Marine Conditions 2008–2019 Report Series: Sediment

December 2022

King County

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Appendices

Appendix A: Metals and Organics Sediment Quality Criteria
Appendix B: Trend Analysis Results

ABBREVIATIONS AND ACRONYMS

AET	Apparent Effects Threshold
CSL	Cleanup screening level
CSO	combined sewer overflow
CVAA	cold-vapor atomic absorption spectrophotometry
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DF	Detection frequency
dw	dry weight
ECD	electron capture detector
Ecology	Washington State Department of Ecology
GC	gas chromatography
GC/MS	gas chromatography/mass spectrometry
HPAH	high molecular weight polycyclic aromatic hydrocarbon
ICP	inductively coupled plasma
KCEL	King County Environmental Laboratory
LPAH	low molecular weight polycyclic aromatic hydrocarbon
MDL	method detection limit
MLLW	mean lower low water
NCI	negative chemical ionization
nMDS	non-metric multidimensional scaling
NPDES	National Pollution Discharge Elimination System
OC	organic carbon
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ethers
PCB	polychlorinated biphenyls
PSD	particle size distribution
PSEP	Puget Sound Estuary Program
SAP	sampling and analysis plan
SCI	Sediment Chemistry Index
SDI	Swartz's Dominance Index
SIM	selected ion monitoring
SMS	Sediment Management Standards
SQS	Sediment Quality Standards
TOC	total organic carbon
TP	treatment plant
TS	treatment station

1.0 INTRODUCTION

For over 50 years, King County has conducted extensive water quality monitoring to assess conditions in the Central Puget Sound Basin (King County waters). The King County Marine Monitoring Program is managed by scientists in the Water and Land Resources Division within the Department of Natural Resources. The program includes two types of monitoring (1) baseline monitoring to assess background conditions (ambient monitoring) and (2) monitoring to assess conditions near King County's wastewater treatment plant (TP), combined sewer overflow (CSO), and CSO wet weather treatment station (TS) marine outfalls (outfall monitoring).

The goals of the Marine Monitoring Program are to characterize water quality and food web (phytoplankton and zooplankton) conditions in King County receiving waters, provide information for management decisions, and evaluate the status and trends of marine waters within King County. These data provide insight into both short and long-term variations and form a baseline from which marine conditions can be assessed on multiple temporal and spatial scales. Please see *Marine Conditions Report Series 2008–2019: Marine Monitoring Program Overview* (King County, 2022a) for a more detailed description of the background and purpose of the Marine Monitoring Program.

This document presents results of the sediment monitoring component of the Marine Monitoring Program for data collected between 2009–2019 (no sediment samples collected in 2008). The sediment monitoring component of the Marine Monitoring Program consists of three types of sampling efforts:

- **Intertidal (beach)** – intertidal sediment collected at beaches near wastewater outfalls and ambient sediment collected at sites removed from point sources
- **Subtidal Outfall (offshore)** – subtidal sediment collected near three wastewater treatment plant outfalls (Brightwater, West Point, and South Plant)
- **Routine Subtidal (offshore)** – ambient subtidal non-outfall sediment collected from the Central Basin including Elliott Bay, smaller embayments, and mainstem locations.

Sediment samples are analyzed for a suite of physical and chemical parameters. Total solids, total organic carbon (TOC), grain size, metals, and a suite of organic compounds were analyzed in all samples. All samples were analyzed for the 47 chemicals of concern listed in marine sediment management standards (SMS) (Chapter 173–204 WAC [Ecology, 2013]). A select number of samples are analyzed for ammonia, total sulfides, benthic community metrics, and toxicity (bioassays).

Several overlapping goals are applicable to all three sampling components:

- Evaluate sediment chemical concentrations relative to the current marine sediment quality standards (SQS) of the SMS (Chapter 173–204 WAC [Ecology, 2013])

- Evaluate spatial and temporal variation of sediment chemical concentrations
- Gather sufficient data to determine both short and long-term sediment quality conditions
- Support coordinated regional monitoring efforts
- Collect scientific data of high quality to inform water quality management decisions.

An additional goal is applicable to samples collected from outfall and routine subtidal locations:

- Evaluate spatial differences in benthic community assemblages, as well as compare benthic community assemblages in the monitoring area to regional Puget Sound benthic community data collected by other agencies.

Analysis at some outfall sites is required per King County's National Pollution Discharge Elimination System (NPDES) permit:

- Conduct sediment bioassay tests to determine the nature and extent of toxicity.

The Marine Monitoring Program monitors multiple physical and chemical parameters concurrently at each sampling location. A summary of all data collected at each station is provided in *Marine Conditions Report Series 2008–2019: Marine Monitoring Program Overview* (King County, 2022a). Results for other Marine Monitoring Program components sampled between 2008–2019, (except pH), are provided in separate reports with hyperlinks (click on titles to access reports) below and include the following topics:

- Marine Monitoring Program overview
- Nutrients in offshore waters
- Nutrients in beach waters
- Dissolved oxygen in offshore waters
- Temperature, salinity, and density in offshore waters
- Temperature and salinity in beach waters
- Water clarity in offshore waters
- Fecal indicator bacteria in beach and offshore waters
- Chlorophyll in offshore waters
- Phytoplankton
- Zooplankton
- Chemical parameters in clam tissues.

2.0 METHODS

As described above, sediment samples are collected as part of three types of monitoring efforts: intertidal, subtidal outfall, and routine subtidal. The three sample types are collected on different schedules (Table 1). Sampling location information and sampling and analysis methods are described below.

Table 1. Sediment sampling types and years sampled.

Sampling Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Intertidal			✓					✓				
Subtidal Outfall				✓						✓	✓*	
Routine Subtidal		✓		✓	✓	✓		✓		✓		✓

*Results for 2 compounds in samples from a subset of stations near the West Point and South Plant outfalls exceeded sediment standards in 2017. These sites were resampled in 2018 to meet permit requirements.

For more detail on individual sampling events associated with data presented here please refer to the Sampling and Analysis Plans (SAP) for each sampling event:

- Intertidal sampling (King County, 2010a, 2015a)
- Subtidal outfall (King County, 2010b, 2010c, 2011b, 2011c, 2017b, 2017c)
- Routine subtidal (King County, 2009, 2011a, 2012b, 2015b, 2017a, 2019).

2.1 Sampling Locations

The following section provides an overview of the intertidal, subtidal outfall, and routine subtidal sampling locations.

2.1.1 Intertidal Sampling Locations

Sediments from the intertidal zone were collected from 16 stations located along the King County shoreline from Edwards Point to the north and to Dumas Bay to the south (Table 2, Figure 1). Seven stations were located near outfalls and nine were located away from point sources and considered ambient locations. All intertidal sampling stations are collocated with water sampling stations, except one outfall station located nearshore of the Alki TS outfall (LSKS04). Several sampling sites were also collocated with clam tissue contaminant monitoring sites (monitoring discontinued after 2010 see King County, 2022c).

Table 2. Intertidal sediment station names listed north to south.

Locator	Name	Station Type	First Year of Record
ITEDWARDSPT	Edwards Point	Ambient	2010
JSVW04	Richmond Beach	Ambient	1987
ITCARKEEKP	Carkeek Park	Ambient	2010
KSHZ03	Carkeek Park - Piper's Creek Outflow	Outfall	1987
KSLU03	Golden Gardens Park	Ambient	1987
KSSN04	West Point North Beach	Outfall	1987
KSSN05	West Point South Beach	Outfall	1987
KSYV02	Magnolia CSO	Outfall	1985
LSKS04	Alki Point – South Side	Outfall	2010
LSVW01	Fauntleroy Cove Beach	Ambient	1985
MTEC01	Seahurst Park	Ambient	1989
MSJL01	Vashon Outfall Beach	Outfall	2002
MTLD03	Normandy Park	Outfall	1999
MSXK01	Burton Acres Park	Ambient	2010
NTFK01	Redondo Beach	Ambient	2010
NSJY01	Dumas Bay	Ambient	2010

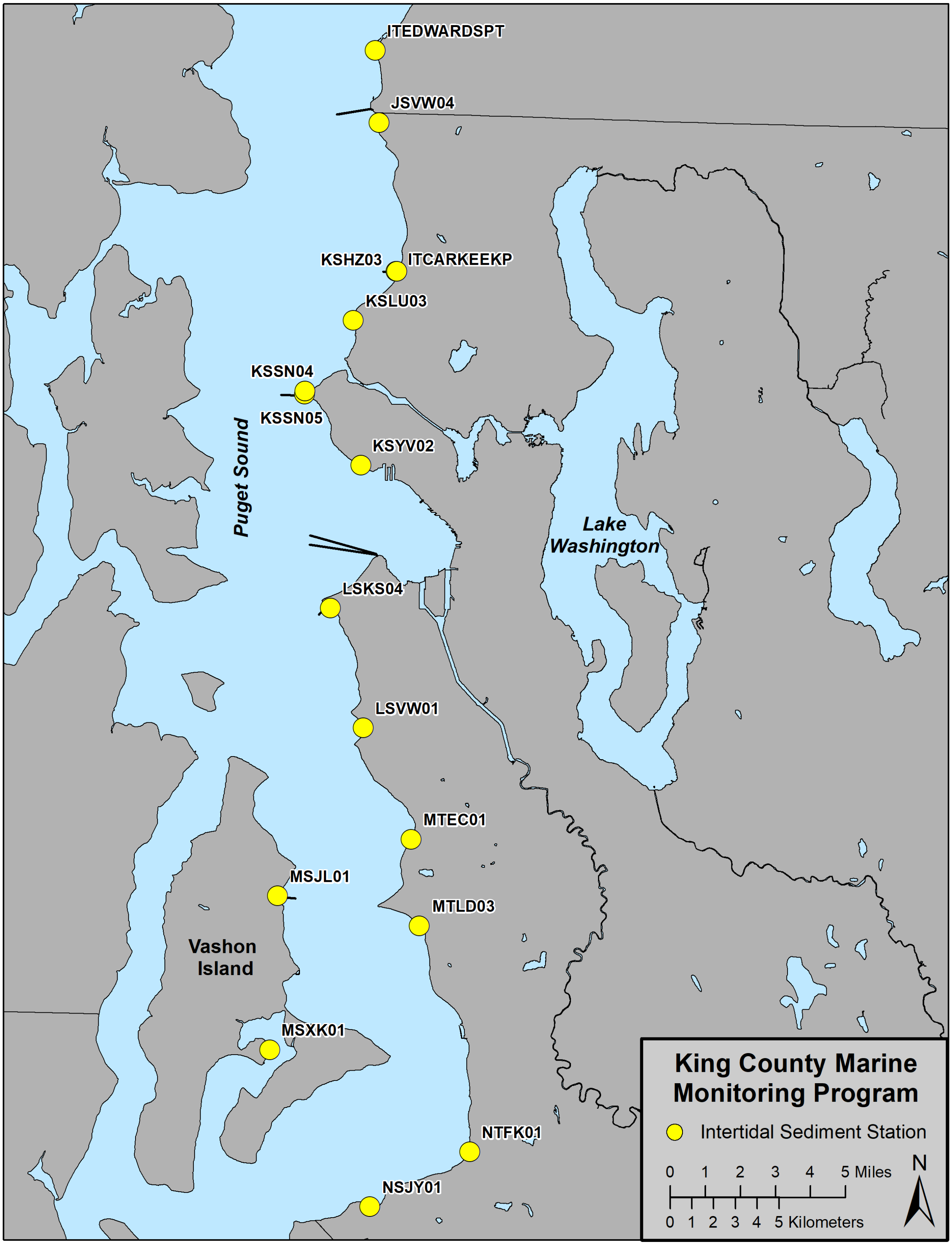

Figure 1. Intertidal sediment sampling locations.

2.1.2 Subtidal Sampling Locations

Subtidal sampling locations include sites near outfalls (Brightwater, West Point, and South TP). These sampling locations have changed over time but were consistent for the timeframe of this report. Routine monitoring site locations (Elliott Bay, Central Basin mainstem stations, and embayments) are removed from direct point sources and sometime referred to as ambient, but some are still located near non-point sources and/or areas of historic contamination. Subtidal monitoring sampling locations are described below.

Subtidal Outfall

Sediments near the Brightwater, West Point, and South TP outfalls were collected in 2011 and 2017[1] (Table 3 and Figure 2). A subset of stations located near South Plant and West Point TPs were resampled in 2018 to meet NPDES permit requirements[2]. Sediments are not sampled near the Vashon TP outfall due to the rocky habitat surrounding the terminus of the outfall. Eight to ten sampling stations near each outfall are generally located along transects in a north-to-south alignment (prevailing net current direction is north) with respect to distance from the discharge point. The deep Brightwater (~185 m) and South TP outfalls (~195 m) sampling locations are in depositional areas, while the shallower West Point TP outfall (~75 m) sampling location is in an area subject to high bottom currents with minimal deposition.

Table 3. Subtidal outfall station locators.

Brightwater TP	West Point TP	South TP
BWND800N	WP420NW	STP820NE
BWSD800N	WP430N	STP460N
BWND400N	WP215N	STP625NP
BWSD400N	WP410W	STP610MN
BWND600P	WP280W	STP570MS
BWSD600P	WP230P	STP625SP
BWND400S	WP430S	STP460S
BWSD400S	WPD215N	STP770SE
BWND800S		
BWSD800S		

Routine Subtidal

Routine subtidal samples are collected from 14 Central Basin stations on two different sampling intervals. Eight Elliott Bay stations are sampled every two years, most recently in 2019 (Table 4 and Figure 2). Three mainstem and three embayment stations are sampled every five years (Table 4 and Figure 2). Mainstem and embayment station data presented here were collected in 2012 and 2017.

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[1] A subset of Brightwater TP outfall sites were sampled in 2017 and analyzed for conventional parameters and benthic infauna.

[2] Sediment chemistry results in 2017 indicated SQS exceedances for benzoic acid and benzyl alcohol at some locations. Per NPDES permit-requirements, these sites were resampled/analyzed in 2018. Data from both events are part of the same "permit monitoring event".

Table 4. Routine subtidal sampling location, location type, locator name, and sampling frequency.

Location Type	Locator	Name	Sampling Frequency
Elliott Bay	KSZY01	Piers 90/91	Every 2 years
	LTAA02	Elliott Bay Grain Terminal	
	LSCW02	Outer Elliott Bay	
	LTCA02	Mid-Outer Elliott Bay	
	LTDF01	Seattle waterfront (near Pier 66)	
	LTED04	Central Elliott Bay	
	LTGF01	Harbor Island (north end)	
	LSHZ08	Seacrest Park (Cove 2)	
Mainstem	KSBP01	Point Jefferson	Every 5 years.
	LSML01	West Seattle	
	NSEX01	East Passage	
Embayment	KSUR03	Outer Salmon Bay	
	LSVV01	Fauntleroy Cove	
	MSVK01	Inner Quartermaster Harbor	

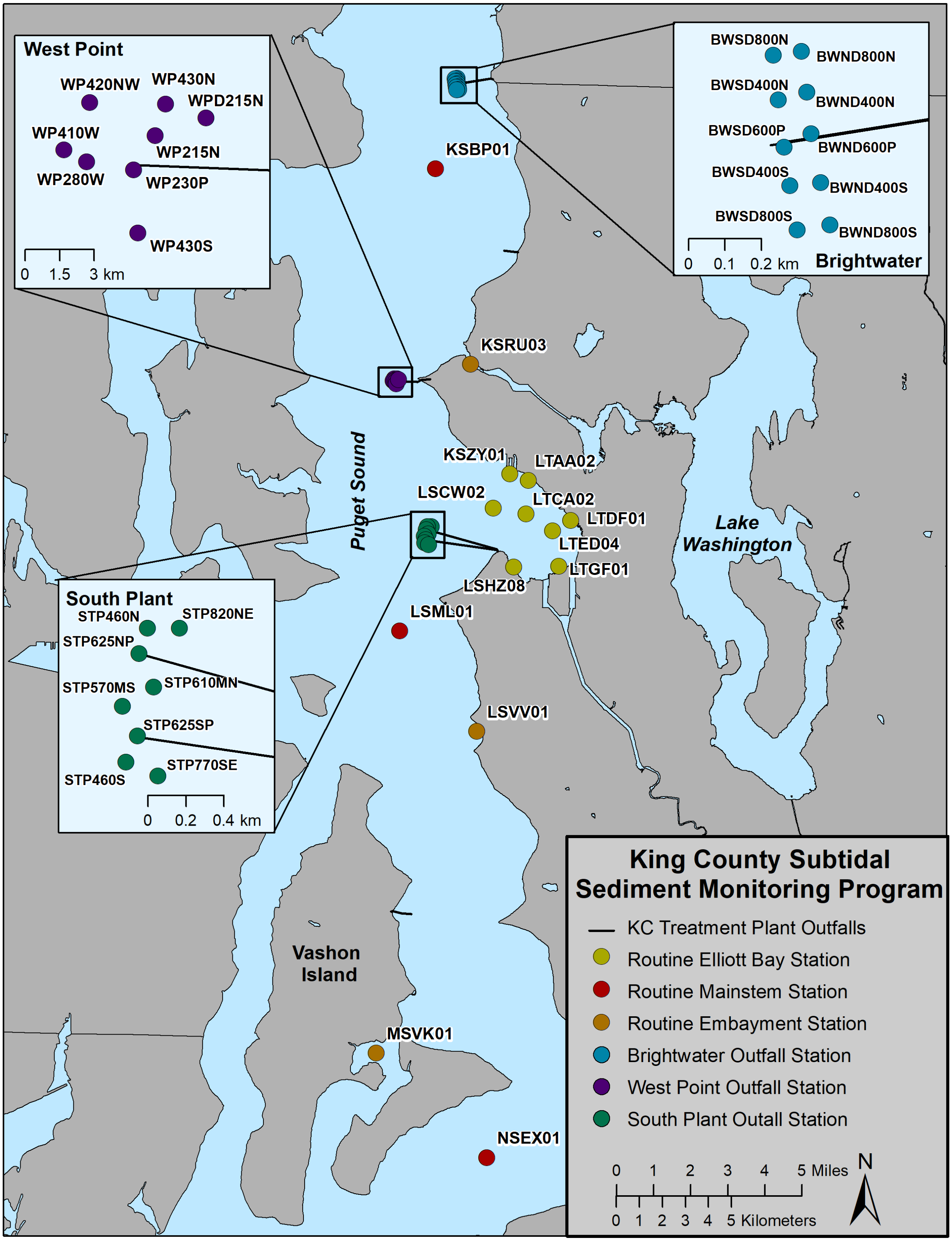


Figure 2. Routine subtidal and subtidal outfall (Brightwater, West Point, and South TP) sediment sampling locations.

2.2 Sampling and Analysis Methods

The following sections provide an overview of the intertidal, subtidal outfall, and routine subtidal sampling and analysis methods. For more detail on individual sampling events, refer to the SAPs for each sampling event.

2.2.1 Sample Collection and Processing

The following sections provide an overview of the intertidal, subtidal outfall, and routine subtidal sample collection and processing methods.

Intertidal Sediments
The top 5 cm of intertidal sediments were collected at the +6.5 ft mean lower low water (MLLW) tidal elevation at each location, located using tide charts, a stadia rod, and "peashooter" sight level. Sediments were collected using hand-held 2-inch diameter stainless steel coring tube. Once the required sample amount was obtained, sediments were homogenized in a stainless-steel bowl before transfer to sample containers.

Subtidal Sediments
All sediment samples were collected in accordance with the Puget Sound Estuary Program (PSEP) Recommended Protocols (PSEP, 1997). Offshore sediment samples for chemical analysis were collected using two stainless steel 0.1 m^2 modified van Veen grab samplers deployed in tandem off the research vessel. If sample acceptability criteria were met, the top 2 (routine subtidal samples) or 10 cm (subtidal outfall samples) of sediment from a minimum of two subsamples (grabs) were composited, homogenized, and placed in sample containers for conventional parameter and chemistry analysis.

Toxicity testing on some outfall samples is required to meet NPDES permit requirements. Composited and homogenized sediment from 2011 West Point outfall samples and the resampling of 2017 West Point and South TP outfall events (collected in 2018) were placed in additional jars for toxicity testing. Control and reference sediments for all West Point toxicity tests were collected from West Beach on Whidbey Island, WA.
Reference sediments for South Plant toxicity tests were collected from Carr Inlet, WA. Control sediments for South Plant were collected from West Beach (chronic polychaete toxicity tests) or San Francisco Bay, CA (amphipod toxicity tests, where amphipods were collected). Amphipods used for toxicity testing were collected from West Beach (West Point tests) or San Francisco Bay (South Plant tests). All other test organisms were obtained from Aquatic Toxicology Support (Bremerton, WA).

Benthic taxonomy samples were collected in triplicate, concurrent with chemistry samples, and consisted of the entire contents of a single van Veen grab. Sediments were rinsed through a 1 mm sieve using saltwater and organisms were preserved in buffered formalin in the field, then transferred to subcontracted personnel for later sorting, identification, and quantification.

2.2.2 Sample Analysis

Conventional Parameters and Chemistry

All sediment samples were analyzed for conventional parameters (total solids, grain size, TOC) and the 47 chemicals included in the marine SMS (WAC 173–204) (Table 5). Chemicals with SMS criteria include metals, polycyclic aromatic hydrocarbons (PAHs), phthalates, polychlorinated biphenyls (PCBs), chlorinated semi-volatile organics, and miscellaneous polar and non-polar organics. Depending on the program, samples were also analyzed for additional parameters including nutrients, additional metals, butyltins, chlorinated pesticides, polybrominated diphenyl ether (PBDE) congeners, and other miscellaneous organic parameters (Table 5).

Table 5. Parameters analyzed in sediment collected from intertidal, subtidal outfall, and routine subtidal stations.

Parameter Type	Parameter(s)	Intertidal	Subtidal Outfall	Routine Subtidal	SMS Criteria?
Conventionals	Total solids, grain size, TOC	✓	✓	✓	No
Nutrients	Ammonia, total sulfides		✓	✓	No
Metals*	SMS metals	✓	✓	✓	Yes
	Aluminum, iron, nickel	✓		✓	No
	Manganese, selenium	✓			No
	Tin			✓	No
Organics*	PAHs	✓	✓	✓	Yes
	Phthalates	✓	✓	✓	Yes
	PCB Aroclors	✓	✓	✓	Yes**
	SMS chlorinated semi-volatile organics	✓	✓	✓	Yes
	SMS misc. non-polar organics	✓	✓	✓	Yes
	SMS polar organics	✓	✓	✓	Yes
	Butyltins			✓	No
	Chlorinated pesticides			✓	No
	Total 4-nonylphenol and coprostanol		✓	✓	No
	PBDEs congeners	✓		✓	No
Toxicity	2 acute, 1 chronic test		✓***		Yes
Benthic infauna	Taxa identification and abundance		✓***	✓***	No

*Please see individual SAPs for a full list of individual parameters analyzed
**Total PCBs SMS based on sum of Aroclors
***Toxicity tests and benthic infauna analyzed for a subset of sampling events
SMS = Sediment Management Standards; TOC = total organic carbon

Total solids were measured by a gravimetric method and grain size/particle size distribution (PSD) was determined by a combination of sieve and hydrometer analyses. PSD results include both phi sizes and four broad classifications of clay, silt, sand, and gravel. The clay and silt fractions were also summed to report a result for percent fines. TOC analysis was conducted by a high-temperature combustion with infrared spectroscopy method.

Ammonia analysis used a potassium chloride extraction followed by fluorometric analysis of the extract. Total sulfide was analyzed by distillation following acidification and colorimetric analysis of the distillate.

All metals were analyzed using inductively coupled plasma (ICP) emission spectrometry except mercury, which was analyzed using cold-vapor atomic absorption spectrophotometry (CVAA).

Semi-volatile organics were extracted with an organic solvent and then analyzed by gas chromatography/mass spectrometry (GC/MS). Chlorinated pesticides and PCBs were extracted with organic solvents and then analyzed using a GC equipped with an electron capture detector (ECD). Butyltins and PBDEs were extracted with organic solvents and analyzed using GC/ MS in NCI (negative chemical ionization) SIM (selected ion monitoring) mode.

Modifications to analytical methods and detection limits have changed over time. Therefore, detailed information regarding analytical methods and detection limits for sediment parameters included in this report can be found in the SAPs for intertidal and subtidal sampling events.

Sediment Toxicity

Amphipod and larval echinoderm bioassays were used to assess acute toxicity, and the juvenile polychaete bioassay was used to assess chronic toxicity. All analyses were performed at KCEL.

The acute amphipod tests were run according to ASTM (1993) and the Puget Sound Estuary Program (1995). The amphipod *Rhepoxynius abronius* was used to test coarser-grained sediment (West Point). The amphipod *Ampelisca abdita* was used to test fine-grained sediments (South Plant).

The acute echinoderm larvae test was conducted using the sea urchin *Strongylocentrotus purpuratus* in initial 2011 West Point toxicity samples and the sand dollar *Dendraster excentricus* in repeated 2011 West Point and all 2018 toxicity samples. The tests were conducted, according to KCEL SOP 405, following protocols and procedures established by the PSEP (1995) and later modified in *SCUM II* (Ecology, 2017) for samples collected in 2018. Additionally, a second set of test chambers were prepared for side-by-side echinoderm larvae testing using a modified screen tube manipulation method described by Philips *et al.* (2003) on all but the initial 2011 samples. This method was used to isolate physical effects of the sediment on survival, such as turbidity.

Juvenile polychaete (*Neanthes* sp.) growth rate was used as a chronic toxicity test following methods outlined by the PSEP (1995).

Detailed methodologies including laboratory QA/QC procedures for each bioassay are available in SAPs for each individual sampling event referenced above (Section 2.0).

Benthic Infauna
Whole benthic taxonomy replicate samples (three replicate samples per site/event) were sorted and individuals were counted and identified to the lowest practical taxonomic unit (often to species). Abundance of each taxon was recorded, and wet weight (ww) biomass of each major taxonomic group (Crustacea, Mollusca, Polychaeta, and miscellaneous taxa) was measured.

For quality control purposes, a 20% aliquot of each sample was resorted to ensure 95% efficiency of all samples. Additionally, at least 5% of all replicate samples were re-identified by a separate taxonomist to ensure 95% taxonomic similarity. Discrepancies between analysts were discussed and data were reconciled prior to data being used.

All samples were analyzed by a contract laboratory; analysis included taxonomic identification and taxa abundance. Different contract laboratories were used over the monitoring period (Allan Fukuyama [2009-2015] and EcoAnalysts, Inc. [2017–2019]).

2.2.3 Data Analysis

Conventional Parameters and Chemistry
All sample results included in this report were reviewed prior to data analysis. Data assigned a "B" (blank contamination), "SH" (sample handling criterion not met), or "J" (estimated value) qualifier were assessed for usability. Data assigned an "R" (rejected) or deemed suspect were removed prior to data analysis.

Chemistry results were compared to applicable chemical criteria in the SMS including the SQS (WAC 173-204-320) and benthic cleanup screening level (CSL) (WAC 173-204-562). Results for non-polar organic compounds were normalized to organic carbon (OC) content for comparison to the SQS and CSL. However, if TOC content is < 0.5% or > 3.5%, dry weight (dw) based results for these compounds were compared to the Apparent Effects Thresholds (AET), which are based on dw concentrations and referred to here as "dw-equivalent SQS" (dw SQS) (Ecology, 2019) (Appendix A). This adjustment is made because sediments with very low or high OC can bias results (Ecology, 1992). For consistency between the sections, all sediment data presented here are reported on a dw basis, but samples were also OC-normalized as appropriate and compared to SQS during the data analysis process and OC-normalized values above the SQS are called out.

For regulatory purposes, the SMS are applied to results for samples collected from the top 10 cm of sediment (typically considered the biologically active zone). However, not all samples for chemical analysis were collected from the top 10 cm and these results should not be compared to SMS for regulatory purposes (i.e., intertidal and routine subtidal sediment samples were collected from < top 10 cm). However, comparison to chemical criteria provides context to interpret the data and help identify areas of potential concern.

Sediment chemistry results can also be evaluated using the sediment chemistry index (SCI). The SCI was developed by Ecology (2018c) as part of the Puget Sound Vital Signs[3] to evaluate potential exposure of benthic organisms to chemical mixtures. While not used for regulatory purposes, the SCI provides a measure of overall chemical exposure. It compares concentrations of 32 SMS chemicals (metals and organics)[4] to their respective SQS. The SCI is a component of the Sediment Quality Triad Index, one of three indicators used in the Puget Sound Partnership's (PSP) Marine Sediment Quality Vital Signs (Ecology, 2018c). Because TOC in many of our samples was low (<0.5%), the SCI was adjusted to be consistent with the SMS and how marine standards are applied per the *Sediment Cleanup User's Manual* (Ecology, 2019) (i.e., compared to dw equivalent SQS when TOC <0.5 or >3.5%). The SCI is calculated as described below (italics emphasize changes to SCI to assess samples with TOC <0.5 or > 3.5%):

1. Calculate SQS quotients - Divide each chemical concentration by appropriate SQS (OC normalized *or dw equivalent* for organic compounds *[depending on TOC content]*, dw normalized for metals). Note: Non-detects excluded from calculation unless it is a sum (e.g., total polychlorinated biphenyls [PCBs]), and then maximum reporting limit is used.
2. Calculate mean SQS quotient of all chemicals (mSQSq).
3. Calculate SCI – Divide mSQSq by regional maximum value (1.5) and subtract that fraction from 1 and multiply that value by 100.

$$SCI = 100*(1-(mSQSq/1.5))$$

The resulting SCI scores are then categorized into the following exposure categories:

- $>93.\overline{3}$ — 100.0 = **Minimum exposure**
- >80.0 — $93.\overline{3}$ = **Low exposure**
- $>66.\overline{6}$ — 80.0 = **Moderate exposure**
- 0 — $66.\overline{6}$ = Maximum exposure

Regional SCI values used as part of PSP's Vital Signs are compared to the threshold value of the minimum exposure category (PSP, 2022).

Long-term trend analysis of sediment chemical concentrations was conducted using the cenken function in the NADA package in R using data from stations with at least 10 samples collected between 1985 and 2019. This function can accommodate non-detects in the dataset, although the parameters chosen for analysis were always or nearly always detected. Trends were calculated for metals at intertidal and routine subtidal stations, as

[3] "The Puget Sound Vial Signs are measures of ecosystem health that guide the assessment of progress toward Puget Sound recovery goals." – Puget Sound Partnership (2022) https://www.psp.wa.gov/evaluating-vital-signs.php

[4] Phenols (5 chemicals), benzyl alcohol, benzoic acid, N-nitrosodiphenylamine, 1,2,4-Trichlorobenzene1,2-dichlorobenzene, 1,4-dichlorobenzene, hexachlorobenzene, hexachlorobutadiene, and total LPAHs and HPAHs are excluded from SCI calculation (individual PAHs are included).

well as PAHs and PCBs at routine subtidal stations since these chemicals have consistently been detected. The presence and significance of trends were determined for: (1) individual sites and (2) overall, for all five long-term stations pooled together (only five with >10 samples).

Sediment Toxicity

Three sediment toxicity tests were run on a subset of subtidal outfall samples:

- **Acute Amphipod –** amphipod mortality and number of amphipods that rebury within one hour (recorded as a measure of viability of surviving amphipods) were measured. The endpoint was amphipod mortality
- **Acute Larval Echinoderm –**number of normally and abnormally developed embryos, and total number of embryos developed from fertilized eggs. The calculated endpoint was normal survivorship
- **Chronic Juvenile Polychaete –** individual growth rate was recorded in dw and ash-free dw; mortality was also reported. The primary endpoint for this test was individual growth rate.

Results of each test were interpreted by comparing to SMS interpretive criteria.

Benthic Community Structure

Benthic infauna sample were collected at a subset of subtidal (outfall and routine) sites. Taxonomic identification and taxa counts were used to calculate the following indices for each sample replicate:

- Abundance -
  - **Total Abundance -** number of individual organisms per sample
  - **Abundance of Major Taxonomic Groups –** number of individual polychaetes, molluscs, crustaceans, and miscellaneous taxa per sample
- Richness –
  - **Total Richness** - number of unique taxa (generally species) per sample
  - **Richness of Major Taxonomic Groups** - number of unique polychaete, mollusc, crustacean, and miscellaneous taxa per sample
- Biomass –
  - **Total Biomass** - combined mass (ww) of all organisms per sample
  - **Biomass of Major Taxonomic Groups** - combined mass (ww) of all polychaetes, molluscs, crustaceans, and miscellaneous taxa per sample
- **Shannon-Wiener Diversity** (calculated using $\log_e$) - a measure of the relationship between taxa richness and abundance. Higher index values indicate a more diverse benthic community
- **Pielou's Evenness** - another measure of diversity expressed as the observed diversity of a sample in proportion to maximum possible diversity. The highest

possible evenness score of 1 represents a sample composed of multiple species with similar abundances, while a score closer to 0 might represent a sample with a single species of high abundance, with few more that are all proportionally very low in abundance

- **Swartz's Dominance Index (SDI)** - describes the minimum number of taxa/species that make up 75% of the total abundance in a sample.

The results presented below in Section 3.4 are based on the average of the three replicate samples for a given site and sampling event.

While benthic infauna abundance can be used as a chronic toxicity test under SMS, these data were not collected for that purpose. Appropriate accepted reference sites (of similar depth and physical characteristics) are not available for comparison to treatment plant outfalls. Therefore, benthic infauna data from subtidal outfall and routine subtidal sites were collected to provide an understanding the overall benthic community composition and health at these sites, as well as to track changes over time.

There were inconsistencies in data reporting over the data collection period represented in this report due to use of different contract laboratories. This made year to year comparisons challenging. To address these issues and standardize results we removed incidental taxa (e.g., nematodes, pelagic organisms, etc.), colonial taxa (e.g., bryozoans, colonial tunicates, etc.), and encrusting taxa (e.g., barnacles, sponges, etc.) from the data set. In addition, taxonomic names that changed since individuals were originally identified were corrected. The World Register of Marine Species (https://www.marinespecies.org) was used to identify synonyms of each taxon; the current accepted name was used when possible. For some taxa, like those later determined to be a paraphyletic group (e.g., Anopla), an unaccepted name could not be updated. The next step in standardization was determined based on how data were analyzed:

- Benthic results used for univariate measures, (e.g., benthic index values), were standardized by individual replicates. All taxa (except incidental, colonial, or encrusting organisms) were included in abundance calculations. Within a replicate, higher taxonomic levels were dropped prior to calculating all other index values if other taxa were identified to a lower level (e.g., delete family level identification when individual species within family also identified)
- Benthic results used for multivariate analysis or comparing taxa across multiple sampling sites and years, were standardized across the entire dataset, leading to lumping or dropping taxa that may have been identified to different taxonomic levels. When redundant taxa were present (one or more lower levels), Ecology protocols for taxonomic standardization were followed (Ecology, 2018b – Appendix G).

3.0 RESULTS

3.1 Intertidal Sediment Chemistry Results

This section presents the chemistry results for two intertidal sediment monitoring events (2010 and 2015). Results and a nonregulatory comparison to SQS (sample collected from 0-5 cm rather than 0-10 cm) are presented below.

Conventional Parameters

Total solids ranged from 66.2 to 97.8% (mean = 88.2%). TOC was generally low and ranged from below method detection limits (MDL) (<0.049%) to 0.804% (Figure 3 and Table 6). TOC content was > 0.5% in two samples in 2010. TOC was at least 0.3% TOC higher at three of 16 sites in 2010 than in 2015 (Carkeek Park - Piper's Creek Outflow - KSHZ03, Alki Point - LSKS04, and Burton Acres Park - MSXK01).

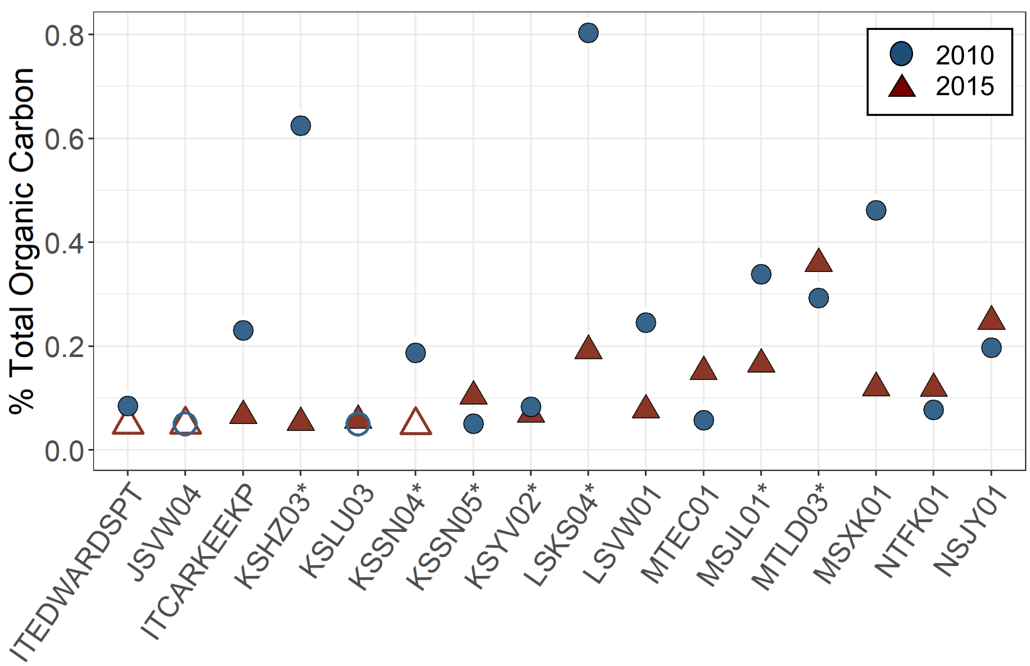


Figure 3. Percent total organic carbon (TOC) in samples from intertidal sites (2010 and 2015). Empty symbols represent method detection limits (MDL) when concentrations < MDL. *Outfall sites.

Sediment grain size results indicate all sites were dominated by sand and gravel (Figure 4). Percent fines (silt and clay) was low in all samples (<MDL - 14%; mean = 1.9%). Percent gravel was higher in 2015 than in 2010 at four of 16 sites (KSLU03, LSKS04, MSJL01, and MSXK01). Higher gravel content was associated with a lower sand content in 2015 at those sites and lower percent fines at Alki Point (LSKS04), Vashon Outfall (MSJL01), and Burton Acres Park (MSXK01) (Figure 4).

Table 6. Summary of results for conventional parameters measured at intertidal monitoring sites.

Parameter	2010				2015			
	DF	Min	Mean*	Max	DF	Min	Mean*	Max
% Solids	N/A	66.20	86.16	97.80	N/A	83.00	90.26	97.80
% TOC	14/16	(0.050)	0.267	0.804	13/16	(0.049)	0.137	0.359
% Fines	9/16	(0.48)	4.00	14.00	15/16	(0.53)	1.63	4.70
% Clay	5/16	(0.48)	2.32	3.50	12/16	(0.51)	1.42	3.00
% Silt	8/16	(0.48)	3.06	11.60	8/16	(0.50)	0.90	2.10
% Sand	16/16	23.50	57.06	91.80	16/16	37.60	56.59	71.30
% Gravel	15/16	(0.14)	42.46	76.10	16/16	28.30	42.92	61.60

*Mean calculated with detected values.
Values in parenthesis indicate method detection limit (MDL) when concentrations <MDL.
DF – detection frequency; TOC – total organic carbon

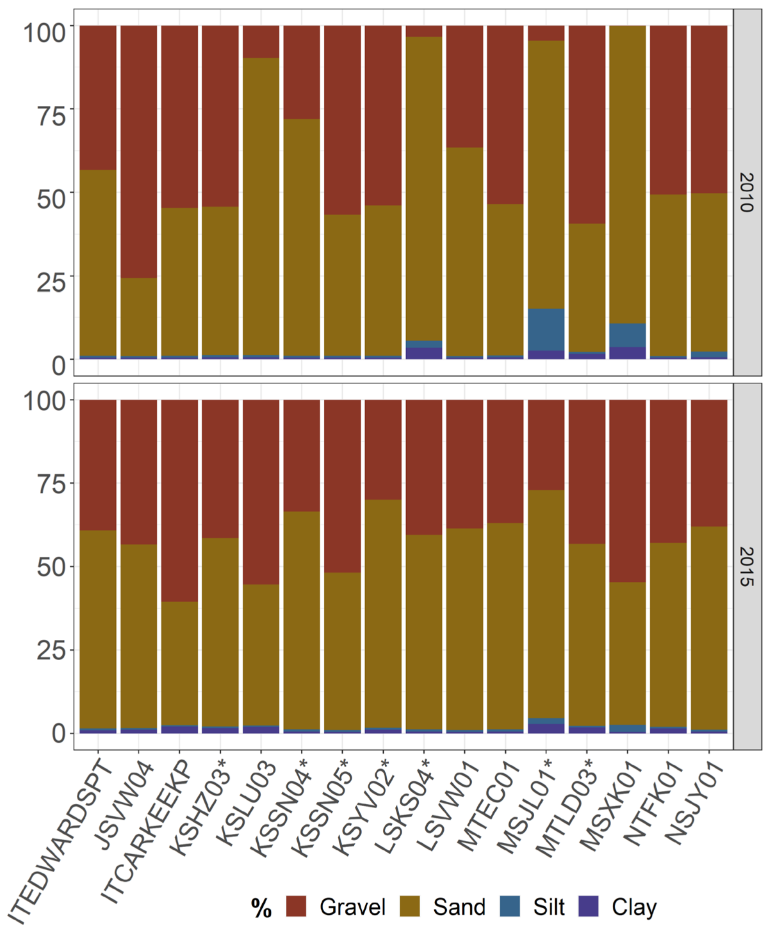


Figure 4. Percent grain size in samples from intertidal sites (2010 and 2015) (normalized to 100%). *Outfall sites.

Metals

Most of the 13 metals analyzed were detected in all samples except arsenic, cadmium, mercury, selenium, and silver (Table 7). Selenium and silver were never detected, as is typical for these metals. No metal concentrations were above their respective SQS.

Table 7. Summary of metals results in samples from intertidal sites (2010 and 2015).

Parameter	SQS	2010				2015			
		DF	Concentration (mg/Kg dw)			DF	Concentration (mg/Kg dw)		
			Min	Mean*	Max		Min	Mean*	Max
Aluminum	N/A	16/16	4580	5800	7980	16/16	4980	7140	10800
Arsenic	57	14/16	(1.5)	2.75	6.64	11/16	(1.3)	1.91	2.70
Cadmium	5.1	1/16	(0.10)	0.15	0.15	1/16	(0.10)	0.140	0.140
Chromium	260	16/16	9.04	15.0	31.7	16/16	8.89	14.5	22.5
Copper	390	16/16	4.45	9.01	16.7	16/16	5.26	9.18	23.4
Iron	N/A	16/16	7510	10100	14000	16/16	8150	10800	13300
Lead	450	16/16	1.8	4.21	10.4	16/16	1.8	3.11	6.98
Manganese	N/A	16/16	103	153	228	16/16	107	154	234
Mercury	0.41	16/16	0.0057	0.0102	0.029	15/16	(0.0053)	0.0130	0.045
Nickel	N/A	16/16	12.5	18.6	33.2	16/16	10.4	18.1	25
Selenium	N/A	0/16	(1.3)	N/A	(2.0)	0/16	(1.2)	N/A	(1.6)
Silver	6.1	0/16	(0.20)	N/A	(0.3)	0/16	(0.20)	N/A	(0.24)
Zinc	410	16/16	18.3	26.8	43	16/16	18.1	25.4	31.9

*Mean calculated with detected values.
Values in parenthesis indicate method detection limits (MDL) when concentrations < MDLs.
SQS = Sediment Quality Standard; DF = detection frequency

Long-term monitoring of metals at select intertidal sites has occurred at some locations since 1988. Ten or more years of data were available for five sites (JSVW04, KSHZ03, KSLU03, KSSN04, KSSN05). Metals data collected from these sites between 1988 and 2015 were used to assess trends (Figure 5). The data were pooled and analyzed together for an overall trend as well as a trend by site. When all data were combined, we observed a significant decreasing trend in chromium, lead, and nickel concentrations (Table 8). When evaluated by site, significant decreasing trends in concentrations of these metals were observed at some locations (Table 8). No increasing trends in metal concentrations were identified at any site; the data indicate over the last few decades metals concentrations at these sites are stable or decreasing (Figure 5). All trends (overall and individual sites) are available in Appendix B.

Table 8. Metals with discernable overall trend (p < .05); all data combined (1988–2015) for five sites. Individual sites with significant trend in same direction also listed.

Parameter	Overall Trend	Overall Trend p-value	Sites with significant trend
Chromium	Decreasing	7.74E-05	KSHZ03, KSLU03
Lead	Decreasing	3.98E-08	KSHZ03, KSLU03, KSSN05
Nickel	Decreasing	1.02E-03	KSHZ03

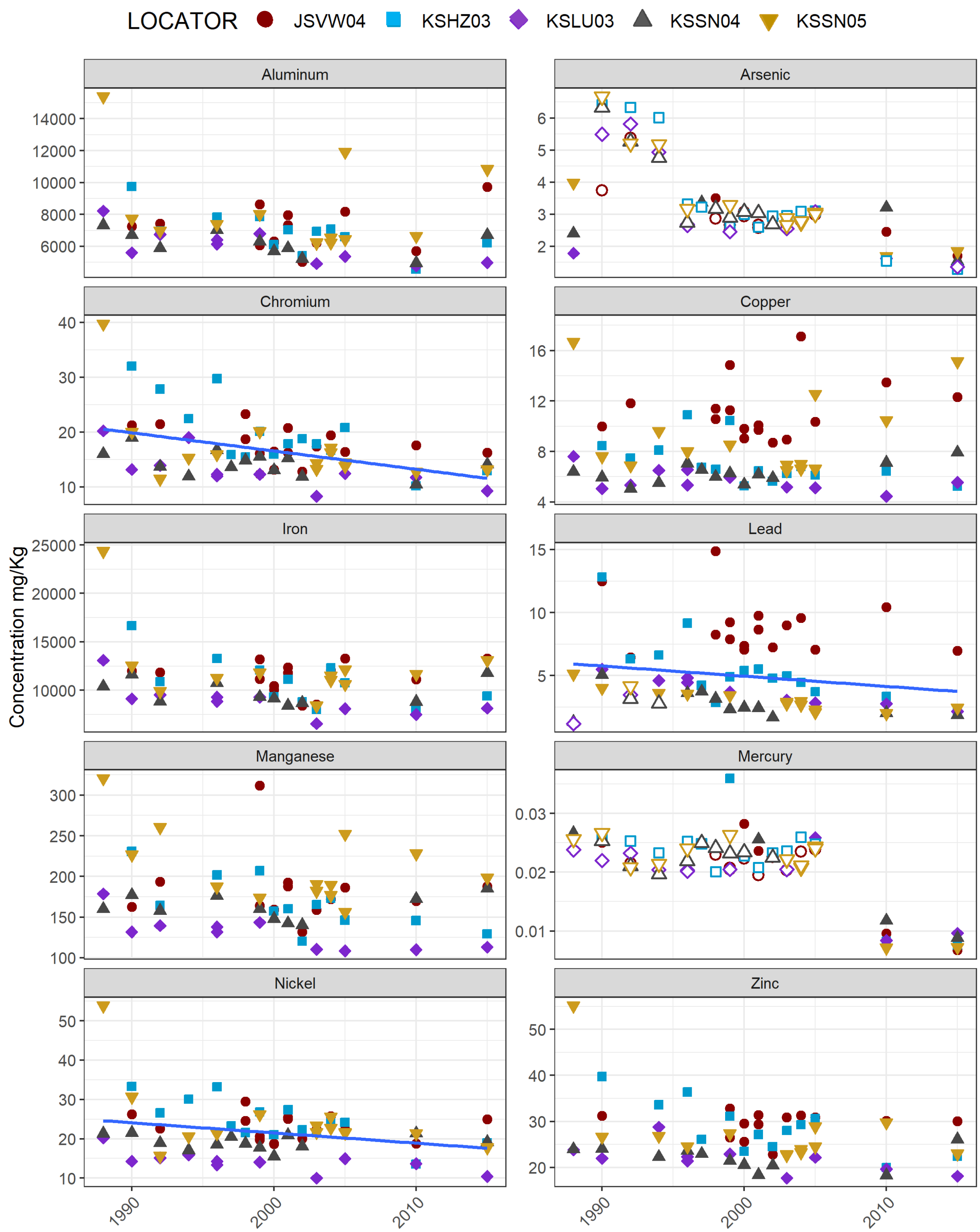


Figure 5. Metal concentrations (dw, mg/Kg) at five long-term (1988–2015) intertidal sites, by station and year. Solid symbols represent detected concentrations and open symbols represent method detection limits (MDL) when <MDL. Note MDL differences due to analytical method changes over time. Blue lines indicate overall trend for all sites when data pooled and $p < .05$.

Organic Compounds

Intertidal sediment samples were analyzed for 57 organic compounds (phthalates, chlorinated semi-volatile compounds, PCB Aroclors, PAHs, PBDEs, and several miscellaneous chemicals). TOC was low (<0.5%) in all but two samples; results for low TOC samples were compared to AETs (dw equivalent SQS). While not presented in the summary tables, results for two samples with TOC ≥0.5% were OC normalized for comparison to SQS.

PAHs

PAHs are components of fuels, oils, creosote, and asphalts. PAHs with high molecular weights (HPAHs) are more persistent in the environment than low molecular weight PAHs (LPAHs). One or more PAH compound was detected in samples collected at ten sites in 2010 and five sites in 2015. HPAHs were more frequently detected than LPAHs during both sampling events. Concentrations of individual PAHs, as well as total HPAHs and LPAHs were below their respective SQSs (Table 9).

Table 9. Summary of PAH results in samples from intertidal sites (2010 and 2015).

Parameter	dw SQS*	2010				2015			
		DF	Concentration (µg/Kg dw)			DF	Concentration (µg/Kg dw)		
			Min	Mean**	Max		Min	Mean**	Max
2-Methylnaphthalene	670	1/16	(2.0)	3.6	3.6	0/16	(5.4)	N/A	(6.4)
Acenaphthene	500	1/16	(2.0)	5.54	5.54	1/16	(5.4)	6.5	6.5
Acenaphthylene	1300	3/16	(2.0)	5.9	10.9	0/16	(5.4)	N/A	(6.4)
Anthracene	960	9/16	(2.0)	14.4	49.2	2/16	(5.4)	11	12
Fluorene	540	3/16	(2.0)	6.62	11.7	1/16	(5.4)	6.8	6.8
Naphthalene	2100	0/16	(2.0)	N/A	(10)	0/16	(5.4)	N/A	(6.4)
Phenanthrene	1500	10/16	(2.0)	18.6	65.4	2/16	(5.4)	29.9	43.2
Total LPAHs***	5200	10/16	(2.0)	35.8	108	2/16	(5.4)	47.6	68.5
Benzo(a)anthracene	1300	11/16	(2.0)	27.7	78.3	3/16	(5.4)	40.2	72.6
Benzo(a)pyrene	1600	9/16	(2.0)	33.4	106	3/16	(5.4)	24.7	37.1
Benzo(b,j,k)fluoranthene	3200	9/16	(2.0)	70.2	206	4/16	(5.4)	47.8	111
Benzo(g,h,i)perylene	670	6/16	(2.0)	22.5	63.9	4/16	(5.4)	12.3	16.2
Chrysene	1400	13/16	(2.0)	36.2	140	3/16	(5.4)	48.0	99.7
Dibenzo(a,h)anthracene	230	5/16	(2.0)	9.04	13.6	0/16	(5.4)	N/A	(6.4)
Fluoranthene	1700	12/16	(2.0)	71.4	288	5/16	(5.4)	55.8	162
Indeno(1,2,3-Cd)Pyrene	600	6/16	(2.0)	22.9	55.2	4/16	(5.4)	14.8	21.7
Pyrene	2600	11/16	(2.0)	58.4	248	5/16	(5.4)	45.0	123
Total HPAHs	12000	13/16	(2.0)	222	850	5/16	(5.4)	228	639

*Dry weight equivalent Sediment Quality Standard (SQS)
** Mean calculated with detected values.
***2-methylnaphthalene not used in total LPAH sum.
Values in parenthesis represent method detection limit (MDL) when concentrations < MDL.
DF = detection frequency

Phthalates

Several phthalates were detected (Table 10). These commonly used plasticizers are ubiquitous in the environment, and some are common laboratory contaminants. Benzyl butyl phthalate, bis(2-ethylhexyl)phthalate, diethyl phthalate, and dimethyl phthalate were detected in one to six samples in 2010. At Fauntleroy Cove Beach (LSVW01) dimethyl phthalate was detected above the SQS (dw equivalent, 1,610 µg/Kg dw); however, this result was flagged as an estimate because it was above the instrument calibration range. Dimethyl phthalate; was not detected at this site in 2015. All di-N-butyl phthalate measurements in 2010 samples were treated as non-detects because detected concentrations were similar to levels in the method blanks (all values < 5x method blank). The highest concentration of di-N-butyl phthalate (15.5 µg/Kg dw) was < SQS (dw equivalent). Bis(2-ethylhexyl)phthalate and diethyl phthalate were the only phthalates detected in 2015.

Table 10. Summary results for phthalates in samples from intertidal sites (2010 and 2015).

Parameter	dw SQS*	2010				2015			
		DF	Concentration (µg/Kg dw)			DF	Concentration (µg/Kg dw)		
			Min	Mean**	Max		Min	Mean**	Max
Benzyl Butyl Phthalate	63	3/16	(1.0)	1.1	1.8	0/16	(8.2)	N/A	(9.6)
Bis(2-Ethylhexyl)Phthalate	1300	6/16	(4.1)	7.6	22.5	3/16	(11)	18.0	22.9
Diethyl Phthalate	200	1/16	(4.1)	21.3	21.3	10/16	(11)	26.3	57.8
Dimethyl Phthalate	71	3/16	(4.1)	545	**1610**	0/16	(11)	N/A	(13)
Di-N-Butyl Phthalate***	1400	0/16	Blank Contamination***			0/16	(11)	N/A	(13)
Di-N-Octyl Phthalate	6200	0/16	(4.1)	N/A	(30)	0/16	(11)	N/A	(13)

*Dry weight equivalent Sediment Quality Standard (SQS)
**Mean calculated with detected values.
***Blank contamination effected some results - results < 5x method blank concentration considered non-detects
Bold values > SQS
Values in parenthesis indicate method detection limit (MDL) when concentration < MDL
DF = detection frequency

PCBs

PCBs were domestically manufactured (largely as Aroclors) from 1929 until production was banned in 1979. Due to their non-flammability, chemical stability, high boiling point and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications. Although no longer commercially produced in the United States, PCBs may be present in some products and materials produced before the 1979 ban. In addition, inadvertent production of PCBs can occur in chemical processing involving chlorine. PCBs are persistent and bioaccumulative chemical mixtures. Sediment samples were analyzed for seven PCB Aroclors; however, only Aroclor 1254 was detected in one sample (2.5 µg/Kg dw at Burton Acres Park [MSXK01]) in 2010. No other Aroclors were detected and total PCB concentrations (sum of detected Aroclors) were all below SQS.

Chlorinated Semi-volatile Organic Compounds

Chlorinated semi-volatile organic compounds were infrequently detected, except for 1,4-Dichlorobenzene, which was detected in all samples in 2010. 1,2-Dichlorobenzene was detected in the method blank; all sample results were < 5x the method blank concentration and treated as non-detects. However, the highest measured concentration in these samples was 1.08 µg/Kg dw, well below the dw equivalent SQS. All other sample results were below their respective SQSs (Table 11).

Table 11. Summary results for chlorinated organics in samples from intertidal sites (2010 and 2015).

Parameter	dw SQS*	2010				2015			
		DF	Concentration (µg/Kg dw)			DF	Concentration (µg/Kg dw)		
			Min	Mean**	Max		Min	Mean**	Max
1,2,4-Trichlorobenzene	31	2/16	(0.10)	0.17	0.51	1/16	(0.54)	1.38	1.38
1,2-Dichlorobenzene***	35	0/16	Blank Contamination***			0/16	(5.4)	N/A	(6.4)
1,4-Dichlorobenzene	110	16/16	0.26	0.26	1.44	0/16	(8.2)	N/A	(9.6)
Hexachlorobenzene	22	3/16	(0.10)	4.39	11.6	1/16	(0.54)	5.99	5.99
Hexachlorobutadiene	11	0/16	(0.51)	N/A	(2.6)	0/16	(2.8)	N/A	(3.3)
Pentachlorophenol****	360	0/16	(10)	N/A	(15)	0/16	(82)	N/A	(96)

*Dry weight equivalent Sediment Quality Standard (SQS)
**Mean calculated with detected values.
*** Blank contamination effected some results - all concentrations < 5x method blank concentration considered non-detects
****Pentachlorophenol is always compared to SQS on a dw basis and never OC normalized.
Values in parenthesis indicate MDL when concentrations < MDL
DF = detection frequency

Miscellaneous Non-Polar Organics

Results for two miscellaneous non-polar organic chemicals are summarized below. Dibenzofuran was detected in one sample in 2010 (Alki Point [LSKS04], 3.3 µg/Kg dw) (Table 12) and N-Nitrosodiphenylamine was not detected. No concentrations were above SQS.

Table 12. Summary results for miscellaneous non-polar organics in samples from intertidal sites (2010 and 2015).

Parameter	dw SQS*	2010				2015			
		DF	Concentration (µg/Kg dw)			DF	Concentration (µg/Kg dw)		
			Min	Mean**	Max		Min	Mean**	Max
Dibenzofuran	540	1/16	(2.0)	3.3	3.3	0/16	(5.4)	N/A	(6.4)
N-Nitrosodiphenylamine	28	0/16	(4.1)	N/A	(6.0)	0/16	(14)	N/A	(16)

*Dry weight equivalent Sediment Quality Standard (SQS) ** Mean calculated with detected values.
Values in parenthesis indicate MDL when concentrations < MDL.
DF = detection frequency

Polar Organics

Except for phenol, the polar organic compounds analyzed were infrequently detected (Table 13). Benzoic acid, with both anthropogenic (food preservation, dyes, and cigarettes) and natural sources (organic matter degradation), was detected in 2010 samples. However, blank contamination was present in 2010 samples, and most benzoic acid results were < 5x the method blank concentration and treated as non-detects. Of the five detected concentrations, one value (653 µg/Kg dw at Alki Point [LSKS04]) was just above the SQS. It is unknown if blank contamination may have high biased the concentration, but benzoic acid was not detected at that site in 2015. Phenol concentrations were above the SQS in 2010 at Alki Point [LSKS04], and in 2015 at Seahurst Park [MTEC01]; phenol was not detected at Alki Point [LSKS04] in 2015 or at Seahurst Park [MTEC01] in 2010.

Table 13. Summary results for polar organic compounds in samples from intertidal sites (2010 and 2015).

Parameter	SQS	2010				2015			
		DF	Concentration (µg/Kg dw)			DF	Concentration (µg/Kg dw)		
			Min	Mean*	Max		Min	Mean*	Max
2,4-Dimethylphenol	29	1/16	(1.0)	1.8	1.8	0/16	(5.4)	N/A	(6.4)
2-Methylphenol	63	1/16	(2.0)	15.7	15.7	0/16	(5.4)	N/A	(6.4)
3-,4-Methylphenol	670	3/16	(4.1)	232	615	0/16	(28)	N/A	(33)
Benzoic Acid	650	5/16**	117	341	**653**	1/16	(110)	188	188
Benzyl Alcohol	57	0/16	(2.0)	N/A	(3.0)	0/16	(14)	N/A	(16)
Phenol	420	9/16	(4.1)	129	**1070**	3/16	(28)	219	**489**

SQS = Sediment Quality Standard
*Mean calculated with detected values.
**Blank contamination effected some results - results < 5x method blank concentration considered non-detects
Bolded values >SQS.
Values in parenthesis indicate method detection limit (MDL) when concentrations < MDL.
DF = detection frequency

PBDEs

PBDEs are man-made chemical flame retardants. Manufacture, sale, and distribution of most PBDEs was severely restricted in Washington State in 2008 by RCW 70.76. At least one PBDE congener[5] was detected at 11 sites in 2010 and 2015 (Table 14). HexaBDE-154 and PentaBDE-100 were detected in half the 2010 samples. Most PentaBDE-99, and all TetraBDE-47 results in 2010 were considered non-detects because levels were < 5x the method blank concentration. In 2015, TetraBDE-47 was detected in samples from 10 sites, while all other PBDE compounds occurred in less than half the samples. The maximum summed PBDE concentration was 5.94 µg/Kg dw at Fauntleroy Cove (LSVW01) in 2015. Total PBDE concentrations in 2010, including samples with blank contamination, were < 1.0 µg/Kg dw. There are no SQS for this class of compounds.

[5] PBDEs are mixtures of several brominated compounds referred to as congeners.

Table 14. Summary results for PBDEs in samples from intertidal sites (2010 and 2015).

Parameter	2010				2015			
	DF	Concentration (µg/Kg dw)			DF	Concentration (µg/Kg dw)		
		Min	Mean*	Max		Min	Mean*	Max
DecaBDE-209	6/16	(0.041)	0.180	0.261	1/16	(0.41)		1.05
HeptaBDE-183	0/16	(0.0082)	N/A	(0.012)	0/16	(0.033)	N/A	(0.039)
HeptaBDE-190	0/16	(0.0082)	N/A	(0.012)	0/16	(0.033)	N/A	(0.039)
HexaBDE-138	3/16	(0.0082)	0.0495	0.0917	0/16	(0.033)	N/A	(0.039)
HexaBDE-153	2/16	(0.0082)	0.0299	0.0312	1/16	(0.033)	0.233	0.233
HexaBDE-154	8/16	(0.0082)	0.0604	0.114	1/16	(0.036)	0.199	0.199
PentaBDE-100	8/16	(0.0082)	0.0225	0.0456	1/16	(0.092)	0.542	0.542
PentaBDE-85	2/16	(0.0082)	0.0167	0.0184	1/16	(0.033)	0.15	0.15
PentaBDE-99**	4/16	(0.01)	0.180	0.287	6/16	(0.55)	2.1	4.7
TetraBDE-47**	3/16	0.130	0.153	0.184	10/16	(0.30)	0.59	1.9
TetraBDE-66	0/16	(0.0082)	N/A	(0.012)	1/16	(0.047)	0.111	0.111
TetraBDE-71	0/16	(0.0082)	N/A	(0.012)	1/16	(0.033)	0.045	0.045
TriBDE-17	0/16	(0.0082)	N/A	(0.012)	3/16	(0.033)	0.0713	0.111
TriBDE-28	0/16	(0.0082)	N/A	(0.012)	1/16	(0.033)	0.113	0.113
Sum PBDEs	11/16	(0.0082)	0.288	0.821	11/16	(0.034)	1.92	5.94

*Mean calculated with detected values.
** Blank contamination effected some results - all PentaBDE-99 and TetraBDE-47 results < 5x method blank concentration considered non-detects
Values in parenthesis indicate method detection limit (MDL) when concentrations < MDL
DF = detection frequency

Key Findings

Despite the generally low concentrations of detected metals and organic chemicals, we observed patterns in the data over the two sampling years. While all metals concentrations were below SQS, levels at some sites were slightly higher than others. Two of the highest lead concentrations were detected at Point Wells (JSVW04) which is located near an old petroleum products facility. Some of the highest metal concentrations were detected at Fauntleroy Cove (LSVW01), Magnolia Bluff (KSYV01), and Burton Acres Park (MSXK01) (Figure 6).

Some of the highest PAH concentrations were detected at West Point North Beach (KSSN04) and Burton Acres Park (MSXK01) in 2010, Normandy Park (MTLD03) in 2015, and Fauntleroy Cove (LSVW01) in both years (Figure 6). Concentrations of PAHs at numerous stations in the subtidal zone along the north shelf of West Point were above the SQS in the 1990s, particularly further offshore, and prompted sampling of offshore sediments in 2019 (King County, 2021). The Fauntleroy Cove site is located near several potential PAH sources including the ferry terminal, Fauntleroy Creek, a storm drain, and two combined sewer outfalls (CSO).

Samples collected in 2010 from Alki Point (LSKS04), contained higher concentrations of a few miscellaneous organic chemicals (e.g., benzoic acid, 3-,4-methylphenol[6], dibenzofuran, and phenol) than were detected at other sites. However, in 2015, these chemicals were either not detected or found at low concentrations (Figure 6). TOC content in the 2010 sample from Alki Point (LSKS04) was higher than TOC detected in other intertidal samples, including the 2015 sample from Alki Point, indicating the inherent heterogeneity of intertidal sediments. Patchiness in the nearshore environment may be due to spatial variability as well as sample heterogeneity, which is common in samples with low percent fines. Differences could also be due to site specific freshwater and land-based inputs.

[6] Measured as 4-methylphenol in 2010 data; analytical method updates now quantify this as 3,4-methylphenol.

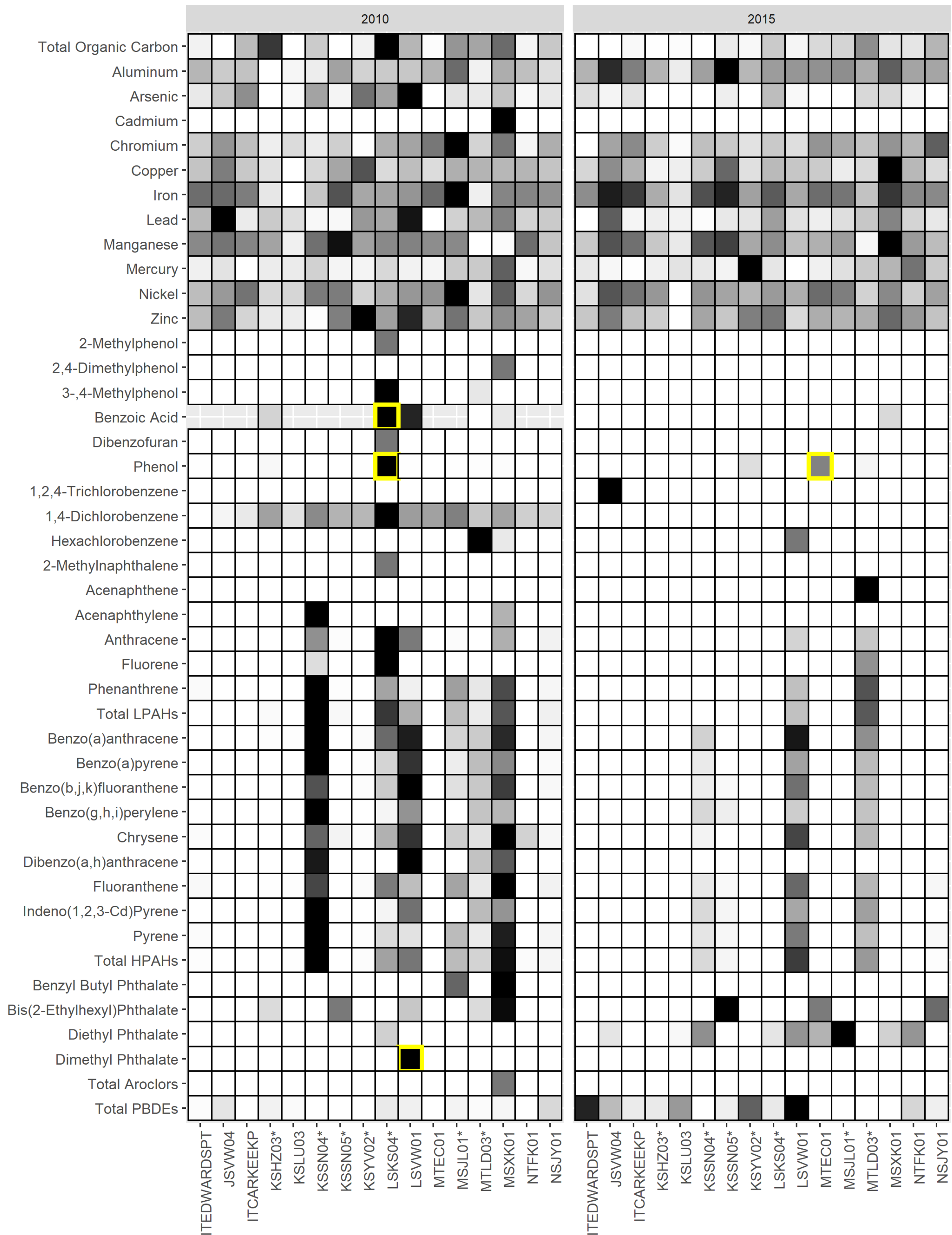


Figure 6. **Heatmap of intertidal sediment chemical concentrations (2010 and 2015) normalized by parameter (i.e., not concentration, but represent relative range of detected concentrations for a parameter from non-detect/low (white) to highest value (black). 2010 benzoic acid results < 5x detected blank concentration not displayed (grey checkered background). Yellow boxes indicate concentrations > SQS (or dw SQS equivalent – comparison only due to sample depth interval). *Outfall sites.**

3.2 Subtidal Sediment Chemistry

This section presents results for subtidal sediment sampling events in the Central Basin. Samples were collected for NPDES permit requirements near TP outfalls (subtidal outfall samples) and elsewhere in the Central Basin (routine subtidal). Due to differences in collection frequency, sampling depth and purpose of monitoring, results are initially discussed separately and then summarized together in Section 3.5.

3.2.1 Subtidal Outfall Sediment Chemistry

Seven NPDES required sediment chemistry monitoring events occurred near King County's largest TP outfalls between 2008 and 2019. Samples were collected near the Brightwater outfall in 2011[7] (King County, 2013) and South Plant and West Point outfalls in 2011 and 2017 (King County, 2012a,c; King County, 2018a,b). Follow up sampling to 2017 occurred at South Plant and West Point outfalls in 2018 at a subset of sites (King County, 2018a,b). Outfall site location information is available in Table 3 and Figure 2. Data for samples (top 10 cm) are summarized below. Samples were analyzed for a variety of parameters; however, only data for parameters (conventional parameters and chemical contaminants) consistently measured across all sampling events are presented here. More detailed results from these outfall sediment monitoring events have been published previously and can be found in the reports referenced above.

Conventional Parameters

Total solids content was highest at the West Point Outfall stations (68.3–75.7%) and lower at the Brightwater (39.3–46.5%) and South Plant (28.6–32.8%) outfall stations. The lower solids content observed at the two deeper stations is consistent with the depositional pattern of finer material as described below.

Sediment grain size varied between the three sites. Sediments near the Brightwater outfall were dominated by silt (followed by clay and sand). Silt and clay dominated sediments near the South Plant outfall with little sand present. Sediment grain size near the shallower West Point outfall site was slightly more variable but dominated by sand. A summary of percent fines data at the three sites is presented in Table 15 and Figure 7.

[7] Sediment samples collected at four sites in 2017 near the Brightwater Outfall and only analyzed for conventional parameters and benthic infauna taxonomy.

Table 15. Summary results for conventional parameters in samples from subtidal outfall sites (2011, 2017, 2018).

Area	Parameter	DF	Min	Mean*	Max
Brightwater**	% Solids	N/A	39.3	44.5	46.5
	% TOC	14/14	1.32	1.41	1.6
	% Fines	14/14	66.3	78.0	84.6
	% Clay	14/14	19.9	23.7	26.4
	% Silt	14/14	42.8	54.3	60.4
	% Sand	14/14	15.2	24.2	30.7
	% Gravel	2/14	(0.25)	0.4	0.4
West Point	% Solids	N/A	68.9	73.1	75.7
	% TOC	20/20	0.093	0.397	0.969
	% Fines	20/20	3.2	10.0	22.1
	% Clay	20/20	3.1	6.5	11.7
	% Silt	18/20	(0.61)	3.9	11.1
	% Sand	20/20	47.6	78.2	97.4
	% Gravel	20/20	0.2	12.0	27.2
South Plant	% Solids	N/A	28.6	30.7	32.8
	% TOC	21/21	1.9	2.1	2.8
	% Fines	21/21	87.7	96.0	102.9
	% Clay	21/21	33.5	40.1	52.8
	% Silt	21/21	46.7	55.8	65.1
	% Sand	21/21	0.9	1.8	6.8
	% Gravel	2/21	(0.37)	0.5	0.5

Values in parenthesis indicate method detection limit (MDL) when concentrations < MDL.
*Mean calculated with detected values.
**Conventional parameters also measured in 2017 at four Brightwater sites where benthic infauna samples collected.
DF = detection frequency; TOC – total organic carbon

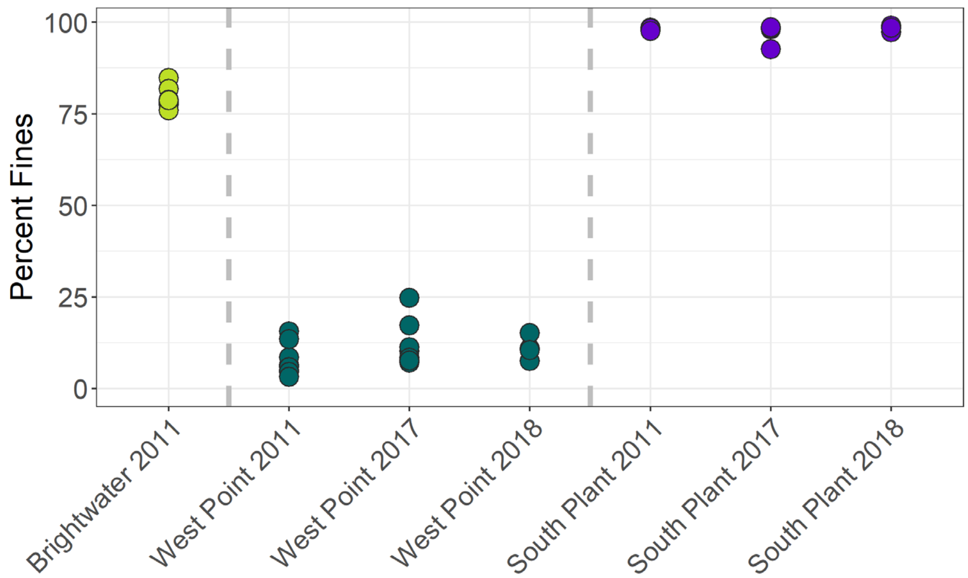


Figure 7. Total percent fines (percent silt + clay) in samples from subtidal outfall sites by date (2011, 2017, 2018).

TOC content at each site was similar to the pattern observed for percent fines (Figure 8) (i.e., highest TOC and percent fines observed at South Plant site and lowest TOC and percent fines at West Point site). TOC content was highest in South Plant outfall samples (1.92 - 2.77%) and lower in Brightwater (1.32 - 1.50%) and West Point (0.093 - 0.97%) outfall samples. TOC content in Brightwater and South Plant samples was within the TOC range that requires OC normalization for non-polar organic compound comparison to SQS. TOC results for most West Point outfall samples were < 0.5%, requiring samples to be compared to the dw SQS.

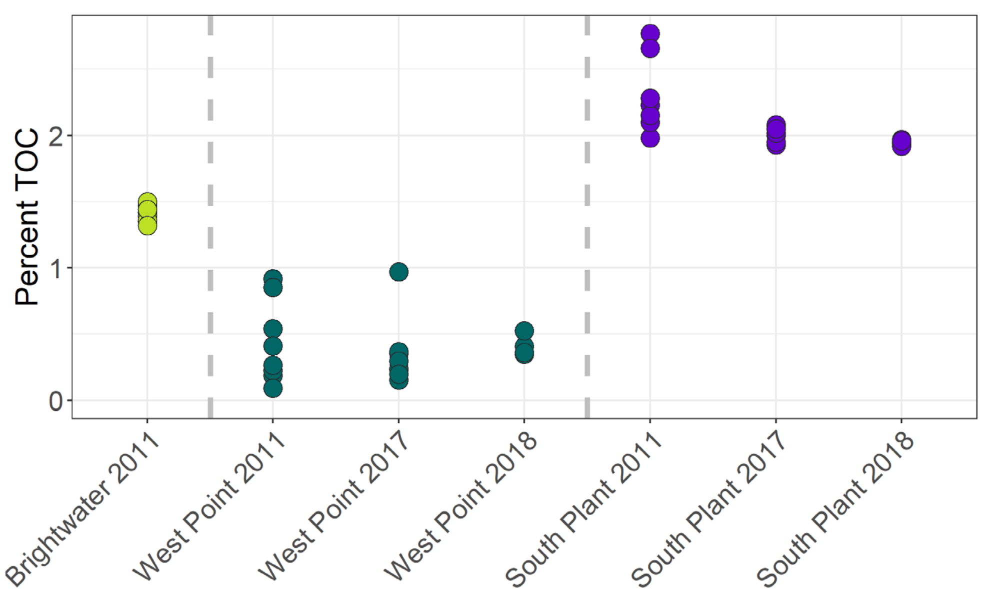


Figure 8. Percent total organic carbon (TOC) in samples from subtidal outfall sites by date (2011, 2017, 2018).

Total ammonia (ammonia-nitrogen) was detected in all samples except one West Point sample in 2011. Ammonia was highest in South Plant (5.22 -14.3 mg/Kg dw) and Brightwater (4.41 - 9.84 mg/Kg dw) outfall samples, and lowest in West Point outfall samples (< MDL [0.13] - 27.6 mg/Kg dw). Except for three samples collected near the West Point outfall in 2017, ammonia concentrations followed a pattern like that observed for percent fines and TOC. Concentrations of all three parameters were on average higher in Brightwater and South Plant samples than in West Point's outfall samples (Figure 9).

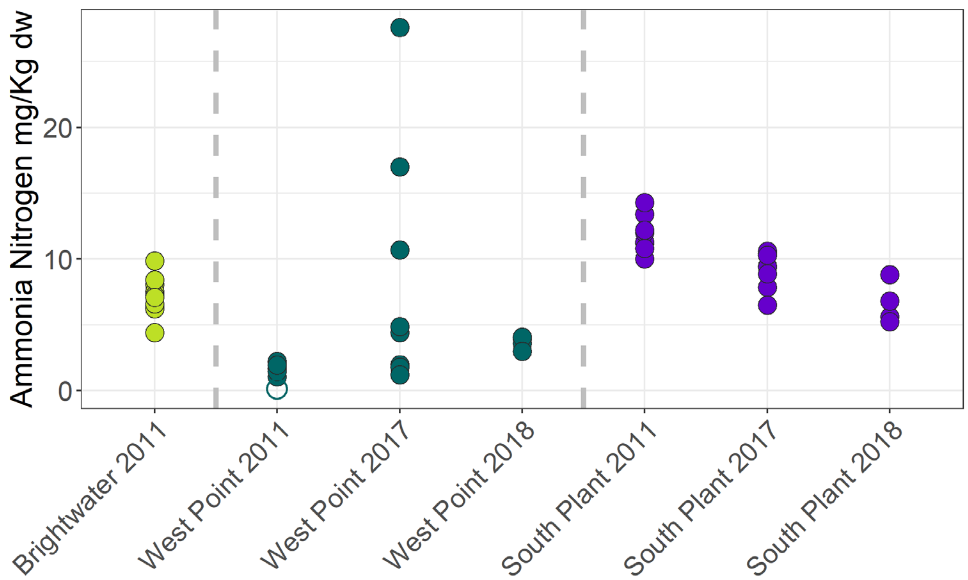


Figure 9. Ammonia nitrogen concentration (mg/Kg dw) in samples from subtidal outfall sites by date (2011, 2017, 2018). Empty symbols represent method detection limit (MDL) when concentrations < MDL.

Total sulfide concentrations followed a pattern like those observed for other conventional parameters. Total sulfide levels were generally higher in Brightwater (183 - 560 mg/Kg) and South Plant (88.4 - 655 mg/Kg) outfall samples and lower in West Point outfall (<MDL [0.63 mg/Kg dw] - 6.44 mg/Kg dw) samples. (Figure 10). Variability in total sulfide levels at the Brightwater and South Plant outfall sites may be influenced by their location in a depositional environment with anoxic conditions compared to West Point sites which are located in a more dynamic area.

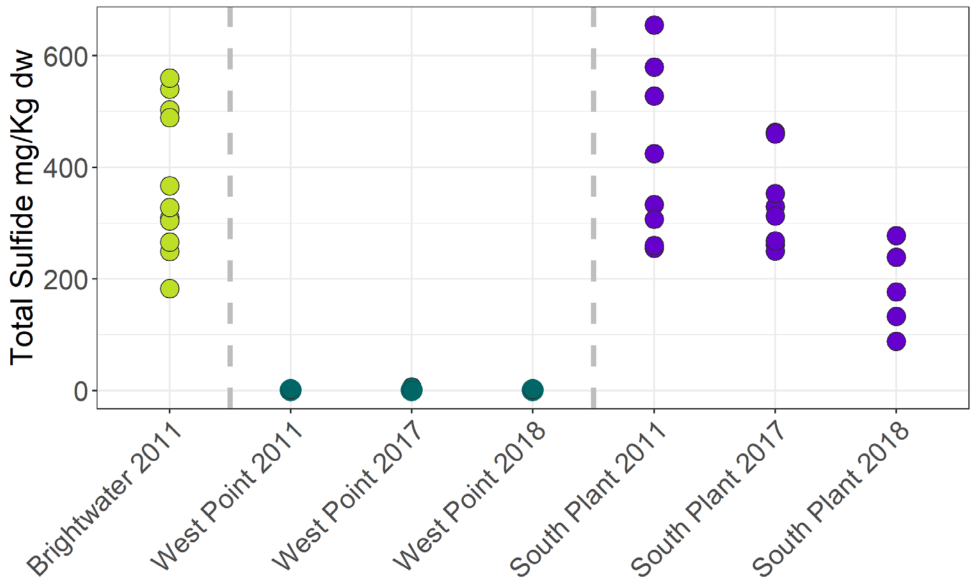


Figure 10. Total sulfide concentration (mg/Kg dw) in samples from subtidal outfall sites by date (2011, 2017, 2018).

Metals

Of the eight metals with SQS, most were detected in all samples except for arsenic (34/52 samples), cadmium (28/52 samples), and silver (8/52). Silver was only detected in West Point outfall samples in 2011. All metals were detected at concentrations below their respective SQS (Figure 11).

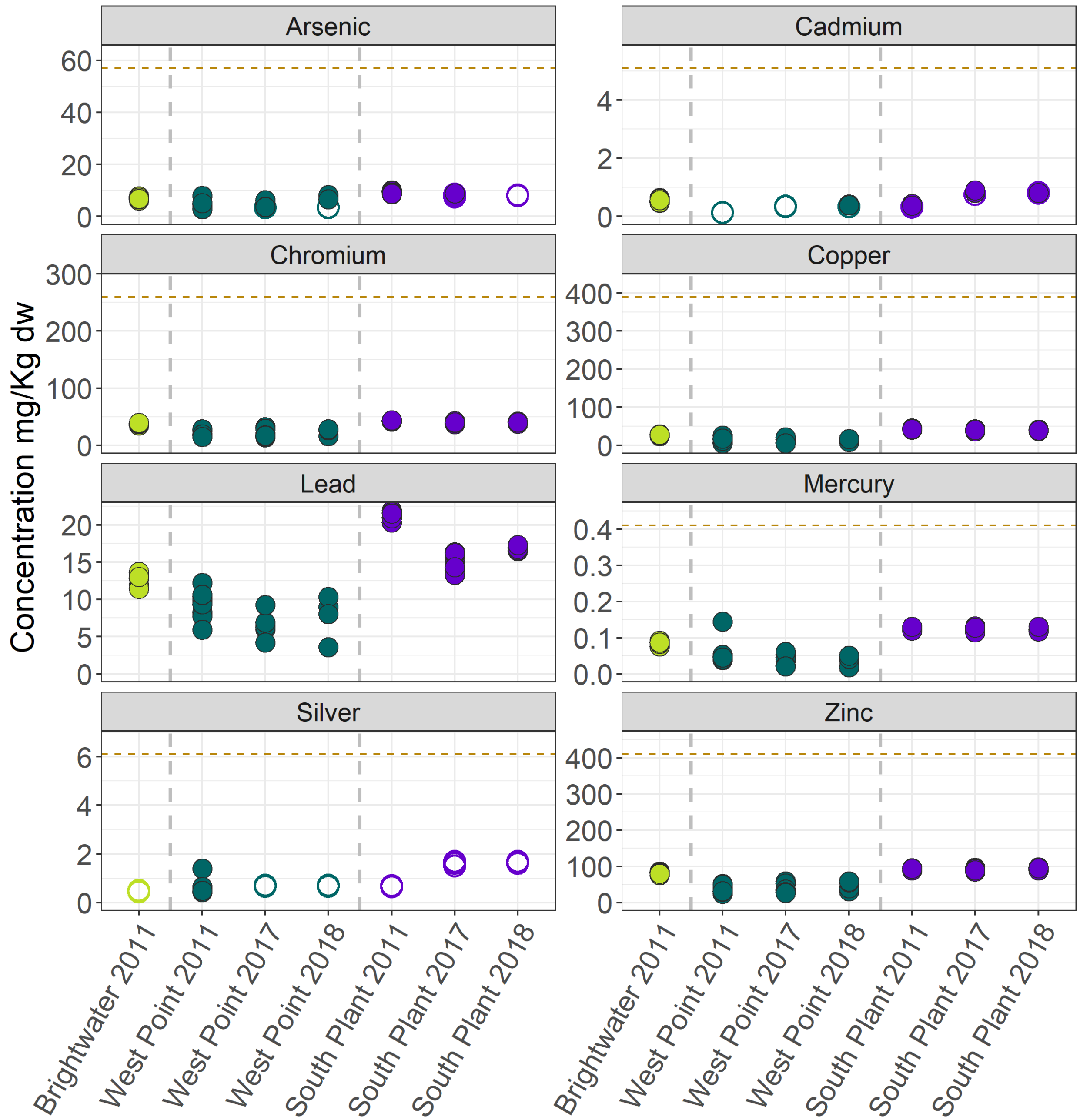


Figure 11. Metal concentrations (mg/Kg dw) in subtidal outfall site samples by date (2011, 2017, 2018). Empty symbols represent method detection limits (MDL) when concentrations < MDL. Gold broken line represents SQS.

Organic Compounds

Results for polar and nonpolar compounds are presented below. Due to the range of TOC content in these samples, dw normalized concentrations are presented below and criteria exceedances are noted in the text.

PAHs

All PAHs analyzed were detected during at least one sampling event, while some HPAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b,j,k)fluoranthene, fluoranthene, pyrene, and

chrysene) were detected in every sample (Figure 12 and Figure 13). Total LPAH (2.8 - 1,030 µg/Kg dw) and HPAH (60 - 4,130 µg/Kg dw) concentrations were variable. PAH concentrations were highest in West Point outfall samples, but all detected concentrations were below their respective SQS.

Phthalates

Phthalates are commonly used plasticizers and ubiquitous both in the environment and as laboratory contaminants. Most phthalates were rarely detected except for bis(2-ethylhexyl)phthalate, which was commonly detected (Figure 14). Phthalates are common laboratory contaminants and detections in method blanks are not uncommon. Method blank results indicated that some outfall site samples were contaminated with benzyl butyl phthalate, bis(2-ethylhexyl)phthalate, di-N-butyl phthalate, and diethyl phthalate. When detected sample values were < 5x the method blank concentration, results were treated as non-detects. Most results were well below SQS; the two detections in 2011 exceeding SQS are discussed below. There were no SQS exceedances for phthalates in samples collected near the TP outfalls in 2017 or 2018.

In 2011, bis(2-ethylhexyl)phthalate was detected at one South Plant outfall site (3,090 µg/Kg dw [116 mg/Kg OC]; STP625SP) and exceeded the CSL (78 mg/Kg OC). Triplicate samples were reanalyzed resulting in an average concentration of 3.5 mg/Kg OC. Based on these results, it was concluded that the original result was not representative of site conditions and did not exceed the CLS or SQS.

Also, in 2011, levels of dimethyl phthalate (75.2 µg/Kg dw) at a West Point outfall site (WP215N) exceeded the SQS (71 µg/Kg dw).

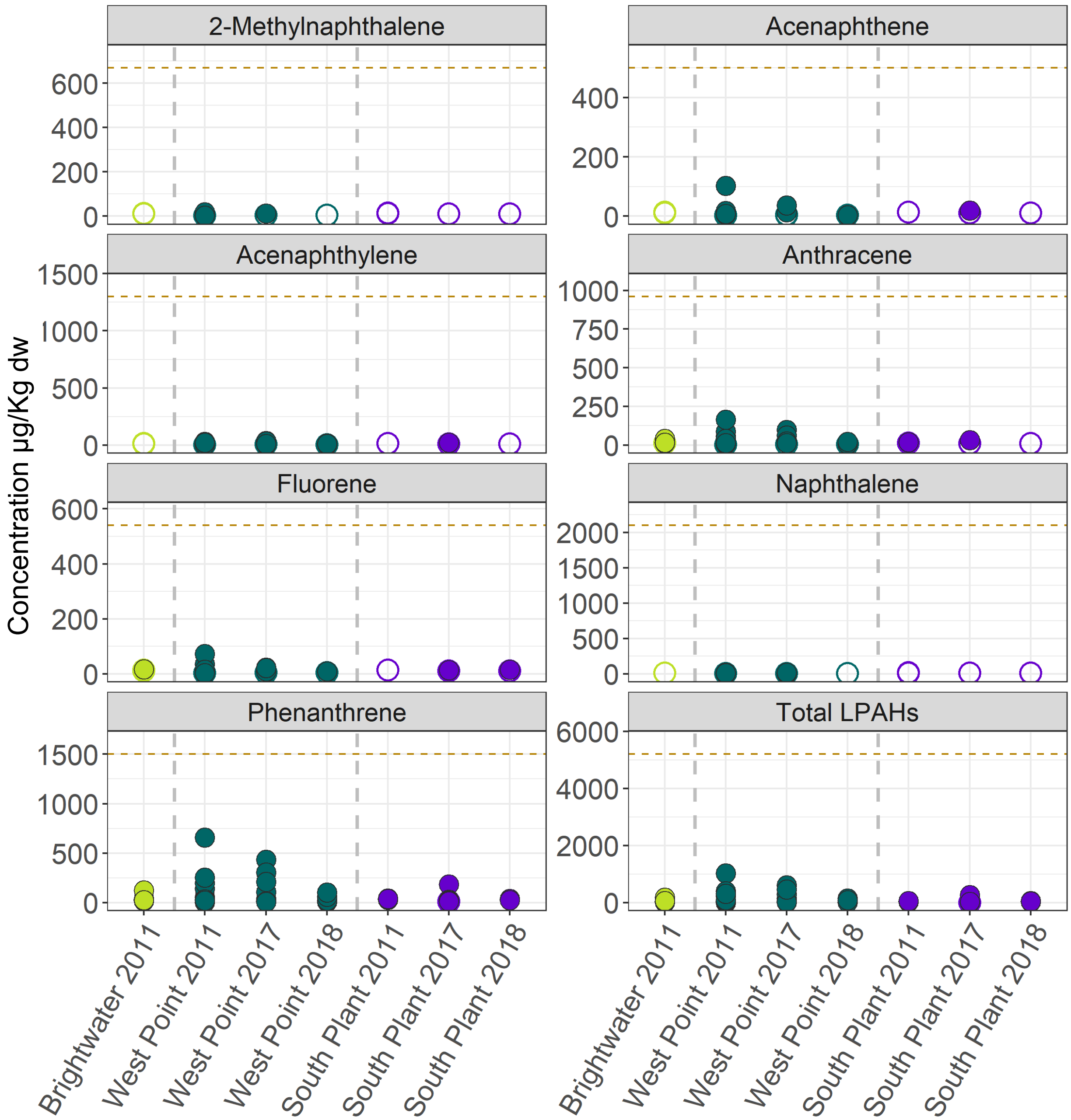


Figure 12. LPAH concentrations (µg/Kg dw) in subtidal outfall site samples by date (2011, 2017, 2018). Empty symbols represent method detection limits (MDL) when concentrations < MDL. Gold broken line represents the dw SQS.

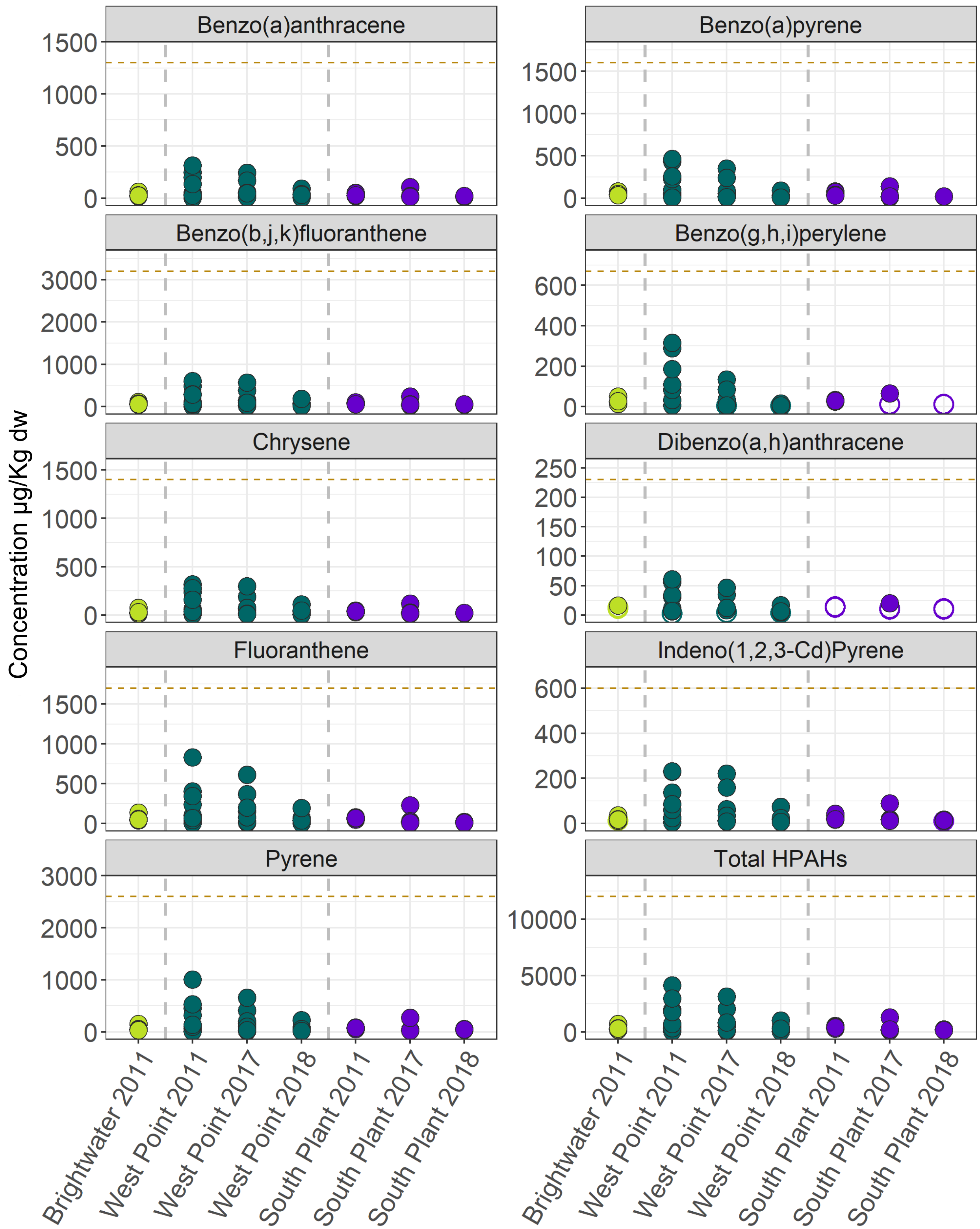


Figure 13. HPAH concentrations (µg/Kg dw) in subtidal outfall site samples by date (2011, 2017, 2018). Empty symbols represent method detection limits (MDL) when concentrations < MDL. Gold broken line represents dw SQS.

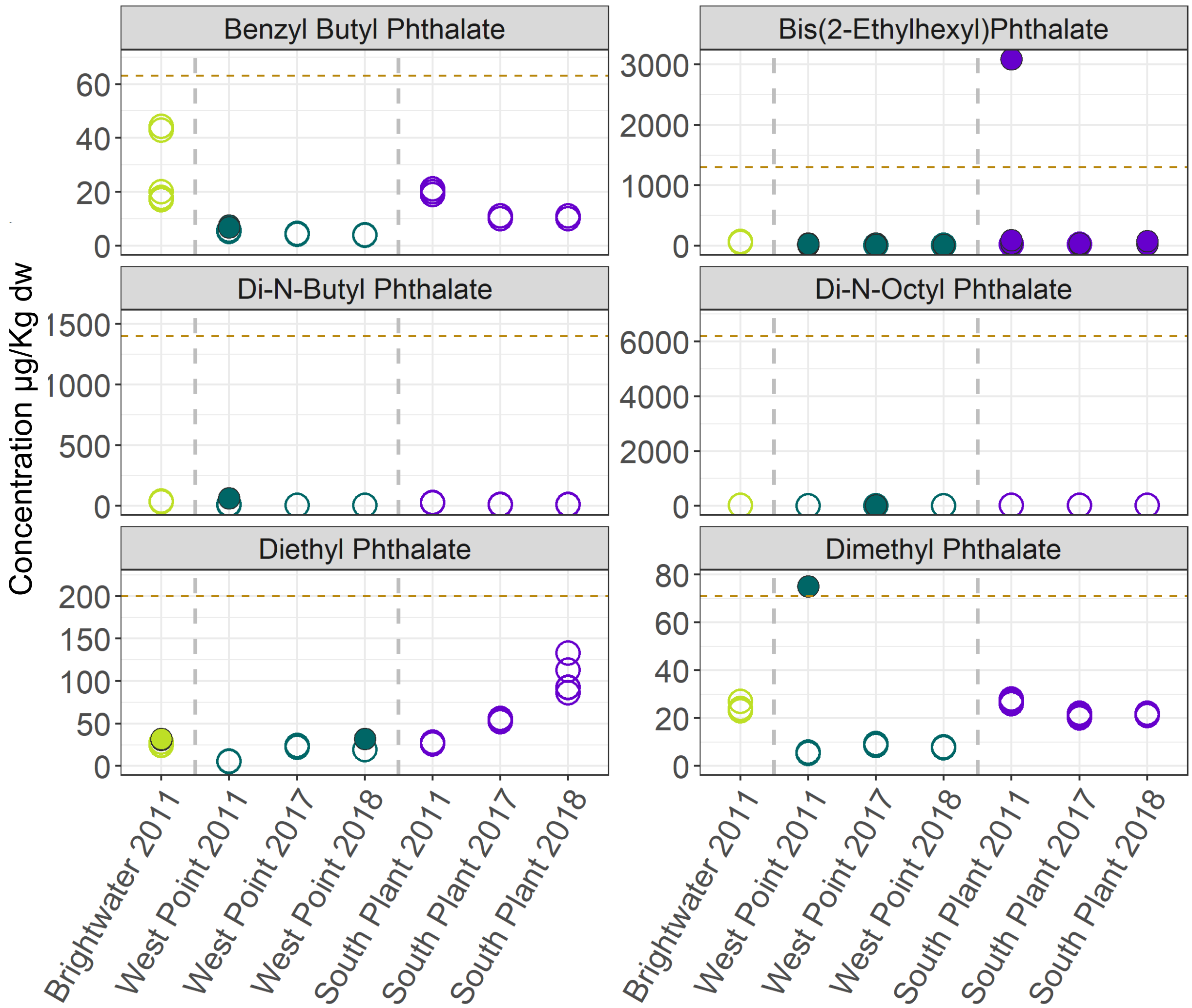


Figure 14. Phthalate concentrations (µg/Kg dw) in subtidal outfall site samples by date (2011, 2017, 2018). Empty symbols represent method detection limits (MDL) when concentrations < MDL. Gold broken line represents dw SQS. Note: bis(2-ethylhexyl)phthalate levels in two samples exceeded OC-based SQS.

PCBs

While most PCB production and use has been discontinued, these persistent and bioaccumulative chemical mixtures were widely used for their insulating and cooling properties for several decades. Three of the seven PCB Aroclors (1016, 1221, and 1232) analyzed were never detected, while 1242, 1248, 1254, and 1260 were detected in more than one sample. Aroclors 1254 and 1260 were detected most frequently and at the highest concentrations. Total PCB concentrations were highest in samples collected from two sites (WP230P and WP420NW) near the West Point outfall in 2011; both samples exceeded the SQS (Figure 15). PCB concentrations in all other samples were below the SQS.

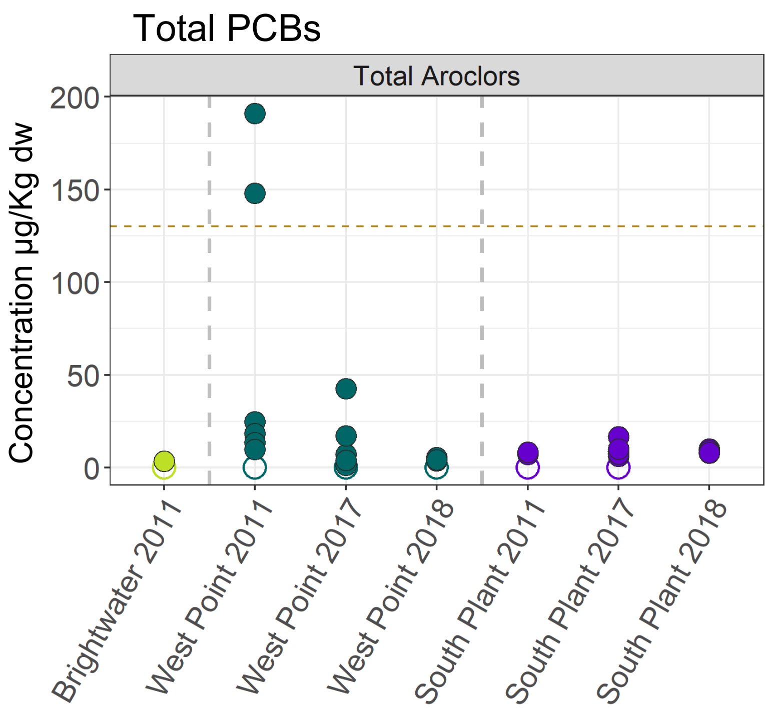


Figure 15. PCB Aroclor (µg/Kg dw) concentrations in subtidal outfall site samples by date (2011, 2017, 2018). Empty symbols represent method detection limits (MDL) when concentrations < MDL. Gold broken line represents dw SQS. Note: PCB levels in two samples exceeded OC-based SQS.

Chlorinated Semi-Volatile Organic Compounds

None of the six chlorinated semi-volatile organic compounds (1,2,4-trichlorobenzene 1,2-dichlorobenzene, 1,4-dichlorobenzene, hexachlorobenzene, hexachlorobutadiene, and pentachlorophenol) analyzed were detected in any samples collected near the outfalls. Additionally, MDLs for all parameters were well below their respective SQS.

Miscellaneous Non-Polar Organic Compounds

Dibenzofuran was only detected (< MDL – 6.33 µg/Kg dw) at three sites (WP280W, WP430N, and WP420NW) near the West Point outfall in 2011. N-nitrosodiphenylamine was detected (< MDL – 14.3 µg/Kg dw) in samples from two West Point outfall sites (WP430N and WP420NW) in 2011. All concentrations were < SQS (Figure 16).

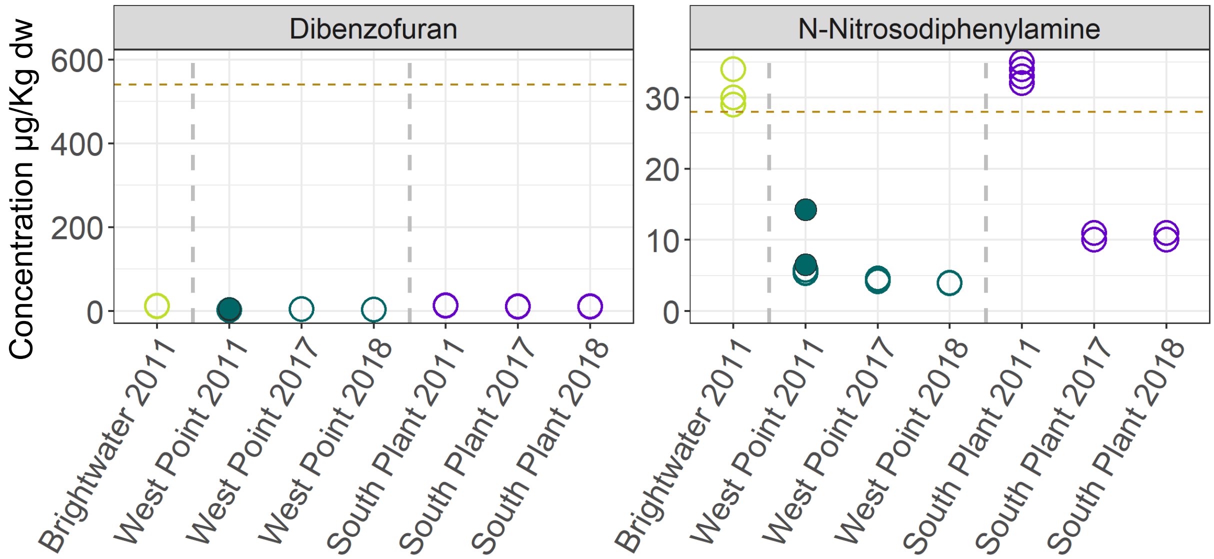


Figure 16. Miscellaneous non-polar organics (µg/Kg dw) in subtidal outfall site samples by date (2011, 2017, 2018). Empty symbols represent method detection limits when concentrations < MDL. Gold broken line represents dw SQS.

Polar Organic Compounds

Six polar organic compounds with SQS were analyzed (benzyl alcohol, benzoic acid, and four phenolic compounds) (Figure 17). Two phenols (2-methylphenol and 2,4-dimethylphenol) were never detected and 3-,4-methylphenol and phenol were detected in a subset of samples collected near the West Point outfall in 2011. All concentrations were below SQS. Benzyl alcohol was detected in two samples collected near the South Plant outfall in 2017 and five samples collected near the West Point outfall in 2017. The Benzyl alcohol concentration in one of the West Point samples exceeded the SQS (Figure 17). Follow up sampling in 2018 yielded no detections of benzyl alcohol in samples from near either outfall. Benzoic acid was detected in most samples collected in 2017 near the South Plant and West Point outfalls and exceeded the combined SQS/CSL (650 µg/Kg dw) in five South Plant and four West Point samples (max = 1,530 µg/Kg dw near South Plant). Benzoic acid was also elevated elsewhere in the Central Basin in 2017 (see Section 3.2.2). Subsequent sampling of the same sites in 2018 yielded only one SQS exceedance for benzoic acid at the South Plant outfall site (Figure 17).

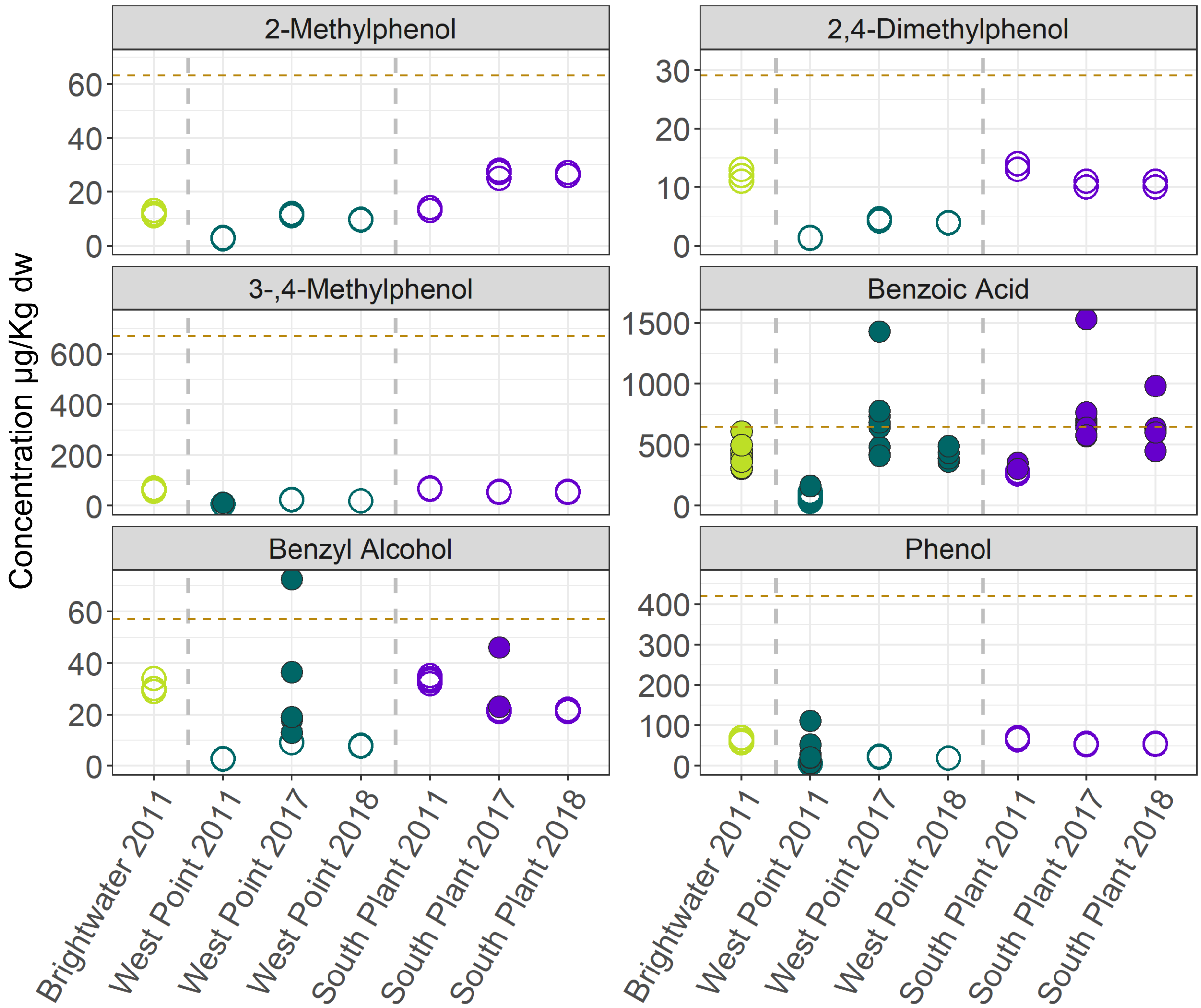


Figure 17. Polar organic compound concentrations (µg/Kg dw) in subtdial outfall site samples by date (2011, 2017, 2018). Empty symbols represent method detection limits (MDL) when concentrations were < MDL detection. Gold broken line represents SQS.

Additional Organic Chemicals

SQS have not been developed for total 4-nonylphenol and coprostanol; however, they were analyzed in all samples because wastewater effluent is a pathway for their entry into the marine environment. Additionally, 4-nonlyphenol is considered an endocrine disrupting compound and a chemical of concern. Coprostanol, a derivative of cholesterol, was detected at one of eight sites near West Point in 2017 (130 µg/Kg dw) and three of four sites in 2018 (81 - 100 µg/Kg dw). Coprostanol was not detected in samples collected near South Plant. Total 4-nonylphenol, a surrogate for alkyl phenols (used in plastics and as surfactants), was only detected in one sample (500 µg/Kg dw) collected near the South Plant outfall in 2018. Total 4-nonylphenol was not detected in samples from near the West Point outfall. Neither chemical was detected in sediments near the Brightwater Outfall.

Sediment Chemistry Index

Mean (all samples/years) SCI scores for sites near the Brightwater Outfall were 97.0 (range 95.8 - 97.6) (Table 16) and 97.4 (individual site mean range 97.0 - 98.9) for sites near South Plant (Table 17). SCI scores for these deep outfalls are indicative of minimal chemical exposure. The mean SCI score for West Point sites was 96.3 (individual site mean range 92.3 -97.8)[8], which correspond to expected low to minimal chemical exposure (Table 18). One site (WP420NW) had a mean SCI score (92.3) below 93.3 (threshold for minimal exposure). Samples from this site exceeded the SQS for total PCBs in 2011 and benzoic acid in 2017 (benzoic acid not used to calculate SCI).

Outfall Sediment Chemistry Patterns

Sites near the Brightwater outfall are ~185–190 m deep and characterized by high percent fines (~80%) consisting mostly of silt and TOC content of about 1.5%. The Brightwater outfall began operation in September 2011 and results presented here are for samples collected prior to operation of the outfall. Chemical concentrations in all Brightwater samples were below SQS (Table 16).

Sites near the South Plant outfall are ~ 195 m deep. Sediments in this area are dominated by fines (~ 98%, silt and clay) and a mean TOC content of 2.0–2.5%. Chemical concentrations in 2011 and 2017 only exceeded the benzoic acid SQS at five sites in 2017, while repeat sampling in 2018 indicated an exceedance at only one site (Table 17).

The West Point outfall sampling area is shallower than the other two outfalls, and samples were collected from ~ 75–80 m deep. Sediments here are dominated by sand (47.6–97.4%) and variable amounts of fines (2.7–18.5%) and gravel (0.2–27.2%). TOC is variable, typically < 1%, often < 0.5%. SQS exceedances during the last two sampling events included dimethyl phthalate at one site (2011), total PCBs at two sites (2011), benzyl alcohol at one site (2017), and benzoic acid at four sites (2017) (Table 18).

While some SQS exceedances have occurred at sites located near outfalls, they are not temporally consistent. Except for benzoic acid, chemical exceedances have not occurred more than once at the same site for the same chemical. Benzoic acid is commonly detected 0elsewhere in Puget Sound (including several routine subtidal sites in 2017) and has both anthropogenic and natural sources. Further comparisons to routine subtidal sediment data are included in Section 3.2.2.

[8] Sediment Chemistry Index (SCI) calculated based on OC normalized or dry weight comparisons to SMS, depending on TOC content (see Section 2.2.3).

Table 16. Summary of physical and chemical sediment characteristics of Brightwater outfall sites (2011).

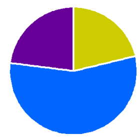
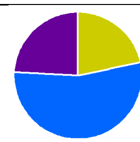
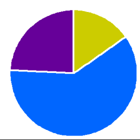
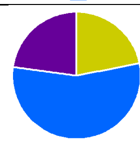
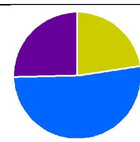
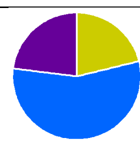
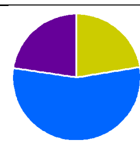
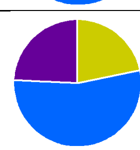
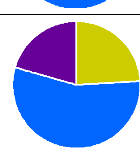
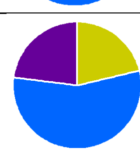
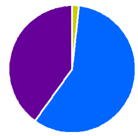
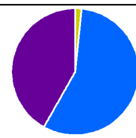
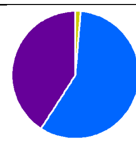
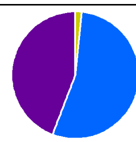
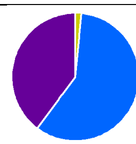
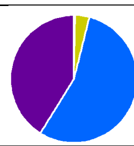
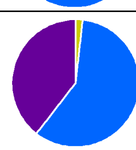
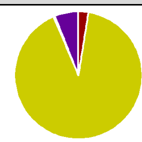
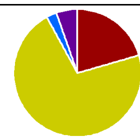
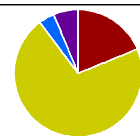
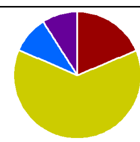
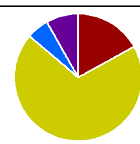
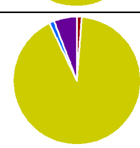
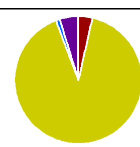
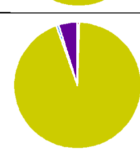
Site/ Number of Sampling Events	Approx. Depth (m)	% TOC	% Fines	Grain Size Clay Silt Sand Gravel	Exceed SQS?	Mean SCI and Exposure Level Minimum Low Moderate High
BWND400N N=1	185	1.39	78.8		No	97.4
BWND400S N=1	187	1.35	78.4		No	97.4
BWND600P N=1	186	1.46	84.8		No	97.6
BWND800N N=1	184	1.32	78.2		No	96.3
BWND800S N=1	190	1.50	77.4		No	96.1
BWSD400N N=1	189	1.39	78.8		No	95.8
BWSD400S N=1	183	1.32	77.6		No	97.5
BWSD600P N=1	189	1.51	78.2		No	97.3
BWSD800N N=1	185	1.41	75.9		No	97.5
BWSD800S N=1	188	1.38	78.8		No	97.3

Table 17. Summary of physical and chemical sediment characteristics of South Plant outfall sites (mean 2011, 2017, and 2018 [follow up from 2017 event]).

Site/ Number of Sampling Events	Approx. Depth (m)	Mean % TOC	Mean % Fines	Mean Grain Size (Clay, Silt, Sand, Gravel)	Exceed SQS?	Mean SCI and Exposure Level (Minimum, Low, Moderate, High)
STP460N N=2	193	2.01	98.3		No	97.4
STP460S N=3	194	2.10	98.4		Benzoic acid (2017/2018)	97.5
STP570MS N=3	195	2.22	98.4		Benzoic acid (2017)*	97.6
STP610MN N=3	194	2.00	98.7		Benzoic acid (2017)*	97.4
STP625NP N=2	195	2.06	98.4		No	97.6
STP625SP N=3	195	2.52	98.5		No	98.9
STP770SE N=3	194	2.06	96.1		Benzoic acid (2017)*	97.0
STP820NE N=3	193	2.04	98.2		Benzoic acid (2017)*	97.5

*Resampling in 2018 yielded no exceedances of benzoic acid

Table 18. Summary of physical and chemical sediment characteristics of West Point outfall sites (2011, 2017, and 2018 [follow up from 2017 event]).

Site/ Number of Sampling Events	Approx. Depth (m)	Mean % TOC	Mean % Fines	Mean Grain Size (Clay, Silt, Sand, Gravel)	Exceed SQS?*	Mean SCI** and Exposure Level (Minimum, Low, Moderate, High)
WP215N N=2	76	0.288	6.4		Dimethyl phthalate (2011)	97.5
WP230P N=3	74	0.425	8.0		Total PCBs (2011); Benzoic acid and benzyl alcohol (2017)***	96.0
WP280W N=3	74	0.405	10.3		Benzoic acid (2017)***	96.3
WP410W N=3	81	0.566	18.5		Benzoic acid (2017)***	97.2
WP420NW N=3	80	0.727	13.8		Total PCBs (2011); Benzoic acid (2017)***	92.3
WP430N N=2	79	0.459	7.1		No	97.2
WP430S N=2	79	0.250	5.7		No	97.8
WPD215N N=2	75	0.265	5.6		No	97.8

*When TOC content <0.5 or >3.5% data compared to dw SQS
**SCI calculated based on comparison to appropriate SQS depending on TOC content (see Section 2.2.3).
***Resampling in 2018 yielded no SQS exceedances of benzoic acid or benzyl alcohol

3.2.2 Routine Subtidal Sediment Chemistry

The current routine subtidal offshore sediment monitoring includes three components that occur on two different sampling frequencies. Samples are collected from eight sites in Elliott Bay every two years, while samples from six sites in the Central Basin mainstem and

smaller embayments are collected every five years (Table 19). Sampling location information is available in Section 2.1.2. Results and a nonregulatory comparison to SQS (sample collected from 0-2 cm rather than 0-10 cm) are presented below.

Table 19. Routine subtidal sediment sampling events.

Sampling Location	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Elliott Bay (8 sites)	✓		✓		✓		✓		✓		✓
Mainstem (3 sites)				✓					✓		
Embayments (3 sites)		*		✓					✓		

*Sediment samples collected from embayment site MSVK01 in 2010 for separate project (King County, 2010d) are included here.

Data for samples collected from 0–2 cm sediment depth are summarized below. These data include results for conventional parameters and chemical compounds that were consistently analyzed across all sampling events.

Conventional Parameters

Elliott Bay samples were collected from sites with a range of depths (~20 to 180 m). Depths at mainstem sites ranged from 175 to 280 m, while embayment site depths ranged from approximately 6 to 12 m. Samples were analyzed for solids, grain size, TOC, ammonia nitrogen, and total sulfides (Table 20). Total solids at all sites ranged from 27.4 to 75.1%. TOC content was variable by site and ranged from 0.216 to 7.96% (Figure 18).

Table 20. Summary results for conventional parameters measured in samples from routine subtidal sites (2009–2019).

Parameter	DF	Min	Mean*	Max
% Total Solids	61/61	27.4	51.5	75.1
% TOC	61/61	0.216	1.55	7.96
% Fines	61/61	3.1	48.5	99
% Clay	61/61	3.1	17.2	44.3
% Silt	60/61	(0.6)	31.9	60.6
% Sand	61/61	3.00	44.0	94.2
% Gravel	39/61	(0.1)	8.4	57
Ammonia Nitrogen (mg/Kg dw)	61/61	0.994	4.95	21.2
Total Sulfide (mg/Kg dw)	52/61	(0.66)	120	1190

Values in parenthesis represent method detection limit (MDL) when concentrations < MDL.
DF = detection frequency; TOC = total organic carbon

Grain size composition was also variable. Deep sites, such as those in central Elliott Bay (LSCW02, LTCA02, and LTED04), East Passage (NSEX01), and off West Seattle (LSML01), as well as the much shallower Quartermaster Harbor site (MSVK01) had the highest percentage of fines, followed by sites near Harbor Island and the Elliott Bay waterfront (LTGF01 and LTDF01) (Figure 19).

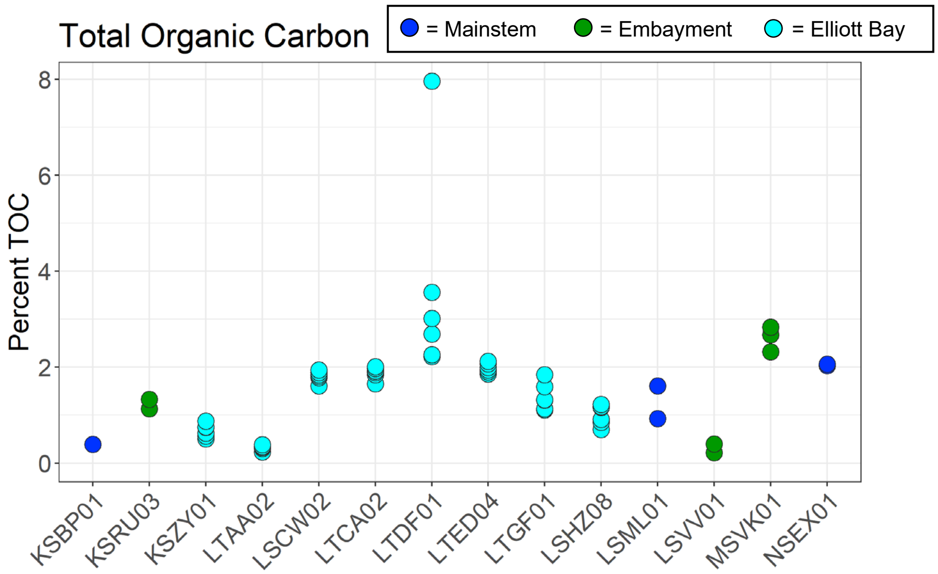


Figure 18. Total organic carbon content in samples from routine subtidal sites; all data (2009–2019) combined.

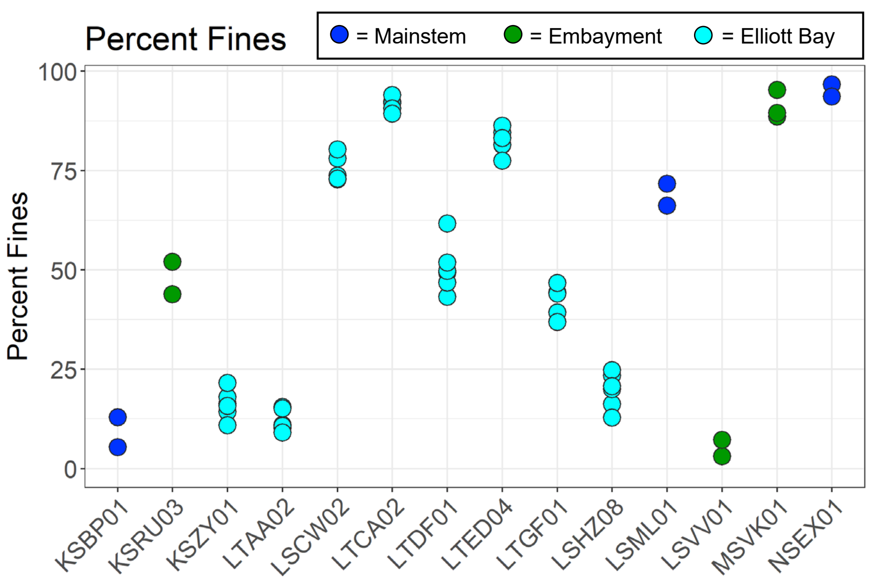


Figure 19. Total percent fines (percent silt + clay) in samples from routine subtidal sites; all data (2009–2019) combined.

Ammonia was detected in all samples (0.994–21.2 mg/Kg dw), with the highest concentrations detected in inner Quartermaster Harbor (MSVK01) (Figure 20). Total sulfide results demonstrated a similar pattern to ammonia, although sulfide was not detected in all samples. The highest sulfide level was found in inner Quartermaster Harbor (1,190 mg/Kg dw) (Figure 20).

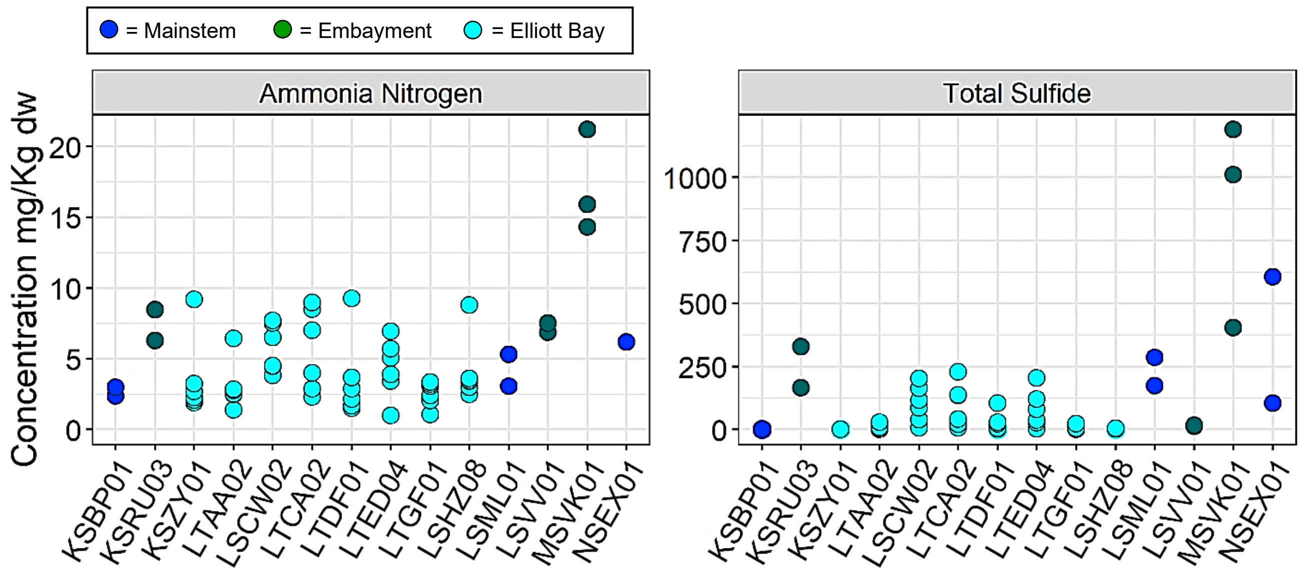


Figure 20. Ammonia nitrogen and total sulfide concentrations (mg/Kg dw) in samples from routine subtidal sites; all data (2009–2019) combined.

Metals

Except for cadmium, silver and tin, all other metals analyzed (aluminum, arsenic, chromium, copper, iron, lead, mercury, nickel, and zinc) were always or nearly always detected in samples. Concentrations of all metals except mercury were well below SQS (Table 21). Mercury concentrations were above the SQS (0.41 mg/Kg dw) in 12 of 61 samples. Elevated mercury concentrations were found in one or more sample collected at Piers 90/91 (KSZY01), Seattle waterfront (LTDF01), Harbor Island (LTGF01), and inner Quartermaster Harbor (MSVK01). The mercury level in one sample collected near Harbor Island in 2019 (0.806 mg/Kg dw) was above the SQS (0.41 mg/Kg dw) and CSL (0.59 mg/Kg dw).

Generally, concentrations of both crustal/earth metals (e.g., aluminum and iron), as well as those more indicative of anthropogenic sources, were highest at sites with higher TOC content. Except for mercury and the crustal metals, metal concentrations were similar across sites. The exception was inner Quartermaster Harbor, where mercury levels were higher compared to other sites. Elevated mercury levels at this site are likely due to historic emissions from the Asarco Smelter in Tacoma; other metals indicative of those emissions were also higher at this site compared to other routine subtidal sites (e.g., arsenic, cadmium, and to a lesser extent, lead) (Figure 21).

Table 21. Summary results for metals in samples from routine subtidal sites (2009–2019).

Parameter	SQS	DF	Concentration (mg/Kg dw)			# Samples > SQS
			Min	Mean*	Max	
Aluminum	N/A	61/61	6310	13800	22800	N/A
Arsenic	57	60/61	2.5	8.58	24.2	0
Cadmium	5.1	35/61	0.14	0.458	1.95	0
Chromium	260	61/61	14.8	32.9	55.4	0
Copper	390	61/61	5.41	40.8	81.6	0
Iron	N/A	61/61	9050	21400	43100	N/A
Lead	450	60/61	3.5	31.4	64	0
Mercury	0.41	61/61	0.0149	0.259	0.806	**12**
Nickel	N/A	60/60	13.1	28.5	41.4	N/A
Silver	6.1	18/61	0.15	0.551	1.5	0
Tin	N/A	48/60	(1.3)	4.25	8.1	N/A
Zinc	410	61/61	22	75.2	110	0

*Mean calculated from detected values.
Values in parenthesis indicate method detection limit (MDL) when concentration < MDL.
SQS = Sediment Quality Standard; DF = detection frequency

Sufficient data (≥ 15 samples collected > ten years) were available from five routine subtidal monitoring sites (Elliott Bay at LTDF01, LSCW02, LTCA02, LTED04 and off West Seattle at LSML01) to conduct long-term trend analysis (Figure 22). Data for samples collected between 1985 and 2019 were used for the analysis; silver was excluded from the analysis due to low detection frequency and tin was excluded because < ten sampling events were available.

When data for all five sites were pooled, significant decreasing trends were observed for lead and mercury (Figure 22). Conversely, an overall slightly positive trend was detected for iron (crustal/earth metal). For each significant trend for the pooled dataset, individual sites with significant trends were also identified (Table 22). Complete trend data, including results from all individual sites, are included in Appendix B.

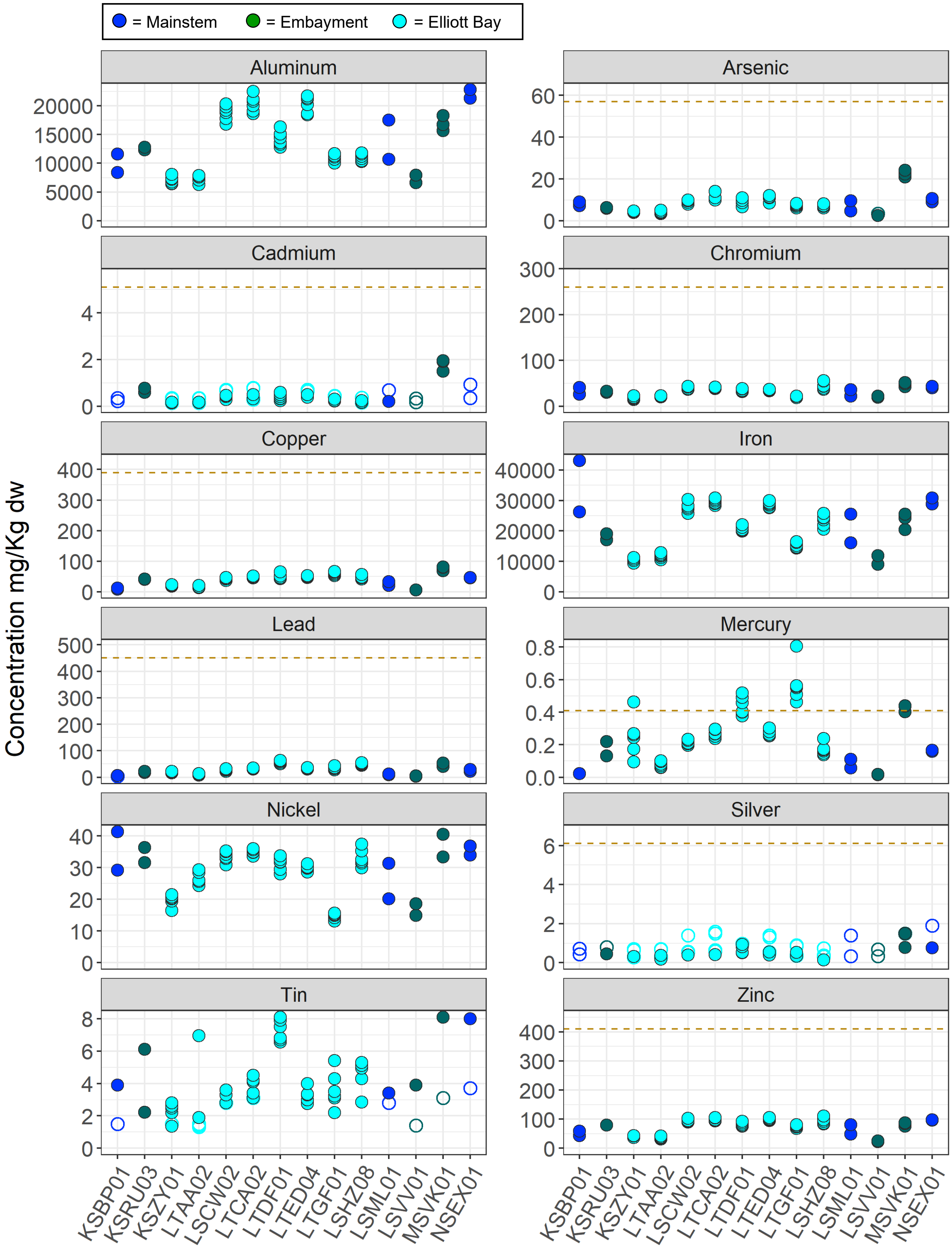


Figure 21. **Metals concentrations (mg/Kg dw) in samples from routine subtidal sites; all data (2009–2019) combined. Empty symbols represent method detection limit (MDL) when concentrations < MDL. Gold broken line represents SQS.**

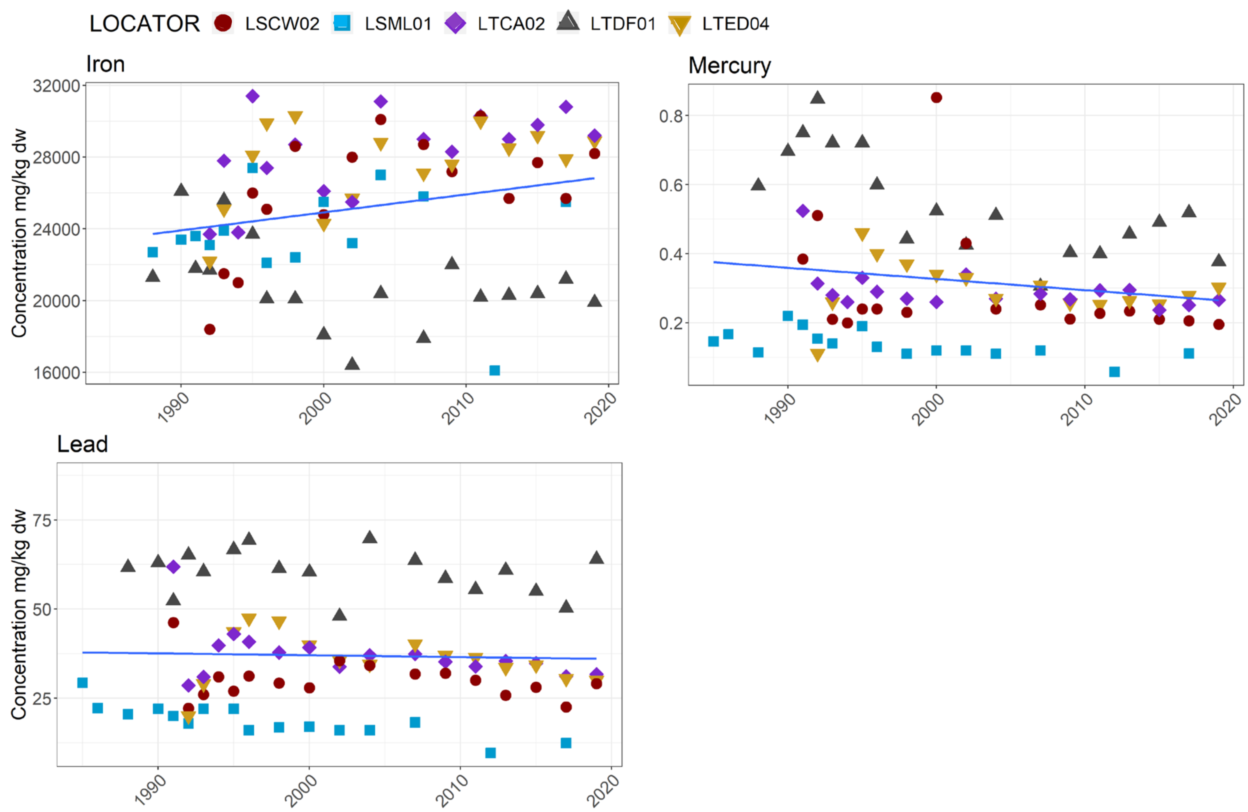


Figure 22. Metals concentrations at five long-term routine subtidal sites (1985–2019) with significant trends. Empty symbols represent method detection limit (MDL) when concentrations < MDLs.

Table 22. Metals with discernable overall trend (p < .05) at five offshore sites; all data (1985–2019) combined. Individual sites with significant trend in same direction also listed.

Parameter	Trend	p-value	Sites with significant trend
Iron	**Increasing**	1.14 E-4	LSCW02, LTCA02, LTED04
Lead	**Decreasing**	3.00 E-6	LSML01, LTCA02, LTED04
Mercury	**Decreasing**	8.49 E-9	LSCW02, LSML01, LTCA02, LTDF01

Organic Compounds

Offshore sediments were analyzed for 84 organic chemicals during most sampling events. The chemicals analyzed included butyltins, phthalates, chlorinated semi-volatile organics, PCB Aroclors, PAHs, PBDEs, and several other polar and non-polar organic chemicals. Results for chemicals with SQS criteria are summarized first.

PAHs

Of the 16 PAHs analyzed, all were detected in 21 or more of the 61 samples (Table 23). Of the LPAHs, phenanthrene was most frequently detected and at the highest concentrations. All total LPAH concentrations were below SQS (Table 23) and ranged from < MDL at Point Jefferson (KSBP01) to 2,280 µg/Kg dw at the Elliott Bay Waterfront (LTDF01) (Figure 23).

Of the HPAHs, benzo(b,j,k)fluoranthene, fluoranthene, and pyrene were most frequently detected and at the highest concentrations (Table 23). Like LPAHs, total HPAH levels were highest at the Seattle waterfront (LTDF01 - 10,600 µg/Kg dw) (Figure 24). HPAH concentrations in only two samples were above the SQS:

- Benzo(g,h,i)perylene (KSRU03, 2012) - 37.7 mg/Kg OC (SQS – 31 mg/Kg OC)
- Fluoranthene (LTDF01, 2013) - 2,100 µg/Kg dw (dw SQS – 1,700 µg/Kg dw)

All PAH concentrations were lowest at mainstem stations, which are removed from many urban sources. The highest PAH concentrations were detected in Elliott Bay near the Seattle Waterfront (LTDF01), Outer Salmon Bay (KSUR03), and North Harbor Island (LTGF01) (Figure 23 and Figure 24). Sites with higher PAH concentrations correspond to areas with a high density of creosote pilings or located near storm drains along the shoreline. While the Fauntleroy Cove site (LSVV01) is located near creosote treated wood pilings, PAH concentrations were lower than those in Elliott Bay, which also contains a high density of creosote pilings. These differences may be due to the low percentage of fine grain sediments and OC at this site. Where sources of PAHs are present, higher concentrations tend to be found in depositional environments characterized by sediments with higher percentages of OC and fines.

Data collected between 1986–2019 at five routine subtidal monitoring sites allowed for long-term trend analysis for total LPAHs and HPAHs (Figure 25). When data were pooled, an overall significant decreasing trend was detected for both LPAHs and HPAHs. These trends were also significant at most individual sites (Table 24). All sites with a significant decreasing trend were within Elliott Bay. Complete trend data, including results from all individual sites, is included in Appendix B.

Table 23. Summary of PAH results for samples collected from routine subtidal sites (2009–2019).

Parameter	dw SQS	DF	Concentration (µg/Kg dw)			# Samples > SQS*
			Min	Mean**	Max	
2-Methylnaphthalene	670	21/61	3.3	14.2	81.1	0
Acenaphthene	500	23/61	(4.5)	23.4	147	0
Acenaphthylene	1300	24/61	(3.0)	27.9	90.8	0
Anthracene	960	50/61	(4.9)	66.3	495	0
Fluorene	540	35/61	(4.5)	30.2	158	0
Naphthalene	2100	22/61	(4.5)	20.5	132	0
Phenanthrene	1500	57/61	(4.9)	142	1250	0
Total LPAHs* **	**5200**	**57/61**	**(4.9)**	248	**2280**	**0**
Benzo(a)anthracene	1300	60/61	6.5	139	813	0
Benzo(a)pyrene	1600	57/61	5.3	185	1030	0
Benzo(b,j,k)fluoranthene	3200	60/61	(8.2)	360	2080	0
Benzo(g,h,i)perylene	670	56/61	(4.9)	96.5	501	**1**
Chrysene	1400	58/61	(4.9)	204	1400	0
Dibenzo(a,h)anthracene	230	40/61	(4.5)	41.4	126	0
Fluoranthene	1700	60/61	(8.2)	263	2100	**1**
Indeno(1,2,3-Cd)Pyrene	600	54/61	(4.9)	104	431	0
Pyrene	2600	61/61	10.3	286	2370	0
Total HPAHs	**12000**	**61/61**	**41.2**	**1610**	**10600**	**0**

Only detected values used to sum LPAHs and HPAHs.
*Count based on comparison to appropriate SQS or dw SQS based on TOC
**Mean calculated from detected values.
***2-methylnaphthalene not used in calculation of total LPAHs.
Values in parenthesis indicate MDL when concentrations < MDL.
SQS = Sediment Quality Standard; DF = detection frequency

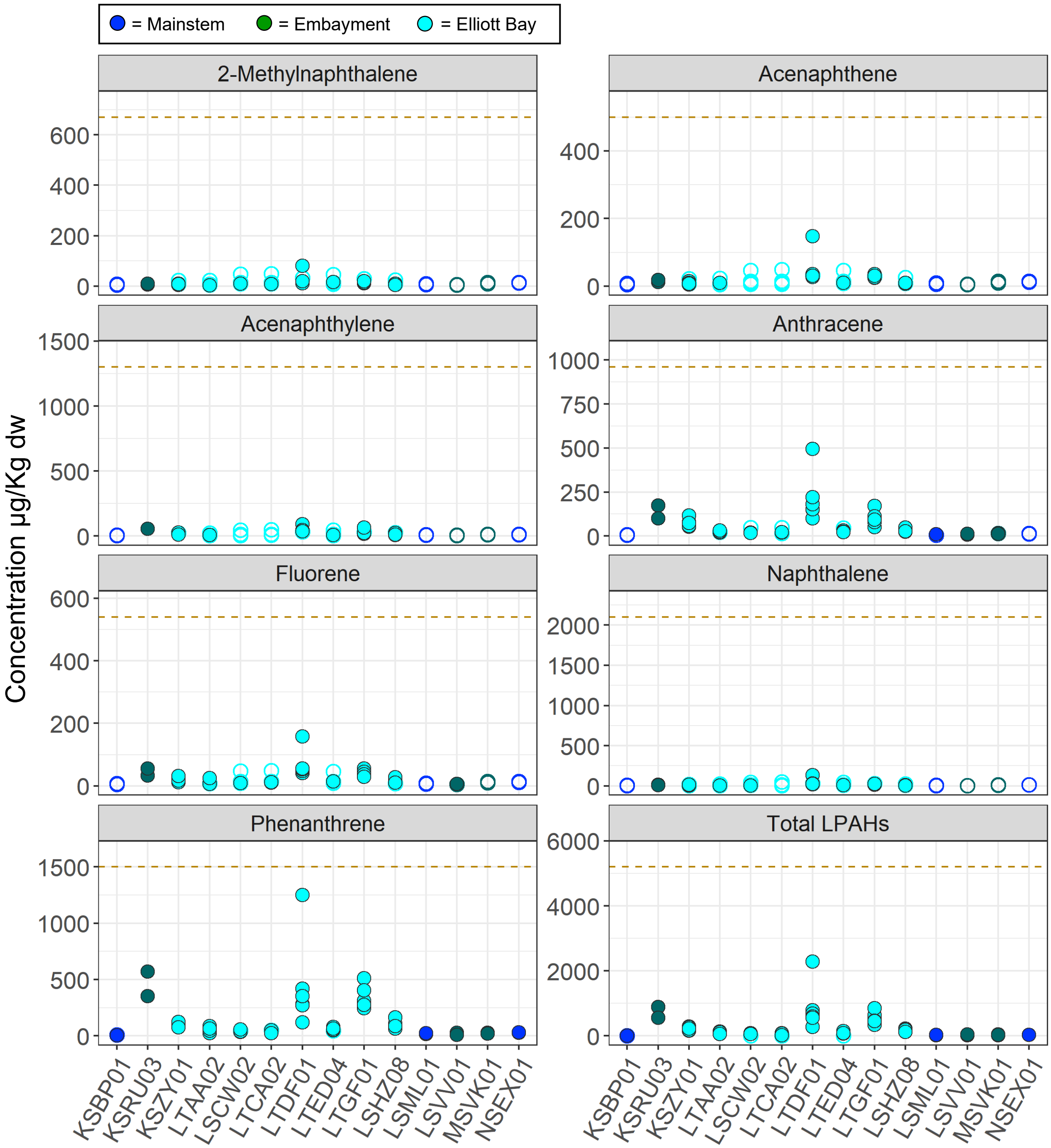


Figure 23. LPAH concentrations (µg/Kg dw) in samples from routine subtidal sites (2009–2019. Empty symbols represent method detection limit (MDL) when concentrations < MDL. Gold broken line represents the dry weight equivalent SQS.

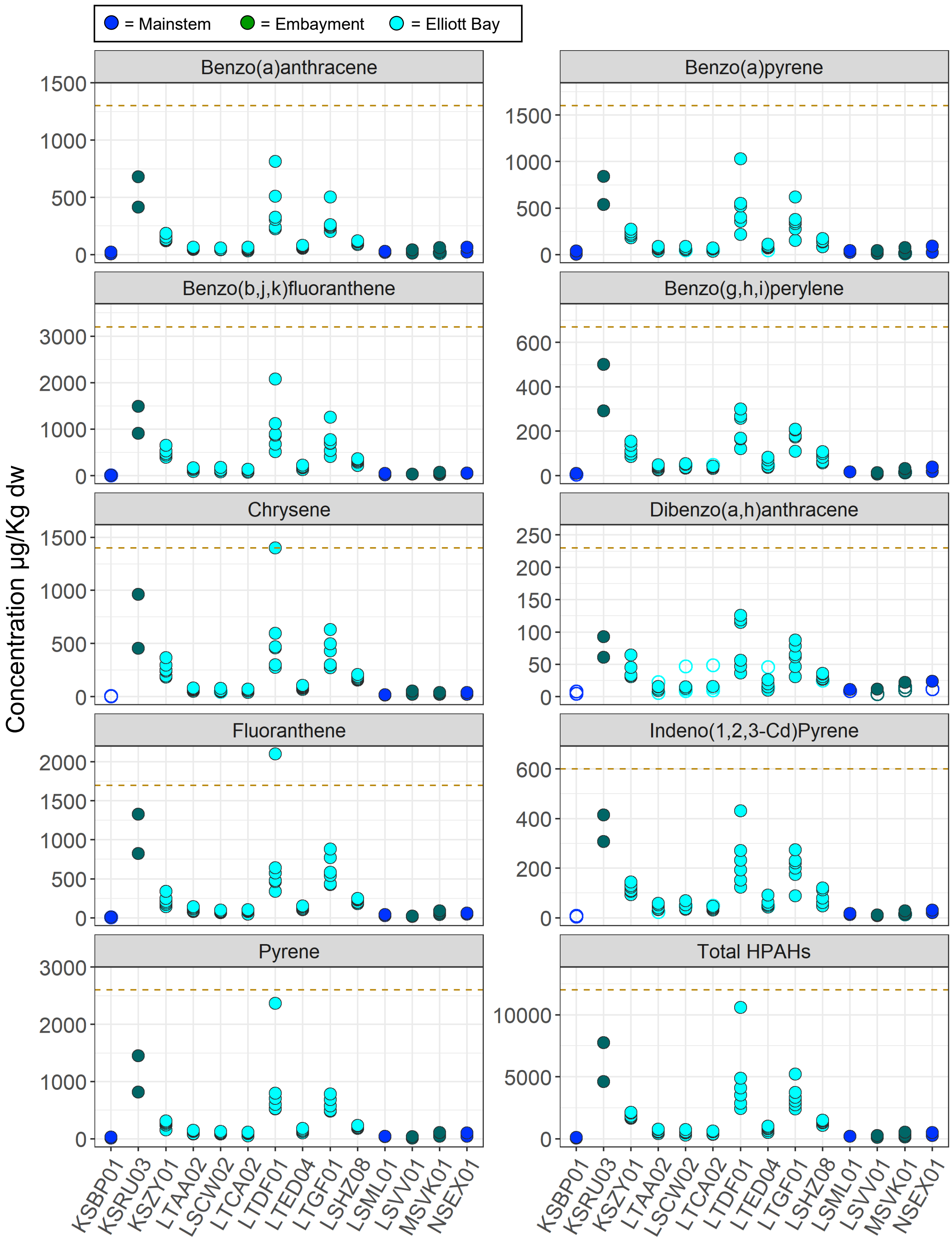


Figure 24. HPAH concentrations (µg/Kg dw) in samples from routine subtidal sites (2009–2019). Empty symbols represent the method detection limit (MDL) when concentrations < MDL. Gold broken line represents the dry weight equivalent SQS.

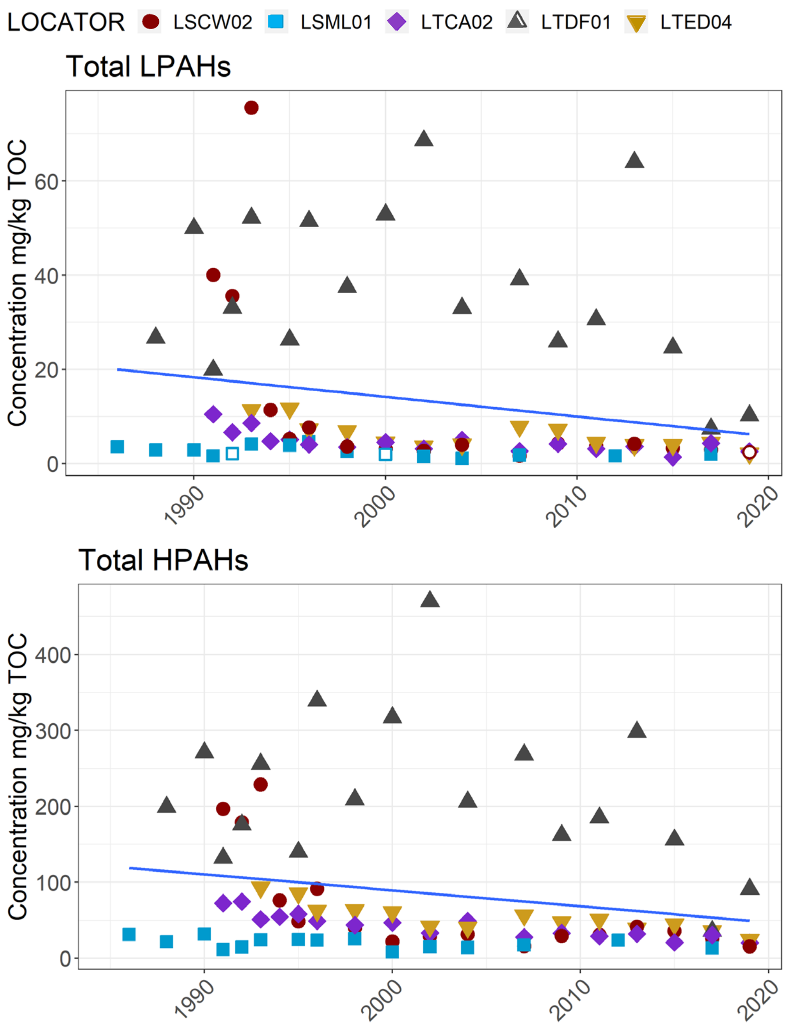


Figure 25. Concentrations (mg/kg TOC) of total LPAHs and HPAHs in samples from five long-term routine subtidal sites (1986–2019). Solid symbols represent detected concentrations and open symbols represent method detection limits (MDL) when concentrations < MDL.

Table 24. OC-normalized PAHs with discernable overall trend ($p < .05$) at five offshore sites; all data (1986–2019) combined. Individual sites with significant trend (increasing or decreasing) in same direction also listed.

Parameter	Trend	p-value	Sites with significant trend
Total LPAHs	**Decreasing**	8.73 E-7	LSCW02, LTCA02
Total HPAHs	**Decreasing**	4.47 E-8	LSCW02, LTCA02, LTED04

Phthalates

Six phthalate compounds were analyzed in all samples. Some concentrations of bis(2-ethylhexyl)phthalate and di-N-butyl phthalate were treated as non-detects due to blank contamination. Despite blank contamination issues, bis(2-ethylhexyl)phthalate was the most frequently detected phthalate and occurred at the highest concentrations. Bis(2-ethyhexyl)phthalate concentrations in two samples in 2009 (Harbor Island - LTGFO1 and

Piers 90/91 - KSZY01) were above the SQS (Table 25). The concentration at Piers 90/91 (KSZY01) was also above the benthic CSL.

Other phthalates were detected at lower frequencies; dimethyl phenol was never detected, and no other phthalate concentrations were above SQS (Table 25, Figure 26).

Table 25. Summary results for phthalates in samples from routine subtidal sites (2009–2019).

Parameter	dw SQS	DF	Concentration (µg/Kg dw)			# Samples >SQS*
			Min	Mean**	Max	
Benzyl Butyl Phthalate	63	23/61	(4.5)	20.4	61.3	0
Bis(2-Ethylhexyl)Phthalate	1300	39/61	(4.9)	109	792	**2**
Di-N-Butyl Phthalate	1400	11/61	(4.5)	16.6	38	0
Di-N-Octyl Phthalate	6200	1/61	(5.9)	47	47	0
Diethyl Phthalate	200	5/61	(5.9)	52	131	0
Dimethyl Phthalate	71	0/61	(5.9)	N/A	(99)	0

*Count based on comparison to appropriate SQS or dw SQS based on TOC.
**Mean calculated from detected values.
Blank contamination effected some sample results - bis(2-ethylhexyl)phthalate and di-n-butyl phthalate; results <5x method blank concentration considered non-detects
Values in parenthesis indicate method detection limit (MDL) when concentration < MDL.
SQS = Sediment Quality Standard; DF = detection frequency

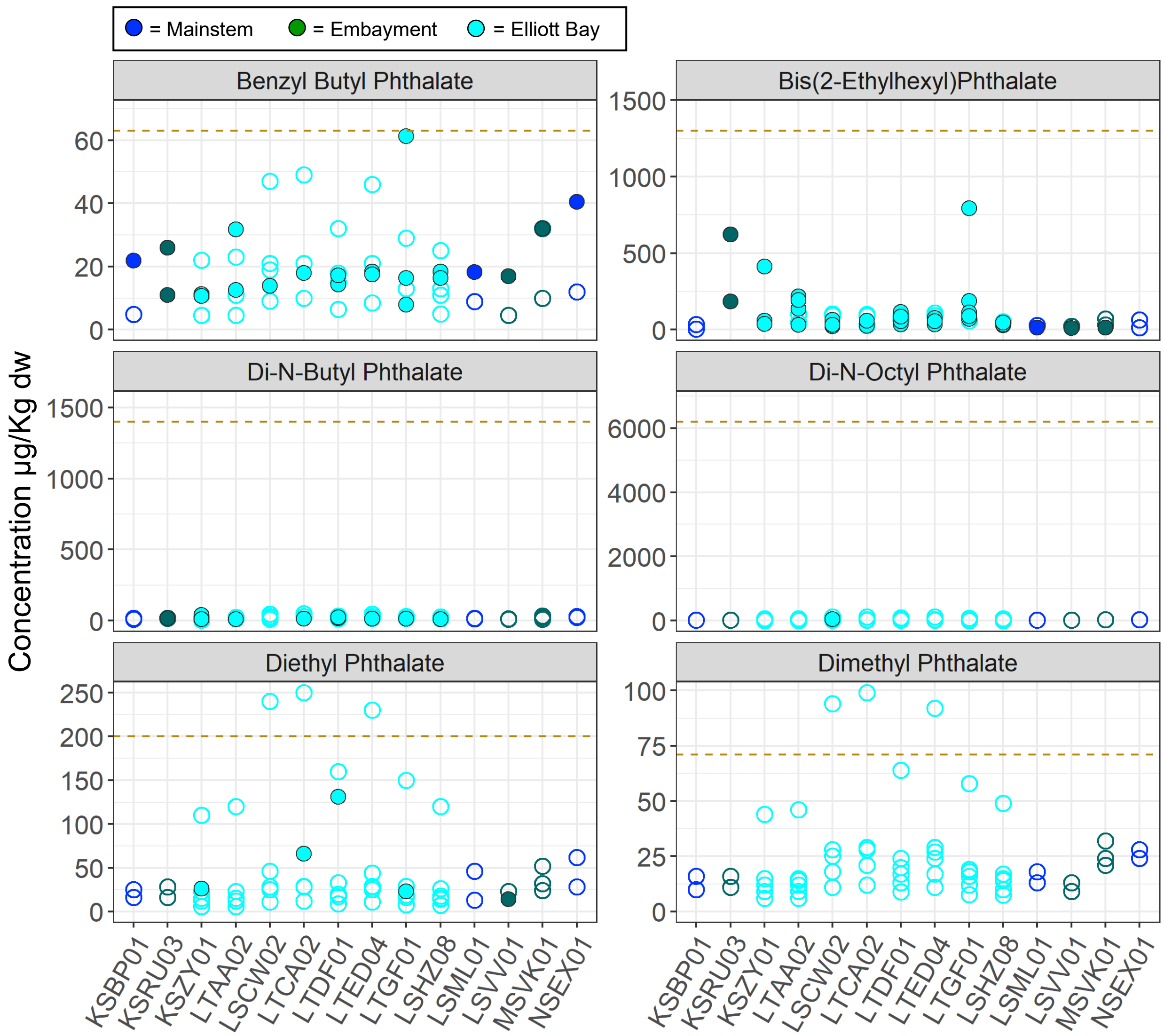


Figure 26. Phthalate concentrations (µg/Kg dw) in samples from routine subtidal sites (2009–2019). Empty symbols represent method detection limit (MDL) when concentrations < MDL. Gold broken line represents dw SQS. Note: two bis(2-ethylhexyl)phthalate concentrations > OC-based SQS.

PCBs

Seven PCB Aroclors were measured in all routine subtidal samples. Three Aroclors (1016, 1221, and 1232) were never detected while 1254 and 1260 were most frequently detected (Table 26). Total PCB concentrations (sum detected Aroclors) ranged from < MDLs at most mainstem and embayment sites to 498 µg/Kg dw in central Elliott Bay (LTED04) (Figure 27). PCB concentrations in Elliott Bay samples were generally the highest and levels in six samples were above the SQS:

- PCB levels were above SQS (12 mg/Kg OC) in samples from Harbor Island (LTGF01) (2013 and 2015), Piers 90/91 (KSZY01) (2011), and Central Elliott Bay (LTED04) (2011) where the highest OC-normalized concentration (25.0 mg/Kg OC) was detected.

- PCB levels were above the dw SQS (130 µg/Kg dw) twice: Elliott Bay Grain Terminal (LTAA02) in 2009 (235 µg/Kg dw; TOC <0.5%) and Seattle Waterfront (LTDF01) in 2013 (137 µg/Kg dw, TOC >3.5%).

Total PCB data from five routine subtidal monitoring sites (1988–2019) were sufficient to conduct long term trend analysis. No significant overall trend was detected when data from all sites were pooled; however, a significant decreasing trend in total PCBs at the Seattle Waterfront in Elliott Bay (LTDF01) was detected ($p = 4.68$ E-4) (Figure 28). Complete trend data, including results from all individual sites, is included in Appendix B.

Table 26. Summary of PCB Aroclor results at routine subtidal sites (2009–2019).

Parameter	dw SQS	DF	Concentration (µg/Kg dw)			# Samples > SQS*
			Min	Mean**	Max	
Aroclor 1016	NA	0/61	(1.1)	NA	(15)	N/A
Aroclor 1221	NA	0/61	(2.5)	NA	(36)	N/A
Aroclor 1232	NA	0/61	(2.5)	NA	(36)	N/A
Aroclor 1242	NA	29/61	(1.1)	9.60	18.5	N/A
Aroclor 1248	NA	8/61	(1.1)	16.0	40.1	N/A
Aroclor 1254	NA	53/61	(1.1)	35.1	170	N/A
Aroclor 1260	NA	51/61	(1.1)	36.1	413	N/A
Total PCBs	**130**	**53/61**	**(1.1)**	**77.5**	**498**	**6**

*Count based on comparison to appropriate SQS based on TOC.
**Mean calculated from detected values.
Values in parenthesis indicate the method detection limit (MDL) when concentrations <MDL.
SQS = Sediment Quality Standard; DF = detection frequency

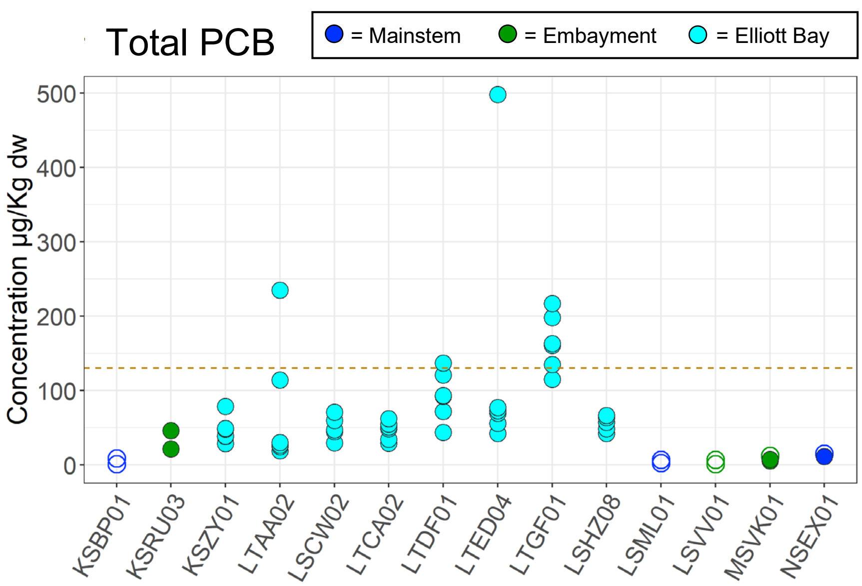


Figure 27. Total PCB concentrations (µg/Kg dw) in samples from routine subtidal sites (2009–2019). Empty symbols represent method detection limit (MDL) when concentrations < MDL. Gold broken line represents dw SQS. Note: six total PCB concentrations > SQS.

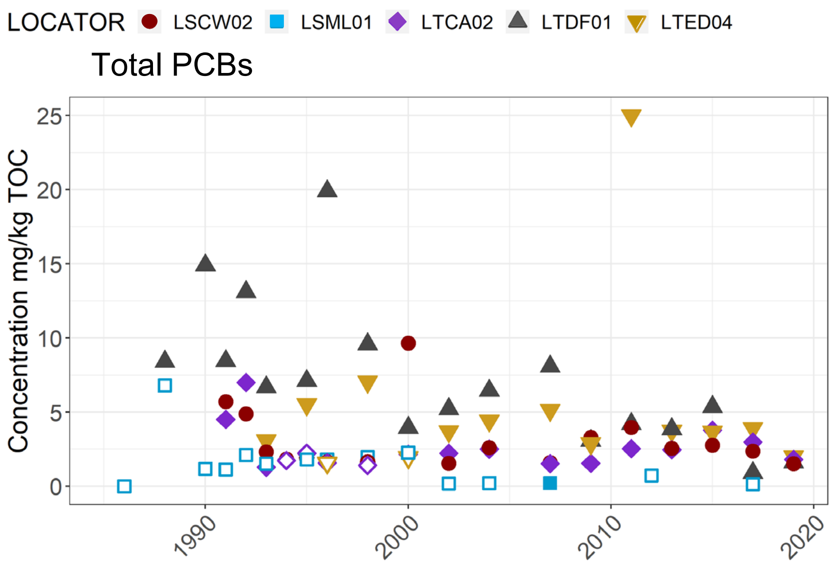


Figure 28. Total PCB concentration (mg/kg TOC) in samples from five long-term routine subtidal sites; all data (1986–2019) combined. Solid symbols represent detected concentrations and open symbols represent method detection limits (MDL) when concentrations < MDL.

Chlorinated Semi-volatile Organic Compounds

Six chlorinated semi-volatile organic compounds were analyzed in all samples. Three chlorobenzenes (1,2-dichlorobenzene, 1,2,4-trichlorobenzene, and 1,4-dichlorobenzene,) were never detected. Hexachlorobenzene was detected in a single sample (3.71 µg/Kg dw) in 2012 from inner Quartermaster Harbor (MSVK01) (below SQS). Hexachlorobutadiene was never detected. Pentachlorophenol was detected in two samples at concentrations well below the SQS (Table 27).

Table 27. Summary of chlorobenzene results at routine subtidal sites (2009–2019).

Parameter	dw SQS	DF	Concentration (µg/Kg dw)			# Samples >SQS*
			Min	Mean**	Max	
1,2-Dichlorobenzene	35	0/61	(0.29)	N/A	(25)	0
1,2,4-Trichlorobenzene	31	0/61	(0.15)	N/A	(25)	0
1,4-Dichlorobenzene	110	0/61	(0.29)	N/A	(25)	0
Hexachlorobenzene	22	1/61	(0.15)	3.71	3.71	0
Hexachlorobutadiene	11	0/61	(0.73)	N/A	(9.9)	0
Pentachlorophenol	360	2/61	40.1	185	330	0

*Count based on comparison to appropriate SQS based on TOC.
**Mean calculated from detected values.
1,2-dichlorobenzene results < 5x method blank concentration considered non-detects
Values in parenthesis represent method detection limit (MDL) when concentrations < MDL.
SQS = Sediment Quality Standard; DF = detection frequency

Miscellaneous Non-Polar Organics

N-nitrosodiphenylamine was never detected. Dibenzofuran was detected in 23 of 61 samples; the maximum concentration (83.7 µg/Kg dw) was below the SQS (Table 28).

Concentrations of dibenzofuran were slightly higher in Elliott Bay compared to mainstem and embayment sites (Figure 29).

Table 28. Summary of miscellaneous non-polar organics results at routine subtidal sites (2009–2019).

Parameter	dw SQS	DF	Concentration (µg/Kg dw)			# Samples > SQS*
			Min	Mean**	Max	
Dibenzofuran	540	23/61	4.5	17.4	83.7	0
N-Nitrosodiphenylamine	28	0/61	(4.5)	N/A	(49)	0

*Count based on comparison to appropriate SQS based on TOC.
**Mean calculated from detected values.
Values in parenthesis represent method detection limit (MDL) when concentration < MDL .
SQS = Sediment Quality Standard; DF = detection frequency

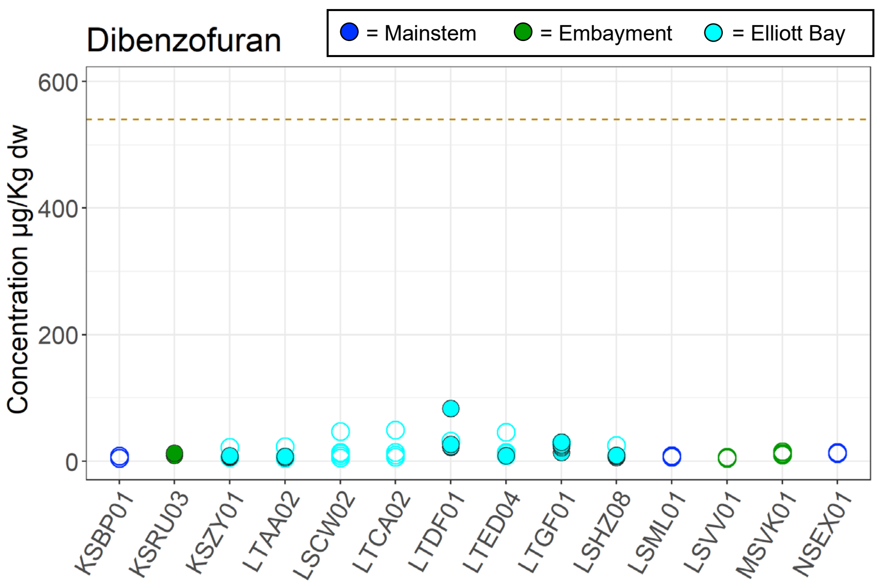


Figure 29. Dibenzofuran concentrations (µg/Kg dw) in samples from routine subtidal sites (2009–2019). Empty symbols represent method detection limit (MDL) when concentrations < MDL. Gold broken line represents dw SQS.

Polar Organic Compounds

Six polar organic chemicals were analyzed (benzoic acid, benzyl alcohol, and four phenolic compounds). Benzyl alcohol and the phenolic compounds were never detected (Table 29). Benzoic acid was detected in approximately half the samples with a maximum concentration of 1,050 µg/Kg dw. Detected concentrations of benzoic acid in six samples were above the SQS and CSL (both SQS and CSL = 650 µg/Kg dw) (Figure 30). In all cases, concentrations above the SQS were only detected once per site during the monitoring period. Five of the six elevated benzoic acid concentrations occurred during the 2017 sampling event; the same year that benzoic acid concentrations above the SQS were observed at outfall sites (see Section 3.2.1).

Table 29. Summary of polar organic results in samples from routine subtidal sites (2009–2019).

Parameter	SQS	DF	Concentration (µg/Kg dw)			# Samples > SQS
			Min	Mean*	Max	
2-Methylphenol	63	0/61	(2.9)	N/A	(120)	0
2,4-Dimethylphenol	29	0/61	(1.5)	N/A	(49)	0
3-,4-Methylphenol	670	0/61	(5.9)	N/A	(250)	0
Benzoic Acid	650	33/61	140	389	1050	**6**
Benzyl Alcohol	57	0/61	(2.9)	N/A	(99)	0
Phenol	420	0/61	(5.9)	N/A	(250)	0

*Mean calculated from detected values.
Benzoic acid results < 5x method blank concentration considered non-detects
Values in parenthesis indicate method detection limit (MDL) when concentrations <MDL.
SQS = Sediment Quality Standard; DF = detection frequency

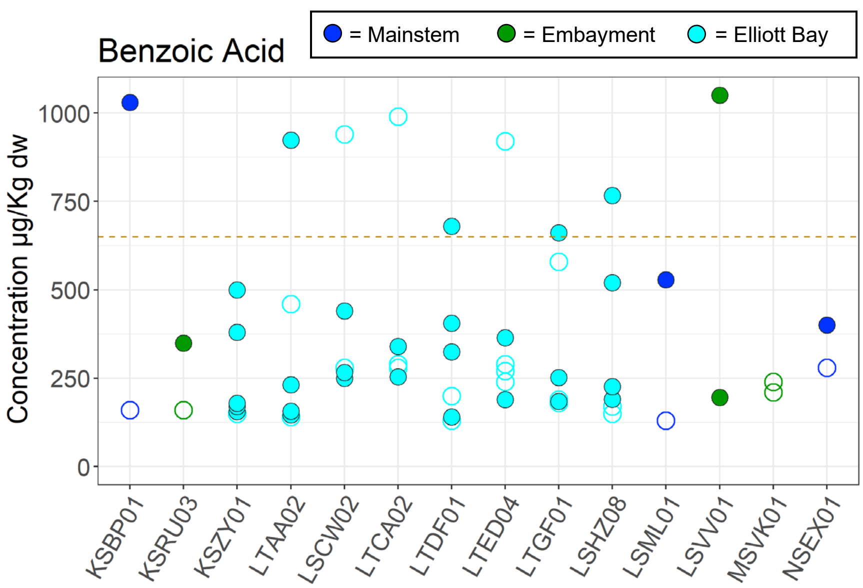


Figure 30. Benzoic acid concentrations (µg/Kg dw) in samples from routine subtidal sites (2009–2019). Empty symbols represent method detection limit (MDL) when concentrations < MDL. Gold broken line represents SQS.

Butyltins

Four butyltin isomers were analyzed in routine subtidal sediment samples. Historically, tri-n-butyltin was used extensively as an anti-fouling agent to prevent marine organisms from attaching to boat hulls. After the 1980s, its use in anti-fouling paint was restricted to vessels larger than 25 meters and use was banned in 2008. All four butyltin isomers were detected in at least one sample; tri-n-butyltin was detected most frequently (Table 30). The highest butyltin concentrations were detected at the Harbor Island site (LTGF01), followed by Outer Salmon Bay (KSRU03) and the Grain Terminal in Elliott Bay (LTAA02) (Figure 31), all areas with heavy large vessel usage. While there are no established SQS for butyltins, they are known to have harmful effects on benthic organism (Bryan and Gibbs, 1991; Alzieu, 2000).

Table 30. Summary of butyltin results at routine subtidal sites (2009–2019).

Parameter	DF	Concentration (µg/Kg dw)		
		Min	Mean*	Max
Di-n-Butyltin	25/52	(2.8)	20.2	74.2
Mono-n-Butyltin	11/52	(2.8)	9.3	30
Tetra-n-Butyltin	1/52	(1.3)	3.5	3.5
Tri-n-Butyltin	37/52	(2.8)	38.8	176

*Mean calculated from detected values.
Values in parenthesis represent method detection limit (MDL) when concentrations < MDL.
DF = detection frequency

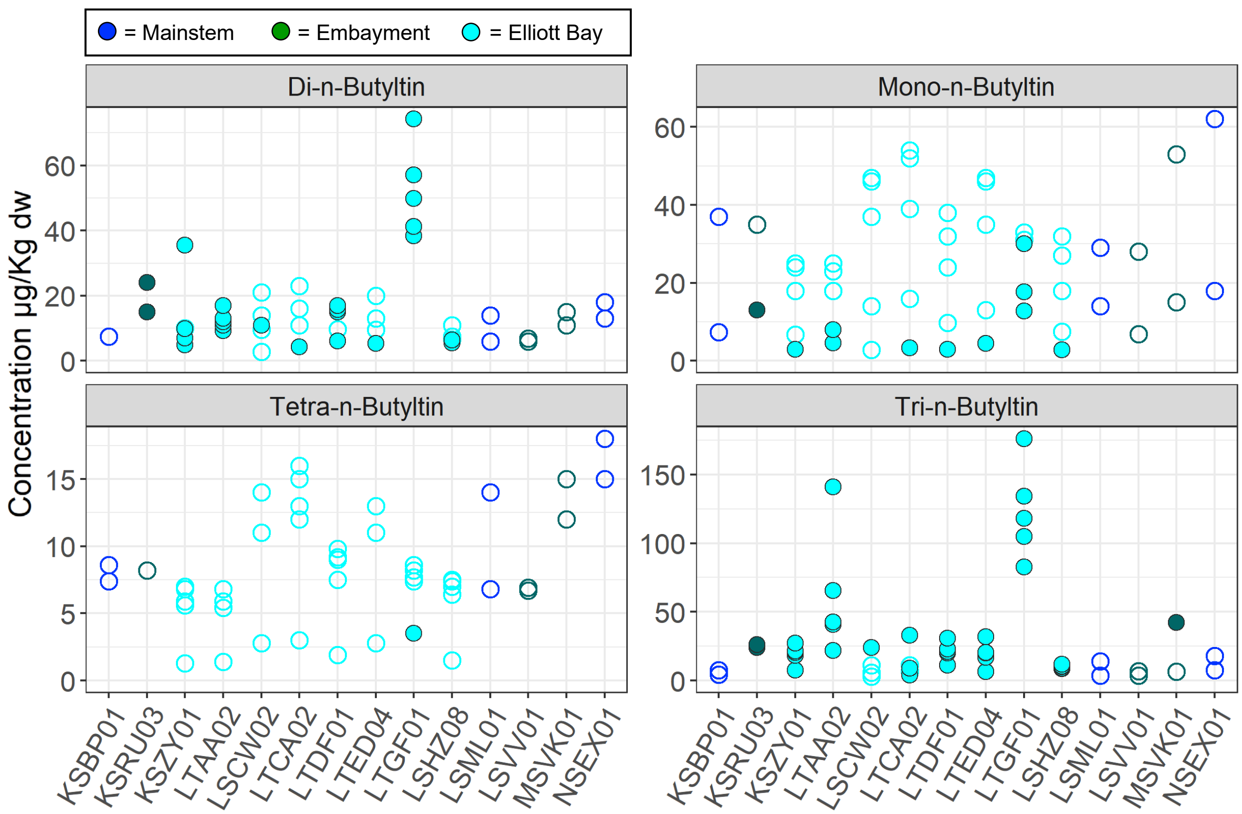


Figure 31. Butyltin concentrations (µg/Kg dw) in samples from routine subtidal sites (2009–2019). Empty symbols represent method detection limit (MDL) when concentrations < MDL.

Chlorinated Pesticides

Of the 20 chlorinated pesticides analyzed in routine subtidal samples, most (14 of 20) were never detected. Beta-BHC was only detected in one inner Quartermaster Harbor (MSVK01) sample, while dieldrin and heptachlor epoxide were only detected in one Harbor Island (LTGF01) sample. DDT and its metabolites (DDE and DDD) were the most frequently detected pesticides (Table 31) and detected at several sites in Elliott Bay (Figure 32). DDE and DDT were each detected once in Salmon Bay (KSRU03).

Table 31. Summary of chlorinated pesticide results at routine subtidal sites (2009 - 2019).

Parameter	DF	Concentration (µg/Kg dw)		
		Min	Mean*	Max
4,4'-DDD	22/60	(0.23)	1.82	6.62
4,4'-DDE	12/60	(0.23)	0.675	1.33
4,4'-DDT	14/60	(0.23)	2.48	6.39
Aldrin	0/44	(0.23)	N/A	(2.9)
Alpha-BHC	0/44	(0.23)	N/A	(2.9)
Alpha-Chlordane	0/44	(0.23)	NA	(2.9)
Beta-BHC	1/44	(0.23)	0.745	0.745
Delta-BHC	0/44	(0.23)	N/A	(2.9)
Dieldrin	1/44	(0.23)	1.11	1.11
Endosulfan I	0/44	(0.23)	N/A	(2.9)
Endosulfan II	0/44	(0.23)	N/A	(2.9)
Endosulfan Sulfate	0/44	(0.23)	N/A	(2.9)
Endrin	0/44	(0.23)	N/A	(2.9)
Endrin Aldehyde	0/44	(0.23)	N/A	(2.9)
Gamma-BHC (Lindane)	0/44	(0.23)	N/A	(2.9)
Heptachlor	0/44	(0.23)	N/A	(2.9)
Heptachlor Epoxide	1/44	(0.23)	0.653	0.653
Methoxychlor	0/44	(1.1)	N/A	(15)
Toxaphene	0/44	(9.8)	N/A	(61)
trans-Chlordane	0/44	(0.23)	N/A	(2.9)

*Mean calculated from detected values.
Values in parenthesis indicate method detection limit (MDL) when concentrations < MDL.
DF = detection frequency

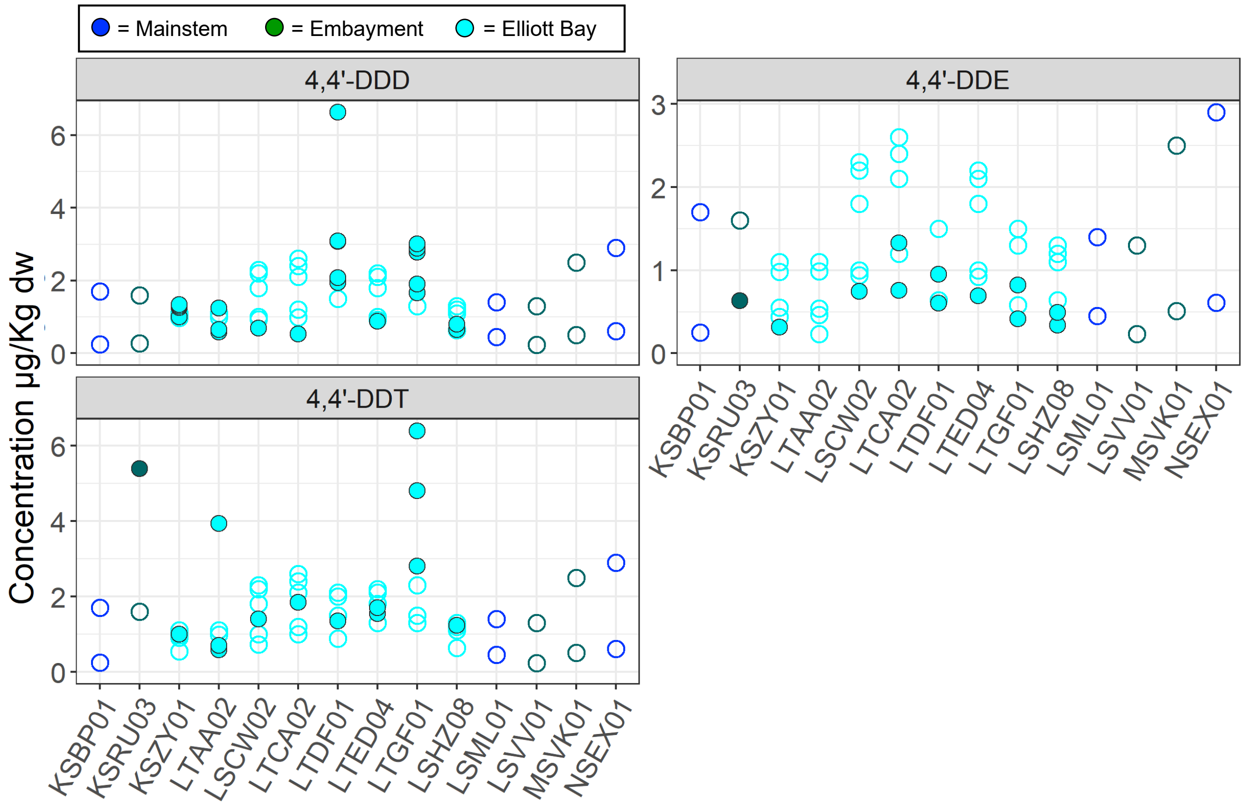


Figure 32. DDT, DDE, and DDD chlorinated pesticide concentrations (µg/Kg dw) in samples from routine subtidal sites (2009–2019). Empty symbols represent method detection limit (MDL) when concentrations < MDL.

PBDEs

PBDE congeners were analyzed due to their bioaccumulative properties and toxicity potential. SQS have not been developed for PBDEs. All PBDE congeners were detected in at least a few samples. DecaBDE-209 was detected most frequently and at the highest concentration of any congener (Table 32). Summed PBDE concentrations were generally highest in Elliott Bay with the highest concentrations (13.0 µg/Kg dw) detected near Harbor Island (LTGF01) (Figure 33).

Table 32. Summary of PBDE results at routine subtidal sites (2009-2019).

Parameter	DF	Concentration (µg/Kg dw)		
		Min	Mean*	Max
DecaBDE-209	56/61	(0.11)	3.33	10.2
HeptaBDE-183	15/61	(0.0092)	0.391	4.98
HeptaBDE-190	17/61	(0.0091)	0.0964	0.607
HexaBDE-138	10/61	(0.0091)	0.143	0.319
HexaBDE-153	23/61	(0.0092)	0.0996	0.885
HexaBDE-154	34/61	(0.010)	0.0892	0.298
PentaBDE-100	33/61	(0.023)	0.143	0.675
PentaBDE-85	8/61	(0.0091)	0.0788	0.184
PentaBDE-99**	36/61	0.082	0.992	6.89
TetraBDE-47**	27/61	0.081	0.774	2.29
TetraBDE-66	4/61	(0.013)	0.0534	0.0697
TetraBDE-71**	27/61	(0.010)	0.120	0.268
TriBDE-17	26/61	(0.0091)	0.0850	0.197
TriBDE-28/-33	15/61	(0.0091)	0.0661	0.124
Sum PBDEs	59/61	(0.0092)	4.58	13.0

*Mean calculated from detected values.
**Blank contamination effected some sample results - PentaBDE-99, TetraBDE-47, and TetraBDE-71 results > 5x method blank concentration considered non-detects
Values in parenthesis indicate method detection limit (MDL) when concentrations < MDL.
DF = detection frequency

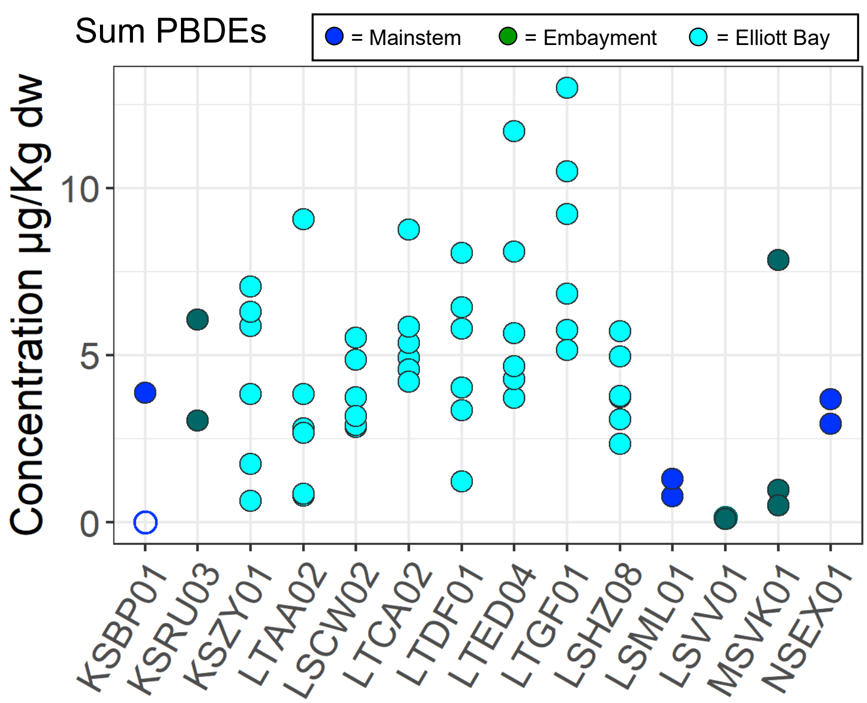


Figure 33. Sum of PBDE concentrations (µg/Kg dw) in samples from routine subtidal sites (2009–2019). Empty symbols represent method detection limit (MDL) when concentrations < MDL.

Sediment Chemistry Index

SCI scores for routine subtidal sites classified the sampling locations in a range of minimum to low exposure. SCI scores for individual samples ranged from 80.4 to 99.3 (mean = 93.1)[9]. Mean SCI scores (mean of multiple sampling events) ranged from 83.1 to 98.7 (Table 33).

SCI scores at five sites indicated low chemical exposure. These nearshore (< 35 m) sites were in Elliott Bay, except for one outer Salmon Bay site, and were located near a variety of point and non-point sources. Concentrations of some chemicals in one or more samples at each site were above the SQS during the monitoring period, most frequently mercury or PCBs (Table 33). SCI scores at the remaining sites indicated minimum chemical exposure.

Routine Subtidal Sediment Chemistry Patterns

Routine subtidal monitoring sites varied widely in terms of depth, percent fines, and OC content. Shallow sites in Elliott Bay generally had higher chemical concentrations and number of chemicals above the SQS compared to other routine subtidal sites (Table 33).

While percent fines and OC content at deep mainstem sites varied widely, chemical concentrations were very low at these sites compared to other routine subtidal sites and a comparison to SQS. Of these sites, only Point Jefferson (KSBP01), had a chemical concentration above the SQS (benzoic acid in 2017), like several other routine subtidal and outfall sites during that year. SCI scores for routine subtidal sites were high, indicative of minimal chemical exposure.

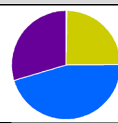
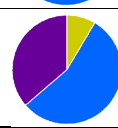
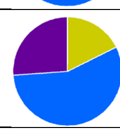
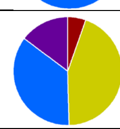
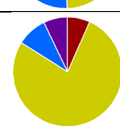
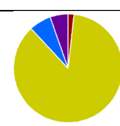
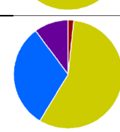
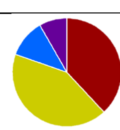
At least one chemical concentration was above the SQS at all embayment sites. Outer Salmon Bay (KSRU03) had an SCI score indicative of low chemical exposure driven by concentrations of PAHs, which could be due to a high density of creosote pilings in Salmon Bay or PAHs coming from the Lake Washington Ship Canal. SCI scores at the other two embayment sites were higher, indicative of minimum chemical exposure. Chemical concentrations above the SQS were measured once at the Fauntleroy site (LSVV01 - benzoic acid) and twice in Inner Quartermaster Harbor (MSVK01- mercury) (likely influenced by the historic Asarco Smelter plume).

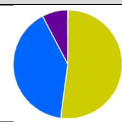
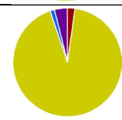
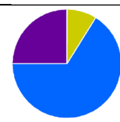
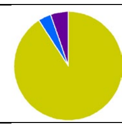
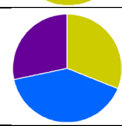
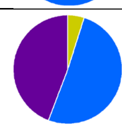
Of the routine subtidal monitoring areas, the highest overall chemical concentrations were measured in Elliott Bay, although none were below the SCI's low exposure threshold. The SCI for the deepest sites in Elliott Bay (> 90 m) indicated minimum chemical exposure. LTED04, in mid-Elliott Bay, was the only deep site with chemical concentrations above the SQS (i.e., total PCBs, during one event). SCI scores for shallower sites located closer to anthropogenic sources, were slightly depressed (low exposure category). Concentrations of a variety of chemicals detected at these sites were above the SQS (mercury, total PCBs, benzoic acid, fluoranthene, and bis[2-ethylhexyl]phthalate). Higher concentrations of non-SMS chemicals (DDTs, PBDEs, and butyltins), were also elevated at these sites, and were highest near Harbor Island (LTGF01).

[9] SDI from one or more sample from four of the sites (KSBP01, LSVV01, LTAA02, and LTDF01) were calculated by comparing dry weight organic concentrations because samples had low or very high TOC (<0.5%, >3.5%) (See Section 2.2.3).

During any given sampling event, chemical concentrations above SQS at routine subtidal monitoring sites were generally rare. However, mercury and total PCBs are exceptions to this pattern and elevated concentrations are somewhat common at some routine subtidal sites. Mercury concentrations above the SQS have mostly occurred at the same site multiple times (LTGF01 - Harbor Island, LTDF01 - Seattle waterfront, and MSVK01 - inner Quartermaster Harbor). Total PCB concentrations are generally higher and more widespread throughout Elliott Bay where concentrations above SQS have been measured six times across the different sites. However, none of the elevated concentrations were detected during the last two sampling events in 2017 and 2019.

Table 33. Summary of physical and chemical characteristics at routine subtidal sites (2009–2019).

Type	Site/ Number of Sampling Events	Approx. Depth (m)	Mean % TOC	Mean % Fines	Grain Size (Clay, Silt, Sand, Gravel)	Above SQS?	Mean SCI** (Minimum, Low, Moderate, High)
Elliott Bay	LSCW02 N=6	180	1.81	75.1		No	96.0
	LTCA02 N=6	130	1.88	91.5		No	95.7
	LTED04 N=6	90	1.98	82.4		Total PCB Aroclors (1 year)	94.5
	LTDF01* N=6	35	3.62	50.4		Mercury (3 years), Total PCB Aroclors (1 years), Fluoranthene (1 year)	92.9
	KSZY01 N=6	20	0.677	16.1		Mercury, Total PCB Aroclors, and Bis(2-Ethyhexyl)Phthalate (each 1 year)	88.0
	LTAA02* N=6	25	0.330	11.9		Total PCB Aroclors (1 year), Benzoic Acid (1 year)	96.5*
	LTGF01 N=6	30	1.38	41.3		Mercury (6 years), Total PCB Aroclors (2 years), Benzoic Acid (1 year), Bis(2-Ethyhexyl)Phthalate (1 year)	85.8
	LSHZ08 N=6	25	1.00	19.6		Benzoic Acid (1 year)	92.3

Type	Site/ Number of Sampling Events	Approx. Depth (m)	Mean % TOC	Mean % Fines	Grain Size (Clay, Silt, Sand, Gravel)	Above SQS?	Mean SCI** (Minimum, Low, Moderate, High)
Embayment	KSRU03 *** N=3	10	1.23	47.9		Benzo(g,h,i)perylene (1 year)	83.1
	LSVV01* N=2	12	0.305	5.2		Benzoic Acid (1 year)	96.9*
	MSVK01 N=2	6	2.61	91.1		Mercury (2 years)	93.9
Mainstem	KSBP01* N=2	280	0.39	9.1		Benzoic Acid (1 year)	98.7
	LSML01 N=2	250	1.27	68.9		No	97.2
	NSEX01 N=2	175	2.05	95.1		No	96.2

*When TOC < 0.5% or > 3.5%, comparisons based on dw SQS .
**SCI calculated based on SQS appropriate for TOC content
***KSRU03 also sampled in 2010; N=3 sampling events.

3.3 Subtidal Sediment Toxicity

Sediment toxicity (bioassay) analysis is not part of routine sediment monitoring. However, occasionally bioassays are conducted as part of the NPDES permit-required sampling for the South Plant and West Point outfalls. Bioassays were required in 2011 at all West Point sites, and in 2017 at the West Point and South Plant outfalls. In 2017, bioassays were required only if the initial chemistry analysis indicated results that exceeded SQS.

Toxicity testing included three sediment bioassays (two acute and one chronic) and followed testing requirements outlined in the SMS (WAC 173-204-315) and Ecology's Sediment Cleanup User's Manual current at the time of the testing. Bioassays were conducted on the following samples:

- West Point 2011 – all eight sites
- West Point 2017 – four sites with initial SMS exceedances
- South Plant 2017 – five sites with initial SMS exceedances

In 2011, bioassays were performed on samples from the eight West Point outfall sites (Figure 2). Three bioassays were performed on each sample and included two acute tests (amphipod survival, and larval echinoderm) and one chronic test (juvenile polychaete growth). Results of the amphipod or juvenile polychaete tests did not exceed SQS biological criteria. However, samples from all eight sites failed the larval echinoderm test with exceedances of the CSL. However, during the test, many larvae developed to the normal four-armed pluteus stage and then died. Additionally, there was no correlation between chemical concentrations and percent normal survivorship. It was suspected that the turbid overlying water or sediment abrasion from the samples caused the failed survivorship, rather than chemical exposure, and that results were not reflective of sediment toxicity.

Larval echinoderm bioassays were repeated in 2011 due to low survivorship and the suspected influence of physical factors (e.g., turbidity). These samples were tested in a side-by-side comparison using two methods. All samples tested with the “standard” larval echinoderm method failed. However, the second set of samples were run using a “modified screen tube manipulation” method described by Phillips et al. (2003), used to isolate physical effects of the sediment, such as turbidity. Seven of eight samples tested with the modified method passed the SQS biological criterion. One sample (WP430S) exceeded the CSL biological criteria despite the chemistry data not supporting a toxicological response. Overall results of the repeated larval echinoderm testing showed that low survival was likely due to physical factors, rather than sediment chemical toxicity.

Benzoic acid exceeded SQS at four West Point sites in 2017, and benzyl alcohol exceeded SQS at one of those sites. These results triggered the need for follow up chemistry and toxicity testing at those sites in 2018. Like in 2017, the bioassays included the acute amphipod, acute larval echinoderm, and chronic juvenile polychaete tests. Both the standard and modified (screen tube manipulation) versions of the larval echinoderm test were conducted on all samples. Once again, samples from all four sites passed the acute amphipod and chronic juvenile polychaete tests, while only one passed the standard larval echinoderm test. The three remaining samples exceeded the CSL for the standard larval echinoderm test. All four sites passed the modified screen tube version of the larval echinoderm test, supporting the theory that physical structure/turbidity of the sample was negatively influencing the test results rather than sediment chemical toxicity.

At South Plant in 2017, sediments from five sites exceeded the SQS chemical criteria for benzoic acid, triggering repeated sampling in 2018 for sediment chemistry and toxicity at those sites. Three bioassays (two acute and one chronic) including the acute amphipod survival, acute larval echinoderm, and chronic juvenile polychaete growth tests were conducted. Because of the suspected influence of physical factors on larval echinoderm survival noted in West Point samples, concurrent standard and modified (screen tube manipulation) versions of the larval echinoderm test were conducted simultaneously on South Plant samples. All sites passed the acute amphipod and chronic juvenile polychaete tests. However, all five sites failed the standard larval echinoderm test, and all passed the modified test. Test results indicated there was no apparent toxicity effects related to chemical contamination at these sites.

Sediment samples collected near the South Plant and West Point outfalls have occasionally exceeded SQS chemical criteria in the past (Section 3.2.1). However, recent sediment bioassay results show that sediment toxicity is not a persistent concern near these outfalls. Previous reports (King County 2011d, 2012a,b, 2018a,b) contain detailed results and discussion from the most recent monitoring events. In all but one case (2011 West Point - WP430S), the biological toxicity testing results overrode any SMS chemistry exceedances.

3.4 Offshore Benthic Community Structure

The follow sections describe results of benthic infauna monitoring (2008–2019). Like the sediment chemistry results, benthic community results for subtidal outfall and routine subtidal samples are discussed separately. Three replicates were collected at each site and replicate-averaged sample data are presented below.

3.4.1 Subtidal Outfall Benthic Community

The following section summarizes results of benthic infauna monitoring from 2011 and 2017 at sites located near King County's three largest TP outfalls. Samples were collected near Brightwater in October of 2011 and 2017[10], West Point in April 2011 and September 2017, and South Plant outfalls in September 2017. A summary of chemical and physical characteristics of these sites are presented in Table 16 - Table 18. Results of these monitoring efforts are also documented in permit-required monitoring reports (King County, 2013, 2018a,b). Data reported here may not match the exact results documented in previously published reports, particularly for index values such as richness, diversity, evenness, and dominance, due to taxonomic standardization needed to compare these monitoring data across multiple sites and years (see Section 2.2.3).

Abundance

Total abundance varied widely (56–1,100 individuals) and was highest in Brightwater outfall samples and lowest in South Plant samples (Figure 34). Abundance in Brightwater outfall samples ranged from 680 to 976 individuals (mean= 798) and samples were dominated by molluscs (Figure 35). Abundance in West Point outfall samples was variable (56–1,100 individuals; mean = 424) and samples were dominated by polychaetes, followed by miscellaneous taxa (various nemertean [ribbon] and sipunculid [peanut] worms, ascidiaceans [tunicates], actiniarians [sea anemones], and echinoderms) (Figure 35). Abundance in South Plant outfall samples ranged from 141 to 202 individuals (mean = 180) and was dominated by molluscs (Figure 35).

[10] 2017 Brightwater benthic infauna samples were collected as part of a special benthic reference study and not collected in tandem with NPDES permit-required sediment chemistry samples.

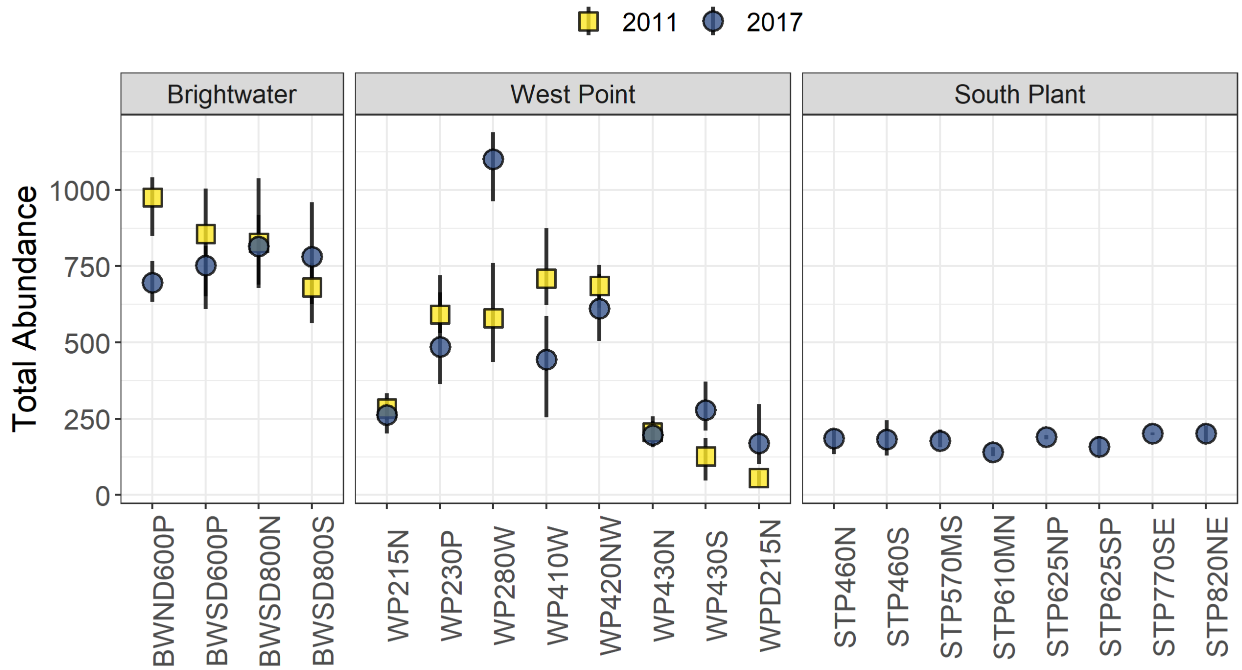


Figure 34. Benthic infauna total abundance (replicate average) (individuals / 0.1 m²) near subtidal outfall sites (2011 and 2017). Colored symbols represent mean (n=3), and lines indicate range.

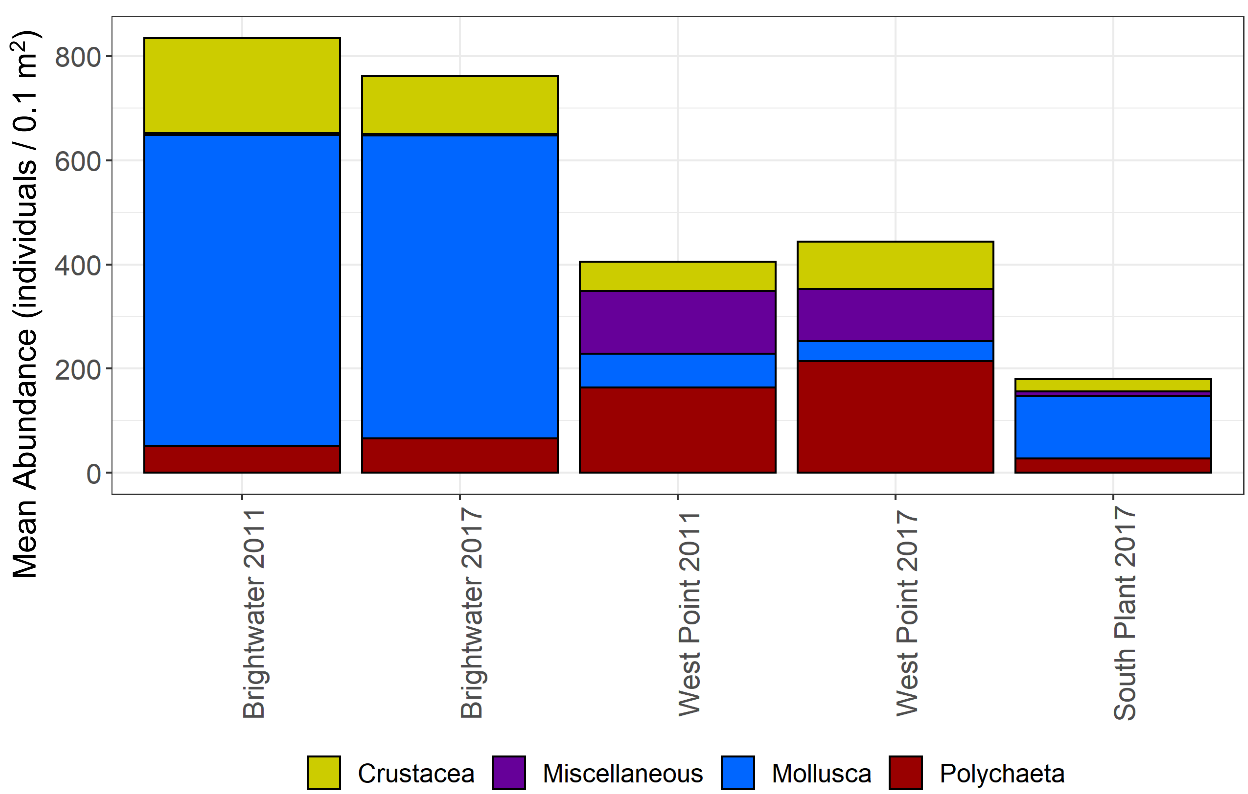


Figure 35. Mean (n=3) abundance (individuals / 0.1 m²) of major taxonomic groups at subtidal outfall sites by event.

Richness

Taxa richness at the two deeper outfalls (Brightwater mean = 44; and South Plant mean = 33) was much lower than at the shallower outfall (West Point mean = 87) (Figure 36). Across all three outfalls, polychaetes had the most unique taxa, while miscellaneous taxa were the least represented (not unusual for this group) (Figure 37).

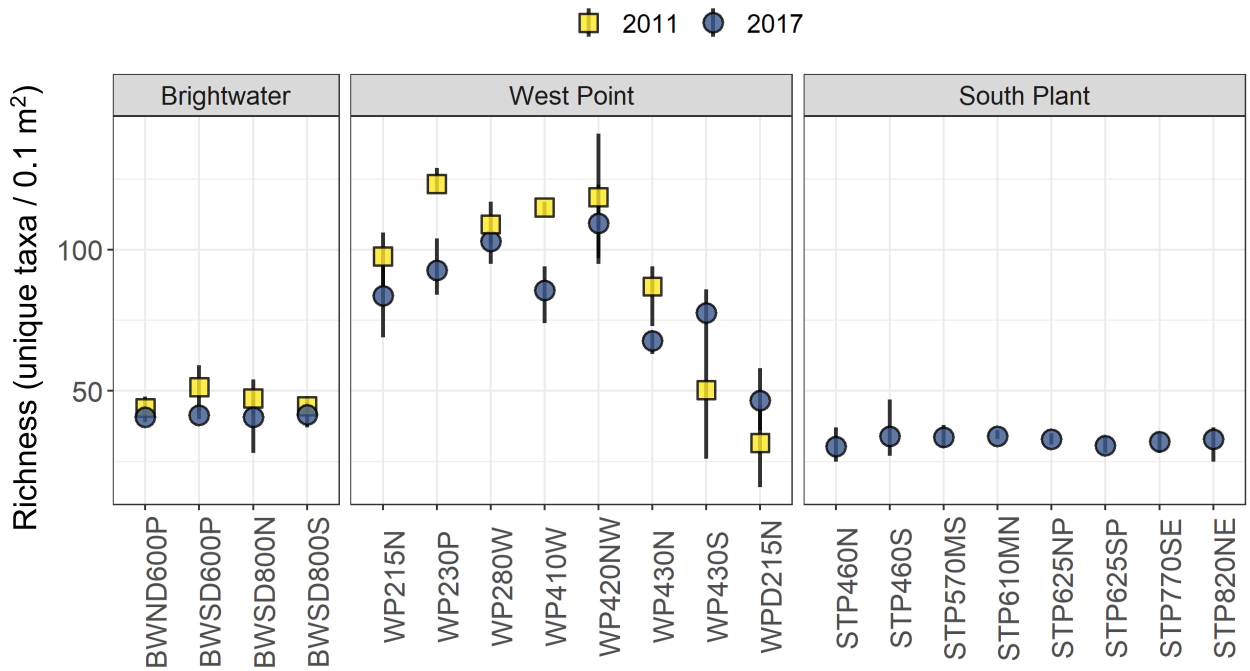


Figure 36. Benthic infuana total richness (unique taxa / 0.1 m^2) at subtidal outfall sites (2011 and 2017). Colored symbols represent mean (n=3), and lines indicate range

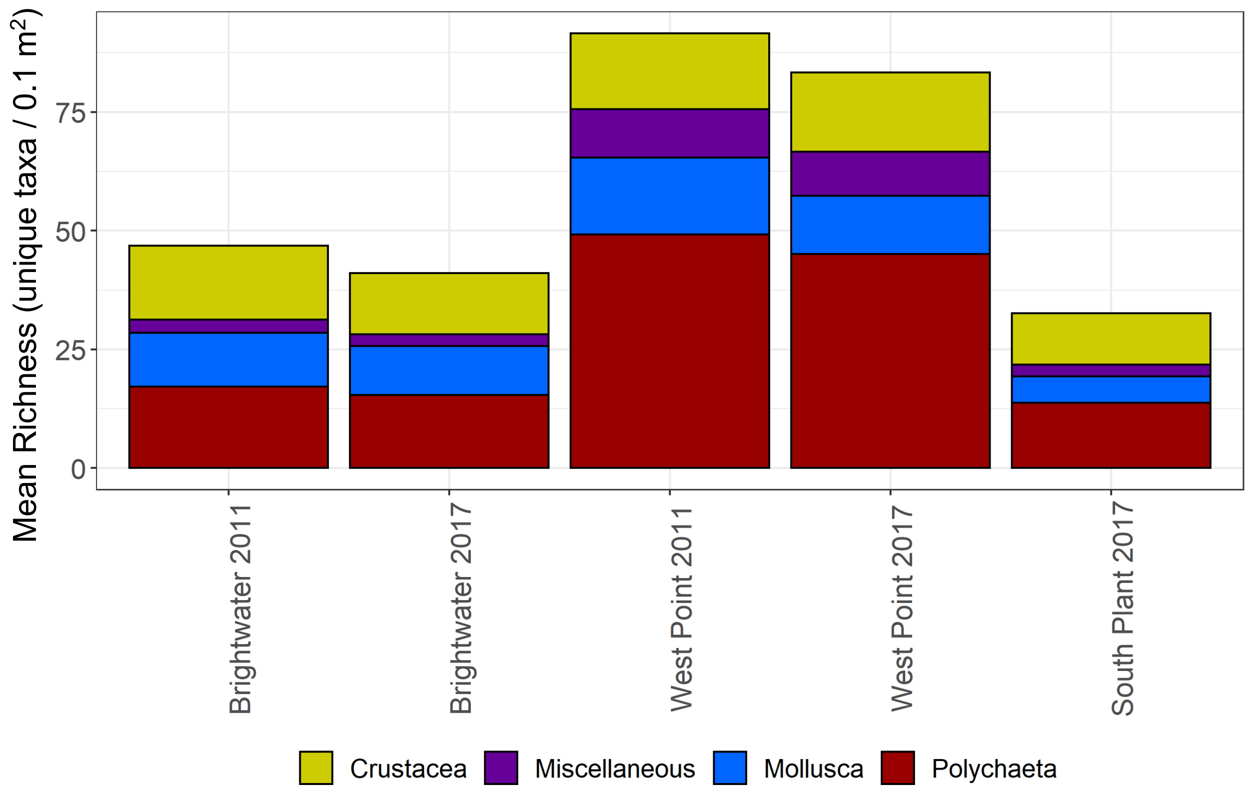


Figure 37. Mean (n=3) benthic infuana richness (unique taxa / 0.1 m^2) of major taxonomic groups at subtidal outfall sites by event.

Biomass

Mean total biomass by outfall was highly variable and ranged from 14.2 g / 0.1 m^2 at West Point outfall sites to 182.2 g / 0.1 m^2 at South Plant outfall sites (Figure 38). Total biomass at all three sites was largely driven by miscellaneous taxa (Figure 39), particularly the presence of echinoderms (urchins and sea cucumbers), which tend to be larger in size than other taxa. The higher biomass in South Plant outfall samples was mostly due to the number (4-13 per replicate) of *Molpadia intermedia* (sea cucumber) collected. Many of the largest organisms collected were miscellaneous taxa. A single large individual can skew the biomass results, which is why biomass isn't typically a key metric.

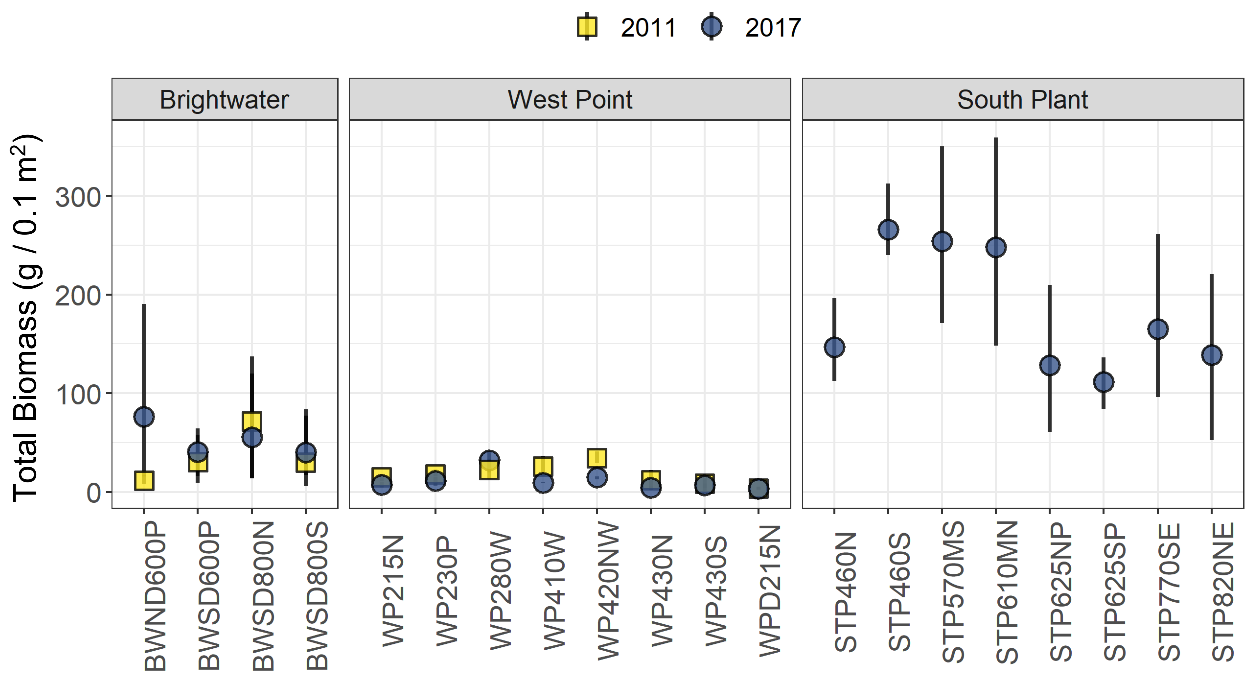


Figure 38. Total benthic infauna biomass (g / 0.1 m^2) at subtidal outfall sites (2011 and 2017). Colored symbols represent mean (n=3), and lines indicate range

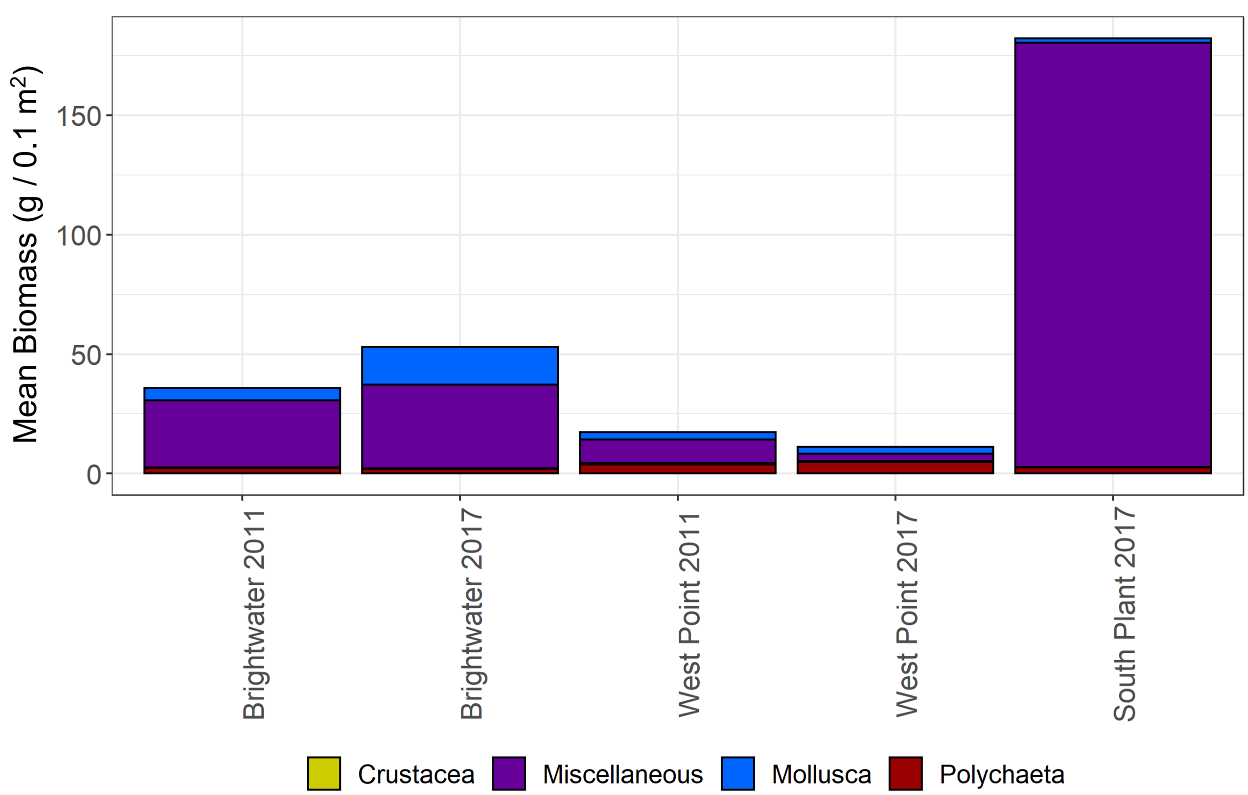


Figure 39. Mean (n=3) benthic infauna biomass (g / 0.1 m^2) of major taxonomic groups at subtidal outfall sites by event.

Evenness

Mean evenness scores by outfall ranged from 0.43 in Brightwater outfall samples to 0.81 in West Point outfall samples (Figure 40). The greatest variability was observed in West Point outfall samples.

Diversity

Overall diversity was much lower in samples collected from deeper depositional areas than shallower sandy habitats (Figure 40). Mean Shannon diversity values by outfall ranged from 1.64 in samples near the Brightwater outfall to 3.53 in samples near the West Point outfall.

Dominance

The pattern of dominance near the three outfalls was like that observed for evenness and diversity. The highest (SDI) values were measured in shallower, sandy habitats (Figure 40). Mean SDI by outfall ranged from 2.54 in samples collected near the Brightwater outfall to 26.1 in samples collected near the West Point outfall.

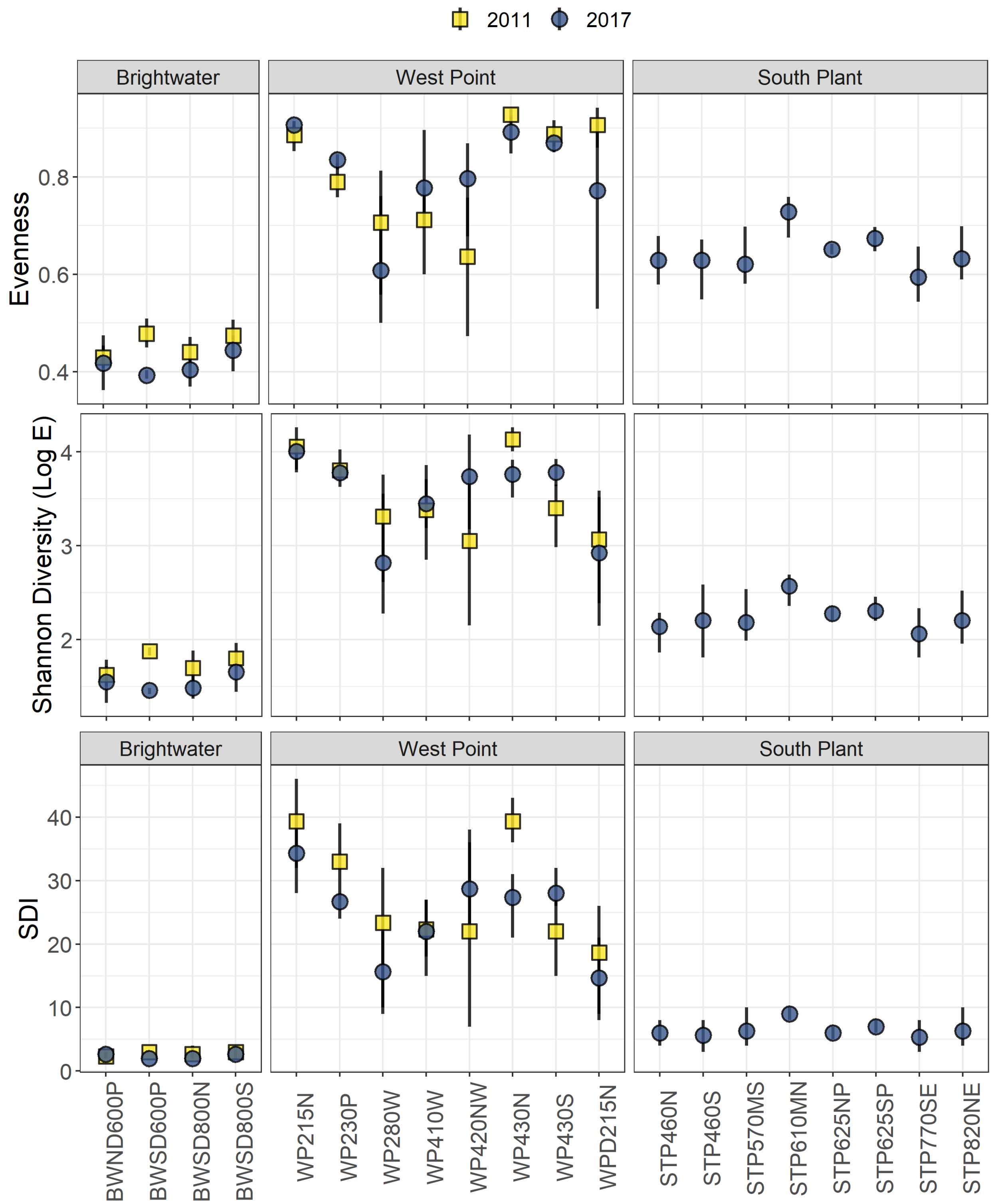


Figure 40. Evenness, Shannon Diversity, and Swartz's Dominance Index (SDI) for benthic infauna at subtidal outfall sites (2011 and 2017). Colored symbols represent mean (n=3), and lines indicate range.

Outfall Benthic Infauna Patterns

The benthic communities surrounding King County's three largest TP outfalls were very different from one another. While we would expect the benthic community near the shallower West Point outfall to be distinctly different from those near South Plant and Brightwater, even communities at the two deeper outfall areas differed from one another.

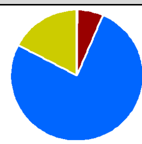
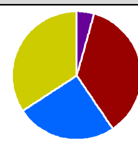
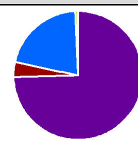
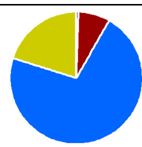
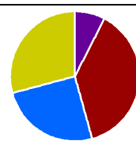
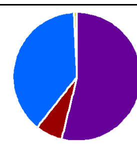
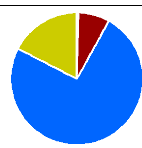
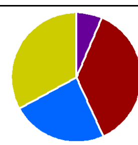
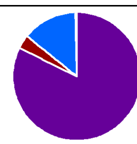
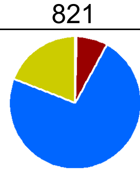
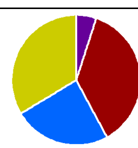
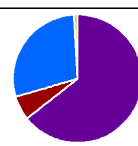
The benthic community near the Brightwater outfall was characterized by high abundance and somewhat low species richness. Molluscs were the most abundant taxa and were largely comprised of small moderately pollution-tolerant clams (*Macoma* sp.*, Parvilucina tenuisculpta,* and *Axinopsida serricata)*, which are common to deep depositional areas of the sound. Crustacean species of *Euphilomedes*, a type of pollution tolerant ostracod, were common, as was the pollution-sensitive cumacean *Eudorella* sp. Biomass at these sites was mostly driven by miscellaneous taxa, which included a few echinoderms such as sea cucumbers, as well as molluscs. However, the dominance of a few species led to low evenness, diversity, and dominance scores at this site during both sampling events. Benthic index values were similar across all Brightwater sites, likely due to the fairly heterogenous physical characteristics of the site (Table 16). A site-by-site summary of diversity indices is provided in Table 34.

Index values for benthic infauna samples collected near the South Plant outfall were quite different than those for samples collected near the Brightwater outfall despite being of similar depth and having similar dominant taxa. Differences may be driven by percent fines in this area (~100% fines near South Plant outfall, versus 80% near Brightwater outfall) or higher TOC near the South Plant outfall. Abundance was much lower in samples collected near the South Plant outfall than in Brightwater samples, but samples were still dominated by pollutant-tolerant molluscs common to deep depositional habitats in the sound (*Macoma* spp., *Axinopsida serricata*, and *Parvilucina tenuisculpta*, with the addition of the sea cucumber *Molpadia intermedia)*. While not the most abundant, several pollution-sensitive taxa were also present including, the amphipods *Heterophoxus affinis* and *Paraphoxus* sp. with the highest abundance, and the cumacean *Eudorella* sp. Richness in South Plant samples was lower than in Brightwater outfall samples, driven by fewer unique mollusc taxa, with polychaete and crustacean taxa nearly equally represented at all sites. Biomass in South Plant samples was high due to the abundance of sizable *Molpadia intermedia* (sea cucumber) collected in every sample. Because the benthic community was not dominated by a single species, evenness, diversity, and dominance scores were higher near the South Plant outfall than near Brightwater. Benthic index values were similar across all South Plant sites. A site-by-site summary of diversity indices is provided in Table 35.

The benthic community near the West Point outfall was the most diverse and variable both temporally and spatially. Abundance was highly variable at these stations and taxa were dominated mostly by polychaetes or miscellaneous taxa. The most abundant organism changed over the two sampling events as timing appeared to correspond to a large recruitment of the tunicate *Molgula pacifica* in 2011 (April) and actiniid sea anemones in 2017 (September) at some sites. Prior to 2011, large numbers of these taxa had not previously been encountered at these sites. Other abundant organisms included the

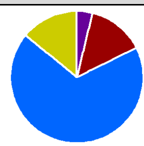
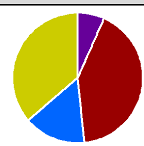
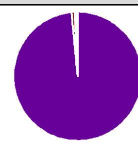
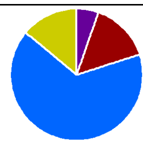
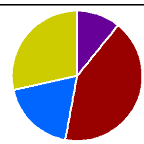
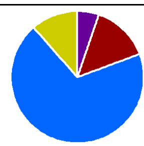
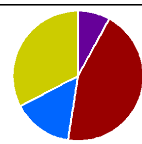
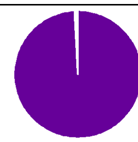
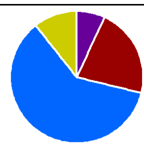
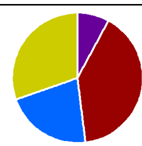
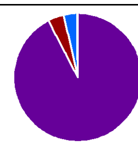
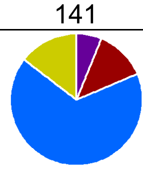
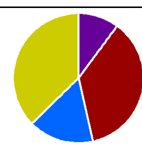
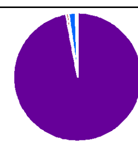
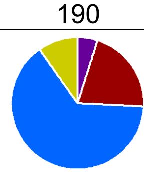
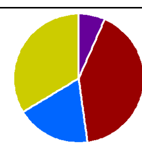
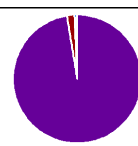
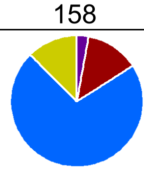
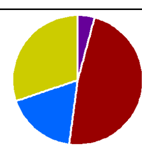
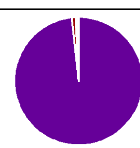
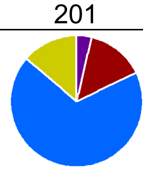
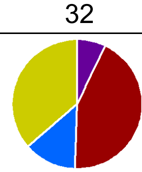
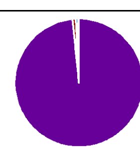
pollution-sensitive amphipod *Ericthonius rubricornis*, bivalve *Hiatella arctica*, and polychaete *Pholoides asperus*. No pollution-tolerant taxa were dominant near the West Point outfall. Polychaetes contributed approximately half of all unique taxa encountered and overall richness was generally about twice as high as near the other outfalls. Unlike the other two outfalls, miscellaneous taxa did not consistently contribute overwhelmingly to total biomass. Small sea cucumbers (e.g., *Cucumaria piperata* and *Pentamera* sp.), *Molgula pacifica*, and actiniid sea anemones greatly contributed to biomass when encountered in large numbers, but generally miscellaneous taxa contributed half or less of the total biomass. Because no single taxa dominated near the West Point outfall, measures of evenness, diversity, and dominance were high for these sites, which is typical of sandy habitats (Ecology, 2018b). Benthic index values were more variable at West Point sites than near the other two outfalls, as were the physical characteristics of the site. A site-by-site summary of diversity indices is provided in Table 36.

Table 34. Summary of benthic community index results at Brightwater outfall sites (2011 and 2017).

Site/ Number of Sampling Events	Approx. Depth (m)	Abundance Crustaceans Molluscs Polychaetes Misc.	Richness Crustaceans Molluscs Polychaetes Misc.	Biomass (g) Crustaceans Molluscs Polychaetes Misc.	Evenness	Diversity	SDI
BWND600P N=2	186	 836	 42	 43.8	0.423	1.59	2.5
BWSD600P N=2	189	 805	 46	 35.6	0.435	1.67	2.5
BWSD800N N=2	185	 821	 44	 63.4	0.422	1.59	2.3
BWSD800S N=2	188	 731	 43	 34.8	0.459	1.73	2.8

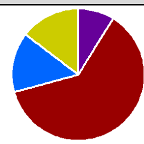
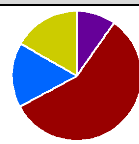
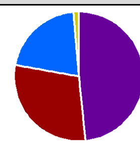
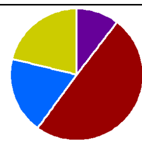
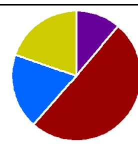
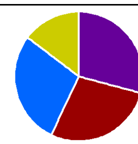
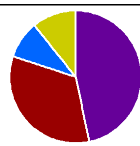
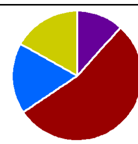
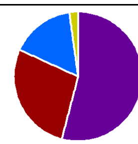
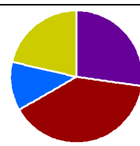
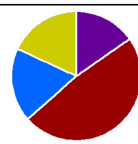
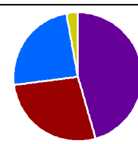
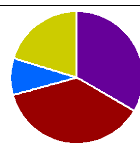
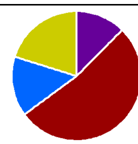
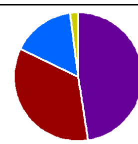
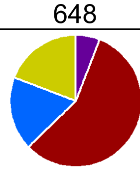
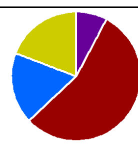
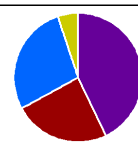
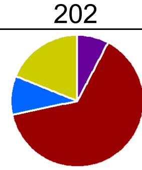
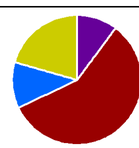
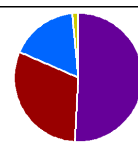
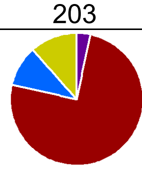
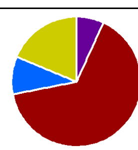
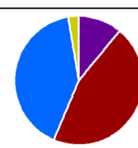
N = number of sampling events (3 replicates/event). Index results represent average of six replicates collected in 2011 and 2017.
SDI = Swartz's Dominance Index

Table 35. Summary of benthic community index results at South Plant outfall sites (2017).

Site/ Number of Sampling Events	Approx. Depth (m)	Abundance (Crustaceans, Molluscs, Polychaetes, Misc.)	Richness (Crustaceans, Molluscs, Polychaetes, Misc.)	Biomass (g) (Crustaceans, Molluscs, Polychaetes, Misc.)	Evenness	Diversity	SDI
STP460N N=1	193	 185	 30	 146.8	0.629	2.14	6.0
STP460S N=1	194	 181	 34	 265.9	0.620	2.21	5.7
STP570MS N=1	195	 178	 34	 253.9	0.621	2.19	6.3
STP610MN N=1	194	 141	 34	 247.8	0.728	2.57	9.0
STP625NP N=1	195	 190	 33	 128.3	0.651	2.28	6.0
STP625SP N=1	195	 158	 31	 111.5	0.673	2.30	7.0
STP770SE N=1	194	 201	 32	 165.1	0.594	2.06	5.3
STP820NE N=1	193	 202	 33	 138.6	0.632	2.20	6.3

N = number of sampling events (3 replicates/event). Index results represent average of 3 replicates collected in 2017.
SDI = Swartz's Dominance Index

Table 36. Summary of benthic community index results at West Point outfall sites (2011 and 2017).

Site/ Number of Sampling Events	Approx. Depth (m)	Abundance (Crustaceans, Molluscs, Polychaetes, Misc.)	Richness (Crustaceans, Molluscs, Polychaetes, Misc.)	Biomass (g) (Crustaceans, Molluscs, Polychaetes, Misc.)	Evenness	Diversity	SDI
WP215N N=2	76	 273	 91	 11.2	0.896	4.03	36.8
WP230P N=2	74	 539	 108	 14.6	0.812	3.79	29.8
WP280W N=2	74	 840	 106	 27.2	0.657	3.07	19.5
WP410W N=2	81	 577	 100	 17.6	0.745	3.42	22.2
WP420NW N=2	80	 648	 114	 24.4	0.717	3.39	25.3
WP430N N=2	79	 202	 77	 8.1	0.910	3.95	33.3
WP430S N=2	79	 203	 64	 7.5	0.879	3.59	25.0
WPD215N N=2	75	 113	 39	 3.4	0.839	3.00	16.7

N = number of sampling events (3 replicates/event). Index results based on average of 6 replicates from 2011 and 2017 events. SDI = Swartz's Dominance Index

3.4.2 Routine Subtidal Benthic Community

The following section summarizes results of routine benthic infauna monitoring at routine subtidal sites located in Elliott Bay and Central Basin mainstem and smaller embayments in 2015, 2017 and 2019. These benthic samples were collected concurrently with sediment samples. Benthic community analysis was added to routine subtidal monitoring at a subset of stations in 2015 and expanded to all sites in 2017. All routine subtidal benthic samples were collected during June of each year. Data for physical and chemical characteristics at these sites are presented in Section 3.2.2.

Abundance

Total abundance of benthic organisms varied widely and ranged from 26 to 1,514 individuals per grab. In general, sites with low abundance (mean <200) were located in deep or depositional environments (Inner Quartermaster Harbor [MSVK01], Mid-Outer Elliott Bay [LTCA02], East Passage [NSEX01], and Point Jefferson [KSBP01]) (Figure 41). Abundance was highest at Seacrest Park (LSHZ08), Outer Salmon Bay (KSRU03), Elliott Bay Grain Terminal (LTAA02), and Harbor Island (LTGF01) (Figure 41). Abundance in samples from the four Elliott Bay sites collected in 2015 was higher than in 2017 and 2019 (Figure 41), which was largely driven by the number of crustaceans (mostly ostracods) in those samples. Abundance at all routine subtidal sites in subsequent years was largely driven by polychaete and/or mollusc abundance (Figure 42).

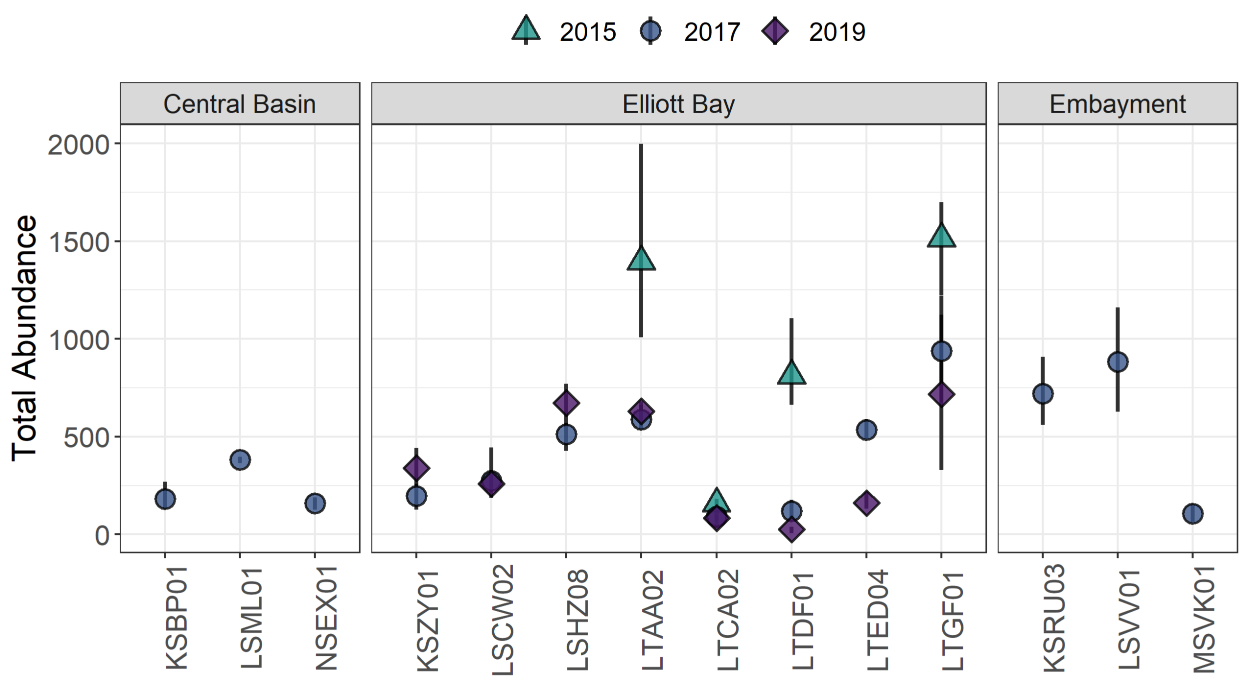


Figure 41. Total abundance (individuals / 0.1 m²) of benthic infauna at routine subtidal sites by date. Colored symbols indicate mean (n=3), and lines indicate range.

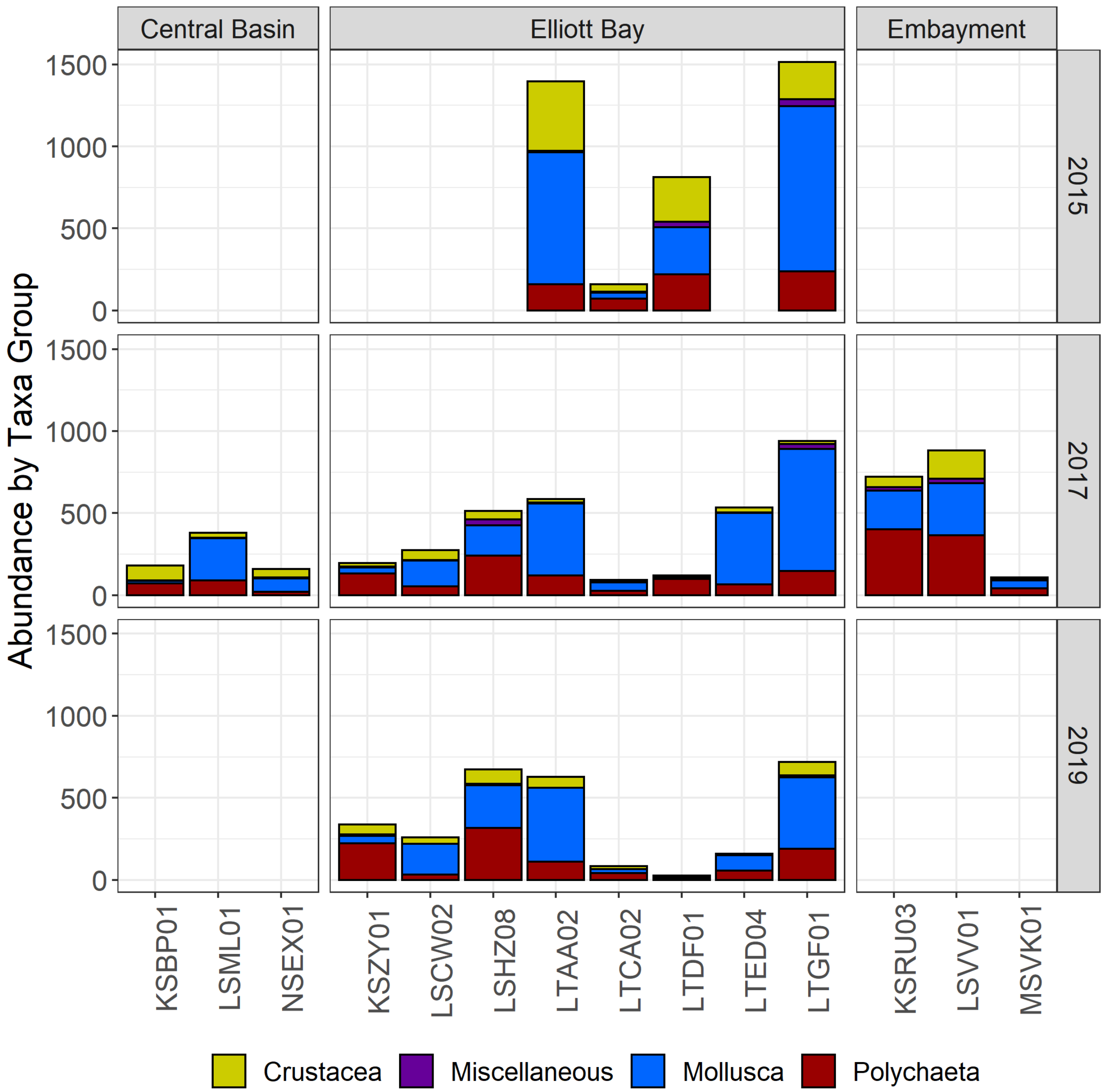


Figure 42. Mean (n=3) abundance (individuals / 0.1 m²) of major taxonomic groups at routine subtidal sites by date.

Richness

Taxa richness at routine subtidal sites was variable and ranged from 16 to 89 taxa (species) (Figure 43). Mean taxa richness values at sites with a depth ≥ 90 m (KSBP01, LSML01, NSEX01, LTED04, LSCW02) were less than 50 (Figure 43). Variability across years was greatest in samples from the Seattle Waterfront site (LTDF01) where richness was high in 2015 and low in subsequent years (Figure 43). Polychaetes had the most unique taxa at all sites, typically followed by either crustaceans or molluscs (Figure 44).

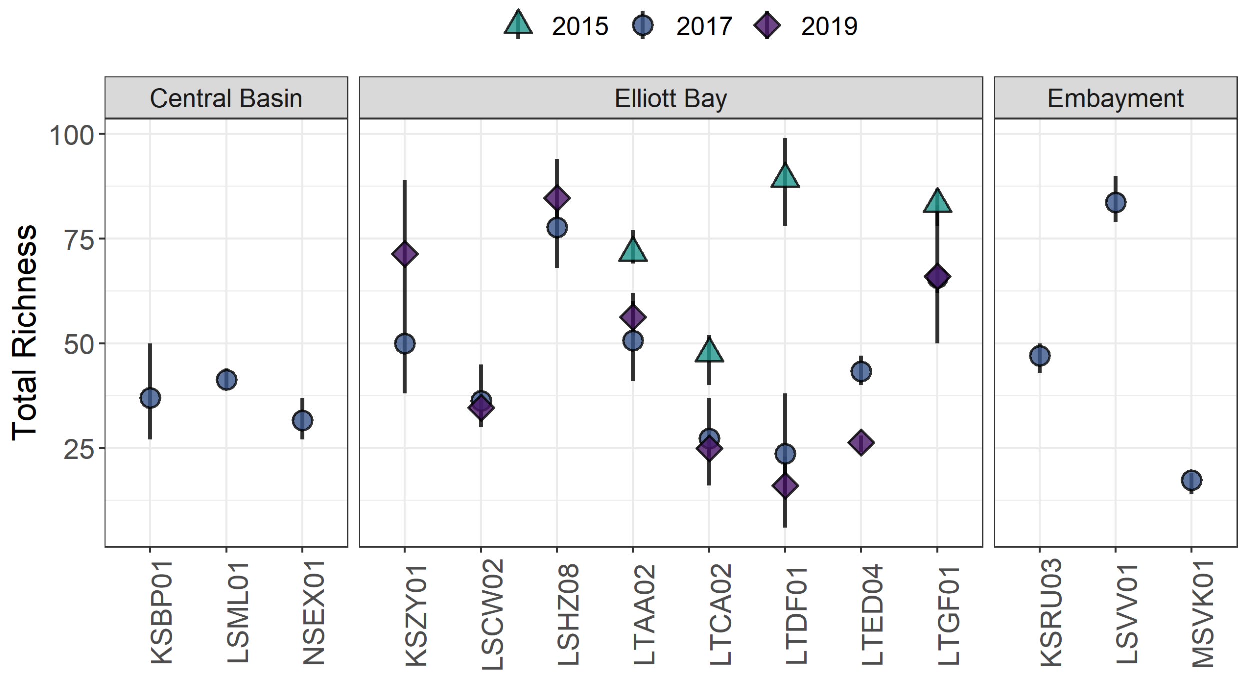


Figure 43. Total richness (unique taxa / 0.1 m^2) of benthic infauna at routine subtidal sites by date. Colored symbols represent mean (n=3), and lines indicate range.

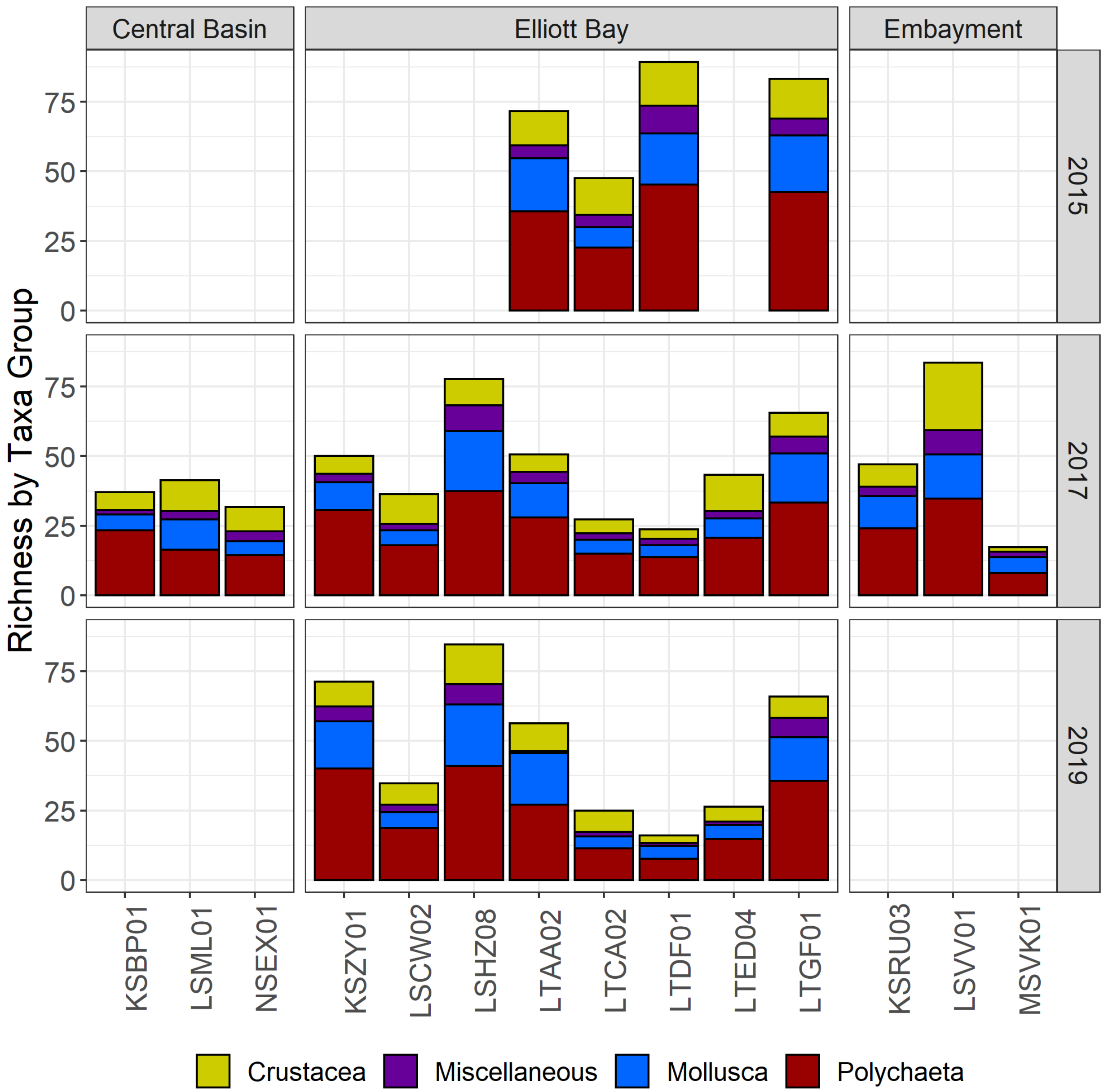


Figure 44. Mean (n=3) richness (unique taxa / 0.1 m^2) of major taxonomic groups at routine subtidal sites by date.

Biomass

Biomass of routine subtidal benthic samples ranged from 0.127 to 46.9 g / 0.1 m^2 (Figure 45). Variability in biomass is influenced by the presence of large organisms. Biomass measured in one Inner Quartermaster Harbor (MSVK01) replicate sample was very high 135.7 g / 0.1 m^2 largely due to presence of the clams *Clinocardium nuttallii* and *Macoma nasuta*. Biomass at deep, depositional sites is often high, driven by large deposit feeders like sea cucumbers and urchins. Samples with high biomass were typically dominated by few large molluscs or miscellaneous taxa, while those with lower biomasses had higher contributions of small molluscs and polychaetes (Figure 46).

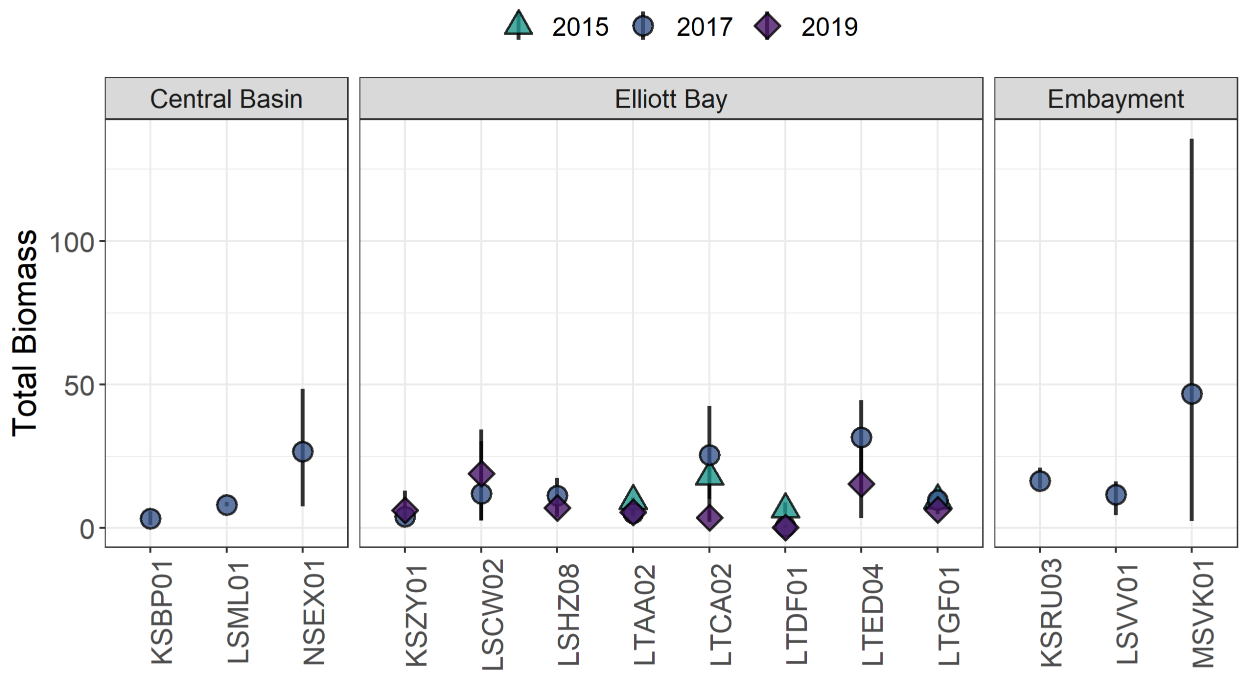


Figure 45. Total biomass (g / 0.1 m^2) of benthic infauna at routine subtidal sites by date. Colored symbols represent mean (n=3), and lines indicate range.

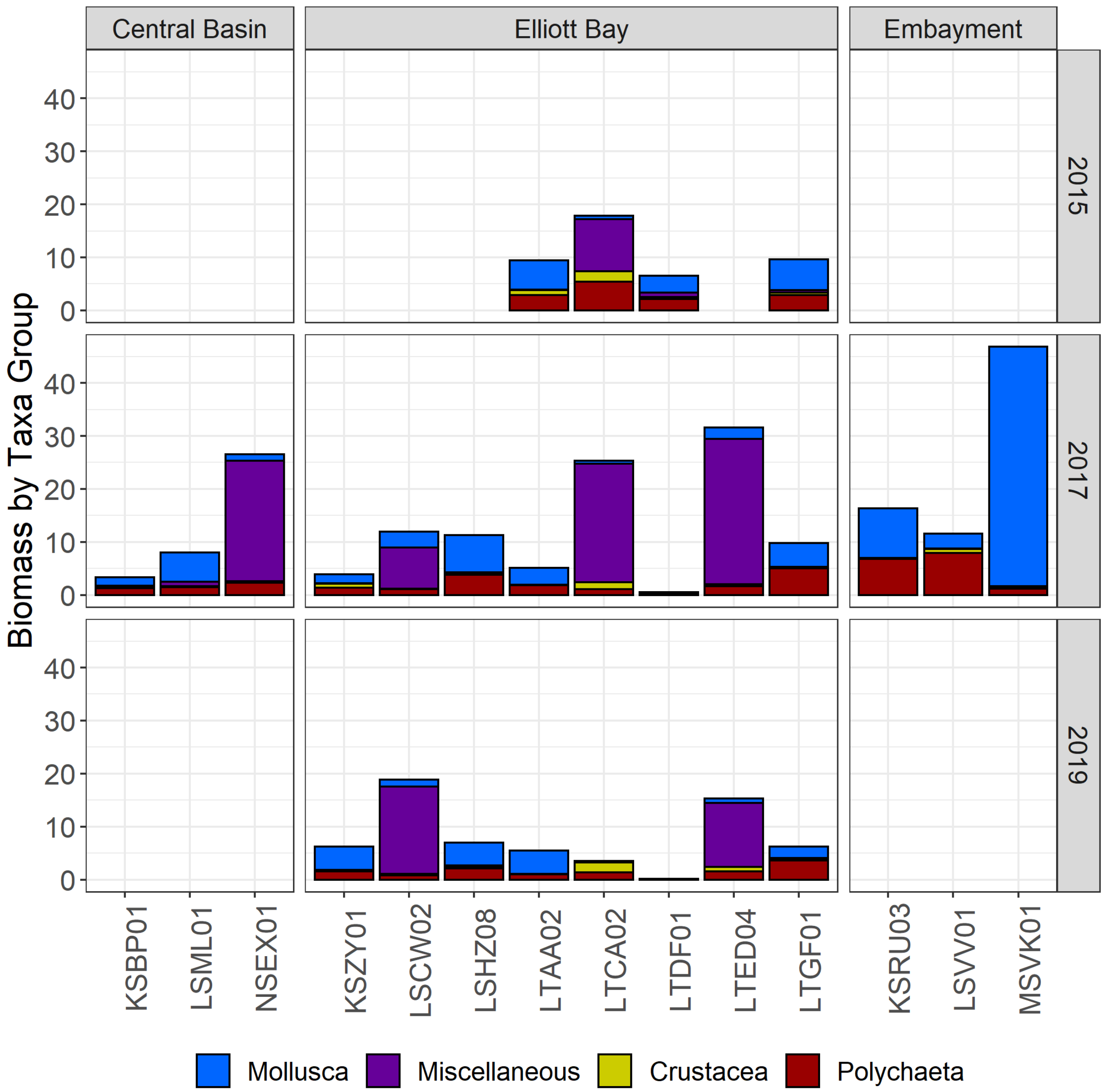


Figure 46. Mean biomass (g / 0.1 m^2) of major taxonomic groups in samples from routine subtidal sites by date.

Evenness

Evenness scores for individual samples ranged from 0.33 to 0.95 (Figure 47). The lowest evenness scores were observed at Central Elliott Bay (LTED04), Elliott Bay Grain Terminal (LTAA02), and Harbor Island (LTGF01), while the highest scores were at Fauntleroy Cove (LSVV01), Piers 90/91 (KSZY01), Mid-Outer Elliott Bay (LTCA02), and the Seattle Waterfront (LTDF01) (Figure 47). Sites with high scores typically had many taxa with similar abundances (i.e., evenly distributed abundance) while those with low scores had one or very few species (often a small clam or ostracod crustacean) that were much more abundant than other species encountered.

Diversity

Shannon diversity of individual samples ranged from 1.26 to 3.58 (Figure 47) and followed a pattern like that observed for evenness where lower scores were measured in Central Elliott Bay (LTED04) and Elliott Bay Grain Terminal (LTAA02) sites and higher scores at Piers 90/91 (KSZY01) and Seacrest Park (LSHZ08) (Figure 47). However, some pattern differences were detected. Although relatively high evenness was found at the Inner Quartermaster Harbor site (MSVK01) diversity was low. Fauntleroy Cove (LSVV01) samples had high diversity despite evenness being about average relative to other routine subtidal monitoring sites (Figure 47). The contrasting differences between diversity and evenness at these sites were driven by overall taxa richness, which was low in Inner Quartermaster Harbor samples and high in Fauntleroy Cove samples.

Dominance

Swartz's Dominance Index ranged from 1 to 22. (Figure 47). Like the pattern observed for species diversity, the lowest scores were measured in Central Elliott Bay (LTED04) and Inner Quartermaster Harbor (MSVK01), particularly Central Elliot Bay with a mean score of only 2.7. Conversely, the highest mean dominance scores were observed at Piers 90/91 (KSZY01 - 20.3) and Seacrest Park (LSHZ08 - 18) (Figure 47).

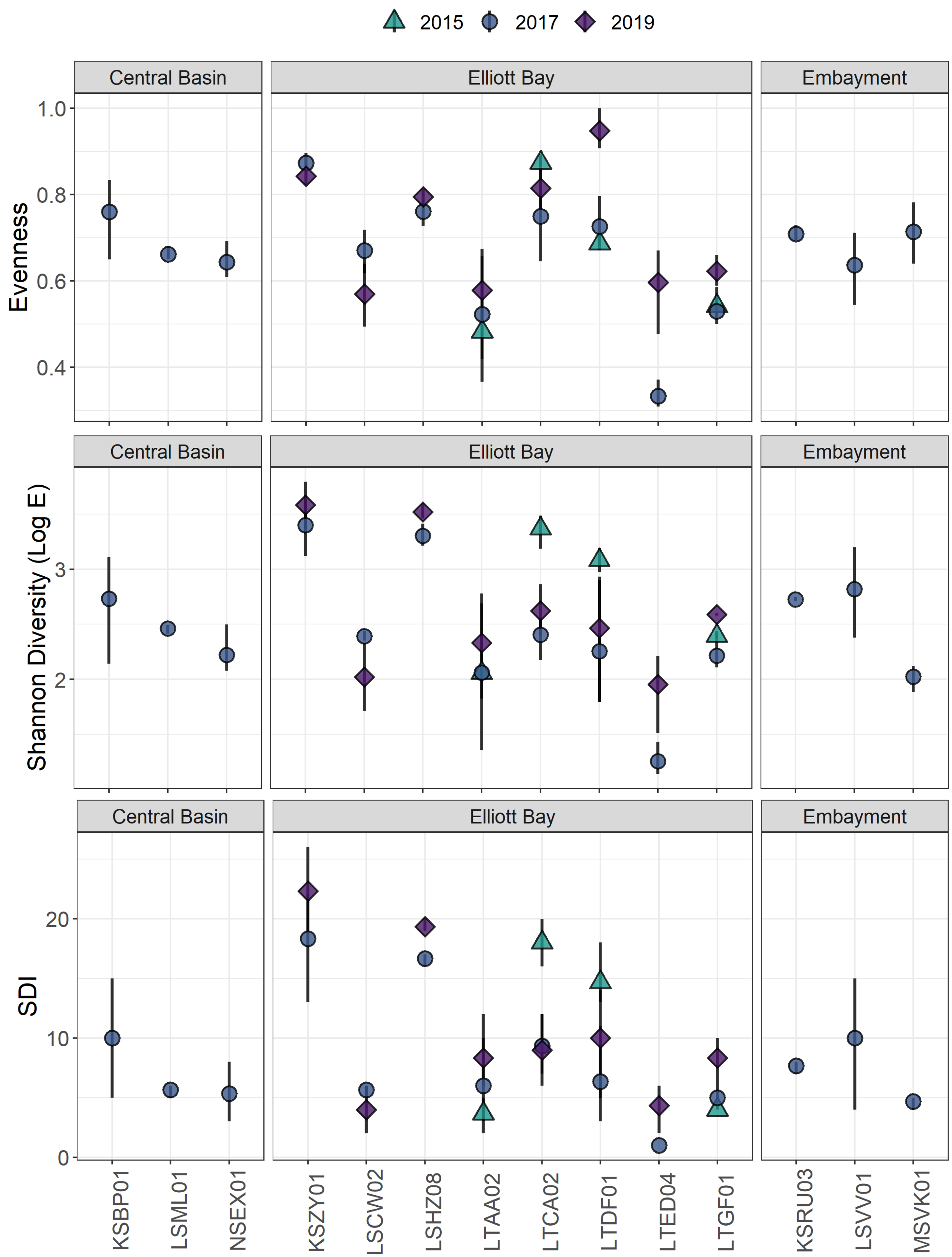


Figure 47. Evenness, Shannon Diversity, and Swartz's Dominance Index (SDI) in samples from routine subtidal sites by date. Colored symbols represent mean (n=3), and lines indicate range.

Routine Subtidal Benthic Infauna Patterns

While there is insufficient data to assess trends at these sites, some patterns within sites are starting to emerge and temporal variability in the benthic community is apparent.

Temporally, the most striking difference between years was the higher abundance and richness observed at the four Elliott Bay sites in 2015 compared to 2017 and 2019 results. Despite these differences, biomass in samples across all three sampling events was generally similar to 2015 except in Elliott Bay waterfront (LTDF01) samples where the highest biomass was measured in 2015. Measures of evenness, diversity, and dominance showed no clear temporal pattern, and were generally consistent over the three sampling events. The exception was a deep Elliott Bay site (LTED04), where benthic index values were much lower in 2017 than in 2019. Lower index values were not observed at the other deep Elliott Bay sites in 2017.

Overall, similarities in the benthic community at the routine subtidal sampling sites were associated with depth and grain size. Deep depositional areas like in central Elliott Bay (LTED04, LTCA02, and LSCW02), East Passage (NSEX01), and off West Seattle (LSML01) tended to have somewhat lower measures of taxa richness, evenness, diversity, and dominance than shallower sites. These lower scores are associated with prevalence of fine sediments. Taxa composition at these sites was dominated by molluscs compared to most other sites where polychaetes were more common. The most abundant taxa included bivalve species such as *Axinopsida serricata*, *Macoma* sp., and *Parvilucina tenuisculpta,* which are moderately pollutant tolerant, but also common in deep depositional areas across Puget Sound.

Despite its depth (~280 m), Point Jefferson (KSBP01) substrate is dominated by sand, and the benthic community in this area was different from other deep sites. Like other deep sites, abundance, richness, and biomass were low at Point Jefferson; however, benthic community composition was quite different. Abundance at Point Jefferson was dominated by crustaceans including pea crabs (*Pinnixa* sp.), the amphipod *Orchomenella pacifica*, and the cumacean *Diastylis pellucida*, followed by polychaetes *Nephtys* sp, and *Spiochaetopterus costrarum*.

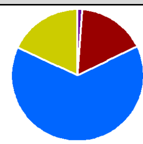
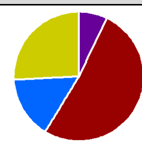
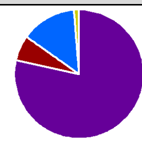
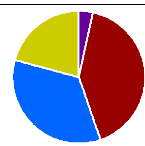
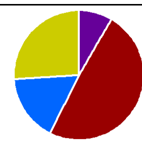
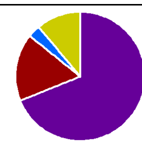
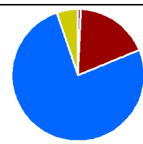
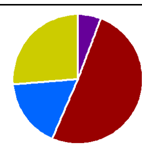
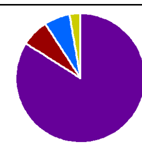
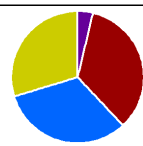
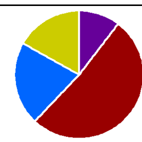
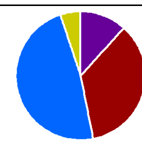
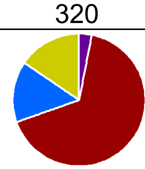
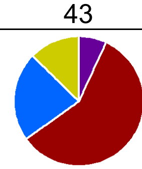
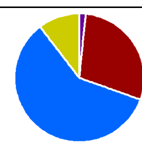
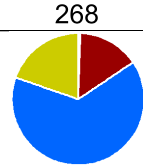
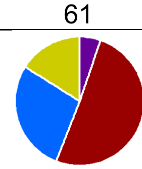
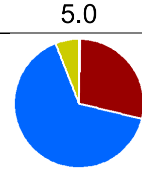
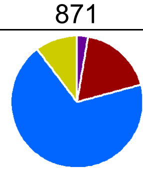
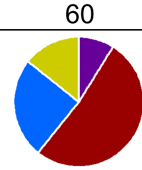
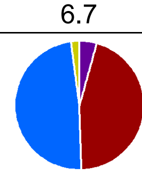
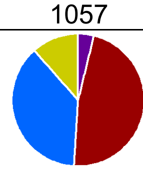
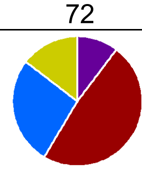
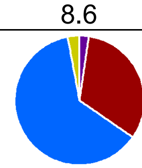
Benthic index values in samples from shallow (< 35 m) Elliott Bay sites (LTAA02, LTGF01, LSHZ08 and KSZY01) and embayment sites including Fauntleroy Cove (LSVV01) and outer Salmon Bay (KSRU03) were more variable than deeper sites, but typically had higher abundance and richness values than deep sites. Some of the most common high abundance taxa at these sites included the pollution tolerant bivalves *Parvilucina tenuisculpta* and *Axinopsida serricata*, and ostracods *Euphilomedes* sp., although each site had a slightly different community composition. The community differences were most apparent at the three shallowest sites (≤ 20 m) where the most abundant taxa at Piers 90/91(KSZY01), Fauntleroy Cove (LSVV01), and Salmon Bay (KSRU03) were the polychaetes *Aphelochaeta glandaria* (complex – pollution tolerant), *Mesochaetopterus taylori*, and *Heteromastus filobranchus* (pollution tolerant), respectively.

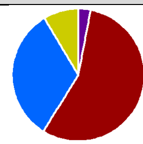
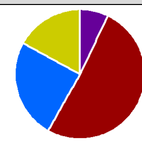
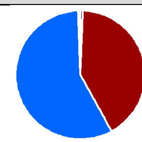
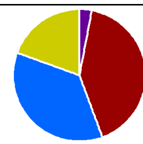
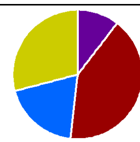
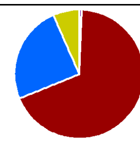
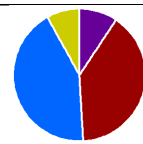
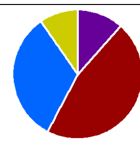
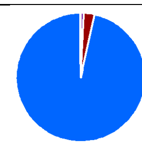
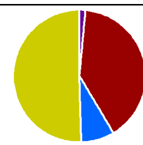
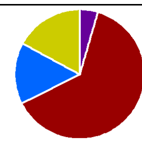
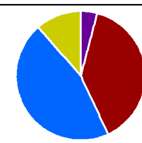
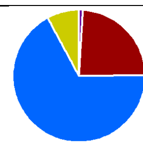
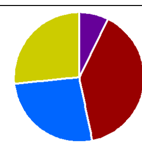
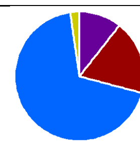
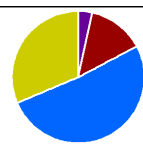
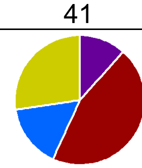
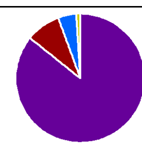
Benthic results for Elliott Bay waterfront (LTDF01) samples stood out from other shallow Elliott Bay sites. Samples at this site contained more silt than sites of similar depth, had higher TOC content, and were full of bits of wood. Except for the 2015 samples noted above, replicate samples from this site had some of the lowest abundance, richness, and biomass of the routine subtidal samples. The most abundant taxa at this site included pollution tolerant species such as the *Euphilomedes* ostracods, clams *Axinopsida serricata* and *Macoma* sp., and various types of polychaete worms.

The Inner Quartermaster Harbor site (MSVK01) was also unique. The site has high TOC and percent fines, is shallow (~ 6 m), and experiences large daily swings in dissolved oxygen (King County, 2022b). These conditions influence the benthic community with low abundance, richness, diversity, and dominance values observed. Evenness scores at this site were average compared to other routine subtidal sites due to the uniform small number of taxa. Sample biomass was variable and driven by mollusc biomass from the occasional collection of large clams. The dominant taxa in inner Quartermaster Harbor included the small bivalve *Kurtiella tumida*, the polychaete *Micronephthys cornuta*, the hypoxia tolerant polychaete *Paraprionospio alata*, *Pinnixa* crabs, and nemertean worms (Anopla).

Overall, the routine subtidal monitoring sites shared similar benthic infauna characteristics with sites of similar depth, grain size, and TOC content. A summary of benthic community indices at each routine subtidal sampling site is available in Table 37.

Table 37. Summary of benthic community index results at routine subtidal sites.

Type	Site/ Number of Sampling Events	Approx. Depth (m)	Abundance (Crustaceans, Molluscs, Polychaetes, Misc.)	Richness (Crustaceans, Molluscs, Polychaetes, Misc.)	Biomass (g) (Crustaceans, Molluscs, Polychaetes, Misc.)	Even-ness	Diver-sity	SDI
Elliott Bay	LSCW02 N=2	180	 266	 36	 15.4	0.620	2.21	4.8
	LTCA02 N=3	130	 111	 33	 15.6	0.813	2.80	12.1
	LTED04 N=2	90	 347	 35	 23.5	0.464	1.60	2.7
	LTDF01 N=3	35	 320	 43	 2.4	0.787	2.60	10.3
	KSZY01 N=2	20	 268	 61	 5.0	0.858	3.49	20.3
	LTAA02 N=3	25	 871	 60	 6.7	0.527	2.15	6.0
	LTGF01 N=3	30	 1057	 72	 8.6	0.565	2.40	5.8
	LSHZ08 N=2	25	 592	 81	 9.2	0.777	3.41	18.0

Type	Site/ Number of Sampling Events	Approx. Depth (m)	Abundance (Crustaceans, Molluscs, Polychaetes, Misc.)	Richness (Crustaceans, Molluscs, Polychaetes, Misc.)	Biomass (g) (Crustaceans, Molluscs, Polychaetes, Misc.)	Even-ness	Diver-sity	SDI
Embayment	KSRU03 N=1	10	 721	 47	 16.4	0.709	2.72	7.7
	LSVV01 N=1	12	 882	 84	 11.6	0.636	2.82	10.0
	MSVK01 N=1	6	 107	 17	 46.9	0.714	2.02	4.7
Mainstem	KSBP01 N=1	280	 182	 37	 3.3	0.760	2.73	10.0
	LSML01 N=1	250	 381	 41	 8.1	0.662	2.46	5.7
	NSEX01 N=1	175	 158	 32	 26.6	0.644	2.22	5.3

N = number of sampling events (3 replicates/event). Index results based on mean of 3 replicates/event in 2015, 2017 and 2019.
SDI= Swartz's Dominance Index

3.5 Offshore Sediment Summary

Looking at the full suite of sediment chemistry, toxicity, and benthic community data from all components of the monitoring program can give us a clearer understanding of overall benthic community health in areas of the Central Basin. However, comparisons across monitoring components are challenging due to differences in sediment sample depths (e.g., 0–2 cm at routine subtidal sites, 0-10 cm at subtidal outfall sites), frequency (every 2 vs. 5 yrs.), and seasonality (June for routine subtidal, and fall for most subtidal outfall samples). In 2017, chemistry and benthic infauna were monitored at all offshore sites for the first time in the program's history. However, samples near the Brightwater outfall were only

collected to assess the benthic community (no chemistry), to support a separate benthic reference study. This section provides key findings of sediment monitoring results at routine subtidal and outfall sites. Due to the comprehensive sampling in 2017, maps illustrating data from that year are used to highlight spatial differences in chemistry and benthic infauna data (Figure 48 - Figure 56).

Physical/Chemistry - Key Findings

In general, TOC content and percent fines at Central Basin monitoring sites were positively correlated. Depositional sites, such as those located in central Elliott Bay, deep in the Central Basin (e.g., off South Plant, Alki and East Passage), and in Quartermaster Harbor tended to have high percent fines and TOC (Figure 48 and Figure 49). The highest TOC was measured at the Elliott Bay waterfront site (LTDF01), but not the highest percent fines. This site contained decomposing wood chips, which likely contributed to high TOC. The other shallow sites, Point Jefferson (KSBP01), and sites near the West Point outfall, were sandier (some contained gravel), with low percent fines and TOC content (Figure 48 and Figure 49).

Sediment chemistry results over the monitoring period indicate that chemical concentrations in some areas of the Central Basin are low, while levels in other areas are higher and sporadically or chronically above the SQS. The most common chemical SQS exceedances in the Central Basin include total PCBs in Elliott Bay and at two sites in 2011 near the West Point outfall, and mercury in Elliott Bay and Quartermaster Harbor. Phthalates and individual PAHs also occasionally exceeded SQS within the basin.

In 2017, no samples exceeded the SQS for any phthalates, PAHs, or total PCBs. Fourteen sites (9 outfall and 5 routine subtidal) exceeded the benzoic acid benthic CSL. The routine subtidal sites that exceeded the benzoic acid CSL included routine subtidal mainstem sites at Point Jefferson (KSBP01) and Fauntleroy Cove (LSVV01), as well as Elliott Bay sites near Seacrest Park (LSHZ08), the Seattle Grain Terminal (LTAA02), and Harbor Island (LTGF01) (Figure 50). Other SQS exceedances that year included benzyl alcohol at a site near the West Point outfall, as well as mercury at the Seattle waterfront, Harbor Island, and Quartermaster Harbor (MSVK01) locations.

Despite some repeated chemical SQS exceedances, there are signs that concentrations of some measured chemicals in the Central Basin may be decreasing. Chemistry results (pooled data) collected between 1985 and 2019 from five long-term monitoring sites (West Seattle and four within Elliott Bay) indicate a significant decrease in lead and mercury levels, while iron (crustal/earth metal) has increased. Concentrations of other metals did not have a significant trend but were below SQS. However, total LPAH and HPAH concentrations have significantly decreased over time. While an overall trend in PCB concentrations was not seen, levels have significantly decreased at the Seattle Waterfront site in Elliott Bay (LTDF01).

Across the monitoring components, SCI scores were typically high, indicating minimal chemical exposure to benthic organisms. The exceptions were one West Point site, four shallow (≤35 m) Elliott Bay sites, and outer Salmon Bay, where SCI scores indicated low

chemical exposure. The five routine subtidal sites with SCI scores indicating low chemical exposure were in nearshore areas, near a mix of point and non-point sources. At least one chemical concentration was above the SQS at each of those sites during the monitoring period.

Toxicity - Key Findings
Toxicity (bioassay) testing was conducted on samples collected at the South Plant and West Point outfalls. The results do not indicate a chronic toxicity problem in these areas.

Benthic Infauna - Key Findings
The benthic organisms that live within the sediment can be reflective of the overall health of that habitat. Key characteristics of a healthy benthic community include an abundance that's not extremely high (> approximately 1,000 individuals/0.1 m^2) if dominated by pollution tolerant organisms, high taxa richness, and high measures of evenness, diversity, and dominance. Total biomass isn't as important for assessing overall habitat health since it can be skewed by the presence (or absence) of a few large organisms.

Benthic community abundance near the Brightwater outfall was high, but not >1,000 individuals per sample. Abundance in samples collected near the West Point outfall surpassed 1,000 individuals per sample at a few sites when large recruitments occurred (i.e., tunicate *Molgula pacifica* in 2011 and actiniid anemones in 2017). The high abundances near the West Point outfall were not driven by pollution-tolerant taxa, and several pollution-sensitive taxa, including actiniid anemones and the amphipods *Ericthonius rubricornis* and *Caprella mendax* were among some of the most abundant taxa there. High abundances were also measured at Elliott Bay's Seattle Waterfront (LTDF01), grain terminal (LTAA02), and Harbor Island (LTGF01) sites, as well as Fauntleroy Cove (LSVV01). Except for West Point sites, most samples with high abundance were dominated by molluscs and except for Brightwater sites, were < 80 m (Figure 51).

Taxa richness was highest near the West Point outfall and other similarly sandy locations in the Central Basin, most others of which were shallow (< 35 m) in depth. Richness was lowest in depositional areas, such as near the South Plant and Brightwater outfalls, deep Elliott Bay sites, and inner Quartermaster Harbor (MSVK01) (Figure 52). The exception was the Seattle Waterfront site (LTDF01), which despite being shallow and sandy, had very low taxa richness, and was unique in the presence of decaying wood chips. Overall, polychaetes were the most diverse taxonomic group in the Central Basin (Figure 52).

Biomass varied greatly and was heavily influenced by large taxa such as *Molpadia* (sea cucumber) near the South Plant outfall, or large recruitment events such as the sea anemone recruitment near the West Point outfall in 2017. Overall, biomass tended to be higher in depositional areas due to the presence of larger deposit feeders such as urchins and sea cucumbers (Figure 53).

Other benthic index values such as evenness, diversity, and dominance, were generally lowest at deep and depositional locations. Sites surrounding the Brightwater outfall had particularly low measures of evenness, diversity, and dominance. This is largely due to the

dominance of a few taxa which included pollution tolerant clams (e.g., *Macoma* sp., *Parvilucina tenuisculpta*, and *Axinopsida serricata*) and *Euphilomedes* ostracods. These taxa were also dominant in 2011, prior to operation of the Brightwater outfall and are common at other deep depositional sites (e.g., South Plant outfall, deep Elliott Bay sites, East Passage [NSEX01], and off West Seattle [LSML01]).

Other sites with low evenness (<0.6) included Central Elliott Bay (LTED04), the Grain Terminal (LTAA02), and Harbor Island (LTGF01) (Figure 54). Diversity tends to be lower (<2.25) at deep sites such as those near the South Plant outfall, East Passage (NSEX01), and deep Elliott Bay sites (LTED04 and LSCW02). At shallow sites, diversity was low near the grain terminal (LTAA02), the Seattle Waterfront (LTDF01), Harbor Island (LTGF01), and inner Quartermaster Harbor (MSVK01) (Figure 55). Taxa dominance was also low (≤5 taxa per sample) at the same sites (Figure 56).

Non-metric multidimensional scaling (nMDS) analysis of replicate-average benthic community data collected between 2011 and 2017 was used to assess how similar the benthic communities were to one another across all sites and sampling events. Data were limited since there were three or less sampling events during the monitoring period. However, annual shifts in the benthic community could be observed during this short time period, illustrating interannual variability (Figure 57). Both outfall and routine subtidal sites generally clustered together based on physical characteristics:

- **Mid-depth, low fines, and low TOC** – West Point outfall sites
- **Mixed depth, low fines, low TOC –** Largely includes shallow Elliott Bay sites, along with Salmon Bay (KSRU03), Fauntleroy Cove (LSVV01), and the deep but sandy Point Jefferson site (KSBP01)
- **Shallow, high fines, high TOC –** Seattle Waterfront site (LTDF01) and Quartermaster Harbor (MSVK01), but nMDS analysis did not show these sites as clustered together
- **Deep, high fines, high TOC –** All Brightwater and South Plant outfall sites, deep Elliott Bay sites, East Passage (NSEX01), and off West Seattle (LSML01).

We know from other Puget Sound studies that physical site characteristics (e.g., percent fines, TOC, and depth) are the key factors in determining benthic community composition at a site (Ecology, 2018a,b). Therefore, it is expected that we would see differences in benthic infauna across different habitat types. Similarities between sites and their dominant taxa can be observed in Figure 58, which compares abundance of the 50 most abundant taxa across all monitoring sites ordered by depth. While some sites have lower benthic infauna metrics than others, similarity of the benthic communities at sites with similar depth, grain size and TOC suggest that sediment chemistry, at least based on the low frequency of SQS exceedances, appears less influential on the benthic community than other site characteristics.

We monitor sediment associated chemicals and look for changes over time due to our concern for their potential to negatively impact marine life in Puget Sound, particularly

benthic organism and demersal fish. The chemical concentrations that we observe don't appear to be driving large changes in the benthic infauna community. However, benthic infauna are an important component in the marine food web, and the chemicals that we monitor (e.g., PCBs, PBDEs, and DDT and degradation products) are known to bioaccumulate within the food web. In addition, long-term sediment monitoring and trend analysis allow us to observe if changes in stormwater management, CSO control, and source control (through chemical product substitutions or bans), combined with natural recovery processes, are leading to improved sediment conditions. It is, therefore, important to continue monitoring sediment chemistry and the benthic infauna to observe any changes over time.

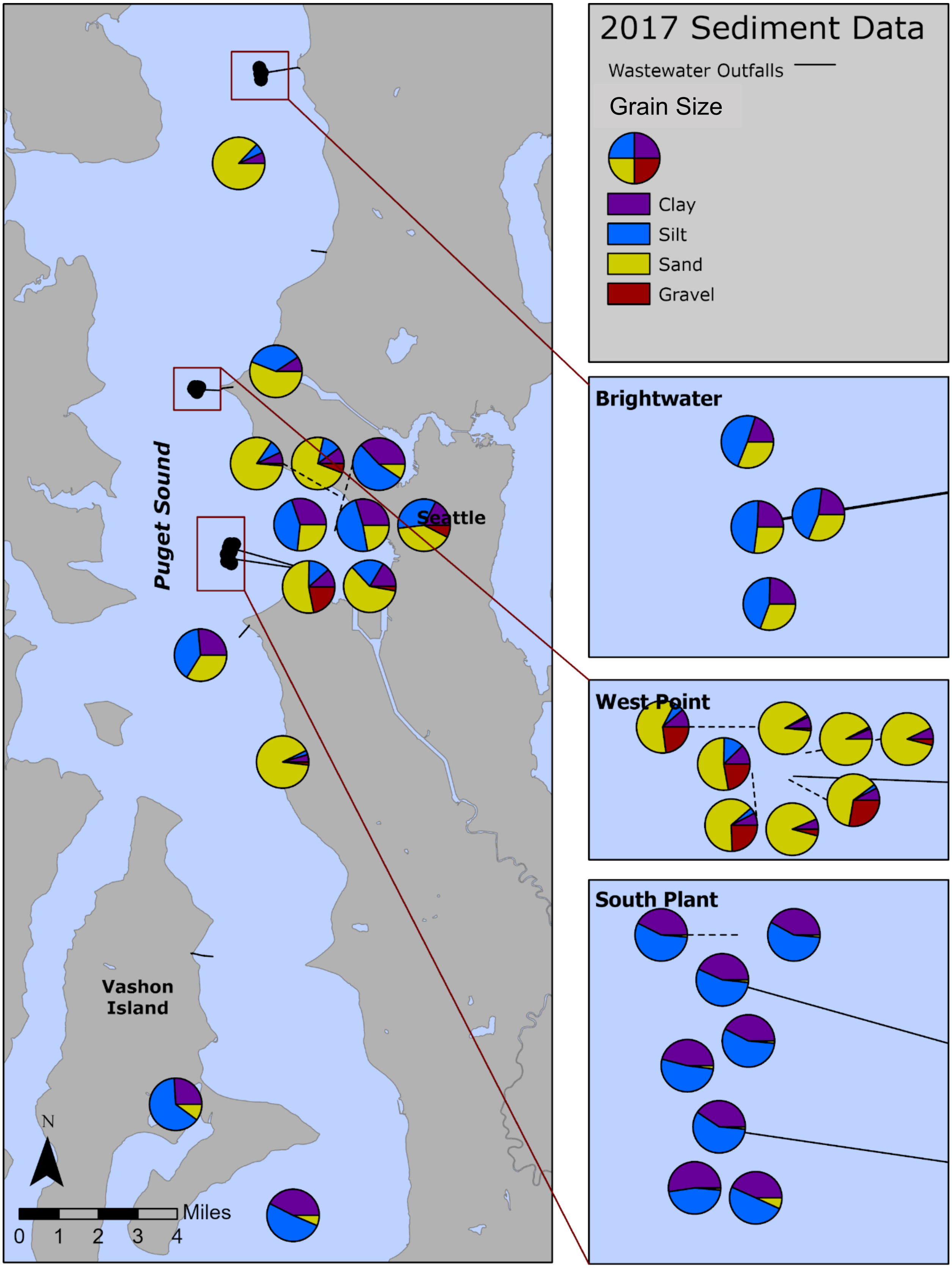


Figure 48. Map illustrating grain size distribution at outfall and routine subtidal locations (2017).

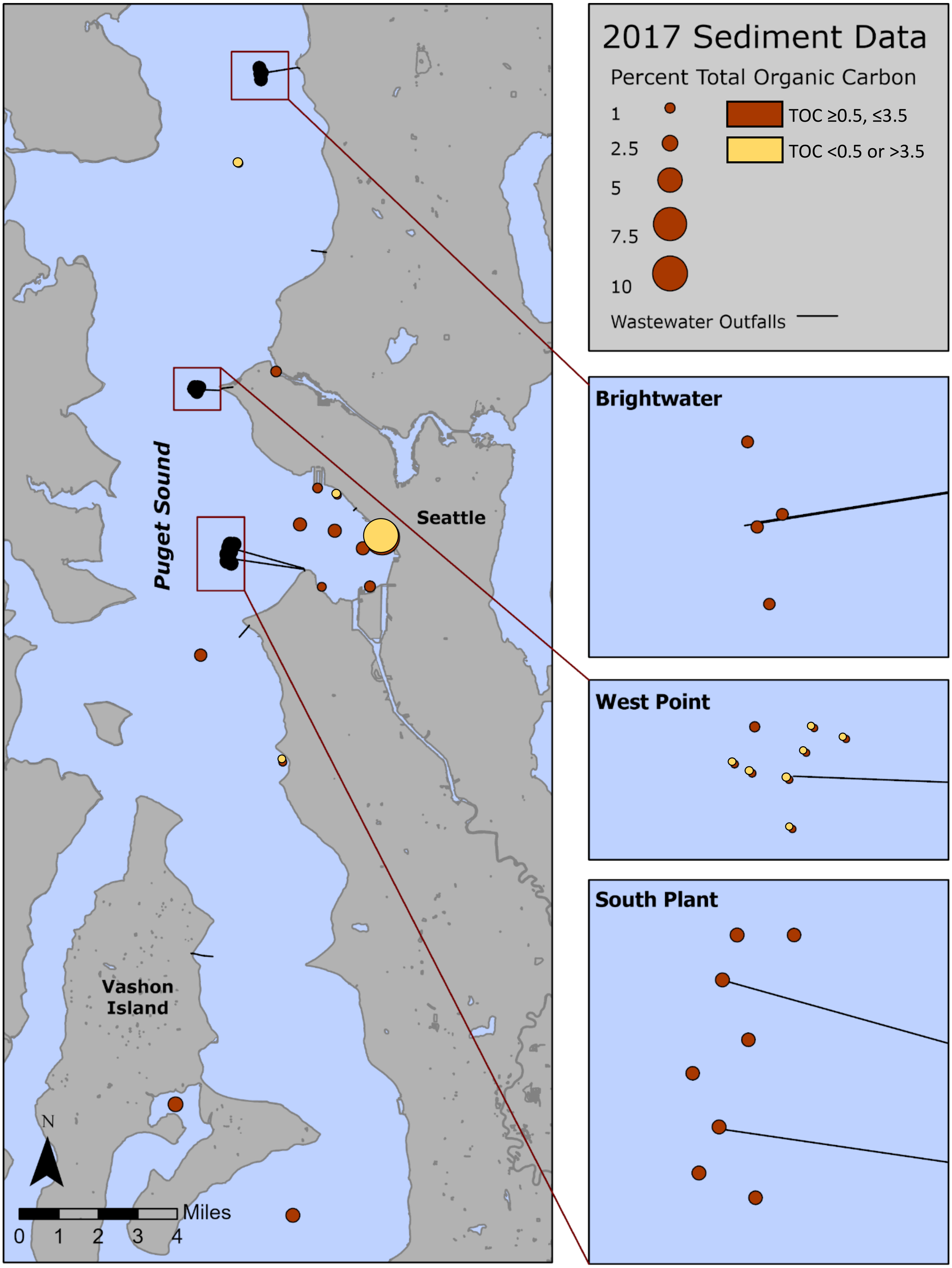


Figure 49. Map illustrating total organic carbon (TOC) at outfall and routine subtidal locations (2017). Bubble size reflects percent TOC: color reflects range for SMS comparison.

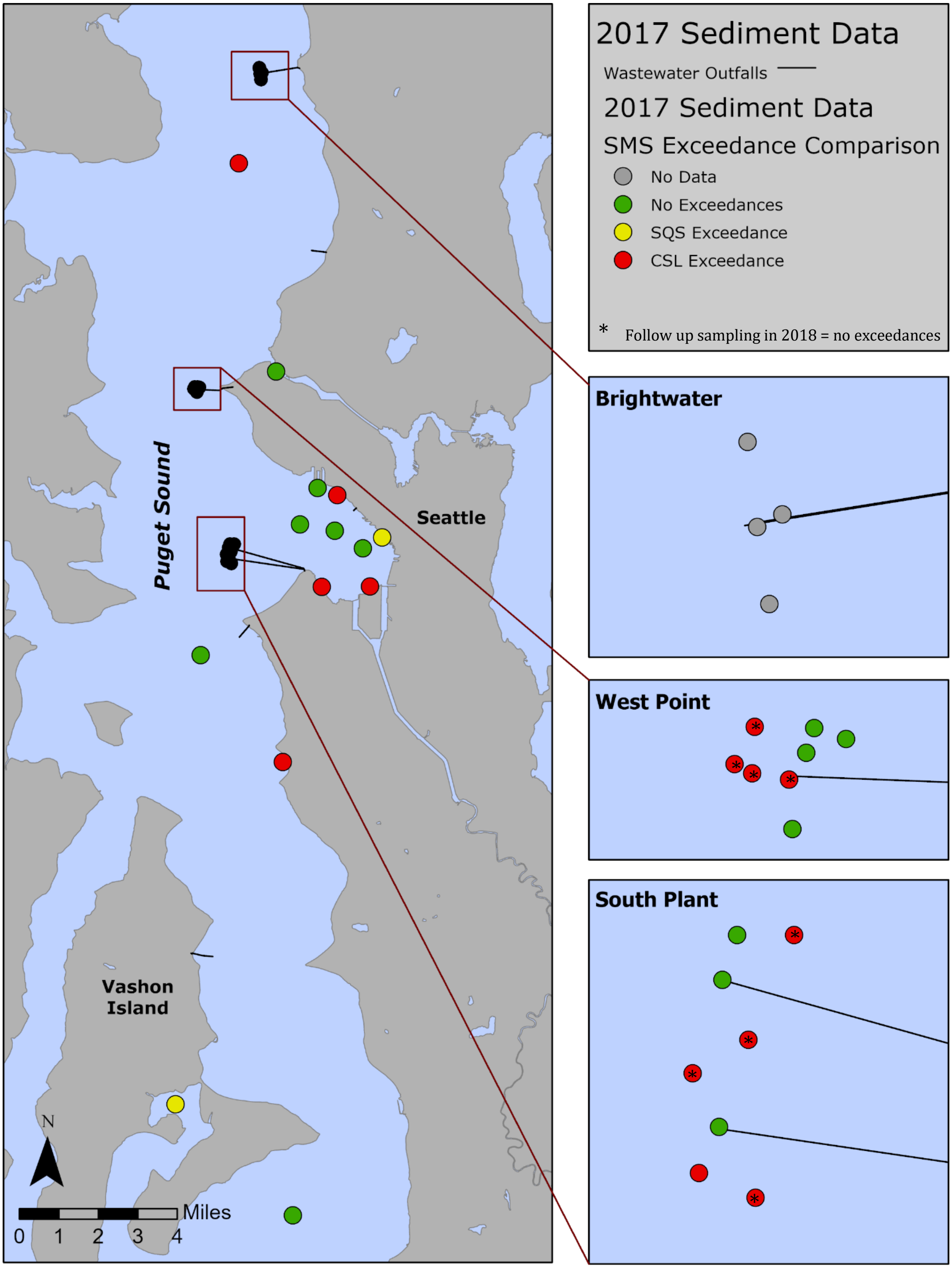


Figure 50. Map illustrating comparison of sediment chemistry results to Sediment Management Standards at outfall and routine subtidal locations (2017).

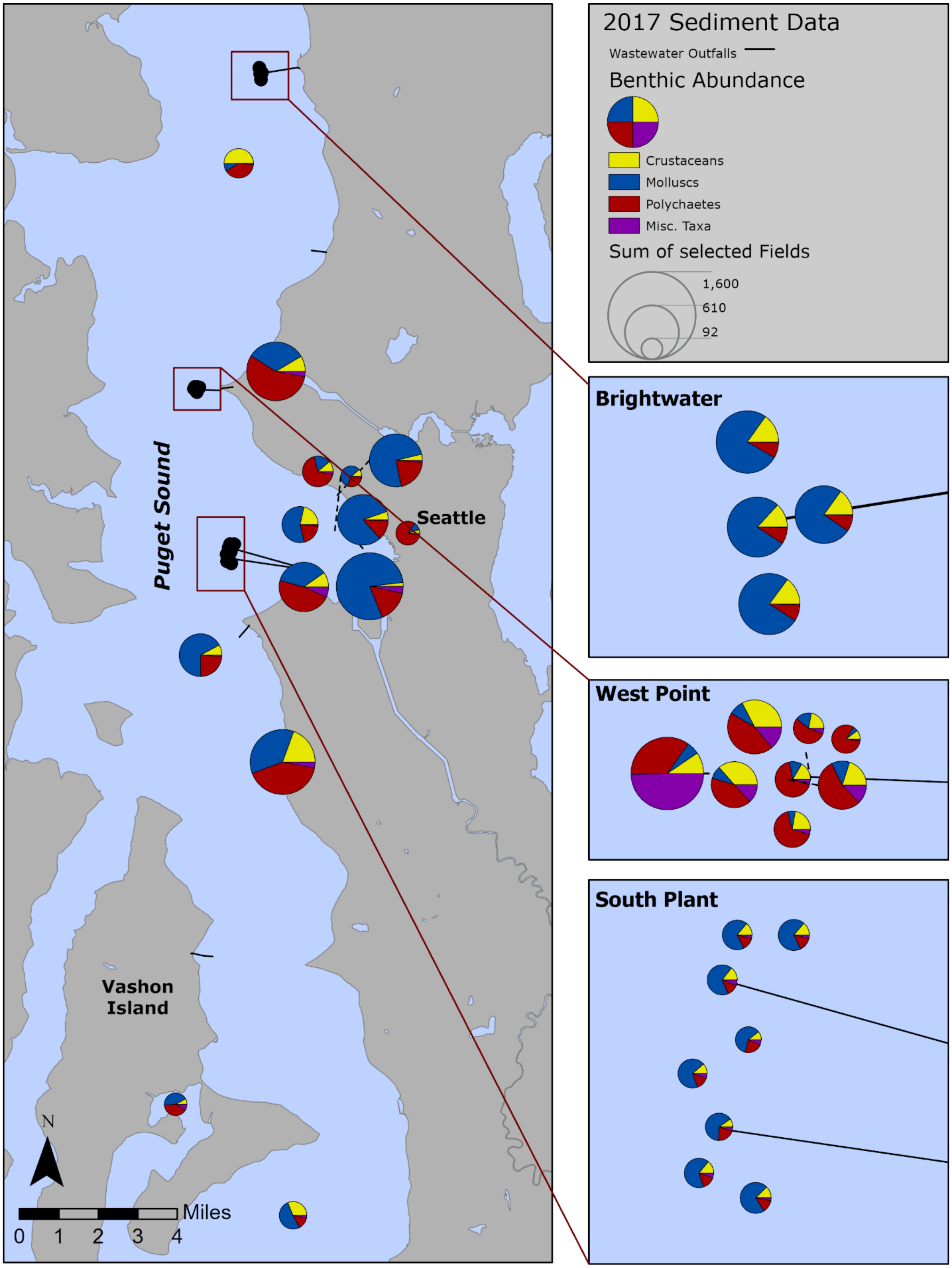


Figure 51. Map illustrating mean benthic infauna abundance/0.1 m^2 by major taxonomic group at outfall and routine subtidal locations (2017). Bubble size reflects total abundance.

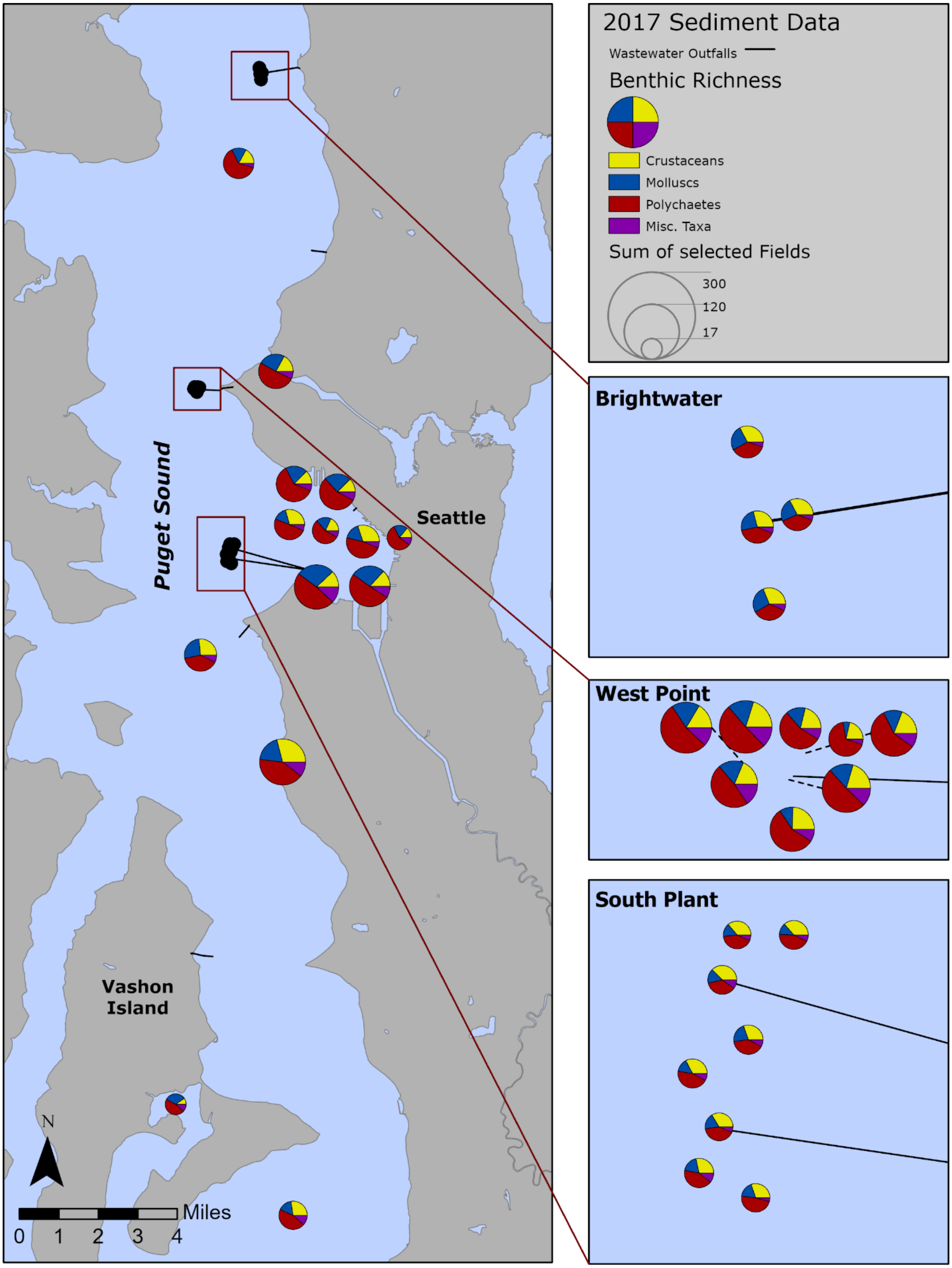


Figure 52. Map illustrating mean benthic infauna richness/0.1 m^2 by major taxonomic group at outfall and routine subtidal locations (2017). Bubble size reflects total richness.

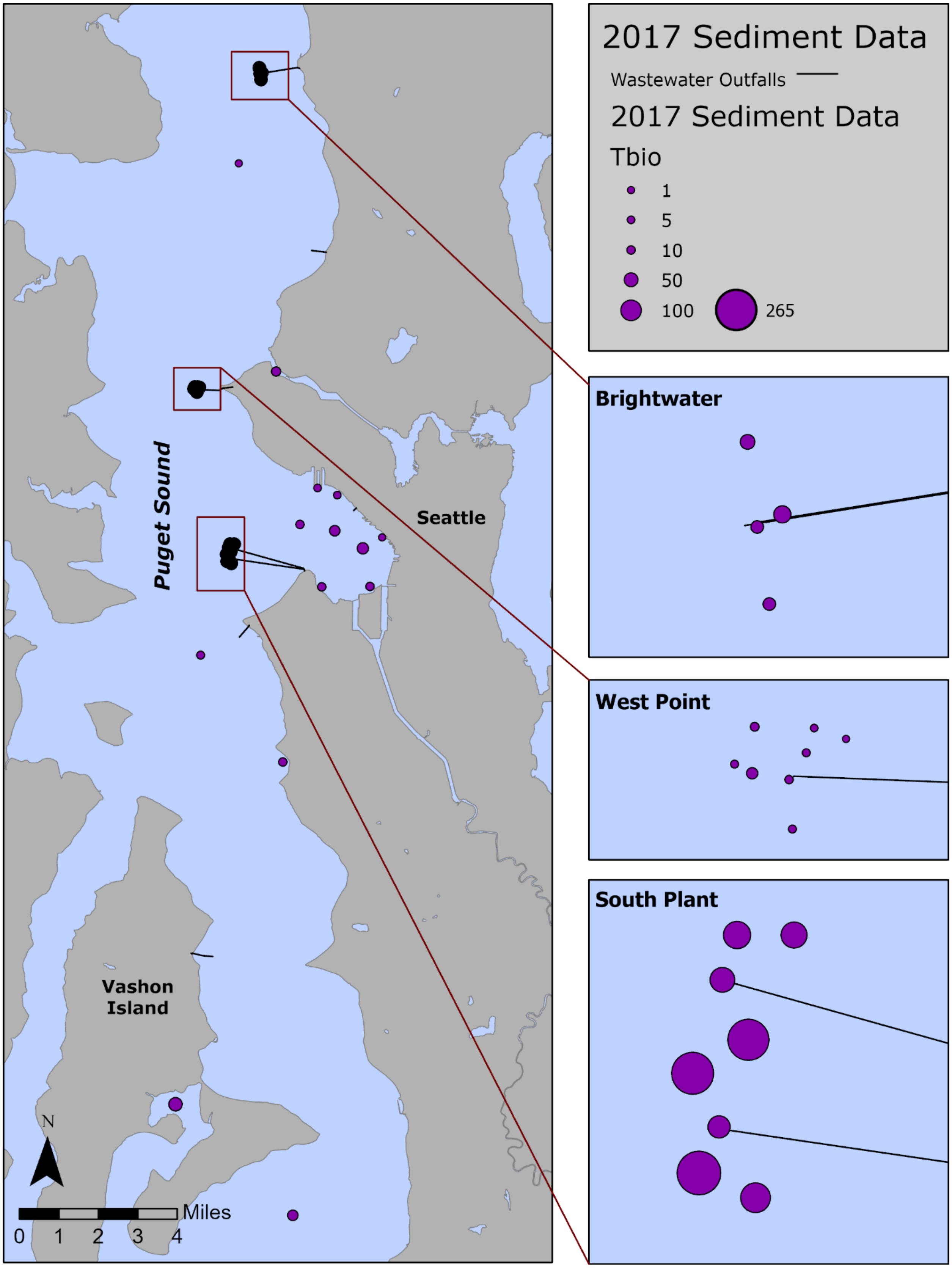


Figure 53. Map illustrating mean benthic infauna biomass (g/0.1 m^2) at outfall and routine subtidal locations (2017). Bubble size reflects total biomass.

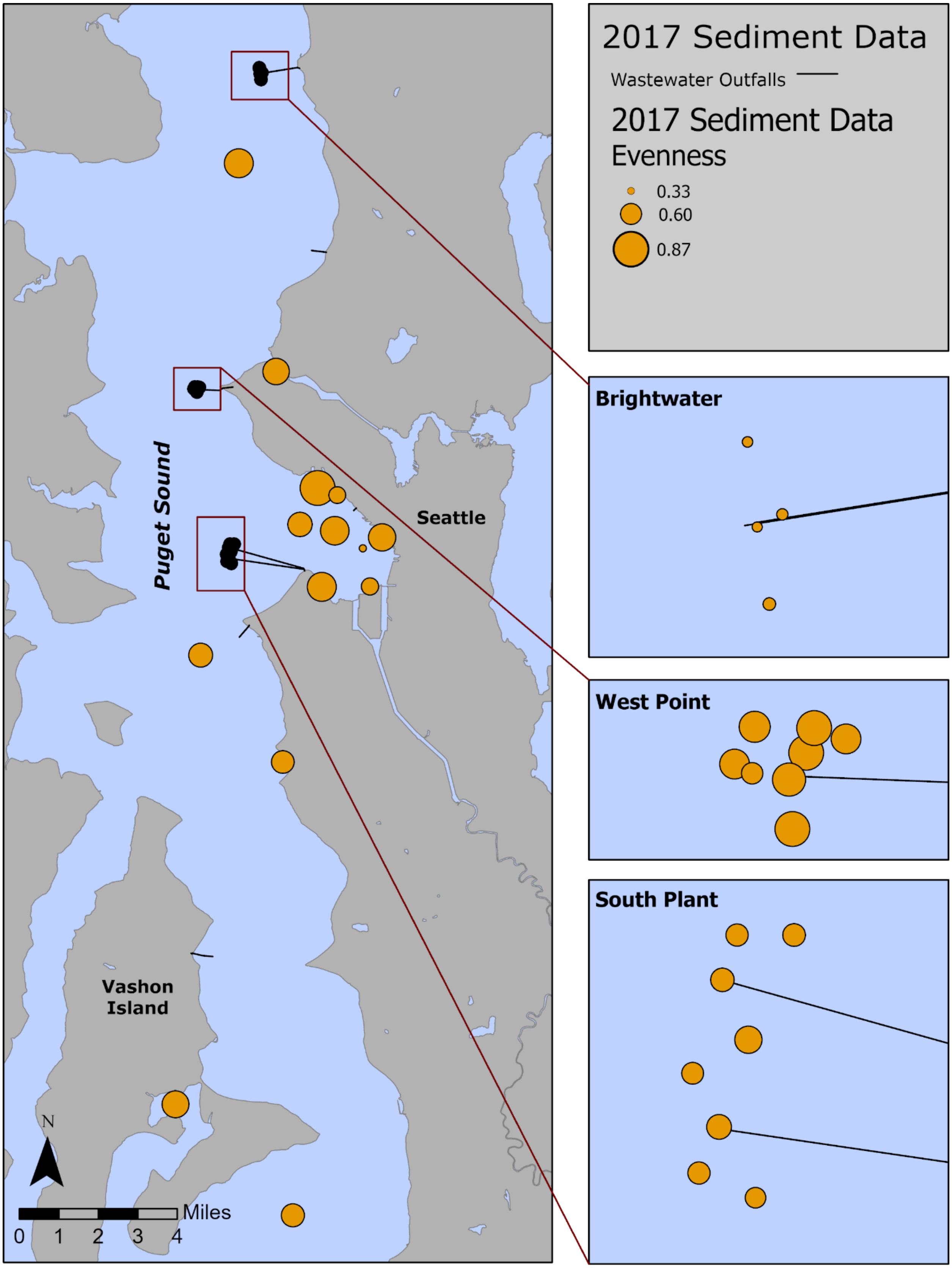


Figure 54. Map illustrating mean benthic infauna evenness at outfall and routine subtidal locations (2017). Bubble size reflects eveness value.

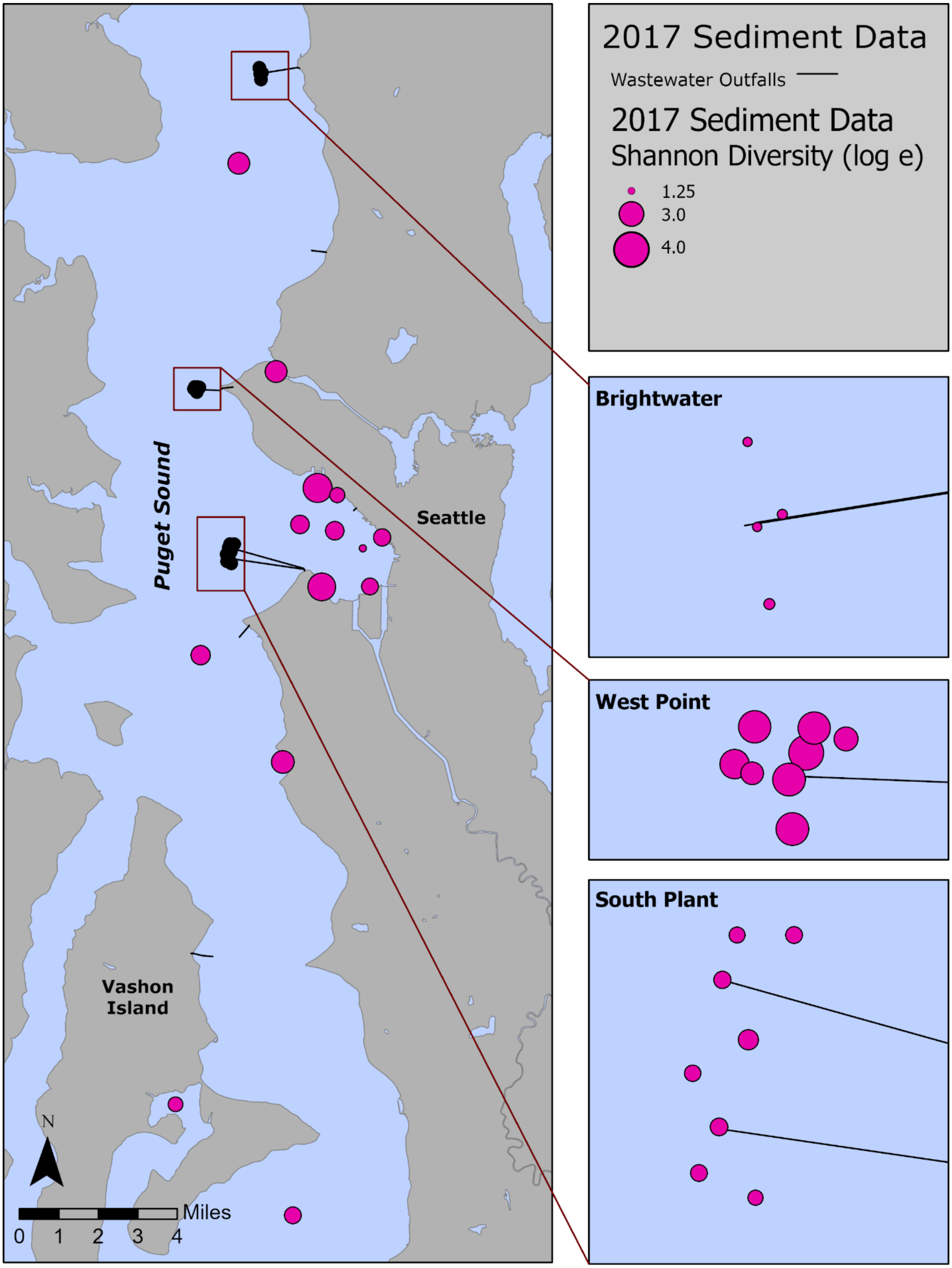


Figure 55. Map illustrating mean benthic infauna diversity at outfall and routine subtidal locations (2017). Bubble size reflects diversity value.

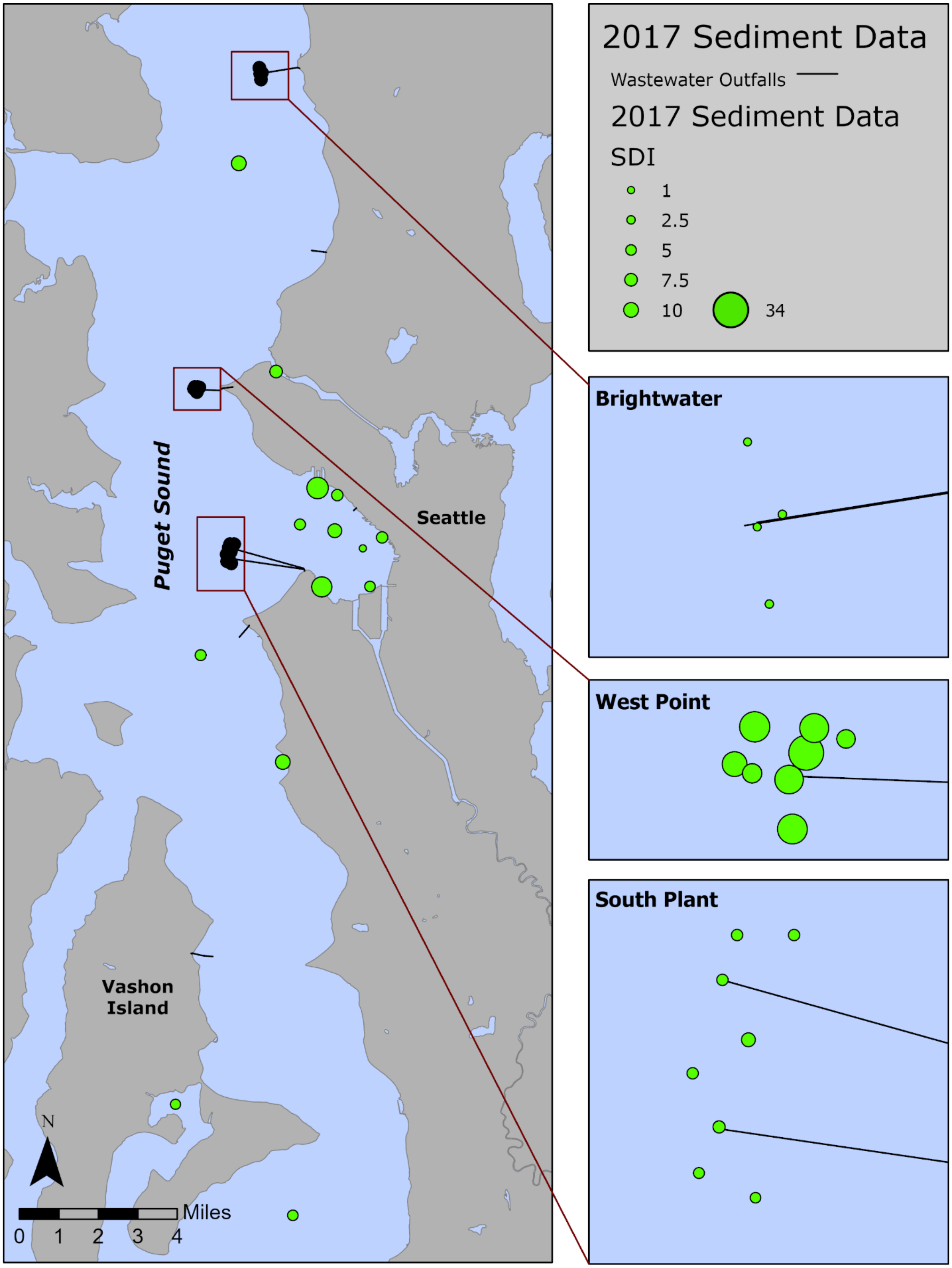


Figure 56. Map illustrating mean benthic infauna Swartz's dominance index at outfall and routine subtidal locations (2017). Bubble size reflects dominance value.

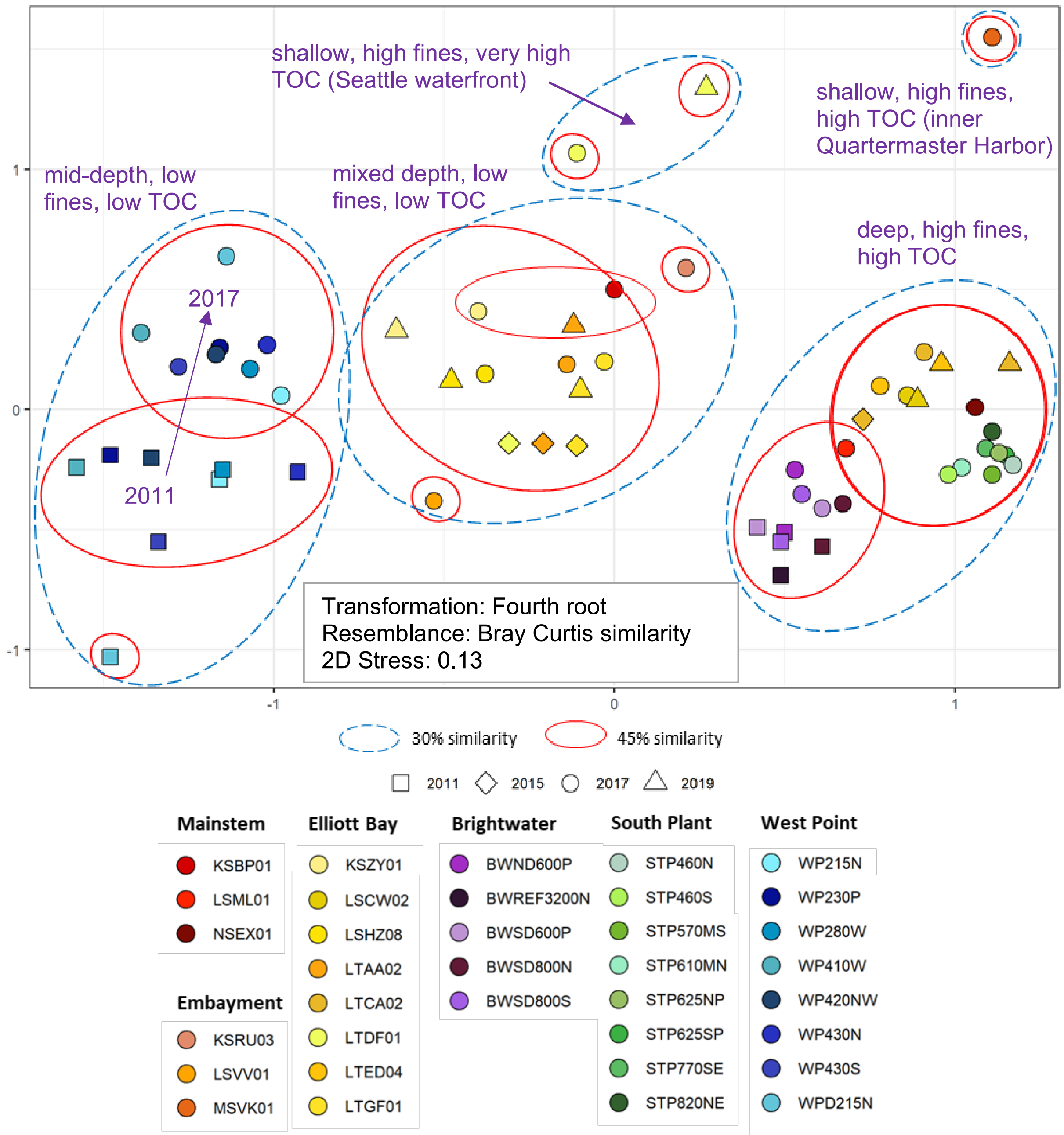


Figure 57. Non-metric multidimensional scaling (nMDS) analysis of replicate-averaged benthic community samples. Each sample location represented by a different color and each year by a different symbol. Symbols located closer together represent benthic communities that are more similar to one another than those further apart.

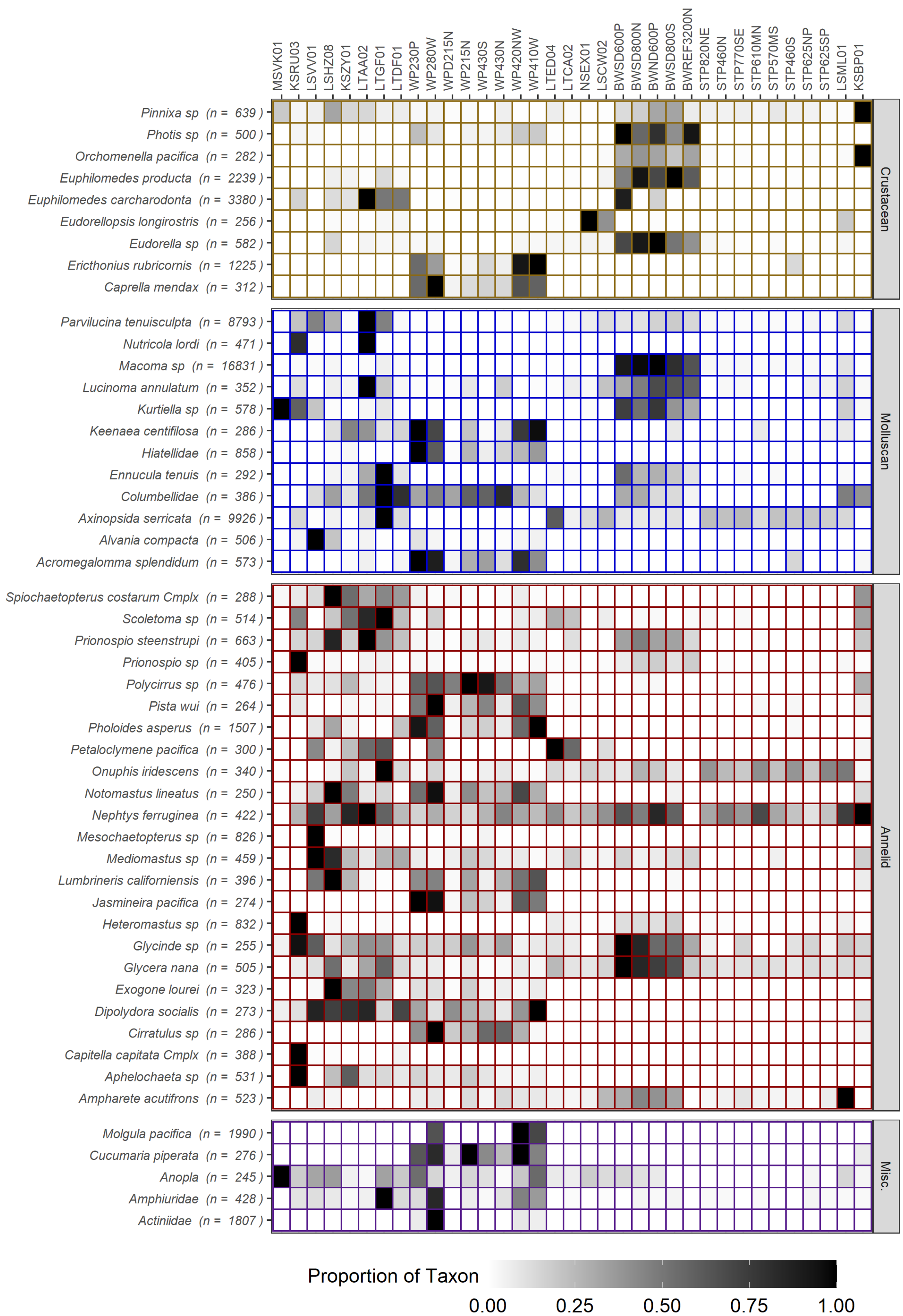


Figure 58. Average proportion of individuals of 50 most abundant taxa collected by site. Sites arranged by depth (shallowest at left to deepest at right) and taxa are grouped by major taxonomic group.

4.0 SUMMARY

Key findings from the sediment sampling results presented above include:

Intertidal

- Very few chemicals, including no metals, exceeded SMS at intertidal sites. When exceedances of a SQS did occur, they only occurred at a site during one of the two sampling events during the study period
- Chemistry results indicated a patchiness in the nearshore environment, which may be due to spatial variability as well as sample heterogeneity, common in samples with a low percentage of fines
- There was a significant decreasing trend in chromium, lead, and nickel concentrations at intertidal sites.

Subtidal (Outfall and Routine)

- The most common chemical SQS exceedances in the Central Basin include:
  - total PCBs in Elliott Bay and at two sites in 2011 near the West Point outfall, and
  - mercury in Elliott Bay and Quartermaster Harbor
- Phthalates and individual PAHs also occasionally exceeded criteria within the basin.
- SCI scores were typically high, indicating minimal chemical exposure. The exceptions included one West Point site, four shallow (≤ 35 m) Elliott Bay sites, and outer Salmon Bay, which had SCI scores indicating low chemical exposure
- For five long-term monitoring sites, including one off West Seattle and four within Elliott Bay, pooled data from as far back as 1985 indicated that:
  - concentrations of lead and mercury have significantly decreased over time while the crustal/earth metal iron has increased,
  - total LPAHs and HPAHs have significantly decreased over time, and
  - total PCBs showed no overall trend but have significantly decrease at the Seattle Waterfront site in Elliott Bay (LTDF01)
- Toxicity data from samples collected near the South Plant and West Point outfalls do not indicate a chronic toxicity problem
- While some sites do appear to have lower benthic infauna metrics, the similarity of the benthic communities at sites with similar depth, grain size and organic carbon content suggest that sediment chemistry, at least at the low frequency of SQS exceedances measured, appears less influential on the benthic community than the physical characteristics.

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Appendix A: Metals and Organics Sediment Quality Criteria

Table A-1 Washington State Department of Ecology marine sediment chemical criteria (Ecology *SCUM*, 2021 Appendix A Table A-1).

Analyte	SMS Marine Sediment[a]		Marine Sediment AETs[b]	
	SQS/SCO	CSL/SIZmax	SCO	CSL/SIZmax
Metals	**mg/kg dw**		**mg/kg dw**	
Arsenic	57	93	57	93
Cadmium	5.1	6.7	5.1	6.7
Chromium	260	270	260	270
Copper	390	390	390	390
Lead	450	530	450	530
Mercury	0.41	0.59	0.41	0.59
Silver	6.1	6.1	6.1	6.1
Zinc	410	960	410	960
Organic Chemicals	**µg/kg dw (except *)**		**µg/kg dw**	
2,4-Dimethylphenol	29	29	29	29
2-Methylphenol	63	63	63	63
4-Methylphenol	670	670	670	670
Benzoic acid	650	650	650	650
Benzyl alcohol	57	73	57	73
Dibenzofuran	15*	58*	540	540
Phenol	420	1200	420	1200
N-nitrosodiphenylamine	11*	11*	28	40
Phthalates	**mg/kg OC**		**µg/kg dw**	
Bis(2-Ethylhexyl)phthalate	47	78	1300	1900
Butylbenzyl phthalate	4.9	64	63	900
Diethyl phthalate	61	110	200	>1200
Dimethyl phthalate	53	53	71	160
Di-n-butyl phthalate	220	1700	1400	1400
Di-n-octyl phthalate	58	4500	6200	6200
PCBs	**mg/kg OC**		**µg/kg dw**	
Total Aroclors	12	65	130	1000
Polycyclic Aromatic Hydrocarbons	**mg/kg OC**		**µg/kg dw**	
Total LPAH	370	780	5200	5200
Naphthalene	99	170	2100	2100
Acenaphthylene	66	66	1300	1300
Acenaphthene	16	57	500	500
Fluorene	23	79	540	540
Phenanthrene	100	480	1500	1500
Anthracene	220	1200	960	960
2-Methylnaphthalene	38	64	670	670

Analyte	**SMS Marine Sediment[a]**		**Marine Sediment AETs[b]**	
	SQS/SCO	**CSL/SIZmax**	**SCO**	**CSL/SIZmax**
Total HPAH	960	5300	12000	17000
Fluoranthene	160	1200	1700	2500
Pyrene	1000	1400	2600	3300
Benz[a]anthracene	110	270	1300	1600
Chrysene	110	460	1400	2800
Total benzofluoranthenes	230	450	3200	3600
Benzo[a]pyrene	99	210	1600	1600
Indeno[1,2,3-c,d]pyrene	34	88	600	690
Dibenzo[a,h]anthracene	12	33	230	230
Benzo[g,h,i]perylene	31	78	670	720
Chlorinated Organics	**mg/kg OC**		**µg/kg dw**	
1,2,4-Trichlorobenzene	0.81	1.8	31	51
1,2-Dichlorobenzene	2.3	2.3	35	50
1,4-Dichlorobenzene	3.1	9	110	110
Hexachlorobenzene	0.38	2.3	22	70
Hexachlorobutadiene	3.9	6.2	11	120
Pentachlorophenol	360**	690**	360	690

[a] Marine SMS values are dry weight normalized for metals and polar organics and normalized to total organic carbon for nonpolar organics.
[b] Dry weight normalized AETs are recommended when total organic carbon is outside the recommended range of 0.5 – 3.5% for organic carbon normalization.
* mg/kg OC
** Pentachlorophenol is in µg/kg dry weight

Appendix B: Trend Analysis Results

Table B-1 Overall intertidal sediment chemistry trends (pooled from five sites, 1988–2015). Metals concentrations were measured in mg/Kg dry weight.

Parameter	p-value	Significant?	Trend
Aluminum	.1528	No	N/A
Arsenic	.3013	No	N/A
Chromium	7.74E-05	Yes	↓
Copper	.9292	No	N/A
Iron	.2961	No	N/A
Lead	3.98E-08	Yes	↓
Manganese	.0696	No	N/A
Mercury	.5344	No	N/A
Nickel	.0010	Yes	↓
Zinc	.0757	No	N/A

Table B-2 Intertidal sediment chemistry trends from individual sites (1988–2015). Metals concentrations were measured in mg/Kg dry weight.

Parameter	Locator	Thiel-Sen Slope	p-value	Significant?	Trend
Aluminum	JSVW04	16.1817	.9561	No	N/A
	KSHZ03	-59.4944	.2496	No	N/A
	KSLU03	-67.2753	.2415	No	N/A
	KSSN04	-45.5063	.4363	No	N/A
	KSSN05	-27.6927	.7833	No	N/A
Arsenic	JSVW04	-0.0612	.5399	No	N/A
	KSHZ03	-0.1559	.7442	No	N/A
	KSLU03	-0.0616	.7445	No	N/A
	KSSN04	-0.0494	.8537	No	N/A
	KSSN05	-0.0858	.5350	No	N/A
Chromium	JSVW04	-0.1772	.3425	No	N/A
	KSHZ03	-0.4535	.0168	Yes	↓
	KSLU03	-0.1606	.0392	Yes	↓
	KSSN04	-0.1079	.1253	No	N/A
	KSSN05	-0.2196	.0661	No	N/A
Copper	JSVW04	-0.0215	.9639	No	N/A
	KSHZ03	-0.0780	.1871	No	N/A
	KSLU03	-0.0222	.6800	No	N/A
	KSSN04	0.0791	.1005	No	N/A
	KSSN05	0.0342	.8039	No	N/A
Iron	JSVW04	10.5918	.7833	No	N/A
	KSHZ03	-154.0671	.1705	No	N/A
	KSLU03	-69.9476	.2415	No	N/A
	KSSN04	-1.1020	1.0000	No	N/A
	KSSN05	-7.2889	.9561	No	N/A
Lead	JSVW04	-0.0592	.5567	No	N/A
	KSHZ03	-0.2532	2.04E-04	Yes	↓
	KSLU03	-0.1212	.0427	Yes	↓
	KSSN04	-0.0951	.0815	No	N/A
	KSSN05	-0.1200	8.22E-05	Yes	↓
Manganese	JSVW04	-0.1793	.7833	No	N/A
	KSHZ03	-1.6479	.1118	No	N/A
	KSLU03	-1.1755	.2415	No	N/A
	KSSN04	0.3204	.7555	No	N/A
	KSSN05	-2.1752	.2961	No	N/A
Mercury	JSVW04	-6.49E-04	.4595	No	N/A
	KSHZ03	-5.13E-04	.8543	No	N/A
	KSLU03	2.56E-04	.8123	No	N/A
	KSSN04	-5.60E-04	.5037	No	N/A

Parameter	Locator	Thiel-Sen Slope	p-value	Significant?	Trend
	KSSN05	9.87E-05	.9086	No	N/A
Nickel	JSVW04	-0.0701	.4422	No	N/A
	KSHZ03	-0.5198	.0168	Yes	↓
	KSLU03	-0.1540	.1305	No	N/A
	KSSN04	-0.0517	.5112	No	N/A
	KSSN05	-0.2888	.0821	No	N/A
Zinc	JSVW04	-0.0259	.8061	No	N/A
	KSHZ03	-0.3820	.1245	No	N/A
	KSLU03	-0.1320	.3100	No	N/A
	KSSN04	-0.2286	.3037	No	N/A
	KSSN05	0.0019	1.0000	No	N/A

Table B-3 Overall subtidal sediment chemistry trends (pooled from five sites, 1985–2019). Metals concentrations were measured in mg/Kg dry weight and organics were measured in mg/kg organic carbon.

Parameter	p-value	Significant?	Trend
Aluminum	.4161	No	N/A
Arsenic	.1189	No	N/A
Cadmium	.9673	No	N/A
Chromium	.2292	No	N/A
Copper	.4154	No	N/A
Iron	1.14E-04	Yes	↑
Lead	3.00E-06	Yes	↓
Mercury	8.49E-09	Yes	↓
Nickel	.4787	No	N/A
Tin	.1075	No	N/A
Zinc	.1153	No	N/A
Total PCBs	.0681	No	N/A
Total HPAHs	4.47E-08	Yes	↓
Total LPAHs	8.73E-07	Yes	↓

Table B-4 Subtidal sediment chemistry trends from individual sites (1985–2019). Metals concentrations were measured in mg/Kg dry weight and organics were measured in mg/Kg organic carbon.

Parameter	Locator	Thiel-Sen Slope	p-value	Significant?	Trend
Aluminum	LSCW02	95.4437	.0894	No	N/A
	LSML01	-53.7793	.2446	No	N/A
	LTCA02	92.5323	.2483	No	N/A
	LTDF01	-122.2222	.2110	No	N/A
	LTED04	88.8889	.2350	No	N/A
Arsenic	LSCW02	-0.0350	.5820	No	N/A
	LSML01	-0.1650	.3272	No	N/A
	LTCA02	0.0171	.6081	No	N/A
	LTDF01	-0.1000	.0155	Yes	↓
	LTED04	0.0000	.8514	No	N/A
Cadmium	LSCW02	0.0012	.9282	No	N/A
	LSML01	-0.0171	.2821	No	N/A
	LTCA02	-0.0056	.7151	No	N/A
	LTDF01	0.0025	.4310	No	N/A
	LTED04	0.0037	.8288	No	N/A
Chromium	LSCW02	0.0842	.4487	No	N/A
	LSML01	-0.2716	.0103	Yes	↓
	LTCA02	0.0471	.4954	No	N/A
	LTDF01	-0.2375	.0689	No	N/A
	LTED04	0.0067	.9641	No	N/A
Copper	LSCW02	0.1609	.2393	No	N/A
	LSML01	-0.0562	.5576	No	N/A
	LTCA02	0.0304	.4947	No	N/A
	LTDF01	-0.5500	.0087	Yes	↓
	LTED04	-0.0715	.7526	No	N/A
Iron	LSCW02	202.2461	5.77E-04	Yes	↑
	LSML01	96.0000	.2740	No	N/A
	LTCA02	151.5808	2.97E-04	Yes	↑
	LTDF01	-56.2500	.0982	No	N/A
	LTED04	146.4611	.0065	Yes	↑
Lead	LSCW02	0.0550	.7121	No	N/A
	LSML01	-0.3933	1.70E-07	Yes	↓
	LTCA02	-0.3091	.0013	Yes	↓
	LTDF01	-0.0769	.5877	No	N/A
	LTED04	-0.4500	.0096	Yes	↓
Mercury	LSCW02	-0.0020	.0150	Yes	↓
	LSML01	-0.0027	.0044	Yes	↓
	LTCA02	-0.0021	.0187	Yes	↓

Parameter	Locator	Thiel-Sen Slope	p-value	Significant?	Trend
	LTDF01	-0.0104	.0011	Yes	↓
	LTED04	-0.0033	.0791	No	N/A
Nickel	LSCW02	0.1143	.1972	No	N/A
	LSML01	-0.0667	.3425	No	N/A
	LTCA02	0.0524	.2717	No	N/A
	LTDF01	-0.0437	.4207	No	N/A
	LTED04	0.0448	.3434	No	N/A
Total PCBs	LSCW02	-0.0187	.4910	No	N/A
	LSML01	0.0071	1.0000	No	N/A
	LTCA02	0.0251	.2976	No	N/A
	LTDF01	-0.2639	4.68E-04	Yes	↓
	LTED04	-0.0336	.7287	No	N/A
Total HPAHs	LSCW02	-2.6824	.0031	Yes	↓
	LSML01	-0.3633	.1659	No	N/A
	LTCA02	-1.3680	6.89E-05	Yes	↓
	LTDF01	-2.0375	.2629	No	N/A
	LTED04	-1.4647	.0075	Yes	↓
Total LPAHs	LSCW02	-0.3050	5.62E-04	Yes	↓
	LSML01	-0.0608	.1596	No	N/A
	LTCA02	-0.1424	.0057	Yes	↓
	LTDF01	-0.5323	.1617	No	N/A
	LTED04	-0.1968	.0925	No	N/A
Zinc	LSCW02	0.5455	.0408	Yes	↑
	LSML01	-0.3008	.7184	No	N/A
	LTCA02	0.4000	.0956	No	N/A
	LTDF01	-0.3308	.2480	No	N/A
	LTED04	0.3267	.1493	No	N/A