Toxics Biological Observation System (TBiOS),
Puget Sound Ecosystem Monitoring Program (PSEMP)

Stormwater Action Monitoring 2019/2020 Puget Sound Nearshore Mussel Monitoring Survey

Final Report
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Data from the Stormwater Action Monitoring (SAM) program mussel monitoring will be available on Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim/index.htm. Search Study ID, SAM_MNM. Data from Pierce County will be under Study ID SAM_PC_MNM.

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Executive Summary

Monitoring pollutants from contaminated stormwater and their effects on the marine biota of Puget Sound is critical to inform best management practices and remediation efforts in this large and diverse estuary. The Stormwater Action Monitoring (SAM) Status and Trends in Receiving Waters program conducts monitoring in Puget Sound small streams and nearshore marine waters to provide a regional assessment of whether collective stormwater management actions are leading to improved receiving water conditions. The SAM Puget Sound Nearshore Mussel Monitoring studies focuses on the bioaccumulation of pollutants in caged native bay mussels (*Mytilus trossulus*) to evaluate the current status and trends of nearshore conditions.

In the winter of 2019/2020 the Washington Department of Fish and Wildlife (WDFW), with the help of citizen science volunteers, other agencies, tribes, and non-governmental organizations, conducted the third of a series of biennial, nearshore mussel monitoring efforts under the Stormwater Action Monitoring (SAM) program. The first SAM Puget Sound Nearshore Mussel Monitoring survey was conducted in the winter of 2015/2016 (Lanksbury et al., 2017) and the second in the winter of 2017/2018 (Langness and West, 2020).

The 2019/2020 monitoring survey provided the first opportunity to evaluate changes in contamination of nearshore biota residing inside the urban growth areas (UGAs) of Puget Sound occurring between the first three surveys conducted in 2015/2016, 2017/2018 and 2019/2020 (hereafter referred to as 2016, 2018 and 2020 respectively). In each survey year, relatively uncontaminated mussels from a local aquaculture source were transplanted to over forty SAM monitoring locations along the Puget Sound urban growth area (UGA) shoreline, covering a broad range of upland land-use types from rural to highly urban. Two reference sites were established, one in Penn Cove and one in Hood Canal. The Hood Canal reference site was sampled each survey year and subsequently used to establish regional scale thresholds as it had no obvious sources of contamination and had consistent low contaminant concentrations (lower than Penn Cove). At the end of each study, after approximately three months of exposure, the concentration of several major contaminants in the mussels' soft tissues were measured including several classes of organic chemicals, such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs, or flame retardants), and chlorinated pesticides (including dichlorodiphenyltrichloroethane compounds, or DDTs) and six metals (arsenic, cadmium, copper, lead, mercury, zinc).

To characterize changes in the spatial patterns of nearshore biota contamination, the changes in the distribution of mussel tissue contaminant concentrations along the Puget Sound UGA nearshore between each survey year (2016, 2018, 2020) were examined. The spatial extent of organic contaminant concentrations in each survey year showed that the concentration of organic contaminants in the UGA nearshore were consistently greater than the clean reference site. Most of the sampled UGA nearshore in each survey year (2016, 2018, 2020) had $\sum_{16}$PAHs, TPCBs, $\sum_{11}$PBDEs , and $\sum_{6}$DDTs concentrations above the Hood Canal reference site concentration indicating mussels accumulated these contaminants at nearshore sites within the UGA, with the spatial extent of these contaminants showing little to no decline during the three survey years. Similarly, the spatial extent of metal concentrations in most survey years showed that concentrations in the UGA nearshore for these contaminants were largely greater than the clean reference site. Most of the sampled UGA nearshore in two or more surveys had arsenic, cadmium, copper, lead, mercury, and zinc concentrations above the Hood Canal reference site concentration. The spatial extent of arsenic, cadmium, lead, and zinc contamination showed little to no decline during the three survey years. However, copper and mercury contamination declined between 2016 and 2020, with 87% of the UGA nearshore in the 2020 survey with copper concentrations equal to or less than the Hood Canal Reference, and 95% of UGA nearshore in the 2020 survey with mercury concentrations equal to or less than the reference.

To track temporal changes in contaminant concentrations of nearshore biota, the changes in the central tendency concentrations of key contaminants in mussels between each survey year (2016, 2018, 2020) were evaluated. Three of the four most frequently detected organic contaminants ($\sum_{16}$PAHs, $\sum_{11}$PBDEs, and $\sum_{6}$DDTs) had significantly lower central tendency concentrations in mussels from the 2020 survey than in the 2016 and/or 2018 survey. TPCBs data were inconclusive as there was no significant difference in mean concentration values attributable to survey year. Although additional sampling years are needed to infer conclusions regarding any significant trends in these organic contaminant concentrations, the declining $\sum_{11}$PBDEs concentrations but stable TPCBs concentrations were congruent with the temporal pattern in two other WDFW-TBiOS indicator species (English sole and Pacific herring) reported in the Toxics in Aquatic Life Vital Sign (Puget Sound Partnership 2022c). Two of the six metals measured (cadmium and zinc) had significantly higher concentrations in mussels from the 2018 and 2020 surveys than in the 2016 survey, and two other metals (copper and mercury) had significantly lower concentrations in mussels from the 2020 survey than in both the 2016 and 2018 surveys. Although a statistically significant increase or decrease was observed in these metal concentrations, additional sampling years are needed to infer conclusions regarding any significant trends. Arsenic concentrations in mussels significantly increased in the 2018 survey and then decreased in the 2020 survey, indicating variable concentration conditions of these metals in the UGA nearshore. Lead data were inconclusive as there was no significant difference in mean concentration values attributable to survey year.

Lastly, to evaluate where contaminant concentration changes were associated with levels of nearshore land development (using % impervious surface in adjacent nearshore watersheds as a proxy), additional spatial analyses were performed on the organic contaminant data where significant differences among concentration means between survey years was observed. The observed decline in $\sum_{16}$PAHs concentrations in the 2020 survey occurred within areas with a medium level of land development, where the adjacent nearshore watershed unit to a site had 20 to <40% impervious surface (IS). The decline in $\sum_{11}$PBDEs concentrations occurred within areas with the least (< 10 % IS), medium (20 to < 40 % IS), and high levels of development (40 to 100 % IS).

Acknowledgements

This study would not have been possible without substantial help from individual volunteers and volunteer groups. Our volunteer partners helped evaluate potential monitoring sites, measure and bag mussels, deploy and retrieve mussel cages, and process mussels in the lab. Over 100 volunteers spent well over 500 hours helping us to execute this study and we are grateful for their efforts.

SAM and WDFW recognize the following organizations, their staff and volunteers for their assistance:

Bainbridge Beach Naturalists, Feiro Marine Life Center, Friends of Skagit Beaches, Harbor WildWatch, Jamestown S'Klallam Tribe, King County, Kitsap County Public Works, Penn Cove Shellfish, Port Townsend Marine Science Center, Port of Tacoma, Puget Soundkeeper Alliance, Salish Sea Stewards, San Juan County Marine Resources Committee (MRC), Seattle Aquarium, Snohomish County MRC, Sound Water Stewards of Island County, South Puget Sound Salmon Enhancement, Stillaguamish Tribe, Suquamish Tribe, Tulalip Tribe, University of Puget Sound, Vashon Nature Center, Washington Conservation Corps, Washington Department of Natural Resources Aquatic Reserves Program, Washington State University, Western Washington University, and Whatcom County MRC.

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Bainbridge Beach Naturalists, City of Bellingham, Jamestown S'Klallam Tribe, Jefferson County, King County, Kitsap County Public Works, Makah Tribe, NOAA's National Centers for Coastal Ocean Science, Port of Tacoma, Rich Passage Estates Homeowners' Association, and the Washington Department of Natural Resources Aquatic Reserves Program.

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Introduction

Stormwater runoff is considered one of the biggest water pollution problems in urban areas of Washington State (EnviroVision Corporation et al., 2008). The volumes and entrained contaminants in stormwater damages habitat, degrades aquatic environments, exacerbates flooding, and plays a major role in Puget Sound's deteriorating health (PSAT, 2005). Monitoring pollutants in the nearshore and their effects on the marine biota of Puget Sound is critical to inform stormwater best management practices and remediation efforts in this large and diverse estuary (Hamel, 2015).

The Puget Sound Ecosystem Monitoring Program (PSEMP) Stormwater Work Group (SWG) is a formal stakeholder coalition comprising federal, tribal, state and local governments, businesses, environmental and agricultural entities, and academic researchers, all with interests and a stake in the health of the Puget Sound ecosystem. The SWG was created in October 2007 at the request of municipal stormwater permittees, the Washington State Department of Ecology (Ecology), and the Puget Sound Partnership (PSP) to develop a regional stormwater monitoring strategy and to recommend monitoring requirements for National Pollutant Discharge Elimination System (NPDES) municipal stormwater permits issued by Ecology. In 2010, the SWG finalized an overall strategy for monitoring, in a document entitled "2010 Stormwater Monitoring and Assessment Strategy for the Puget Sound Region (SWAMPPS)" (SWG, 2010). It promoted an integrated approach to quantifying stormwater pollutant impacts in Puget Sound, providing information to efficiently, effectively, and adaptively manage stormwater and reduce harm to the ecosystem.

A result of the SWG's overall strategy was the formation of the Stormwater Action Monitoring (SAM) program. SAM includes three study components: 1) Status and Trends in Receiving Waters, 2) Effectiveness Monitoring of Stormwater Management Program Activities, and 3) Source Identification Information Repository. The Status and Trends in Receiving Waters component of SAM monitors changes in Puget Sound lowland streams and Puget Sound urban shoreline areas in relation to stormwater management. Contaminant monitoring of mussels in the urban growth areas (UGAs) of Puget Sound's marine nearshore, referred to as SAM Puget Sound Nearshore Mussel Monitoring (hereafter called SAM Mussel Monitoring), is part of SAM's Status and Trends in Receiving Waters.

The purpose of SAM Mussel Monitoring is to identify existing stormwater-related challenges to the health of nearshore biota. The objectives of the SAM Mussel Monitoring survey are to; 1) characterize the spatial extent of contamination to which nearshore biota residing inside the UGA sampling frame may be exposed, using mussels (*Mytilus* sp.) as the primary indicator organism, and 2) track changes in tissue contamination over time inside the UGA sampling frame. This second objective is aimed at answering the question, "Is the health of biota in the urban nearshore improving, deteriorating, or remaining the same related to stormwater management?".

The 2019/20 SAM Mussel Monitoring survey represents the third successful deployment of mussels in Puget Sound for the purpose of tracking toxic contaminants in nearshore biota over time, and the fourth Puget Sound-wide synoptic survey using transplanted mussels (Lanksbury et al., 2014; Lanksbury et al., 2017; Langness and West, 2020). In this survey report we provide information on the status of contamination in the nearshore by describing the detection frequency and distribution of contaminant concentration data from the 2020 survey. We further evaluate changes in the spatial extent of contamination within the UGAs and concentrations of key contaminants over the first three SAM surveys conducted in 2015/2016, 2017/2018 and 2019/2020 (hereafter referred to as 2016, 2018 and 2020 respectively). For organic contaminants with significant differences among concentration means between survey years, we identify where changes are occurring based on levels of nearshore development using percent impervious surface in adjacent nearshore watersheds as a proxy.

Methods

Study area

This study largely took place in the greater Puget Sound, which is a fjord-like marine estuary on the northwestern coast of Washington State with many interconnected marine waterways and basins. Puget Sound is connected to the Pacific Ocean primarily via the Strait of Juan de Fuca, is part of the larger Salish Sea that stretches into Canada, and is strongly influenced by freshwater input through major river systems. Stormwater Action Monitoring (SAM) mussel monitoring focused on a single landscape scale, the shoreline parallel to cities and other developed lands in the established urban growth areas (UGAs) of the Puget Sound. A shoreline sampling frame was defined to include the basins, channels, and embayments of Puget Sound from the US/Canada border to the southernmost bays and inlets near Olympia and Shelton, it also included the Hood Canal, portions of Admiralty Inlet, the San Juan Islands, and the eastern portion of the Strait of Juan de Fuca.

GRTS Study Design and Site Selection

The SAM nearshore monitoring site locations were selected using a probabilistic random stratified sampling design that targeted the land based UGA boundaries of Puget Sound (Figure 1). Details on the study design are available in the Quality Assurance Project Plan (QAPP) for this study (Lanksbury and Lubliner, 2015). In brief, the sampling framework was based on the EPA's spatially balanced, generalized random tessellation stratified (GRTS) multi-density survey design, as described by Stevens (1997, 2003), and Stevens and Olsen (1999, 2004). Sitka Technology Group, LLC, using the GRTS design, generated a linear Puget Sound shoreline sampling frame. The result was 2,048 possible nearshore sites in the Puget Sound, each representing approximately 800 meters (m) of UGA shoreline.

Ecology's 2013-2018 permits included a second option for jurisdictions to conduct monitoring in their area and contribute to the data, but not pay-in to SAM pooled resources. Pierce County selected this option and sampled qualifying (Option 2) shoreline sites in their own unincorporated UGAs within Pierce County for the surveys conducted in 2016 and 2018. For the 2020 survey under Ecology's 2019-2023 permit, Pierce County opted-in to the SAM pooled resources and discontinued sampling of the Option 2 unincorporated UGA sites. Though the SAM and Pierce County mussel sites were selected from a random list of locations along the UGAs of Puget Sound, the unincorporated UGA Pierce County sites came from a much smaller substratum of the original UGA sample frame than the rest of the SAM nearshore sites. Because of this difference in geography, the spatial weights of the regional SAM nearshore sites and the Pierce County nearshore sites are different.

For each survey year, several of the original candidate sites for both SAM and Pierce County Option 2 sampling were dropped due to limited accessibility, safety issues, and mussel cages lost during the deployment period. Thus, the actual sampled nearshore length was smaller than the initial study nearshore length. The spatial representation for both SAM and Option 2 sites in each survey year are detailed in Table 1. SAM sites represented the majority of the total sampled length of shoreline (over 98.9%) in each survey.

Table 1. Results of spatial weights calculations for SAM and Option 2 mussel monitoring sites for the 2016, 2018, and 2020 surveys.

		2016 SAM	2016 Option 2	2016 Total	2018 SAM	2018 Option 2	2018 Total	2020 SAM	2020 Option 2	2020 Total
Initial Design	# of candidate sites	2008	40	2048	2008	40	2048	2008	40	2048
	Initial study lengh (km)	1,606	32	1,638	1,606	32	1,638	1,606	32	1,638
Site Information	# of evaluated candidate sites	49	20	69	56	20	76	56	N/A	56
	# of sampled sites	36	7	43	40	8	48	38	0	38
	# of rejected/lost sites	13	13	26	16	12	28	18	0	18
Adjusted length of nearshore in Puget Sound UGAs	Adjusted length (km) per site	32.8	1.6	-	28.7	1.6	-	28.7	N/A	-
	Total sampled length (km)	1180	11	1191	1147	13	1160	1090	0	1090
Contribution	Contribution to total sampled length (%)	99.1	0.9	100	98.9	1.1	100	100.0	0.0	100
	Lost contribution by rejected sites to each option length (%)	26.5	65.0	-	28.6	60.0	-	32.1	N/A	-

Field/Lab Methods

Field and laboratory methods for this study followed those detailed in the first SAM mussel survey report, Stormwater Action Monitoring 2015/16 Mussel Monitoring Survey (Lanksbury et al., 2017), and in the [Quality Assurance Project Plan (QAPP)] (Lanksbury and Lubliner, 2015).

WDFW was informed in 2018, subsequent to the Lanksbury and Lubliner (2015) QAPP and its Lanksbury et al. (2017) amendment, of a change regarding the analysis methodology for arsenic, cadmium, copper, zinc, and lead at the King County Environmental Laboratory (KCEL). These metals are analyzed via Thermo Elemental X Series II CCT (Collision Cell Technology) Inductively Coupled Plasma Mass Spectrometer (ICP-MS) following KCEL SOP 624. KCEL adopted a change in the tissue digestion method, notably the addition of 1% HCl to samples during digestion. This change occurred between the 2015/16 and 2017/18 mussel analyses. The subsequent comparison of pre- and post-2017 metals data was omitted from the previous 2017-2018 report until a review of the two analytical methods were completed. Analysis of the results generated by the previous and current KCEL methods have since been conducted and do not suggest that a correction factor is needed to compare pre-2017 data.

Overview of Sampling Efforts

2019-2020 Survey

WDFW staff, volunteers, and partners deployed mussel cages to 43 SAM sites, 41 nearshore monitoring sites and 2 reference sites. Mussel cages were recovered from 40 of those sites, 38 monitoring and 2 reference sites (Table 2, Figure 1). Mussel cages were lost from the following three monitoring sites due to storms:

1. SAM Site #20 (Port Angeles Harbor)
2. SAM Site #28 (Oak Harbor)
3. SAM Site #52 (Port Angeles Yacht Club)

Mussel cages were deployed at approximately the 0.0 (zero) foot mean lower low water mark during low tides on the evenings of October 27 to 30, 2019. To provide an initial condition of contaminants in mussels for the study, WDFW also collected three replicate samples from the Penn Cove Shellfish aquaculture facility at the start of the study, on October 30, 2019; these samples are hereafter referred to as the Baseline mussels (location in Table 2, Figure 1). Exposure to local conditions at each mussel-monitoring site lasted approximately three months. The deployed mussel cages were recovered during low tides on the evenings of January 20 to 25, 2020.

The reference site established in the 2018 survey on the Penn Cove shoreline, near our aquaculture source, was revisited in this 2020 survey. In addition, we revisited a reference site in Hood Canal (Holly). This site was sponsored by a local interest group during the 2013 WDFW mussel monitoring pilot study, and sampling has continued in each survey year since. This site has had consistently low concentrations of contaminants (often lower than the Penn Cove Reference) in all survey years and was subsequently used to establish regional scale thresholds as it had no obvious sources of contamination.

Table 2. Site location information for forty-three (43) SAM Puget Sound Nearshore Mussel Monitoring/reference sites and Penn Cove pre-deployment samples (baseline) in the 2019-2020 survey. Map IDs are used to identify sites in Figure 1.

Map ID	Site ID	Site Name	Latitude	Longitude	County	Status
1	WB_PCB	Baseline (i.e., Penn Cove, pre-deployment samples)	48.21863	-122.70797	Island	Retrieved
2	WB_PCR	Penn Cove Reference	48.21423	-122.71897	Island	Retrieved
3	HC_HO	Hood Canal Holly Reference	47.57017	-122.97122	Kitsap	Retrieved
4	Site #2	Arroyo Beach	47.50161	-122.38593	King	Retrieved
5	Site #3	Brackenwood Ln	47.68230	-122.50640	Kitsap	Retrieved
6	Site #4	Cherry Point	48.85844	-122.74074	Whatcom	Retrieved
7	Site #5	Salmon Beach	47.29464	-122.53053	Pierce	Retrieved
8	Site #6	Eagle Harbor Dr	47.61889	-122.52750	Kitsap	Retrieved
9	Site #8	Chimacum Creek delta	48.04906	-122.77240	Jefferson	Retrieved
10	Site #10	Fletcher Bay, Fox Cove	47.64445	-122.57621	Kitsap	Retrieved
11	Site #11	South Bay Trail	48.72569	-122.50631	Whatcom	Retrieved
12	Site #13	Ruston Way	47.29210	-122.49420	Pierce	Retrieved
13	Site #14	Point Heron East	47.57011	-122.60693	Kitsap	Retrieved
14	Site #15	Tugboat Park	48.48922	-122.67616	Skagit	Retrieved
15	Site #16	Meadowdale Beach	47.85609	-122.33469	Snohomish	Retrieved
16	Site #17	Budd Inlet, West Bay	47.07124	-122.92052	Thurston	Retrieved
17	Site #18	Seahurst	47.46322	-122.36907	King	Retrieved
18	Site #19	Skiff Point	47.66142	-122.49884	Kitsap	Retrieved
19	Site #20	Port Angeles Harbor	48.11780	-123.42336	Clallam	Lost
20	Site #21	Point Defiance Ferry	47.30620	-122.51450	Pierce	Retrieved
21	Site #22	Beach Dr E	47.55953	-122.59684	Kitsap	Retrieved
22	Site #23	Wing Point	47.62252	-122.49631	Kitsap	Retrieved
23	Site #24	S of Skunk Island	48.02667	-122.75076	Jefferson	Retrieved
24	Site #25	Blair Waterway	47.27580	-122.41740	Pierce	Retrieved
25	Site #26	N of Illahee State Park	47.60190	-122.59630	Kitsap	Retrieved
26	Site #27	Chuckanut, Clark's Point	48.69068	-122.50425	Whatcom	Retrieved
27	Site #28	Oak Harbor	48.27141	-122.63749	Island	Lost
28	Site #29	Liberty Bay	47.73680	-122.65128	Kitsap	Retrieved
29	Site #30	Kitsap St Boat Launch	47.54166	-122.64033	Kitsap	Retrieved
30	Site #31	Eastsound, Fishing Bay	48.69368	-122.90985	San Juan	Retrieved
31	Site #34	Elliott Bay, Harbor Island, Pier 17	47.58766	-122.35065	King	Retrieved
32	Site #35	Williams Olson Park	47.66586	-122.56698	Kitsap	Retrieved
33	Site #37	Saltar's Point	47.16922	-122.61295	Pierce	Retrieved
34	Site #38	Rocky Point	47.60255	-122.66992	Kitsap	Retrieved
35	Site #39	Smith Cove, Terminal 91	47.63237	-122.37869	King	Retrieved
36	Site #42	Evergreen Rotary Park	47.57577	-122.62816	Kitsap	Retrieved
37	Site #43	N Avenue Park	48.52108	-122.61531	Skagit	Retrieved

38	Site #46	Appletree Cove	47.78724	-122.49421	Kitsap	Retrieved
39	Site #47	Birch Bay	48.89549	-122.78263	Whatcom	Retrieved
40	Site #48	Naketa Beach	47.92750	-122.30972	Snohomish	Retrieved
41	Site #49	Donkey Creek Delta	47.33775	-122.59014	Pierce	Retrieved
42	Site #52	Port Angeles Yacht Club	48.12801	-123.45672	Clallam	Lost
43	Site #54	Dyes Inlet, Chico Bay	47.61053	-122.70734	Kitsap	Retrieved
44	Site #56	Fidalgo Island, Swinomish Res	48.39871	-122.54354	Skagit	Retrieved

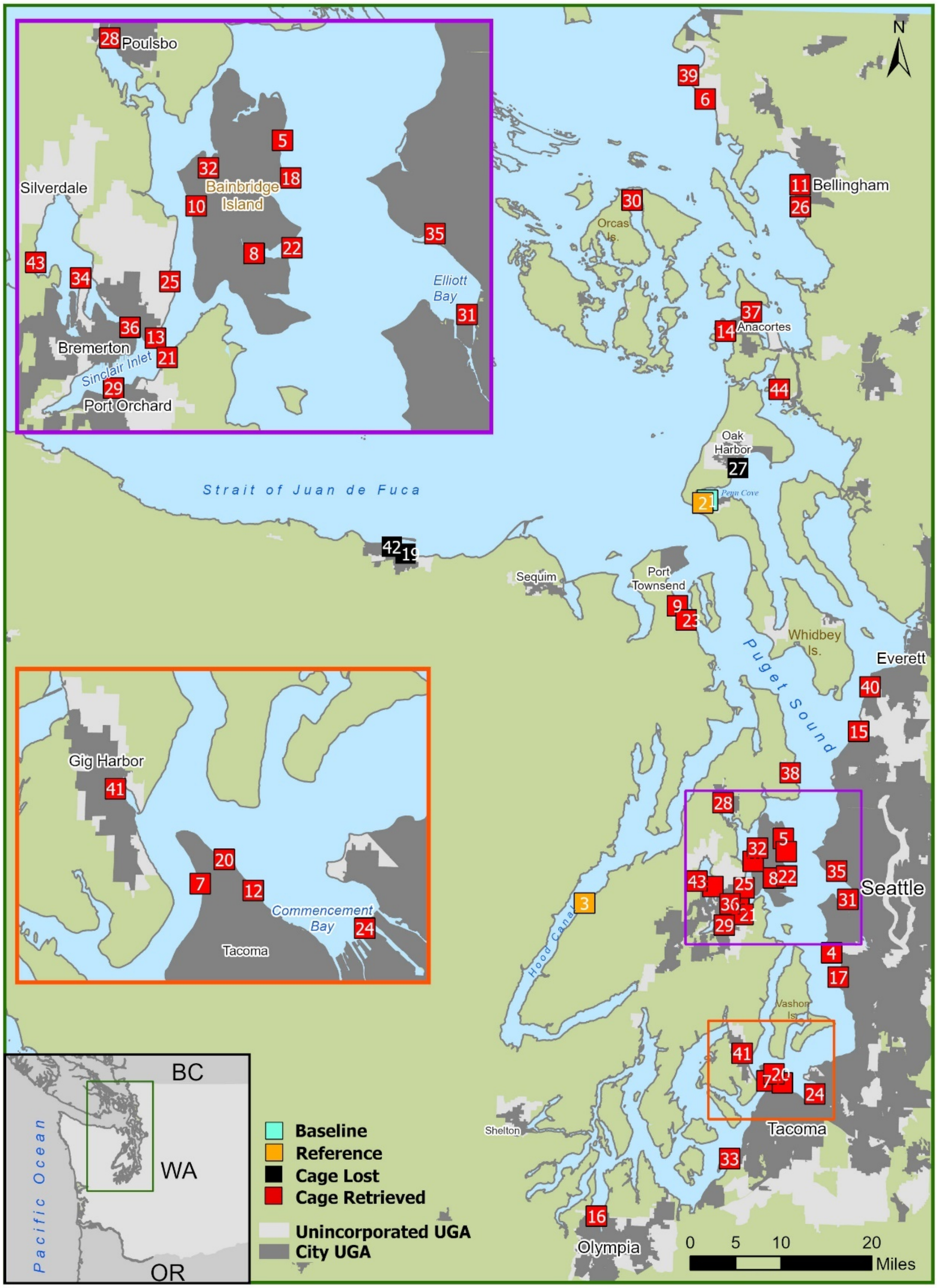

Figure 1. 2019-2020 SAM Nearshore Mussel Monitoring sites in the Puget Sound Urban Growth Areas (UGAs). Site labels correspond to the "Map ID" column in Table 2. Grey shading on land represents municipal land-use designations based on urban growth area (UGA) boundaries; dark grey representing City UGA and light grey representing Unincorporated UGA.

2016, 2018, 2020 Surveys – Repeated Sites

Thirty-five (35) SAM Puget Sound Nearshore Mussel Monitoring sites were revisited in each 2016, 2018, and 2020 survey (Table 3, Figure 2). These 35 sites were used to track temporal changes in the central tendency concentrations of key contaminants in mussels between each survey year, with results detailed in the following Changes in Concentrations of Key Contaminants and Contaminant Concentration Changes and Nearshore Development sections.

Table 3. Site location information for thirty-five (35) SAM Puget Sound Nearshore Mussel Monitoring sites with repeated visits in 2016, 2018, and 2020 surveys. Map IDs are used to identify sites in Figure 2.

Map ID	Site ID	Site Name	Latitude	Longitude	County
1	Site #2	Arroyo Beach	47.50161	-122.38593	King
2	Site #3	Brackenwood Ln	47.68234	-122.50640	Kitsap
3	Site #4	Cherry Point North	48.85844	-122.74074	Whatcom
4	Site #5	Salmon Beach	47.29464	-122.53053	Pierce
5	Site #6	Eagle Harbor Dr	47.61889	-122.52750	Kitsap
6	Site #8	Chimacum Creek delta	48.04906	-122.77240	Jefferson
7	Site #10	Fletcher Bay, Fox Cove	47.64445	-122.57621	Kitsap
8	Site #11	South Bay Trail	48.72569	-122.50631	Whatcom
9	Site #13	Ruston Way	47.29210	-122.49420	Pierce
10	Site #14	Point Heron East	47.57011	-122.60693	Kitsap
11	Site #15	Tugboat Park	48.48922	-122.67616	Skagit
12	Site #16	Meadowdale Beach	47.85609	-122.33469	Snohomish
13	Site #17	Budd Inlet, West Bay	47.07124	-122.92052	Thurston
14	Site #18	Seahurst	47.46322	-122.36907	King
15	Site #19	Skiff Point	47.66142	-122.49884	Kitsap
16	Site #21	Point Defiance Ferry	47.30620	-122.51450	Pierce
17	Site #22	Beach Dr E	47.55953	-122.59684	Kitsap
18	Site #23	Wing Point	47.62252	-122.49631	Kitsap
19	Site #24	S of Skunk Island	48.02667	-122.75076	Jefferson
20	Site #25	Blair Waterway	47.27568	-122.41730	Pierce
21	Site #26	N of Illahee State Park	47.60237	-122.59608	Kitsap
22	Site #27	Chuckanut, Clark's Point	48.69068	-122.50425	Whatcom
23	Site #29	Liberty Bay	47.73680	-122.65128	Kitsap
24	Site #30	Kitsap St Boat Launch	47.54167	-122.64034	Kitsap
25	Site #31	Eastsound, Fishing Bay	48.69368	-122.90985	San Juan
26	Site #35	Williams Olson Park	47.66586	-122.56698	Kitsap
27	Site #37	Saltar's Point	47.16922	-122.61295	Pierce
28	Site #38	Rocky Point	47.60255	-122.66992	Kitsap
29	Site #39	Smith Cove, Terminal 91	47.63237	-122.37869	King
30	Site #42	Evergreen Rotary Park	47.57577	-122.62816	Kitsap
31	Site #43	N Avenue Park	48.52108	-122.61531	Skagit
32	Site #46	Appletree Cove	47.78724	-122.49421	Kitsap
33	Site #47	Cherry Point Aq Reserve, Birch Bay South	48.89549	-122.78263	Whatcom
34	Site #48	Naketa Beach	47.92750	-122.30972	Snohomish
35	Site #49	Donkey Creek Delta	47.33775	-122.59014	Pierce

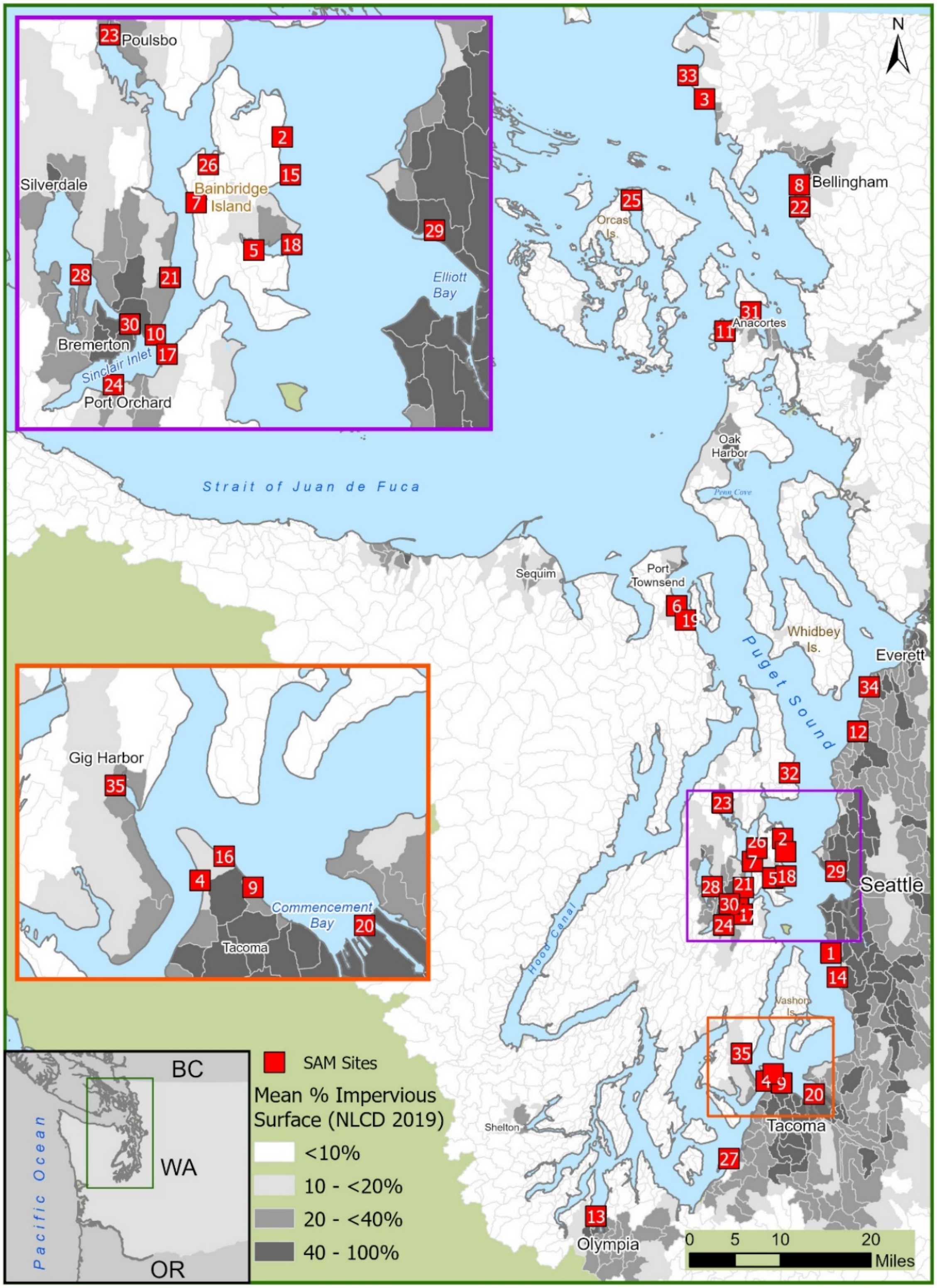

Figure 2. SAM Puget Sound Nearshore Mussel Monitoring sites with repeated visits in 2016, 2018, and 2020 surveys.

Data Analyses

Analytes

The analytes measured for this survey report and all prior survey years consist of a suite of persistent organic pollutants (POPs) that include polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenylethers (PBDEs), and organochlorine pesticides (OCPs): dichlorodiphenyltrichloroethanes (DDTs), hexachlorocyclohexanes (HCHs), hexachlorobenzene (HCB), chlordanes, dieldrin, aldrin, mirex, and endosulfan 1. A suite of metals that include arsenic, cadmium, copper, lead, total mercury, and zinc were measured as well.

Reporting Concentrations

Throughout this report concentration results are presented as dry weight, to be consistent with reporting from historical mussel monitoring programs (NOAA Mussel Watch) and the previous 2016 and 2018 SAM surveys. All results for organic chemicals are presented as ng/g dry weight, commonly referred to parts per billion (ppb). All results for metals are presented as mg/kg dry weight, commonly referred to parts per million (ppm). All dry and wet weights are presented to three significant figures. Summary tables of both the wet and dry weight concentration of organic contaminants and metals in 2020 mussels at each site are presented in Appendix A and B (SAM data) and Appendix C (partner data).

Mussel contaminant data are presented as summed concentrations for organic analyte groups (Table 4), except in cases with fewer than two analytes per group (dieldrin, aldrin, HCB, mirex, endosulfan 1). Summed analytes are the sum of all detected values, with zeros substituted for non-detected analytes, within each group. In cases where all analytes in a group were not detected, the greatest limit of quantitation (LOQ) for any single analyte in the group was used as the summation concentration, and the value was preceded by a "<" (less than) qualifier. The summation of PAHs had in prior survey reports been reported as the sum of all detected PAHs (parental and alkylated homologues) and has since been changed to the sum of 16 PAHs identified in Table 4. This PAH summation is commonly used in other mussel monitoring programs (e.g., NOAA Mussel Watch) and allows for easier comparison to historic mussel monitoring data. PCBs concentrations are presented as an estimated total calculated using the sum of 17 congeners (identified in Table 4), then multiplied by two.

Table 4. Analyte groups summed for the SAM Nearshore Mussel Monitoring Surveys.

Sum 3 Hexachlorocyclohexanes (HCHs)	**Sum 8 Chlordanes**	**Estimated Total Polychlorinated biphenyls (PCBs)***	**Sum 6 Dichlorodiphenyltri chloroethanes (DDTs)**	**Sum 11 Polybrominated diphenyl ethers (PBDEs)**	**Sum of 16 Polycyclic Aromatic Hydrocarbons (PAHs)**	
					Low Molecular Weight	**High Molecular Weight**
alpha hexachlorocyclohexane	alpha chlordane	PCB018	pp-DDD	PBDE028	acenaphthylene (ACY)	fluoranthene (FLA)
beta hexachlorocyclohexane	beta chlordane	PCB028	pp-DDE	PBDE047	acenaphthene (ACE)	pyrene (PYR)
lindane	cis nonachlor	PCB044	pp-DDT	PBDE049	fluorene (FLU)	benz[*a*]anthracene (BAA)
	heptachlor	PCB052	op-DDD	PBDE066	phenanthrene (PHN)	chrysene (CHR)[a]
	heptachlor epoxide	PCB095	op-DDE	PBDE085	anthracene (ANT)	benzo[*b*]fluoranthene (BBF)
	nonachlor3	PCB101	op-DDT	PBDE099		benzo[*k*]fluoranthene (BKF)[b]
	Oxychlordane	PCB105		PBDE100		benzo[*e*]pyrene (BEP)
	trans Nonachlor	PCB118		PBDE153		benzo[*a*]pyrene (BAP)
		PCB128		PBDE154		indeno[*1,2,3-cd*]pyrene (IDP)
		PCB138		PBDE155		dibenz[*a,h*]anthracene (DBA)[c]
		PCB153		PBDE183		benzo[g,h,i]perylene (BZP)
		PCB170				
		PCB180				
		PCB187				
		PCB195				
		PCB206				
		PCB209				

**Sum of 17 congeners, then multiplied by two,* [a] coelutes with triphenylene, [b] coelutes with benzo[j]flouranthene, [c] coelutes with dibenz[a,c]anthracene

Data Transformations and Statistical Analyses

All organic contaminants and metals were reported by the analytical labs on a wet weight basis, however, to maintain consistency with the majority of published mussel contaminant studies we converted wet weight to dry weight using the percent moisture value derived from the analytical process. In addition, all contaminant data were log10-transformed prior to analysis to achieve normality and equality of variances for statistical testing.

All contaminant concentration comparisons between survey years (2016, 2018, 2020) were made using the thirty-five SAM sites with repeated visits in each survey year (Table 3, Figure 2) and performing a one-way Analysis of Variance (ANOVA) (α set to 0.05) and post hoc pairwise multiple comparison procedure (Holm-Sidak method) on statistically significant ANOVA effects. In cases where the normality (Shapiro-Wilk) test failed ($P < .05$) and difference in mean values were not significant, a Kruskal-Wallis One Way ANOVA on Ranks was performed, and post hoc pairwise multiple comparisons (Tukey method) was performed on significant ANOVA effects. In cases where normality failed but passed an equal variance test ($P <.05$) and showed significant differences in mean values, we accepted the non-normal data since the sample size was large enough, and proceeded with the Holm-Sidak pairwise comparison. Although all statistical comparisons were made on log-10 transformed data to help reduce heteroscedasticity for the ANOVAs, results for all data are presented using arithmetic metrics.

For contaminants with significant differences among concentration means between survey years an additional analysis was conducted to evaluate where changes were occurring based on levels of nearshore development. The percent of impervious surface cover in watersheds adjacent to monitoring sites was used as a proxy for nearshore development and stratified into four strata: least developed (<10%), low development (10 to <20%), medium development (20 to <40%), and high development (40 to 100%) (Figure 2). These strata were selected from the new SAM study design (starting 2021/2022) as described in the 2021-2025 SAM Status and Trends Monitoring of Marine Nearshore Mussels Quality Assurance Project Plan (Langness and Song, 2022). The thirty-five repeated SAM sites were binned into one of these strata categories and contaminant concentration means between survey years were compared within each stratum using an ANOVA and post hoc pairwise multiple comparison test to determine significant differences.

Percent impervious surface in adjacent watersheds were determined by overlaying percent impervious surface land cover data from the 2019 National Land Cover Dataset (NLCD) onto predefined, watershed catchment areas adjacent to the Puget Sound shoreline. The NLCD Percent Developed Imperviousness dataset uses Landsat satellite data with a spatial resolution of 30 meters (Homer et al., 2020). This dataset is updated every five years, allowing us to describe how urbanization is changing over time. The watershed catchment areas were originally developed by Ecology for another purpose (Stanley et al., 2012), but were determined to be of a size appropriate for use in this study (median area of 8.8 kilometer^2 or 3.4 mile^2). Using these GIS layers, we calculated the average value (i.e., percent intensity) of impervious surface within each watershed adjacent to mussel sites. Each mussel site was matched with the watershed closest in proximity and assigned the corresponding mean percent impervious value.

Data Presentation

Data presented in the following Results section reports on SAM monitoring sites only. However, the 2020 survey included partnerships with a number of returning and new partners, including the NOAA National Centers for Coastal Ocean Science (NCCOS) Mussel Watch program. The national Mussel Watch program resampled their historic monitoring sites using the caged mussel method employed by this program, instead of sampling wild mussels as done in all historic sampling years. Data from the NOAA Mussel Watch, WDFW and local partner sponsored sites are presented in Appendix C (site map/table showing location data and tables of chemical concentration data). Partners can refer to this appendix to view their data and determine how conditions at their sponsored site compares with conditions in the SAM UGA sites. In turn, SAM program managers and other interested parties can view data from non-UGA sites and additional sites of interest.

Results and Discussion

2020 Survey: Detection Frequency and Distribution of Contaminant Concentration Data

Organic Contaminants

Overall, Σ_{16}PAHs, TPCBs, $\sum_{11}$PBDEs, and $\sum_{6}$DDTs were the most abundant organic contaminants measured in mussels from this study. The same four contaminant groups were the most abundant in the 2016 and 2018 surveys (Lanksbury et al., 2017; Langness and West, 2020). The Σ_{16}PAHs and TPCBs groups were detected in mussels from all 38 (100%) SAM monitoring sites; $\sum_{6}$DDTs at 89% of the sites, and $\sum_{11}$PBDEs at 82% of the sites (Figure 3). Four other organic contaminants were less frequently detected; $\sum_{8}$Chlordanes and dieldrin were detected at 21% of the sites, mirex at 11%, and $\sum_{3}$HCHs at 5% of the sites. The remaining organic contaminants, hexachlorobenzene (HCB), aldrin, and endosulfan-1 were not detected at any sites.

The Σ_{16}PAH had the highest central tendency and broadest range of concentrations (ng/g dry wt.) observed (mean = 305 median = 130 , range = 3314). TPCBs had the second highest concentrations (ng/g dry wt.) observed (mean = 66 , median = 57 , range = 162) followed by $\sum_{11}$PBDEs (mean = 3.7 , median = 3.3 , range = 18.3) and $\sum_{6}$DDTs (mean = 3.7 , median = 2.3 , range = 25.3) (Figure 4).

Σ_{16}PAHs and TPCBs were detected in all the Baseline Site (initial condition pre-deployment mussels) replicate samples (n = 3). $\sum_{11}$PBDEs, $\sum_{6}$DDTs, $\sum_{8}$Chlordanes, $\sum_{3}$HCHs, dieldrin, aldrin, HCB, mirex, and endosulfan 1 were not detected above the LOQ in any of the Baseline Site replicate samples. Concentrations at the mussel source (average of 3 replicate samples) were below the concentrations at all of the study sites for three of the dominant organic contaminants, Σ_{16}PAHs, $\sum_{11}$PBDEs, and $\sum_{6}$DDTs (Figure 4), indicating that all deployed cages accumulated additional contaminant loads from their deployment locations for these chemicals. TPCBs however, had a higher starting concentration closer to the median value of all the sites, with a little more than half of the sites accumulating additional PCB loads after the exposure period. The mean TPCBs concentration of the 2020 baseline mussels was significantly higher than the mean concentrations in the prior 2016 and 2018 surveys (ANOVA of log-transformed PCB concentration by Year, Holm-Sidak post hoc pairwise comparison, $P < 0.001$). Despite this change in the starting TPCBs concentrations, we believe the initial conditions of Penn Cove mussels continue to represent an effective baseline.

Σ_{16}PAHs, TPCBs, and $\sum_{6}$DDTs were detected in deployed mussels from the Penn Cove Reference site (n = 1), and none of the other organic analytes were detected above the LOQ. For the Hood Canal Holly Reference site (n = 1), Σ_{16}PAHs and TPCBs were detected, and none of the other organic analytes were detected above the LOQ. The concentration of Σ_{16}PAHs, $\sum_{11}$PBDEs, and $\sum_{6}$DDTs in the reference site mussels were detected at low concentrations, in the 25th or lower percentile of all samples in this survey year. However, both reference sites had higher TPCBs concentrations observed than in previous survey years, with the Penn Cove Reference site concentration in the 75th percentile and the Hood Canal Holly site concentration near the median value of all the sites.

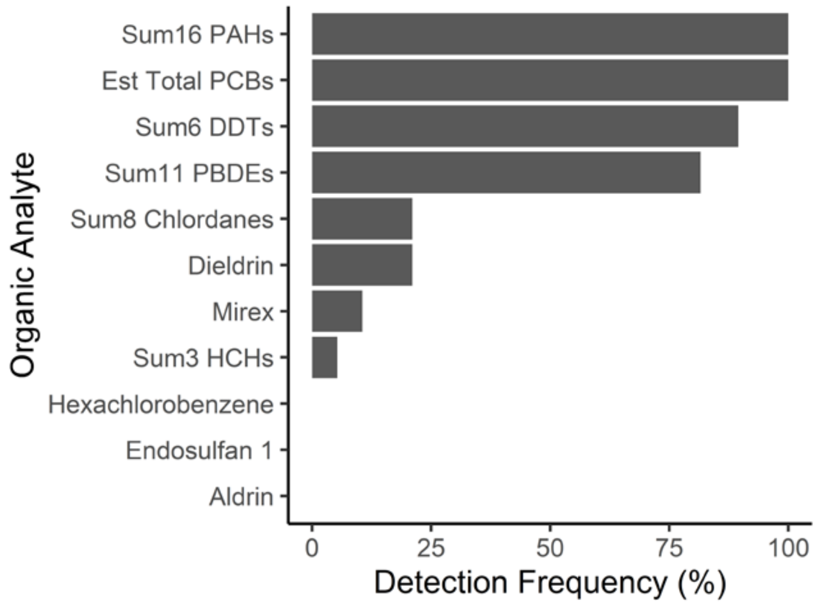

Figure 3. Detection frequency of organic analytes measured in mussels from the 2020 SAM Mussel Monitoring sites.

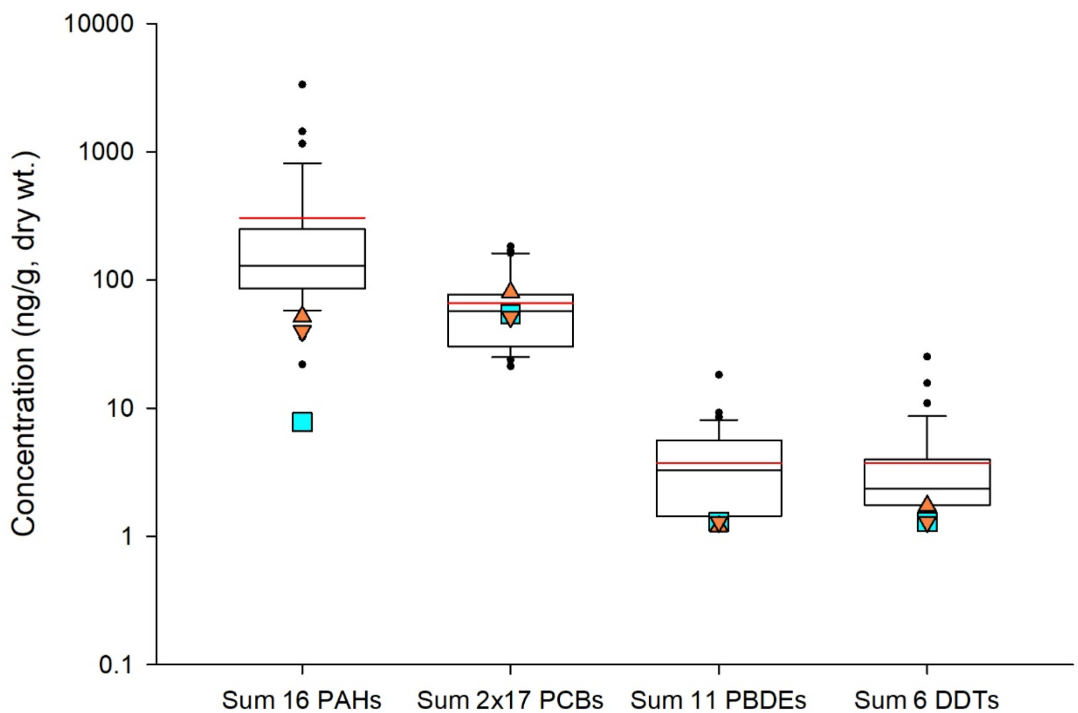

Figure 4. Box plots of the four most frequently detected organic contaminants at SAM Mussel Monitoring sites in the 2020 survey; lower and upper hinges correspond to the 25th and 75th percentiles, whiskers are 1.5 IQR, black lines in box are median concentrations, red lines are mean concentrations, single black circles are outliers, cyan squares are baseline concentrations, orange up triangles are the Penn Cove Reference site concentrations and down triangles are the Hood Canal Holly Reference site concentrations. Y-scale is logarithmic.

Metals

All six of the metals measured in this study (arsenic, cadmium, copper, lead, mercury, and zinc) were detected in mussels from all 38 (100%) SAM monitoring sites, as well as all the Baseline Site replicate samples and the Penn Cove and Hood Canal Holly Reference sites.

Similar to prior survey years, we observed a narrow range of concentrations for each metal, with zinc having the highest central tendency concentrations observed, followed by arsenic, copper, cadmium, lead, and mercury (Figure 5). The concentration of arsenic, lead, mercury, and zinc in the baseline (average of 3 replicate samples) were detected at low concentrations, in the 25th or lower percentile of all samples in this survey, indicating that most of deployed cages accumulated additional loads of these metals from their deployment locations. Baseline concentration values of copper and cadmium fell within the interquartile range indicating mussels from a similar number of locations accumulated and depurated metals during the deployment period. Reference sites (Penn Cove and Hood Canal Holly) had concentration values for most all the metals within the interquartile range. Metals occur naturally in marine waters and so can come from both natural and anthropogenic sources; this fact, along with the variation in metal concentrations along the Puget Sound nearshore, makes it difficult separate anthropogenic from natural sources.

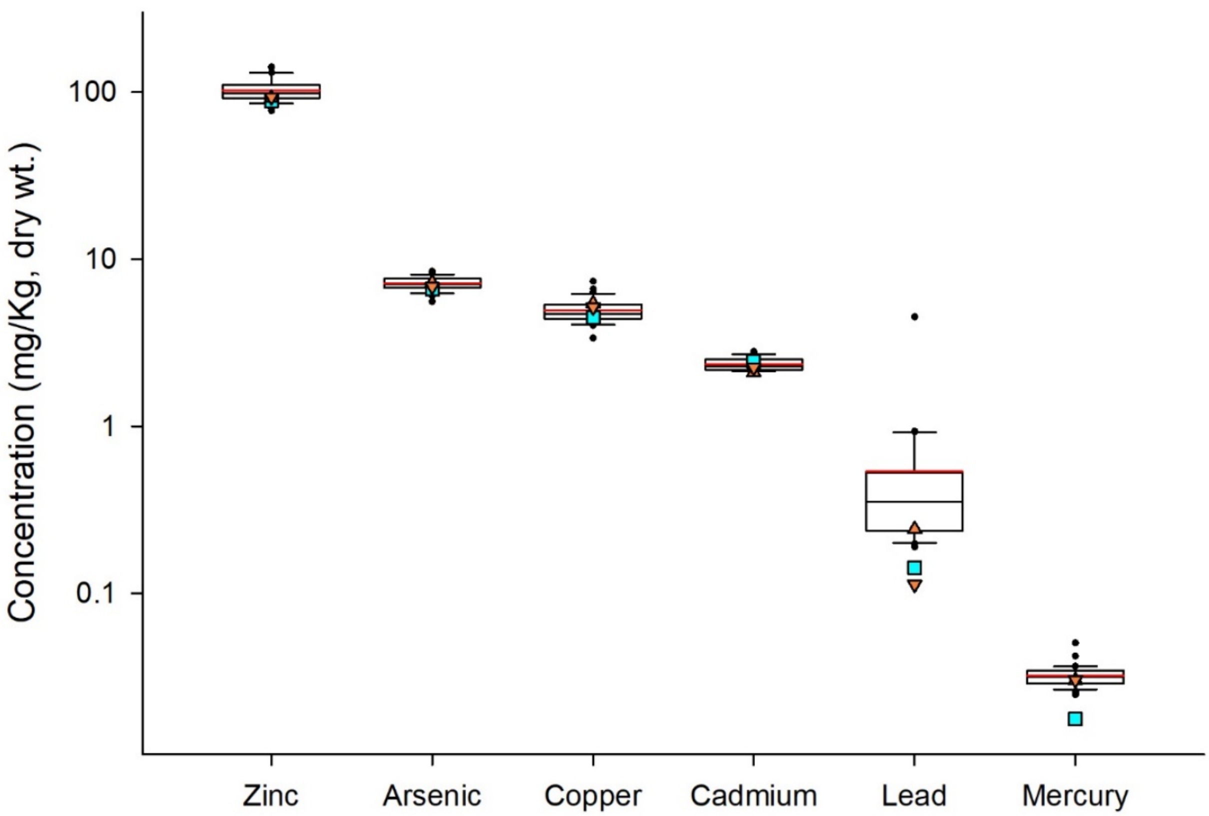

Figure 5. Box plots of metals detected at SAM Mussel Monitoring sites in the 2020 survey; lower and upper hinges correspond to the 25th and 75th percentiles, whiskers are 1.5 IQR, black lines in box are median concentrations, red lines are mean concentrations, single black circles are outliers, cyan squares are baseline concentrations, orange up triangles are the Penn Cove Reference site concentrations and down triangles are the Hood Canal Holly Reference site concentrations. Y-scale is logarithmic.

Tracking Changes in Nearshore Contamination

Changes in Spatial Extent of Key Contaminants

The following section describes changes occurring in the spatial extent of key contaminants (PAHs, PCBs, PBDEs, DDTs, arsenic, copper, cadmium, lead, mercury, zinc) in mussels deployed inside the urban growth area (UGA) sampling frame of the 2016, 2018, and 2020 surveys. Here we present the distribution of mussel tissue contaminant concentrations along the Puget Sound UGA (all beaches, SAM and Pierce Co.) using cumulative frequency distribution (CFD) plots (Figure 6 – 15). As the spatial weight of the Pierce County (Option 2) sites only represented approximately 1 % in total UGA nearshore length, the CFD patterns for the 2016 and 2018 surveys were largely driven by the results from SAM sites (99% contribution). The CFD pattern for the 2020 survey was driven entirely by the SAM sites (100%), as there was no subset of Pierce Co. sites sampled that year. This change in protocol in addition to the increasing number of rejected and/or lost cage sites each year, contributed to the loss of approximately 100 km in total UGA nearshore sampled length by the end of the 2020 survey (Table 1). It is possible that the decreasing sampled nearshore length and the loss of potential high leverage points from dropped sites could account for differences observed in that sampling year. Therefore, we interpret changes observed between survey years with caution.

On each of the CFD plots presented, the Y-axis indicates the cumulative percentage (%) of UGA nearshore length covered by this study design, while the X-axis represents the concentration of each contaminant. Thus, if the reader drew a horizontal line from the 80% tick mark on the Y-axis to the data line and then a vertical line down from that point to the X-axis to a concentration of 100 ng/g, it would be interpreted as meaning 80% of the total UGA nearshore length had a contaminant concentration below 100 ng/g, while 20% had a concentration above that value. In the following plots, we interpret changes in the spatial extent of key contaminants by selecting a consistent %UGA nearshore length value of 80%[1] with which to compare the related contaminant concentrations in each survey year. Additionally, for each survey year we estimate the percent of UGA nearshore length with a concentration equal to or less than the average (three survey years) concentration of the Hood Canal Holly Reference site, a site with no known or suspected significant contaminant sources. The mean Holly Reference concentration is shown as a vertical dashed yellow line in the CFD plots, and it provides a way to determine approximately how much of the UGA nearshore had mussels that accumulated contaminants at levels greater than a clean reference site.

Pi

[1]One could select any percentage on the y axis for comparison. We chose 80% because it is near to the inflection point on many of the graphs, making it easy to discuss changes in the shape of the CFD curves.

PAHs

PAH concentrations in mussels from almost all deployed UGA locations (>95% of the nearshore length) in all years exceeded the Hood Canal Reference site average concentration (40 ng/g, dry wt.). The CFD patterns for PAHs in each survey year were also similar, in that they were all more skewed toward the low concentrations (<1000 ng/g, dry wt.), suggesting a ubiquitous relatively low-level presence of PAHs in the UGA nearshore. Approximately 10% of UGA nearshore length exhibited much higher concentrations, up to 7000 ng/g dry wt., perhaps attributable to site specific PAH point sources (e.g., marinas or ferry/shipping terminals).

When comparing concentrations between survey years, the 2018 survey had the highest maximum concentrations observed (shown as the terminus of each line), up to 7000 ng/g, dry wt., followed by 4800 ng/g in 2016, and 3300 ng/g in 2020. The CFD pattern for the 2018 survey also had the highest concentrations observed across the cumulative percentage of UGA nearshore, followed by 2016 and 2020. For example, 80% of the total UGA nearshore length had concentrations below approximately 750 ng/g in 2018 (red dotted arrow), below 400 ng/g in 2016 (black dotted arrow), and below 200 ng/g in 2020 (blue dotted arrow, Figure 6). Additional future sampling will be needed to evaluate the statistical significance of any temporal trends these data may imply.

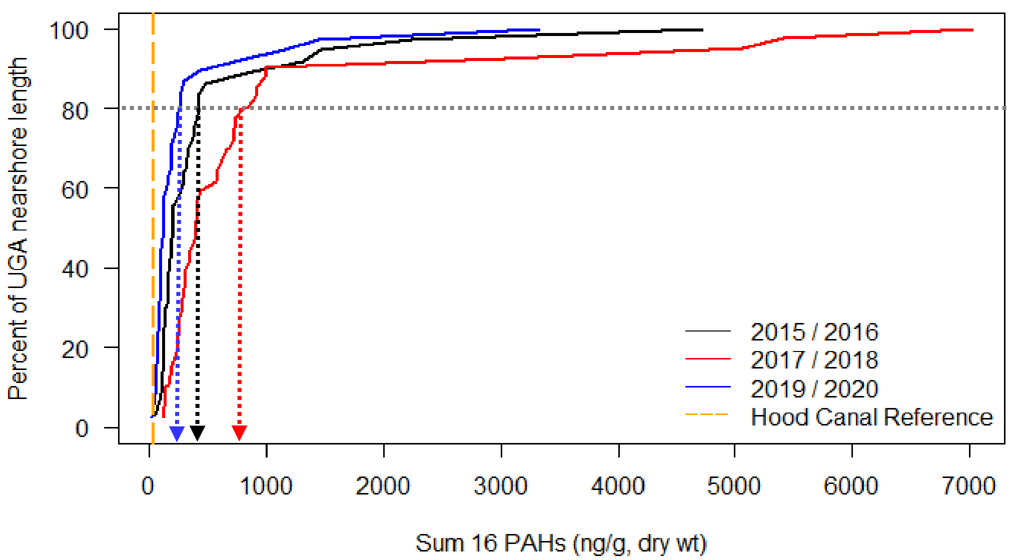

Figure 6. Cumulative frequency distribution (CFD) of Σ_{16}PAHs concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

PCBs

When comparing concentrations in the UGA nearshore to the Hood Canal Reference site average concentration (37 ng/g, dry wt.), we see that 52% of UGA nearshore in the 2016 survey, 17% in the 2018 survey, and 40% in the 2020 survey had concentrations equal to or less than the Hood Canal Reference. The significance of the PCB concentration patterns at these low concentrations is difficult to interpret because they are near the limit of quantitation for the analytical method. Slight changes in analytical performance between years could influence the comparison of low PCB concentrations in UGA samples with the Hood Canal Reference. The CFD patterns (shape of the curves) for PCBs in each survey year were similar in that they all had a gradual contaminant accumulation as the cumulative percentage of UGA shoreline length increased, suggesting elevated exposures of this contaminant are more widely dispersed within the Puget Sound UGA shoreline than PAHs.

When comparing concentrations between survey years, the 2016 survey had the highest maximum concentrations observed, up to 236 ng/g, dry wt., followed by 214 ng/g in 2018, and 180 ng/g in 2020. The CFD pattern for the 2018 survey had the highest concentrations across the total cumulative UGA nearshore, followed by 2020 and 2016. For example, 80% of the total UGA nearshore length had concentrations below approximately 113 ng/g in 2018, below 80 ng/g in 2020, and below 70 ng/g in 2016 (Figure 7). Additional future sampling will be needed to evaluate the statistical significance of any temporal trends these data may imply. However, the observed distribution of PCB concentrations in each survey year indicates that conditions in the UGA nearshore for this contaminant showed little change in recent surveys (2018 and 2020).

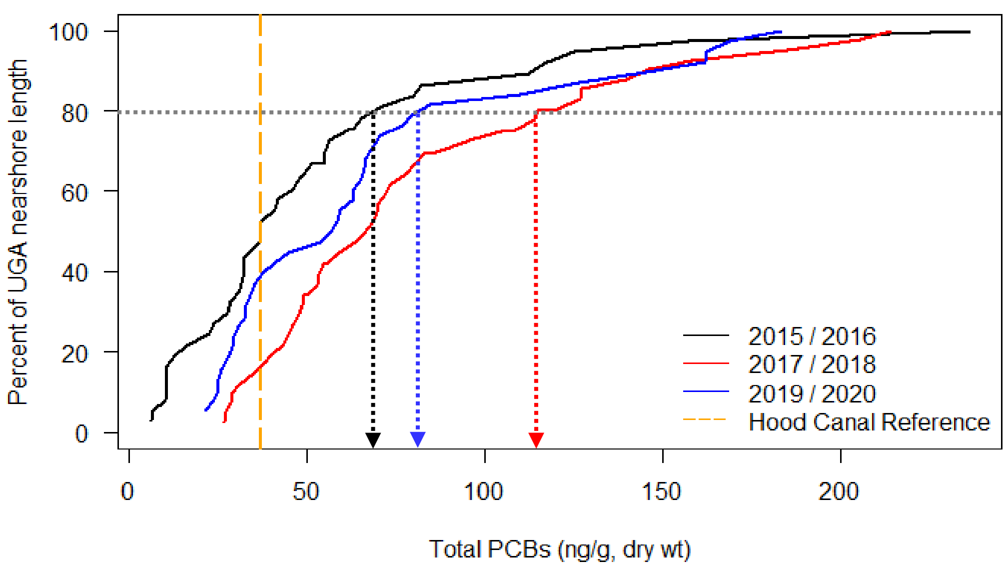

Figure 7. Cumulative frequency distribution (CFD) of TPCBs concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

PBDEs

When comparing concentrations in the UGA nearshore to the Hood Canal Reference site average concentration (1.5 ng/g, dry wt.), we see that 29% of UGA nearshore in the 2020 survey and 16% in the 2016 survey had concentrations equal to or less than the Hood Canal Reference. Similar to PCBs, these concentrations are near to the lower limit of quantitation for the analytical method, so the significance of these differences is uncertain. Although some UGA samples in 2018 exhibited PBDE concentrations near to the Hood Canal reference in 2018, the entire sampled UGA nearshore (100%) in that survey had concentrations above the reference concentration. The observed distribution of PBDE concentrations in each survey year indicate that overall, PBDEs in most of the UGA nearshore exceeded the uncontaminated reference site. The CFD patterns for PBDEs (shape of the curves) in each survey year were similar in that they were all more skewed toward the low concentrations (with 80% of the shoreline for each sampling year below approximately 12 ng/g dry wt), suggesting that the majority of Puget Sound UGA shorelines had concentrations of these contaminants within the lower range and that only a few sites had much higher concentrations, perhaps from proximity to site specific point sources.

When comparing concentrations between survey years, the 2018 survey had the highest maximum concentrations observed, up to 47 ng/g, dry wt., followed by 2016 (30 ng/g), and then 2020 (18 ng/g). The CFD pattern for the 2018 and 2016 surveys were similar, with most of the UGA nearshore having concentrations below 15 ng/g, whereas the 2020 survey exhibited lower concentrations of PBDEs overall, with most of the UGA nearshore having concentrations below 6 ng/g, and nearly 20% of the UGA shoreline with PBDEs undetected in mussel tissue (Figure 8). Additional future sampling will be needed to evaluate the statistical significance of any temporal trends these data may imply, however the lower PBDE concentrations across the full CFD in 2020 (compared to the previous years) is consistent with Puget Sound-wide declines in other WDFW-TBiOS indicator species (English sole and Pacific herring) reported in the Toxics in Aquatic Life Vital Sign (Puget Sound Partnership 2022c).

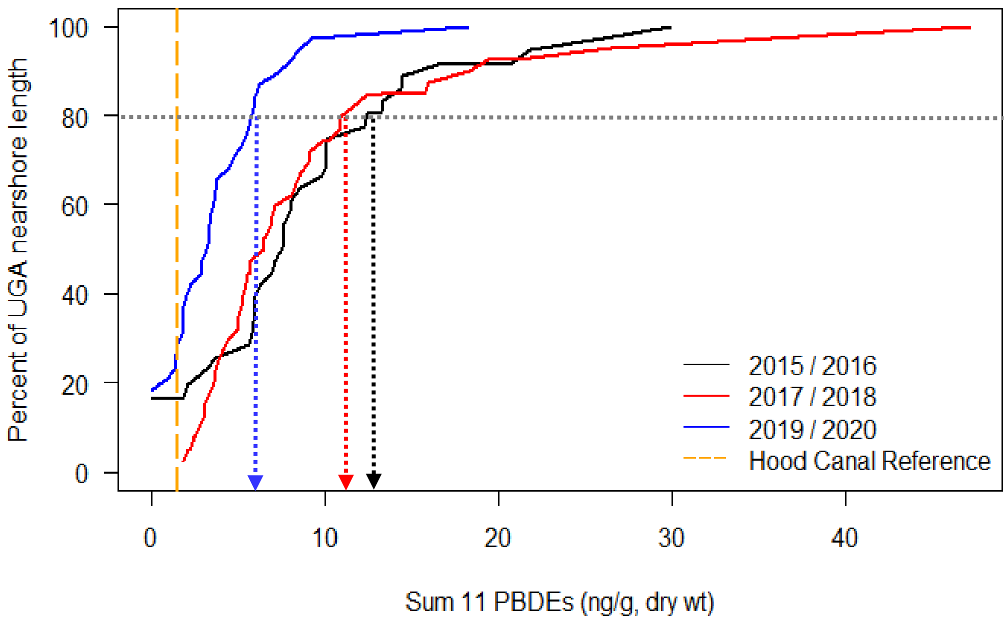

Figure 8. Cumulative frequency distribution (CFD) of $\sum_{11}$PBDEs concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

DDTs

When comparing concentrations in the UGA nearshore to the Hood Canal Reference site average concentration (1.5 ng/g, dry wt.), we see that only 20% of UGA nearshore in the 2020 survey and 16% in the 2016 survey had concentrations equal to or less than the Hood Canal Reference concentration. The entire sampled UGA nearshore (100%) in the 2018 survey had concentrations above the reference concentration. Similar to PCBs and PBDEs, these concentrations are near to the lower limit of quantitation for the analytical method, so the significance of these differences is uncertain. The observed distribution of DDT concentrations in each survey year indicates that overall, DDTs in most of the UGA nearshore exceeded the uncontaminated reference site. The CFD patterns for DDTs in each survey year were similar to each other in that they were all more skewed toward the low concentrations (approximately 90% of all shoreline sites in all years were below 8 ng/g dry wt.), suggesting that the majority of Puget Sound UGA shorelines had concentrations of these contaminants within the lower range and that only a few sites had much higher concentrations, perhaps from proximity to site specific point sources.

When comparing concentrations between survey years, the 2016 survey had the highest maximum concentrations observed, up to 50 ng/g, dry wt., followed by 33 ng/g in 2018, and 25 ng/g in 2020. The CFD pattern for the 2016 and 2020 surveys were very similar, with most of the UGA nearshore having concentrations below 4 ng/g, and approximately 11 to 14% of the UGA shoreline with DDTs undetected in mussel tissue (Figure 9). The CFD pattern for the 2018 survey had slightly higher concentrations, above 6 ng/g in 20% of UGA nearshore. All years exhibited a nearly identical pattern (lines overlapped) of CFD between the concentrations of 8 and 26 ng/g dry wt. Additional future sampling will be needed to evaluate the statistical significance of any temporal trends these data may imply, however there seems weak evidence from these results of any change over the sampling period represented here.

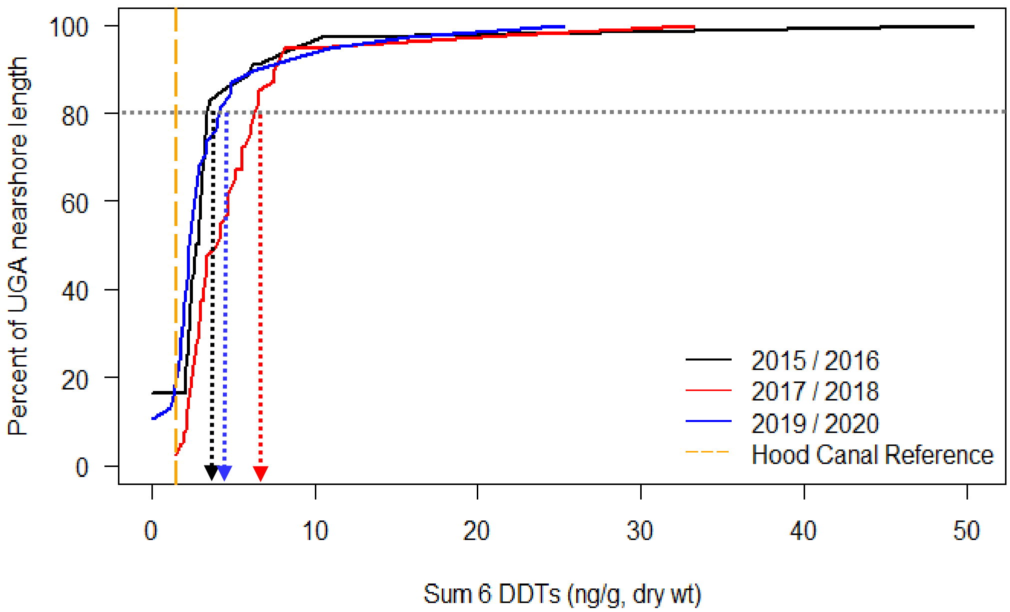

Figure 9. Cumulative frequency distribution (CFD) of $\sum_6$DDTs concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

Arsenic

When comparing concentrations in the UGA nearshore to the Hood Canal Reference site average concentration (6.9 mg/kg, dry wt.), we see that 72% of UGA nearshore in the 2016 survey and 37% in the 2020 survey had concentrations equal to or less than the reference. The entire sampled UGA nearshore (100%) in the 2018 survey had concentrations above the reference concentration. The observed distribution of arsenic concentrations each survey year indicate the spatial extent of arsenic contamination was variable between survey years. The CFD patterns for arsenic in each survey year were similar in that they all had a gradual contaminant accumulation as the cumulative percentage of UGA shoreline length increased, suggesting elevated exposures of this contaminant are more widely dispersed within the Puget Sound UGA shoreline.

When comparing concentrations between survey years, the 2018 survey had the highest maximum concentrations observed, up to 14.3 mg/kg, dry wt., followed by 2020 (8.5 mg/kg), and then 2016 (7.9 mg/kg). The CFD pattern for the 2018 survey had the highest concentrations across the total cumulative UGA nearshore, followed by 2020 and 2016. For example, 80% of the total UGA nearshore length had concentrations below approximately 8.7 mg/kg in 2018, below 7.6 mg/kg in 2020, and below 7.0 mg/kg in 2016 (Figure 10).

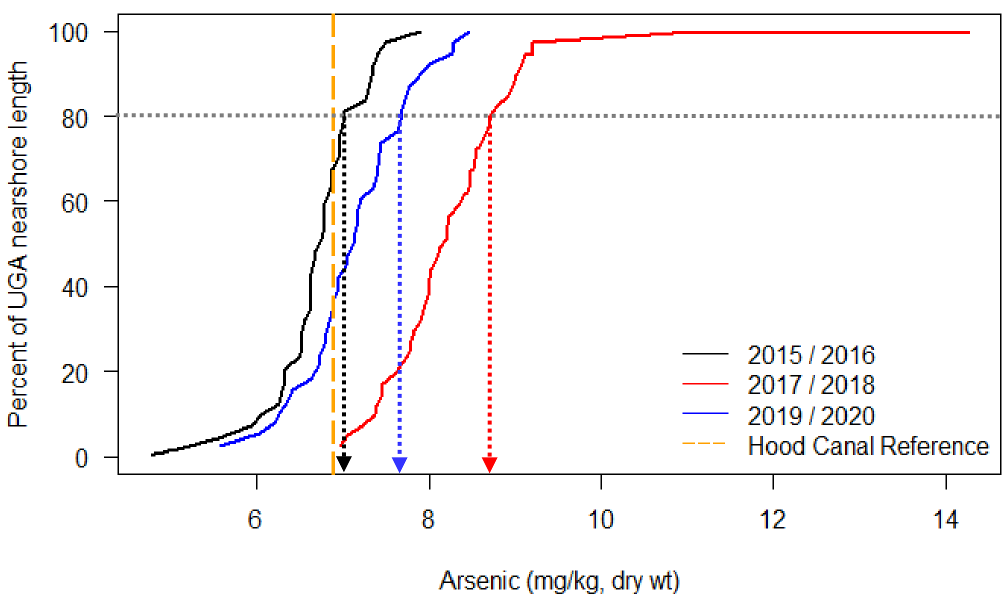

Figure 10. Cumulative frequency distribution (CFD) of arsenic concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

Copper

When comparing concentrations in the UGA nearshore to the Hood Canal Reference site average concentration (6.1 mg/kg, dry wt.), we see that 87% of UGA nearshore in the 2020 survey and 16% in the 2016 survey had concentrations equal to or less than the Hood Canal Reference. The entire sampled UGA nearshore (100%) in the 2018 survey had concentrations above the reference concentration. The observed distribution of copper concentrations in the 2020 survey indicates that the spatial extent of copper contamination declined from previous survey years. The CFD patterns for copper in each survey year were similar in that they were all more skewed toward the low concentrations, suggesting that the majority of Puget Sound UGA shorelines have concentrations of these contaminants within the lower range (approximately 95% of all shoreline sites in all years were below 20 mg/kg dry wt.), and that only a few sites have much higher concentrations, perhaps from site specific point sources.

When comparing concentrations between survey years, the 2018 survey had the highest maximum concentrations observed, up to 94 mg/kg, dry wt., followed by 12.6 mg/kg in 2016, and 6.3 mg/kg in 2020. The CFD pattern for the 2018 survey also had the highest concentrations observed across the cumulative percentage of UGA nearshore, followed by 2016 and 2020. For example, 80% of the total UGA nearshore length had concentrations below approximately 11.7 mg/kg in 2018 (red dotted arrow), below 8.7 mg/kg in 2016 (black dotted arrow), and below 5.5 mg/kg in 2020 (blue dotted arrow, Figure 11). Additional future sampling will be needed to evaluate the statistical significance of any temporal trends these data may imply, however the lower copper concentrations across the full CFD in 2020 (compared to the previous years) is notable.

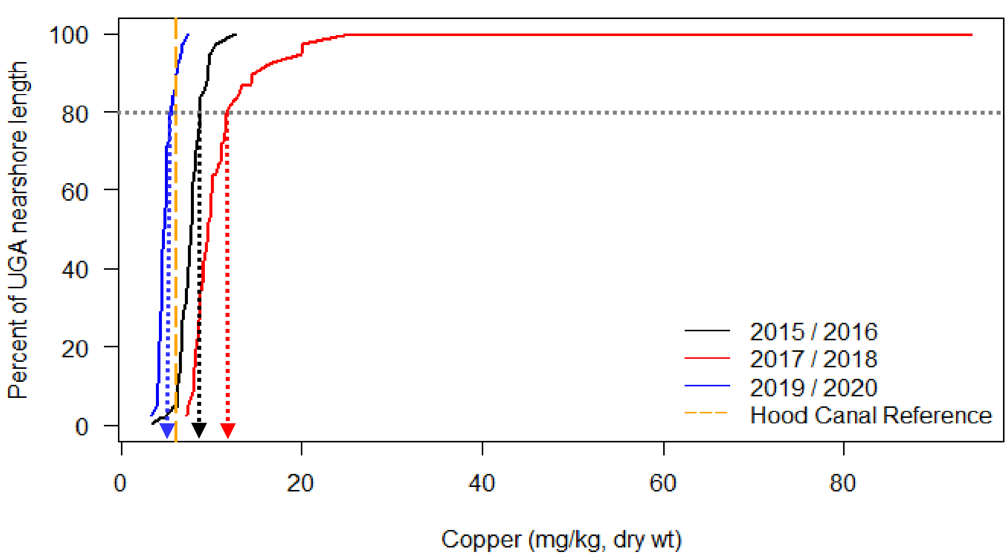

Figure 11. Cumulative frequency distribution (CFD) of copper concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

Cadmium

When comparing concentrations in the UGA nearshore to the Hood Canal Reference site average concentration (2.0 mg/kg, dry wt.), we see that 93% of UGA nearshore in the 2016 survey and 19% in the 2018 survey had concentrations equal to or less than the reference. The entire sampled UGA nearshore (100%) in the 2020 survey had concentrations above the reference concentration. The observed distribution of cadmium concentrations in the 2018 and 2020 surveys indicates that the spatial extent of cadmium contamination increased. The CFD patterns for cadmium in each survey year were similar in that they all had a gradual contaminant accumulation as the cumulative percentage of UGA shoreline length increased, suggesting elevated exposures of this metal are more widely dispersed within the Puget Sound UGA shoreline.

When comparing concentrations between survey years, the 2018 survey had the highest maximum concentrations observed, up to 3.7 mg/kg, dry wt., followed by 2.8 mg/kg in 2020, and 2.1 mg/kg in 2016. The CFD pattern for the 2020 survey had the highest concentrations across the total cumulative UGA nearshore, followed by 2018 and 2016. For example, 80% of the total UGA nearshore length had concentrations below approximately 2.6 mg/kg in 2020, below 2.4 mg/kg in 2018, and below 1.8 mg/kg in 2016 (Figure 12). Additional future sampling will be needed to evaluate the statistical significance of any temporal trends these data may imply, however the increased cadmium concentrations across the full CFD in 2018 and 2020 is notable.

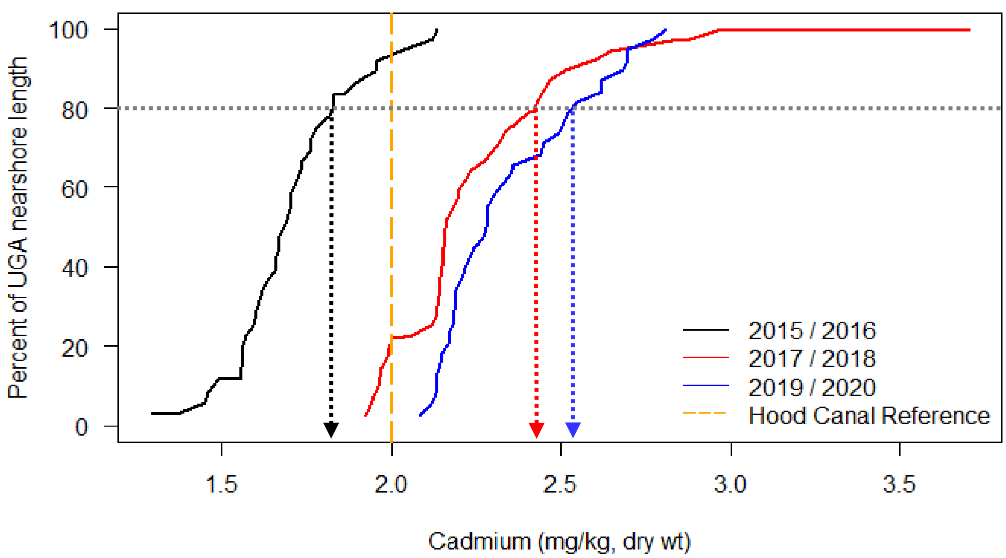

Figure 12. Cumulative frequency distribution (CFD) of cadmium concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

Lead

When comparing concentrations in the UGA nearshore to the Hood Canal Reference site average concentration (0.18 mg/kg, dry wt.), we see that only 14% of UGA nearshore in the 2016 survey had concentrations equal to or less than the Hood Canal Reference. The entire sampled UGA nearshore (100%) in the 2018 and 2020 surveys had concentrations above the reference concentration. The observed distribution of lead concentrations in each survey year indicates that overall, lead in most of the UGA nearshore exceeded the uncontaminated reference site. The CFD patterns for lead in each survey year were very similar in that they were all more skewed toward the low concentrations (80% of the UGA nearshore with concentrations between 0.53 and 0.76 mg/kg) suggesting that the majority of Puget Sound UGA shorelines have concentrations of these contaminants within the lower range and that only a few sites have much higher concentrations, perhaps from site specific point sources.

When comparing concentrations between survey years, the 2020 survey had the highest maximum concentrations observed, up to 4.5 mg/kg, dry wt., followed by 2.3 mg/kg in 2018, and 0.97 mg/kg in 2016. All years exhibited a similar pattern of CFD (lines overlapped) between the concentrations of 0.18 and 1.0 mg/kg dry wt. Additional future sampling will be needed to evaluate the statistical significance of any temporal trends these data may imply, however there seems weak evidence from these results of any change over the sampling period represented here.

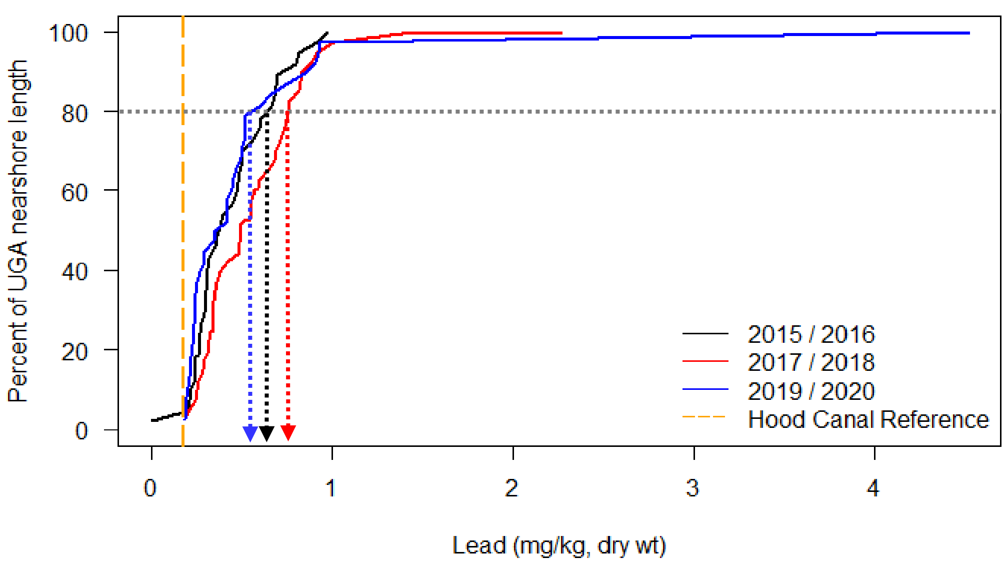

Figure 13. Cumulative frequency distribution (CFD) of lead concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

Mercury

When comparing concentrations in the UGA nearshore to the Hood Canal Reference site average concentration (0.0415 mg/kg, dry wt.), we see that 95% of UGA nearshore in the 2020 survey, 35% in the 2016 survey, and 6% in the 2018 survey had concentrations equal to or less than the reference. The observed distribution of mercury concentrations in the recent 2020 survey indicates that the spatial extent of mercury contamination declined from previous survey years. The CFD patterns for mercury in each survey year were similar in that they all had a more gradual contaminant accumulation as the cumulative percentage of UGA shoreline length increased, suggesting elevated exposures of this contaminant are more widely dispersed within the Puget Sound UGA shoreline.

When comparing concentrations between survey years, the 2018 survey had the highest maximum concentrations observed, up to 0.0955 mg/kg, dry wt., followed by 0.0578 mg/kg in 2016, and 0.0504 mg/kg in 2020. The CFD pattern for the 2018 survey had the highest concentrations across the total cumulative UGA nearshore, followed by 2016 and 2020. For example, 80% of the total UGA nearshore length had concentrations below approximately 0.0701 mg/kg in 2018, below 0.0515 mg/kg in 2016, and below 0.03443 mg/kg in 2020 (Figure 14). Additional future sampling will be needed to evaluate the statistical significance of any temporal trends these data may imply, however the lower mercury concentrations across the full CFD in 2020 (compared to the previous years) is notable.

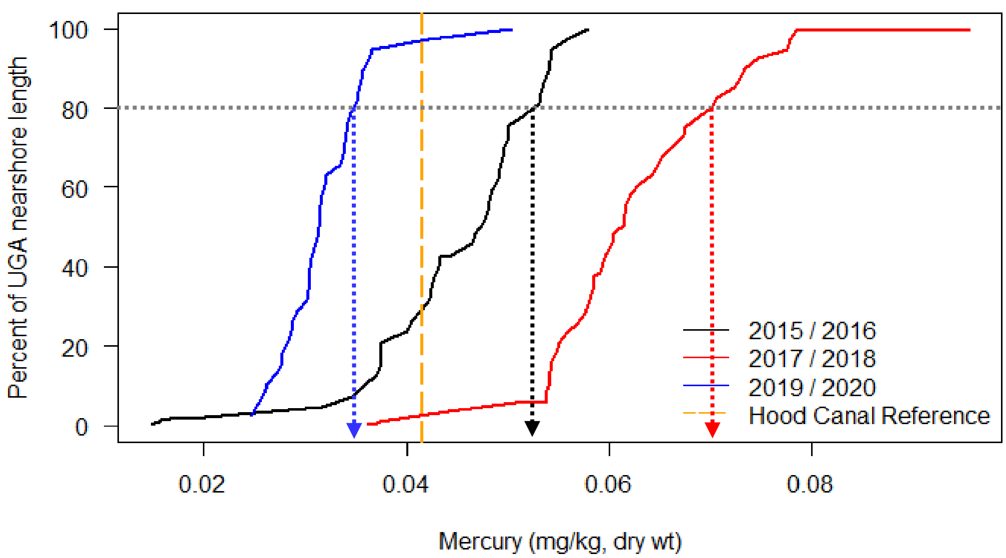

Figure 14. Cumulative frequency distribution (CFD) of mercury concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

Zinc

When comparing concentrations in the UGA nearshore to the Hood Canal Reference site average concentration (81 mg/kg, dry wt.), we see that 23% of UGA nearshore in the 2016 survey, 2% in the 2018 survey, and 5% in the 2020 survey had concentrations equal to or less than the reference. The observed distribution of zinc concentrations in each survey year indicates that overall, zinc in most of the UGA nearshore exceeded the uncontaminated reference site. The CFD patterns for zinc in each survey year were similar in that they all had a gradual contaminant accumulation as the cumulative percentage of UGA shoreline length increased, suggesting elevated exposures of this contaminant are more widely dispersed within the Puget Sound UGA shoreline.

When comparing concentrations between survey years, the 2018 survey had the highest maximum concentrations observed, up to 177 mg/kg, dry wt., followed by 141 mg/kg in 2020, and 122 mg/kg in 2016. The CFD pattern for the 2018 and 2020 surveys were similar, with most of the UGA nearshore (80%) having concentrations below 111 mg/kg. The CFD pattern for the 2016 survey had slightly lower concentrations, with 80% of the UGA nearshore having concentrations below 99 mg/kg. Additional future sampling will be needed to evaluate the statistical significance of any temporal trends these data may imply, however there seems weak evidence from these results of any change over the sampling period represented here.

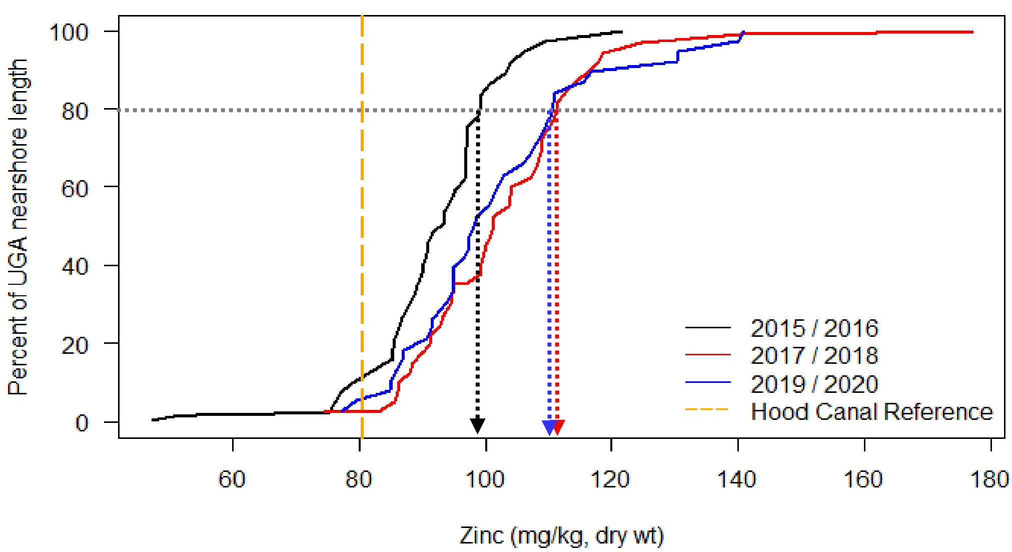

Figure 15. Cumulative frequency distribution (CFD) of zinc concentrations in mussels from 2016, 2018, and 2020 SAM and Pierce County (Option 1+2) study sites, representing the total sampled length of nearshore in Puget Sound UGAs. The solid black line represents the CFD for 2016 sites, the solid red lines for 2018 sites, and the solid blue line for 2020 sites. The dashed yellow line represents the Hood Canal Holly Reference site established as a regional threshold with which to compare against. Dotted lines are guides to read the plot, pointing to the concentrations observed in each survey year at 80% of the total sampled UGA nearshore length.

Changes in Concentrations of Key Contaminants

The following section describes changes occurring in the concentrations of contaminants measured in mussels collected from 35 SAM monitoring sites with repeated visits in each of the first three SAM surveys conducted in 2016, 2018 and 2020 (Figure 2). These results focus on a subset of repeated SAM sites to determine if observed changes in contaminant concentrations UGA-wide between survey years were statistically significant. Pierce County opt-out sites and SAM sites without contaminant concentration data for each survey year were eliminated and thus do not include all the data from sites presented in the earlier spatial extent of contamination section. Overall, the distribution of all organics followed a similar pattern, with most concentrations occurring at a relatively low level, with positive skewness and a few outlying, high leverage concentrations at a high extreme. This log-normal distribution and heteroscedasticity (unequal distribution of variance across concentrations) is similar to contaminant distributions in other indicator species reported in the Toxics in Aquatic Life Vital Sign and necessitated transformation (using log10-transformed data) to achieve, or come closer to, normal distributions and homoscedasticity.

Results are presented using box and violin plots showing the original, untransformed distribution and density of concentrations in each year, with significant differences observed between the mean or median concentrations (based on ANOVAs of log 10 transformed data) in each year indicated by different letters (Figures 16 and 17). Inferring temporal trends in contaminant condition over a short time period based on statistically significant differences in contaminant concentrations between years are done with caution below.

Organic Contaminants

The distribution of the PAH concentration data was positively skewed in each survey year, with the greatest frequency (median) of sites within the UGA occurring around 250 ng/g dry wt. in 2016 and 2018, and 100 ng/g in 2020. There were also extreme outliers in each survey indicating several sites that had very high relative concentrations of PAHs in mussels. Mean concentration (ng/g dry wt.) steadily declined from 500 in 2016, to 416 in 2018, to 286 in 2020. The decline in mean concentration between the 2016 and 2020 survey was statistically significant (ANOVA of log-transformed PAH concentration by Year; Holm-Sidak post hoc pairwise comparison, $P = 0.032$); whereas the mean concentration of PAHs in 2018 was intermediate, with no significant difference between 2018 and 2016 or 2020 (same test, $P > 0.05$) (Figure 16).

The distribution of PCB concentration data was positively skewed in each survey year, with the greatest frequency of sites occurring around 50 ng/g dry wt. in 2016 and 2018, and 30 ng/g in 2020. Although mean PCB concentration (ng/g dry wt.) increased from 68.1 in 2016 to 78.1 in 2018, and declined down to 61.4 in 2020, there was no significant difference in mean concentration values attributable to survey year (ANOVA of log-transformed PCB concentration by Year, $F_{(2,102)} = 2.153$, $P = 0.121$), as the power of the ANOVA was insufficient (0.248) to detect a trend if it existed. These results are consistent with PCB time trends in English sole (Puget Sound Partnership 2022a) and Pacific herring (Puget Sound Partnership 2022b) from

UGA areas, reported in the Toxics in Aquatic Life Vital sign (Puget Sound Partnership 2022c), which have shown no significant declining trend over the past 20 years.

The distribution of PBDE concentration data was positively skewed in each survey year, with the greatest frequency of sites occurring around 8 ng/g dry wt. in 2016 and 2018, and 1 ng/g in 2020. Mean concentration (ng/g dry wt.) decreased from 11.1 in 2016, to 8.91 in 2018, to 4.06 in 2020. This significant decline in mean concentration between both the 2016 and 2020 survey (ANOVA of log-transformed PBDE concentration by Year; Holm-Sidak post hoc pairwise comparison*,* $P < 0.001$) and 2018 and 2020 survey ($P < 0.001$) is congruent with PBDE declines in two other WDFW-TBiOS indicator species, English sole (Puget Sound Partnership 2022a) and Pacific herring (Puget Sound Partnership 2022b), in several UGA areas where those species were sampled (Figure 16).

The distribution of DDT concentration data was positively skewed in each survey year, with greatest frequency of sites occurring around 2.5 ng/g dry wt. in 2016, and 3 ng/g in 2018 and 2020. There were also extreme outliers in each survey indicating several sites that had high relative concentrations of DDTs in mussels. Log-transformation of DDT concentration data was insufficient to achieve homoscedasticity so the non-parametric Kruskal Wallis comparison was employed here, which compared ranked DDT concentrations between years. Median concentration (ng/g dry wt.) increased from 3.08 in 2016 to 3.37 in 2018, and down to 2.3 in 2020. Although a significant decline in median concentration between the 2018 and 2020 survey ($P = 0.014$) was observed (Figure 16), more sampling years are needed to infer conclusions regarding a significant declining trend.

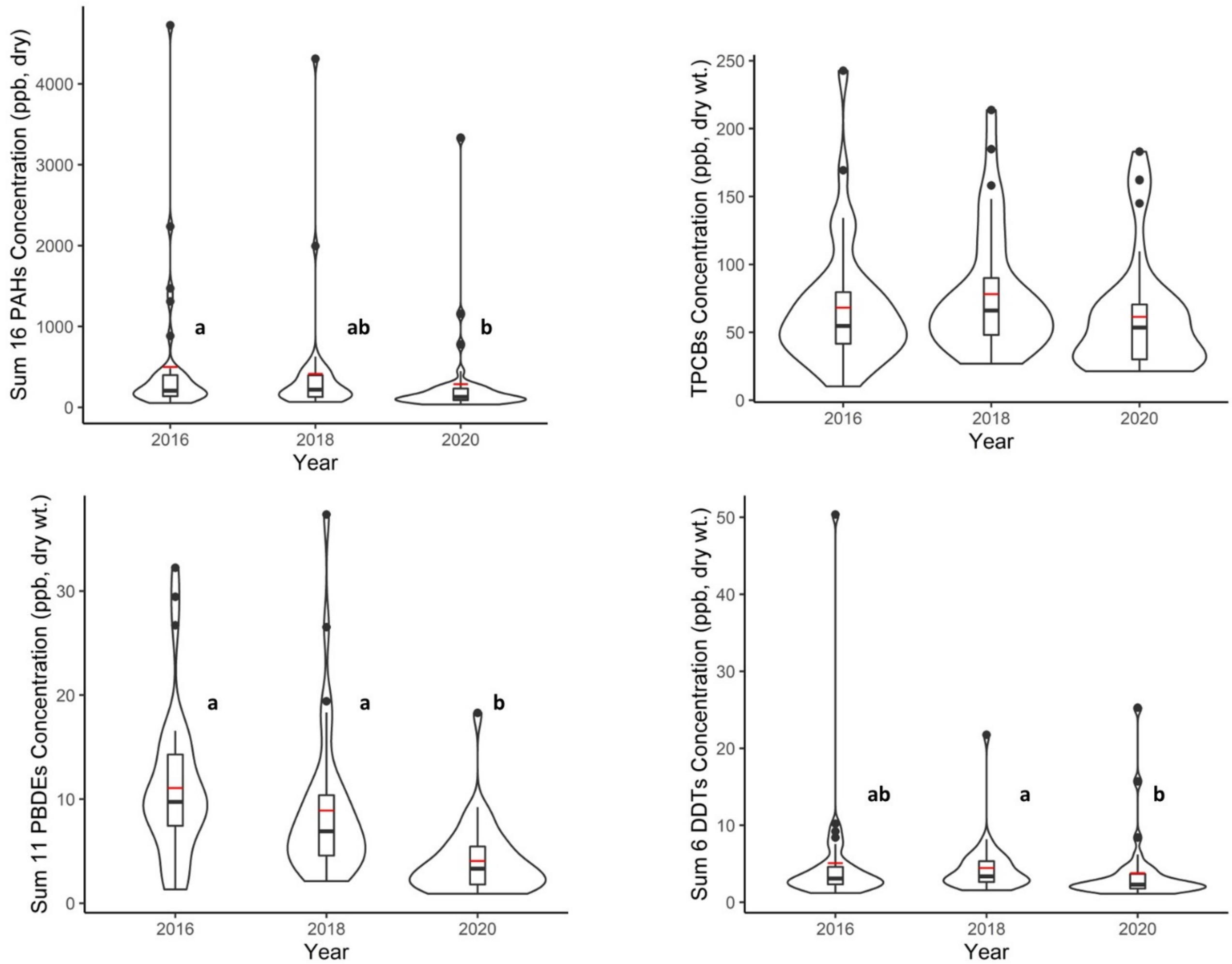

Figure 16. Comparison of key organic contaminant concentrations measured in mussels collected from 35 SAM monitoring sites with repeated visits in each of the first three SAM surveys conducted in 2016, 2018 and 2020. Box and violin plots show the distribution and density of concentrations in each year, with significant differences observed between the mean or median concentrations (log 10 transformed) in each year indicated by different letters. Box plot lower and upper hinges correspond to the 25th and 75th percentiles, black lines in box are median concentrations, red lines are mean concentrations, single black circles are outliers.

Metals

The distribution of concentration data for metals were in general more normally distributed in comparison to the organic contaminants (Figure 17). Arsenic concentrations in the UGA nearshore were variable, with a significant increase in mean concentration of arsenic between 2016 and 2018 and a subsequent decrease in concentration between 2018 and 2020 ($P < 0.001$). A significant increase in mean cadmium and zinc concentrations between both the 2016 and 2018 survey ($P < 0.001$, $P = 0.022$) and the 2016 and 2020 survey ($P < 0.001$, $P = 0.022$) was observed. Copper and mercury concentrations were lowest in the recent 2020 survey: significantly lower than in both the 2016 and 2018 surveys ($P = < 0.001$). Although a statistically significant increase (cadmium and zinc) or decrease (copper and mercury) was observed in these metal concentrations, additional sampling years are needed to infer conclusions regarding any significant trends. Lead, unlike the other metals, had a more positively skewed distribution, and tests for significant differences among mean ($F_{(2,102)} = 1.418$, $P = 0.247$) and median concentrations ($P = 0.085$) attributable to survey year were inconclusive.

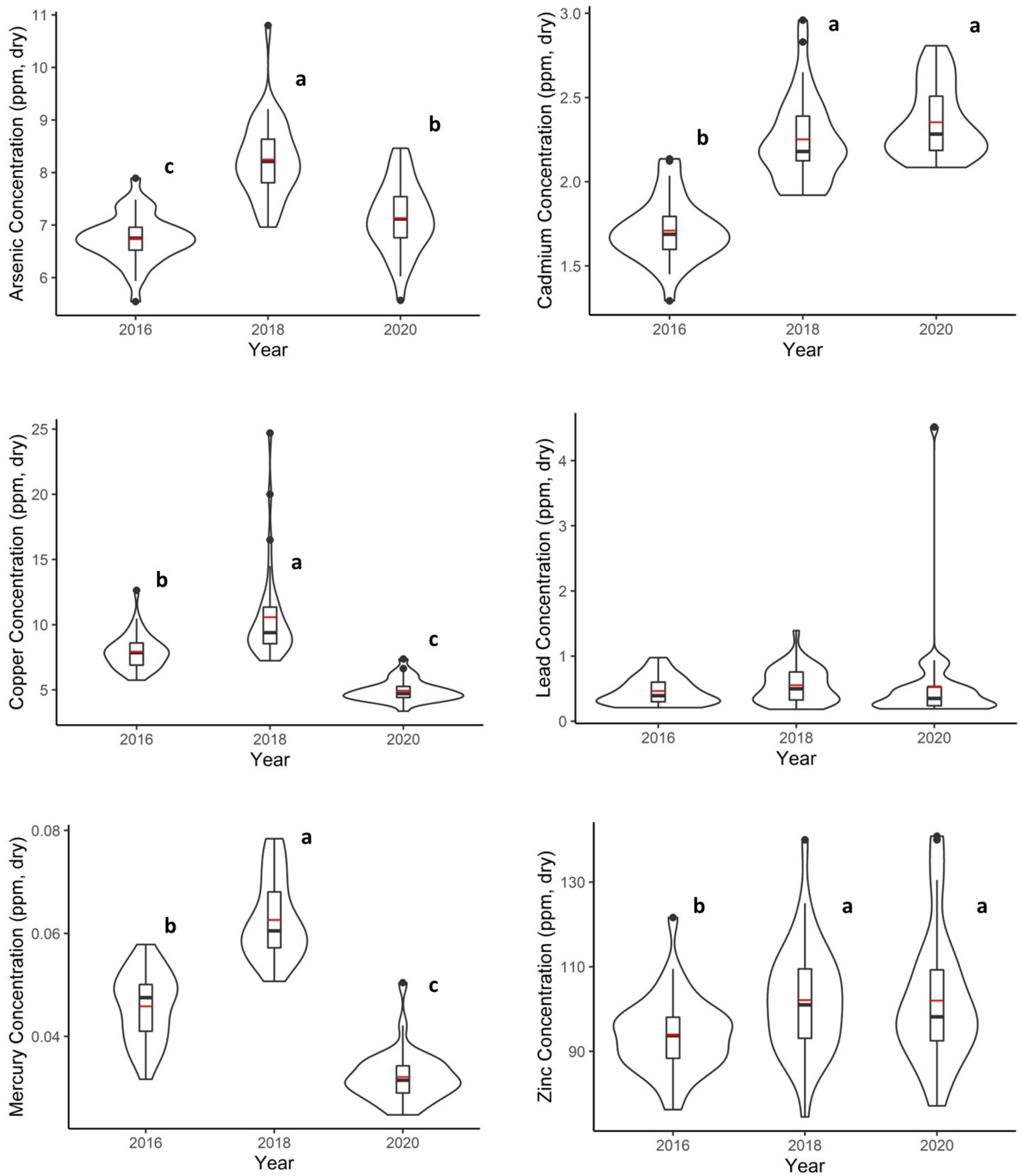

Figure 17. Comparison of metal concentrations measured in mussels collected from 35 SAM monitoring sites with repeated visits in each of the first three SAM surveys conducted in 2016, 2018 and 2020. Box and violin plots show the distribution and density of concentrations in each year, with significant differences observed between the mean concentrations (log 10 transformed) in each year indicated by different letters. Box plot lower and upper hinges correspond to the 25th and 75th percentiles, black lines in box are median concentrations, red lines are mean concentrations, single black circles are outliers.

Contaminant Concentration Changes and Nearshore Development

To further evaluate where contaminant concentration changes were occurring based on nearshore development, additional spatial analyses were performed on the organic contaminant data where significant differences among concentration means between survey years was observed. We selected only organic contaminant data because results from prior survey years showed a significant positive correlation between the average percent impervious surface (%IS) in adjacent watersheds and concentrations of all four main classes of organic contaminants (Langness and West, 2020; Lanksbury et al., 2017). Metals were omitted from this analysis as there was a weak or no correlation observed in those studies.

Analyses performed on the PAHs and PBDEs data showed significant differences among the mean concentrations between survey years. For each contaminant we evaluated significant changes in concentration between survey years within each %IS strata: least developed (<10%), low development (10 to <20%), medium development (20 to <40%), and high development (40 to 100%). The results showed that PAH concentrations were significantly lower in the 2020 survey within the medium development strata (Figure 18). The decline in 2020 PBDE concentrations occurred within the least, medium, and high development strata (Figure 19). Differences among the median DDT concentrations between survey years was observed; however, comparisons within each stratum were not significantly different (P = 0.638, P = 0.120, P = 0. 287, P = 0.620).

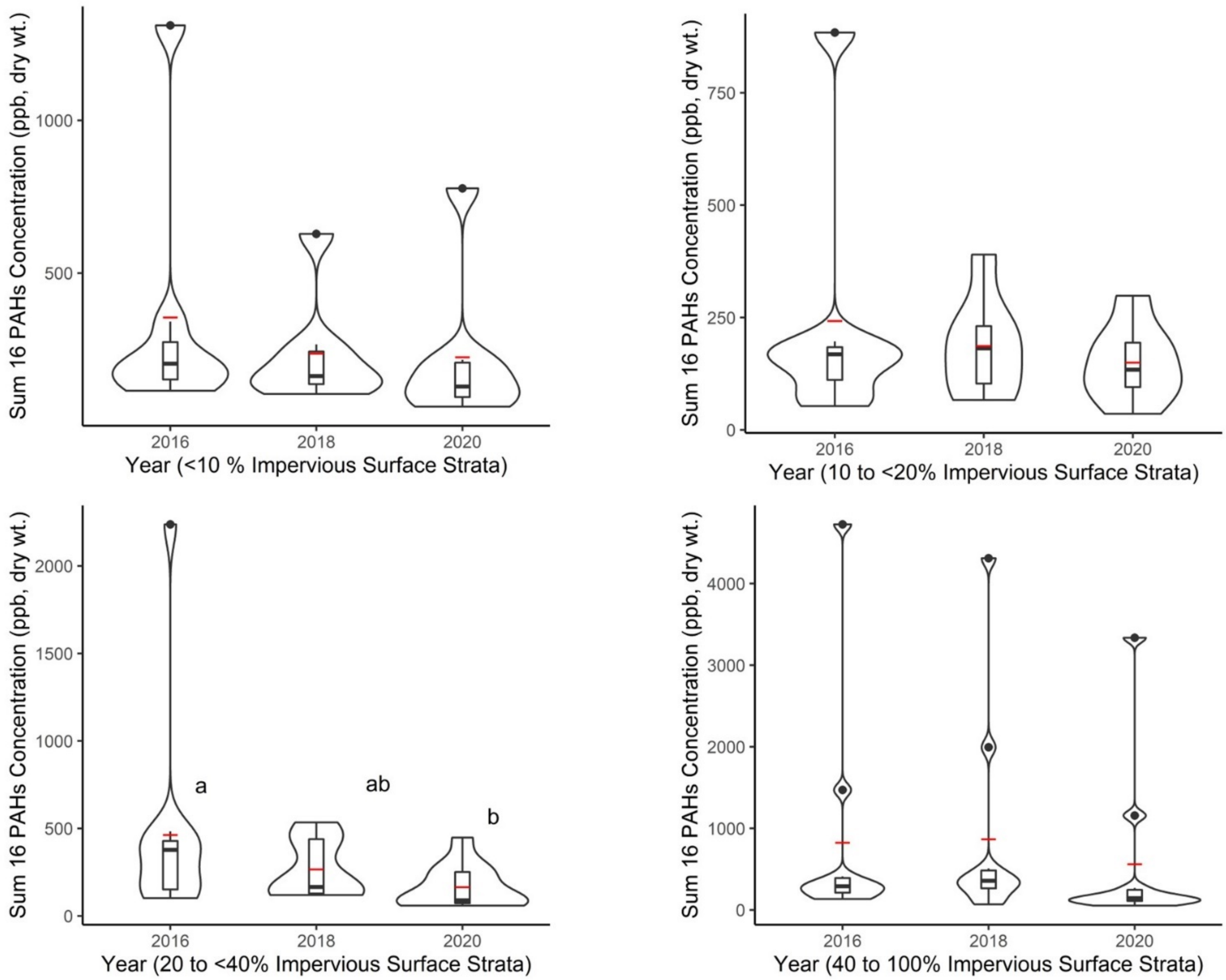

Figure 18. Comparison of PAHs concentrations between survey years within each %IS strata: least developed (<10%), low development (10 to <20%), medium development (20 to <40%), and high development (40 to 100%). Box and violin plots show the distribution and density of concentrations in each year, with significant differences observed between the mean or median concentrations (log 10 transformed) in each year indicated by different letters. Box plot lower and upper hinges correspond to the 25th and 75th percentiles, black lines in box are median concentrations, red lines are mean concentrations, single black circles are outliers.

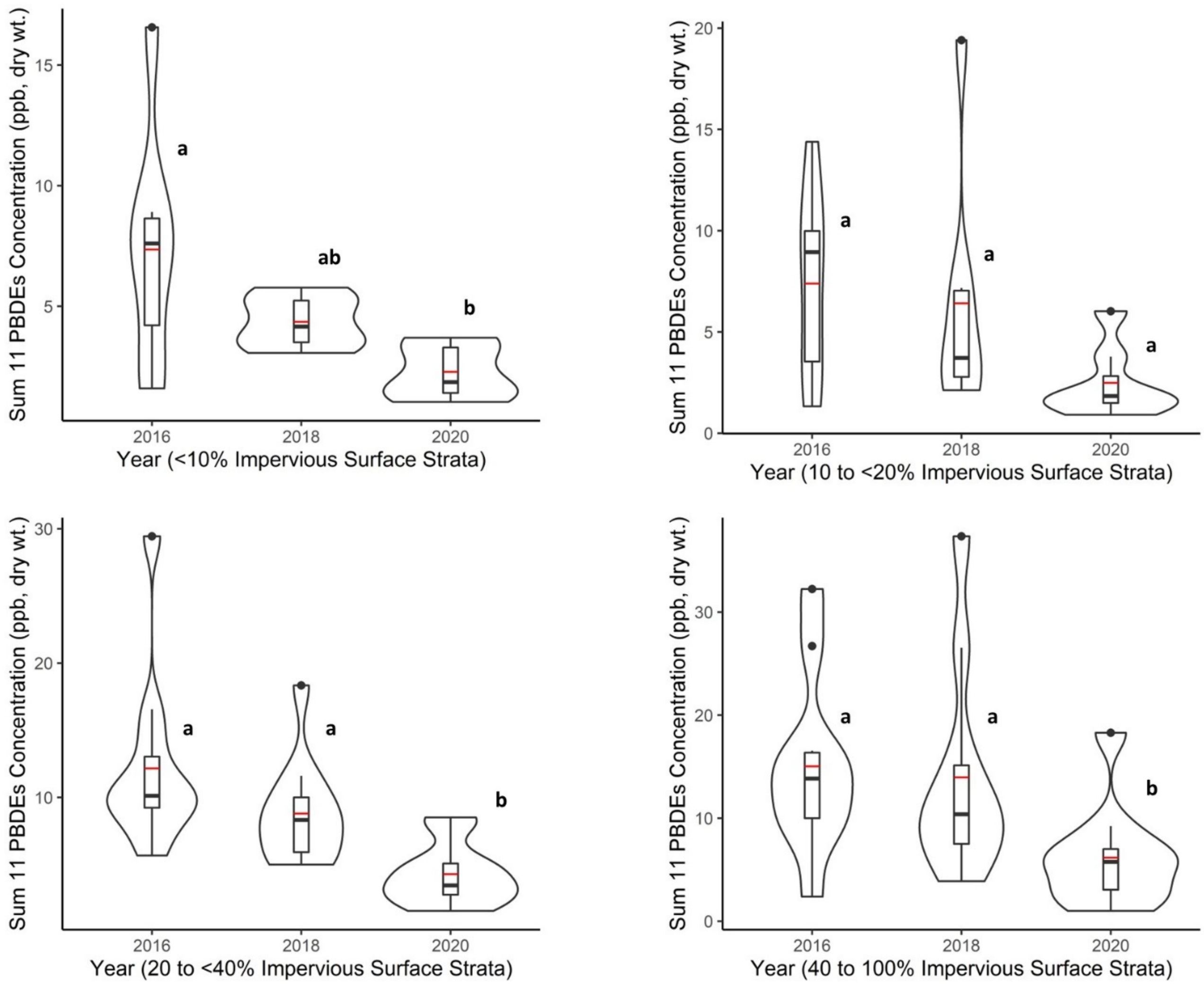

Figure 19. Comparison of PBDEs concentrations between survey years within each %IS strata: least developed (<10%), low development (10 to <20%), medium development (20 to <40%), and high development (40 to 100%). Box and violin plots show the distribution and density of concentrations in each year, with significant differences observed between the mean or median concentrations (log 10 transformed) in each year indicated by different letters. Box plot lower and upper hinges correspond to the 25th and 75th percentiles, black lines in box are median concentrations, red lines are mean concentrations, single black circles are outliers.

Conclusions

The 2019/2020 Nearshore Mussel Monitoring survey represented the third successful deployment of mussels in Puget Sound for the purpose of tracking toxic contaminants in nearshore biota. From this survey we provided the status of contamination by describing the detection frequency and distribution of contaminant concentration data, described changes in the spatial extent of key mussel contaminants inside the UGA sampling frame during the first three SAM surveys (2016, 2018, 2020), determined if observed changes in contaminant concentrations between survey years were significant, and determined where organic contaminant concentration changes were occurring based on nearshore development. From this analysis the following conclusions are drawn:

- Similar to prior survey years, $\sum_{16}$PAHs, TPCBs, $\sum_{11}$PBDEs , and $\sum_{6}$DDTs continue to be the most abundant organic contaminants detected in mussels of the Puget Sound nearshore, with Σ_{16}PAHs and TPCBs detected at 100% of the 2020 SAM sites, $\sum_{6}$DDTs at 89% of the sites, and $\sum_{11}$PBDEs at 82% of the sites.
- Similar to prior survey years, Σ_{16}PAHs had the highest central tendency and broadest range of concentrations observed in mussels from the 2020 SAM sites. TPCBs had the second highest concentrations observed followed by $\sum_{11}$PBDEs and $\sum_{6}$DDTs.
- All metals continue to be frequently detected in mussels; at 100% of the 2020 SAM sites.
- Similar to prior survey years, each metal analyte continued to have a narrow range of concentrations, with zinc having the highest central tendency concentrations observed in mussels from the 2020 SAM sites, followed in descending order by arsenic, copper, cadmium, lead, and mercury.
- The cumulative frequency distribution (CFD) patterns for Σ_{16}PAHs, $\sum_{11}$PBDEs, and $\sum_{6}$DDTs were similar in that they all were more skewed toward lower concentrations, suggesting that the majority of Puget Sound UGA shorelines have concentrations of these contaminants within the lower range and that only a few sites have much higher concentrations, perhaps from site specific point sources. The CFD pattern for TPCBs had a more gradual contaminant accumulation as the shoreline length increased, suggesting elevated exposures of this contaminant are more widely dispersed within the Puget Sound UGA shoreline.
- The spatial extent of the four most frequently detected organic contaminants concentrations in each survey year showed that the concentration of these organic contaminants in the UGA nearshore were consistently greater than the clean reference site. Most of the sampled UGA nearshore in each survey year (2016, 2018, 2020) had $\sum_{16}$PAHs, TPCBs, $\sum_{11}$PBDEs , and $\sum_{6}$DDTs concentrations above the Hood Canal reference site concentration, with the spatial extent of these contaminants showing little to no decline during the three survey years.
- The CFD patterns for most of the metals (arsenic, cadmium, mercury, and zinc) had a more gradual contaminant accumulation as the shoreline increased, suggesting elevated exposures of these metals are more widely dispersed within the Puget Sound UGA shoreline. The CFD patterns for copper and lead had a pattern more skewed to the lower concentrations, suggesting that the majority of Puget Sound UGA shorelines have concentrations of these metals within the lower

range and that only a few sites have much higher concentrations, perhaps from site specific point sources.

- The spatial extent of metal concentrations in most survey years showed that concentrations in the UGA nearshore for these contaminants were largely greater than the clean reference site. Most of the sampled UGA nearshore in two or more surveys had arsenic, cadmium, copper, lead, mercury, and zinc concentrations above the Hood Canal reference site concentration. The spatial extent of arsenic, cadmium, lead, and zinc contamination showed little to no decline during the three survey years. However, copper and mercury contamination declined between 2016 and 2020, with 87% of the UGA nearshore in the 2020 survey with copper concentrations equal to or less than the Hood Canal Reference, and 95% of UGA nearshore in the 2020 survey with mercury concentrations equal to or less than the reference.
- The central tendency concentrations of $\sum_{16}$PAHs , $\sum_{11}$PBDEs , and $\sum_{6}$DDTs in mussels were significantly lower in the 2020 survey than in the 2016 and/or 2018 survey. TPCB data were inconclusive as there was no significant difference in mean concentration values attributable to survey year. Additional sampling years are needed to infer conclusions regarding any significant trends in these organic contaminant concentrations; however, the declining $\sum_{11}$PBDEs concentrations but stable TPCB concentrations are congruent with the temporal pattern in two other WDFW-TBiOS indicator species (English sole and Pacific herring) monitored for over 20 years, and reported in the Toxics in Aquatic Life Vital Sign.
- The observed decline in $\sum_{16}$PAHs concentrations in the 2020 survey occurred within areas with a medium level of land development, where the adjacent nearshore watershed unit to a site had 20 to <40% impervious surface (IS). The decline in $\sum_{11}$PBDEs concentrations occurred within areas with the least (< 10 % IS), medium (20 to < 40 % IS), and high levels of development (40 to 100 % IS).
- Cadmium and zinc concentrations in mussels were significantly higher in the 2018 and 2020 surveys than the 2016 survey, while copper and mercury concentrations were significantly lower in the 2020 survey than in both the 2016 and 2018 surveys. Although a statistically significant increase or decrease was observed in these metal concentrations, additional sampling years are needed to infer conclusions regarding any significant trends.
- Arsenic concentrations in mussels significantly increased in the 2018 survey and then decreased in the 2020 survey, indicating variable concentration conditions of these metals in the UGA nearshore.
- There was no significant difference in mean concentration values of lead attributable to survey year.

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Appendix A: Dry and Wet Weight Concentrations of Organic Contaminants in Mussels at SAM Sites

* Mean of three replicate samples from Penn Cove, Whidbey Island aquaculture facility, the source of mussels for this effort (i.e., starting condition)

< Indicates the concentration was not measured above the limit of quantitation (LOQ), which is the value reported instead

Table A- 1. Dry weight concentrations (ng/g) of organic contaminants in mussels at each 2019-2020 SAM mussel monitoring site.

Site Type	Site ID	Site Name	Concentrations in ng/g, dry weight (ppb)							
			$\sum$16PAHs	TPCBs	$\sum_{11}$PBDEs	$\sum_6$ DDTs	$\sum_8$ Chlordanes	$\sum_3$ HCHs	Dieldrin	Mirex
Baseline	PCB_MEAN	Penn Cove, Pre-test Baseline Mean	7.81	54.1	<1.3	<1.32	<1.3	<1.3	<1.3	<1.3
Reference	WB_PCR	Penn Cove Reference	52	80.2	<1.23	1.73	<1.23	<1.23	<1.23	<1.23
Reference	HC_HO	Hood Canal, Holly	40.1	51.6	<1.34	<1.34	<1.34	<1.34	<1.34	<1.34
Monitoring	Site #2	Arroyo Beach	157	29.5	6.23	1.92	<1.3	<1.3	<1.3	<1.3
Monitoring	Site #3	Brackenwood Ln	198	53.5	3.69	2.68	<0.701	<0.701	0.828	<0.701
Monitoring	Site #4	Cherry Point North	216	32.7	1.44	1.7	<0.98	<0.98	<0.98	<0.98
Monitoring	Site #5	Salmon Beach	134	28.8	1.84	<1.72	<1.72	<1.72	<1.72	<1.72
Monitoring	Site #6	Eagle Harbor Dr	777	145	3.62	8.41	1.09	<0.797	1.01	3.84
Monitoring	Site #8	Chimacum Creek Delta	35.8	26	<0.909	1.1	<0.909	<0.909	<0.909	<0.909
Monitoring	Site #10	Fletcher Bay, Fox Cove	121	70.5	2.95	3.4	<0.628	<0.628	1.15	<0.628
Monitoring	Site #11	South Bay Trail	109	30.7	2.93	2.29	<1.07	<1.07	1.79	<1.07
Monitoring	Site #13	Ruston Way	98.1	58.3	5.58	3.37	<0.92	<0.859	0.982	<0.92
Monitoring	Site #14	Point Heron East	58.9	63.3	3.33	2.04	<1.16	<1.16	<1.16	<1.16
Monitoring	Site #15	Tugboat Park	110	27.5	1	1.44	<0.875	<0.875	<0.875	<0.875
Monitoring	Site #16	Meadowdale Beach	133	56.5	8.05	4.78	1.88	0.552	0.974	0.442
Monitoring	Site #17	Budd Inlet, West Bay	89.8	35.4	2.32	2.01	<1.1	<1.1	<1.1	<1.1
Monitoring	Site #18	Seahurst	71.5	37.4	4.52	4.06	1.03	<0.968	<0.968	<0.968
Monitoring	Site #19	Skiff Point	192	44.9	3.78	2.44	<0.962	<0.962	<0.962	<0.962
Monitoring	Site #21	Point Defiance Ferry	250	62.9	4.84	3.96	<0.881	<0.881	<0.881	<0.881
Monitoring	Site #22	Beach Dr E	100	79.5	6.03	2.38	<1.32	<1.32	<1.32	<1.32
Monitoring	Site #23	Wing Point	448	70.5	5.32	4.23	1.28	<1.22	<1.22	1.54
Monitoring	Site #24	S of Skunk Island	67.2	21.3	<1.03	1.29	<1.03	<1.03	<1.03	<1.03

Monitoring	Site #25	Blair Waterway	130	32.9	18.3	6.2	1.65	<1.27	<1.2	<1.27
Monitoring	Site #26	N of Illahee State Park	73.7	66.7	3.45	2.24	<1.09	<1.09	<1.09	<1.09
Monitoring	Site #27	Chuckanut, Clark's Point	63	25.2	<1.37	1.98	<1.37	<1.37	<1.37	<1.37
Monitoring	Site #29	Liberty Bay	270	59.2	3.4	2.52	<1.22	<1.22	<1.22	<1.22
Monitoring	Site #30	Kitsap St Boat Launch	252	162	8.51	4.87	<1.23	<1.23	<1.23	<1.23
Monitoring	Site #31	East Sound, Fishing Bay	196	21.3	<1.29	<1.29	<1.29	<1.29	<1.29	<1.29
Monitoring	Site #34	Elliott Bay, Harbor Island, Pier 17	1440	169	5.71	10.9	2.27	<1.3	2.27	<1.3
Monitoring	Site #35	Williams Olson Park	129	76.9	1.86	2.31	<1.28	<1.28	<1.28	<1.28
Monitoring	Site #37	Saltar's Point	52.4	25.2	<1.77	<1.77	<1.77	<1.77	<1.77	<1.77
Monitoring	Site #38	Rocky Point	89.8	84.4	2.01	2.21	<1.23	<1.23	<1.23	<1.23
Monitoring	Site #39	Smith Cove, Terminal 91	3340	183	9.23	25.3	5.28	<1.41	2.32	12
Monitoring	Site #42	Evergreen Rotary Park	173	110	5.94	2.9	<1.23	<1.23	<1.23	<1.23
Monitoring	Site #43	N Avenue Park	1160	41	7.27	15.7	2.73	1.24	<0.994	<0.994
Monitoring	Site #46	Appletree Cove	90.3	34	1.86	1.6	<1.35	<1.35	<1.35	<1.35
Monitoring	Site #47	Cherry Point Aq Reserve, Birch Bay	298	23.8	<1.69	<1.69	<1.69	<1.69	<1.62	<1.69
Monitoring	Site #48	Naketa Beach	72.3	66.3	3.19	1.81	<1.39	<1.39	<1.33	<1.39
Monitoring	Site #49	Donkey Creek Delta	268	162	1.55	2.82	<1.34	<1.34	<1.34	<1.34
Monitoring	Site #54	Dyes Inlet, Chico Bay	107	127	1.45	2.71	<1.39	<1.39	<1.39	<1.39
Monitoring	Site #56	Fidalgo Island, Swinomish Res	22	65.2	<1.7	1.77	<1.7	<1.7	<1.7	<1.7

Table A- 2. Wet weight concentrations (ng/g) of organic contaminants in mussels at each 2019-2020 SAM mussel monitoring site.

Site Type	Site ID	Site Name	Concentrations in ng/g, wet weight (ppb)							
			$\sum_{16}$PAHs	TPCBs	∑11PBDEs	∑6 DDTs	∑8 Chlordanes	∑3 HCHs	Dieldrin	Mirex
Baseline	PCB_MEAN	Penn Cove, Pre-test Baseline Mean	1.4	9.7	<0.233	<0.237	<0.233	<0.233	<0.233	<0.233
Reference	WB_PCR	Penn Cove Reference	8.42	13	<0.2	0.28	<0.2	<0.2	<0.2	<0.2
Reference	HC_HO	Hood Canal, Holly	6.3	8.1	<0.21	<0.21	<0.21	<0.21	<0.21	<0.21
Monitoring	Site #2	Arroyo Beach	22.9	4.3	0.91	0.28	<0.19	<0.19	<0.19	<0.19
Monitoring	Site #3	Brackenwood Ln	31.1	8.4	0.58	0.42	<0.11	<0.11	0.13	<0.11
Monitoring	Site #4	Cherry Point North	33.1	5	0.22	0.26	<0.15	<0.15	<0.15	<0.15
Monitoring	Site #5	Salmon Beach	21.9	4.7	0.3	<0.28	<0.28	<0.28	<0.28	<0.28
Monitoring	Site #6	Eagle Harbor Dr	107	20	0.5	1.16	0.15	<0.11	0.14	0.53
Monitoring	Site #8	Chimacum Creek Delta	5.51	4	<0.14	0.17	<0.14	<0.14	<0.14	<0.14
Monitoring	Site #10	Fletcher Bay, Fox Cove	18.9	11	0.46	0.53	<0.098	<0.098	0.18	<0.098
Monitoring	Site #11	South Bay Trail	15.2	4.3	0.41	0.32	<0.15	<0.15	0.25	<0.15
Monitoring	Site #13	Ruston Way	16	9.5	0.91	0.55	<0.15	<0.14	0.16	<0.15
Monitoring	Site #14	Point Heron East	8.66	9.3	0.49	0.3	<0.17	<0.17	<0.17	<0.17
Monitoring	Site #15	Tugboat Park	17.6	4.4	0.16	0.23	<0.14	<0.14	<0.14	<0.14
Monitoring	Site #16	Meadowdale Beach	20.5	8.7	1.24	0.736	0.29	0.085	0.15	0.068
Monitoring	Site #17	Budd Inlet, West Bay	14.7	5.8	0.38	0.33	<0.18	<0.18	<0.18	<0.18
Monitoring	Site #18	Seahurst	11.1	5.8	0.7	0.63	0.16	<0.15	<0.15	<0.15
Monitoring	Site #19	Skiff Point	30	7	0.59	0.38	<0.15	<0.15	<0.15	<0.15
Monitoring	Site #21	Point Defiance Ferry	39.8	10	0.77	0.63	<0.14	<0.14	<0.14	<0.14
Monitoring	Site #22	Beach Dr E	15.2	12	0.91	0.36	<0.2	<0.2	<0.2	<0.2
Monitoring	Site #23	Wing Point	69.8	11	0.83	0.66	0.2	<0.19	<0.19	0.24
Monitoring	Site #24	S of Skunk Island	10.4	3.3	<0.16	0.2	<0.16	<0.16	<0.16	<0.16
Monitoring	Site #25	Blair Waterway	20.5	5.2	2.89	0.98	0.26	<0.2	<0.19	<0.2
Monitoring	Site #26	N of Illahee State Park	12.2	11	0.57	0.37	<0.18	<0.18	<0.18	<0.18
Monitoring	Site #27	Chuckanut, Clark's Point	8.25	3.3	<0.18	0.26	<0.18	<0.18	<0.18	<0.18
Monitoring	Site #29	Liberty Bay	39.7	8.7	0.5	0.37	<0.18	<0.18	<0.18	<0.18
Monitoring	Site #30	Kitsap St Boat Launch	38.8	25	1.31	0.75	<0.19	<0.19	<0.19	<0.19

Monitoring	Site #31	East Sound, Fishing Bay	30.3	3.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Monitoring	Site #34	Elliott Bay, Harbor Island, Pier 17	222	26	0.88	1.68	0.35	<0.2	0.35	<0.2
Monitoring	Site #35	Williams Olson Park	20.1	12	0.29	0.36	<0.2	<0.2	<0.2	<0.2
Monitoring	Site #37	Saltar's Point	7.7	3.7	<0.26	<0.26	<0.26	<0.26	<0.26	<0.26
Monitoring	Site #38	Rocky Point	13.8	13	0.31	0.34	<0.19	<0.19	<0.19	<0.19
Monitoring	Site #39	Smith Cove, Terminal 91	474	26	1.31	3.59	0.75	<0.2	0.33	1.7
Monitoring	Site #42	Evergreen Rotary Park	26.8	17	0.92	0.45	<0.19	<0.19	<0.19	<0.19
Monitoring	Site #43	N Avenue Park	186	6.6	1.17	2.53	0.44	0.2	<0.16	<0.16
Monitoring	Site #46	Appletree Cove	14.1	5.3	0.29	0.25	<0.21	<0.21	<0.21	<0.21
Monitoring	Site #47	Cherry Point Aq Reserve, Birch Bay	38.8	3.1	<0.22	<0.22	<0.22	<0.22	<0.21	<0.22
Monitoring	Site #48	Naketa Beach	12	11	0.53	0.3	<0.23	<0.23	<0.22	<0.23
Monitoring	Site #49	Donkey Creek Delta	38.1	23	0.22	0.4	<0.19	<0.19	<0.19	<0.19
Monitoring	Site #54	Dyes Inlet, Chico Bay	17.8	21	0.24	0.45	<0.23	<0.23	<0.23	<0.23
Monitoring	Site #56	Fidalgo Island, Swinomish Res	3.1	9.2	<0.24	0.25	<0.24	<0.24	<0.24	<0.24

Appendix B: Dry and Wet Weight Concentrations of Metals in Mussels at SAM Sites

* Mean of three replicate samples from Penn Cove, Whidbey Island aquaculture facility, the source of mussels for this effort (i.e., starting condition)
< Indicates the concentration was not measured above the reporting detection limit (RDL), which is the value reported instead
NT = Not tested; sample was not submitted for metals analysis due to lack of funding

Table B - 1. Dry weight concentrations (mg/kg) of metals in mussels at each SAM mussel monitoring site.

Site Type	Site ID	Site Name	Concentrations in mg/kg, dry weight (ppm)					
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
Baseline	PCB_MEAN	Penn Cove, Pre-test Baseline Mean	6.59	2.45	4.49	0.142	0.0177	88.1
Reference	WB_PCR	Penn Cove Reference	7.22	2.1	5.43	0.241	0.0302	92
Reference	HC_HO	Hood Canal, Holly	6.86	2.25	5.17	0.113	0.0304	93.5
Monitoring	Site #2	Arroyo Beach	7.42	2.62	4.97	0.47	0.0334	96.7
Monitoring	Site #3	Brackenwood Ln	7.78	2.49	4.9	0.203	0.0364	95.1
Monitoring	Site #4	Cherry Point North	6.73	2.19	4.01	0.198	0.0271	85.9
Monitoring	Site #5	Salmon Beach	5.57	2.44	3.37	0.189	0.0248	77.1
Monitoring	Site #6	Eagle Harbor Dr	7.68	2.7	6.63	0.93	0.0504	106
Monitoring	Site #8	Chimacum Creek Delta	6.21	2.21	4.04	0.225	0.0304	94.3
Monitoring	Site #10	Fletcher Bay, Fox Cove	7.04	2.19	5.07	0.423	0.0315	101
Monitoring	Site #11	South Bay Trail	7.13	2.23	4.72	4.52	0.032	102
Monitoring	Site #13	Ruston Way	6.37	2.3	4.46	0.349	0.0283	86.9
Monitoring	Site #14	Point Heron East	6.62	2.19	4.26	0.421	0.0319	97.4
Monitoring	Site #15	Tugboat Park	6.79	2.08	4.4	0.239	0.0254	91.5
Monitoring	Site #16	Meadowdale Beach	6.71	2.19	4.44	0.237	0.0311	98.7
Monitoring	Site #17	Budd Inlet, West Bay	6.95	2.17	5.05	0.251	0.0307	85
Monitoring	Site #18	Seahurst	6.81	2.28	4.56	0.298	0.0316	95
Monitoring	Site #19	Skiff Point	7.41	2.14	4.62	0.246	0.0304	90.7
Monitoring	Site #21	Point Defiance Ferry	6.28	2.77	5.4	0.524	0.0277	141
Monitoring	Site #22	Beach Dr E	6.88	2.29	5.12	0.508	0.0353	111

Monitoring	Site #23	Wing Point	7.35	2.15	5.37	0.351	0.0356	117
Monitoring	Site #24	S of Skunk Island	6.42	2.13	4.6	0.521	0.0287	95
Monitoring	Site #25	Blair Waterway	6.02	2.14	4.18	0.22	0.0305	79.5
Monitoring	Site #26	N of Illahee State Park	7.12	2.36	4.08	0.45	0.0366	101
Monitoring	Site #27	Chuckanut, Clark's Point	8	2.81	4.67	0.243	0.0315	103
Monitoring	Site #29	Liberty Bay	6.89	2.28	5.78	0.606	0.0341	116
Monitoring	Site #30	Kitsap St Boat Launch	6.84	2.25	6.35	0.91	0.0337	130
Monitoring	Site #31	East Sound, Fishing Bay	7.69	2.27	4.22	0.299	0.0278	97.4
Monitoring	Site #34	Elliott Bay, Harbor Island, Pier 17	6.94	2.51	6.75	0.418	0.0263	109
Monitoring	Site #35	Williams Olson Park	8.29	2.32	5.6	0.525	0.0344	91.8
Monitoring	Site #37	Saltar's Point	7.21	2.62	4.26	0.224	0.0293	87.1
Monitoring	Site #38	Rocky Point	7.39	2.17	5.15	0.501	0.0314	107
Monitoring	Site #39	Smith Cove, Terminal 91	7.45	2.7	7.38	0.851	0.035	130
Monitoring	Site #42	Evergreen Rotary Park	8	2.52	6.08	0.935	0.0421	140
Monitoring	Site #43	N Avenue Park	7.04	2.45	4.62	0.458	0.0259	108
Monitoring	Site #46	Appletree Cove	7.18	2.35	5.08	0.244	0.0301	111
Monitoring	Site #47	Cherry Point Aq Reserve, Birch Bay	8.27	2.55	4.55	0.198	0.0357	93.2
Monitoring	Site #48	Naketa Beach	7.64	2.15	4.77	0.215	0.0288	98.2
Monitoring	Site #49	Donkey Creek Delta	8.46	2.69	6.11	0.755	0.0341	110
Monitoring	Site #54	Dyes Inlet, Chico Bay	7.78	2.12	5.36	0.654	0.0339	110
Monitoring	Site #56	Fidalgo Island, Swinomish Res	7.18	2.22	5.15	0.267	0.0308	85.2

Table B - 2. Wet weight concentrations (mg/kg) of metals in mussels at each SAM mussel monitoring site.

Site Type	Site ID	Site Name	Concentrations in mg/kg, wet weight (ppm)					
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
Baseline	PCB_MEAN	Penn Cove, Pre-test Baseline Mean	1.19	0.443	0.813	0.0257	0.00321	15.9
Reference	WB_PCR	Penn Cove Reference	1.17	0.34	0.879	0.0391	0.00489	14.9
Reference	HC_HO	Hood Canal, Holly	1.05	0.345	0.791	0.0173	0.00465	14.3
Monitoring	Site #2	Arroyo Beach	1.12	0.396	0.751	0.0709	0.00505	14.6
Monitoring	Site #3	Brackenwood Ln	1.26	0.404	0.793	0.0329	0.00589	15.4
Monitoring	Site #4	Cherry Point North	1.05	0.341	0.626	0.0309	0.00423	13.4
Monitoring	Site #5	Salmon Beach	0.924	0.405	0.559	0.0314	0.00411	12.8
Monitoring	Site #6	Eagle Harbor Dr	1.09	0.383	0.942	0.132	0.00716	15
Monitoring	Site #8	Chimacum Creek Delta	0.981	0.349	0.638	0.0356	0.00481	14.9
Monitoring	Site #10	Fletcher Bay, Fox Cove	1.12	0.348	0.806	0.0672	0.00501	16.1
Monitoring	Site #11	South Bay Trail	1.02	0.319	0.675	0.646	0.00458	14.6
Monitoring	Site #13	Ruston Way	1.07	0.387	0.749	0.0586	0.00476	14.6
Monitoring	Site #14	Point Heron East	1	0.33	0.643	0.0635	0.00482	14.7
Monitoring	Site #15	Tugboat Park	1.12	0.344	0.726	0.0394	0.00419	15.1
Monitoring	Site #16	Meadowdale Beach	1.06	0.346	0.701	0.0374	0.00492	15.6
Monitoring	Site #17	Budd Inlet, West Bay	1.16	0.363	0.844	0.0419	0.00512	14.2
Monitoring	Site #18	Seahurst	1.09	0.365	0.73	0.0477	0.00506	15.2
Monitoring	Site #19	Skiff Point	1.2	0.346	0.748	0.0399	0.00492	14.7
Monitoring	Site #21	Point Defiance Ferry	1.03	0.455	0.885	0.086	0.00454	23.1
Monitoring	Site #22	Beach Dr E	1.08	0.359	0.804	0.0797	0.00554	17.4
Monitoring	Site #23	Wing Point	1.19	0.348	0.87	0.0569	0.00576	18.9
Monitoring	Site #24	S of Skunk Island	1.02	0.339	0.731	0.0828	0.00456	15.1
Monitoring	Site #25	Blair Waterway	0.97	0.344	0.673	0.0355	0.00491	12.8
Monitoring	Site #26	N of Illahee State Park	1.21	0.401	0.694	0.0765	0.00623	17.1
Monitoring	Site #27	Chuckanut, Clark's Point	1.04	0.365	0.607	0.0316	0.0041	13.4
Monitoring	Site #29	Liberty Bay	1.02	0.338	0.855	0.0897	0.00505	17.1
Monitoring	Site #30	Kitsap St Boat Launch	1.06	0.348	0.984	0.141	0.00522	20.2
Monitoring	Site #31	East Sound, Fishing Bay	1.2	0.354	0.658	0.0467	0.00434	15.2
Monitoring	Site #34	Elliott Bay, Harbor Island, Pier 17	1.09	0.394	1.06	0.0657	0.00413	17.1

Monitoring	Site #35	Williams Olson Park	1.31	0.367	0.885	0.0829	0.00544	14.5
Monitoring	Site #37	Saltar's Point	1.06	0.385	0.626	0.0329	0.0043	12.8
Monitoring	Site #38	Rocky Point	1.16	0.341	0.809	0.0787	0.00493	16.8
Monitoring	Site #39	Smith Cove, Terminal 91	1.05	0.38	1.04	0.12	0.00494	18.4
Monitoring	Site #42	Evergreen Rotary Park	1.24	0.391	0.942	0.145	0.00653	21.7
Monitoring	Site #43	N Avenue Park	1.14	0.397	0.748	0.0742	0.0042	17.5
Monitoring	Site #46	Appletree Cove	1.12	0.367	0.793	0.038	0.0047	17.3
Monitoring	Site #47	Cherry Point Aq Reserve, Birch Bay	1.1	0.339	0.605	0.0263	0.00475	12.4
Monitoring	Site #48	Naketa Beach	1.26	0.354	0.787	0.0354	0.00475	16.2
Monitoring	Site #49	Donkey Creek Delta	1.21	0.384	0.874	0.108	0.00488	15.8
Monitoring	Site #54	Dyes Inlet, Chico Bay	1.26	0.343	0.868	0.106	0.00549	17.8
Monitoring	Site #56	Fidalgo Island, Swinomish Res	1.02	0.315	0.731	0.0379	0.00438	12.1

Appendix C: Partner Site Location and Contaminant Concentration Data

Table C- 1. Site location information for forty-seven (47) partner Nearshore Mussel Monitoring sites in the 2019-2020 survey. Map IDs are used to identify sites in Figure C- 1.

Map ID	Site ID	Site Name	Latitude	Longitude	County	Sponsor
1	WBNA	Nahcotta	46.49548	-124.02650	Pacific	NOAA-NCCOS
2	GHWJ	Westport Jetty	46.91222	-124.11757	Pacific	NOAA-NCCOS
3	SSBI	Budd Inlet	47.09898	-122.89488	Thurston	NOAA-NCCOS
4	CBTP	Tahlequah Point	47.33249	-122.50813	King	NOAA-NCCOS
5	PSSS	South Seattle	47.52993	-122.40157	King	NOAA-NCCOS
6	SIWP	Waterman Point	47.58443	-122.56737	Kitsap	NOAA-NCCOS
7	EBDH	Duwamish Head	47.59543	-122.38760	King	NOAA-NCCOS
8	EBFR	Four-Mile Rock	47.63874	-122.41330	King	NOAA-NCCOS
9	PSEF	Edmonds Ferry	47.81425	-122.38235	Snohomish	NOAA-NCCOS
10	PSHC	Hood Canal	47.83244	-122.68713	Jefferson	NOAA-NCCOS
11	WIPP	Possession Point	47.90535	-122.37787	Island	NOAA-NCCOS
12	PSMF	Mukilteo	47.94990	-122.30190	Snohomish	NOAA-NCCOS
13	PSEH	Everett Harbor	47.97280	-122.22984	Snohomish	NOAA-NCCOS
14	PSPT	Port Townsend	48.10439	-122.77840	Jefferson	NOAA-NCCOS
15	PSCC	Cavalero County Park	48.17611	-122.47883	Island	NOAA-NCCOS
16	BBSM	Squalicum Marina	48.75360	-122.49890	Whatcom	NOAA-NCCOS
17	PSKP	Kayak Point	48.13400	-122.36600	Snohomish	NOAA-NCCOS
18	PSTB	Tulalip Bay	48.06170	-122.29293	Snohomish	NOAA-NCCOS
19	PSEM	Edmonds Marina	47.81092	-122.38808	Snohomish	NOAA-NCCOS
20	CB_CBSW	Comm Bay Skookum	47.28950	-122.40853	Pierce	WDFW-TBiOS
21	CB_CBTF	Thea Foss Waterway	47.25930	-122.43480	Pierce	WDFW-TBiOS
22	CPS_PNP	Point No Point	47.90739	-122.52585	Kitsap	WDFW-TBiOS
23	CPS_QMH	Quartermaster Harbor	47.40493	-122.43991	King	WDFW-TBiOS
24	CPS_SB	Salmon Bay, Commodore Park	47.66630	-122.40180	King	WDFW-TBiOS
25	EB_P59	Seattle Aquarium, Pier 59	47.60734	-122.34368	King	WDFW-TBiOS
26	HC_HO	Hood Canal Holly	47.57060	-122.97170	Kitsap	WDFW-TBiOS
27	NPS_CPAR4	Cherry Point Aq Reserve, Conoco Phillips	48.82092	-122.71016	Whatcom	WDFW-TBiOS
28	SPS_SH	Shelton	47.21563	-123.08428	Mason	WDFW-TBiOS
29	CPS_EMB	Edmonds Marina Beach	47.80618	-122.39589	Snohomish	WDFW-TBiOS
30	PAC_TYB	Tsooyess Beach	48.31898	-124.66851	Clallam	Local-Makah Tribe
31	SJD_NBM	Neah Bay Marina	48.37637	-124.62948	Clallam	Local-Makah Tribe
32	AI_OB	Oak Bay County Park	48.02257	-122.72717	Jefferson	Local-Jefferson Co. Environmental Health
33	AI_MMB	Mats Bay Boat Ramp	47.95118	-122.68673	Jefferson	Local-Jefferson Co. Environmental Health
34	CPS_RP	Rich Passage	47.57808	-122.52489	Kitsap	Local-Rich Passage Est. Homeowners Ass.

35	SPS_HIMP	Meyer's Point - Henderson Inlet	47.11794	-122.83356	Thurston	Local-Bainbridge Beach Naturalists
36	SPS_PBL	Purdy, Burley Lagoon	47.38702	-122.63670	Pierce	Local-Bainbridge Beach Naturalists
37	NPS_BLSC	Bellingham Little Squalicum Creek	48.76390	-122.51750	Whatcom	Local-City of Bellingham
38	NPS_FBAR	Fidalgo Bay Aq Reserve, Weaverling Spit	48.48259	-122.58394	Skagit	Local-DNR Aquatic Reserves
39	SJD_JSK	Jamestown	48.02700	-122.99900	Clallam	Local-Jamestown S'Klallam Tribe
40	CPS_SHLB	Shilshole Bay	47.67168	-122.40666	King	Local-King Co.
41	EB_ME	Elliot Bay Myrtle Edwards	47.61854	-122.36101	King	Local-King Co.
42	CPS_MASO	Manchester, Stormwater Outfall	47.55626	-122.54283	Kitsap	Local-Kitsap Co.
43	CPS_SQSO	Suquamish, Stormwater Outfall	47.72940	-122.55060	Kitsap	Local-Kitsap Co.
44	WPS_SVD	Silverdale, Dyes Inlet	47.64278	-122.69667	Kitsap	Local-Kitsap Co.
45	CPS_KM	Kingston Marina	47.79690	-122.50140	Kitsap	Local-Kitsap Co.
46	CB_DGL	Comm Bay, Dick Gilmur Launch	47.29230	-122.41180	Pierce	Local-Port of Tacoma
47	CB_MW	Comm Bay, Milwaukee Waterway	47.27000	-122.42000	Pierce	Local-Port of Tacoma

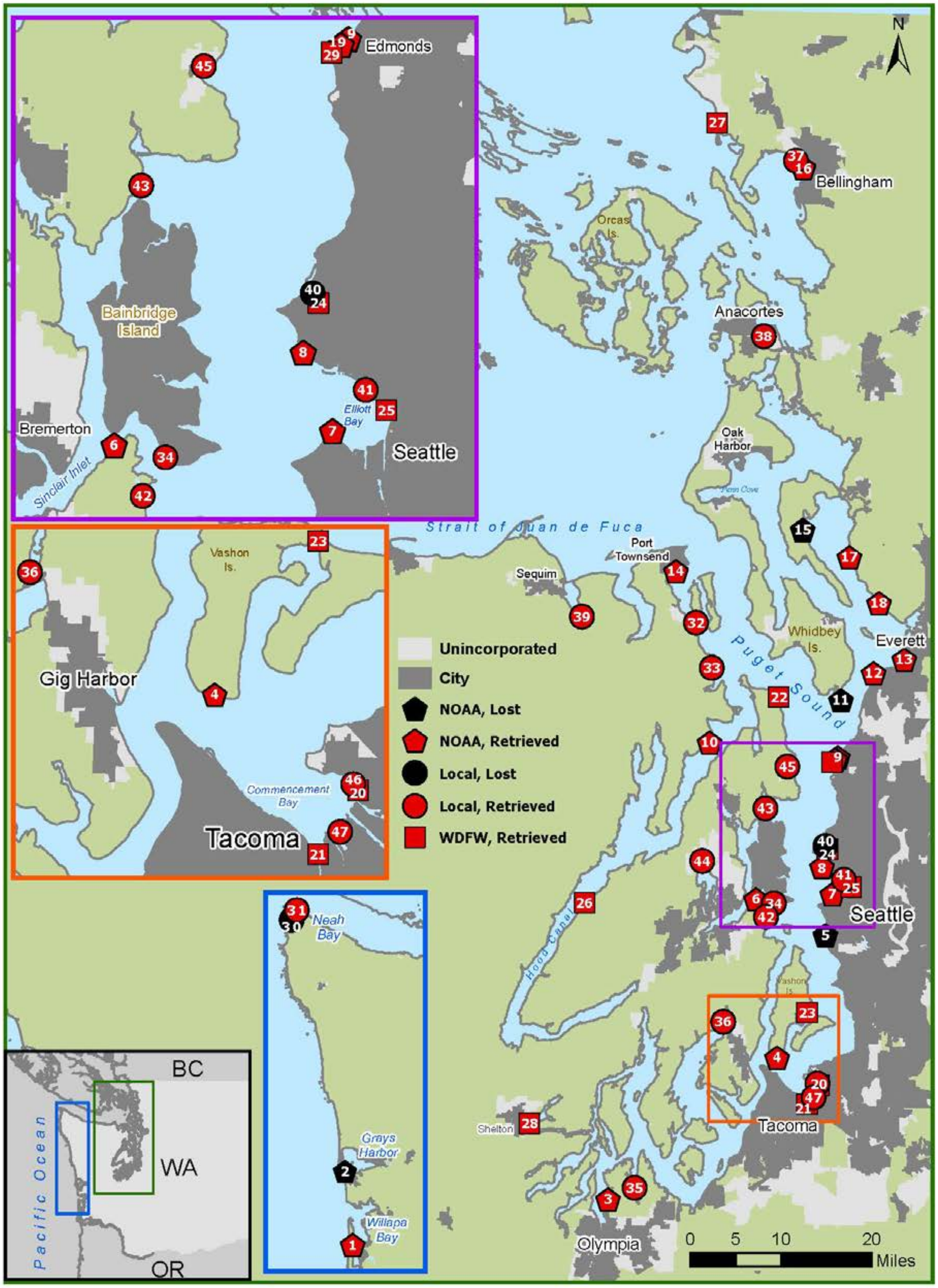

Figure C- 1. Nearshore mussel monitoring sites in the Puget Sound and Washington Pacific Coast. Site labels correspond to the "Map ID" column in Table C-1. Grey shading on land represents municipal land-use designations based on urban growth area (UGA) boundaries; dark grey representing City UGA and light grey representing Unincorporated UGA.

Wet Weight Concentrations of Organic Contaminants in Mussels at Partner Sites

< Indicates the concentration was not measured above the limit of quantitation (LOQ), which is the value reported instead

Table C- 2. Wet weight concentrations (ng/g) of organic contaminants in mussels at each partner monitoring site

Site ID	Site Name	Concentrations in ng/g, wet weight (ppb)								
		$\sum_{16}$PAHs	TPCBs	$\sum_{11}$PBDEs	$\sum_{6}$ DDTs	$\sum_{8}$ Chlordanes	$\sum_{3}$ HCHs	Dieldrin	Endosulfan 1	Mirex
AI_MMB	Mats Bay Boat Ramp	10.7	5.3	0.34	0.18	<0.13	<0.13	<0.13	<0.13	<0.13
AI_OB	Oak Bay County Park	6.25	4.3	2.71	<0.22	<0.22	<0.22	<0.22	<0.22	<0.22
BBSM	Squalicum Marina	33	11	0.77	0.93	<0.19	<0.18	<0.18	<0.18	<0.19
CB_CBSW	Comm Bay Skookum	59	22	2.53	2.59	<0.21	<0.21	<0.21	<0.21	<0.21
CB_CBTF	Thea Foss Waterway	73.6	17	1.01	1.49	0.38	<0.19	<0.19	<0.19	<0.19
CB_DGL	Comm Bay, Dick Gilmur Launch	71.3	17	2.52	2.85	0.48	<0.22	<0.21	<0.22	<0.22
CB_MW	Comm Bay, Milwaukee Waterway	23.8	6.5	2.2	0.89	0.36	<0.16	<0.16	<0.16	<0.16
CBTP	Tahlequah Point	44.5	12	0.77	0.34	<0.18	<0.18	<0.18	<0.18	<0.18
CPS_KM	Kingston Marina	18.1	4.8	0.29	0.23	<0.21	<0.21	<0.21	<0.21	<0.21
CPS_MASO	Manchester, Stormwater Outfall	14.3	6.4	0.49	0.25	<0.14	<0.14	<0.14	<0.14	<0.14
CPS_PNP	Point No Point	25.7	12	0.28	0.25	<0.2	<0.2	<0.2	<0.2	<0.2
CPS_QMH	Quartermaster Harbor	32	14	0.28	0.37	<0.25	<0.25	<0.25	<0.25	<0.25
CPS_RP	Rich Passage	14.2	6.3	2.06	0.26	<0.19	<0.19	<0.19	<0.19	<0.19
CPS_SB	Salmon Bay, Commodore Park	80.7	24	2.19	3.56	1.39	<0.18	0.47	<0.18	0.3
CPS_SQSO	Suquamish, Stormwater Outfall	24.2	7.2	0.55	0.27	<0.16	<0.16	<0.16	<0.16	<0.16
EB_ME	Elliot Bay Myrtle Edwards	1580	24	0.97	2	<0.21	0.4	<0.2	<0.21	<0.21
EB_P59	Seattle Aquarium, Pier 59	585	46	1.93	4.73	1.59	<0.19	<0.19	<0.19	2.1
EBDH	Duwamish Head	74.9	19	0.88	0.41	<0.25	<0.25	<0.25	<0.25	<0.25
EBFR	Four-Mile Rock	130	24	0.89	0.94	0.22	<0.21	<0.21	<0.21	<0.21
NPS_BLSC	Bellingham Little Squalicum Creek	13.1	2.1	<0.21	0.25	<0.21	<0.21	<0.21	<0.21	<0.21
NPS_CPAR4	Cherry Point Aquatic Reserve, Conoco Phillips	27.9	8.3	<0.28	<0.28	<0.28	<0.28	<0.28	<0.28	<0.28
NPS_FBAR	Fidalgo Bay Aq Reserve, Weaverling Spit	21.8	3.2	<0.18	0.71	<0.18	<0.18	<0.18	<0.18	<0.18

PSEF	Edmonds Ferry	37.9	3.3	0.68	0.29	<0.24	<0.24	<0.24	<0.24	<0.24
PSEH	Everett Harbor	20.2	2.7	<0.26	0.66	<0.26	<0.26	<0.25	<0.26	<0.26
PSEM	Edmonds Marina	41.5	2.8	0.87	<0.28	<0.28	<0.28	<0.28	<0.28	<0.28
PSHC	Hood Canal	5.58	1.4	<0.23	<0.23	<0.23	<0.23	<0.23	<0.23	<0.23
PSKP	Kayak Point	19.8	1.5	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
PSMF	Mukilteo	30.8	3	<0.25	0.29	<0.25	<0.25	<0.25	<0.25	<0.25
PSPT	Port Townsend	146	4.2	<0.25	<0.25	<0.25	<0.25	<0.24	0.28	<0.25
PSTB	Tulalip Bay	14	2.3	<0.23	0.28	<0.23	<0.23	<0.23	<0.23	<0.23
SIWP	Waterman Point	12.6	6.6	0.31	0.3	<0.22	<0.22	<0.22	<0.22	<0.22
SJD_JSK	Jamestown	4.88	2.8	<0.14	<0.14	<0.14	<0.14	<0.14	<0.14	<0.14
SJD_NBM	Neah Bay Marina	209	7.8	<0.23	2.79	0.32	0.47	<0.23	<0.23	0.25
SPS_HIMP	Meyer's Point - Henderson Inlet	7.66	2.8	<0.26	<0.26	<0.26	<0.26	<0.26	<0.26	<0.26
SPS_PBL	Purdy, Burley Lagoon	7.11	4.9	<0.23	<0.24	<0.23	<0.23	<0.23	<0.23	<0.23
SPS_SH	Shelton	17	9.9	<0.28	<0.28	<0.28	<0.28	<0.28	<0.28	<0.28
SSBI	Budd Inlet	36.8	8.4	0.95	0.33	<0.19	<0.19	<0.19	<0.19	<0.19
WBNA	Nahcotta	1.5	0.59	<0.27	<0.27	<0.27	<0.27	<0.26	<0.27	<0.27
WPS_SVD	Silverdale, Dyes Inlet	19.6	13	0.4	0.35	<0.15	<0.15	<0.15	<0.15	<0.15

Dry Weight Concentrations of Organic Contaminants in Mussels at Partner Sites

< Indicates the concentration was not measured above the limit of quantitation (LOQ), which is the value reported instead

Table C- 3. Dry weight concentrations (ng/g) of organic contaminants in mussels at each partner monitoring site.

Site ID	Site Name	Concentrations in ng/g, dry weight (ppb)								
		$\sum_{16}$PAHs	TPCBs	$\sum_{11}$PBDEs	$\sum_6$ DDTs	$\sum_8$ Chlordanes	$\sum_3$ HCHs	Dieldrin	Endosulfan 1	Mirex
AI_MMB	Mats Bay Boat Ramp	65.8	32.5	2.09	1.1	<0.798	<0.798	<0.798	<0.798	<0.798
AI_OB	Oak Bay County Park	38.3	26.4	16.6	<1.35	<1.35	<1.35	<1.35	<1.35	<1.35
BBSM	Squalicum Marina	228	75.9	5.31	6.41	<1.31	<1.24	<1.24	<1.24	<1.31
CB_CBSW	Comm Bay Skookum	362	135	15.5	15.9	<1.29	<1.29	<1.29	<1.29	<1.29
CB_CBTF	Thea Foss Waterway	497	115	6.82	10.1	2.57	<1.28	<1.28	<1.28	<1.28
CB_DGL	Comm Bay, Dick Gilmur Launch	414	98.8	14.7	16.6	2.79	<1.28	<1.22	<1.28	<1.28
CB_MW	Comm Bay, Milwaukee Waterway	143	39.2	13.3	5.36	2.17	<0.964	<0.964	<0.964	<0.964
CBTP	Tahlequah Point	275	74.1	4.75	2.1	<1.11	<1.11	<1.11	<1.11	<1.11
CPS_KM	Kingston Marina	108	28.7	1.74	1.38	<1.26	<1.26	<1.26	<1.26	<1.26
CPS_MASO	Manchester, Stormwater Outfall	89.1	39.8	3.04	1.55	<0.87	<0.87	<0.87	<0.87	<0.87
CPS_PNP	Point No Point	163	75.9	1.77	1.58	<1.27	<1.27	<1.27	<1.27	<1.27
CPS_QMH	Quartermaster Harbor	196	85.9	1.72	2.27	<1.53	<1.53	<1.53	<1.53	<1.53
CPS_RP	Rich Passage	88.3	39.1	12.8	1.61	<1.18	<1.18	<1.18	<1.18	<1.18
CPS_SB	Salmon Bay, Commodore Park	593	176	16.1	26.2	10.2	<1.32	3.46	<1.32	2.21
CPS_SQSO	Suquamish, Stormwater Outfall	157	46.8	3.57	1.75	<1.04	<1.04	<1.04	<1.04	<1.04
EB_ME	Elliot Bay Myrtle Edwards	9360	142	5.74	11.8	<1.24	2.37	<1.18	<1.24	<1.24
EB_P59	Seattle Aquarium, Pier 59	3590	282	11.8	29	9.75	<1.17	<1.17	<1.17	12.9
EBDH	Duwamish Head	443	112	5.21	2.43	<1.48	<1.48	<1.48	<1.48	<1.48
EBFR	Four-Mile Rock	887	164	6.1	6.44	1.51	<1.44	<1.44	<1.44	<1.44
NPS_BLSC	Bellingham Little Squalicum Creek	99.2	15.9	<1.59	1.89	<1.59	<1.59	<1.59	<1.59	<1.59
NPS_CPAR4	Cherry Point Aquatic Reserve, Conoco Phillips	220	65.4	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
NPS_FBAR	Fidalgo Bay Aq Reserve, Weaverling Spit	131	19.2	<1.08	4.25	<1.08	<1.08	<1.08	<1.08	<1.08

PSEF	Edmonds Ferry	253	22	4.53	1.93	<1.6	<1.6	<1.6	<1.6	<1.6
PSEH	Everett Harbor	137	18.4	<1.77	4.49	<1.77	<1.77	<1.7	<1.77	<1.77
PSEM	Edmonds Marina	269	18.2	5.65	<1.82	<1.82	<1.82	<1.82	<1.82	<1.82
PSHC	Hood Canal	38	9.52	<1.56	<1.56	<1.56	<1.56	<1.56	<1.56	<1.56
PSKP	Kayak Point	130	9.87	<1.64	<1.64	<1.64	<1.64	<1.64	<1.64	<1.64
PSMF	Mukilteo	185	18.1	<1.51	1.75	<1.51	<1.51	<1.51	<1.51	<1.51
PSPT	Port Townsend	890	25.6	<1.52	<1.52	<1.52	<1.52	<1.46	1.71	<1.52
PSTB	Tulalip Bay	97.9	16.1	<1.61	1.96	<1.61	<1.61	<1.61	<1.61	<1.61
SIWP	Waterman Point	70.1	36.7	1.72	1.67	<1.22	<1.22	<1.22	<1.22	<1.22
SJD_JSK	Jamestown	28	16.1	<0.805	<0.805	<0.805	<0.805	<0.805	<0.805	<0.805
SJD_NBM	Neah Bay Marina	1370	51.3	<1.51	18.4	2.11	3.09	<1.51	<1.51	1.64
SPS_HIMP	Meyer's Point - Henderson Inlet	53.9	19.7	<1.83	<1.83	<1.83	<1.83	<1.83	<1.83	<1.83
SPS_PBL	Purdy, Burley Lagoon	49.4	34	<1.6	<1.67	<1.6	<1.6	<1.6	<1.6	<1.6
SPS_SH	Shelton	136	79.2	<2.24	<2.24	<2.24	<2.24	<2.24	<2.24	<2.24
SSBI	Budd Inlet	230	52.5	5.94	2.06	<1.19	<1.19	<1.19	<1.19	<1.19
WBNA	Nahcotta	10.3	4.04	<1.85	<1.85	<1.85	<1.85	<1.78	<1.85	<1.85
WPS_SVD	Silverdale, Dyes Inlet	130	86.1	2.65	2.32	<0.993	<0.993	<0.993	<0.993	<0.993

Wet Weight Concentrations of Metals in Mussels at Partner Sites

Table C- 4. Wet weight concentrations (mg/kg) of metals in mussels at each partner monitoring site.

Site ID	Site Name	Concentrations in mg/kg, wet weight (ppm)					
		Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
AI_MMB	Mats Mats Bay Boat Ramp	1.1	0.322	0.718	0.0455	0.00426	15.8
AI_OB	Oak Bay County Park	1.18	0.396	0.74	0.0366	0.00463	17.6
BBSM	Squalicum Marina	1.02	0.356	0.961	0.0317	0.00418	14.9
CB_CBSW	Comm Bay Skookum	1.1	0.357	0.904	0.0674	0.00472	14.4
CB_CBTF	Thea Foss Waterway	1.15	0.407	1.11	0.0827	0.0039	15
CB_DGL	Comm Bay, Dick Gilmur Launch	1.16	0.362	0.928	0.0869	0.00453	19.2
CB_MW	Comm Bay, Milwaukee Waterway	1.02	0.367	0.727	0.0424	0.00401	13.7
CBTP	Tahlequah Point	1.08	0.406	0.648	0.0419	0.00522	14.6
CPS_EMB	Edmonds Marina Beach	1.15	0.355	0.703	0.0465	0.00604	17
CPS_KM	Kingston Marina	1.18	0.331	0.856	0.0518	0.00478	15.8
CPS_MASO	Manchester, Stormwater Outfall	1.07	0.348	0.709	0.0636	0.0048	22.2
CPS_PNP	Point No Point	1.13	0.383	0.757	0.0288	0.00586	15.1
CPS_QMH	Quartermaster Harbor	1.33	0.357	0.964	0.174	0.0077	13.8
CPS_RP	Rich Passage	1.16	0.367	0.63	0.0495	0.00443	14.2
CPS_SB	Salmon Bay, Commodore Park	0.999	0.361	1.03	0.0801	0.00571	14.1
CPS_SQSO	Suquamish, Stormwater Outfall	1.16	0.352	0.748	0.0478	0.00556	16.8
EB_ME	Elliot Bay Myrtle Edwards	0.975	0.376	0.702	0.0436	0.00456	16.8
EB_P59	Seattle Aquarium, Pier 59	1.14	0.368	0.928	0.0892	0.00566	17.7
EBDH	Duwamish Head	1.26	0.433	0.778	0.0581	0.00779	17.5
EBFR	Four-Mile Rock	1.06	0.339	0.933	0.0745	0.00724	18.7
NPS_BLSC	Bellingham Little Squalicum Creek	0.98	0.272	0.628	0.0242	0.00375	10.9
NPS_CPAR4	Cherry Point Aquatic Reserve, Conoco Phillips	1.08	0.31	0.584	0.0326	0.00481	13.1
NPS_FBAR	Fidalgo Bay Aq Reserve, Weaverling Spit	1.17	0.371	0.774	0.0419	0.00434	13.9
PSEF	Edmonds Ferry	1.15	0.334	0.673	0.045	0.00634	15.4
PSEH	Everett Harbor	1.09	0.379	0.794	0.107	0.00769	14.3
PSEM	Edmonds Marina	1.02	0.346	0.753	0.04	0.00699	15.2

PSHC	Hood Canal	1.13	0.376	0.716	0.0321	0.00735	13.7
PSKP	Kayak Point	1.09	0.354	0.957	0.0361	0.00611	15.7
PSMF	Mukilteo	1.12	0.436	0.815	0.0487	0.0088	16.6
PSPT	Port Townsend	1.16	0.35	0.774	0.0441	0.00594	15.2
PSTB	Tulalip Bay	0.929	0.352	0.716	0.0383	0.00608	12.5
SIWP	Waterman Point	1.24	0.451	0.755	0.0731	0.00724	16.7
SJD_JSK	Jamestown	1.16	0.381	0.722	0.0359	0.0041	13.4
SJD_NBM	Neah Bay Marina	1.08	0.317	0.758	0.0628	0.00509	15
SPS_HIMP	Meyer's Point - Henderson Inlet	0.958	0.319	0.577	0.0345	0.00442	11.7
SPS_PBL	Purdy, Burley Lagoon	1.08	0.367	0.657	0.0347	0.00408	14.1
SPS_SH	Shelton	1.04	0.357	0.707	0.0865	0.00458	12.3
SSBI	Budd Inlet	1.24	0.337	0.925	0.049	0.00623	16.2
WBNA	Nahcotta	0.947	0.355	0.627	0.0209	0.00535	11.5
WPS_SVD	Silverdale, Dyes Inlet	1.09	0.338	0.784	0.11	0.00551	16.4

Dry Weight Concentrations of Metals in Mussels at Partner Sites

Table C- 5. Dry weight concentrations (mg/kg) of metals in mussels at each partner site.

Site ID	Site Name	Concentrations in mg/kg, dry weight (ppm)					
		Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
AI_MMB	Mats Mats Bay Boat Ramp	6.59	1.93	4.3	0.272	0.0255	94.6
AI_OB	Oak Bay County Park	7.11	2.39	4.46	0.22	0.0279	106
BBSM	Squalicum Marina	6.99	2.44	6.58	0.217	0.0286	102
CB_CBSW	Comm Bay Skookum	6.83	2.22	5.61	0.419	0.0293	89.4
CB_CBTF	Thea Foss Waterway	7.82	2.77	7.55	0.563	0.0265	102
CB_DGL	Comm Bay, Dick Gilmur Launch	6.63	2.07	5.3	0.497	0.0259	110
CB_MW	Comm Bay, Milwaukee Waterway	6.07	2.18	4.33	0.252	0.0239	81.5
CBTP	Tahlequah Point	6.75	2.54	4.05	0.262	0.0326	91.3
CPS_EMB	Edmonds Marina Beach	7.57	2.34	4.63	0.306	0.0397	112
CPS_KM	Kingston Marina	6.94	1.95	5.04	0.305	0.0281	92.9
CPS_MASO	Manchester, Stormwater Outfall	6.52	2.12	4.32	0.388	0.0293	135
CPS_PNP	Point No Point	7.2	2.44	4.82	0.183	0.0373	96.2
CPS_QMH	Quartermaster Harbor	8.06	2.16	5.84	1.05	0.0467	83.6
CPS_RP	Rich Passage	7.16	2.27	3.89	0.306	0.0273	87.7
CPS_SB	Salmon Bay, Commodore Park	7.14	2.58	7.36	0.572	0.0408	101
CPS_SQSO	Suquamish, Stormwater Outfall	7.34	2.23	4.73	0.303	0.0352	106
EB_ME	Elliot Bay Myrtle Edwards	5.7	2.2	4.11	0.255	0.0267	98.2
EB_P59	Seattle Aquarium, Pier 59	7.08	2.29	5.76	0.554	0.0352	110
EBDH	Duwamish Head	7.46	2.56	4.6	0.344	0.0461	104
EBFR	Four-Mile Rock	7.31	2.34	6.43	0.514	0.0499	129
NPS_BLSC	Bellingham Little Squalicum Creek	7.21	2	4.62	0.178	0.0276	80.1
NPS_CPAR4	Cherry Point Aquatic Reserve, Conoco Phillips	8	2.3	4.33	0.241	0.0356	97
NPS_FBAR	Fidalgo Bay Aq Reserve, Weaverling Spit	6.88	2.18	4.55	0.246	0.0255	81.8
PSEF	Edmonds Ferry	7.67	2.23	4.49	0.3	0.0423	103
PSEH	Everett Harbor	7.22	2.51	5.26	0.709	0.0509	94.7
PSEM	Edmonds Marina	6.54	2.22	4.83	0.256	0.0448	97.4

PSHC	Hood Canal	7.69	2.56	4.87	0.218	0.05	93.2
PSKP	Kayak Point	7.08	2.3	6.21	0.234	0.0397	102
PSMF	Mukilteo	6.79	2.64	4.94	0.295	0.0533	101
PSPT	Port Townsend	7.16	2.16	4.78	0.272	0.0367	93.8
PSTB	Tulalip Bay	6.54	2.48	5.04	0.27	0.0428	88
SIWP	Waterman Point	6.93	2.52	4.22	0.408	0.0404	93.3
SJD_JSK	Jamestown	6.59	2.16	4.1	0.204	0.0233	76.1
SJD_NBM	Neah Bay Marina	6.92	2.03	4.86	0.403	0.0326	96.2
SPS_HIMP	Meyer's Point - Henderson Inlet	6.56	2.18	3.95	0.236	0.0303	80.1
SPS_PBL	Purdy, Burley Lagoon	7.35	2.5	4.47	0.236	0.0278	95.9
SPS_SH	Shelton	8.06	2.77	5.48	0.671	0.0355	95.3
SSBI	Budd Inlet	7.85	2.13	5.85	0.31	0.0394	103
WBNA	Nahcotta	6.58	2.47	4.35	0.145	0.0372	79.9
WPS_SVD	Silverdale, Dyes Inlet	7.08	2.19	5.09	0.714	0.0358	106