Washington Department of FISH & WILDLIFE

SAM Stormwater Action Monitoring

Stormwater Action Monitoring Program Puget Sound Nearshore Mussel Monitoring: 2021/2022 Status Report

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Key Messages

The Stormwater Action Monitoring (SAM) Status and Trends in Receiving Waters program conducts monitoring in Puget Sound 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. The 2021/2022 survey was the first conducted under the new SAM study design, whereby the sampling area expanded to the entire nearshore of the Puget Lowland ecoregion and the study sites were stratified into four categories by estimates of average percentage of total impervious area (TIA%) of the contributing upland watersheds. In this survey report we provide information on the *status* of contamination in the Puget Sound nearshore. Where appropriate, results from this survey are compared to prior surveys conducted under the original study design, without additional analyses conducted to measure statistical significance. The statistical significance of temporal trends in the survey data will be evaluated in the next survey report, and will consider the study design changes that occurred between survey years. Key findings from the 2021/2022 survey include:

- Similar to prior survey years, Σ16PAHs, TPCBs, Σ11PBDEs, and Σ6DDTs continue to be the most abundant organic contaminants detected in mussels of the Puget Sound nearshore. Though, the detection frequency for PBDEs noticeably reduced in this survey. All the metals (arsenic, cadmium, copper, lead, mercury, zinc) also continue to be frequently detected in mussels.
- The central tendency concentrations of most of the measured organic and metal contaminants in mussels at survey sites across the Puget Sound shoreline were similar or lower when compared to concentrations from prior surveys with sites within the urban growth areas only.
- Estimates of the spatial extent of mussel tissue contamination in the Puget Lowland ecoregion indicate that most of the Puget Sound nearshore length (approximately 50-90%) had low concentrations of Σ16PAHs, TPCBs, Σ11PBDEs, and Σ6DDTs based on project-specific thresholds, and less than approximately 5% of the nearshore length had high concentrations.
- Most of the Puget Sound nearshore length (approximately 50-75%) had low concentrations of cadmium, lead, and mercury, and intermediate concentrations of zinc and copper. For the majority of the metal analytes (cadmium, copper, lead, mercury, zinc), a small proportion (approximately 0-10%) of the nearshore length had values exceeding the high concentration threshold. Arsenic was the only measured contaminant where the majority of the nearshore length (approximately 75%) had concentrations exceeding the high concentration threshold, with sites located across all TIA% categories.
- Most of the organic and metal contaminant distribution patterns shifted toward lower concentrations across the nearshore when the sampling area expanded to the entire Puget Lowland ecoregion. A higher proportion of the nearshore length had values below the low concentration threshold, and a lower proportion of the nearshore length had values above the high concentration threshold.
- Sites located adjacent to the upland watersheds with a higher percentage of impervious area had greater exposure to Σ16PAHs, TPCBs, Σ11PBDEs, Σ6DDTs, and zinc. Results were congruent with prior surveys, and support the hypothesis that impervious surface continues to provide a transport pathway for several toxic chemicals from terrestrial to aquatic habitats in Puget Sound.

About Puget Sound Nearshore Mussel Monitoring for Stormwater Management

The Stormwater Action Monitoring (SAM) Puget Nearshore Mussel (PNM) Monitoring program monitors the health of biota in the marine nearshore, providing a regional status and trends assessment that will determine whether collective stormwater management actions implemented in the region are leading to improved nearshore contaminant levels within the Puget Lowland ecoregion. Mussels were selected as the indicator species, or sentinel, to monitor contaminant conditions in the nearshore. As filter feeders, they ingest particles from the water and accumulate contaminants. This allows them to be used as a means to integrate measurable contaminant conditions over time, overcoming many of the difficulties and limitations related to measuring contamination in receiving waters directly. Results from this long-term monitoring study will characterize the spatial extent of contamination to which nearshore biota are exposed each survey period, and will track changes in tissue contamination over time.

Methods: How are Nearshore Receiving Waters Monitored and Reported?

GRTS Study Design and Site Selection

The SAM PNM program continues to use the same probabilistic random stratified sampling design that was used in the three prior monitoring surveys conducted in the winters of 2015/2016, 2017/2018, and 2019/2020. The sampling framework is based on the EPA's spatially balanced, generalized random tessellation stratified (GRTS) multi-density survey design and is described by Stevens (1997, 2003), and Stevens and Olsen (1999, 2004). The survey area for the initial sampling conducted between 2016 and 2020 covered the Urban Growth Areas, a portion (approximately 45 percent) of the of the entire Puget Sound nearshore. The new study design first implemented in this 2021/2022 survey (hereafter referred to as 2022 survey) has changed the sampling area to target the entire nearshore of the Puget Lowland ecoregion (Langness et al., 2022). The Puget Lowland ecoregion occupies the north-south depression between the Olympic Mountains and the western slopes of the Cascade Mountains. The region extends from the Canadian border to the lower Columbia River along the Oregon border, and encompasses the shoreline of the greater Puget Sound (Pater et al., 1998). Another core monitoring design modification includes the stratification of the study area sites into four different groups by estimates of average percentage of total impervious cover of the contributing watersheds. This stratification was necessary because most of the study area is still undeveloped, where contamination is likely low. Using impervious cover in the random selection of the candidate sites ensures that shorelines in medium and highly developed areas are sampled every year.

The four different strata categories based on total percent impervious area (TIA%) in upland watersheds are:

- Least: <10 % (also reported as 0-10)
- Low: 10 to <20 % (10-20)
- Medium: 20 to <40 % (20-40)
- High: 40 to 100 % (40-100)

For each biennial survey, 33 total sites spanning the gradient of impervious cover categories are selected. The sites are comprised of a combination of new and revisited sites to improve status assessment and trend detection power. A list of candidate sites for evaluation in each survey year was created for the first 20 years of the SAM PNM project. A list of backup sites was provided for cases where evaluated sites were deemed unsuitable for sampling for reasons such as unsafe sampling conditions or the inability to access the site,

obtain landowner permission, or physically anchor a mussel cage. The candidate site list for the 2021-2022 sampling and further details on the updated study design as well as field/lab methods can be found in the Quality Assurance Project Plan for the 2021 to 2025 monitoring period (Langness et al., 2022).

In addition to the 33 survey sites, three reference sites within the Puget Lowland ecoregion were sampled. One reference site is located near the study's aquaculture source of mussels based in Penn Cove, Whidbey Island. The other two sites are located in Hood Canal (named Holly and Broad Spit). These sites had consistently low concentrations for most contaminants in all survey years and were subsequently used to establish regional scale thresholds as it had no obvious sources of contamination. These reference sites allow for comparison of the results from the annual sampling sites to a "least-disturbed" condition that accounts for all metabolic processes and field conditions occurring during the deployment period. Additionally, three replicate samples were collected from the Penn Cove Shellfish aquaculture facility at the time of deployment to assess the baseline biological and chemical conditions of the starting population. These mussels represent the "initial condition" (concentration) of the study mussels for each contaminant at the time of deployment and allow for estimation of accumulated or depurated contaminants within the 3-month exposure period.

Analytes and Reporting Concentrations

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, mercury, and zinc (totals) were measured as well.

Throughout this report concentration results are presented as dry weight, to be consistent with reporting from historical mussel monitoring programs (NOAA Mussel Watch) and all the previous SAM surveys. All results for organic chemicals are presented as ng/g dry weight, equivalent to parts per billion (ppb). All results for metals are presented as mg/Kg dry weight, equivalent to parts per million (ppm). All contaminant data are presented using significant figures matching as reported from analytical labs; two significant figures for organic contaminants and three significant figures for metals.

Mussel contaminant data are presented as summed concentrations for organic analyte groups (Appendix A), 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. For data analysis, a substitution method using one-half the censoring limit (greatest LOQ for summed analyte groups) was assigned. As the proportion of nondetects in our data appears to be increasing for some key reporting contaminants (e.g., PBDEs), we may in the future explore more sophisticated methods to handle nondetects. Summary tables of both the wet and dry weight concentration of organic contaminants and metals in 2022 SAM survey mussels at each site are presented in Appendix B.

Concentration Threshold Categories using Percentiles

To allow for additional comparison of contaminant concentrations between sites and determine possible problem areas, we established three concentration range categories: values below the 25th percentile, values between the 25th and 75th percentiles, and values above the 75th percentile. Percentile values for each reported analyte group were determined using combined data from the first five mussel surveys conducted to date, which include all sites from the initial WDFW 2012/13 Mussel Watch Pilot Expansion (MWPE) study and the four SAM PNM surveys conducted in 2016, 2018, 2020, and 2022 (>200 unique SAM, WDFW, and partner sites). These percentiles were selected to provide a consistent frame of reference for comparison with future surveys. Updated percentile values replace those that were used in the SAM 2017/2018 survey report (Langness and West, 2020) and will remain as fixed values to be used in future data analyses. The percentile values presented in the 2017/2018 report were based on the limited data available at the time, using only data from the 2012/13 and 2015/16 surveys for organic analytes and the 2017/18 data for the metal analytes (did not use prior survey data until the metal analysis methodology change was evaluated for potential bias introduction). It was planned to update the values once the first 10 years of data (5 surveys completed) were available and baseline concentrations were established to help solidify the project specific thresholds.

Concentration values at or below the 25th percentile are considered relatively low, concentration values at or above the 75th percentile are considered relatively high, and values in between (interquartile range, IQR) are considered intermediate. These categories reflect the concentration ranges from previous Puget Sound mussel monitoring studies and are not intended to represent or take the place of seafood consumption advisory screening levels (human health) or shellfish health thresholds. The concentration range for each category is listed for each contaminant in Appendix C.

Results: Puget Sound Nearshore Biota Status in 2022

Overview of Sampling Efforts

WDFW staff evaluated 40 candidate sites and confirmed 33 sites with suitable locations to anchor a mussel cage. Original target coordinates were evaluated and, in some cases, adjusted within the limits of the nearshore beach segment length in order to optimize cage placement for better anchorage, safer access for volunteers, and to accommodate site access permissions. Seven sites were rejected, including two new sites in the 0-10% total impervious area stratum, three in the 20-40%, one in the 40-100%, and one past (revisit) site in the 10-20% stratum (Appendix D). Sites were rejected for the inability to gain site access permission, the presence of dangerous sampling conditions, or high energy conditions at the site risking loss of cage during winter storms.

At the 33 confirmed sites and 3 reference sites, mussel cages were deployed at approximately the 0.0 (zero) foot mean lower low water mark during low tides on the evenings of November 4 to 8, 2021. Exposure to local conditions at each monitoring site lasted approximately three months. The deployed mussel cages were recovered during low tides on the evenings of January 27 to 31, 2022. Mussel cages from two new sites, one in the 0-10% and one in the 10-20% TIA stratum were lost due to winter storms (Appendix D). For the 2022 survey, a total of 31 selected monitoring sites and 3 reference sites were sampled (Figure 1, Appendix E). In addition, three replicate “initial condition” samples from the Penn Cove Shellfish source were collected at the start of the study.

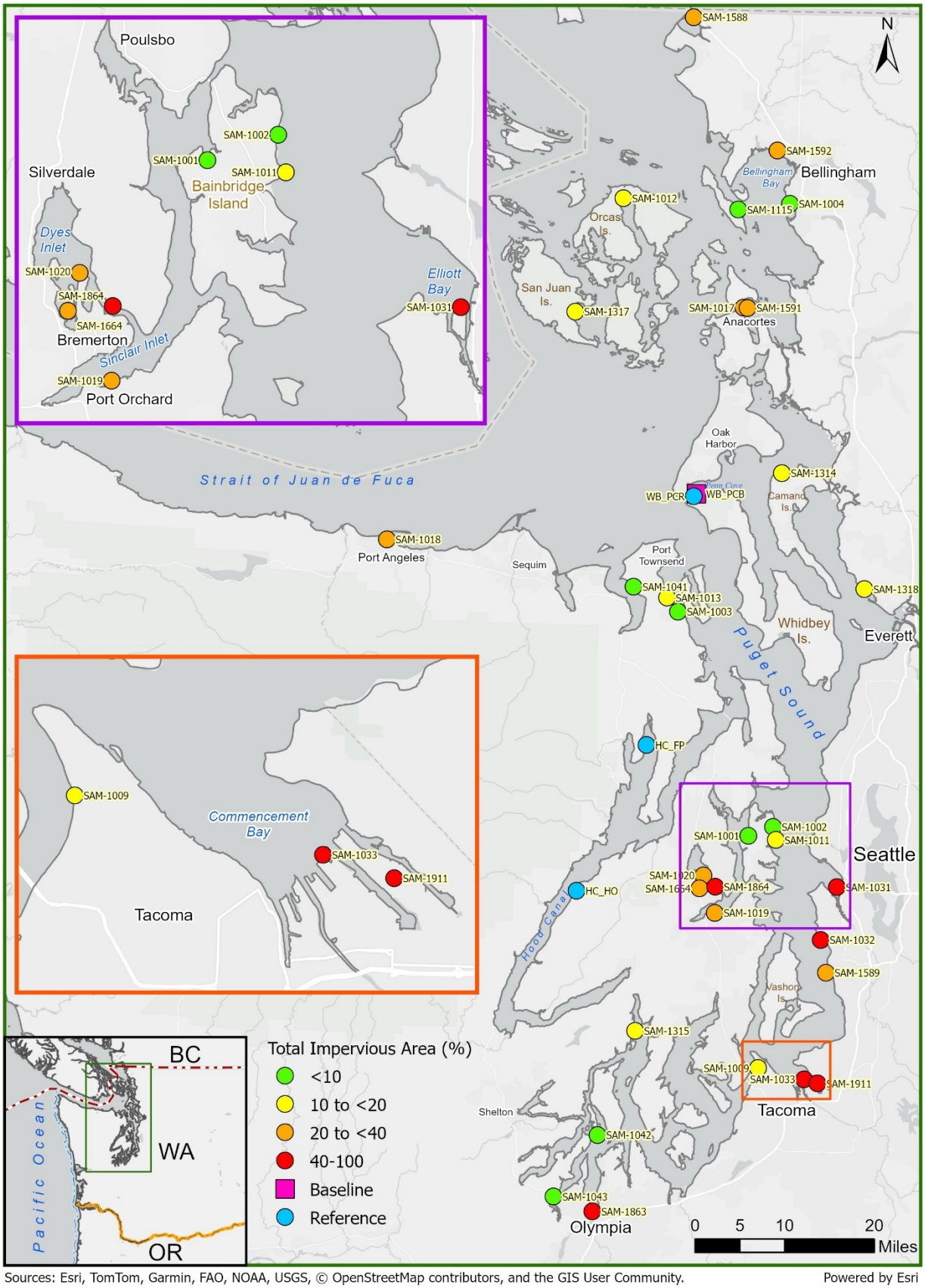

Figure 1. 2021-2022 SAM Nearshore Mussel Monitoring sites in the Puget Lowland nearshore.

The 2021/2022 Puget Nearshore Mussel Monitoring survey represents the fourth successful deployment of mussels for the SAM program study and the fifth Puget Sound-wide synoptic survey using transplanted mussels (Lanksbury et al., 2014; Lanksbury et al., 2017; Langness and West, 2020; Langness et al., 2022). In this survey report we provide information on the status of contamination in the nearshore by describing the (a) detection frequency and distribution of contaminant concentration data, (b) the spatial extent of contamination in the Puget Sound Lowland ecoregion for the 2022 survey, (c) the contaminant concentrations as it relates to nearshore development based on total impervious area in adjacent watersheds, and (d) identified local sites of concern. Throughout the report, contaminant results are compared against established thresholds for low, intermediate, and high relative concentrations. Where appropriate, the results from this survey are compared to prior surveys conducted under the original study design. We describe how key findings in this survey are either in line with or contrast previous survey findings, without additional analyses conducted to measure statistical significance. Trend analyses using prior survey data are not performed in this report. A comprehensive report on the data collected from the first 5 survey years (2015/2016, 2017/2018, 2019/2020, 2021/2022, 2023/2024) will address the statistical significance of any changes in the spatial extent of contamination and concentrations across nearshore categories, and is expected at the end of each permit cycle, with the first expected after the 2025 calendar year.

All data presented in this report are available from the Washington Department of Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim/ . Search Study ID, SAM_MNM.

Detection Frequency of Contaminants

The detection frequency of the mussel tissue chemistry varied across chemical groups. For the organic contaminants measured in mussel tissues collected from study sites (31 monitoring and 3 reference sites; n=34), the Σ16PAHs, TPCBs, ∑11PBDEs, and ∑6DDTs were the most frequently detected (47-100%; Figure 2; Appendix F). The same four contaminant groups were the most abundant in the 2016, 2018, and 2020 surveys (Lanksbury et al., 2017; Langness and West, 2020; Langness et al., 2022). Though, the detection frequency for PBDEs has noticeably reduced in this survey. At previous survey sites (within the urban growth areas only), PBDEs were detected at a frequency greater than 80%, while detections at current sites across the entire Puget Sound are now below 50%. Less frequently detected organic contaminants (9-21%) included ∑3HCHs, ∑8Chlordanes, and dieldrin. The remaining organic contaminants, mirex, hexachlorobenzene (HCB), aldrin, and endosulfan-1 were not detected at any sites above the reporting limits. For the initial condition pre-deployment mussels (baseline) replicate samples (n=3), Σ16PAHs, TPCBs, and Σ6DDTs were detected, while Σ11PBDEs, ∑3HCHs, ∑8Chlordanes, dieldrin, mirex, hexachlorobenzene, aldrin, and endosulfan were not detected above LOQ.

Similar to prior survey years, all the metals were frequently detected in mussels from the SAM monitoring and reference sites (94%-100%; Figure 2, Appendix F). One site did not have enough mussel tissue available to conduct metal analyses, thus the total number of samples for metals were reduced to 33. Baseline samples had all metals but mercury detected.

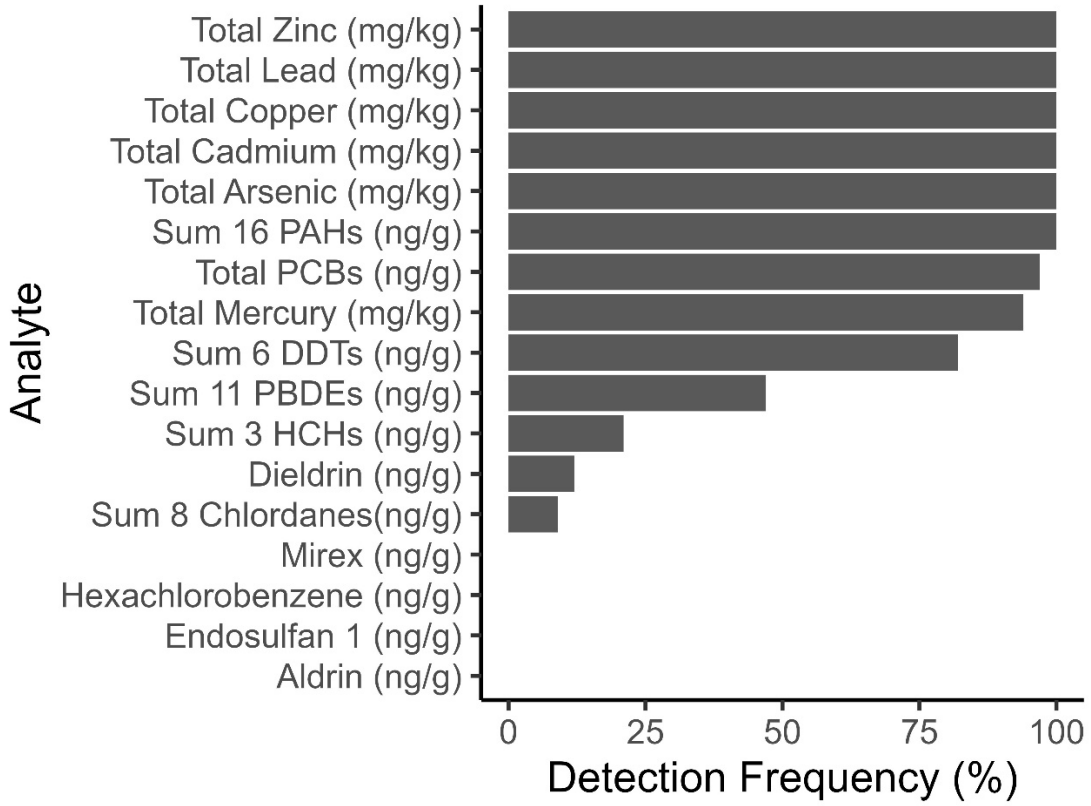

Figure 2. Detection frequency of analytes measured in mussels from the 2022 SAM Mussel Monitoring sites.

Distribution of Contaminant Concentration Data

The Σ16PAHs had the highest central tendency and broadest range of concentrations observed at the 31 monitoring sites. TPCBs had the second highest concentrations observed followed by Σ6DDTs and Σ11PBDEs (Table 1; Figure 3). The central tendency concentrations of these four main organic contaminants at survey sites across the Puget Sound shoreline were similar or lower and the range narrower when compared to prior surveys where sites were located within the urban growth area boundaries (Lanksbury et al., 2017; Langness and West, 2020; Langness et al., 2022).

Concentrations at the mussel source (average of 3 baseline replicate samples) were below the concentrations at all 31 monitoring sites for two of the dominant organic contaminants, Σ16PAHs and Σ11PBDEs (Figure 3), indicating that deployed mussels had accumulated additional contaminant loads from most of the sites for these chemicals. TPCBs and Σ6DDTs concentrations at the mussel source were detected at low concentrations, in the 25th or lower percentile of all samples in this survey year, indicating that mussels at most of the sites accumulated these chemicals but that depuration occurred at some sites. At the three reference sites, Hood Canal (n=2) and Penn Cove (n=1), Σ16PAHs and TPCBs were detected at low concentrations (<25th percentile in this survey) and Σ11PBDEs were not detected. Σ6DDTs were not detected at the two Hood Canal reference sites, while the Penn Cove site had a concentration near the median value of all the sites.

Analyte	n	Min	1st Qtr.	Median	Mean	3rd Qtr.	Max	Range
Σ16PAHs	31	32	76	130	260	230	1900	1868
TPCBs	31	10	19	30	38	43	140	130
Σ11PBDEs	31	0.45	0.73	1.4	2.9	3.9	16	15.55
Σ6DDTs	31	0.78	1.5	2.4	3.9	4.4	18	17.22
Arsenic	30	7.25	8.12	8.54	8.53	8.84	10.3	3.05
Cadmium	30	1.55	1.72	1.80	1.81	1.90	2.29	0.74
Copper	30	4.77	5.81	6.21	7.46	7.10	30.5	25.73
Lead	30	0.159	0.191	0.240	0.269	0.289	0.511	0.352
Mercury	30	0.0130	0.0297	0.0319	0.0318	0.0340	0.0456	0.0326
Zinc	30	68.3	83.5	89.9	88.6	94.1	106	37.7

Table 1. Descriptive statistics for analyte concentrations measured in mussels from the 2022 SAM Mussel Monitoring sites.

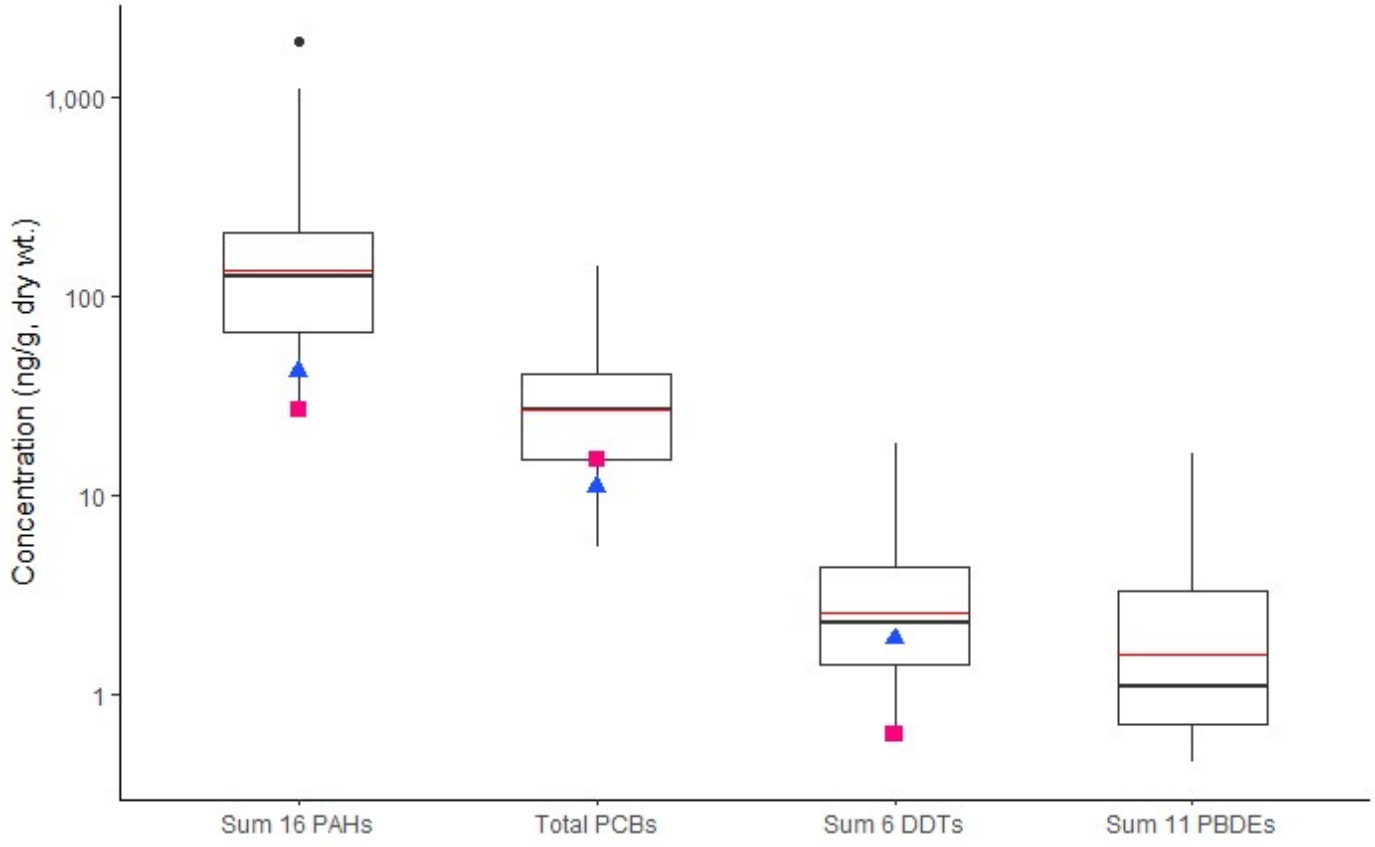

Figure 3. Box plots of the four most frequently detected organic contaminants at SAM Mussel Monitoring sites in the 2022 survey in descending order of median concentration; lower and upper hinges correspond to the 25th and 75th percentiles, whiskers are 1.5 IQR, black lines in box are median concentrations, red lines are mean concentrations, single black circles are outliers, pink squares are baseline concentrations (<LOQ if missing), blue triangles are average concentrations of three reference sites. Y-scale is logarithmic.

Similar to prior survey years, we observed a narrow range of concentrations for each metal, with zinc having the highest central tendency concentrations, followed by arsenic, copper, cadmium, lead, and mercury (Table 1; Figure 4). The central tendency concentrations of most of the metals at survey sites across the Puget Sound shoreline were similar or lower when compared to prior surveys where sites were located within the urban growth area boundaries (Lanksbury et al., 2017; Langness and West, 2020; Langness et al., 2022).

The concentration of zinc, arsenic, copper, lead, and mercury in the baseline sample (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 the deployed mussels accumulated additional contaminant loads of these metals from their sampling locations. Baseline concentration values of cadmium fell within the interquartile range, indicating mussel from a similar number of locations accumulated and depurated the metal during the deployment period.

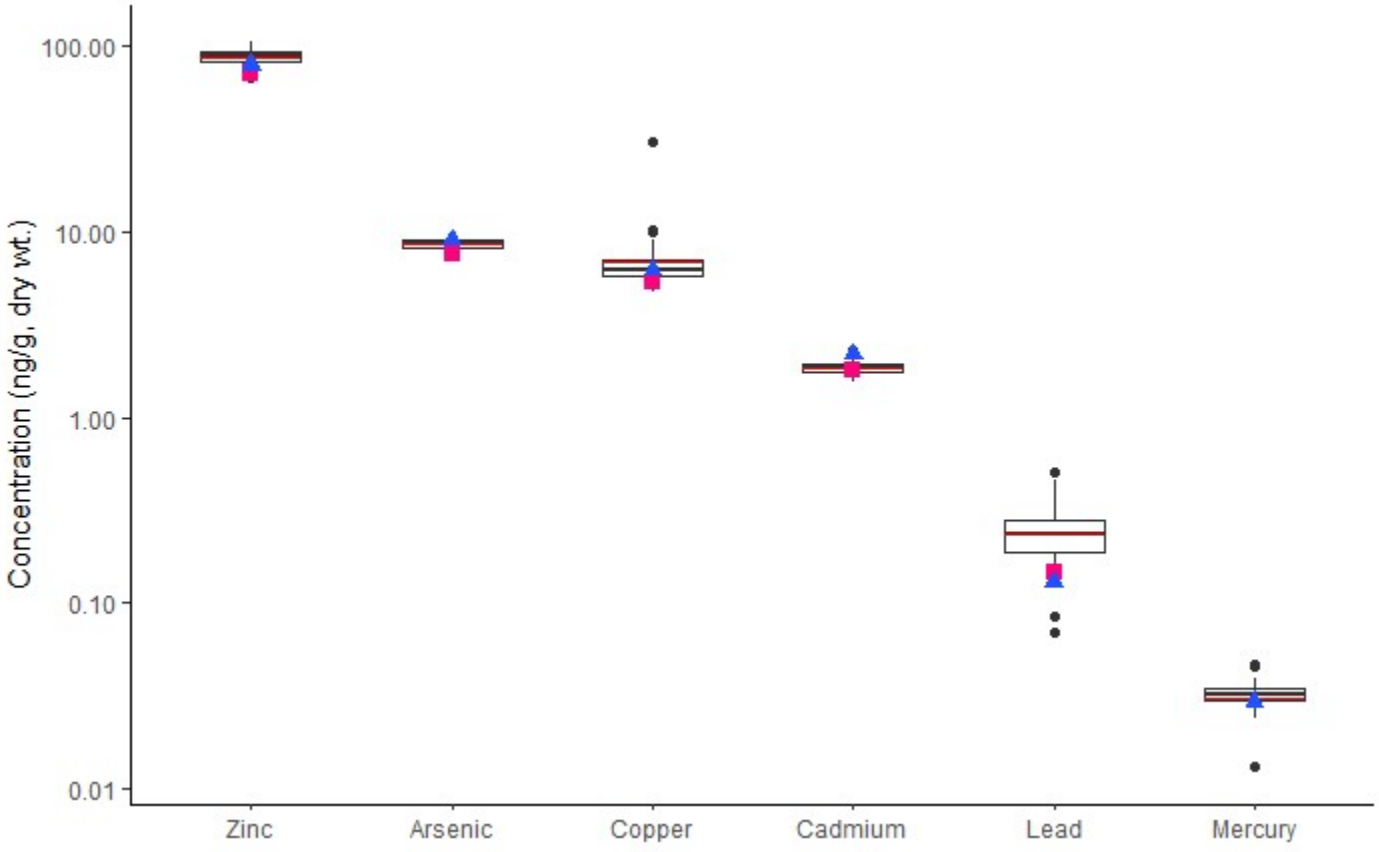

Figure 4. Box plots of metals detected at SAM Mussel Monitoring sites in the 2022 survey in descending order of median concentration; lower and upper hinges correspond to the 25th and 75th percentiles, whiskers are 1.5 IQR, black lines in box are median concentrations, red lines are mean concentrations, single black circles are outliers, pink squares are baseline concentrations (<LOQ if missing), blue triangles are average concentrations of three reference sites. Y-scale is logarithmic.

Spatial Extent of Contamination

The distribution of mussel tissue contaminant concentrations along the entire Puget Sound nearshore are shown using cumulative distribution function (CDF) plots (Figure 5 and 6). A CDF plot shows the accumulated probability of observing a specific contaminant concentration. The Y-axis indicates the cumulative percentage of Puget Sound Lowland nearshore length covered by this study design, and the X-axis the concentration of each contaminant. As the x-axis progresses, the y-value increases, representing the proportion of nearshore length with concentrations less than or equal to that value. CDF patterns are compared against the established lower (25^{th} percentile) and upper concentration (75^{th} percentile) thresholds.

The CDF patterns (shape of the curves) for Σ16PAHs, Σ11PBDEs, and Σ6DDTs had steep slopes with values skewed toward the low concentrations, suggesting that the majority of the nearshore in Puget Sound had concentrations of these contaminants within the lower value range and that only a few sites had much higher concentrations, perhaps from proximity to site specific point sources (Figure 5). The CFD pattern for TPCBs were slightly shallower in slope, showing a more gradual contaminant accumulation with increasing shoreline length, suggesting elevated exposures of this contaminant are more widely dispersed within the Puget Sound nearshore.

When the CFD patterns are compared against the established lower (25th percentile) and upper concentration (75th percentile) thresholds, the proportion of nearshore length with values below or above the upper thresholds were similar across the four organic analytes. Most of the nearshore length (approximately 50-90%) had Σ16PAHs, TPCB, Σ11PBDEs, and Σ6DDT concentrations at or below the low concentration threshold (25^{th} percentile), and less than approximately 5% of the nearshore length had values exceeding the high concentration threshold (75th percentile).

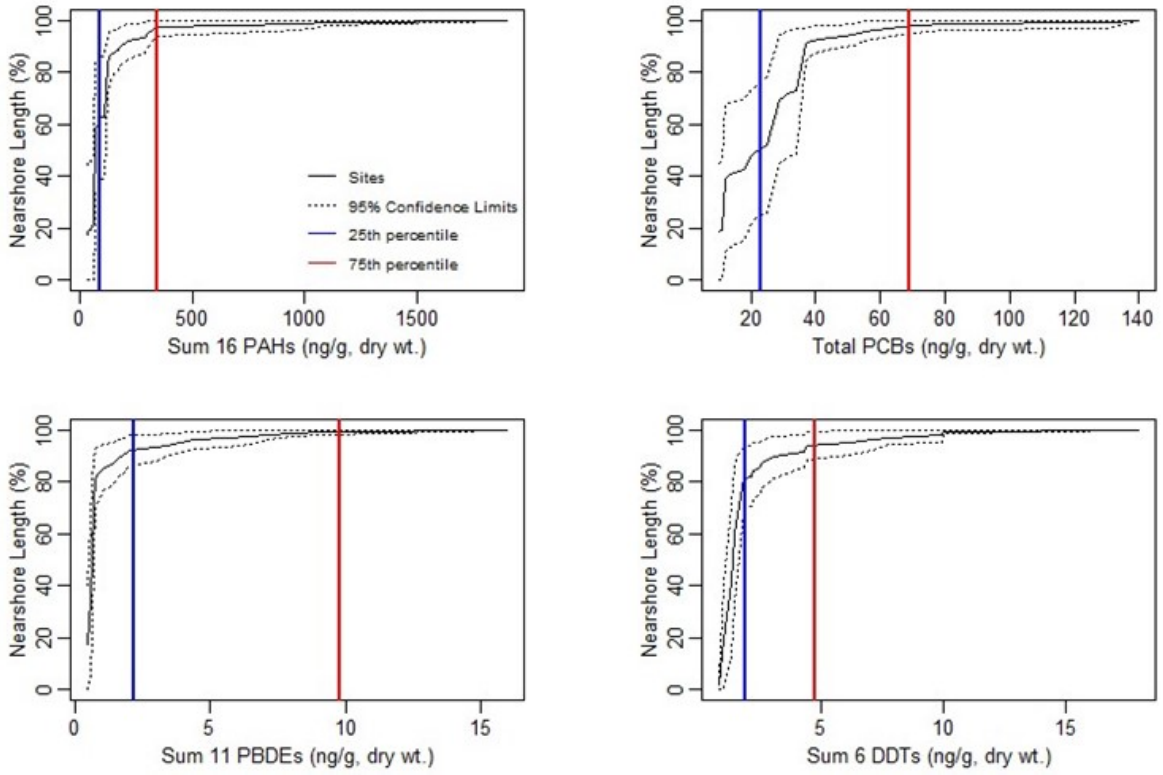

Figure 5. Cumulative distribution function (CDF) plot of Σ16PAHs, TPCBs, Σ11PBDEs, and Σ6DDTs concentrations in mussels from the 2021/2022 SAM study sites. Values to the left of the blue line represent low concentrations, and values to the right of red line represent high concentrations based on project-specific threshold values determined using percentiles (25th and 75th).

The CDF patterns for most of the metals (arsenic, cadmium, lead, mercury, and zinc) had a more gradual contaminant accumulation as the nearshore length increased, suggesting elevated exposures of these contaminants are more widely dispersed within the Puget Sound nearshore (Figure 6). The CDF pattern for copper was unlike the other metals, having a pattern more skewed to the lower concentrations, suggesting the majority of the nearshore in Puget Sound had concentrations within a lower value range and that only a few sites had much higher concentrations.

When the CFD patterns are compared against the established lower (25th percentile) and upper concentration (75th percentile) thresholds, the proportion of nearshore length with values below or above the upper thresholds varied between the metal analytes. Approximately 50-75% of the nearshore length is estimated to have cadmium, lead, and mercury concentrations at or below the low concentration threshold, and intermediate concentrations of zinc and copper. The estimated proportion of nearshore length with zinc, copper and arsenic values below the lower threshold was smaller, between 0 and 25%. For the majority of the metal analytes (cadmium, copper, lead, mercury, zinc), a small proportion (approximately 0-10%) of the nearshore length had values exceeding the high concentration threshold (75th percentile). Arsenic was the only metal analyte where the majority of the nearshore length (approximately 75%) had values exceeding the high concentration threshold. Many natural processes, such as rock weathering and geothermal activities (marine hydrothermal fluids), contribute to the background arsenic concentrations in the natural environment, whereas metal mining, smelting, and industrial/agricultural chemicals are anthropogenic sources of arsenic in the water. The ubiquitous nature of the increased arsenic concentrations across the study

sites and across areas of both low and high development (TIA% strata) suggest elevated background concentrations rather than a widespread increase in anthropogenic sources of arsenic. Approximately half of the sites were resampled from prior surveys and the new sampling sites in this study do not appear to be within proximity to any obvious anthropogenic sources. Further, arsenic concentrations have been variable in our prior studies, significantly increasing in the 2018 survey and then decreasing in the 2020 survey (Langness et al., 2022).

The observed CDF patterns (shape of the curves) for Σ16PAHs, TPCB, Σ11PBDEs, Σ6DDTs and all six metal analytes in this study were similar to those from prior survey years, suggesting that the distribution of the mussel tissue contaminant concentrations along the entire nearshore in the Puget Lowland ecoregion follow similar patterns to when the prior study area was limited to within the nearshore along urban growth areas (Langness et al., 2022). When visually compared to prior surveys, most of the organic and metal contaminant distribution patterns shifted toward lower concentrations across the nearshore when the sampling area expanded to the entire Puget Lowland ecoregion. A higher proportion of the nearshore length had values below the low concentration threshold, and a lower proportion of the nearshore length had values above the high concentration threshold. The statistical significance of any temporal trend this may imply will be evaluated in the next survey report, and will consider the study design changes that occurred between surveys.

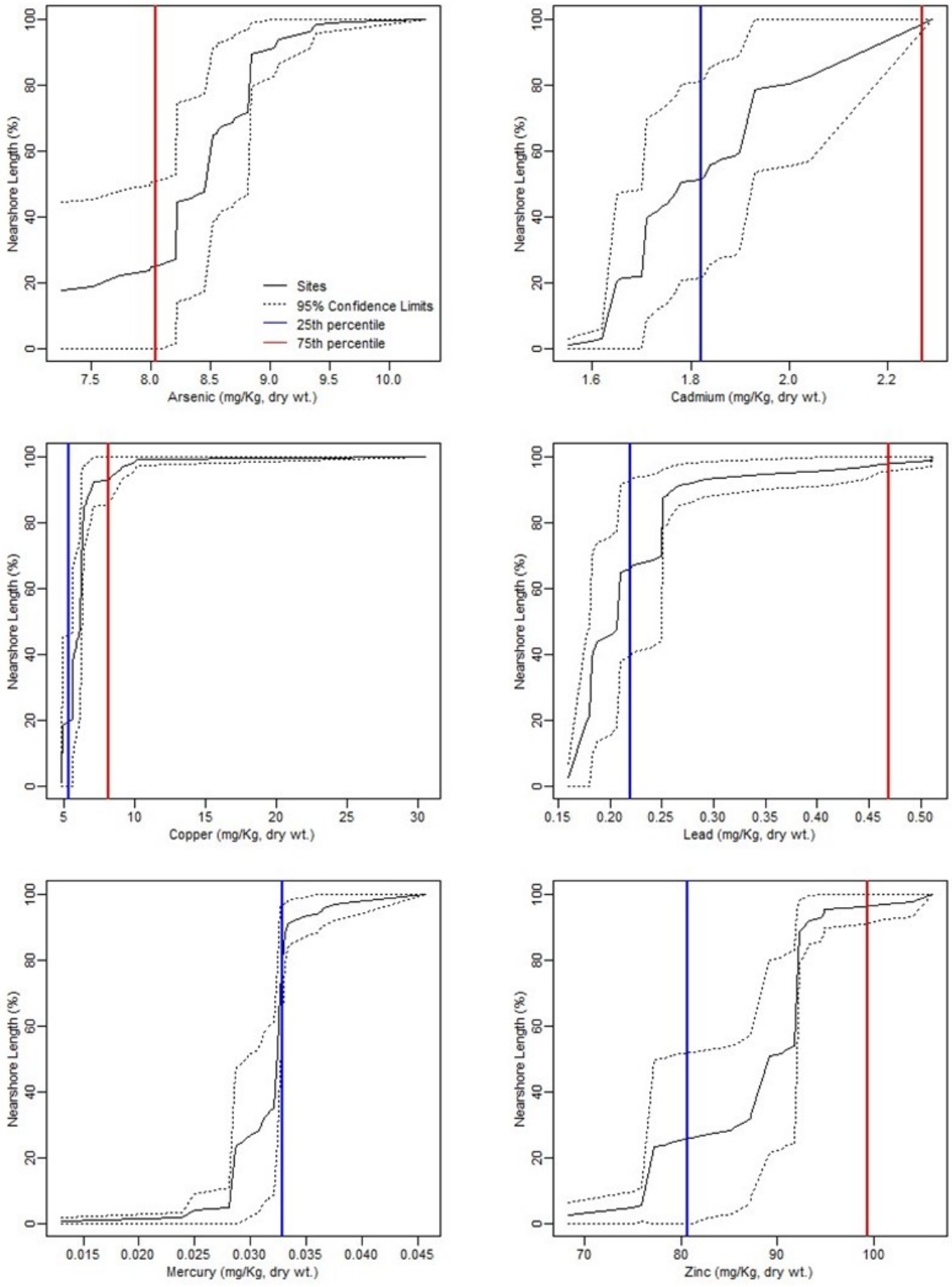

Figure 6. Cumulative distribution function (CDF) plot of arsenic, cadmium, copper, lead, mercury, and zinc concentrations in mussels from the 2021/2022 SAM study sites. Values to the left of the blue line represents low concentrations, and values to the right of red line represent high concentrations based on project-specific threshold values determined using percentiles (25th and 75th).

Contaminant Concentrations and Nearshore Development

For the four most frequently detected organic contaminant groups (Σ16PAHs, TPCBs, ∑11PBDEs, and ∑6DDTs) , concentrations increased with increasing impervious area in the upland watersheds, and median values were highest in the 40-100 TIA% category (Figure 7). Overall, sites located adjacent to the upland watersheds with a higher percentage of impervious areas had greater exposure to these organic contaminants. The results were congruent with prior survey findings, and support the hypothesis that impervious surface continues to provide a transport pathway for several toxic chemicals from terrestrial to aquatic habitats in Puget Sound (Lanksbury et al., 2014; Lanksbury et al., 2017; Langness and West, 2020; Langness et al., 2022). The reference sites for the four organic contaminants often had the lowest observed concentrations, with median values mostly lower than any of the median concentrations observed in the four TIA% categories. Thus, these reference sites continue to have limited exposure to the four organic contaminants and remain in a "least-disturbed" condition.

When comparing against the established thresholds for low (25th percentile), intermediate (IQR), and high relative concentrations (75th percentile) for the four organic contaminants, most of the sites fell within the low to intermediate concentration categories (Table 1, Figure 7). Median concentrations for ∑6DDTs remained below the low concentration threshold for the reference sites and the sites within the two lower TIA% groups (0-10, 10-20). Median concentration for the 20-40 TIA% group was intermediate, while the sites within the highest TIA% group (40-100) had a median value above the high concentration threshold. Median concentrations for ∑11PBDEs were below the low concentration threshold for most site groups including the reference, 0-10, 10-20, and 20-40 TIA%. However, for the highest 40-100 TIA% group, the median concentration fell within the intermediate value range. For TPCBs, median values for the reference and 10-20 TIA% group were low, and for the 0-10, 20-40, and 40-100 TIA% groups median values were intermediate. Σ16PAHs median values across all four TIA% groups were considered intermediate, while the reference sites value was low. Tables listing site concentrations from lowest to highest values under each percentile-based category are in Appendix G.

Table 2. Organic contaminant thresholds established to categorize nearshore monitoring sites (n=34) into low, intermediate, or high relative concentration categories. Values established using 25th and 75th percentiles and the interquartile range of the data collected from the first five surveys occurring over a ten-year period (2012-2022). Numbers in parentheses represent the number of sites within each category.

Analyte (ng/g)	Low-25th	Intermediate-IQR	High-75th
Sum 16 PAHs	≤88 (13)	89 - 339 (17)	≥340 (4)
Total PCBs	≤23 (15)	24-68 (16)	≥69 (3)
Sum 11 PBDEs	≤2.2 (23)	2.3-9.7 (10)	≥9.8 (1)
Sum 6 DDTs	≤1.9 (13)	2.0-4.6 (14)	≥4.7 (7)

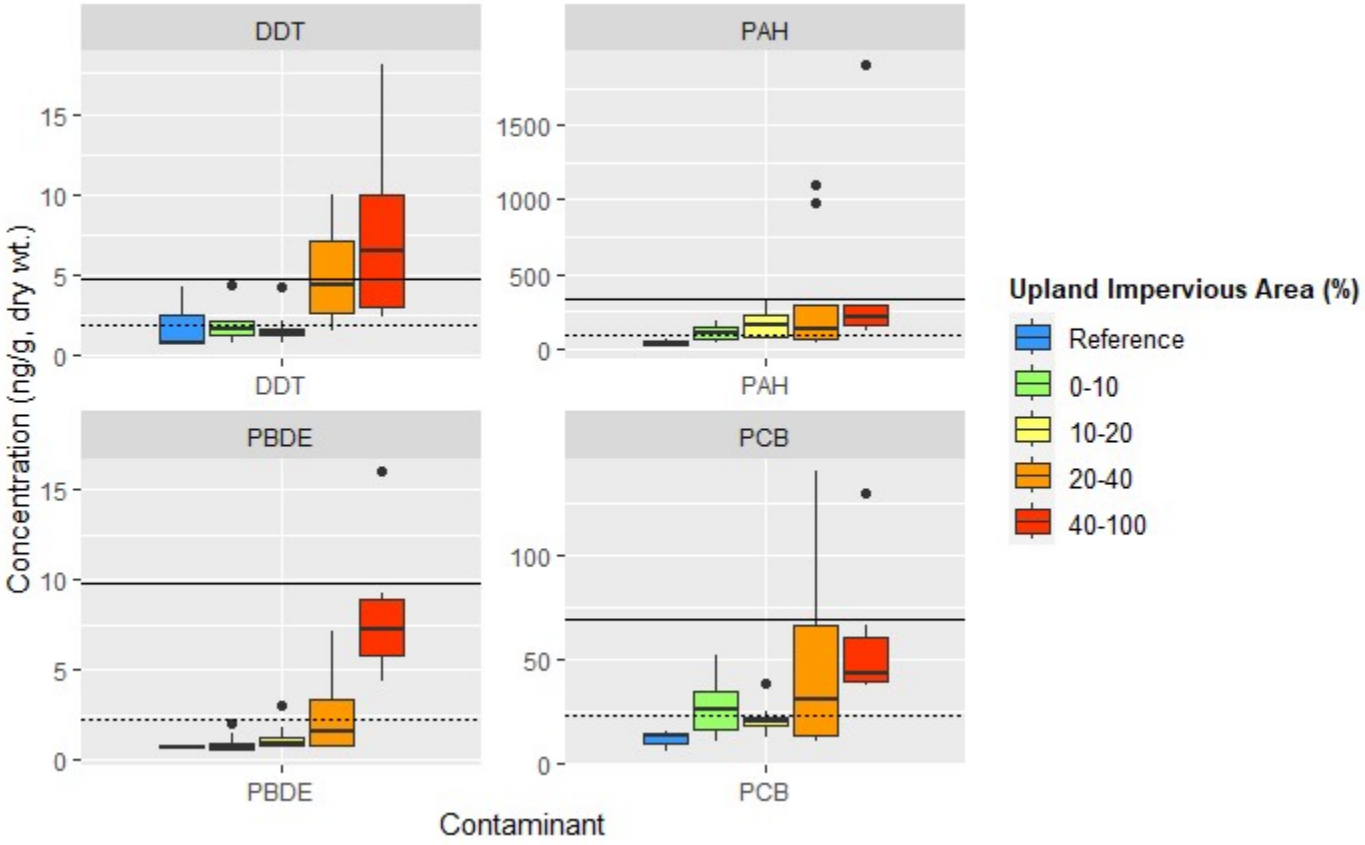

Figure 7. Organic contaminant concentrations measured in mussels collected from 34 sampled sites across total impervious area categories. The dashed line represents the 25th percentile of all contaminant data collected from 2016-2022 and the solid line represents the 75th percentile. Data below the dashed line represent relative low concentrations, and data above the solid line represent relative high concentrations based on project-specific threshold values determined using percentiles.

Metals concentrations varied with TIA%. For cadmium, copper, and mercury, concentrations were largely similar across the four TIA% groups (Figure 3). For arsenic, the highest median concentrations were found in the 10-20 TIA% group, while for lead it was the 20-40 TIA% group. The distribution of the zinc concentration data was more like the organic contaminants, showing increasing concentrations with increasing impervious area in the upland watersheds and the highest concentrations in the 40-100 TIA% group. Much like prior surveys, most of the metals showed no relationship between concentrations of metals in mussels and levels of impervious surface in the adjacent watershed. Similar to a prior survey (2018), zinc was an exception, though the positive correlation in that study was weak (Langness and West, 2020). The reference sites concentrations for lead, mercury, and zinc had median values lower than any of the median concentrations observed in the four TIA% groups. Generally, the reference sites continue to have limited exposure to lead, mercury, and zinc, and remain in a “least-disturbed” condition. Copper concentrations at the reference sites were similar to the other four TIA% groups. Unlike the other contaminants, arsenic and cadmium concentrations at the reference sites were the highest, above all four TIA% groups. Higher concentrations of arsenic at the reference sites have been reported in prior surveys (Lanksbury et al., 2017; Langness and West, 2020) and it may be that one or more of the reference sites has an ongoing source, either natural or anthropogenic.

When comparing against the established thresholds for low (25th percentile), intermediate (IQR), and high relative concentrations (75th percentile) for metals, most of the sites fell within the low to intermediate

concentration categories (Table 2, Figure 8). Arsenic was the only metal where the majority of the sites (n = 25) from all TIA% groups and the reference sites had concentrations at or above the high concentration threshold. Median concentrations for cadmium remained below the low concentration threshold for the 0-10 and 20-40 TIA% groups, and within the intermediate category for the 10-20 and 40-100 TIA% groups and reference sites. Lead concentrations between TIA% groups varied as well, with median concentrations for the 0-10, 20-40, and 40-100 groups within the intermediate category, and the 10-20 TIA% group and reference sites in the low category. Median concentrations of copper and zinc fell within the intermediate category across all four TIA% groups and reference sites. Mercury was the only metal analyte where the majority of the sites (n=21) from all TIA% groups and the reference sites had concentrations at or below the low concentration threshold. Tables listing site concentrations from lowest to highest values under each percentile-based category are in Appendix G.

Table 3. Trace element thresholds established to categorize nearshore monitoring sites (n=33) into low, intermediate, or high relative concentration categories. Values established using 25th and 75th percentiles and the interquartile range of the data collected from the first five surveys occurring over a ten-year period (2012-2022). Numbers in parentheses represent the number of sites within each category.

Analyte (mg/kg)	Low-25th	Intermediate-IQR	High-75th
Arsenic	≤6.16 (0)	6.17-8.04 (8)	≥8.05 (25)
Cadmium	≤1.82 (15)	1.83-2.26 (17)	≥2.27 (1)
Copper	≤5.33 (4)	5.34-8.14 (23)	≥8.15 (6)
Lead	≤0.220 (14)	0.221-0.468 (17)	≥0.469 (2)
Mercury	≤0.0328 (21)	0.0329-0.0489 (12)	≥0.0490 (0)
Zinc	≤80.7 (7)	80.8-99.2 (23)	≥99.3 (3)

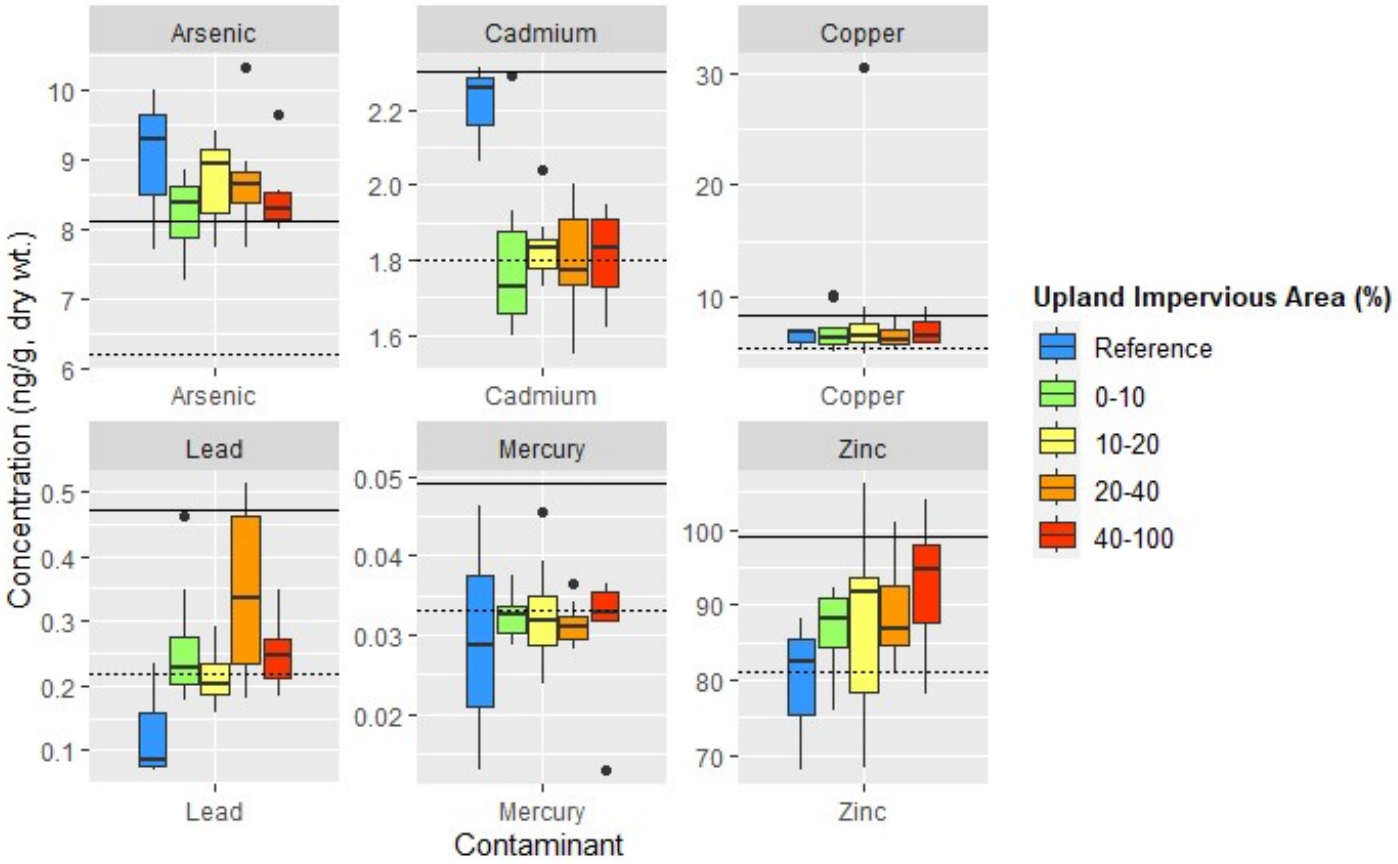

Figure 8. Trace element concentrations measured in mussels collected from 33 sampled sites across total impervious area categories. Data below the dashed line represent relative low concentrations, and data above the solid line represent high concentrations based on project-specific threshold values determined using percentiles (25th and 75th).

Identifying Local Sites of Concern

Only a few sites fell within the relative high concentration categories for the organic contaminants (Table 2). Seven sites (#1017, 1018, 1019, 1031, 1033, 1591, 1911) located within the north and central Puget Sound areas (Fidalgo Bay/Guemes Channel, Sinclair Inlet, Commencement Bay, Elliott Bay) and Strait of Juan de Fuca (Port Angeles) had high ∑6DDTs concentrations (Figure 1). Four sites (#1017, 1018, 1031, 1317) had high Σ16PAHs concentrations, and were also broadly located across the Puget Sound, from as far north as the San Juan Islands and south to Elliott Bay and east to Port Angeles. The three sites (#1019, 1020, 1031) within the high TPCB concentration category were located in the central Puget Sound area, within Sinclair/Dyes Inlet and Elliott Bay. Only one site (#1033) from the Commencement Bay area fell within the high PBDE concentration category.

Similar to the organic contaminant data, there were only a few sites that fell within the high concentration categories for most of the metal analytes (Table 3). Six sites (#1001, 1004, 1013, 1019, 1031, 1315) had relative high copper concentrations located across the north, central, and south Puget Sound areas. Three sites (#1020, 1032, 1315) in the central and south Puget Sound areas had relative high zinc concentrations, while two sites (# 1019, 1664) located in the north and central Sound had high lead concentrations. Cadmium

concentrations were highest at one of the reference sites located in Hood Canal (Holly, HC_HO). Arsenic was the only metal analyte where the majority of sites (n = 25) had concentrations above the high concentration thresholds, which were broadly located across all areas of Puget Sound.

Sites with high concentrations of two or more main contaminants included Site# 1031 Elliott Bay-Harbor Island-Pier 17 (Seattle), #1019 Kitsap St. Boat Launch (Port Orchard), #1033 Blair Waterway (Tacoma), #1017 N Avenue Park (Anacortes), and #1018 Port Angeles Yacht Club (Port Angeles) (Table 4). All five of these sites were within the medium to high TIA% watershed categories (20-40% and 40-100%), and were located near urbanized and/or industrialized upland areas (Figure 1, Appendix E). These sites were all past SAM sites that were randomly selected to be revisited this survey year, which allowed for comparison of concentrations to prior survey years. Contaminant concentrations at the five sites have remained high over multiple survey years, suggesting local non-point sources or sites specific point sources are ongoing and may warrant further study or possible remediation (Lanksbury et al., 2017; Langness and West, 2020; Langness et al., 2022). Under the new SAM study design which uses a rotating panel of sites, these sites are removed from future site selection/revisitation. However, all five sites have become index sites for the larger WDFW Mussel Watch program and will be monitored in future surveys. Tables listing site concentrations from lowest to highest values under each percentile-based category are in Appendix G.

Table 4. SAM Nearshore Mussel Monitoring sites with high concentrations based on project-based thresholds for two or more contaminants (listed) over multiple survey years.

Site ID	TIA%	Watershed size (acres)	County	Site Name	Contaminant				
SAM-1031	94	406	King	Elliott Bay, Harbor Island, Pier 17	PAHs	PCBs	DDTs	copper	
SAM-1019	30	595	Kitsap	Kitsap St Boat Launch	PCBs	DDTs	copper	lead	arsenic
SAM-1017	37	593	Skagit	N Avenue Park	PAHs	DDTs	arsenic		
SAM-1018	37	544	Clallam	Port Angeles Yacht Club	PAHs	DDTs	arsenic		
SAM-1033	77	2207	Pierce	Blair Waterway	PBDEs	DDTs	arsenic		

Summary: What's Important for Stormwater Management?

The 2021/2022 Puget Nearshore Mussel Monitoring survey represents the fourth successful deployment of mussels for the SAM program study and the first under the new sampling design. From this survey the status of contamination in the nearshore was reported by describing the detection frequency and distribution of contaminant concentration data and the spatial extent of contamination in the Puget Sound Lowland ecoregion. Additionally, contaminant concentrations as it relates to nearshore development based on total impervious area in adjacent watersheds were described, and local sites of concern based on ongoing high contaminant concentrations were identified. Results were further compared against established thresholds for low, intermediate, and high relative concentrations, and where appropriate, results were compared to prior surveys conducted under the original study design. From this analysis the following conclusions are of interest:

- Similar to prior survey years, Σ16PAHs, TPCBs, Σ11PBDEs, and Σ6DDTs continue to be the most abundant organic contaminants detected in mussels of the Puget Sound nearshore. Though, the detection frequency for PBDEs noticeably reduced in this survey. All the metals (arsenic, cadmium, copper, lead, mercury, zinc) also continue to be frequently detected in mussels.
- The central tendency concentrations of most of the measured organic and metal contaminants in mussels at survey sites across the Puget Sound shoreline were similar or lower when compared to concentrations from prior surveys with sites within the urban growth areas only.
- Estimates of the spatial extent of mussel tissue contamination in the Puget Lowland ecoregion indicate that most of the Puget Sound nearshore length (approximately 50-90%) had low concentrations of Σ16PAHs, TPCBs, Σ11PBDEs, and Σ6DDTs based on project-specific thresholds, and less than approximately 5% of the nearshore length had high concentrations.
- Most of the Puget Sound nearshore length (approximately 50-75%) had low concentrations of cadmium, lead, and mercury, and intermediate concentrations of zinc and copper. For the majority of the metal analytes (cadmium, copper, lead, mercury, zinc), a small proportion (approximately 0-10%) of the nearshore length had values exceeding the high concentration threshold.
- Arsenic was the only measured contaminant where the majority of the nearshore length (approximately 75%) had concentrations exceeding the high concentration threshold. The ubiquitous nature of the increased arsenic concentrations across the study sites, many of them resampled from prior surveys, and across areas of both low and high development (all TIA% strata) suggest elevated background concentrations rather than a widespread increase in anthropogenic sources of arsenic.
- The cumulative distribution of the mussel tissue contaminant concentrations along the entire nearshore in the Puget Lowland ecoregion follow similar patterns (shape of CDF curves) to when the prior study area was limited to within the nearshore along urban growth areas.
- Most of the organic and metal contaminant distribution patterns shifted toward lower concentrations across the nearshore when the sampling area expanded to the entire Puget Lowland ecoregion. A higher proportion of the nearshore length had values below the low concentration threshold, and a lower proportion of the nearshore length had values above the high concentration threshold.
- Sites located adjacent to the upland watersheds with a higher percentage of impervious area had greater exposure to Σ16PAHs, TPCBs, Σ11PBDEs, Σ6DDTs, and zinc. Results were congruent with prior surveys, and support the hypothesis that impervious surface continues to provide a transport pathway for several toxic chemicals from terrestrial to aquatic habitats in Puget Sound.

- Sites with high concentrations of two or more main contaminants included Site# 1031 Elliott Bay-Harbor Island-Pier 17 (Seattle), #1019 Kitsap St. Boat Launch (Port Orchard), #1033 Blair Waterway (Tacoma), #1017 N Avenue Park (Anacortes), and #1018 Port Angeles Yacht Club (Port Angeles). Contaminant concentrations at the five sites have remained high over multiple survey years, suggesting local non-point sources or site-specific point sources are ongoing and may warrant further study or possible remediation.

Next Steps

The Puget Nearshore Mussel Monitoring Program study will continue monitoring 33 sites spanning the gradient of impervious cover categories and the 3 reference sites. The panel design used in this study is used to adequately characterize the entire nearshore of Puget Sound with the continuous addition of new sites, while maximizing power for trend detection by revisiting each site over a 12-year period. The next two surveys, conducted in the winters of 2023/2024 and 2025/2026 will have a completely new set of 33 monitoring sites. Data collected each year will be provided in summary reports. A larger status and trends report will be completed every 5 years, at the end of each permit cycle, with the first expected after the 2025 calendar year.

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Appendix A. Summed concentrations for organic analyte groups

Sum 3 Hexachlorocyclohexanes (HCHs)	Sum 8 Chlordanes	Estimated Total Polychlorinated biphenyls (PCBs)*	Sum 6 Dichlorodiphenyltrichloroethanes (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**

Appendix B. Wet and dry weight concentration of organic contaminants and metals in 2022 SAM survey mussels at each site

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

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

Organic contaminants, wet weight

Site Type	Site ID	Site Name	Concentrations in ng/g, wet weight (ppb)							
			∑16PAHs	TPCBs	∑11PBDEs	∑6 DDTs	∑8 Chlordanes	∑3 HCHs	Dieldrin	Mirex
Monitoring	SAM-1001	Williams Olson Park	25	8.7	0.24	0.36	<0.23	<0.19	<0.18	<0.23
Monitoring	SAM-1002	Brackenwood Ln	30	5.8	0.34	0.37	<0.27	<0.22	<0.21	<0.27
Monitoring	SAM-1003	S of Skunk Island	24	3.0	<0.26	<0.26	<0.26	<0.22	<0.20	<0.26
Monitoring	SAM-1004	Chuckanut, Clark's Point	14	3.8	<0.23	0.77	<0.23	<0.19	<0.18	<0.23
Monitoring	SAM-1009	Salmon Beach	36	6.3	0.3	0.26	<0.26	<0.22	<0.20	<0.26
Monitoring	SAM-1011	Skiff Point	36	3.6	<0.37	0.35	<0.37	<0.31	<0.29	<0.37
Monitoring	SAM-1012	Eastsound, Fishing Bay	53	2.8	0.54	0.25	<0.25	<0.21	<0.19	<0.24
Monitoring	SAM-1013	Chimacum Creek delta	11	3.0	<0.25	<0.25	<0.25	<0.21	<0.20	<0.25
Monitoring	SAM-1017	N Avenue Park	180	5.6	0.62	1.9	<0.23	0.19	<0.18	<0.23
Monitoring	SAM-1018	Port Angeles Yacht Club	180	11	<0.24	1.3	<0.23	<0.20	<0.18	<0.23
Monitoring	SAM-1019	Kitsap St Boat Launch	60	27	1.4	1.4	<0.23	0.26	<0.18	<0.23
Monitoring	SAM-1020	Rocky Point	22	13	0.31	0.41	<0.20	0.12	<0.16	<0.20
Monitoring	SAM-1031	Elliott Bay, Harbor Island, Pier 17	330	22	0.77	1.8	<0.24	0.18	0.22	<0.24
Monitoring	SAM-1032	Arroyo Beach	28	6.5	0.94	0.40	0.52	<0.19	<0.18	<0.23
Monitoring	SAM-1033	Blair Waterway	45	7.5	2.9	1.8	0.79	0.16	<0.19	<0.24
Monitoring	SAM-1041	E Discovery Bay	25	2.6	<0.19	0.22	<0.19	<0.16	<0.15	<0.19
Monitoring	SAM-1042	Squaxin Island	11	4.5	<0.21	0.20	<0.21	<0.17	<0.16	<0.20
Monitoring	SAM-1043	Eld Inlet	12	6.9	<0.23	0.27	<0.23	<0.19	<0.18	<0.23
Monitoring	SAM-1115	Aiston Preserve	5.2	1.7	<0.18	0.30	<0.18	<0.15	<0.14	<0.18
Monitoring	SAM-1314	North Camano	10	3.2	<0.24	0.68	<0.24	<0.20	<0.19	<0.24
Monitoring	SAM-1315	Reach Island	14	4.2	<0.25	0.25	<0.25	<0.21	<0.19	<0.25
Monitoring	SAM-1317	Friday Harbor	54	3.1	<0.22	0.21	<0.22	<0.19	<0.17	<0.22

Monitoring	SAM-1318	Tulalip Reservation	21	2.1	0.18	0.22	<0.17	<0.15	<0.14	<0.17
Monitoring	SAM-1588	Drayton Harbor	2.8	<2.0	<0.23	<0.23	<0.23	<0.19	<0.18	<0.23
Monitoring	SAM-1589	Three Tree Point	22	5.3	0.74	0.48	0.23	<0.19	0.19	<0.23
Monitoring	SAM-1591	Cap Sante	10	1.7	<0.22	0.97	<0.21	0.17	<0.17	<0.21
Monitoring	SAM-1592	Locust Beach	7.2	1.6	<0.23	0.68	<0.23	<0.19	0.22	<0.22
Monitoring	SAM-1664	Madrona Pont	18	9.1	0.27	0.43	<0.21	<0.17	<0.16	<0.20
Monitoring	SAM-1863	West Bay Park	24	6.7	1.2	0.44	<0.24	<0.20	<0.18	<0.23
Monitoring	SAM-1864	Lions Park	18	10	0.99	0.46	<0.24	<0.20	<0.18	<0.23
Monitoring	SAM-1911	Blair Waterway #2	49	6.1	1.5	2.9	<0.28	0.16	0.41	<0.28
Baseline*	WB_PCB	Penn Cove Baseline Avg	5.0	2.8	<0.15	0.03	<0.15	<0.12	<0.11	<0.14
Reference	WB_PCR	Penn Cove Reference	8.8	1.8	<0.19	0.59	<0.19	<0.15	<0.14	<0.18
Reference	HC_BS	Broad Spit	5.3	2.2	<0.19	<0.19	<0.19	<0.16	<0.15	<0.19
Reference	HC_HO	Hood Canal Holly	3.6	0.8	<0.23	<0.23	<0.23	<0.19	<0.18	<0.23

Metals, wet weight

Site Type	Site ID	Site Name	Concentrations in mg/kg, wet weight (ppm)					
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
Monitoring	SAM-1001	Williams Olson Park	1.50	0.291	1.78	0.0611	0.00539	15.2
Monitoring	SAM-1002	Brackenwood Ln	1.47	0.314	1.05	0.0372	0.00633	15.3
Monitoring	SAM-1003	S of Skunk Island	1.40	0.306	0.998	0.0809	0.00502	13.3
Monitoring	SAM-1004	Chuckanut, Clark's Point	1.36	0.290	1.79	0.0431	0.00636	15.8
Monitoring	SAM-1009	Salmon Beach	1.41	0.328	0.854	0.0335	0.00426	14.2
Monitoring	SAM-1011	Skiff Point	1.57	0.337	1.11	0.0396	0.00700	16.5
Monitoring	SAM-1012	Eastsound, Fishing Bay	1.67	0.320	1.11	0.0382	0.00555	16.8
Monitoring	SAM-1013	Chimacum Creek delta	1.42	0.312	5.18	0.0496	0.00555	16.1
Monitoring	SAM-1017	N Avenue Park	1.81	0.339	1.02	0.0787	0.00641	16.7
Monitoring	SAM-1018	Port Angeles Yacht Club	1.47	0.305	1.22	0.0440	0.00481	15.7
Monitoring	SAM-1019	Kitsap St Boat Launch	1.59	0.302	1.62	0.0994	0.00616	17.0
Monitoring	SAM-1020	Rocky Point	1.46	0.336	1.03	0.0692	0.00575	17.0
Monitoring	SAM-1031	Elliott Bay, Harbor Island, Pier 17	1.39	0.316	1.58	0.0486	0.00581	16.5
Monitoring	SAM-1032	Arroyo Beach	1.64	0.332	0.956	0.0412	0.00612	17.7
Monitoring	SAM-1033	Blair Waterway	1.42	0.284	1.02	0.0447	0.00561	17.3
Monitoring	SAM-1041	E Discovery Bay	1.56	0.353	1.03	0.0384	0.00596	16.9
Monitoring	SAM-1042	Squaxin Island	1.29	0.359	1.00	0.0285	0.00508	14.0
Monitoring	SAM-1043	Eld Inlet	1.54	0.298	1.08	0.0436	0.00497	16.0
Monitoring	SAM-1115	Aiston Preserve	1.21	0.276	0.825	0.0296	0.00552	12.9
Monitoring	SAM-1314	North Camano	1.56	0.304	1.15	0.0457	0.00784	12.9
Monitoring	SAM-1315	Reach Island	1.56	0.341	1.51	0.0265	0.00417	17.7
Monitoring	SAM-1317	Friday Harbor	1.69	0.320	1.26	0.0331	0.00600	16.8
Monitoring	SAM-1318	Tulalip Reservation	1.27	0.301	0.96	0.0330	0.00510	11.2
Monitoring	SAM-1589	Three Tree Point	1.47	0.303	1.05	0.0325	0.00510	15.0
Monitoring	SAM-1591	Cap Sante	1.27	0.312	0.869	0.0295	0.00486	13.3
Monitoring	SAM-1592	Locust Beach	1.47	0.291	1.12	0.041	0.00513	13.6
Monitoring	SAM-1664	Madrona Pont	1.54	0.303	0.998	0.090	0.00538	15.0
Monitoring	SAM-1863	West Bay Park	1.28	0.289	1.03	0.0316	0.00494	12.2
Monitoring	SAM-1864	Lions Park	1.37	0.308	0.987	0.0558	0.00584	15.1

Monitoring	SAM-1911	Blair Waterway #2	1.39	0.283	1.35	0.0307	NA	14.2
Baseline*	WB_PCB	Penn Cove Baseline Avg	1.53	0.366	1.06	0.0292	NA	14.5
Reference	WB_PCR	Penn Cove Reference	1.44	0.325	0.972	0.0336	0.00667	12.7
Reference	HC_BS	Broad Spit	1.18	0.315	0.774	0.0107	NA	10.4
Reference	HC_HO	Hood Canal Holly	1.43	0.356	1.04	0.0131	0.00444	12.7

Organic contaminants, dry weight

Site Type	Site ID	Site Name	Concentrations in ng/g, dry weight (ppb)							
			∑16PAHs	TPCBs	∑11PBDEs	∑6 DDTs	∑8 Chlordanes	∑3 HCHs	Dieldrin	Mirex
Monitoring	SAM-1001	Williams Olson Park	150	52	1.4	2.2	<1.4	<1.1	<1.1	<1.4
Monitoring	SAM-1002	Brackenwood Ln	180	34	2	2.2	<1.6	<1.3	<1.2	<1.6
Monitoring	SAM-1003	S of Skunk Island	140	18	<1.6	<1.6	<1.6	<1.3	<1.2	<1.6
Monitoring	SAM-1004	Chuckanut, Clark's Point	80	22	<1.3	4.4	<1.3	<1.1	<1.0	<1.3
Monitoring	SAM-1009	Salmon Beach	210	38	1.8	1.5	<1.5	<1.3	<1.2	<1.5
Monitoring	SAM-1011	Skiff Point	210	21	<2.2	2.1	<2.2	<1.8	<1.7	<2.2
Monitoring	SAM-1012	Eastsound, Fishing Bay	290	15	3	1.4	<1.4	<1.2	<1.0	<1.3
Monitoring	SAM-1013	Chimacum Creek delta	69	19	<1.6	<1.6	<1.6	<1.3	<1.2	<1.6
Monitoring	SAM-1017	N Avenue Park	980	30	3.4	10	<1.2	1.0	<0.98	<1.2
Monitoring	SAM-1018	Port Angeles Yacht Club	1100	66	<1.4	7.8	<1.4	<1.2	<1.1	<1.4
Monitoring	SAM-1019	Kitsap St Boat Launch	300	140	7.1	7.1	<1.2	1.3	<0.91	<1.2
Monitoring	SAM-1020	Rocky Point	130	79	1.9	2.5	<1.2	0.73	<0.97	<1.2
Monitoring	SAM-1031	Elliott Bay, Harbor Island, Pier 17	1900	130	4.4	10	<1.4	1.0	1.3	<1.4
Monitoring	SAM-1032	Arroyo Beach	170	39	5.6	2.4	3.1	<1.1	<1.1	<1.4
Monitoring	SAM-1033	Blair Waterway	250	41	16	9.9	4.3	0.88	<1.0	<1.3
Monitoring	SAM-1041	E Discovery Bay	120	12	<0.89	1.0	<0.89	<0.75	<0.71	<0.89
Monitoring	SAM-1042	Squaxin Island	71	29	<1.4	1.3	<1.4	<1.1	<1.0	<1.3
Monitoring	SAM-1043	Eld Inlet	64	37	<1.2	1.4	<1.2	<1.0	<0.97	<1.2
Monitoring	SAM-1115	Aiston Preserve	32	10	<1.1	1.8	<1.1	<0.91	<0.85	<1.1
Monitoring	SAM-1314	North Camano	63	20	<1.5	4.3	<1.5	<1.3	<1.2	<1.5
Monitoring	SAM-1315	Reach Island	82	25	<1.5	1.5	<1.5	<1.2	<1.1	<1.5
Monitoring	SAM-1317	Friday Harbor	340	19	<1.4	1.3	<1.4	<1.2	<1.1	<1.4
Monitoring	SAM-1318	Tulalip Reservation	120	12	1.1	1.3	<1.0	<0.88	<0.83	<1.0
Monitoring	SAM-1588	Drayton Harbor	36	<26	<3.0	<3.0	<3.0	<2.5	<2.3	<3.0
Monitoring	SAM-1589	Three Tree Point	130	31	4.4	2.8	1.4	<1.1	1.1	<1.4
Monitoring	SAM-1591	Cap Sante	64	11	<1.4	6.2	<1.3	1.1	<1.1	<1.3
Monitoring	SAM-1592	Locust Beach	46	10	<1.5	4.4	<1.5	<1.2	1.4	<1.4
Monitoring	SAM-1664	Madrona Pont	110	55	1.6	2.6	<1.3	<1.0	<0.96	<1.2

Monitoring	SAM-1863	West Bay Park	160	45	8.1	3	<1.6	<1.3	<1.2	<1.6
Monitoring	SAM-1864	Lions Park	120	66	6.5	3	<1.6	<1.3	<1.2	<1.5
Monitoring	SAM-1911	Blair Waterway #2	300	37	9.2	18	<1.7	0.98	2.5	<1.7
Baseline*	WB_PCB	Penn Cove Baseline Avg	27	15	<0.80	0.13	<0.78	<0.65	<0.6	<0.76
Reference	WB_PCR	Penn Cove Reference	64	13	<1.4	4.3	<1.4	<1.1	<1.0	<1.3
Reference	HC_BS	Broad Spit	35	15	<1.3	<1.3	<1.3	<1.1	<1.0	<1.3
Reference	HC_HO	Hood Canal Holly	25	5.5	<1.6	<1.6	<1.6	<1.3	<1.2	<1.6

Metals, dry weight

Site Type	Site ID	Site Name	Concentrations in mg/kg, dry weight (ppm)					
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc
Monitoring	SAM-1001	Williams Olson Park	8.57	1.66	10.2	0.349	0.0308	86.9
Monitoring	SAM-1002	Brackenwood Ln	8.70	1.86	6.21	0.220	0.0375	90.5
Monitoring	SAM-1003	S of Skunk Island	8.00	1.75	5.70	0.462	0.0287	76.0
Monitoring	SAM-1004	Chuckanut, Clark's Point	7.51	1.60	9.89	0.238	0.0351	87.3
Monitoring	SAM-1009	Salmon Beach	7.88	1.83	4.77	0.187	0.0238	79.3
Monitoring	SAM-1011	Skiff Point	8.82	1.89	6.24	0.222	0.0393	92.7
Monitoring	SAM-1012	Eastsound, Fishing Bay	9.03	1.73	6.00	0.206	0.03	90.8
Monitoring	SAM-1013	Chimacum Creek delta	8.35	1.84	30.5	0.292	0.0326	94.7
Monitoring	SAM-1017	N Avenue Park	10.3	1.93	5.80	0.447	0.0364	94.9
Monitoring	SAM-1018	Port Angeles Yacht Club	8.60	1.78	7.13	0.257	0.0281	91.8
Monitoring	SAM-1019	Kitsap St Boat Launch	8.15	1.55	8.31	0.510	0.0316	87.2
Monitoring	SAM-1020	Rocky Point	8.69	2.00	6.13	0.412	0.0342	101
Monitoring	SAM-1031	Elliott Bay, Harbor Island, Pier 17	7.99	1.82	9.08	0.279	0.0334	94.8
Monitoring	SAM-1032	Arroyo Beach	9.65	1.95	5.62	0.242	0.036	104
Monitoring	SAM-1033	Blair Waterway	8.11	1.62	5.83	0.255	0.0321	98.9
Monitoring	SAM-1041	E Discovery Bay	8.52	1.93	5.63	0.210	0.0326	92.3
Monitoring	SAM-1042	Squaxin Island	8.22	2.29	6.37	0.182	0.0324	89.2
Monitoring	SAM-1043	Eld Inlet	8.85	1.71	6.21	0.251	0.0286	92.0
Monitoring	SAM-1115	Aiston Preserve	7.25	1.65	4.94	0.177	0.0331	77.2
Monitoring	SAM-1314	North Camano	9.07	1.77	6.69	0.266	0.0456	75.0
Monitoring	SAM-1315	Reach Island	9.34	2.04	9.04	0.159	0.025	106
Monitoring	SAM-1317	Friday Harbor	9.39	1.78	7.00	0.184	0.0333	93.3
Monitoring	SAM-1318	Tulalip Reservation	7.74	1.84	5.85	0.201	0.0311	68.3
Monitoring	SAM-1589	Three Tree Point	8.45	1.74	6.03	0.187	0.0293	86.2
Monitoring	SAM-1591	Cap Sante	7.74	1.90	5.30	0.180	0.0296	81.1
Monitoring	SAM-1592	Locust Beach	8.96	1.77	6.83	0.250	0.0313	82.9
Monitoring	SAM-1664	Madrona Pont	8.75	1.72	5.67	0.511	0.0306	85.2
Monitoring	SAM-1863	West Bay Park	8.21	1.85	6.60	0.203	0.0317	78.2

Monitoring	SAM-1864	Lions Park	8.56	1.93	6.17	0.349	0.0365	94.4
Monitoring	SAM-1911	Blair Waterway #2	8.37	1.70	8.13	0.185	NA	85.5
Baseline*	WB_PCB	Penn Cove Baseline Avg	7.61	1.83	5.28	0.146	NA	72.1
Reference	WB_PCR	Penn Cove Reference	10.0	2.26	6.75	0.233	0.0463	88.2
Reference	HC_BS	Broad Spit	7.71	2.06	5.06	0.0699	NA	68.0
Reference	HC_HO	Hood Canal Holly	9.29	2.31	6.75	0.0851	0.0288	82.5

Appendix C. Concentration threshold categories by percentiles

Analyte	Category by Percentile	Concentration Range (POPs ng/g and metals mg/Kg, dry wt.)
PAHs	Low, 25th	≤88
	Intermediate	89 - 339
	High, 75th	≥340
PCBs	Low, 25th	≤23
	Intermediate	24-68
	High, 75th	≥69
PBDEs	Low, 25th	≤2.2
	Intermediate	2.3-9.7
	High, 75th	≥9.8
DDTs	Low, 25th	≤1.9
	Intermediate	2.0-4.6
	High, 75th	≥4.7
Arsenic	Low, 25th	≤6.16
	Intermediate	6.17-8.04
	High, 75th	≥8.05
Cadmium	Low, 25th	≤1.82
	Intermediate	1.83-2.26
	High, 75th	≥2.27
Copper	Low, 25th	≤5.33
	Intermediate	5.34-8.14
	High, 75th	≥8.15
Lead	Low, 25th	≤0.220
	Intermediate	0.221-0.468
	High, 75th	≥0.469
Mercury	Low, 25th	≤0.0328
	Intermediate	0.0329-0.0489
	High, 75th	≥0.0490
Zinc	Low, 25th	≤80.7
	Intermediate	80.8-99.2
	High, 75th	≥99.3

Appendix D. Rejected candidate monitoring sites and selected sites where cages were lost over the sampling period

Site ID	Site Name	Latitude	Longitude	Group	Visit History	Status	Comment
SAM-1044	Polnell Point	48.27326	-122.55994	0-10	New	Lost Cage	Cage lost during winter storm
SAM-1316	Fort Worden	48.14311	-122.77387	10-20	New	Lost Cage	Cage lost during winter storm
SAM-1010	Admiralty Inlet	48.13083	-122.76217	10-20	Past	Rejected Site	Not suitable due to high energy and seasonal swimmer safety
SAM-1040	Dungeness	48.13662	-123.09987	0-10	New	Rejected Site	Not suitable due to high energy
SAM-1114	Command Point	47.45472	-122.53268	0-10	New	Rejected Site	Not suitable due to inability to gain site access permission
SAM-1590	Priest Point Park	47.06997	-122.89893	20-40	New	Rejected Site	Not suitable due to dangerous sinking mud
SAM-1662	The Lagoon	48.08296	-123.05332	20-40	New	Rejected Site	Not suitable due to inability to gain site access permission
SAM-1663	Big Gulch WWTP	47.90676	-122.32297	20-40	New	Rejected Site	Not suitable due to

							safety concerns regarding railroad tracks
SAM-1862	Harbor Island Shipping	47.58223	-122.34605	40-100	New	Rejected Site	Not suitable due to limited access and busy shipping dock

Appendix E. Site information for all sampling locations from the 2022 SAM Puget Sound Nearshore Mussel Monitoring survey

[Includes 31 selected monitoring sites, 3 reference sites, and the Penn Cove pre-deployment (initial condition) samples.; ID = identifier; latitude and longitude in North American Datum 1983; Group = total percent impervious upland watershed area adjacent to site (strata category); Visit History – Past = revisited site, New = new site]

Site ID	Site Name	County	Latitude	Longitude	Group	Visit History
SAM-1001	Williams Olson Park	Kitsap	47.66726	-122.56549	0-10	Past
SAM-1002	Brackenwood Ln	Kitsap	47.68262	-122.50706	0-10	Past
SAM-1003	S of Skunk Island	Jefferson	48.02680	-122.74896	0-10	Past
SAM-1004	Chuckanut, Clark's Point	Whatcom	48.69108	-122.50417	0-10	Past
SAM-1009	Salmon Beach	Pierce	47.29181	-122.52806	10-20	Past
SAM-1011	Skiff Point	Kitsap	47.66154	-122.49952	10-20	Past
SAM-1012	Eastsound, Fishing Bay	San Juan	48.69258	-122.91127	10-20	Past
SAM-1013	Chimacum Creek delta	Jefferson	48.04868	-122.77652	10-20	Past
SAM-1017	N Avenue Park	Skagit	48.52109	-122.61104	20-40	Past
SAM-1018	Port Angeles Yacht Club	Clallam	48.12801	-123.45672	20-40	Past
SAM-1019	Kitsap St Boat Launch	Kitsap	47.54111	-122.64058	20-40	Past
SAM-1020	Rocky Point	Kitsap	47.60149	-122.66985	20-40	Past
SAM-1031	Elliott Bay, Harbor Island, Pier 17	King	47.58771	-122.35063	40-100	Past
SAM-1032	Arroyo Beach	King	47.50175	-122.38600	40-100	Past
SAM-1033	Blair Waterway	Pierce	47.27578	-122.41737	40-100	Past
SAM-1041	Discovery Bay	Jefferson	48.06496	-122.85752	0-10	New
SAM-1042	Squaxin Island	Mason	47.17650	-122.90465	0-10	New
SAM-1043	Eld Inlet	Thurston	47.07439	-123.00398	0-10	New
SAM-1115	Smuggler's Cove	Whatcom	48.67938	-122.63006	0-10	New
SAM-1314	North Camano	Island	48.25536	-122.50701	10-20	New
SAM-1315	Reach Island	Mason	47.34654	-122.82236	10-20	New
SAM-1317	Friday Harbor	San Juan	48.50694	-123.01944	10-20	New
SAM-1318	Tulalip Reservation	Snohomish	48.07080	-122.30098	10-20	New
SAM-1588	Blaine	Whatcom	48.98852	-122.75211	20-40	New
SAM-1589	Three Tree Point	King	47.44896	-122.37227	20-40	New
SAM-1591	Cap Sante	Skagit	48.52097	-122.60072	20-40	New
SAM-1592	Locust Beach, Bellingham	Whatcom	48.77637	-122.53787	20-40	New
SAM-1664	Madrona Point	Kitsap	47.57996	-122.67860	20-40	New
SAM-1863	West Bay Park	Thurston	47.05236	-122.91091	40-100	New
SAM-1864	Lions Park	Kitsap	47.58335	-122.64146	40-100	New
SAM-1911	Blair Waterway #2	Pierce	47.26923	-122.38574	40-100	New
WB_PCR	Penn Cove Reference	Island	48.21407	-122.71910	Reference	Past
HC_HO	Hood Canal Holly	Kitsap	47.57019	-122.97178	Reference	Past
HC_FP	Broad Spit	Jefferson	47.80934	-122.81556	Reference	New
WB_PCB	Penn Cove Baseline	Island	48.21805	-122.71236	Baseline	Past

Appendix F. Detection frequency of mussel tissue analytes

Analyte Name	Number of Samples	Detection Frequency, percent
Sum 16 PAHs (ng/g)	34	100
Total PCBs (ng/g)	34	97
Sum 11 PBDEs (ng/g)	34	47
Sum 6 DDTs (ng/g)	34	82
Sum 3 HCHs (ng/g)	34	21
Sum 8 Chlordanes (ng/g)	34	9
Dieldrin (ng/g)	34	12
Aldrin (ng/g)	34	0
Hexachlorobenzene (ng/g)	34	0
Mirex (ng/g)	34	0
Endosulfan 1 (ng/g)	34	0
Total Arsenic (mg/kg)	33	100
Total Cadmium (mg/kg)	33	100
Total Copper (mg/kg)	33	100
Total Lead (mg/kg)	33	100
Total Mercury (mg/kg)	33	94
Total Zinc (mg/kg)	33	100

Appendix G. Mussel monitoring sites by concentration threshold categories

Sum 16 PAHs

Site Category by Percentile	Site ID	Site Name	Sum 16 PAHs Concentration (ng/g, dry wt.)
25th	HC_HO	Hood Canal Holly	25
	WB_PCB	Penn Cove Baseline Avg	27
	SAM-1115	Aiston Preserve	32
	HC_BS	Broad Spit	35
	SAM-1588	Drayton Harbor	36
	SAM-1592	Locust Beach	46
	SAM-1314	North Camano	63
	SAM-1591	Cap Sante	64
	SAM-1043	Eld Inlet	64
	WB_PCR	Penn Cove Reference	64
	SAM-1013	Chimacum Creek delta	69
	SAM-1042	Squaxin Island	71
	SAM-1004	Chuckanut, Clark's Point	80
	SAM-1315	Reach Island	82
IQR	SAM-1664	Madrona Pont	110
	SAM-1041	Discovery Bay	120
	SAM-1864	Lions Park	120
	SAM-1318	Tulalip Reservation	120
	SAM-1589	Three Tree Point	130
	SAM-1020	Rocky Point	130
	SAM-1003	S of Skunk Island	140
	SAM-1001	Williams Olson Park	150
	SAM-1863	West Bay Park	160
	SAM-1032	Arroyo Beach	170
	SAM-1002	Brackenwood Ln	180
	SAM-1011	Skiff Point	210
	SAM-1009	Salmon Beach	210
	SAM-1033	Blair Waterway	250
	SAM-1012	Eastsound, Fishing Bay	290
	SAM-1911	Blair Waterway #2	300
	SAM-1019	Kitsap St Boat Launch	300
75th	SAM-1317	Friday Harbor	340
	SAM-1017	N Avenue Park	980
	SAM-1018	Port Angeles Yacht Club	1100
	SAM-1031	Elliott Bay, Harbor Island, Pier 17	1900

Total PCBs

Site Category by Percentile	Site ID	Site Name	Total PCBs Concentration (ng/g, dry wt.)
25th	SAM-1588	Drayton Harbor	<LOQ
	HC_HO	Hood Canal Holly	5.5
	SAM-1592	Locust Beach	10
	SAM-1115	Aiston Preserve	10
	SAM-1591	Cap Sante	11
	SAM-1041	Discovery Bay	12
	SAM-1318	Tulalip Reservation	12
	WB_PCR	Penn Cove Reference	13
	WB_PCB	Penn Cove Baseline Avg	15
	HC_BS	Broad Spit	15
	SAM-1012	Eastsound, Fishing Bay	15
	SAM-1003	S of Skunk Island	18
	SAM-1013	Chimacum Creek delta	19
	SAM-1317	Friday Harbor	19
	SAM-1314	North Camano	20
	SAM-1011	Skiff Point	21
	SAM-1004	Chuckanut, Clark's Point	22
IQR	SAM-1315	Reach Island	25
	SAM-1042	Squaxin Island	29
	SAM-1017	N Avenue Park	30
	SAM-1589	Three Tree Point	31
	SAM-1002	Brackenwood Ln	34
	SAM-1043	Eld Inlet	37
	SAM-1911	Blair Waterway #2	37
	SAM-1009	Salmon Beach	38
	SAM-1032	Arroyo Beach	39
	SAM-1033	Blair Waterway	41
	SAM-1863	West Bay Park	45
	SAM-1001	Williams Olson Park	52
	SAM-1664	Madrona Pont	55
	SAM-1018	Port Angeles Yacht Club	66
	SAM-1864	Lions Park	66
75th	SAM-1020	Rocky Point	79
	SAM-1031	Elliott Bay, Harbor Island, Pier 17	130
	SAM-1019	Kitsap St Boat Launch	140

Sum 11 PBDEs

Site Category by Percentile	Site ID	Site Name	Sum 11 PBDEs Concentration (ng/g, dry wt.)
25th	SAM-1588	Drayton Harbor	<LOQ
	SAM-1011	Skiff Point	<LOQ
	HC_HO	Hood Canal Holly	<LOQ
	SAM-1003	S of Skunk Island	<LOQ
	SAM-1013	Chimacum Creek delta	<LOQ
	SAM-1314	North Camano	<LOQ
	SAM-1592	Locust Beach	<LOQ
	SAM-1315	Reach Island	<LOQ
	SAM-1018	Port Angeles Yacht Club	<LOQ
	SAM-1591	Cap Sante	<LOQ
	WB_PCR	Penn Cove Reference	<LOQ
	SAM-1317	Friday Harbor	<LOQ
	SAM-1042	Squaxin Island	<LOQ
	SAM-1004	Chuckanut, Clark's Point	<LOQ
	HC_BS	Broad Spit	<LOQ
	SAM-1043	Eld Inlet	<LOQ
	SAM-1115	Aiston Preserve	<LOQ
	SAM-1041	Discovery Bay	<LOQ
	WB_PCB	Penn Cove Baseline Avg	<LOQ
	SAM-1318	Tulalip Reservation	1.1
	SAM-1001	Williams Olson Park	1.4
	SAM-1664	Madrona Pont	1.6
	SAM-1009	Salmon Beach	1.8
	SAM-1020	Rocky Point	1.9
	SAM-1002	Brackenwood Ln	2.0
IQR	SAM-1012	Eastsound, Fishing Bay	3.0
	SAM-1017	N Avenue Park	3.4
	SAM-1589	Three Tree Point	4.4
	SAM-1031	Elliott Bay, Harbor Island, Pier 17	4.4
	SAM-1032	Arroyo Beach	5.6
	SAM-1864	Lions Park	6.5
	SAM-1019	Kitsap St Boat Launch	7.1
	SAM-1863	West Bay Park	8.1
	SAM-1911	Blair Waterway #2	9.2
75th	SAM-1033	Blair Waterway	16

Sum 6 DDTs

Site Category by Percentile	Site ID	Site Name	Sum of 6 DDTs Concentration (ng/g, dry wt.)
25th	SAM-1588	Drayton Harbor	<LOQ
	HC_HO	Hood Canal Holly	<LOQ
	SAM-1003	S of Skunk Island	<LOQ
	SAM-1013	Chimacum Creek delta	<LOQ
	HC_BS	Broad Spit	<LOQ
	WB_PCB	Penn Cove Baseline Avg	0.13
	SAM-1041	Discovery Bay	1.0
	SAM-1042	Squaxin Island	1.3
	SAM-1318	Tulalip Reservation	1.3
	SAM-1317	Friday Harbor	1.3
	SAM-1012	Eastsound, Fishing Bay	1.4
	SAM-1043	Eld Inlet	1.4
	SAM-1315	Reach Island	1.5
	SAM-1009	Salmon Beach	1.5
	SAM-1115	Aiston Preserve	1.8
IQR	SAM-1011	Skiff Point	2.1
	SAM-1001	Williams Olson Park	2.2
	SAM-1002	Brackenwood Ln	2.2
	SAM-1032	Arroyo Beach	2.4
	SAM-1020	Rocky Point	2.5
	SAM-1664	Madrona Pont	2.6
	SAM-1589	Three Tree Point	2.8
	SAM-1863	West Bay Park	3.0
	SAM-1864	Lions Park	3.0
	WB_PCR	Penn Cove Reference	4.3
	SAM-1314	North Camano	4.3
	SAM-1592	Locust Beach	4.4
	SAM-1004	Chuckanut, Clark's Point	4.4
75th	SAM-1591	Cap Sante	6.2
	SAM-1019	Kitsap St Boat Launch	7.1
	SAM-1018	Port Angeles Yacht Club	7.8
	SAM-1033	Blair Waterway	9.9
	SAM-1031	Elliott Bay, Harbor Island, Pier 17	10
	SAM-1017	N Avenue Park	10
	SAM-1911	Blair Waterway #2	18

Arsenic

Site Category by Percentile	Site ID	Site Name	Arsenic Concentration (mg/kg, dry wt.)
IQR	SAM-1115	Aiston Preserve	7.25
	SAM-1004	Chuckanut, Clark's Point	7.51
	WB_PCB	Penn Cove Baseline Avg	7.61
	HC_BS	Broad Spit	7.71
	SAM-1318	Tulalip Reservation	7.74
	SAM-1591	Cap Sante	7.74
	SAM-1009	Salmon Beach	7.88
	SAM-1031	Elliott Bay, Harbor Island, Pier 17	7.99
	SAM-1003	S of Skunk Island	8.00
75th	SAM-1033	Blair Waterway	8.11
	SAM-1019	Kitsap St Boat Launch	8.15
	SAM-1863	West Bay Park	8.21
	SAM-1042	Squaxin Island	8.22
	SAM-1013	Chimacum Creek delta	8.35
	SAM-1911	Blair Waterway #2	8.37
	SAM-1589	Three Tree Point	8.45
	SAM-1041	Discovery Bay	8.52
	SAM-1864	Lions Park	8.56
	SAM-1001	Williams Olson Park	8.57
	SAM-1018	Port Angeles Yacht Club	8.60
	SAM-1020	Rocky Point	8.69
	SAM-1002	Brackenwood Ln	8.70
	SAM-1664	Madrona Pont	8.75
	SAM-1011	Skiff Point	8.82
	SAM-1043	Eld Inlet	8.85
	SAM-1592	Locust Beach	8.96
	SAM-1012	Eastsound, Fishing Bay	9.03
	SAM-1314	North Camano	9.07
	HC_HO	Hood Canal Holly	9.29
	SAM-1315	Reach Island	9.34
	SAM-1317	Friday Harbor	9.39
	SAM-1032	Arroyo Beach	9.65
	WB_PCR	Penn Cove Reference	10.0
	SAM-1017	N Avenue Park	10.3

Cadmium

Site Category by Percentile	Site ID	Site Name	Cadmium Concentration (mg/kg, dry wt.)
25th	SAM-1019	Kitsap St Boat Launch	1.55
	SAM-1004	Chuckanut, Clark's Point	1.60
	SAM-1033	Blair Waterway	1.62
	SAM-1115	Aiston Preserve	1.65
	SAM-1001	Williams Olson Park	1.66
	SAM-1911	Blair Waterway #2	1.70
	SAM-1043	Eld Inlet	1.71
	SAM-1664	Madrona Pont	1.72
	SAM-1012	Eastsound, Fishing Bay	1.73
	SAM-1589	Three Tree Point	1.74
	SAM-1003	S of Skunk Island	1.75
	SAM-1314	North Camano	1.77
	SAM-1592	Locust Beach	1.77
	SAM-1317	Friday Harbor	1.78
	SAM-1018	Port Angeles Yacht Club	1.78
IQR	SAM-1031	Elliott Bay, Harbor Island, Pier 17	1.82
	WB_PCB	Penn Cove Baseline Avg	1.83
	SAM-1009	Salmon Beach	1.83
	SAM-1013	Chimacum Creek delta	1.84
	SAM-1318	Tulalip Reservation	1.84
	SAM-1863	West Bay Park	1.85
	SAM-1002	Brackenwood Ln	1.86
	SAM-1011	Skiff Point	1.89
	SAM-1591	Cap Sante	1.90
	SAM-1864	Lions Park	1.93
	SAM-1017	N Avenue Park	1.93
	SAM-1041	Discovery Bay	1.93
	SAM-1032	Arroyo Beach	1.95
	SAM-1020	Rocky Point	2.00
	SAM-1315	Reach Island	2.04
	HC_BS	Broad Spit	2.06
	WB_PCR	Penn Cove Reference	2.26
	SAM-1042	Squaxin Island	2.29
75th	HC_HO	Hood Canal Holly	2.31

Copper

Site Category by Percentile	Site ID	Site Name	Copper Concentration (mg/kg, dry wt.)
25th	SAM-1009	Salmon Beach	4.77
	SAM-1115	Aiston Preserve	4.94
	HC_BS	Broad Spit	5.06
	WB_PCB	Penn Cove Baseline Avg	5.28
	SAM-1591	Cap Sante	5.30
IQR	SAM-1032	Arroyo Beach	5.62
	SAM-1041	Discovery Bay	5.63
	SAM-1664	Madrona Pont	5.67
	SAM-1003	S of Skunk Island	5.70
	SAM-1017	N Avenue Park	5.80
	SAM-1033	Blair Waterway	5.83
	SAM-1318	Tulalip Reservation	5.85
	SAM-1012	Eastsound, Fishing Bay	6.00
	SAM-1589	Three Tree Point	6.03
	SAM-1020	Rocky Point	6.13
	SAM-1864	Lions Park	6.17
	SAM-1043	Eld Inlet	6.21
	SAM-1002	Brackenwood Ln	6.21
	SAM-1011	Skiff Point	6.24
	SAM-1042	Squaxin Island	6.37
	SAM-1863	West Bay Park	6.60
	SAM-1314	North Camano	6.69
	WB_PCR	Penn Cove Reference	6.75
	HC_HO	Hood Canal Holly	6.75
	SAM-1592	Locust Beach	6.83
	SAM-1317	Friday Harbor	7.00
	SAM-1018	Port Angeles Yacht Club	7.13
	SAM-1911	Blair Waterway #2	8.13
75th	SAM-1019	Kitsap St Boat Launch	8.31
	SAM-1315	Reach Island	9.04
	SAM-1031	Elliott Bay, Harbor Island, Pier 17	9.08
	SAM-1004	Chuckanut, Clark's Point	9.89
	SAM-1001	Williams Olson Park	10.20
	SAM-1013	Chimacum Creek delta	30.50

Lead

Site Category by Percentile	Site ID	Site Name	Lead Concentration (mg/kg, dry wt.)
25th	HC_BS	Broad Spit	0.0699
	HC_HO	Hood Canal Holly	0.0851
	WB_PCB	Penn Cove Baseline Avg	0.146
	SAM-1315	Reach Island	0.159
	SAM-1115	Aiston Preserve	0.177
	SAM-1591	Cap Sante	0.180
	SAM-1042	Squaxin Island	0.182
	SAM-1317	Friday Harbor	0.184
	SAM-1911	Blair Waterway #2	0.185
	SAM-1589	Three Tree Point	0.187
	SAM-1009	Salmon Beach	0.187
	SAM-1318	Tulalip Reservation	0.201
	SAM-1863	West Bay Park	0.203
	SAM-1012	Eastsound, Fishing Bay	0.206
	SAM-1041	Discovery Bay	0.210
IQR	SAM-1002	Brackenwood Ln	0.220
	SAM-1011	Skiff Point	0.222
	WB_PCR	Penn Cove Reference	0.233
	SAM-1004	Chuckanut, Clark's Point	0.238
	SAM-1032	Arroyo Beach	0.242
	SAM-1592	Locust Beach	0.250
	SAM-1043	Eld Inlet	0.251
	SAM-1033	Blair Waterway	0.255
	SAM-1018	Port Angeles Yacht Club	0.257
	SAM-1314	North Camano	0.266
	SAM-1031	Elliott Bay, Harbor Island, Pier 17	0.279
	SAM-1013	Chimacum Creek delta	0.292
	SAM-1864	Lions Park	0.349
	SAM-1001	Williams Olson Park	0.349
	SAM-1020	Rocky Point	0.412
	SAM-1017	N Avenue Park	0.447
	SAM-1003	S of Skunk Island	0.462
75th	SAM-1019	Kitsap St Boat Launch	0.510
	SAM-1664	Madrona Point	0.511

Mercury

Site Category by Percentile	Site ID	Site Name	Mercury Concentration (mg/kg, dry wt.)
25th	HC_BS	Broad Spit	<LOQ
	SAM-1911	Blair Waterway #2	<LOQ
	WB_PCB	Penn Cove Baseline Avg	<LOQ
	SAM-1009	Salmon Beach	0.0238
	SAM-1315	Reach Island	0.0250
	SAM-1018	Port Angeles Yacht Club	0.0281
	SAM-1043	Eld Inlet	0.0286
	SAM-1003	S of Skunk Island	0.0287
	HC_HO	Hood Canal Holly	0.0288
	SAM-1589	Three Tree Point	0.0293
	SAM-1591	Cap Sante	0.0296
	SAM-1012	Eastsound, Fishing Bay	0.0300
	SAM-1664	Madrona Pont	0.0306
	SAM-1001	Williams Olson Park	0.0308
	SAM-1318	Tulalip Reservation	0.0311
	SAM-1592	Locust Beach	0.0313
	SAM-1019	Kitsap St Boat Launch	0.0316
	SAM-1863	West Bay Park	0.0317
	SAM-1033	Blair Waterway	0.0321
	SAM-1042	Squaxin Island	0.0324
	SAM-1041	Discovery Bay	0.0326
	SAM-1013	Chimacum Creek delta	0.0326
IQR	SAM-1115	Aiston Preserve	0.0331
	SAM-1317	Friday Harbor	0.0333
	SAM-1031	Elliott Bay, Harbor Island, Pier 17	0.0334
	SAM-1020	Rocky Point	0.0342
	SAM-1004	Chuckanut, Clark's Point	0.0351
	SAM-1032	Arroyo Beach	0.0360
	SAM-1017	N Avenue Park	0.0364
	SAM-1864	Lions Park	0.0365
	SAM-1002	Brackenwood Ln	0.0375
	SAM-1011	Skiff Point	0.0393
	SAM-1314	North Camano	0.0456
	WB_PCR	Penn Cove Reference	0.0463

Zinc

Site Category by Percentile	Site ID	Site Name	Zinc Concentration (mg/kg, dry wt.)
25th	HC_BS	Broad Spit	68.0
	SAM-1318	Tulalip Reservation	68.3
	WB_PCB	Penn Cove Baseline Avg	72.1
	SAM-1314	North Camano	75.0
	SAM-1003	S of Skunk Island	76.0
	SAM-1115	Aiston Preserve	77.2
	SAM-1863	West Bay Park	78.2
	SAM-1009	Salmon Beach	79.3
IQR	SAM-1591	Cap Sante	81.1
	HC_HO	Hood Canal Holly	82.5
	SAM-1592	Locust Beach	82.9
	SAM-1664	Madrona Pont	85.2
	SAM-1911	Blair Waterway #2	85.5
	SAM-1589	Three Tree Point	86.2
	SAM-1001	Williams Olson Park	86.9
	SAM-1019	Kitsap St Boat Launch	87.2
	SAM-1004	Chuckanut, Clark's Point	87.3
	WB_PCR	Penn Cove Reference	88.2
	SAM-1042	Squaxin Island	89.2
	SAM-1002	Brackenwood Ln	90.5
	SAM-1012	Eastsound, Fishing Bay	90.8
	SAM-1018	Port Angeles Yacht Club	91.8
	SAM-1043	Eld Inlet	92.0
	SAM-1041	Discovery Bay	92.3
	SAM-1011	Skiff Point	92.7
	SAM-1317	Friday Harbor	93.3
	SAM-1864	Lions Park	94.4
	SAM-1013	Chimacum Creek delta	94.7
	SAM-1031	Elliott Bay, Harbor Island, Pier 17	94.8
	SAM-1017	N Avenue Park	94.9
	SAM-1033	Blair Waterway	98.9
75th	SAM-1020	Rocky Point	101
	SAM-1032	Arroyo Beach	104
	SAM-1315	Reach Island	106

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