page) during quarterly surveys in 2018 (left half of pie) and 2019 (right half).

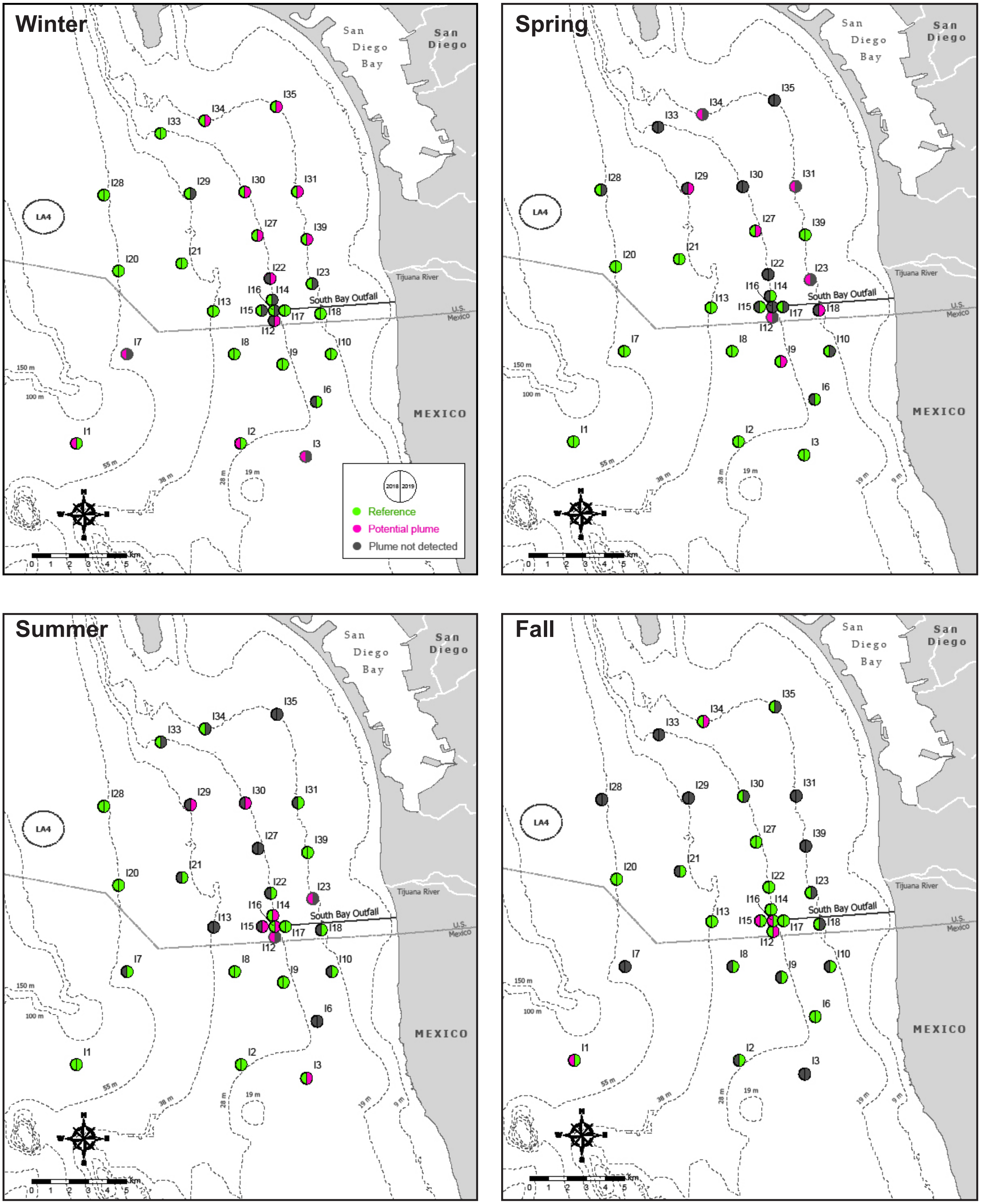

Figure 3.11 *continued*

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Chapter 4
Sediment Quality

Chapter 4. Sediment Quality

Introduction

Ocean sediment samples are analyzed by the City of San Diego (City) as part of the Ocean Monitoring Program to examine the effects of wastewater discharge from the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO), and other anthropogenic inputs, on the marine benthic environment. Analyses of various sediment contaminants are conducted as anthropogenic inputs to the marine ecosystem, including municipal wastewater, can lead to increased concentrations of pollutants within the local environment. The relative proportions of sand, silt, clay, and other particle size parameters are also examined as 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 as 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 changes in sediment condition and quality over time and space is, thus, crucial to assessing corresponding 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 (Emery 1960). 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 in 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, which may 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 as 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, during 2018 and 2019, from core benthic monitoring stations throughout the PLOO and SBOO regions. The three primary goals of this chapter are to: (1) document sediment conditions at core monitoring stations; (2) identify possible effects of wastewater discharge on sediment quality; (3) identify other potential natural or anthropogenic sources of sediment contamination. For additional information, a broader regional assessment of benthic conditions throughout the entire San Diego region, which is presented in Chapter 6, is based on a subset of the data reported in this chapter combined with a suite of randomly selected stations sampled during the summer of 2019.

Materials and Methods

Field Sampling

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 PLOO and SBOO, during winter (January) and summer (July) of 2018 and 2019 (Figure 4.1). 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. 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, and SBOO stations I12, I14, I15 and I16. During the summer of 2018, only E15 and the primary core stations from the PLOO and SBOO regions were sampled, due to a resource exchange granted by the San Diego Regional Water Quality Control Board for participation in the region-wide Bight'18 sampling project.

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 analyses, and one grab per cast used for benthic community analysis (see Chapters 5 and 6). 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 2018).

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 (2019a, 2020a). Briefly, sediment sub-samples were analyzed on a dry weight basis to determine concentrations of various indictors of organic loading (biochemical oxygen demand, total organic carbon, total nitrogen, total sulfides, 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 F.1). However, concentrations below MDLs were included as estimated values, if presence of the specific constituent was verified by mass-spectrometry. A variety of laboratory technical issues resulted in a significant amount of non-reportable sediment chemistry data for 2018 and 2019 as detailed in Addendum 4 and City of San Diego (2019b). Impacted data include alpha-endosulfan, and total values for chlordane, DDT, PCB, and PAH. Averages representing conditions for 2018 and 2019 and historical comparisons involving these parameters should therefore be interpreted with caution.

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

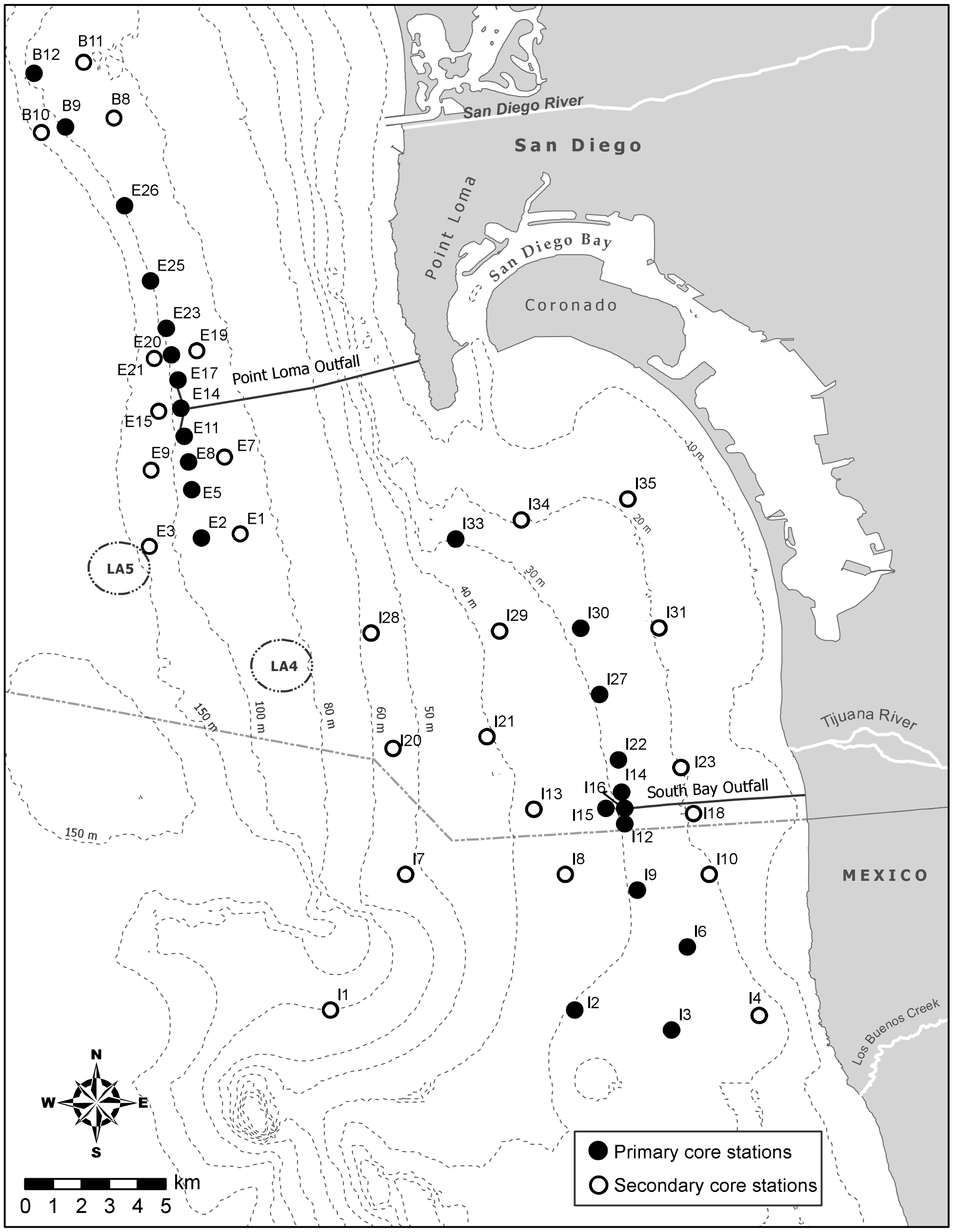

Figure 4.1

Benthic station locations sampled around the PLOO and SBOO as part of the City of San Diego's Ocean Monitoring Program.

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 F.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 was used with mesh sizes of 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, 75 µm, and 63 µm to divide the samples into seven sub-fractions.

Data Analyses

Sediment particle size and sediment chemistry data for PLOO and SBOO core stations sampled in 2019 are listed in Addenda 4-1 through 4-10, while data collected during 2018 were reported previously (City of San Diego 2019b) and are available online (City of San Diego 2020b). Data summaries for the various sediment parameters included detection rate, minimum, maximum, and mean 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 in the data (i.e., analyte concentrations <MDL). Total chlordane, total DDT (tDDT), total hexachlorocyclohexane (tHCH), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all individual constituents with reported values (see above and Addenda 4-9, 4-10, City of San Diego 2019). Where possible, contaminant concentrations were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995). The 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 2019) and various functions within the reshape2, plyr, dplyr, tidyr, tidyverse, zoo, stringr, vegan, stats, psych, ggplot2, and ggpubr packages (Zeileis and Grothendieck 2005, Oksanen et al. 2019, Revelle 2019, Wickham 2007, 2011, 2017, 2019a,b, Wickham et al. 2020, Wickham and Henry 2018, Wickham et al. 2019, Kassambara 2019).

Results

Particle Size Distribution

Ocean sediments sampled at the core PLOO stations during 2018 and 2019 were composed primarily of fine silts and clays (percent fines), plus fine sands. Percent fines ranged from a minimum of 12.5% to a maximum of 80.8% per sample, while fine sands ranged from 19.2% to 84.1%, medium-coarse sands ranged from <1% to 27.8%, and coarse particles ranged from 0 to 23.4% (Table 4.1). Coarser particles often included shell hash, black sand, and/or gravel (Addendum 4-1, City of San Diego 2019b). Overall, there were no significant spatial patterns in sediment composition relative to proximity to the PLOO discharge site over the past two years (Figure 4.2, Appendix F.3). Instead, several farfield stations had larger proportions of medium-coarse sands and/or coarse particles during one or more surveys than the nearfield stations and other farfield stations. These included northern stations B11 and B12, as well as the southern stations E1, E2, E3 and E9. Nearfield station E17 also had a mean proportion of 14% coarse material during summer 2019. Additionally, fine particles appeared to increase between 2018 and 2019 across the region.

Despite the sudden surge in fine particles during 2019, there was no evidence that fines have been accumulating over time at any of the nearfield or farfield primary core PLOO stations since wastewater discharge began at the current discharge site in late 1993 (Figure 4.3). Instead, temporal variability of sediment composition at these sites has been primarily in the sand and coarse fractions (see 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, black sands were observed at stations E9, E15, and E14 during the winter 2018, station E9 during winter 2019, and E9, E15, and E14 during summer 2019 (Addendum 4-1, City of San Diego 2019b), 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 2018 and 2019. Percent fines ranged from a minimum of 0 to a maximum of 95.3% per sample at these stations, while fine sands ranged from 1% to 93%, medium-coarse sands ranged from <1% to 91.3%, and coarse particles ranged from 0 to 44.8% (Table 4.2). Coarser particles at the SBOO stations often comprised shell hash, red relict sands, black sand, gravel or cobble (Addendum 4-2, City of San Diego 2019). There were no spatial patterns in sediment composition relative to proximity to the SBOO discharge site

Table 4.1

Summary of particle sizes and chemistry concentrations in sediments from PLOO benthic stations sampled historically (1991–2017) and during the current reporting period (2018–2019). 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 (1991–2017)					Current (2018–2019)				
Parameter	**n**	**DR**	**min**	**max**	**mean**	**n**	**DR**	**min**	**max**	**mean**
Particle Size (%)										
Coarse Particles	624	23	0.0	64.2	4.2	79	19	0.0	23.4	6.3
Med-Coarse Sands	624	96	0.0	64.5	3.5	79	100	0.1	27.8	3.2
Fine Sands	624	100	11.7	85.6	55.6	79	100	19.2	84.1	48.7
Fine Particles	624	100	10.8	55.2	40.1	79	100	12.5	80.8	46.9
Organic Indicators										
BOD (ppm)	622	91	nd	980	303	37	100	159	584	292
Sulfides (ppm)	636	96	nd	89.50	5.79	79	92	nd	108.00	5.45
TN (% weight)	636	93	nd	0.192	0.051	79	100	0.031	0.100	0.051
TOC (% weight)	636	94	nd	4.85	0.66	79	100	0.29	3.27	0.62
TVS (% weight)	636	100	0.2	5.4	2.3	79	100	1.2	3.7	2.0
Metals (ppm)										
Aluminum	576	100	3130	22,800	9422	79	100	4380	11,300	7041
Antimony	625	43	nd	13.0	1.6	79	71	nd	1.8	1.1
Arsenic	636	100	1.18	7.81	3.04	79	100	1.32	5.30	2.62
Barium	360	100	10.3	155.0	36.8	79	100	14.9	87.5	29.2
Beryllium	636	44	nd	3.06	0.44	79	70	nd	0.29	0.17
Cadmium	636	48	nd	5.70	0.60	79	67	nd	0.11	0.07
Chromium	636	100	7.0	40.6	17.2	79	100	10.3	25.4	15.1
Copper	636	99	nd	82.4	7.5	79	97	nd	10.2	4.6
Iron	600	100	4840	27,200	12,931	79	100	6680	20,900	10,748
Lead	636	64	nd	15.5	5.1	79	100	2.0	6.9	3.3
Manganese	528	100	31.5	317.0	103.0	79	100	51.4	122.0	78.1
Mercury	628	66	nd	0.093	0.028	79	72	nd	0.053	0.022
Nickel	636	96	nd	29.0	7.3	79	100	3.6	9.5	5.4
Selenium	636	47	nd	0.90	0.27	79	34	nd	0.64	0.49
Silver	636	15	nd	5.8	1.2	79	1	nd	67.4	67.4
Thallium	636	9	nd	113.0	10.6	79	0	—	—	—
Tin	528	65	nd	42.0	1.4	79	92	nd	1.1	0.6
Zinc	636	100	12.4	176.0	28.8	79	100	16.4	39.1	24.7
Pesticides (ppt)										
Total Chlordane	623	2	nd	2000	239	78	19	nd	549	61
Total DDT	623	60	nd	44,830	1208	78	100	112	1083	419
Dieldrin	623	< 1	nd	270	270	78	0	—	—	—
Endrin aldehyde	623	< 1	nd	970	970	78	0	—	—	—
Beta-endosulfan	623	< 1	nd	11	11	78	2	nd	11	11
HCB	528	11	nd	3300	436	58	48	nd	3250	235
Total HCH	623	1	nd	370	96	78	27	nd	305	64
Mirex	623	< 1	nd	66	66	78	0	—	—	—
Total PCB (ppt)	455	19	nd	22,690	1176	77	100	12	5054	639
Total PAH (ppb)	626	33	nd	3063	100	78	100	3	363	50

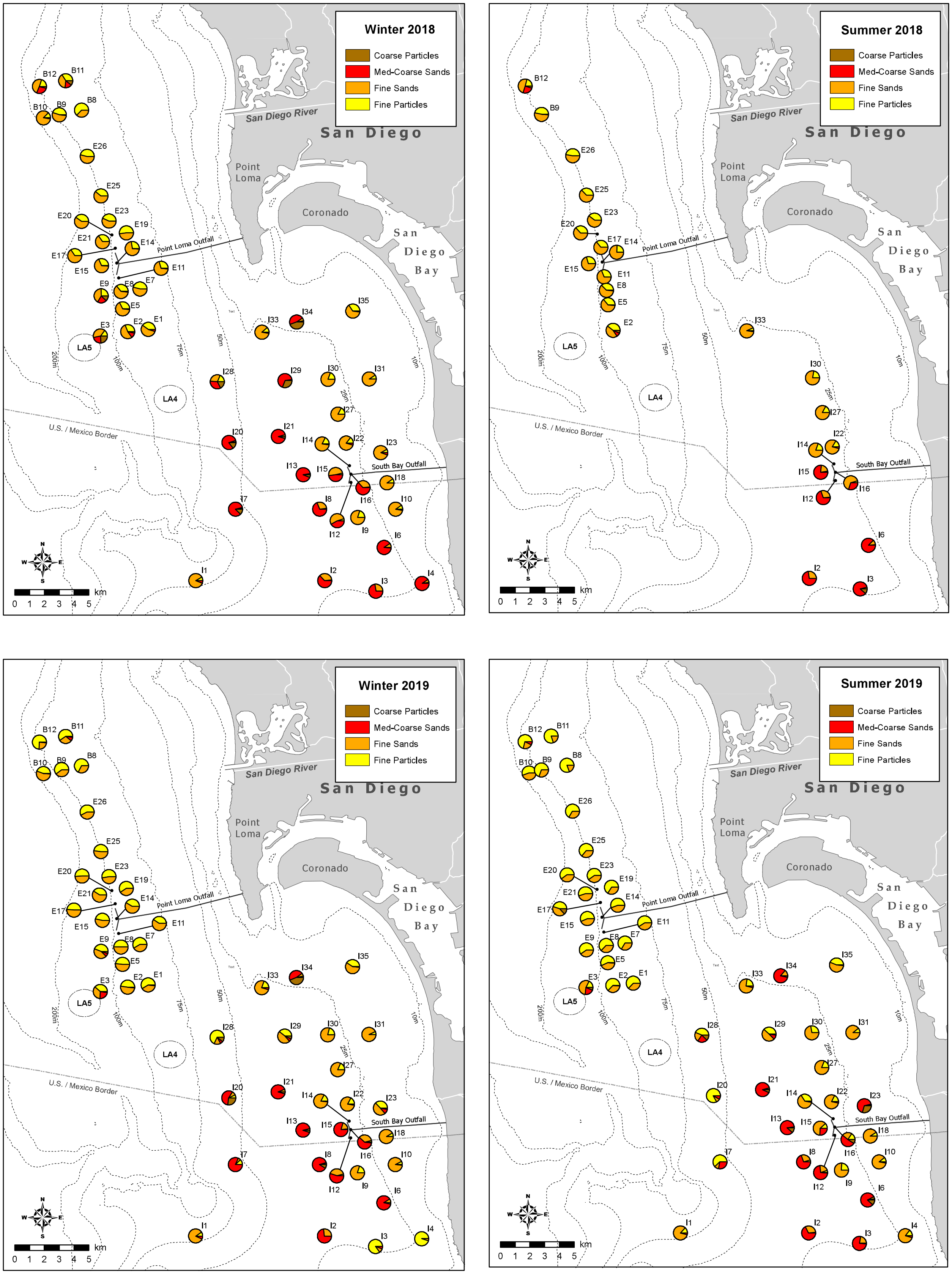

Figure 4.2

Sediment composition at PLOO and SBOO benthic stations during winter and summer surveys of 2018 and 2019. Only primary core stations were sampled during summer 2018 (see text).

over the past two years (Figure 4.2, Appendix F.4). Sediments from SBOO near-ZID stations I12, I15, and I16 averaged 51.2–59.7% medium coarse sands per sample, which was generally similar to sediments found at farfield stations located to the west and south of the outfall (I2, I3, I4, I6, I7, I8, I13, I21). In contrast, sediments from near-ZID station I14 averaged just 1.9% medium coarse sand, 75.9% fine sand, and 22.2% fine particles, which more closely resembled sediments from farfield stations located to the north (I22, I27, I30, I31). This north/south (southwest) split has been present in the SBOO monitoring region since sampling began in 1995 (Figure 4.3). It is interesting to note that fine particles also appeared to increase between 2018 and 2019 at some SBOO primary core stations. Previous analysis of particle size data revealed considerable temporal variability at some sites within the SBOO region 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 2018–2019 reporting period (Tables 4.1, 4.2, Addenda 4-3, 4-4, City of San Diego 2019). Only total volatile solids (TVS) was detected in all sediment samples from both regions. In contrast, total nitrogen (TN) and total organic carbon (TOC) were detected in 100% of the PLOO sediment samples, but only in 82% of the SBOO samples. Detection rates for sulfides ranged from 57% in the SBOO region to 92% in the PLOO region. Although not a required parameter for any of the PLOO or SBOO permits, biochemical oxygen demand (BOD) has long been measured by the City at PLOO benthic stations; this parameter was detected in samples collected from all primary core stations sampled during winter and summer 2018, and summer 2019 (BOD was not measured in winter 2019). Overall, results for all five indicators were consistent with historical detection rates of 87% or more since monitoring began (see Tables 4.1 and 4.2).

Sediments off Point Loma, in 2018 and 2019, had BOD concentrations ≤584 ppm, while sulfides were ≤108 ppm, TN was ≤0.10% weight, TOC was ≤3.27% weight, and TVS was ≤3.7% 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 4.4, Appendix F.5, Addendum 4-3, City of San Diego 2019b). In contrast, BOD and sulfide distributions were more variable over this period. For example, the four highest concentrations of BOD (≥448 ppm) occurred in two samples from northern farfield station B12, one sample from near-ZID station E14, and one sample from near-ZID station E15. The highest sulfide concentration, by almost an order of magnitude, occurred in sediments from farfield station E5 during summer 2018. The next four highest concentrations (≥14.3 ppm) occurred in one sample from northern farfield station B9, one sample from near-ZID station E17, and two samples from near-ZID station E14. In general, only sulfide and BOD have shown any changes in concentrations near the PLOO that appear consistent with possible organic enrichment (Figure 4.3) (see also City of San Diego 2015).

Sediments surrounding the SBOO, in 2018 and 2019, had sulfide concentrations ≤37.4 ppm, while TN concentrations were ≤0.062% weight, TOC concentrations were ≤1.84% weight, and TVS concentrations were ≤1.6% weight per sample (Table 4.2). There was little evidence of any significant organic enrichment near the SBOO discharge site during these two years; the highest concentrations of the various organic loading indicators were widely distributed throughout the region (Figure 4.4, Appendix F.6). For TOC, TN and TVS, variable concentrations may be linked to regional differences in sediment particle composition since these parameters can co-vary with the amount of percent fines (see City of San Diego 2014b). In contrast to the overall survey

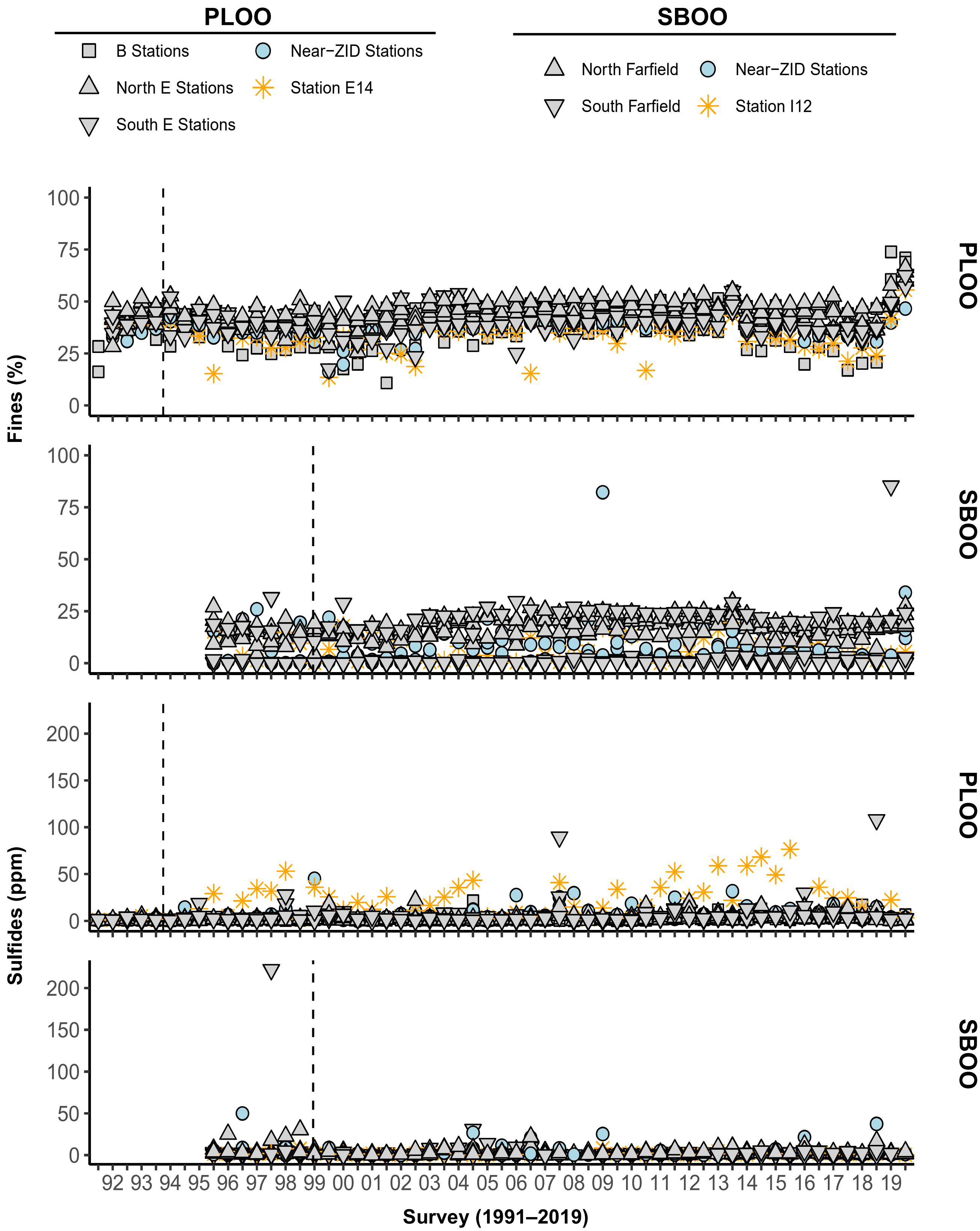

Figure 4.3
Percent fines and concentrations of organic indicators in sediments sampled during winter and summer surveys at PLOO primary core stations from 1991 through 2019 and at SBOO primary core stations from 1995 through 2019. Data represent detected values from each station, n≤12 samples per survey. Dashed lines indicate onset of discharge from the PLOO or SBOO. Biochemical Oxygen Demand (BOD) only measured at PLOO stations.

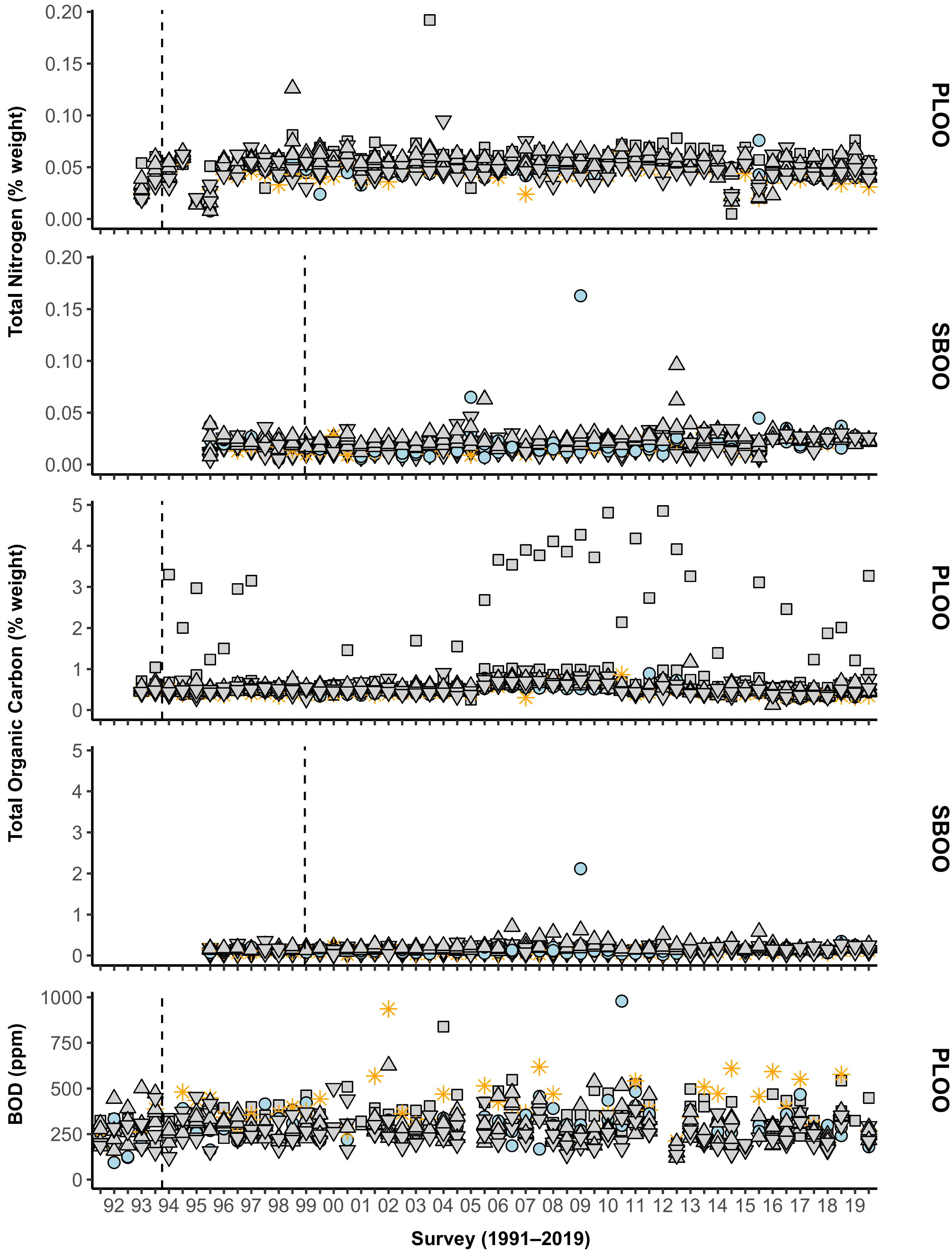

Figure 4.3 *continued*

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

Seven of the 18 trace metals analyzed were detected in all sediment samples collected at the PLOO and SBOO core benthic stations, in 2018 and 2019, including: aluminum, barium, chromium, iron, lead, manganese, and zinc (Tables 4.1, 4.2, Addenda 4-5, 4-6, City of San Diego 2019). Detection rates for antimony, arsenic, beryllium, cadmium, copper, mercury, nickel, tin, were higher in the PLOO region (67–100%) than in the SBOO region (43–94%). Detection rates for selenium also varied considerably between regions, ranging from 34% at the PLOO stations to only 5% at the SBOO stations. Silver was detected in only 1% of PLOO samples and none of the SBOO samples. Thallium was not detected in any samples collected during the 2-year reporting period.

Of the nine metals with published ERLs and ERMs (Long et al. 1995), only arsenic was reported at levels above its threshold during 2018 or 2019 (Table 4.3, Addenda 4-5, 4-6, City of San Diego 2019b). Arsenic exceeded its ERL in all three samples collected at SBOO station I21 during winter 2018, winter 2019, and summer 2019. Since I21 is a secondary core station, it was not sampled during summer 2018 (see Methods). In addition to low overall values, metal concentrations varied in sediments throughout the two regions, with no discernible patterns relative to proximity 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 (e.g., Figure 4.5, see also Appendix F.7). Only cadmium tended to be highest near the PLOO, with seven of the 10 highest values recorded over the past two years in sediments from near-ZID stations E11, E14, and E17. Note, though, that the maximum value recorded at these sites (0.11 ppm) was well below the ERL of 1.2 ppm. Metals were extremely variable across the SBOO region with no consistent pattern. However, stations I9, I29, and I35 often had the highest concentrations of aluminum, antimony, barium, beryllium, chromium, copper, iron, manganese, nickel, and zinc. As mentioned above, arsenic was consistently high at stations I21, I13, and I7 (Figure 4.5, Appendix F.8).

Detection rates have been relatively high for several different metals since monitoring began at the PLOO stations in 1991 and at the SBOO stations in 1995. For example, aluminum, arsenic, barium, chromium, copper, iron, manganese, nickel and zinc have been detected in ≥76% of the sediment samples collected in these areas over the past 25 to 29 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 (historical 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 (SCB) (Dodder et al. 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 F.9).

Pesticides, PCBs, PAHs

Based on reportable results (Addenda 4-7, 4-8, City of San Diego 2019b), a total of five chlorinated pesticides were detected in benthic sediments off San Diego during 2018 and 2019, including chlordane, DDT, dieldrin, hexachlorobenzene (HCB), and HCH (Tables 4.1, 4.2). The most common of these pesticides, DDT, was detected in 100% of the PLOO samples and 72% of the SBOO samples, with total DDT concentrations ≤1083 ppt and ≤5753 ppt per region, respectively. The second most common pesticide, HCB, was detected in 46–48% of PLOO and SBOO samples, with concentrations ≤3250 ppt and ≤2000 ppt per region, respectively. Thirdly, HCH was detected in 17–27% of PLOO and SBOO samples, with concentrations ≤305 ppt and ≤771 ppt per region, respectively. Chlordane had a detection rate of 19% for PLOO samples, but was found in only 1% of the SBOO samples, with a maximum concentration of 549 ppt for both regions. The spatial distribution of these pesticides varied in sediments from throughout the two regions over the past two years, with no discernible patterns relative to either outfall (Appendices F.10, F.11). For example, similar to many of the metals, the highest DDT values tended to be detected at the northern 'B' or southern 'E' stations over the past two years (Figure 4.7). However, only one of these samples had total DDT concentrations above the ERL threshold of 1580ppt. This exceedance occurred at SBOO farfield station I28 sampled in summer 2019 (see Addendum 4-8).

During the 2018–2019 reporting period, PCBs and PAHs were detected in all samples collected from the PLOO region, but PCBs were found in just 35% of SBOO samples, and PAHs in 69% of SBOO samples (Tables 4.1, 4.2). Total PCB concentrations were ≤5054 ppt at PLOO stations, and ≤946 ppt at SBOO stations, while total PAH concentrations were ≤363 ppb at PLOO stations, and ≤85 ppb at SBOO stations. The maximum total PAH concentration of 363 ppb, which occurred in sediments from PLOO farfield station E3, was well below the ERL threshold of 4022 ppb. Concentrations of total PCB and total PAH varied in sediments from throughout the two regions over the past two years, with no discernible patterns relative to either outfall. Instead, both contaminant types tended to be highest at the southern 'E' stations (e.g., Figure 4.7, see also Appendices F.10, F.11).

Although historical comparisons of pesticide, PCB and PAH results indicate considerably higher detection rates in 2018–2019 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 (Dodder et al. 2016). 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 25–29 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 long-term patterns that can be associated with wastewater discharge via either outfall (Figure 4.8).

Discussion

Particle size composition at PLOO and SBOO stations, during the current reporting period (2018–2019), were generally similar to that observed historically (e.g., Emery 1960, MBC-ES 1988, City of San Diego 2016b, 2018). However, this does not include an apparent increase in fine particles across the entire PLOO region and part of the SBOO region between 2018 and 2019, for which further investigation is required to determine the origins of this dramatic change. Within the PLOO region, percent fines (silt and clay) and fine sands continued to comprise the largest proportion of sediments. Within the SBOO region, sands continued to comprise the largest proportion of sediments, 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 the 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. Variability in the composition of Point Loma sediments is likely affected by both anthropogenic and natural

Table 4.2

Summary of particle sizes and chemistry concentrations in sediments from SBOO benthic stations sampled historically (1995–2017) and during the current reporting period (2018–2019). 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 (1995–2017)					Current (2018–2019)				
Parameter	**n**	**DR**	**min**	**max**	**mean**	**n**	**DR**	**min**	**max**	**mean**
Particle Size (%)										
Coarse Particles	537	34	0.0	12.3	2.6	93	52	0.0	44.8	7.4
Med-Coarse Sands	537	99	0.0	99.8	31.3	93	100	0.1	91.3	34.4
Fine Sands	537	100	0.0	96.1	57.0	93	100	0.9	93.0	46.7
Fine Particles	537	90	0.0	82.3	12.5	93	89	0.0	95.3	16.9
Organic Indicators										
Sulfides (ppm)	538	87	nd	222.00	3.20	93	57	nd	37.40	3.11
TN (% weight)	539	92	nd	0.163	0.020	93	47	nd	0.062	0.027
TOC (% weight)	539	98	nd	2.12	0.14	93	82	nd	1.84	0.22
TVS (% weight)	525	100	0.2	8.2	0.9	93	100	0.3	1.6	0.7
Metals (ppm)										
Aluminum	539	100	495	30,100	5224	93	100	572	7500	3277
Antimony	539	30	nd	5.6	0.7	93	61	nd	1.0	0.5
Arsenic	539	99	nd	9.18	1.81	93	90	nd	9.78	2.43
Barium	360	100	0.7	177.0	22.6	93	100	1.1	39.8	15.5
Beryllium	539	35	nd	2.10	0.18	93	57	nd	0.14	0.07
Cadmium	539	29	nd	1.00	0.15	93	43	nd	0.07	0.04
Chromium	539	99	nd	38.2	9.8	93	100	2.5	13.8	8.4
Copper	539	83	nd	37.6	3.5	93	45	nd	5.1	2.3
Iron	539	100	559	29,300	5964	93	100	1090	8910	5046
Lead	539	60	nd	20.0	2.2	93	100	0.8	3.2	1.6
Manganese	527	100	5.2	473.0	67.0	93	100	5.3	93.6	41.6
Mercury	527	31	nd	0.135	0.009	93	22	nd	0.020	0.008
Nickel	539	76	nd	22.8	3.2	93	94	nd	5.2	1.8
Selenium	539	14	nd	0.56	0.22	93	5	nd	0.41	0.28
Silver	539	14	nd	4.6	0.7	93	0	—	—	—
Thallium	539	6	nd	11.0	2.0	93	0	—	—	—
Tin	527	49	nd	4.5	1.0	93	63	nd	0.8	0.3
Zinc	539	91	nd	126.0	15.0	93	100	1.7	22.9	10.3
Pesticides (ppt)										
Aldrin	521	< 1	nd	500	500	93	0	—	—	—
Total Chlordane	521	1	nd	1620	349	93	1	nd	80	80
Total DDT	521	21	nd	9400	494	93	72	nd	5753	179
Dieldrin	521	0	—	—	—	93	1	nd	60	60
Beta-endosulfan	521	< 1	nd	820	820	93	0	—	—	—
HCB	378	16	nd	6200	429	67	46	nd	2000	310
Total HCH	521	1	nd	3880	1024	93	17	nd	771	145
Total PCB (ppt)	452	11	nd	11,320	572	93	35	nd	946	149
Total PAH (ppb)	536	23	nd	752	112	84	69	nd	85	11

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 (Emery 1960). Several SBOO stations are also located within or near an accretion 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 sediment samples collected throughout the PLOO and SBOO regions in 2018 and 2019. 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, 2018). 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 driver of 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 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. However, 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). 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

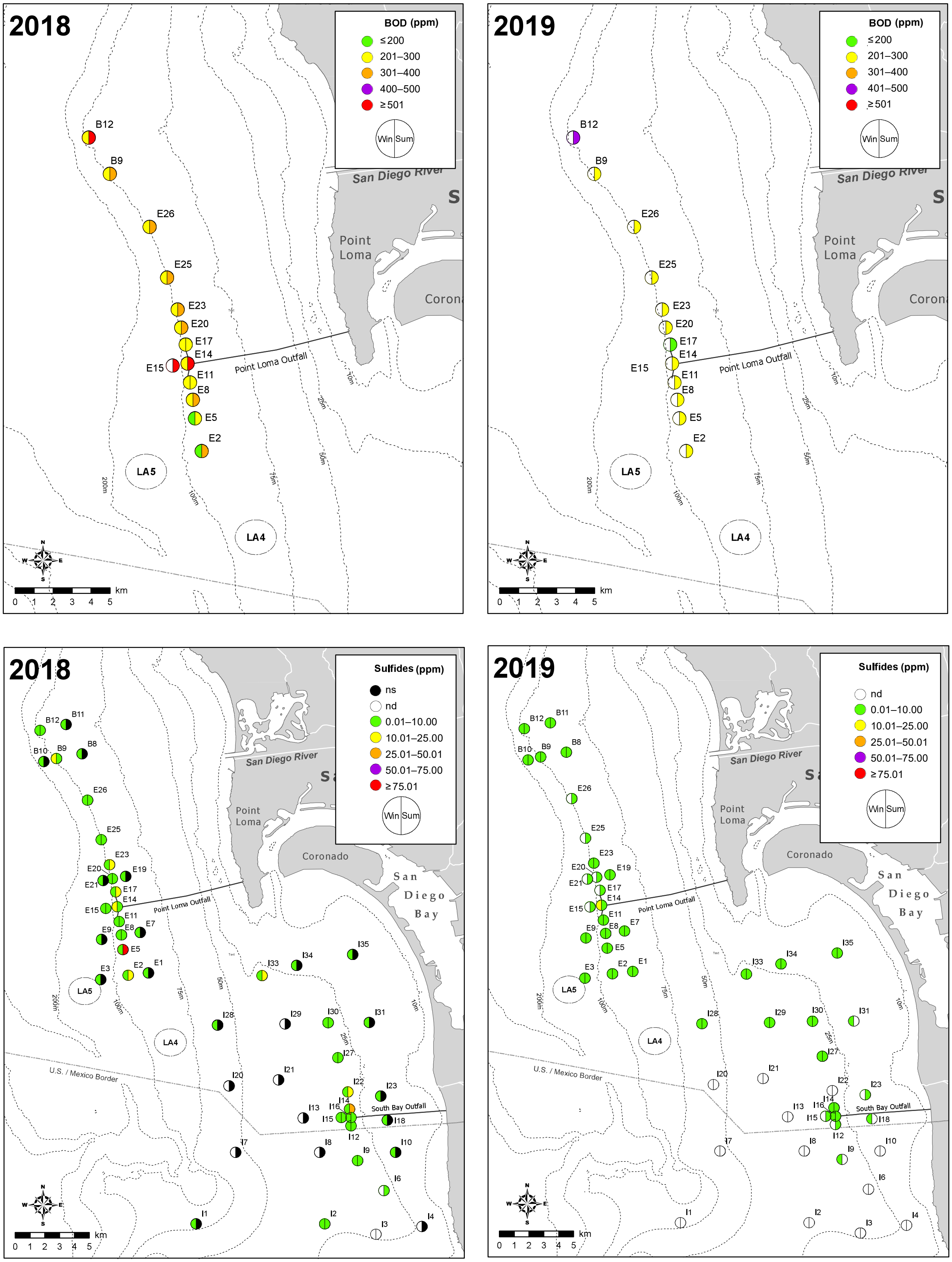

Figure 4.4

Distribution of select organic loading indicators in sediments from the PLOO and SBOO regions during winter and summer surveys of 2018 and 2019. BOD is only measured at PLOO primary core stations during summer surveys; nd = not detected; ns = not sampled.

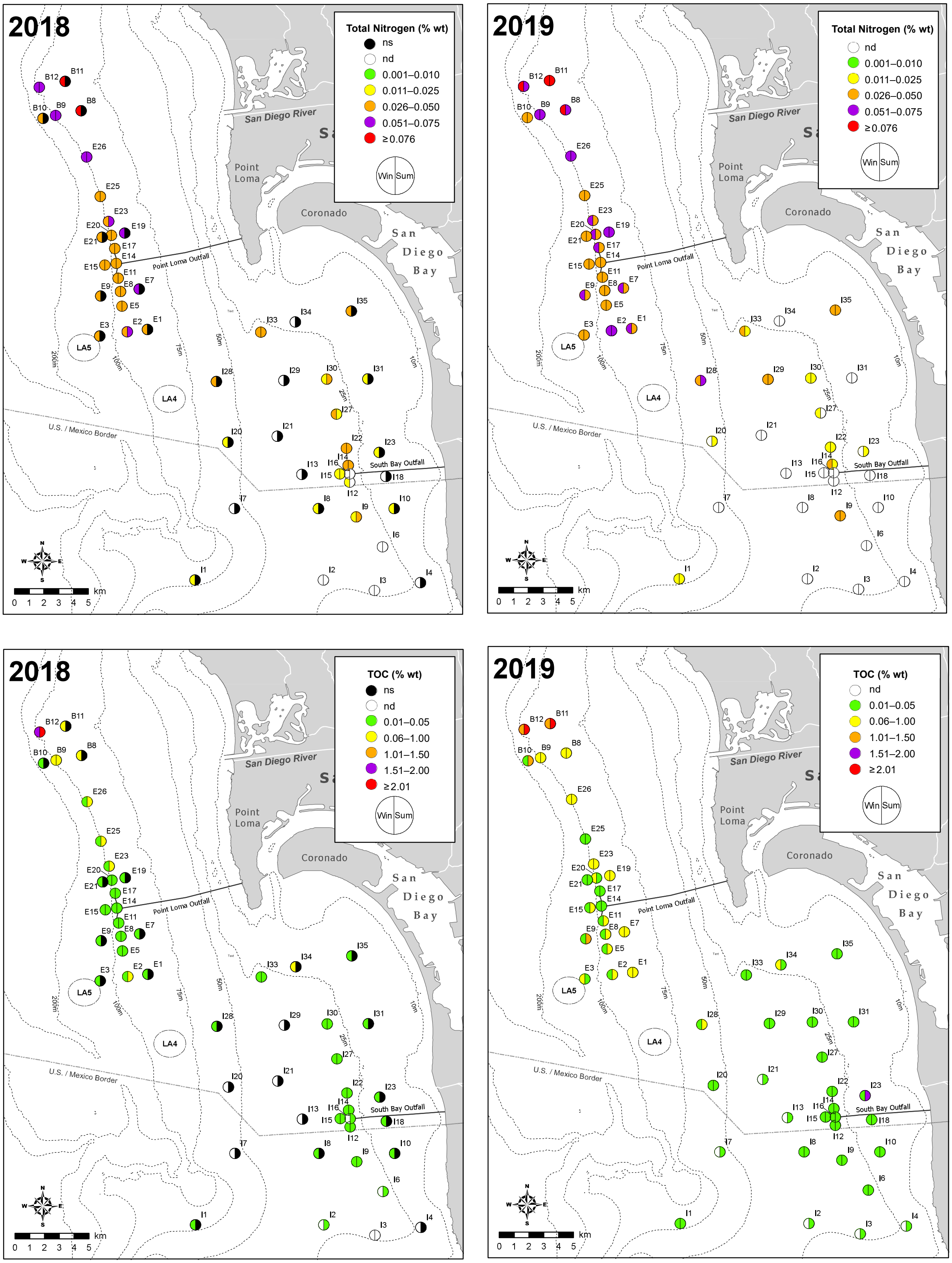

Figure 4.4 *continued*

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 (1991–2017) and during the current reporting period (2018–2019). 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		1991–2017		2018–2019		1995–2017		2018–2019	
Parameter	**ERL**	**ERM**	**%ERL**	**%ERM**	**%ERL**	**%ERM**	**%ERL**	**%ERM**	**%ERL**	**%ERM**
Metals										
Arsenic	8.2	70.0	0	0	0	0	0.2	0	3.2	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	0	0	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	1.0	3.7	6.1	0.6	1.3	0	3.7	0.4	0	0
Zinc	150	410	0.2	0	0	0	0	0	0	0
Pesticides										
tDDT	1580	461,000	9.1	0	0	0	1.0	0	1.1	0
tPAH	4022	44,792	0	0	0	0	0	0	0	0

(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 be reflect any significant organic enrichment. The only sustained effects have been restricted to a few sites located within 200 m of the PLOO (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 2018 and 2019 was similar to previous years with overall contaminant concentrations remaining relatively low compared to available thresholds, or values found in other southern California coastal areas (Schiff and Gossett 1998, Noblet et al. 2002, Schiff et al. 2006, 2011, Maruya and Schiff 2009). Consequently, 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 (i.e., Chapters 5–7).

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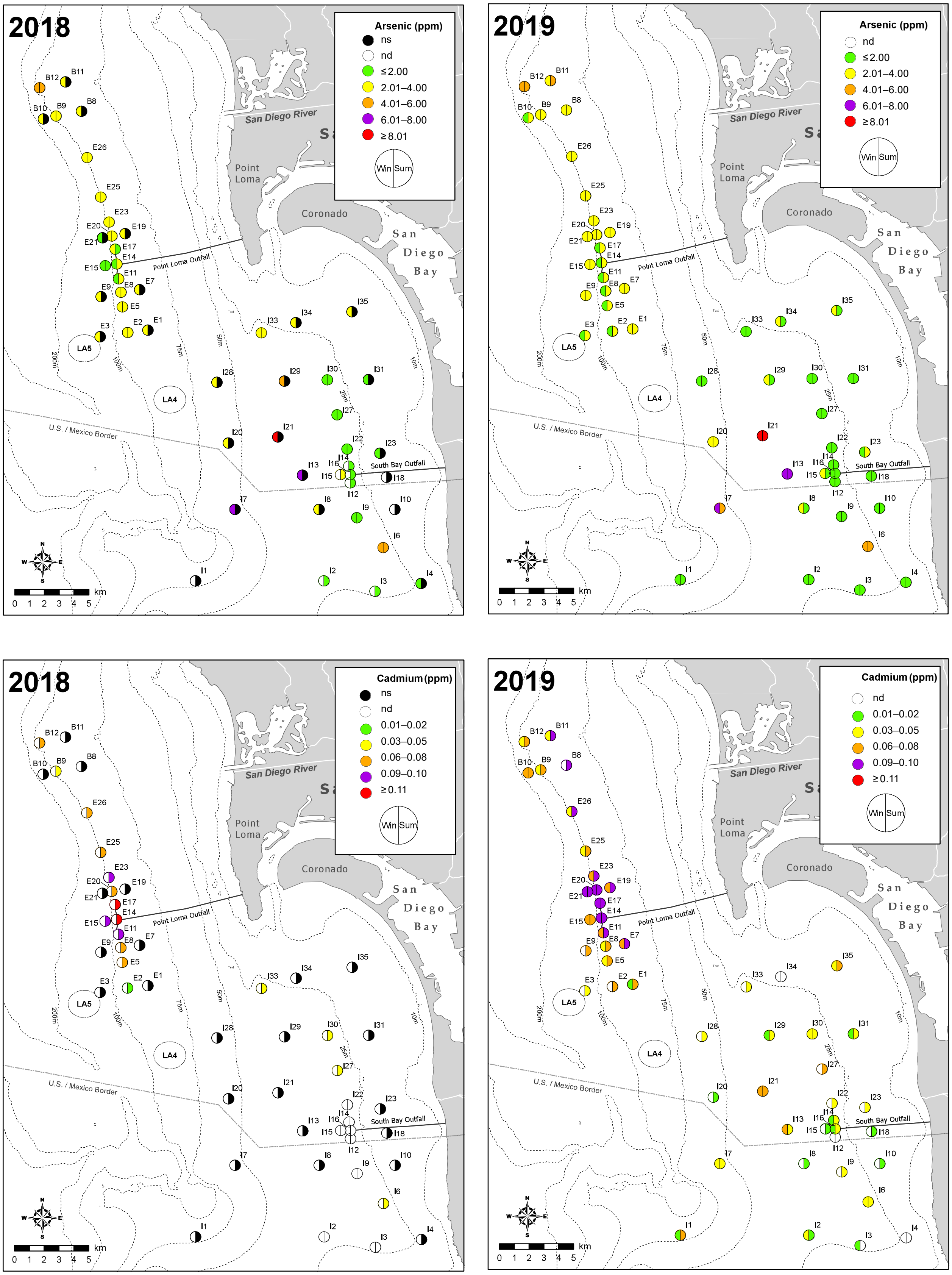

Figure 4.5

Distribution of select metals (ppm) in sediments from the PLOO and SBOO regions during winter and summer surveys of 2018 and 2019. Only primary core stations were sampled during summer 2018 (see text).

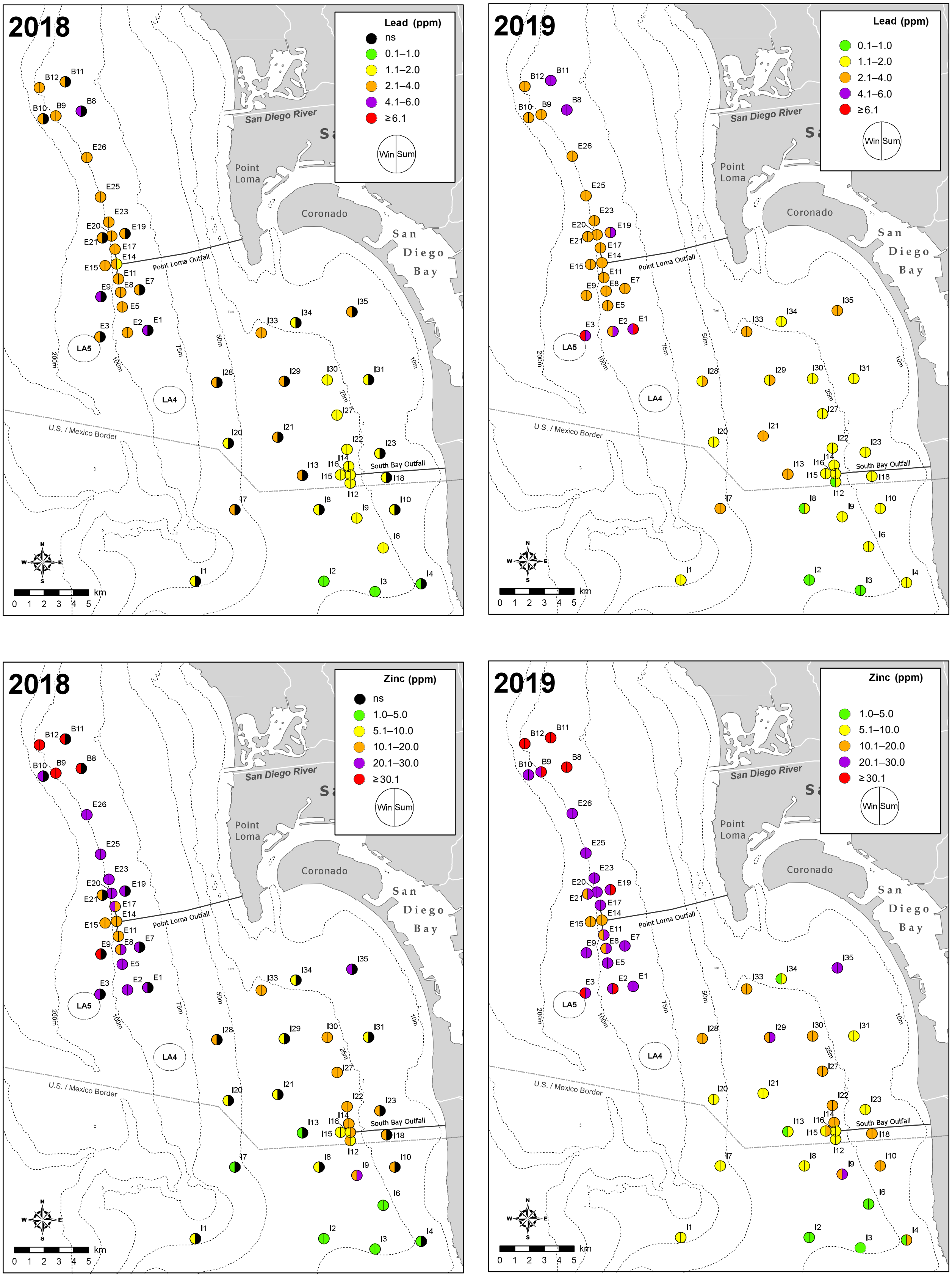

Figure 4.5 *continued*

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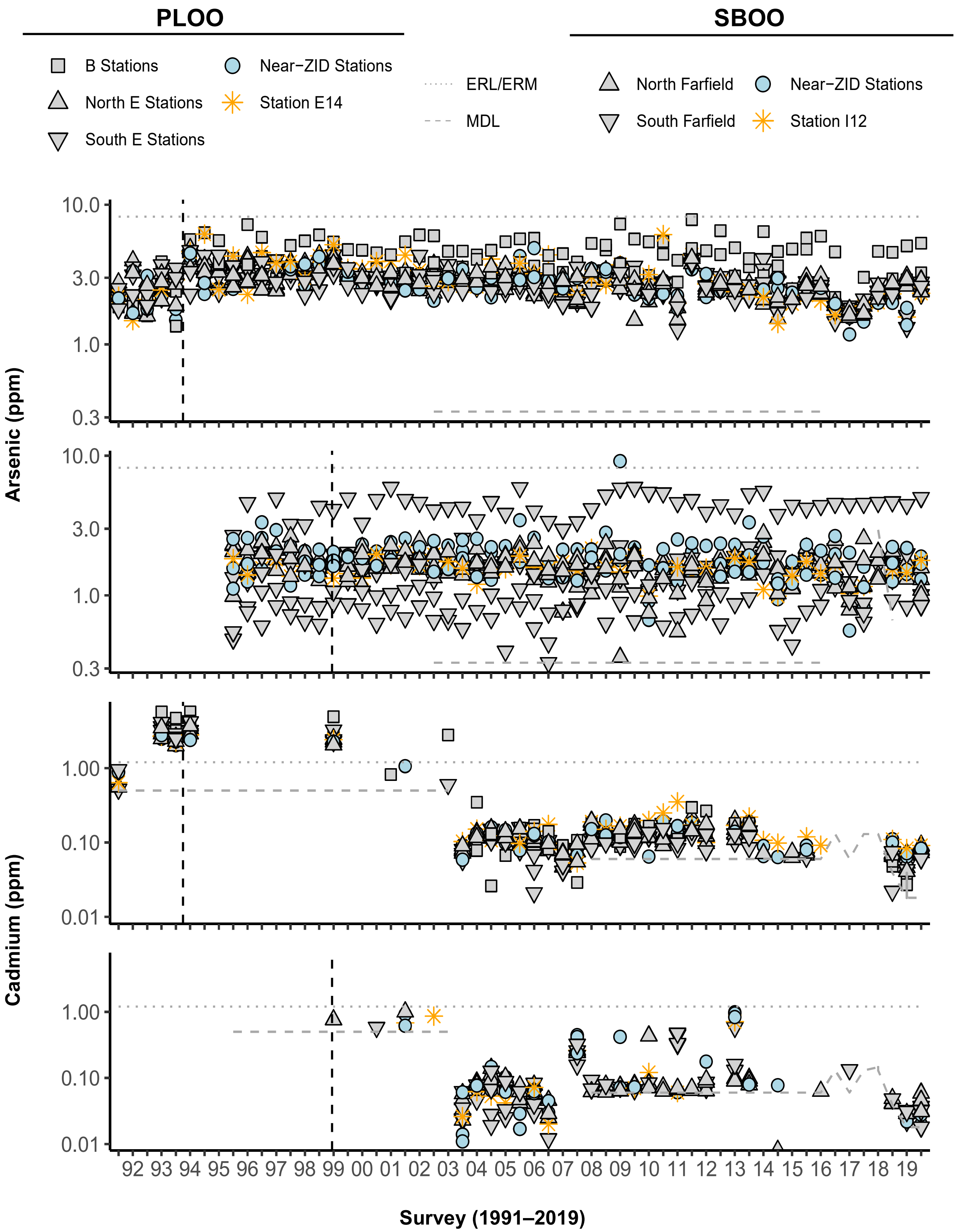

Figure 4.6

Concentrations of select metals in sediments sampled during winter and summer surveys at PLOO primary core stations from 1991 through 2019 and at SBOO primary core stations from 1995 through 2019. 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.

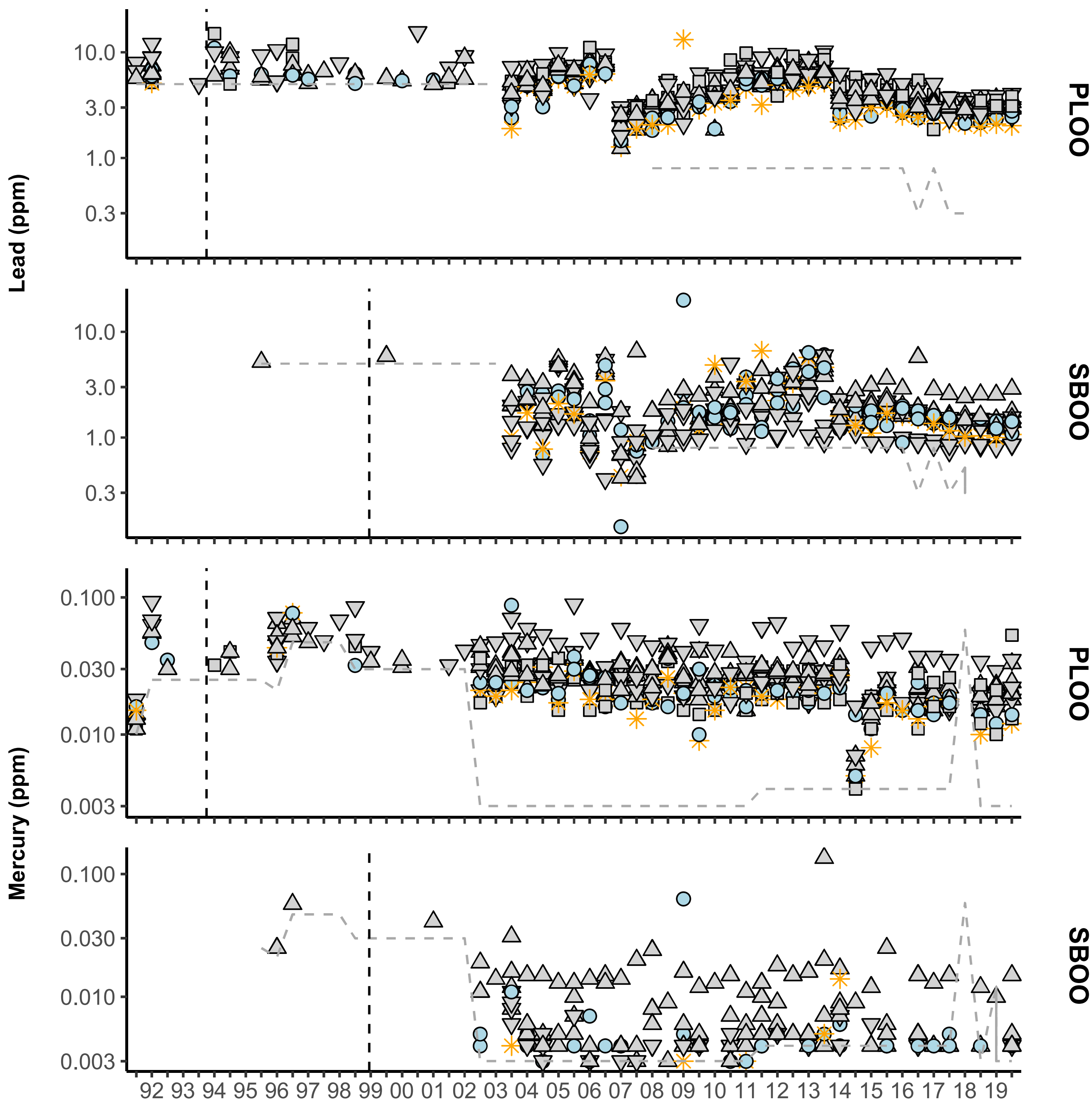

Figure 4.6 *continued*

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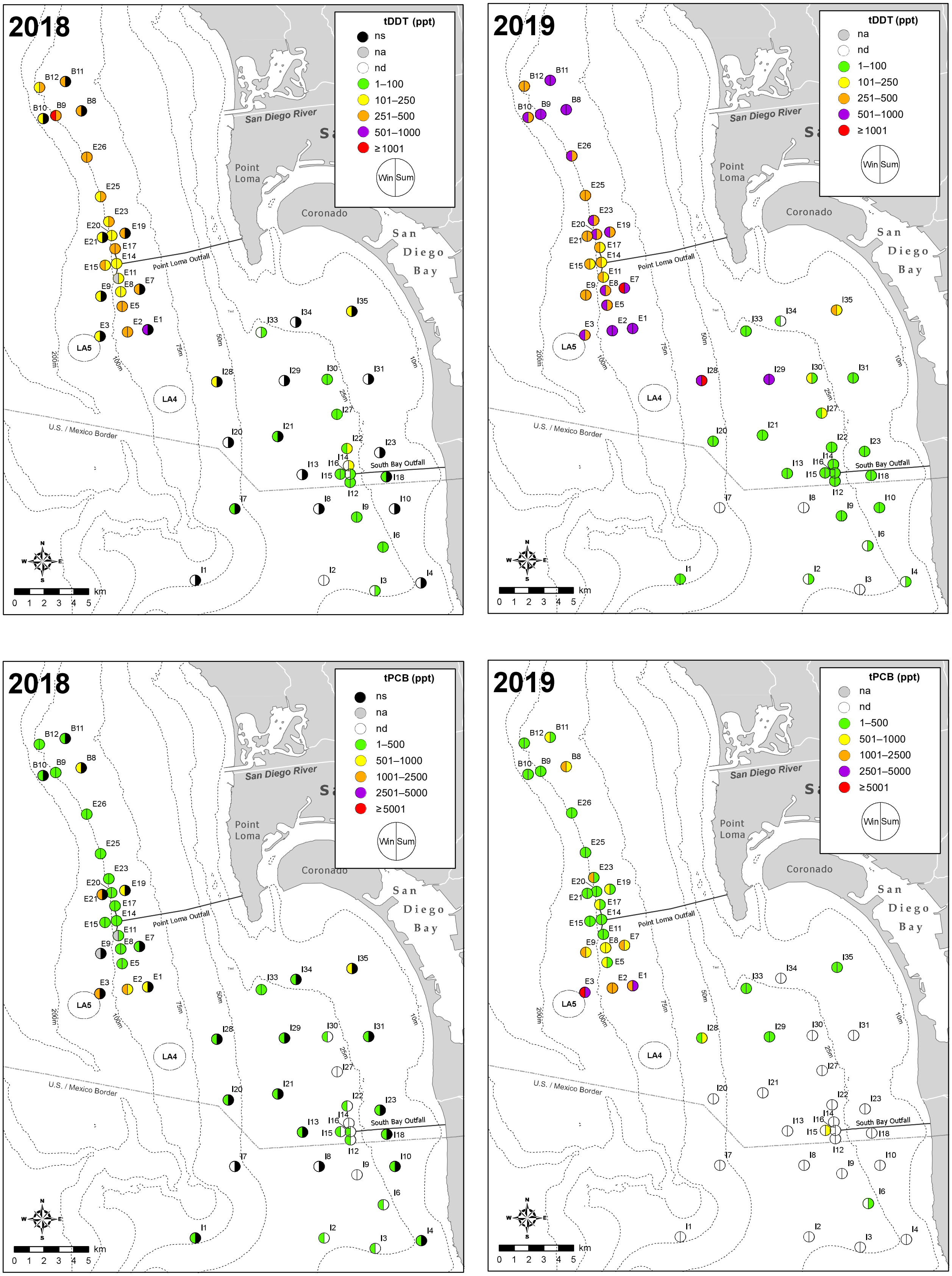

Figure 4.7

Distribution of total DDT and total PCB in sediments from the PLOO and SBOO regions during winter and summer surveys of 2018 and 2019; nd = not detected; ns = not sampled; na = not analyzed.

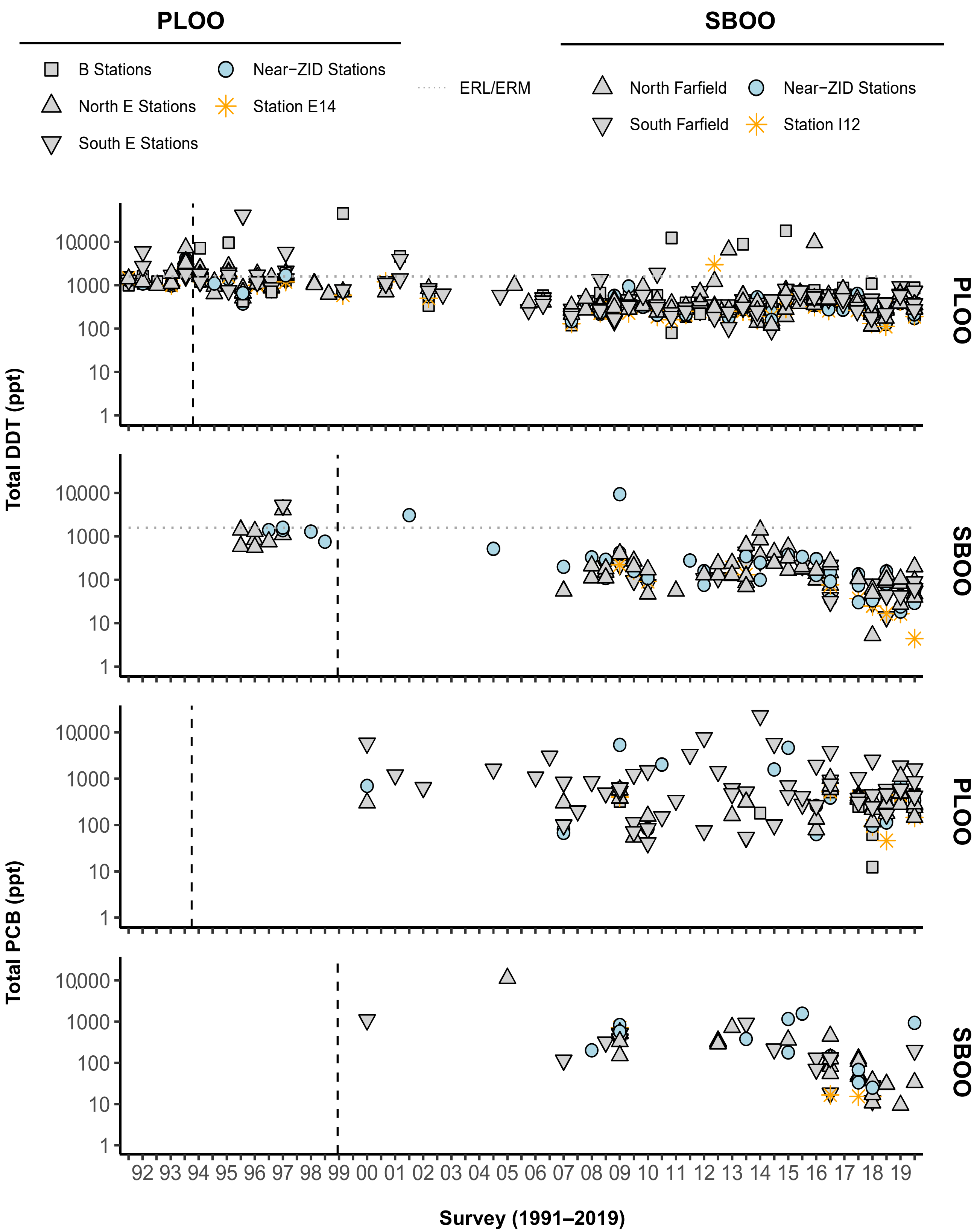

Figure 4.8
Concentrations of total DDT, total PCB, and total PAH in sediments sampled during winter and summer surveys at PLOO primary core stations from 1991 through 2019 and at SBOO primary core stations from 1995 through 2019. Data represent detected values from each station, n ≤ 12 samples per survey. Dashed lines indicate onset of discharge from the PLOO or SBOO. See Table 4.3 for values of ERLs and ERMs.

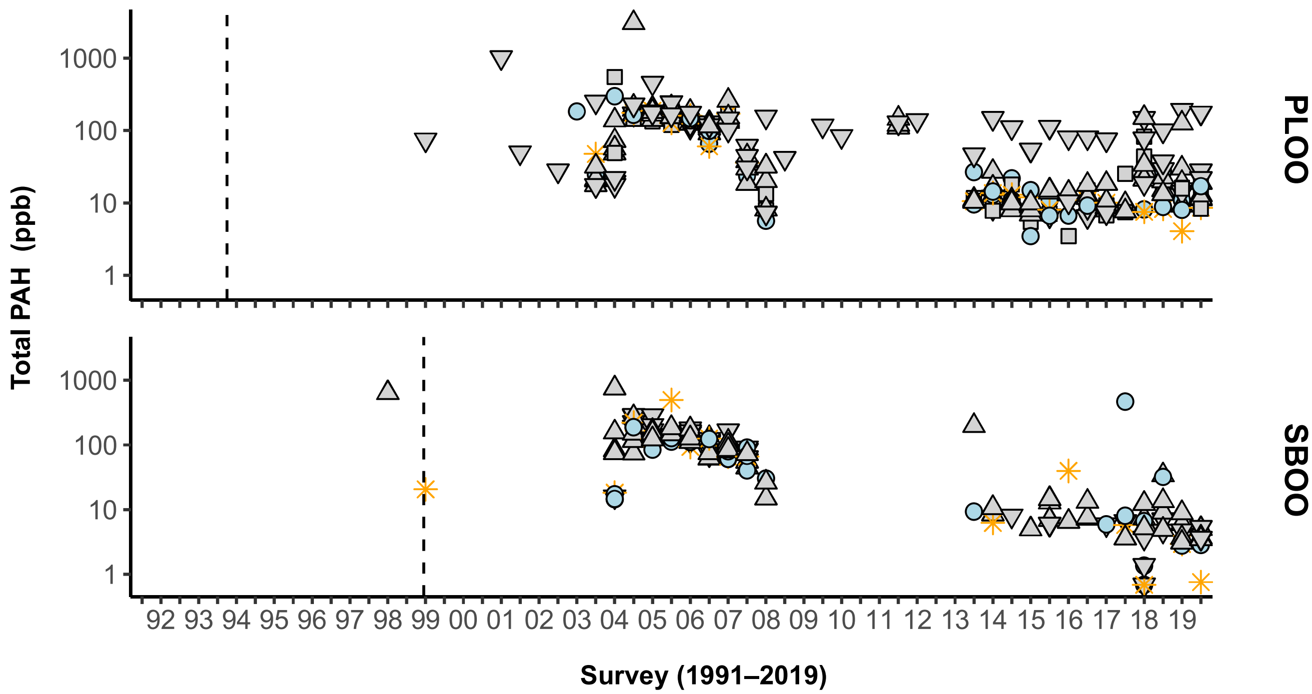

Figure 4.8 *Continued*

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Chapter 5
Macrobenthic Communities

Chapter 5. Macrobenthic Communities

Introduction

The City of San Diego (City) 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). Additionally, a number of randomly selected (regional) stations, distributed throughout the broader San Diego coastal region, are sampled in order to characterize the status of the local marine ecosystem and to identify any possible effects of wastewater discharge or other anthropogenic or natural influences. Benthic macrofauna (e.g., worms, crabs, clams, brittle stars, other small invertebrates) are targeted when 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). As many macrobenthic species live relatively long and stationary lives, they may exhibit 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 thus monitoring changes in discrete populations, or more complex communities, can help identify areas 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 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 decreases in dominance, by a few pollution-tolerant species (Pearson and Rosenberg 1978).

This chapter presents analysis and interpretation of macrofaunal data collected at core benthic monitoring stations throughout the PLOO and SBOO regions, during 2018 and 2019. 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. For further information, a broader regional assessment of benthic conditions throughout the entire San Diego region, based on a subset of data reported in this chapter, and combined with a suite of randomly selected stations sampled during the summer of 2019, is presented in Chapter 6.

Materials and Methods

Field Sampling

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 PLOO and SBOO, during winter (January) and summer (July) of 2018 and 2019 (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. 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, and SBOO stations I12, I14, I15, and I16. During the summer of 2018, only E15 and the primary core stations from the PLOO and SBOO regions were sampled, due to a resource exchange granted by the San Diego Regional Water Quality Control Board for participation in the region-wide Bight'18 sampling project.

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 Chapters 4 and 6) 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). 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) 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. After a minimum of 72 hours, but no more than 10 days, 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, pycnogonids), Molluscs (e.g., bivalves, gastropods, scaphopods), non-ophiuroid Echinoderms (e.g., sea urchins, sea stars, sea cucumbers), Ophiuroids (i.e., brittle stars), and other phyla (e.g., flatworms, nemerteans, 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 2018).

Data Analyses

Macrofaunal community parameter data for each PLOO and SBOO core station sampled in 2019 are listed in Addenda 5-1 and 5-2 while taxonomic listings of all specimens identified are listed in Addenda 5-3 and 5-4. Data collected during 2018 were reported previously (City of San Diego 2019). This report is available online (City of San Diego 2020). 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 the computational software package R (R Core Team 2019) and various functions within the ggpubr, reshape2, Rmisc, RODBC, scales, tidyverse, and vegan packages (Kassambara 2019, Wickham 2007, 2017, 2018, Hope 2013, Oksanen et al. 2017, Ripley and Lapsley 2017).

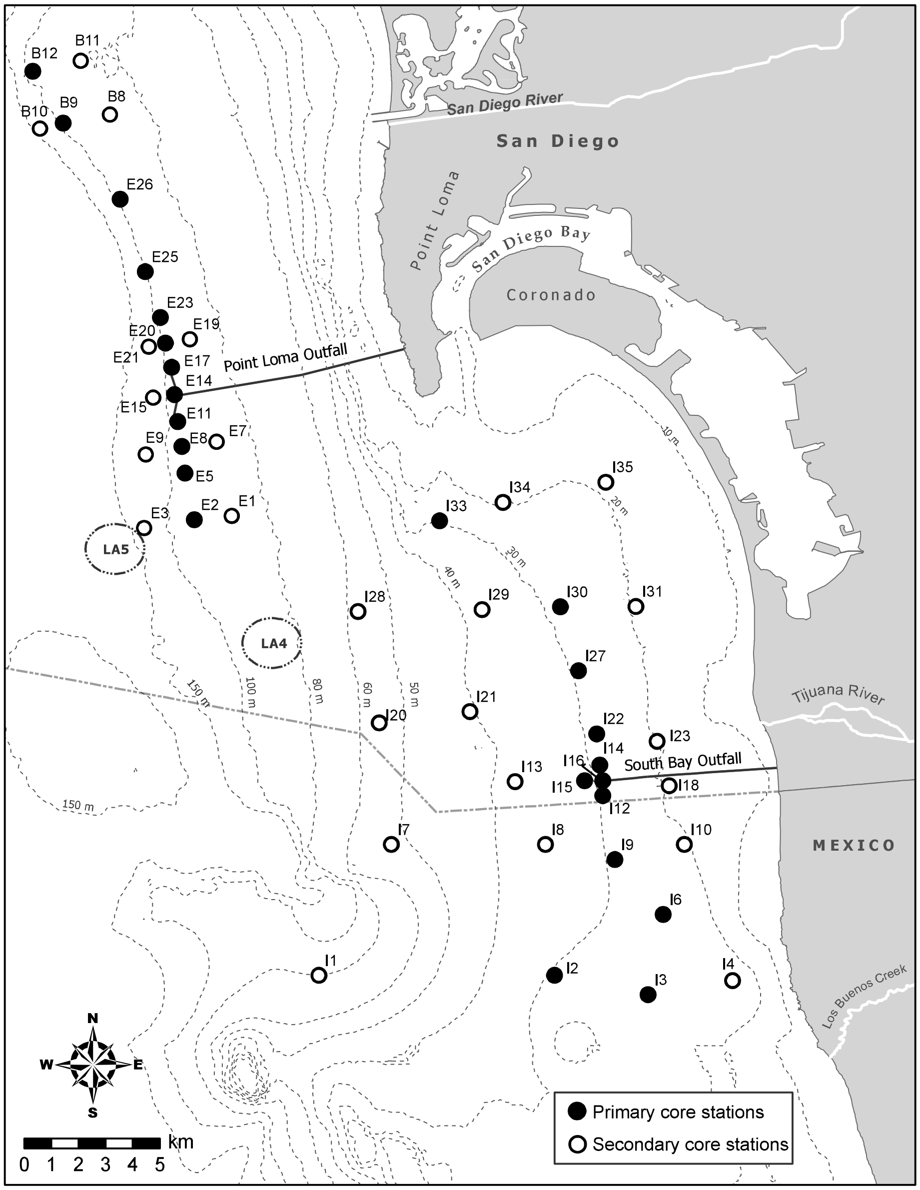

Figure 5.1
Benthic station locations sampled around the PLOO and SBOO as part of the City of San Diego's Ocean Monitoring Program.

Results and Discussion

Community Parameters

Species richness
A total of 894 different taxa were identified from the 172 grabs collected at 22 core PLOO stations, and 27 core SBOO stations during 2018 and 2019 (Addenda 5-3, 5-4, City of San Diego 2019). Approximately 76% (n=683) of these taxa were fully identified to species, while the remainder could only be identified to genus or higher taxonomic levels. From the relatively deeper (88–116 m) mid-shelf waters off Point Loma, 546 taxa were identified during this period, of which at least 418 (77%) were distinct species. In contrast, 723 taxa were identified from the shallower (19–55 m) inner to mid-shelf waters in the SBOO region. Of these, 551 (76%) were distinct species. Most taxa occurred at multiple stations, although 31% (n=167) of the PLOO taxa and 30% (n=216) of the SBOO taxa were recorded only once. Four new taxa were reported that had not previously been recorded by the City's Ocean

Monitoring Program, including the polychaetes *Dipolydora giardia*, *Alitta succinea*, *Caulleriella hamata*, and a representative of the *Heteromastus filiformis* species complex.

During 2018 and 2019, species richness ranged from a mean of 60 to 113 taxa per grab at the PLOO stations, and 24 to 140 taxa per grab at the SBOO stations (Tables 5.1 and 5.2, respectively). The greatest number of taxa (n=136) in the PLOO region were identified at northern farfield station B12 during summer of 2019, while the fewest taxa (n=44) were identified during summer of 2018 at near-ZID station E15 (Addendum 5-1, City of San Diego 2019). In the SBOO region, the winter sample from 2018 at northern station I28 had the greatest number of taxa (n=164), while inshore station I31 and southern farfield station I4 from winter of 2019 had the fewest taxa identified (n=20) (Addendum 5-2, City of San Diego 2019). These values were within the historical range of 13–192 taxa per grab for these stations reported from 1991 through 2015 (City of San Diego 2018). Comparisons of these parameters among near-ZID stations, versus northern and southern farfield stations, sampled during pre-discharge, historical post-discharge, and current discharge periods did not reveal any clear spatial patterns that could be attributed to wastewater discharge (Figure 5.2, Tables 5.1, 5.2).

Macrofaunal abundance

A total of 54,096 macrofaunal animals were recorded for all core PLOO and SBOO stations sampled during 2018 and 2019. Abundance per grab ranged from a mean of 269 to 653 animals in the PLOO region and from 52 to 568 animals per grab in the SBOO region (Tables 5.1, 5.2). As shown for species richness, there were no clear patterns in abundance relative to their proximity to either outfall (see Figure 5.2, Tables 5.1, 5.2). The highest abundance in the PLOO region occurred during summer of 2019 at near-ZID station E17 (n=788), while the lowest abundance occurred at southern station E3 in summer of 2019 (n=241) (Addendum 5-1, City of San Diego 2019). In the SBOO region, the highest abundance occurred in the winter of 2019 at northern inshore station I34 (n=828), while the lowest abundance was observed at inshore station I31 (n=33), also in the winter of 2019 (Addendum 5-2, City of San Diego 2019). These values were within the range of 21 to 2843 organisms per grab reported from 1991 to 2015 (City of San Diego 2018).

Species diversity, evenness, and dominance

Shannon Diversity Index (H') values ranged from a mean of 3.2 to 4.1 per grab at the PLOO stations, and 2.4 to 4.2 per grab at the SBOO stations, during 2018 and 2019 (Tables 5.1, 5.2). In the PLOO region, the highest diversity occurred at southern farfield station E3 in winter 2018 (H'=4.2), and the lowest diversity was observed at both the near-ZID station E15 in summer of 2018 as well as northern station B8 in summer of 2019 (H'=3.1). In the SBOO region, the highest diversity occurred at northern farfield station I28 in winter 2018 (H'=4.4), and the lowest diversity was observed at southern farfield station I6 in winter of 2019 (H'=2.0).

Pielou's Evenness Index (J') values ranged from a mean of 0.77 to 0.90 in the PLOO region, and 0.64 to 0.90 in the SBOO region. In the PLOO region, the highest evenness values occurred at southern farfield station E3 in winter 2018 (J'=0.92), and the lowest evenness values occurred at both the near-ZID station E11 in summer of 2018 as well as northern station B8 in summer of 2019 (J'=0.73) (Addendum 5-1, City of San Diego 2019). In the SBOO region, the highest evenness occurred at northern farfield station I30 in winter of 2019 (J'=0.96), and lowest value occurred at northern station I34 in summer of 2019 (J'=0.59) (Addendum 5-2, City of San Diego 2019).

Swartz Dominance Index values ranged from a mean of 15 to 39 taxa per grab at PLOO stations, and 7 to 43 taxa per grab at SBOO stations (Table 5.1, 5.2). In the PLOO region, the highest dominance (i.e., lowest index value) occurred at near-ZID station E15 in summer 2018 (12), and the lowest dominance (i.e., highest index value) occurred at southern station E3 in winter of 2018 (44) (Addendum 5-1, City of San Diego 2019). In the SBOO region, the highest dominance occurred at southern farfield station I6 in winter of 2019 (3), and the lowest dominance occurred at northern station I28 in winter of 2018 (52) (Addendum 5-2, City of San Diego 2019).

Table 5.1

Summary of macrofaunal community parameters for PLOO benthic stations sampled during 2018 and 2019. Data for each station are expressed as biennial means (n ≥ 3). SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = Pielou's evenness; Dom = Swartz dominance; BRI = benthic response index; CI = confidence interval. 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	112	402	4.0	0.85	37	10
	B8	73	343	3.4	0.78	19	9
	E19	80	582	3.4	0.79	17	11
	E7	82	487	3.5	0.81	19	12
	E1	93	468	3.8	0.84	26	8
98-m Depth Contour	B12	113	429	4.0	0.84	37	13
	B9	101	438	3.9	0.85	31	10
	E26	90	466	3.7	0.83	25	11
	E25	75	517	3.5	0.80	18	12
	E23	80	569	3.5	0.80	18	11
	E20	80	524	3.5	0.80	18	13
	E17 [a]	86	653	3.4	0.77	17	15
	E14 [a]	78	481	3.4	0.79	18	30
	E11 [a]	83	535	3.4	0.78	19	17
	E8	84	388	3.7	0.84	25	10
	E5	90	464	3.8	0.84	26	9
	E2	98	442	3.9	0.86	30	11
116-m Depth Contour	B10	85	308	3.8	0.85	28	14
	E21	70	455	3.3	0.79	16	15
	E15 [a]	60	406	3.2	0.80	15	14
	E9	90	420	3.7	0.83	26	11
	E3	95	269	4.1	0.90	39	10
All Grabs	Mean	86	461	3.6	0.82	24	13
	95% CI	4	28	0.1	0.01	2	1
	Minimum	44	241	3.1	0.73	12	6
	Maximum	136	788	4.2	0.92	44	34

[a] Near-ZID station

Overall, these results indicate that the PLOO and SBOO benthic communities remain characterized by relatively diverse assemblages of evenly distributed species. Values for all three of the above parameters, in 2018 and 2019 (Addenda 5-1, 5-2, City of San Diego 2019), were within historical ranges (see City of San Diego 2018), and there remain no patterns that appear related to wastewater discharge in either region (see Figure 5.2, Tables 5.1, 5.2).

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 conditions, and values greater than 34 represent increasing levels of degradation (Smith et al. 2001).

Table 5.2

Summary of macrofaunal community parameters for SBOO benthic stations sampled during 2018 and 2019. Data for each station are expressed as biennial means (n ≥ 3 grabs). SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = Pielou's evenness; Dom = Swartz dominance; BRI = benthic response index; CI = confidence interval. Stations are listed north to south from top to bottom for each depth contour.

	Station	SR	Abun	H'	J'	Dom	BRI
19-m Depth Contour	I35	54	143	3.5	0.88	22	24
	I34	51	568	2.5	0.64	7	17
	I31	41	113	3.2	0.90	17	21
	I23	49	184	3.2	0.82	17	13
	I18	42	105	3.3	0.90	20	15
	I10	74	213	3.6	0.84	27	20
	I4	25	52	2.8	0.89	12	10
28-m Depth Contour	I33	86	264	4.0	0.90	35	25
	I30	61	166	3.6	0.89	26	23
	I27	58	152	3.6	0.89	24	23
	I22	74	276	3.7	0.87	26	25
	I14[a]	69	223	3.7	0.86	26	25
	I16[a]	40	161	2.9	0.79	13	14
	I15[a]	32	107	2.8	0.80	10	18
	I12[a]	44	140	2.9	0.76	15	18
	I9	72	198	3.8	0.90	30	24
	I6	36	120	2.7	0.76	11	8
	I2	24	87	2.4	0.77	8	15
	I3	32	126	2.7	0.79	11	9
38-m Depth Contour	I29	84	292	3.6	0.81	28	12
	I21	34	97	3.0	0.87	14	10
	I13	33	89	3.1	0.88	15	8
	I8	41	130	2.9	0.77	16	23
55-m Depth Contour	I28	140	540	4.2	0.85	43	15
	I20	55	259	3.1	0.77	14	7
	I7	43	125	3.3	0.87	19	3
	I1	79	277	3.7	0.85	28	13
All Grabs	Mean	54	190	3.2	0.83	20	17
	95% CI	6	28	0.1	0.02	2	2
	Minimum	20	33	2.0	0.59	3	-2
	Maximum	164	828	4.4	0.96	52	30

[a] Near-ZID station

Overall, 89% (n = 153) of all individual benthic samples collected in the combined PLOO and SBOO regions during 2018 and 2019 were characteristic of reference conditions (Addenda 5-1, 5-2, City of San Diego 2019). No stations had BRI values considered indicative of degradation (i.e., all stations had a BRI ≤ 34).

Almost all of the individual samples (95%) in the PLOO region had BRI values indicative of reference conditions. Only near-ZID station E14, with individual BRI scores ranging from 26 to 34, appeared to show evidence of slight deviations from reference conditions (Addendum 5-1). The other three PLOO near-ZID stations (E11, E15, E17) all

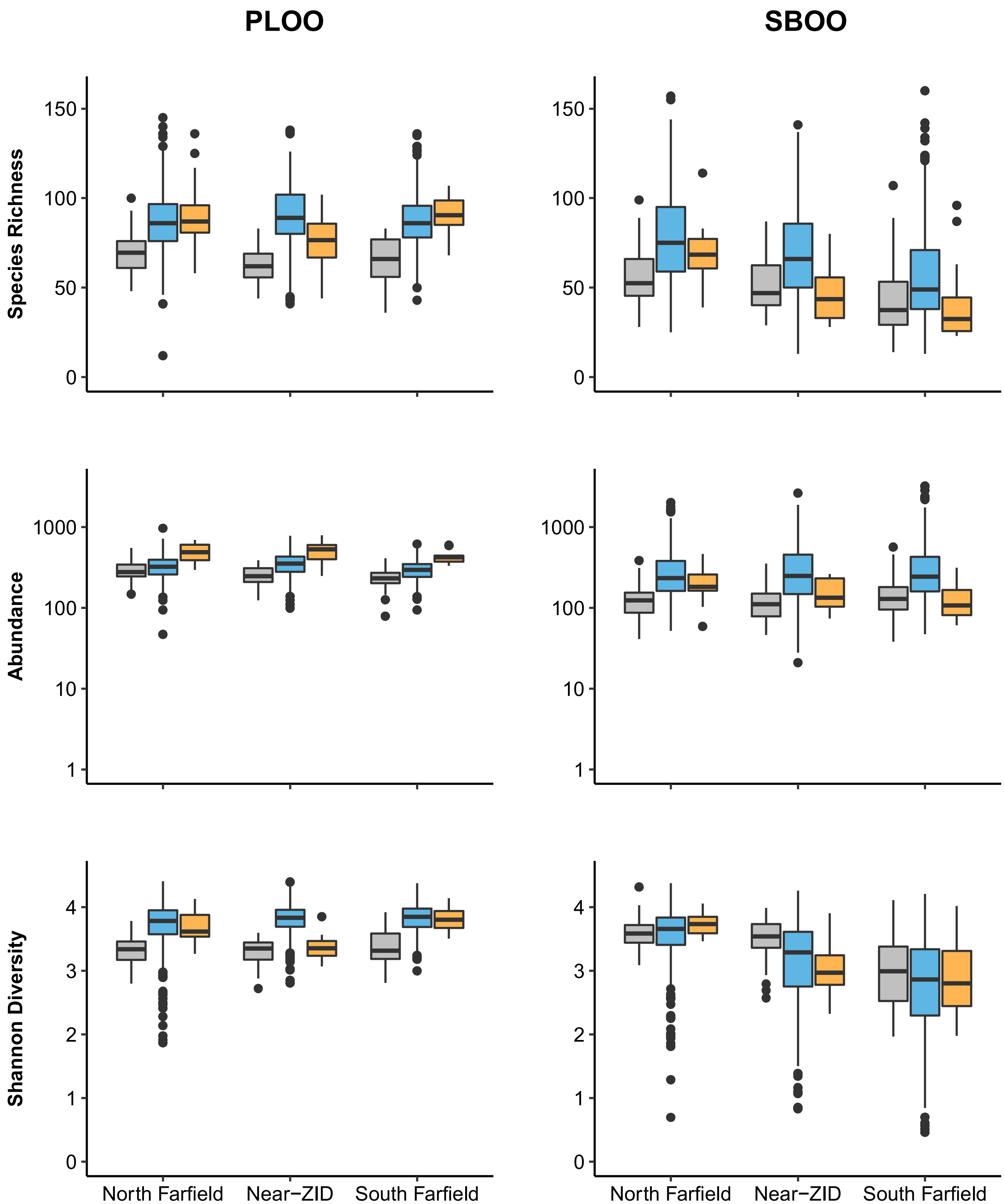

Figure 5.2
Species richness, abundance, and diversity (H') of benthic infauna collected from PLOO and SBOO north farfield, near-ZID, and south farfield primary core stations during pre-discharge (grey), historical post-discharge (blue), and current post-discharge (orange); Boxes = median, upper, and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

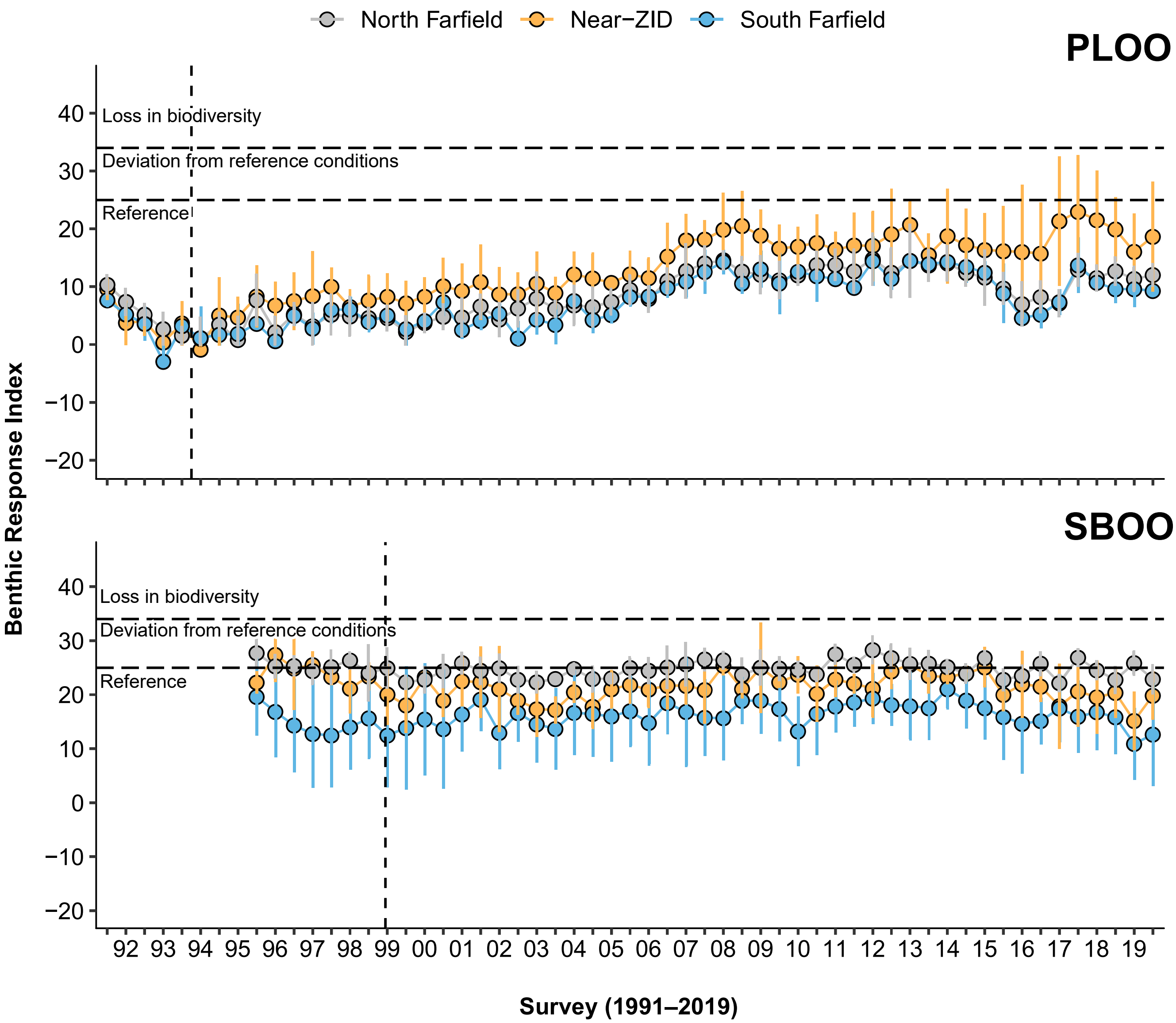

Figure 5.3
Benthic Response Index at PLOO and SBOO north farfield, near-ZID, and south farfield primary core stations sampled from 1991 through 2019. Data for each station group are expressed as means ±95% confidence intervals per grab (n ≤ 8). Vertical dashed lines indicate onset of wastewater discharge at each outfall.

had BRI values only slightly higher than sites located farther from the outfall (an average of 16 versus 11, respectively). Station E14 was distinguished from the other primary core "E" stations, located along the 98-m PLOO discharge depth contour, as it had a higher proportion of coarse sediment particles and lower proportion of very fine particles (see Chapter 4). This difference in habitat may contribute to the elevated BRI score at station E14, as it may decrease the presence of certain 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 (see Figures 4.2, 5.3, Table 5.1).

In the SBOO region, BRI values ranged from -2 at southern station I4 to 30 at offshore station I8 during 2018–2019, with about 84% of these being indicative of reference condition (see Addendum 5-2, City of San Diego 2019). No SBOO samples had BRI values > 34 that would indicate any significant environmental disturbance. Individual sample BRI values corresponding to possible minor deviation from reference condition (≥25) occurred

Table 5.3

Percent composition and abundance of major taxonomic groups in PLOO and SBOO benthic grabs sampled during 2018 and 2019.

	PLOO		SBOO	
Phyla	Species (%)	Abundance (%)	Species (%)	Abundance (%)
Annelida (Polychaeta)	54	69	47	62
Arthropoda (Crustacea)	17	6	21	19
Mollusca	14	15	16	6
Echinodermata	4	7	4	3
Other Phyla	11	3	12	10

at a total of eight stations (I4, I8, I9, I14, I22, I30, I33, I35) (Addendum 5-2, City of San Diego 2019). However, only three of these stations consistently exceeded the threshold value of 25 during the current reporting period: near-ZID station I14, and northern farfield stations I22 and I33. All three of these stations are located along the 28-m depth contour. The slightly higher BRI values at these stations are not unexpected, due to naturally higher levels of organic matter that may occur at depths <30 m (Smith et al. 2001). Historically, BRI values at the near-ZID SBOO stations have been similar to values observed for northern farfield SBOO stations, while BRI has been consistently lower at the southern farfield SBOO stations (Figure 5.3). Although these southern stations are also located along the 28-m depth contour, their sediments favor the presence of aggregations of the sand dollar, *Dendraster terminalis*, a pollution sensitive species that yields low BRI values.

Species of Interest

Dominant taxa

Annelid polychaete worms were the dominant taxonomic group found in both the PLOO and SBOO regions during 2018–2019, accounting for 54% and 47% of all taxa collected, respectively (Table 5.3). Crustaceans accounted for 17 to 21% of the taxa per region, molluscs for 14 to 16%, echinoderms 4%, and all other taxa combined 11 to 12%. Polychaetes were also the most abundant organisms encountered, accounting for 69% and 62% of all macrofauna in the PLOO and SBOO regions, respectively. Crustaceans, molluscs, echinoderms, and "other phyla" each contributed to ≤19% 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 (e.g., 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 2018–2019 included eight species of polychaetes, one species of bivalve, and one ophiuroid (Table 5.4). Together, these species accounted for about 47% of all invertebrates identified during this period. The numerically dominant polychaetes included the spionids *Spiophanes duplex* and *Prionospio jubata,* the ampharetid *Eclysippe trilobata*, capitellids in the genus *Mediomastus*, the terebellid *Phisidia sanctaemariae*, the cirratulid species complex *Aphelochaeta glandaria*, the onuphid *Paradiopatra parva*, and the maldanid *Praxillella pacifica*. The dominant bivalve was *Axinopsida serricata,* while the brittle star *Amphiodia urtica* was the dominant ophiuroid. *Amphiodia urtica* populations have been declining across the region since monitoring at the current stations began in 1991, especially since the warm water period of 2015–2016 (see Figure 2.6, Appendix G.1). However, they are still a dominant taxon, accounting for ~4% of all invertebrates collected in the region and occurring in 85% of grabs with a mean abundance of ~19 individuals per grab. Historically, the polychaetes *Phisidia sanctaemariae* and *Spiophanes duplex* (Figure 5.4), as well as *Proclea* sp A (Figure 5.5), have also been numerically dominant. However, another

Table 5.4

The 10 most abundant macroinvertebrate taxa collected from PLOO benthic stations during 2018 and 2019. 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 = 79).

Species	Taxonomic Classification	Percent Abundance	Frequency of Occurrence	Abundance per Grab
Spiophanes duplex	Polychaeta: Spionidae	10	100	44
Axinopsida serricata	Mollusca: Bivalvia	8	87	36
Eclysippe trilobata	Polychaeta: Ampharetidae	5	97	24
Mediomastus sp	Polychaeta: Capitellidae	5	100	24
Phisidia sanctaemariae	Polychaeta: Terebellidae	5	92	21
Amphiodia urtica	Echinodermata: Ophiuroidea	4	85	19
Aphelochaeta glandaria Cmplx	Polychaeta: Cirratulidae	3	87	13
Prionospio jubata	Polychaeta: Spionidae	3	97	12
Paradiopatra parva	Polychaeta: Onuphidae	2	92	11
Praxillella pacifica	Polychaeta: Maldanidae	2	94	10

historically dominant species, the oweniid *Myriochele striolata*, was not as abundant during the most recent reporting period (Appendix G.1). *Proclea* sp A and *M. striolata* have not been abundant in the region since 2005.

The 10 most abundant taxa in the SBOO region, during 2018–2019, included five polychaetes, two amphipods, one ostracod, one tanaid, and members of the phylum Nematoda (Table 5.5). The dominant polychaetes included the spionids *Spiophanes norrisi* and *S. duplex*, the capitellid *Mediomastus* sp, the amphinomid *Pareurythoe californica,* and the sigalionid *Pisione* sp. The dominant amphipods were *Ampelisca cristata microdentata* and *Rhepoxynius menzies,* while the most abundant ostracod was *Euphilomedes carcharodonta* and the tanaid was represented by the species complex *Chondrochelia dubia*. The polychaete worm *Spiophanes norrisi* was the most abundant of all these species during the past two years, accounting for 9% of invertebrates collected in the SBOO area and occurring in 94% 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 (Figure 5.6), 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 taxa collected during the current reporting period averaged 10 individuals or fewer per grab (Table 5.5). Three other numerically dominant species occurred in ≥ 54% of the samples, including *Spiophanes duplex, Mediomastus* sp, and *Rhepoxynius menziesi,* (Table 5.5). The remaining six of the top 10 taxa occurred in 2–51% of the samples with average abundances per grab of 2–4 animals. Historically, the polychaetes *S. norrisi*, *S. duplex*, *Mediomastus* sp, *Kirkegaardia siblina* and the maldanid species complex Euclymeninae sp A/B were the most numerically dominant taxa (Figure 5.6, Appendix G.2).

Indicator species

Several species known to be useful indicators of environmental change that occur in the PLOO and SBOO regions 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

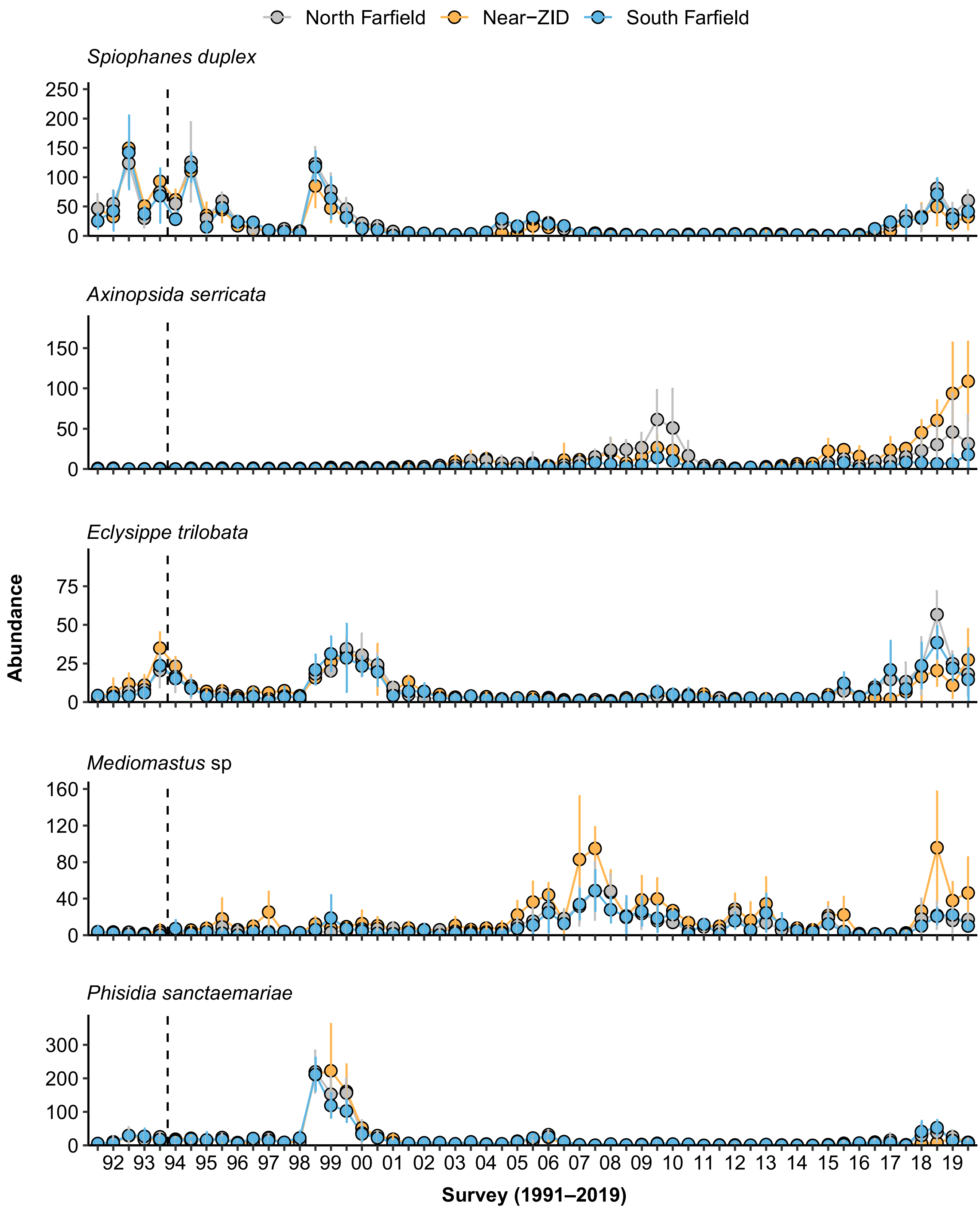

Figure 5.4

Abundances of the five most numerically dominant species recorded during 2018 and 2019 (presented in order) at PLOO north farfield, near-ZID, and south farfield primary core stations from 1991 through 2019. Data for each station group are expressed as means per survey ± 95% confidence intervals (n ≤ 8). Dashed lines indicate onset of wastewater discharge.

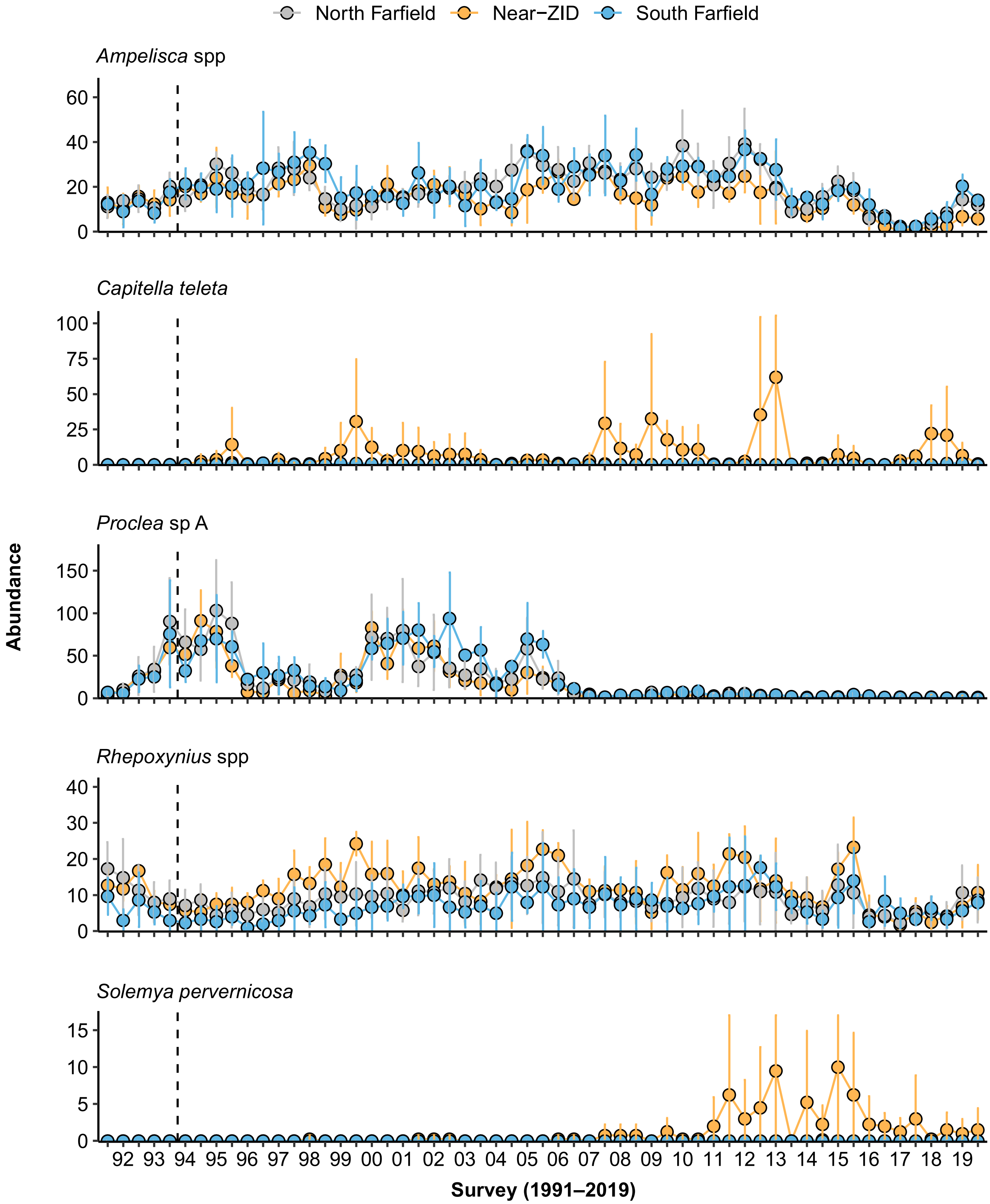

Figure 5.5

Abundances of representative ecologically important indicator taxa collected at PLOO north farfield, near-ZID, and south farfield primary core stations from 1991 through 2019. Data for each station group are expressed as means per survey ±95% confidence intervals (n ≤ 8). Dashed lines indicate onset of wastewater discharge.

Table 5.5
The 10 most abundant macroinvertebrate taxa collected from SBOO benthic stations during 2018 and 2019. 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 = 93).

Species	Taxonomic Classification	Percent Abundance	Frequency of Occurrence	Abundance per Grab
Spiophanes norrisi	Polychaeta: Spionidae	9	94	17
Spiophanes duplex	Polychaeta: Spionidae	5	66	10
Mediomastus sp	Polychaeta: Capitellidae	3	54	5
Ampelisca cristata microdentata	Arthropoda: Amphipoda	2	37	4
Nematoda	Nematoda	2	52	3
Euphilomedes carcharodonta	Arthropoda: Ostracoda	1	45	3
Chondrochelia dubia Cmplx	Arthropoda: Tanaidacea	1	51	3
Rhepoxynius menziesi	Arthropoda: Amphipoda	1	61	2
Pisione sp	Polychaeta: Sigalionidae	1	5	2
Pareurythoe californica	Polychaeta: Amphinomidae	1	2	2

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 2018 and 2019, a total of 223 individuals of *C. teleta* were found in samples collected across the entire region distributed among 13 different sites (stations B10, B11, B12, E2, E7, E8, E11, E14, E17, E21, I2, I21, I28), while a total of 26 individuals of *S. pervernicosa* were identified in samples from five different sites (stations E14, E15, I14, I22, I27). Despite occasionally exceeding regional tolerance intervals of 0–1 animal per grab (see City of San Diego 2015), abundances of *C. teleta* and *S. pervernicosa* remained characteristic of relatively undisturbed habitats (Figures 5.5, 5.7). For example, *C. teleta* commonly reaches densities as high as 600 individuals per 0.1-m^2 grab in polluted sediments (Reish 1957, Swartz et al. 1986). Changes in abundance of *Ampelisca* and *Rhepoxynius* amphipod species varied at all PLOO primary core stations regardless of proximity to the outfall, which may be influenced by the invasion of large populations of pelagic red crabs since 2016 (Figure 5.5, see Chapter 7).

Summary

Analyses of macrofaunal data, for the 2018–2019 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. Values for most community parameters are similar at stations located both near and far from the discharge areas. Major community metrics, such as species richness, abundance, diversity, evenness, and dominance were 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 95% of the PLOO sites and 84% of the SBOO sites were considered characteristic of undisturbed habitats, while all of the remaining samples (11%) had values suggestive of only a

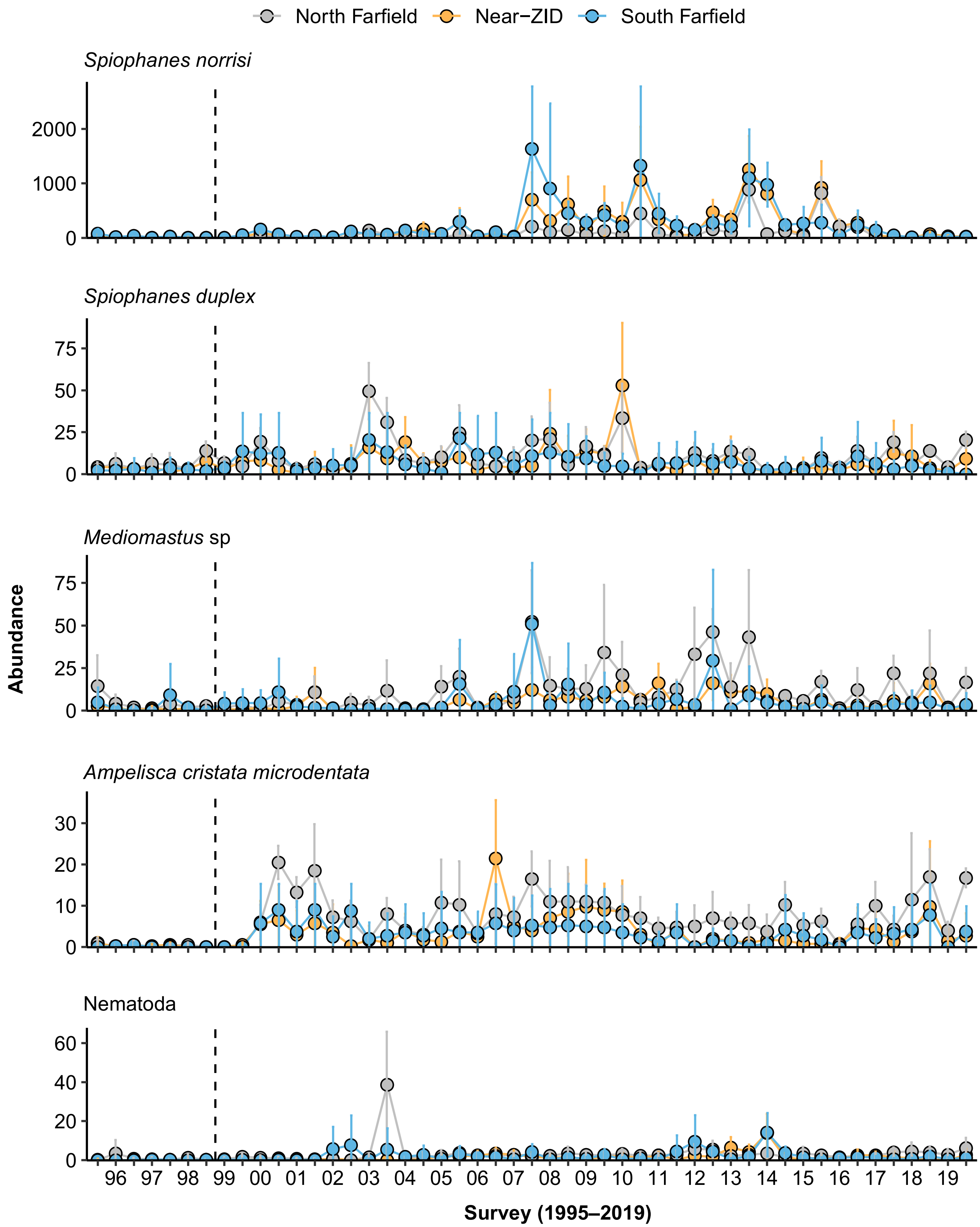

Figure 5.6
Abundances of the five most numerically dominant species (presented in order) recorded during 2018 and 2019 at SBOO north farfield, near-ZID, and south farfield primary core stations from 1995 through 2019. Data for each station group are expressed as means per survey ±95% confidence intervals (n≤8). Dashed lines indicate onset of wastewater discharge.

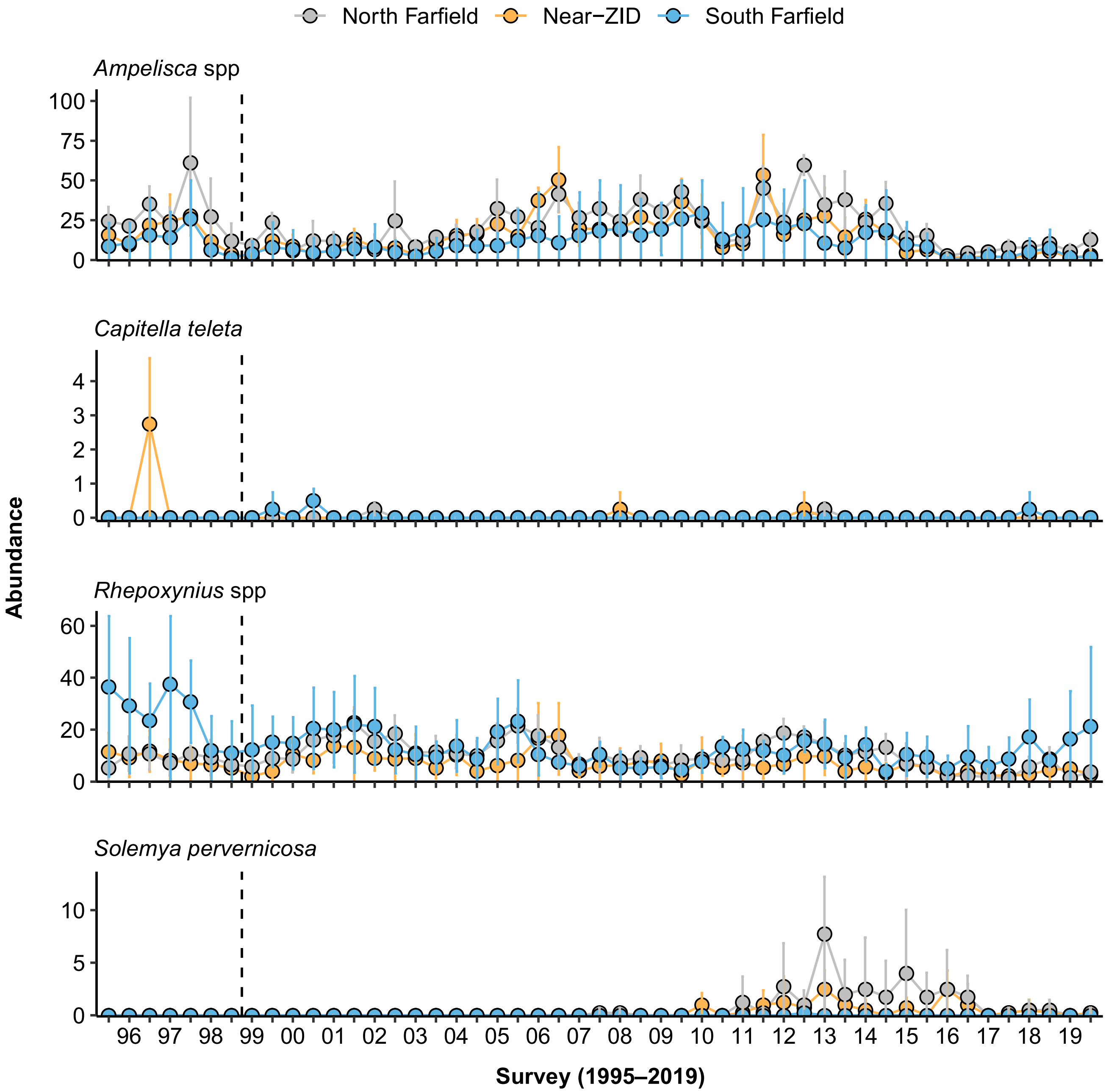

Figure 5.7

Abundances of representative ecologically important indicator taxa collected at SBOO north farfield, near-ZID, and south farfield primary core stations from 1995 through 2019. Data for each station group are expressed as means per survey ± 95% confidence intervals (n ≤ 8). Dashed lines indicate onset of wastewater discharge.

possible minor deviation from reference 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. 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 example, the brittle star *Amphiodia urtica* is a well-known dominant species of the mid-shelf, fine sediment habitats, in the SCB that is sensitive to changes near wastewater outfalls. Abundances of *A. urtica* off Point Loma remained within the range of natural variation in SCB populations (Gillett et al. 2017). Further, populations of opportunistic species such as the polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa* remained low during 2018 and 2019, while populations of pollution-sensitive amphipods in the genera *Ampelisca* and *Rhepoxynius* have generally co-varied between near-ZID 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 correspond to natural changes in large-scale oceanographic conditions. Further support for this hypothesis is shown by the continued relatively low abundances of *S. norrisi* at all station groups during 2018 and 2019, compared to what would be expected at negatively impacted areas.

In conclusion, benthic macrofaunal communities appear to be in good condition overall throughout the PLOO and SBOO regions. Communities remain largely similar to those observed prior to outfall operations, and are representative of natural communities from similar habitats on the southern California continental shelf. Overall, 89% of all benthic sites surveyed for the combined region, in 2018 and 2019, were classified as being in reference condition, based on assessments using the BRI. The few, slightly elevated, BRI values found at near-ZID stations, or along the outfall discharge depth contour, 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 (City) 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 (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, 2013, and 2018 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, SCCWRP 2018). In total more than 880 samples from 831 different regional stations have been sampled off San Diego over the past 26 years (1994–2019).

This chapter presents an overall assessment of regional benthic conditions on the continental shelf and upper slope off San Diego during 2019. Included are analyses of particle size, sediment chemistry, sediment toxicity, and macrofaunal community data collected from a total of 89 regional or core benthic stations sampled during the summer of 2019. These data 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., SCCWRP 2018). Data from the 2018 SCB Regional Monitoring Program are not yet available, and are, therefore, not included herein. Additional analysis of spatial patterns, winter vs. 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

Benthic samples analyzed in this chapter were collected during the summer of 2019 at a total of 89 stations that ranged from Del Mar southward to below the USA/Mexico border (Figure 6.1). A total of 40 of these stations 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 11 to 314 m spanning four distinct depth strata off southern California. These included 7 regional stations along the inner shelf (11–30 m), 14 regional stations along the mid-shelf (30–120 m), 13 regional stations along the outer shelf (120–200 m), and 6 regional stations on the upper slope (200–314 m). In addition to the above, the results of summer sampling at the 49 core PLOO and SBOO monitoring stations located at inner to mid-shelf depths as described in Chapters 4 and 5 are also analyzed in this chapter. Stations located

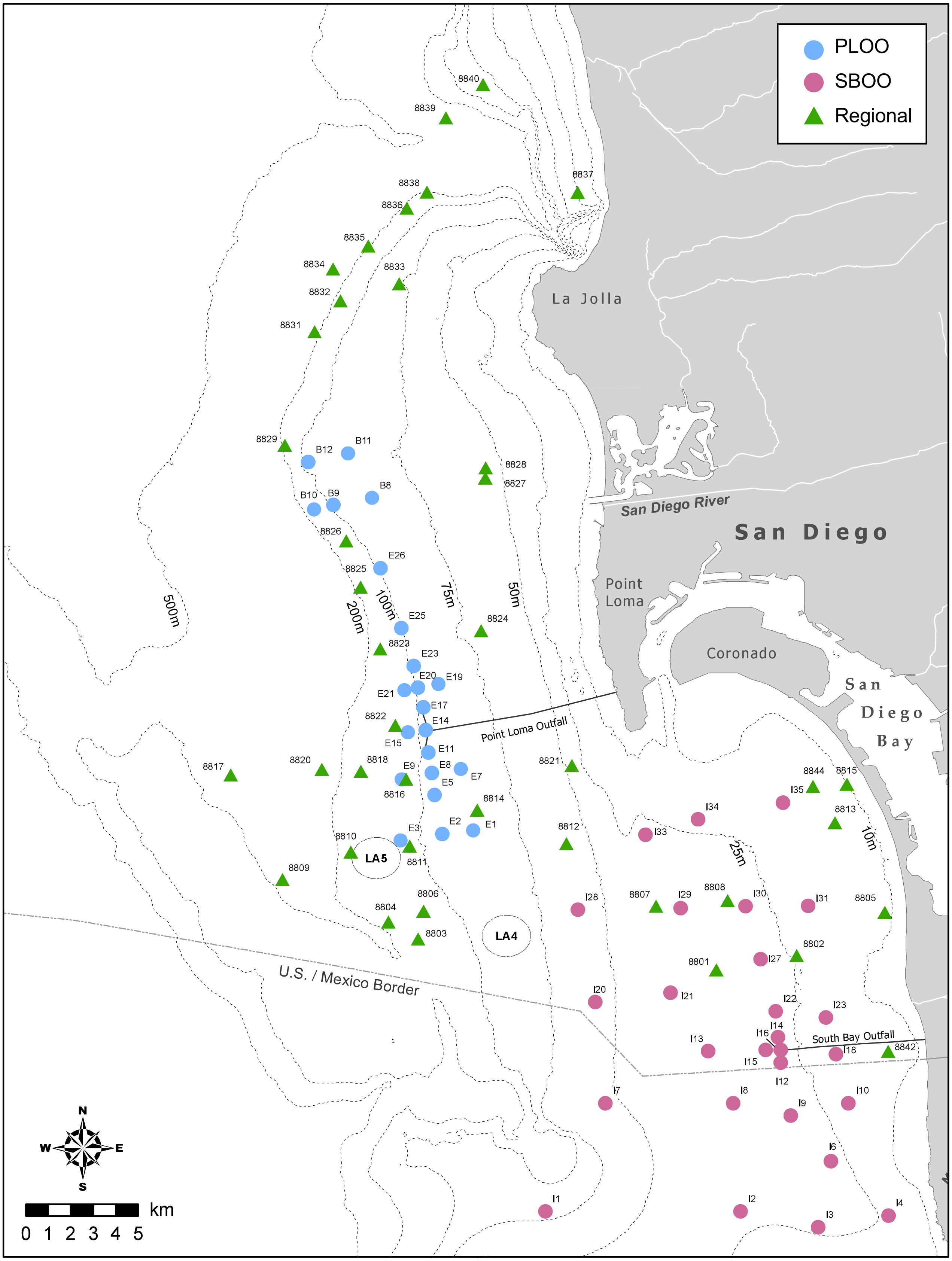


Figure 6.1
Distribution of 40 regional and 49 core (PLOO/SBOO) benthic stations sampled off San Diego and northern Baja California during the summer of 2019.

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, E17, SBOO stations I12, I14, I15, I16, and regional station 8822 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 (see Chapter 4), and one grab per cast used for benthic community analysis (see Chapter 5). 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 2018). 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) 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. After a minimum of 72 hours, but no more than 10 days, 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 pycnogonids), Molluscs (e.g., clams, snails, scaphopods), non-ophiuroid Echinoderms (e.g., sea urchins, sea stars, sea cucumbers), Ophiuroids (brittle stars), and other phyla (e.g., flatworms, nemerteans, 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 City Marine Biologists. All identifications followed nomenclatural standards established by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT 2018).

In addition to the above, supplemental sediment grabs were collected for sediment toxicity testing at the eight near-ZID PLOO and SBOO stations during the summer of 2019. These samples were collected as an extension of the sediment toxicity pilot study, which took place between 2016 and 2018 (City of San Diego 2015c). All methods and results from this pilot study were documented in the final project report (City of San Diego 2019b) that has been updated with results from testing conducted during 2019 (see Appendix C).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City's Environmental Chemistry Laboratory. A detailed description of the analytical protocols used can be found in City of San Diego (2020). 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), including: 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 F.1). However, concentrations below MDLs were included as estimated values, if presence of a specific constituent was verified by mass-spectrometry. A variety of laboratory technical issues resulted in a significant amount of non-reportable PAH data for the 2019 benthic survey (see Addenda 4, 6), prohibiting the inclusion of total PAH 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 4 main size fractions, based on the Wentworth scale (Folk 1980) (see Appendix F.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, 75 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 2019 are listed in Addenda 6-1 through 6-5, while data collected from PLOO and SBOO core stations during 2019 are listed in Addenda 4-1 through 4-10 (see Chapter 4). Data summaries for the various sediment parameters included detection rate, minimum, maximum, and mean values. All means were calculated using detected values only, with no substitutions made for non-detects in the data (analyte concentrations < MDL). Total chlordane, total DDT (tDDT), total hexachlorocyclohexane (tHCH), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all individual constituents with reported values (see above and Addendum 6-5). When applicable, contaminant concentrations were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines (Long et al. 1995). 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 2019) and various functions within the ggpubr, reshape2, plyr, dplyr, tidyr, tidyverse, zoo, stringr, vegan, stats, psych, ggplot2, Rmisc, and ROBDC packages (Kassambara 2019, Wickham 2007, 2011, 2017, 2019, Wickham and Henry 2018, Wickham et al. 2020, Oksanen 2019, Revelle 2019, Wickham et al. 2019, Zeileis and Grothendieck 2005, Hope 2013, Ripley and Lapsley 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 2019 in Addendum 6-6, while community parameter values from PLOO and SBOO core stations sampled during 2019 are listed in Addenda 5-1 and 5-2 (see Chapter 5). Unless otherwise noted, analyses were performed using the computational software package R (R Core Team 2019) and various functions within the ggpubr reshape2, Rmisc, RODBC, scales, tidyverse, and vegan packages (Kassambara 2019, Wickham 2007, 2017, 2018, Hope 2013, Oksanen et al. 2019, 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 89 regional and core stations sampled during summer 2019 (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 (characteristic species) and between-group dissimilarity for retained clusters.

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: (1) determine which subsets of sediment sub-fractions were the best explanatory variables for the similarity between the particle size and sediment chemistry resemblance matrices; (2) 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 89 benthic stations sampled during the 2019 summer survey. The proportion of fine silt and clay particles (combined as 'percent fines' or 'fines') ranged from a minimum of 0 to a maximum of 85.5% per sample, while fine sands ranged from 1.8 to 90.4%, medium-coarse sands ranged from < 1 to 89.1%, and coarse particles ranged from 0 to 29.5% (Table 6.1). Overall, and as expected, sediment composition varied by depth and region (e.g., City of San Diego 2008–2014, 2015a,b, 2016a,b, 2018). For example, the amount of percent fines at regional stations increased with depth, with a mean of 32.7% per sample along the inner shelf, 52.5% along the middle shelf, 59.2% along the outer shelf, and 74.4% along the upper slope. Furthermore, correlation analysis confirmed that percent fines tended to increase with depth throughout the San Diego (Figure 6.2, Appendix H.1), but not as strongly as previously reported (e.g., $r^s = 0.62$ for samples collected in summer 2019 versus $r^s = 0.76$ for samples collected in the summers of 2016 and 2017; see City of San Diego 2018). These results are due to several exceptions to this overall pattern during 2019, where percent fines were higher or lower than expected by depth. Exceptions were found at several mid-shelf SBOO stations located offshore and to the south of the outfall, regional station 8829 located at 178 m offshore of Mission Bay, and PLOO station E3 and regional station 8811 located near the boundary of the EPA designated LA-5 dumpsite for dredged materials (Appendix H.2).

Cluster and ordination analyses of the sediment particle data, described above, resulted in seven ecologically-relevant SIMPROF-supported particle size clusters (groups A–G) (Figure 6.3, Table 6.2). According to BEST/BVSTEP results ($\rho = 0.964, p \leq 0.001$, number of permutations = 999), these seven clusters were primarily distinguished by differing proportions of very fine sand and fine particles. Additionally, these groups were distributed to some degree by depth strata, but more so by monitoring region. For example, cluster groups A, B, D, E and G primarily occurred at inner- and mid-shelf depths within the SBOO monitoring region. Cluster group C, however, primarily occurred at middle shelf, outer shelf, and upper slope depths within the PLOO monitoring region. Station E17, one of the five samples collected nearest the PLOO discharge site (near-ZID stations E11, E14, E15, E17, tregional station 8822) had coarser sediments than other surrounding mid-shelf stations (group E versus group C), while the four samples collected nearest the SBOO discharge site (near-ZID stations I12, I14, I15, I16) fell into three different clusters (groups B, E, F) that were characterized by varying proportions of fine particles and sand. The main characteristics and

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 survey of 2019. 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
	2019 Survey Area				SBOO	Reg	PLOO	SBOO	Reg	Reg	Reg
Parameters	**DR**	**Min**	**Max**	**Mean**	**n=17**	**n=7**	**n=22**	**n=10**	**n=14**	**n=13**	**n=6**
Particle Size (%)											
Coarse particles	25	0	29.5	2.0	8.1	0.1	9.8	5.8	12.6	6.2	0
Med-coarse sands	100	0.1	89.1	11.9	28.7	3.7	1.8	39.8	6.1	3.2	0.3
Fine sands	100	1.8	90.4	40.9	53.9	63.7	36.9	25.6	37.1	37.2	25.2
Fines	98	0	85.5	45.3	15.3	32.7	60.6	35.0	52.5	59.2	74.4
Organic Indicators											
Sulfides (ppm)	80	nd	407.00	6.89	1.91	3.23	2.19	1.54	2.71	34.51	7.08
TN (% weight)	80	nd	0.237	0.045	0.025	0.024	0.047	0.035	0.049	0.070	0.156
TOC (% weight)	100	0.09	3.36	0.72	0.27	0.19	0.81	0.24	0.70	1.16	2.22
TVS (% weight)	100	0.3	7.6	2.0	0.8	1.0	2.0	0.6	2.1	3.1	5.4
Trace Metals (ppm)											
Aluminum	100	741	19,200	6762	4021	5614	7386	2546	7608	9341	13,043
Antimony	100	0.2	3.2	1.1	0.6	0.8	1.1	0.6	1.2	1.5	2.1
Arsenic	100	0.64	8.55	2.44	1.56	1.41	2.98	3.18	2.05	2.46	3.81
Barium	100	1.3	89.7	31.7	21.2	30.3	31.5	10.1	38.9	41.3	61.5
Beryllium	58	nd	0.45	0.09	0.07	0.09	0.18	0.06	0.17	0.20	0.31
Cadmium	84	nd	0.42	0.08	0.04	0.04	0.07	0.04	0.08	0.28	0.36
Chromium	100	3.6	34.9	14.5	8.8	10.7	15.7	8.9	14.8	19.7	27.4
Copper	90	nd	20.4	6.1	3.0	3.2	6.8	3.2	6.5	10.1	15.0
Iron	100	1090	22,900	9443	5199	7161	11,040	5380	10,371	12,698	15,833
Lead	100	0.9	9.4	3.2	1.5	2.0	3.5	1.9	3.5	5.0	5.5
Manganese	100	5.3	185.0	75.4	51.6	71.1	80.7	30.5	87.9	98.5	124.1
Mercury	82	nd	0.079	0.021	0.007	0.007	0.026	0.013	0.022	0.039	0.054
Nickel	100	0.6	19.5	5.5	2.2	3.3	6.1	1.9	5.7	8.5	14.0
Selenium	9	nd	0.64	0.03	nd	nd	nd	nd	nd	0.28	0.53
Silver	0	—	—	—	—	—	—	—	—	—	—
Thallium	0	—	—	—	—	—	—	—	—	—	—
Tin	98	nd	1.7	0.6	0.3	0.4	0.7	0.2	0.7	0.8	1.1
Zinc	100	1.7	65.3	23.1	11.9	18.1	26.1	9.0	26.2	33.1	44.3
Pesticides (ppt)											
Total DDT	96	nd	11,006	574	62	42	404	865	1149	653	1582
Total HCH	6	nd	134	2	33	nd	nd	134	11	9	nd
Total Chlordane	17	nd	241	7	nd	nd	31	80	29	63	23
Hexachlorobenzene	29	nd	2000	67	186	nd	235	613	39	164	90
Aldrin	1	nd	24	0.3	nd	nd	nd	nd	24	nd	nd
Dieldrin	1	nd	60	1	nd	nd	nd	60	nd	nd	nd
Total PCB (ppt)	73	nd	40,838	1079	129	41	648	643	3412	1786	1383

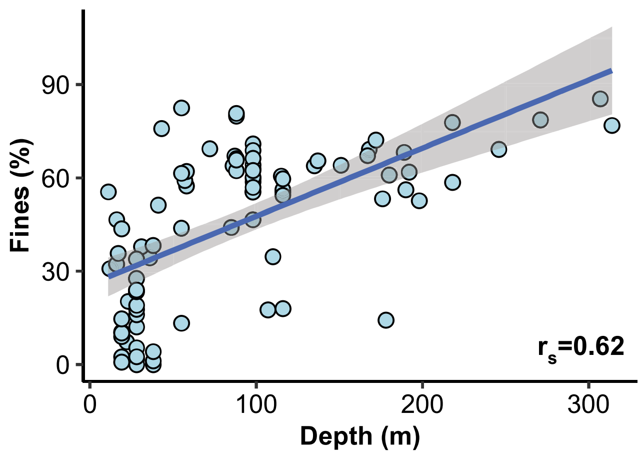


Figure 6.2
Scatterplot of concentrations of fine particles (Fines) versus depth for sediments collected from San Diego regional and core benthic stations during the summer of 2019. Shaded areas indicated 95% confidence interval.

distribution of each of the seven particle size cluster groups are described below.

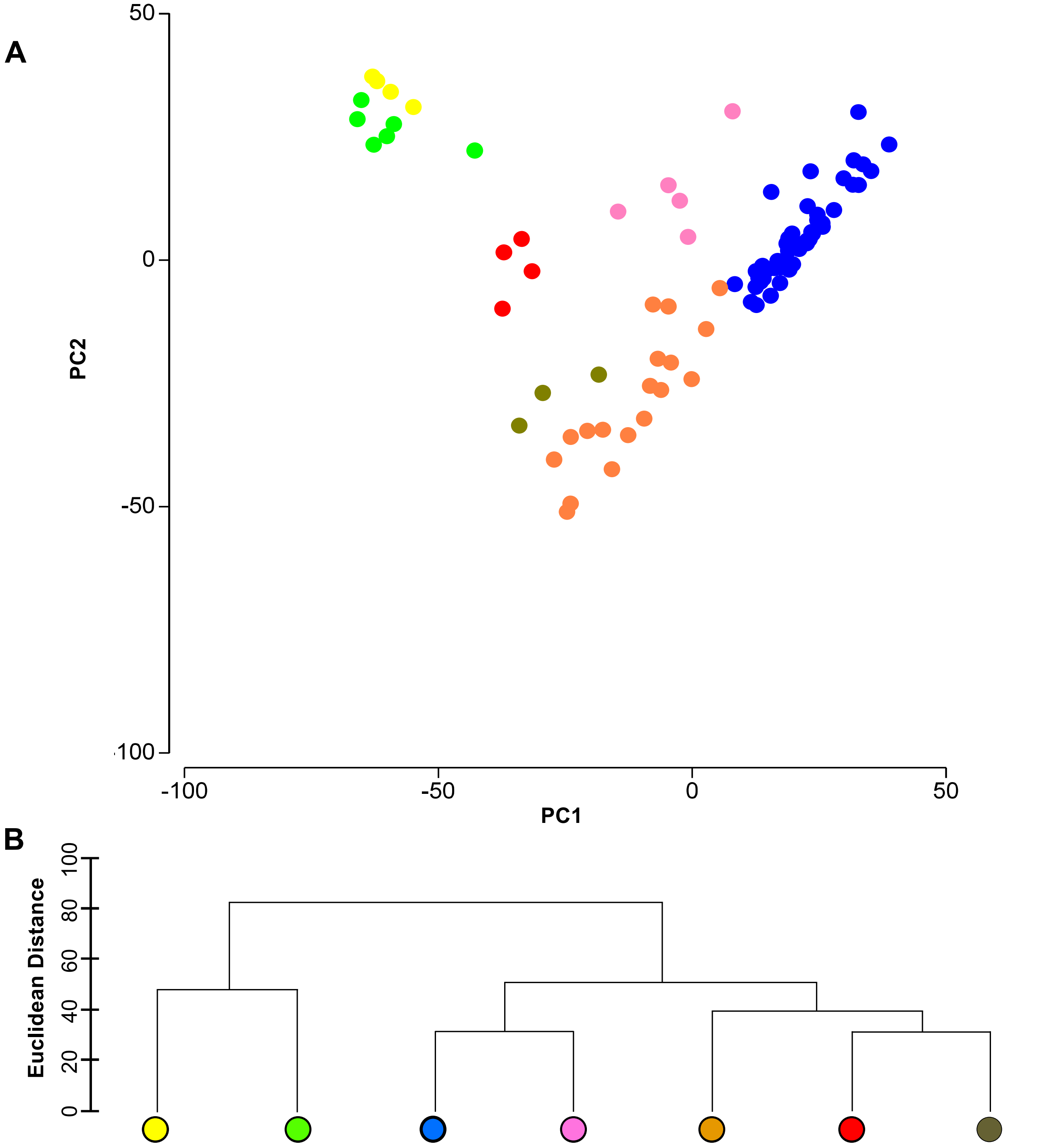
Particle size cluster group A comprised a total of four samples collected from SBOO farfield stations I6, I13, I21, and I23 located on the inner and middle shelf, and ranging in depth from 19 to 38 m (Figure 6.3). These sediments had the largest mean proportion of granules (3.9%), very coarse sand (11.5%), and coarse sand (51.7%), and the lowest mean proportions of fine sand (2.5%), very fine sand (0.5%), and fine particles (1.6%) (Table 6.2).

Particle size cluster group B comprised a total of six samples collected from SBOO stations that also ranged in depth from 19 to 38 m, including near-ZID stations I12 and I16, and farfield stations I2, I3, I8, and I34 (Figure 6.3). Sediments represented by this cluster group had the highest mean proportion of medium sand (52.5%), the second highest mean proportion of coarse sand (17.6%), as well as the second lowest mean proportions of very fine sand (3.0%) and fine particles (4.7%) (Table 6.2).

Particle size cluster group C was the largest group, comprising 49 sediment samples from stations widely distributed throughout the entire survey area at depths ranging from 11 m on the inner shelf to 314 m on the upper slope (Figure 6.3). This group encompassed 91% (n = 20) of the PLOO middle shelf stations, including near near-ZID stations E11, E14, and E15. Group C also encompassed 70% (n = 28) of the regional stations, which were primarily located on the middle shelf, outer shelf, or upper slope in the PLOO monitoring region. Only one station, regional station 8815, was located on the inner shelf. This group was distinguished from all others by having the highest mean proportion of fine particles (64.8%). It also averaged 26.0% very fine sand, 8.0% fine sand, <1% medium sand, <1% coarse sand, <1% very coarse sand, with no granules present (Table 6.2)

Particle size cluster group D was also widely distributed off San Diego, comprising five samples from regional stations located at depths from 16 to 85 m (Figure 6.3). These included one station (regional station 8844) located on the inner shelf, just off Silver Strand Beach (Coronado Island), and four stations located on the middle shelf, either offshore and to the north of the SBOO (regional station 8801, SBOO farfield stations I7, I28), or offshore of Point La Jolla (regional station 8833). Sediments from these widespread locations had the second largest mean proportion of fine particles (46.1%), very coarse sand (6.0%), and granules (3.2%) (Table 6.2). Relative to particle size, group C and group D sediments had lower levels of very fine sand (14.7%) and higher levels of medium sand (10.6%) and coarse sand (9.3%).

Particle size cluster group E was the second largest group, comprising samples from 18 stations, 78% (n = 14) of which were located at inner shelf depths of 12–28 m within the SBOO monitoring region (Figure 6.3). These stations included near-ZID station I14, farfield stations I4, I9, I10, I18, I22, I27, I30, I31, I35, and regional stations 8802, 8805, 8813, and 8842. The remaining four stations were located at mid-shelf depths of 31–110 m within the SBOO region (SBOO farfield station I29, regional station 8808) or within the PLOO region (PLOO nearfield station E17, regional station 8816). The sediments associated with this cluster group were distinguished by having the largest mean proportion of very fine sands (51.8%) (Table 6.2). Sediments at these sites also had 27.1% fines, 17.4% fine sand, and <2% medium sand, coarse sand, very coarse sand and granules.



Cluster:	A	B	C	D	E	F	G
n	4	6	49	5	18	4	3
Depth (m)	31	28	128	49	32	107	35
	(19-38)	(19-38)	(11-314)	(16-85)	(12-110)	(28-178)	(22-55)

Figure 6.3

Results of ordination and cluster analysis of particle size sub-fraction data from San Diego regional and core benthic stations sampled during the summer survey of 2019. Results are presented as (A) two-dimensional Principal Components Analysis ordination; (B) a dendrogram of main cluster groups; (C) a map showing the distribution of cluster groups throughout the region. Depth presented as means (ranges) calculated over all stations within a cluster group (n).

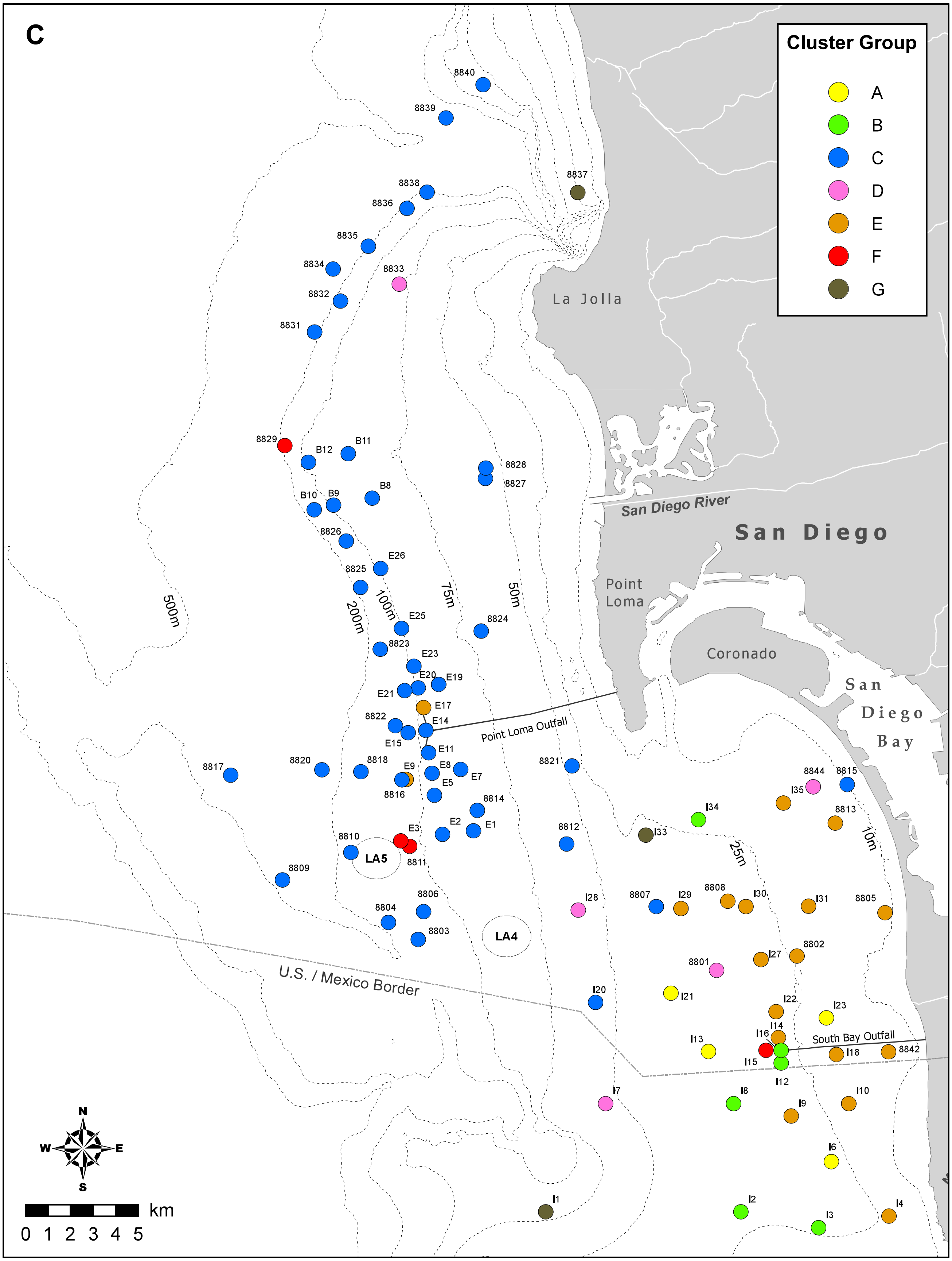


Figure 6.3 *continued*

Table 6.2

Particle size (%) summary for each cluster group A-G (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						
	A	B	C	D	E	F	G
n	4	6	49	5	18	4	3
Depth (m)	30.8 (19.0-38.0)	28.2 (19.0-38.0)	128.4 (11.0-314.0)	49.4 (16.0-85.0)	32.2 (12.0-110.0)	107.2 (28.0-178.0)	35.0 (22.0-55.0)
Fines	1.6 (0-2.5)	4.7 (0-16.1)	64.8 (51.3-85.5)	46.1 (34.3-61.5)	27.1 (9.0-46.6)	15.5 (12.1-18.0)	14.7 (7.3-23.5)
VFSand	0.5 (0-1.0)	3.0 (1.2-6.3)	26.0 (5.4-38.8)	14.7 (5.1-22.8)	51.8 (32.5-72.4)	21.3 (14.7-28.9)	40.3 (37.5-43.4)
FSand	2.5 (1.3-4.3)	19.9 (12.7-28.0)	8.0 (3.1-15.0)	10.9 (5.0-17.9)	17.4 (8.9-28.8)	30.2 (20.3-37.0)	41.3 (32.7-45.7)
MSand	28.9 (24.0-35.1)	52.5 (41.0-57.7)	0.8 (0-6.8)	10.6 (6.8-16.5)	2.0 (0.2-5.2)	19.6 (13.3-25.2)	3.7 (3.5-3.8)
CSand	51.7 (39.6-62.6)	17.6 (11.6-28.8)	0.2 (0-5.1)	9.3 (4.3-16.1)	0.7 (0-6.6)	8.1 (3.5-10.8)	0 —
VCSand	11.5 (6.8-17.0)	1.7 (0.4-3.8)	0.2 (0-11.7)	6.0 (0-11.4)	0.9 (0-8.3)	3.4 (0-5.6)	0 —
Granules	3.9 (0.5-12.5)	0.8 (0-5.0)	0 (0-1.6)	3.2 (0-9.2)	0.4 (0-5.6)	1.9 (0-3.6)	0 —

Particle size cluster group F comprised a total of four samples collected from one SBOO farfield station located on the inner shelf a depth of 28 m (nearfield station I15), two stations located on the middle shelf at depths of 107–116 m next to the LA-5 dumpsite (regional station 8811, PLOO farfield station E3), and one station located on the outer shelf at a depth of 178 m offshore of Mission Beach (regional station 8829) (Figure 6.3). Sediments represented by this cluster group had the second highest mean proportion of fine sand (30.2%) and the third highest mean proportion of medium sand (19.6%), very coarse sand (3.4%), and granules (1.9%) (Table 6.2).

Particle size cluster group G comprised a total of three samples collected from two SBOO farfield stations, I1 and I35, located at depths of 55 and 28 m, respectively, and regional station 8837 located at a depth of 22 m on the north side of the La Jolla canyon (Figure 6.3). Sediments represented by group G were distinguished from all other groups by having the highest mean proportion of fine sand (41.3%) and the second highest mean proportion of very fine sand (40.3%) (Table 6.2). Additionally, while groups F and G had similar, moderate levels of fine particles (~15%), group G had less medium sand (3.7%) and no coarse sand, very coarse sand, or granules.

Sediment Chemistry

Sediments collected throughout the San Diego region during the summer of 2019 had indicators of organic loading, metals, pesticides, and PCB concentrations below ERL and ERM thresholds (Long et al. 1995), and were within historical ranges (Table 6.1; see also Chapter 4). Of all samples collected during this survey, only 8% (n = 7) had elevated concentrations of just two parameters (Appendix H.3, Addenda 4-6, 4-8, 6-4). Arsenic exceeded its ERL at SBOO farfield station I21. Total DDT exceeded its ERL at SBOO farfield station I28, regional station 8801 located northwest of the SBOO, regional stations 8817 and 8820 located on the upper slope directly west of the PLOO, regional station 8834 located on the upper slope west of Point La Jolla, and regional station 8839 located on the upper slope off Del Mar. As in previous surveys (e.g., City of San Diego 2008–2014, 2015a,b, 2016a,b, 2018), several parameters had increasing concentrations across depth strata, mimicking the pattern described above for percent fines. For example, total nitrogen at regional stations averaged 0.024% wt per sample along the inner shelf, 0.049% wt along the middle shelf, 0.070% wt along the outer shelf, and 0.156% wt along the upper slope. This parameter, along with total volatile solids, aluminum, antimony, chromium, copper, iron, mercury, nickel, and zinc, had a strong, positive correlation ($r^s > 0.70$) with depth (Appendix H.1, select examples Appendix H.3).

Cluster and ordination analyses of the sediment chemistry data, described above, resulted in nine ecologically-relevant SIMPROF-supported sediment chemistry clusters (groups A–I) (Figure 6.4). According to BEST/BVSTEP results ($\rho = 0.952$, $p \leq 0.0001$, number of permutations = 999), these nine cluster groups were primarily distinguished by 12 specific indicators: total organic carbon, barium, cadmium, copper, lead, nickel, tin, aldrin, hexachlorobenzene, total DDT, total PCB, and total HCH (e.g., Figure 6.5). Furthermore, according to RELATE results ($\rho = 0.304$, $p \leq 0.0001$, number of permutations = 9999), overall patterns in combined sediment chemistry concentrations were weakly linked to sediment particle size composition. Granules, very coarse sand, and fine particles were most highly correlated to the distribution of sediment chemistry parameters (BEST/BIOENV, $\rho = 0.337$, $p \leq 0.001$, number of permutations = 999). This weak association is due to the combination of parameters that tend to co-vary with percent fines (e.g., total nitrogen, aluminum, mercury, nickel, tin), and those that do not, such as sulfides, total organic carbon, arsenic, total DDT, and total PCB (Appendices H.1, H.2, H.3). Instead, 80% of all samples, including all nine sediment samples collected from stations located near the PLOO and SBOO discharge sites, occurred within the sediment chemistry cluster group indicative of background conditions off San Diego (see group I). The distribution and main characteristics of each cluster group are described below.

Sediment chemistry cluster groups A–H represented small "outlier" groups with one or two stations that differed from group I, primarily due to very high, or very low, values of just a few select contaminants (Figures 6.4, 6.5, Addenda 4, 6). For example, sediments from SBOO farfield station I2 (sediment chemistry group A) had the lowest proportion of fine particles (1.7%), undetectable levels of sulfides, total nitrogen, copper, mercury, and tin, as well as the highest concentration of total HCH (133 ppt), and the only detected value for dieldrin (59.6 ppt). In contrast, sediments from regional station 8839 (sediment chemistry group B), located west of Del Mar at a depth of 307 m, had the highest proportion of fine particles (85.5%), the highest concentrations of parameters that tend to co-vary with fine particles (e.g., total nitrogen, aluminum, antimony, barium, chromium, copper, iron, manganese, mercury, and zinc), and the highest concentration of sulfides (25.9 ppm). Cluster group C, comprising regional stations 8817 and 8820 located on the upper slope, but offshore of the PLOO, had 77.4% fines and the highest concentrations of nickel and selenium (18.5–19.5 ppm and 0.63–0.64 ppm, respectively). Regional station 8810 (sediment chemistry group D) was located on the western boundary of the LA-5 dumpsite at a depth of 189 m and had the highest concentration of total chlordane (241.4 ppt). Regional station 8833 (sediment chemistry group E), located offshore of Point La Jolla at a depth of 85 m, was the only site where the pesticide aldrin was detected (24.0 ppt). Regional station 8812 (sediment chemistry group F) located southwest of the tip of Point Loma at a depth of 58 m had the highest concentration of total PCB (40,838 ppt). Regional station 8801 (sediment chemistry group G) located northwest of the SBOO at a depth of 36 m had the highest concentration of total DDT (11,006 ppt). Sediments from SBOO farfield station I29 (sediment chemistry group H) had the highest concentration of the pesticide hexachlorobenzene (24 ppt).

Sediment chemistry group I represented by far the largest cluster, which included 90% (n = 80) of the 89 samples analyzed for the 2019 summer survey (Figures 6.4, 6.4, Addenda 4, 6). These samples were collected from a wide range of inner to upper slope stations that spanned the entire San Diego region at depths ranging from 11 to 271 m. Included in this group were all eight samples collected from the near-ZID PLOO and SBOO sites, as well as one other near-ZID regional station. According to SIMPER results, a wide range of analytes accounted for 55% of the within-group similarity for group I, including the absence of aldrin and

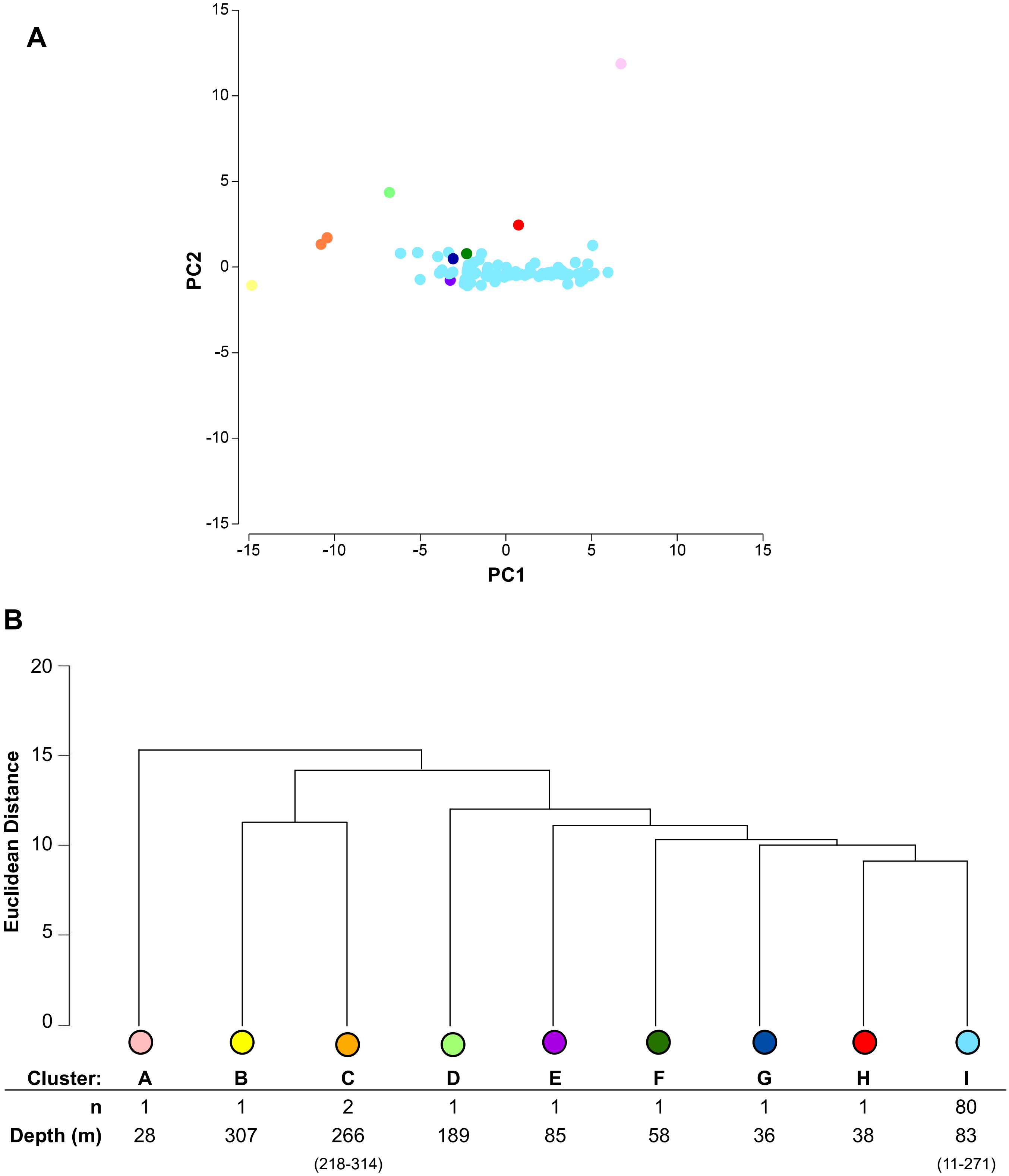


Figure 6.4

Results of ordination and cluster analysis of sediment chemistry data from San Diego regional and core benthic stations sampled during the summer survey of 2019. Results are presented as (A) two-dimensional Principal Components Analysis ordination; (B) a dendrogram of main cluster groups; (C) a map showing the distribution of cluster groups throughout the region. Depth presented as means (ranges) calculated over all stations within a cluster group (n).

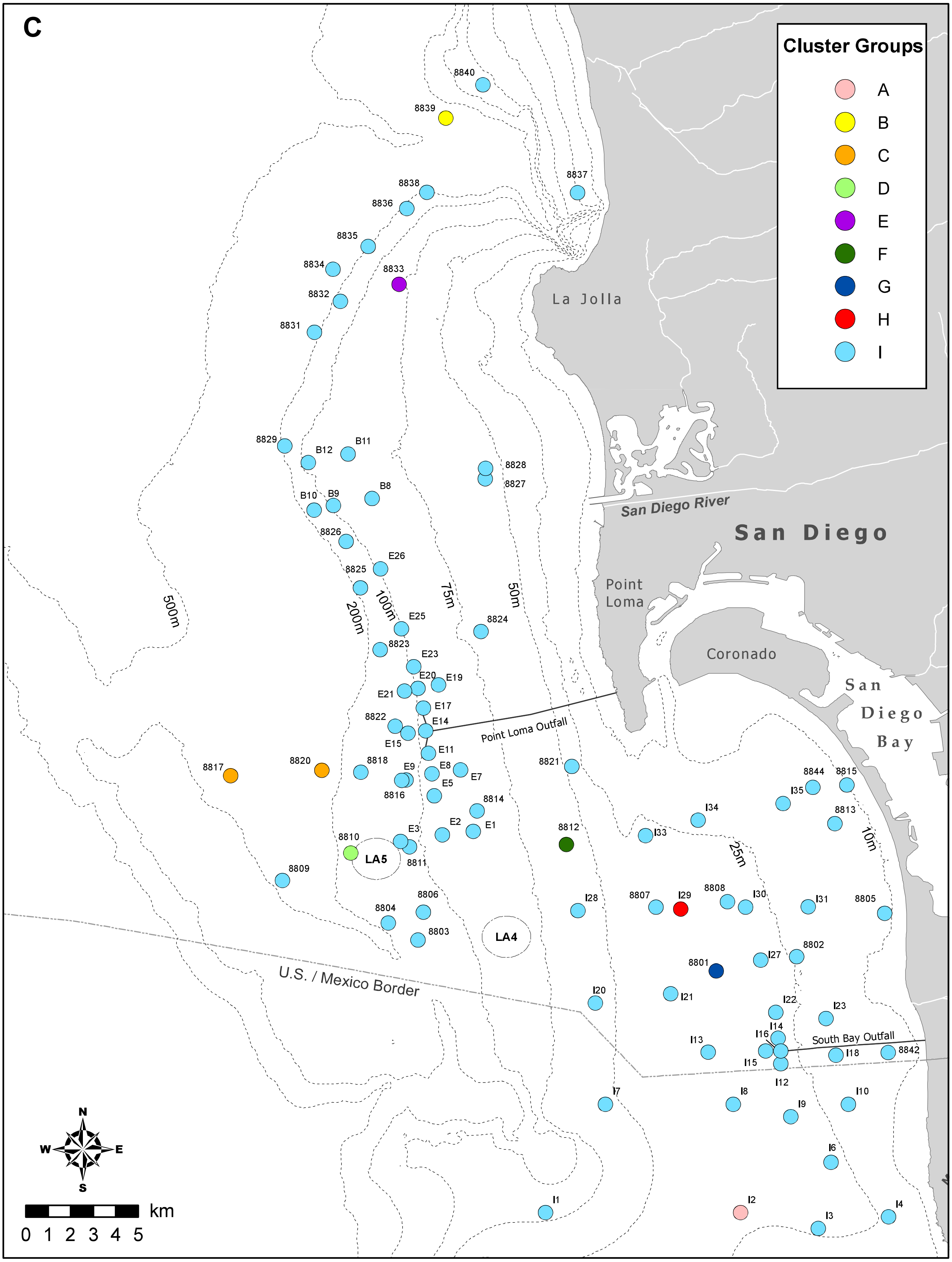


Figure 6.4 *continued*

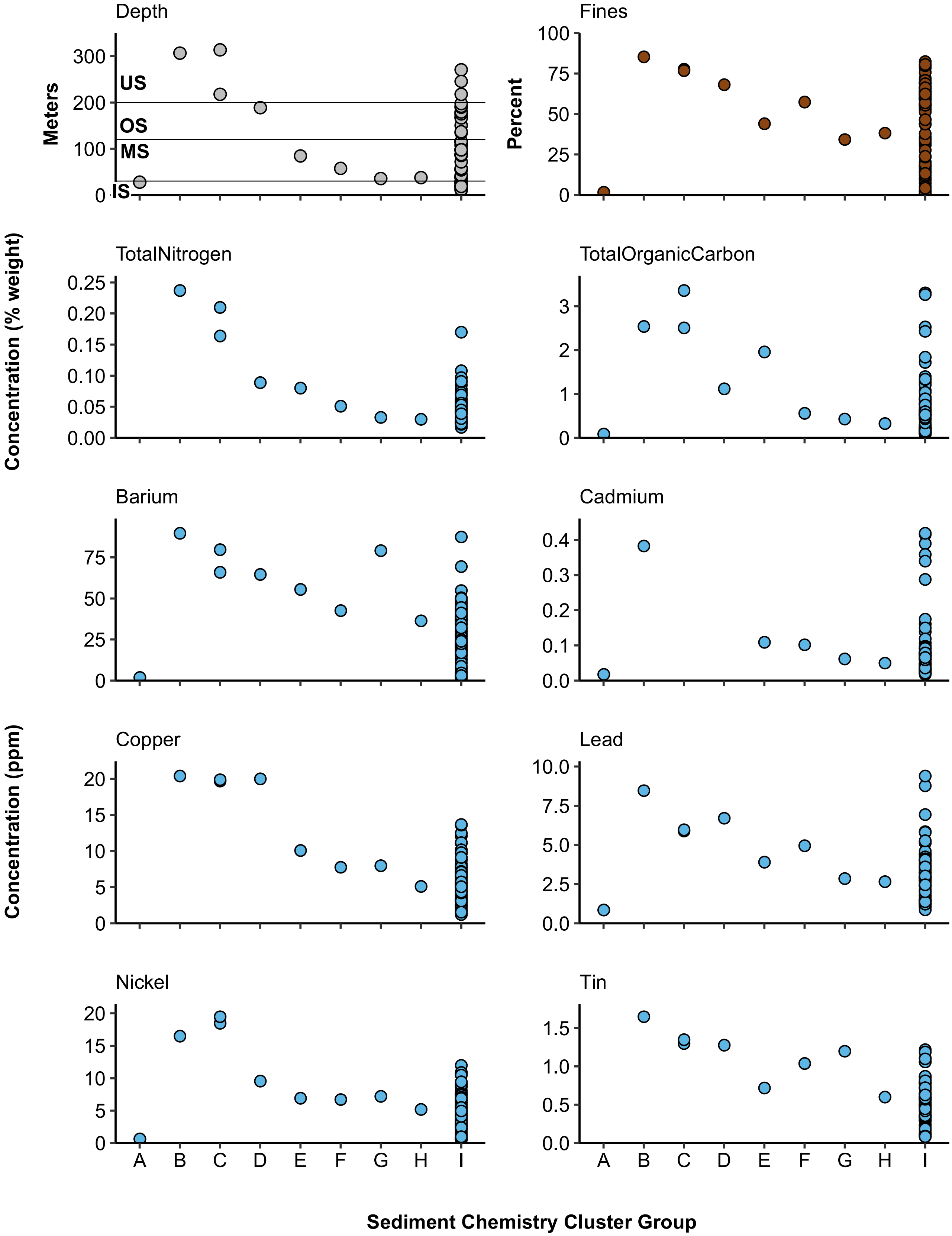


Figure 6.5
Depth, percent fines, and several other parameters that contributed to sediment chemistry cluster group dissimilarities during the summer of 2019 (see Figure 6.4).Each data point represents a single sample. IS=inner shelf; MS=mid-shelf; OS=outer shelf; US=upper slope.

dieldrin, and variable concentrations of sulfides, total nitrogen, total volatile solids, aluminum, antimony, barium, chromium, copper, nickel, selenium, tin, zinc, total DDT, total chlordane, total HCH, hexachlorobenzene, and total PCB (e.g., Figure 6.5). It is likely that this cluster group represents background conditions for continental shelf habitats in the San Diego region.

Sediment Toxicity

Results of all sediment toxicity testing conducted for the PLOO and SBOO regions, during a 3-year pilot study (2016–2018) and the summer of 2019, did not indicate any evidence of toxicity at any of the region's monitoring sites. For full analysis and interpretation, refer to Appendix C.

Regional Macrobenthic Communities

A total of 26,063 macrobenthic invertebrates were identified from the 89 grabs collected during the summer 2019 survey at depths ranging from 11 to 314 m off San Diego. Of the 732 taxa recorded, 79% (n = 575) 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 7 to 136 taxa per grab; macrofaunal abundance ranging from 20 to 788 individuals per grab; Shannon Diversity Index (H') ranging from 1.5 to 4.2 per grab; Pielou's Evenness Index (J') ranging from 0.59 to 0.93 per grab; and Swartz Dominance Index ranging from 1 to 43 per grab (Table 6.3). Reported values for each parameter, and the variation observed between strata, generally correspond to findings reported previously for the San Diego region (e.g., City of San Diego 2016a,b, 2018). 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 (BRI < 25) (Smith et al. 2001). This remained true for the 2019 summer survey with 88% of samples (n = 73), collected from BRI-validated depths, having BRI values indicative of reference condition (Appendix H.4). A total of 10 samples (~12%) had slightly elevated BRI values between 25–34, which may indicate a minor deviation from reference condition; these samples were collected at near-ZID PLOO station E14, SBOO farfield stations I4, I9, I22, and I35, and regional stations 8813, 8832, 8835, 8836, and 8838. None of the stations sampled in summer 2019 had BRI values >34, which would indicate increasing levels of disturbance or environmental degradation.

Cluster and ordination analyses of the macrofaunal data, described above, resulted in nine ecologically-relevant SIMPROF-supported macrofauna clusters (groups A–I) (Figure 6.6, Appendices H.5, H.6). These macrofauna cluster groups each represented up to 37 grabs. The composition of each cluster group varied in terms of the specific taxa present and their relative abundance, as well as depth and sediment composition. For example, the macrofaunal assemblages represented by cluster groups A, B, C, D, E occurred along the inner and middle shelf at depths of 11–55 m, with all but one sample (from station 8821) located within the SBOO monitoring region. Macrofaunal assemblages associated with cluster group F, the largest group (n = 37), spanned a significant portion of the middle and outer shelf off San Diego. Group F also included all samples collected at stations located near the PLOO discharge site. Assemblages associated with cluster groups G, H and I represented a total of 14 samples that occurred along the outer shelf and upper slope at depths of 172–314 m. Similar patterns of variation occurred in the macrofaunal and sediment similarity/dissimilarity matrices used to generate cluster dendrograms (RELATE $\rho = 0.63$, $p \leq 0.0001$, number of permutations = 9999). The sediment sub-fractions that were most highly correlated with the macrofaunal communities included coarse sand, medium sand, very fine sand, and fine particles (BEST/BIOENV $\rho = 0.637$, $p \leq 0.0001$, number of permutations = 999).

Species richness ranged from a mean of 17 to 82 taxa per grab for each cluster group, while mean abundance ranged from 34 to 413 individuals per grab (Figure 6.6). According to BEST/BVSTEP ($\rho = 0.947$, $p \leq 0.001$, number of permutations = 999), a total of 34 species best described the overall pattern (gradient) of the cluster dendrogram, including the polychaetes

Table 6.3

Macrofaunal community summary statistics calculated for San Diego regional and core benthic stations sampled during the summer survey of 2019. 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	17	55 (27-83)	192 (72-342)	3.3 (2.4-4.0)	0.82 (0.59-0.92)	19 (6-35)	18 (5-28)
	Regional	7	42 (31-57)	164 (84-249)	3.0 (2.3-3.5)	0.82 (0.65-0.91)	14 (6-22)	22 (20-26)
	All Inner Shelf	24	51	184	3.2	0.82	18	20
Middle Shelf								
	PLOO	22	85 (68-136)	469 (241-788)	3.6 (3.1-4.1)	0.82 (0.73-0.89)	24 (15-43)	12 (7-33)
	SBOO	10	63 (25-124)	224 (104-473)	3.3 (2.5-4.2)	0.82 (0.76-0.90)	22 (8-41)	15 (8-24)
	Regional	14	93 (62-131)	382 (142-622)	3.8 (3.5-4.1)	0.85 (0.81-0.89)	30 (21-39)	15 (11-22)
	All Middle Shelf	46	83	390	3.6	0.83	25	14
Outer Shelf								
	Regional	13	49 (24-70)	241 (119-464)	3 (2.5-3.5)	0.79 (0.73-0.85)	13 (6-23)	20 (8-30)
Upper Slope								
	Regional	6	33 (7-64)	101 (20-174)	2.7 (1.5-3.7)	0.82 (0.74-0.93)	12 (3-26)	—
	All Stations	89	66 (7-136)	293 (20-788)	3.4 (1.5-4.2)	0.82 (0.59-0.93)	21 (3-43)	16 (5-33)

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

Amphicteis scaphobranchiata, *Chloeia pinnata*, Euclymeninae sp A, *Goniada littorea*, *Kirkegaardia siblina*, *Maldane sarsi*, *Onuphis* sp A, *Paradiopatra parva*, *Polydora cirrosa*, *Praxillella pacifica*, *Prionospio dubia*, *Scoletoma tetraura* Cmplx, *Spiophanes kimballi*, *Sternaspis affinis*, and *Travisia brevis*, the amphipods *Ampelisca cristata cristata*, *Ampelisca careyi*, *Ampelisca pugetica*, *Ampelisca cristata microdentata*, *Foxiphalus obtusidens*, and *Rhepoxynius heterocuspidatus*, the cumacean *Hemilamprops californicus*, the ostracod *Euphilomedes carcharodonta*, the ophiuroid *Amphiodia urtica*, the bivalves *Cooperella subdiaphana*, *Kurtiella tumida*, *Nuculana* sp A, *Parvilucina tenuisculpta*, and *Tellina carpenteri*, the nemerteans *Tubulanus polymorphus* and *Carinoma mutabilis*, and the brachiopod *Glottidia albida*. Most of these species occurred primarily in grabs represented by cluster groups D, F and/or G (see below and select examples in Figure 6.7, Appendix H.5). The main characteristics and distribution of each cluster group are described below.

Macrofauna cluster group A represented inner shelf assemblages present at five regional stations (stations 8805, 8813, 8815, 8842, 8844) located at depths of 11–17 m along the Coronado "Silver Strand" beach and south Imperial Beach (Figure 6.6). These assemblages averaged 39 taxa and 160 individuals per grab. According to SIMPER, the five most characteristic species for cluster group A were the polychaetes *Ampharete labrops* (3/grab), *Goniada littorea* (11/grab), *Pectinaria californiensis*

(4/grab) and *Spiophanes duplex* (8/grab) and the bivalve *Cooperella subdiaphana* (7/grab) (Appendix H.6). Relative to other groups, these were the highest numbers of *G. littorea, C. subdiaphana, P. californiensis,* and *A. labrops* (e.g., Figure 6.7). Sediments associated with this cluster group were unusual for the associated depths, with a relatively high mean proportion of fines (40.2%). These sediments also averaged 40.3% very fine sand, 15.5% fine sand, 3.2% medium sand, 0.9% coarse sand, and had no very coarse sand or granules (Appendix H.7).

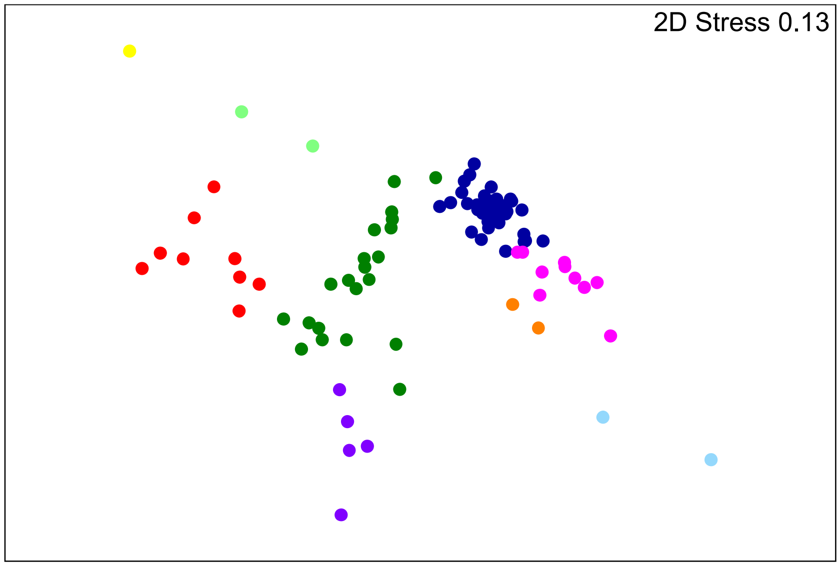
Macrofauna cluster group B represented a unique inner shelf assemblage present at SBOO farfield station I23 (Figure 6.6). A total of 39 taxa and 288 individuals were found in this assemblage. The five most abundant taxa were the polychaetes *Saccocirrus* sp (n = 84), *Mystides* sp (n = 43), *Hesionura coineaui difficilis* (n = 36), *Paramphinome* sp (n = 27), and *Lumbrinerides platypygos* (n = 26) (Appendix H.6). This was the only sample in which *Saccocirrus* sp, *Mystides* sp, *H. coineaui difficilis*, and *Paramphinome* sp occurred, and had the highest number of *L. platypygos* compared to all other groups (Figure 6.7). Sediments associated with this sample averaged 2.5% fine particles, 0.6% very fine sand, 1.3% fine sand, 26.5% medium sand, 39.6% coarse sand, 17% very coarse sand, and 12.5% granules (Appendix H.7). These sediments had the lowest proportions of fine particles, very fine sand, and fine sand, and the highest proportions of coarse sand, very coarse sand, and granules.

Macrofauna cluster group C represented assemblages from nine grabs collected from two SBOO near-ZID stations (stations I12, I16) and seven SBOO farfield stations (I2, I3, I6, I8, I13, I21, I34) located on the inner and mid-shelf at depths of 19–38 m (Figure 6.6). These assemblages averaged 38 taxa and 142 individuals per grab, and were characterized by the highest numbers of the polychaete *Spiophanes norrisi* (46/grab), the amphipod *Rhepoxynius heterocuspidatus* (8/grab), and the sand dollar *Dendraster terminalis* (7/grab) (Figure 6.7, Appendix H.6). The polychaetes *Lumbrinerides platypygos* (3/grab) and *Spiochaetopterus costarum Cmplx* (2/grab) were also characteristic of group C. The sediments associated with this cluster group averaged 3.5% fine particles, 2.2% very fine sand, 14.2% fine sand, 44.9% medium sand, 30.3% coarse sand, 4.3% very coarse sand, and <1% granules (Appendix H.7). These sediments were similar to those of cluster group B with very low mean proportions of fine particles and very fine sand, and relatively high mean proportions of medium and coarse sand, but they exhibited higher mean proportions of fine sand and lower mean proportions of very coarse sand and granules.

Macrofauna cluster group D was the second largest group (n = 21), representing assemblages from inner to mid shelf depths of 19–55 m located around and to the north of the SBOO (Figure 6.6). These included assemblages present in two grabs from near-ZID stations I14 and I15. Assemblages represented by group D averaged 77 taxa and 275 individuals per grab, and were characterized by the highest numbers of the brachiopod *Glottidia albida* (8/grab) and the amphipod *Ampelisca cristata microdentata* (7/grab), the second highest numbers of the polychaetes *Spiophanes duplex* (33/grab) and *Spiophanes norrisi* (18/grab), and the third highest number of the polychaete *Mediomastus* sp (9/grab) (Figure 6.7, Appendix H.6). The sediments associated with cluster group D averaged 27.1% fines, 45.0% very fine sand, 21.3% fine sand, 3.8% medium sand, and <2% coarse sand, very coarse sand and granules (Appendix H.7). These sediments had the highest mean proportions of very fine and fine sand compared to all other cluster groups.

Macrofauna cluster group E represented two mid-shelf assemblages present at SBOO farfield stations I7 and I20, both located at a depth of 55 m offshore of the outfall (Figure 6.6). These two assemblages averaged 58 taxa and 198 individuals per grab. The five most characteristic taxa for cluster group E were the polychaetes *Lanassa venusta venusta* (11/grab) and *Spiophanes norrisi* (9/grab), the ophiuroid *Amphipholis squamata* (9/grab), the amphipod *Foxiphalus obtusidens* (6/grab) and the phoronid *Phoronis* sp (5/grab) (Appendix H.6). Apart from *S. norrisi*, this was the highest number of these species found across all cluster groups

A



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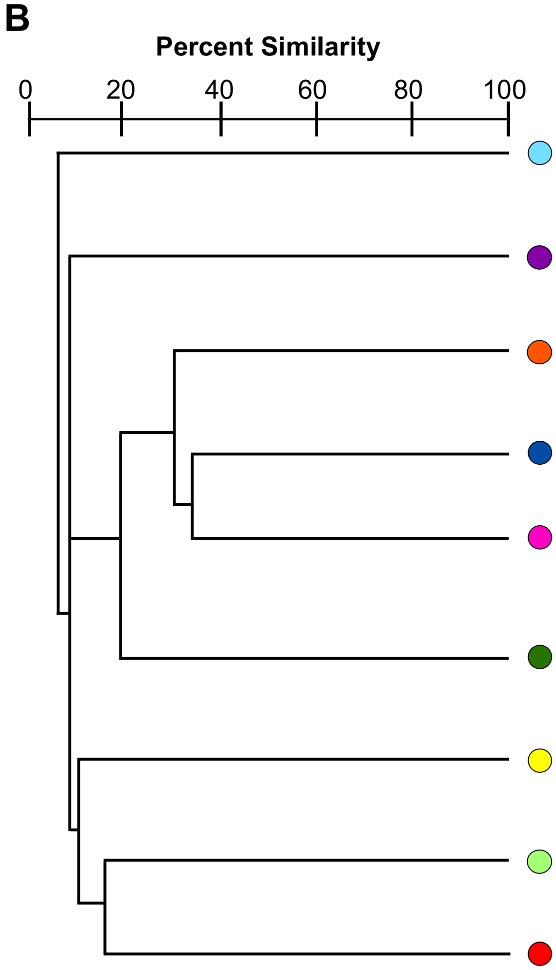
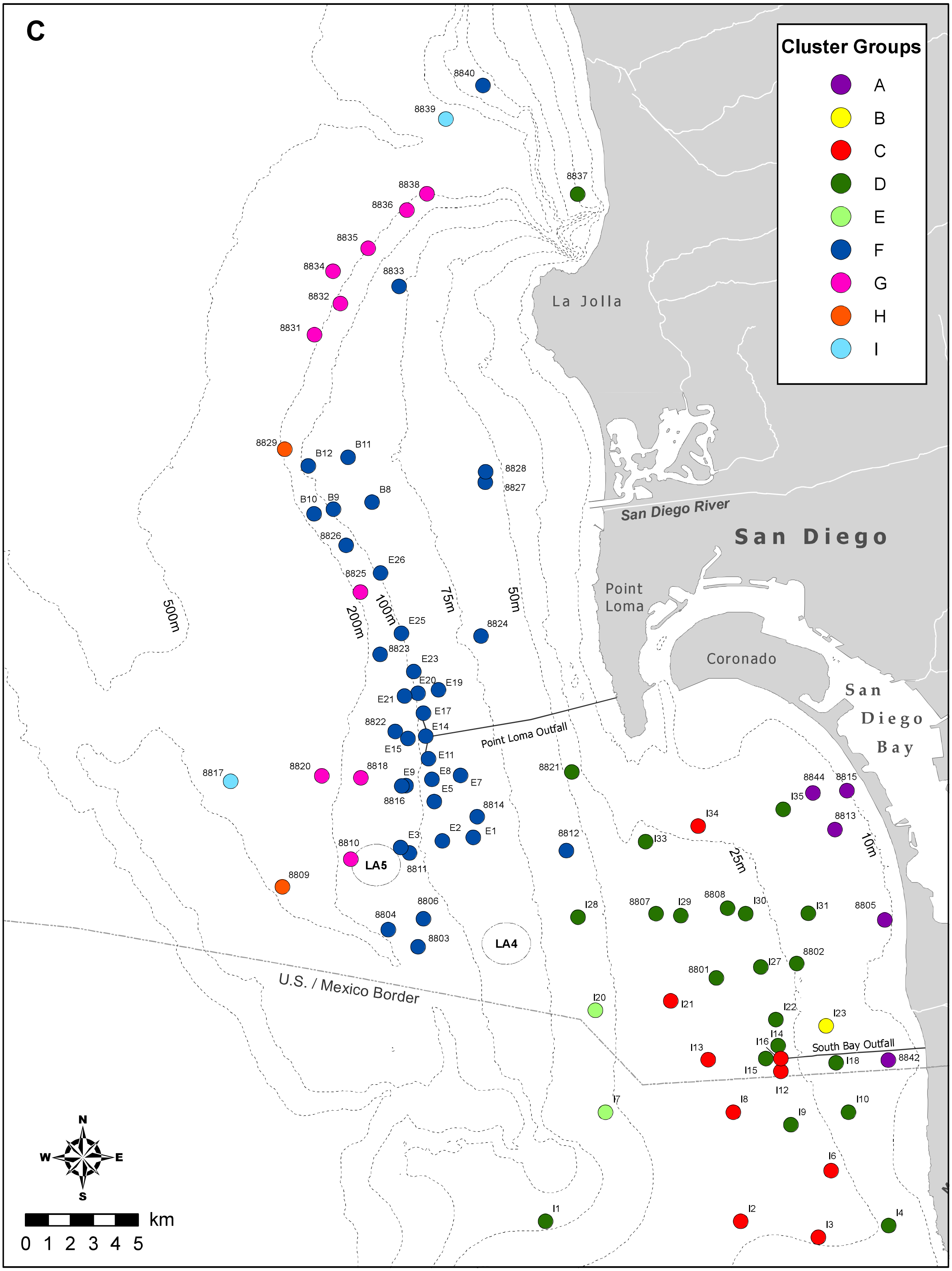


Cluster Group	n	Depth Range (m)	Community Metric SR	Community Metric Abun
I	2	307-314	17	34
A	5	11-17	39	160
H	2	178-271	57	147
F	37	57-168	82	413
G	10	172-246	37	189
D	21	19-55	77	275
B	1	19	39	288
E	2	55-55	58	198
C	9	19-38	38	142

Figure 6.6
Results of ordination and cluster analysis of macrofauna data from San Diego regional and core benthic stations sampled during the summer survey of 2019. Results are presented as (A) nMDS ordination; (B) a dendrogram of main cluster groups; (C) a map showing the distribution of cluster groups throughout the region. Data are mean values over all stations in each group (n); SR = species richness; Abun = abundance. Cluster groups are named in order of increasing depth.



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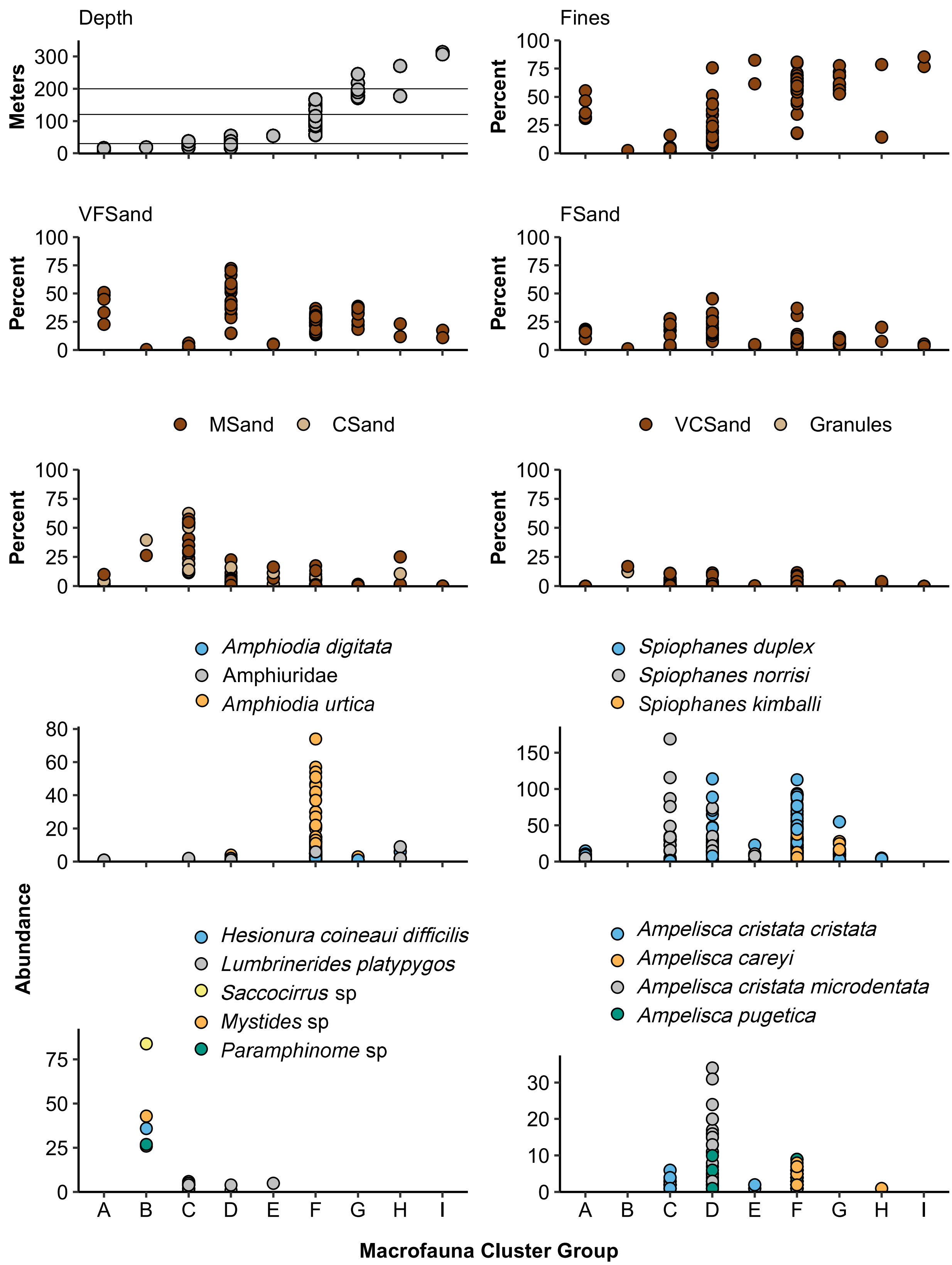

Figure 6.7
Depth, sediment composition, and abundances of select species that contributed to macrofauna cluster group dissimilarities during the summer of 2019 (see Figure 6.6). Each data point represents a single sediment or grab sample; IS = inner shelf; MS = mid-shelf; OS = outer shelf; US = upper slope; VF = very fine; F = fine; M = medium; C = coarse; VC = very coarse.

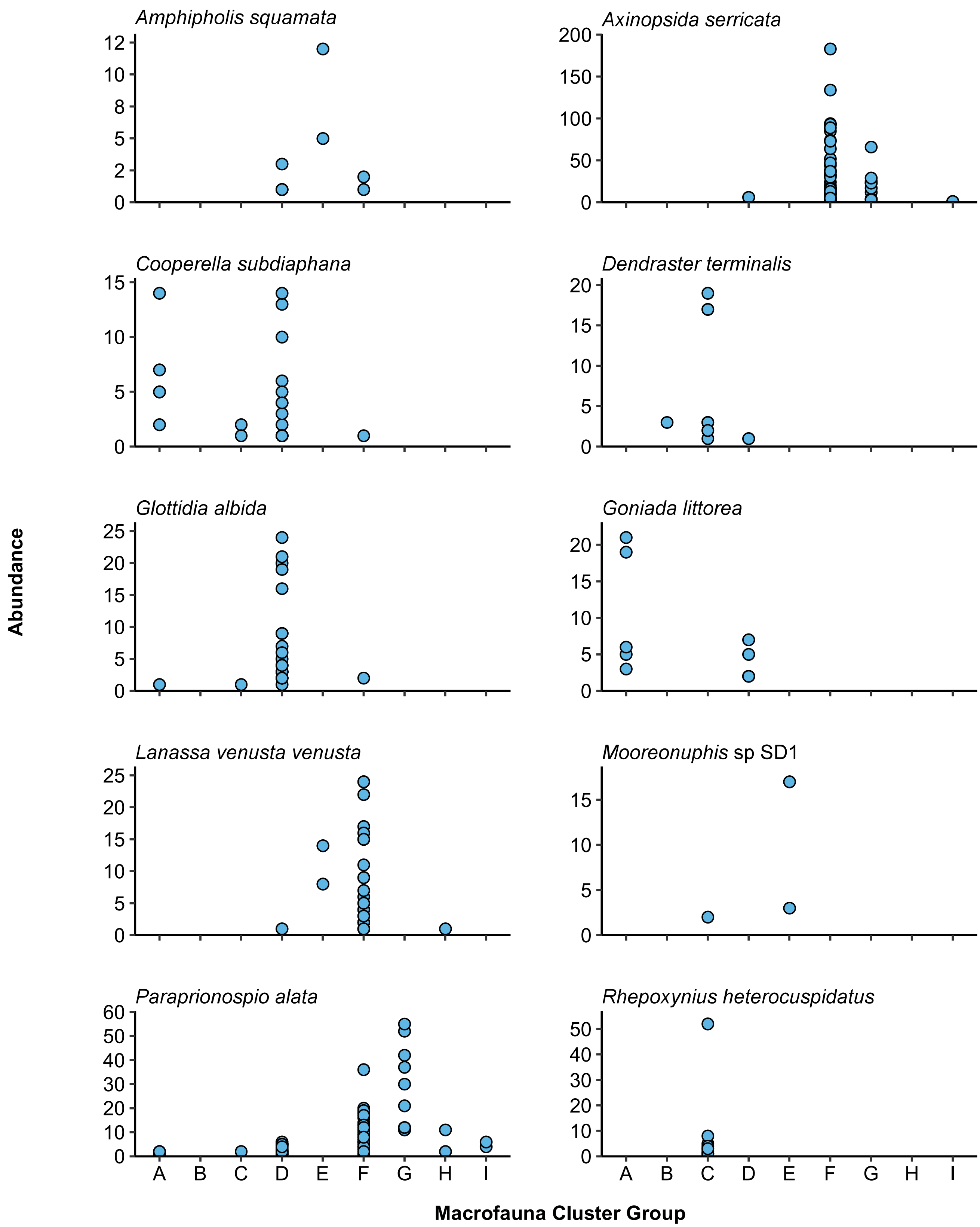

Figure 6.7 *continued*

(e.g., Figure 6.7, Appendix H.5). The sediments associated with cluster group E averaged 72% fine particles, 5.2% very fine sand, 4.2% fine sand, 11.6% medium sand, 6.7% coarse sand, and <1% very coarse sand and no granules (Appendix H.7). Overall, this was the second highest mean proportion of fine particles of all cluster groups.

Macrofauna cluster group F was the largest group (n = 37), representing assemblages from most of the middle to outer shelf sites at depths ranging from 57 to 168 m, and including all of the near-ZID and farfield PLOO stations sampled during summer 2019 (Figure 6.6). This group averaged 82 taxa and 413 individuals per grab. The five most characteristic taxa for cluster group F were the polychaetes *Spiophanes duplex* (46/grab), *Mediomastus* sp (17/grab), *Prionospio jubata* (17/grab), *Spiophanes kimballi* (15/grab), and *Paradiopatra parva* (14/grab) (Appendix H.6). These were the highest numbers of these species found across all cluster groups (e.g., Figure 6.7). The sediments associated with this cluster group averaged 59.4% fines, 26.1% very fine sand, 9.9% fine sand, 1.8% medium sand, and 1% coarse sand, very coarse sand, and granules (Appendix H.7).

Macrofauna cluster group G represented deep water assemblages sampled from 10 sites located on the outer shelf and upper slope at depths between 172 and 246 m west of Point La Jolla (regional stations 8831, 8832, 8834, 8835, 8836, 8838), the San Diego River (regional station 8825), and Point Loma (regional stations 8810, 8818, 8820) (Figure 6.6). These assemblages averaged 37 taxa and 189 individuals per grab, and were characterized by the polychaetes *Paraprionospio alata* (28/grab), *Spiophanes duplex* (13/grab), *Spiophanes kimballi* (12/grab), and *Mediomastus* sp (9/grab) and the bivalve *Axinopsida serricata* (21/grab) (Appendix H.6). This was the highest number of *P. alata* found across all cluster groups (Figure 6.7). The sediments associated with this cluster group averaged 63.1% fine particles, 30.0% very fine sand, 6.6% fine sand, and <1% medium sand, with no coarse sand, very coarse sand, or granules present (Appendix H.7). These sediments had the third highest mean proportion of fine particles.

Macrofauna cluster group H represented another deep-water community sampled at one outer shelf site located west of San Diego River at a depth of 178 m (regional station 8829) and one upper slope site located on the eastern side of the Coronado Bank at a depth of 271 m (regional station 8809) (Figure 6.6). These assemblages averaged 57 taxa and 147 individuals per grab and were characterized by the highest numbers of the ophiuroid *Amphiodia digitata* (4/grab), ophiuroids in the family Amphiuridae (5/grab), and the polychaete *Aphelochaeta* sp (5/grab). The polychaetes *Mediomastus* sp (17/grab) and *Spiophanes duplex* (5/grab) were also characteristic of this group. For these depths, the sediments associated with these two stations had relatively low mean proportion of fine particles (46.5%) and relatively high mean proportions of fine sand (14.0%), medium sand (13.4%), and coarse sand (5.4%) (Appendix H.7).

Macrofauna cluster group I represented the deepest assemblages sampled during summer 2019. This group comprised two upper slope sites at depths of 307–314 m, including regional station 8817 located on the eastern edge of the Coronado Bank, and regional station 8839 located off Del Mar (Figure 6.6). These assemblages averaged 17 taxa and 34 individuals per grab and were characterized by the polychaete *Paraprionospio alata* (5/grab) and the bivalve *Axinopsida serricata* (1/grab) (Figure 6.7, Appendix H.6). The sediments associated with these two stations had the highest mean proportions of fine particles (81.2%), as well as 14.3% very fine sand, 4.4% fine sand, 0.1% medium sand, and no coarse sand, very coarse sand, or granules (Appendix H.7).

Discussion

Benthic habitats and associated macrofaunal communities found on the continental shelf and upper slope off San Diego remained in good condition during the 2019 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 2019, was typical for this portion of the southern California coast (Emery 1960), and is consistent with results of previous surveys off San Diego (e.g., City of San Diego 2008–2014, 2015a,b, 2016a,b, 2018). 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 of medium and coarse sands, whereas stations sampled along the middle and outer shelf within the PLOO region were typically characterized by much finer sediments (see also Chapter 4). Much of the variability in particle size distributions off San Diego is likely 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 excellent throughout the entire San Diego region in 2019. 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, which may accumulate over time (e.g., organic indicators, trace metals). In addition, results of sediment toxicity testing in offshore San Diego waters revealed no evidence of toxicity at any of the near-ZID or regional stations tested from 2016 to 2019 (Appendix C). Sediment contamination patterns during the current reporting period were also similar to those seen in previous years. Although, a number of indicators of organic loading (e.g., trace metals, pesticides, and PCBs) were detected in sediment samples throughout the San Diego region, but 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, 2016a,b, 2018). Furthermore, 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 depth and, to a lesser degree, with increased percent fines. However, 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 to 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 2019, with assemblages consistent with those observed during previous regional surveys conducted from 1994 to 2017 (City of San Diego 2010–2014, 2015a,b, 2016b, 2018). Benthic Response Index (BRI) results revealed little evidence of disturbance off San Diego, with 88% of all calculated BRI values being indicative of reference condition and another 12% being characteristic of only a possible minor deviation. These results reflect assemblages characterized by expected abundances of pollution sensitive species, such as the amphipods *Ampelisca* spp and *Rhepoxynius* spp., expected abundances of pollution tolerant species, such as the polychaete *Capitella teleta* and the bivalve *Solemya pervernicosa* (see also Chapter 5). Comparison of the results for 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 2019 survey. Furthermore, values for each of these community structure metrics remain within, or near, the range of tolerance intervals calculated for their specific habitats (see City of San Diego 2015a).

Most of the macrofaunal assemblages identified in 2019 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. 2000, Mikel et al. 2007). Several of the inner to mid-shelf assemblages (cluster groups A–E) described in this chapter were similar to those previously described in other shallow habitats across southern California (Barnard 1963, Jones 1969, Thompson et al. 1987, 1993a,b, 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 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 dominated by macrofauna cluster group F, which represented assemblages from 63% of the samples analyzed at these depths during the summer of 2019. These assemblages occurred in sediments with close to 60% fines and larger proportions very fine and fine sand. Benthic communities dominated by polychaete worms such as *S. duplex* have long been common off Point Loma, and in similar seafloor habitats in other areas of 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 even finer sediments of upper slope stations sampled off San Diego in 2019 (cluster groups G–I) were 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, 2016b, 2018).

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 2019, which may be attributed to anthropogenic factors, such as wastewater discharge via the PLOO or SBOO, or other point sources. Macrobenthic communities appeared to be in good condition overall, with none of the sites surveyed showing evidence consistent with environmental disturbance. This result is similar to findings in Gillett et al. (2017) whom 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 natural and/or anthropogenic 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 as 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 are exposed to sediment conditions, which may be 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 megabenthic invertebrate communities vary widely and are 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, may affect migration patterns or the recruitment of certain fish species (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 determine whether observed differences or changes in community structure may be related to anthropogenic activity. 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 designated monitoring stations throughout the PLOO and SBOO regions, during 2018 and 2019. Included are descriptions of the different fish and invertebrate communities present in these two regions, along with

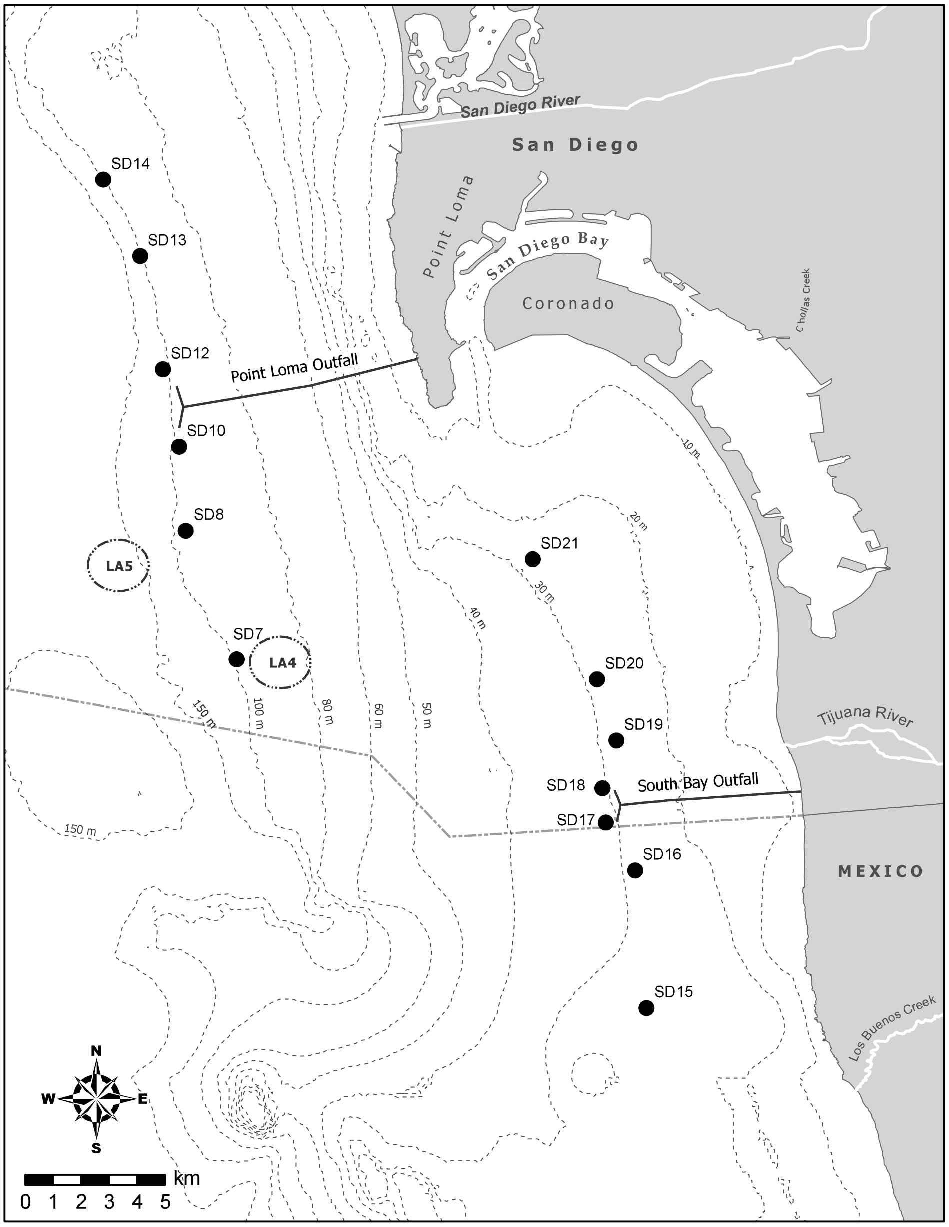


Figure 7.1
Trawl station locations sampled around the Point Loma and South Bay Ocean Outfalls as part of the City of San Diego's Ocean Monitoring Program.

comparisons of spatial patterns and long-term changes over time. The three primary goals of this chapter 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 PLOO and SBOO; (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 2018, winter 2019, and summer 2019 (Figure 7.1). These included six PLOO stations located along the 100-m depth contour (discharge depth) ranging from 9 km south to 8 km north of the outfall, and seven SBOO stations located along the 28-m depth contour (discharge depth) ranging from 7 km south to 8.5 km north of the outfall. The two PLOO stations (SD10, SD12) and two SBOO stations (SD17, SD18) located within 1000 m of the outfall structures are considered to represent nearfield conditions. Trawl sampling was not conducted in either region during the summer of 2018 due to a resource exchange granted by the San Diego Regional Water Quality Control Board for participation in the region-wide Bight'18 sampling project.

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. Standard sampling procedures required towing the net for a total of 10 minutes bottom time per trawl, at a speed of around 2 knots, along a predetermined heading. Pressure-temperature sensors were attached to one of the trawl doors to measure water temperature, depth, and time of the individual trawls. Data collected by these sensors were used to confirm bottom time and depth of each trawl. 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 (Eschmeyer and Herald 1998, Page et al. 2013, SCAMIT 2018). If an animal could not be accurately identified to species in the field, it was returned to the laboratory for further identification where possible. 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; total length (TL) was measured for cartilaginous fishes while standard length (SL) was measured for bony fishes (SCCWRP 2018). For trawl-caught invertebrates, only the total number of individuals was recorded for each species. In contrast to previous years, parasitic invertebrates no longer attached to their hosts, including the cymothoid isopod *Elthusa vulgaris* and leeches in the subclass Hirudinea, were recorded as present/absent rather than being counted individually, and are, therefore, no longer included in the analyses presented herein. This change aligns with Bight methods (SCCWRP 2018). Visual observations of weather, sea conditions, and human and animal activity were also recorded at the time of sampling (see Addendum 1-2).

Data Analyses

Demersal fish and megabenthic invertebrate data for each trawl conducted during 2019 are listed in Addenda 7-1 through 7-6. Data collected during 2018 were previously reported in City of San Diego 2019 and are available online (City of San Diego 2020). 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 per species), and the Shannon Diversity Index (H'). Total biomass was also calculated for each fish species captured. These analyses were performed using R (R Core Team 2019) and various functions within the dplyr, ggalt, ggplot2, ggpubr, gtools, plyr, psych, reshape2, Rmisc, RODBC, R.utils, stats, stringr, sqldf, and vegan packages (Bengtsson 2003, Wickham 2007, 2011, 2016, Hope 2013, Grothendieck 2014, Oksanen et al. 2015, Ripley and Lapsley 2015, Warnes et al. 2015, Revelle 2017, Kassambara 2018, 2019, Wickham 2016, Wickham and Francois 2016, Wickham et al. 2018).

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 2019 (see Clarke 1993,

Table 7.1

Demersal fish species collected from 18 trawls conducted in the PLOO region during 2018 and 2019. 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	39	100	162	162	Bigmouth Sole	<1	39	<1	1
Halfbanded Rockfish	34	78	143	183	Greenstriped Rockfish	<1	11	<1	4
Dover Sole	6	100	27	27	Curlfin Sole	<1	11	<1	2
Longspine Combfish	4	89	18	21	California Skate	<1	17	<1	1
Plainfin Midshipman	3	89	11	13	Rockfish Unidentified	<1	11	<1	2
English Sole	2	94	8	8	Rosethorn Rockfish	<1	11	<1	2
Yellowchin Sculpin	2	33	7	22	Spotfin Sculpin	<1	11	<1	2
Shortspine Combfish	2	83	7	9	White Croaker	<1	11	<1	2
Stripetail Rockfish	2	72	6	9	Bigfin Eelpout	<1	6	<1	2
Pink Seaperch	1	83	5	6	Bluebanded Ronquil	<1	11	<1	1
California Lizardfish	1	72	4	6	Flag Rockfish	<1	6	<1	2
Hornyhead Turbot	<1	83	3	3	Greenspotted Rockfish	<1	11	<1	1
California Tonguefish	<1	50	2	4	Specklefin Midshipman	<1	6	<1	2
Pacific Argentine	<1	22	2	8	Blacktip Poacher	<1	6	<1	1
Squarespot Rockfish	<1	11	2	14	Cowcod	<1	6	<1	1
Vermilion Rockfish	<1	11	1	13	Fantail Sole	<1	6	<1	1
Longfin Sanddab	<1	56	1	2	Rosy Rockfish	<1	6	<1	1
Spotted Cusk-eel	<1	56	1	2	Roughback Sculpin	<1	6	<1	1
California Scorpionfish	<1	39	1	3	Shiner Perch	<1	6	<1	1
Slender Sole	<1	22	<1	3					

Warwick 1993, Clarke et al. 2014). Prior to these analyses, all data were limited to summer surveys to reduce statistical noise from natural seasonal variations evident in previous studies (e.g., City of San Diego 1997, 2013a,b). A one-way analysis of similarity (ANOSIM) was conducted to determine whether demersal fish and megabenthic invertebrate communities varied by region. Additional analyses included ordination (non-metric multidimensional scaling; nMDS), as well as hierarchical agglomerative clustering (cluster analysis) with group-average linking. The Bray-Curtis measure of similarity was used as the basis for the ordination and 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. Similarity profile analysis (SIMPROF) was used to confirm the non-random structure of the resultant cluster dendrogram (Clarke et al. 2008), with major ecologically-relevant clusters receiving SIMPROF support retained as cluster groups. A BEST test using the BVSTEP procedure was conducted to determine which subset of species best described patterns within the resulting cluster dendrograms. Similarity percentages analysis (SIMPER) was used to determine which species were responsible for >70% of the contributions to within-group similarity (characteristic species) by region (to support ANOSIM tests) and by cluster group (to support cluster group selection).

Results and Discussion

Demersal Fish Populations in 2018–2019

A total of 11,191 fishes were captured from the 39 trawls conducted within the PLOO and

Table 7.2

Demersal fish species collected from 21 trawls conducted in the SBOO region during 2018 and 2019. 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	40	100	71	71	Kelp Pipefish	<1	19	<1	1
California Lizardfish	29	90	52	57	Pacific Sanddab	<1	19	<1	1
Longfin Sanddab	10	71	17	24	Pipefish Unidentified	<1	19	<1	1
California Tonguefish	6	90	10	12	California Scorpionfish	<1	14	<1	1
White Croaker	5	19	9	50	California Skate	<1	10	<1	2
Northern Anchovy	2	19	4	20	Barcheek Pipefish	<1	5	<1	2
Hornyhead Turbot	1	76	3	3	Giant Kelpfish	<1	5	<1	2
Yellowchin Sculpin	1	24	2	8	Shovelnose Guitarfish	<1	10	<1	1
California Halibut	<1	67	2	3	Barred Sand Bass	<1	5	<1	1
English Sole	<1	24	1	4	Basketweave Cusk-eel	<1	5	<1	1
Longspine Combfish	<1	14	<1	5	Pacific Pompano	<1	5	<1	1
Round Stingray	<1	29	<1	3	Pacific Sardine	<1	5	<1	1
Fantail Sole	<1	43	<1	1	Pygmy Poacher	<1	5	<1	1
Roughback Sculpin	<1	24	<1	3	Sarcastic Fringehead	<1	5	<1	1
Plainfin Midshipman	<1	24	<1	2	Shiner Perch	<1	5	<1	1
Queenfish	<1	10	<1	5	Spotted Cusk-eel	<1	5	<1	1
Specklefin Midshipman	<1	38	<1	1	Thornback	<1	5	<1	1
Spotted Turbot	<1	24	<1	1					

SBOO monitoring regions during 2018 and 2019, representing at least 55 different species from 27 families (Tables 7.1, 7.2, Appendix I.1, I.2). Pacific Sanddabs continued to dominate PLOO demersal fish assemblages over the past two years, occurring in every haul and accounting for 39% of the fishes collected (Table 7.1). Halfbanded Rockfish were also numerically dominant in PLOO assemblages during this period, occurring in 78% of the trawls and accounting for 34% of the fishes collected. Other species of fish that were collected in at least 50% of the trawls, but in relatively low numbers (≤27 fish per haul), included Dover Sole, Longspine Combfish, Plainfin Midshipman, English Sole, Shortspine Combfish, Stripetail Rockfish, Pink Seaperch, California Lizardfish, Hornyhead Turbot, California Tonguefish, Longfin Sanddab, and Spotted Cusk-eel. Fish assemblages in the SBOO region were dominated by Speckled Sanddabs, which occurred in all hauls and accounted for 40% of the fishes collected, and by California Lizardfish, which occurred in 90% of the hauls and accounted for 29% of the fishes collected (Table 7.2). California Tonguefish also occurred in 90% of SBOO trawls, but only accounted for 6% of the total catch. Other species that were collected in at least 50% of these trawls, but in relatively low numbers (≤17 fish per haul), included Longfin Sanddab, Hornyhead Turbot, and California Halibut.

More than 99% of the fishes collected in the PLOO and SBOO monitoring regions were <30 cm in length. California Skate was the only species collected from PLOO stations with a mean length ≥30 cm, including three individuals that ranged from 40 to 50 cm (Appendix I.1). Within the SBOO region, larger fishes with mean lengths ≥30 cm included Shovelnose Guitarfish (n=2, 32−49 cm), California Skate (n=3, 28−41 cm), Thornback (n=1, 40 cm), and California Halibut (n=36, 22−70 cm) (Appendix I.2).

Table 7.3

Summary of demersal fish community parameters for PLOO and SBOO trawl stations sampled during 2018 and 2019. Data are included for species richness, abundance, diversity (H'), and biomass (kg, wet weight); ns = not sampled.

		2018[a]		2019		2018[a]		2019	
	Station	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
		Species Richness				*Abundance*			
PLOO	SD7	16	ns	15	12	240	ns	393	140
	SD8	19	ns	20	15	642	ns	321	385
	SD10	10	ns	14	13	292	ns	2164	125
	SD12	14	ns	11	9	229	ns	275	174
	SD13	15	ns	12	14	187	ns	249	262
	SD14	16	ns	18	16	344	ns	708	349
SBOO	SD15	6	ns	3	4	39	ns	36	50
	SD16	4	ns	12	10	283	ns	119	60
	SD17	11	ns	11	10	492	ns	213	120
	SD18	9	ns	16	8	208	ns	163	103
	SD19	8	ns	8	9	281	ns	257	177
	SD20	7	ns	8	16	182	ns	247	225
	SD21	12	ns	12	11	137	ns	164	156
		Diversity				*Biomass*			
PLOO	SD7	1.5	ns	1.9	1.0	3.5	ns	2.1	7.4
	SD8	1.5	ns	1.9	1.4	5.9	ns	4.2	5.4
	SD10	1.1	ns	0.8	1.7	5.3	ns	29.0	5.0
	SD12	0.9	ns	1.4	1.2	5.5	ns	6.6	5.7
	SD13	1.0	ns	1.6	1.6	6.0	ns	4.7	6.7
	SD14	1.6	ns	1.8	1.4	11.7	ns	7.6	7.5
SBOO	SD15	1.1	ns	0.3	0.4	2.2	ns	0.3	1.5
	SD16	0.4	ns	1.5	1.5	4.8	ns	1.9	3.2
	SD17	0.9	ns	1.1	1.2	7.8	ns	6.4	2.9
	SD18	1.3	ns	1.9	1.0	9.3	ns	10.7	2.9
	SD19	1.1	ns	1.2	1.3	3.8	ns	2.8	4.7
	SD20	0.9	ns	1.0	1.7	3.6	ns	6.3	10.0
	SD21	1.4	ns	1.8	1.4	4.0	ns	4.6	6.6

[a] No trawls conducted during the summer of 2018 due to Bight'18 resource exchange (see text)

The median lengths per haul for the four most abundant fishes in the PLOO region ranged from 6 to 12 cm for Pacific Sanddab, 7 to 12 cm for Halfbanded Rockfish, 10 to 14 cm for Dover Sole, and 8 to 14 cm for Longspine Combfish (Appendix I.3, City of San Diego 2019). Overall, there were no significant spatial patterns in fish lengths recorded relative to their proximity to the PLOO discharge site. Instead, the smallest Pacific Sanddabs tended to occur at the southernmost stations (SD7, SD8), while the largest Pacific Sanddabs tended to occur north of the outfall at station SD13. The median lengths per haul for the four most abundant fishes in the SBOO region

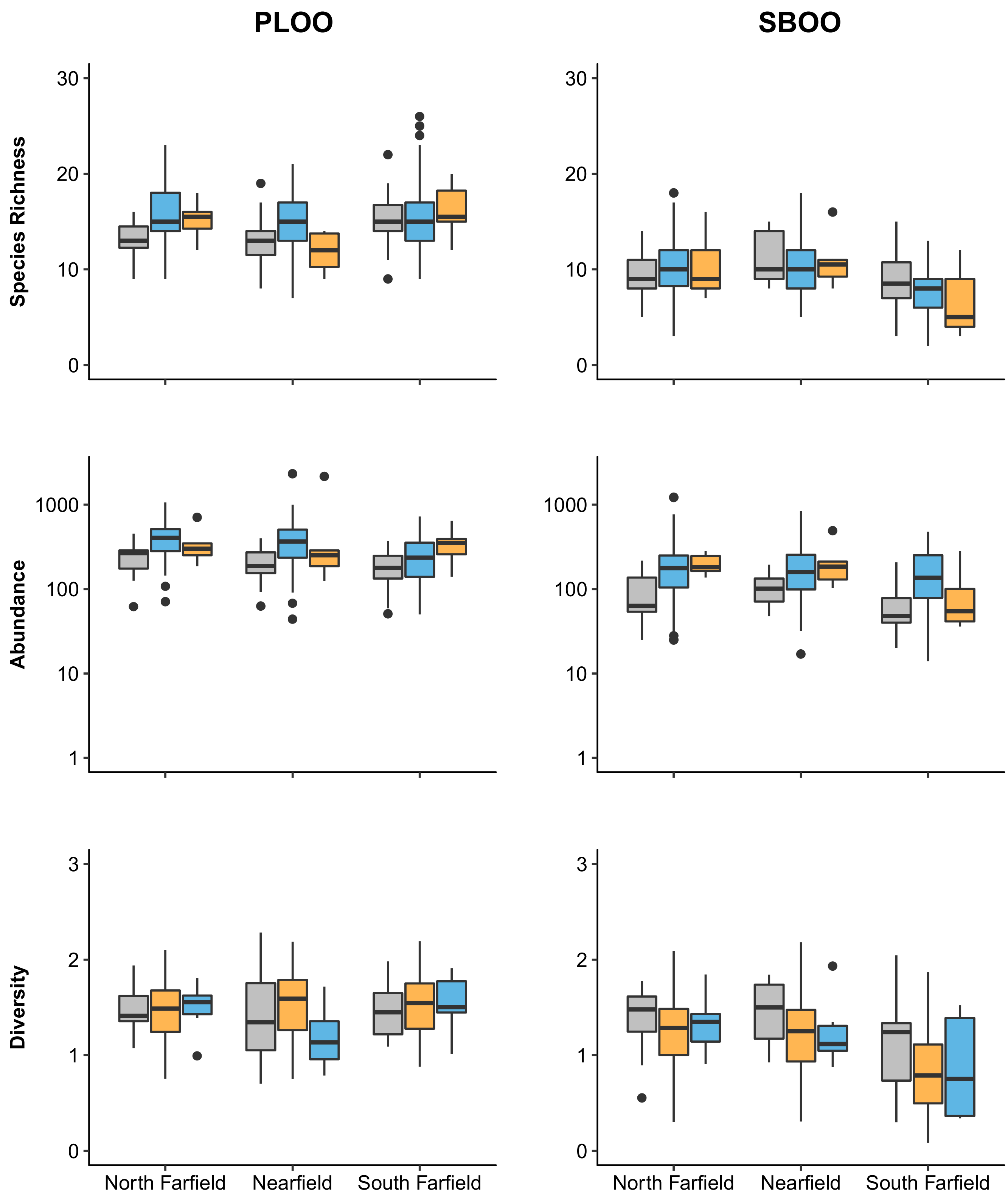


Figure 7.2
Species richness, abundance, and diversity (H') of demersal fishes collected from PLOO and SBOO north farfield, nearfield, and south farfield during pre-discharge (gray), historical post-discharge (blue), and current post-discharge (orange) periods. Data limited to 10-minute trawls. Boxes = 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.

ranged from 7 to 9 cm for Speckled Sanddab, 9 to 18 cm for California Lizardfish, 8 to 15 cm for Longfin Sanddab, and 9 to 15 cm for California Tonguefish (Appendix I.4). As in the PLOO region, overall, there were no significant patterns in fish lengths observed relative to their proximity to the SBOO discharge site, with one possible exception; the largest California Lizardfish were generally collected at nearfield stations SD17 and SD18.

Demersal Fish Community Structure Parameters

No significant spatial patterns in demersal fish community parameters were observed relative to the proximity of the PLOO or SBOO discharge sites during 2018–2019 (Table 7.3, Addenda 7-1, 7-2, 7-3, 7-4, City of San Diego 2019). Results were generally consistent with previous findings for the two regions, and elsewhere in the SCB (e.g., Allen et al. 1998, 2002, 2007, 2011, City of San Diego 1995, 1998, Walther et al. 2017); species richness and diversity were consistently low (SR≤20 species; H'≤1.9); and fish abundance and biomass remained variable among both nearfield and farfield stations and between surveys over the past two years, with values ranging from 36 to 2164 fish/trawl and 0.3 to 29.0 kg/trawl, respectively.

Within the PLOO region, the largest hauls of ≥642 fishes occurred at PLOO station SD8 in winter 2018, and stations SD10 and SD14 in winter 2019 (Table 7.3). These three hauls included substantial numbers of Pacific Sanddab (199–258 per trawl) and Halfbanded Rockfish (153–1740 per trawl) (Addendum 7-1, City of San Diego 2019). The heaviest hauls with ≥11.7 kg of fishes occurred during winter 2018 at station SD14, and winter 2019 at station SD10, due to the collection of 4.4 and 18.7 kg of Halfbanded Rockfish, respectively (Table 7.3, Addendum 7-3, City of San Diego 2019). The smallest hauls of ≤174 fishes occurred in the summer of 2019, at stations SD7, SD10, and SD12 (Table 7.3). These hauls included relatively few Pacific Sanddabs (55–108), Halfbanded Rockfish (0–3), and low numbers of all other species (≤46 individuals per species) (Addendum 7-1). The lightest trawls with ≤5.0 kg of fishes were collected from station SD7 in winter 2018, and stations SD7, SD8, and SD13 in winter 2019 (Addendum 7-3, City of San Diego 2019). Unexpectedly, hauls with low abundance and low biomass did not correspond to high numbers of the red crab *Pleuroncodes planipes* (Addendum 7-5, City of San Diego 2019).

Within the SBOO region, the largest hauls of ≥281 fishes occurred during winter 2018 at stations SD16, SD17, and SD19 (Table 7.3). Hauls at stations SD16 and SD17 comprised 254 and 381 California Lizardfish, respectively, while the haul at SD19 comprised 114 California Lizardfish and 130 Speckled Sanddab (City of San Diego 2019). The smallest hauls of ≤50 fishes occurred at station SD15 during all three surveys, co-occurring with the lowest species richness and diversity values recorded over the past two years (Addendum 7-2, City of San Diego 2019). Biomass at SBOO trawl stations ranged from 0.3 to 10.7 kg (Table 7.3) and tended to reflect the total number of individuals collected, with one exception; the trawl from station SD20 during summer 2019 weighed 10.0 kg and included 4.3 kg of large California Halibut (n=4) (Addendum 7-4).

Historical comparisons indicate no significant spatial patterns in demersal fish community parameters relative to the proximity to the PLOO or SBOO discharge sites, or to the onset of wastewater discharge that began in 1994 or 1999, respectively (Figure 7.2). Over the past 25–29 years, mean species richness and diversity values for demersal fishes collected from PLOO and SBOO stations have remained below 23 and 1.9 per haul, respectively. However, there has been considerably greater variability in mean abundance (40–1065 fishes per haul). The latter was largely due to population fluctuations of a few numerically dominant species in each region (Figures 7.3, 7.4). 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

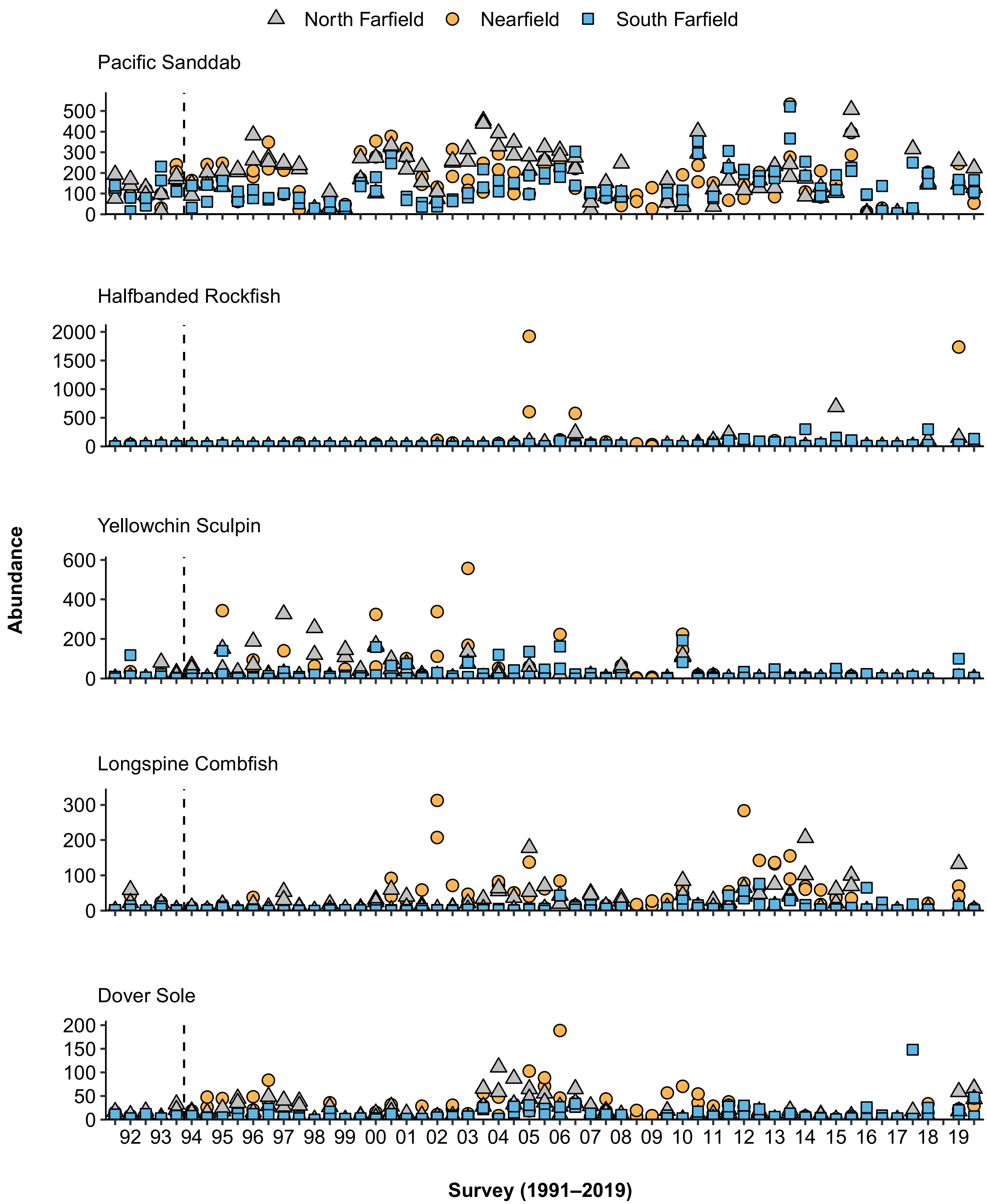


Figure 7.3
The ten most abundant demersal fish species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2019. Data are limited to 10-minute trawls and are total values per haul. Dashed lines indicate onset of wastewater discharge.

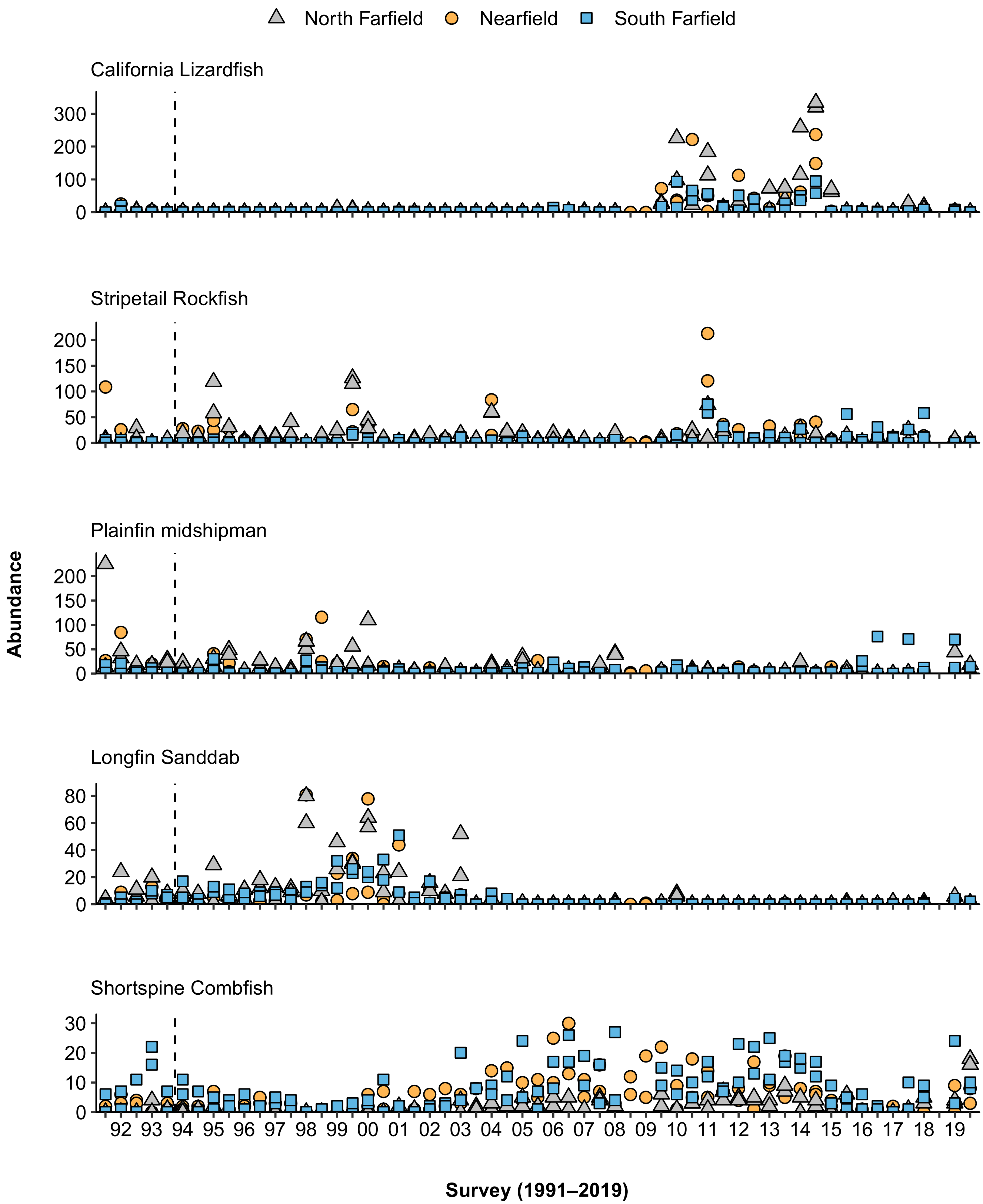


Figure 7.3 *continued*

dominant in these regions since monitoring began. In addition, occasional spikes in fish abundances within the PLOO region have been due to large hauls of other common species, such as Halfbanded Rockfish, Yellowchin Sculpin, Longspine Combfish, Dover Sole, California Lizardfish, Stripetail Rockfish, Plainfin Midshipman, Longfin Sanddab, and Shortspine Combfish (Figure 7.3). In contrast, periodic spikes within the SBOO region have been due to large hauls of California Lizardfish, Longfin Sanddab, White Croaker, Yellowchin Sculpin, California Tonguefish, Hornyhead Turbot, Roughback Sculpin, Longspine Combfish, and English Sole (Figure 7.4). None of the observed changes appear to be associated with wastewater discharge from either outfall.

Physical Abnormalities and Parasitism in Demersal Fishes

Demersal fish populations appeared healthy in the PLOO and SBOO regions in 2018–2019, with abnormalities reported for just 0.06% of fishes collected. There were no incidences of fin rot on any fish sampled during the last two years, while other recorded abnormalities were limited to: (1) four instances of tumors: two found in winter 2018 on individuals of Dover Sole collected from stations SD10 and SD14, and two found in winter 2019 on a Dover Sole and a Halfbanded Rockfish collected from station SD10; (2) a lesion, found on the same Dover Sole collected from station SD14 in winter 2018; (3) two instances of ambicoloration, one on a California Tonguefish collected from station SD19 in winter 2019, and one on a Longfin Sanddab collected from station SD21 in summer 2019; (4) one instance of deformation of a Speckled Sanddab collected from station SD20 in summer 2019 (Appendix I.5).

Evidence of parasitism was also very low (0.4%) for trawl-caught fishes from both outfall regions over the past two years (Appendix I.5). Incidences included: (1) the copepod eye parasite *Phrixocephalus cincinnatus* that infested one to nine Pacific Sanddabs collected from all PLOO stations; (2) two specimens of the cymothoid isopod *Elthusa vulgaris* (a gill parasite of fishes) that were reported on Pacific Sanddabs at station SD12 (winter) and station SD13 (summer) in 2019 (Appendix I.5). Several additional *E. vulgaris* specimens were noted as being present during each survey. Since *E. vulgaris* often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were 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 323 trawls conducted during summer surveys from 1991 through 2019 at 13 PLOO and SBOO stations. These fish assemblages were found to be significantly different (one-way ANOSIM, $\rho=0.993$, $p\leq0.001$, number of permutations=999). Ordination analyses further demonstrated a distinct separation of the PLOO and SBOO regions (Figure 7.5). Based on SIMPER analysis (not shown), the two regions had an average dissimilarity of 88%. The most characteristic species of PLOO assemblages included Pacific Sanddab, Dover Sole, Longspine Combfish, Halfbanded Rockfish, and Shortspine Combfish, whereas Speckled Sanddab, California Lizardfish, and Hornyhead Turbot were the most characteristic species of SBOO assemblages. Based on these results, subsequent multivariate analyses were performed separately on data from each outfall region.

PLOO Region

Cluster and ordination analyses resulted in four ecologically-relevant SIMPROF-supported groups, or types of fish assemblages, in the PLOO region over the past 29 years (cluster groups A–D; Figure 7.6, Appendix I.6). These assemblages represented from 1 to 127 hauls each, and varied in terms of species present, as well as the relative abundances of individual species. A BEST/BVSTEP ($\rho=0.952$, $p\leq0.001$, number of permutations=999)

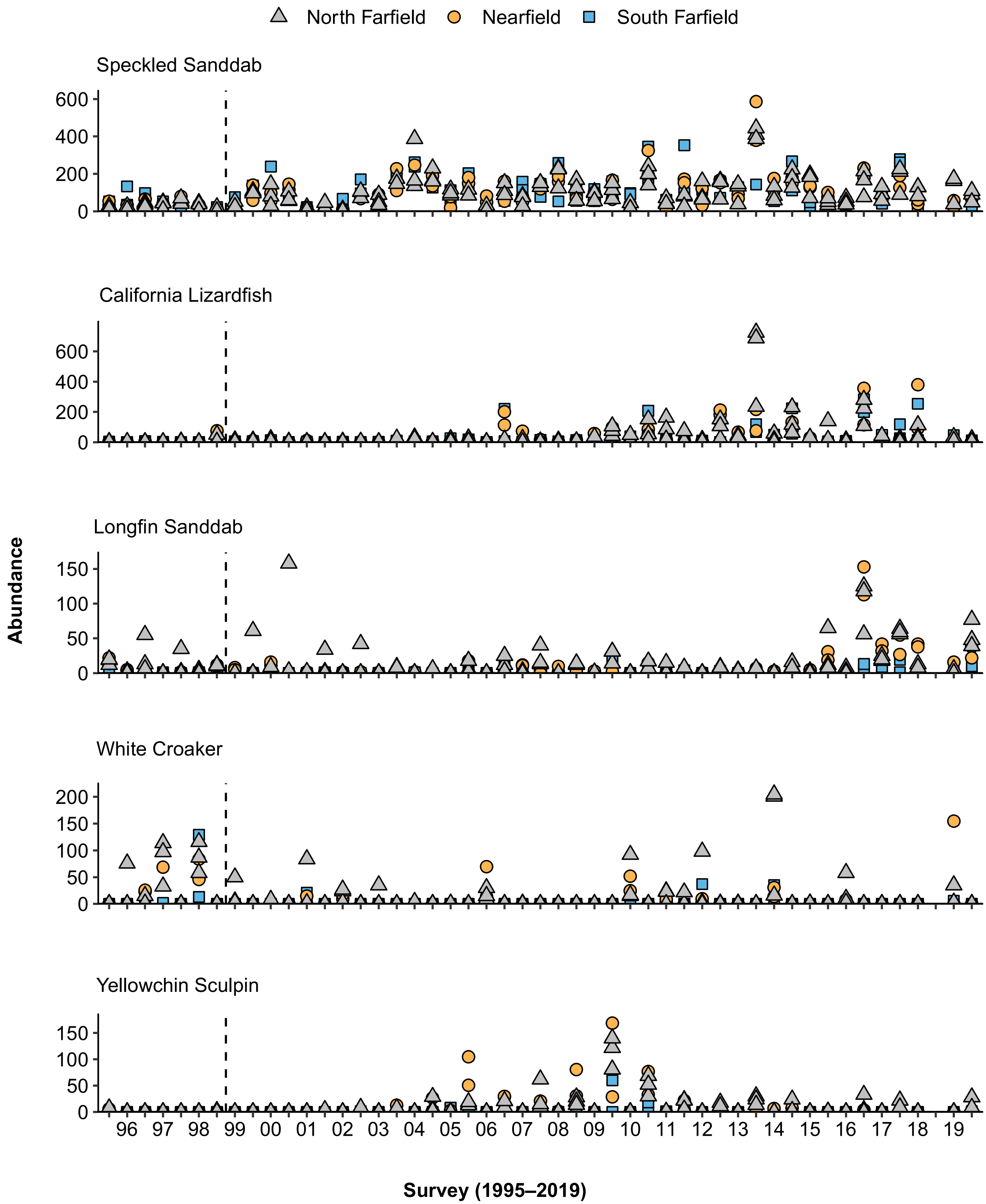
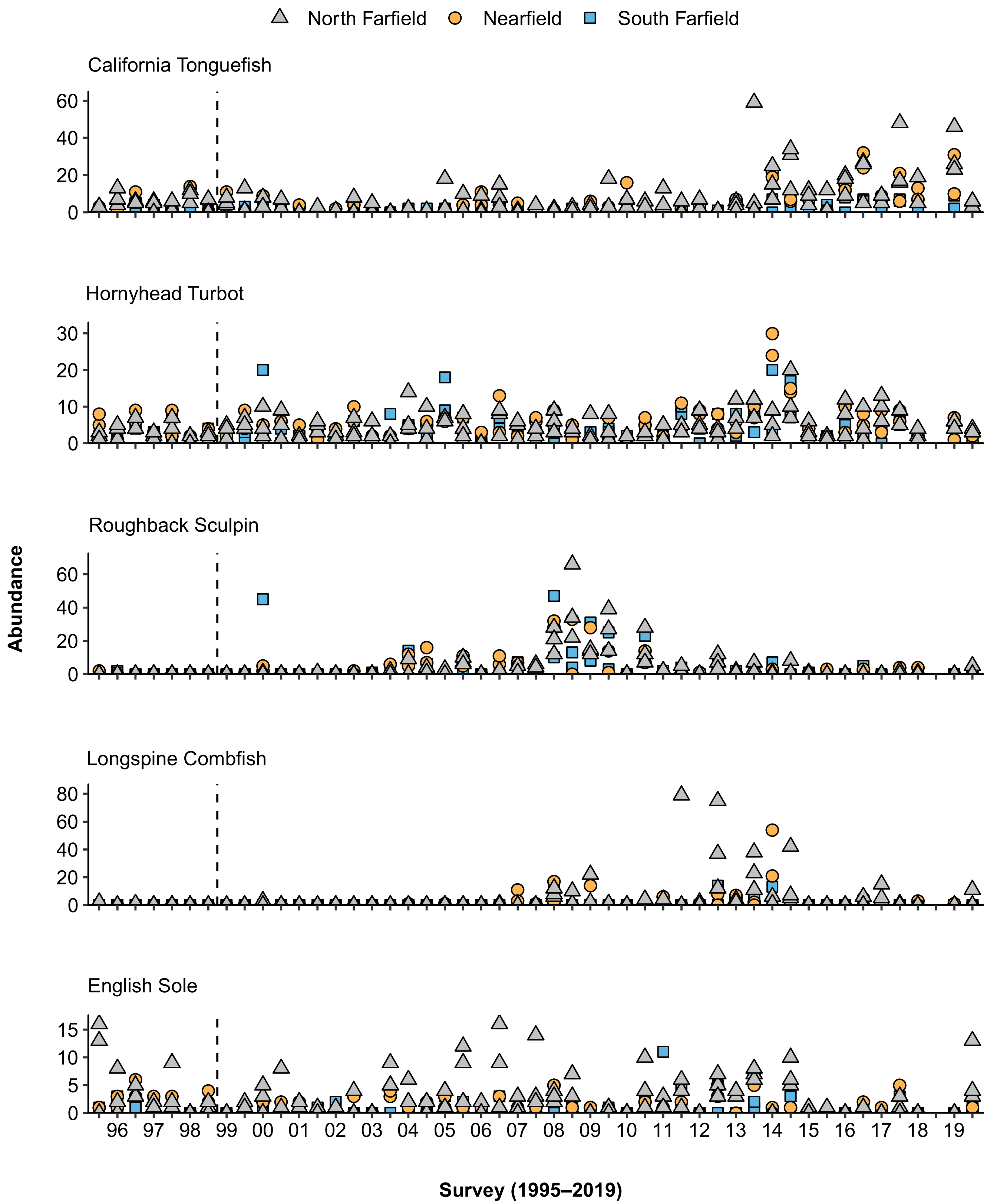


Figure 7.4
The ten most abundant demersal fish species (presented in order) collected from SBOO trawl stations sampled from 1995 through 2019. Data are limited to 10-minute trawls and are total values per haul. Dashed lines indicate onset of wastewater discharge.



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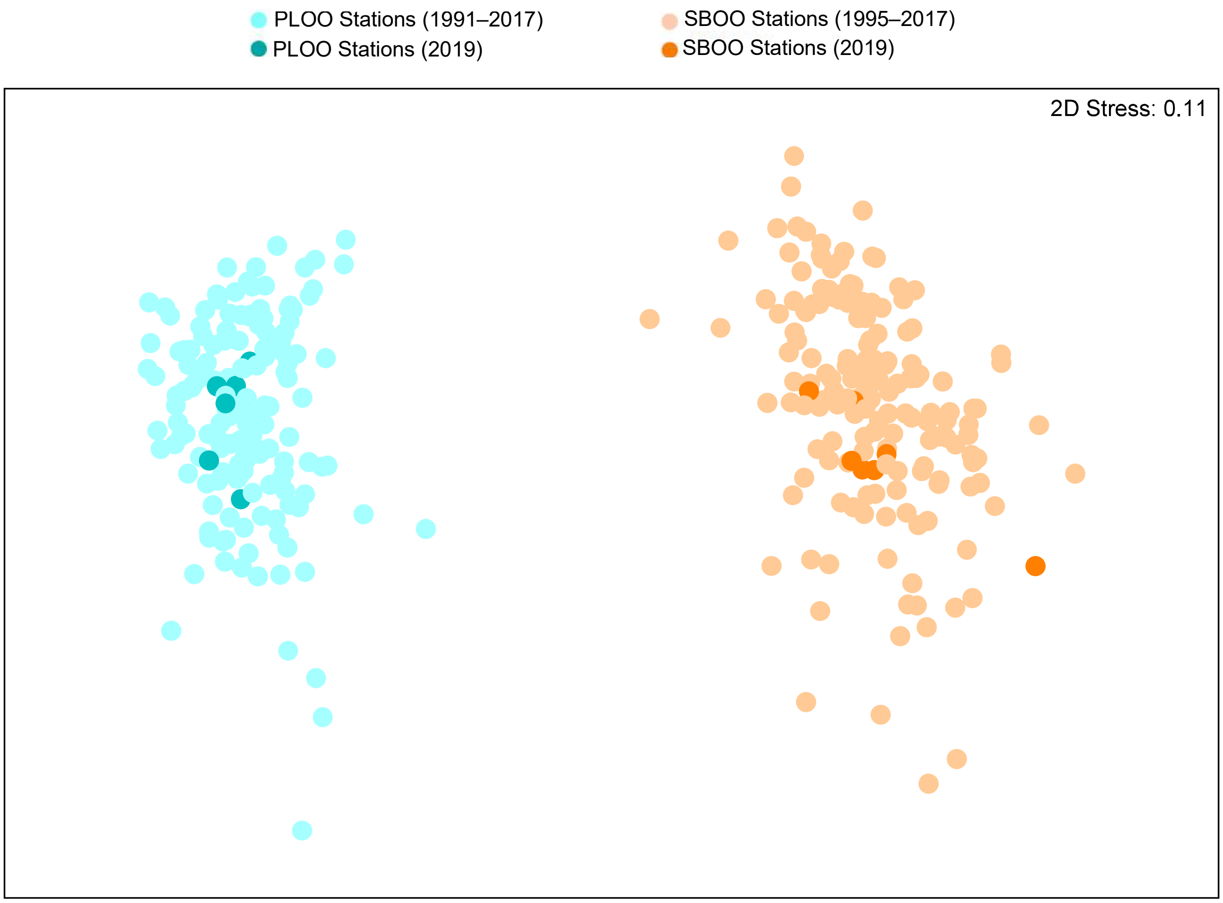

Figure 7.5

Results of nMDS ordination of demersal fish assemblages from PLOO and SBOO trawl stations sampled from 1991 through 2019. Data are limited to 10 minute trawls from summer surveys.

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. Overall, there were no discernible patterns in the demersal fish assemblages associated with proximity to the PLOO discharge site (Figure 7.6). Instead, assemblages appeared to be 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 B). The species composition and main descriptive characteristics of each of the four cluster groups are included below.

PLOO fish cluster groups A and C each represented a unique assemblage sampled at a single nearfield trawl station (Figure 7.6, Appendix I.6). 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). The assemblage represented by cluster group C 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 B was the second largest group, representing assemblages from a total of 26 hauls that included 91% (n=20) of the trawls conducted at south farfield stations SD7 and SD8 from 1992 to 2002 (Figure 7.6). This cluster group also included the trawls from station SD12 sampled in 1992 and 1995, the trawls

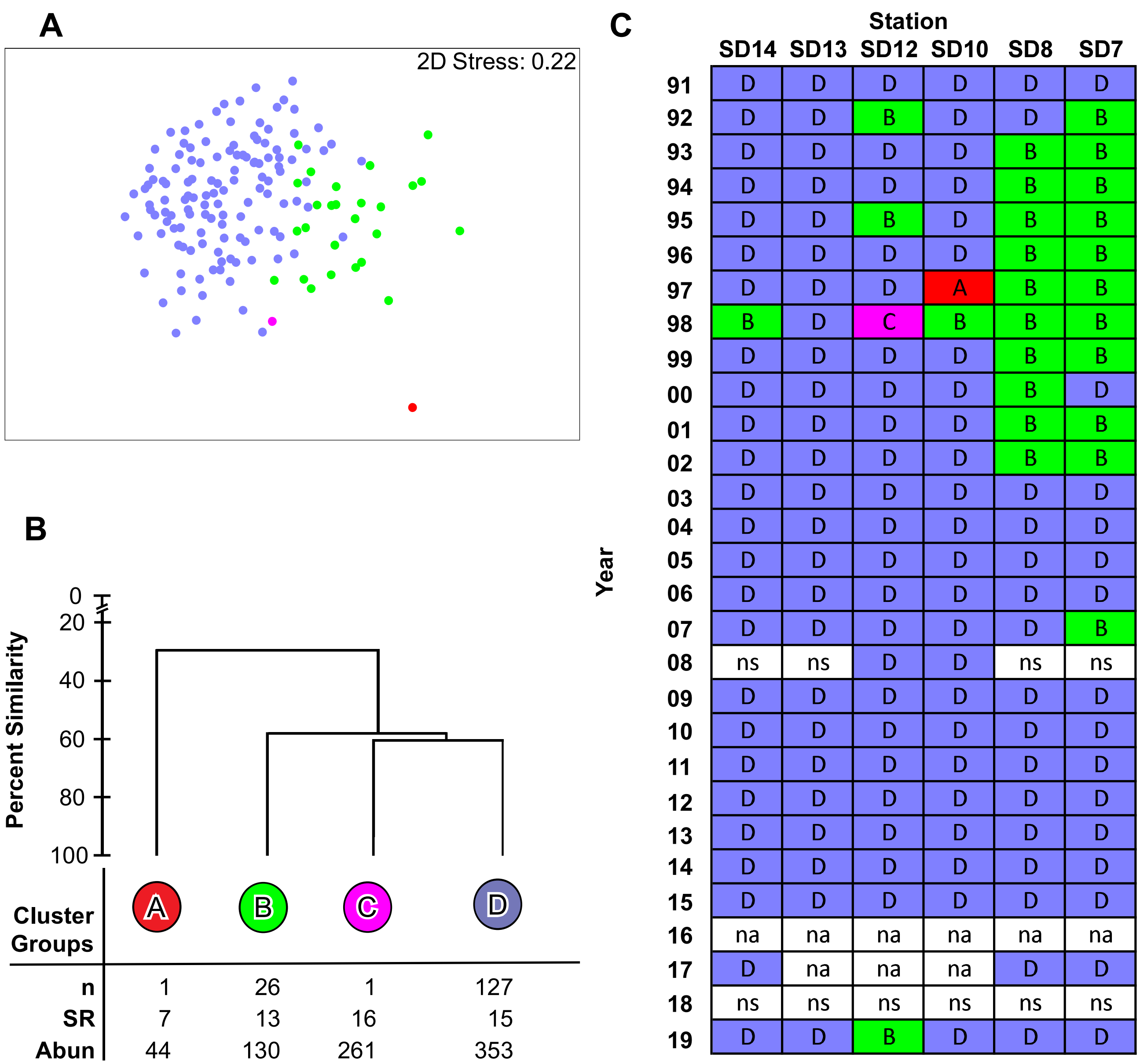

Figure 7.6

Results of ordination and cluster analysis of demersal fish assemblages from PLOO trawl stations (listed north to south) sampled from 1991 through 2019. Data are limited to 10-minute trawls from summer surveys and presented as (A) nMDS 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; na = not analyzed; ns = not sampled.

from stations SD10 and SD14 sampled in 1998, the trawl from station SD7 sampled in 2007, and the trawl from station SD12 sampled in 2019. These assemblages averaged 13 species of fish, 130 individuals, and 83 Pacific Sanddab per haul (Figure 7.6, Appendix 7.6). Along with Pacific Sanddabs, Dover Sole (9/haul), Longfin Sanddab (7/haul), and California Tonguefish (3/haul) were the other three most characteristic species of these assemblages.

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

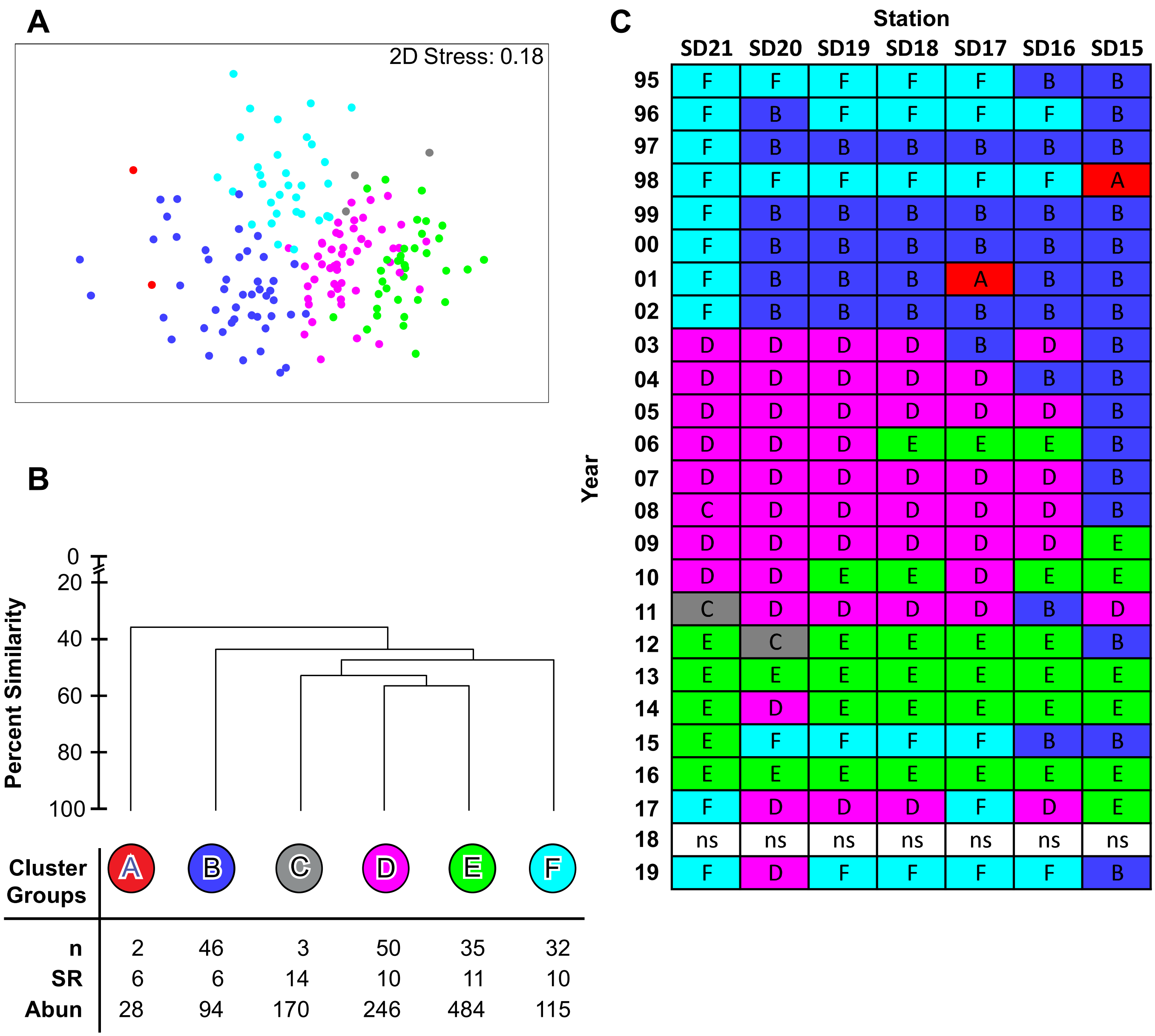

Figure 7.7

Results of ordination and cluster analysis of demersal fish assemblages from SBOO trawl stations (listed north to south) sampled from 1995 through 2019. Data are limited to 10-minute trawls from summer surveys and presented as (A) nMDS 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 = not sampled.

127 hauls that included 64% (n=46) of the trawls conducted from 1991 through 2002, and 98% (n=82) of the trawls conducted from 2003 through 2019 (Figure 7.6). These assemblages averaged 15 species and 353 individuals per haul. The most characteristic species of cluster group D were Pacific Sanddab (208/haul), Dover Sole (24/haul), Halfbanded Rockfish (23/haul), Longspine Combfish (18/haul), and Stripetail Rockfish (11/haul) (Appendix I.6).

SBOO Region

Cluster and ordination analyses resulted in six ecologically-relevant SIMPROF-supported groups, or types of fish assemblages in the South Bay outfall region over the past 25 years (cluster groups A–F; Figure 7.7, Appendix I.7). These assemblages represented from 2 to 50 hauls each, and varied in terms of species present, as well as the relative abundances of individual species. A BEST/BVSTEP test ($\rho=0.96$, $p\leq0.001$, number of permutations = 999) implicated California Lizardfish, California Tonguefish, English Sole, Hornyhead Turbot, Longfin Sanddab, Roughback Sculpin, Speckled Sanddab, White Croaker, and Yellowchin Sculpin as being influential to the overall pattern (gradient) of the cluster dendrogram. Overall, there were no discernable patterns associated with proximity to the SBOO discharge site (Figure 7.7). Instead, as observed in the PLOO region, SBOO fish assemblages appear to be influenced by the distribution of the more abundant species or the unique characteristics of a specific station location. For example, cluster group F was distinguished by comparatively low abundances of Speckled Sanddab 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 B), 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 two trawls that included station SD15 sampled in 1998, and station SD17 sampled in 2001 (Figure 7.7). This cluster group averaged the lowest species richness (6 species/haul, tied with group B), lowest abundance (28 fish/haul) and the fewest number of Speckled Sanddab (15/haul). Low numbers of California Lizardfish (8/haul) were also characteristic of these two trawls (Appendix I.7).

SBOO fish cluster group B comprised 46 hauls, including 67% (n = 16) of the trawls from station SD15 and 37% (n = 9) of the trawls from station SD16 over the past 25 years (Figure 7.7). This cluster group also included 95% (n = 19) of the trawls from stations SD17–SD20 conducted in 1997, 1999−2002. The remaining two hauls from group B occurred at station SD20 in 1996, and SD17 in 2003. This type of fish assemblage never occurred at station SD21. The assemblages represented by cluster group B averaged 6 species and 94 fish per haul. These assemblages had the third highest average numbers of Speckled Sanddab (81/haul) (Appendix I.7).

SBOO fish cluster group C represented assemblages from three trawls that included station SD20 sampled in 2012 and station SD21 sampled in 2008 and 2011 (Figure 7.7). This cluster group averaged the highest number of species (14/haul) and the third highest abundance (170/haul). The most characteristic species for this group were Speckled Sanddab (49/haul), California Lizardfish (34/haul), Longspine Combfish (34/haul), Roughback Sculpin, (11/haul), Longfin Sanddab (8/haul), and Yellowchin Sculpin (8/haul) (Appendix I.7).

SBOO fish cluster group D was the largest group, representing the assemblages from a total of 50 trawls, including 80% (n = 43) of the trawls conducted at stations SD16–SD21 from 2003 through 2011 (Figure 7.7). The remaining seven hauls from group D occurred at station SD15 in 2011, SD20 in 2014, stations SD16, SD18, SD19, and SD20 in 2017, and station SD20 in 2019. Assemblages represented by cluster group D averaged 10 species, 246 individuals, and 154 Speckled Sanddab per haul (Figure 7.7, Appendix I.7). In addition to Speckled Sanddab, the most characteristic species for this group were Yellowchin Sculpin (31/haul) and California Lizardfish (22/haul).

SBOO fish cluster group E comprised 35 trawls, including 87% (n = 26) of the trawls conducted at stations SD15–SD21 from 2012 through 2016 (Figure 7.7). Nine additional hauls from group E occurred at stations SD16-SD18 in 2006, station SD15 in 2009, stations SD15−SD16, SD18−SD19 in 2010, and station SD15 in 2017. This cluster group had the second highest species richness (11/haul), the highest abundance (484/haul), the highest number of Speckled Sanddab (218/haul), and the highest number of California Lizardfish (191/haul) (Appendix I.7).

SBOO fish cluster group F comprised 32 hauls, including 10 trawls from station SD21 sampled in 1995–2002, 2017 and in 2019, four trawls from stations SD17−SD20 sampled in 1995, four trawls

Table 7.4

Megabenthic invertebrate species collected from 18 trawls conducted in the PLOO region during 2018 and 2019. 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
Pleuroncodes planipes	88	67	3174	4761	*Ophiothrix spiculata*	<1	11	<1	1
Lytechinus pictus	11	100	380	380	*Pandalus danae*	<1	6	<1	2
Strongylocentrotus fragilis	1	17	22	133	*Pleurobranchaea californica*	<1	11	<1	1
Sicyonia ingentis	1	72	21	29	*Suberites latus*	<1	11	<1	1
Crangon alaskensis	<1	50	4	9	*Acanthodoris brunnea*	<1	6	<1	1
Platymera gaudichaudii	<1	67	4	5	*Acanthoptilum* sp	<1	6	<1	1
Apostichopus californicus	<1	61	1	2	*Aphorme horrida*	<1	6	<1	1
Sicyonia penicillata	<1	22	1	6	*Araiofusus eueides*	<1	6	<1	1
Luidia foliolata	<1	39	1	3	*Coryrhynchus lobifrons*	<1	6	<1	1
Crangonidae	<1	6	1	13	*Dallinella occidentalis*	<1	6	<1	1
Astropecten californicus	<1	44	1	1	*Florometra serratissima*	<1	6	<1	1
Octopus rubescens	<1	33	1	2	*Lepidozona scrobiculata*	<1	6	<1	1
Luidia armata	<1	11	<1	4	*Megasurcula carpenteriana*	<1	6	<1	1
Ophiura luetkenii	<1	11	<1	4	*Metridium farcimen*	<1	6	<1	1
Ophiopholis bakeri	<1	11	<1	2	*Ophiacantha diplasia*	<1	6	<1	1
Adelogorgia phyllosclera	<1	11	<1	2	*Ophiopteris papillosa*	<1	6	<1	1
Lepidozona retiporosa	<1	6	<1	3	*Paguristes bakeri*	<1	6	<1	1
Neocrangon zacae	<1	6	<1	3	*Paguristes turgidus*	<1	6	<1	1
Doryteuthis opalescens	<1	11	<1	1	*Parapagurodes laurentae*	<1	6	<1	1
Luidia asthenosoma	<1	6	<1	2	*Pilumnoides rotundus*	<1	6	<1	1
Neverita draconis	<1	11	<1	1					

from stations SD16–SD19 sampled in 1996, five trawls from stations SD16–SD20 sampled in 1998, four trawls from stations SD17–SD20 sampled in 2015, the trawl from SD17 sampled in 2017, and four trawls from stations SD16−SD19 sampled in 2019 (Figure 7.7). Assemblages represented by cluster group F averaged 10 species and 115 individuals per haul. This group was characterized by relatively low numbers of Speckled Sanddab (52/haul), California Lizardfish (10/haul), and Hornyhead Turbot (4/haul), and relatively high numbers of Longfin Sanddab (30/haul) (Appendix I.7).

Megabenthic Invertebrate Populations in 2018–2019

A total of 66,194 invertebrates were captured from the 39 trawls conducted within the PLOO and SBOO monitoring regions in 2018–2019, representing at least 75 species from seven phyla (Annelida, Arthropoda, Brachiopoda, Echinodermata, Mollusca, Cnidaria, Silicea) (Tables 7.4, 7.5, Appendices I.8, I.9). The pelagic red crab *Pleuroncodes planipes* continued to dominate PLOO trawl-caught invertebrates during the current reporting period, occurring in 67% of the hauls and accounting for 88% of the invertebrates collected (Table 7.4). The sea urchin *Lytechinus pictus* occurred in every PLOO trawl, but only accounted for 11% of the total catch. Other species that were collected in at least 50% of the trawls, but in low numbers (≤ 21 invertebrates per haul), included the shrimps *Sicyonia ingentis* and *Crangon alaskensis*, the crab *Platymera gaudichaudii,* and the sea cucumber *Apostichopus californicus*. In contrast to the PLOO region, no single species dominated

Table 7.5
Megabenthic invertebrate species collected from 21 trawls conducted in the SBOO region during 2018 and 2019. 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
Crangon nigromaculata	24	81	13	16	*Pugettia producta*	<1	10	<1	2
Portunus xantusii	14	48	8	16	*Heptacarpus brevirostris*	<1	10	<1	2
Sicyonia penicillata	13	76	7	9	*Heptacarpus palpator*	<1	10	<1	2
Philine auriformis	10	29	6	20	*Pugettia dalli*	<1	10	<1	2
Astropecten californicus	6	62	3	5	*Aphrodita armifera*	<1	10	<1	1
Farfantepenaeus californiensis	5	14	3	20	*Hemisquilla californiensis*	<1	10	<1	1
Ophiothrix spiculata	5	43	3	6	*Neverita recluziana*	<1	10	<1	1
Dendraster terminalis	5	14	3	18	*Acanthodoris brunnea*	<1	5	<1	1
Lytechinus pictus	4	38	2	6	*Acanthodoris rhodoceras*	<1	5	<1	1
Lovenia cordiformis	2	19	<1	5	*Caesia perpinguis*	<1	5	<1	1
Crangon alba	1	14	<1	5	*Calliostoma gloriosum*	<1	5	<1	1
Pagurus spilocarpus	<1	24	<1	2	*Crassispira semiinflata*	<1	5	<1	1
Platymera gaudichaudii	<1	19	<1	3	*Dendronotus venustus*	<1	5	<1	1
Loxorhynchus grandis	<1	14	<1	3	*Doryteuthis opalescens*	<1	5	<1	1
Kelletia kelletii	<1	24	<1	2	*Lamellaria diegoensis*	<1	5	<1	1
Crossata ventricosa	<1	24	<1	1	*Latulambrus occidentalis*	<1	5	<1	1
Ericerodes hemphillii	<1	14	<1	2	*Pagurus armatus*	<1	5	<1	1
Octopus rubescens	<1	19	<1	2	*Pandalus platyceros*	<1	5	<1	1
Pleurobranchaea californica	<1	24	<1	1	*Pteropurpura festiva*	<1	5	<1	1
Luidia armata	<1	19	<1	1	*Pyromaia tuberculata*	<1	5	<1	1
Metacarcinus anthonyi	<1	24	<1	1	*Randallia ornata*	<1	5	<1	1
Calliostoma tricolor	<1	10	<1	2	*Suberites latus*	<1	5	<1	1
Heptacarpus stimpsoni	<1	10	<1	2	*Suberites* sp	<1	5	<1	1
Metacarcinus gracilis	<1	10	<1	2	*Triopha maculata*	<1	5	<1	1
Paguristes bakeri	<1	14	<1	1					

SBOO trawls over the past two years. Three species occurred in at least 50% of the hauls and accounted for 6 to 24% of the total catch, including the shrimp *Crangon nigromaculata* and *Sicyonia penicillata*, and the sea star *Astropecten californicus*.

Megabenthic Invertebrate Community Structure Parameters

No significant spatial patterns in megabenthic invertebrate community parameters were observed relative to the proximity of the PLOO or SBOO discharge sites during 2018–2019 (Table 7.5, Addenda 7-5, 7-6, City of San Diego 2019). Results were generally consistent with previous findings for the two regions and elsewhere in the SCB (e.g., Allen et al. 1998, 2002, 2007, 2011, City of San Diego 1995, 1998, Walther et al. 2017). For example, species richness and diversity were consistently low (SR ≤ 21 species; H' ≤ 2.2). Invertebrate abundance remained highly variable among both nearfield and farfield stations and between surveys over the past two years, with values ranging from 2–17,269 individuals/trawl.

Within the PLOO region, the highest species richness (21 species) occurred at station SD8 in winter 2019; the highest abundances (≥ 7799

Table 7.6

Summary of megabenthic invertebrate community parameters for PLOO and SBOO trawl stations sampled during 2018 and 2019. Data are included for species richness, abundance, diversity (H'); ns = not sampled.

	Station	2018 [a] Winter	2018 [a] Summer	2019 Winter	2019 Summer	2018 [a] Winter	2018 [a] Summer	2019 Winter	2019 Summer
		Species Richness				*Abundance*			
PLOO	SD7	5	ns	10	9	302	ns	418	92
PLOO	SD8	10	ns	21	12	1230	ns	1974	896
PLOO	SD10	5	ns	8	3	36	ns	42	17,269
PLOO	SD12	4	ns	5	6	170	ns	7799	11,765
PLOO	SD13	7	ns	7	6	68	ns	11,268	11,330
PLOO	SD14	8	ns	11	5	14	ns	156	223
SBOO	SD15	12	ns	13	6	114	ns	50	49
SBOO	SD16	10	ns	14	2	57	ns	109	2
SBOO	SD17	8	ns	8	9	38	ns	59	23
SBOO	SD18	7	ns	14	4	36	ns	66	4
SBOO	SD19	7	ns	9	5	27	ns	121	20
SBOO	SD20	3	ns	8	6	5	ns	113	14
SBOO	SD21	9	ns	10	11	27	ns	183	25
		Diversity							
PLOO	SD7	0.3	ns	0.4	1.0				
PLOO	SD8	0.1	ns	0.2	0.2				
PLOO	SD10	1.0	ns	1.6	0.1				
PLOO	SD12	0.4	ns	0.6	0.1				
PLOO	SD13	0.8	ns	0.0	0.1				
PLOO	SD14	1.9	ns	1.4	0.2				
SBOO	SD15	1.7	ns	2.2	1.2				
SBOO	SD16	1.7	ns	1.1	0.7				
SBOO	SD17	1.5	ns	1.5	1.6				
SBOO	SD18	1.6	ns	2.1	1.4				
SBOO	SD19	1.5	ns	1.5	0.9				
SBOO	SD20	1.0	ns	1.4	1.6				
SBOO	SD21	1.5	ns	1.5	2.1				

[a] No trawls conducted during the summer of 2018 due to Bight'18 resource exchange (see text)

individuals) occurred at stations SD12 and SD13 in winter 2019 and stations SD10, SD12, and SD13 in summer 2019; and the highest diversity values (≥1.4 units) occurred at station SD14 in winter 2018 and 2019, and at station SD10 in winter 2019 (Table 7.6). The lowest species richness (≤5 species) occurred at stations SD7, SD10, and SD12 in winter 2018, stations SD12 in winter 2019, and stations SD10 and SD14 in summer 2019; and the lowest abundances (≤92 individuals) occurred at stations SD10, SD13 and SD14 in winter 2018, stations SD10 in winter 2019, and station SD7 in summer 2019. The lowest diversity values (≤0.1 units)

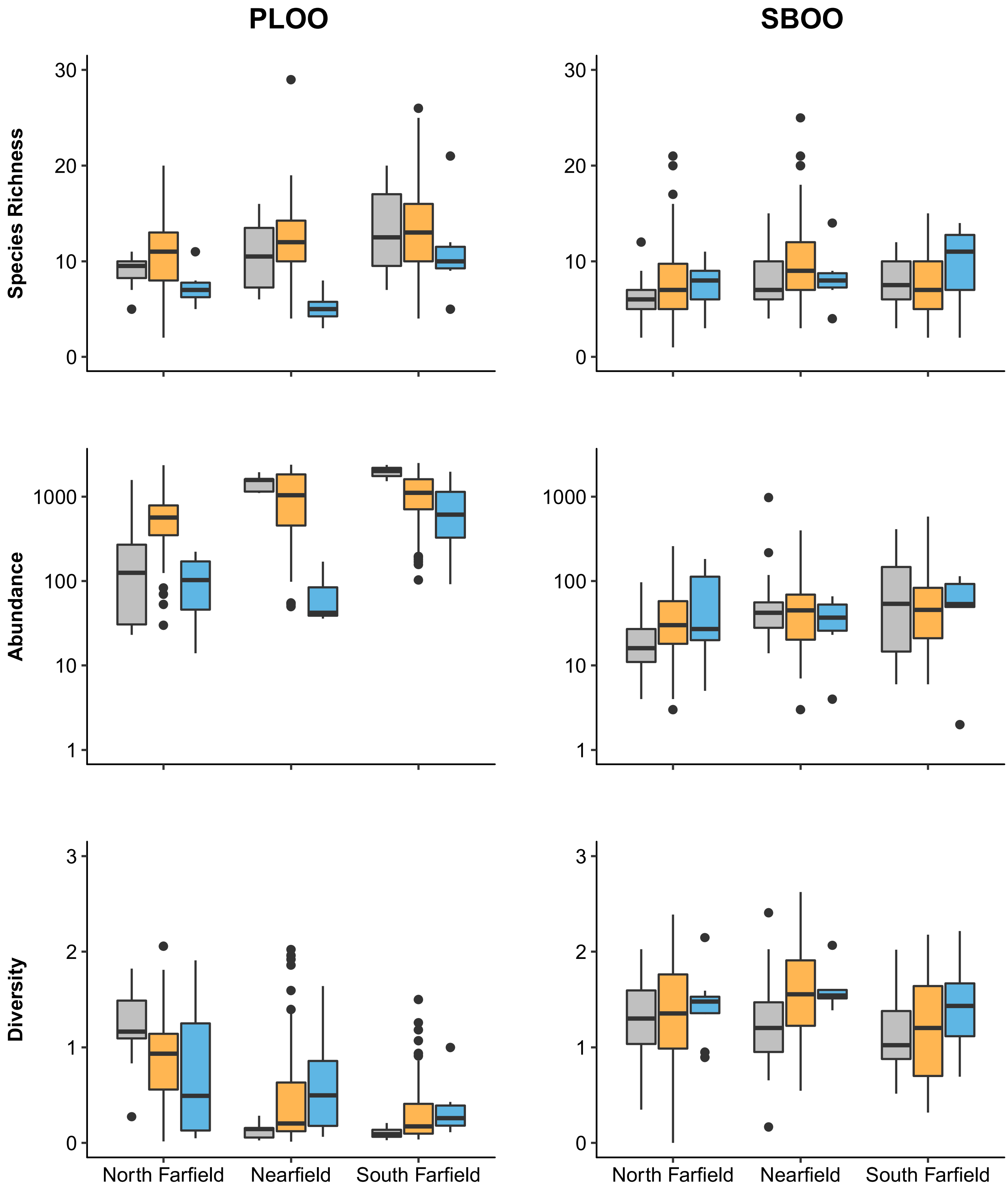

Figure 7.8
Species richness, abundance, and diversity (H') of megabenthic invertebrates collected from PLOO and SBOO north farfield, nearfield, and south farfield trawl stations during pre-discharge (gray), historical post-discharge (blue) and current post-discharge (orange) periods. Data are limited 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.

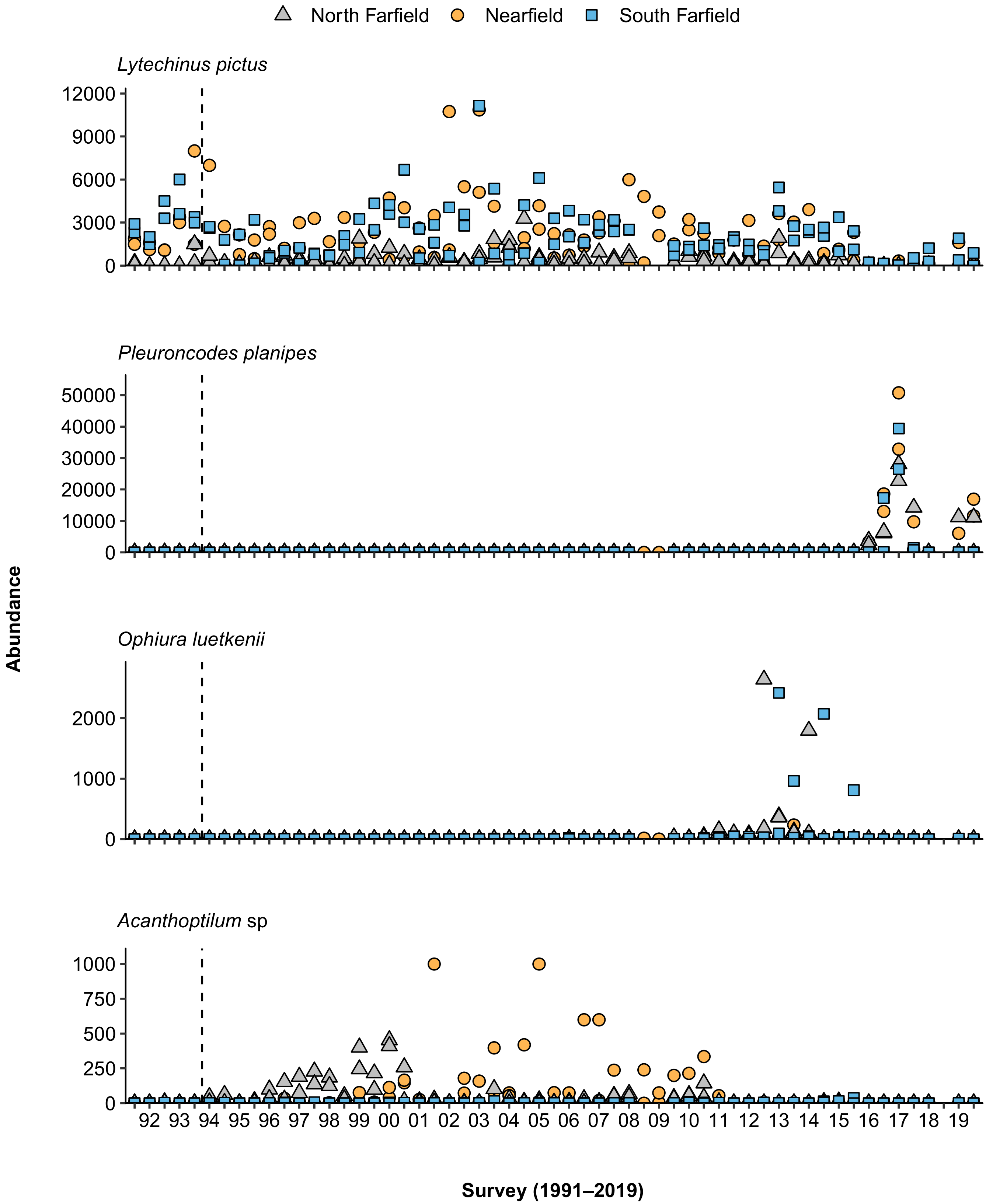

Figure 7.9
The eight most abundant megabenthic invertebrate species (presented in order) collected from PLOO trawl stations sampled from 1991 through 2019. Data are limited to 10-minute trawls and are total values per haul. Dashed lines indicate onset of wastewater discharge.

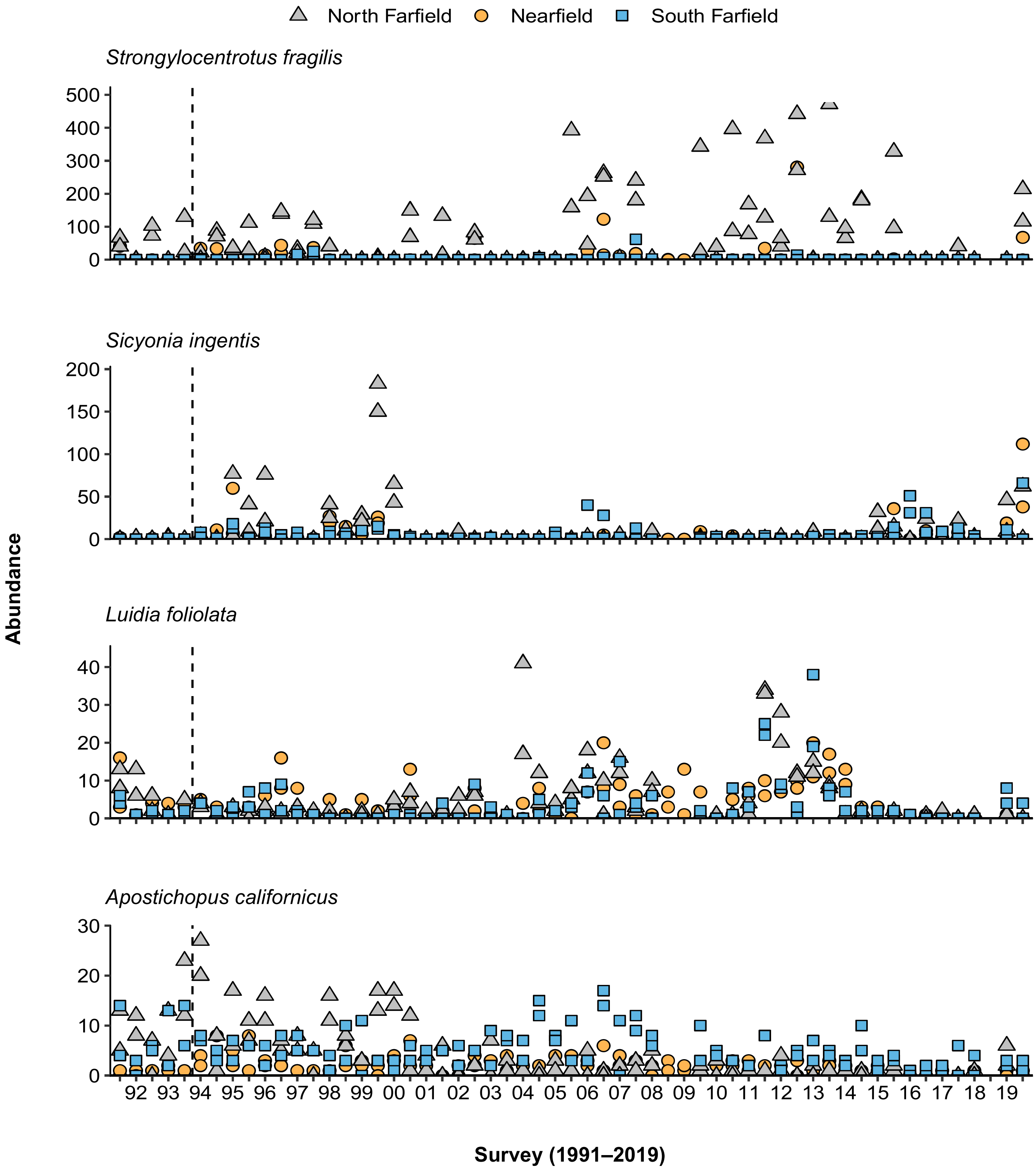

Figure 7.9 *continued*

corresponded to high abundances at station SD8 in winter 2018, station SD13 in winter 2019, and stations SD10, SD12, and SD13 in summer 2019. These large trawls with low diversity reflected substantial hauls of *Lytechinus pictus* or *Pleuroncodes planipes* (Addendum 7-5).

Within the SBOO region, the highest species richness (≥13 species) occurred at stations SD15, SD16, and SD18 in winter 2019; and the highest abundances (≥109 individuals) occurred at station SD15 winter 2018 and stations SD16, SD19, SD20, and SD21 in winter 2019. The haul from station SD16 contained

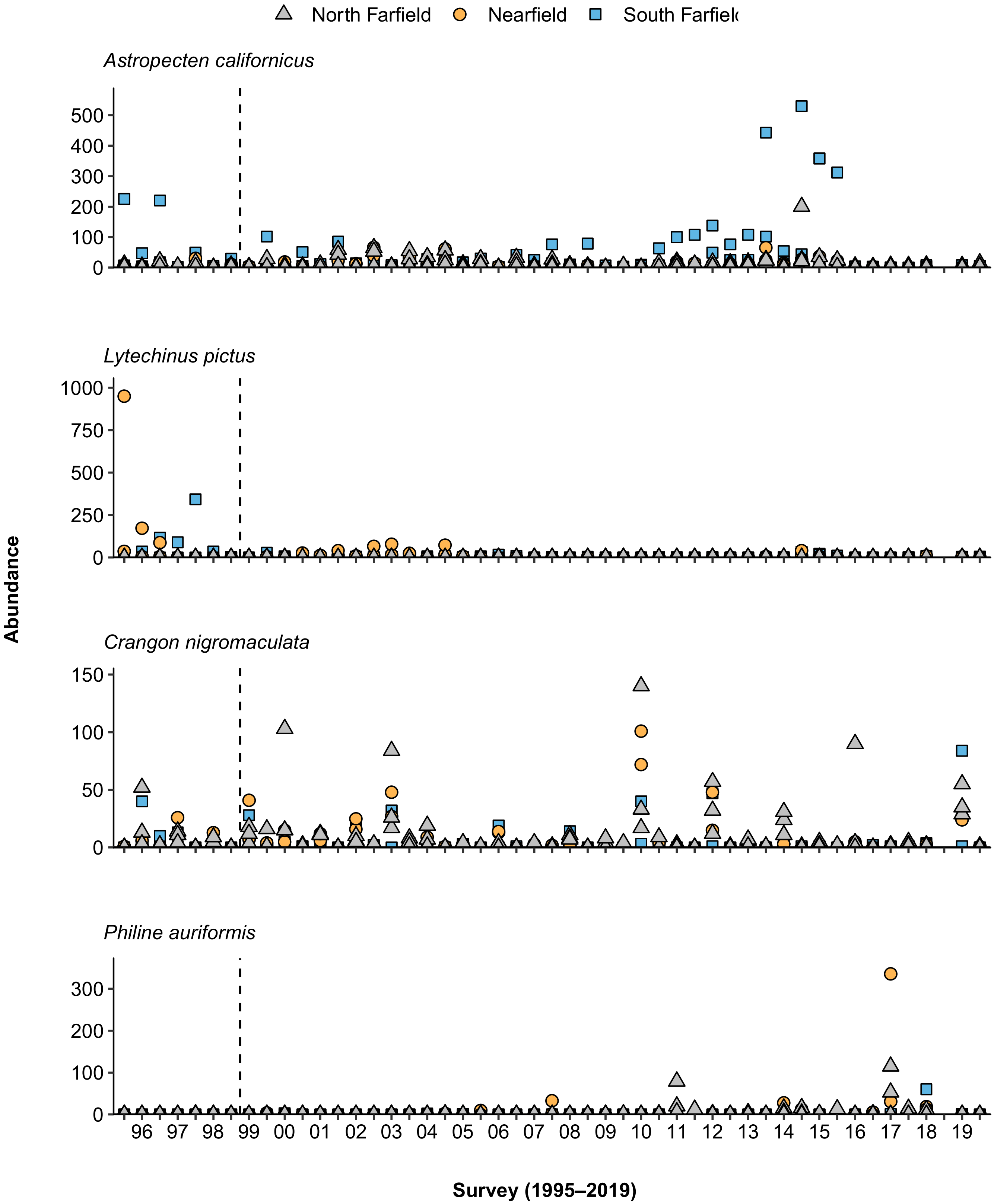

Figure 7.10
The eight most abundant megabenthic invertebrate species (presented in order) collected from SBOO trawl stations sampled from 1995 through 2019. Data are limited to 10-minute trawls and are total values per haul. Dashed lines indicate onset of wastewater discharge.

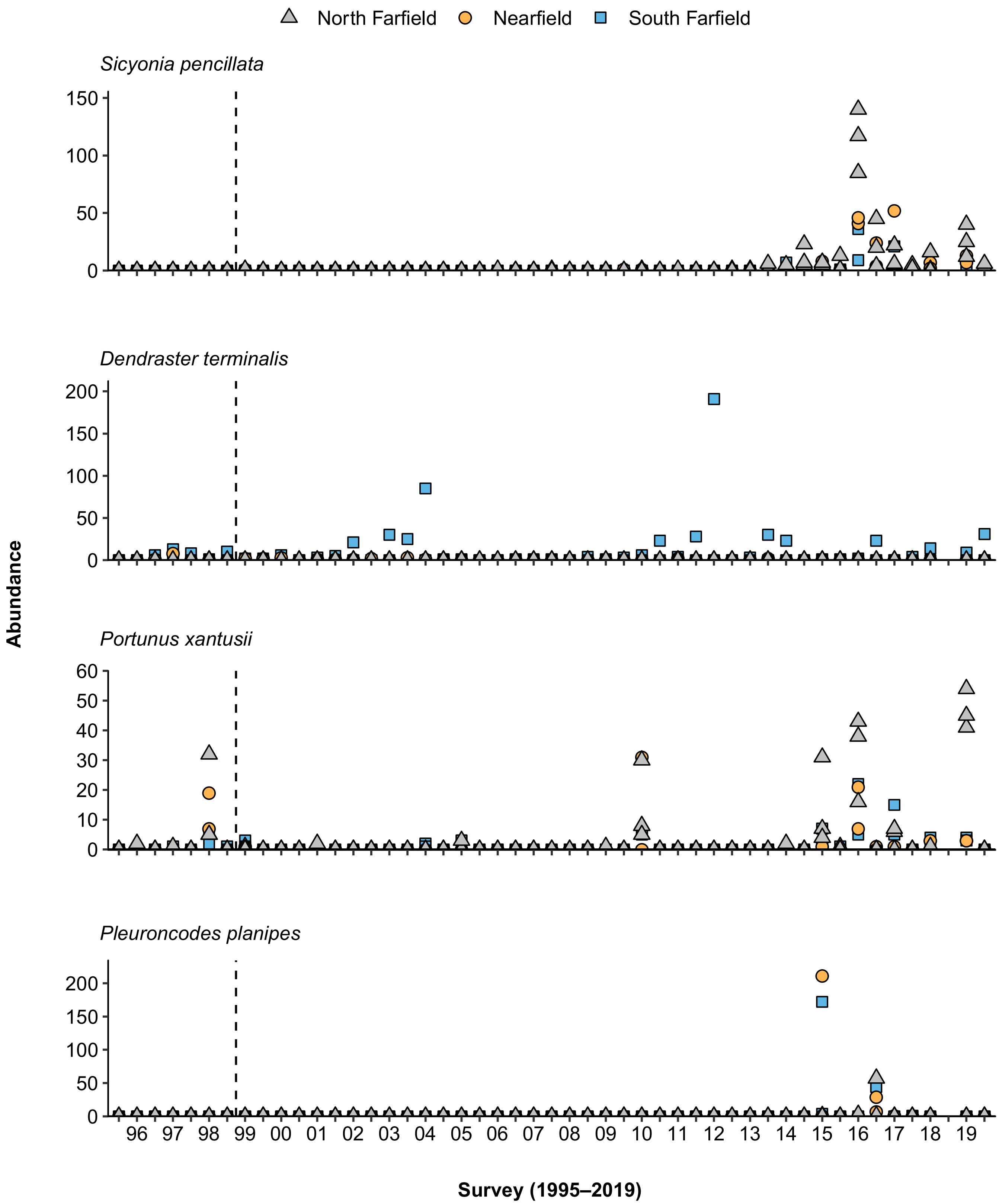

Figure 7.10 *continued*

relatively large numbers of *Crangon nigromaculata* (n=84), while hauls from stations SD19−SD21 contained relatively large numbers of *C. nigromaculata* (n=29–55), *Portunus xantusii* (n=41–54) and *Sicyonia pencillata* (n=12–40) (Addendum 7-6). Low diversity values (≤1.0) at SBOO stations co-occurred with low species richness (≤3 species) and abundance (≤5 individuals) at station SD20 in winter 2018 and station SD16 in summer 2019 (Table 7.6).

Historical comparisons indicate no significant spatial patterns in megabenthic invertebrate community parameters relative to the proximity of the PLOO or SBOO discharge sites, or to the onset of wastewater discharge that began in 1994 or 1999, respectively (Figure 7.8). Over the past 25–29 years, mean species richness has remained below 24 per haul and mean diversity has remained below 2.3 per haul. However, there has been considerably greater variability in mean abundance (10−5613 individuals per haul). The latter was largely due to population fluctuations of a few numerically dominant species in each region (Figures 7.9, 7.10). 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 *Apostichopus 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 the sea star *Astropecten californicus*, the shrimps *Crangon nigromaculata* and *Sicyonia penicillata*, the sea snail *Philine auriformis*, the sand dollar Dendraster terminalis, and the swimming crab *Portunus xantusii* (Figure 7.10). 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 323 trawls conducted during summer surveys only from 1991 through 2019 at 13 PLOO and SBOO stations. These invertebrate assemblages were found to be significantly different (one-way ANOSIM, $\rho=0.833$, $p\leq0.001$, number of permutations=999). Ordination analyses further demonstrated a distinct split between the two outfall regions (Figure 7.11). Based on SIMPER analysis (not shown), the two regions had an average dissimilarity of 92%. The most characteristic species of PLOO assemblages included the sea urchins *Lytechinus pictus* and *Strongylocentrotus fragilis*, whereas the sea stars *Apostichopus californicus* and *Pisaster brevispinus*, along with the elbow crab *Latulambrus occidentalis*, were the most characteristic species of SBOO assemblages. Based on these results, subsequent analyses were performed separately on data from each region.

PLOO Region

Cluster and ordination analyses resulted in eight ecologically-relevant SIMPROF-supported groups or types of megabenthic invertebrate assemblages in the PLOO region over the past 29 years (cluster groups A–H) (Figure 7.12, Appendix I.10). 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 test ($\rho=0.96$, $p\leq0.001$, number of permutations=999) implicated the sea urchins *Lytechinus pictus* and *Strongylocentrotus fragilis*, the pelagic red crab *Pleuroncodes planipes*, and the sea pen *Acanthoptilum* sp as being influential to the overall pattern (gradient) of the cluster dendrogram. 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 (cluster group G). The species composition and main descriptive characteristics of each of the five cluster groups are included below.

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

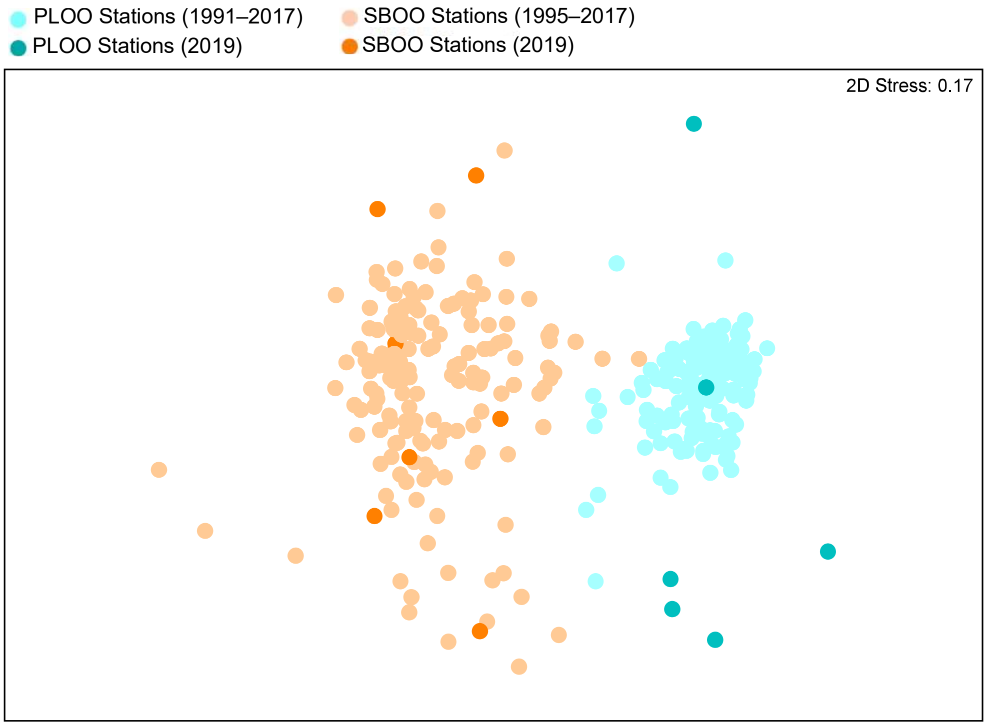

Figure 7.11
Results of nMDS ordination of megabenthic invertebrate data from PLOO and SBOO trawl stations sampled from 1991 through 2019. Data are limited to 10-minute trawls from summer surveys.

hauls, including 97% (n=68) of the trawls from stations SD7, SD8 and SD10 and 54% (n=13) of the trawls from station SD12, but only 17% (n=8) 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) and the fourth highest total abundance (2310 individuals/haul) (Appendix I.10). This group was characterized by the highest average number of *Lytechinus pictus* (2170/haul).

PLOO invertebrate cluster group G was the second largest group, representing assemblages from a total of 49 hauls that included 83% (n=38) of the trawls conducted at stations SD13 and SD14 over the past 29 years, as well as the trawls from station SD8 sampled in 1994 and 1995, and from station SD12 sampled in 1994, 1996, 1999, 2002, 2008, and 2011–2014 (Figure 7.12). These group G assemblages averaged 11 species and 449 individuals per haul. The two most characteristic species of group G were *Lytechinus pictus* (232/haul) and *Strongylocentrotus fragilis* (136/haul) (Appendix I.10).

Each of the six remaining PLOO invertebrate groups represented small "outlier" clusters that included from one to four trawls. For example, cluster group A comprised the trawl from station SD10 sampled in 2019, which had just three species, including 16,989 *Pleuroncodes planipes*, 168 *Lytechinus pictus*, and 112 of the shrimp S*icyonia ingentis* (Figure 7.12, Appendix I.10). Cluster group B comprised the trawls from stations SD12 and SD13 sampled in 2019, which averaged 6 species and 11,548 individuals per haul, including 11,393 *P. planipes* on average. Cluster group C represented assemblages from a total of four trawls conducted at stations SD12 and SD14 in 1998, station SD12 in 2007 and 2009. These assemblages had the second highest species richness (13 species/haul), the second lowest abundance (171 individuals/haul), and were characterized by *Acanthoptilum* sp (121/haul), *S. ingentis* (9/haul), the sea star A*stropecten californicus* (4/haul), and the brittle star *Ophiura luetkenii* (2/haul). Cluster group D comprised the trawl from station SD14 in 2012, which had 9 species and 3204 individuals,

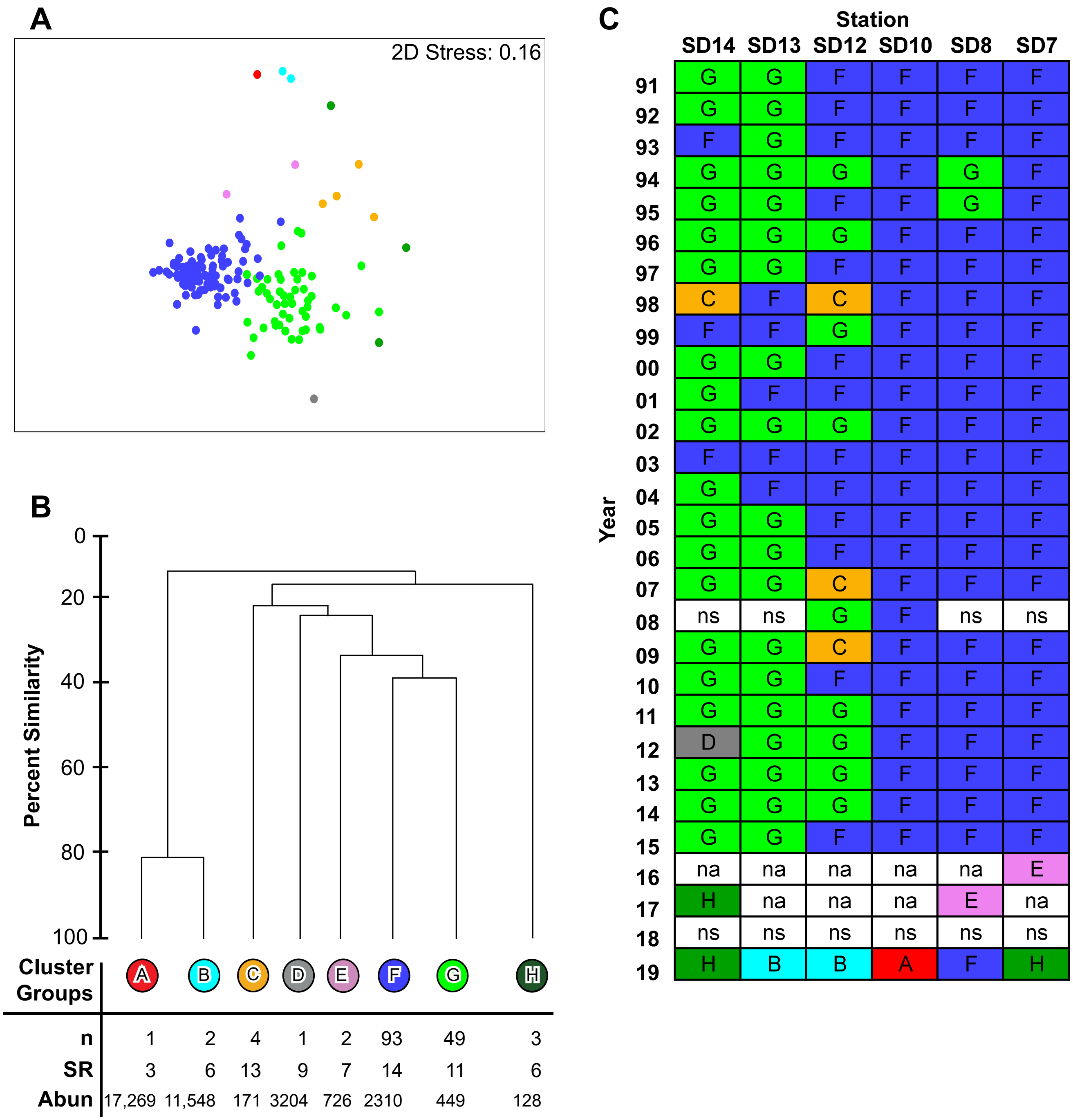

Figure 7.12

Results of ordination and cluster analysis of megabenthic invertebrate assemblages from PLOO trawl stations (listed north to south) sampled from 1991 through 2019. Data are limited to 10-minute trawls from summer surveys and presented as (A) nMDS 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; na = not analyzed; ns=not sampled.

2640 of which were *O. luetkenii*. Cluster group E comprised the trawls from station SD7 sampled in 2016 and SD8 sampled in 2017, and averaged 7 species and 726 individuals per haul, including 407 *P. planipes* and 302 *L. pictus* on average. Cluster group H comprised the trawls from station SD14 sampled in 2017 and stations SD7 and SD14 sampled in 2019. These assemblages averaged

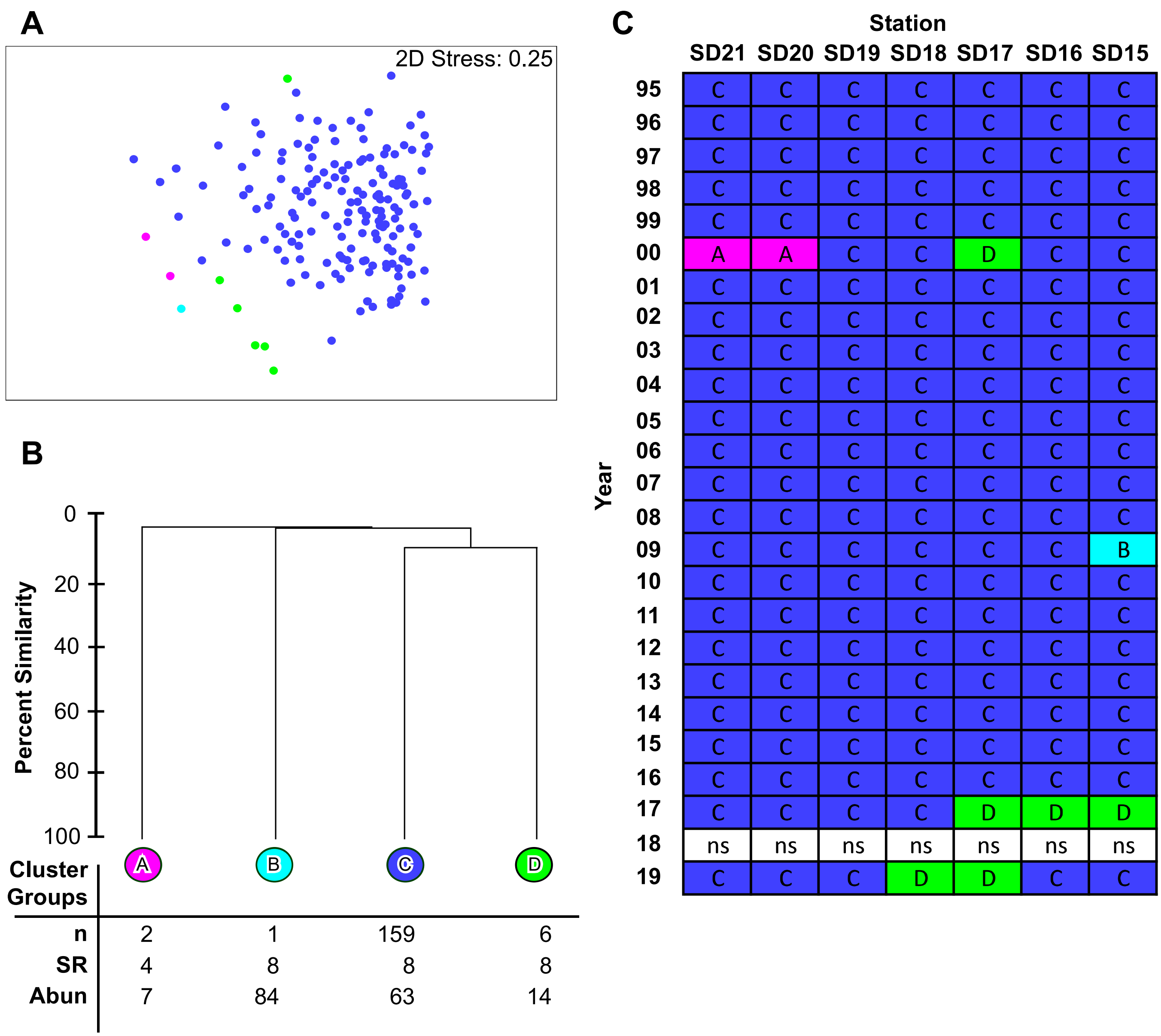

Figure 7.13

Results of ordination and cluster analysis of megabenthic invertebrate assemblages from SBOO trawl stations (listed north to south) sampled from 1995 through 2019. 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 = not sampled.

6 species and 128 individuals per haul and were characterized by *Strongylocentrotus fragilis* (85/haul) and *S. ingentis* (30/haul).

SBOO Region

Cluster and ordination analyses resulted in four ecologically-relevant SIMPROF-supported groups or types of megabenthic invertebrate assemblages in the SBOO region over the past 25 years (cluster groups A–D; Figure 7.13, Appendix I.11). These assemblages represented from 1 to 159 hauls each, and varied in terms of species present, as well as the relative abundances of individual species. A BEST/BVSTEP test ($\rho = 0.95$, $p \leq 0.001$, number of permutations = 999) implicated the sea urchin *Lytechinus pictus*, brittle star *Ophiothrix spiculata*, the cephalopod *Octopus rubescens*, the sea stars *Astropecten californicus* 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*, *Platymera gaudichaudii*, and *Metacarcinus gracilis*, and the shrimps *Sicyonia penicillata*, *Heptacarpus stimpsoni*, and *Crangon nigromaculata* as being influential to the overall pattern (gradient) of the cluster dendrogram. Overall, there were no discernible patterns associated with proximity to the SBOO discharge site (Figure 7.13). Instead, assemblages appear influenced by the distribution of the more abundant species during specific time periods (groups A and D) versus background conditions (group C). The species composition and main descriptive characteristics of each of the six cluster groups are included below.

SBOO invertebrate cluster groups A and B represented small "outlier" clusters that included one or two trawls (Figure 7.13, Appendix I.11). Cluster group A comprised trawls from stations SD20 and SD21 sampled in 2000, which averaged 4 species and 7 individuals per haul. These assemblages were primarily characterized by *Crangon nigromaculata* (2/haul). Cluster group B represented a unique assemblage that occurred at station SD15 in 2009. This assemblage had 8 species, 84 individuals, and included 72 specimens of the brittle star *Ophiura luetkenii*, three *Dendraster terminalis*, three *Ophiothrix spiculata*, one *Octopus rubescens*, and one each of the crab *Pagurus spilocarpus* and the sea snail *Megastraea turbanica*.

SBOO invertebrate cluster group C comprised 159 trawls, and was found at all stations a majority of the time between 1995 and 2019, likely reflecting background conditions within the region (Figure 7.13). Assemblages represented by cluster group C averaged 8 species and 63 individuals per haul, and were primarily characterized by *Astropecten californicus* (31/haul) and *Pisaster brevispinus* (1/haul) (Appendix I.11).

SBOO invertebrate cluster group D represented assemblages from a total of 6 hauls, including trawls from station SD17 sampled in 2000, stations SD15−SD17 sampled in 2017, and stations SD17−SD18 sampled in 2019 (Figure 7.13). This group averaged 8 species and 14 individuals per haul. The most characteristic species for cluster group D assemblages were *Lytechinus pictus* (2/haul), *Kelletia kelletii* (1/haul), *Platymera gaudichaudii* (1/haul), and the sea snail *Crossata ventricosa* (1/haul) (Appendix I.11).

Summary

Analyses of the demersal fish and megabenthic invertebrate data collected during 2018 and 2019 demonstrated that wastewater discharged through the Point Loma and South Bay outfalls has not negatively impacted these communities in the coastal waters off San Diego. Community parameters are similar at stations located both near and far from the outfall discharge sites in both regions. 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, 2018), 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. 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 began in each region. Halfbanded Rockfish were also prevalent in PLOO assemblages during 2018–2019, while California Lizardfish were also prevalent within the SBOO region during this period, as they have been in nine of the past eleven years. Other commonly captured, but less abundant fishes, collected from the PLOO and SBOO regions included California Halibut, California Tonguefish, Dover Sole, English Sole, Hornyhead Turbot, Longfin Sanddab, Longspine Combfish, Pink Seaperch, Plainfin Midshipman, Shortspine Combfish, Spotted Cusk-eel, and Stripetail Rockfish.

Of the 66,194 megabenthic invertebrates encountered during 2018 and 2019, 86% were the pelagic red crab *Pleuroncodes planipes*, collected exclusively at PLOO trawl stations. In contrast to the PLOO region, no single species of invertebrate dominated SBOO trawls over the past two years. Other commonly captured, but less abundant, trawl-caught invertebrates collected from the PLOO and SBOO regions included the sea urchin *Lytechinus pictus*, the shrimps *Sicyonia ingentis*, *S. penicillata*, *Crangon nigromaculata*, and *C. alaskensis*, the crab *Platymera gaudichaudii*, the sea cucumber *Apostichopus californicus* and the sea star *Astropecten californicus*.

There is no evidence that wastewater discharged through the PLOO or SBOO affected demersal fish or megabenthic invertebrate communities in 2018–2019. The abundance and distribution of species varied similarly at stations located near and far from the outfalls in both regions. The high degree of variability in these assemblages, during this reporting period, was similar to that observed in previous years, including before wastewater discharge began through either outfall (City of San Diego 2000, 2005a–2016b, 2018). Furthermore, this sort of variability has been observed in similar habitats elsewhere off the coast of southern California (Allen et al. 1998, 2002, 2007, 2011, Walther et al. 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. Finally, the rarity 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 (demersal) fishes are collected by the City of San Diego (City) as part of the Ocean Monitoring Program to evaluate the presence of contaminants in their tissues, which may result from the discharge of wastewater from the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO). Anthropogenic inputs to coastal waters can result in increased concentrations of pollutants within the local marine environment, which may subsequently accumulate 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 also the ingestion / 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 bottom dwelling fishes throughout the Southern California Bight (SCB) are often linked to those found in the surrounding 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 to be of recreational and commercial importance, and thus directly relevant to human health concerns. Consequently, muscle samples are analyzed from these fishes as this is the tissue most often consumed by humans. All liver and muscle tissue samples collected were analyzed for contaminants specified in the National Pollutant Discharge Elimination System (NPDES) discharge permits that govern monitoring requirements for the PLOO and SBOO regions (see Chapter 1).

This chapter presents analysis and interpretation of all chemical analyses performed on the tissues of fishes collected in the PLOO and SBOO regions during 2019. No fish tissue samples were collected during 2018 due to a resource exchange granted by the San Diego Regional Water Quality Control Board for participation in the region-wide Bight'18 sampling project. The primary goals of this 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 fall (October) 2019 from a total of nine trawl zones (TZ1–TZ9) and four rig fishing zones (RF1–RF4) that span the PLOO and SBOO 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 "nearfield" area within a 1-km radius of PLOO stations SD10 and SD12, which are 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

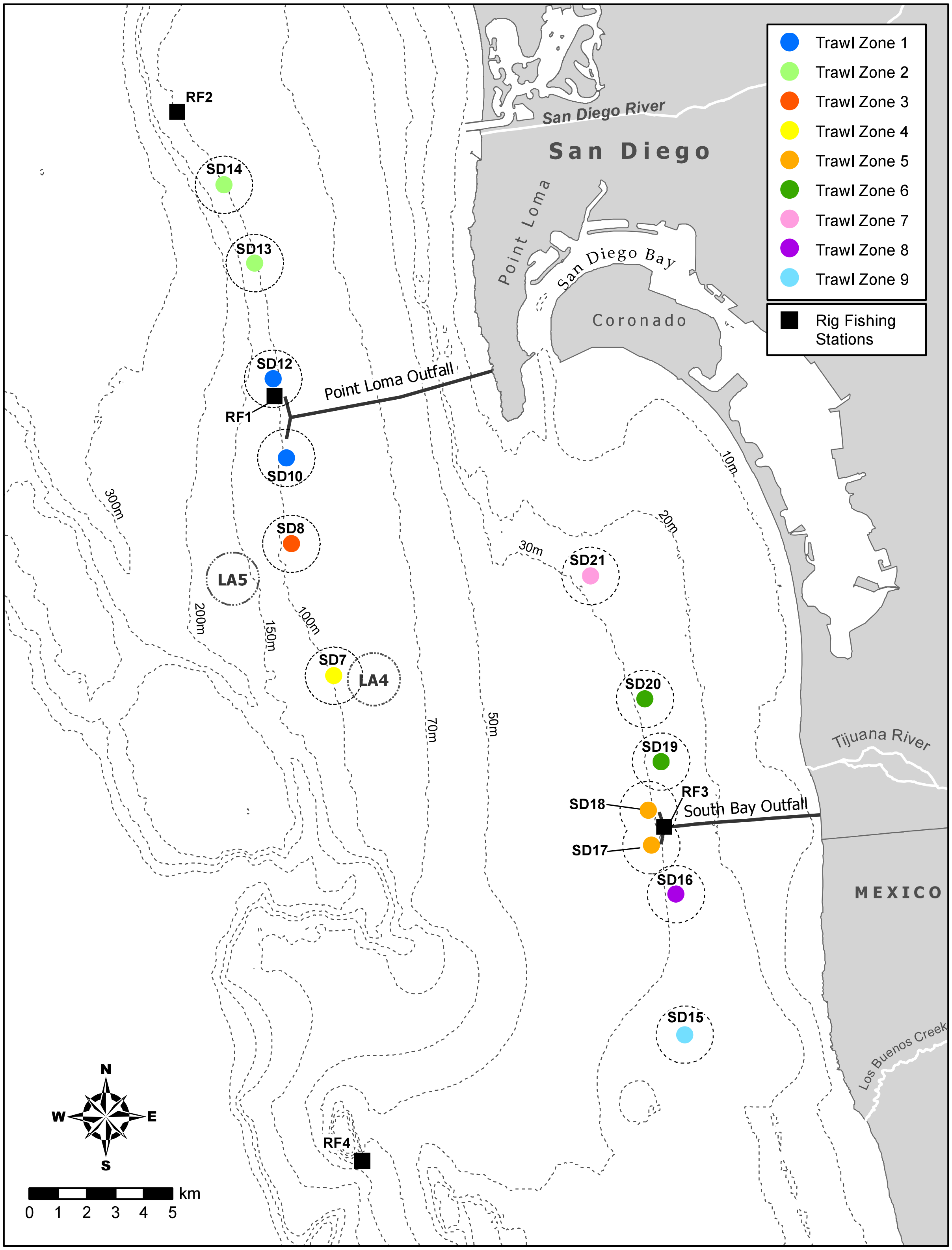

Figure 8.1
Trawl and rig fishing zone locations sampled around the PLOO and SBOO as part of the City of San Diego's Ocean Monitoring Program.

Table 8.1
Species of fish collected from each PLOO and SBOO trawl and rig fishing zone during 2019.

	Zone	Composite 1	Composite 2	Composite 3
PLOO	Rig Fishing Zone 1 (RF1)	Vermilion Rockfish	Vermilion Rockfish	Vermilion Rockfish
2019	Rig Fishing Zone 2 (RF2)	Starry Rockfish	Greenstriped Rockfish	Mixed Rockfish[a]
	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	Rig Fishing Zone 3 (RF3)	California Scorpionfish	California Scorpionfish	Mixed Rockfish[b]
2019	Rig Fishing Zone 4 (RF4)	California Scorpionfish	California Scorpionfish	California Scorpionfish
	Trawl Zone 5 (TZ5)	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
	Trawl Zone 6 (TZ6)	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
	Trawl Zone 7 (TZ7)	Longfin Sanddab	Hornyhead Turbot	Fantail Sole
	Trawl Zone 8 (TZ8)	Longfin Sanddab	Hornyhead Turbot	Fantail Sole
	Trawl Zone 9 (TZ9)	Spotted Turbot	Fantail Sole	No sample

[a]Includes Flag, Greenspotted, and Speckled Rockfish; [b]includes Brown Rockfish and Treefish

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, which are located just south and north of the outfall discharge site, respectively. Trawl Zone 6 includes the area within a 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 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. Efforts to collect target species by trawl were limited to five 10-minute (bottom time) trawls per site, while rig fishing effort was limited to 5 hours at each station. Occasionally, insufficient numbers of target species are obtained despite this effort; during 2019, this resulted in inadequate amounts of tissue at Trawl Zone 9 to complete three full composite samples.

A total of 14 species of fish were collected for analysis of liver and muscle tissues during the 2019 survey (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*), Longfin Sanddab (*Citharichthys xanthostigma*), Fantail Sole (*Xystreurys liolepis*), Hornyhead Turbot (*Pleuronichthys verticalis*), and Spotted Turbot (*Pleuronichthys ritteri*). These flatfish were collected from regular trawls at the SBOO stations, and by alternative hook and line methods at the PLOO stations. An additional nine species of fish 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*), Flag Rockfish (*Sebastes* *rubrivinctus*), Greenspotted Rockfish (*Sebastes chlorostictus*), Greenstriped Rockfish (*Sebastes elongatus*), Speckled Rockfish (*Sebastes ovalis*), Starry Rockfish (*Sebastes constellatus*), Treefish (*Sebastes serriceps*), and Vermilion Rockfish (*Sebastes miniatus*).

Only fishes with standard lengths ≥11 cm were retained to ensure the collection of sufficient tissue for analysis while minimizing total catch necessary. 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 (2020b) 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). 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 (2020a). 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). Data were generally limited to values above the method detection limit (MDL) for each parameter (Appendix J.1). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A variety of laboratory technical issues resulted in a significant amount of non-reportable fish tissue chemistry data for 2019 as detailed in Addenda 8-3 through 8-7. Impacted data include copper, hexachlorobenzene (HCB), and total values for chlordane, DDT, HCH, PCB, and PAH. Averages representing conditions for 2019 and historical comparisons involving these parameters should therefore be interpreted with caution.

Data Analyses

Data for each chemical parameter analyzed in PLOO and SBOO fish tissues sampled during fall (October) 2019 are listed in Addenda 8-3 through 8-7. Data summaries for each parameter include detection rate, minimum, maximum, and mean 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 (analyte concentrations <MDL). Total chlordane, total DDT (tDDT), total hexachlorocyclohexane (tHCH), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values for individual constituents (Addendum 8-7). For comparative historical analyses, data were limited as follows: (1) fall (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 (Appendices J.2, J.3). 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 R (R Core Team 2020) using various functions within the reshape2, plyr, scales, tidyverse, zoo, vegan, psych, and ggpubr packages (Zeileis and Grothendieck 2005, Oksanen et al. 2019, Revelle 2019, Wickham 2007, 2011, 2019, Wickham et al. 2019, Kassambara 2020).

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

Seven of the 18 trace metals analyzed were detected in fish liver tissue samples from PLOO and SBOO trawl zones in 2019, including: arsenic, cadmium, iron, manganese, mercury, tin, and zinc (Table 8.2, Addendum 8-3). Copper was detected in all fish liver tissue samples with reportable results. Detection rates for selenium were slightly less at 92–93% per region, while chromium was detected at rates ≤14% per region. Lead, nickel, and silver were detected in 7, 7, and 57% of the liver tissue samples from the SBOO region, respectively, but were not detected in liver tissue samples from the PLOO region. Aluminum, antimony, barium, beryllium, and thallium were not detected in any fish liver tissue samples from either region during 2019. 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).

Detection rates have been relatively high for several different metals in liver tissues of fishes captured at trawl zones since 1995 (Table 8.3). For example, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected in ≥87% of all Sanddab, Scorpionfish, and Hornyhead Turbot liver samples analyzed from the PLOO and SBOO trawl zones over the past 25 years. Detection rates for other metals varied by species. For example, arsenic was detected in ≥85% of all Sanddab and Hornyhead Turbot liver samples, but only 44% of Scorpionfish samples. Chromium and silver were each found in 79% of the Hornyhead Turbot samples from the SBOO region, but were detected in ≤65% of samples from the other species. Antimony, beryllium, lead, nickel, and thallium were detected in ≤30% of samples from both regions. Metal concentrations have also been highly variable over these past 25 years, with most being detected within ranges reported elsewhere in the SCB (e.g., Mearns et al. 1991, CLA 2015, OCSD 2018). While relatively high values of various metals have been occasionally recorded in liver tissues from fishes collected from nearfield zones, when compared to farfield zones, there were no discernable intra-species patterns that could be associated with proximity to either outfall (Figure 8.3, Appendix J.4).

Pesticides

Based on reportable results (Addendum 8-4), a total of seven chlorinated pesticides were detected in fish liver tissue samples from PLOO and SBOO trawl zones in 2019 (Table 8.4). Total DDT was detected in all samples from both regions, at concentrations ≤531.9 ppb. Total chlordane was detected in 100% of the PLOO samples and 64% of the SBOO samples, at concentrations ≤13.1 ppb. Total HCH was detected in 100% of the PLOO samples and 21% of the SBOO samples, at concentrations ≤15.5 ppb. Hexachlorobenzene (HCB) was detected in 100% of the PLOO samples at concentrations ≤12.3 ppb. This pesticide was non-reportable for all samples from the SBOO region. Mirex was detected in 58% of the PLOO samples at concentrations ≤1.1 ppb, while dieldrin was detected in 42% of these samples at concentrations ≤3.2 ppb, and *beta*-endosulfan was detected in 8% of these samples at a concentration of 4.7 ppb. During the 2019 survey, these three pesticides were not detected in fish liver tissue samples from SBOO trawl zones, and the pesticides (or pesticide constituents) aldrin, *alpha*-endosulfan, endosulfan sulfate, endrin, and endrin aldehyde were not detected in any liver samples from fishes collected

Table 8.2

Summary of metals (ppm) in liver tissues of fishes collected from PLOO and SBOO trawl zones during 2019. 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	Tl	Sn	Zn
PLOO	Pacific Sanddab																		
	n	0	0	12	0	0	12	1	4	12	0	12	12	0	11	0	0	12	12
	Min	—	—	4.6	—	—	1.64	nd	3.4	45.2	—	0.7	0.094	—	nd	—	—	1.7	20.8
	Max	—	—	8.5	—	—	4.33	0.15	5.6	105.0	—	1.4	0.280	—	1.18	—	—	2.4	32.1
	Mean	—	—	6.7	—	—	2.56	0.15	4.4	66.0	—	1.0	0.149	—	0.79	—	—	2.1	26.8
	Total Samples	12	12	12	12	12	12	12	4	12	12	12	12	12	12	12	12	12	12
	Detection Rate (%)	0	0	100	0	0	100	8	100	100	0	100	100	0	92	0	0	100	100
	Max	nd	nd	8.5	nd	nd	4.33	0.15	5.6	105.0	nd	1.4	0.280	nd	1.18	nd	nd	2.4	32.1
SBOO	Fantail Sole																		
	n	0	0	3	0	0	3	0	3	3	0	3	3	0	3	3	0	3	3
	Min	—	—	8.9	—	—	2.23	—	20.2	179.0	—	0.9	0.072	—	0.87	0.2	—	0.8	83.1
	Max	—	—	13.0	—	—	7.08	—	36.6	227.0	—	1.2	0.138	—	1.11	0.2	—	1.0	117.0
	Mean	—	—	10.5	—	—	4.84	—	28.5	210.3	—	1.1	0.095	—	0.99	0.2	—	0.9	101.0
	Hornyhead Turbot																		
	n	0	0	3	0	0	3	1	3	3	1	3	3	1	3	3	0	3	3
	Min	—	—	6.2	—	—	3.99	nd	8.5	78.4	nd	0.8	0.071	nd	1.00	0.2	—	0.9	66.0
	Max	—	—	18.8	—	—	7.10	0.31	41.7	263.0	0.6	3.2	0.089	0.10	3.38	0.3	—	3.6	233.0
	Mean	—	—	13.3	—	—	5.44	0.31	20.2	142.7	0.6	1.6	0.081	0.10	1.98	0.2	—	1.8	128.5
	Longfin Sanddab																		
	n	0	0	7	0	0	7	1	7	7	0	7	7	0	7	2	0	7	7
	Min	—	—	4.6	—	—	0.62	nd	4.2	62.1	—	0.6	0.032	—	0.29	nd	—	1.5	18.1
	Max	—	—	8.1	—	—	1.54	0.11	7.2	104.0	—	0.9	0.066	—	1.08	0.2	—	2.2	26.4
	Mean	—	—	6.0	—	—	1.08	0.11	5.9	84.8	—	0.8	0.045	—	0.73	0.1	—	2.0	22.1
	Spotted Turbot																		
	n	0	0	1	0	0	1	0	1	1	0	1	1	0	0	0	0	1	1
	Min	—	—	11.6	—	—	0.98	—	5.9	157.0	—	1.4	0.052	—	—	—	—	2.3	37.0
	Max	—	—	11.6	—	—	0.98	—	5.9	157.0	—	1.4	0.052	—	—	—	—	2.3	37.0
	Mean	—	—	11.6	—	—	0.98	—	5.9	157.0	—	1.4	0.052	—	—	—	—	2.3	37.0
	Total Samples	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
	Detection Rate (%)	0	0	100	0	0	100	14	100	100	7	100	100	7	93	57	0	100	100
	Max	nd	nd	18.8	nd	nd	7.10	0.31	41.7	263.0	0.6	3.2	0.138	0.10	3.38	0.3	nd	3.6	233.0

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

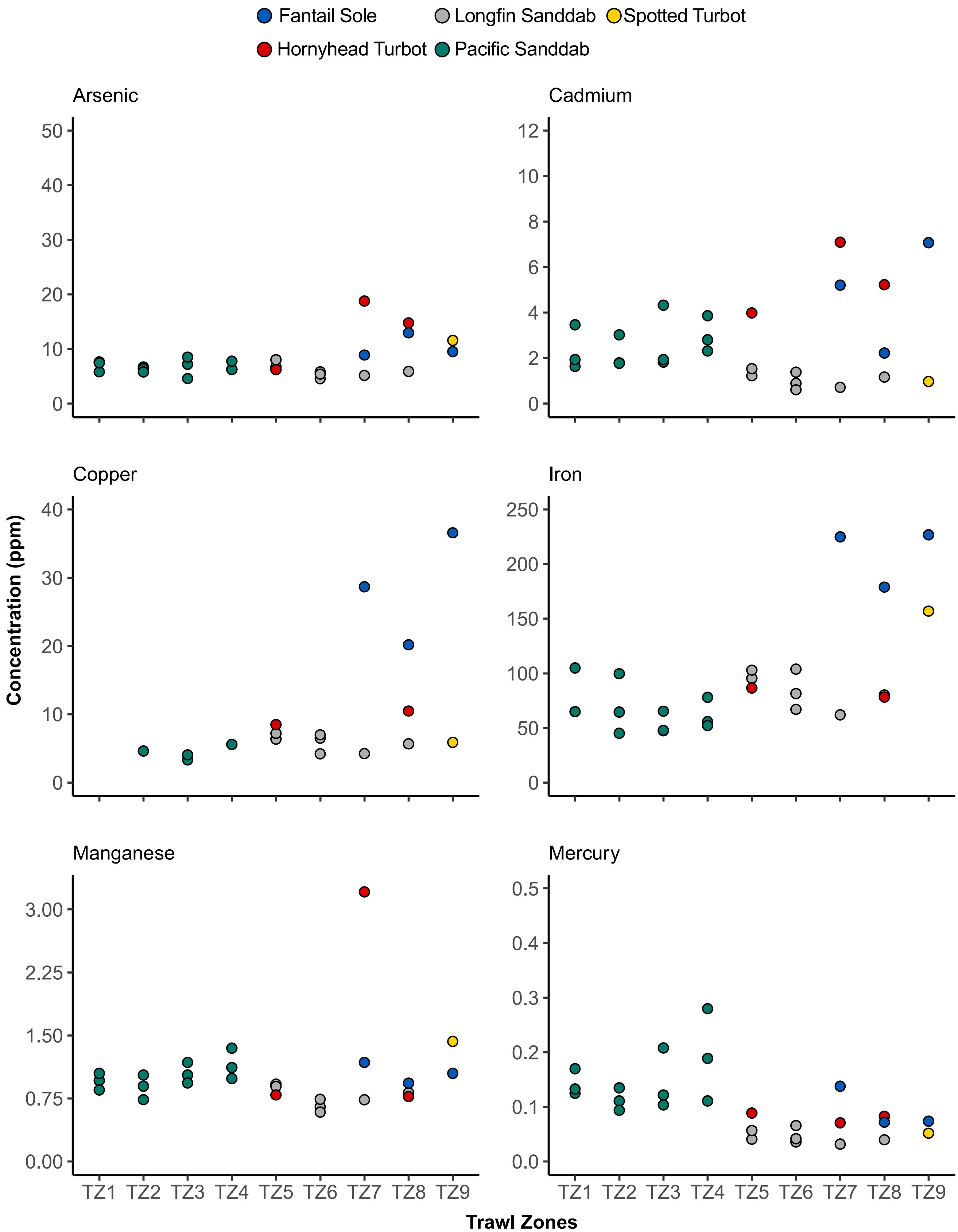

Figure 8.2
Concentrations of metals with detection rates ≥20% in liver tissues of fishes collected from each PLOO and SBOO trawl zone during 2019. Zones TZ1 and TZ5 are considered nearfield stations.

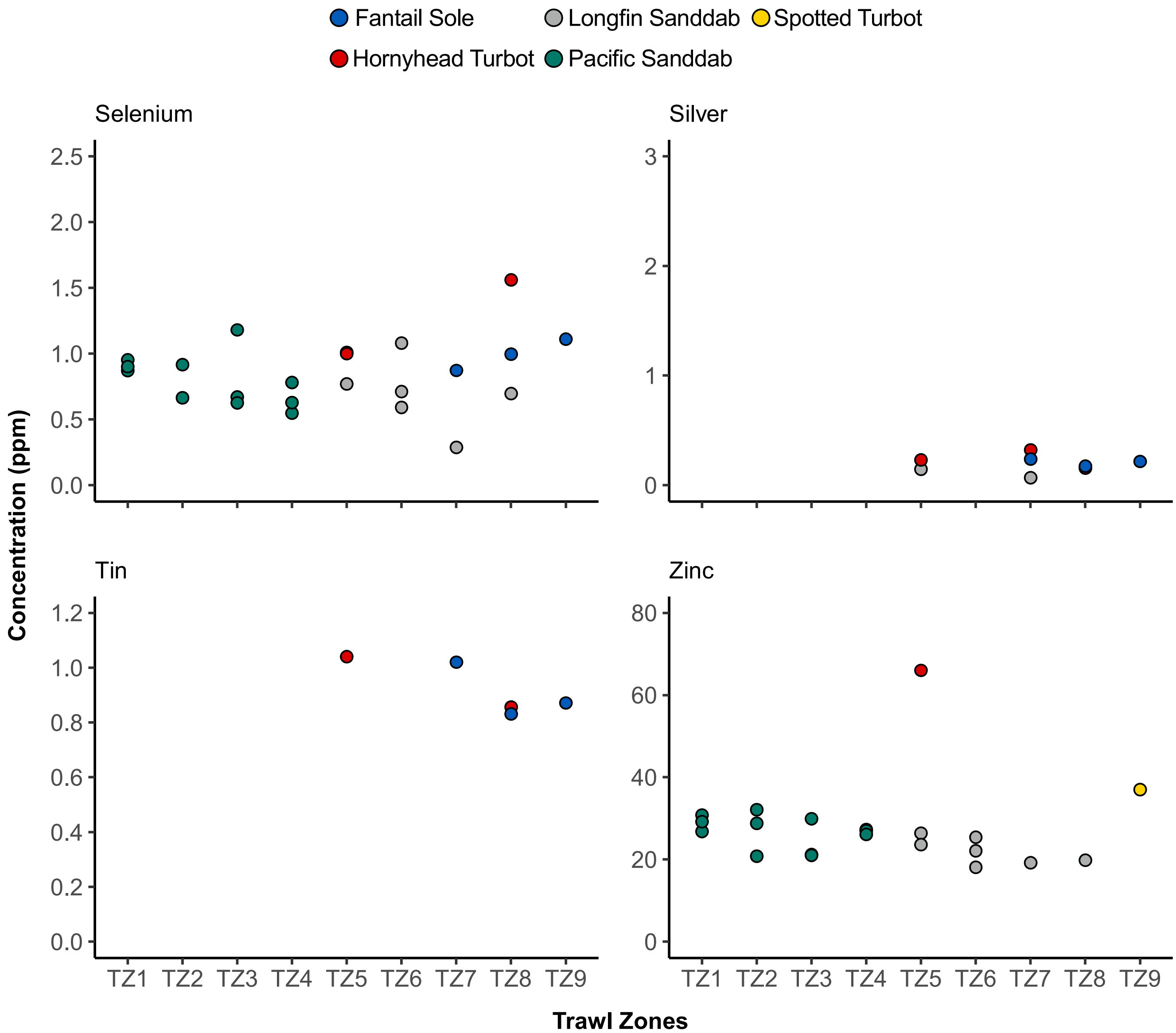

Figure 8.2 *continued*

from either region. 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 DDT, HCB, and chlordane have been frequently detected in liver tissues from trawl-zone fishes since 1995 (Table 8.5). Historical detection rates were 99–100% per species (or species group) for DDT, 50–71% for HCB, and 7–66% for total chlordane over these past 25 years. In contrast, long-term detection rates were 3–13% for total HCH, ≤7% for mirex and ≤2% for aldrin, dieldrin, *alpha*-endosulfan, *beta*-endosulfan, endosulfan sulfate, and endrin. Endrin aldehyde has never been detected in any liver tissue samples from PLOO or SBOO trawl zones. As with metals, pesticide 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 relatively high values of various pesticides have been occasionally recorded in liver tissues from nearfield zones, when compared to farfield zones, there were no discernable intra-species patterns that could be associated with proximity to either outfall (Figure 8.5, Appendix J.5).

Table 8.3

Summary of metals (ppm) in liver tissues of fishes collected from PLOO and SBOO trawl zones from 1995 through 2019. 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	307	307	307	198	307	307	307	299	307	307	307	309	307	308	307	295	307	307
	DR%	64	16	90	62	12	93	64	100	100	17	98	89	18	99	26	26	53	100
	min	nd	nd	nd	nd	nd	nd	nd	0.9	27.0	nd	nd	nd	nd	nd	nd	nd	nd	8.6
	max	45.0	9.7	123.0	15.2	0.18	19.20	22.80	28.7	233.0	8.8	5.5	0.579	18.90	4.37	2.2	6.4	277.0	74.2
	mean	12.0	1.4	5.2	0.3	0.02	4.24	0.64	5.4	97.2	0.9	0.8	0.095	0.70	1.14	0.2	1.6	3.7	24.0
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	20.5
	max	59.8	1.7	8.1	0.6	0.06	6.92	5.34	81.1	481.0	8.1	2.5	0.695	2.67	2.82	1.2	5.3	3.4	207.0
	mean	13.6	0.9	2.3	0.1	0.01	2.63	0.92	22.9	179.2	1.4	0.6	0.175	0.42	0.88	0.3	4.2	1.3	96.9
	Hornyhead Turbot																		
	n	131	131	131	111	131	131	131	131	131	131	131	131	131	132	131	127	131	131
	DR%	65	8	91	56	5	99	79	100	100	16	99	98	16	99	79	20	61	100
	min	nd	nd	nd	nd	nd	nd	nd	2.3	19.4	nd	nd	nd	nd	nd	nd	nd	nd	23.0
	max	27.8	1.8	25.0	0.3	0.02	12.00	7.67	41.7	263.0	3.3	3.2	0.407	4.61	3.38	1.3	3.8	88.2	233.0
	mean	7.0	1.1	4.2	0.1	0.01	3.89	0.40	7.9	55.6	0.6	1.1	0.108	0.51	0.84	0.2	1.7	2.1	62.2
	Longfin Sanddab																		
	n	157	157	157	110	157	157	157	157	157	157	157	157	157	158	157	149	157	157
	DR%	63	17	85	51	4	91	65	100	100	13	97	87	21	100	45	30	62	100
	min	nd	nd	nd	nd	nd	nd	nd	1.4	33.0	nd	nd	nd	nd	0.27	nd	nd	nd	10.3
	max	49.0	2.4	12.1	0.5	0.04	9.31	3.56	23.2	449.0	14.3	2.0	0.438	1.59	1.77	1.6	2.7	4.6	109.0
	mean	12.6	0.9	5.4	0.1	0.02	1.94	0.44	6.2	76.2	1.1	1.0	0.087	0.44	0.88	0.2	0.9	1.5	23.6

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

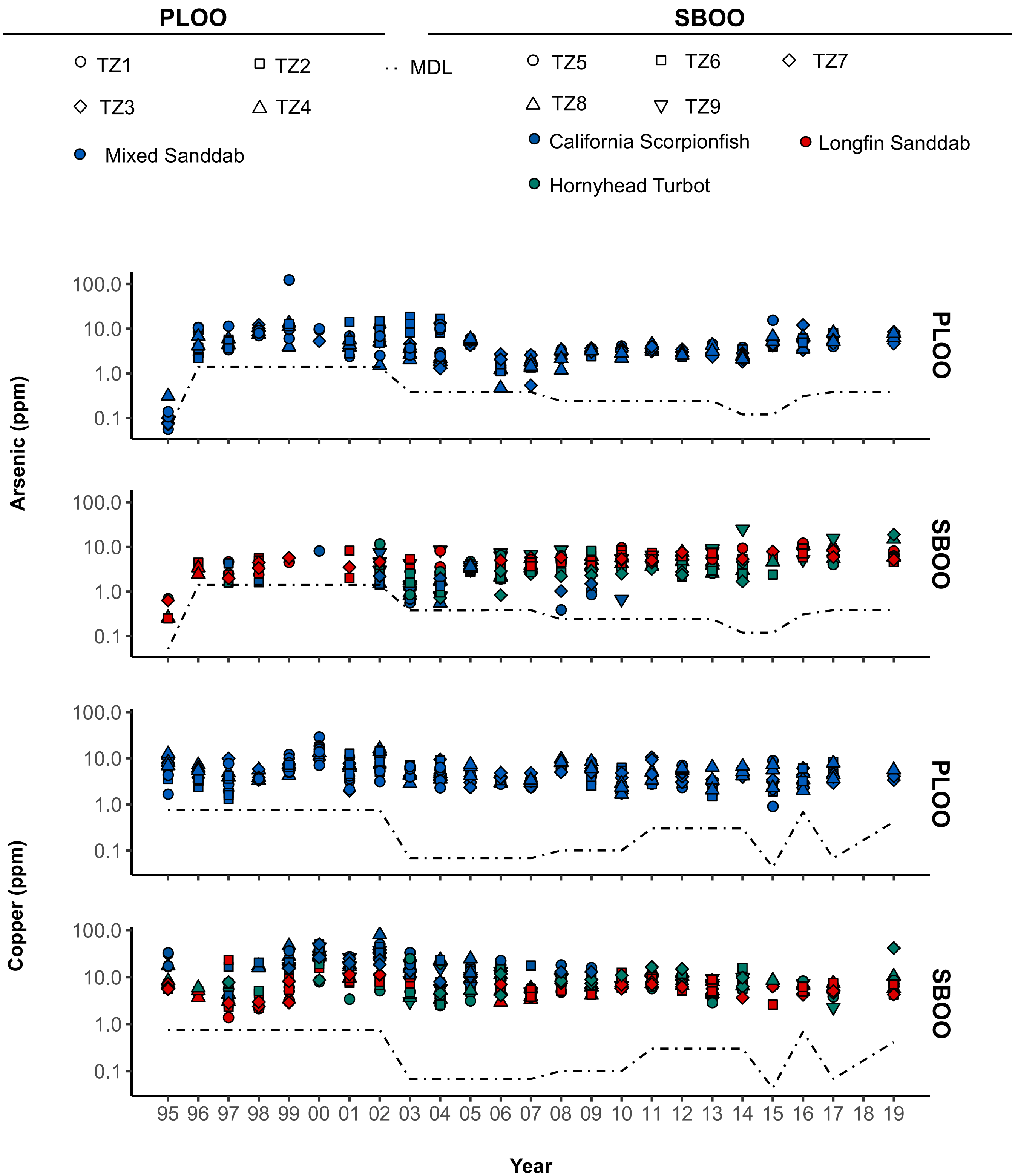

Figure 8.3
Concentrations of select metals in liver tissues of fishes collected from PLOO and SBOO trawl zones from 1995 through 2019. Zones TZ1 and TZ5 are considered nearfield. No samples were collected in 2018 (see text).

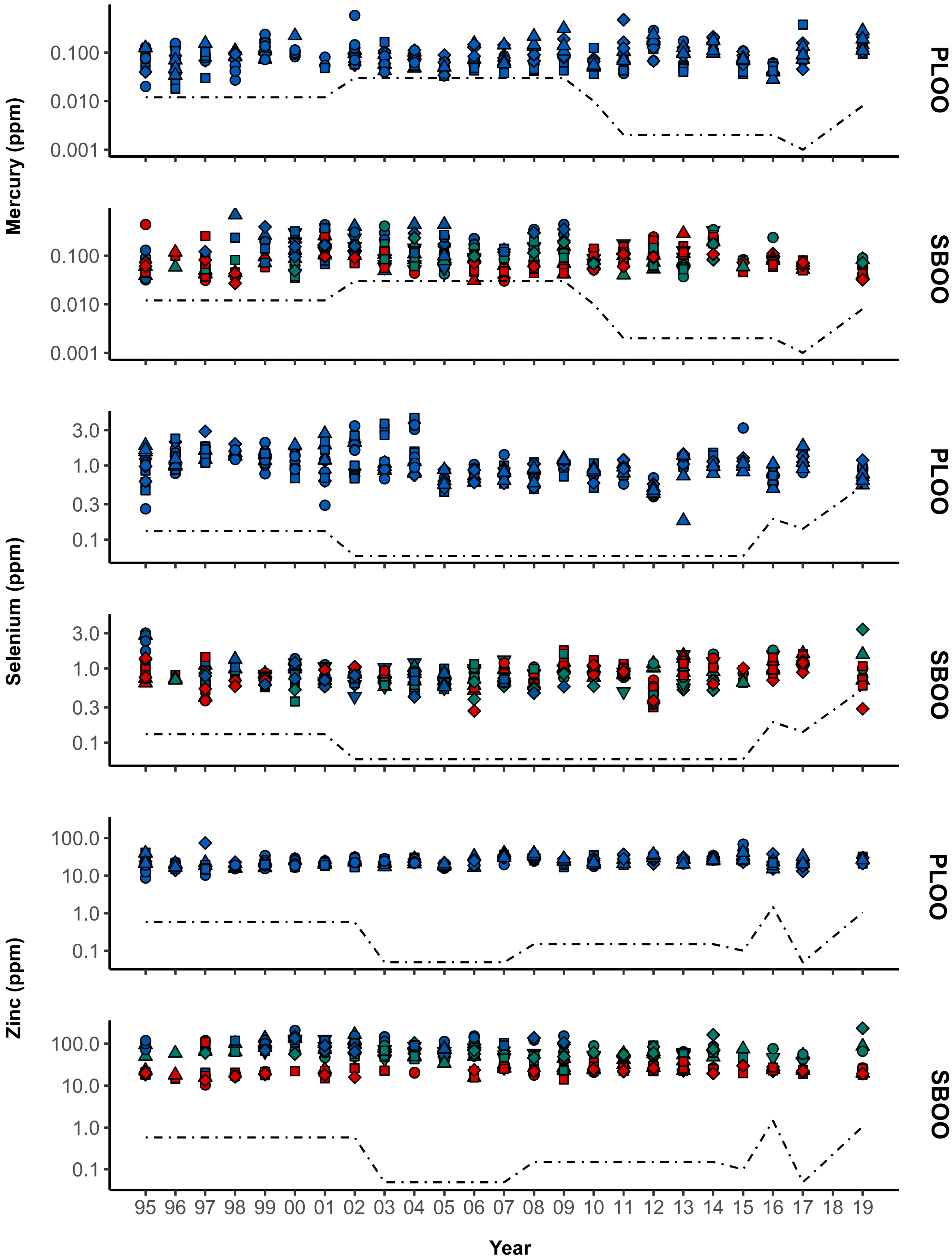

Figure 8.3 *continued*

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 2019. 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; B-Endo = *beta*-endosulfan ; na = not analyzed; nd = not detected; nr = not reportable. See Addendum 8-4 for missing parameters, and Addendum 8-7 for values of individual constituents summed for total chlordane (tChlor), tDDT, tHCH, tPCB, and tPAH.

		Pesticides									
		tChlor	tDDT	Dieldrin	B-Endo	HCB	tHCH	Mirex	tPCB	tPAH	Lipids
PLOO	Pacific Sanddab										
	n	12	12	5	1	10	12	7	12	8	12
	Min	5.8	259.2	nd	nd	8.1	1.67	nd	143.2	nd	40.0
	Max	13.1	531.9	3.2	4.7	12.3	15.49	1.1	3193.5	80.0	54.7
	Mean	9.2	345.3	2.8	4.7	9.9	4.67	0.8	502.3	58.0	46.3
	Total Samples	12	12	12	12	10	12	12	12	12	12
	Detection Rate (%)	100	100	42	8	100	100	58	100	66.7	100
	Max	13.1	531.9	3.2	4.7	12.3	15.49	1.1	3193.5	80.0	54.7
SBOO	Fantail Sole										
	n	1	3	0	0	nr	0	0	3	2	3
	Min	nd	21.3	—	—	—	—	—	16.4	nd	4.0
	Max	1.7	62.4	—	—	—	—	—	95.6	25.7	6.3
	Mean	1.7	38.9	—	—	—	—	—	48.1	19.7	5.4
	Hornyhead Turbot										
	n	0	3	0	0	nr	1	0	3	1	3
	Min	—	30.9	—	—	—	nd	—	16.1	nd	7.8
	Max	—	58.2	—	—	—	0.44	—	37.8	19.0	8.8
	Mean	—	40.8	—	—	—	0.44	—	26.4	19.0	8.1
	Longfin Sanddab										
	n	7	7	0	0	nr	2	0	7	0	7
	Min	1.6	122.0	—	—	—	nd	—	64.8	—	36.9
	Max	8.8	305.8	—	—	—	5.20	—	273.6	—	48.3
	Mean	4.4	236.9	—	—	—	3.60	—	155.6	—	41.2
	Spotted Turbot										
	n	1	1	0	0	nr	0	0	1	0	1
	Min	8.8	12.6	—	—	—	—	—	154.2	—	3.5
	Max	8.8	12.6	—	—	—	—	—	154.2	—	3.5
	Mean	8.8	12.6	—	—	—	—	—	154.2	—	3.5
	Total Samples	14	14	14	14	nr	14	14	14	14	14
	Detection Rate (%)	64	100	0	0	—	21	0	100	21	100
	Max	8.8	305.8	—	—	—	5.20	—	273.6	25.7	48.3

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

PCBs

Based on reportable results (Addendum 8-4), PCBs were detected in all fish liver tissue samples from PLOO and SBOO trawl zones in 2019, at concentrations ≤ 3193.5 ppb. (Table 8.4). 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 total PCB varying widely across the different zones

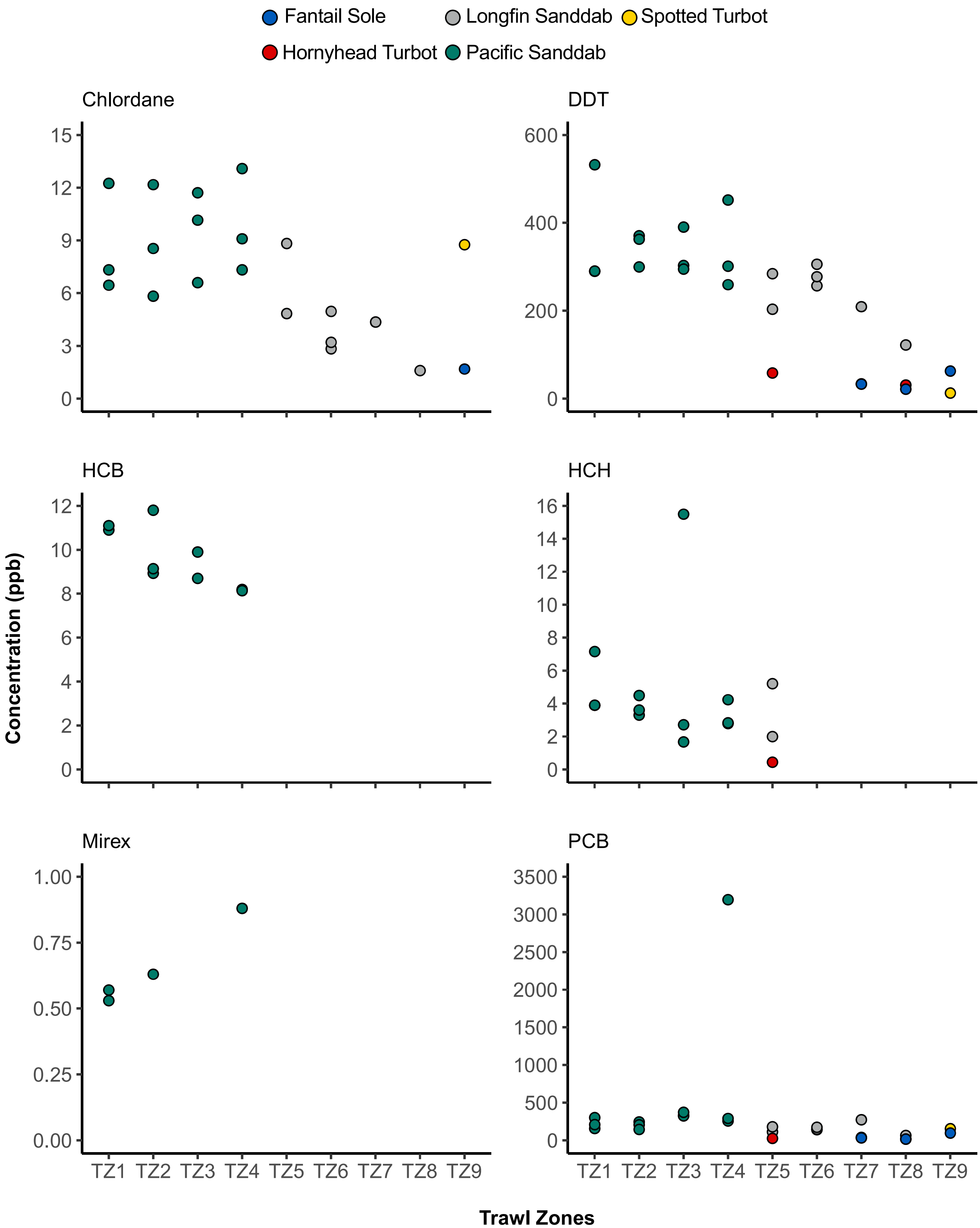

Figure 8.4
Concentrations of pesticides and total PCB in liver tissues of fishes collected from each PLOO and SBOO trawl zone during 2019. Zones TZ1 and TZ5 are considered nearfield stations.

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 2019. 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; A-Endo = *alpha*-endosulfan; B-Endo = *beta*-endosulfan; E-Sul = endosulfan sulfate.

		Pesticides													
		Aldrin	tChlor	tDDT	Dieldrin	A-Endo	B-Endo	E-Sulf	Endrin	HCB	tHCH	Mirex	tPCB	tPAH	Lipids
PLOO	Mixed Sanddab														
	n	305	316	316	293	305	137	160	293	304	316	316	317	142	313
	DR%	0	62	99	2	0	1	0	0	69	13.29	7	100	14	100
	min	—	nd	nd	nd	—	nd	—	—	nd	nd	nd	35.2	nd	6.9
	max	—	128.0	3800.0	15.8	—	4.7	—	—	120.0	22.00	48.0	3193.5	1353.0	69.6
	mean	—	18.2	727.3	6.2	—	4.7	—	—	6.6	4.91	3.6	470.8	212.2	38.1
SBOO	California Scorpionfish														
	n	93	93	93	93	93	39	39	93	93	93	93	107	72	105
	DR%	2	66	100	2	2	0	0	2	57	3	0	95	0	100
	min	nd	nd	2.6	nd	nd	—	—	nd	nd	nd	—	nd	—	6.4
	max	19.0	215.8	15,503.0	63.0	9.6	—	—	66.0	37.3	278.00	—	2187.9	—	45.4
	mean	12.1	20.1	1237.4	38.5	9.0	—	—	55.0	3.2	142.00	—	362.8	—	19.7
	Hornyhead Turbot														
	n	134	137	137	132	134	47	52	132	133	137	137	139	122	136
	DR%	0	7	100	0	0	0	0	0	50	4	0	89	5	100
	min	—	nd	3.5	—	—	—	—	—	nd	nd	—	nd	nd	0.1
	max	—	32.0	2802.0	—	—	—	—	—	41.0	5.90	—	841.9	330.5	32.2
	mean	—	9.5	132.6	—	—	—	—	—	2.9	1.69	—	48.6	133.7	9.6
	Longfin Sanddab														
	n	151	154	154	142	151	70	82	142	143	154	154	158	130	157
	DR%	0	38	99	0	0	0	2	0	71	12	6	99	4	100
	min	—	nd	nd	—	—	—	nd	—	nd	nd	nd	nd	nd	6.2
	max	—	120.0	3600.0	—	—	—	0.2	—	51.3	5.20	2.0	6781.9	43,167.0	62.4
	mean	—	10.0	674.5	—	—	—	0.1	—	4.2	2.61	1.3	594.4	8678.3	35.9

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

(Figure 8.4). Historically, PCBs have been detected in 89–100% of the liver tissue samples from Sanddabs, Scorpionfish, and Hornyhead Turbot analyzed since 1995 (Table 8.5), with total PCB concentrations 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 discernable intra-species patterns that could be associated with proximity to either outfall over the past 25 years (Figure 8.5).

PAHs

Based on reportable results (Addendum 8-4), PAHs were detected in 67% of PLOO liver tissue samples and 21% of SBOO liver tissue samples, at concentrations ≤ 80.0 ppb (Table 8.4). 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 total PAH varying widely across the different zones (Addendum 8-4). Historically, PAHs have been detected in ≤ 14% of the liver tissue samples from Sanddabs, Scorpionfish, and Hornyhead Turbot analyzed since 1995, with total PAH concentrations 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 discernable intra-species patterns that could be associated with proximity to either outfall during the years that PAH was analyzed (Appendix J.5).

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 2019, lipid levels in liver tissues of Pacific Sanddabs collected from the PLOO region ranged from 40 to 55% weight (Table 8.4). Within the SBOO region, liver lipid levels ranged from 4 to 6% weight for Fantail Sole, from 8 to 9% weight for Hornyhead Turbot, from 37 to 48% weight for Longfin Sanddab, and were 3.5% weight for the single sample of Spotted Turbot. 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 2019 reporting period as well as over the past 25 years (Groce 2002).

Contaminants in Fish Muscle Tissues

Trace Metals

Eight of the 18 trace metals analyzed were detected in all fish muscle tissue samples from PLOO and SBOO rig fishing zones, during 2019, including: arsenic, cadmium, chromium, iron, mercury, selenium, tin, and zinc (Table 8.6, Addendum 8-5). Detection rates for other relatively common metals were 83–100% for copper and 50–83% for nickel per region. Beryllium was found in 33% of the muscle tissue samples from the PLOO region, but was not detected in muscle tissue samples from the SBOO region. Aluminum, antimony, barium, lead, manganese, silver, and thallium were not detected in any muscle tissue samples from either region during 2019. 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 (Groce 2002). Of the 12 rockfish muscle tissue samples collected from PLOO and SBOO rig fishing zones in 2019, 100% exceeded the median international standard for arsenic, 83% exceeded this standard for selenium, and 8% exceeded this standard for chromium. A single California Scorpionfish sample from zone RF3 exceeded the OEHHA limit for mercury, but all samples were below the USFDA mercury action limit. All samples were also below the OEHHA limit for selenium.

Detection rates have been relatively high for several different metals in muscle tissues of fishes captured at rig fishing zones since 1995 (Table 8.7). For example, arsenic, copper, iron, mercury, selenium, and zinc were detected in ≥ 59% of all California Scorpionfish and rockfish muscle samples analyzed from the PLOO and SBOO rig fishing over the past 25 years.

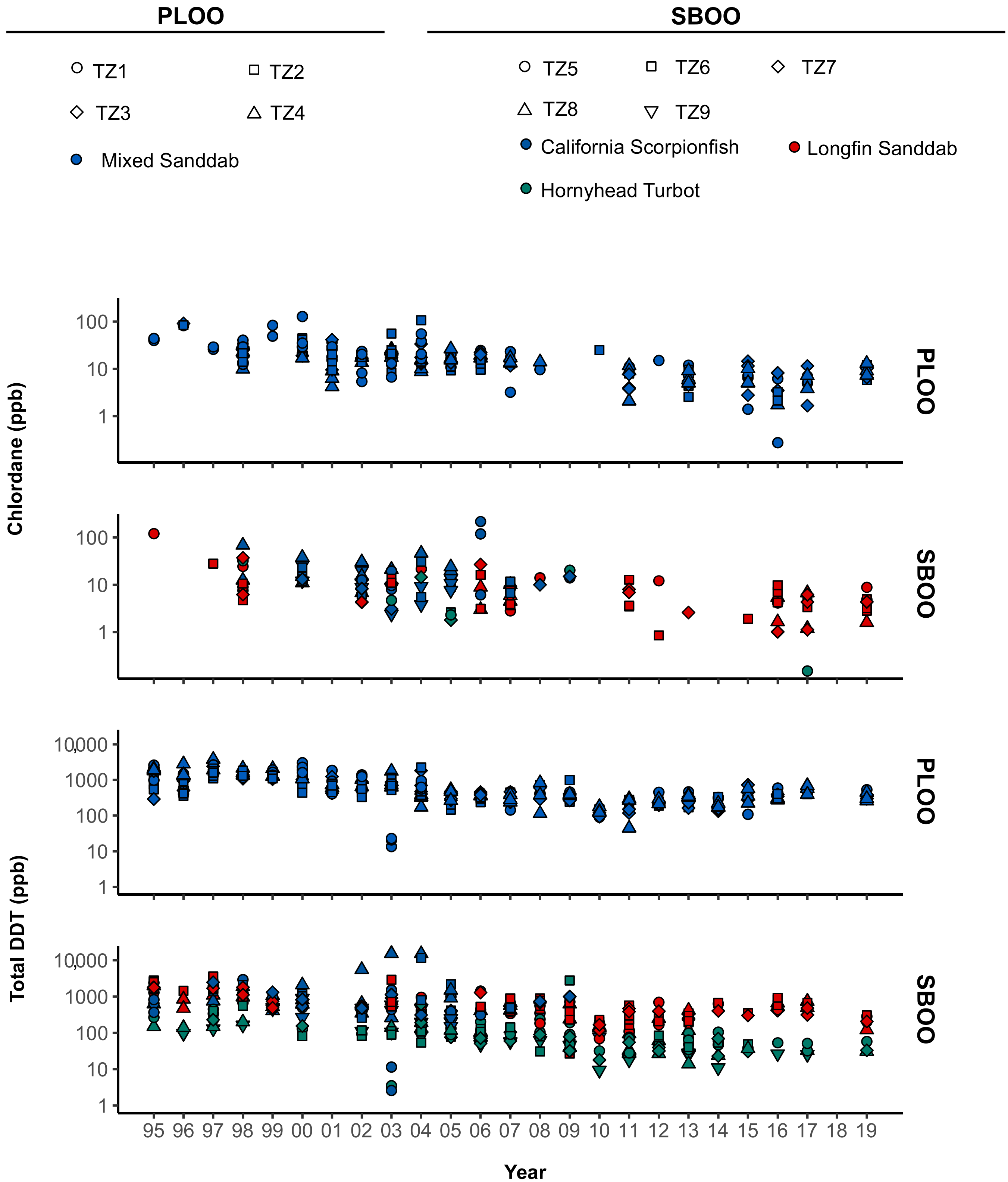

Figure 8.5
Concentrations of pesticides and total PCB in liver tissues of fishes collected from PLOO and SBOO trawl zones from 1995 through 2019. Zones TZ1 and TZ5 are considered nearfield. No samples were collected in 2018 (see text).

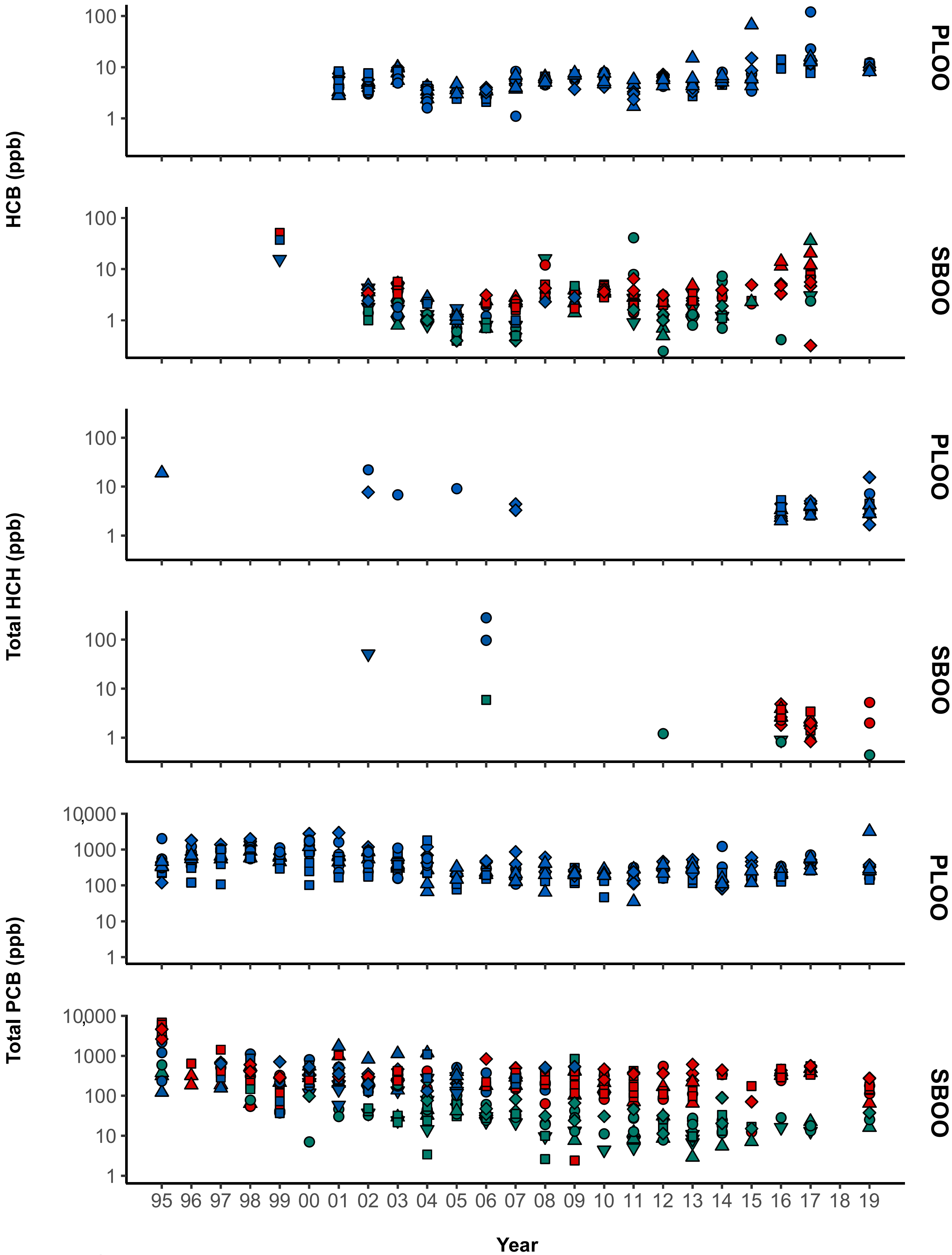

Figure 8.5 *continued*

Table 8.6

Summary of metals (ppm) in muscle tissues of fishes collected from PLOO and SBOO rig fishing zones during 2019. 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.

		Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
PLOO	Vermilion Rockfish																		
	n	0	0	3	0	1	3	3	2	3	0	0	3	1	3	0	0	3	3
	Min	—	—	4.07	—	nd	0.049	0.043	0.00	2.30	—	—	0.052	nd	0.412	—	—	0.74	3.89
	Max	—	—	6.27	—	0.002	0.072	0.082	0.50	3.44	—	—	0.071	0.050	0.439	—	—	0.85	4.06
	Mean	—	—	5.10	—	0.002	0.060	0.062	0.39	3.04	—	—	0.064	0.050	0.425	—	—	0.81	3.98
	Greenstriped Rockfish																		
	n	0	0	1	0	1	1	1	1	1	0	0	1	1	1	0	0	1	1
	Value	—	—	4.31	—	0.001	0.053	0.056	0.50	3.12	—	—	0.184	0.028	0.451	—	—	0.88	3.18
	Mixed Rockfish																		
	n	0	0	1	0	0	1	1	1	1	0	0	1	0	1	0	0	1	1
	Value	—	—	2.23	—	—	0.030	0.068	0.21	257.00	—	—	0.094	—	0.379	—	—	1.36	3.83
	Starry Rockfish																		
	n	0	0	1	0	0	1	1	1	1	0	0	1	1	1	0	0	1	1
	Value	—	—	1.60	—	—	0.020	0.114	0.21	1.67	—	—	0.125	0.035	0.331	—	—	0.82	3.00
	Total Samples	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	Detection rate(%)	0	0	100	0	33	100	100	83	100	0	0	100	50	100	0	0	100	100
	Max	—	—	6.27	—	0.002	0.072	0.114	0.50	257.00	—	—	0.184	0.050	0.451	—	—	1.36	4.06
SBOO	California Scorpionfish																		
	n	0	0	5	0	0	5	5	5	5	0	0	5	4	5	0	0	5	5
	Min	—	—	1.93	—	—	0.025	0.047	0.30	1.18	—	—	0.117	nd	0.265	—	—	0.72	3.34
	Max	—	—	3.18	—	—	0.040	1.010	0.95	10.30	—	—	0.229	0.089	0.567	—	—	0.85	4.34
	Mean	—	—	2.48	—	—	0.033	0.249	0.62	4.13	—	—	0.174	0.069	0.428	—	—	0.78	3.64
	Mixed Rockfish																		
	n	0	0	1	0	0	1	1	1	1	0	0	1	1	1	0	0	1	1
	Value	—	—	2.31	—	—	0.038	0.052	0.20	4.46	—	—	0.053	0.033	0.298	—	—	0.81	4.74
	Total Samples	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	Detection rate(%)	0	0	100	0	0	100	100	100	100	0	0	100	83	100	0	0	100	100
	Max	—	—	3.18	—	—	0.040	1.010	0.95	10.30	—	—	0.229	0.089	0.567	—	—	0.85	4.74
	OEHHA[b]	na	na	na	na	na	na	na	na	na	na	na	0.22	na	7.4	na	na	na	na
	USFDA Action Limit[c]	na	na	na	na	na	na	na	na	na	na	na	1	na	na	na	na	na	na
	Median IS[c]	na	na	1.4	na	na	1.0	1.0	20	na	2	na	0.50	na	0.3	na	na	175	70

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

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, 60% of all muscle tissue samples from both outfall regions exceeded the median international standard for arsenic, 53% exceeded the standard for selenium, 3% exceeded the standard for mercury, and 2% exceeded the standard for chromium. The OEHHA fish contaminant goal for selenium was never exceeded. Since 1995, only 17% of the samples exceeded the OEHHA goal for mercury, and only one sample (0.35%) exceeded the USFDA action limit for mercury. While relatively high values of various metals have been occasionally recorded in muscle tissues from fishes collected off San Diego, there were no discernable patterns at the rig fishing zones, which could be associated with proximity to either the PLOO or the SBOO (Figure 8.7, Appendix J.6).

Pesticides

Based on reportable results (Addendum 8-6), a total of five chlorinated pesticides were detected in fish muscle tissue samples from PLOO and SBOO rig fishing zones in 2019 (Table 8.8). Total DDT was detected in 100% of the PLOO samples and 83% of the SBOO samples, at concentrations ≤34.89 ppb. Total chlordane was detected in 50% of the PLOO samples and 50% of the SBOO samples, at concentrations ≤0.32 ppb. Total HCH was detected in 33% of the PLOO samples and 17% of the SBOO samples, at concentrations ≤0.09 ppb. HCB was detected in 100% of the PLOO samples at concentrations ≤4.79 ppb, while dieldrin was detected in 17% of these samples at concentrations ≤0.12 ppb. During the 2019 survey, these two pesticides were not detected in fish muscle tissue samples from SBOO rig fishing zones. Additionally, the pesticides (or pesticide constituents) aldrin, *alpha*-endosulfan, *beta*-endosulfan, endosulfan sulfate, endrin, endrin aldehyde, and mirex were not detected in any muscle samples from fishes collected from either region. Concentrations of DDT, chlordane, HCB, and HCH in muscle tissue samples were variable, substantially lower than in liver tissues, generally below available thresholds, and demonstrated no discernable patterns with proximity to either outfall (Figure 8.8). One sample from zone RF4 exceeded the OEHHA limit for DDT.

Historically, only five 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 8.9). Long-term detection rates were 50 to 95% per species (or species group) for DDT, 0–59% for HCB, 0–19% for total chlordane, 0–10% for total HCH, and 0–1% for dieldrin. Other pesticides such as aldrin, endrin, endrin aldehyde, *alpha*-endosulfan, *beta*-endosulfan, endosulfan sulfate, and mirex have never been detected in muscle tissue samples from these species collected from the PLOO or SBOO regions over the past 25 years. As with metals, 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). Since 1995, only 13% of the samples exceeded the OEHHA goal for DDT, and all samples were below USFDA action limits. Chlordane never exceeded its OEHHA contaminant goal or USFDA action limit in either region. While relatively high values of various pesticides have been occasionally recorded in muscle tissues of fishes collected off San Diego, there were no discernable patterns at the rig fishing zones, which could be associated with proximity to either the PLOO or the SBOO (Figure 8.9, Appendix J.7).

PCBs

Based on reportable results (Addendum 8-6), PCBs were detected in all muscle tissue samples from PLOO and SBOO rig fishing zones in 2019, at concentrations ≤10.98 ppb (Table 8.8). Four samples had PCB levels in exceedance of the OEHHA threshold of 3.6 ppb. These elevated values occurred at RF1, RF3, and RF4 (Figure 8.8). Historically, PCB detection rates were 74–77% per species (or species group) in muscle tissue samples, with highly variable concentrations 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 discernable patterns that could be associated with proximity

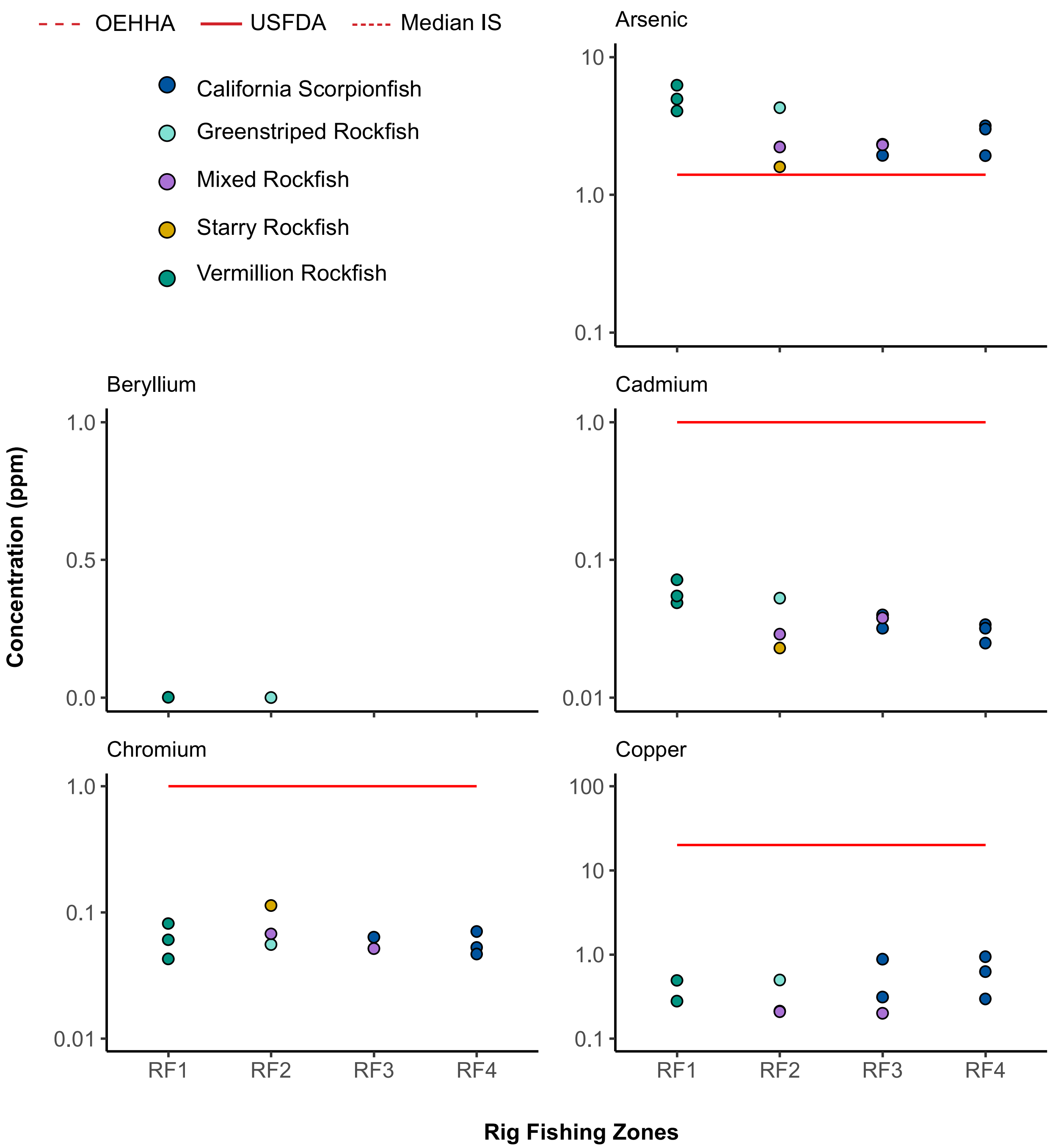

Figure 8.6
Concentrations of metals with detection rates ≥20% in muscle tissues of fishes collected from each rig fishing zone during 2019. See Table 8.6 for thresholds. Zones RF1 and RF3 are considered nearfield.

to either outfall (Table 8.9, Figure 8.9). Of the 286 muscle tissues samples analyzed for PCBs over the past 25 years, only 23% exceeded the OEHHA fish contaminant goal for total PCB.

PAHs
Based on reportable results (Addendum 8-6), PAHs were detected in 17% of the muscle tissue samples from PLOO and SBOO rig fishing zones in 2019, at concentrations ≤61.4 ppb (Table 8.8).

The PAH values were recorded in a single sample from RF1 and a single sample from RF4 (Figure 8.8). Historically, PAH detection rates were 0–7% per species (or species group) in muscle tissue samples, with highly variable concentrations

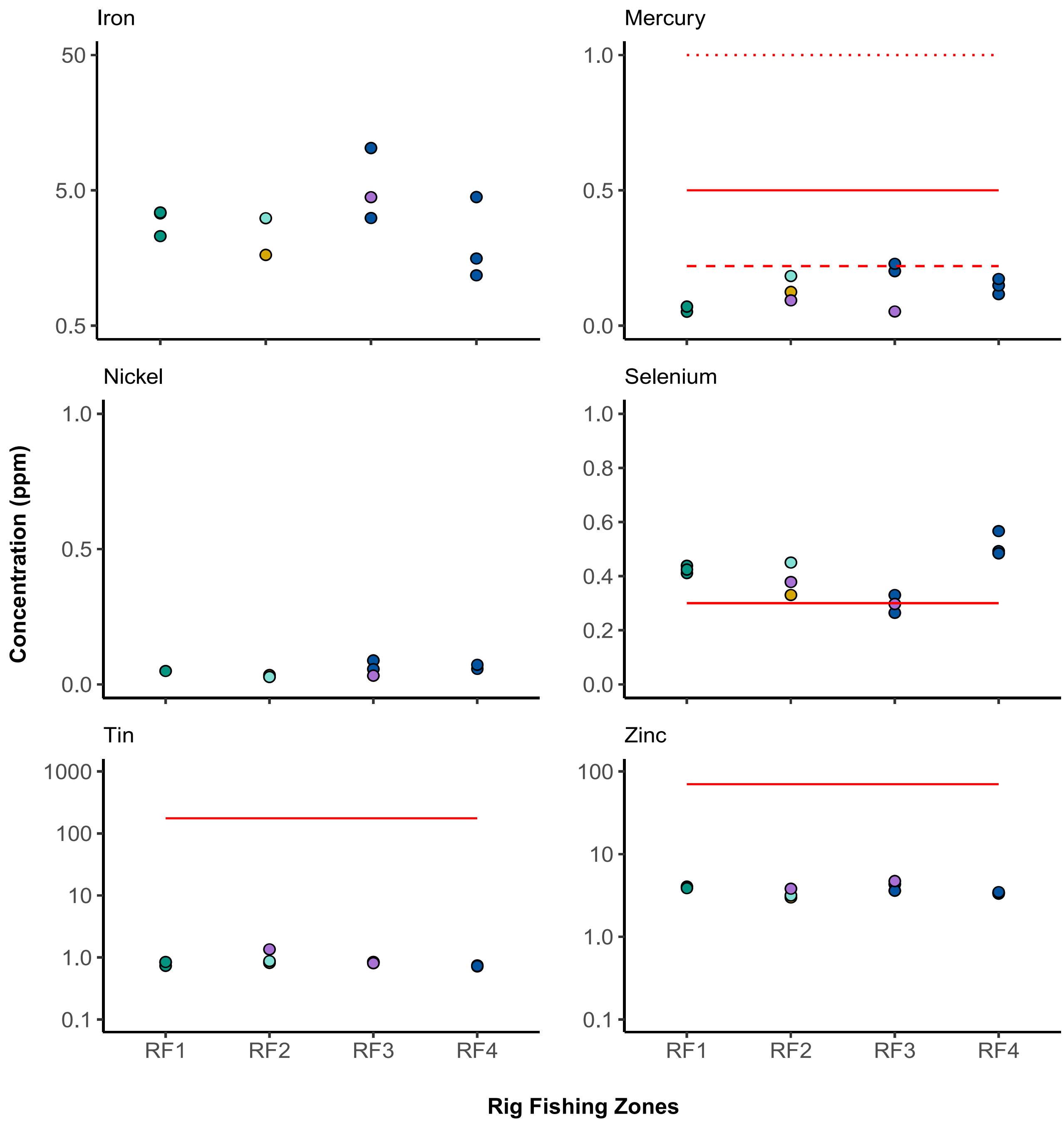

Figure 8.6 *continued*

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 discernable patterns that could be associated with proximity to either outfall (Table 8.9, Appendix J.7).

Lipids

During 2019, lipid levels in fish muscle tissue samples from PLOO and SBOO rig fishing zones were generally much lower than levels found in liver tissues, a pattern that is similar to historical results observed since 1995 (Tables 8.4, 8.8, 8.9). Muscle lipid content was $<1\%$ weight for the current reporting period and $\leq 4.4\%$ weight over the past 25 years for all species (or species groups). These low lipid concentrations indicate that these species do not store fat in their muscle tissues (see Groce 2002), which likely explains some of the generally lower levels of contaminants found in these tissues.

Table 8.7

Summary of metals (ppm) in muscle tissues of fishes collected from PLOO and SBOO rig fishing zones from 1995 through 2019. 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	130	130	130	91	130	130	130	130	130	130	130	128	130	130	130	124	130	130
	DR%	38	9	84	47	4	24	56	59	76	3	38	96	12	99	5	15	42	99
	min	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	max	22.10	1.11	13.50	0.19	0.042	0.180	1.780	8.96	257.00	0.42	5.30	0.790	0.378	0.730	0.50	2.93	2.12	5.90
	mean	6.40	0.62	2.66	0.06	0.010	0.069	0.251	1.01	7.51	0.29	0.59	0.161	0.146	0.396	0.12	1.27	0.96	3.69
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	—	—	—	—	—	—	—	—	3.20	—	—	0.230	—	nd	—	—	—	nd
	max	—	—	—	—	—	—	—	—	6.65	—	—	0.362	—	0.710	—	—	—	5.01
	mean	—	—	—	—	—	—	—	—	4.64	—	—	0.294	—	0.663	—	—	—	4.41
	California Scorpionfish																		
	n	76	76	76	43	76	76	76	76	76	76	76	76	76	76	76	73	76	76
	DR%	41	1	71	40	5	20	47	67	79	5	26	96	9	93	4	19	32	100
	min	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.92
	max	19.40	0.23	5.35	0.15	0.03	0.08	2.21	5.11	21.20	0.38	1.85	1.540	0.221	0.630	0.11	2.74	1.96	6.77
	mean	6.49	0.23	2.42	0.06	0.01	0.05	0.29	1.11	5.43	0.28	0.18	0.199	0.103	0.263	0.09	1.06	0.84	3.91
	Mixed Rockfish																		
	n	57	57	57	48	57	57	57	57	57	57	57	57	57	57	57	55	57	57
	DR%	35	16	91	54	0	23	79	72	70	4	53	95	18	100	4	25	54	100
	min	nd	nd	nd	nd	—	nd	nd	nd	nd	nd	nd	nd	nd	0.144	nd	nd	nd	1.42
	max	16.10	1.57	11.20	0.20	—	0.20	0.81	3.80	9.50	0.44	2.60	0.330	0.730	0.740	0.07	2.87	2.43	6.16
	mean	5.64	0.77	2.33	0.06	—	0.10	0.26	0.67	3.59	0.38	0.20	0.098	0.202	0.302	0.07	1.13	0.95	3.78
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

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 monitoring regions in 2019. Many of the same metals, pesticides, PCBs, and PAHs were detected during this reporting period, as have been documented historically in California Scorpionfish and rockfish muscle tissues, albeit generally less frequently and/or in lower concentrations. Although tissue contaminant concentrations varied among different species of fish and across 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 year, arsenic and selenium were found to exceed their median international standards for human consumption in ≥83% of the muscle tissue samples from sport fish collected in the PLOO and SBOO regions. In contrast, all muscle tissue samples 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 collected from both survey areas.

The frequent occurrence of different trace metals and chlorinated hydrocarbons in the tissues of fish collected from the PLOO and SBOO regions is likely influenced by multiple factors. For example, 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 and among individuals of the same species depending on migration pathways (Otway 1991). Fishes may be exposed to contaminants in a highly polluted area and then move into areas free of contamination. 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, San Diego Bay, Tijuana River, and offshore dredged material disposal sites (see Chapters 2–4 and Parnell et al. 2008). However, 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 2019 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 with 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, 2015a, Parnell et al. 2008). Finally, there were no other indications of poor fish health in the region, such as the presence of fin rot or other indicators of disease (see Chapter 7).

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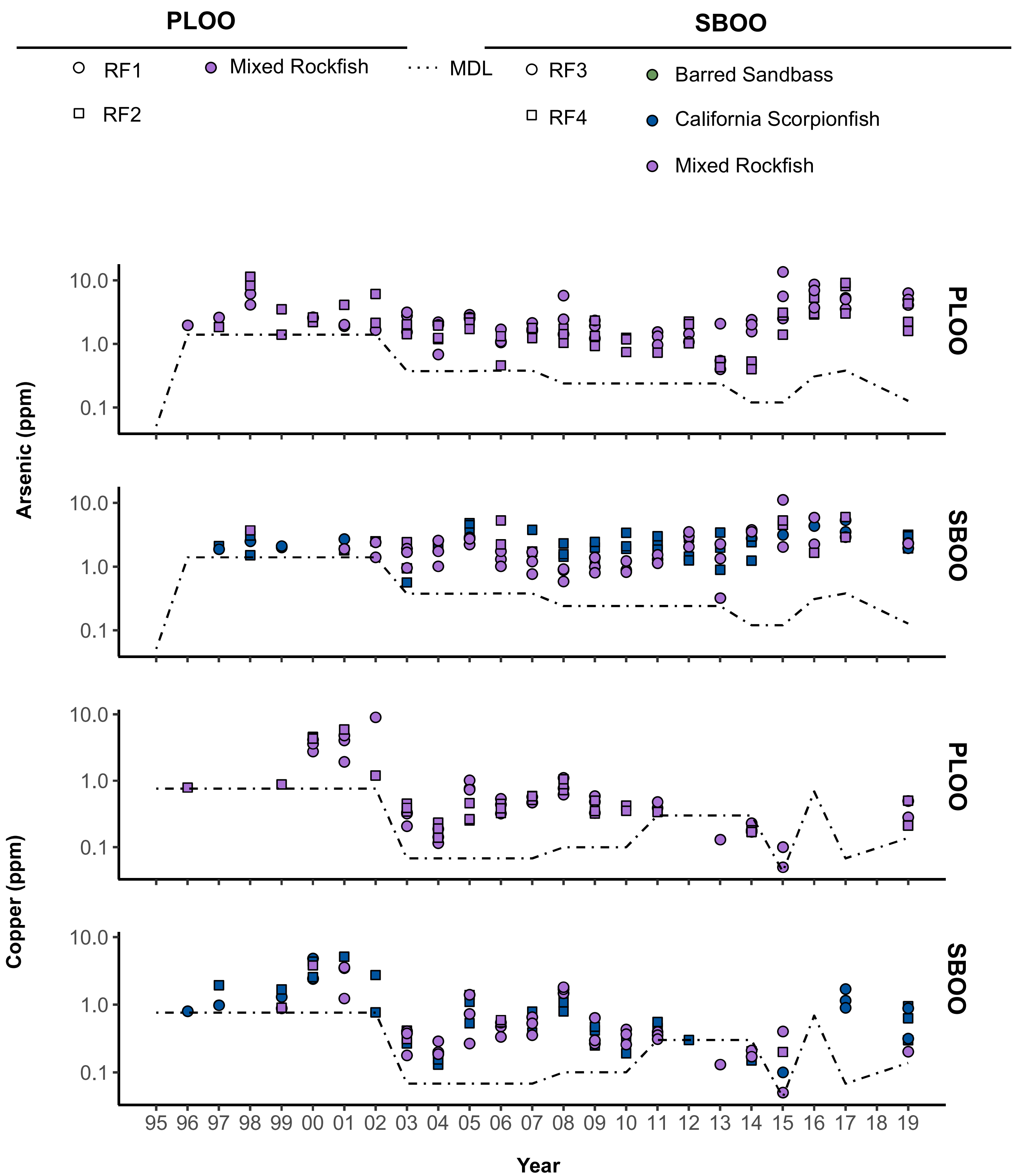

Figure 8.7
Concentrations of select metals detected in muscle tissues of fishes collected from PLOO and SBOO rig fishing zones from 1995 through 2019. Zones RF1 and RF3 are considered nearfield. No samples were collected in 2018 (see text).

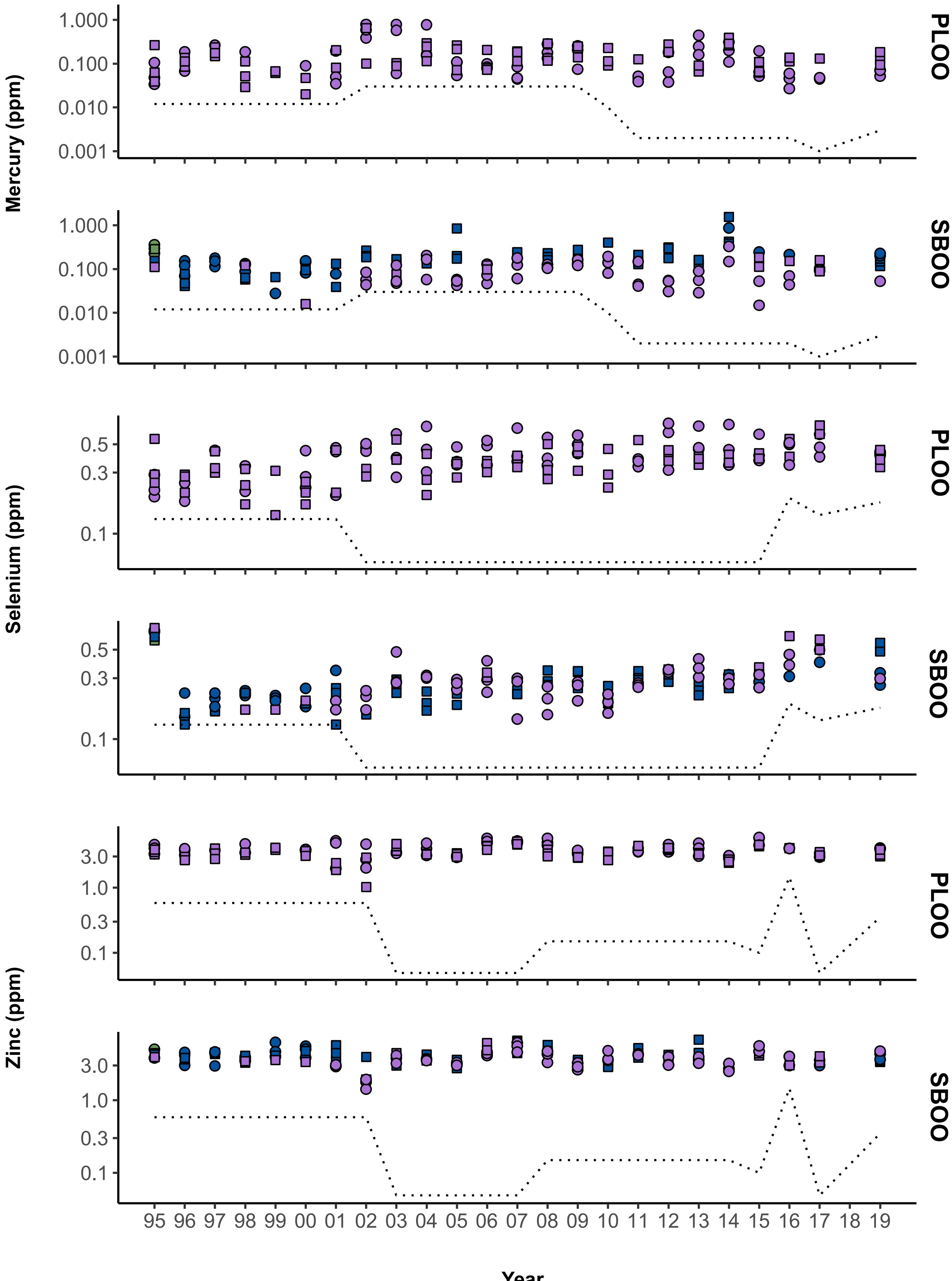

Figure 8.7 *continued*

Table 8.8

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 stations during 2019. 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; na = not available. See Addendum 8-4 for missing parameters, and Addendum 8-7 for values of individual constituents summed for total chlordane (tChlor), tDDT, tHCH, tPCB, and tPAH. IS = international standard.

		Pesticide							
		tChlor	tDDT	Dieldrin	HCB	tHCH	tPCB	tPAH	Lipids
PLOO	Vermilion Rockfish								
	n	3	3	1	1	1	3	1	3
	Min	nd	5.6	nd	nd	nd	3.0	nd	0.4
	Max	0.3	11.9	0.1	4.8	0.07	6.6	61.4	1.0
	Mean	0.1	7.9	0.1	4.8	0.07	4.8	61.4	0.6
	Greenstriped Rockfish								
	n	0	1	0	1	0	1	0	1
	Value	—	3.1	—	1.3	—	1.7	—	0.3
	Mixed Rockfish								
	n	0	1	0	0	0	1	0	1
	Value	—	6.1	—	—	—	2.3	—	0.4
	Starry Rockfish								
	n	0	1	0	0	1	1	0	1
	Value	—	5.5	—	—	0.04	2.1	—	0.3
	Total Samples	6	6	6	2	6	6	6	6
	Detection rate(%)	50	100	17	100	33	100	17	100
	Max	0.3	11.9	0.1	4.8	0.07	6.6	61.4	1.0
SBOO	California Scorpionfish								
	n	3	5	0	0	1	5	1	5
	Min	nd	1.2	—	—	nd	0.3	nd	0.1
	Max	0.2	34.9	—	—	0.09	11.0	14.1	0.7
	Mean	0.1	13.0	—	—	0.09	4.9	14.1	0.3
	Mixed Rockfish								
	n	0	0	0	0	0	1	0	1
	Value	—	—	—	—	—	0.36	—	0.2
	Total Samples	6	6	6	1	6	6	6	6
	Detection rate(%)	50	83	0	0	17	100	17	100
	Max	0.2	34.9	—	—	0.09	11.0	14.1	0.7
	OEHHA[b]	5.6	21	na	na	na	3.6	na	—
	USFDA Action Limit[c]	na	5000	na	300	na	na	na	—
	Median IS[c]	100	5000	na	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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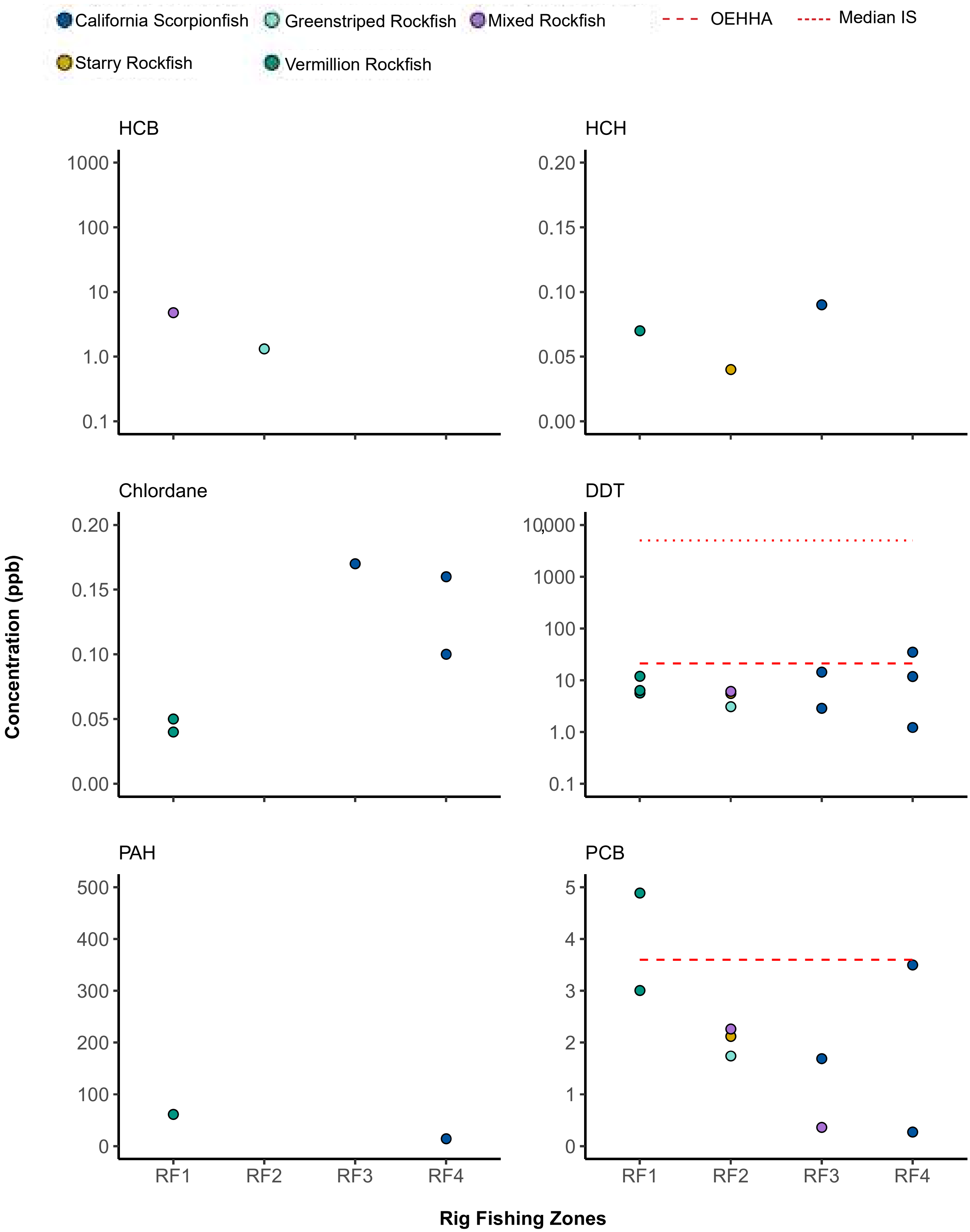

Figure 8.8
Concentrations of pesticides, total PCB and total PAH in muscle tissues of fishes collected from each PLOO and SBOO rig fishing zone during 2019. Zones RF1 and RF3 are considered nearfield.

Table 8.9

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 2019. 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	Dieldrin	HCB	tHCH	tPCB	tPAH	Lipids
PLOO	Mixed Rockfish								
	n	130	130	118	120	130	130	57	130
	DR (%)	19	95	1	59	12	76	7	99
	min	nd	nd	nd	nd	nd	nd	nd	0.0
	max	4.3	217.3	0.1	15.0	13.40	76.8	360.1	4.4
	mean	0.9	13.6	0.1	0.6	1.09	7.3	151.0	0.9
SBOO	Barred Sand Bass								
	n	4	4	4	4	4	4	4	4
	DR (%)	0	50	0	0	0	75	0	100
	min	—	nd	—	—	—	nd	—	0.7
	max	—	13.0	—	—	—	32.0	—	1.4
	mean	—	9.6	—	—	—	20.0	—	1.0
	California Scorpionfish								
	n	72	72	70	67	72	76	55	76
	DR (%)	7	94	0	19	3	74	4	100
	min	nd	nd	—	nd	nd	nd	nd	0.1
	max	1.0	195.7	—	0.4	0.09	49.3	22.7	2.6
	mean	0.3	17.9	—	0.2	0.06	4.7	18.4	0.6
	Mixed Rockfish								
	n	55	55	48	51	55	57	53	57
	DR (%)	7	82	0	43	13	77	4	100
	min	nd	nd	—	nd	nd	nd	nd	0.1
	max	0.2	15.1	—	7.2	0.90	5.6	35.0	3.0
	mean	0.1	3.5	—	0.5	0.35	1.2	25.1	0.6
OEHHA[b]		na	21	na	na	na	3.6	na	—
USFDA Action Limits[c]		300	5000	300	300	na	na	na	—
Median IS[c]		100	5000	100	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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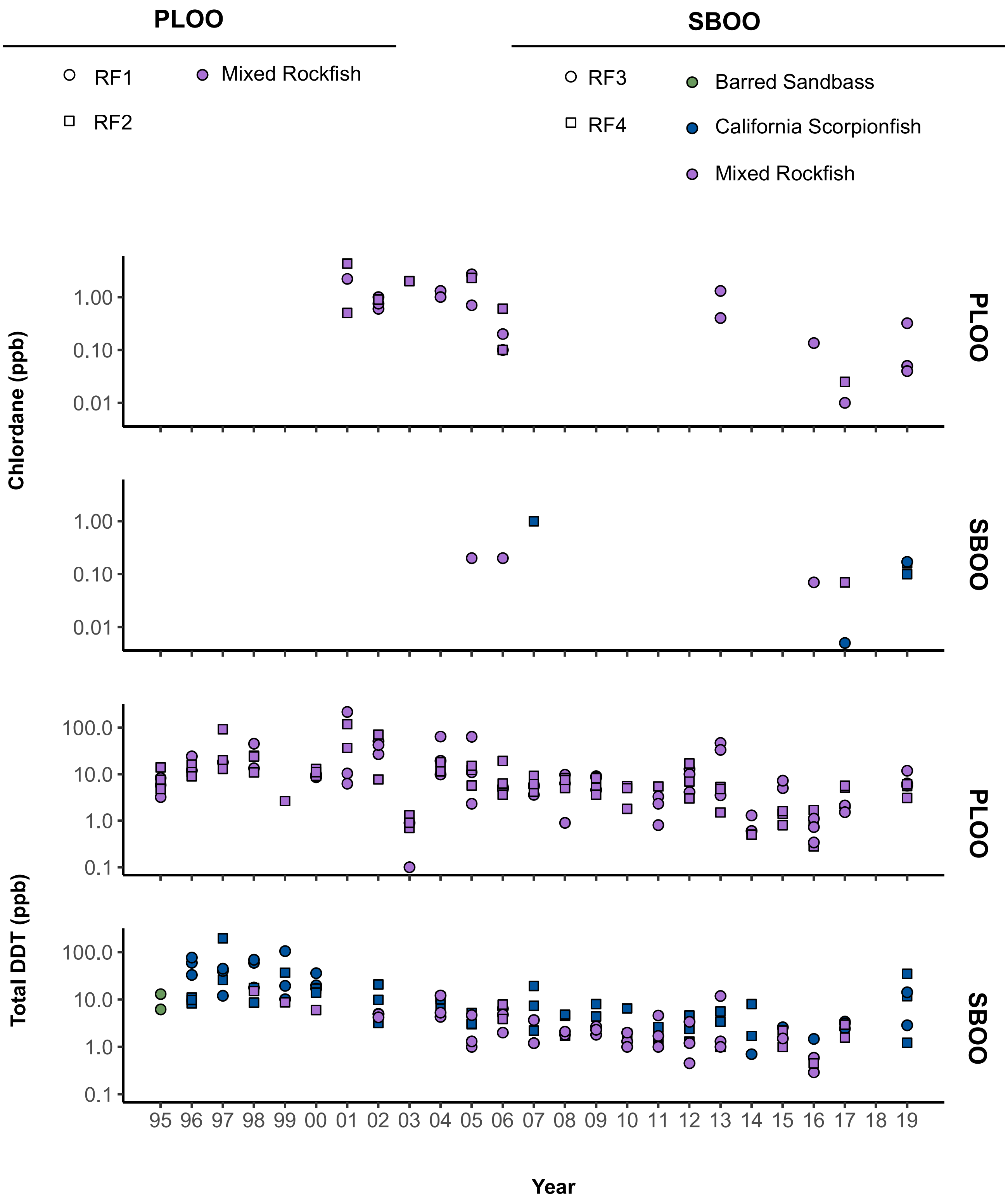

Figure 8.9
Concentrations of pesticides and total PCB in muscle tissues of fishes collected from PLOO and SBOO rig fishing zones from 1995 through 2019. Zones RF1 and RF3 are considered nearfield. No samples were collected in 2018 (see text).

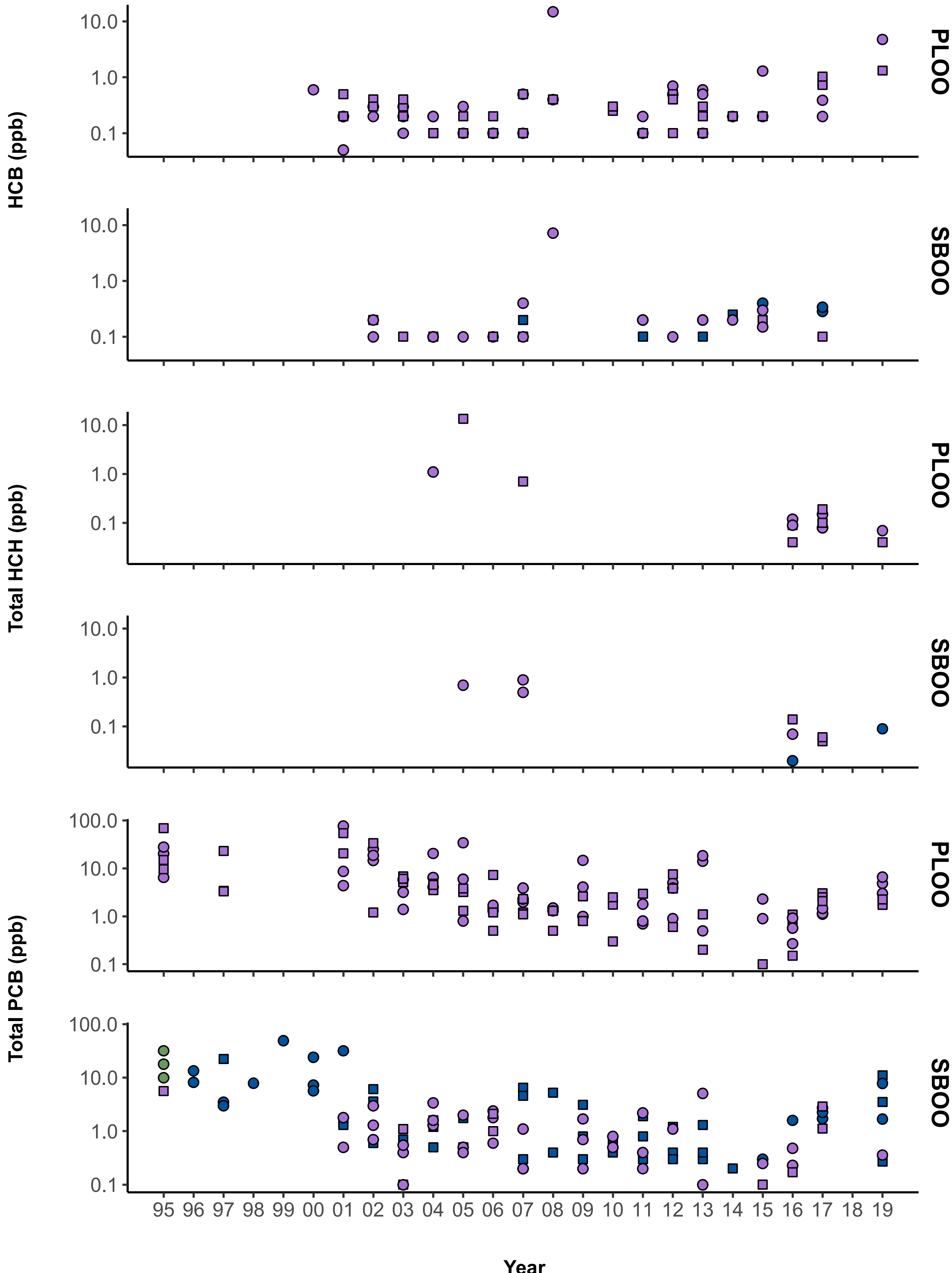

Figure 8.9 *continued*

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Appendices

Appendix A

Evaluation of Anthropogenic Impacts on the San Diego Coastal Kelp Forest Ecosystem (Biennial Project Report)

2018–2019

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Public Utilities Department
Contract No. H146233

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Appendix A. Evaluation of Anthropogenic Impacts on the San Diego Coastal Kelp Forest

Executive Summary

The City of San Diego (City) may be the most "ocean oriented" city in the world. The kelp forests off San Diego provide habitat to hundreds of species and are the focus of millions of dollars of commercial and recreational fishing. In fact, the Point Loma kelp forest is the largest kelp forest in the world and supports perhaps the most valuable commercial and recreational coastal fisheries in southern California. It is one of the most important areas for recreational diving in the country. Like coral reefs, kelp forests are one of the most charismatic marine communities, and because they are the most intensively studied kelp forests ecosystems worldwide, San Diego's kelp forests are an icon of the habitat. They represent the charismatic and valuable habitat in the minds of people worldwide. However, environmental perturbations associated with climate change are altering the local kelp forests in such a way that the giant kelp (*Macrocystis pyrifera*) itself may eventually disappear. Localized human impacts such as waterborne pollution can potentially accelerate this loss if not properly managed by interfering with kelp forest recovery after larger scale ocean climate disturbances.

Kelp forests are highly productive, characterized by the rapid growth of their structural species, *Macrocystis pyrifera*, whose 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 fishes and invertebrates as well as cohabiting species of algae. These forests occupy the inner margins of the continental shelf and offshore islands extending from the offshore edge of tidepools to depths as great as thirty 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. The kelp forests off Point Loma and La Jolla are among the most important commercial fishing grounds for the red sea urchin (*Mesocentrotus franciscanus*) and spiny lobster (*Panulirus interruptus*) fisheries off California. The kelp forests of La Jolla and Point Loma are the largest contiguous kelp forests off the western coast of the U.S. They host complex marine communities supported by their eponymous species, giant kelp (*M. pyrifera*), which provides structure and food for hundreds of species of fish and invertebrates.

Kelp forests off southern California are subjected to both natural and human-induced disturbance. El Niño Southern Oscillations (ENSO) are the primary ocean climate mode that affects kelp abundance, growth, and reproduction along the west coast of the Americas. Positive ENSOs known as El Niño are associated with warm water, depressed concentrations of nitrate (the principal nutrient limiting giant kelp), and a more energetic storm environment off southern California. Both phenomena can severely stress giant kelp and accompanying species of algae. The opposite conditions occur during negative ENSO events, termed La Niña, enhancing both the growth and reproduction of kelps. Together, the two ocean climate modes drive the greatest amount of annual variability in surface canopy cover of *Macrocystis pyrifera* off southern and Baja California. The periodicity of El Niño 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 Niño with recovery afterwards. Rates of recovery depend on growth conditions after an El Niño ebbs. The kelp forests off San Diego have been studied by researchers at the Scripps Institution of Oceanography (SIO), of UC San Diego, since the 1950s, and baseline data began in the 1970s. Currently, kelps and associated animals are monitored at twenty permanent study sites located among the Point Loma, La Jolla, and North County kelp forests.

During the current reporting period (2018–2019), the kelp forests off California have been recovering from 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. An anomalous surface warm pool extended across much of the NE Pacific from 2014–2015. This warm pool, unique in the climate record of the NE Pacific, was coined the BLOB and resulted from large scale wind patterns in the NE Pacific. This causative forcing is therefore different in nature and scale than ENSO cycles which are caused by anomalous winds along the equatorial Pacific. A strong El Niño occurred during fall of 2015 and the winter of 2016 just as the BLOB dissipated. Together, these consecutive warm periods are now referred to as the NE Pacific marine heat wave, and manifested as the longest and warmest period ever observed in the 104-year-old sea surface temperature record at the SIO pier. Cooler conditions returned to the equatorial eastern Pacific and the Southern California Bight (SCB) by late 2016. The spring upwelling seasons of 2017–2019 brought cool nutrient-laden waters up onto the inner continental shelf of southern California creating favorable conditions for giant kelp recovery. However, the variability of El Niño climate cycles is superimposed onto a larger scale trend of increasing ocean temperatures within the California Current System and the world's oceans generally, and it is likely that conditions supportive of giant kelp growth and reproduction will decrease in frequency and duration over the next century. As a result, deleterious effects due to climate are likely within the next decade. This will result in an increased susceptibility to anthropogenic stress and an overall decreased resilience after heat wave disturbances as the century progresses. Presently, however, there is no evidence of direct human stress on the marine algae of San Diego County due to wastewater discharge from the Point Loma Ocean Outfall (PLOO).

The marine heat wave and associated depressed nutrient conditions decimated *Macrocystis pyrifera* and cohabiting algal species off San Diego. Pooled across 20 kelp forest sites off San Diego, densities of adult *M. pyrifera* were reduced by more than 90%. Unlike previous warm events attributed to El Niño, the coupled marine heat wave resulted in warming and low nutrient exposure of understory kelp species for prolonged periods of time leading to dramatic reductions of those species in addition to giant kelp. 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. The two events affected kelp at the study sites differently, and the historic pattern of synchronized mortality and recovery was disrupted. Growth conditions returned to normal with the onset of mild La Niña conditions in the spring of 2017. Rates of giant kelp recovery have since varied among study sites and were initially slower than previous recovery periods and non-existent at some study sites. Surface canopy cover in some areas was precluded by increases in understory species density. Some of these areas will likely remain devoid of giant kelp canopy for years since understory species are long-lived and competitively interfere with giant kelp recruitment. Favorable conditions for kelp growth and reproduction returned with the 2018 spring upwelling season and continued through 2019. Numerous study sites experienced significant giant kelp recruitment that has successfully matured. However, the giant kelp canopy off San Diego County remains patchy due to a combination of competition with understory species in the shallower margins of the kelp forests and a lack of recruitment in many deeper areas through early 2018, likely due to decreased light levels caused by phytoplankton blooms. Giant kelp is presently recovering in those areas as the deeper sites experienced recruitment in 2018 and 2019.

An anomalously warm surface layer, limited to the upper 3–5 meters of the ocean's surface, bathed much of the southern California coast during the summer of 2018. Sea surface temperatures reached 27°C, exceeding the all-time high temperature record for the SIO Pier sea surface temperature series by ~2°C. Summer surface temperature maxima in this record are typically ~23°C. This surface warm pool degraded the giant kelp canopy tissue, which was mostly lost from the offshore forests and drifted onto nearby beaches. However, cooler temperatures persisted closer to the bottom, and most of the giant kelp plants in the initial recovery cohorts of 2017 and 2018 survived and regrew to the surface when the warm pool dissipated by the fall of 2018. The marine heat wave decimated what remained of the North County kelp forests and the warm surface anomaly resulted in almost total loss of giant kelp within these forests. Recruitment in these forests has been extremely limited and unsuccessful.

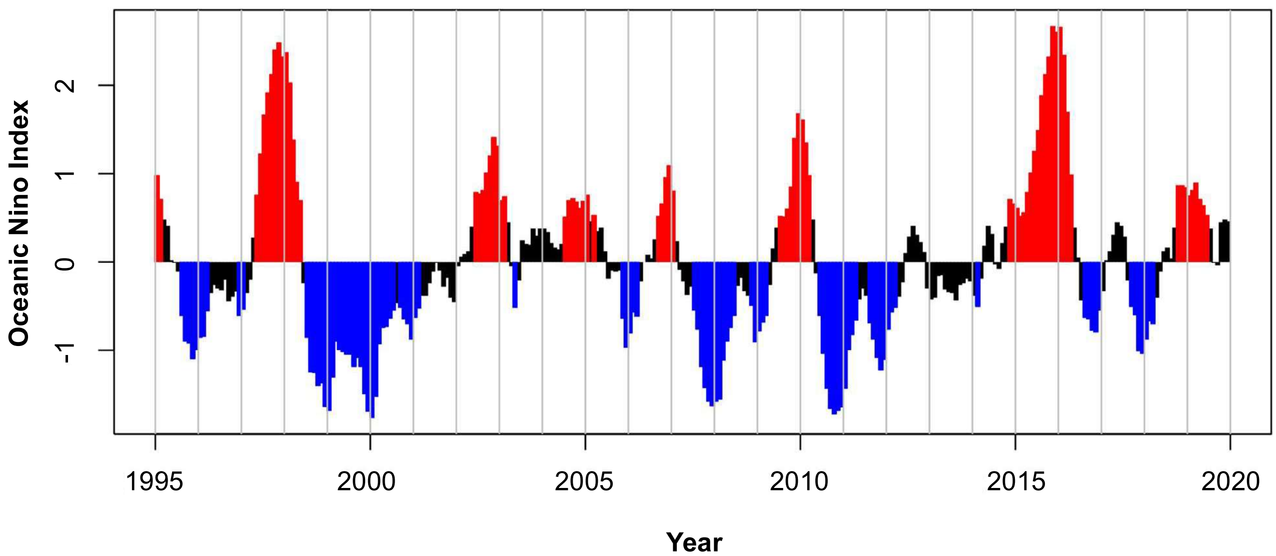
Presently, giant kelp densities are ~20% of their all-time historic highs when averaged across the longest observed study sites off Point Loma (since 1983). Giant kelp stipe densities (the metric most related to surface canopy cover) is presently ~47% of the all-time high, which was observed in 2012. Giant kelp densities are currently the greatest in the northern and central portions of the Point Loma kelp forest, and the southern portions of the La Jolla kelp forest. Giant kelp densities are near, or at, zero in all North County kelp forests, including areas off Del Mar, Solana Beach, and Cardiff.

Diseases in many invertebrates, including sea urchins (echinoids) and predatory seastars (asteroids), are common during warm events. Mass mortality of red (*Mesocentrotus franciscanus*) and 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 was observed until 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, can persist in some areas for decades. The kelp recovery that began in 2017 and continued into 2018 has not been affected by these young sea urchin cohorts due to their low adult densities and small size. However, the 2017–2018 sea urchin cohort may eventually overgraze some areas off San Diego as this cohort emerges from nursery habitat and begins to actively forage. This cohort could lead to overgrazing in some areas of the kelp forests especially in south Point Loma where a unique combination of topography and turbidity emanating from San Diego Bay contribute to resilient barrens. Some recruitment of the seastars *Pisaster giganteus* and *Patiria miniata*, two important kelp forest predators, has been observed off Point Loma and La Jolla. However, adult densities are presently near zero and it is difficult to predict whether the initial bouts of post-disease recruitment will be adequate to recover their populations anytime soon.

Abalone, another important kelp forest grazer and the target of a once extensive fishery, depend primarily on giant kelp for food. Abalone once supported a large recreational and commercial fishery off southern California until all harvest was closed in 1996 due to depletion from overfishing and disease associated with warm periods. Abalone off San Diego County suffered further mortality during and after the warm event of 2014–2016 due to disease and lack of food. Abundances of all abalone species at the study sites off La Jolla and Point Loma have since declined to near zero with the exception of pink abalone (*Haliotis corrugata*) where there has been some recovery at the two shallowest study sites that began around 2010.

The La Niña conditions that occurred during 2017 and 2018 and resulted in kelp recovery off San Diego County shifted to El Niño conditions in the eastern equatorial Pacific. However, conditions have since been neutral, and no El Niño is forecast through all of 2020. The mild equatorial El Niño of 2019 did not prevent spring upwelling in 2019, and bottom temperatures have remained conducive for kelp recruitment and growth since the fall of 2017. Giant kelp off San Diego County should continue to increase in aerial cover through the spring and early summer of 2020.

Sargassum horneri, an invasive algal species that has replaced patches of giant kelp in some protected kelp forests off southern California, was first observed in the kelp forests off San Diego in 2014. By 2018, this species had been observed at 13 of



Appendix A.1

Barplot of the Oceanic Nino Index (ONI) since 1995. Red bars indicate El Niño conditions, blue bars indicate La Nina conditions, and black bars indicate ENSO neutral conditions (data from NOAA, 2020). The ONI index is based on equatorial sea surface temperatures in the Eastern Pacific.

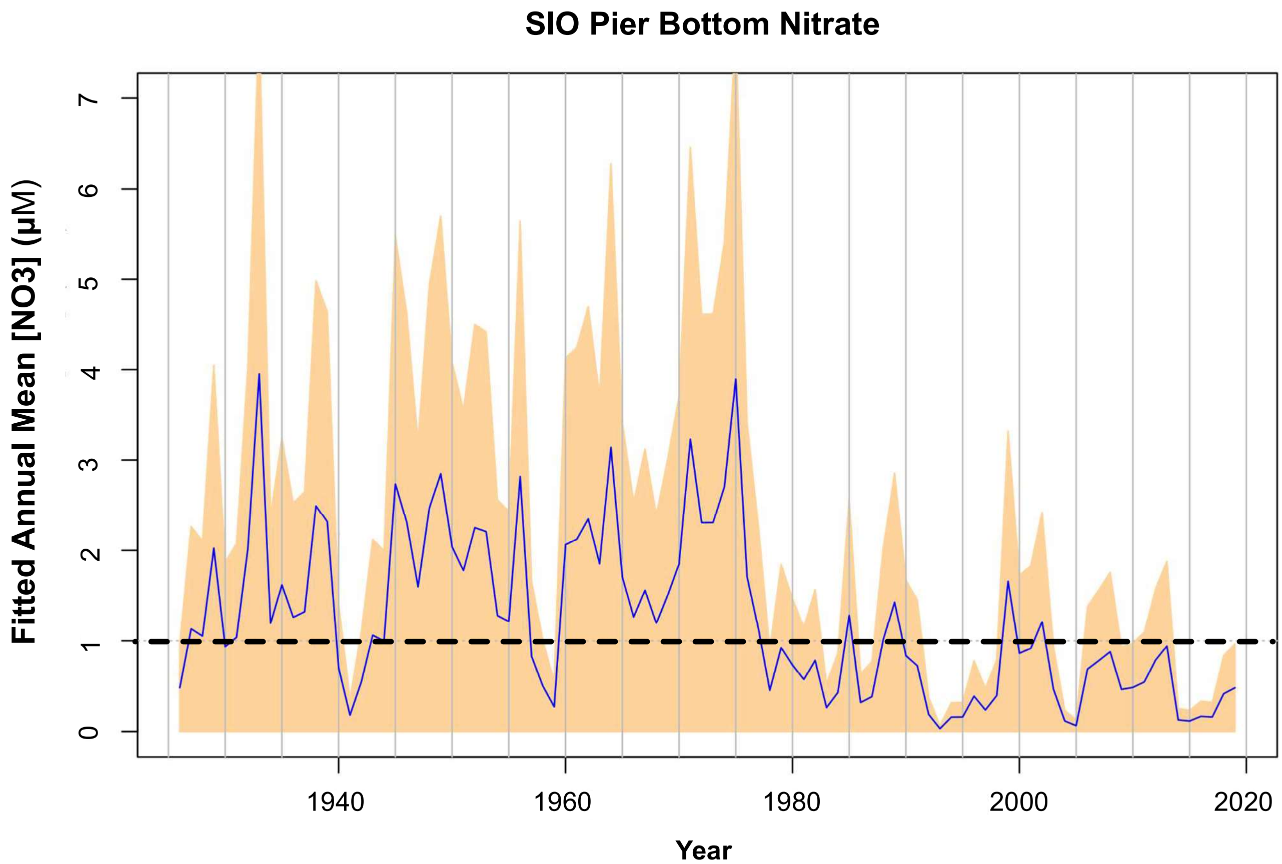
20 study sites, most densely off the deeper portions of the La Jolla kelp forest. However, it has not appeared at any of the remaining study sites through 2019, and has not increased in coverage at the sites where it has been observed. Therefore, this species may not pose as great a risk to San Diego County forests as it has to protected kelp forests off some of the California Channel Islands and mainland.

Introduction

Kelp forests are susceptible to human disturbance because of their proximity to urbanized coasts exposing them to overfishing, polluted surface and groundwater discharge, as well as the discharge of wastewater. Perhaps the largest effect is that due to increased turbidity which limits light penetration for kelps to grow, germinate, and reproduce (Clendenning and North 1960). Dramatic reductions in kelp forest canopy off Palos Verdes have been attributed to the combined effects of wastewater disposal and an energetic El Niño in the late 1950s (Grigg 1978). Nearshore turbidity, due to wastewater discharge, has since been mitigated by increasing the offshore distances and depths of discharge, and improved outfall design (Roberts 1991). Beach replenishment can also negatively impact kelp forests via sedimentation and burial. This has been observed at kelp forests off northern San Diego County where replenished sediments erode from beaches and partially bury the low relief kelp supporting habitat as eroded sediments redistribute offshore.

The PLOO discharges advanced primary treated wastewater through a deep-water open ocean outfall. The PLOO was extended into deeper waters in 1993, and presently discharges treated wastewater ~7.2 km offshore in marine waters ~98 m deep. The PLOO is situated approximately 5 km offshore of the outer edge of the Point Loma kelp forest. Due to its proximity, wastewater discharge through the PLOO presents at the very least a perceived risk to the health of the nearby kelp forest community off Point Loma. Local human risks to kelp forests can magnify risks posed by larger scale natural disturbances by reducing the resilience of kelp forests after episodic natural disturbances.

Kelp forests in southern California are disturbed naturally by ocean climate variability that occurs on an interannual (ENSO) (Appendix A.1) and



Appendix A.2

Time series of annual mean nitrate concentrations estimated from daily temperature and salinity sampled 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 (1 µM) for the growth of giant kelp (*M. pyrifera)*. Peach area indicates the 95% confidence limits.

decadal cycle (Pacific Decadal Oscillation - PDO). Positive phases of both ocean climate cycles are associated with a deepened thermocline limiting nutrient delivery to the inner shelf that is necessary for kelp growth and reproduction. These cycles are also associated with increased storm energy which causes giant kelp mortality via plant detachment and abrasion (Seymour et al. 1989). The northeastern Pacific experienced a profound shift in the late 1970s in which the main ocean thermocline deepened, resulting in a steep reduction in nitrate concentrations along the SCB that still persists (Parnell et al. 2010) (Appendix A.2). Concentrations of nitrate, the main limiting nutrient for kelp growth in southern California switched from being conducive for kelp growth most years prior to the shift, with the exception of the most intense El Niño events, to being less adequate most of the time (Parnell et al. 2010) with the exception of strong negative ENSO phases known as La Niña. 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 *Macrocystis pyrifera* individuals (Parnell et al. 2010).

Sea urchin overgrazing is another form of natural disturbance within kelp forests (Leighton et al. 1966). Kelps 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 have been termed barrens. Barrens can be resilient in some areas such as in the southern portion of the Point Loma kelp forest (Parnell 2015), or can alternate with forested periods 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). Overfishing of sea urchin predators, such as spiny lobsters (*Panulirus interruptus*) and California sheephead wrasse (*Semicossyphus pulcher*) in southern California can lead to outbreaks of sea urchin overgrazing.

A more recent source of disturbance has been the introduction of an invasive alga, *Sargassum horneri*, throughout southern California. This species competes with *Macrocystis 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). *S. horneri* is now establishing itself in many areas off San Diego County including the kelp forests, bays, and estuaries.

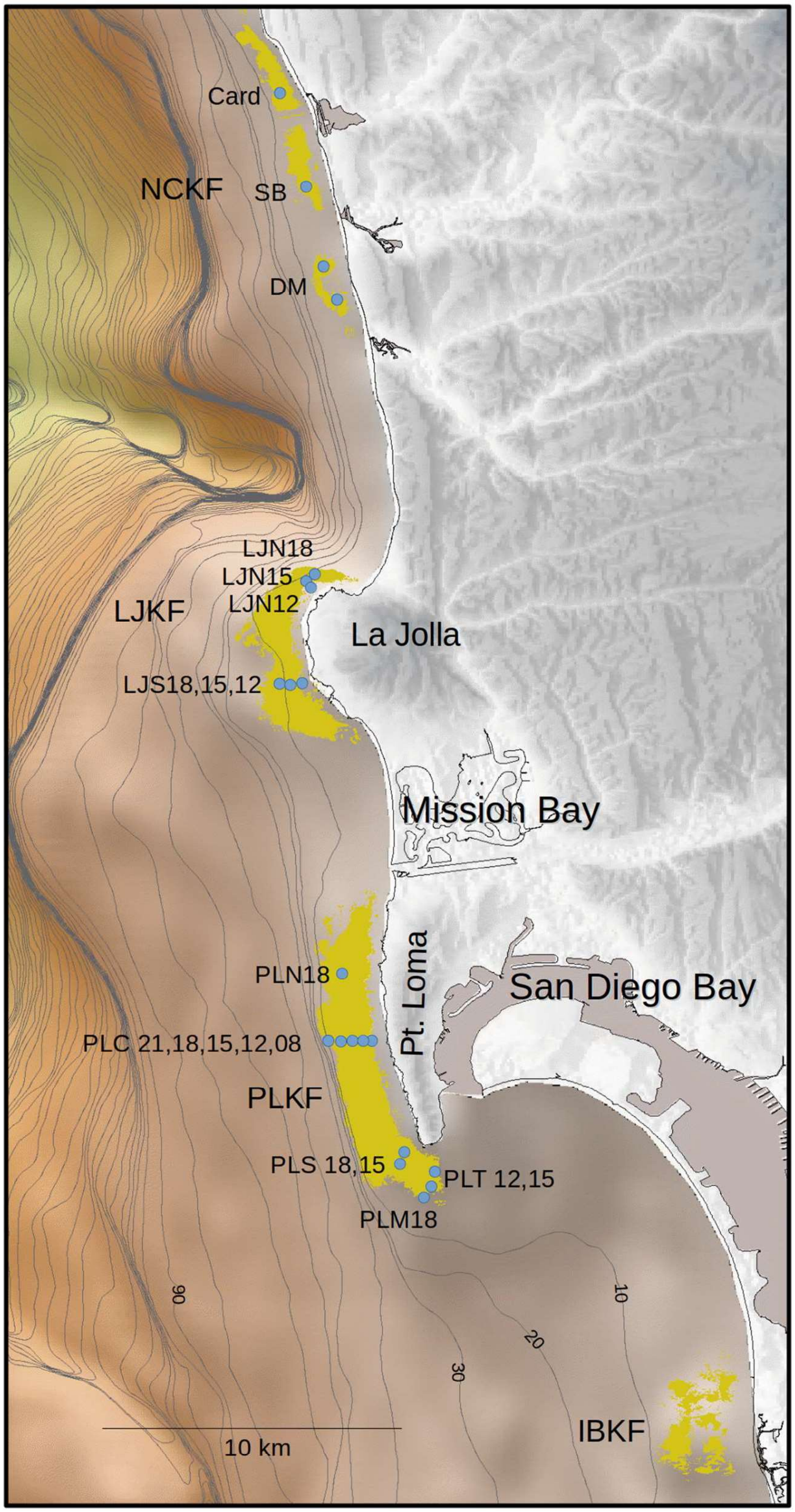
Researchers at SIO have partnered with the City to conduct regular surveys of the kelp forests off San Diego County including the kelp forests off Point Loma, La Jolla and North County. These surveys represent a continuation of ecological studies that began at SIO in the Point Loma (PLKF) and La Jolla (LJKF) kelp forests and continue at some of the sites established in the 1970 and 1980 (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 (North County - NCKF). PLKF and LJKF are the largest contiguous kelp forests off the western United States coast and are historically one of the most studied kelp forest systems in the world.

Materials and Methods

Algae, invertebrates and bottom temperatures are monitored at twenty permanently established study sites (Appendix A.3). Algae and invertebrates are monitored along four replicate parallel permanent band transects oriented perpendicular to shore (25 x 4 m bands separated 3–5 m apart) except at the 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) ocean bottom temperature (which is a proxy of ocean nutrient status). The types of data collected and the frequency of collection are listed in Appendix A.4.

Several life stages of *Macrocystis pyrifera* are enumerated to identify recruitment events and follow the fate of recruiting cohorts into adulthood. Survival of recruitment cohorts to adulthood is highly variable and a lack of successful maturation into adulthood indicates changes in the growth environment in the form of stress by temperature and nutrients, grazers, and/or reduced light. Giant kelp life stages include adults (≥ 4 stipes), pre-adults (plants > 1 m tall but with < 4 stipes), bifurcates (a late post recruitment stage indicated by the presence of a split in the apical meristem which represents the primary dichotomous branching event), and pre-bifurcates (very early post settlement stage lacking the initial dichotomous split). The number of stipes is counted and recorded for each adult plant each visit.

Conspicuous macroalgal species/groups are enumerated or percent cover is estimated within 5 x 2 m (10 m^2) contiguous quadrats along the band transect lines at all sites. Reproduction and growth of *Macrocystis pyrifera*, and the understory kelps *Pterygophora californica* and *Laminaria farlowii*, are measured on permanently tagged plants along the central Point Loma study sites. All conspicuous sessile and mobile invertebrates are enumerated annually within the 10 m^2 quadrats during spring. Size frequencies of red (RSU - *Mesocentrotus franciscanus*) and purple (PSU - *Strongylocentrotus purpuratus*) sea urchins are recorded for > 100 individuals of each species located near all of the study sites except for the NCKF sites which do not have 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.



Appendix A.3

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

Appendix A.4

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)

Bottom temperature is recorded at 10 min 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 *Macrocystis 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 height and diameter of each bundle. This is an indirect measure of reproductive effort. 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 ordinal scale in Appendix A.5.

Growth of *Pterygophora californica* is determined by the method of DeWreede (1984). A hole (6 mm) is punched into 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. 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. Sori are the sites of active spore production in ferns, fungi, and algae and consist

Appendix A.5

Ordinal ranking criteria for *Macrocystis pyrifera* reproductive state.

Reproductive Score	Description
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 zoospore

of clusters of spore producing sporangia. 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 and 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 Point Loma and La Jolla 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 returned to where they were collected.

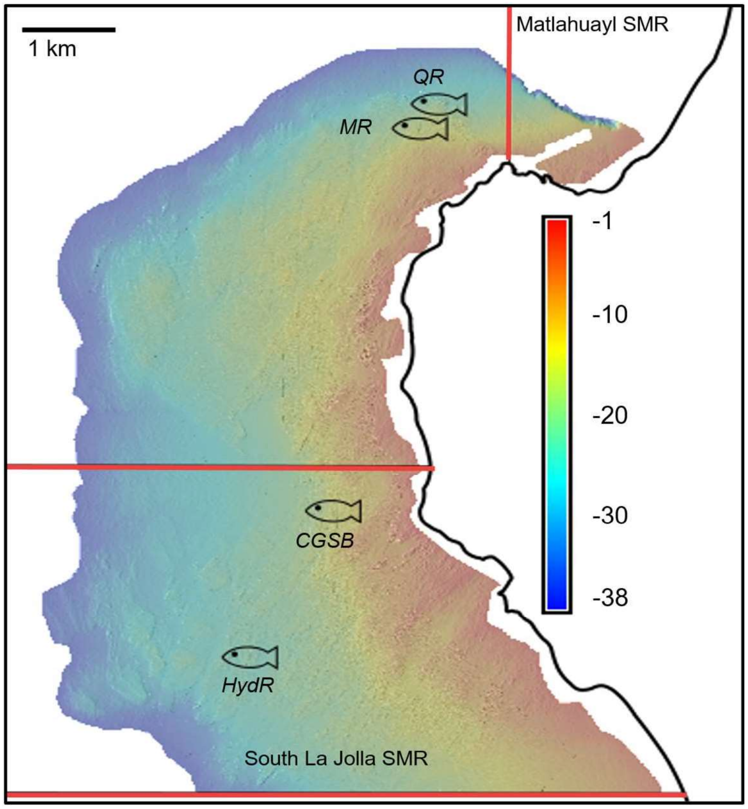
The distribution of algal species among all permanent sites was calculated using factor analysis in R (R Core Team 2018). Factor analysis (Lawley and Maxwell 1971) was used to reduce the multi-dimensional algal data. This technique facilitates the examination of entire algal communities in two or three dimensions that can then be plotted to determine community composition differences among study sites and over time. 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.

Fish surveys were initiated in the fall of 2019 and will continue semi-annually (fall/spring) at four sites within the LJKF (Appendix A.6) and three sites within the PLKF (Appendix A.7). Sites were chosen based on topographic features that fish are known to prefer and are as similar as possible in reef size and rugosity based on previously collected bathymetric data (Parnell 2015). Sites were paired within the LJKF where a large marine protected area (MPA, South La Jolla State Marine Reserve) is located in the southern half (Appendix A.6). The take of all species is prohibited within the MPA which went into effect in 2012. Study sites within the LJKF and PLKF were paired by depth (21 and 15 m) to facilitate comparisons of the fish communities inside and outside the MPA (Appendix A.8). Fish counts are conducted along replicate 30 x 4 m band transects (up to 3 m off the bottom) which include an initial swimming count for conspicuous species followed by a thorough search for cryptic species using a light.

Results and Discussion

Ocean Climate

The ENSO index (ONI – Oceanic Nino Index) (Appendix A.1) is based on equatorial sea surface temperatures in the eastern Pacific Ocean. ENSO warming and cooling of the west coast of the Americas propagates poleward from the tropics, and each El Niño or La Niña event penetrates higher latitudes differently. Therefore, while

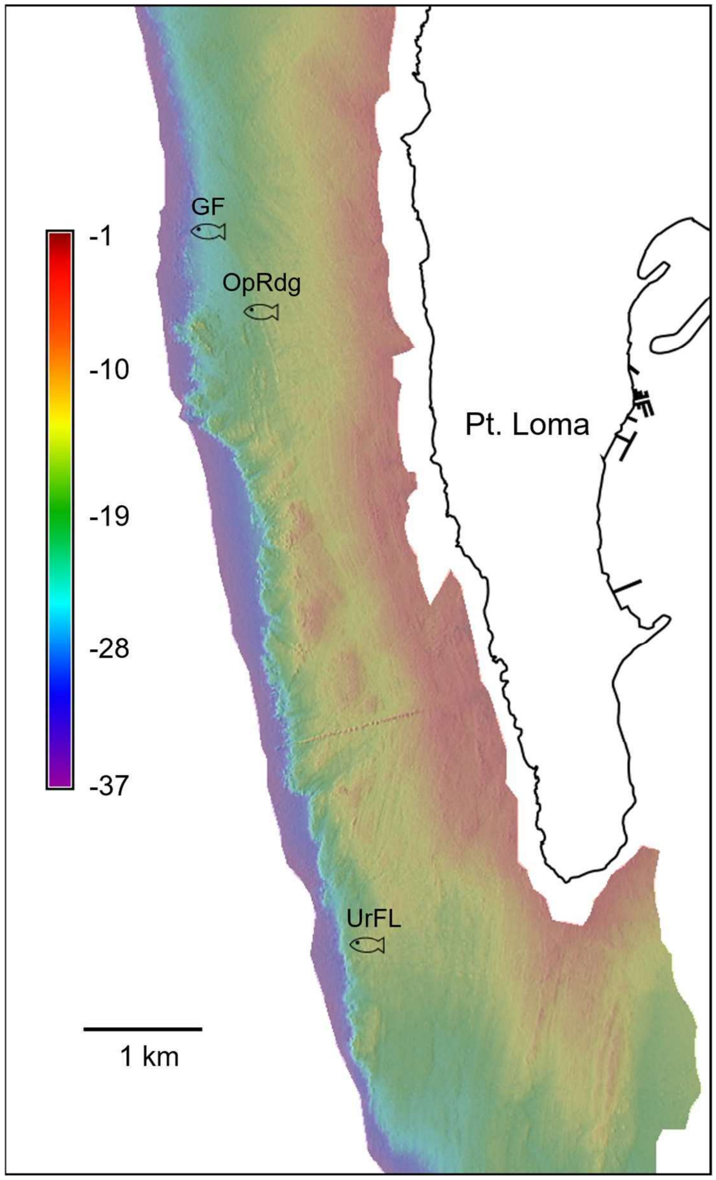


Appendix A.6

Locations of fish survey study sites within the La Jolla kelp forest. Color legend indicates depth in meters. The red lines indicate boundaries of the marine protect areas (SMR = State Marine Reserve).

correlated, the magnitudes of ENSO events at the equator and temperatures along the SCB can be somewhat decoupled.

The bottom temperature record at the central Point Loma study sites extends back to 1983 when the strong 1982/1983 El Niño was ebbing. Since then, the largest temperature signals in the time series include the 1997/98 El Niño and the extended warm period of 2014–2015 that occurred during the present study and was associated with a large scale anomalous NE Pacific warm event (Di Lorenzo and Mantua 2016) termed the BLOB but more recently referred to as a marine heat wave. This was immediately followed by a strong El Niño in 2015/2016 (Appendices A.1, A.9, A.10). The ONI (Appendix A.1) and the Point Loma bottom temperature time series (Appendix A.9) are strongly concordant for the largest ocean climate events including the onset of the coupled BLOB/El Niño warm event beginning in late 2014 which began to ebb by the spring of 2016 immediately followed by cooler La Niña conditions in late 2016 and another cool period between fall 2018 and summer of 2019. The ONI and bottom temperatures off Point Loma indicate rapid cooling both periods separated by a moderate warm event beginning late 2017. An anomalous temperature event occurred during the summer of 2018 in which surface waters (upper 3–5 m) exceeded 27°C and stayed warm through most of the summer. This event was not observed at the bottom at any of the study sites as it was limited to near surface waters, but was evident in the Scripps Pier temperature time series (Appendix A.10) and included the warmest temperatures ever observed in the 103-year time series. This warm event caused significant deterioration of the giant kelp surface canopy which virtually disappeared over the summer. However, most plants were still growing and healthy beneath the warm surface layer at the study sites where recovery from the BLOB/ El Niño warm event had occurred, because bottom temperatures remained relatively cool during the summer of 2018. Bottom and surface



Appendix A.7

Locations of fish survey study sites within the Point Loma kelp forest. Color legend indicates depth in meters.

temperatures cooled in 2019 particularly during the spring and summer upwelling periods when nutrient conditions for giant kelp growth and reproduction improved (see Appendix A.9).

Less pronounced warm periods occurred between the 1997/1998 and 2016/2017 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 also decreases with depth. This physical forcing is a fundamental mechanism that controls space competition between understory and canopy kelps. Strong El Niño events, such as the 1997/1998 El Niño and the 2014–2016 marine heat wave, penetrate to the bottom for extended periods even at the offshore edge of the forest stressing all kelps including understory species. By contrast, milder El Niño events do not typically penetrate to the bottom of the forests for extended periods (e.g., > 1 month), and therefore primarily stress the surface canopy kelps (mainly *Macrocystis pyrifera*) more than the understory kelps where temperatures are cooler. Repeated

Appendix A.8

Site details and species richness for fish surveys.

Site	Kelp Forest	Depth (m)	MPA	MPA Pairings	Species Richness
QR	La Jolla	21	No	A	12
HydR	La Jolla	21	Matlahuayl SMR	A	8
MR	La Jolla	15	No	B	12
CGSB	La Jolla	15	Matlahuayl SMR	B	14
UrFL	Pt. Loma	15	No	A	9
OpRdg	Pt. Loma	15	No	A	13
GF	Pt. Loma	21	No	B	14

cycles of mild to moderate El Niño events over many years in the absence of large storm waves can lead to understory domination at the expense of giant kelp canopy cover.

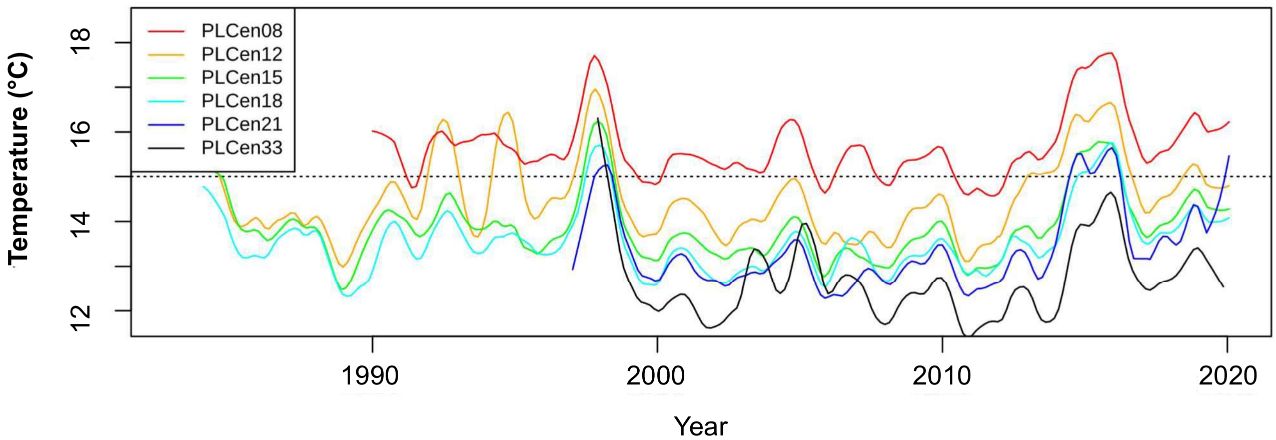
Currently, bottom temperatures have been cool since the spring of 2018 (< 15°C at all sites except for the central Point Loma 8-m site) leading to recruitment and growth at many of the study sites. Despite, warming occurring during the fall and winter of 2018/2019, temperatures at the study sites were typically < 13°C, due to their depth of > 12 m. ENSO neutral conditions have dominated along the equator since June of 2019 and are forecast to persist well into the fall of 2020 (NOAA 2020). The mild El Niño that persisted through the winter and spring along the equator did not appear to have a negative impact on San Diego County kelp forests.

Giant Kelp Status and Reproduction

The primary abundance pattern for *Macrocystis pyrifera* since the 1980s includes rapid declines associated with El Niños followed by step increases in plant and stipe density due to mainly discrete pulses of recruitment leading to varying levels of recovery, or failed recovery if a cohort fails to reach adulthood. In addition to the temporal variation of regional ocean climate, the recruitment, maturation, and establishment of adult giant kelp plants are highly variable in space even within a single kelp forest. Densities of all life stages and stipes are shown in Appendices A.12–A.15. Densities for these life stages at all 18-m deep sites off La Jolla and Point Loma, are plotted in Appendix A.16 for comparisons among the outer kelp forest sites where bottom temperatures are cool relative to shallower sites, and conditions are therefore more persistently conducive for the recruitment and growth of early giant kelp life stages. Presently, mean giant kelp adult and stipe densities for the pooled long-term central Point Loma study sites at 12, 15, and 18 m (1983–2019) are 19% and 47% (respectively) of their all-time highs.

The 2014–2016 warm period caused massive mortality of giant kelp off San Diego County mainly through a combination of nutrient and temperature stress. Giant kelp surface canopy was nearly entirely lost off most of San Diego, Orange, and Los Angeles counties during 2016 (MBC 2017). Densities of adult *Macrocystis pyrifera* plants (Appendix A.11) and stipes (Appendix A.15) decreased dramatically at all study sites off San Diego. *M. pyrifera* has since recruited in some areas of the forests beginning as early as 2016 with subsequent recruitment cohorts observed in 2017 and 2018, with low levels of recruitment continuing into the spring of 2019 (Appendices A.12, A.13). Some of the 2016 site cohorts at least partially matured into pre-adults and adults at a subset of the sites. Presently, sites with the greatest densities of adult and pre-adult giant kelp include the central Point Loma sites at 18 and 21 m (PLC18 and PLC21), the southern La Jolla site at 18 m (LJS18), and the northern Point Loma site at 18 m (PLN18).

No or very few adult giant kelp plants remain at the North County sites even though significant recruitment occurred off Cardiff in late 2017. An



Appendix A.9

Ocean bottom temperature trends along the central Point Loma study sites. Horizontal gray line indicates the temperature (15°C) above which nitrate concentrations are typically limiting for giant kelp growth.

earlier cohort that recruited in 2016 near the end of the El Niño off Solana Beach, has mostly failed to thrive. No giant kelp has been observed off Del Mar since early 2016.

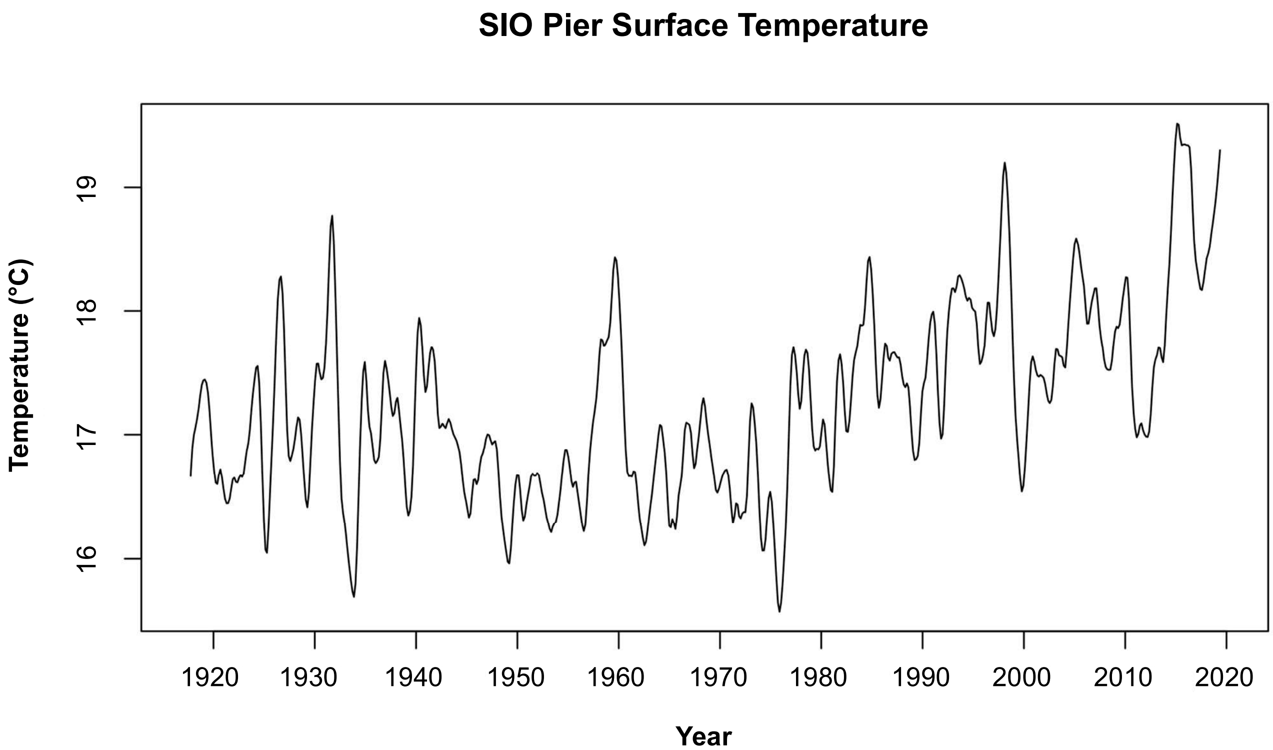
Post warm-event recruitment was observed at the La Jolla study sites including LJN15, and all three of the southern La Jolla sites. Recruitment off southern La Jolla was by far the greatest at the 18-m site. Moderate densities of giant kelp are now present at the LJN15, LJS18, and LJS15 study sites.

Giant kelp recovery at the Point Loma study sites has been highly variable among study sites. Recruitment occurred during the 2015 warm event at PLC12 but that cohort died completely by late 2017. At other sites, where giant kelp adults currently exhibit moderate densities (>0.1 m^{-2}), recruitment occurred beginning as early as 2016 and some sites experienced additional recruitment in 2017 and 2018. These sites include PLC21, PLC8, PLT12, PLS15, and PLS18. Recruitment occurred but did not successfully mature into adult stands at PLC18, PLC15, PLT15, and PLM18. An early-colonizing post-disturbance brown alga, *Desmerestia ligulata*, has dominated the PLT15 and PLM18 study sites until recently, interfering with giant kelp recovery at those sites. Limited recovery at the deeper sites such as PLC18 and PLC21 was limited through 2018 but is now evident. The delayed recovery at the deeper sites may be partly due to decreased light levels reducing rates of kelp germination. However, light penetration data were not available during that period.

The reproductive state of giant kelp along the central Point Loma study sites was greatly diminished by the end of the 2016 El Niño (Appendix A.17). Reproductive capacity was uniformly the lowest among all study sites over the entire time series dating back to before the 1997/1998 El Niño. Sporophyll volumes were greatly reduced by the end of the 2016 El Niño and sporophylls were not reproductive at the PLC8 and PLC21 study sites where adult plants were the most abundant. Diminished reproductive capacity of giant kelp is an indicator of how stressful the warm water events of 2014–2016 were for the species. Additionally, it likely limited the rate at which giant kelp were able to recover since that time given the relationship between reproductive capacity and number of stipes for each individual plant (Appendix A.18). The only study site where reproductive capacity has at least briefly recovered is the central Point Loma site at 15 m.

Understory Kelp Status and Reproduction

Understory kelps and turf algae grow close to the bottom, and unlike the local canopy forming kelps (*Macrocystis pyrifera*, *Egregia menziesii*, and *Pelagophycus porra*), do not have buoyant pneumatocysts to support photosynthetic tissue up in the water column where light is more abundant.



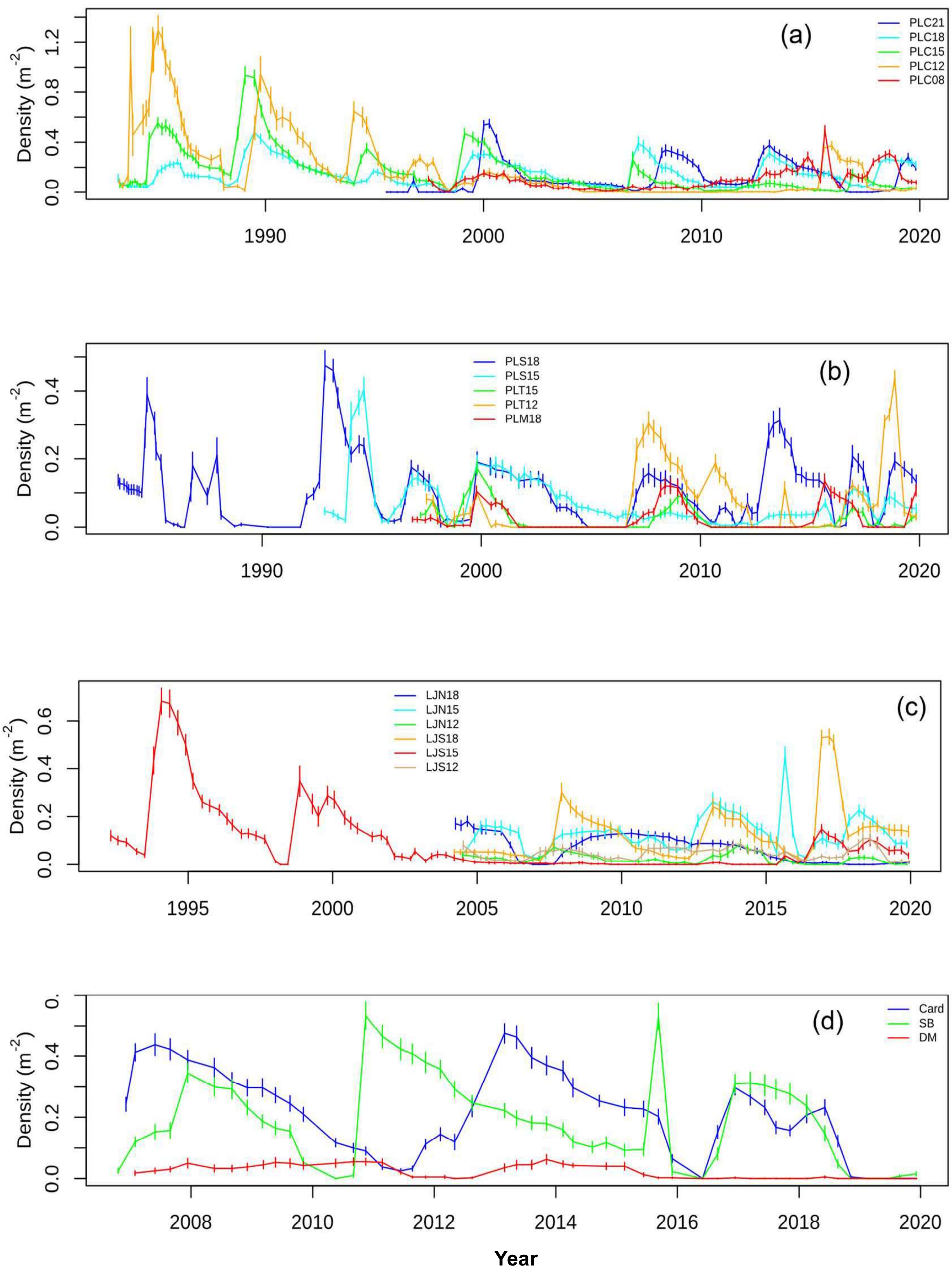
Appendix 10

Trend of surface temperature at the Scripps Institution of Oceanography (SIO) Pier. Data inclusive through Fall 2019.

Therefore, high densities of canopy forming kelps outcompete understory kelps and turf algae. El Niño events modulate this competition between the two types of canopy guilds. Warm and nutrient deplete water is nearest the surface where most of the photosynthetic and nutrient absorbing tissue for giant kelp is distributed. Therefore, giant kelp is disproportionately stressed by El Niño events as giant kelp is stressed by low nutrient and high temperature conditions. By contrast the understory and turf canopy guilds are exposed to cooler and more nutrient replete waters. And as the surface canopy kelps begin to lose tissue and die, the light field for the lower canopy guilds increases leading to rapid growth and reproduction.

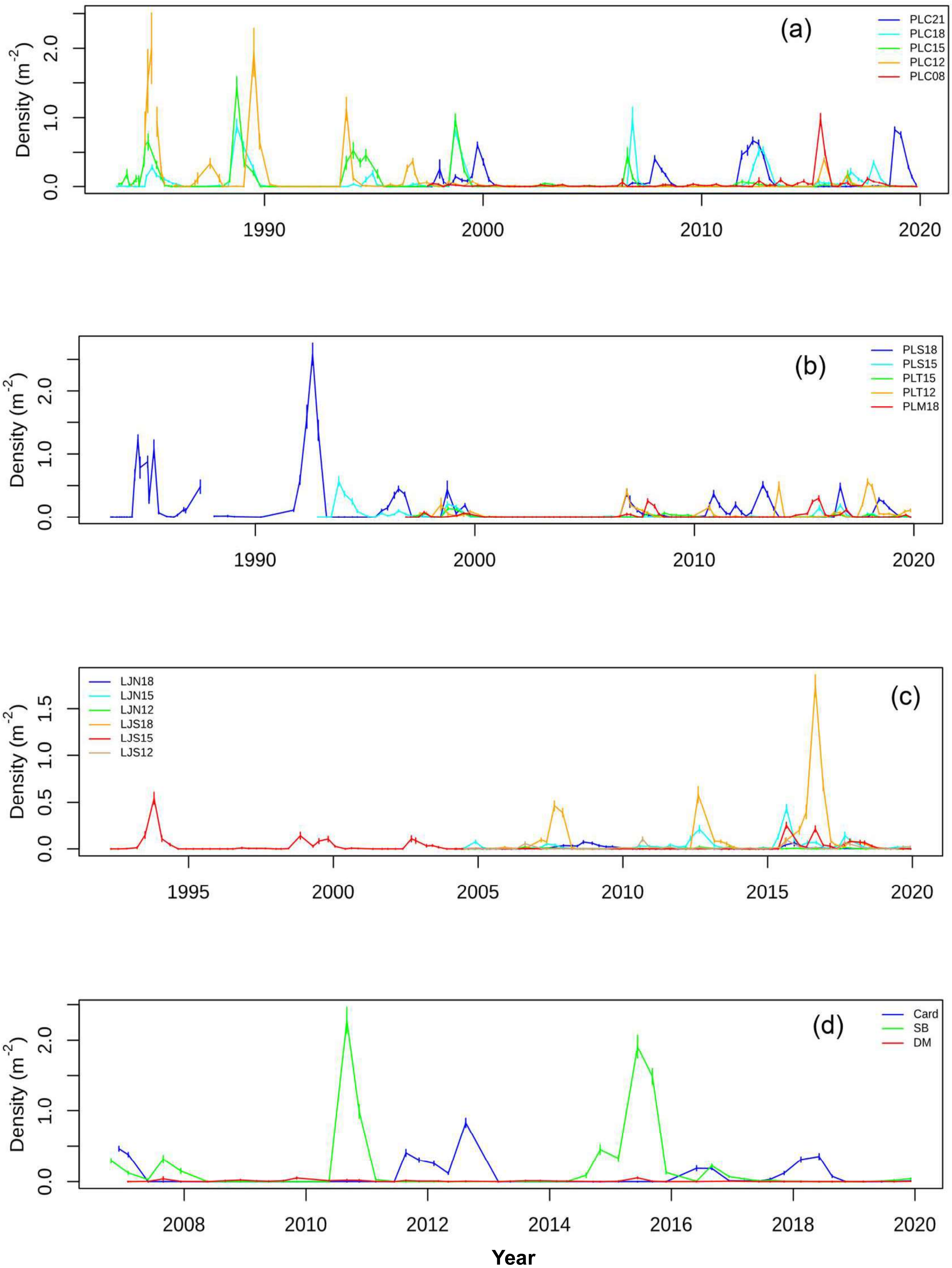
Pterygophora californica, a stipitate understory kelp has a central woody stipe that supports photosynthetic blades from below. Stipes can grow up to 2 m in height off the bottom and individuals can persist for decades. The growth form consists of a ribbed terminal blade that grows outward from the end of the stipe. Sporophyll blades grow horizontally outward from the narrowed margins of the stipe. Soral (reproductive) tissue develops on these side branching sporophyll blades. *Laminaria farlowii*, a prostrate understory kelp grows as a long blade along the bottom where it is attached by a small woody stipe and holdfast. Soral tissue develops along the length of the blade. Reproduction and growth is seasonally offset in both species with growth occurring during late spring and summer while reproductive tissue development peaks in winter.

Pterygophora californica and *Laminaria farlowii*, were affected differently by the consecutive warm periods. The main effects of the warm periods on *P. californica* were exemplified by two groups of sites (Appendix A.19). The first group included sites where densities decreased dramatically with the BLOB and remained low during and after the 2016 El Niño (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 (PLC15, LJS18, LJS15). Densities of *P. californica* at the North County sites have been persistently



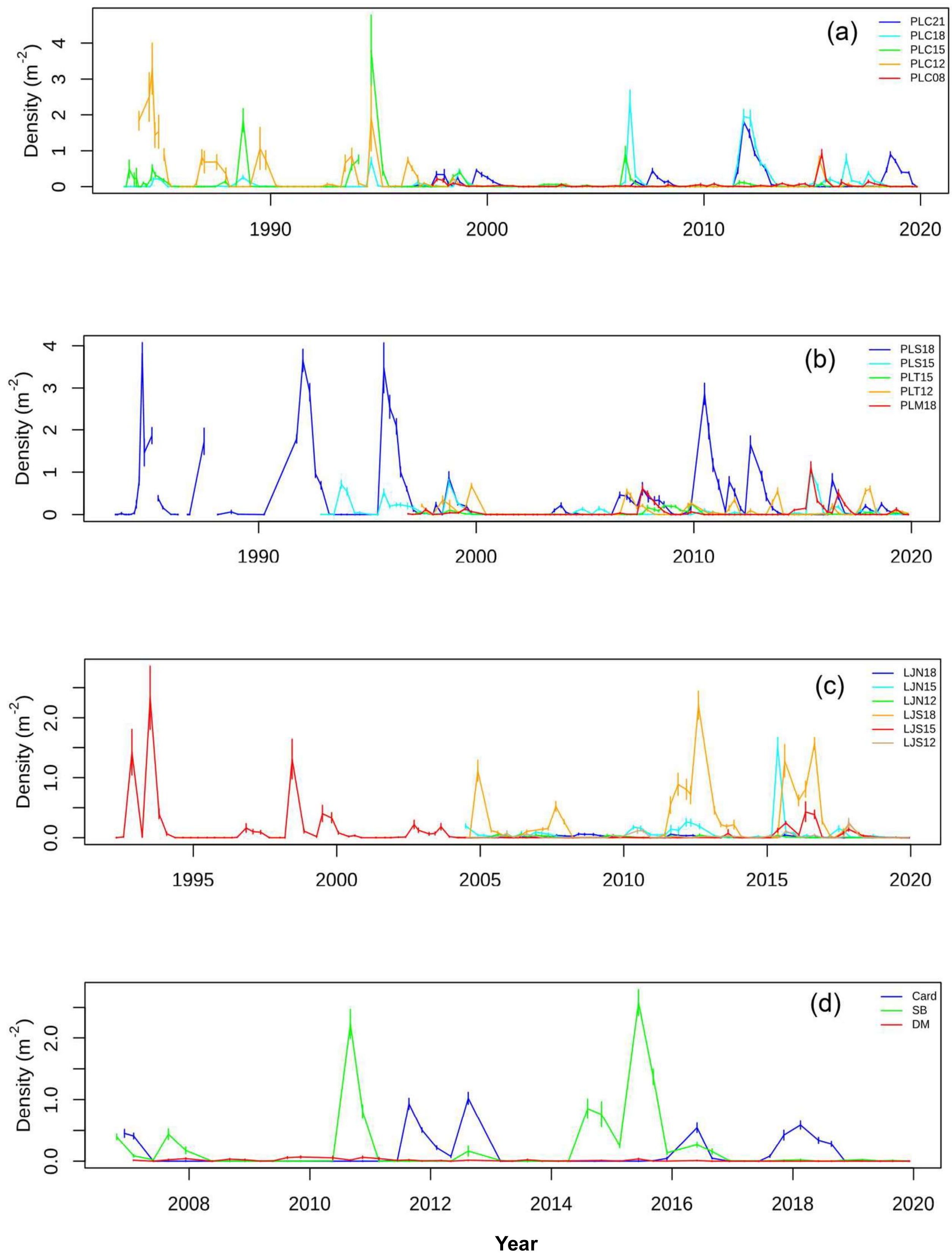
Appendix A.11

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.



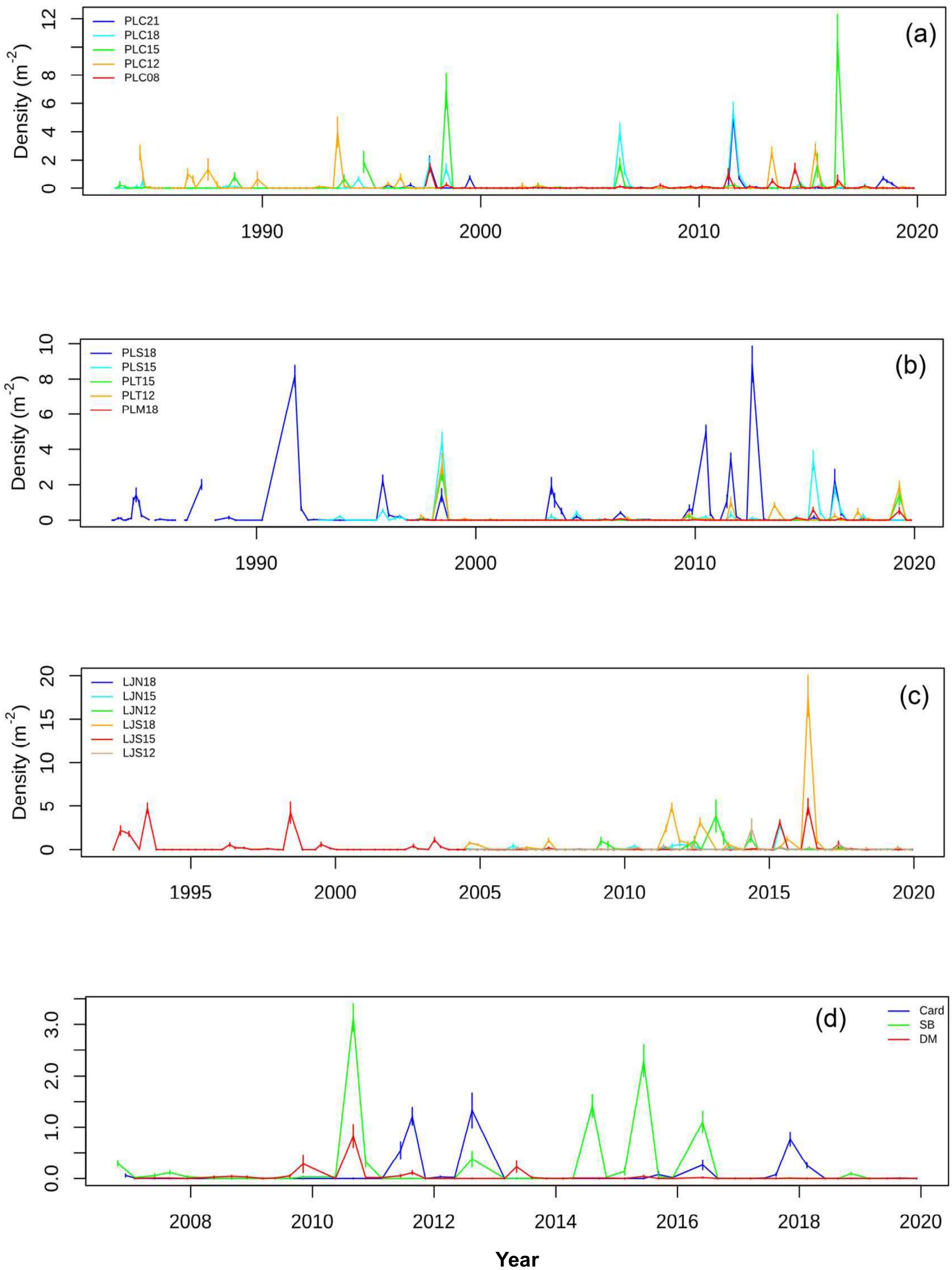
Appendix A.12

Mean densities of *Macrocystis pyrifera* pre-adults (≤4 stipes): (a) central Point Loma, (b) south Point Loma, (c) La Jolla, and (d) North County study sites. Error bars indicate standard errors.



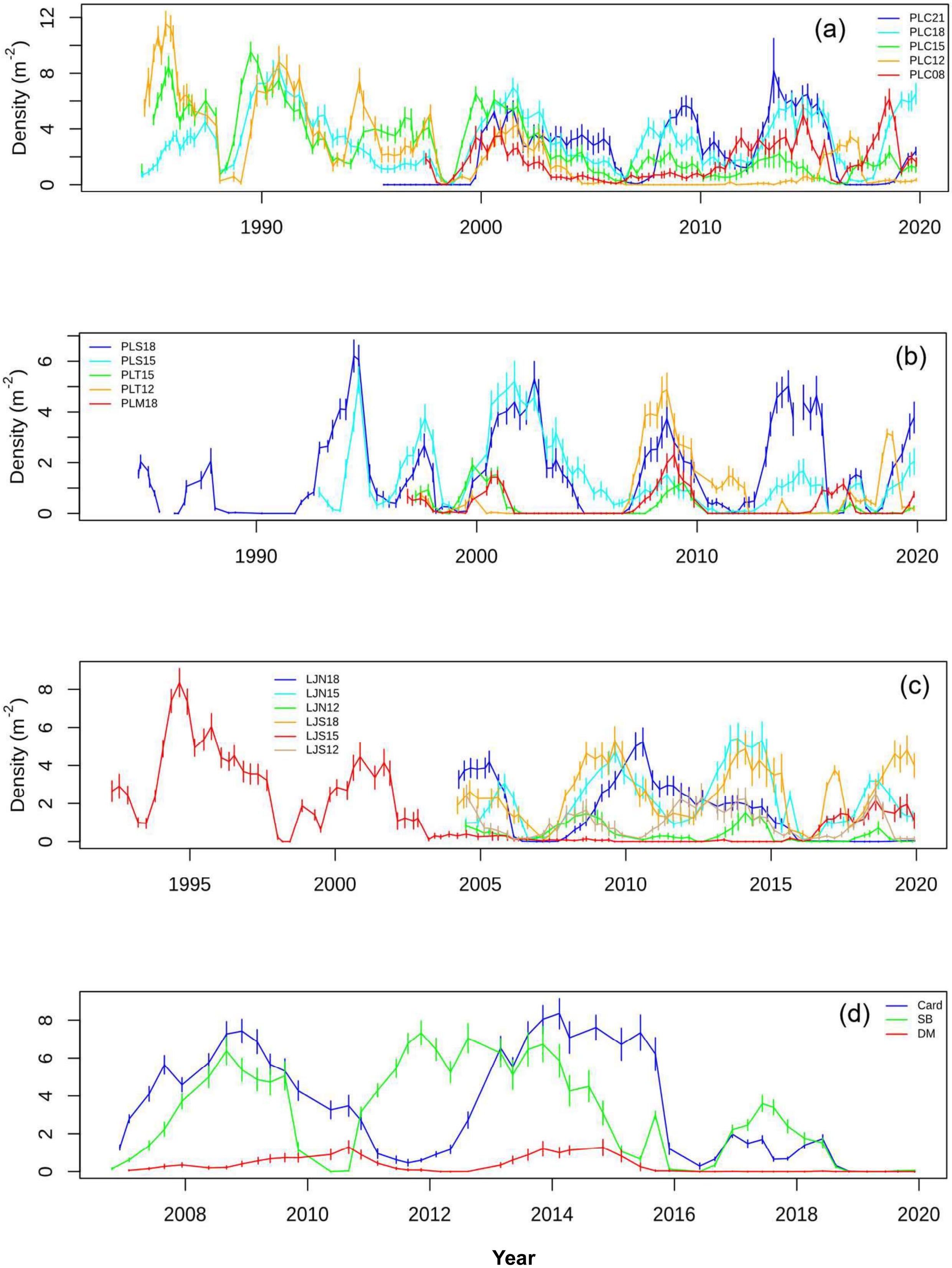
Appendix A.13

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



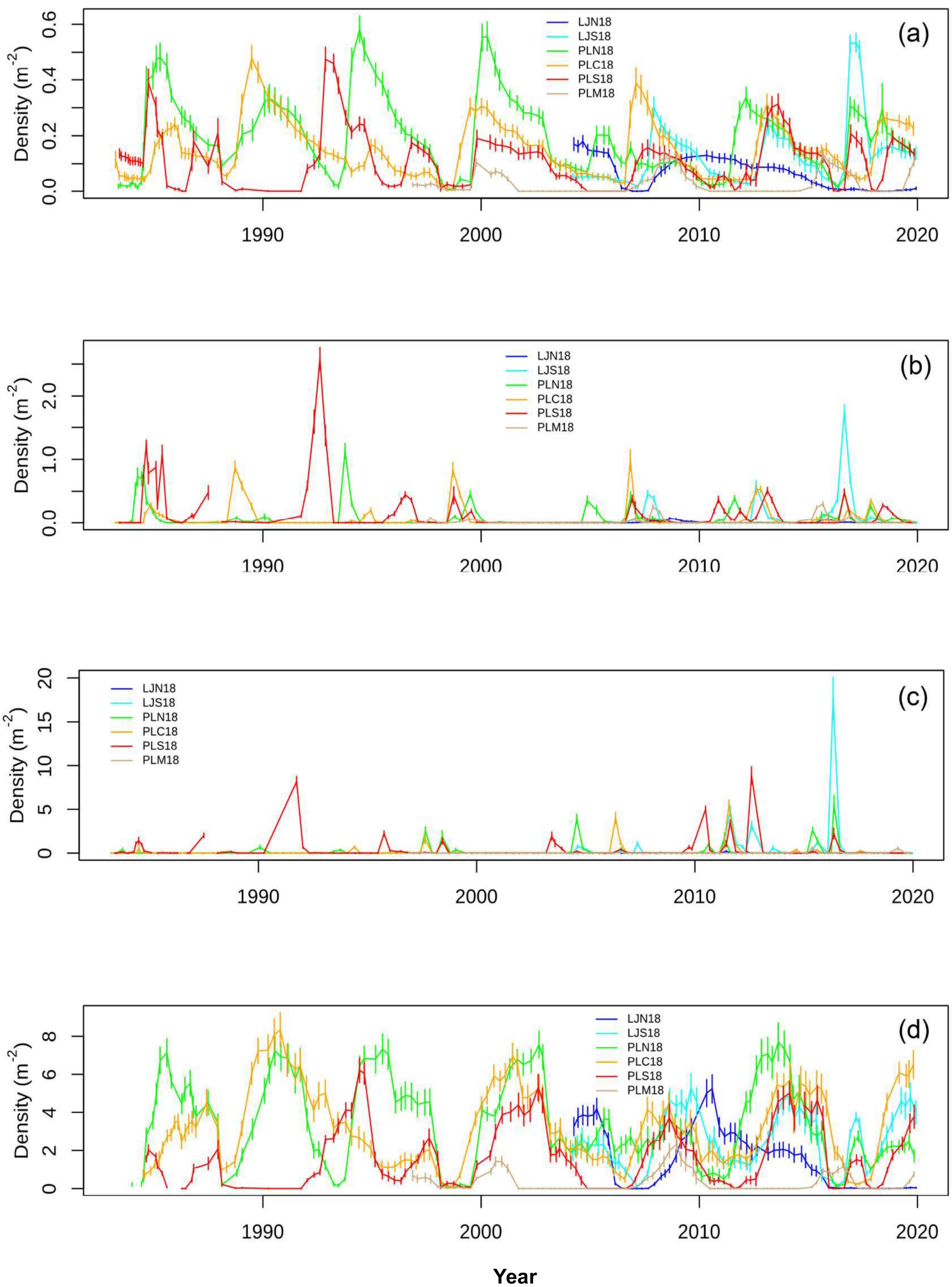
Appendix A.14

Mean densities of *Macrocystis pyrifera* pre-bifurcates: (a) central Point Loma, (b) south Point Loma, (c) La Jolla, and (d) North County study sites. Error bars indicate standard errors.



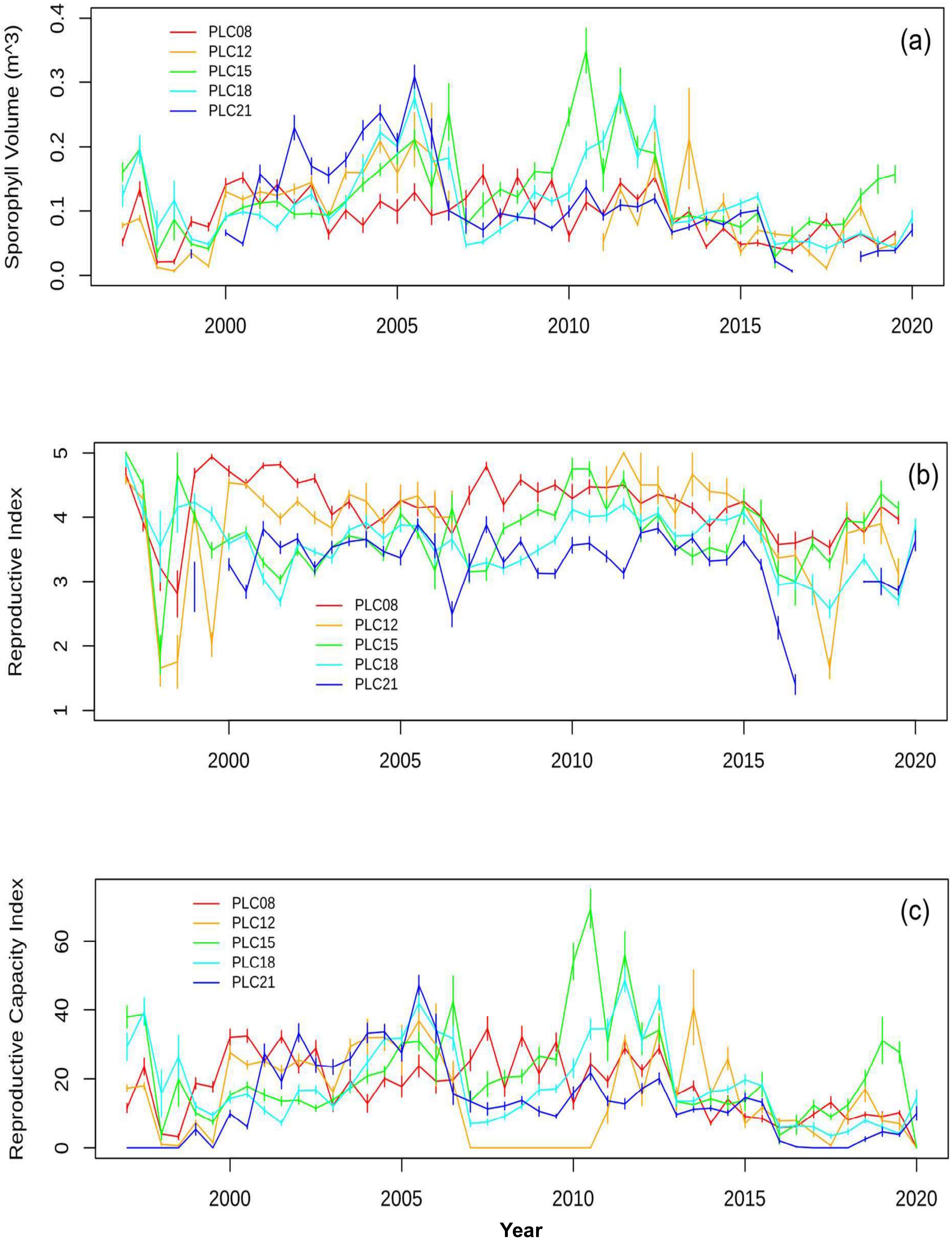
Appendix A.15

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



Appendix A.16

Mean densities of *Macrocystis pyrifera* (a) adults, (b) pre-adults, (c) pre-bifurcates, and (d) stipes along the 18-m sites off La Jolla and Point Loma. Error bars indicate standard errors.



Appendix A.17

Reproductive states of *Macrocystis pyrifera* at the central Point Loma study sites: (a) sporophyll volume, (b) reproductive index (see Appendix A.5), and (c) reproductive capacity (derived index of relative among-site reproductive potential - see Methods). Means are plotted and error bars indicate standard errors.

low and remain low at present with the exception of a 2017 cohort that died by late 2018. Presently, *P. californica* is present in at least moderate density (>1 m^{-2}) at the LJS18, LJS15, PLC15, PLT12 study sites. The 2016 cohort is presently still thriving at the sites where post El Niño recruitment was greatest (PLC15, LJS18, LJS15).

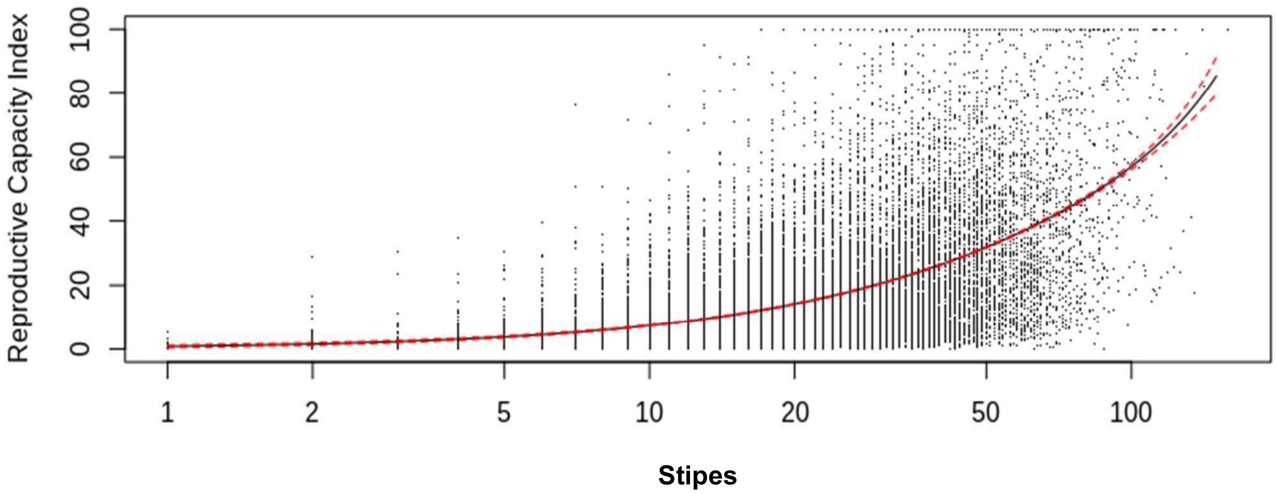
The response of *Laminaria farlowii* to the recent consecutive warm periods was more variable among study sites (Appendix A.20). Three types of responses were observed. First, previously high densities at many sites quickly decreased during the BLOB with subsequent increases during the 2016 El Niño (e.g., PLC15, LJS18, LJS15). Relatively high cover at other sites decreased due to the BLOB and remained reduced through the 2016 El Niño. These mainly include the sites off La Jolla and Del Mar. The third response occurred at PLS15 where cover was increasing prior to the BLOB, which caused a notable decrease, followed by a rapid increase during and after the 2016 El Niño. Currently, *L. farlowii* is present at densities of at least 1 m^{-2} at all of the central and south Point Loma study sites with the exception of PLM18 and PLT15, and all of the La Jolla study sites. *L. farlowii* densities continue to be very low in North County but have recently begun to increase, albeit at much lower densities than most other study areas.

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 *Macrocystis pyrifera* surface canopy. The three states 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 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 (Appendix A.9). 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 both *Pterygophora californica* (Appendices A.21, A.22) and *Laminaria farlowii* (Appendices A.23, A.24) were reduced during the BLOB but increased afterward. Both growth and reproduction of *P. californica* remained depressed at the deeper central Point Loma sites until 2017. 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 modes. Such forcing can result in long term dominance over giant kelp than can persist for several years until the occurrence of a new major disturbance. For both species, growth, and reproduction, to a more limited extent, have recovered at all the study sites off central Point Loma. Growth and reproduction of *P. californica* was clearly more affected than *L. farlowii* by the marine heat wave of 2014–2016 and has been somewhat slower to recover.

Algal Community Analysis

Algal community composition among all of the study sites for the last two years is shown in Appendices A.25 and A.26. These plots result from the factor analyses of all algal species and derived bare space. When plotted against one another, the first two factors graphically depict the community-wide state of algae at each site. Together, these factors account for ~31% of the overall variance in the dataset and therefore provide a good representation of the algal communities over time. Factor 1 indicates a continuum of understory algal guild composition ranging (from positive to negative) from fleshy red and articulated coralline algae to the stipitate brown algal species, *Eisenia arborea*, and *Pterygophora californica*, the prostrate brown alga *Laminaria farlowii*, to the post-disturbance pioneer brown alga *Desmerestia ligulata*, to bare



Appendix A.18

Reproductive capacity of *Macrocystis pyrifera* as a function of the number of stipes. Fit is a second order polynomial fit and dashed red curves indicate 95% confidence intervals. Data are inclusive between 1997–2019.

space. This factor encompasses a depth gradient effect from shallow to deep (positive to negative). Factor 2 indicates the condition of *Macrocystis pyrifera*, whether sites are dominated by adults and abundant stipes (positive values) or young recruits and pre-adults (values near zero). The largest changes between 2018 and 2019 reflect the increases in kelp cover at PLC18 and decrease in understory including turf algae, and loss of kelp at the expense of turf species at PLC08. The southern Point Loma sites, with the exception of PLS18, remained dominated by a combination of bare space and *D. ligulata* and low giant kelp density. A major grouping of sites having low giant kelp densities with high turf and understory cover include LJN18, PLC12, LJN12, LJS12.

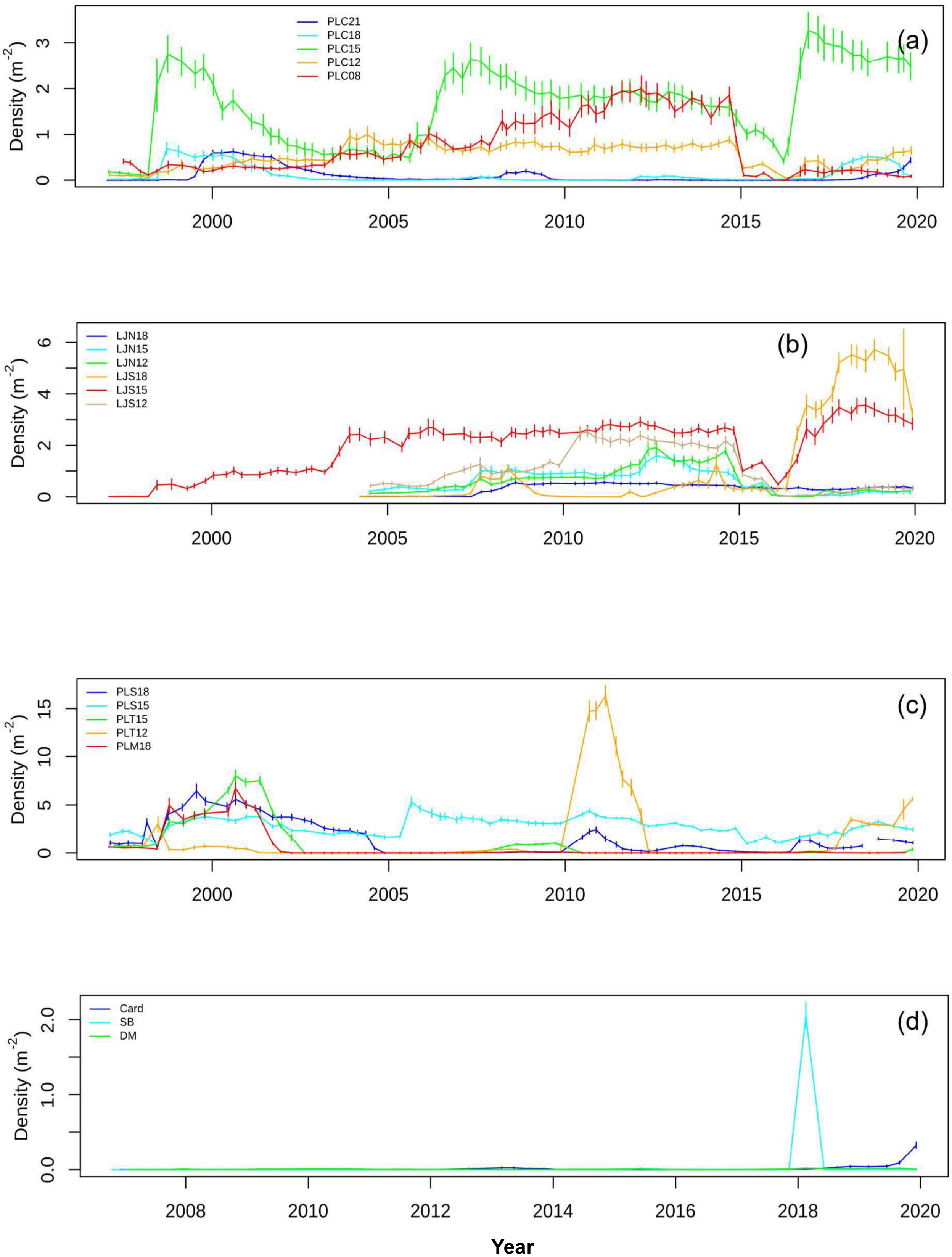
Invasive Algal Species

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. *S. horneri* dominates some areas formerly dominated by *Macrocystis pyrifera* including areas off Santa Catalina Island and the Northern Channel Islands off Santa Barbara. *S. horneri* was first observed in the kelp forests off San Diego at the beginning of the study period in 2014 and spread to 13 of our study sites. Initially, it was only observed near some of the study sites, but has subsequently become established within the permanent band transects at several sites. Appendix A.28 lists first sightings within the actual band transects and Appendix A.27 shows relative abundances and frequency among the study sites pooled over time. The greatest percent cover observed thus far was at LJN18 in the fall of 2017 when mean percent cover exceeded 3%. This was followed by increases approaching 2.5% at LJN18. However, while *S. horneri* invaded an increasing number of sites up to 2018, no new sites were invaded in 2019 and there does not appear to be an upward trend for this invasive species (Appendix A.29).

Clearly, *Sargassum horneri* poses a risk to *Macrocystis pyrifera* and other algal species due to its potential seasonal growth rates. It is not implausible for it to take over some areas of the San Diego kelp forests especially after a future major disturbance that reduces the densities and cover of native algal species. Presently, it is too sparsely distributed to be significantly affecting giant kelp with the exception of the LJN18 study site and the deeper portions of the northern La Jolla kelp forest.

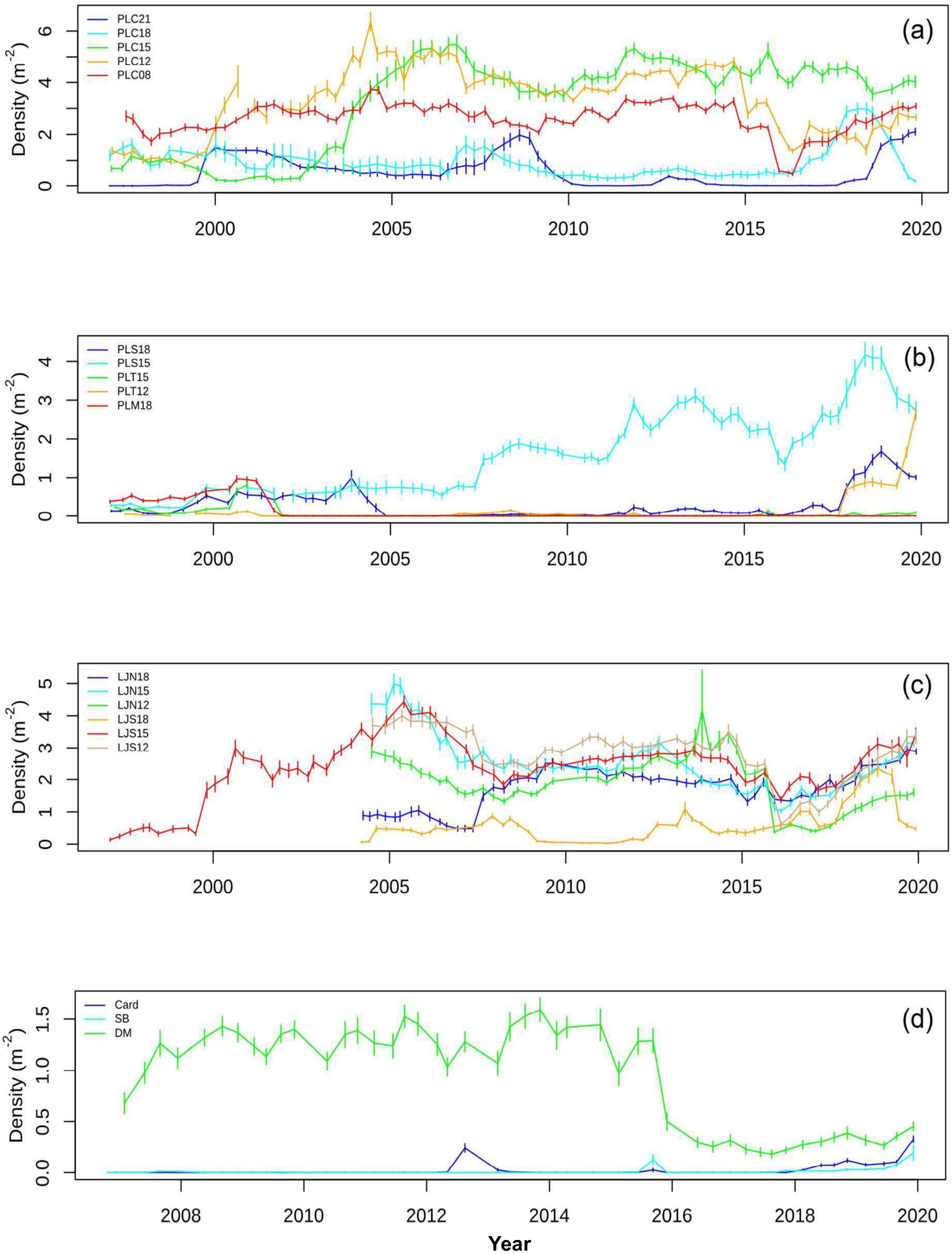
Invertebrates

Many species of invertebrates were also stressed by the 2014–2016 warm event. Sea urchins (Echinoids)



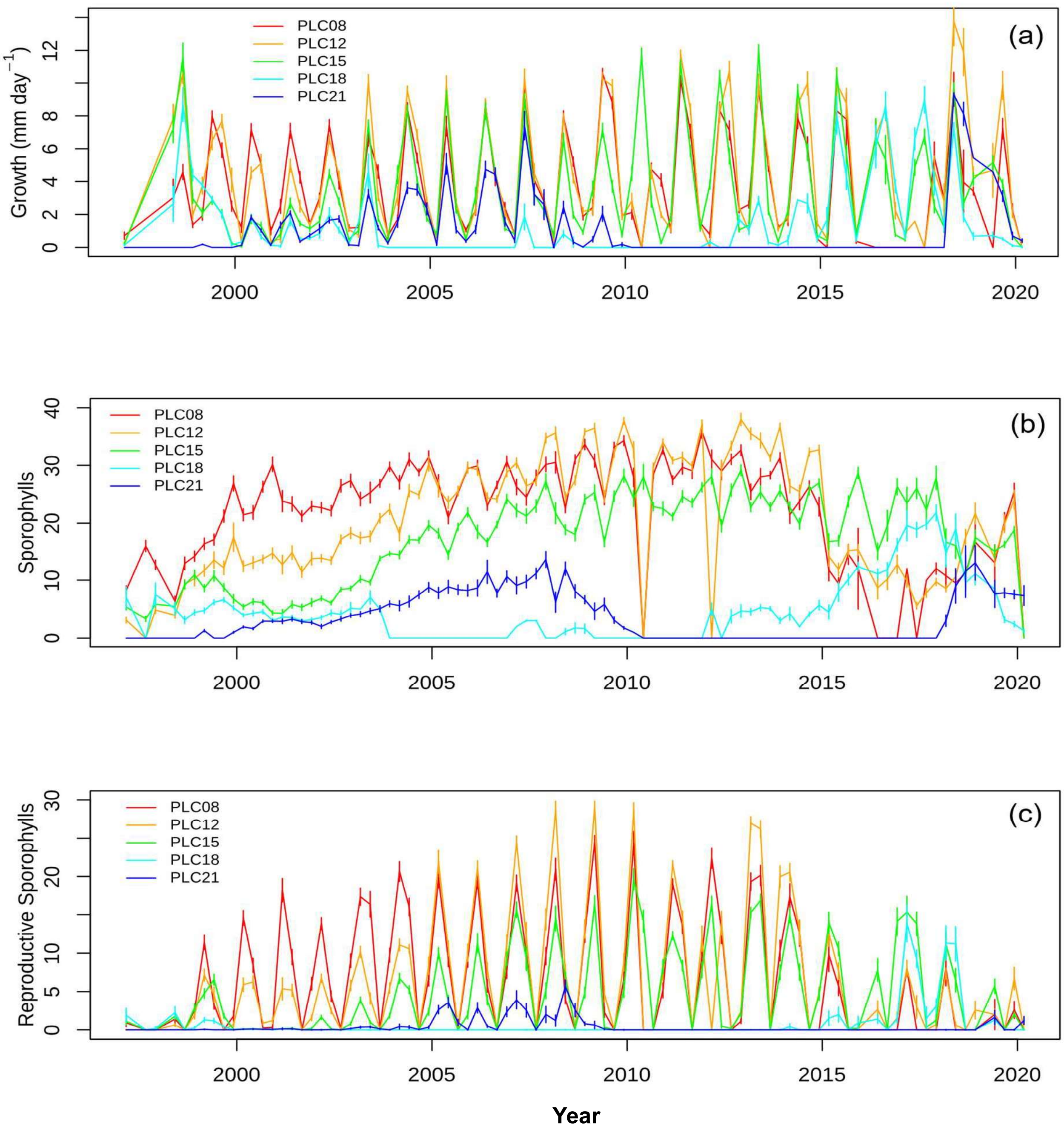
Appendix A.19

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



Appendix A.20

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

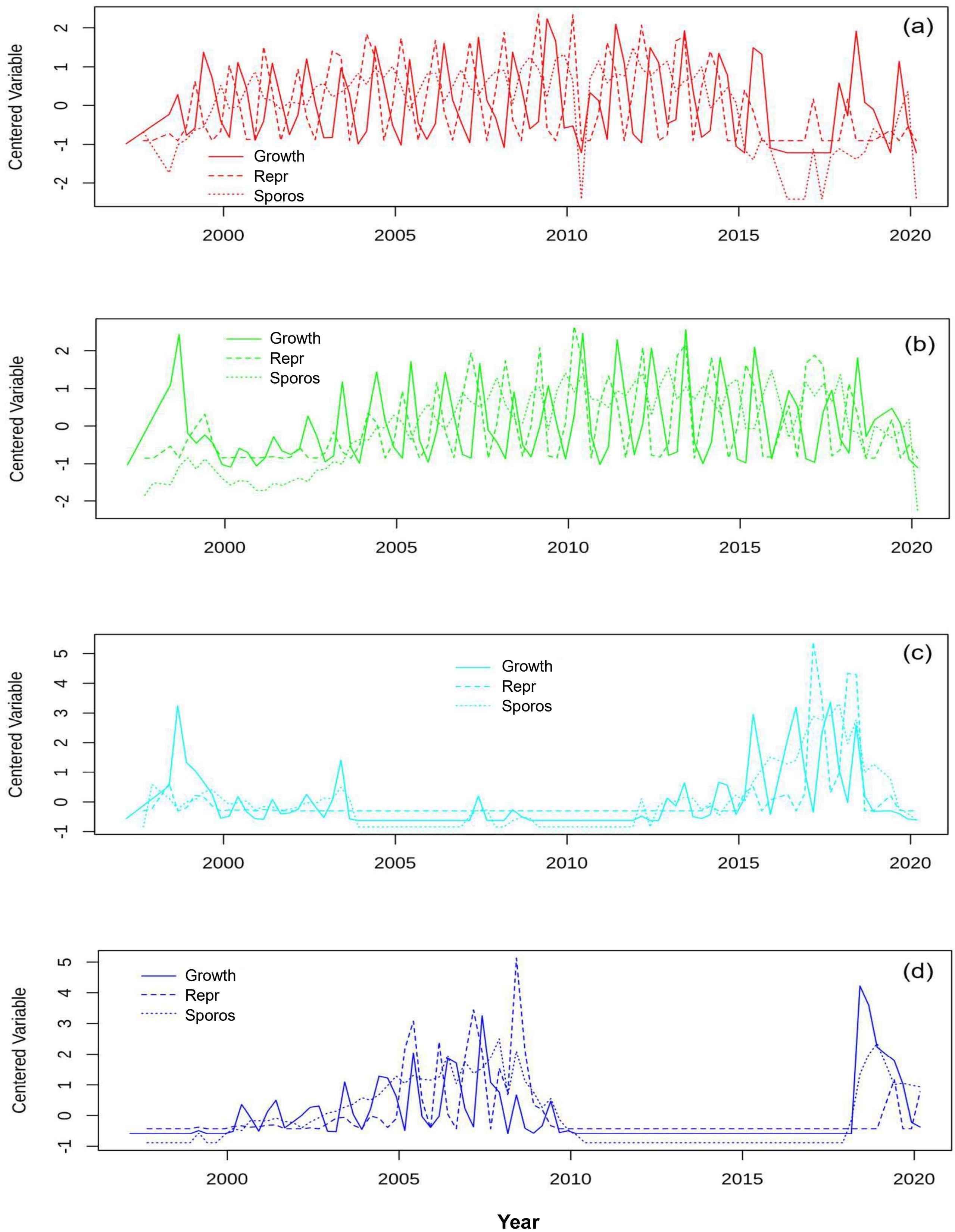


Appendix A.21

Growth and reproduction of the understory kelp *Pterygophora californica* at the central Point Loma study sites: (a) growth, (b) # sporophylls, and (c) # reproductive sporophylls. Means are plotted and error bars indicate standard errors.

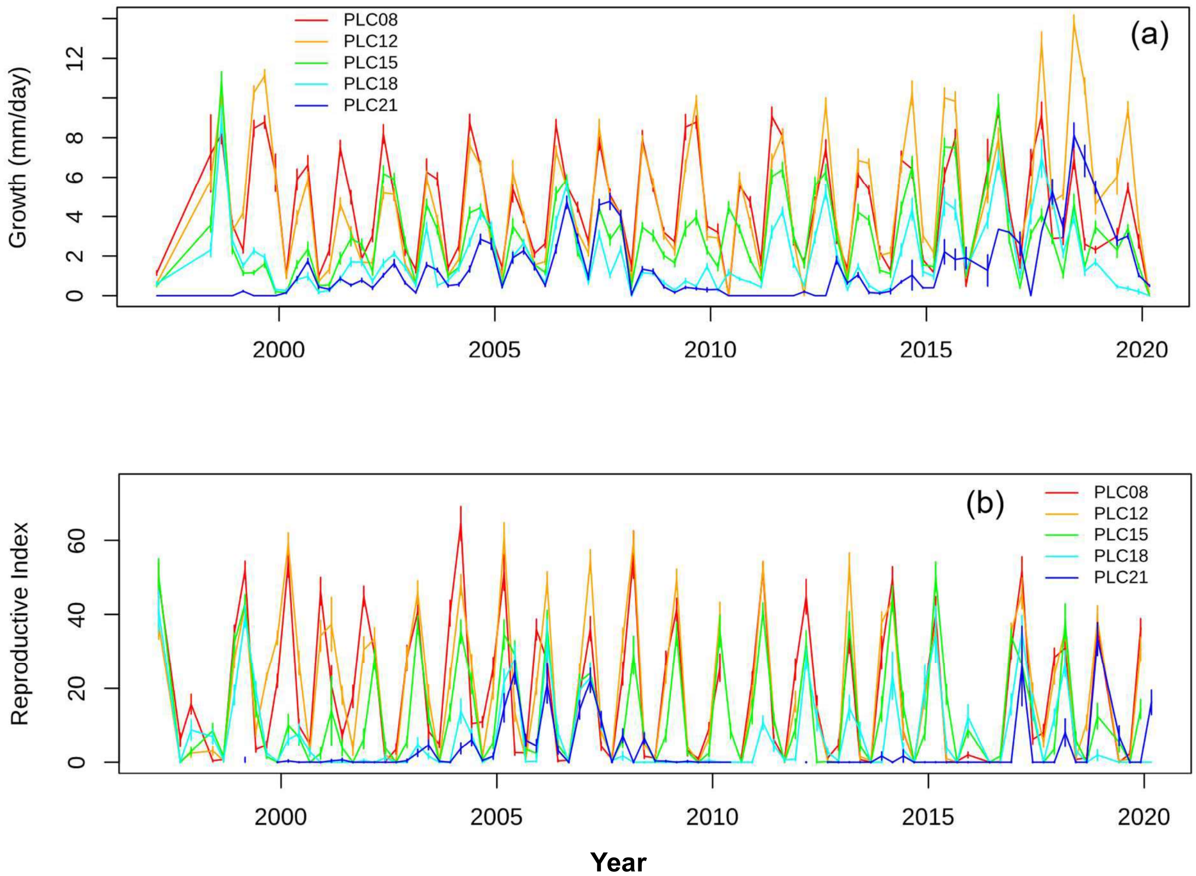
and seastars (Asteroids) were most affected. Both groups have important functions within kelp forests. Sea urchins are major grazers of algae and can overgraze kelp forests if they become too numerous and mobile. Seastars are important benthic predators. Both groups suffered heavy mortality off San Diego during the warm event and remain depressed.

Densities of both red (*Mesocentrotus franciscanus*) and purple (*Strongylocentrotus purpuratus*) sea urchins (RSU and PSU, respectively) either crashed in response to the consecutive warm periods or were already experiencing disease mortality. Sea urchin densities are shown in Appendices A.30–A.33 for the sites where these species were most abundant



Appendix A.22

Centered means of *Pterygophora californica* growth rates, sporophylls, and number of reproductive sporophylls for (a) PLC08, (b) PLC15, (c) PLC18, and (d) PLC21 study sites.



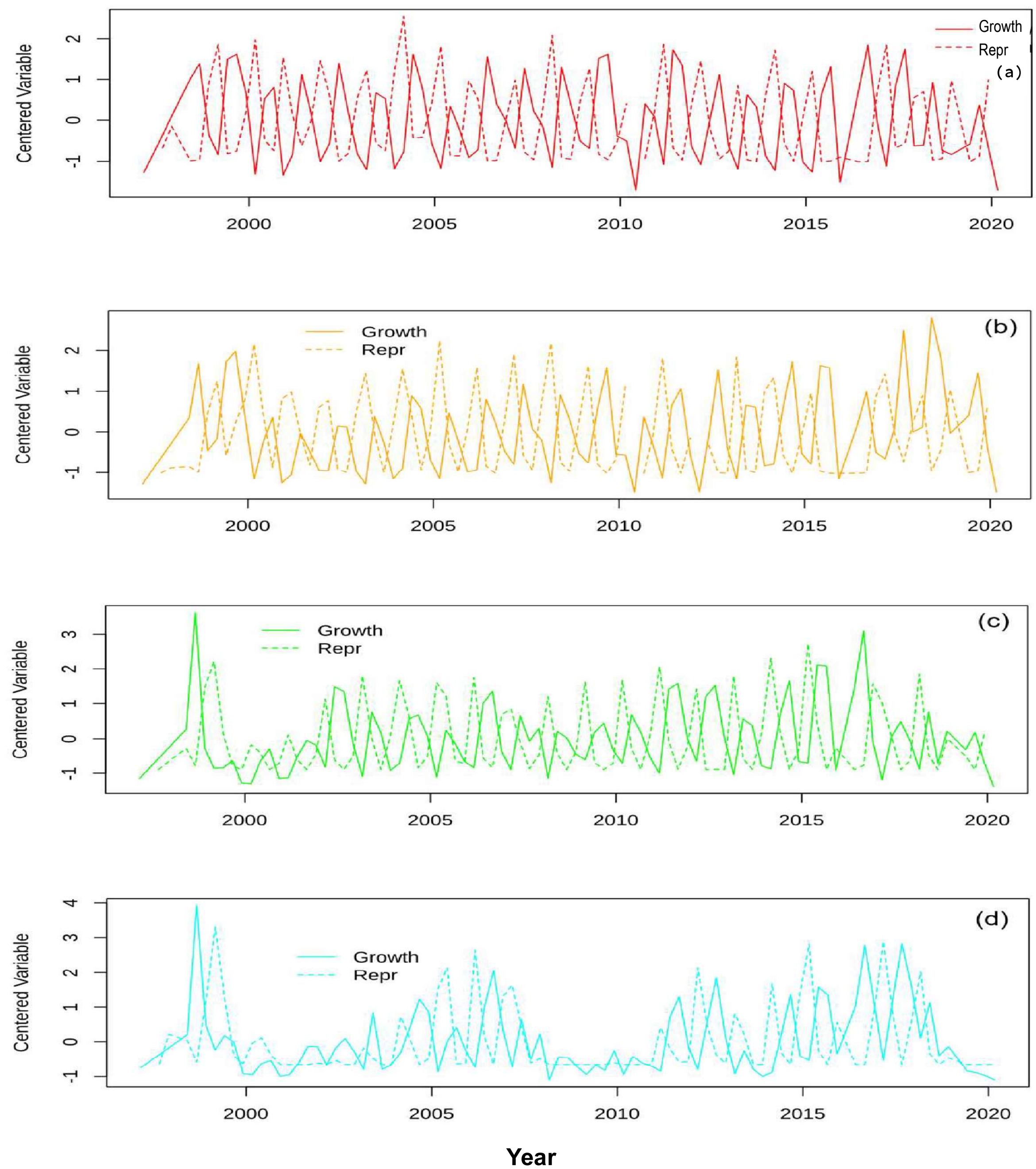
Appendix A.23

Growth and reproduction of the understory kelp *Laminaria farlowii* at the central Point Loma study sites: (a) growth, and (b) % of blade that is sorus (reproductive), Means are plotted and error bars indicate standard errors.

prior to 2014. 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 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). However, red sea urchin densities at the PLC21 and PLC18 sites have remained fairly stable though at low density (Appendix A.31). Additionally, sea urchin recruitment was absent or extremely limited at all 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 has since increased at several sites (Appendix A.34). The largest increases were observed mainly at the southern Point Loma sites, and all sites off La Jolla. Recruitment of RSU was robust at the outer central Point Loma stations (PLC18 and PLC21).

Sea urchins are nonetheless not likely to have any immediate effects on kelp recovery due to their reduced abundance and delayed recruitment. However, the fall 2017 and 2018 sea urchin recruitment cohorts may eventually lead to overgrazing at some sites as the sea urchins mature and migrate away from sheltering juvenile habitat and begin to actively seek forage. Thus, sea urchin overgrazing may occur at some sites by late 2020 as the fall 2017–2018 cohort matures.

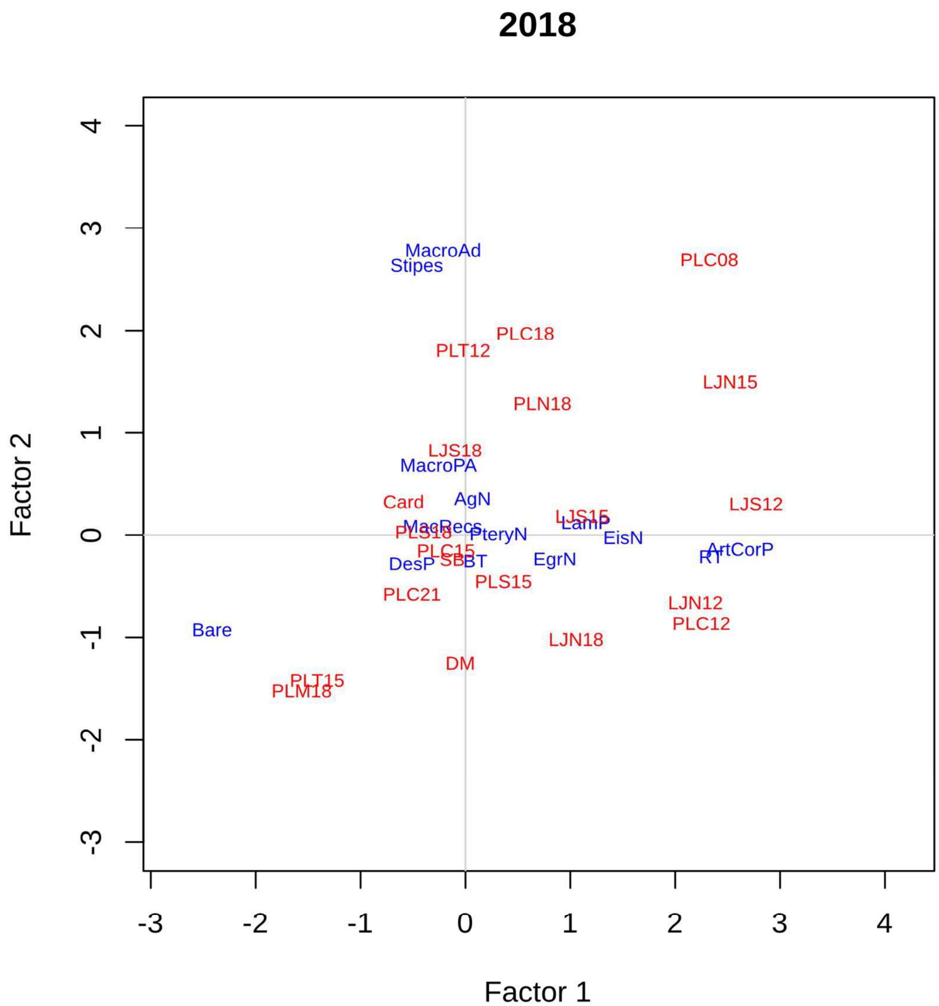
Diseases affecting echinoderms also caused mass mortality of several asteroid species throughout the Southern California Bight during the consecutive warm periods (Hewson et al. 2014). Species that suffered the greatest mortality at our study sites



Appendix A.24

Centered mean growth and reproduction of the understory kelp *Laminaria farlowii* at the central Point Loma study sites (a) PLC08, (b) PLC12, (c) PLC15, and (d) PLC18.

included *Pisaster giganteus* (Appendix A.35) and *P. brevispinus* 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 fronds off Point Loma beginning in 2017 and continuing into 2018, thus heralding their recovery. However, disease has also decimated *Pycnopodia helianthoides*, an important sea urchin predator (Moitoza and Phillips 1979). This species has not been observed anywhere off Point Loma since 2014 even in areas where they were once common. *P. helianthodes* was in decline even prior to the BLOB event.



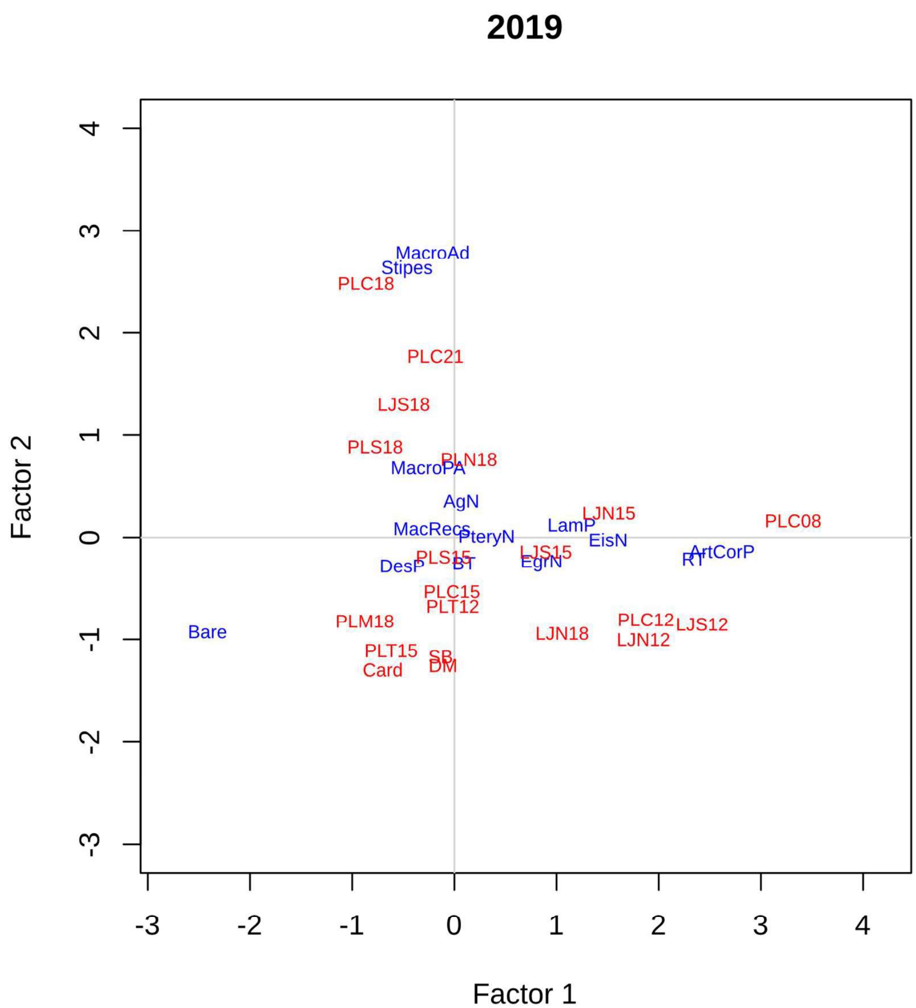
Appendix A.25

Plot of first two factors resulting from the factor analysis of algal groups among the 20 permanent study sites in 2018. Algal group definitions: Bare = derived bare space, MacRecs = *Macrocystis 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.

Abalones are marine mollusks that once supported an economically important commercial fishery throughout California until the 1980s. 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 1970s, 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 were lost during the recent prolonged warm periods. At the same time, densities of pink abalone (*H. corrugata*) have been steadily increasing at PLC8 since 2012 (Appendix A.36), exhibiting steady population increases throughout the warm period.

North County Sedimentation

Sediments at the NCKF sites have been relatively stable since 2008. Sediment horizons have varied



Appendix A.26

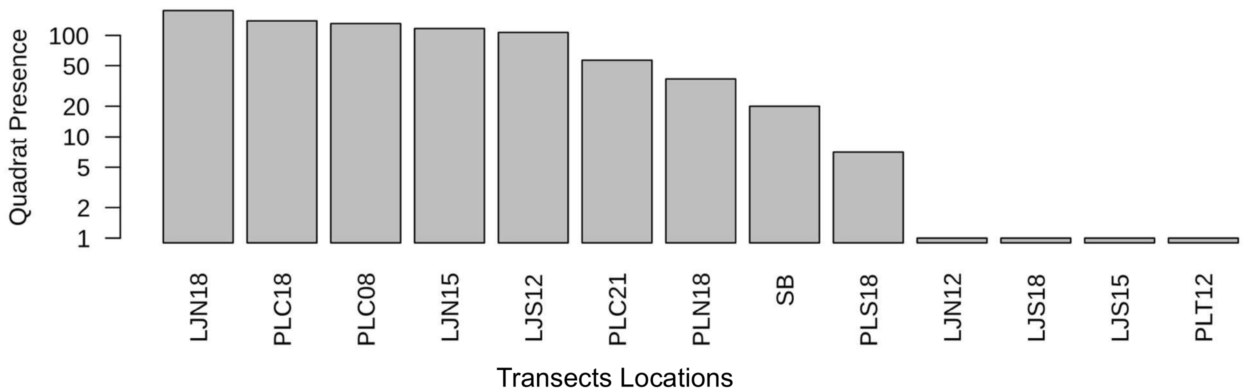
Plot of first two factors resulting from the factor analysis of algal groups among the 20 permanent study sites in 2019. See Appendix A.25 for description of plot.

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 have recently been replenished as part of a project that is slated to last four years. The grain size of sediments used for 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.

Summary of Findings

(1) The kelp forests of southern California, including those off San Diego, were decimated by the marine heat wave of 2014–2016. Cooler and more nutritive conditions for kelps returned by the spring of 2017 when many of the kelp forests off San Diego began their recovery. This recovery has included the recruitment and growth of at least two giant kelp cohorts and their subsequent successful reproductive recovery. Reproduction and growth of the understory kelps have also resumed.

(2) The recovery of San Diego kelp forests has varied both among and within the forests. The La Jolla and Point Loma kelp forests have recovered



Appendix A.27
Presence of the invasive alga, *Sargassum horneri*, among the study sites where it has been observed within the permanent band transects. Quadrat presence indicates the total number of 5 x 2 m quadrats along the transects where it has been observed over time since first sighting at each individual site.

the most and are presently at ~47% of their all-time historic highs in terms of giant kelp stipe density. There was limited recruitment of giant kelps off Del Mar, Solana Beach, and Cardiff, but that initial recovery has been unsuccessful and there is little kelp in those areas due to space competition with understory species and likely limited light levels due to turbidity.

(3) Ocean climate conditions forecast for the upcoming year are conducive for the further recovery of the kelp forests off La Jolla and Point Loma.

(4) The distribution and density of the invasive alga *Sargassum horneri* appear to have stabilized indicating it may not be as great a threat to the open coastal kelp forests off San Diego as initially thought.

(5) Sea urchins, which are major herbivores of giant kelp, were decimated by a combination of disease and lack of their giant kelp food source during the marine heat wave. Since the heat wave has dissipated, sea urchin recruitment has been strong at many of the study sites and these new cohorts of sea urchins may pose overgrazing risks to some areas of the kelp forests off San Diego, particularly the southern portion of the Point Loma kelp forest where resilient sea urchin barrens have been observed over ~200 hectares for at least 80 years.

(6) Associated with the marine heat wave and just prior to it, several species of seastars were nearly extirpated off San Diego due to wasting disease. There has been limited recruitment of some species, but even these species are presently in very low abundances. Some of these species are important predators of sea urchins including the seastar *Pycnopodia helianthoides*, which has not been observed anywhere off San Diego since the onset of the marine heat wave.

(7) Abalone densities remain low or at zero at most study sites with the exception of the shallowest study sites off central Point Loma where densities of pink abalones, *Haliotis corrugata*, have been recently increasing.

(8) There is no evidence that discharge of wastewater through the Point Loma ocean outfall has negatively affected the nearby kelp forest.

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Appendix 28

List of study sites and date of first observation of the invasive alga, *Sargassum horneri*, within band transects.

Study Site	Date 1st Observed
SB	Sep. 9, 2105
PLC18	Oct. 10, 2015
PLN18	Dec. 2, 2015
LJN15	Dec. 3, 2015
LJS12	Feb. 8, 2016
PLC08	Mar. 31, 2016
LJS18	May 03, 2016
LJS15	May 03, 2016
PLT12	May 11, 2016
LJN18	May 19, 2016
PLC21	Apr. 18, 2017
LJN12	Jun. 30, 2017
PLS18	May 30, 2018

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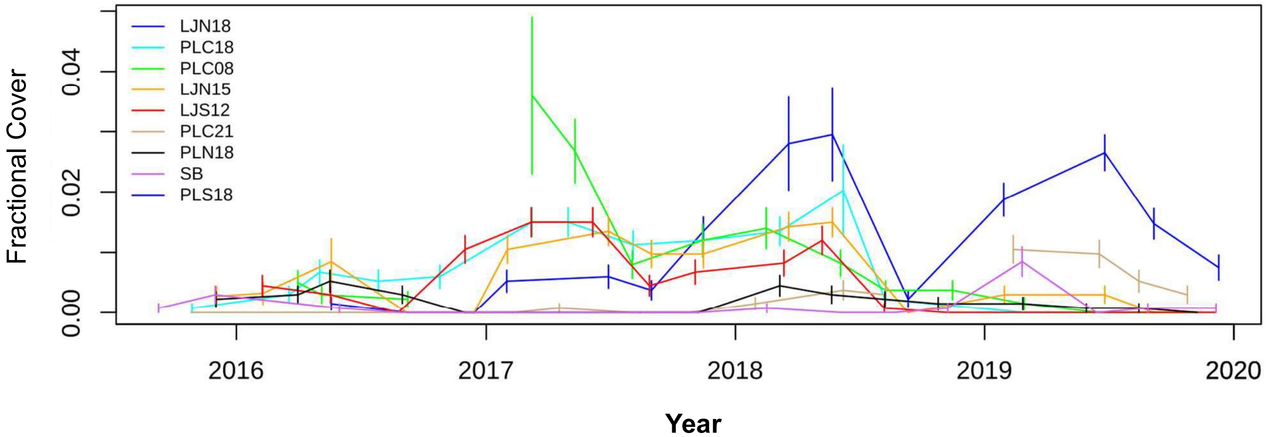
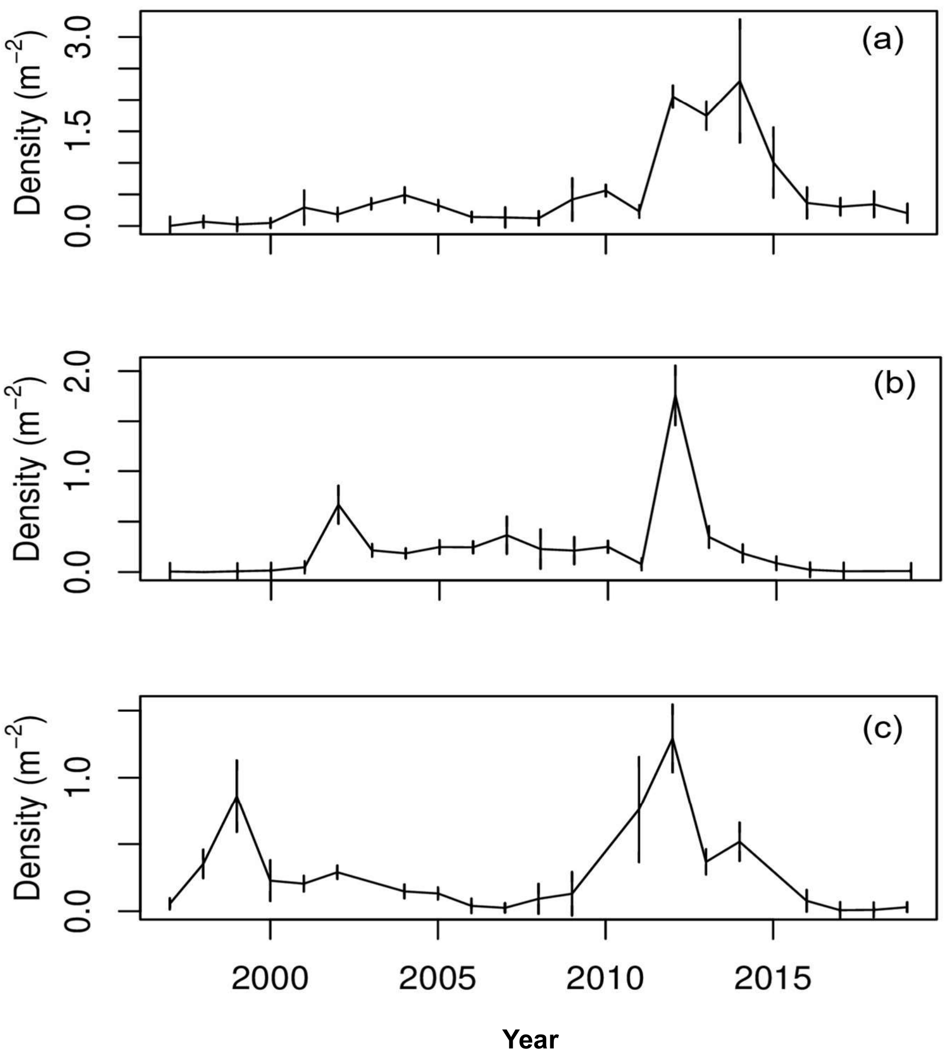


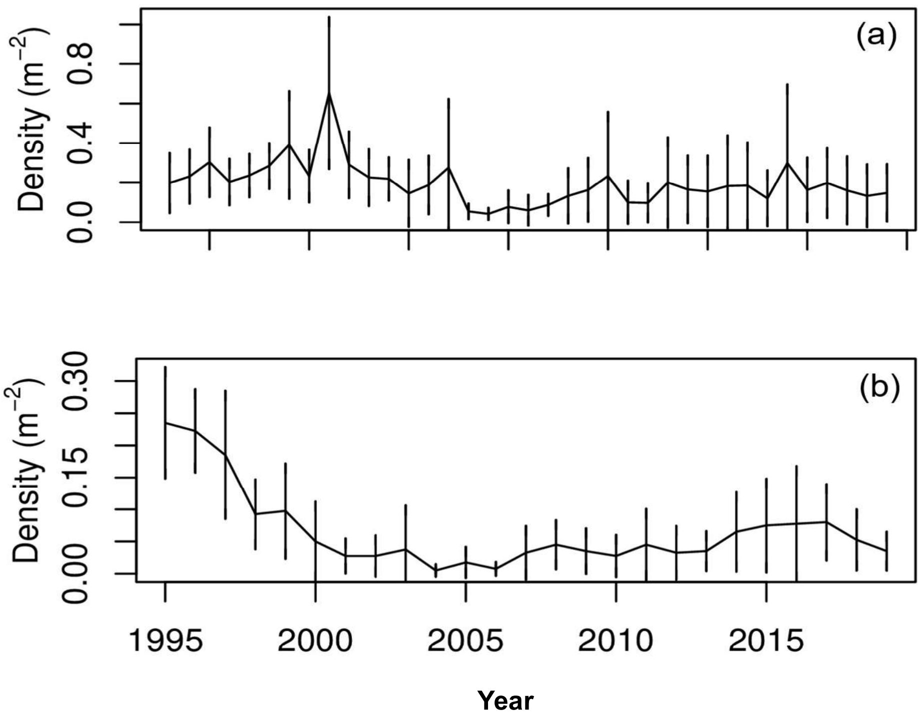
Appendix A.29

Fractional cover of the invasive alga *Sargassum horneri* over time beginning when it was first observed in the kelp forests off San Diego (see Appendix A.28).



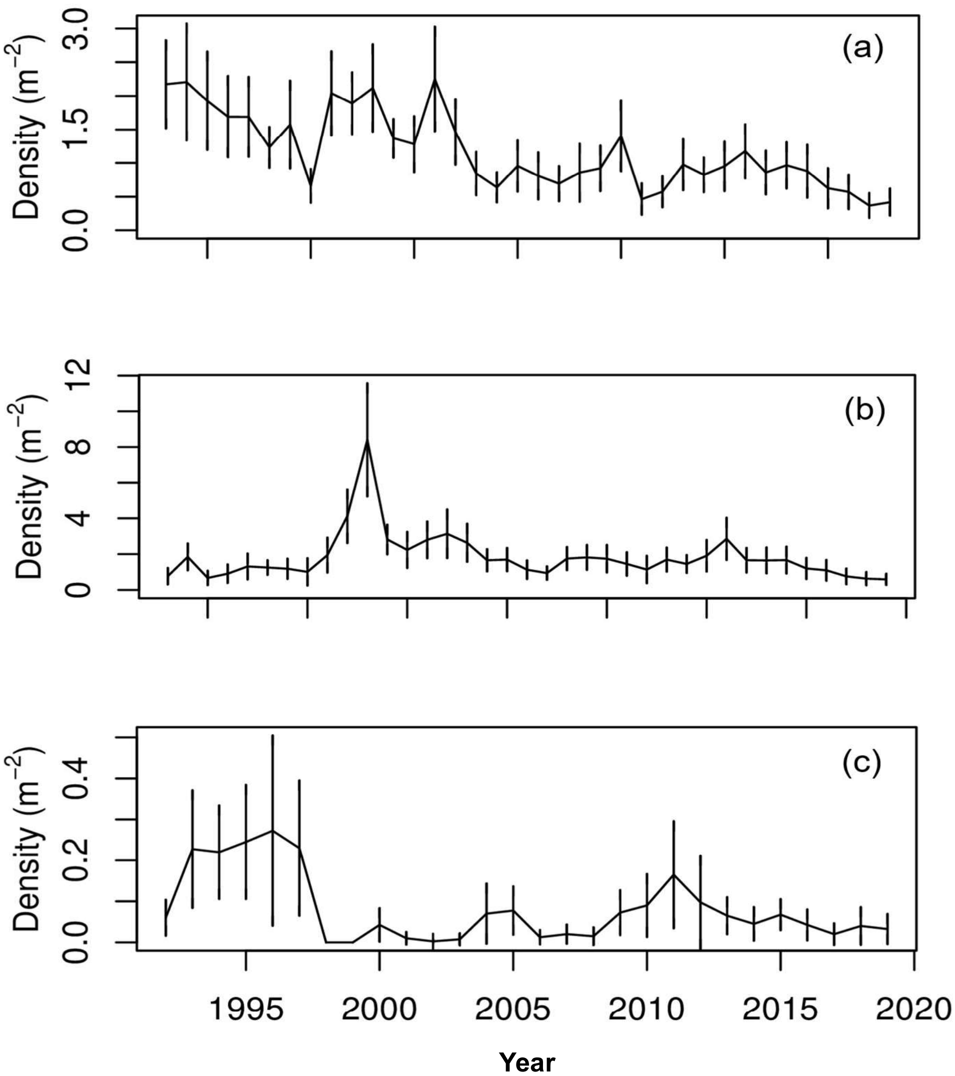
Appendix A.30

Time series of the red sea urchin (*Mesocentrotus franciscanus*) mean densities at the (a) PLM18, (b) PLT15, and (c) PLT12 study sites. Error bars are standard errors.



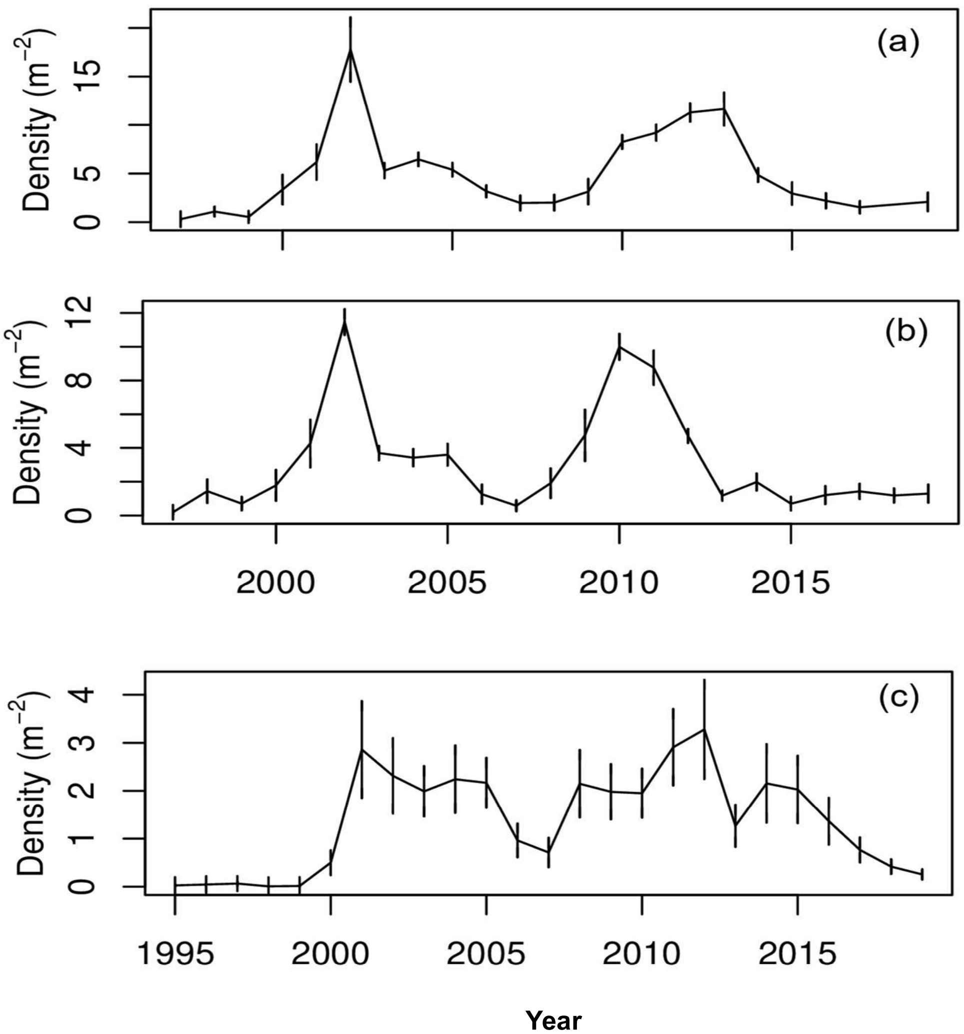
Appendix A.31

Time series of the red sea urchin *(Mesocentrotus franciscanus*) mean densities at the (a) PLC18, and (b) PLC21 study sites. Error bars are standard errors.



Appendix A.32

Time series of purple sea urchin (S*trongylocentrotus purpuratus*) mean densities at the (a) PLC15, (b) PLN18, and (c) LJS15 study sites. Error bars are standard errors.



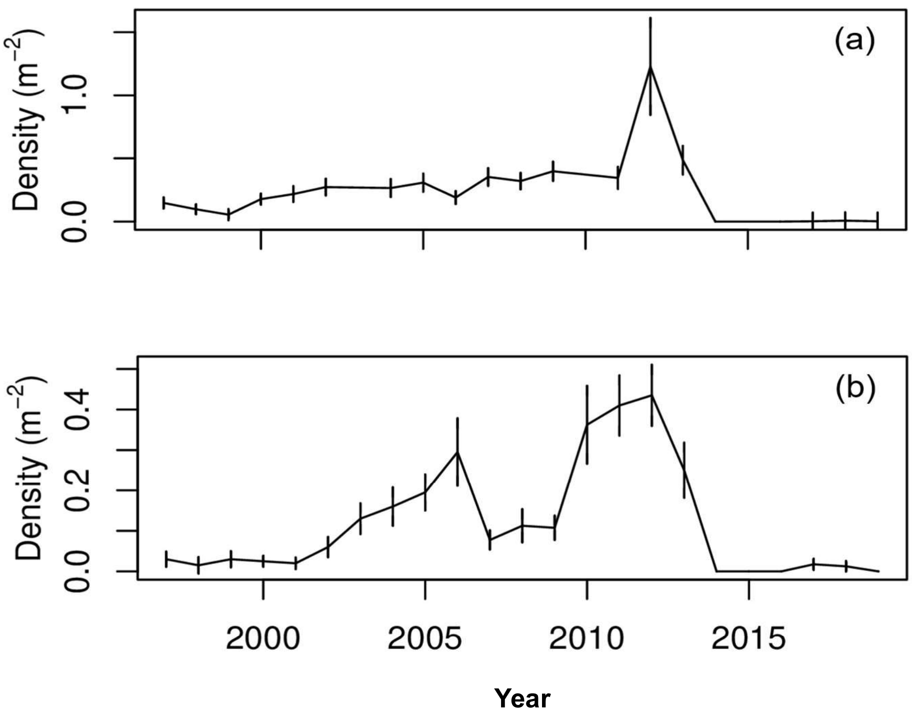
Appendix A.33

Time series of purple sea urchin (*Strongylocentrotus purpuratus*) mean densities at the (a) PLT15 (b) PLM18, and (c) PLC21 study sites. Error bars are standard errors.

Appendix A.34

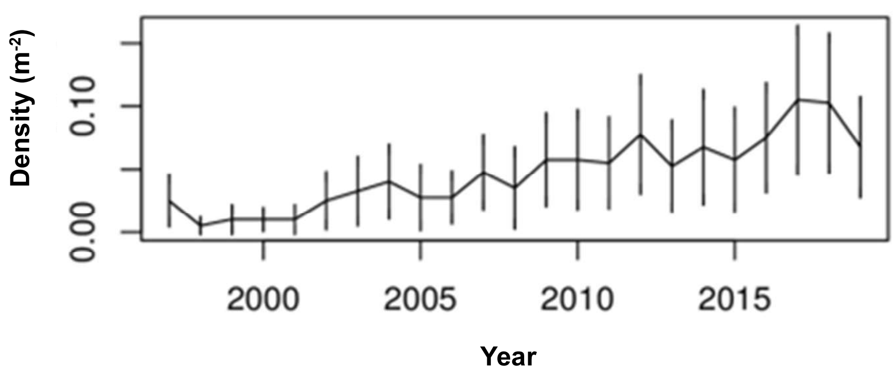
Recruitment rates for red and purple sea urchins (*Mesocentrotus franciscanus* and *Strongylocentrotus purpuratus*, respectively) during the spring and fall of 2019. Recruitment percent is the fraction of ~1 year old individuals sampled within quadrats. Size thresholds for RSU and PSU recruits are <35 and <25 mm, respectively. “*” refers to sites where too few sea urchins were available for measurement (n<30).

	Mesocentrotus franciscanus		*Strongylocentrotus purpuratus*	
Site	**Spring**	**Fall**	**Spring**	**Fall**
LJNorth12	0.38	0.54	0.30	0.30
LJNorth15	0.48	0.19	0.24	0.06
LJNorth18	0.15	0.16	0.16	0.11
LJSouth12	0.33	0.18	0.11	0.17
LJSouth15	0.33	0.25	0.27	0.28
LJSouth18	0.64	0.13	0.24	0.16
PLCen12	*	*	0.11	0.02
PLCen15	0.16	0.00	0.08	0.04
PLCen18	0.21	0.13	0.25	0.13
PLCen21	0.56	0.51	0.49	0.12
PLCen8	*	*	0.27	0.09
PLCenW18	0.31	0.06	0.22	0.17
PLMouth18	0.33	0.28	0.56	0.15
PLNorth18	0.19	0.03	0.06	0.04
PLSouth15	0.36	0.11	0.13	0.03
PLSouth18	0.33	0.38	0.33	0.10
PLSouthW18	0.00	0.08	0.01	0.39
PLTip12	0.41	0.25	0.29	0.14
PLTip15	0.54	0.91	0.88	0.20



Appendix A.35

Time series of the seastar *Pisaster giganteus* mean densities at the (a) PLT12 and (b) PLM18 study sites. Error bars are standard errors



Appendix A.36

Time series of pink abalone (*Haliotis corrugata)* mean densities at the PLC8 study site. Error bars are standard errors.

Appendix B

Enhanced Monitoring Near San Diego Ocean Outfalls:

Initial Results from Real-Time Oceanographic Mooring Systems

2017–2019

Appendix B. Enhanced Monitoring Near San Diego Ocean Outfalls: Initial Results from Real-Time Oceanographic Mooring Systems

Introduction

The City of San Diego (City) collects a comprehensive suite of oceanographic data utilizing Real-Time Oceanographic Mooring Systems (RTOMS) located at the terminal end of the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO). The RTOMS are anchored buoys suspended in the water column, configured with a range of oceanographic instruments, collecting physical and biogeochemical observations at one or more depths. They are valued for their ability to measure temporal variability through the collection of continuous oceanographic data and to provide near-real time information of changing conditions. These observations enable the assessment of environmental or ecosystem conditions and the impact of oceanographic and anthropogenic events on coastal regions. These data can be further used to validate predictive models that seek to characterize changes, which may cause environmental degradation. The ability to monitor in near real-time is an essential component of wastewater plume tracking, as it provides the City with the ability to predict potential shoreward-based movement of wastewater plumes, which may otherwise present a hazard to people utilizing recreational waters along the shoreline. Furthermore, real-time monitoring allows the City to quickly identify issues with equipment to facilitate long-term maintenance.

Following an independent review of its ocean monitoring program (SIO 2004), the City collaborated with Scripps Institution of Oceanography (SIO) to develop and conduct enhanced monitoring intended to provide an improved understanding of physical circulation and current movement patterns in local coastal waters surrounding the PLOO. Initially, non-telemetered moored temperature loggers (thermistor strings) and Acoustic Doppler Current Profilers (ADCPs) were utilized to characterize the thermocline structure and current regime in the area surrounding the PLOO (Storms et al. 2006). The use of these "static" moorings was later expanded to include both the PLOO and SBOO regions where the resultant data have been a valuable part of the City's annual receiving waters reports (e.g., City of San Diego 2018a).

Subsequent studies of the fate and behavior of wastewater discharged to the ocean via the SBOO (Terrill et al. 2009) and the PLOO (Rogowski et al. 2012a, 2012b, 2013) included recommendations to use RTOMS and advanced sampling technologies to better understand nearshore coastal water quality and the impacts of local ocean currents and tidal fluxes on effluent plume dynamics. Based on these recommendations, the City, U.S. Section of the International Boundary and Water Commission (USIBWC), San Diego Regional Water Quality Control Board (SDRWQCB), and US Environmental Protection Agency (USEPA), reached an agreement that initial plume tracking and real-time monitoring requirements for the PLOO and SBOO regions should include, but not be limited to, the following main elements: (1) design and installation of permanent RTOMS located near the north diffuser leg of the PLOO and south diffuser leg of the SBOO; (2) development of a schedule and monitoring work plan for implementation and testing of these RTOMS, including data acquisition and processing (City of San Diego 2018b); (3) networking the RTOMS to be fully compatible with each other, and a third system, which is operated by SIO in the coastal waters (100-m depth) off the City of Del Mar; (4) development of a schedule and work plan for using advanced oceanographic sampling instrumentation and technologies, such as a Remotely Operated Towed Vehicle (ROTV), in conjunction with the RTOMS to enhance the collection of water quality data and provide high-resolution maps of plume dispersion and location (City of San Diego 2018b).

This appendix presents preliminary analysis and interpretation of RTOMS data collected from 2017 through 2019 in the PLOO and SBOO regions. The primary goals of this appendix are to: (1) provide in-depth evaluations, interpretations, discussions, and conclusions concerning the state of the local receiving waters; (2) measure the direction and velocity of subsurface currents as well as ocean stratification. In future reports, results from the City's Adaptive Plume Tracking Pilot Study (City of San Diego 2020a) will also be included. This study aims to evaluate the efficacy of using the City's ScanFish III ROTV alongside the RTOMS to enhance the collection of water quality data and provide high-resolution maps of plume dispersion and location.

Materials and Methods

Real-Time Oceanographic Mooring Systems

Deployment

In partnership with SIO, the City deployed two RTOMS at the terminal ends of the PLOO and SBOO (Appendix B.1, Addendum 9-1). The RTOMS were anchored at a distance far enough from the diffuser ports to be outside the area of active plume rise. The PLOO RTOMS was anchored at a depth of approximately 100 m, just west of the northern diffuser leg, and the SBOO RTOMS was anchored at a depth of approximately 30 m, just west of the southern diffuser leg terminus. Each mooring was deployed for a period of approximately one year, during which time SIO closely monitored and evaluated technical performance of the component sensors and supporting hardware to certify overall system functionality. If issues were detected that could not be corrected remotely, City staff attempted to repair the problem onsite. Upon completion of a year-long deployment, each RTOMS was retrieved and replaced as soon as possible following the servicing of sensors and equipment.

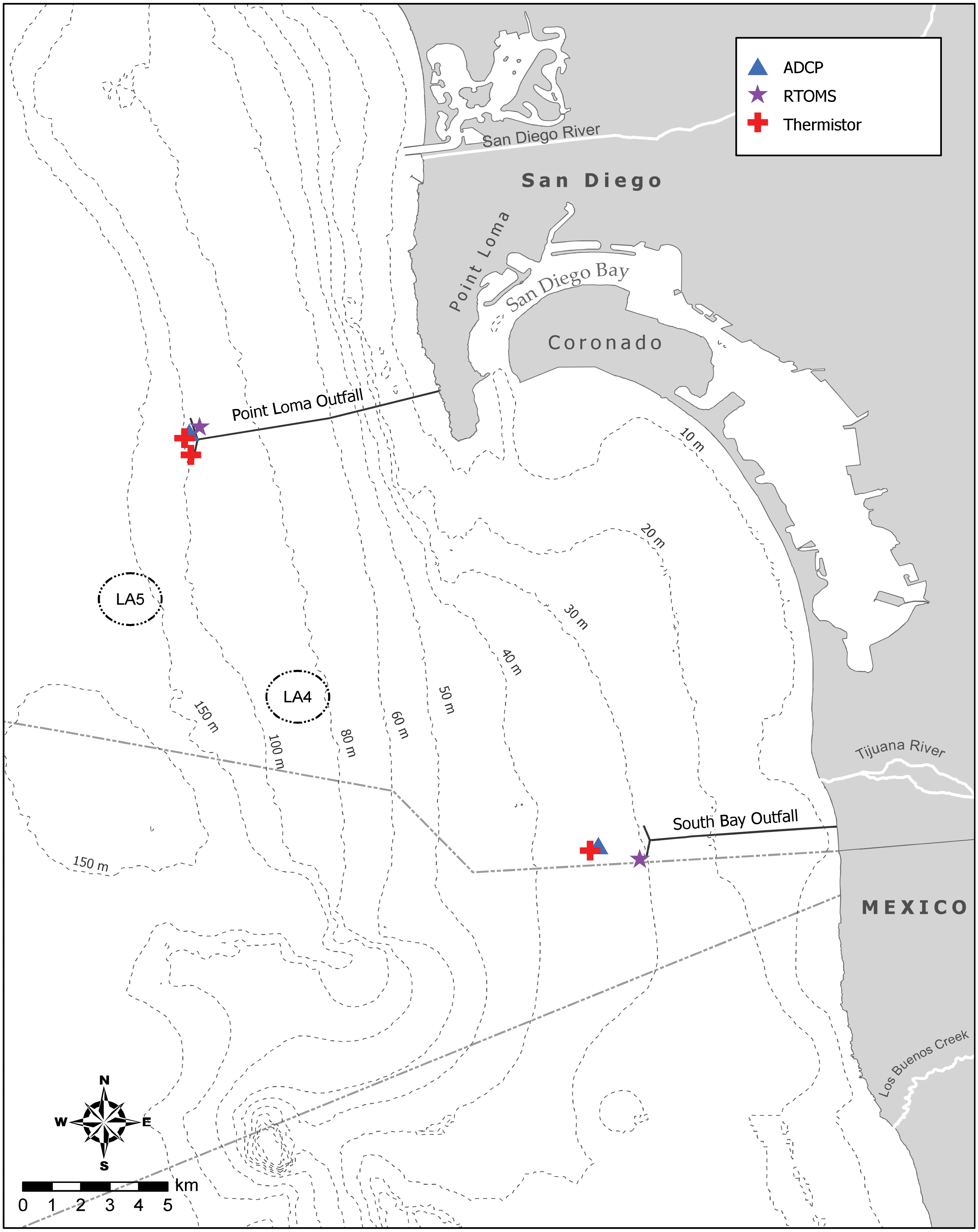
Each RTOMS was outfitted with a series of instruments/sensors (Appendices B.2, B.3). Critical parameters that were measured on a real-time basis, by both systems, included temperature, conductivity (salinity), total pH, dissolved oxygen (DO), dissolved carbon dioxide (xCO_2), nitrogen (nitrate plus nitrite), chlorophyll *a*, colored dissolved organic matter (CDOM), biological oxygen demand (BOD), and current direction and velocity.

Data Collection

Real-time data management and integration support was, and continues to be, provided by SIO, whom are under contract with the City through 2022. This includes, but is not limited to: (1) maintaining the data management system (i.e., servers and modems); (2) conducting preliminary data processing and verification; (3) hosting real-time data and posting data to an accessible website (see: http://mooring.ucsd.edu/dev/); (4) providing ongoing technical support and training for real-time mooring technology to City staff. SIO is also responsible for networking the PLOO and SBOO real-time moorings with the existing SIO Del Mar mooring to form a comprehensive state-of-the-art ocean observing system for the San Diego region.

Data and Equipment Issues

Deployment and retrieval of the RTOMS has presented a number of significant challenges that were not anticipated in the original work plan (City of San Diego 2018b), which has resulted in disruptions to planned operations and subsequent gaps in data collection. Manufacturer calibration and equipment repair delays, and sensor failures have been the primary factors disrupting planned RTOMS deployments, and subsequent data gaps (City of San Diego 2020b). However, data gaps also exist due to loss of communication with the RTOMS via the onboard modem communication system. To help minimize delays and streamline the redeployment process in the future, the City intends to obtain additional back-up sensors, and plan for longer equipment service times with manufacturers. Furthermore, to reduce the loss of data resulting from network and communication failure with the RTOMS, data were, and will continue to be, recovered and downloaded directly from the RTOMS. Furthermore, for the current mooring deployment cycle, the PLOO and SBOO redeployments were staggered six months apart to allow more time for sensors to be serviced.



Appendix B.1
Locations of RTOMS and static moorings (ADCPs and thermistor string arrays) deployed at the terminal ends of the PLOO and SBOO as part of the City's Ocean Monitoring Program.

Appendix B.2

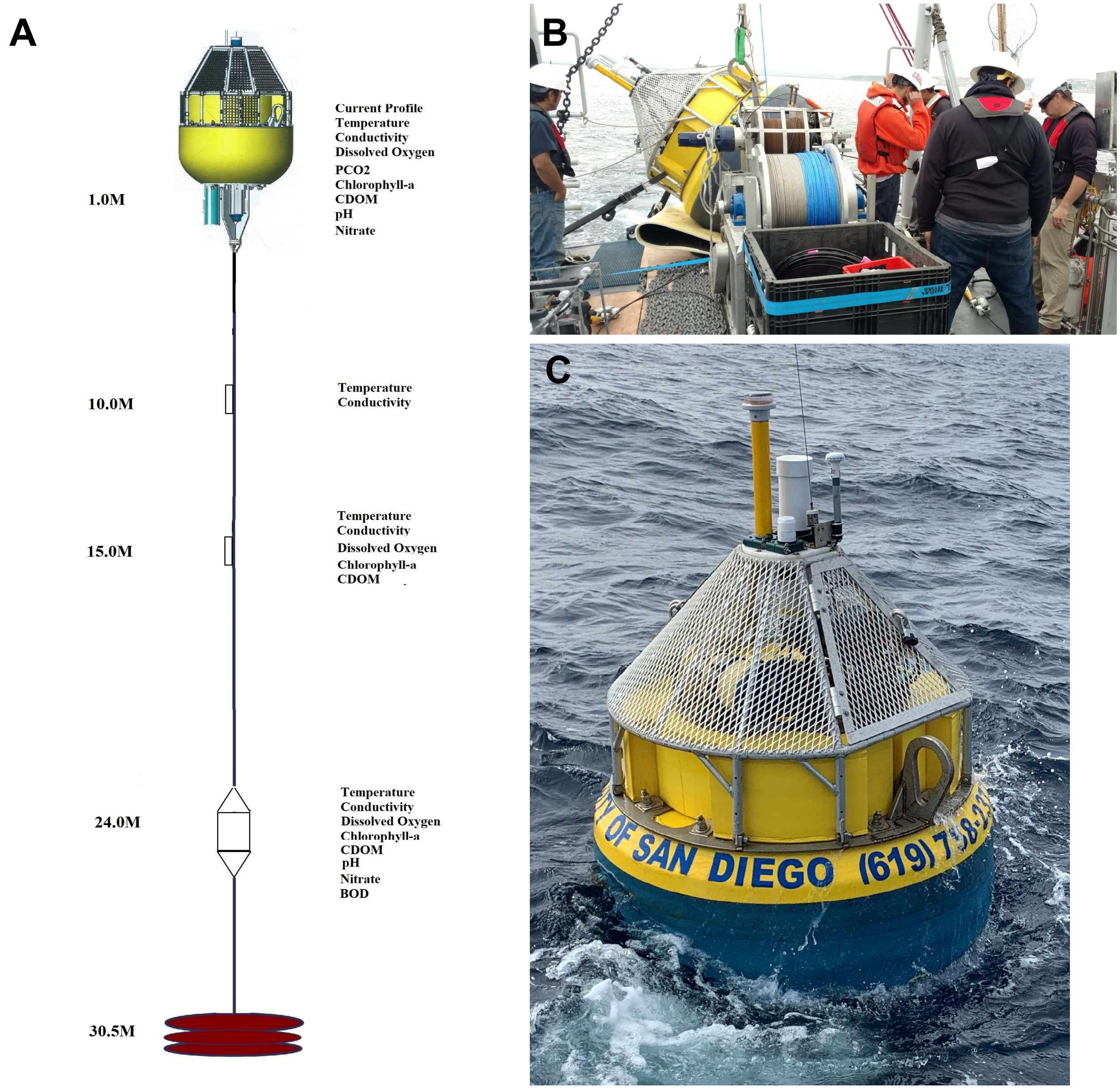
Present sensor configuration and model type for the real-time oceanographic moorings by site and depth.

Sensor Depth		
PLOO	SBOO	Parameters Measured (Sensor Types)
1 m (surface)	1 m (surface)	Temperature, conductivity, pH (total), dissolved oxygen (Sea-Bird SeapHOx)
		Ocean currents (RDI 300kHz ADCP)
		Partial pressure of carbon dioxide (Pro-Oceanus pCO2 System)
		Chlorophyll *a*, CDOM, turbidity (Sea-Bird ECO triplet)
		Nitrate (Sea-Bird SUNA V2)
10 m	10 m	Temperature, conductivity (Sea-Bird MicroCAT)
	18 m	Temperature, conductivity, dissolved oxygen (Sea-Bird MicroCAT ODO)
		Chlorophyll *a*, CDOM, turbidity (Sea-Bird ECO triplet)
20 m		Temperature, conductivity (Sea-Bird MicroCAT)
	26 m (cage)	Temperature, conductivity, pH, dissolved oxygen (Sea-Bird SeapHOx)
		Chlorophyll *a*, CDOM, turbidity (Sea-Bird ECO triplet)
		Nitrate (Satlantic SUNA V2)
		BOD (Chelsea UviLux)
30 m (cage-1)		Temperature, conductivity, pH, dissolved oxygen (Sea-Bird SeapHOx)
		Chlorophyll *a*, CDOM, turbidity (Sea-Bird ECO triplet)
		BOD (Chelsea UviLux)
45 m		Temperature, conductivity (Sea-Bird MicroCAT)
60 m		Temperature, conductivity (Sea-Bird MicroCAT)
75 m		Temperature, conductivity (Sea-Bird MicroCAT)
90 m (cage-2)		Temperature, conductivity, pH, dissolved oxygen (Sea-Bird Deep SeapHOx)
		Chlorophyll *a*, CDOM, turbidity (Sea-Bird ECO triplet)
		Nitrate (Sea-Bird SUNA V2)
		BOD (Chelsea UviLux)

Due to the aforementioned equipment servicing delays and sensor failures, data from the SBOO mooring are unavailable from October 14, 2017 to August 2, 2018, and September 19, 2019 to December 17, 2019. Data are also unavailable for the PLOO mooring from March 16, 2019 to October 6, 2019. RTOMS data presented here includes only data collected in real-time from all deployments, which were initially processed and consolidated by SIO (Addendum 9-1). In the future, data recovered and downloaded directly from the RTOMS will also be used to fill in data gaps where mooring communication failures occurred. For additional information on specific sensor issues and challenges experienced, see the most recent Plume Tracking Monitoring Plan Progress Report (City of San Diego 2020b).

Data Processing and Analysis

Prior to any data analysis taking place, all data were subject to a comprehensive suite of quality assurance/quality control (QA/QC) procedures following Quality Assurance of Real-Time Oceanographic Data (QARTOD) methodologies (US IOOS 2020). QARTOD is a collaborative effort formed to address the data quality issues of the U.S. Integrated Ocean Observing System (US IOOS) community. QARTOD outlines the recommended minimum standards for QA/QC methods, and provides guidelines and manuals for applying automated data qualifier flags specific to each parameter (US IOOS 2017, 2020). QARTOD tests were applied to all data prior to analysis (Appendix B.4, see Addenda 9-2 through 9-4 for details). In addition to these



Appendix B.3

Diagram of SBOO RTOMS showing general sensor configuration (A); Preparing to deploy the SBOO RTOMS aboard the M/V Oceanus (B); Surface buoy of the SBOO RTOMS following successful deployment in December 2016 (C). Note, this diagram does not necessarily reflect the current configuration of deployed RTOMS.

automated tests, all data were reviewed manually and flagged to identify questionable data, which may result from biofouling, interference from bubbles, sensor drift, or other malfunctions. Major data and sensor problems are highlighted in Appendix B.5. A detailed log of data flagged manually by parameter, site, depth, and date range is available on request. After review, all data that were flagged as suspect or bad, either manually or from automated QARTOD tests, were excluded from further analyses and are not presented in this report.

Note that pH is reported in total scale from moored instruments, while pH is reported in NBS (National Bureau of Standards) scale historically and in other chapters. Total pH scale is intended specifically for seawater, while the NBS scale was initially developed for freshwater use; thus, there is no direct method to convert between the pH scales (Martz et al. 2010, Marion et al. 2011). Therefore, pH ranges reported in this appendix may be generally lower than those reported in other chapters in this report, and direct comparison should be taken with caution.

Appendix B.4

Automated QC tests completed for processing and flagging RTOMS data; follows national data standards for qualifying real-time data (US IOOS 2017). See Addenda 9-2 to 9-4 for QC flag definitions and ranges used in tests 4 and 5.

Test #	Test Name	Parameters:	Notes
1	Gap Test	All	Completed in real-time by SIO
2	Syntax Test	All	Completed in real-time by SIO
3	Location Test	Physical latitude/longitude	Data logged by SIO; no flag applied yet in real-time
4	Gross Range Test	All	Completed in post-processing by City
5	Climatological Test	All	Completed in post-processing by City

Analyses and plotting were performed in R (R Development Core Team 2019) using functions within various packages (i.e., data.table, dplyr, ggplot2, lubridate, purrr, reshape2 and mixOmics) (Wickham 2007, Grolemund and Wickham 2011, Wickham 2016, Le Cao et al. 2017, Henry and Wickham 2019, Dowle and Srinivasan 2020, Wickham et al. 2020). Contour plots were generated in MATLAB (2016) using default settings, which display fixed isolines, and fill areas between isolines with constant colors. Density calculations and temperature-salinity plots were created using the SEAWATER toolbox library for MATLAB, version 3.3.1 (Morgan and Pender 2014). Annual time series of raw and daily-averaged data were plotted at each depth and site for all parameters that passed review, with the exception of ADCP data (described below). In addition, summary statistics were completed at each depth, site, and year with the following seasonal periods that align with quarterly water quality sampling: winter (January–March); spring (April–June); summer (July–September); fall (October–December). Large data gaps were identified as seasons/years with <40% data recovery, based on expected number of samples for sensor-specific sampling intervals, and were excluded from summary analyses (Addendum 9-5). Vertical profiles were constructed for daily-averages of temperature, salinity, and density, as these parameters had the most coverage through the water column. Density gradients were calculated by differences in daily-averaged density between sensors and dividing by the depth.

Ocean current data collected by downward-facing surface-mounted RTOMS ADCP instruments (Teledyne RD Instruments 300 kHz Workhorse Broadband) were checked for quality by eliminating those measurements that did not meet echo intensity criteria (i.e., minimum average intensity >100 counts and minimum correlation among the four beams of >70%). Following this initial screening, tidal frequency data were removed using the PL33 filter (Alessi et al. 1984) and compass direction was corrected to true north (+12.8 degrees). For all the SBOO RTOMS deployments, ADCP data were summarized by season and select depth bins. For the PLOO RTOMS, only data from the first deployment was summarized, due to a change in data collection method, where the bin size increased from 1 to 2 m. The generalized axes of current direction and magnitude were determined by linear regression of all RTOMS ADCP northern versus eastern velocities for select depth bins.

Static Moorings

Non-telemetered (static) upward-facing bottom-mounted ADCPs (Teledyne RD Instruments 300 KHz Workhorse Monitor) and thermistor (Onset Tidbit temperature loggers) string arrays were moored near the RTOMS at the terminal end of the PLOO and SBOO as part of the original Moored Observation System Pilot Study (Storms et al. 2006). These data were subsequently used to verify the accuracy and reliability of the RTOMS and/or to supplement data gaps between RTOMS deployments (Appendix B.1, Addendum 9-6). Current data from bottom-mounted ADCPs were used to supplement RTOMS ADCP data, and are reported separately for comparison (see Addenda 9-10 through 9-14). These ADCP data were collected every five minutes in 4-m depth bins, ranging from 9 to 93 m at the PLOO and from 6 to 30 m at the SBOO. Similar

Appendix B.5

Summary of manual QA/QC review findings, including major sensor problems and data quality issues for the PLOO and SBOO RTOMS. Gaps in data resulted during time periods data were not collected or flagged as bad or suspect.

Parameter	RTOMS	Depths	Time Period	Problem	Action Taken
Nitrate+ nitrite	PLOO	1, 89 m	02 Mar 2018 to 15 Mar 2019, 07 Oct 2019 31 Dec 2019 for 1 m	SUNA sensors displayed large negative values, noise, and linear upward drift through deployment	All data qualifed as bad or suspect and not reported
CDOM	PLOO	1, 30, 89 m	02 Mar 2018 to 15 Mar 2019	Turner sensors displayed noise and linear negative drift through deployments, and severe biofouling	All data qualifed as bad or suspect and not reported
CDOM	SBOO	1, 18, 26 m	21 Dec 2016 to 13 Oct 2017	Turner sensors displayed noise and linear negative drift through deployments, and proper calibrations not provided from manufacturer	All data qualifed as bad or suspect and not reported
ADCP	SBOO	1 m	31 Jan 2017 to 07 Feb 2017	ADCP Battery pack drained due to modem connections issues	Missing data for some days during first deployment
Salinity	SBOO	1 m	03 Apr 2019 to 23 Aug 2019	Sea-Bird MicroCAT displayed sudden step change and excess noise in data outside of expected climatological range	Data qualifed as suspect and not reported
Chlorophyll *a* and turbidity	PLOO and SBOO	All	PLOO: 07 Oct 2019 31 Dec 2019; SBOO: 03 Aug 2018 to 18 Sep 2019	ECO triplet sensors improperly configured for narrow oceanic range	No data available >~30 ug/L for chlorophyll or>~10 NTU for turbidity
Total pH	PLOO	30 m	02 Mar 2018 to 15 Mar 2019	SeaFET pH sensor failed at beginning of deployment	No data collected
All	PLOO	89 m	08 Mar 2018 to 15 Mar 2019	Bottom mooring controller failed and lost communication with sensors at beginning of deployment	No data collected
All	SBOO	All	21 Dec 2016 to 13 Oct 2017	Intermittent gaps in real-time data due to modem communication problems	Missing data for some days during first deployment
All	SBOO	All	06 Aug 2017 to 13 Oct 2017	Data record cut short at 1 and 26 m due to battery failures	Missing data for some days during first deployment

to RTOMS data processing, ocean current data collected by static ADCP instruments were checked for quality by eliminating measurements that did not meet echo-intensity criteria (i.e., minimum average intensity >100 counts and minimum correlation among the four beams of >70%). Following this initial screening, tidal frequency data were removed using the PL33 filter (Alessi et al. 1984), compass direction was corrected to true north (+12.8 degrees), and data were hourly averaged. All reportable static mooring deployments were also summarized by season and depth bin. Temperature data were collected from the vertical series of thermistors every 10 minutes from duplicate arrays. The thermistors were deployed on mooring lines at each site starting at 2 m above the seafloor

Appendix B.6

Summary of temperature (°C) recorded at the PLOO RTOMS during 2018 and 2019. Data include sample size (n), minimum, maximum, and mean values for each depth by season. Sample sizes differed due to variations in sampling interval, deployment date, and data quality (see Addenda 9-1 to 9-5).

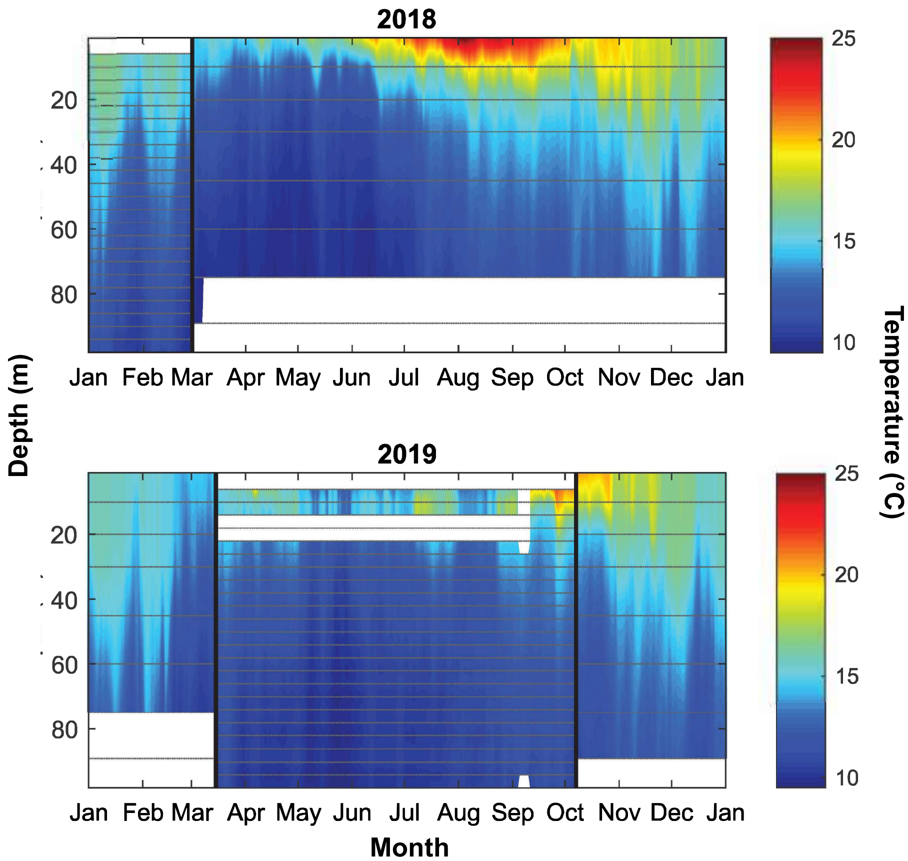
Year	Season		1 m	10 m	20 m	30 m	45 m	60 m	75 m	89 m
2018	Winter[a]	min	—	11.6	11.0	10.6	10.1	9.8	9.7	9.4
		max	—	17.2	17.0	16.9	16.5	15.6	14.8	13.7
		mean	—	15.4	14.4	13.5	12.5	11.6	11.2	10.7
		n	0	12,959	12,959	12,959	12,959	12,959	12,959	12,959
	Spring	min	13.4	10.7	10.1	10.0	9.7	9.6	9.5	—
		max	21.8	19.7	16.0	14.3	12.3	11.2	10.8	—
		mean	17.4	13.6	11.8	11.1	10.5	10.1	10.0	—
		n	2079	12,521	12,538	4158	12,538	12,534	12,530	0
	Summer	min	20.1	12.7	12.3	11.3	10.4	10.1	10.0	—
		max	26.0	24.3	19.2	16.3	14.9	13.7	13.5	—
		mean	23.1	18.2	15.3	13.9	12.9	12.0	11.4	—
		n	2070	12,484	12,490	4151	12,498	12,514	12,516	0
	Fall	min	15.7	12.6	13.9	13.3	12.1	11.5	11.1	—
		max	21.7	20.7	19.5	18.3	17.2	16.0	15.2	—
		mean	18.5	17.8	16.6	15.3	14.2	13.3	12.7	—
		n	2164	12,998	12,999	4325	12,998	13,000	12,998	0
2019	Winter	min	12.8	12.4	11.8	11.4	10.6	10.2	10.0	—
		max	16.6	16.3	16.2	16.2	16.2	15.9	15.5	—
		mean	15.3	15.1	14.9	14.5	13.5	12.6	11.9	—
		n	1738	10,418	10,420	3480	10,434	10,445	10,445	0
	Spring[a]	min	—	10.9	10.5	10.4	9.8	9.6	9.7	9.7
		max	—	18.7	16.9	15.1	12.8	12.1	11.5	11.0
		mean	—	15.0	12.8	12.1	11.1	10.5	10.4	10.3
		n	0	13,103	13,103	13,103	13,103	13,103	13,103	13,103
	Summer[a]	min	—	12.6	11.8	11.3	10.5	10.2	10.2	10.2
		max	—	22.1	18.3	16.2	14.7	13.6	13.2	12.2
		mean	—	16.3	13.9	13.1	12.0	11.4	11.1	10.9
		n	0	12,210	12,210	13,233	13,233	13,233	13,233	13,233
	Fall	min	15.2	14.5	13.3	12.6	11.6	11.0	10.6	10.3
		max	21.8	20.8	19.4	17.9	17.1	15.1	14.4	13.8
		mean	17.9	17.3	16.0	15.1	13.9	13.0	12.3	11.8
		n	12,311	12,312	12,312	11,066	12,312	12,312	12,312	10,783

[a] Static thermistor data during period where real-time mooring data were unavailable; nearest thermistor depths are 10, 22, 30, 46, 62, 74, and 90 m, respectively; there was no thermistor data for 1-m depth

Appendix B.7

Summary of temperature (°C) recorded at the SBOO RTOMS from 2017 through 2019. Data include sample size (n), minimum, maximum, and mean values for each depth by season. Sample sizes differed due to variations in sampling interval, deployment date, and data quality (see Addenda 9-1 to 9-5); id = insufficient data (see text).

Year	Season		1 m	10 m	18 m	26 m
2017	Winter	min	13.0	11.4	11.2	11.1
		max	16.1	15.5	15.2	14.8
		mean	14.8	14.6	14.2	13.7
		n	3099	7023	7174	3315
	Spring	min	13.9	10.7	10.4	10.2
		max	20.2	18.6	17.1	13.0
		mean	16.9	13.1	11.4	11.0
		n	6175	9212	9219	5347
	Summer	min	—	12.3	11.8	—
		max	—	23.0	20.1	—
		mean	—	15.7	13.7	—
		n	id	10,423	10,398	id
	Fall	n	0	id	id	0
2018	Summer	min	15.5	13.8	13.4	13.1
		max	26.1	25.6	21.7	16.0
		mean	21.6	17.1	15.1	14.2
		n	1322	7952	7952	1323
	Fall	min	14.6	14.0	13.5	13.3
		max	20.1	19.7	19.0	18.2
		mean	17.8	17.0	16.4	15.7
		n	2180	13,098	13,140	2181
2019	Winter	min	13.3	11.9	11.3	11.2
		max	16.5	15.9	15.9	15.8
		mean	15.0	14.7	14.3	13.8
		n	2099	12,627	12,677	2091
	Spring	min	13.6	11.0	10.7	10.5
		max	19.5	18.6	17.1	15.3
		mean	16.9	14.1	12.5	11.9
		n	2116	12,761	12,839	2111
	Summer	min	16.5	11.3	11.0	10.9
		max	23.7	21.4	20.0	13.5
		mean	20.1	15.3	13.1	12.1
		n	1885	11,225	8786	1087
	Fall	n	id	id	id	id



Appendix B.8

Temperature recorded near the PLOO by the RTOMS or thermistor array during 2018 and 2019. Data are daily averaged values. Horizontal gray lines indicate depths at which sensors were located. Vertical black lines indicate time periods when thermistor array data were used to replace missing RTOMS data due to gaps between deployments (01 Jan 2018 to 01 Mar 2018 and 16 Mar 2019 to 06 Oct 2019). Additional missing data due to instrument failure or loss shown as white spaces.

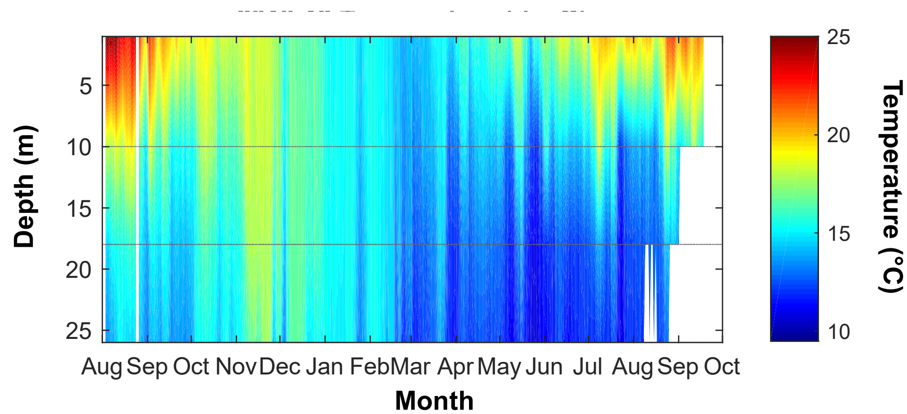
and extending through the water column every 4 m to within 6 m of the surface. Data from the PLOO thermistor strings were used to supplement RTOMS data gaps during winter 2018 and spring/ summer 2019. However, there were large gaps in the data collected from the SBOO thermistor strings due to thermistors lost at sea during 2018 and 2019. Therefore, it was not possible to supplement the SBOO RTOMS temperature data.

Results and Discussion

Oceanographic Conditions Observed by RTOMS

Water Temperature

Ocean temperatures observed at the PLOO from 2018 through 2019 ranged from a minimum of 9.4 to a maximum of 17.2°C in winter, 9.5 to 21.8°C in spring, 10.0 to 26.0°C in summer, and 10.3 to 21.8°C in fall (Appendix B.6, Addendum 9-7). Similarly, water temperatures at the SBOO from 2017 through 2019 ranged from a minimum of 11.1 to a maximum of 16.5°C in winter, 10.2 to 20.2°C in spring, 10.9 to 26.1°C in summer, and 13.3 to 20.1°C in fall (Appendix B.7, Addendum 9-7). The warmest mean water temperatures were recorded at the surface in both regions during the summer of 2018 (PLOO: 23.1°C; SBOO: 21.6°C). Conversely, the coldest mean water temperatures were consistently recorded in the deepest locations for both RTOMS (PLOO: 89 m; SBOO: 26 m) during the spring (PLOO: 9.5°C; SBOO: 10.2°C). These data showed typical seasonal patterns and similar ranges reported from quarterly surveys (see Chapter 2), though capture more seasonal variability, since data were recorded at 10-minute intervals for several months at a time. As a result,



Appendix B.9

Temperature recorded by the SBOO RTOMS from August 2018 through August 2019. Data are daily averaged values. Horizontal gray lines indicate depths at which sensors were located. Missing data due to instrument failure or loss shown as white spaces.

maximum surface summer temperatures for both moorings were up to 1.9°C higher than observations from any sites during 2018–2019 quarterly surveys (see Chapter 2, Appendices B.6, B.7).

Cold waters (daily-averaged temperatures < 11°C) were typically observed throughout much of the water column in spring at the PLOO (Appendix B.8), which is likely a result of the seasonal upwelling conditions that bring deeper oceanic water masses closer to the region. In addition, cool waters (< 12°C) at mid and bottoms depths at the SBOO were recorded over several weeks in the spring and summer seasons (Appendix B.9). Between the summer and early fall, surface waters warmed above 20°C in the upper 10 m and created sharp temperature gradients through the water column; these were particularly apparent during 2018 at both outfalls (Appendices B.8, B.9). In the winter, warmer waters (> 15°C) extended down to 60 m at the PLOO and throughout bottom depths at the SBOO over several weeks from December 2018 through February 2019, suggesting downwelling events.

Salinity

Salinity observed at the PLOO from 2018 through 2019 ranged from a minimum of 32.44 to a maximum of 33.76 PSU in winter, 32.82 to 33.94 PSU in spring, 32.37 to 33.91 PSU in summer, and 32.41 to 33.88 PSU in fall (Appendix B.10, Addendum 9-7). Similarly, salinity at the SBOO from 2017 through 2019 ranged from a minimum of 32.71 to a maximum of 33.79 PSU in winter, to 30.67 to 34.0 PSU in spring, 30.46 to 34.0 PSU in summer, and 33.06 to 33.82 PSU in fall (Appendix B.11, Addendum 9-7). The highest seasonal mean salinities (> 33.7 PSU) at both outfalls were recorded near the surface during the summer of 2018, likely due to evaporation caused by atmospheric warming (Jones et. al 2002). This time period also coincided with the highest recorded water temperatures as described previously. In deeper waters at the PLOO (> 20 m), high seasonal mean salinities (> 33.6 PSU) occurred more frequently in the spring, corresponding with the coldest observed temperatures and support the indication of spring upwelling. Low seasonal mean salinities (< 33.2 PSU) occurred during the winter of 2017 at the SBOO near the surface, and may be related to rain events and river flows as reported previously (City of San Diego 2018a). The lowest seasonal mean salinities at the PLOO were recorded during the summer of 2018 at deep depths, and at the SBOO during the summer of 2017 in the mid-depths.

Subsurface low salinities (< 33.3 PSU) at the PLOO were observed separately in two layers, one in the mid water column (30 m), and the second in deeper waters (60 to 75 m) (Appendix B.12). The lowest salinities recorded occurred at 75 m, which may be influenced by the PLOO effluent plume, due to the proximity of the mooring to the outfall discharge. Furthermore, some of these subsurface salinity minimum layers (SSML) may be influenced

Appendix B.10

Summary of salinity (PSU) recorded at the PLOO RTOMS during 2018 and 2019. Data include sample size (n), minimum, maximum, and mean values for each depth by season. Sample sizes differed due to variations in sampling interval, deployment date, and data quality (see Addenda 9-1 to 9-5); id = insufficient data (see text).

Year	Season		1 m	10 m	20 m	30 m	45 m	60 m	75 m	89 m
2018	Winter	n	id	id	id	id	id	id	id	id
	Spring	min	33.40	33.29	33.35	33.44	33.45	32.93	32.82	—
		max	33.77	33.92	33.77	33.79	33.90	33.86	33.94	—
		mean	33.63	33.57	33.60	33.59	33.68	33.45	33.54	—
		n	2079	12,488	12,537	4158	12,538	12,534	12,530	0
	Summer	min	33.66	33.29	33.33	33.16	33.35	32.62	32.37	—
		max	33.89	33.91	33.73	33.55	33.63	33.49	33.39	—
		mean	33.79	33.59	33.52	33.41	33.47	33.09	32.94	—
		n	2032	12,457	12,488	4127	12,498	12,507	12,514	0
	Fall	min	33.47	33.28	33.32	33.27	33.35	32.66	32.41	—
		max	33.82	33.88	33.78	33.73	33.65	33.55	33.51	—
		mean	33.68	33.60	33.55	33.48	33.52	33.29	33.14	—
		n	1237	12,972	12,839	4192	12,998	13,000	12,995	0
2019	Winter	min	33.34	33.13	33.22	33.10	33.38	33.01	32.44	—
		max	33.72	33.66	33.64	33.65	33.76	33.76	33.69	—
		mean	33.60	33.51	33.50	33.46	33.61	33.46	33.21	—
		n	1692	10,148	10,417	3480	10,434	10,443	10,441	0
	Fall	min	33.38	33.23	33.28	33.22	33.28	33.37	32.72	33.22
		max	33.75	33.82	33.68	33.72	33.77	33.83	33.69	33.83
		mean	33.60	33.53	33.49	33.54	33.52	33.61	33.33	33.58
		n	12,212	12,306	12,308	11,047	12,310	12,312	12,311	10,768

by seasonal evaporation at the surface, and the incursion of the low salinity and low temperature Pacific Subarctic surface water mass (Lynn and Simpson 1987, City of San Diego 2018a). At the SBOO, lower salinities were observed most frequently at mid depths during the summer of 2017 and at mid and near bottom depths during summer 2019, though surface data are missing for much of the spring/summer of 2019, due to sensor failures (Appendix B.13).

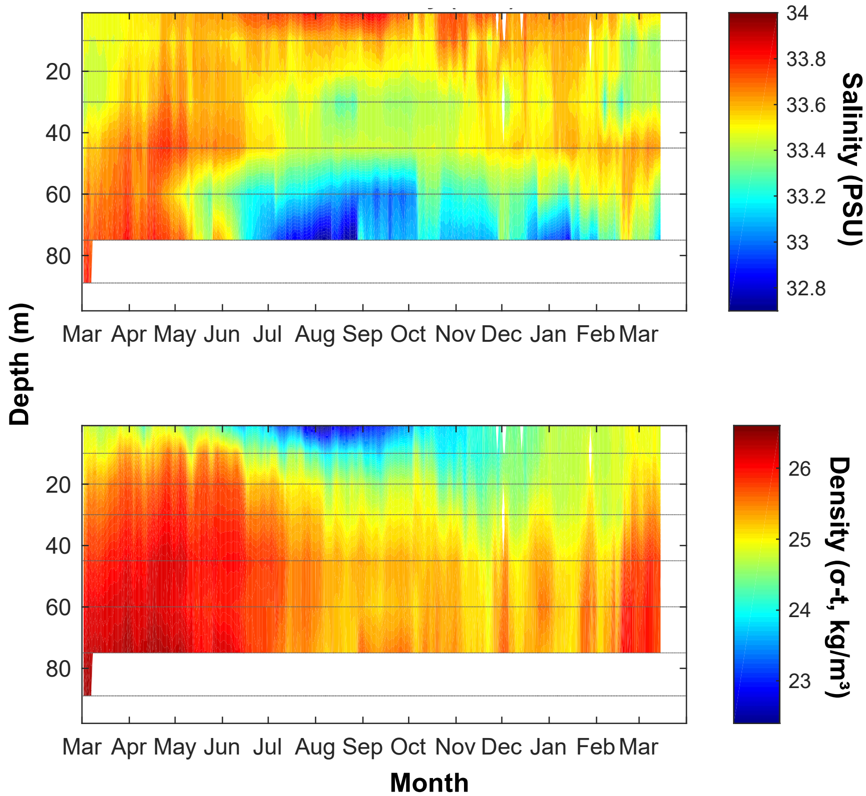
Density and Ocean Stratification

Densities at the PLOO were lowest (<23.5 kg/m^3) near the surface in the summer 2018, and highest (>26 kg/m^3) in the spring 2018 in deeper waters (>45 m) (Appendix B.12). Similarly, the lowest densities (<23.5 kg/m^3) at the SBOO were recorded in the summer and early fall near the surface, and highest densities (>25.6 kg/m^3) at the mid and bottom depths in the spring and early summer (Appendix B.13). These patterns closely follow temperature observations (Appendices B.8, B.9), and align with the finding that density is primarily influenced by temperature differences in the region (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Seasonal changes in ocean stratification at the moorings is therefore associated with the presence and strength of the thermocline. Larger changes in density over a given depth indicate stronger ocean stratification.

Appendix B.11

Summary of salinity (PSU) recorded at the SBOO RTOMS from 2017 through 2019. Data include sample size (n), minimum, maximum, and mean values for each depth by season. Sample sizes differed due to variations in sampling interval, deployment date, and data quality (see Addenda 9-1 to 9-5); id = insufficient data (see text).

Year	Season		1 m	10 m	18 m	26 m
2017	Winter	min	32.71	32.96	32.92	33.19
		max	33.33	33.46	33.58	33.55
		mean	33.19	33.25	33.30	33.35
		n	2787	6976	7126	3293
	Spring	min	33.25	30.67	32.67	33.30
		max	33.53	34.00	33.70	33.66
		mean	33.42	33.2	33.47	33.55
		n	6172	9012	9242	5296
	Summer	min	—	30.46	31.82	—
		max	—	33.74	33.45	—
		mean	—	32.04	33.00	—
		n	id	10,201	10,326	id
	Fall	n	0	id	id	0
2018	Summer	min	33.44	32.99	33.12	33.41
		max	33.89	33.99	33.88	33.58
		mean	33.71	33.54	33.50	33.53
		n	1329	7982	7994	1330
	Fall	min	33.19	33.06	33.18	33.34
		max	33.77	33.82	33.80	33.73
		mean	33.58	33.57	33.58	33.55
		n	2175	13,103	13,146	2172
2019	Winter	min	33.19	33.03	33.25	33.27
		max	33.70	33.66	33.79	33.67
		mean	33.53	33.46	33.60	33.57
		n	2030	12,620	12,444	2087
	Spring	min	—	32.39	33.15	33.36
		max	—	34.00	33.75	33.60
		mean	—	33.35	33.59	33.50
		n	id	12,739	12,839	2110
	Summer	min	—	32.43	33.00	33.16
		max	—	34.00	33.86	33.47
		mean	—	33.33	33.55	33.35
		n	id	11,129	8741	1080
	Fall	n	id	id	id	id



Appendix B.12

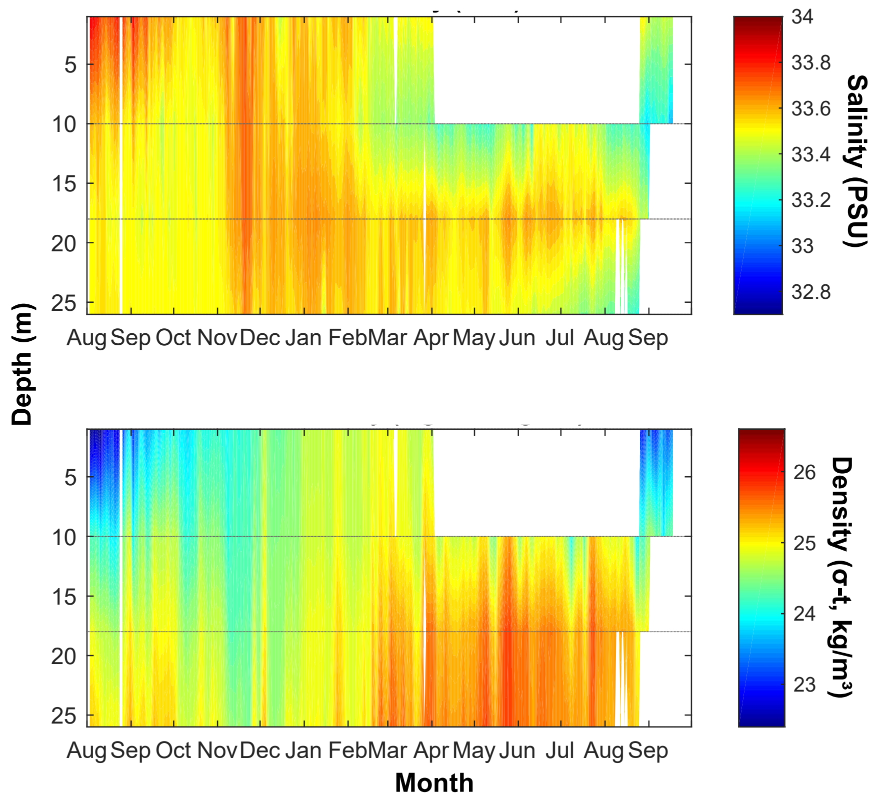
Salinity and density recorded by the PLOO RTOMS from March 2018 through March 2019. Data are daily averaged values. Horizontal gray lines indicate depths at which sensors were located. Missing data due to instrument failure or loss shown as white spaces.

At the PLOO in 2018, the strongest stratification (density gradients >0.1 kg/m^4) occurred from 1 m to 10 m intermittently for several weeks from spring through summer, and persisted daily in summer. Due to a gap between deployments of the PLOO RTOMS, salinity was not recorded for this same period in 2019, so stratification was not calculated between late March through early October 2019. Generally, the water column was minimally stratified to well mixed during late fall and winter periods. While reduced densities in deeper waters (>60 m) were closely associated with low salinities recorded in the SSML at PLOO (Appendix B.12), gradients in density in the upper water column, due to temperature, maintained a stratified water column during much of this time period, particularly in the summer and early fall.

At the SBOO, the strongest stratification (density gradients >0.1 kg/m^4) occurred from 1 to 10 m in the late summer of 2018 and 2019, and in the spring of 2017. Strong density gradients were also observed from 10 to 18 m in the summer of 2017. However, due to equipment failures at the surface and bottom depths, density throughout the water column was not recorded during this time period. In addition, due to gaps in data between deployments, density was not recorded for much of the summer of 2018 and 2019. Generally, the water column was minimally stratified in the fall and well mixed in the winter, particularly in December through February. While density was somewhat influenced by reduced salinities recorded during the spring at 10 m in 2019 (Appendix B.13), the impact on density appeared minimal compared to the influence of temperature (Appendix B.9).

Dissolved Oxygen and pH

Dissolved oxygen (DO) observed at the PLOO from 2018 through 2019 ranged from a minimum of 4.8 to a maximum of 10.4 mg/L in winter,



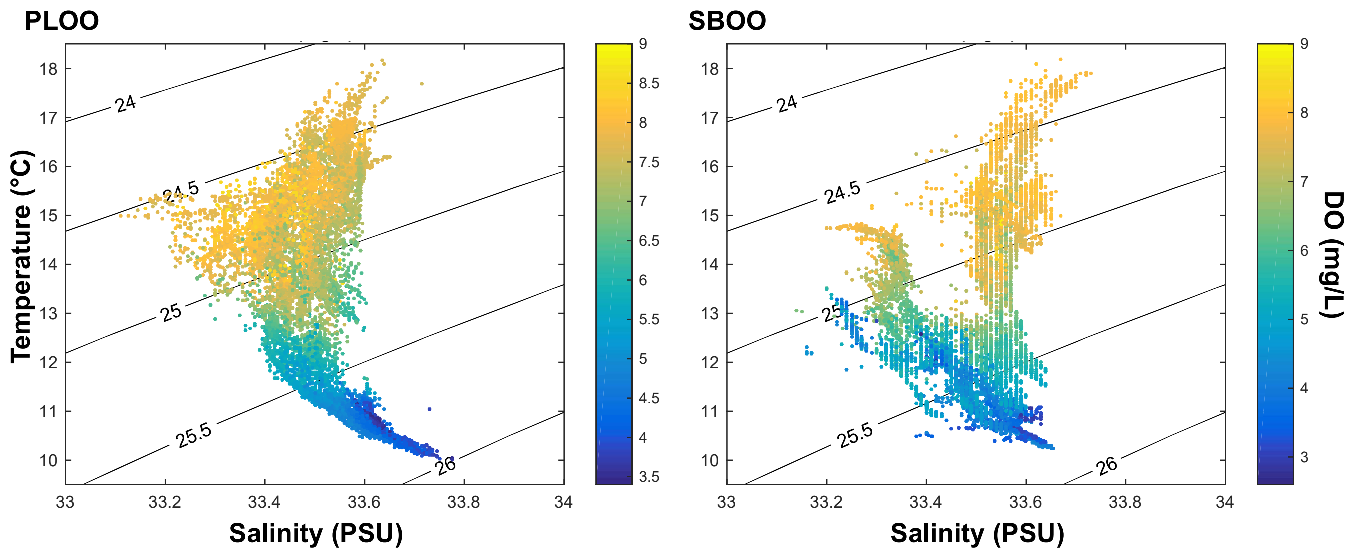
Appendix B.13

Salinity and density recorded by the SBOO RTOMS from August 2018 through September 2019. Data are daily averaged values. Horizontal gray lines indicate depths at which sensors were located. Missing data due to instrument failure or loss shown as white spaces.

3.4 to 11.2 mg/L in spring, 5.1 to 12.5 mg/L in summer, and 3.0 to 8.9 mg/L in fall, while total pH near the surface ranged from a minimum of 7.9 to a maximum of 8.1 in winter, 8.0 to 8.2 in spring, 7.9 to 8.4 in summer, and, across all depths, from 7.7 to 8.1 in fall (Addenda 9-7, 9-8). Due to instrument malfunctions during the first PLOO RTOMS deployment, DO data at bottom depths and pH data at mid and bottom depths are not available with the exception of fall 2019. As a result, the seasonal minimums reported here were higher than expected for the entire water column. At the SBOO, DO recorded from 2017 through 2019 ranged from a minimum of 4.5 to a maximum of 10.7 mg/L in winter, 2.8 to 13.3 mg/L in spring, 2.5 to 14.0 mg/L in summer, and 6.2 to 9.5 mg/L in fall, while total pH ranged from a minimum of 7.8 to a maximum of 8.3 in winter, 7.6 to 8.5 in spring, 7.6 to 8.4 in summer, and 7.7 to 8.2 in fall (Addenda 9-7, 9-8).

Changes in DO and pH were generally aligned and represent reliable indicators of biological activity in coastal waters (Skirrow 1975). Overall, these data align with typical seasonal patterns reported from quarterly surveys (see Chapter 2), but also show greater ranges since data are recorded at much more frequent intervals over longer periods of time, and can better capture short-term events. In addition, as discussed in the Materials and Methods section, pH is reported in total scale from moored instruments, while quarterly CTD surveys reported pH in NBS units. Generally, RTOMS data may have slightly lower pH ranges than those reported from quarterly CTD surveys, due to this difference in pH units.

At both outfalls, the highest seasonal mean DO (>8.9 mg/L) consistently occurred near the surface during the spring, while the single maximum DO and pH (14 mg/L and 8.5) were recorded near the surface at SBOO during the summer and spring



Appendix B.14

DO overlaid on temperature versus salinity at 30 m for PLOO RTOMS during 2018 and 2019, and 26 m for SBOO RTOMS from 2017 through 2019. Data are hourly averaged values. Isopycnals and σ-t values shown by black lines on plot.

of 2019, respectively (Addenda 9-7, 9-8). These conditions likely relate to regional phytoplankton blooms. Conversely, the lowest seasonal mean DO (<4.9 mg/L) was recorded in deeper waters during the spring at each mooring in 2017 and 2018, and during the summer at SBOO in 2019. At the PLOO, the lowest DO values (<4.0 mg/L) at mid depths were closely associated with the coldest and highest salinity water masses (Appendix B.14). Similarly, the lowest DO values at the bottom depth at the SBOO was generally recorded in cold, high salinity waters, although some low DO values were also observed at low salinities and moderate temperatures. These observations further support the role of upwelling in the spring as a significant driver of local conditions, by bringing cold, oxygen-poor, deep water masses inshore (Jackson 1986).

Chlorophyll a, CDOM, Turbidity

Chlorophyll *a* recorded at the PLOO from 2018 through 2019 ranged from a minimum of <0.1 to a maximum of 13 µg/L and <0.1 to >30 µg/L at the SBOO mooring from 2017 through 2019 (Addenda 9-7, 9-8). Generally, higher seasonal average chlorophyll *a* values occurred near the surface and mid depths during the spring, and at mid depths during the summer. Surface seasonal averages were lower during the summer than at mid depths, likely related to seasonal nutrient limitation. While these data show similar patterns reported from quarterly surveys (see Chapter 2), chlorophyll *a* levels reported from the moorings were generally lower. This could be attributed to a low maximum sensor threshold, such that higher chlorophyll values typical in the SBOO region are not captured (Appendix B.5). This sensor issue will be corrected for future deployments. In addition, accumulation of phytoplankton tends to be patchy both horizontally and vertically in the water column, so maximum chlorophyll concentrations may have occurred at depths or locations where no mooring sensors were present.

Colored dissolved organic matter (CDOM) at the PLOO in fall 2019 ranged from a minimum of 0.5 to a maximum of 2.5 ppb, and <0.1 to 24.5 ppb at the SBOO from 2018 through 2019 (Addenda 9-7, 9-8). Due to sensor malfunctions and calibration issues (Appendix B.5), CDOM data from the PLOO RTOMS were only available from deeper waters in the fall 2019, and from the SBOO RTOMS as of August 2018. Higher CDOM levels generally occurred at the surface at the SBOO during spring of 2019, and aligned with high chlorophyll *a* levels. The highest mean CDOM levels were recorded at the SBOO in mid and bottom waters during summer 2019.

Turbidity was a new parameter added to the PLOO RTOMS in fall of 2019, and to the SBOO RTOMS in summer of 2018, so limited data were available for this reporting period. Turbidity ranged from a minimum of <0.1 to a maximum of 3 NTU at the PLOO, and <0.1 to >9 NTU at the SBOO, where 9 NTU was the maximum sensor threshold (Addenda 9-7, 9-8). Generally, high turbidity was associated with high chlorophyll *a* at surface and mid depths in the spring and summer, and with high CDOM at bottom depths in the summer and fall. High turbidity may also be related to resuspension of bottom sediments, which may be caused by underwater currents, waves, or storms (Farnsworth and Warrick 2007).

Nitrate plus nitrite and BOD

Nitrate plus nitrite (nitrate) recorded in deep waters at the PLOO in fall 2019 ranged from a minimum of 8 to a maximum of 29 μM, and <2 to 32 μM at the SBOO, across all depths, between 2017 and 2019 (Addenda 9-7, 9-8). Due to sensor failures, nitrate data were not available for other time periods or depths at the PLOO mooring, and are not representative of annual conditions (Appendix B.5). At the SBOO, the highest nitrate levels generally occurred during the winter and spring, and the lowest levels were recorded during the summer and early fall. Persistent low nitrate concentrations (<2 μM) were recorded near the surface from August through early November during 2018, likely due to uptake from phytoplankton and stratified conditions. Generally, higher nitrate concentrations (>20 μM) occurred in deeper waters, and showed somewhat similar ranges to that of the nearshore mid-water column reported by the California Cooperative Oceanic Fisheries Investigations surveys (SIO 2019).

Biological Oxygen Demand equivalent (BOD) recorded at the PLOO from 2018 through 2019 ranged from a minimum of <0.1 to a maximum of 10 mg/L, and <0.1 to 8 mg/L at the SBOO from 2017 through 2019 (Addenda 9-7, 9-8). Seasonal mean values ranged from 0.1 to 0.15 mg/L at the PLOO at 30 m, and from <0.1 to 0.22 mg/L at the SBOO at 26 m. Given the new instrumentation and methodology, historical and validation data in receiving waters were not available for comparison, and BOD will be evaluated further in future reports.

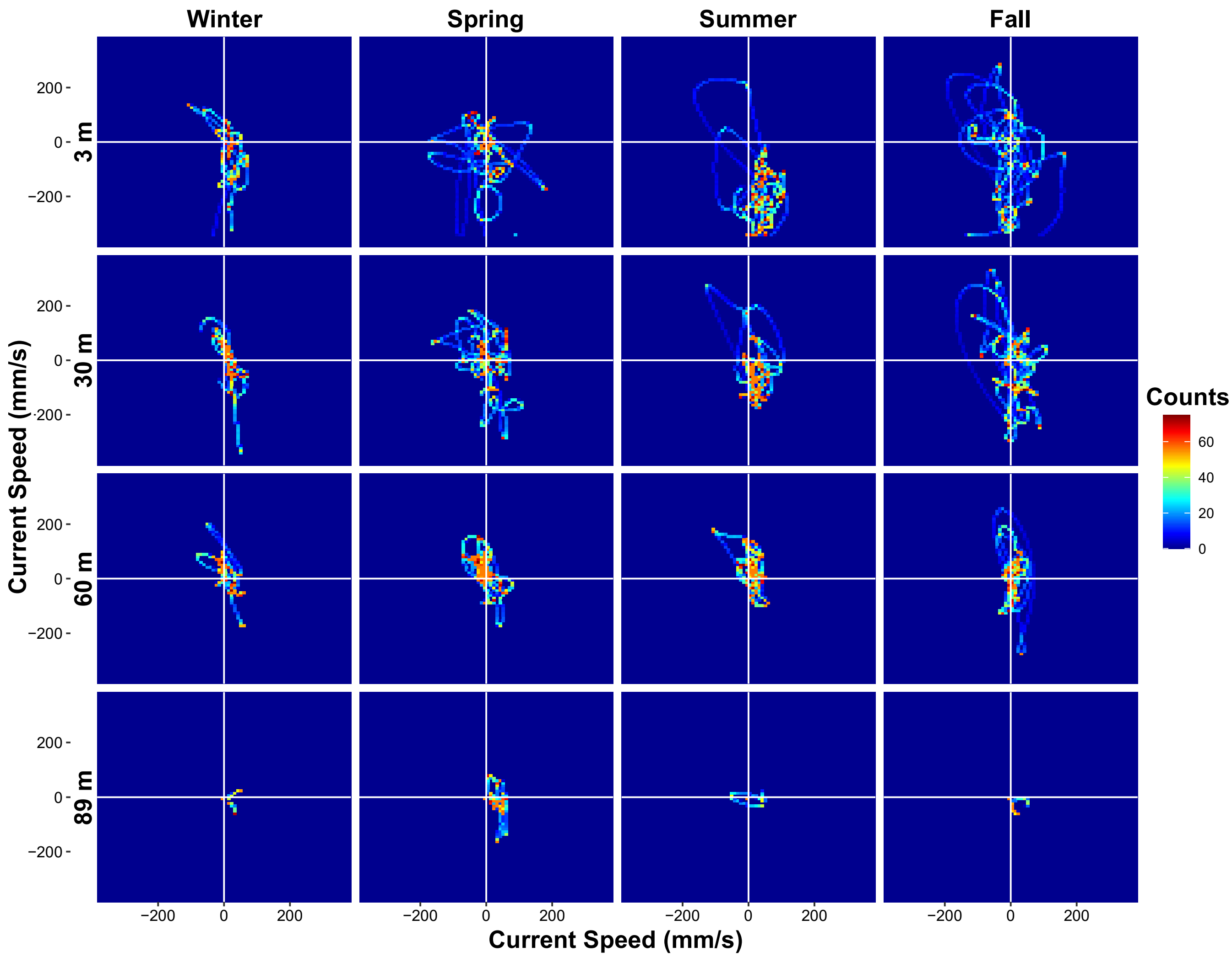
xCO2

Surface seawater carbon dioxide concentrations recorded at the PLOO from 2018 through 2019 ranged from a minimum of 210 to a maximum of 491 ppm, and 252 to 500 ppm at the SBOO from 2017 through 2019 (Addenda 9-7, 9-8). The lowest seasonal mean levels were observed during the spring of 2018 and 2019 at the PLOO and SBOO moorings, respectively (334 and 347 ppm); the highest mean (429 ppm) was observed in summer 2017 at the SBOO mooring. Generally, the largest short-term variability (>100 ppm change between days) was observed during the spring and summer at both moorings, while fall and winter generally show more stable daily values. These observations show similar seasonal variability and ranges to the closest nearshore SIO carbon mooring (California Current Ecosystem mooring 2), where biological productivity and surface water temperatures drive the large seasonal amplitudes in pCO_2 (Sutton et al. 2019).

Summary of Ocean Currents in 2017–2019

Direction and Velocity of Subsurface Currents

Ocean currents surrounding the PLOO and SBOO varied by depth and season during the 2017–2019 reporting period. Seasonal mean current velocities (by 1-m depth bin) at the PLOO RTOMS, from March 2018 through March 2019, ranged from a minimum of 30 to a maximum of 122 mm/s during winter, 53 to 163 mm/s during spring, 28 to 227 mm/s during summer, and 29 to 189 mm/s during fall (Addendum 9-10). Seasonal mean current velocities (by 1-m depth bin) at the SBOO RTOMS, from 2017 through 2019, ranged from a minimum of 54 to a maximum of 102 mm/s during winter, 41 to 107 mm/s during spring, 39 to 134 mm/s during summer, and 48 to 91 mm/s (Addendum 9-11). The highest seasonal mean current velocities typically occurred in surface waters during the spring at the PLOO, while the highest velocities were typically observed in surface waters at the SBOO during the summer. Generally, for all seasons, the highest mean current velocities occurred in the upper 10 m at the PLOO and the upper 6 m at the SBOO. These velocities decreased with depth around both outfalls, with the lowest mean velocities roughly 15 m from



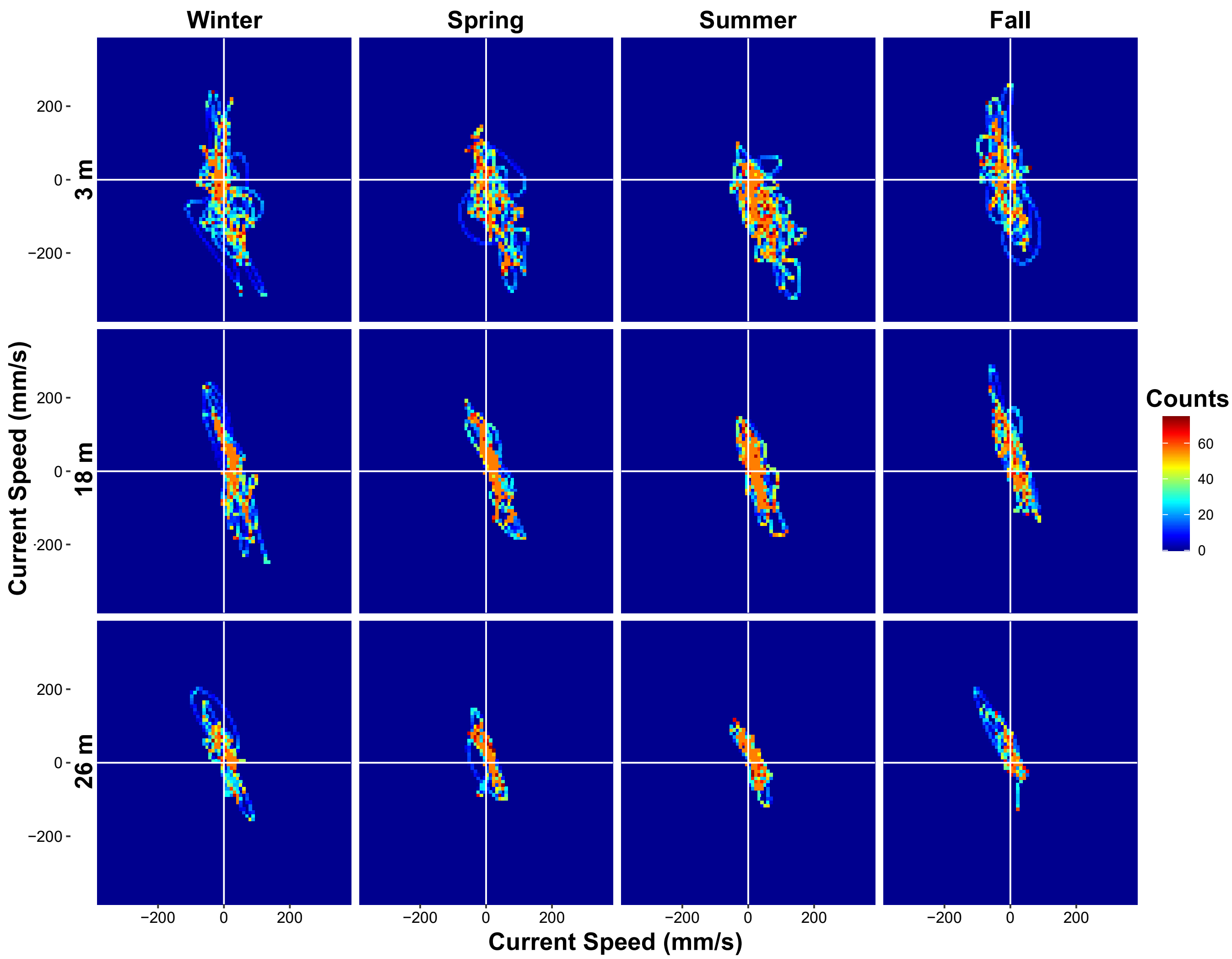
Appendix B.15

Frequency distribution by season of low-pass filtered (tides removed) current speed (mm/s) and direction from the PLOO RTOMS deployment from March 2018 through March 2019. On the x-axis, positive values indicate an eastward direction and negative values indicate westward. On the y-axis, positive values indicate a northward direction and negative values indicate southward.

the bottom at the PLOO and 5 m from the bottom at the SBOO. In regards to current direction, predominant flow followed a north-northwest/south-southeast axis of variation, regardless of season or outfall location (Appendices B.15, B.16). Additionally, linear regression of all current direction observations for each depth generally show that along-coast currents tend to dominate (Appendix B.17). These results are consistent with observations from the nearby bottom-mounted static ADCPs at both locations (Addenda 9-11 through 9-14), and previous studies conducted in the region (Winant and Bratkovich 1981, Rogowski et al. 2012a).

Summary

This report documents the initial findings of the PLOO and SBOO RTOMS deployments from 2017 through 2019, and demonstrates the capability of these mooring systems to observe variability across multiple time scales (days, seasons, years) and identify relationships across water quality indicators and water conditions. While temperature, salinity, DO, and pH showed typical seasonal patterns to those reported in quarterly surveys (see Chapter 2), the moorings captured greater variability and more extreme events due to a higher frequency



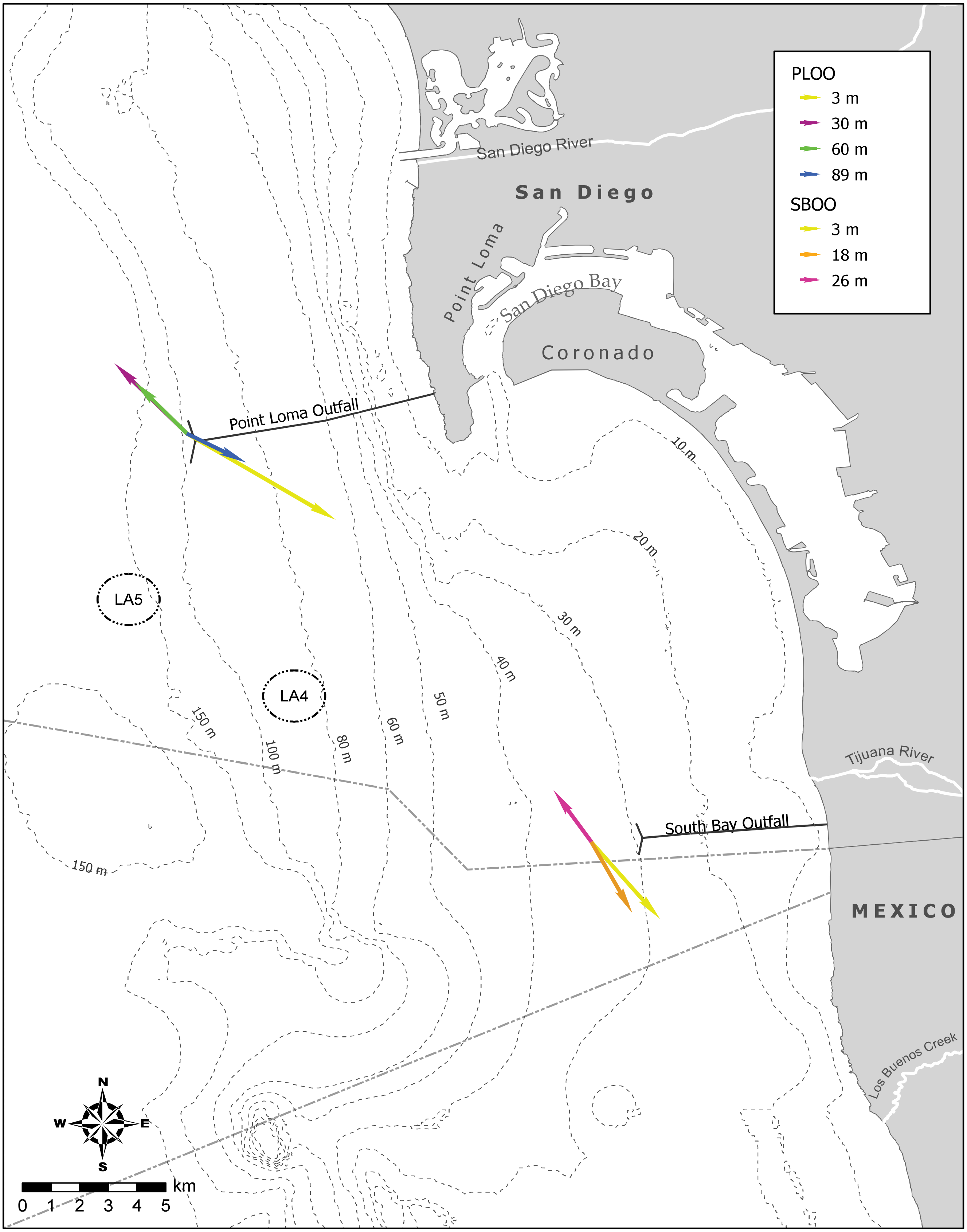
Appendix B.16

Frequency distribution by season of low-pass filtered (tides removed) current speed (mm/s) and direction from the SBOO RTOMS from 2017 through 2019. On the x-axis, positive values indicate an eastward direction and negative values indicate westward. On the y-axis, positive values indicate a northward direction and negative values indicate southward.

of sampling. As a result, the timing of upwelling events, for example, may be more effectively evaluated by the low DO levels recorded by the moorings, as they were more closely associated with the coldest and highest salinity water masses.

The RTOMS also provided access to a range of biogeochemical parameters, which have not previously been reported by the City, such as nitrate plus nitrite, total pH, xCO_2, BOD, and turbidity. As new methods are developed, and data quality improves, the addition of these parameters will greatly improve the characterization of ocean acidification conditions (i.e., total pH and xCO_2), as well as enhance the City's capabilities for potential plume detection in the region (i.e., nitrate plus nitrite, BOD, turbidity). Taken together with other variables like CDOM, ocean currents, and stratification these data will contribute to a greater understanding of conditions associated with the detection of wastewater plumes.

In future reports, as data quality and collection capabilities improve, additional objectives will include: (1) a detailed and thorough evaluation of the frequency of potential plume detections; (2) estimation of the location of wastewater plumes associated with the PLOO and SBOO, with the inclusion of data from the Adaptive Plume Tracking Pilot Study (i.e., ScanFish ROTV); (3) the



Appendix B.17

General current speed and direction as determined by linear regression of all velocities for select depth bins at PLOO and SBOO RTOMS locations. Length of arrow reflects relative current speed.

production of high-resolution maps of plume location and movement through the PLOO and SBOO regions. In addition, SIO is also responsible for networking the PLOO and SBOO real-time moorings with the existing SIO Del Mar mooring to form a comprehensive state-of-the-art ocean observing system for the San Diego region. Such a system will provide valuable information regarding regional oceanographic conditions and the dynamics of emerging issues, such as ocean acidification, hypoxia, nutrient inputs, and algal blooms, as well as helping to predict plume behavior and movement. With the addition of these objectives, we hope to better understand and evaluate the effects of local coastal conditions on wastewater plume dispersion within the San Diego region.

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Appendix C

Sediment Toxicity for the

San Diego Ocean Outfall Monitoring Regions

2016–2019

Appendix C. Sediment Toxicity for the San Diego Ocean Outfall Monitoring Regions, 2016–2019

Introduction

The City of San Diego (City) began marine sediment toxicity testing in 2016 with a focus on the Point Loma Ocean Outfall (PLOO) and South Bay Ocean Outfall (SBOO) monitoring regions. This monitoring requirement was added as a result of recommendations from the City's Sediment Toxicity Monitoring Plan (STMP) (City of San Diego 2015) and associated permits. The STMP was a three year pilot study aimed at assessing sediment toxicity within the PLOO and SBOO monitoring regions. In conjunction with the US International Boundary and Water Commission (USIBWC), San Diego Regional Water Quality Control Board (SDRWQCB), US Environmental Protection Agency (USEPA), and the Southern California Coastal Water Research Project (SCCWRP), the City identified the following questions to be addressed by the STMP: (1) what is the extent and magnitude of sediment toxicity in offshore marine sediments in the Point Loma and South Bay outfall monitoring regions; (2) how does the extent and magnitude of sediment toxicity off San Diego compare among different continental shelf strata (e.g., inner, mid, and outer shelf); (3) how does the extent and magnitude of sediment toxicity off San Diego compare to results from the Southern California Bight regional monitoring surveys.

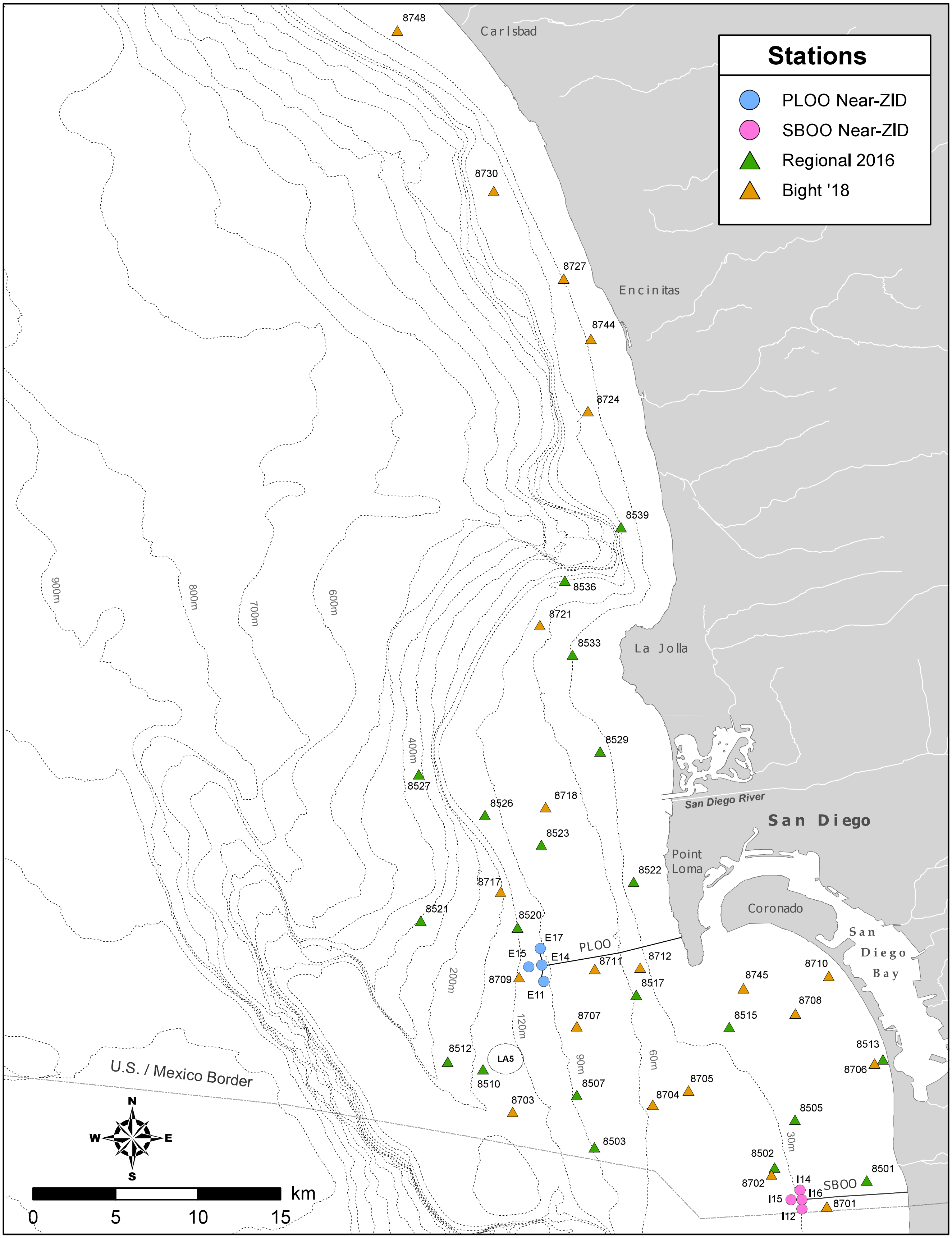
During the three-year STMP pilot study, no sediment toxicity was observed at any offshore monitoring sites in the San Diego region. Despite this, the City, in consultation with the aforementioned agencies, recommended continuation of annual sediment toxicity testing of the PLOO and SBOO regions. Continued testing in the PLOO region was recommended to facilitate monitoring of any potential changes in PLOO discharge flows related to implementation of the City's Pure Water program. Similarly, continued testing in the SBOO region was recommended to monitor possible effects of changes in SBOO discharge flows as a result of changes to treatment processes or transboundary flows. Based on these considerations, a sampling design was approved, by all parties involved, for surveys to be conducted during the summers of 2019–2023, which would include annual testing of a reduced number of samples alternating between permanent fixed monitoring sites and randomly selected sites as follows: (1) Year 1 (summer 2019): retest the eight near-ZID PLOO and SBOO benthic stations that are monitored twice each year for sediment chemistry and benthic infauna (i.e., PLOO stations E11, E14, E15, E17; SBOO stations I12, I14, I15, I16); (2) Year 2 (summer 2020): test subset of 8 of the 40 randomized stations that will be selected for study by the combined PLOO and SBOO monitoring programs. These stations may be targeted for specific areas of interest in consultation between the City, USIBWC, SDRWQCB, USEPA, and SCCWRP; (3) Year 3 (summer 2021): repeat Year 1 sample design; (4) Year 4 (summer 2022): repeat Year 2 sample design; (5) Year 5 (summer 2023): test up to 20 randomly selected sites to be selected as part of the Bight'23 regional monitoring program. The final number of samples will be determined as part of the Bight'23 regulatory relief approval process.

This appendix summarizes the results and conclusions of all sediment toxicity testing conducted for the San Diego ocean outfall areas during the summers of 2016, 2017, and 2018 as previously documented in the pilot study final project report (City of San Diego 2019), as well as additional sampling that occurred during the summer of 2019.

Materials and Methods

Collection and Processing of Samples

A total of 73 sediment samples from 49 stations were tested during the summers of 2016, 2017, 2018, and 2019 (Appendix C.1). These included 32 samples collected in 2016–2019, from the eight near-ZID stations located within 1000 m of



Appendix C.1
Distribution of benthic stations selected for sediment toxicity testing off San Diego from 2016 to 2019.

the PLOO (E11, E14, E17, E15) and the SBOO (I12, I14, I15, I16). Forty-one randomly selected regional stations were also tested, including half of the 40 random stations designated for the regular 2016 regional survey off San Diego, and 21 stations selected from the Bight'18 regional program station draw. Samples were collected using a double 0.1-m^2 Van Veen grab, with one grab per cast used for sediment quality analysis (see Chapters 4, 6), one grab per cast used for benthic community analysis (see Chapters 5, 6), and all subsequent grabs used for sediment toxicity testing. A plastic (high-density polyethylene [HDPE], polycarbonate, or Teflon®) or stainless-steel scoop was used to collect sediment from the top 2 cm of the undisturbed surface material in the grab. Contact with sediment within 1 cm of the sides of the grab was avoided in order to minimize cross-contamination. In most cases, multiple grabs were required to obtain enough sediment for toxicity testing (i.e., up to 6 L sediment). If more than one grab was required, sediment from each grab was added to a Teflon® bag and homogenized thoroughly using either a clean Teflon® or plastic spoon, or by kneading the sample within the bag. Once collected, the samples were stored in the dark at 4°C in the laboratory for no longer than four weeks prior to testing.

Toxicity Testing

All sediment toxicity testing was conducted on marine sediments using the marine amphipod *Eohaustorius estuarius*. These tests were conducted by either Nautilus Environmental (Nautilus) for the 2016 and 2017 surveys, or the City of San Diego Toxicology Laboratory (CSDTL) for the 2018 and 2019 surveys. Both laboratories are certified by the California State Water Resources Control Board (CSWRCB) Environmental Laboratory Accreditation Program (Nautilus = ELAP Certificate No. 1802; CSDTL = ELAP Certificate No. 1989) and follow similar, comparable procedures for sediment bioassays. Specific details for the methods and analyses conducted by the CSDTL in 2018 and 2019 are described below and in City of San Diego (2017). Additional information for the 2016–2017 surveys are available in Nautilus Environmental (2016, 2017).

Amphipod Bioassays

The 10-day amphipod sediment toxicity tests were conducted by the CSDTL in accordance with EPA 600/R-94/0925 (USEPA 1994) and the procedures approved for Southern California Bight 2018 Regional Monitoring Program (Bight'18 Toxicology Committee 2018). Juvenile *E. estuarius*, were exposed for 10 days to both test and control sediments. Response criteria included amphipod mortality, emergence from sediment during exposure, and if considered a measurement of interest, ability of amphipods to rebury in clean sediment at the end of the bioassay. In addition, a reference toxicant test (using seawater only) was conducted concurrently and under identical environmental conditions as the sediment toxicity tests to determine test organism sensitivity.

Preparation of Test Organisms

Juvenile amphipods between 3–5 mm in length were purchased from Northwestern Aquatic Sciences (Newport, OR). These amphipods were collected from uncontaminated sites with large endemic populations and shipped overnight to the CSDTL. The organisms were shipped within control sediment that were collected from the same reference sites and sieved through a 500-micron screen. Upon receipt, temperature and salinity of the shipping sediment were measured and recorded. The condition of the test animals was observed for mortality, and only amphipods deemed healthy and acceptable were used for testing. The test amphipods were then transferred from within their holding containers into larger aquaria and held at 15 ± 1°C. The amphipods were left undisturbed in the home sediment and submerged within an overlying layer of filtered seawater (see Dilution Water below). All test animals were acclimated for between 2 and 10 days prior to test initiation.

Dilution Water

Dilution water for the sediment and reference toxicant tests consisted of natural seawater obtained from the Scripps Institution of Oceanography (La Jolla, CA). Dilution water was collected within 96 hours of first use, and transported to the CSDTL. The seawater was first filtered with an in-line system containing 1.0-µm and 0.2-µm polypropylene filters, then collected and held in 20-L carboys at 15 ± 10°C.

Test chambers

The test chambers consisted of standard 1-L glass jars, with five test replicates per sediment sample plus a sixth replicate used for pore water extraction and water quality measurements. On the day before test initiation, 175 mL of pre-sieved (i.e., through a 1.0 mm mesh screen) test sediment was added to the bottom of each replicate jar to create a 2-cm deep layer, after which the jar was filled with seawater, covered, and placed in a 15°C temperature controlled room. Water in the test containers was gently aerated to promote constant circulation without disturbing the sediment surface. On the following day (Day 0), amphipods were sieved from the holding sediment through a 0.5 mm mesh screen and transferred with large bore plastic pipettes to transfer dishes containing approximately 50 mL of seawater. This process continued until each container contained either 20 amphipods for the sediment tests or 10 amphipods for the reference toxicant test.

Sediment toxicity tests

For the acute sediment toxicity tests, juvenile amphipods were distributed into the test chambers in a randomized manner with minimal disturbance to the test sediment. The amphipods were initially given 5 to 10 minutes to bury into the test sediments. Injured or stressed animals that remained emerged (not buried) were removed and replaced with healthy amphipods from the same sieved population.

A photoperiod of 16h light:8h dark was used for the amphipod testing. Light intensity was maintained between 50–100 ft-candles in all areas of the environmental chamber throughout the test period. The number of emergent (swimming) and surface-trapped amphipods were counted and recorded daily. Any amphipods trapped at the air-water interface were gently pushed down into the water with a wide-bore plastic pipette. The test was terminated after 10 days of exposure.

At completion of the 10-day test period, sediments were sieved through a 0.5 mm screen, and the number of live, dead, or missing amphipods recorded. Missing animals were assumed to have died and decomposed during the 10-day test; these missing animals were subsequently counted as dead when calculating percent survival for each replicate. A dead amphipod was considered any individual that did not exhibit any evidence of movement (e.g., neuromuscular twitch of pleopods or antennae) upon gentle prodding with a probe.

Reference toxicant tests

Reference toxicant tests were conducted in glass containers under constant darkness. Test concentrations for these tests were 0, 15.6, 31.2, 62.5, 125, and 250 mg/L total ammonia. Four 800-mL replicates of each concentration were tested for 96 hours at 15±2°C. The reference toxicant test was terminated after 96 hours of exposure, unless the un-ionized pore water ammonia concentration in any of the sediment samples was ≥0.8 mg/L; in this case, the ammonia reference toxicant test was extended from 4 days to 10 days for better comparison to the 10-day test sample results.

Data analysis procedures

All data were analyzed in accordance with procedures outlined in Sections 12 and 13 of EPA 600/R-94/0925 using the acceptability criterion of ≥90% mean control survival at test termination. Additional information, and the standard operating procedures, for sediment toxicity testing are provided in Appendix B of the CSDTL's Quality Assurance Manual (City of San Diego 2017).

Results & Conclusion

Toxicity testing using the amphipod *Eohaustorius estuarius* was successfully completed for 73 marine sediment samples collected from 49 stations within the PLOO and SBOO monitoring regions during the summers of 2016, 2017, 2018, and 2019 (see Appendix C.1). These sites represented a diverse array of offshore soft-bottom benthic habitats, ranging in depth from 5 to 350 m, that had coarse to fine sediments of 1–80% fine silts and clays combined (see Appendix C.2). These included: (1) 28 inner shelf samples collected from depths of 5–28 m where sediments were relatively coarse, averaging about 12% fines; (2) 35 mid-shelf samples collected from depths of 30–116 m where sediments were typically finer with an average of about 38% fines; (3) six outer shelf samples collected from depths of 130–195 m that averaged even finer sediments of about 50% fines; (4) three upper slope samples collected at depths of 240–350 m that had the finest sediments averaging about 72% fines.

Test results for each lab control and individual station sample are shown in Appendix C.2, while the average amphipod survival for the laboratory controls, near-ZID (outfall) sites, and randomly selected (regional) sites, are summarized for each year in Appendix C.3. Mean survival of *E. estuarius* in the laboratory controls was 99–100% in 2016, 97% in 2017, 96–100% in 2018, and 99% in 2019, all of which satisfied the required protocol of 90% survival for this species. Mean amphipod survival among all sample sites tested ranged from 96 to 100% in 2016 and 2017, from 92 to 100% in 2018, and from 96 to 100% in 2019.

No evidence of sediment toxicity was observed at any offshore station tested in the San Diego region during the past four years, regardless of depth, sediment type, or proximity to either outfall. These results are consistent with findings from previous regional monitoring programs that have demonstrated minimal sediment toxicity on the southern California continental shelf in contrast to offshore submarine canyons or local embayments (e.g., Bay et al. 2015, Parks et al 2020).

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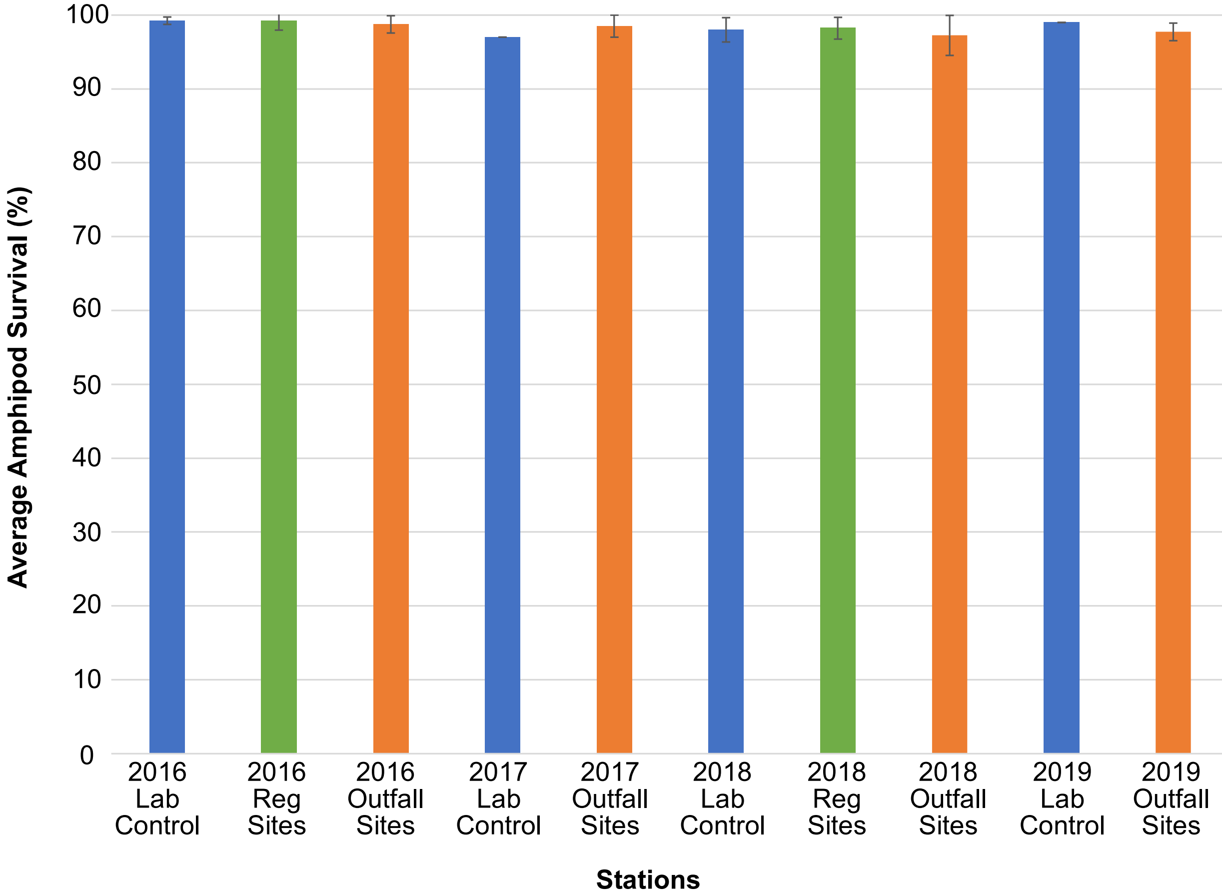
Appendix C.2

Bioassay results (10-day amphipod survival tests) for sediment toxicity testing conducted for benthic stations sampled off San Diego from 2016 through 2019. Percent fines = percentage of silt + clay combined. Test results are expressed as mean percent survival ±1 standard deviation.

Survey	Site/Sample	Depth Stratum	Station Depth (m)	Percent Fines	Sample Date	Test Initiation	% Survival (Mean ± SD)
Summer 2016	Lab Control	—	—	—	—	7/15/16	99 ±2.2
	I12	Inner Shelf	28	9%	7/7/16	7/15/16	100
	I14	Inner Shelf	28	18%	7/7/16	7/15/16	99 ±2.2
	I15	Inner Shelf	28	3%	7/7/16	7/15/16	98 ±2.7
	I16	Inner Shelf	28	6%	7/7/16	7/15/16	100
	8501	Inner Shelf	17	22%	7/7/16	7/15/16	100
	8503	Middle Shelf	92	34%	7/7/16	7/15/16	100
	8507	Middle Shelf	91	38%	7/7/16	7/15/16	99 ±2.2
	Lab Control	—	—	—	—	7/15/16	100
	E11	Middle Shelf	98	35%	7/11/16	7/15/16	98 ±2.7
	E14	Middle Shelf	98	27%	7/11/16	7/15/16	98 ±4.5
	E15	Middle Shelf	116	40%	7/11/16	7/15/16	97 ±4.5
	8502	Middle Shelf	35	28%	7/12/16	7/15/16	99 ±2.2
	8505	Inner Shelf	26	17%	7/12/16	7/15/16	100
	8513	Inner Shelf	5	2%	7/12/16	7/15/16	100
	8515	Inner Shelf	20	3%	7/12/16	7/15/16	98 ±2.7
	Lab Control	—	—	—	—	7/29/16	99 ±2.2
	8520	Outer Shelf	138	47%	7/19/16	7/29/16	99 ±2.2
	8522	Inner Shelf	22	2%	7/19/16	7/29/16	96 ±4.2
	8523	Middle Shelf	81	59%	7/19/16	7/29/16	96 ±4.2
	8526	Middle Shelf	101	50%	7/19/16	7/29/16	100
	8529	Middle Shelf	45	28%	7/19/16	7/29/16	100
	8533	Middle Shelf	36	2%	7/19/16	7/29/16	100
	8536	Outer Shelf	135	32%	7/20/16	7/29/16	99 ±2.2
	8539	Middle Shelf	112	38%	7/20/16	7/29/16	99 ±2.2
	Lab Control	—	—	—	—	8/5/16	99 ±2.2
	E17	Middle Shelf	98	34%	7/27/16	8/5/16	100
	8510	Outer Shelf	195	68%	7/27/16	8/5/16	98 ±2.7
	8512	Upper Slope	240	76%	7/27/16	8/5/16	100
	8517	Middle Shelf	57	34%	7/28/16	8/5/16	100
	8521	Upper Slope	340	80%	7/27/16	8/5/16	99 ±2.2
	8527	Upper Slope	350	61%	7/27/16	8/5/16	100
Summer 2017	Lab Control	—	—	—	—	7/21/17	97 ±2.7
	I12	Inner Shelf	28	3%	7/10/17	7/21/17	96 ±4.2
	I14	Inner Shelf	28	17%	7/10/17	7/21/17	98 ±4.5
	I15	Inner Shelf	28	2%	7/10/17	7/21/17	100
	I16	Inner Shelf	28	1%	7/10/17	7/21/17	100
	E11	Middle Shelf	98	33%	7/11/17	7/21/17	99 ±2.2
	E14	Middle Shelf	98	21%	7/11/17	7/21/17	100
	E15	Middle Shelf	116	30%	7/11/17	7/21/17	97 ±2.7
	E17	Middle Shelf	98	34%	7/11/17	7/21/17	98 ±2.7

Appendix C.2 *Continued.*

Survey	Site/Sample	Depth Stratum	Station Depth (m)	Percent Fines	Sample Date	Test Initiation	% Survival (Mean ± SD)
Summer 2018	Lab Control	—	—	—	—	7/13/2018	98 ±2.7
	8701	Inner Shelf	23	10%	7/11/18	7/13/2018	98 ±2.7
	8702	Middle Shelf	34	27%	7/11/18	7/13/2018	99 ±2.2
	8704	Middle Shelf	57	20%	7/11/18	7/13/2018	98 ±2.7
	8710	Inner Shelf	11	21%	7/11/18	7/13/2018	100
	8724	Middle Shelf	50	40%	7/10/18	7/13/2018	97 ±6.7
	8727	Inner-Mid Shelf	30	11%	7/10/18	7/13/2018	97 ±2.7
	8730	Middle Shelf	74	61%	7/10/18	7/13/2018	98 ±2.7
	Lab Control	—	—	—	—	7/20/2018	98 ±2.7
	8703	Outer Shelf	182	53%	7/11/18	7/20/2018	99 ±2.2
	8706	Inner Shelf	13	48%	7/11/18	7/20/2018	97 ±4.5
	8711	Middle Shelf	77	57%	7/11/18	7/20/2018	99 ±2.2
	8712	Middle Shelf	49	37%	7/11/18	7/20/2018	100
	8717	Outer Shelf	185	61%	7/12/18	7/20/2018	99 ±2.2
	8718	Middle Shelf	76	63%	7/12/18	7/20/2018	98 ±2.7
	8721	Middle Shelf	70	41%	7/12/18	7/20/2018	100
	Lab Control	—	—	—	—	7/31/2018	100
	I12	Inner Shelf	28	1%	7/24/18	7/31/2018	99 ±2.2
	I14	Inner Shelf	28	20%	7/24/18	7/31/2018	99 ±2.2
	I15	Inner Shelf	28	3%	7/24/18	7/31/2018	98 ±2.7
	I16	Inner Shelf	28	5%	7/24/18	7/31/2018	99 ±2.2
	8708	Inner Shelf	20	20%	7/24/18	7/31/2018	97 ±2.7
	8744	Inner Shelf	27	9%	7/26/18	7/31/2018	99 ±2.2
	8748	Inner Shelf	24	24%	7/26/18	7/31/2018	99 ±2.2
	Lab Control	—	—	—	—	8/7/2018	96 ±4.2
	E11	Middle Shelf	98	31%	7/31/18	8/7/2018	99 ±2.2
	E14	Middle Shelf	98	24%	7/31/18	8/7/2018	94 ±8.2
	E15	Middle Shelf	116	29%	7/31/18	8/7/2018	98 ±2.7
	E17	Middle Shelf	98	36%	7/31/18	8/7/2018	92 ±5.7
	8705	Middle Shelf	47	19%	7/31/18	8/7/2018	95 ±3.5
	8707	Middle Shelf	87	51%	7/31/18	8/7/2018	95 ±6.1
	8709	Outer Shelf	130	39%	7/31/18	8/7/2018	99 ±2.2
	8745	Inner Shelf	13	2%	7/31/18	8/7/2018	100
Summer 2019	Lab Control	—	—	—	—	7/20/19	99 ±2.2
	I12	Inner Shelf	28	5%	7/22/19	7/20/19	98 ±4.5
	I14	Inner Shelf	28	34%	7/22/19	7/20/19	98 ±2.7
	I15	Inner Shelf	28	12%	7/22/19	7/20/19	98 ±2.7
	I16	Inner Shelf	28	16%	7/22/19	7/20/19	98 ±4.5
	E11	Middle Shelf	98	59%	7/22/19	7/20/19	97 ±6.5
	E14	Middle Shelf	98	56%	7/22/19	7/20/19	100
	E15	Middle Shelf	116	56%	7/22/19	7/20/19	97 ±4.5
	E17	Middle Shelf	98	47%	7/22/19	7/20/19	96 ±2.2



Appendix C.3

Sediment toxicity testing results for benthic stations sampled off San Diego from 2016 through 2019. Data are mean percent amphipod survival ± 1 standard deviation.[a] Reg Sites = San Diego regional stations (2016) or Bight'18 regional stations (2018); Outfall Sites = Near-ZID sites combined for the PLOO and SBOO.

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[a]These differ from the error bars included the final project report (City of San Diego 2019), which were standard error instead of standard deviation

Appendix D

Coastal Oceanographic Conditions

2018 – 2019 Supplemental Analyses

Appendix D.1

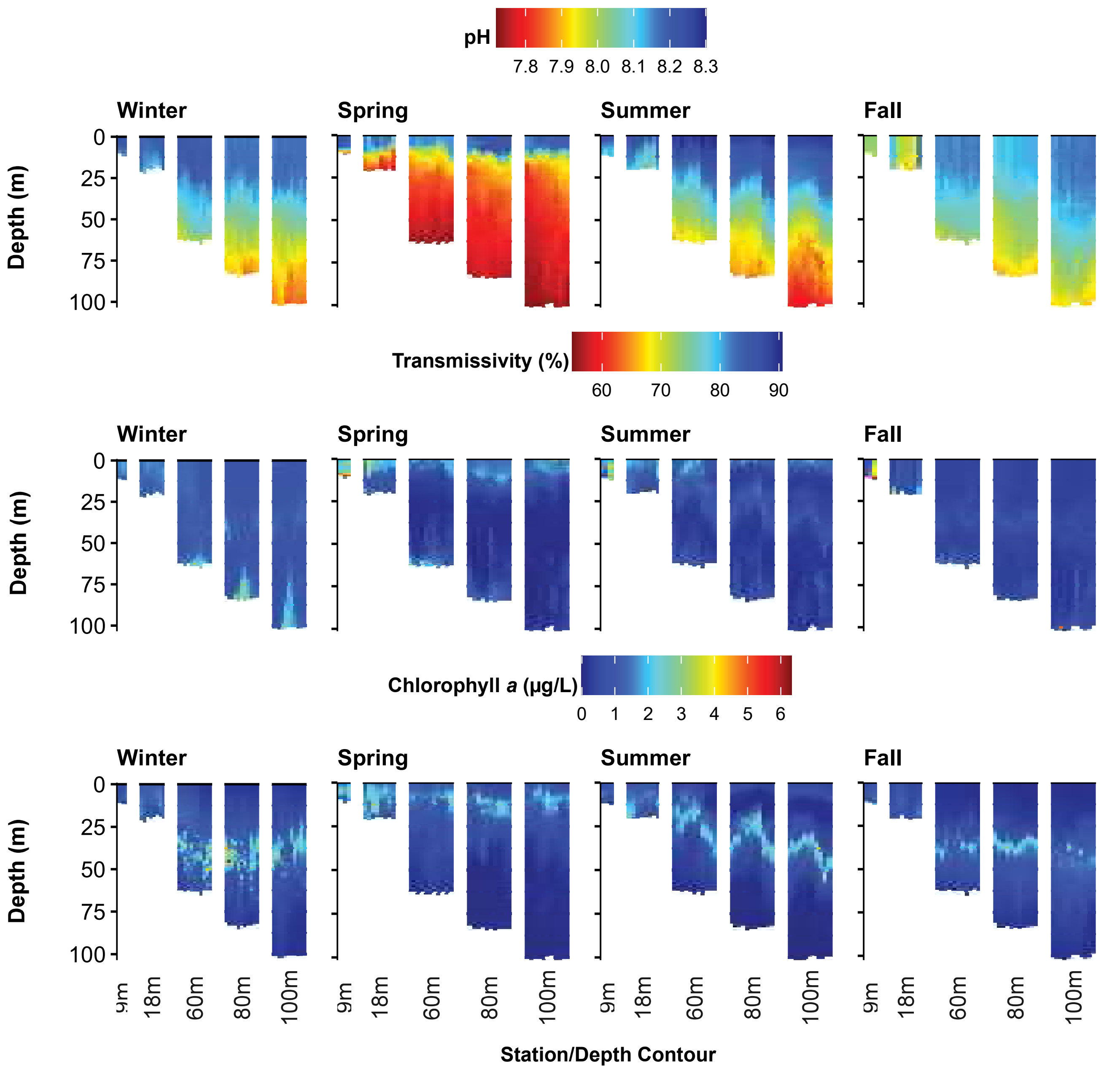
Sample dates for quarterly oceanographic surveys conducted during 2018 and 2019. All stations in each station group were sampled on a single day (see Figure 2.1 for stations and locations).

	Sampling Dates in 2018				Sampling Dates in 2019			
	Winter	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**
PLOO Station Group								
Kelp WQ	Feb-16	Apr-30	Aug-27	Nov-14	Mar-4	May-6	Aug-5	Nov-4
18 & 60-m WQ	Feb-13	May-1	Aug-28	Nov-16	Mar-6	May-8	Aug-8	Nov-6
80-m WQ	Feb-14	May-3	Aug-29	Nov-15	Mar-7	May-9	Aug-9	Nov-7
98-m WQ	Feb-15	May-2	Aug-30	Nov-17	Mar-5	May-7	Aug-7	Nov-5
SBOO Station Group								
Kelp WQ	Feb-5	May-14	Aug-20	Nov-5	Feb-11	May-13	Aug-15	Nov-12
North WQ	Feb-8	May-18	Aug-23	Nov-8	Feb-15	May-15	Aug-14	Nov-15
Mid WQ	Feb-7	May-17	Aug-22	Nov-7	Feb-13	May-16	Aug-13	Nov-14
South WQ	Feb-6	May-15	Aug-21	Nov-6	Feb-12	May-14	Aug-12	Nov-13

Appendix D.2

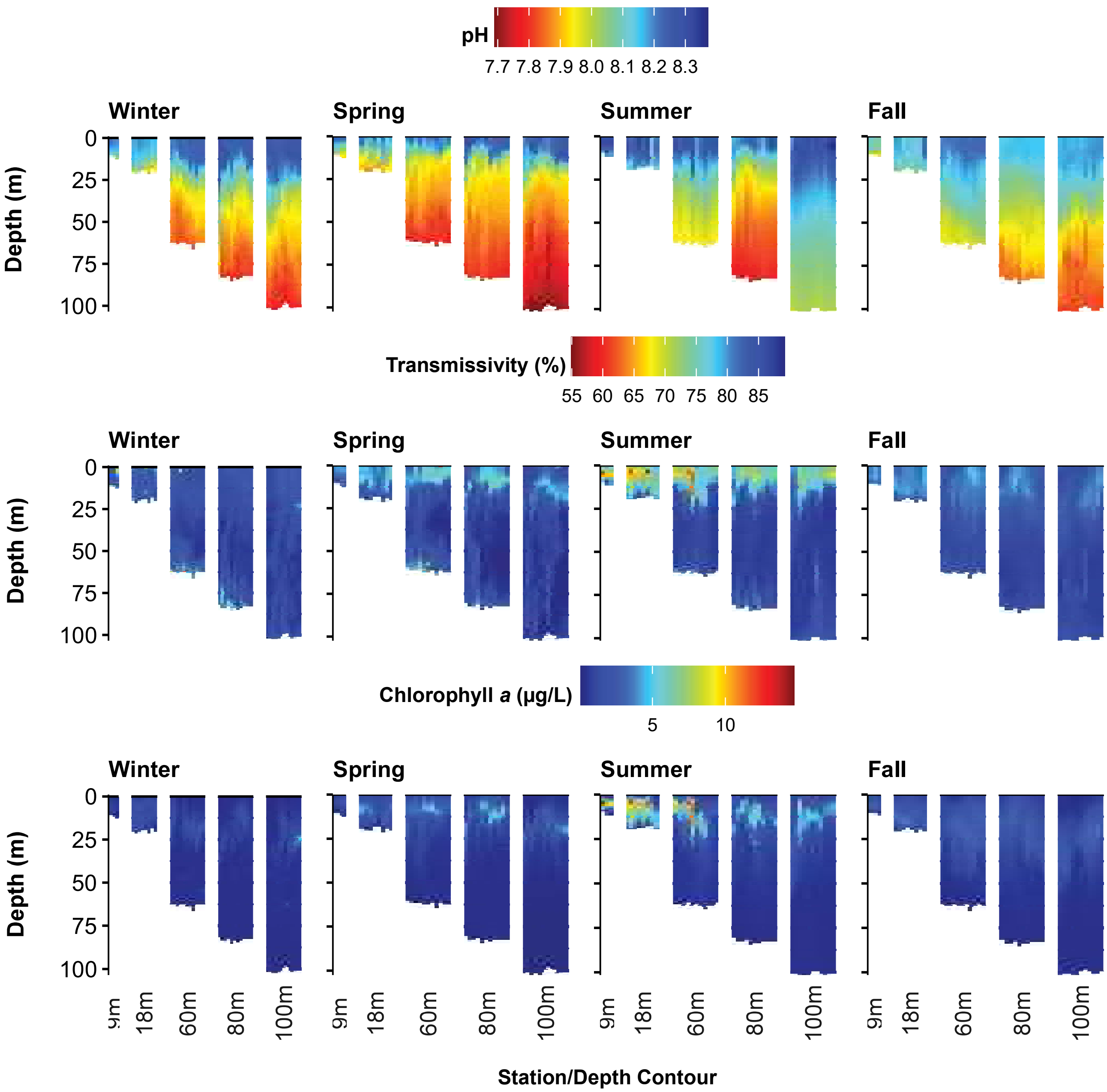
Summary of seasonal buoyancy frequency in the PLOO and SBOO regions during 2018 and 2019. Depth refers to the depth of maximum buoyancy frequency. Max BF refers to the maximum buoyancy frequency, measured in cycles per second. For each quarter: n = 11 (PLOO), n = 13 (SBOO).

	2018		2019	
	Depth (m)	**Max BF (s^{-1})**	**Depth (m)**	**Max BF (s^{-1})**
PLOO Region				
Winter	31	5.64	30	5.34
Spring	9	12.14	9	13.89
Summer	9	15.80	6	13.75
Fall	41	6.51	34	6.56
SBOO Region				
Winter	23	5.36	22	4.74
Spring	11	11.96	10	9.48
Summer	6	15.80	5	16.70
Fall	8	6.76	19	6.84



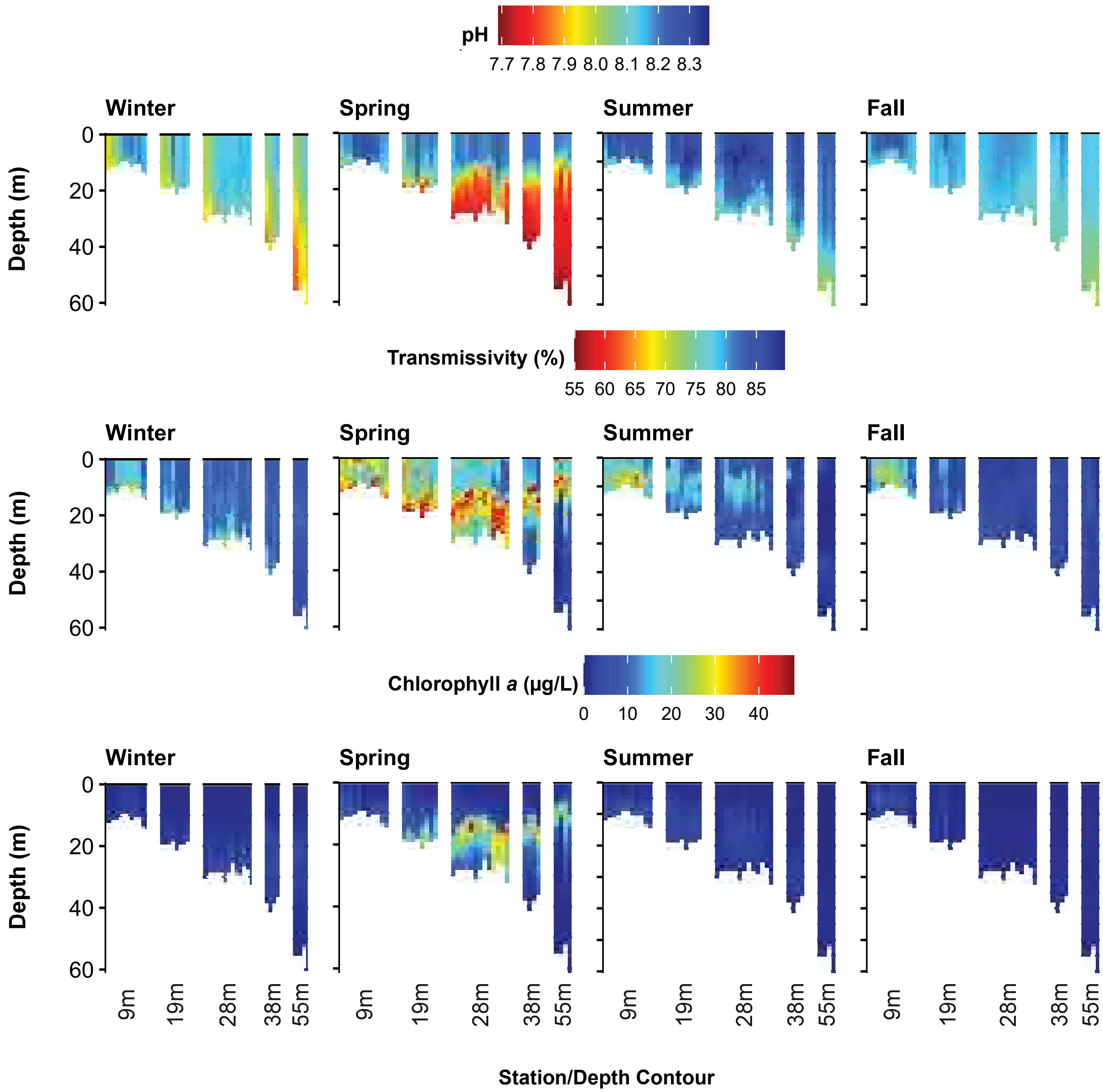
Appendix D.3

Values of pH, transmissivity, and chlorophyll *a* recorded in the PLOO region during 2018. Data are 1-m binned values per depth for each station and were collected over 4–5 days during each quarterly survey. Stations are depicted from north to south along each depth contour.



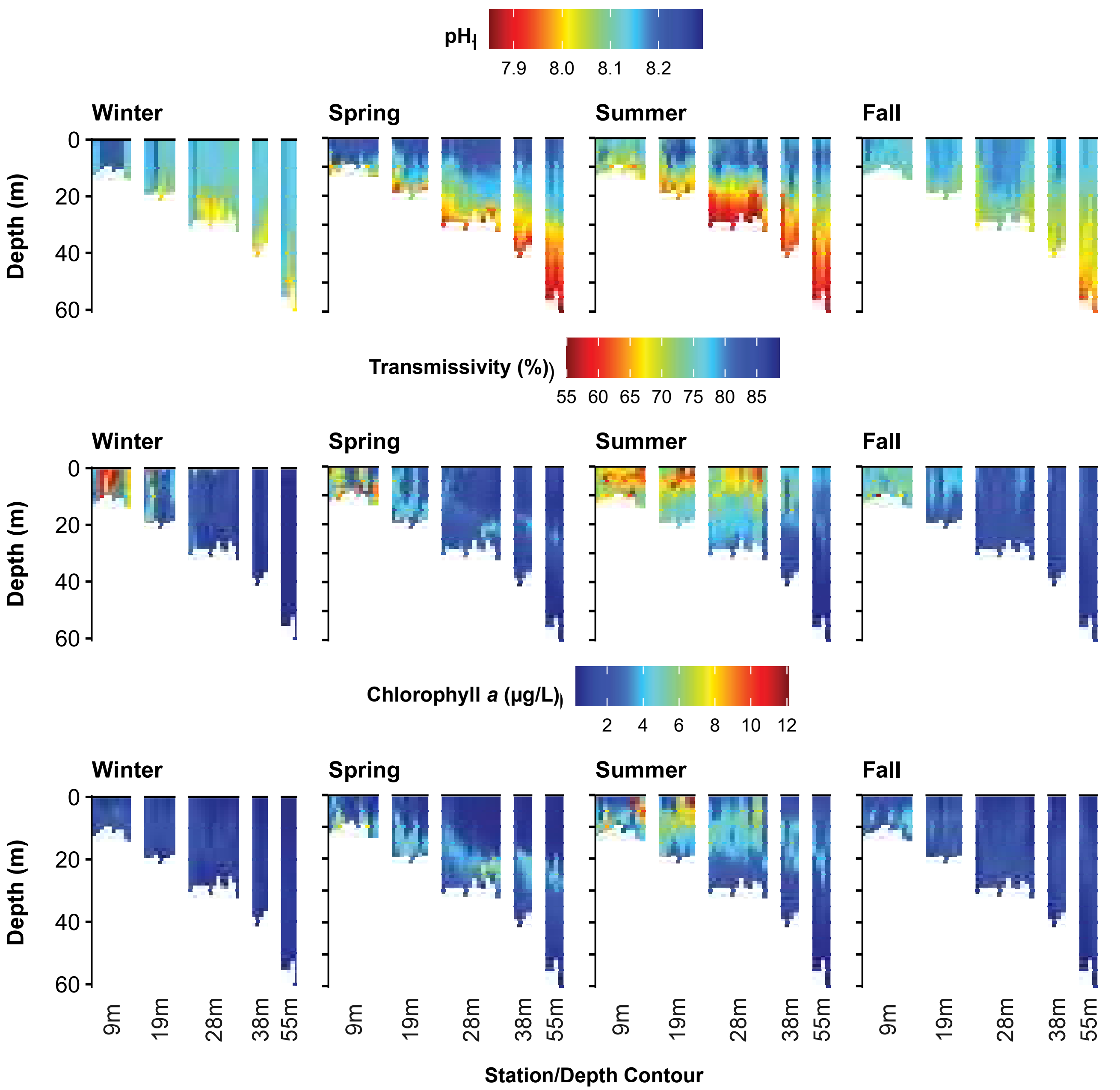
Appendix D.4

Values of pH, transmissivity, and chlorophyll *a* recorded in the PLOO region during 2019. Data are 1-m binned values per depth for each station and were collected over 4–5 days during each quarterly survey. Stations are depicted from north to south along each depth contour.



Appendix D.5

Values of pH, transmissivity, and chlorophyll *a* recorded in the SBOO region during 2018. Data are 1-m binned values per depth for each station and were collected over 4–5 days during each quarterly survey. Stations are depicted from north to south along each depth contour.



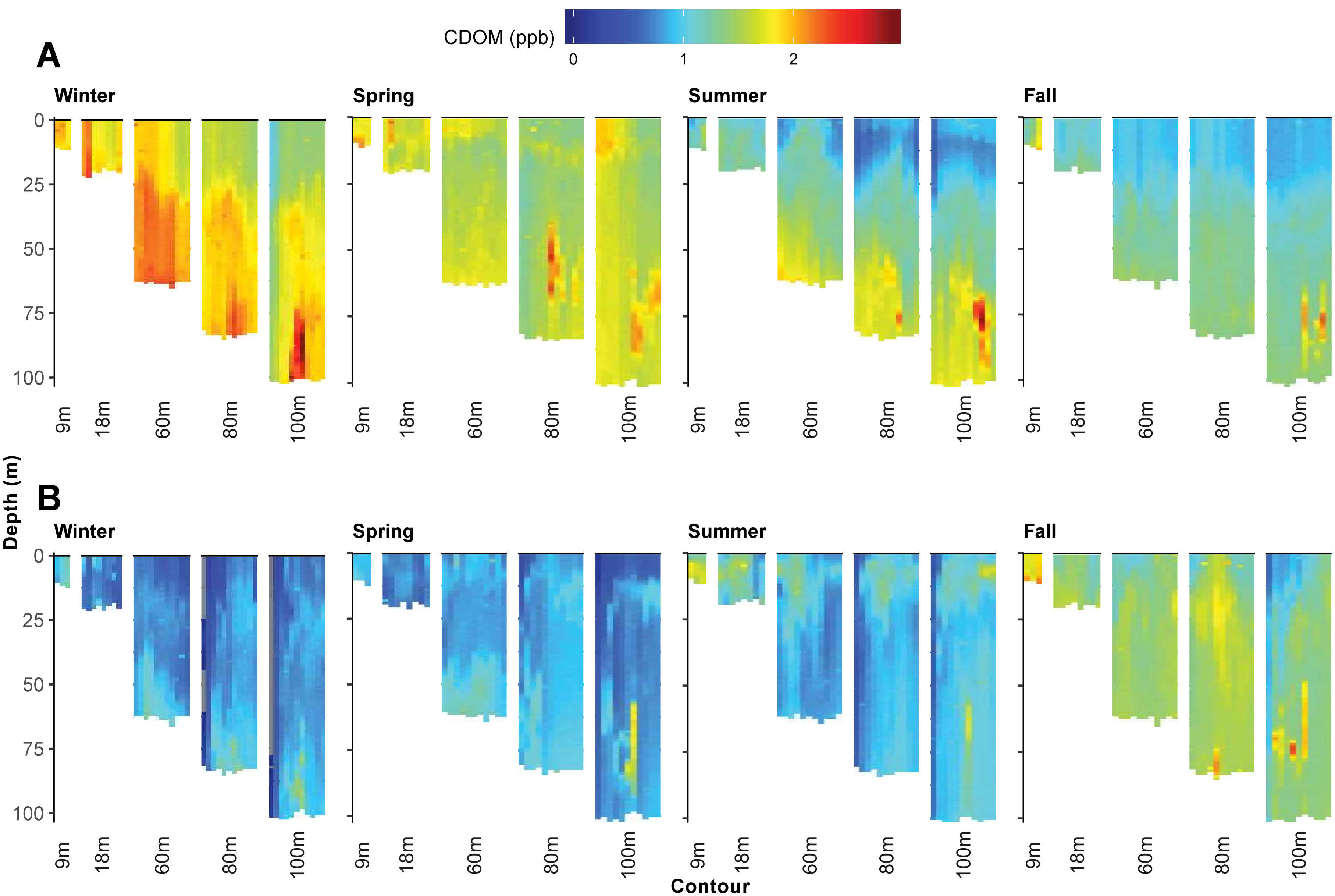
Appendix D.6

Values of pH, transmissivity, and chlorophyll *a* recorded in the SBOO region during 2019. Data are 1-m binned values per depth for each station and were collected over 4–5 days during each quarterly survey. Stations are depicted from north to south along each depth contour.

Appendix E

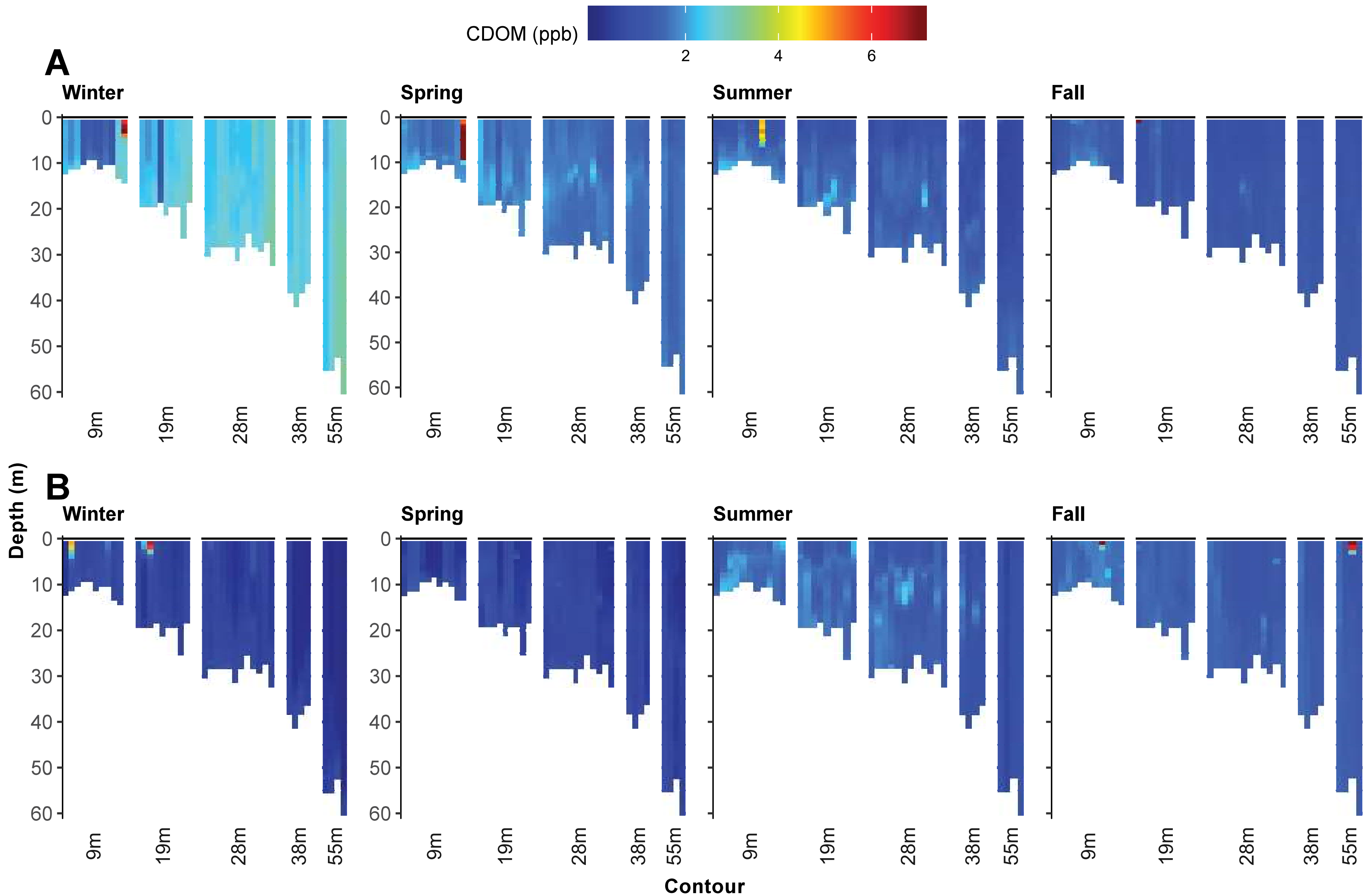
Water Quality Compliance and Plume Dispersion

2018 – 2019 Supplemental Analyses



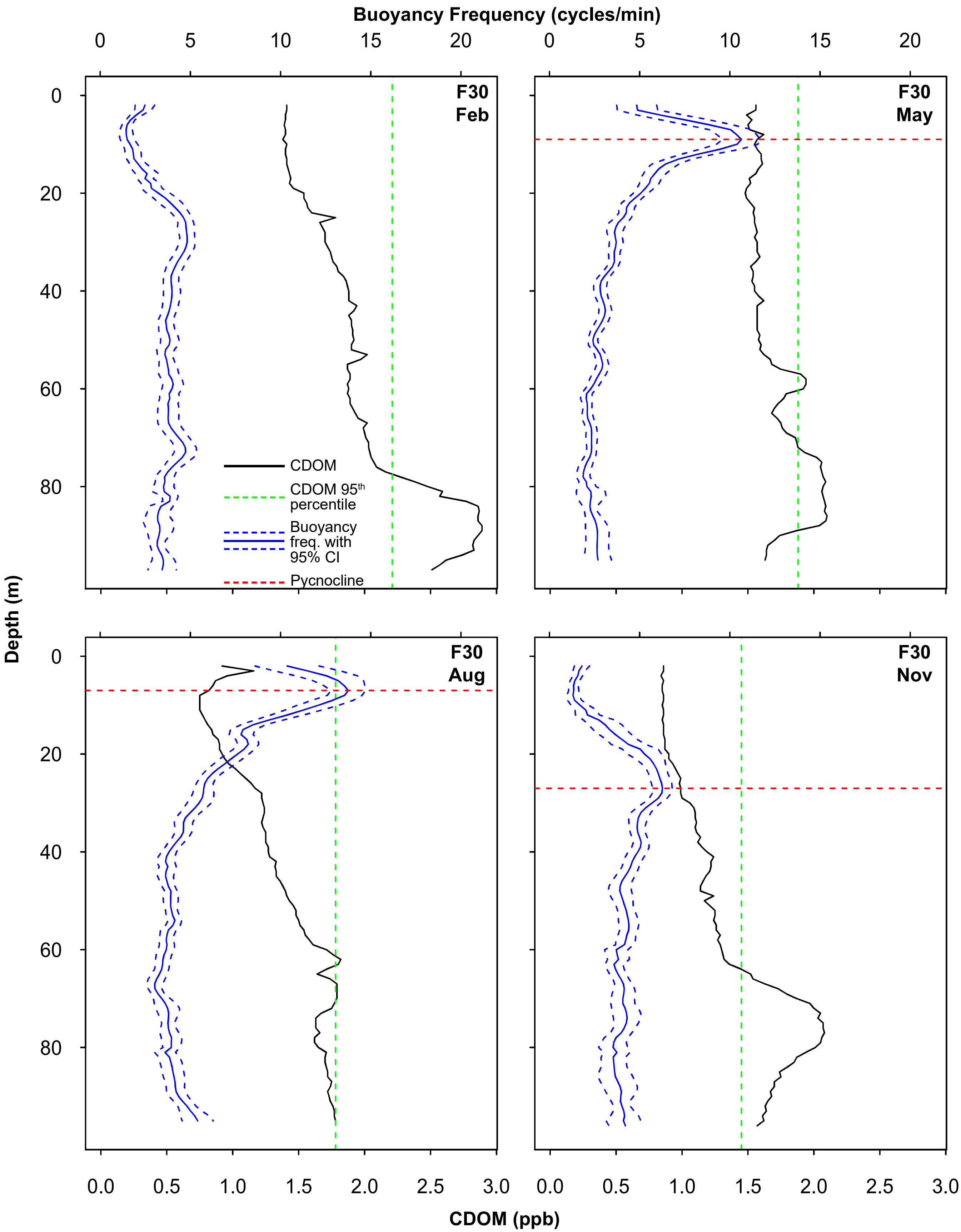
Appendix E.1

Concentrations of CDOM recorded in the PLOO region during (A) 2018 and (B) 2019. 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.



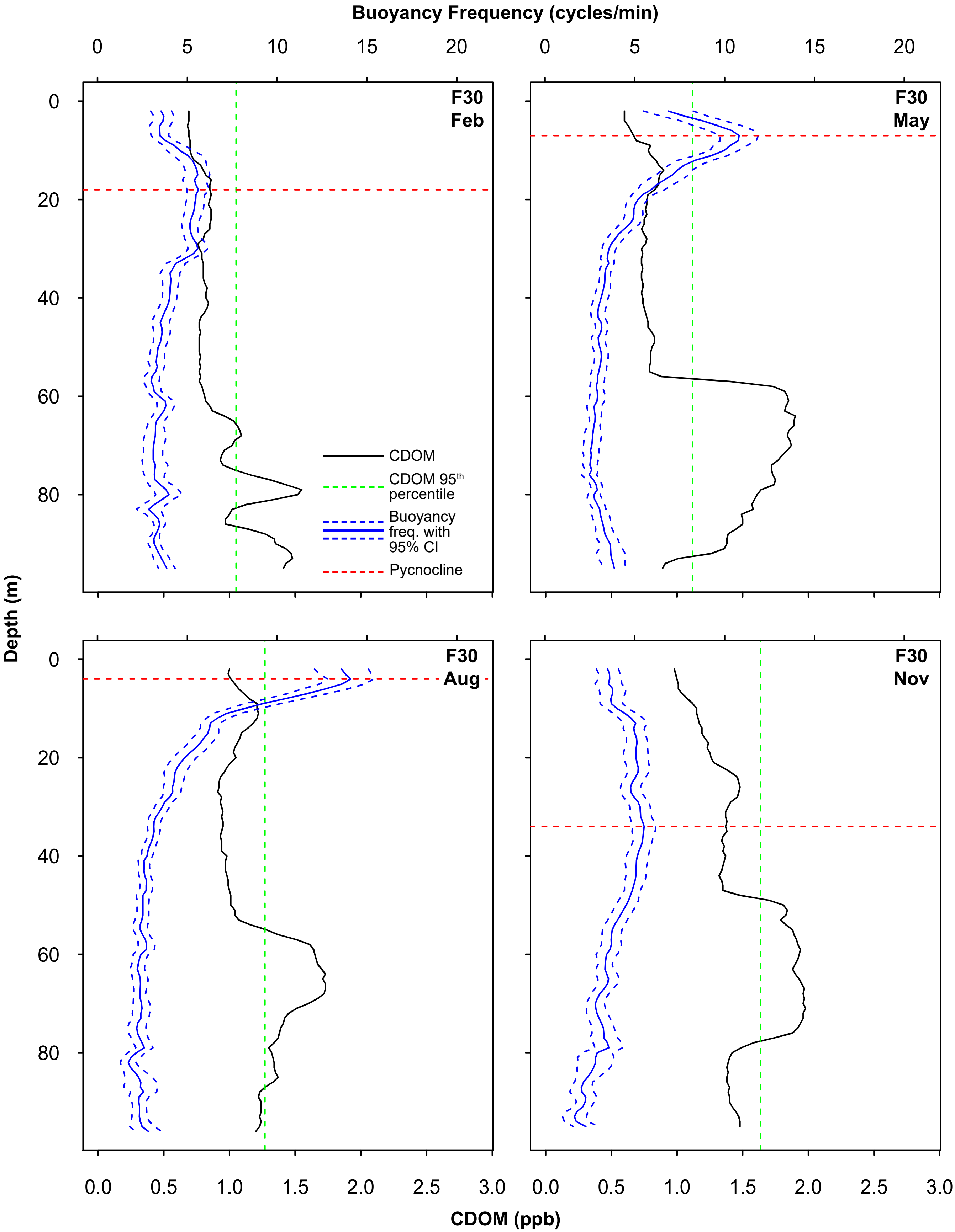
Appendix E.2

Concentrations of CDOM recorded in the SBOO region during (A) 2018 and (B) 2019. 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.



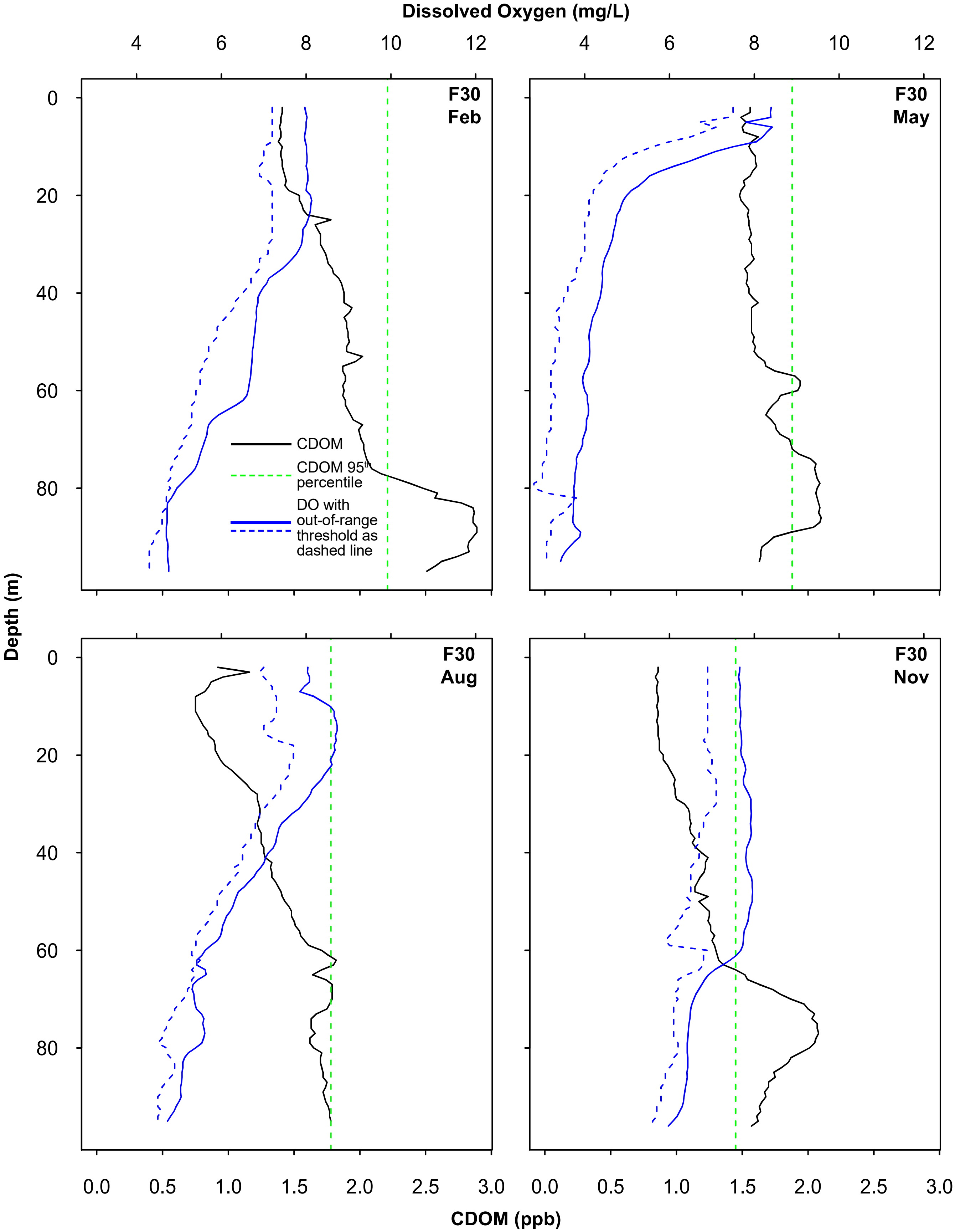
Appendix E.3

Representative vertical profiles of CDOM and buoyancy frequency from PLOO nearfield station F30 during 2018.



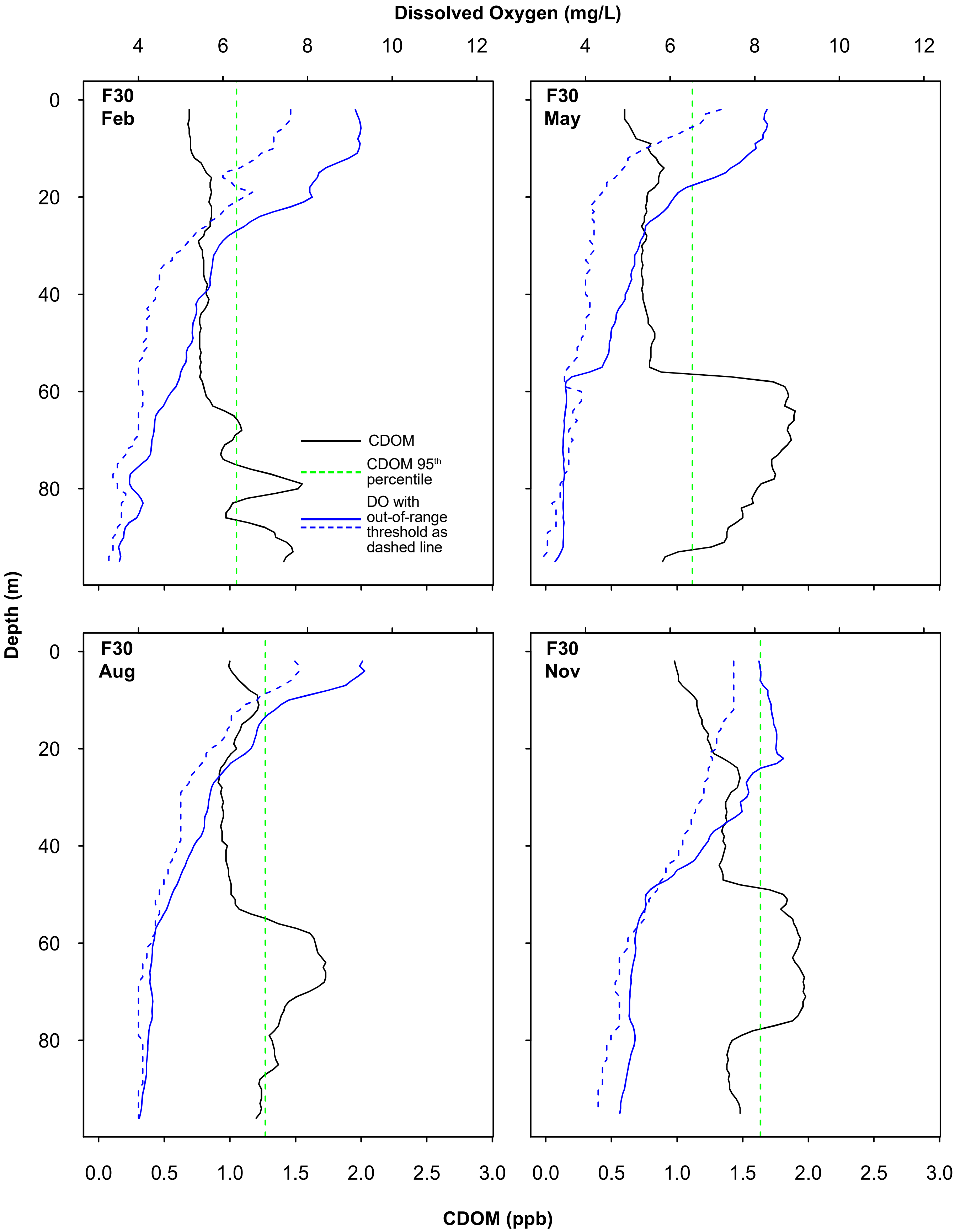
Appendix E.4

Representative vertical profiles of CDOM and buoyancy frequency from PLOO nearfield station F30 during 2019.



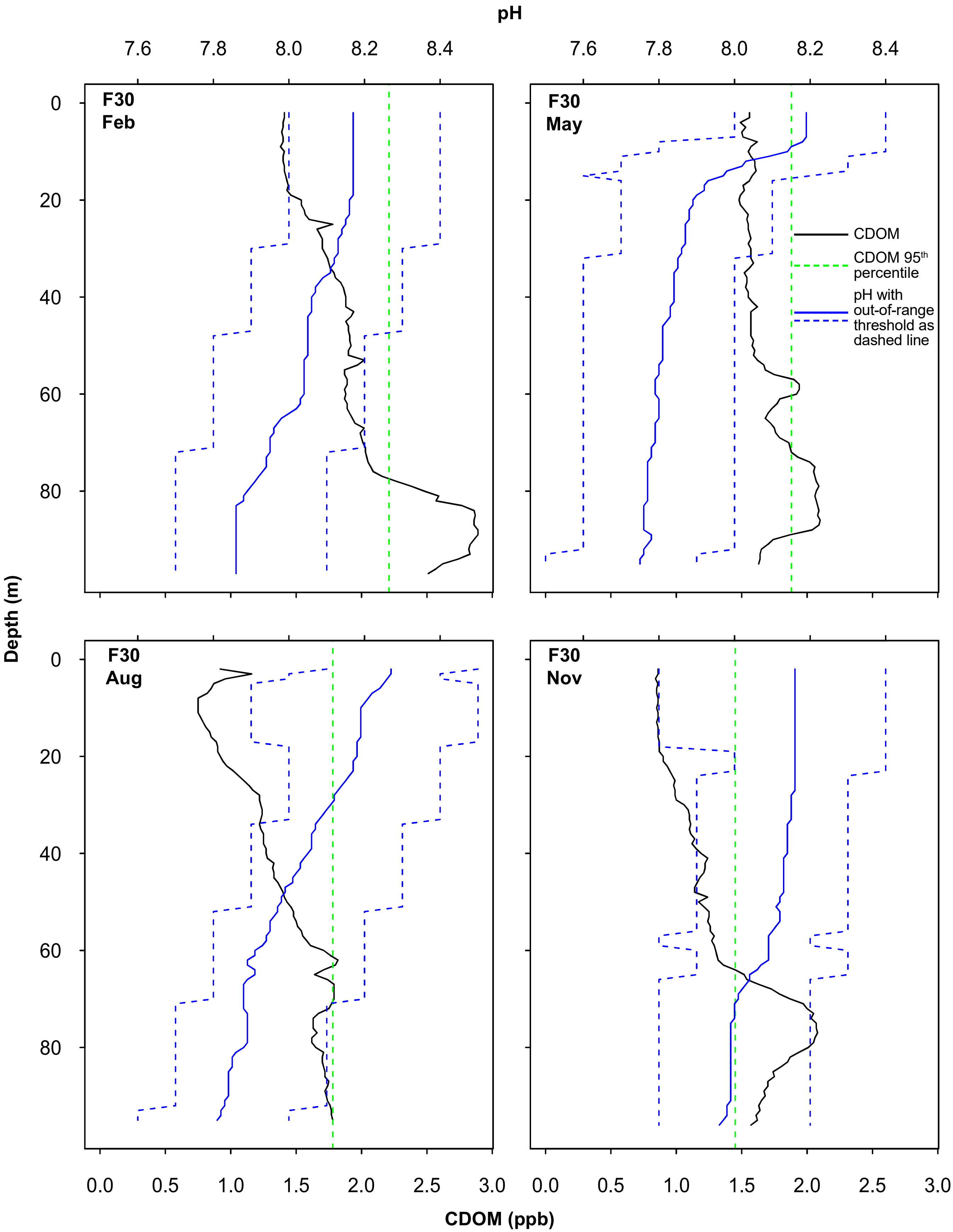
Appendix E.5

Representative vertical profiles of CDOM and DO from PLOO nearfield station F30 during 2018.

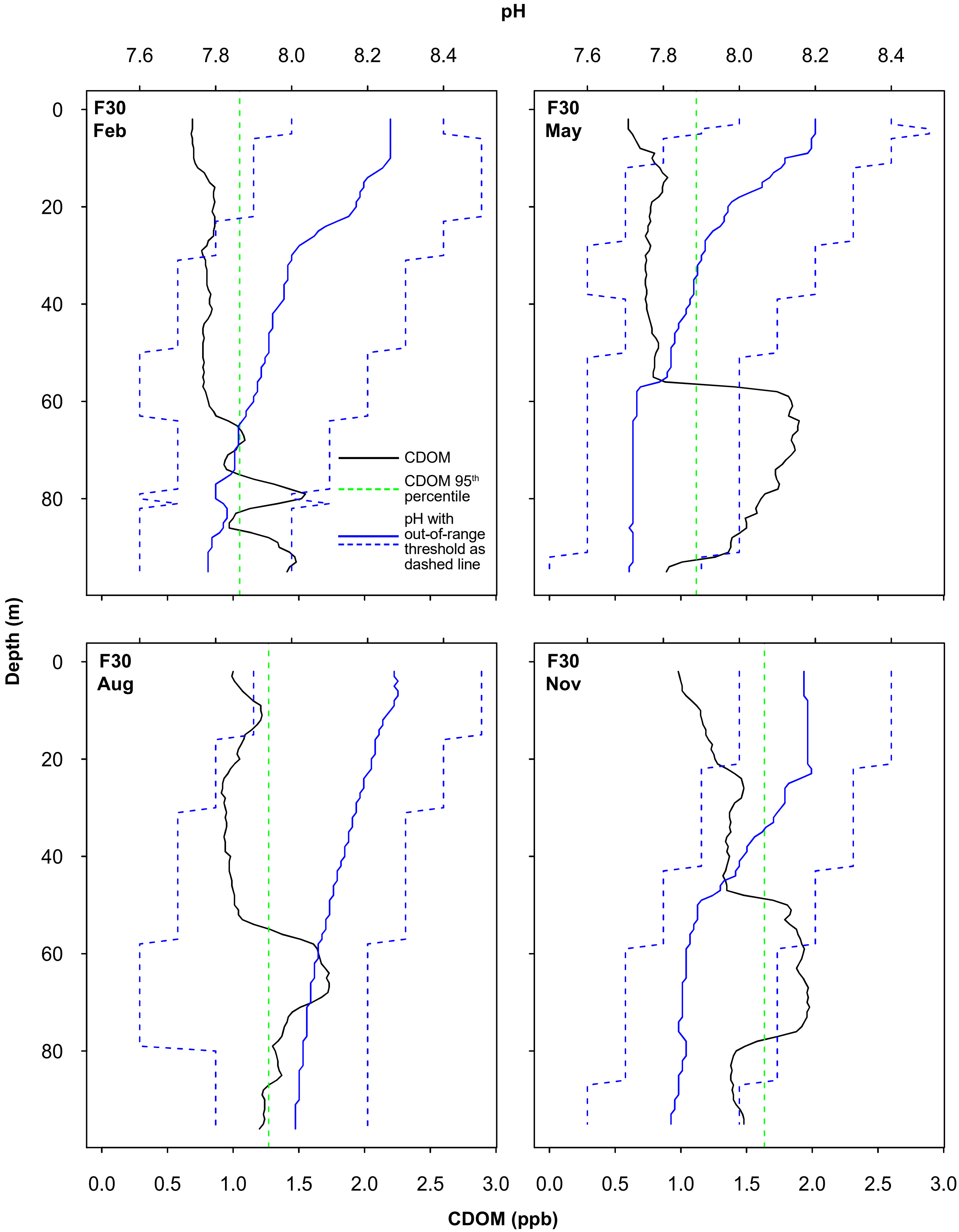


Appendix E.6

Representative vertical profiles of CDOM and DO from PLOO nearfield station F30 during 2019.

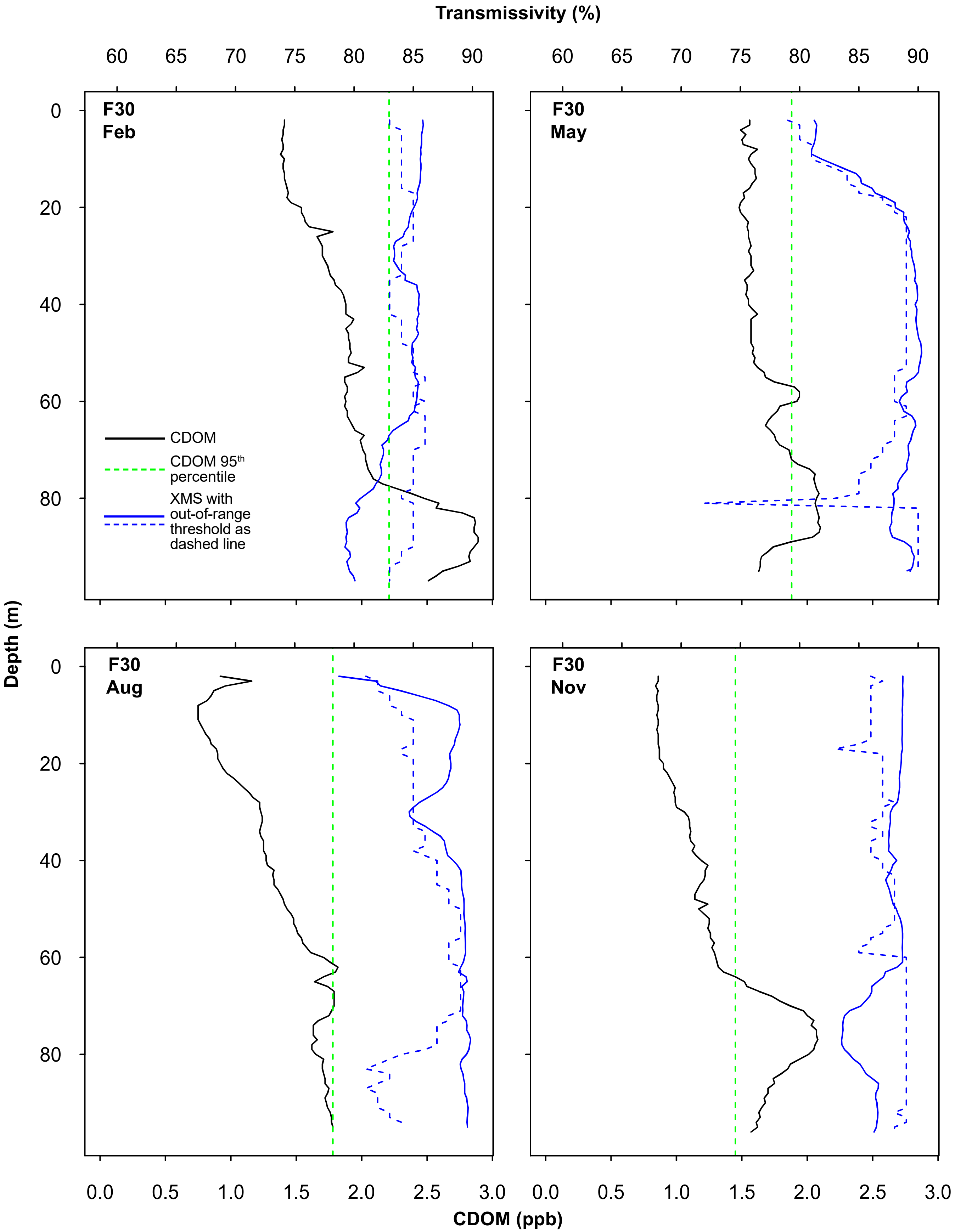


Appendix E.7
Representative vertical profiles of CDOM and pH from PLOO nearfield station F30 during 2018.



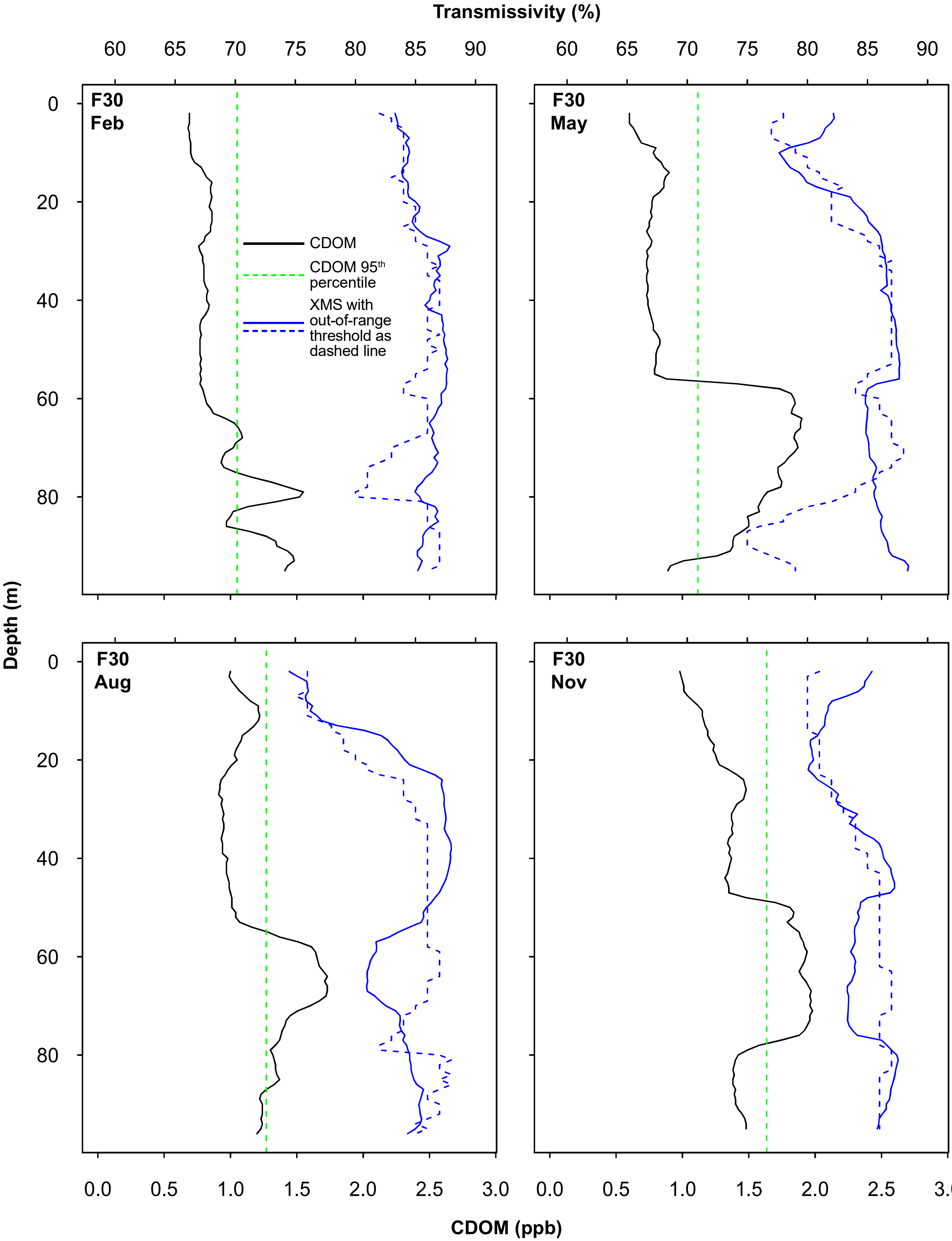
Appendix E.8

Representative vertical profiles of CDOM and pH from PLOO nearfield station F30 during 2019.



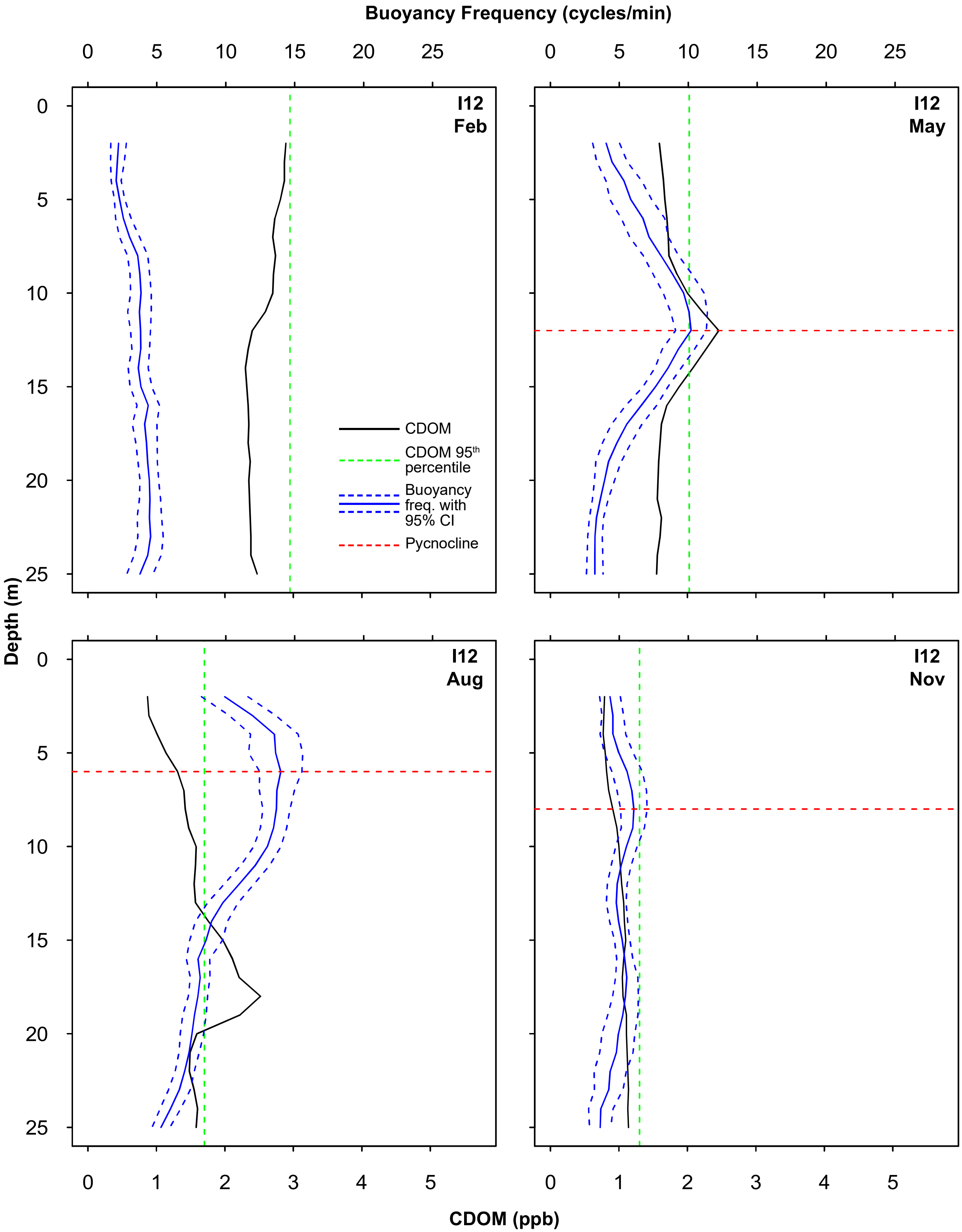
Appendix E.9

Representative vertical profiles of CDOM and transmissivity (XMS) from PLOO nearfield station F30 during 2018.

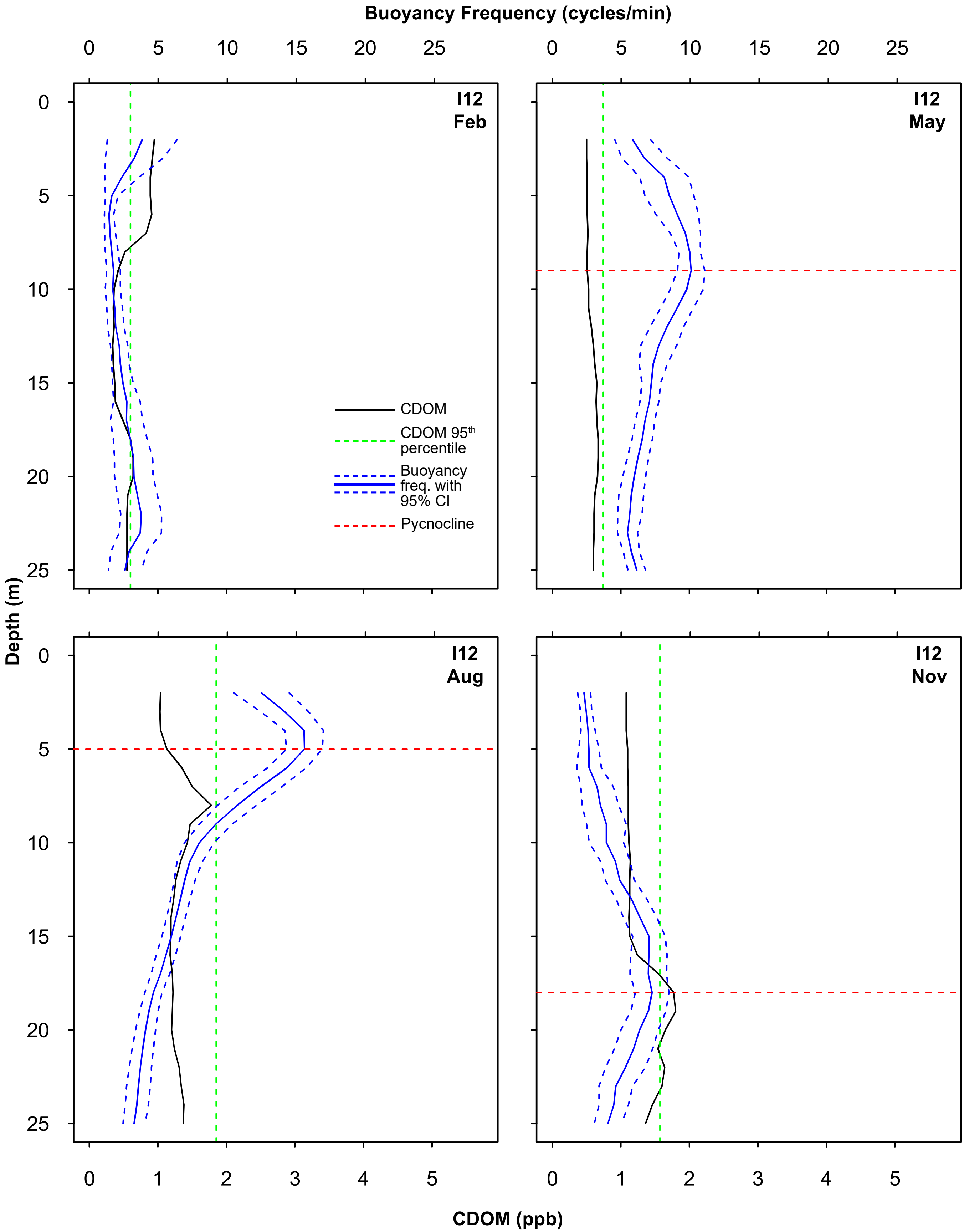


Appendix E.10

Representative vertical profiles of CDOM and transmissivity (XMS) from PLOO nearfield station F30 during 2019.

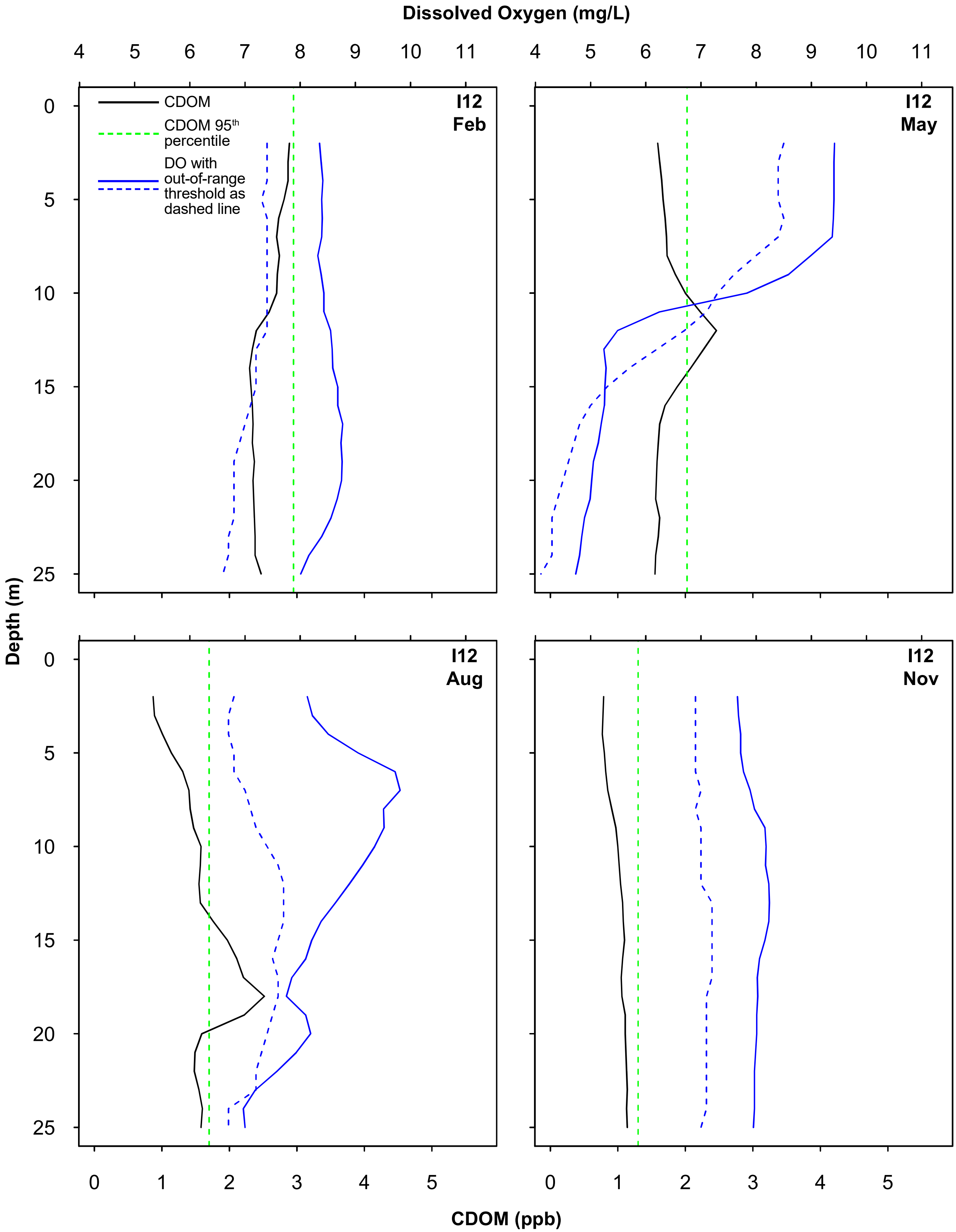


Appendix E.11
Representative vertical profiles of CDOM and buoyancy frequency from SBOO nearfield station I12 during 2018.



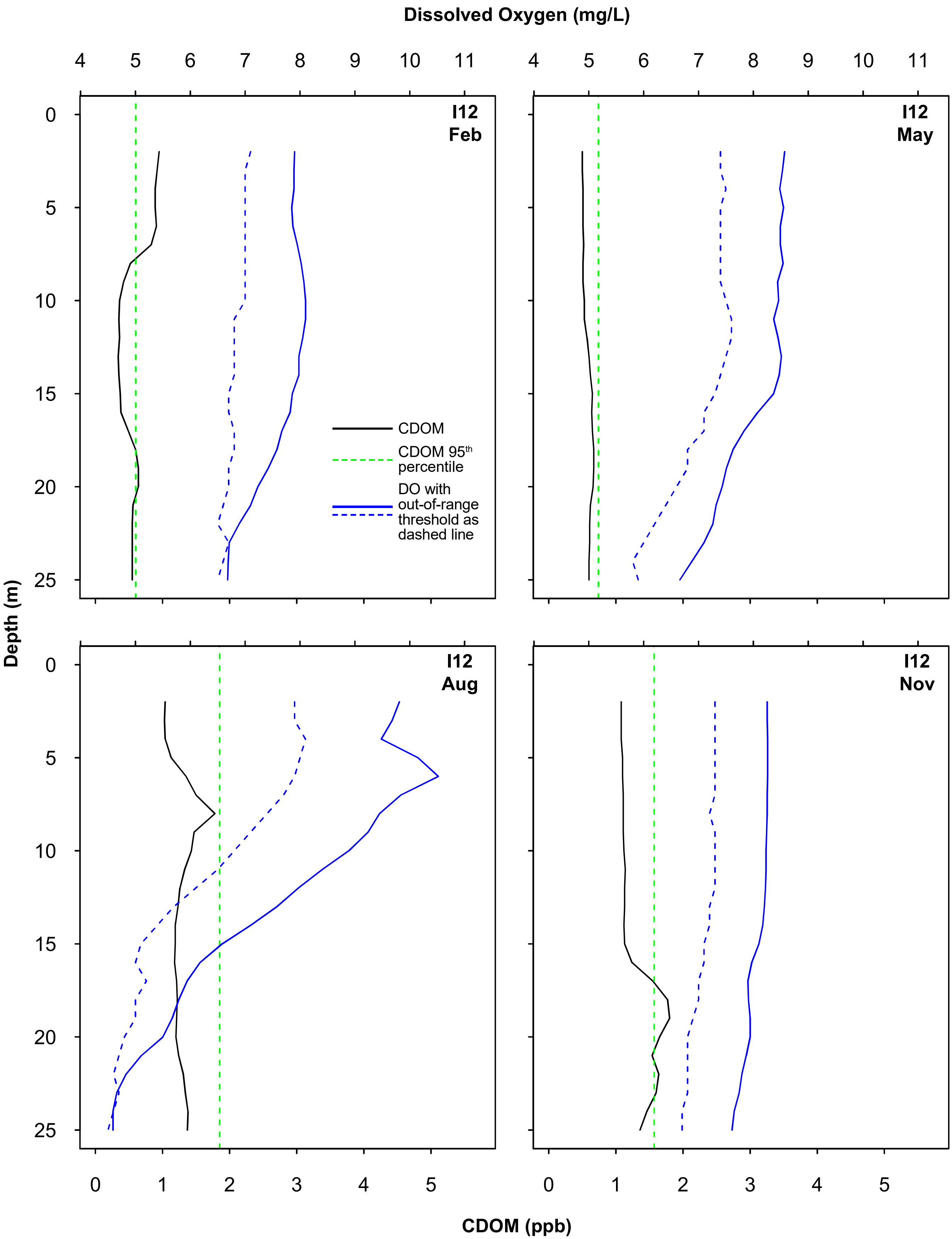
Appendix E.12

Representative vertical profiles of CDOM and buoyancy frequency from SBOO nearfield station I12 during 2019.



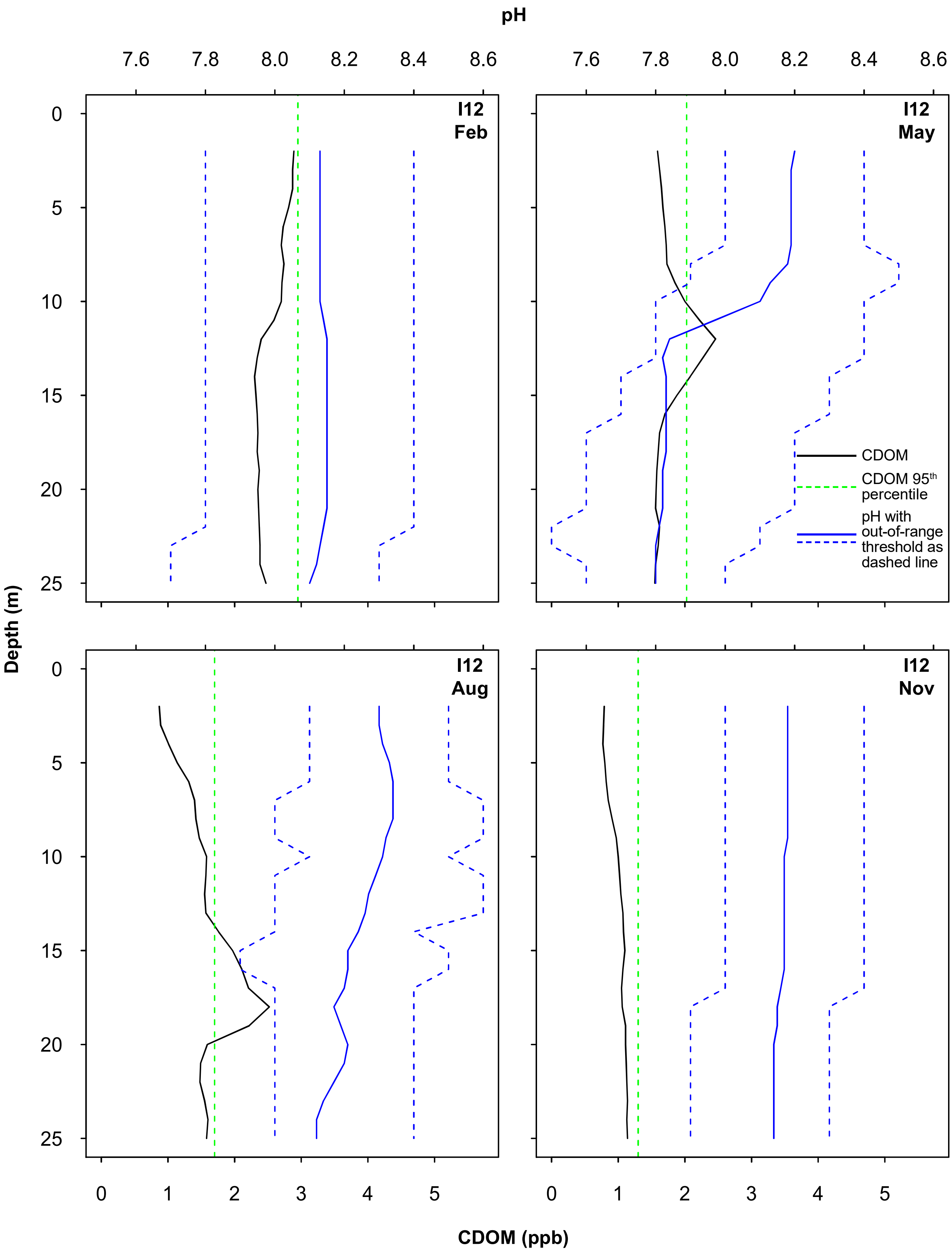
Appendix E.13

Representative vertical profiles of CDOM and DO from SBOO nearfield station I12 during 2018.



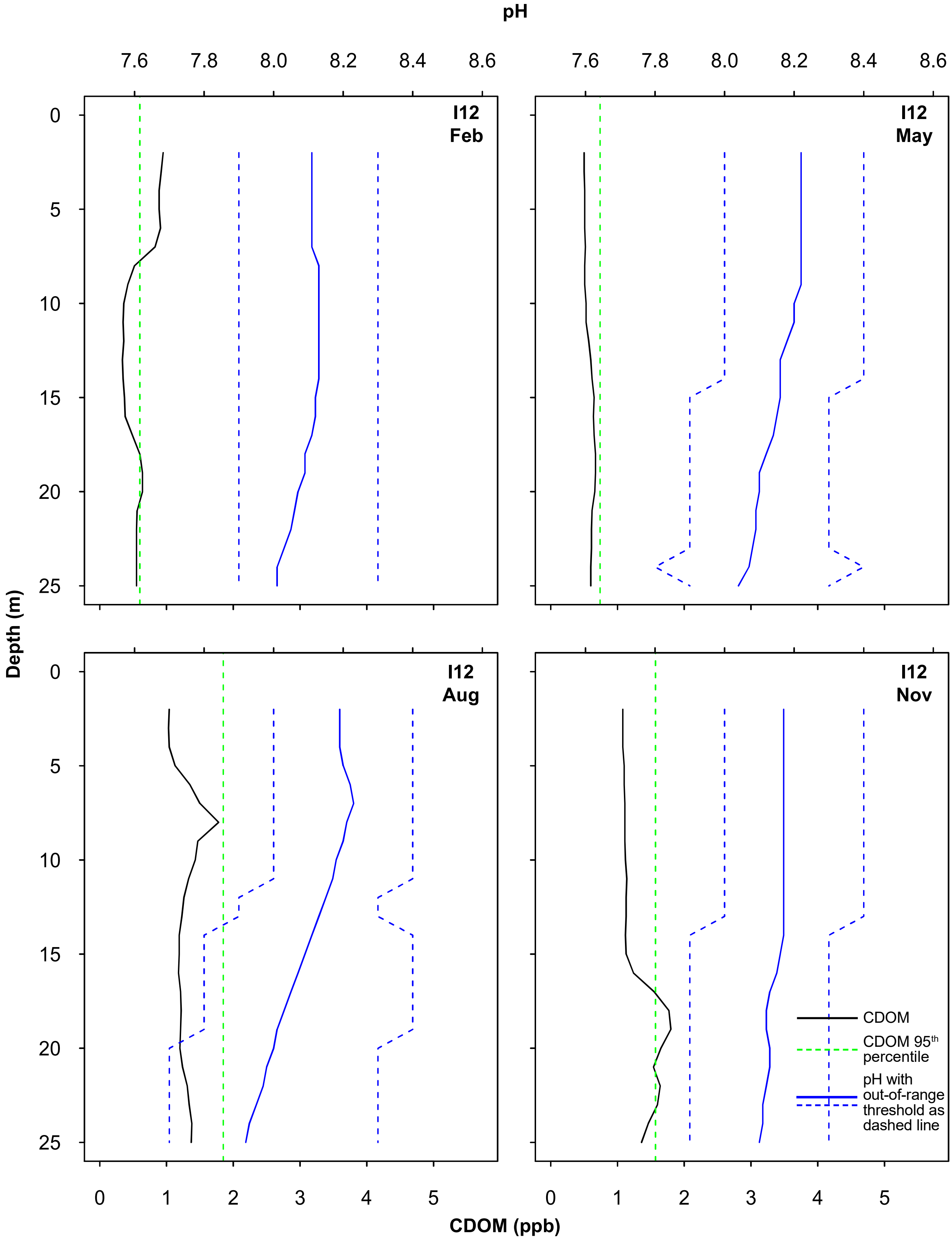
Appendix E.14

Representative vertical profiles of CDOM and DO from SBOO nearfield station I12 during 2019.



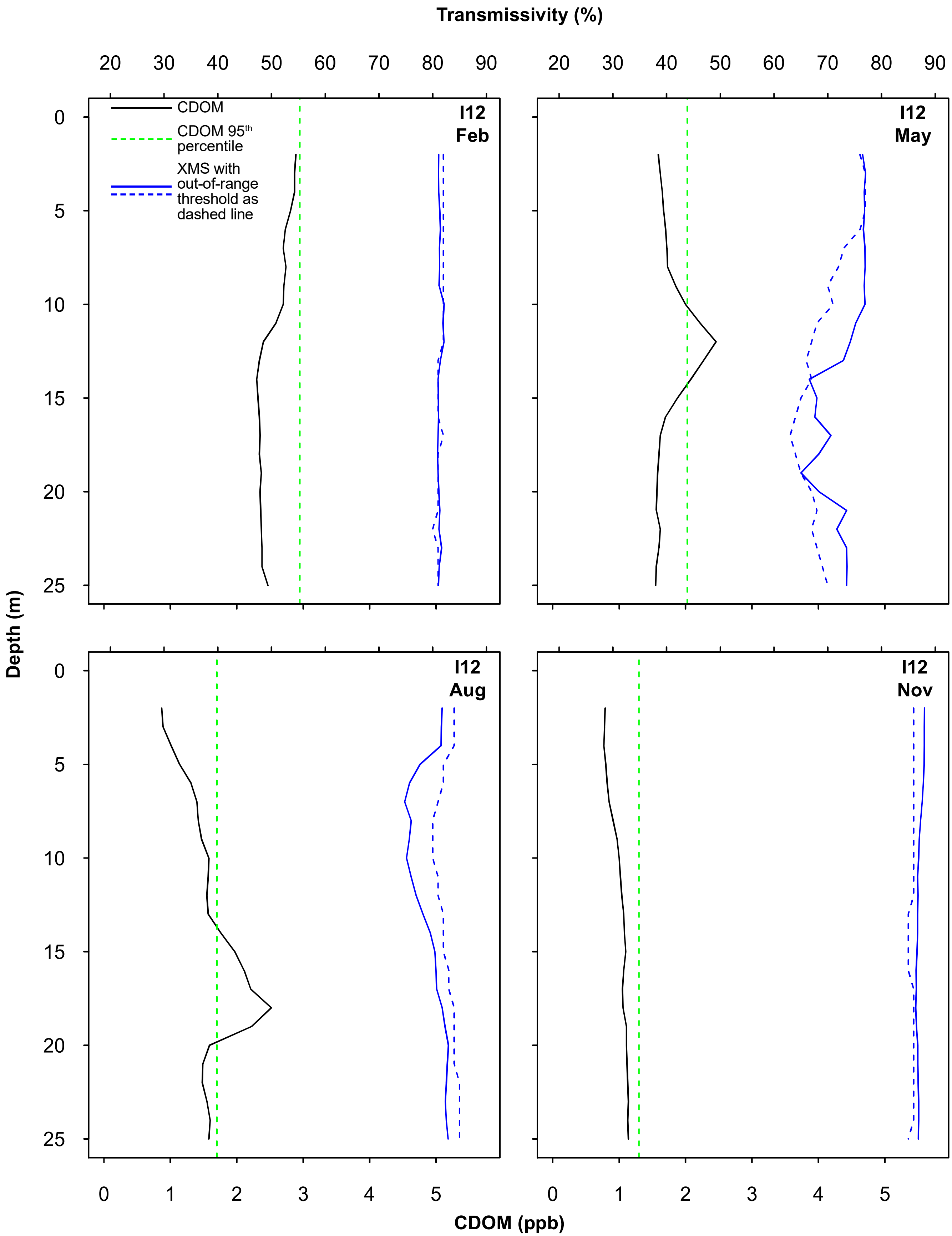
Appendix E.15

Representative vertical profiles of CDOM and pH from SBOO nearfield station I12 during 2018.



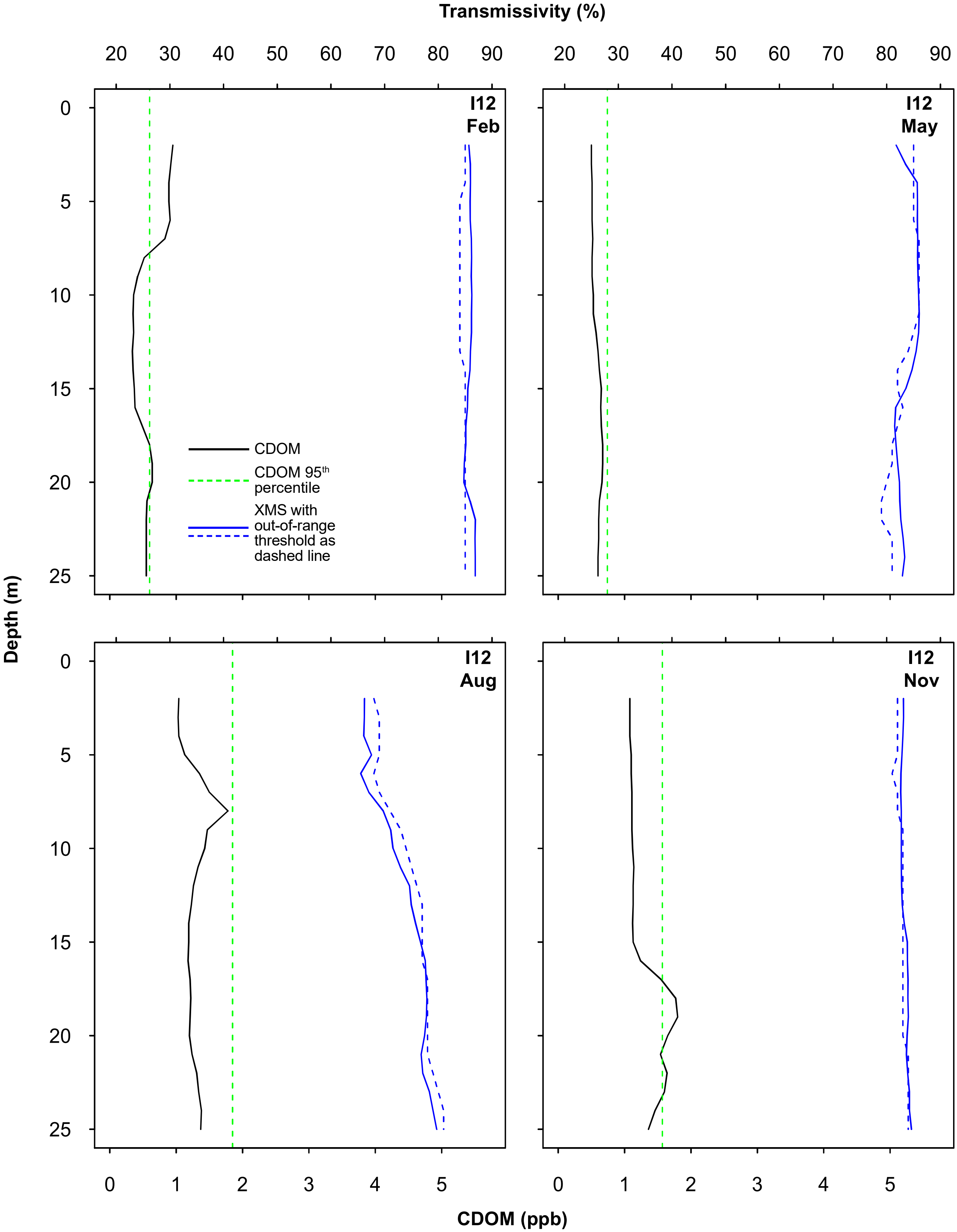
Appendix E.16

Representative vertical profiles of CDOM and pH from SBOO nearfield station I12 during 2019.



Appendix E.17

Representative vertical profiles of CDOM and transmissivity (XMS) from SBOO nearfield station I12 during 2018.



Appendix E.18

Representative vertical profiles of CDOM and transmissivity (XMS) from SBOO nearfield station I12 during 2019.

Appendix F

Sediment Quality

2018 – 2019 Supplemental Analyses

Appendix F.1

Constituents and method detection limits (MDL) used for the analysis of sediments during 2018 and 2019.

Parameter	MDL	Parameter	MDL
Organic Indicators			
BOD (ppm)	2	Sulfides (ppm)	0.38
TN (% wt.)	0.008–0.012	TVS (% wt.)	0.11
TOC (% wt.)	0.063–0.07		
Metals (ppm)			
Aluminum (Al)	2.4–36.1	Lead (Pb)	0.1–0.52
Antimony (Sb)	0.17–0.851	Manganese (Mn)	0.061–0.719
Arsenic (As)	0.152–2.95	Mercury (Hg)	0.003–0.058
Barium (Ba)	0.08–1.02	Nickel (Ni)	0.052–0.3
Beryllium (Be)	0.003–0.161	Selenium (Se)	0.14–2.09
Cadmium (Cd)	0.018–0.146	Silver (Ag)	0.132–0.59
Chromium (Cr)	0.049–0.223	Thallium (Tl)	0.095–0.43
Copper (Cu)	0.695–3.8	Tin (Sn)	0.059–0.722
Iron (Fe)	1.88–11.9	Zinc (Zn)	0.384–1.71
Chlorinated Pesticides (ppt)			
Total Chlordane			
Alpha (cis) Chlordane	39.6–108	Heptachlor epoxide	34.6–67.1
Cis Nonachlor	33.8–293	Methoxychlor	39.4–179
Gamma (trans) Chlordane	27.6–121	Oxychlordane	34.3–142
Heptachlor	88.6–507	Trans Nonachlor	507–570
Total Dichlorodiphenyltrichloroethane (DDT)			
o,p–DDD	29.4–46.6	p,p–DDE	16.7–49.9
o,p–DDE	14.4–43	p,p–DDMU	27.6–189
o,p–DDT	32.2–94	p,p–DDT	21.8–74.7
p,p–DDD	28.4–121		
Hexachlorocyclohexane (HCH)			
HCH, Alpha isomer	26.9–70.6	HCH, Delta isomer	52.2–145
HCH, Beta isomer	31.4–79.2	HCH, Gamma isomer	14.4–75.3
Miscellaneous Pesticides			
Aldrin	31.8–395	Alpha Endosulfan	40.3–326
Dieldrin	31.5–443	Beta Endosulfan	39.1–501
Endrin	40.2–496	Endosulfan Sulfate	27.8–557
Endrin aldehyde	32.5–345	Hexachlorobenzene (HCB)	50.5–1340
		Mirex	28.7–79.5

Appendix F.1 *continued*

Parameter	MDL	Parameter	MDL
Polychlorinated Biphenyl Congeners (PCBs) (ppt)			
PCB 8	40.9–57.7	PCB 126	28.5–115
PCB 18	26.8–91.1	PCB 128	21.2–87.6
PCB 28	22.8–38.9	PCB 138	43.8–81.5
PCB 37	24.8–51.3	PCB 149	21–40.5
PCB 44	22.7–87.5	PCB 151	37–60.2
PCB 49	27.7–42	PCB 153/168	45.7–140
PCB 52	25.9–51.9	PCB 156	19–58.5
PCB 66	22.3–38.1	PCB 157	19.2–37.1
PCB 70	19.3–44.8	PCB 158	23.2–60.1
PCB 74	13.4–40	PCB 167	17.9–49.7
PCB 77	28.5–60.4	PCB 169	24.7–84.7
PCB 81	28.1–60.6	PCB 170	24.1–97.2
PCB 87	26.2–72.5	PCB 177	23.6–45.1
PCB 99	20–101	PCB 180	38.2–60.5
PCB 101	42.3–66.9	PCB 183	27.1–52.3
PCB 105	37.2–58.6	PCB 187	31.7–69.5
PCB 110	21.1–85.1	PCB 189	17.3–33.4
PCB 114	39.6–127	PCB 194	21.9–57.7
PCB 118	18–118	PCB 195	29.2–42.2
PCB 119	30.2–117	PCB 201	28.1–86.6
PCB 123	20.8–70.8	PCB 206	21–66.1
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)			
1-methylnaphthalene	6.02–14.1	Benzo[G,H,I]perylene	3.87–16.4
1-methylphenanthrene	6.71–22.5	Benzo[K]fluoranthene	4–13.9
2-methylnaphthalene	5.84–23.2	Biphenyl	7.77–21.3
2,3,5-trimethylnaphthalene	9.71–18.4	Chrysene	4.32–14.8
2,6-dimethylnaphthalene	6.71–20.2	Dibenzo(A,H)anthracene	1.61–12
3,4-benzo(B)fluoranthene	3.03–9.93	Fluoranthene	2.96–13.6
Acenaphthene	9.9–18.8	Fluorene	10.1–19.2
Acenaphthylene	7.83–15.7	Indeno(1,2,3-CD)pyrene	4.24–11.7
Anthracene	7.39–16.2	Naphthalene	5.14–32.9
Benzo[A]anthracene	4.42–13.5	Perylene	3–14.6
Benzo[A]pyrene	3.25–12.5	Phenanthrene	4.15–14.3
Benzo[e]pyrene	4.06–11.4	Pyrene	5.43–15.4

Appendix F.2

Particle size classification schemes (based on Folk 1980) used in the analysis of sediments during 2018 and 2019. 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]		Sieve Size	Sub-Fraction	Fraction
	Min µm	Max µm			
-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 F.3

Summary of particle size fractions (%) in sediments from PLOO stations sampled during 2018 and 2019. Data are means (range) for each station.

	Fine Particles	Fine Sands	Med-Coarse Sands	Coarse Particles
88-m Depth Contour				
B11	57.7 (33.9-79.9)	29.7 (19.3-39.7)	8.3 (0.7-16.1)	6.3 (0-10.4)
B8	70.4 (63.1-80.8)	29.5 (19.2-36.9)	0.1 (0.1-0.1)	0
E19	59.2 (52.1-66.2)	40.6 (33.6-47.7)	0.1 (0.1-0.1)	0
E7	56.7 (45.9-65.8)	43.1 (34.0-53.9)	0.1 (0.1-0.2)	0
E1	53.6 (39.9-62.3)	44.0 (36.8-55.1)	2.5 (0.9-4.9)	0
98-m Depth Contour				
B12	46.5 (20.2-73.9)	36.1 (21.7-49.6)	15.5 (1.3-27.8)	4.0 (0-4.2)
B9	55.2 (44.9-68.9)	43.8 (30.6-53.3)	1.0 (0.2-1.8)	0
E26	54.6 (46.9-66.3)	45.4 (33.6-53.1)	0.2 (0.1-0.2)	0
E25	46.7 (36.3-64.3)	52.5 (35.6-62.3)	0.6 (0.2-1.0)	0.4 (0-0.4)
E23	48.9 (39.4-60.3)	50.7 (39.5-59.6)	0.2 (0.2-0.4)	0.6 (0-0.6)
E20	46.9 (36.6-59.8)	52.8 (40.0-62.9)	0.3 (0.2-0.6)	0
E17[a]	41.3 (34.1-48.6)	55.5 (42.3-65.2)	0.5 (0.2-0.7)	13.8 (0-13.8)
E14[a]	37.1 (23.9-55.5)	62.2 (43.9-75.9)	0.7 (0.2-1.2)	0
E11[a]	39.7 (29.6-58.7)	59.4 (40.8-69.2)	0.8 (0.5-1.3)	0
E8	46.3 (35.8-62.4)	52.8 (36.9-62.7)	1.0 (0.5-1.6)	0
E5	43.5 (32.4-57.0)	55.1 (41.6-65.7)	1.3 (0.7-1.9)	0
E2	45.4 (31.4-63.0)	45.9 (35.7-53.0)	6.4 (1.4-12.4)	4.7 (0-6.2)
116-m Depth Contour				
B10	37.5 (12.5-55.5)	60.7 (43.6-84.1)	1.6 (0.8-2.7)	0.7 (0-0.7)
E21	43.1 (34.5-54.4)	56.3 (44.8-65.0)	0.6 (0.5-0.7)	0
E15	40.9 (29.2-56.3)	58.3 (43.2-70.1)	0.8 (0.5-1.3)	0
E9	43.0 (25.3-59.7)	41.5 (39.6-43.7)	9.8 (0.6-20.9)	8.5 (0-12.4)
E3	23.8 (14.8-38.5)	43.1 (35.7-55.3)	22.6 (21.0-23.5)	10.5 (2.3-23.4)

[a] Near-ZID station

Appendix F.4

Summary of particle size fractions (%) in sediments from SBOO stations sampled during 2018 and 2019. Data are means (range) for each station.

	Fine Particles	Fine Sands	Med-Coarse Sands	Coarse Particles
19-m Depth Contour				
I35	39.5 (34.4-43.7)	58.8 (54.8-63.5)	1.7 (1.5-2.0)	0
I34	2.2 (0.8-3.0)	9.3 (6.8-13.9)	58.1 (45.6-82.6)	30.3 (2.6-44.8)
I31	8.7 (6.8-10.1)	90.9 (89.4-93.0)	0.4 (0.2-0.6)	0
I23	15.9 (2.5-37.1)	45.7 (1.9-86.2)	27.3 (5.0-66.1)	11.1 (0.6-29.5)
I18	9.0 (8.4-9.7)	90.3 (89.6-90.8)	0.6 (0.5-0.7)	0
I10	9.2 (7.6-10.5)	88.3 (86.5-90.8)	2.5 (1.6-3.0)	0
I4	37.4 (2.2-95.3)	30.9 (4.7-80.8)	31.4 (0.1-89.5)	1.0 (0-1.0)
28-m Depth Contour				
I33	15.3 (7.0-23.5)	81.4 (72.8-90.9)	3.3 (2.0-4.6)	0.1 (0-0.1)
I30	22.5 (19.7-27.7)	76.9 (71.6-79.7)	0.6 (0.5-0.7)	0
I27	17.8 (17.2-19.1)	81.6 (80.3-82.4)	0.6 (0.4-0.7)	0.1 (0-0.1)
I22	16.4 (14.4-17.8)	80.2 (79.3-81.2)	3.4 (2.5-4.4)	0
I14[a]	22.2 (17.4-34.0)	75.9 (63.1-80.9)	1.9 (0.8-3.0)	0
I16[a]	6.6 (1.9-16.1)	39.7 (23.6-65.4)	51.2 (30.0-62.7)	3.7 (0-8.8)
I15[a]	5.3 (2.1-12.1)	37.2 (18.0-61.7)	57.2 (26.1-79.2)	0.5 (0-0.7)
I12[a]	3.9 (1.4-5.4)	36 (20.9-53.4)	59.7 (41.9-72.3)	0.6 (0-1.4)
I9	21.1 (20.0-24.0)	78.2 (75.2-79.4)	0.7 (0.5-0.9)	0
I6	1.9 (0-2.5)	8.9 (5.3-11.3)	85.9 (80.8-88.5)	4.5 (0.7-12.3)
I2	1.2 (0-1.7)	30.0 (26.6-35.9)	68.9 (62.5-72.9)	0.3 (0.1-0.5)
I3	42.7 (0-85.2)	15.7 (3.7-27.2)	59.7 (5.3-84.7)	4.5 (0-11.5)

[a] Near-ZID station

Appendix F.4 *continued*

	Fine Particles	Fine Sands	Med-Coarse Sands	Coarse Particles
38-m Depth Contour				
I29	26.6 (2.3-39.2)	32.6 (0.9-49.5)	27.6 (6.5-65.8)	13.3 (2.0-30.9)
I21	1.2 (0-1.2)	4.4 (2.9-6.3)	90.0 (89.1-91.3)	5.4 (4.2-7.3)
I13	0	2.8 (1.8-3.7)	89.5 (86.6-91.0)	8.0 (5.2-12.5)
I8	3.0 (1.7-4.2)	19.1 (1.4-29.5)	74.8 (68.7-86.5)	3.2 (0.1-9.0)
55-m Depth Contour				
I28	43.6 (18.8-68.0)	22.6 (15.3-30)	20.7 (5.5-33.8)	13.7 (11.1-17.5)
I20	30.4 (1.3-82.5)	7.1 (3.6-8.8)	48.7 (8.7-80.6)	20.7 (0-26.9)
I7	24.9 (1.5-61.5)	6.2 (2.5-10.1)	64.4 (28-83.4)	4.5 (0.4-12.6)
I1	10.6 (9.1-13.3)	83.9 (82.9-85.4)	5.5 (3.8-7.1)	0

Appendix F.5

Summary of organic indicators in sediments from PLOO stations sampled during 2018 and 2019. 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.

	BOD (ppm)	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
88-m Depth Contour					
B11	—	4.33 (2.37-6.50)	0.091 (0.081-0.100)	1.46 (0.88-2.43)	3.6 (3.5-3.7)
B8	—	3.72 (1.44-7.38)	0.075 (0.069-0.079)	0.73 (0.69-0.79)	2.7 (2.7-2.8)
E19	—	2.66 (2.51-2.86)	0.058 (0.051-0.067)	0.57 (0.48-0.66)	2.2
E7	—	2.75 (1.44-3.91)	0.052 (0.040-0.066)	0.57 (0.44-0.74)	2.0 (1.9-2.1)
E1	—	1.20 (0.44-1.61)	0.050 (0.044-0.059)	0.54 (0.40-0.66)	1.7 (1.6-1.8)
98-m Depth Contour					
B12	416 (256-543)	2.61 (0.81-4.62)	0.060 (0.051-0.076)	2.09 (1.21-3.27)	2.9 (2.8-3.0)
B9	283 (213-375)	7.63 (2.42-17)	0.062 (0.056-0.068)	0.69 (0.54-0.89)	2.5 (2.3-2.7)
E26	268 (210-378)	2.19 (nd-3.79)	0.059 (0.053-0.067)	0.58 (0.35-0.70)	2.0 (1.9-2.2)
E25	288 (227-367)	2.68 (nd-3.33)	0.044 (0.041-0.050)	0.44 (0.32-0.55)	1.8 (1.7-1.9)
E23	295 (246-351)	4.57 (0.57-12.20)	0.052 (0.049-0.057)	0.51 (0.40-0.58)	1.9 (1.8-2.0)
E20	272 (215-358)	2.79 (nd-4.79)	0.048 (0.040-0.062)	0.46 (0.34-0.61)	1.7 (1.5-1.9)
E17[a]	256 (181-299)	7.04 (nd-14.70)	0.044 (0.039-0.053)	0.41 (0.32-0.45)	1.6 (1.6-1.7)
E14[a]	351 (204-577)	11.62 (3.31-22.40)	0.036 (0.031-0.041)	0.34 (0.31-0.36)	1.5 (1.4-1.6)
E11[a]	242 (213-270)	3.13 (1.49-5.82)	0.039 (0.037-0.041)	0.39 (0.31-0.51)	1.7 (1.7-1.8)
E8	255 (202-351)	2.95 (1.44-4.41)	0.042 (0.037-0.049)	0.44 (0.32-0.53)	1.7 (1.7-1.8)
E5	221 (165-295)	29.14 (2.10-108.00)	0.044 (0.042-0.045)	0.43 (0.37-0.52)	1.8
E2	259 (159-325)	5.03 (2.02-10.30)	0.050 (0.039-0.055)	0.55 (0.33-0.75)	2.2 (2.0-2.4)
116-m Depth Contour					
B10	—	2.93 (1.70-3.81)	0.045 (0.044-0.047)	0.61 (0.35-1.08)	2.0 (1.9-2.1)
E21	—	2.22 (nd-3.99)	0.042 (0.040-0.045)	0.40 (0.34-0.44)	1.7 (1.6-1.7)
E15	584	4.64 (nd-9.06)	0.042 (0.040-0.047)	0.43 (0.31-0.54)	1.7 (1.6-1.9)
E9	—	3.12 (1.36-5.61)	0.049 (0.047-0.052)	0.70 (0.44-1.21)	1.9
E3	—	2.05 (1.83-2.46)	0.040 (0.033-0.049)	0.45 (0.29-0.57)	1.3 (1.2-1.4)

[a] Near-ZID station

Appendix F.6

Summary of organic indicators in sediments from SBOO stations sampled during 2018 and 2019. 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	4.63 (3.05-6.02)	0.032	0.28 (0.22-0.31)	1.3 (1.2-1.3)
I34	0.78 (0.65-0.86)	nd	0.58 (0.12-0.91)	0.7 (0.6-0.7)
I31	0.62 (nd-0.84)	0.020 (nd-0.020)	0.12 (0.10-0.14)	0.6 (0.5-0.7)
I23	1.60 (nd-1.61)	0.024 (nd-0.024)	0.69 (0.11-1.84)	0.8 (0.7-1.0)
I18	0.81 (nd-0.97)	nd	0.12 (0.07-0.15)	0.6
I10	1.25 (nd-1.25)	0.022 (nd-0.022)	0.13 (0.08-0.16)	0.8 (0.7-0.9)
I4	nd	nd	0.14 (nd-0.14)	0.5 (0.3-0.7)
28-m Depth Contour				
I33	6.21 (1.94-16.80)	0.026 (0.023-0.030)	0.22 (0.17-0.27)	1.2 (1.2-1.3)
I30	3.37 (1.70-6.70)	0.024 (0.020-0.026)	0.20 (0.14-0.24)	1.0 (0.9-1.0)
I27	2.30 (0.94-5.65)	0.024 (nd-0.026)	0.18 (0.15-0.19)	0.9 (0.7-1.0)
I22	8.62 (nd-16.30)	0.024 (0.021-0.028)	0.19 (0.14-0.23)	0.8 (0.7-0.8)
I14[a]	10.56 (1.13-37.40)	0.030 (0.024-0.037)	0.24 (0.18-0.35)	1.0 (1.0-1.1)
I16[a]	2.18 (0.53-6.27)	nd	0.13 (nd-0.14)	0.5 (0.4-0.6)
I15[a]	0.96 (nd-1.40)	0.019 (nd-0.021)	0.14 (0.07-0.18)	0.4 (0.4-0.5)
I12[a]	1.07 (nd-1.69)	0.021 (nd-0.021)	0.11 (0.06-0.13)	0.5 (0.4-0.7)
I9	3.33 (nd-5.43)	0.027 (0.025-0.03)	0.22 (0.14-0.27)	1.0 (0.8-1.1)
I6	0.41 (nd-0.41)	nd	0.11 (nd-0.13)	0.4 (0.4-0.5)
I2	0.53 (nd-0.54)	nd	0.10 (nd-0.11)	0.4 (0.4-0.5)
I3	nd	nd	0.08 (nd-0.08)	0.4 (0.3-0.5)

[a] Near-ZID station

Appendix F.6 *continued*

	Sulfides (ppm)	TN (% wt)	TOC (% wt)	TVS (% wt)
38-m Depth Contour				
I29	0.90 (nd-0.99)	0.028 (nd-0.030)	0.30 (nd-0.33)	1.0 (0.4-1.6)
I21	nd	nd	0.15 (nd-0.15)	0.5 (0.5-0.6)
I13	nd	nd	0.09 (nd-0.09)	0.4
I8	nd	0.021 (nd-0.021)	0.10 (0.07-0.13)	0.5 (0.4-0.5)
55-m Depth Contour				
I28	1.92 (1.03-2.41)	0.052 (0.045-0.062)	0.57 (0.35-0.86)	1.4 (1.2-1.6)
I20	nd	0.020 (nd-0.023)	0.19 (nd-0.22)	0.5 (0.4-0.5)
I7	nd	nd	0.15 (nd-0.15)	0.5 (0.4-0.5)
I1	0.54 (nd-0.54)	0.024 (0.023-0.025)	0.17 (0.13-0.20)	0.8 (0.5-1.0)

Appendix F.7

Summary of metals (ppm) in sediments from PLOO stations sampled during 2018 and 2019. 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	8933 (7950-9880)	1.7 (nd-1.8)	3.46 (2.24-4.17)	35.0 (30.8-40.0)	0.25 (nd-0.25)	0.06 (nd-0.08)	21.1 (19.9-22.2)	7.1 (4.3-10.2)	17,300 (15,700-19,200)
B8	10,247 (9040-11,300)	1.4 (nd-1.5)	2.98 (2.41-3.98)	43.8 (39.4-47.3)	0.23 (nd-0.24)	0.08 (nd-0.08)	20.4 (19.6-21.8)	6.6 (4.8-9.8)	13,900 (13,100-14,400)
E19	9227 (8460-10,200)	1.1 (nd-1.1)	3.04 (2.68-3.34)	37.6 (35.9-38.8)	0.20 (nd-0.20)	0.07 (nd-0.08)	17.2 (16.2-17.8)	5.3 (3.9-7.8)	11,700 (11,200-12,200)
E7	8060 (7110-8590)	1.2 (nd-1.2)	2.87 (2.64-3.11)	34.8 (34.5-35.1)	0.19 (nd-0.20)	0.07 (nd-0.10)	15.9 (15.1-16.6)	5.2 (4.1-7.2)	10533 (10,000-10,800)
E1	7463 (6080-8320)	1.1 (nd-1.1)	2.86 (2.30-3.32)	34.5 (30.7-36.9)	0.17 (nd-0.18)	0.04 (nd-0.06)	14.4 (12.7-15.5)	5.5 (4.0-8.2)	10,083 (8850-11,000)
98-m Depth Contour									
B12	6332 (5990-6840)	1.7 (nd-1.8)	4.89 (4.56-5.30)	17.8 (4.9-19.2)	0.23 (0.06-0.29)	0.05 (nd-0.07)	23.7 (21.8-25.4)	6.2 (nd-6.7)	20,075 (19,200-20,900)
B9	8510 (8120-8890)	1.3 (nd-1.4)	2.93 (2.63-3.25)	57.3 (35.0-87.5)	0.22 (nd-0.24)	0.05 (nd-0.07)	19.9 (18.8-20.5)	4.1 (2.8-7.1)	14,175 (13,600-14,800)
E26	8185 (7120-9420)	1.1 (nd-1.2)	2.77 (2.59-2.89)	31.7 (31.0-32.2)	0.18 (nd-0.19)	0.06 (nd-0.08)	15.8 (14.8-16.7)	4.4 (3.5-6.7)	10,768 (9970-11,400)
E25	6832 (5990-7600)	1.0 (nd-1.1)	2.42 (2.31-2.62)	25.7 (23.2-26.9)	0.15 (nd-0.16)	0.06 (nd-0.07)	13.5 (13.2-13.9)	3.5 (2.7-5.6)	9190 (8900-9480)
E23	7788 (7270-8920)	1.1 (nd-1.1)	2.67 (2.25-2.92)	32.5 (27.7-39.9)	0.17 (nd-0.18)	0.07 (nd-0.08)	15.1 (14.7-15.9)	4.3 (3.3-6.5)	10,250 (10,000-10,700)
E20	6832 (6240-7920)	0.9 (nd-1.0)	2.48 (2.11-3.08)	25.5 (24.2-26.9)	0.15 (nd-0.16)	0.08 (nd-0.09)	13.5 (12.6-14.7)	3.7 (2.7-5.8)	9172 (8450-10,300)
E17[a]	6255 (6050-6380)	0.9 (nd-0.9)	2.23 (1.83-2.82)	23.0 (21.8-24.0)	0.14 (nd-0.14)	0.09 (nd-0.11)	12.8 (12.3-13.4)	4.1 (2.9-5.5)	8500 (8100-8830)
E14[a]	4720 (4380-5050)	0.8 (nd-0.9)	2.05 (1.57-2.32)	17.0 (16.0-18.8)	0.11 (nd-0.11)	0.09 (nd-0.11)	10.6 (10.3-10.9)	3.5 (2.9-4.4)	6750 (6680-6920)
E11[a]	5685 (5150-6300)	0.8 (nd-0.9)	2.05 (1.38-2.62)	20.3 (18.7-21.5)	0.13 (nd-0.14)	0.08 (nd-0.10)	11.7 (11.0-12.2)	3.5 (2.2-5.0)	7858 (7550-8170)
E8	6205 (5420-7320)	1.0 (nd-1.1)	2.07 (1.32-2.43)	23.9 (22.0-25.7)	0.15 (nd-0.15)	0.06 (nd-0.08)	12.7 (12.0-13.3)	3.7 (2.6-5.1)	8632 (8080-9160)
E5	6225 (5800-6640)	1.0 (nd-1.1)	2.31 (1.61-2.74)	25.1 (24.5-25.5)	0.15 (nd-0.15)	0.05 (nd-0.06)	13.1 (12.6-14.0)	3.8 (3.0-5.8)	9028 (8690-9580)
E2	8168 (7120-9220)	1.2 (nd-1.3)	2.25 (1.57-2.78)	39.2 (33.3-42.3)	0.19 (nd-0.22)	0.04 (nd-0.07)	15.7 (14.0-17.3)	6.0 (4.3-9.1)	11,750 (10,800-12,500)
116-m Depth Contour									
B10	5767 (5110-6220)	1.1 (nd-1.3)	2.24 (1.62-2.61)	20.3 (18.6-21.3)	0.16 (nd-0.16)	0.06 (nd-0.07)	15.6 (14.2-16.8)	3.4 (1.8-5.2)	11,133 (9700-12,900)
E21	6230 (5780-6510)	0.9 (nd-0.9)	2.30 (2.00-2.48)	22.0 (19.7-23.3)	0.14 (nd-0.14)	0.08 (nd-0.09)	12.6 (12.3-13.0)	3.6 (2.5-5.3)	8340 (8110-8460)
E15	5602 (5020-6590)	0.7 (nd-0.9)	2.04 (1.76-2.55)	19.2 (18.9-19.6)	0.13 (nd-0.14)	0.07 (nd-0.08)	12.1 (11.6-13.0)	3.4 (2.3-5.0)	7840 (7410-8680)
E9	5717 (5170-6670)	1.2 (nd-1.2)	2.79 (2.19-3.35)	20.7 (16.5-23.3)	0.16 (nd-0.18)	0.07 (nd-0.07)	15.6 (15.0-16.5)	6.7 (6.0-7.8)	10,657 (9970-11,500)
E3	7303 (6730-7810)	0.9 (0.2-1.2)	2.26 (2.00-2.76)	43.1 (41.5-45.7)	0.16 (nd-0.17)	0.04 (nd-0.04)	12.6 (11.8-13.1)	7.3 (6.0-9.8)	10,733 (10,200-11,200)

[a] Near-ZID station

Appendix F.7 *continued*

	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
88-m Depth Contour									
B11	4.2 (3.9-4.4)	111.4 (97.2-122.0)	0.026 (nd-0.028)	7.1 (6.4-7.6)	0.60 (nd-0.60)	nd	nd	0.8	35.3 (32.6-39.1)
B8	4.9 (4.5-5.3)	112.0 (105.0-120.0)	0.036 (nd-0.039)	8.4 (7.8-9.5)	nd	nd	nd	1.0 (0.9-1.1)	33.7 (30.8-36.3)
E19	3.8 (3.4-4.1)	99.8 (95.4-103.0)	0.030 (nd-0.034)	6.9 (6.5-7.5)	0.56 (nd-0.56)	nd	nd	0.8 (0.5-0.9)	28.3 (27.1-30.4)
E7	3.5 (3.0-3.7)	91.0 (83.7-95.9)	0.024 (nd-0.027)	6.6 (6.0-7.3)	0.43 (nd-0.43)	nd	nd	0.8 (0.7-0.9)	26.6 (24.8-28.4)
E1	5.2 (4.2-6.9)	81.9 (72.2-88.7)	0.038 (nd-0.044)	5.6 (4.8-6.6)	0.48 nd-0.48	nd	nd	0.8 (0.6-0.9)	25.6 (22.1-27.6)
98-m Depth Contour									
B12	3.0 (2.9-3.1)	56.2 (53.5-59.3)	0.012 (nd-0.013)	4.3 (4.0-5.0)	0.57 (nd-0.64)	nd	nd	0.4 (nd-0.5)	32.9 (30.8-36.6)
B9	3.6 (3.5-3.8)	95.2 (92.7-99.6)	0.032 (nd-0.053)	6.5 (5.9-7.4)	0.59 (nd-0.63)	nd	nd	0.6 (0.5-0.7)	31.6 (28.4-34.4)
E26	3.5 (3.2-3.7)	88.2 (82.4-96.2)	0.026 (nd-0.033)	6.3 (5.8-6.9)	0.54 (nd-0.57)	nd	nd	0.7 (0.6-0.8)	25.3 (23.8-26.4)
E25	2.9 (2.8-2.9)	76.6 (1.5-80.4)	0.017 (nd-0.018)	5.1 (4.9-5.7)	0.44 (nd-0.44)	nd	nd	0.5 (0.4-0.6)	21.6 (20.4-22.7)
E23	3.2 (3.1-3.4)	85.8 (84.2-89.1)	0.022 (nd-0.024)	6.1 (5.8-6.6)	0.56 (nd-0.56)	nd	nd	0.6 (0.5-0.8)	24.3 (23.6-24.9)
E20	2.8 (2.6-3.1)	76.1 (70.7-80.7)	0.018 (nd-0.020)	5.4 (4.8-5.9)	0.48 (nd-0.50)	nd	nd	0.5 (0.4-0.6)	21.4 (20.4-22.5)
E17[a]	2.7 (2.4-3.1)	70.3 (64.2-75.6)	0.017 (nd-0.020)	5.0 (4.8-5.3)	0.62 (nd-0.62)	nd	nd	0.6 (nd-0.6)	20.8 (19.8-21.8)
E14[a]	2.0 (2.0-2.1)	57.8 (51.9-60.3)	0.011 (nd-0.012)	4.0 (3.8-4.3)	0.41 (nd-0.41)	nd	nd	0.5 (nd-0.5)	17.1 (16.4-17.8)
E11[a]	2.3 (2.1-2.5)	64.8 (56.9-74.0)	0.015 (nd-0.019)	4.3 (4.0-4.9)	0.49 (nd-0.49)	67.4 (nd-67.4)	nd	0.5 (nd-0.5)	18.9 (18.1-20.3)
E8	2.6 (2.5-2.8)	70.1 (63.9-82.0)	0.016 (nd-0.018)	4.7 (4.3-5.0)	0.41 (nd-0.49)	nd	nd	0.6 (0.5-0.6)	20.1 (19.3-21.3)
E5	2.8 (2.7-3.0)	68.9 (66.3-71.7)	0.019 (nd-0.022)	4.9 (4.6-5.5)	0.36 (nd-0.36)	nd	nd	0.5 (0.5-0.6)	20.8 (20.2-21.4)
E2	3.8 (3.4-4.0)	90.3 (82.8-101.0)	0.033 (nd-0.035)	5.8 (4.8-7.1)	0.51 (nd-0.53)	nd	nd	0.7 (0.6-0.8)	28.1 (25.1-31.7)
116-m Depth Contour									
B10	2.6 (2.5-2.7)	62.5 (57.3-65.3)	0.014 (nd-0.017)	4.3 (3.8-4.7)	0.46 (nd-0.46)	nd	nd	0.5 (0.4-0.6)	23.6 (20.6-26.6)
E21	2.8 (2.6-2.9)	69.2 (67.2-71.7)	0.018 (nd-0.019)	4.9 (4.5-5.5)	0.29 (nd-0.29)	nd	nd	0.5 (nd-0.6)	19.5 (18.2-20.9)
E15	2.4 (2.3-2.6)	63.3 (57.3-70.2)	0.027 (nd-0.051)	4.3 (4.0-4.8)	0.44 (nd-0.44)	nd	nd	0.5 (nd-0.5)	18.2 (17.6-19.1)
E9	3.9 (3.2-5.2)	59.8 (51.4-69.9)	0.020 (nd-0.027)	4.4 (3.6-5.4)	0.32 (nd-0.32)	nd	nd	0.5 (0.5-0.6)	28.0 (24.3-30.6)
E3	5.4 (3.8-6.7)	83.2 (79.0-86.0)	0.036 (nd-0.040)	4.1 (3.6-5.0)	0.50 (nd-0.50)	nd	nd	0.7 (0.6-0.7)	29.0 (27.5-30.4)

[a] Near-ZID station

Appendix F.8

Summary of metals (ppm) in sediments from SBOO stations sampled during 2018 and 2019. 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 (3.6-51.6)	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	4288 (3980-4510)	0.6 (nd-0.7)	1.80 (1.53-2.07)	18.9 (17.7-20.6)	0.08 (nd-0.09)	0.04 (nd-0.05)	8.4 (8.2-8.6)	2.5 (1.4-3.4)	5980 (5810-6120)
I30	5820 (5660-6050)	0.7 (nd-0.7)	1.67 (1.30-1.88)	26.6 (25.6-28.0)	0.10 (nd-0.10)	0.04 (nd-0.05)	10.6 (10.4-10.8)	1.9 (nd-3.1)	6185 (5890-6380)
I27	5480 (5230-5760)	0.7 (nd-0.7)	1.47 (1.00-1.85)	26.4 (24.1-28.6)	0.10 (nd-0.10)	0.05 (nd-0.06)	9.9 (9.5-10.4)	1.7 (nd-3)	5972 (5480-6210)
I22	4702 (4170-4970)	0.5 (nd-0.6)	1.31 (1.09-1.51)	24.4 (23.0-27.1)	0.09 (nd-0.09)	0.03 (nd-0.03)	9.4 (8.9-10.0)	1.4 (nd-2.5)	5248 (4900-5640)
I14[a]	6350 (6100-6950)	0.7 (nd-0.8)	1.64 (nd-1.71)	33.5 (31.2-36.7)	0.11 (nd-0.12)	0.03 (nd-0.03)	11.0 (10.7-11.3)	2.7 (nd-3.6)	7002 (6770-7530)
I16[a]	2740 (2530-3100)	0.5 (nd-0.5)	1.33 (nd-1.43)	13.0 (10.9-17.4)	0.06 (nd-0.07)	0.03 (nd-0.03)	6.7 (5.9-7.2)	1.1 (nd-1.2)	4108 (3800-4430)
I15[a]	2498 (1760-3740)	0.5 (nd-0.6)	2.11 (nd-2.23)	8.6 (4.7-15.3)	0.06 (nd-0.06)	0.02 (nd-0.02)	8.9 (8.2-10.1)	1.8 (nd-1.8)	4505 (3930-5450)
I12[a]	2782 (2020-3490)	0.4 (nd-0.5)	1.59 (nd-1.78)	13.7 (8.5-18.0)	0.06 (nd-0.06)	nd	6.9 (5.9-7.5)	1.2 (nd-1.2)	4158 (3260-4890)
I9	6945 (6260-7500)	0.8 (nd-0.8)	1.50 (1.01-1.70)	37.1 (34.8-39.8)	0.12 (nd-0.12)	0.03 (nd-0.03)	11.9 (11.4-12.6)	2.7 (1.4-3.9)	7690 (7370-8140)
I6	956 (766-1110)	0.5 (nd-0.6)	4.69 (4.46-5.01)	2.4 (1.4-3.0)	0.04 (nd-0.04)	0.04 (nd-0.05)	8.0 (7.5-8.3)	nd	3742 (3510-3870)
I2	1022 (955-1110)	0.2 (nd-0.3)	0.87 (nd-0.93)	2.0 (1.8-2.2)	0.02 (nd-0.02)	0.02 (nd-0.03)	5.4 (5.2-5.8)	nd	1200 (1130-1270)
I3	734 (9647-779)	0.2 (nd-0.2)	1.37 (nd-1.98)	1.4 (1.3-1.6)	0.02 (nd-0.03)	0.02 (nd-0.02)	5.4 (4.6-5.9)	nd	1398 (1090-1930)

[a] Near-ZID station

Appendix F.8 *continued*

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe
38-m Depth Contour									
I29	4327 (1250-7090)	0.8 (nd-0.8)	2.52 (1.15-4.11)	19.9 (2.4-36.4)	0.12 (nd-0.14)	0.04 (nd-0.05)	10.4 (7.3-13.8)	3.2 (nd-5.1)	7390 (6390-8910)
I21	1025 (941-1160)	0.7 (nd-0.9)	9.32 (8.55-9.78)	2.2 (1.2-3.4)	0.07 (nd-0.07)	0.06 (nd-0.06)	11.8 (11.3-12.7)	nd	8187 (8060-8370)
I13	927 (861-984)	0.5 (nd-0.6)	6.69 (6.51-7.01)	1.9 (1.1-2.6)	0.05 (nd-0.06)	0.05 (nd-0.06)	9.2 (8.4-10.0)	nd	5530 (5330-5870)
I8	1620 (1310-1820)	0.4 (nd-0.4)	2.09 (1.86-2.28)	3.9 (2.4-4.8)	0.05 (nd-0.06)	0.02 (nd-0.02)	8.5 (6.8-9.4)	nd	4003 (3510-4260)
55-m Depth Contour									
I28	3980 (3220-4630)	0.5 (nd-0.7)	1.93 (1.82-2.10)	17.0 (12.7-20.3)	0.08 (nd-0.08)	0.05 (nd-0.05)	7.9 (6.2-9.2)	2.9 (1.9-4.2)	5860 (5240-6450)
I20	1247 (1130-1370)	0.3 (nd-0.4)	2.80 (2.57-3.08)	3.3 (2.5-4.7)	0.06 (nd-0.06)	0.02 (nd-0.02)	4.9 (4.4-5.4)	nd	4617 (4360-5070)
I7	1144 (963-1250)	0.6 (nd-0.6)	6.09 (5.10-6.71)	2.3 (1.3-3.1)	0.05 (nd-0.06)	0.04 (nd-0.04)	8.1 (7.8-8.7)	nd	6547 (5840-7030)
I1	2580 (2470-2740)	0.4 (nd-0.5)	0.99 (nd-1.13)	9.0 (8.7-9.3)	0.06 nd-0.06)	0.05 (nd-0.07)	6.9 (6.6-7.3)	1.6 (nd-1.7)	3600 (3360-3840)

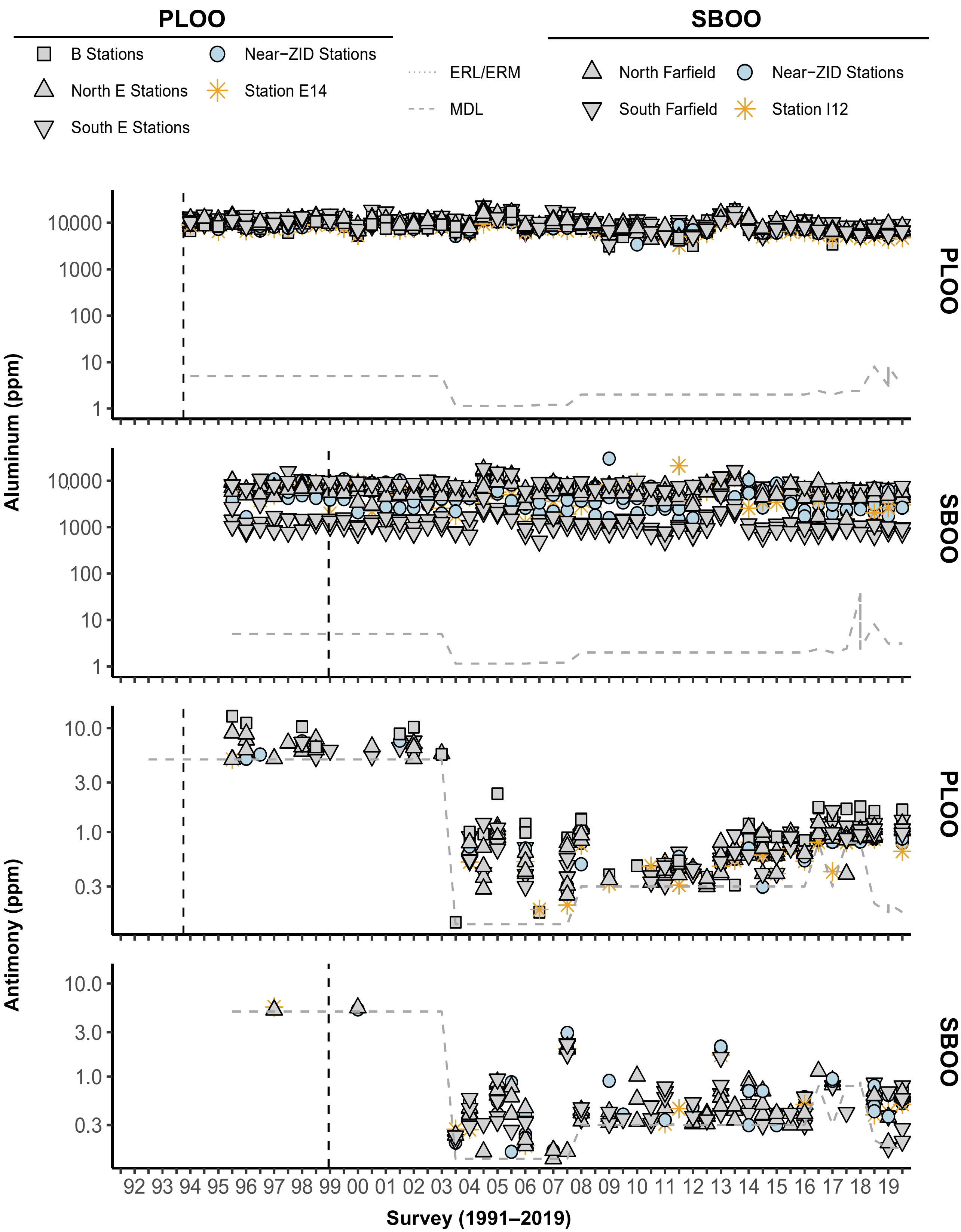
Appendix F.8 *continued*

	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Depth Contour									
I35	2.8 (2.6-3.0)	88.3 (83.2-93.6)	0.017 (nd-0.019)	3.6 (3.4-3.9)	0.41 (nd-0.41)	nd	nd	0.6	22.5 (22.3-22.6)
I34	1.4 (1.4-1.5)	28.1 (23.9-32.4)	0.004 (nd-0.004)	0.5 (0.4-0.8)	nd	nd	nd	0.1 (nd-0.1)	5.3 (4.1-5.9)
I31	1.1 (1.1-1.2)	52.4 (48.3-56.9)	nd	1.3 (1.0-1.6)	nd	nd	nd	0.2 (nd-0.3)	8.6 (7.9-9.5)
I23	1.5 (1.0-1.8)	45.7 (26.1-57.1)	nd	1.5 (0.7-2.3)	nd	nd	nd	0.2 (nd-0.3)	9.5 (6.3-12.3)
I18	1.3 (1.2-1.4)	66.5 (64.7-68.5)	nd	1.9 (1.6-2.2)	nd	nd	nd	0.3 (nd-0.3)	11.9 (11.1-13.1)
I10	1.2 (1.2-1.3)	64.9 (60.2-72.0)	nd	2.3 (1.8-2.7)	nd	nd	nd	0.3 (nd-0.3)	13.6 (11.8-15.5)
I4	1.1 (1.0-1.3)	27.1 (7.3-59.0)	0.004 (nd-0.004)	1.2 (0.4-2.8)	nd	nd	nd	0.2 (nd-0.3)	4.9 (2.0-10.2)
28-m Depth Contour									
I33	2.6 (2.4-2.9)	65.2 (60.5-67.5)	0.012 (nd-0.015)	2.1 (1.7-2.3)	nd	nd	nd	0.5 (0.4-0.8)	15.1 (13.9-16.4)
I30	1.6 (1.5-1.8)	60.9 (59.8-63.1)	0.005 (nd-0.005)	2.8 (2.6-3.2)	0.24 (nd-0.24)	nd	nd	0.3 (nd-0.3)	16.1 (15.6-17.0)
I27	1.4 (1.2-1.5)	61.0 (59.3-64.0)	0.004 (nd-0.004)	2.7 (2.2-3.1)	0.16 (nd-0.16)	nd	nd	0.3 (nd-0.3)	15.2 (13.7-16.4)
I22	1.4 (1.3-1.5)	58.1 (52.4-61.4)	0.004 (nd-0.004)	2.5 (2.3-2.8)	nd	nd	nd	0.3 (nd-0.3)	12.7 (11.2-13.5)
I14[a]	1.4 (1.3-1.5)	71.8 (69.0-74.0)	0.004 (nd-0.004)	3.2 (2.7-3.5)	nd	nd	nd	0.3 (nd-0.4)	17.6 (16.4-20.0)
I16[a]	1.2 (1.0-1.3)	41.0 (36.4-50.3)	nd	1.1 (0.9-1.4)	nd	nd	nd	0.2 (nd-0.2)	9.5 (8.3-10.6)
I15[a]	1.5 (1.4-1.5)	31.4 (19.5-48.4)	nd	1.2 (0.6-2.2)	nd	nd	nd	0.2 (nd-0.3)	8.8 (7.1-11.7)
I12[a]	1.0 (1.0-1.1)	39.0 (27.8-47.6)	nd	1.1 (0.7-1.4)	nd	nd	nd	0.2 (nd-0.2)	9.0 (7.0-11.4)
I9	1.2 (1.1-1.3)	76.4 (73.6-83.4)	0.004 (nd-0.004)	3.7 (3.3-4.3)	0.34 (nd-0.34)	nd	nd	0.3 (nd-0.4)	19.8 (17.8-21.2)
I6	1.5 (1.5-1.6)	9.3 (8.3-10.4)	nd	0.5 (nd-0.7)	nd	nd	nd	0.1 (nd-0.1)	3.5 (2.7-4.0)
I2	0.9 (0.8-0.9)	8.4 (6.9-9.8)	nd	0.6 (0.6-0.7)	nd	nd	nd	0.1 (nd-0.1)	2.4 (2.2-2.7)
I3	0.8 (0.8-0.9)	7.2 (5.2-9.4)	nd	0.5 (0.5-0.6)	nd	nd	nd	0.1 (nd-0.1)	2.0 (1.7-2.6)

[a] Near-ZID station

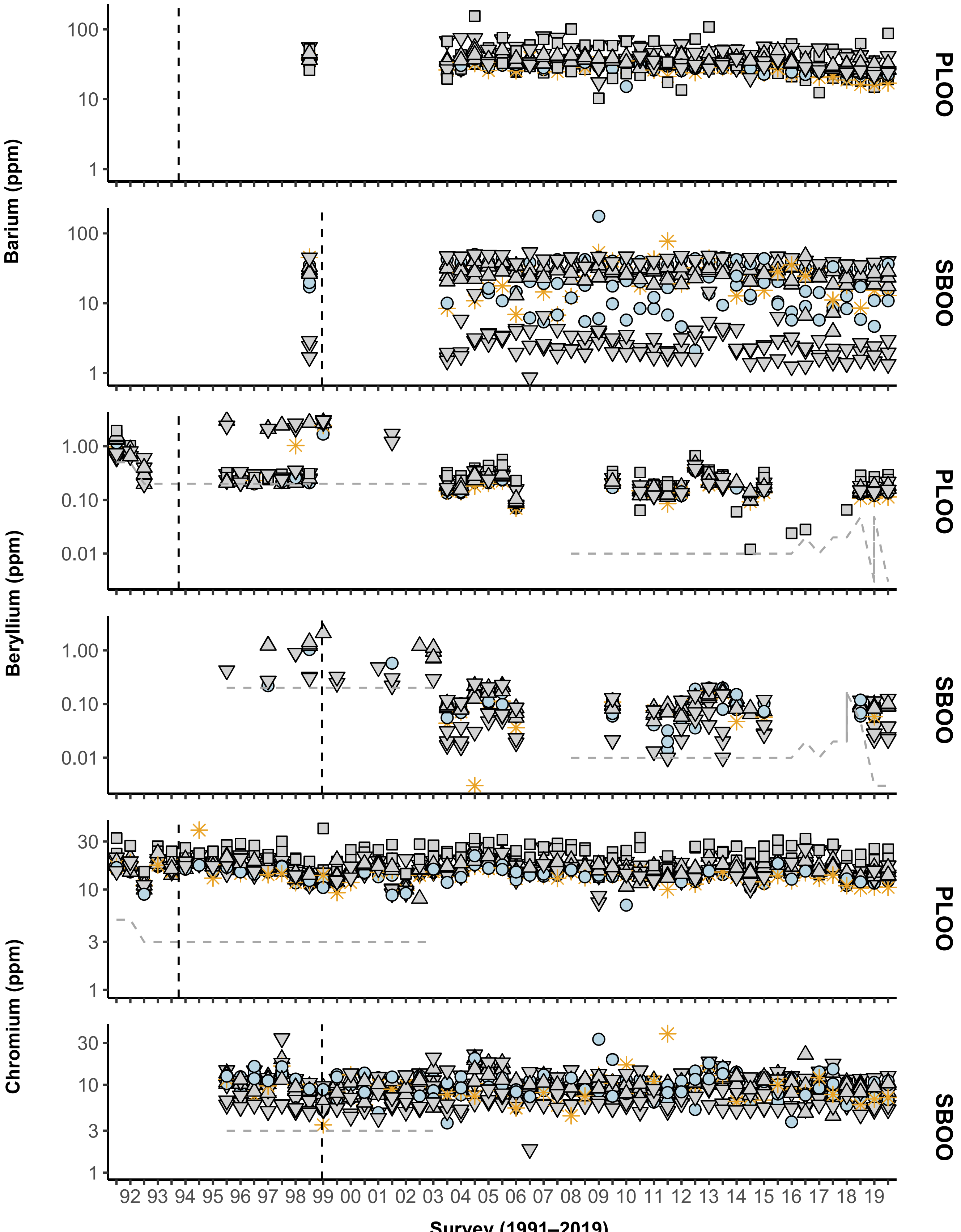
Appendix F.8 *continued*

	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
38-m Depth Contour									
I29	2.2 (1.9-2.7)	50.8 (17.1-81.6)	0.010 (nd-0.015)	2.8 (0.5-5.2)	nd	nd	nd	0.5 (nd-0.6)	14.2 (6.1-22.9)
I21	3.1 (3.0-3.2)	12.7 (11.7-13.7)	nd	0.8 (nd-0.8)	nd	nd	nd	0.1 (nd-0.1)	6.0 (5.7-6.5)
I13	2.2 (2.1-2.4)	14.0 (13.5-14.4)	nd	0.5 (nd-0.7)	nd	nd	nd	0.1 (nd-0.1)	5.0 (4.6-5.6)
I8	1.1 (0.9-1.3)	19.2 (14.6-22.7)	nd	0.8 (0.4-1.1)	nd	nd	nd	0.1 (nd-0.1)	7.0 (5.4-7.8)
55-m Depth Contour									
I28	2.2 (1.8-2.7)	42.4 (35.8-45.7)	0.014 (nd-0.020)	3.6 (92.8-4.5)	0.23 (nd-0.23)	nd	nd	0.4 (nd-0.4)	15.3 (13.4-17.1)
I20	1.5 (1.4-1.6)	16.5 (15.0-18.8)	nd	0.6 (90.4-0.9)	nd	nd	nd	0.1 (nd-0.1)	5.8 (5.6-6.1)
I7	2.1 (2.1-2.1)	14.8 (12.7-16.3)	nd	0.6 (nd-1.0)	nd	nd	nd	0.1 (nd-0.1)	5.3 (4.9-5.5)
I1	1.5 (1.4-1.5)	38.9 (37.3-41.3)	0.005 (nd-0.005)	2.3 (2.1-2.4)	nd	nd	nd	0.2 (nd-0.2)	7.5 (7.2-7.8)

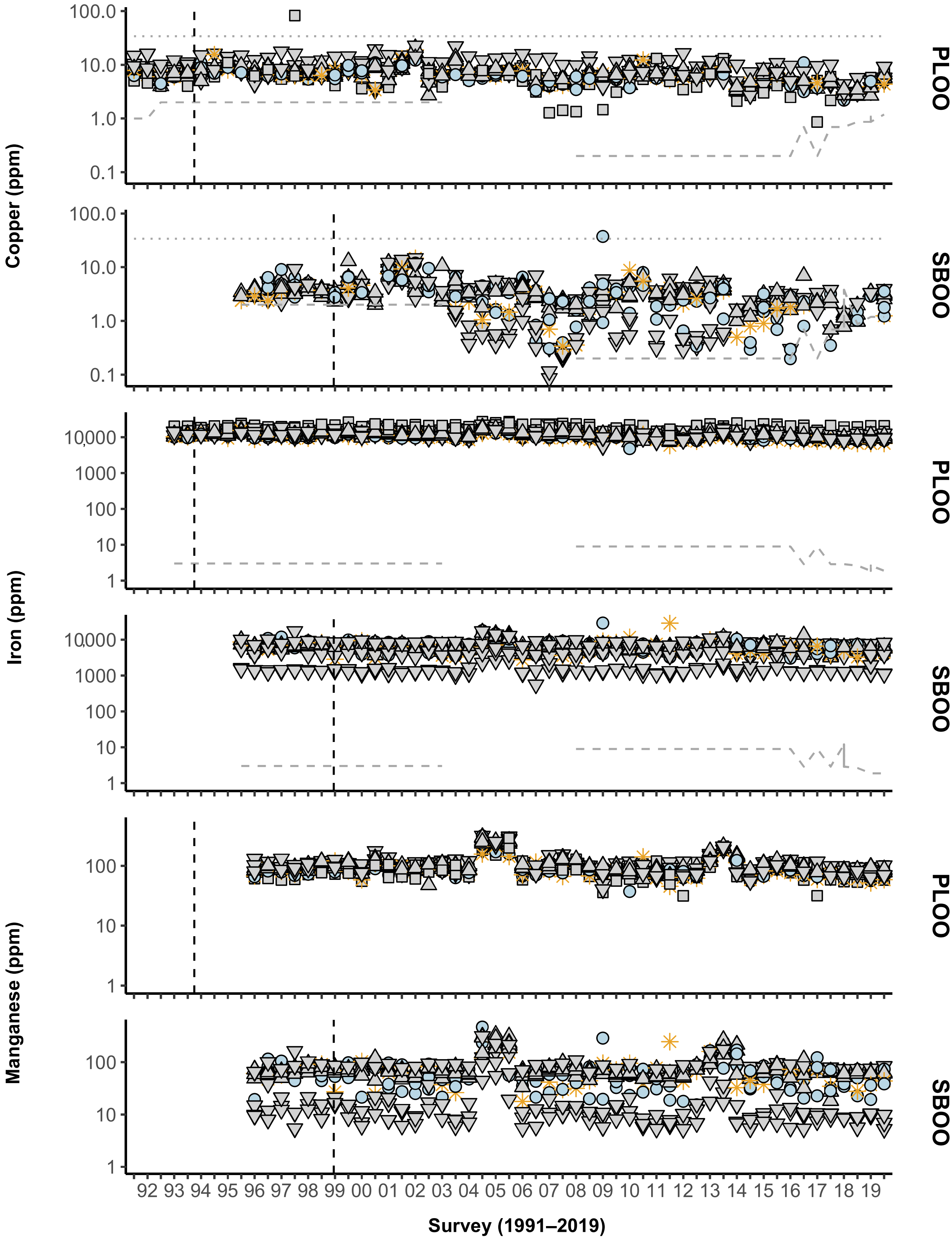


Appendix F.9

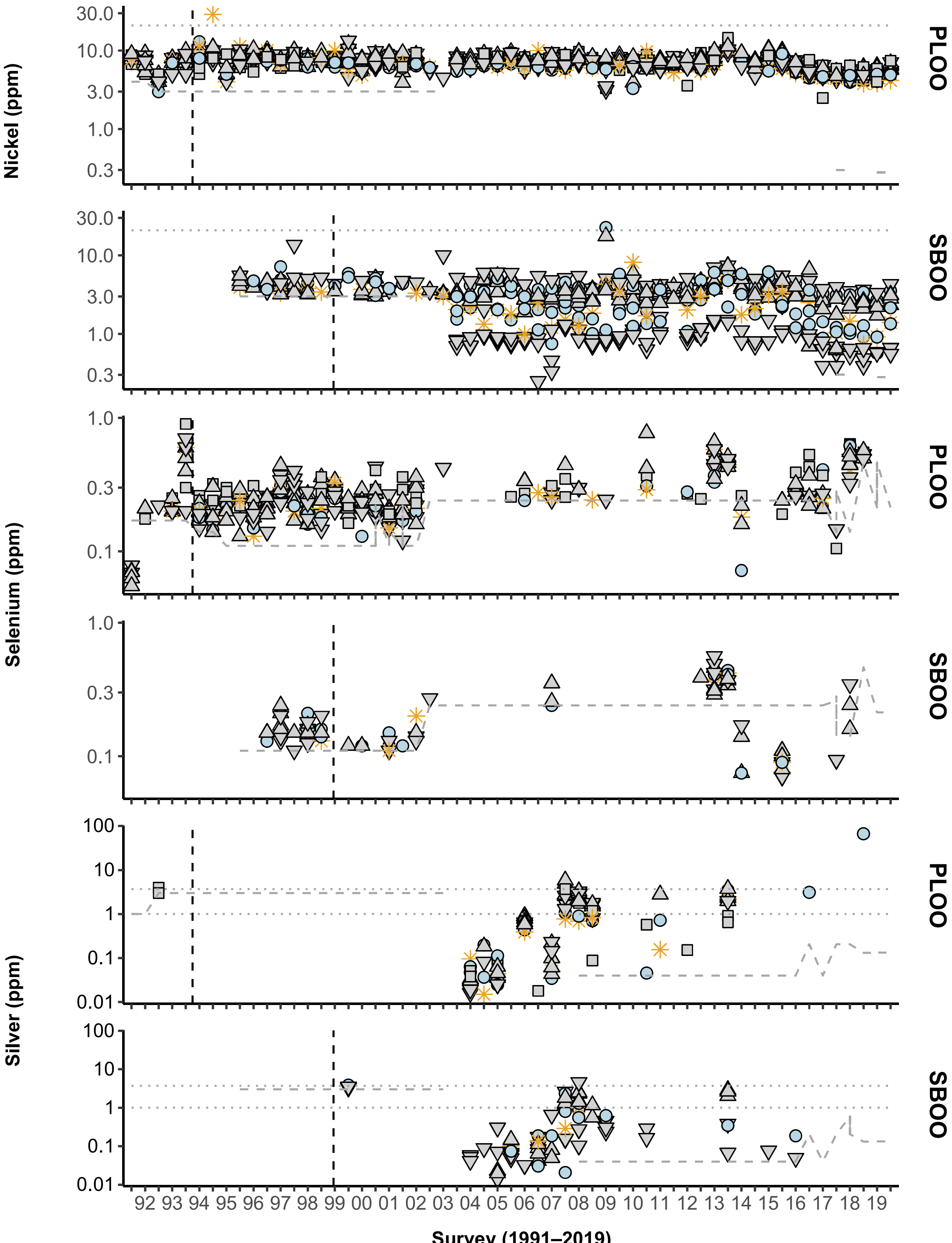
Concentrations of select metals in sediments sampled during winter and summer surveys at PLOO primary core stations from 1991 through 2019 and at SBOO primary core stations from 1995 through 2019. Data represent detected values from each station, n ≤ 12 samples per survey. Vertical dashed lines indicate onset of discharge from the PLOO or SBOO. See Table 4.3 for values of ERLs and ERMs.



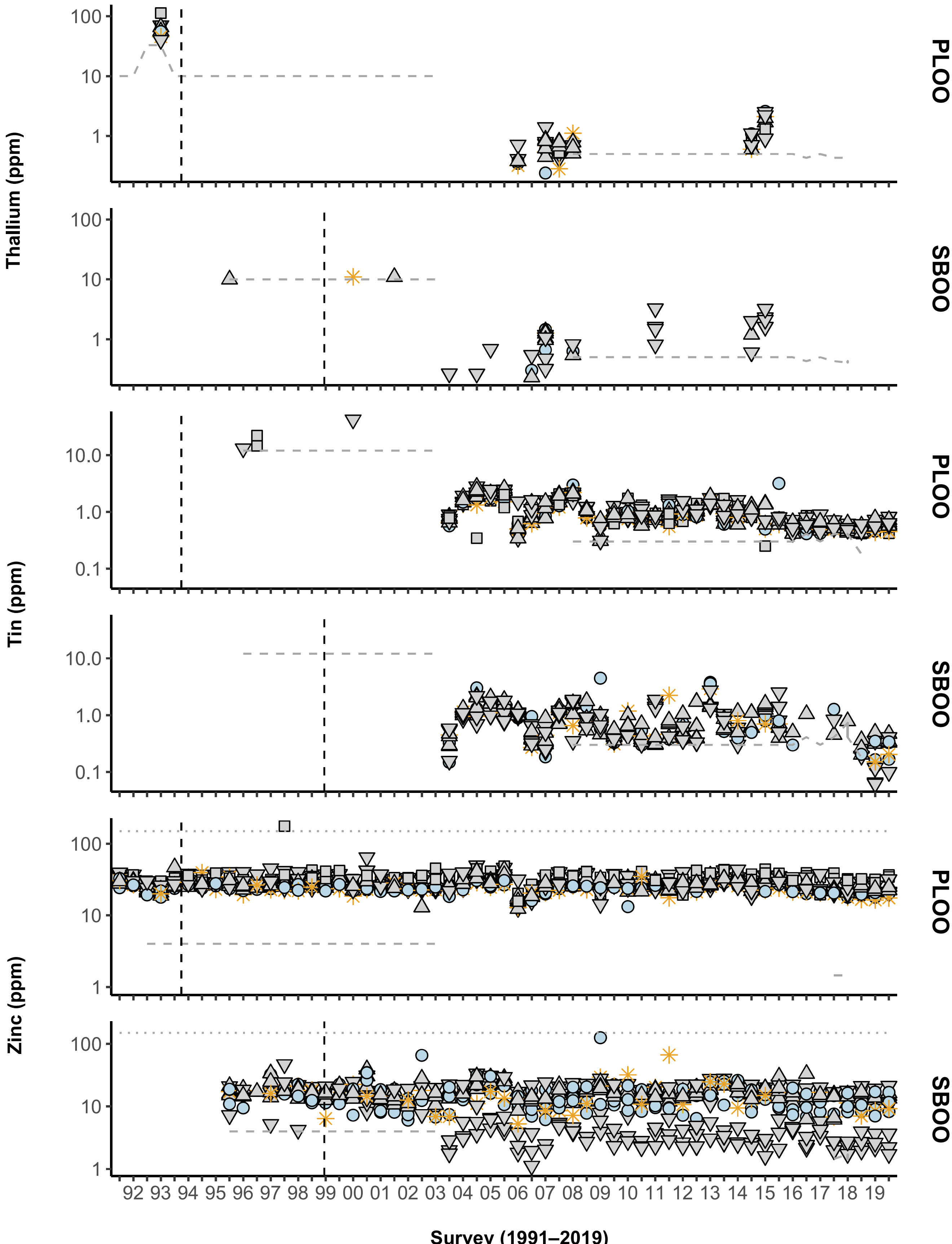
Appendix F.9 *continued*



Appendix F.9 *continued*



Appendix F.9 *continued*



Appendix F.9 *continued*

Appendix F.10

Summary of pesticides (ppt), total PCB (ppt), and total PAH (ppb) in sediments from PLOO stations sampled during 2018 and 2019. 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	HCB	Total HCH	Total PCB	Total PAH
88-m Depth Contour						
B11	nd	634 (496-868)	207 (nd-207)	96 (nd-96)	483 (381-641)	24 (23-25)
B8	nd	676 (327-932)	1894 (nd-3250)	nd	884 (785-1006)	48 (42-55)
E19	5 (nd-5)	517 (437-672)	94 (nd-94)	179 (nd-179)	578 (419-808)	44 (17-72)
E7	12 (nd-12)	650 (397-1042)	101 (nd-101)	13 (nd-13)	665 (336-1090)	50 (26-94)
E1	33 (nd-34)	708 (586-943)	nd	14 (nd-14)	1830 (696-2518)	99 (57-132)
98-m Depth Contour						
B12	nd	321 (202-442)	114 (25-256)	16 (nd-16)	252 (62-458)	30 (8-82)
B9	nd	794 (380-1083)	73 (nd-98)	15 (nd-15)	331 (12-486)	27 (16-44)
E26	nd	377 (257-630)	190 (nd-190)	nd	357 (286-492)	17 (9-34)
E25	nd	289 (114-388)	nd	6 (nd-6)	211 (117-302)	47 (19-126)
E23	29 (nd-29)	355 (211-649)	41 (nd-41)	23 (nd-34)	437 (177-1117)	20 (11-28)
E20	nd	305 (174-535)	155 (nd-155)	15 (nd-17)	319 (239-481)	52 (13-150)
E17[a]	32 (nd-32)	297 (215-431)	56 (nd-72)	229 (nd-229)	331 (96-775)	15 (9-29)
E14[a]	36 (nd-36)	216 (112-429)	15 (nd-15)	111 (nd-111)	182 (46-442)	7 (4-9)
E11[a]	nd	229 (128-384)	nd	nd	253 (123-479)	15 (8-28)
E8	10 (nd-10)	314 (179-582)	90 (23-211)	11 (nd-11)	467 (170-860)	23 (14-37)
E5	20 (nd-20)	440 (372-619)	138 (nd-196)	27 (nd-27)	474 (419-561)	37 (15-77)
E2	11 (nd-13)	617 (348-920)	54 (nd-82)	163 (nd-163)	1643 (583-2498)	154 (100-192)
116-m Depth Contour						
B10	nd	341 (119-620)	nd	nd	235 (97-419)	13 (3-21)
E21	nd	283 (194-378)	38 (nd-38)	12 (nd-12)	769 (213-1790)	52 (9-137)
E15	52 (nd-52)	257 (133-380)	105 (nd-151)	305 (nd-305)	238 (90-486)	67 (10-212)
E9	nd	297 (181-380)	430 (nd-430)	27 (nd-27)	926 (723-1128)	63 (25-109)
E3	310 (nd-549)	441 (161-727)	67 (nd-67)	26 (nd-43)	3089 (1431-5054)	242 (142-363)

[a] Near-ZID station

Appendix F.11

Summary of pesticides (ppt), total PCB (ppt), and total PAH (ppb) in sediments from SBOO stations sampled during 2018 and 2019. 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	HCB	Total HCH	Total PCB	Total PAH
19-m Depth Contour						
I35	nd	194 (117-288)	193 (nd-193)	nd	471 (154-946)	35 (33-37)
I34	nd	8 (nd-8)	nd	nd	67 (nd-67)	nd
I31	nd	32 (nd-37)	nd	49 (nd-49)	151 (nd-151)	3 (nd-3)
I23	nd	18 (nd-26)	509 (nd-509)	nd	46 (nd-46)	10 (nd-10)
I18	nd	28 (21-41)	228 (221-235)	54 (nd-54)	173 nd-173	17 (4-29)
I10	nd	21 (nd-25)	156 (nd-156)	nd	88 (nd-88)	3 (nd-3)
I4	nd	18 (nd-18)	nd	nd	3 (nd-3)	2 (nd-3)
28-m Depth Contour						
I33	nd	55 (nd-98)	47 (nd-47)	9 (nd-9)	23 (9-33)	17 (7-34)
I30	nd	75 (5-104)	54 (nd-54)	9 (nd-9)	11 (nd-11)	8 (5-14)
I27	nd	105 (49-200)	181 (nd-183)	242 (nd-242)	nd	4 (4-5)
I22	nd	83 (48-132)	81 (nd-87)	7 (nd-7)	37 (nd-37)	7 (3-12)
I14[a]	nd	107 (nd-156)	165 (nd-175)	16 (nd-20)	nd	12 (3-32)
I16[a]	nd	45 (nd-82)	66 (nd-113)	nd	25 (nd-25)	2 (nd-3)
I15[a]	nd	51 (18-96)	28 (nd-28)	nd	483 (nd-941)	2 (nd-3)
I12[a]	nd	16 (4-25)	1320 (nd-1320)	nd	15 (nd-15)	1 (nd-3)
I9	nd	62 (43-80)	126 (nd-126)	13 (nd-13)	nd	5 (4-7)
I6	nd	44 (nd-90)	18 (nd-29)	217 (nd-380)	106 (nd-200)	1 (nd-1)
I2	80 (nd-80)	53 (nd-53)	503 (nd-618)	134 (nd-134)	28 (nd-28)	4 (nd-5)
I3	nd	43 (nd-43)	42 (nd-57)	21 (nd-21)	26 (nd-26)	1 (nd-1)

[a] Near-ZID station

Appendix F.11 *continued*

	Total Chlordane	Total DDT	HCB	Total HCH	Total PCB	Total PAH
38-m Depth Contour						
I29	nd	932 (nd-945)	2000 (nd-2000)	nd	113 (30-186)	46 (7-85)
I21	nd	12 (8-17)	178 (nd-178)	48 (nd-48)	51 (nd-51)	15 (nd-26)
I13	nd	8 (nd-11)	1540 (nd-1540)	nd	11 (nd-11)	23 (4-53)
I8	nd	nd	473 (nd-473)	nd	nd	13 (nd-18)
55-m Depth Contour						
I28	nd	2201 (230-5753)	22 (nd-22)	491 (nd-491)	378 (35-801)	29 (29-29)
I20	nd	31 (nd-36)	nd	nd	15 (nd-15)	3 (nd-4)
I7	nd	56 (nd-56)	nd	771 (nd-771)	nd	nd
I1	nd	41 (nd-60)	270 (nd-270)	nd	27 (nd-27)	16 (nd-29)

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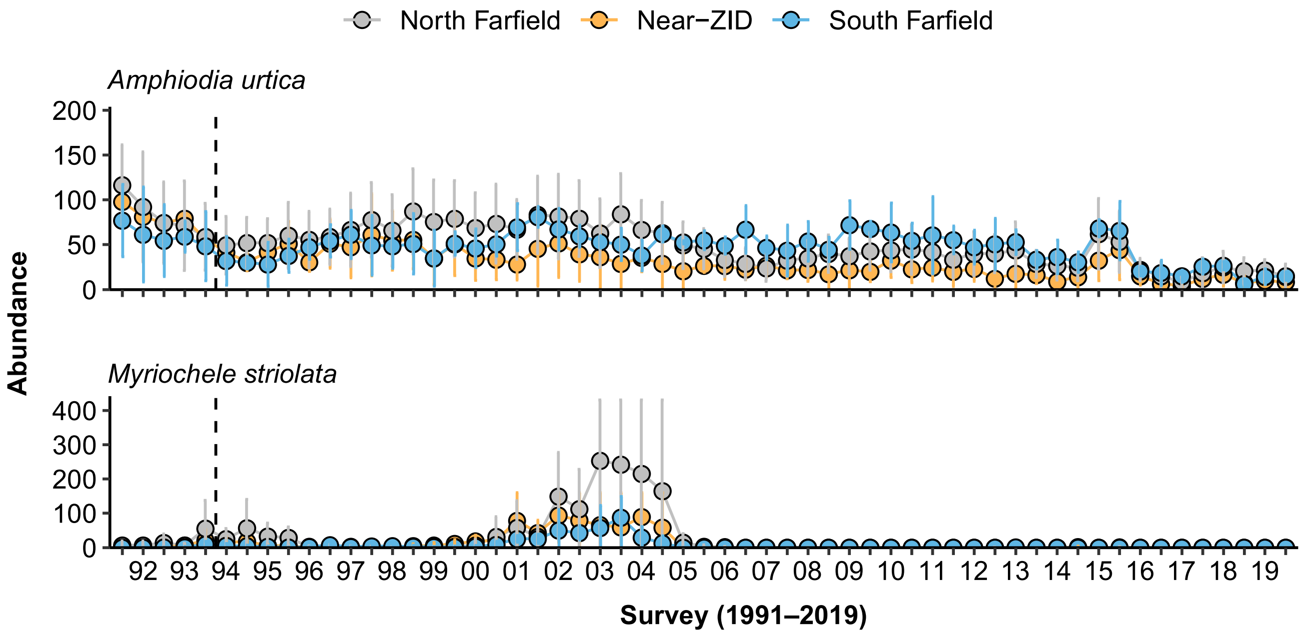
Appendix G

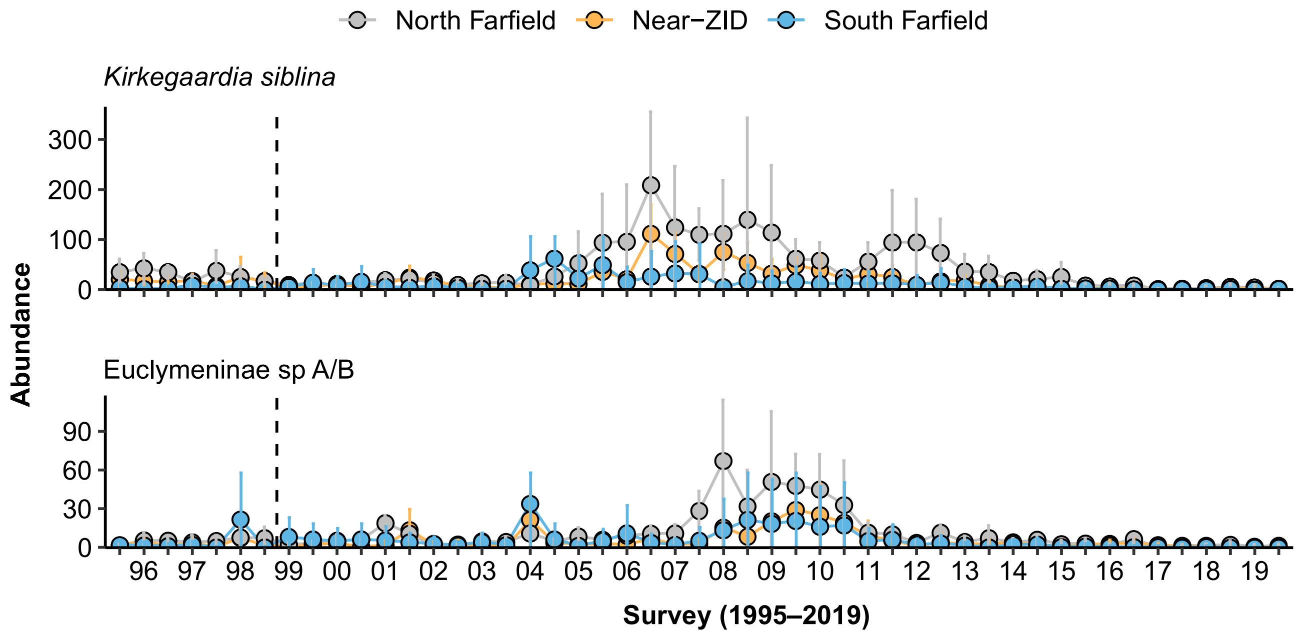
Macrobenthic Communities

2018 – 2019 Supplemental Analyses



Appendix G.1

Two of the five historically most abundant species recorded from 1991 through 2019 at PLOO north farfield, near-ZID, and south farfield primary core stations. The other historically dominant taxa, *Phisidia sanctaemariae, Spiophanes duplex,* and *Proclea* sp A, are shown in Figures 5.4 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 G.2

Two of the five historically most abundant species recorded from 1995 through 2019 at SBOO north farfield, near-ZID, and south farfield primary core stations. The other historically dominant taxa, *Spiophanes norrisi, Spiophanes duplex,* and *Mediomastus* sp, are shown in Figure 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.

Appendix H

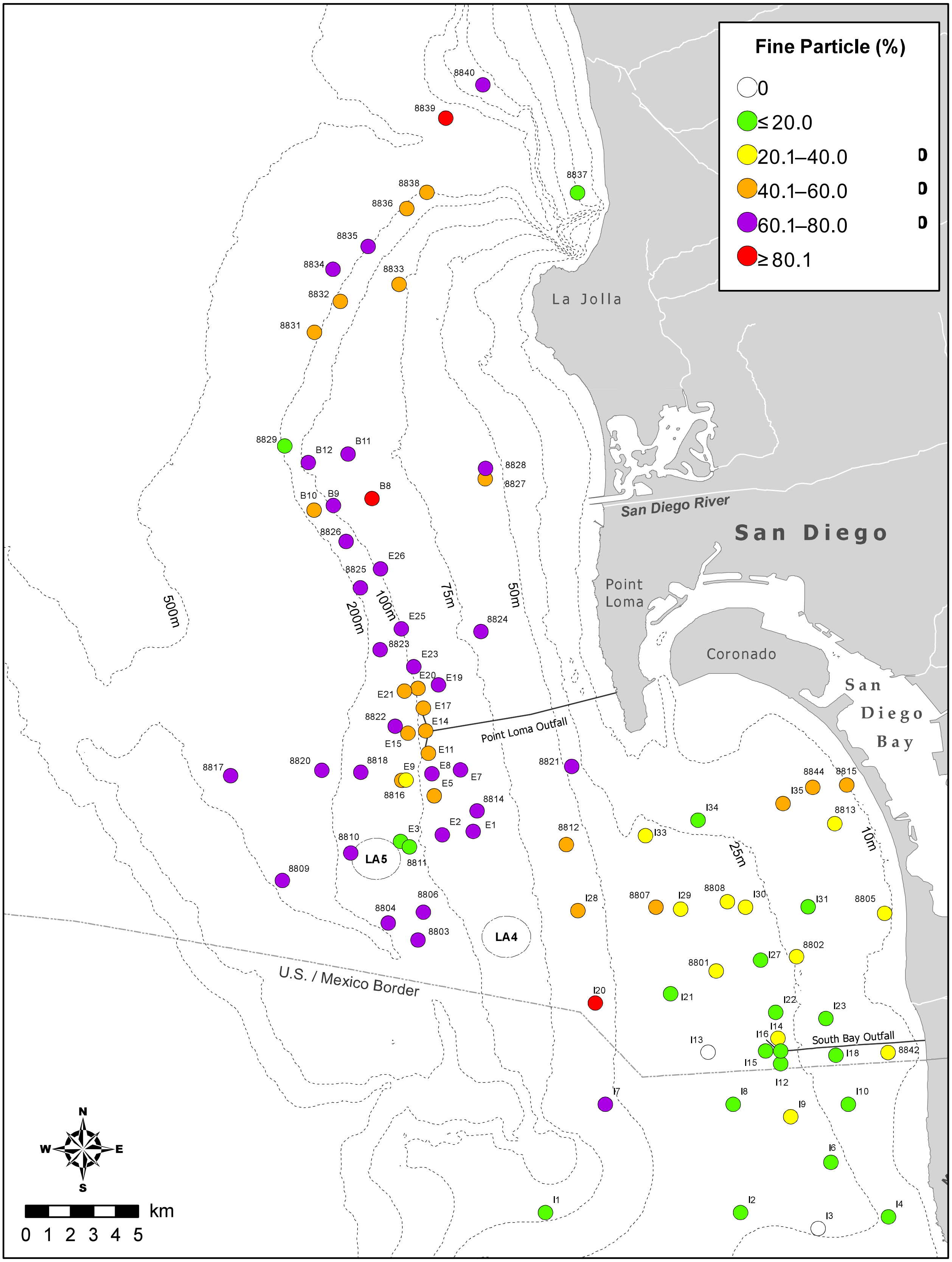
San Diego Regional Benthic Condition Assessment

2019 Supplemental Analyses

Appendix H.1

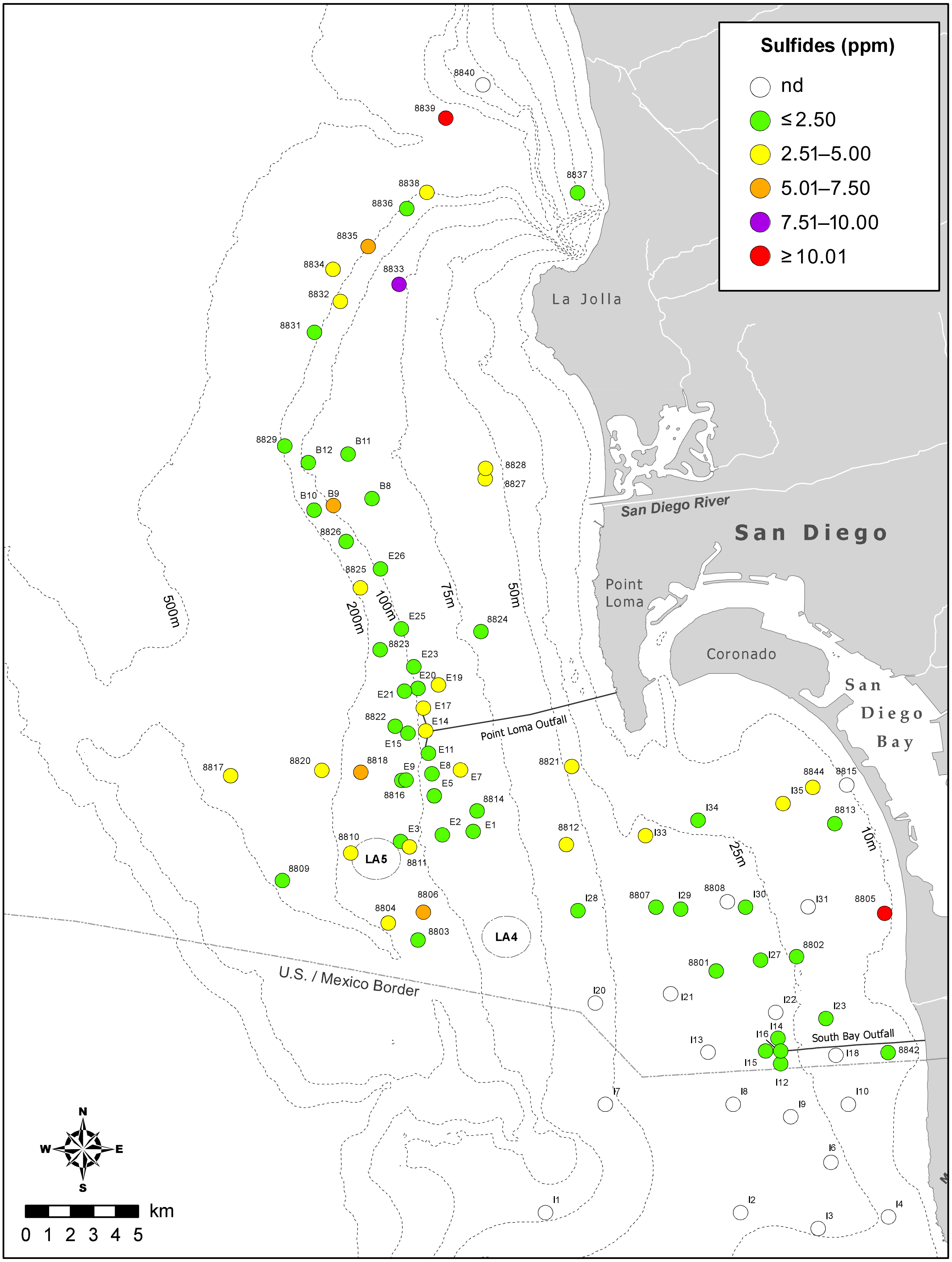
Results of Spearman Rank correlation analyses of various sediment parameters from San Diego regional and core benthic stations sampled during the summer of 2019. Data include the correlation coefficient (r_s) for all parameters with detection rates ≥50% (see Table 6.1). Correlation coefficients r_s ≥0.70 are highlighted.

	Depth	Fines	Sulfides	TN	TOC	TVS	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Sn	Zn	tDDT
Fines	0.62																					
Sulfides	0.47	0.36																				
TN	0.84	0.69	0.63																			
TOC	0.69	0.46	0.41	0.79																		
TVS	0.86	0.67	0.61	0.96	0.81																	
Al	0.71	0.70	0.60	0.85	0.58	0.90																
Sb	0.81	0.66	0.66	0.87	0.70	0.92	0.91															
As	0.35	0.23	0.30	0.36	0.46	0.37	0.18	0.41														
Ba	0.54	0.53	0.57	0.71	0.45	0.76	0.90	0.80	0.07													
Be	0.41	0.33	0.40	0.34	0.26	0.42	0.45	0.50	0.37	0.39												
Cd	0.51	0.31	0.38	0.29	0.16	0.34	0.32	0.49	0.17	0.24	0.46											
Cr	0.81	0.68	0.54	0.88	0.76	0.94	0.92	0.94	0.42	0.79	0.46	0.33										
Cu	0.80	0.66	0.56	0.89	0.72	0.93	0.94	0.90	0.28	0.81	0.42	0.22	0.92									
Fe	0.72	0.69	0.54	0.79	0.76	0.87	0.88	0.94	0.46	0.76	0.49	0.36	0.95	0.86								
Pb	0.69	0.64	0.48	0.77	0.57	0.81	0.82	0.82	0.40	0.70	0.31	0.24	0.81	0.86	0.79							
Mn	0.60	0.66	0.57	0.74	0.45	0.80	0.97	0.86	0.09	0.91	0.44	0.38	0.84	0.86	0.82	0.75						
Hg	0.77	0.70	0.54	0.85	0.59	0.86	0.88	0.84	0.29	0.75	0.41	0.22	0.85	0.93	0.80	0.89	0.79					
Ni	0.83	0.71	0.53	0.92	0.68	0.96	0.95	0.90	0.26	0.81	0.40	0.30	0.94	0.94	0.84	0.81	0.87	0.90				
Sn	0.68	0.71	0.54	0.82	0.54	0.87	0.96	0.86	0.20	0.85	0.39	0.25	0.88	0.93	0.84	0.87	0.93	0.91	0.91			
Zn	0.75	0.72	0.60	0.85	0.68	0.92	0.97	0.95	0.29	0.87	0.49	0.37	0.95	0.94	0.95	0.84	0.93	0.88	0.93	0.94		
tDDT	0.18	0.17	0.17	0.30	0.20	0.32	0.37	0.31	-0.01	0.45	0.21	0.08	0.31	0.32	0.32	0.23	0.37	0.25	0.34	0.43	0.36	
tPCB	0.06	0.14	0.11	0.13	0.06	0.15	0.21	0.18	-0.05	0.17	-0.04	-0.01	0.16	0.21	0.17	0.26	0.18	0.25	0.17	0.30	0.20	0.07



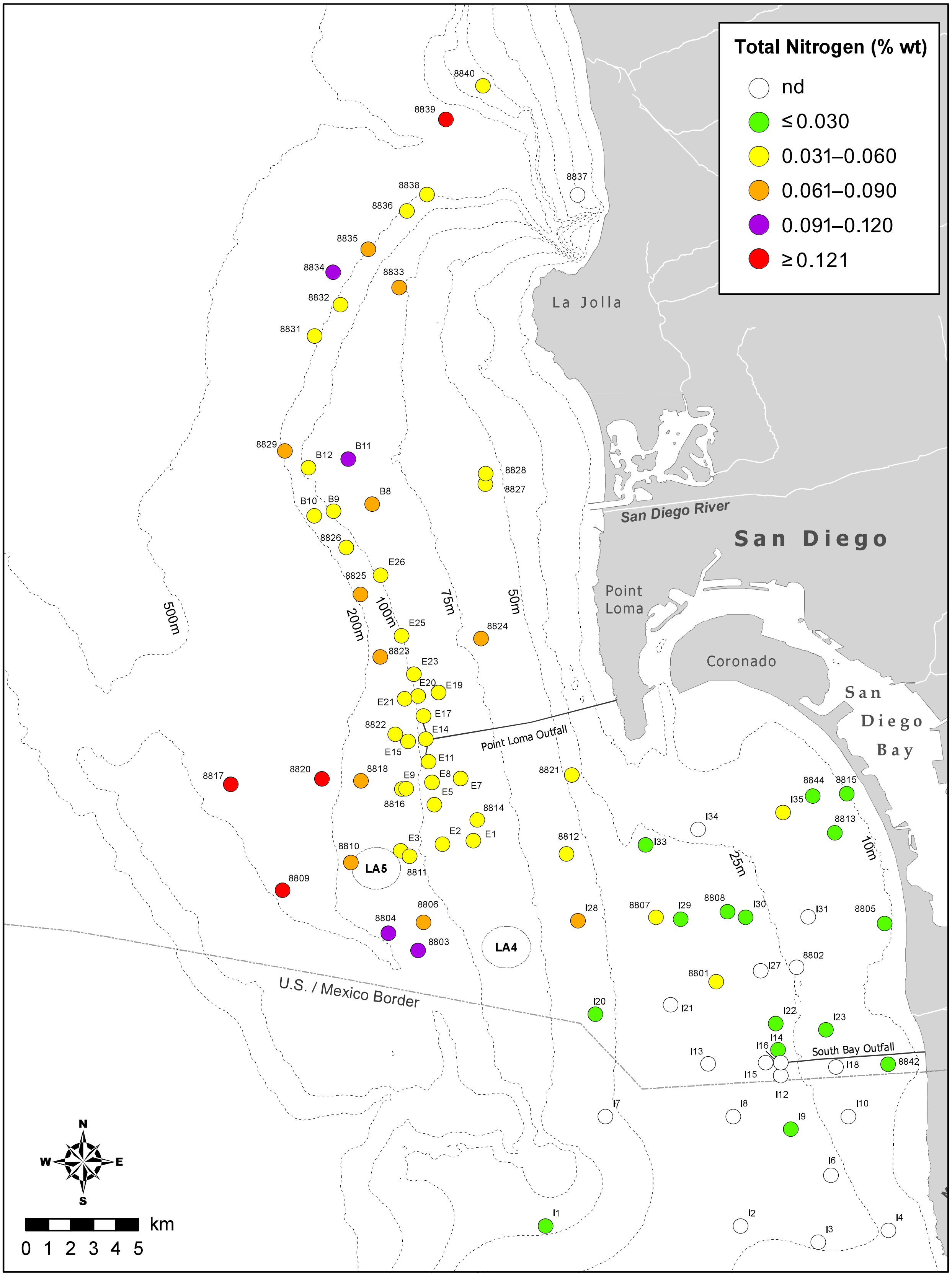
Appendix H.2

Distribution of fine particles in sediments from San Diego regional and core benthic stations sampled during the summer of 2019.

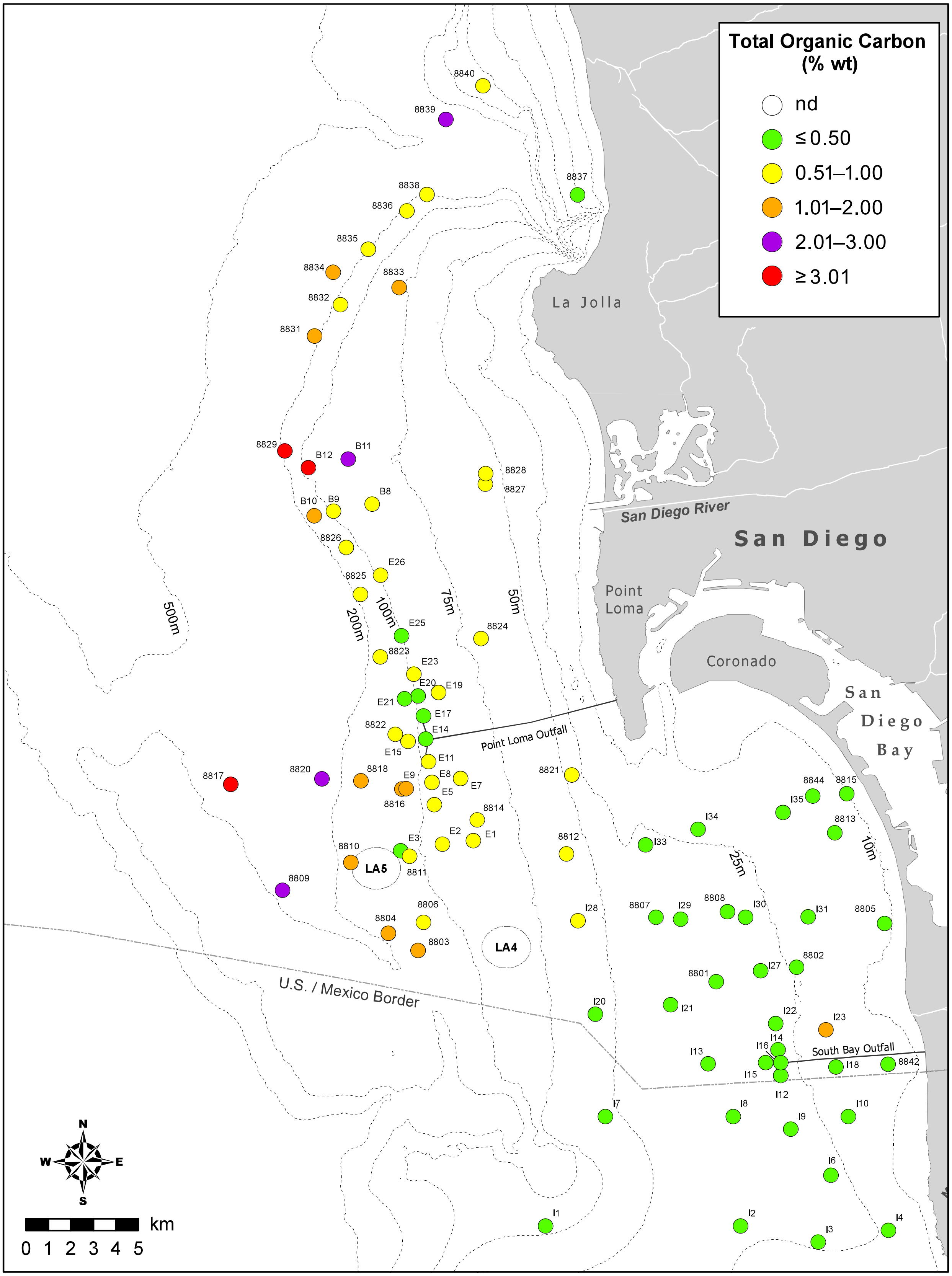


Appendix H.3

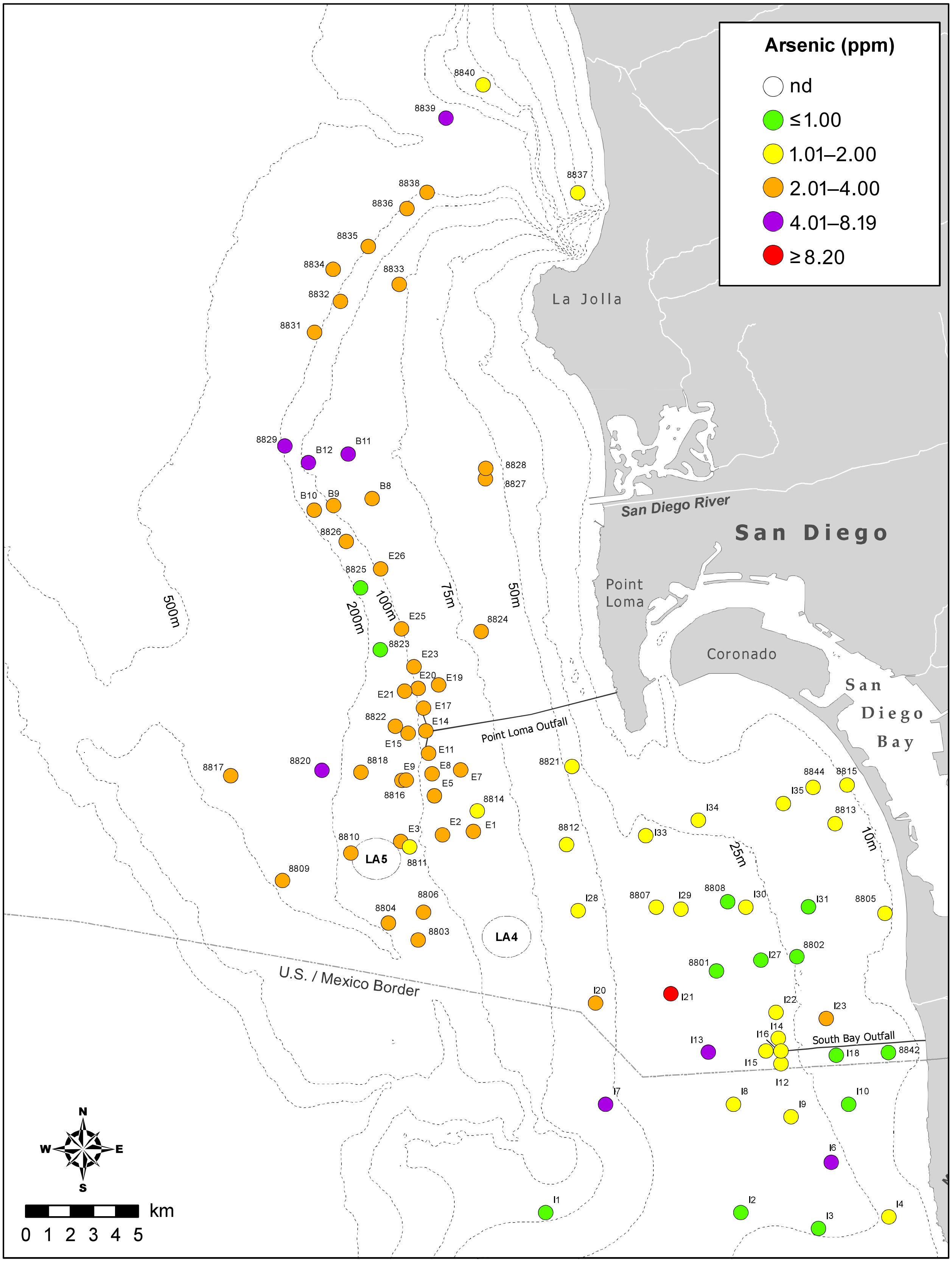
Distribution of select parameters in sediments from San Diego regional and core benthic stations sampled during the summer of 2019; nd = not detected.



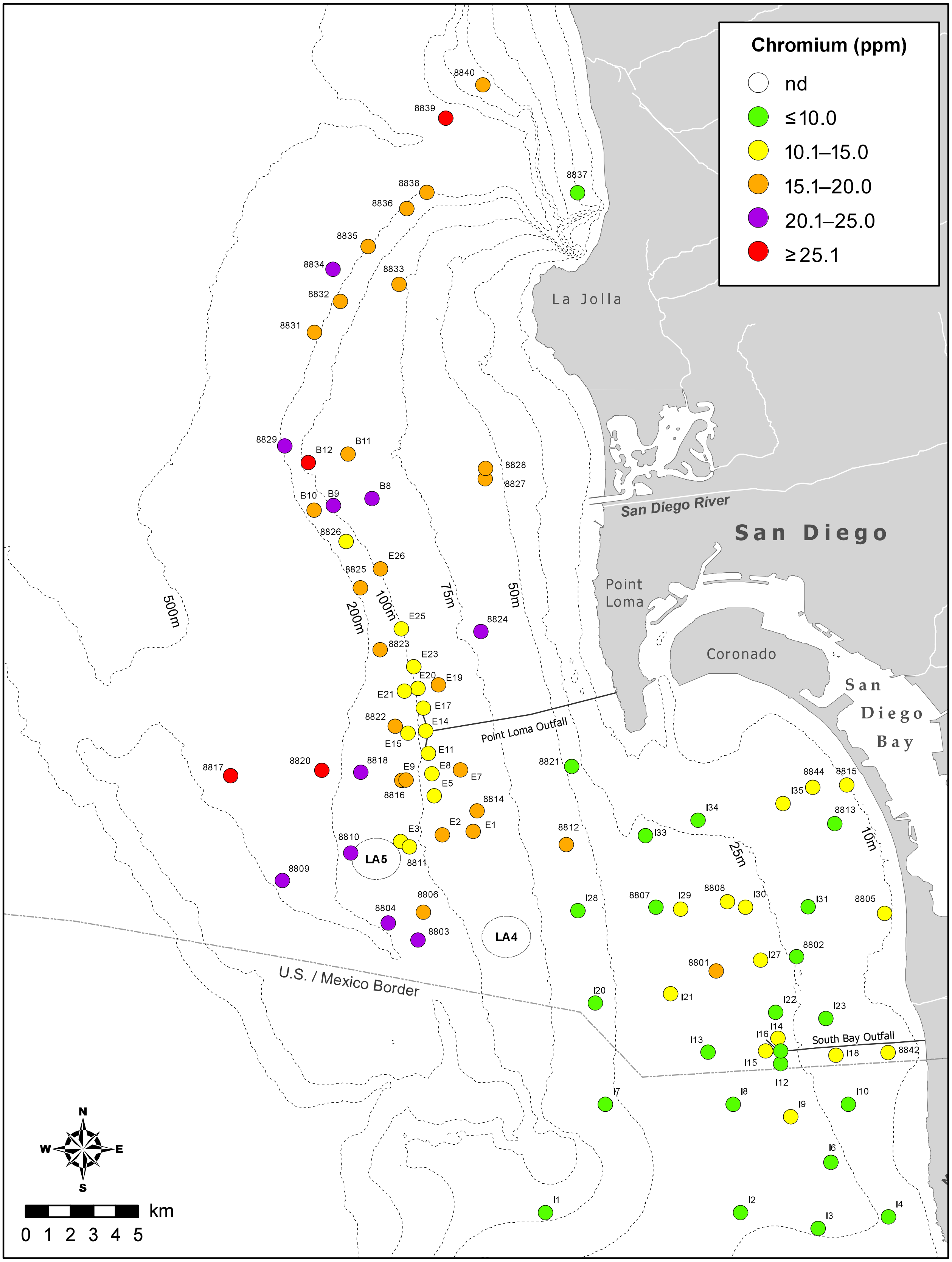
Appendix H.3 *continued*



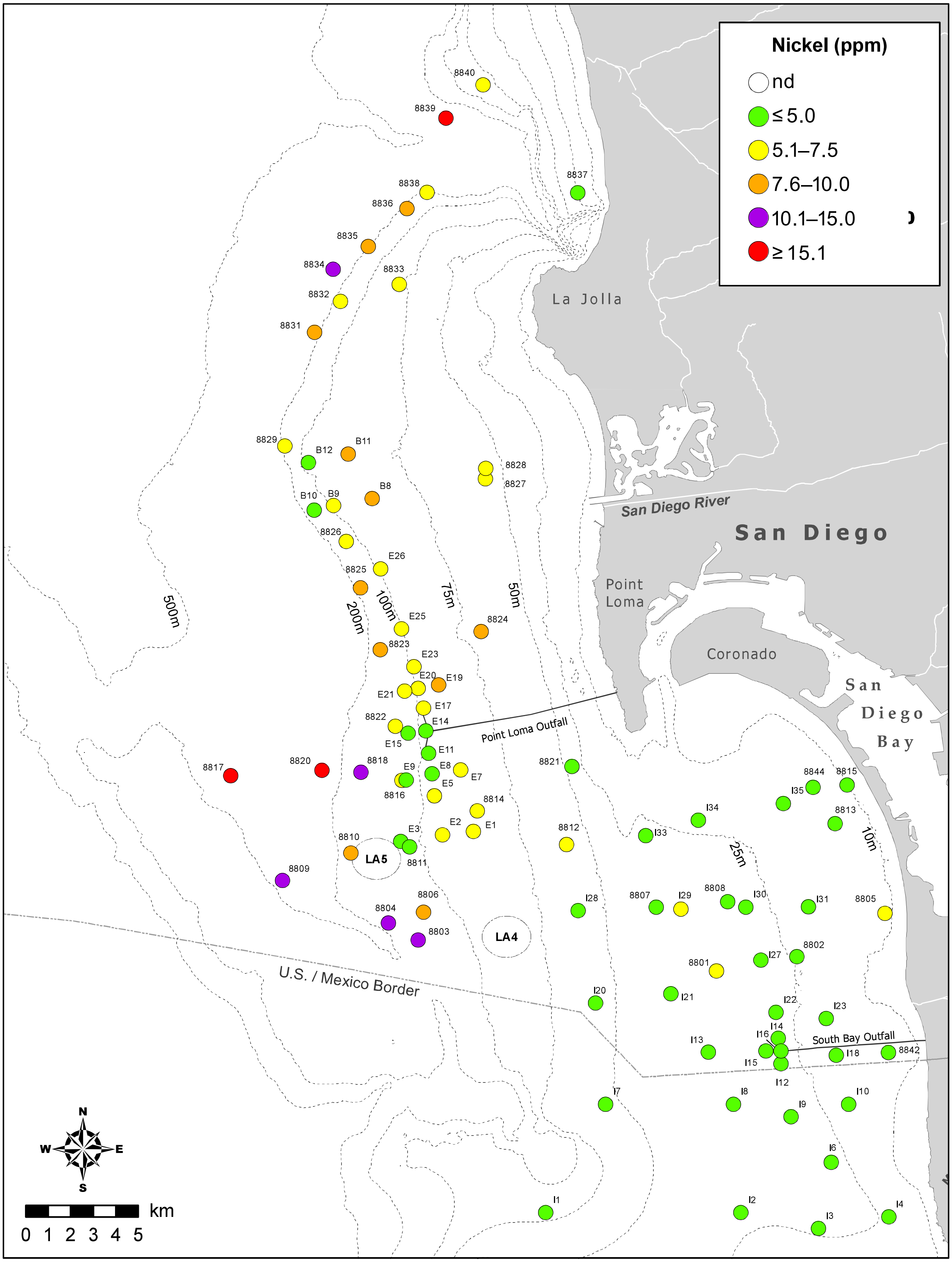
Appendix H.3 *continued*



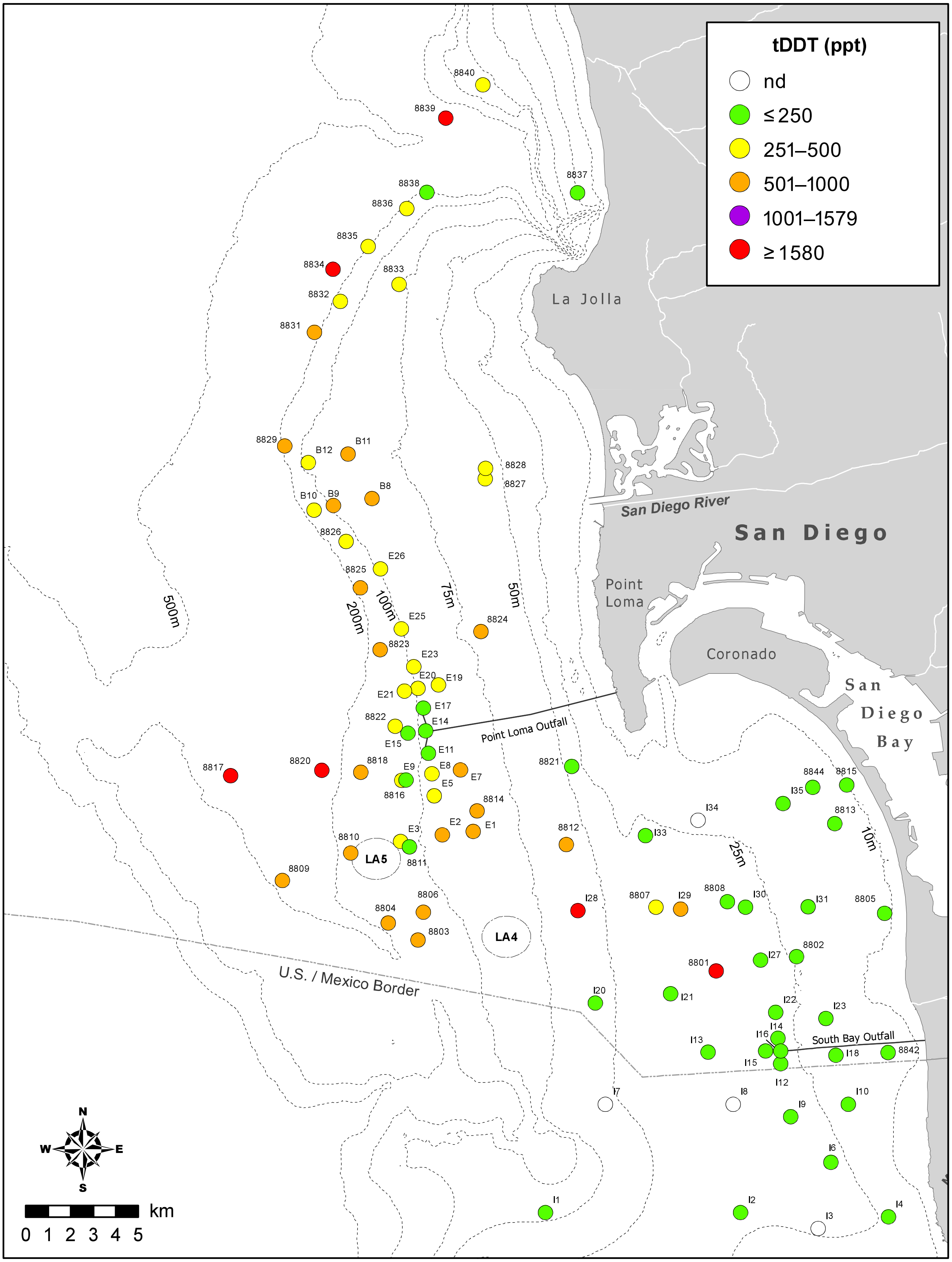
Appendix H.3 *continued*



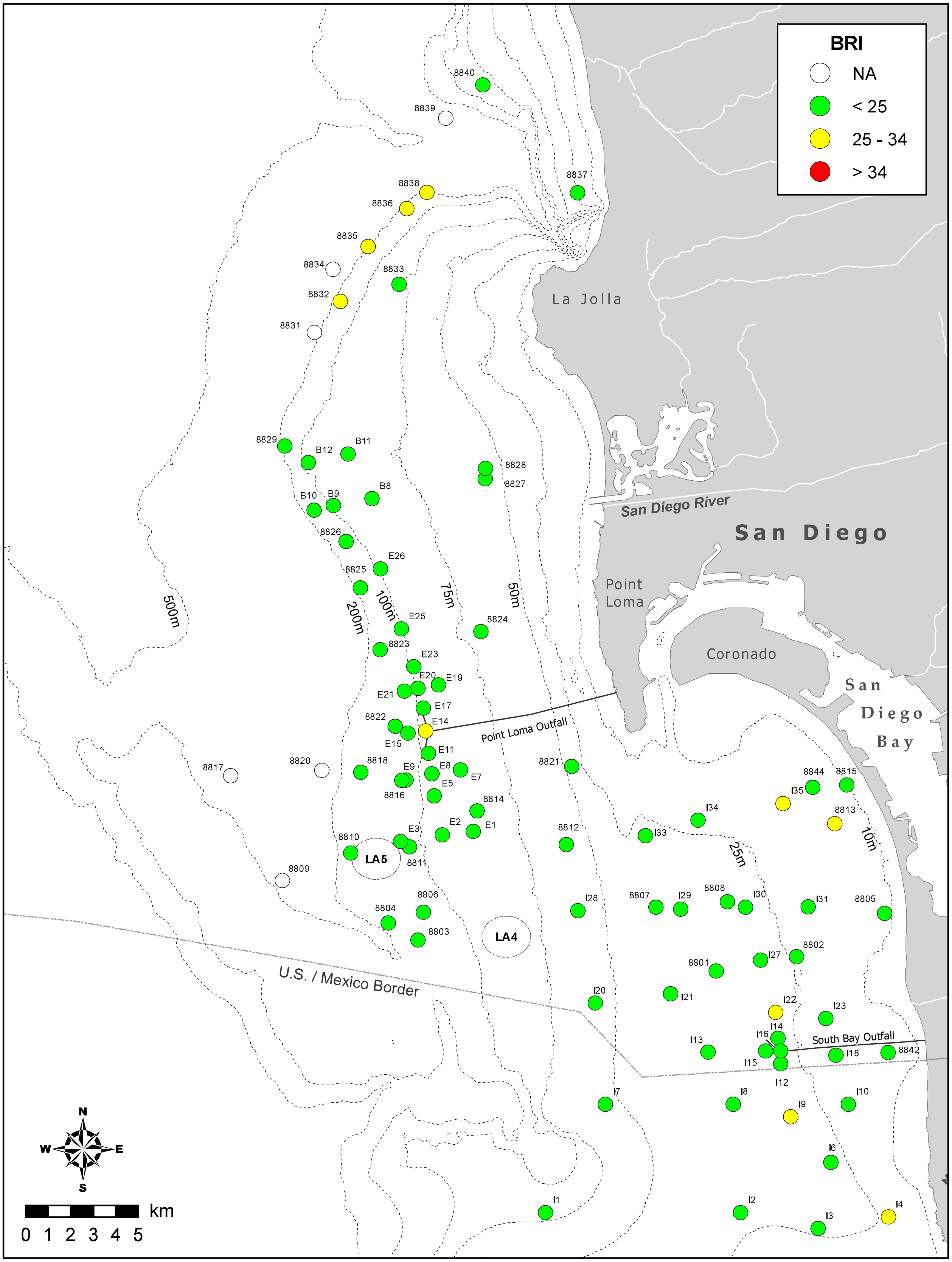
Appendix H.3 *continued*



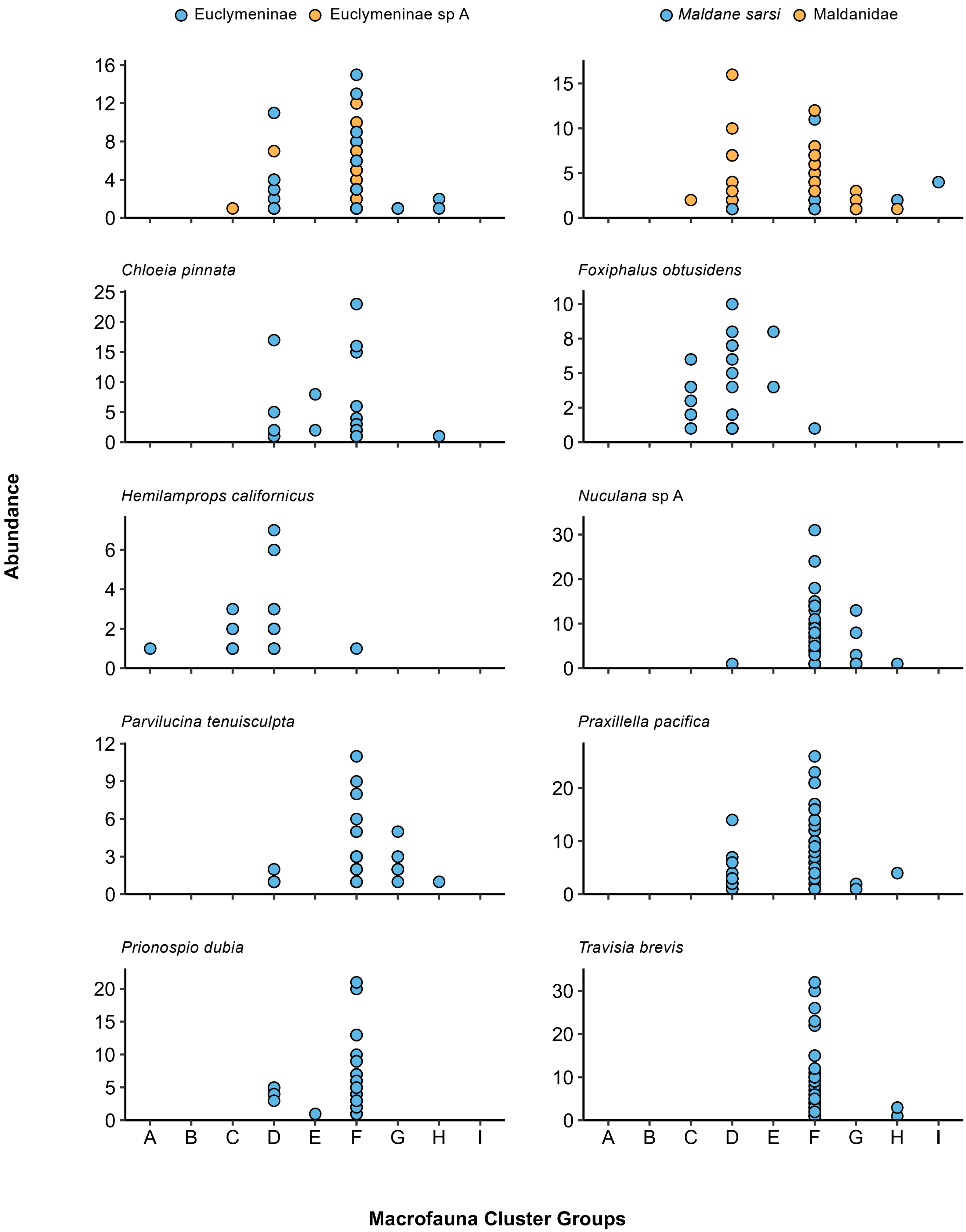
Appendix H.3 *continued*



Appendix H.3 *continued*



Appendix H.4
Distribution of BRI values from San Diego regional and core benthic stations sampled during the summer of 2019; NA = not applicable.



Appendix H.5

Select species that contributed to the variability in cluster analysis results according to the BEST/BVSTEP test (see text).

Appendix H.6

Mean abundance of the characteristic species found in each macrofauna cluster group A–I (defined in Figure 6.6). Highlighted values indicate the top five most characteristic species according to SIMPER analysis.

	Cluster Group								
Taxa	**A**	**B**[a]	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Goniada littorea	11	0	0	1	0	0	0	0	0
Spiophanes duplex	8	0	2	33	13	46	13	5	0
Cooperella subdiaphana	7	0	<1	3	0	0	0	0	0
Pectinaria californiensis	4	0	0	1	0	2	1	3	<1
Ampharete labrops	3	1	1	1	0	0	0	0	0
Saccocirrus sp	0	84	0	0	0	0	0	0	0
Mystides sp	0	43	0	0	0	0	0	0	0
Hesionura coineaui difficilis	0	36	0	0	0	0	0	0	0
Paramphinome sp	0	27	0	0	0	0	0	0	0
Lumbrinerides platypygos	0	26	3	0	3	0	0	0	0
Spiophanes norrisi	3	0	46	18	10	0	0	0	0
Rhepoxynius heterocuspidatus	0	0	8	0	0	0	0	0	0
Dendraster terminalis	0	3	7	0	0	0	0	0	0
Spiochaetopterus costarum Cmplx	<1	0	2	2	4	2	19	0	0
Mediomastus sp	3	0	1	9	0	17	9	17	0
Glottidia albida	<1	0	<1	8	0	<1	0	0	0
Ampelisca cristata microdentata	0	0	<1	7	0	0	0	0	0
Lanassa venusta venusta	0	0	0	0	11	2	0	<1	0
Amphipholis squamata	0	0	0	<1	9	<1	0	0	0
Foxiphalus obtusidens	0	0	1	1	6	0	0	0	0
Phoronis sp	1	0	1	2	5	1	<1	0	0
Prionospio jubata	0	0	<1	4	0	16	3	1	4
Spiophanes kimballi	0	0	0	<1	0	15	12	0	0
Paradiopatra parva	0	0	0	1	0	14	5	14	0
Paraprionospio alata	1	0	0	2	0	10	28	7	5
Axinopsida serricata	0	0	0	<1	0	29	21	0	1
Amphiuridae	<1	0	<1	<1	0	5	<1	6	0
Aphelochaeta sp	0	0	0	<1	0	<1	<1	5	0
Amphiodia digitata	0	0	0	<1	0	1	<1	4	0

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

Appendix H.7

Particle size summary for each macrofauna cluster group A–I (defined in Figure 6.6). Data are presented as means (ranges) calculated over all stations within a cluster group. VF = very fine; F = fine; M = medium; C = coarse; VC = very coarse.

Cluster		Sediments (%)						
Group	n	Fines	VFSand	FSand	MSand	CSand	VCSand	Granules
A	5	40.2 (30.9-55.5)	40.3 (22.8-51.2)	15.5 (10.2-18.6)	3.2 (0.8-10.1)	0.9 (0-4.3)	0 —	0 —
B	1	2.5	0.6	1.3	26.5	39.6	17.0	12.5
C	9	3.5 (0-16.1)	2.2 (0-6.3)	14.2 (1.8-28.0)	44.9 (24.0-57.7)	30.3 (11.6-62.6)	4.3 (0.4-11.2)	0.9 (0-5.0)
D	21	27.1 (7.3-75.9)	45.0 (14.7-72.4)	21.3 (7.4-45.7)	3.8 (0.2-22.6)	1.6 (0-16.1)	1.1 (0-11.4)	0.3 (0-4.0)
E	2	72.0 (61.5-82.5)	5.2 (5.1-5.4)	4.2 (3.5-5.0)	11.6 (6.8-16.5)	6.7 (1.9-11.5)	0.2 (0-0.4)	0 —
F	37	59.4 (17.6-80.8)	26.1 (13.7-36.9)	9.9 (3.1-37.0)	1.8 (0.1-17.5)	1.0 (0-10.3)	1.2 (0-11.7)	0.6 (0-9.2)
G	10	63.1 (52.7-77.8)	30.0 (18.4-38.8)	6.6 (3.8-11.2)	0.3 (0-1.7)	0 —	0 —	0 —
H	2	46.5 (14.3-78.7)	17.6 (12.0-23.3)	14.0 (7.7-20.3)	13.4 (1.6-25.2)	5.4 (0-10.8)	2.0 (0-4)	1.1 (0-2.2)
I	2	81.2 (76.9-85.5)	14.3 (11.0-17.6)	4.4 (3.5-5.4)	0.1 (0.1-0.1)	0 —	0 —	0 —

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Appendix I

Demersal Fishes and Megabenthic Invertebrates

2018 – 2019 Supplemental Analyses

Appendix I.1

Taxonomic listing of demersal fish species captured at PLOO trawl stations during 2018 and 2019. Data are total number of fish (n), biomass (BM, wet weight, kg), minimum, maximum, and mean length (standard length, cm unless otherwise noted). Taxonomic arrangement follows Eschmeyer and Herald (1998) and Page et al. (2013).

				Length (cm)		
Taxonomic Classification	**Common Name**	**n**	**BM**	**Min**	**Max**	**Mean**
RAJIFORMES						
Rajidae						
Raja inornata	California Skate [a]	3	1.7	40	50	44
ARGENTINIFORMES						
Argentinidae						
Argentina sialis	Pacific Argentine	31	0.5	5	8	7
AULOPIFORMES						
Synodontidae						
Synodus lucioceps	California Lizardfish	80	3.1	10	26	18
OPHIDIIFORMES						
Ophidiidae						
Chilara taylori	Spotted Cusk-eel	20	1.1	11	21	16
BATRACHOIDIFORMES						
Batrachoididae						
Porichthys myriaster	Specklefin Midshipman	2	0.1	6	6	6
Porichthys notatus	Plainfin Midshipman	205	2.2	4	20	9
SCORPAENIFORMES						
Scorpaenidae						
Scorpaena guttata	California Scorpionfish	19	1.9	13	21	16
Sebastidae						
Sebastes chlorostictus	Greenspotted Rockfish	2	0.2	5	8	6
Sebastes elongatus	Greenstriped Rockfish	7	0.2	6	9	7
Sebastes helvomaculatus	Rosethorn Rockfish	3	0.5	7	21	15
Sebastes hopkinsi	Squarespot Rockfish	27	1.0	7	22	11
Sebastes levis	Cowcod	1	0.1	7	7	7
Sebastes miniatus	Vermilion Rockfish	26	2.3	14	21	16
Sebastes rosaceus	Rosy Rockfish	1	0.1	8	8	8
Sebastes rubrivinctus	Flag Rockfish	2	0.1	4	8	6
Sebastes saxicola	Stripetail Rockfish	115	1.4	5	10	7
Sebastes semicinctus	Halfbanded Rockfish	2567	30.7	5	17	9
Sebastes sp	Rockfish Unidentified	3	0.2	6	7	6
Hexagrammidae						
Zaniolepis frenata	Shortspine Combfish	128	2.7	8	17	12
Zaniolepis latipinnis	Longspine Combfish	328	2.9	6	17	9
Cottidae						
Chitonotus pugetensis	Roughback Sculpin	1	0.1	7	7	7
Icelinus quadriseriatus	Yellowchin Sculpin	130	0.7	4	9	6
Icelinus tenuis	Spotfin Sculpin	3	0.2	8	9	8
Agonidae						
Xeneretmus latifrons	Blacktip Poacher	1	0.1	14	14	14
PERCIFORMES						
Sciaenidae						
Genyonemus lineatus	White Croaker	3	0.3	15	17	16
Embiotocidae						
Cymatogaster aggregata	Shiner Perch	1	0.1	11	11	11
Zalembius rosaceus	Pink Seaperch	97	1.6	4	14	8

[a] measured as total length (cm)

Appendix I.1 *continued*

Taxonomic Classification			Common Name	n	BM	Length (cm) Min	Max	Mean
	Bathymasteridae							
		Rathbunella hypoplecta	Bluebanded Ronquil	2	0.2	14	17	16
	Zoarcidae							
		Lycodes cortezianus	Bigfin Eelpout	2	0.1	15	17	16
PLEURONECTIFORMES								
	Paralichthyidae							
		Citharichthys sordidus	Pacific Sanddab	2921	48.9	3	26	9
		Citharichthys xanthostigma	Longfin Sanddab	20	1.1	11	17	14
		Hippoglossina stomata	Bigmouth Sole	9	1.7	5	23	17
		Xystreurys liolepis	Fantail Sole	1	0.5	27	27	27
	Pleuronectidae							
		Lyopsetta exilis	Slender Sole	11	0.8	11	18	15
		Microstomus pacificus	Dover Sole	483	9.2	5	20	11
		Parophrys vetulus	English Sole	143	7.1	10	25	15
		Pleuronichthys decurrens	Curlfin Sole	4	0.3	14	18	16
		Pleuronichthys verticalis	Hornyhead Turbot	45	2.9	10	17	13
	Cynoglossidae							
		Symphurus atricaudus	California Tonguefish	32	0.9	5	16	13

Appendix I.2

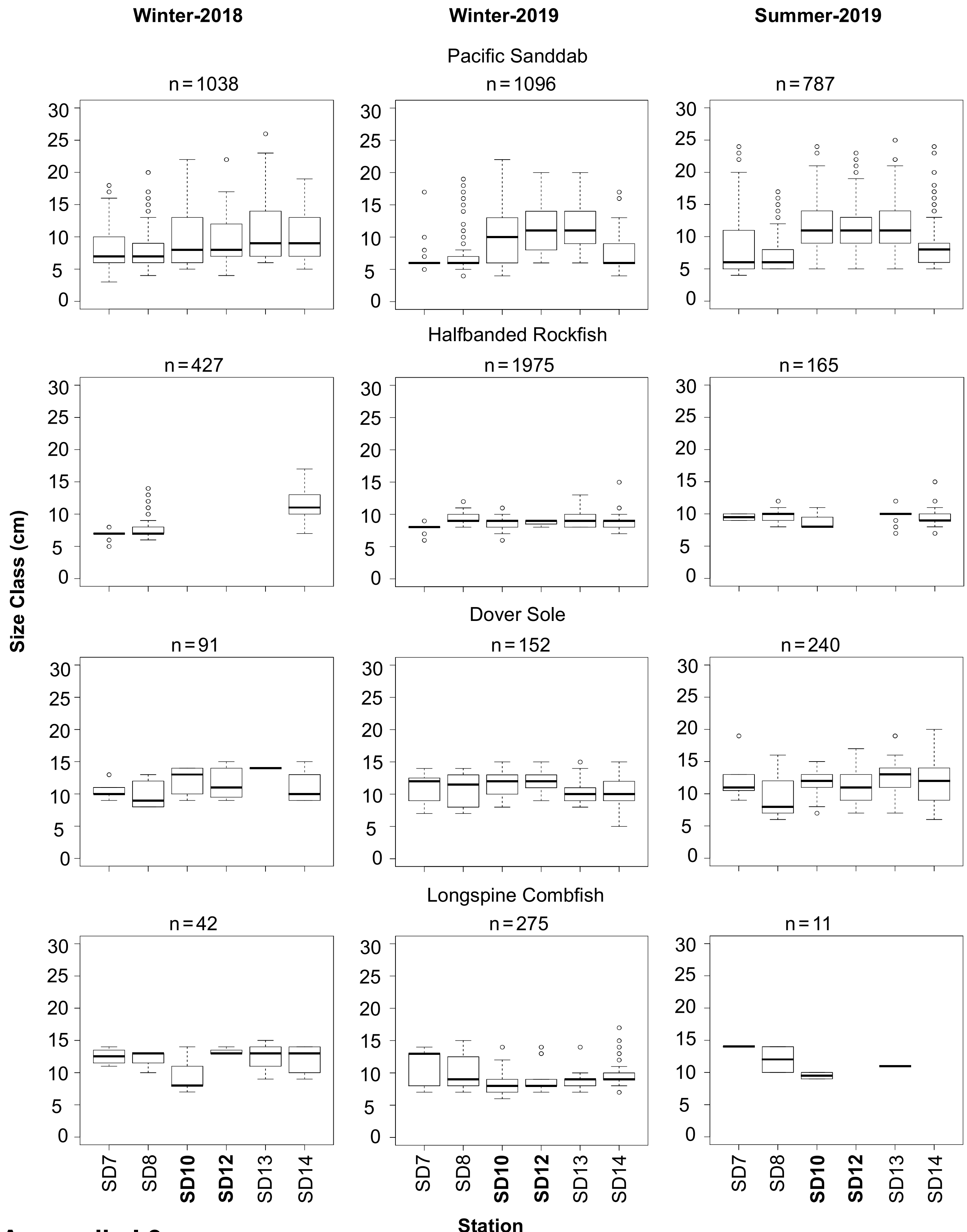
Taxonomic listing of demersal fish species captured at SBOO trawl stations during 2018 and 2019. Data are total number of fish (n), biomass (BM, wet weight, kg), minimum, maximum, and mean length (standard length, cm, unless otherwise noted). Taxonomic arrangement follows Eschmeyer and Herald (1998) and Page et al. (2013).

Taxonomic Classification			Common Name	n	BM	Length (cm) Min	Max	Mean
RAJIFORMES								
	Rhinobatidae							
		Rhinobatos productus	Shovelnose Guitarfish [a]	2	0.6	32	49	40
	Rajidae							
		Raja inornata	California Skate [a]	3	1	28	41	35
	Platyrhynidae							
		Platyrhinoidis triseriata	Thornback [a]	1	0.2	40	40	40
MYLIOBATIFORNES								
	Urolophidae							
		Urobatis halleri	Round Stingray [a]	15	3.4	15	39	22
CLUPEIFORMES								
	Engraulidae							
		Engraulis mordax	Northern Anchovy	79	0.5	9	12	10
	Clupeidae							
		Sardinops sagax	Pacific Sardine	1	0.1	12	12	12
AULOPIFORMES								
	Synodontidae							
		Synodus lucioceps	California Lizardfish	1085	15.3	8	34	12
OPHIDIIFORMES								
	Ophidiidae							
		Chilara taylori	Spotted Cusk-eel	1	0.1	17	17	17
		Ophidion scrippsae	Basketweave Cusk-eel	1	0.1	16	16	16
BATRACHOIDIFORMES								
	Batrachoididae							
		Porichthys myriaster	Specklefin Midshipman	9	0.8	8	21	12
		Porichthys notatus	Plainfin Midshipman	9	0.5	4	9	6
GASTEROSTEIFORMES								
	Syngnathidae							
		Syngnathus californiensis	Kelp Pipefish	4	0.4	19	22	20
		Syngnathus exilis	Barcheek Pipefish	2	0.1	15	17	16
		Syngnathus sp	Pipefish Unidentified	4	0.4	14	21	17
SCORPAENIFORMES								
	Scorpaenidae							
		Scorpaena guttata	California Scorpionfish	3	0.5	14	20	17
	Hexagrammidae							
		Zaniolepis latipinnis	Longspine Combfish	15	0.4	10	16	14
	Cottidae							
		Chitonotus pugetensis	Roughback Sculpin	13	0.5	6	11	9
		Icelinus quadriseriatus	Yellowchin Sculpin	42	0.6	6	8	7
	Agonidae							
		Odontopyxis trispinosa	Pygmy Poacher	1	0.1	8	8	8

[a] measured as total length (cm)

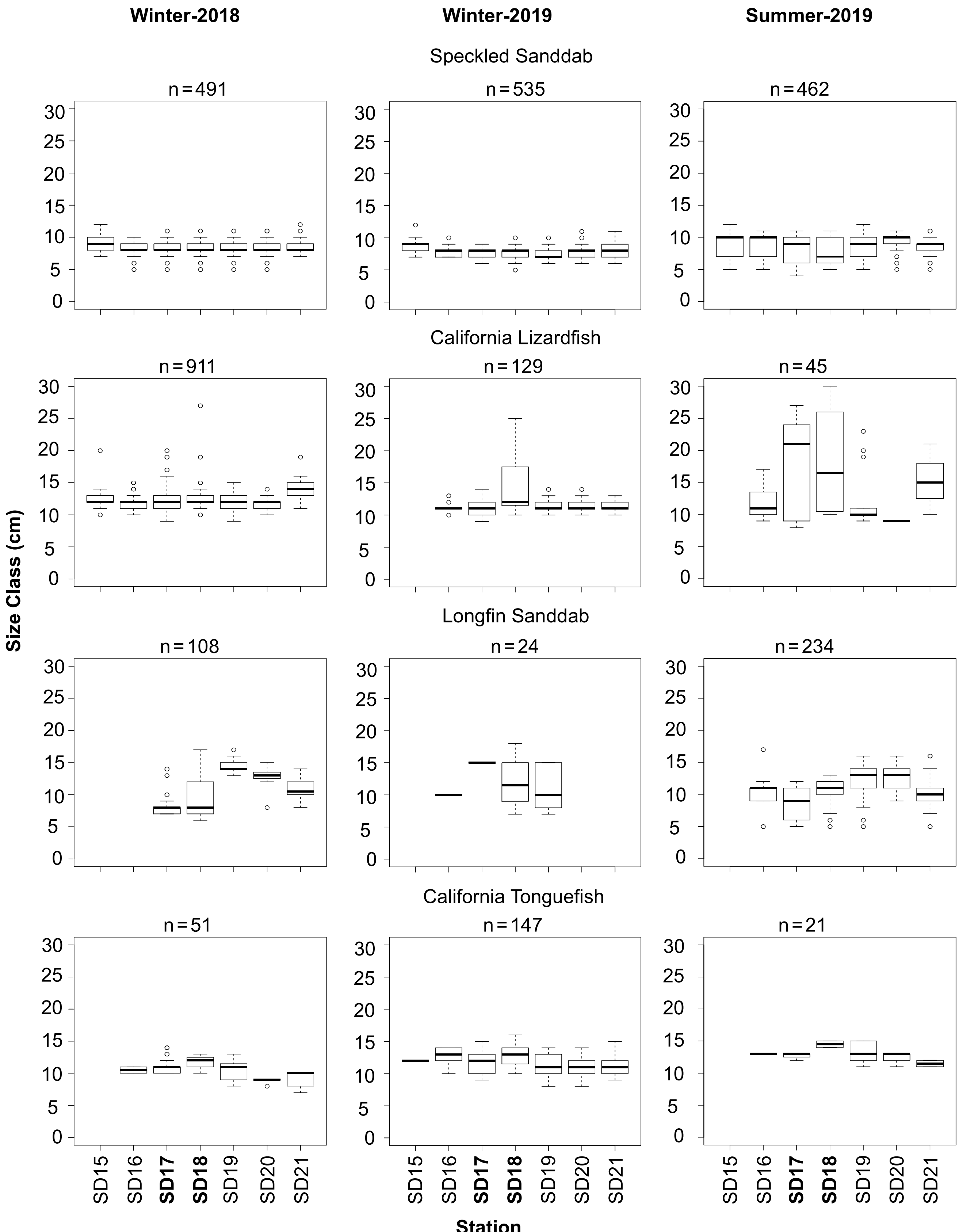
Appendix I.2 *continued*

Taxonomic Classification			Common Name	n	BM	Length (cm) Min	Max	Mean
PERCIFORMES								
	Serranidae							
		Paralabrax nebulifer	Barred Sand Bass	1	0.3	26	26	26
	Scianidae							
		Genyonemus lineatus	White Croaker	199	6.2	8	17	13
		Seriphus politus	Queenfish	9	0.2	13	17	14
	Embiotocidae							
		Cymatogaster aggregata	Shiner Perch	1	0.1	8	8	8
	Clinidae							
		Heterostichus rostratus	Giant Kelpfish	2	0.1	12	13	12
	Labrisomidae							
		Neoclinus blanchardi	Sarcastic Fringehead	1	0.1	12	12	12
	Stromateidae							
		Peprilus simillimus	Pacific Pompano	1	0.1	9	9	9
PLEURONECTIFORMES								
	Paralichthyidae							
		Citharichthys sordidus	Pacific Sanddab	4	0.4	5	12	10
		Citharichthys stigmaeus	Speckled Sanddab	1488	14.1	4	12	8
		Citharichthys xanthostigma	Longfin Sanddab	366	12	5	18	11
		Paralichthys californicus	California Halibut	36	25.1	22	70	33
		Xystreurys liolepis	Fantail Sole	13	4.7	12	26	20
	Pleuronectidae							
		Parophrys vetulus	English Sole	22	1.9	13	24	17
		Pleuronichthys ritteri	Spotted Turbot	7	1.3	14	22	18
		Pleuronichthys verticalis	Hornyhead Turbot	53	4.3	4	22	11
	Cynoglossidae							
		Symphurus atricaudus	California Tonguefish	219	3.8	7	16	12



Appendix I.3

Summary of fish lengths by survey and station for each of the four most abundant species collected in the PLOO region during 2018 and 2019. Data are median, upper and lower quartiles, 1.5 times the interquartile range (whiskers), and outliers (open circles). Stations SD10 and SD12 are considered nearfield (bold; see text).



Appendix I.4

Summary of fish lengths by survey and station for the four most abundant species collected in the SBOO region during 2018 and 2019. Data are median, upper and lower quartiles, 1.5 times the interquartile range (whiskers), and outliers (open circles). Stations SD17 and SD18 are considered nearfield (bold; see text).

Appendix I.5

Summary of demersal fish abnormalities and parasites at PLOO and SBOO trawl stations during 2018 and 2019.

Region/Year	Survey	Station	Species	Abnormalities/Parasite	n
PLOO Region					
2018	Winter	SD7	Pacific Sanddab	*Phrixocephalus cininnatus*	1
	Winter	SD8	Pacific Sanddab	*Phrixocephalus cininnatus*	1
	Winter	SD10	Pacific Sanddab	*Phrixocephalus cininnatus*	5
	Winter	SD10	Dover Sole	Tumor, ventral side	1
	Winter	SD12	Pacific Sanddab	*Phrixocephalus cininnatus*	9
	Winter	SD13	Pacific Sanddab	*Phrixocephalus cininnatus*	5
	Winter	SD14	Pacific Sanddab	*Phrixocephalus cininnatus*	2
	Winter	SD14	Dover Sole	Tumor/lLesion	1
2019	Winter	SD8	Pacific Sanddab	*Phrixocephalus cininnatus*	1
	Winter	SD10	Pacific Sanddab	*Phrixocephalus cininnatus*	2
	Winter	SD10	Dover Sole	Tumor	1
	Winter	SD10	Halfbanded Rockfish	Tumor	1
	Winter	SD12	Pacific Sanddab	*Phrixocephalus cininnatus*	6
	Winter	SD12	Pacific Sanddab	*Elthusa vulgaris*	1
	Winter	SD13	Pacific Sanddab	*Phrixocephalus cininnatus*	7
	Winter	SD14	Pacific Sanddab	*Phrixocephalus cininnatus*	4
	Summer	SD13	Pacific Sanddab	*Elthusa vulgaris*	1
	Summer	SD13	Pacific Sanddab	*Phrixocephalus cininnatus*	1
	Summer	SD14	Pacific Sanddab	*Phrixocephalus cininnatus*	2
SBOO Region					
2019	Winter	SD19	California Tonguefish	Ambicoloration	1
	Summer	SD20	Speckled Sanddab	Skeletal Deformation	1
	Summer	SD21	Longfin Sanddab	Ambicoloration	1

Appendix I.6

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

	Cluster Groups			
Species	**A[a]**	**B**	**C[a]**	**D**
Pacific Sanddab	**23**	**83**	**75**	**208**
Halfbanded Rockfish	**16**	2	0	**23**
Longfin Sanddab	**1**	**7**	0	3
Spotfin Sculpin	**1**	3	0	<1
Pink Seaperch	**1**	1	4	**4**
Greenspotted Rockfish	**1**	<1	0	<1
Gulf Sanddab	**1**	<1	**5**	<1
Dover Sole	0	**9**	**36**	**24**
California Tonguefish	0	**3**	0	<1
Plainfin Midshipman	0	3	**116**	9
Stripetail Rockfish	0	3	1	**11**
Longspine Combfish	0	<1	**7**	**18**

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

Appendix I.7

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

	Cluster Groups					
Species	**A**	**B**	**C**	**D**	**E**	**F**
Speckled Sanddab	**15**	**81**	**49**	**154**	**218**	**52**
California Lizardfish	**8**	2	**34**	**22**	**191**	**10**
Hornyhead Turbot	<1	3	3	5	7	**4**
Longfin Sanddab	<1	<1	**8**	12	22	**30**
Roughback Sculpin	0	<1	**11**	9	4	<1
Yellowchin Sculpin	0	<1	**8**	**31**	9	2
Longspine Combfish	0	0	**34**	<1	8	<1

Appendix I.8

Summary taxonomic listing of megabenthic invertebrate taxa captured at all PLOO trawl stations during 2018 and 2019. Data are total number of individuals (n). Taxonomic arrangement follows SCAMIT (2018).

Taxonomic Classification				n
SILICEA				
	Hexactinellida	Rossellidae	*Aphorme horrida*	1
	Demospongiae	Suberitidae	*Suberites latus*	2
CNIDARIA				
	Anthozoa	Gorgoniidae	*Adelogorgia phyllosclera*	3
		Virgulariidae	*Acanthoptilum* sp	1
		Metridiidae	*Metridium farcimen*	1
MOLLUSCA				
	Polyplacophora	Ischnochitonidae	*Lepidozona retiporosa*	3
			Lepidozona scrobiculata	1
	Gastropoda	Naticidae	*Neverita draconis*	2
		Fasciolariidae	*Araiofusus eueides*	1
		Pseudomelatomidae	*Megasurcula carpenteriana*	1
		Onchidorididae	*Acanthodoris brunnea*	1
		Pleurobranchidae	*Pleurobranchaea californica*	2
	Cephalopoda	Loliginidae	*Doryteuthis opalescens*	2
		Octopodidae	*Octopus rubescens*	11
ARTHROPODA				
	Malacostraca	Sicyoniidae	*Sicyonia ingentis*	376
			Sicyonia penicillata	22
		Pandalidae	*Pandalus danae*	2
		Crangonidae [a]		13
			Crangon alaskensis	77
			Neocrangon zacae	3
		Diogenidae	*Paguristes bakeri*	1
			Paguristes turgidus	1
		Paguridae	*Parapagurodes laurentae*	1
		Munididae	*Pleuroncodes planipes*	57,131
		Calappidae	*Platymera gaudichaudii*	64
		Inachidae	*Coryrhynchus lobifrons*	1
		Pilumnoididae	*Pilumnoides rotundus*	1
ECHINODERMATA				
	Crinoidea	Antedonidae	*Florometra serratissima*	1
	Asteroidea	Luidiidae	*Luidia armata*	8
			Luidia asthenosoma	2
			Luidia foliolata	20
		Astropectinidae	*Astropecten californicus*	11
	Ophiuroidea	Ophiuridae	*Ophiura luetkenii*	7
		Ophiopteridae	*Ophiopteris papillosa*	1
		Ophiacanthidae	*Ophiacantha diplasia*	1
		Ophiopholidae	*Ophiopholis bakeri*	4
		Ophiotrichidae	*Ophiothrix spiculata*	2
	Echinoidea	Toxopneustidae	*Lytechinus pictus*	6846
		Strongylocentrotidae	*Strongylocentrotus fragilis*	398
	Holothuroidea	Stichopodidae	*Apostichopus californicus*	25
BRACHIOPODA				
	Rhynchonellata	Terebrataliidae	*Dallinella occidentalis*	1

[a] Order; family unknown

Appendix I.9

Summary taxonomic listing of megabenthic invertebrate taxa captured at all SBOO trawl stations during 2018 and 2019. Data are total number of individuals (n). Taxonomic arrangement follows SCAMIT (2018).

Taxonomic Classification				n
SILICEA				
	Demospongiae	Suberitidae	*Suberites latus*	1
			Suberites sp	1
MOLLUSCA				
	Gastropoda	Calliostomatidae	*Calliostoma gloriosum*	1
		Calliostomatidae	*Calliostoma tricolor*	4
		Naticidae	*Neverita recluziana*	2
		Bursidae	*Crossata ventricosa*	7
		Velutinidae	*Lamellaria diegoensis*	1
		Buccinidae	*Kelletia kelletii*	8
		Nassariidae	*Caesia perpinguis*	1
		Muricidae	*Pteropurpura festiva*	1
		Pseudomelatomidae	*Crassispira semiinflata*	1
		Onchidorididae	*Acanthodoris brunnea*	1
			Acanthodoris rhodoceras	1
		Polyceridae	*Triopha maculata*	1
		Dendronotidae	*Dendronotus venustus*	1
		Pleurobranchidae	*Pleurobranchaea californica*	7
		Philinidae	*Philine auriformis*	117
	Cephalopoda	Loliginidae	*Doryteuthis opalescens*	1
		Octopodidae	*Octopus rubescens*	7
ANNELIDA				
	Polychaeta	Aphroditidae	*Aphrodita armifera*	2
ARTHROPODA				
	Malacostraca	Hemisquillidae	*Hemisquilla californiensis*	2
		Penaeidae	*Farfantepenaeus californiensis*	61
		Sicyoniidae	*Sicyonia penicillata*	143
		Hippolytidae	*Heptacarpus brevirostris*	3
			Heptacarpus palpator	3
			Heptacarpus stimpsoni	4
		Pandalidae	*Pandalus platyceros*	1
		Crangonidae	*Crangon alba*	16
			Crangon nigromaculata	273
		Diogenidae	*Paguristes bakeri*	4
		Paguridae	*Pagurus armatus*	1
			Pagurus spilocarpus	10
		Calappidae	*Platymera gaudichaudii*	10
		Leucosiidae	*Randallia ornata*	1
		Epialtidae	*Pugettia dalli*	3
			Pugettia producta	4
			Loxorhynchus grandis	9
		Inachidae	*Ericerodes hemphillii*	7
		Inachoididae	*Pyromaia tuberculata*	1
		Parthenopidae	*Latulambrus occidentalis*	1

Appendix I.9 *continued*

Taxonomic Classification				n
		Cancridae	*Metacarcinus anthonyi*	5
			Metacarcinus gracilis	4
		Portunidae	*Portunus xantusii*	161
ECHINODERMATA				
	Asteroidea	Luidiidae	*Luidia armata*	5
		Astropectinidae	*Astropecten californicus*	65
	Ophiuroidea	Ophiotrichidae	*Ophiothrix spiculata*	58
	Echinoidea	Toxopneustidae	*Lytechinus pictus*	49
		Dendrasteridae	*Dendraster terminalis*	54
		Loveniidae	*Lovenia cordiformis*	18

Appendix I.10

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

	Cluster Groups							
Species	**A[a]**	**B**	**C**	**D[a]**	**E**	**F**	**G**	**H**
Pleuroncodes planipes	**16,989**	**11,393**	2	0	**407**	2	<1	6
Lytechinus pictus	**168**	9	10	**102**	**302**	**2170**	**232**	2
Sicyonia ingentis	**112**	50	**9**	0	11	6	2	**30**
Astropecten californicus	0	<1	**4**	0	4	5	3	<1
Strongylocentrotus fragilis	0	92	6	**442**	0	5	**136**	**85**
Acanthoptilum sp	0	0	**121**	0	0	43	37	0
Ophiura luetkenii	0	0	**2**	**2640**	0	48	17	0
Luidia foliolata	0	0	0	**11**	0	4	6	1
Astropecten ornatissimus	0	0	0	**5**	0	<1	<1	0

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

Appendix I.11

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

	Cluster Groups			
Species	**A**	**B** [a]	**C**	**D**
Pyromaia tuberculata	2	**1**	1	<1
Crangon nigromaculata	**2**	0	1	<1
Ophiura luetkenii	0	**72**	<1	0
Dendraster terminalis	0	**3**	1	1
Ophiothrix spiculata	0	**3**	1	2
Crangon alba	0	**2**	<1	0
Octopus rubescens	0	**1**	1	1
Pagurus spilocarpus	0	**1**	<1	<1
Megastraea turbanica	0	**1**	0	0
Astropecten californicus	0	0	**31**	<1
Lytechinus pictus	0	0	13	**2**
Kelletia kelletii	0	0	1	**1**
Pisaster brevispinus	0	0	**1**	0
Platymera gaudichaudii	0	0	<1	**1**
Crossata ventricosa	0	0	<1	**1**

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

Appendix J

Contaminants in Marine Fishes

2019 Supplemental Analyses

Appendix J.1

Constituents and method detection limits (MDL) used for the analysis of liver and muscle tissues of fishes collected during 2019; nr = not reportable.

	MDL			MDL	
Parameter	**Liver**	**Muscle**	**Parameter**	**Liver**	**Muscle**
Metals (ppm)					
Aluminum (Al)	7.79-27.80	2.60	Lead (Pb)	0.368-1.31	0.122
Antimony (Sb)	0.461-1.65	0.153	Manganese (Mn)	0.381-1.36	0.127
Arsenic (As)	0.381-1.36	0.127	Mercury (Hg)	0.008	0.003
Barium (Ba)	0.665-2.31	0.221	Nickel (Ni)	0.092-0.323	0.03
Beryllium (Be)	0.004-0.014	0.001	Selenium (Se)	0.529-1.86	0.176
Cadmium (Cd)	0.040-0.144	0.013	Silver (Ag)	0.117-0.418	0.039
Chromium (Cr)	0.111-0.389	0.037	Tin (Sn)	0.389-2.06	0.686
Copper (Cu)	0.415-1.45	0.138	Zinc (Zn)	1.053-3.71	0.351
Iron (Fe)	3.46-12.40	1.15			
Chlorinated Pesticides (ppb)					
Hexachlorocyclohexane (HCH)					
HCH, Alpha isomer	2.18-2.69	0.26-0.27	HCH, Delta isomer	3.38-4.95	0.48-0.49
HCH, Beta isomer	1.89-2.77	0.27-0.28	HCH, Gamma isomer	2.09-2.78	0.27-0.28
Total Chlordane					
Alpha (cis) chlordane	2.36-3.46	0.34-0.35	Heptachlor epoxide	1.75-2.57	0.25-0.26
Cis nonachlor	2.55-3.15	0.30-0.31	Methoxychlor	1.58-2.31	0.22-0.23
Gamma (trans) chlordane	2.32-3.09	0.30-0.31	Oxychlordane	2.23-3.27	0.32-0.33
Heptachlor	2.69-3.95	0.38-0.39	Trans nonachlor	1.64-2.40	0.23-0.24
Total Dichlorodiphenyltrichloroethane (DDT)					
o,p-DDD	3.9-5.72	0.55-0.57	p,p-DDD	6.23-7.48	0.73-0.74
o,p-DDE	3.08-3.80	0.37-0.38	p,p-DDE	10.4-15.2	1.49-1.52
o,p-DDT	2.65-3.53	0.34-0.35	p,p-DDT	4.34-6.37	0.62-0.63
p,-p-DDMU	2.31-3.39	0.33-0.34			
Miscellaneous Pesticides					
Aldrin	1.96-2.88	0.28-0.29	Endrin	1.15-1.68	0.17
AlphaEndosulfan	1.17-1.71	0.17	Endrin aldehyde	0.48-0.7	0.07
BetaEndosulfan	6.64-9.74	0.94-0.97	Hexachlorobenzene (HCB)	nr	46
Dieldrin	0.95-1.4	0.14	Mirex	6.08-8.1	0.79-0.81
EndosulfanSulfate	2-2.93	0.28-0.29			

Appendix J.1 *continued*

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Polychlorinated Biphenyls Congeners (PCBs) (ppb)					
PCB 18	1.87-2.74	0.26-0.27	PCB 126	1.47-2.16	0.21-0.22
PCB 28	2.55-3.14	0.30-0.31	PCB 128	4.07-5.97	0.58-0.59
PCB 37	1.77-2.60	0.25-0.26	PCB 138	4.46-6.54	0.64-0.65
PCB 44	2.36-3.14	0.30-0.31	PCB 149	3.50-5.13	0.50
PCB 49	2.04-2.99	0.29-0.30	PCB 151	6.3-7.56	0.74-0.75
PCB 52	2.08-3.05	0.29-0.30	PCB 153/168	10.5-15.5	1.52-1.53
PCB 66	3.49-4.52	0.50	PCB 156	1.84-2.70	0.26-0.27
PCB 70	4.07-4.71	0.49-0.50	PCB 157	2.41-2.97	0.29-0.30
PCB 74	4.08-4.31	0.49-0.50	PCB 158	5.25-6.47	0.63-0.64
PCB 77	2.36-3.14	0.30-0.31	PCB 167	3.95-4.61	0.45-0.46
PCB 81	3.02-4.43	0.43-0.44	PCB 169	2.22-3.26	0.32-0.33
PCB 87	1.67-2.45	0.24-0.25	PCB 170	2.28-3.35	0.33-0.34
PCB 99	1.88-2.75	0.26-0.27	PCB 177	4.86-5.99	0.58-0.59
PCB 101	1.83-2.69	0.26-0.27	PCB 180	4.53-6.65	0.65-0.66
PCB 105	3.07-4.50	0.44-0.45	PCB 183	4.78-6.37	0.68-0.70
PCB 110	3.46-5.08	0.50	PCB 187	5.01-7.35	0.72-0.73
PCB 114	4.44-5.77	0.56-0.58	PCB 189	3.37-4.49	0.44-0.45
PCB 118	4.35-6.38	0.63-0.64	PCB 194	5.25-7.70	0.75-0.76
PCB 119	3.86-5.15	0.50-0.51	PCB 201	6.49-9.52	0.92-0.95
PCB 123	5.04-6.21	0.60-0.61	PCB 206	5.94-6.66	0.71-0.72
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
1-methylnaphthalene	16.3-36.2	22.4-23.1	Benzo[G,H,I]perylene	25.5-56.6	57.1-59
1-methylphenanthrene	26.1-58.1	25.4-26.2	Benzo[K]fluoranthene	30.0-66.6	35.8-37.0
2,3,5-trimethylnaphthalene	20.3-45.2	20.7-21.4	Biphenyl	38	nr
2,6-dimethylnaphthalene	33.5-74.5	12.7-13.1	Chrysene	17.0-37.7	22.1-22.8
2-methylnaphthalene	20.3-45.2	18.7-19.3	Dibenzo(A,H)anthracene	35.2-78.3	38.7-40.0
3,4-benzo(B)fluoranthene	28.3-62.9	25.7-26.6	Fluoranthene	18.6-41.4	12.4-12.9
Acenaphthene	27.1-60.2	10.9-11.3	Fluorene	25.6-56.8	10.9-11.4
Acenaphthylene	23.1-51.4	8.74-9.08	Indeno(1,2,3-CD)pyrene	24.0-53.3	44.7-46.1
Anthracene	23.7-52.7	8.07-8.33	Naphthalene	32.0-71.2	nr
Benzo[A]anthracene	44.3-98.5	15.3-15.8	Perylene	17.3-38.5	48.9-50.5
Benzo[A]pyrene	40.2-89.3	17.6-18.2	Phenanthrene	10.9-24.2	12.4-12.8
Benzo[e]pyrene	39.2-87.0	39.0-40.3	Pyrene	8.52-18.9	15.9-16.5

Appendix J.2
Species of fish collected from each PLOO trawl and rig fishing zone[a] during October surveys from 1995 through 2019.

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 J.2 *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 J.2 *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 J.2 *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
2016	RF1	RF1	Vermilion Rockfish	Vermilion Rockfish	Mixed Rockfish
2016	RF2	RF2	Speckled Rockfish	Mixed Rockfish	Mixed Rockfish
2016	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2016	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2016	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2016	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2017	RF1	RF1	Vermilion Rockfish	Vermilion Rockfish	Vermilion Rockfish
2017	RF2	RF2	Vermilion Rockfish	Vermilion Rockfish	Mixed Rockfish
2017	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2017	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2017	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab

Appendix J.2 *continued*

Year	Zone	Station	Composite 1	Composite 2	Composite 3
2017	TZ4	TZ4	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2019	RF1	RF1	Vermilion Rockfish	Vermilion Rockfish	Vermilion Rockfish
2019	RF2	RF2	Starry Rockfish	Greenstriped Rockfish	Mixed Rockfish
2019	TZ1	TZ1	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2019	TZ2	TZ2	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2019	TZ3	TZ3	Pacific Sanddab	Pacific Sanddab	Pacific Sanddab
2019	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 J.3

Species of fish collected from each SBOO trawl and rig fishing zone during October surveys from 1995 through 2019.

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 J.3 *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 J.3 *continued*

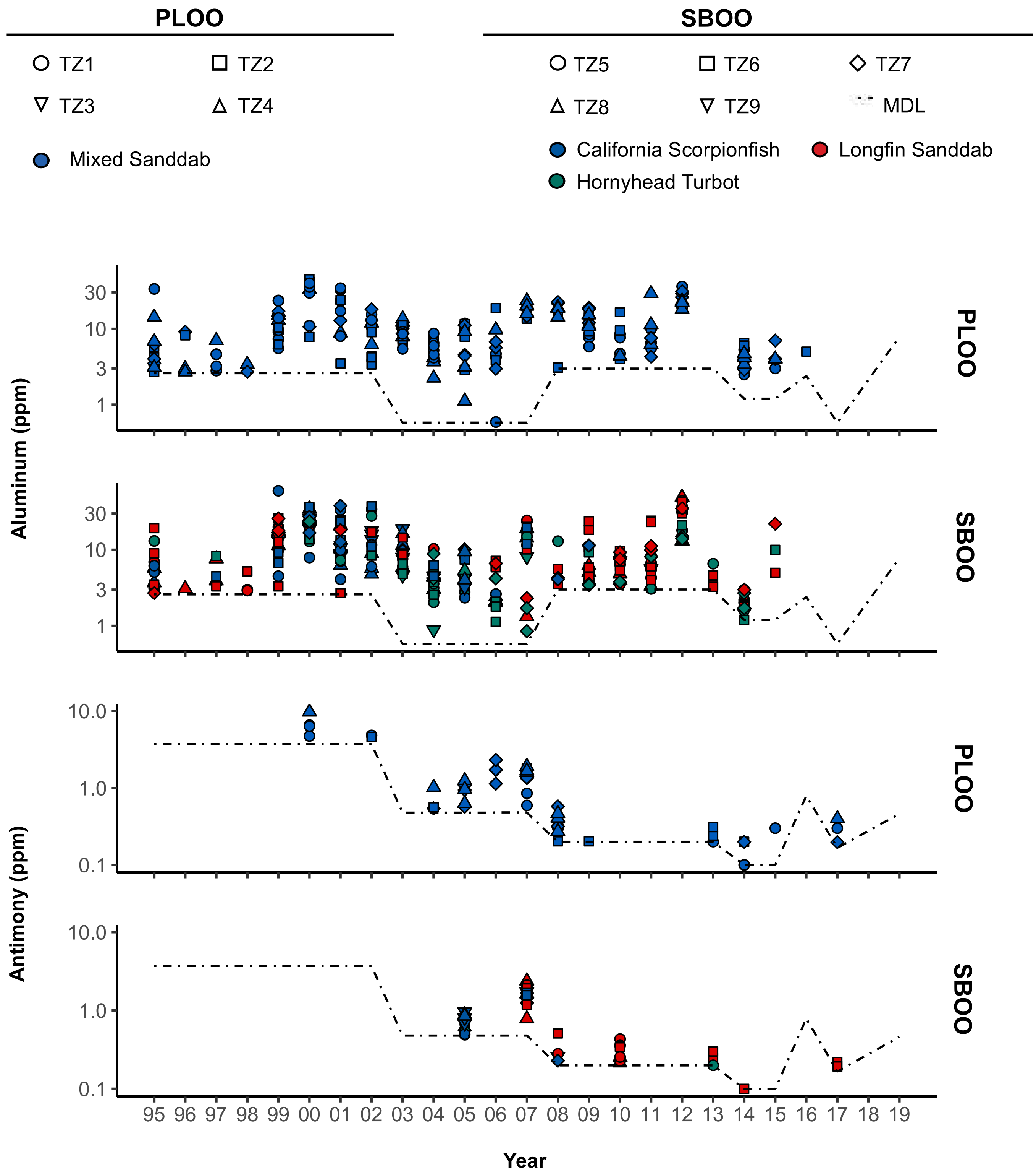
Year	Zone	Station	Composite 1	Composite 2	Composite 3
2004	TZ7	SD21	Hornyhead Turbot	California Scorpionfish	Hornyhead Turbot
2004	TZ8	SD16	Hornyhead Turbot	Hornyhead Turbot	California Scorpionfish
2004	TZ9	SD15	Hornyhead Turbot	California Scorpionfish	California Scorpionfish
2005	RF3	RF3	Brown Rockfish	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 J.3 *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

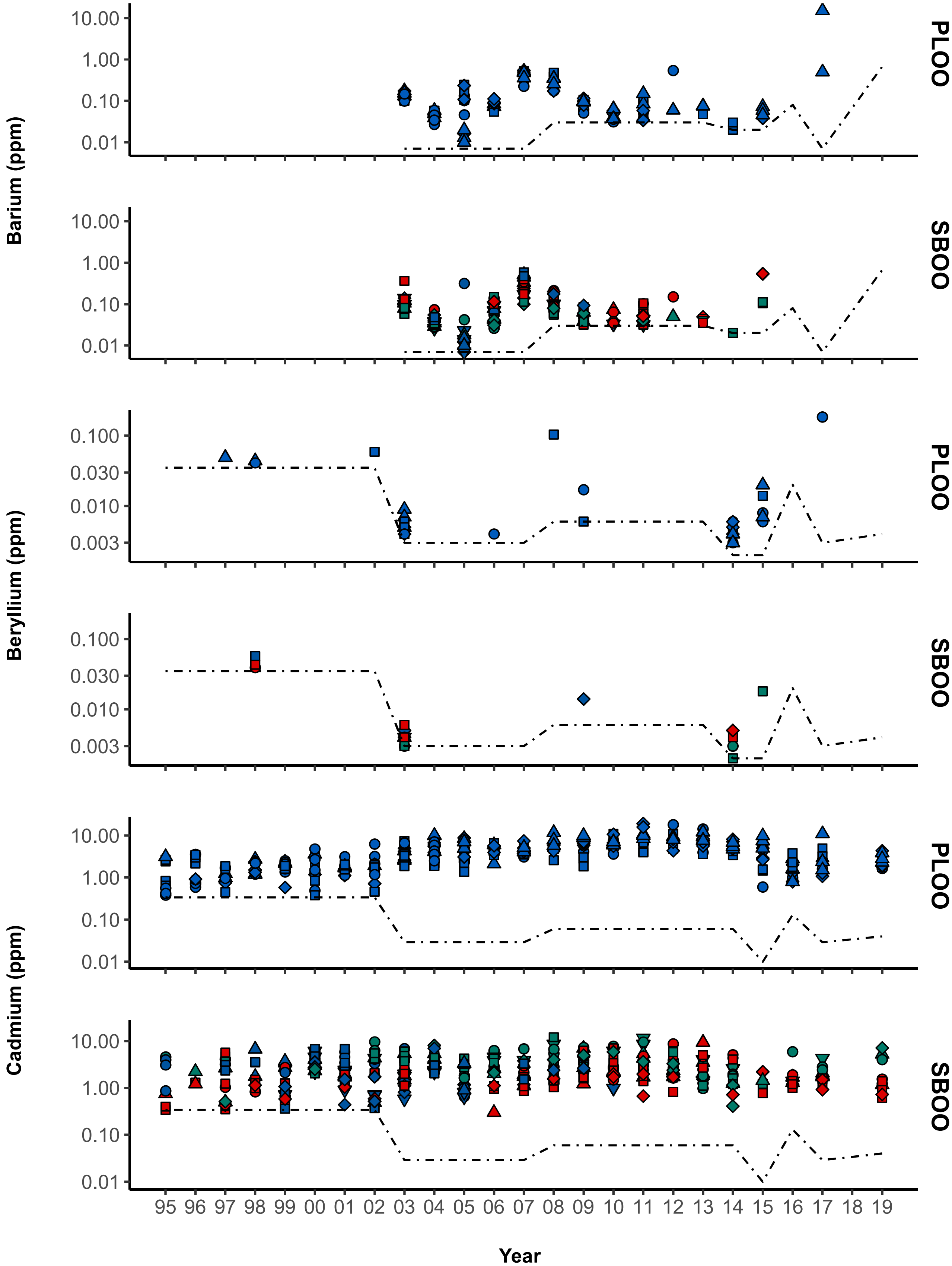
Appendix J.3 *continued*

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
2016	RF3	RF3	California Scorpionfish	Mixed Rockfish	Mixed Rockfish
2016	RF4	RF4	Treefish	Treefish	Starry Rockfish
2016	TZ5	TZ5	Fantail Sole	Hornyhead Turbot	Longfin Sanddab
2016	TZ6	TZ6	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2016	TZ7	TZ7	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2016	TZ8	TZ8	Longfin Sanddab	Longfin Sanddab	Fantail Sole
2016	TZ9	TZ9	Fantail Sole	Spotted Turbot	Hornyhead Turbot
2017	RF3	RF3	California Scorpionfish	California Scorpionfish	California Scorpionfish
2017	RF4	RF4	Gopher Rockfish	Treefish	Mixed Rockfish
2017	TZ5	TZ5	Fantail Sole	Hornyhead Turbot	Hornyhead Turbot
2017	TZ6	TZ6	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2017	TZ7	TZ7	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2017	TZ8	TZ8	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
2017	TZ9	TZ9	Fantail Sole	Hornyhead Turbot	Spotted Turbot
2019	RF3	RF3	California Scorpionfish	California Scorpionfish	Mixed Rockfish
2019	RF4	RF4	California Scorpionfish	California Scorpionfish	California Scorpionfish
2019	TZ5	TZ5	Longfin Sanddab	Longfin Sanddab	Hornyhead Turbot
2019	TZ6	TZ6	Longfin Sanddab	Longfin Sanddab	Longfin Sanddab
2019	TZ7	TZ7	Longfin Sanddab	Hornyhead Turbot	Fantail Sole
2019	TZ8	TZ8	Longfin Sanddab	Hornyhead Turbot	Fantail Sole
2019	TZ9	TZ9	Spotted Turbot	Fantail Sole	no sample

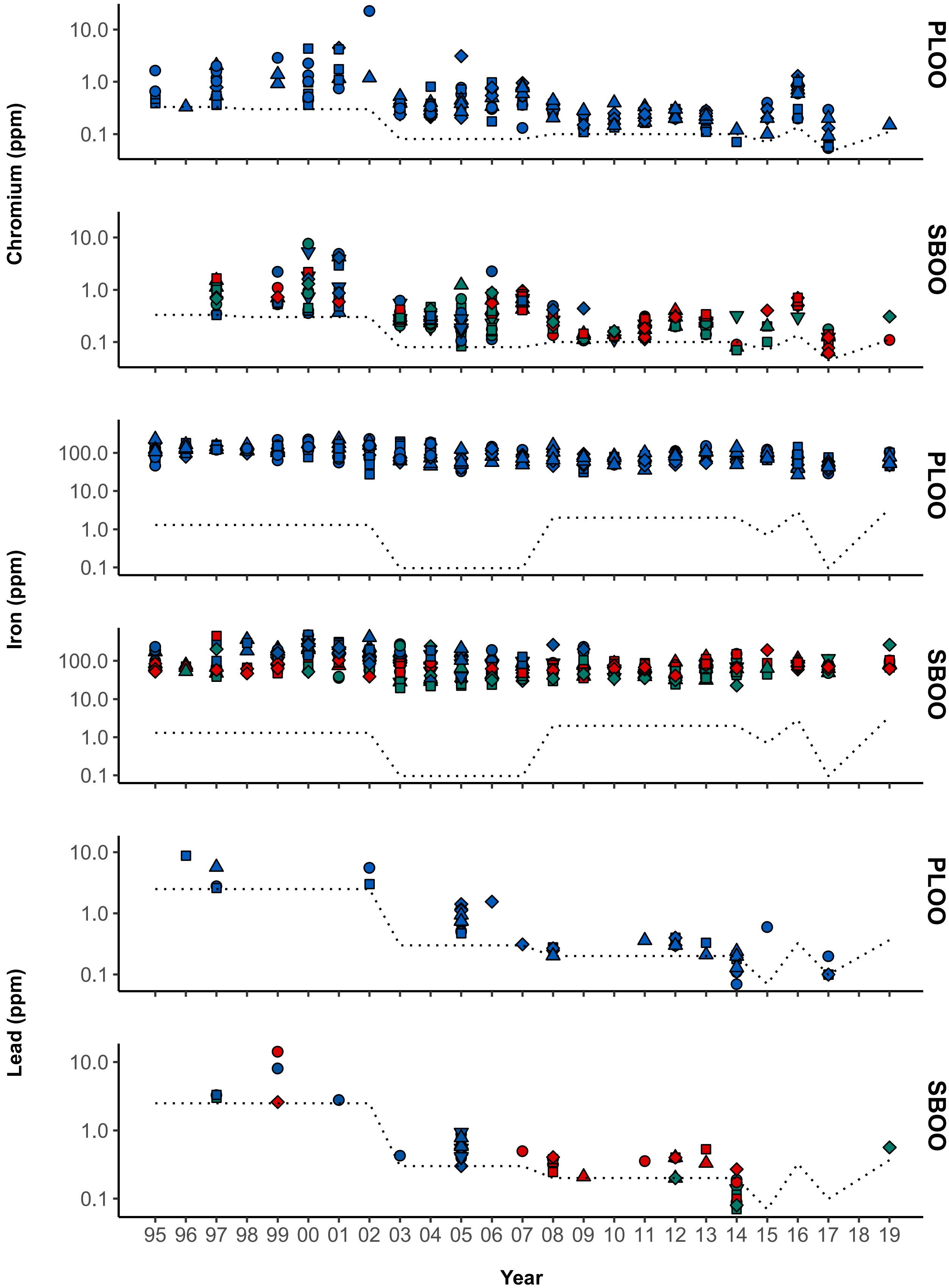


Appendix J.4

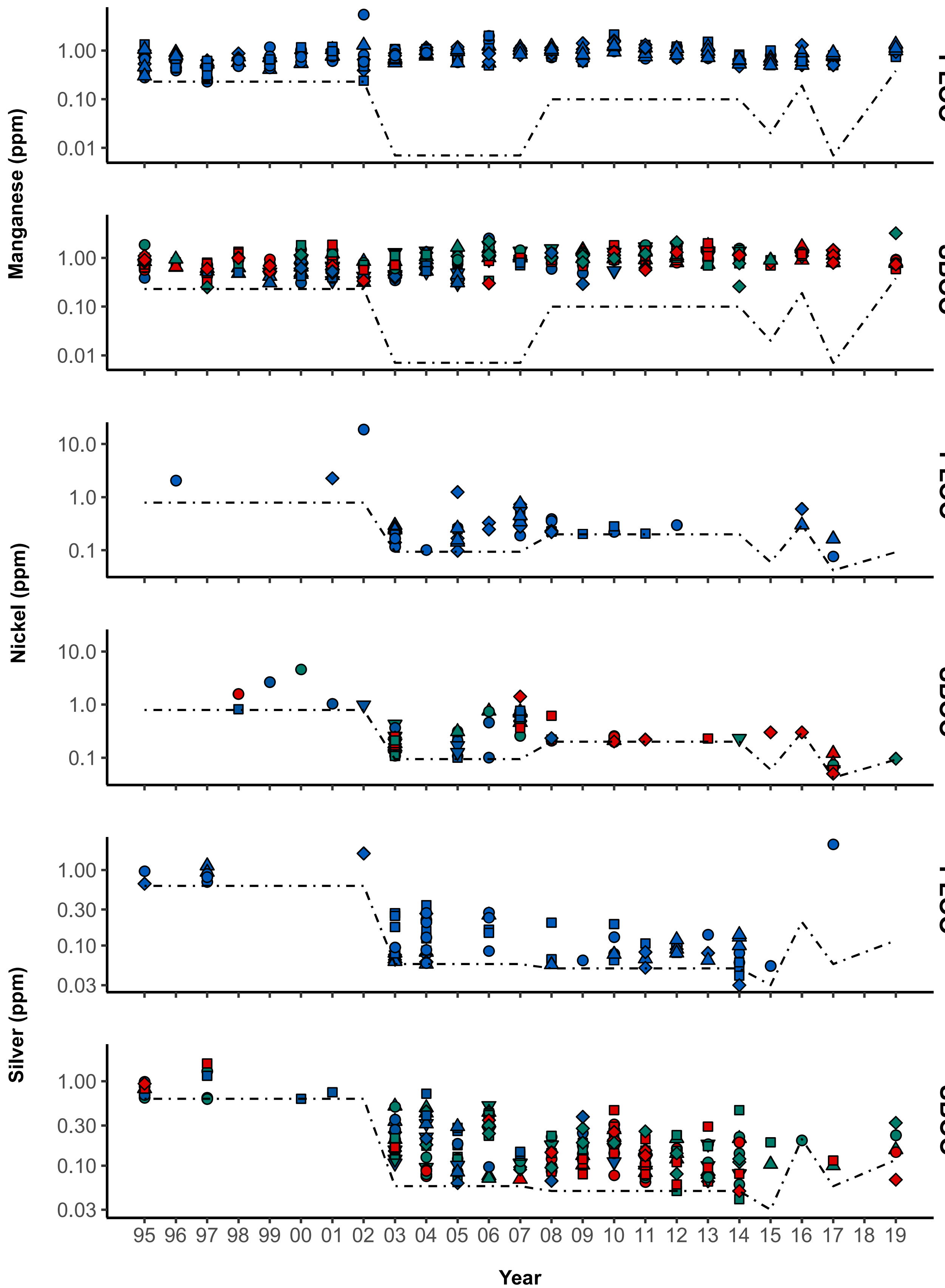
Concentrations of select metals in liver tissues of fishes collected from PLOO and SBOO trawl zones from 1995 through 2019. Zones TZ1 and TZ5 are considered nearfield. No samples were collected in 2018 (see text).



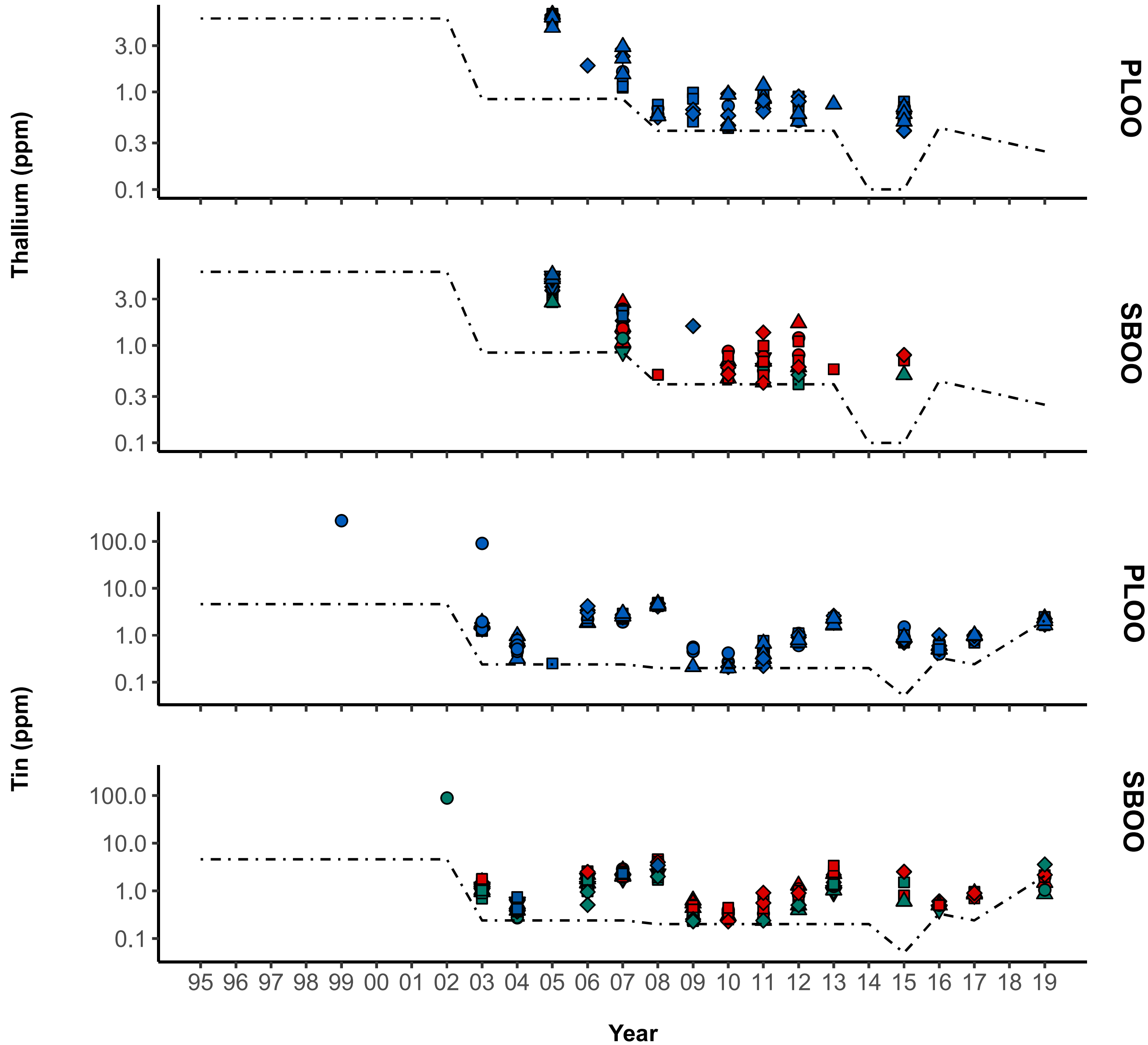
Appendix J.4 *continued*



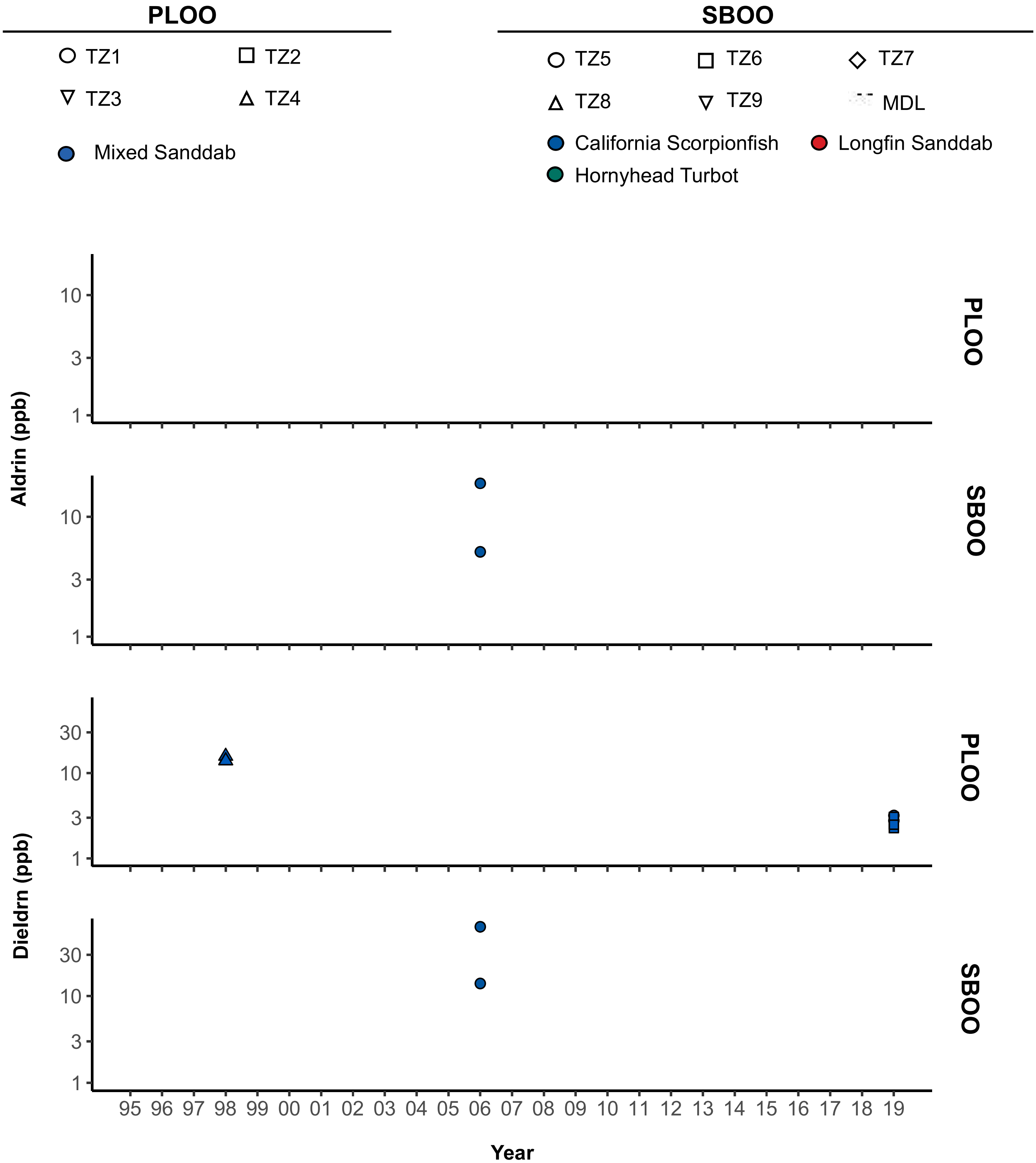
Appendix J.4 *continued*



Appendix J.4 *continued*

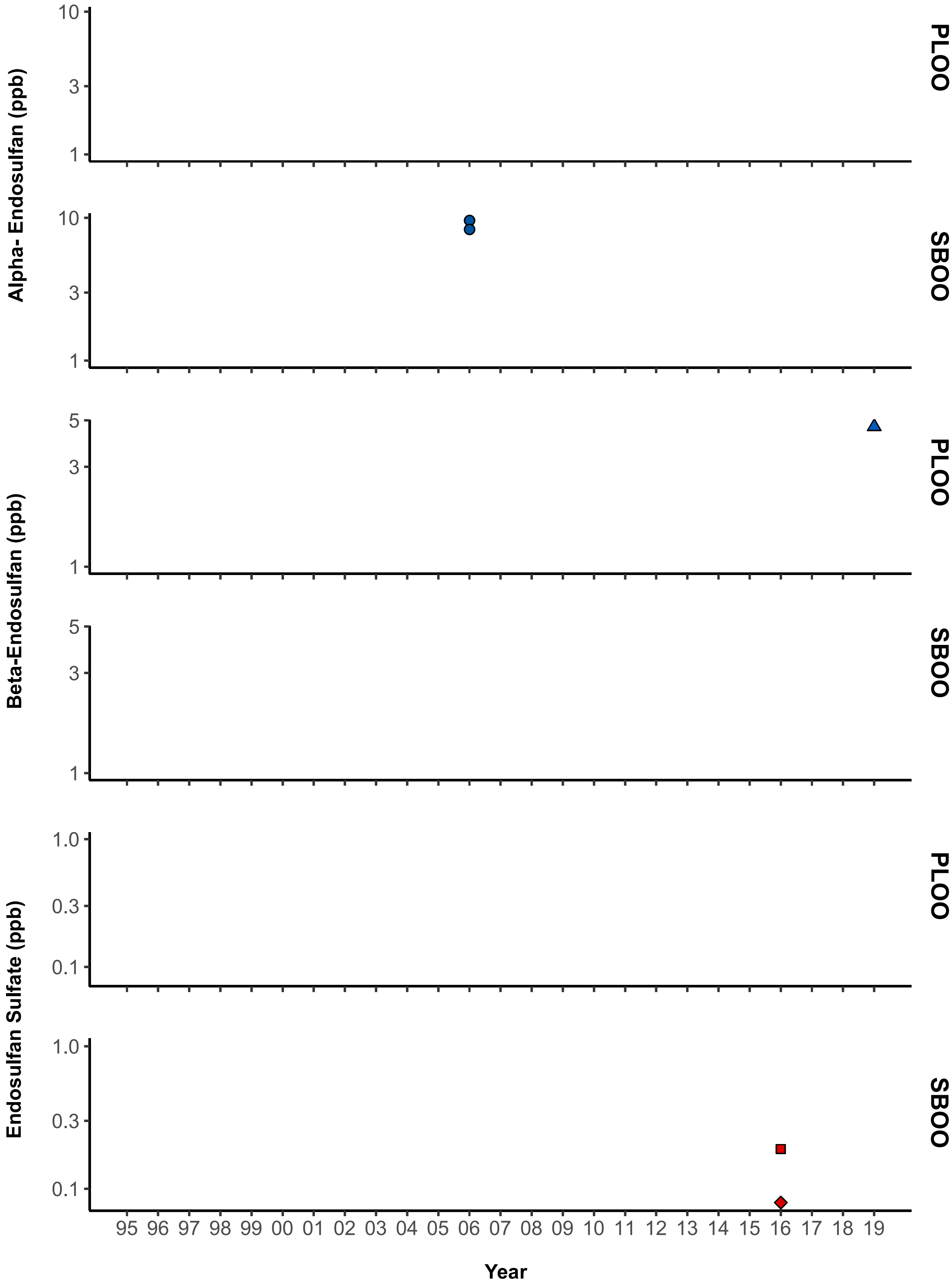


Appendix J.4 *continued*

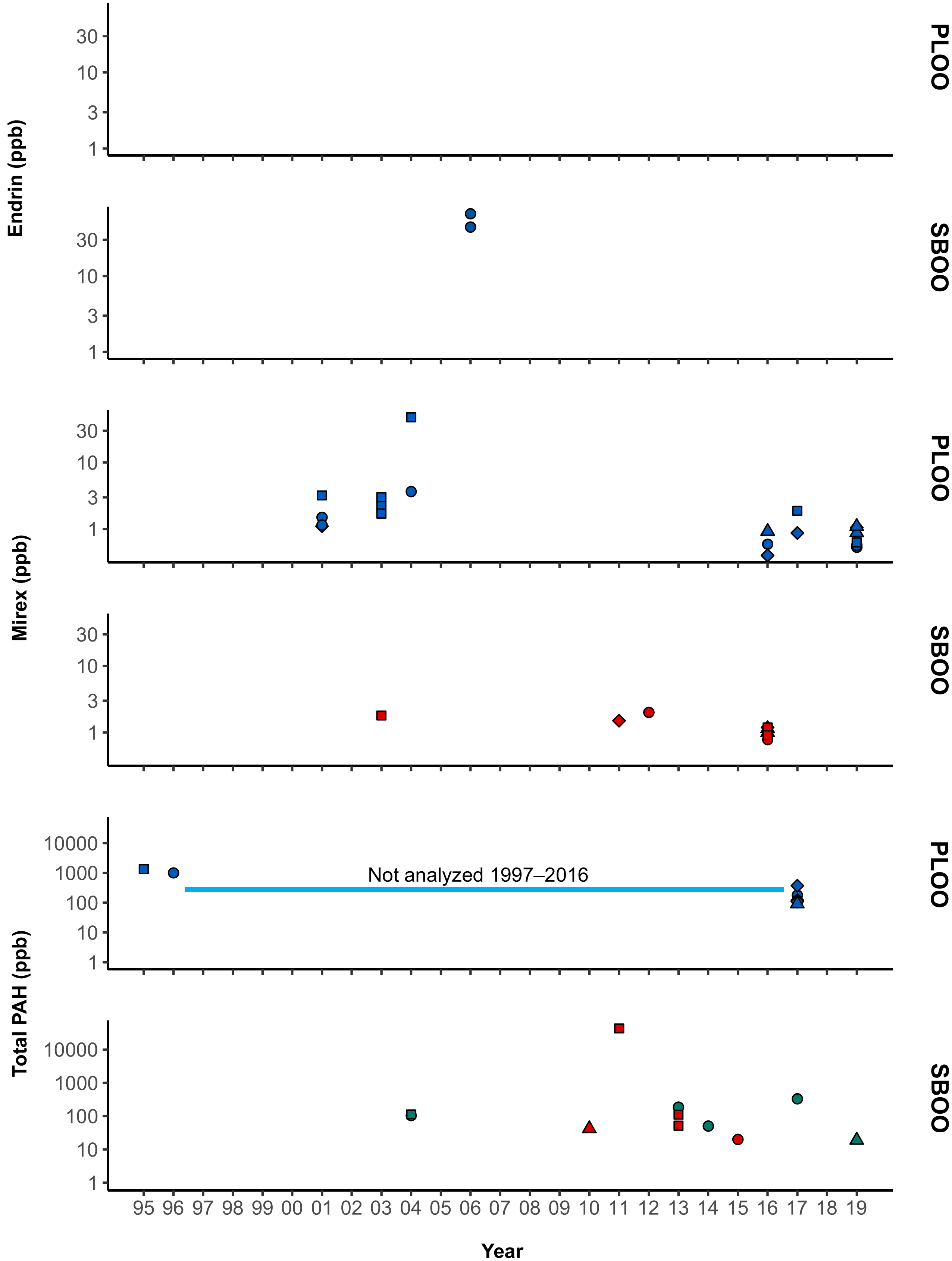


Appendix J.5

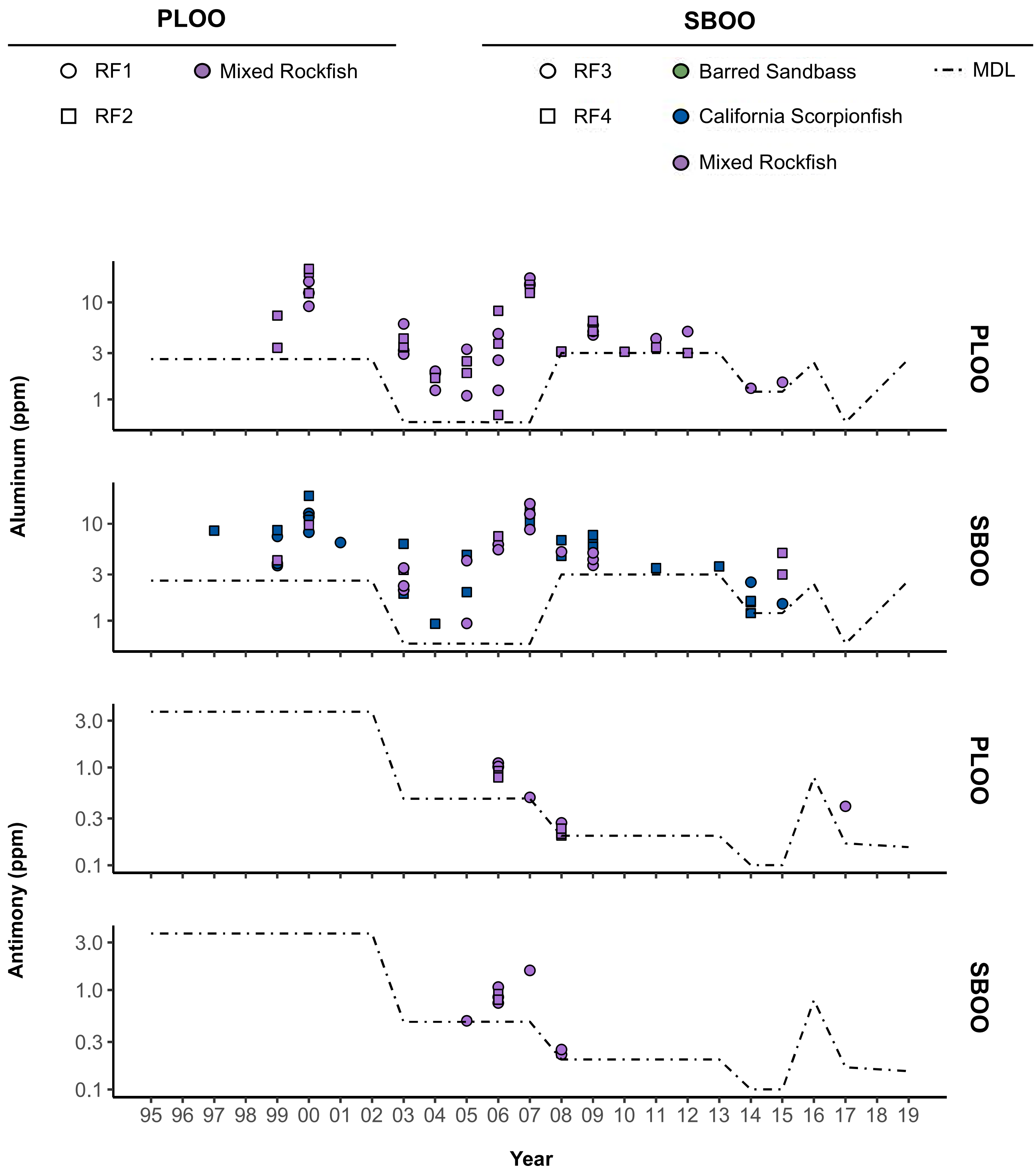
Concentrations of pesticides and total PAH in liver tissues of fishes collected from PLOO and SBOO trawl zones from 1995 through 2019. Zones TZ1 and TZ5 are considered nearfield. No samples were collected in 2018 (see text).



Appendix J.5 *continued*

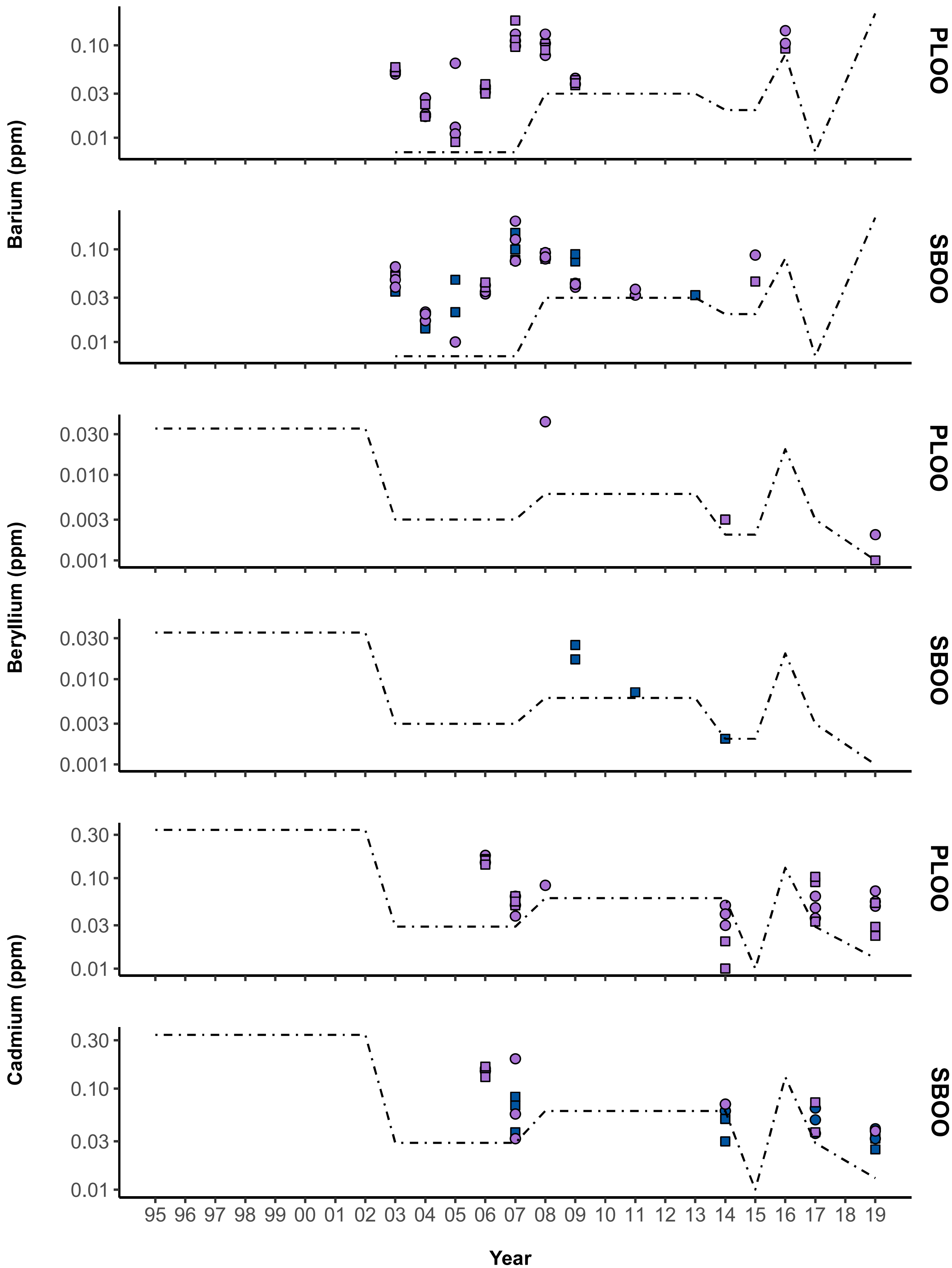


Appendix J.5 *continued*

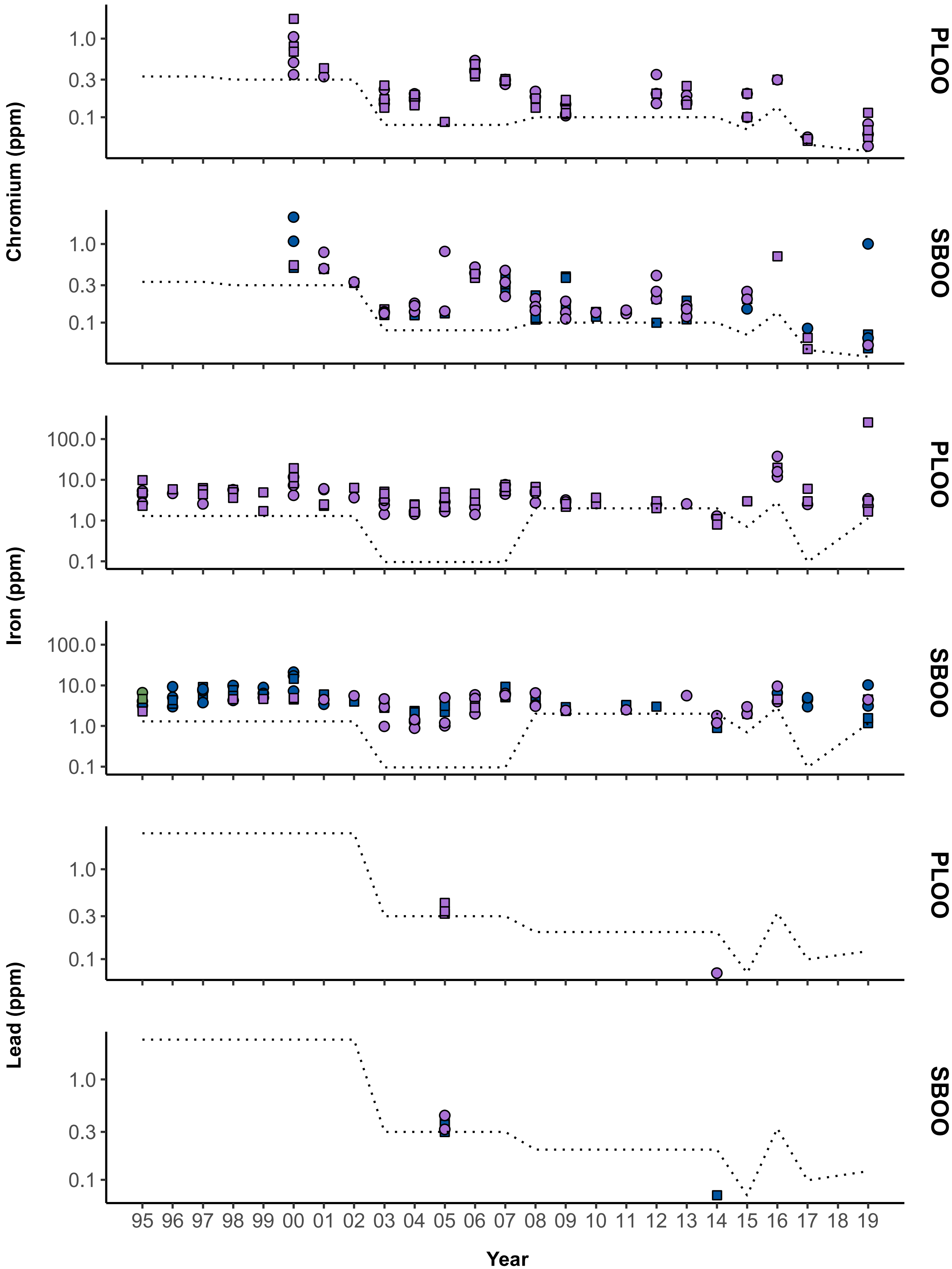


Appendix J.6

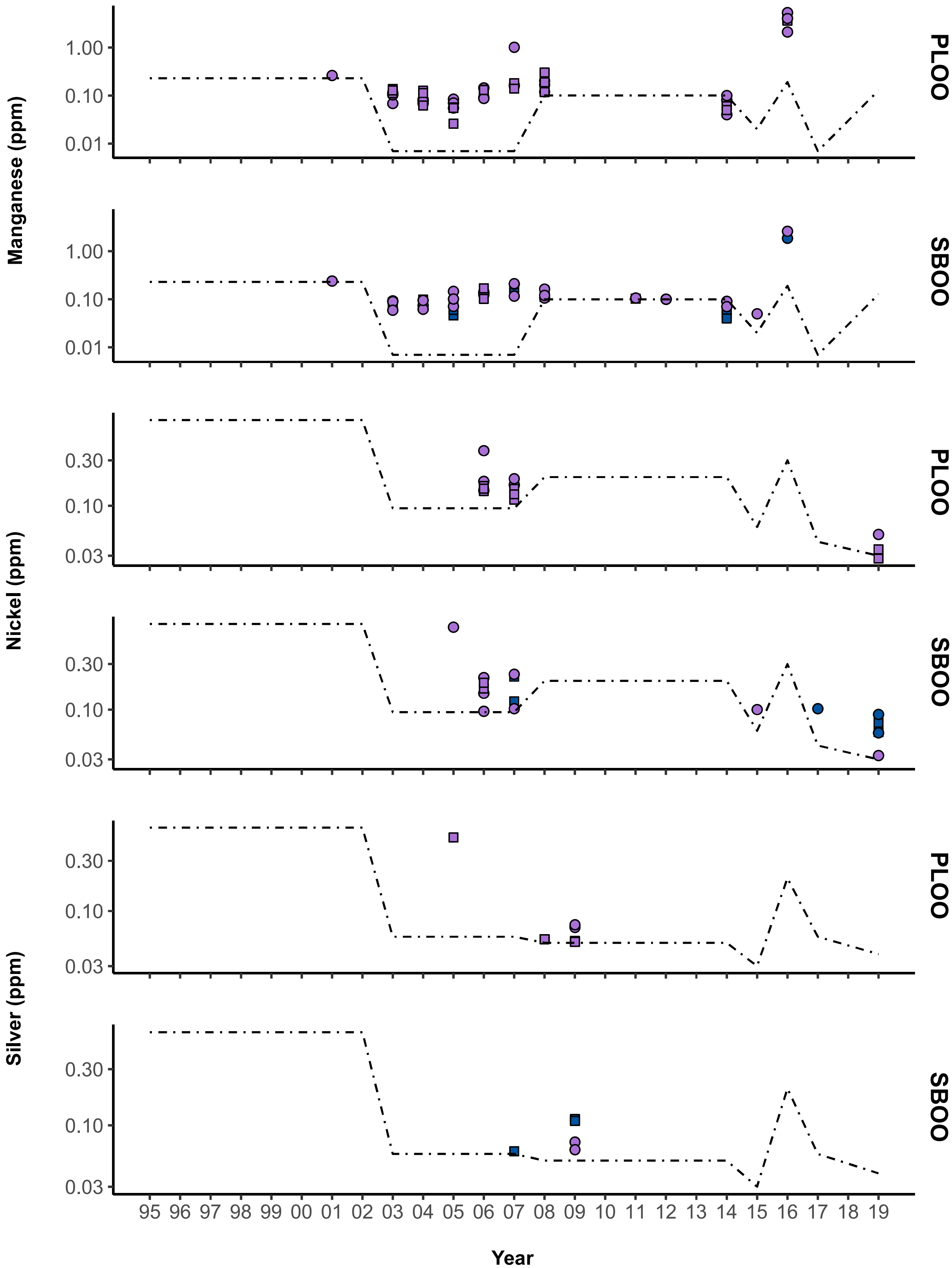
Concentrations of select metals in muscle tissues of fishes collected from PLOO and SBOO rig fishing zones from 1995 through 2019. Zones RF1 and RF3 are considered nearfield. No samples were collected in 2018 (see text).



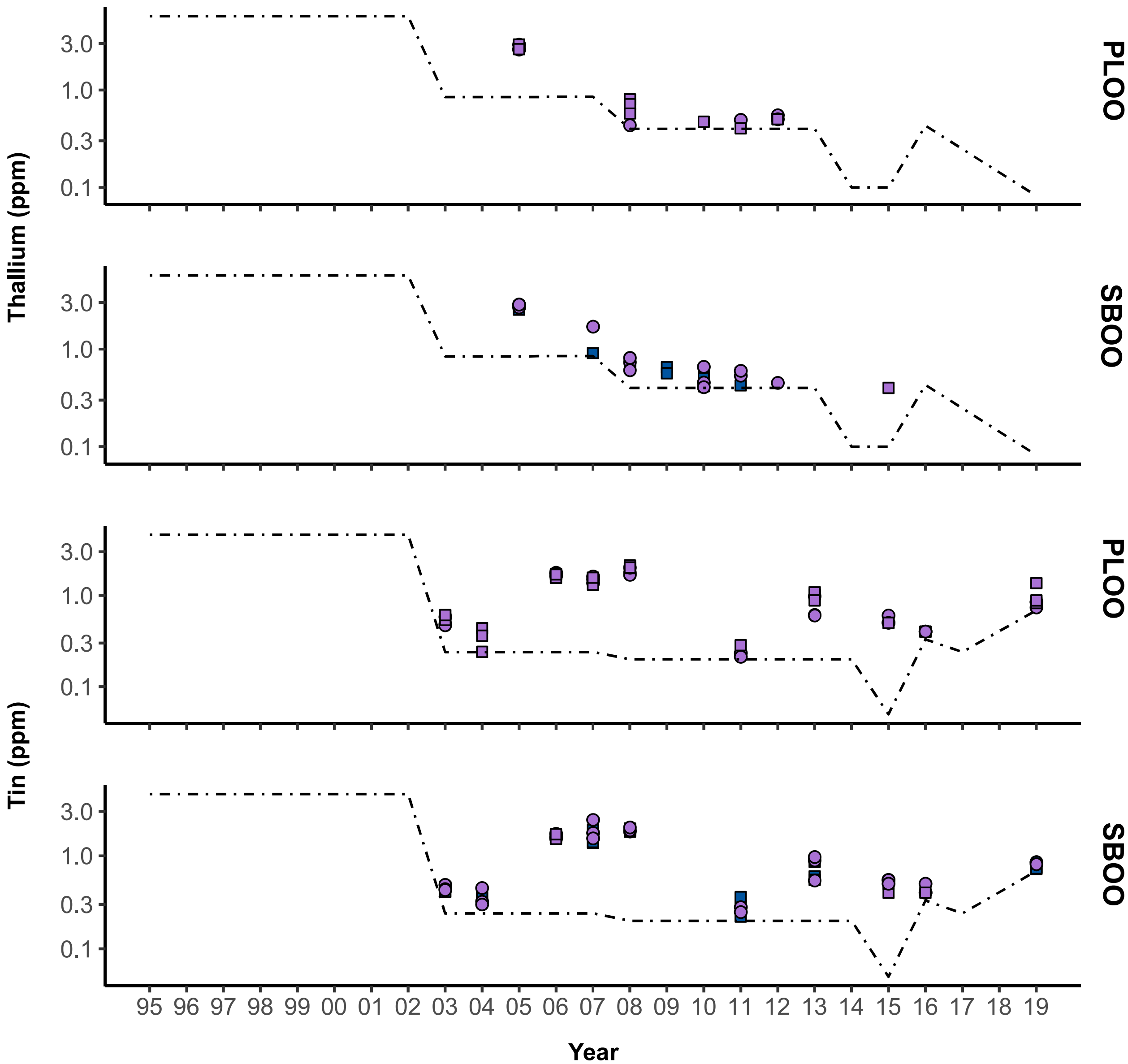
Appendix J.6 *continued*



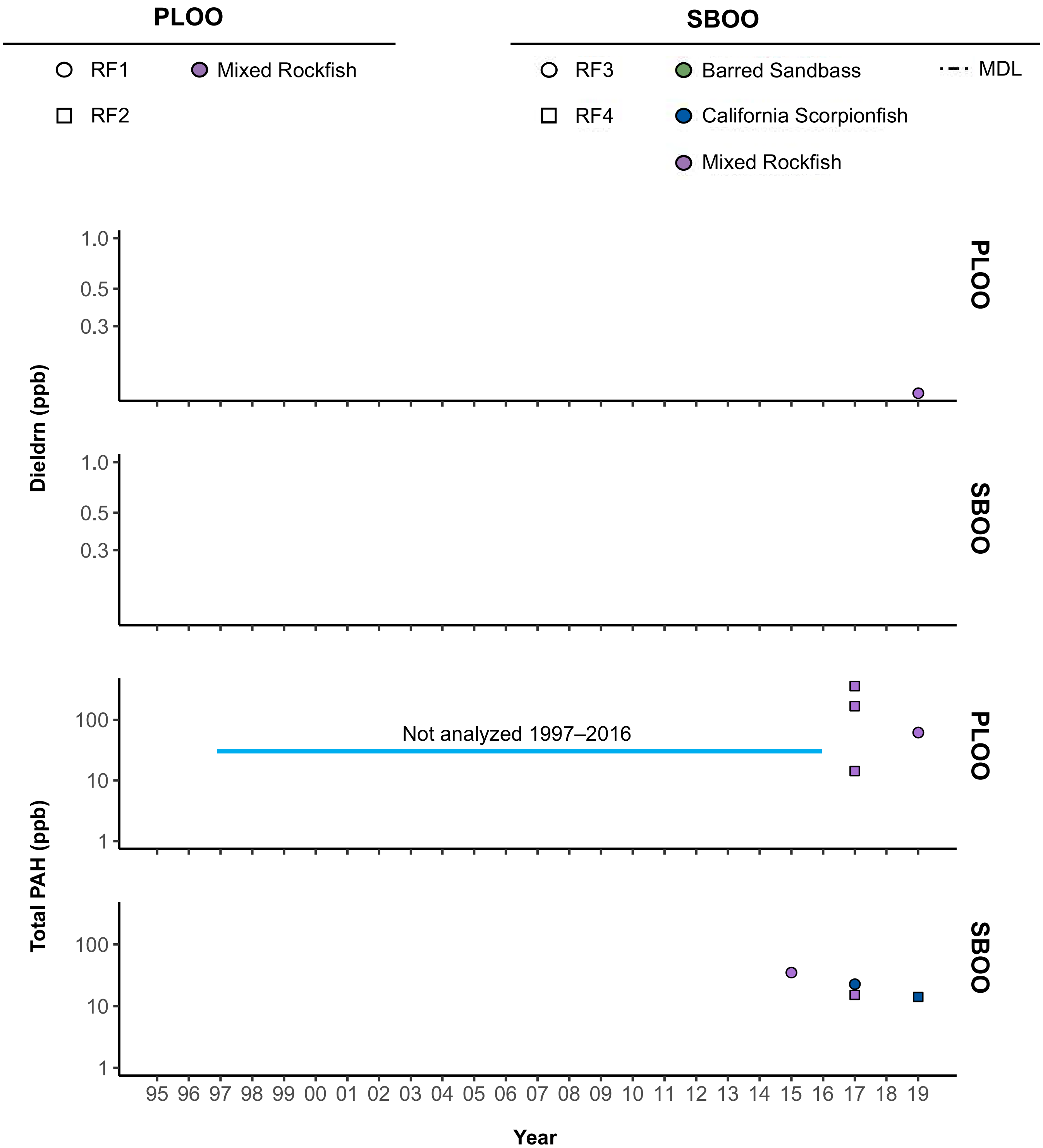
Appendix J.6 *continued*



Appendix J.6 *continued*



Appendix J.6 *continued*



Appendix J.7

Concentrations of dieldrin and total PAH in muscle tissues of fishes collected from PLOO and SBOO rig fishing zones from 1995 through 2019. Zones RF1 and RF3 are considered nearfield. No samples were collected in 2018 (see text).