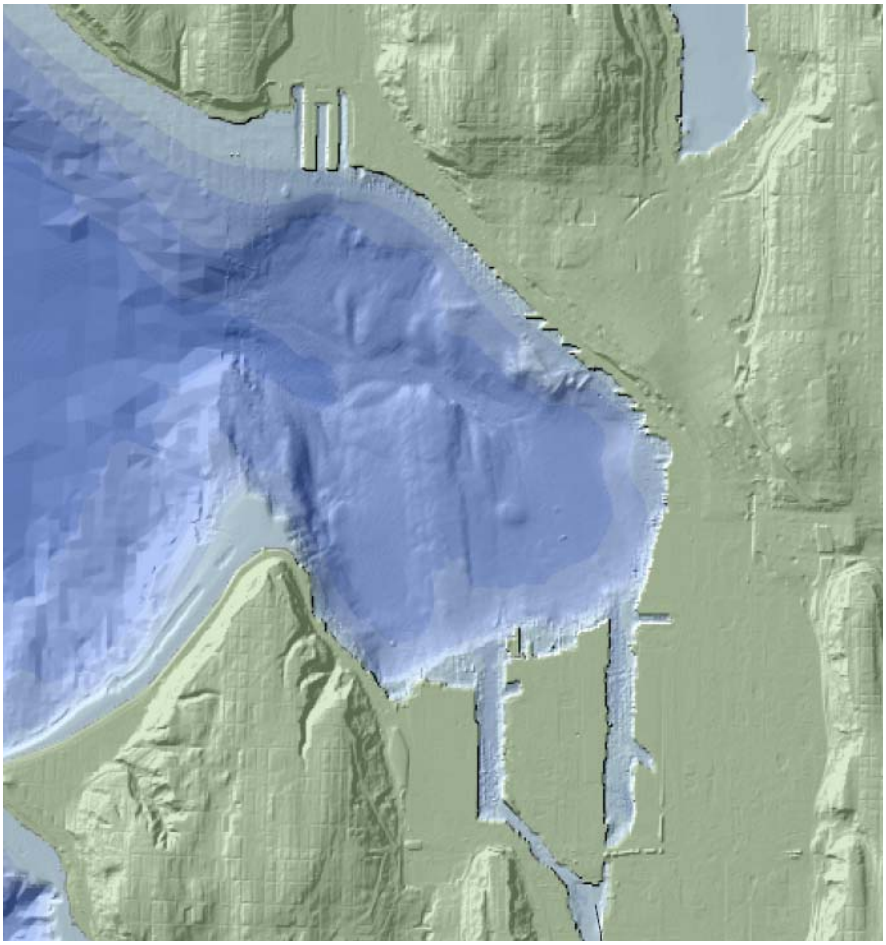
Dioxins, Furans, and other Contaminants in Surface Sediment and English Sole Collected from Greater Elliott Bay (Seattle)



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Cover photo: Light distance and ranging image of Elliott Bay showing water depth and surrounding surface elevations.

Dioxins, Furans, and Other Contaminants in Surface Sediment and English Sole Collected from Greater Elliott Bay (Seattle)

by
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Waterbody Numbers:
WA-09-0010 – Elliott Bay
WA-09-1010 – Duwamish Waterway/River

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List of Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report:

ARI	Analytical Resources Incorporated
cPAHs	Carcinogenic polycyclic aromatic hydrocarbon compounds
CSL	Cleanup screening level
DMMP	Dredged Material Management Program
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database (Department of Ecology)
EPA	U.S. Environmental Protection Agency
HPAHs	High molecular weight polycyclic aromatic hydrocarbon compounds
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Work Group
LPAHs	Low molecular weight polycyclic aromatic hydrocarbon compounds
MEL	Manchester Environmental Laboratory (Department of Ecology)
MSMP	Marine Sediment Monitoring Program (Department of Ecology)
MTCA	Model Toxics Control Act
NTR	National Toxics Rule
PAHs	Polycyclic aromatic hydrocarbon compounds
PCBs	Polychlorinated biphenyl compounds
PRL	Pacific Rim Laboratories
PSAMP	Puget Sound Assessment and Monitoring Program
PSDDA	Puget Sound Dredged Disposal Analysis program
PSEP	Puget Sound Estuary Program (EPA)
QA	Quality assurance
QC	Quality control
SMS	Sediment Management Standards
SQS	Sediment quality standard
TCDD	2,3,7,8-tetrachlorodibenzodioxin
TEQ	Toxic equivalents
TOC	Total organic carbon
USACE	U. S. Army Corps of Engineers (Lead agency of DMMP)
WDFW	Washington Department of Fish and Wildlife

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Abstract

During 2007, the Washington State Department of Ecology (Ecology) collected surface sediment and fish tissue samples from greater Elliott Bay (Seattle) to fulfill needs of various regulatory and monitoring programs.

Sediment chemistry results were intended to:

1. Help define contaminant levels representing an *area background.*
2. Characterize current levels of chlorinated dioxins/furans throughout the area.
3. Determine if levels of contaminants differ between 0-2 and 0-10 cm samples.

In addition, English sole (*Parophrys vetulus*) tissue samples, both whole body and skinless fillets, were tested for levels of dioxins/furans. This was done to augment the scant data available on these contaminants in Puget Sound bottom fish.

Surface sediments from 0-2 and 0-10 cm depth intervals were collected from 30 locations. Sampling locations were chosen using a stratified, random design. Ecology measured selected conventional sediment parameters, trace metals, and organic contaminants (PAHs, PCBs, and chlorinated dioxins/furans) in the 0-2 cm samples. The same parameters were measured in a random subset of 18 matching 0-10 cm samples. A total of 15 fish tissue samples were tested for dioxins/furans only. All laboratory results were usable.

Contaminant levels found in 5 of the 0-10 cm sediment samples may represent area background levels. These results are summarized in the report.

Median values for dioxins/furans for the 0-2 and 0-10 cm samples were 7.7 and 5.9 ng/kg Toxic Equivalents (TEQ), respectively. Levels of most organic contaminants measured in the 0-2 and 0-10 cm samples did not differ. Most trace metals and PCBs, however, were significantly lower in the 0-2 cm sediment samples.

Dioxins/furans in skinless English sole fillets contained 0.26-0.57 ng/kg (wet weight) TEQ. Whole body tissue samples were found to contain 0.99-1.71 ng/kg (wet weight) TEQ. The type of tissue samples tested – skinless fillets vs. whole body – had more influence on results than where fish were collected. Mean levels of 2,3,7,8-tetrachlorodibenzodioxin (TCDD) did not appear to exceed the National Toxics Rule threshold.

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- David Hope and Patrick Pond of Pacific Rim Laboratories for analysis of chlorinated dioxins, chlorinated furans, and fish tissue lipids.
- Washington State Department of Ecology staff:
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Introduction

Study site history

For this study, the outer boundary of greater Elliott Bay is defined by a line drawn between Alki Point and Four Mile Rock (Magnolia Bluff, Seattle) and extending to approximately river mile 4.0 in the Lower Duwamish Waterway (LDW). This is a total area of approximately 26 km^2 that includes sediments ranging from the very shallow intertidal zone to more than 500 feet deep. Land use near the shoreline is primarily urban and industrial, with small pockets of mixed uses and residential.

Previous monitoring studies have identified polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and some trace metals as the main contaminants of concern in this area. Far less is known about chlorinated dioxins and furans[1] in sediments, a more recent concern.

PCBs are no longer being produced or actively used, so ongoing sources are few. Instead, PCBs are cycled within the aquatic environment. In contrast, there are ongoing sources of metals, PAHs, and dioxins/furans. Sources of these contaminants include discharges from heavy land-based industries, light industry, maritime trade, municipal wastewater treatment plants, stormwater and surface runoff, combustion, and aerial deposition. A majority of contaminants are thought to enter the bay as point (discrete) discharges and surface runoff from along the Seattle waterfront, the Lower Duwamish River, and the Green River. Evidence suggests that higher levels of contaminants tend to accumulate near the shoreline (Glass, 2007).

In 1996, Ecology formally listed nearshore areas of Elliott Bay and locations in the Lower Duwamish River as potential areas of concern (Ecology, 1996). In 2000, the EPA and Ecology cleanup programs recognized the LDW, between river miles 0.0 and approximately 5.0, as a sediment cleanup site (EPA, 2000). The detailed studies of surface sediment quality that followed focused on the *biologically-active zone* (0-10 cm depth). One objective of the studies was to collect data that would support calculation of contaminant levels that represent *area background*. The Model Toxics Control Act (MTCA) defines area background as "the concentration of hazardous substances that are consistently present in the environment in the vicinity of a site, and are the results of human activities unrelated to releases from that site."

The Puget Sound Assessment and Monitoring Program (PSAMP) has measured contaminant levels in surface sediments and fish species throughout Puget Sound since 1989. Ecology's Marine Sediment Monitoring Program (MSMP) conducted a detailed survey of greater Elliott Bay in 1998 (Long et al., 2000; 2003), measuring sediment quality in only the most recent sediment deposits (0-2 cm depth). It is not known how sediment quality in the top 0-2 cm compares to the 0-10 cm interval. The Washington Department of Fish and Wildlife (WDFW)

[1] Henceforth referred to as "dioxins/furans" in this report.

administers the "Toxics in Biota" component of PSAMP has routinely measured contaminant levels Elliott Bay. However, neither program has measured dioxins/furans.

Finally, the intent of the recent Urban Waters (Cleanup and Protection) Initiative (UWI) is to strengthen efforts to find and control sources of pollution before pollutants enter urban waters. One of the 3 areas identified in the law is the LDW. Ecology's role in implementing the UWI will be to measure indicators of current surface sediment quality then assess sediment quality again in 5 years. Dioxins/furans will be among the chemical indicators measured.

Project background

This study was requested by Ecology's Aquatic Lands Cleanup Program. Among the study goals was providing results that would help define current sediment quality in Elliott Bay as well as area background conditions. Notably, the study design took advantage of field sampling activities already planned under the Urban Waters Initiative by the MSMP and the Department of Fish and Wildlife's (WDFW) PSAMP staff. Levels of selected conventionals, trace metals, PAHs, and Aroclor PCBs were measured by MSMP staff in 0-2 cm sediment samples collected throughout greater Elliott Bay. The same methods were used to measure the same parameters in 60% of the 0-10 cm samples collected from the same locations. Levels of dioxins/furans were measured in 0-2 and 0-10 cm sediment samples, as well as in English sole tissues.

Results of the study were intended to:

- Establish a dataset that can be used to assess current dioxins/furans levels in Elliott Bay surface sediments.
- Determine if levels of contaminants in 0-2 and 0-10 cm sediment samples are significantly different.
- Provide a line of evidence for defining area background conditions that may include use of the 0-2 cm results (if indistinguishable from 0-10 cm results).
- Provide results for dioxins/furans in sediments and English sole.

Methods

Sample collection

Sediment stations were selected by the MSMP using a probability-based, random sampling design that was applied to greater Elliott Bay. Sediment from 0-2 and 0-10 cm depths was collected from 30 stations (Figure 1). This study randomly chose 0-10 cm sediment from 18 of the 21 stations not located in the LDW for analysis. Sediment sampling was conducted on the *RV Kittiwake.* See Appendix Table A-1 for station details.

Positioning, field sampling, sample handling and storage, chain of custody, and lab analytical methods followed those identified and described in the final Quality Assurance (QA) Project Plan (Gries, 2008). Details of vessel positioning and field sampling are described a companion report being prepared by MSMP staff (Dutch et al., 2008). The only notable deviation from the QA Project Plan was failure to collect a sample at one sampling location (174) resulting in the need to collect sediment at alternate Station 186 (Figure 1).

An equal amount of *recent* 0-2 cm sediment was removed from each quadrant of each double van Veen grab and placed in a pre-cleaned stainless-steel mixing bucket labeled "*0-2 cm"*. The 0-10 cm sediment samples, representing the *biologically active zone,* were collected from the same grabs. These samples were placed in a separate stainless-steel bucket labeled "*0-10 cm*".

The WDFW collected English sole from several trawls in greater Elliott Bay (WDFW, 2007a; 2007b). Trawl locations are shown in Figure 1, and station details are presented in Appendix A (Table A-1). Three whole body composite samples, comprised of 10 individuals each, were prepared from fish caught in a trawl along the Seattle waterfront. WDFW also combined skinless fillets from 20 individual fish into 6 composite samples, from each of the waterfront and LDW trawl sites. Ecology measured levels of dioxins/furans, and the WDFW measured PCB congeners in all 15 tissue samples.

There were no major exceptions to sample handling, tissue post-processing, or sample storage procedures. A few sediment sample jars cracked when frozen. This did not affect resulting analysis because the integrity of the sample jars was not compromised or the jars contained archived sediment that was not needed.

More description of sampling methods can be found in the final QA Project Plan (Gries, 2008).

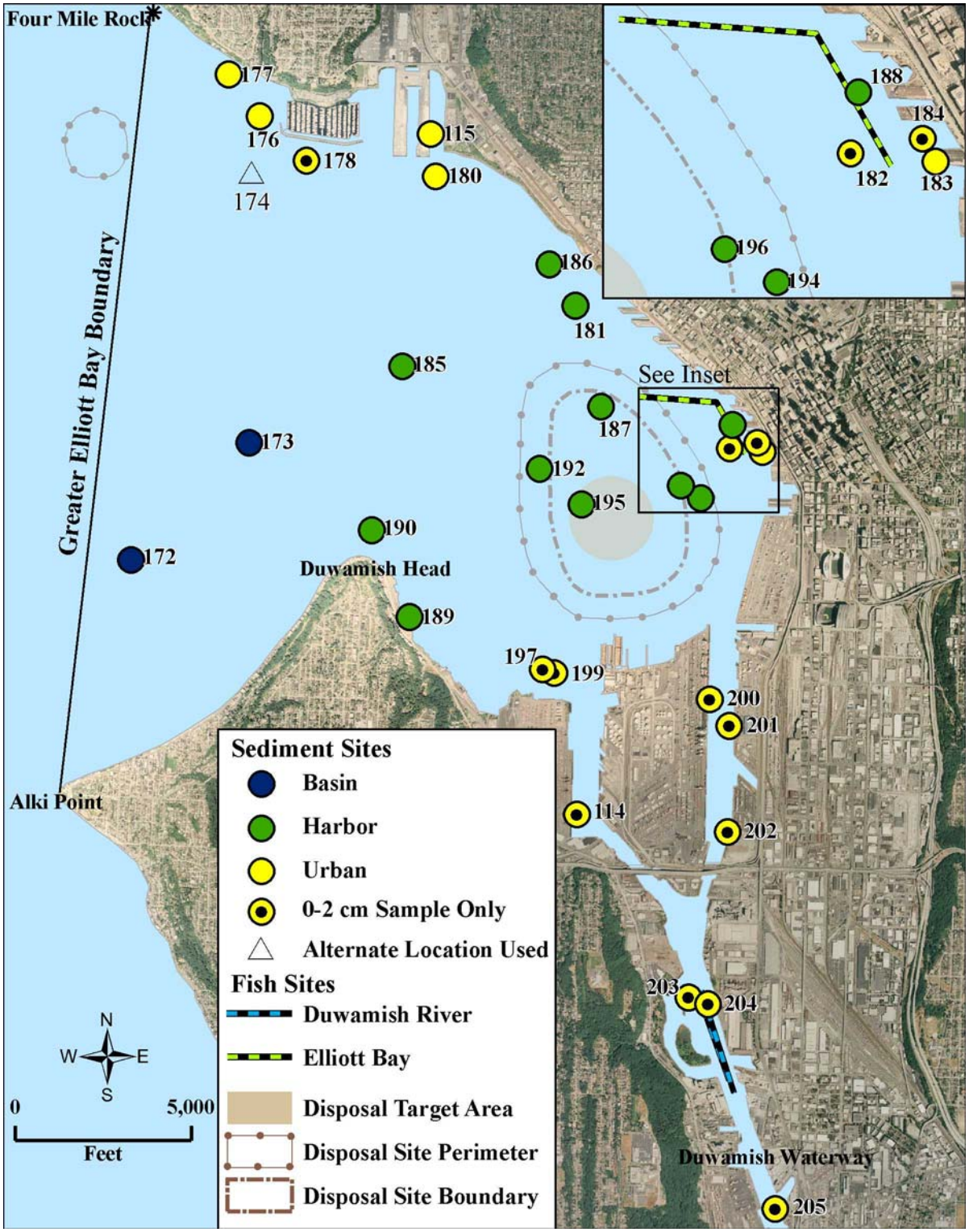

Figure 1. Sediment stations and fish trawl lines in greater Elliott Bay.

Surface sediment samples representing 0-2 and 0-10 cm depths were collected, except as shown in the legend. No sediment could be collected at Station 174, so sediment was collected from alternate Station 186 instead. Fish were collected along trawl lines shown. Disposal site is managed by DMMP for dredging activity.

Analysis

Table 1 lists the analytical methods used for this study. All of the methods were as required in the QA Project Plan, with the following exception. Pacific Rim Laboratories measured % lipids in tissue samples using EPA Method 1613B instead of Sloan et al (2004). The EPA method involves weighing the dried residue of lipids extracted using methylene chloride and hexane, and comparing the residue to the weight of the tissue from which the sample was derived. This method was pre-approved by the principal investigator as an acceptable alternate method.

Table 1. Parameters measured and methods used by each laboratory.

Parameter	Matrix	Laboratory	Method(s)
Total solids	Sediment	ARI and MEL	Analysis: PSEP (1986)
Particle (grain) size distribution	Sediment	ARI	Analysis: PSEP (1986)
Total organic carbon	Sediment	MEL	Analysis: PSEP (1986)
Trace metals (arsenic, cadmium, chromium, copper, lead, nickel, selenium, silver, tin, zinc)	Sediment	MEL	Analysis: EPA 200.8
PAHs	Sediment	MEL	Extraction: EPA 3545 Cleaning: EPA 3630 Analysis: EPA 8270D with isotope dilution
Aroclor PCBs	Sediment	MEL	Extraction: EPA 3665 Cleaning: EPA 3620 Analysis: EPA 8082
Dioxins/furans	Sediment, Fish Tissue	PRL	Analysis: EPA 1613B
Lipids	Fish Tissue	PRL	Analysis: EPA 1613B

ARI = Analytical Resources Inc.
EPA = U.S. Environmental Protection Agency
MEL = Ecology's Manchester Environmental Laboratory
PRL = Pacific Rim Laboratories, Ltd.
PSEP = EPA's Puget Sound Estuary Program

A QA review was performed using results from analysis of all test and quality control (QC) sediment samples. Results are summarized in Appendix Table A-2. In addition to the data verification process, the MEL QC coordinator validated results for dioxins/furans in 10% of the samples collected (5 sediment samples and 1 fish tissue sample)[2]. Results met the measurement quality objectives set forth in the QA Project Plan. Some results were assigned appropriate qualifiers, but no QC sample results exceeded action limits for any parameter.

The following issues did not compromise the usability of the data but were noted by laboratory staff:

- ARI found 2 samples lacked enough mass to measure % fines, and so estimated % fines by difference (total mass of particles minus mass of > 62.5 µm particles).

[2] Validation included confirming instrument calibrations, calibration curves, re-examining instrument responses to test samples, and recalculating result levels.

- MEL re-extracted 3 of the 10 cm sediment samples (17%) before measuring levels of organic contaminants. This was due to matrix effects that caused low surrogate recoveries in the initial batch.
- Pacific Rim Laboratories reported:
  - 19 of the 48 sediment samples (40%) required a second cleanup step before measuring dioxins/furans.
  - Low recoveries of surrogate compounds (QC samples for measuring dioxins/furans) from sediment samples, likely due to high water content or % TOC.
- Age estimated from fish length and gender was uncertain in some of the individual fish in composite tissue samples.

Toxic equivalents (TEQ) for the cPAHs and dioxins/furans were calculated using recent toxic equivalency factors (WHO, 2005). Unless stated otherwise, a level equal to one-half the reporting limit was used for the calculations when an individual PAH compound or dioxin/furan congener was not detected.

Descriptive, exploratory, and other statistics (hypothesis testing) were calculated using SYSTAT software for Windows 11.0 (SYSTAT, 2004). In particular, a paired t-test was used to compare the 0-2 and 0-10 cm sediment sample results. The paired t-test does not compare means of 2 sample populations. Instead, it compares the difference between each pair of results to zero representing no difference between sample pairs. The 2 types of samples are significantly different if the mean of all differences deviates enough from zero.

Results

Sediment chemistry

This section briefly describes results for levels of sediment conventionals and contaminants measured in paired 0-2 and 0-10 cm samples collected at 18 stations in Elliott Bay.

Surface sediments at these 18 stations had a broad range of particle size distributions and contained variable organic carbon content (Table 2). Sandy sediments were generally in shallower water and had low % TOC. Fines ranged from less than 3% to nearly 90%, while TOC ranged from 0.14% to 2.65%. The mean % silt was significantly lower in the 0-2 cm samples than in the 0-10 cm samples.

Table 2. Summary statistics for sediment conventionals in 18 paired sediment samples.

The 0-2 cm results were provided by MSMP staff. Bold font shows means are different at alpha <0.05.

Parameter (%)	Paired T-test	Median		Mean		Minimum		Maximum	
Sample depth (cm):		0-2	0-2	0-10	0-10	0-2	0-10	0-2	0-10
Sand	0.53	52.1	49.8	49.2	52.8	15.3	13.2	96.5	97.2
Silt	**0.03**	30.3	26.9	34.7	32.9	2.9	0.0	57.3	64.1
Clay	0.58	14.7	12.5	12.6	14.3	0.0	2.8	40.2	35.3
Fines	0.06	39.3	45.0	47.2	51.0	3.2	2.8	84.7	86.9
TOC (70°C)	0.66	1.84	1.43	1.41	1.52	0.15	0.14	2.43	2.65

Levels of 10 trace metals in sediments were also variable (Table 3). The difference between the minimum and maximum levels measured was as little as 2-3 times (chromium, nickel, selenium) or as much as nearly 2 orders of magnitude (cadmium) or more (tin). Paired t-tests, with alpha set at 0.05, showed levels of most metals were lower in the 0-2 cm samples. Arsenic and nickel levels were also significantly lower in 0-2 cm samples when alpha was set at 0.10. Tin was the only metal that did not differ between the 2 sample depths.

Table 3. Summary statistics for levels of trace metals in 18 paired sediment samples.

The 0-2 cm results were provided by MSMP staff. For the paired t-test, reporting limits were used when the metal was not detected. Bold font shows results that were significant at alpha <0.05.

Contaminant (mg/kg)	Detection Frequency		Paired T-test	Median		Mean		Minimum		Maximum	
Sample depth (cm):	0-2	0-10		0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
Arsenic	1.00	1.00	0.07	8.41	8.96	7.94	8.55	1.74	2.04	13.7	13.7
Cadmium	0.89	1.00	**0.00**	0.23	0.32	0.25	0.31	0.1U	0.1	0.57	0.71
Chromium	1.00	1.00	**0.00**	29.1	41.1	31.7	40.4	18.5	21.0	49.9	69.4
Copper	1.00	1.00	**0.01**	36.0	41.0	38.3	44.2	5.67	6.84	94.6	83.5
Lead	1.00	1.00	**0.00**	26.7	31.5	32.7	41.6	6.75	7.54	82.5	86.0
Nickel	1.00	1.00	0.08	24.6	30.1	28.6	32.7	16.9	20.1	64.0	57.3
Selenium	0.44	0.56	**0.01**	0.50	0.56	0.58	0.71	0.5U	0.5U	0.99	1.30
Silver	0.89	0.89	**0.00**	0.32	0.41	0.47	0.52	0.01U	0.01U	1.31	1.34
Tin	1.00	1.00	0.15	2.78	2.98	10.4	12.0	0.48	0.70	130	132
Zinc	1.00	1.00	**0.00**	82.5	97.5	78.1	89.7	27.0	26.0	130	136

U = Analyte was tested for, but not detected above, the reporting limit.

Seventeen PAHs were consistently detected in 0-2 and 0-10 cm sediments (Table 4). Maximum levels for individual and summed PAHs were often 3 orders of magnitude greater than minimum levels. Maximum LPAH levels were 5,000 and 3,450 µg/kg dry weight for 0-2 cm and for 0-10 cm samples, respectively (Figure 2a). The mean levels of LPAH in samples of both depths were about 1,000 µg/kg dry weight. The 3 most abundant LPAHs in 0-2 and 0-10 cm samples were phenanthrene, anthracene, and naphthalene.

Maximum HPAH levels were 13,800 and 15,800 µg/kg dry weight in 0-2 and 0-10 cm samples, respectively (Figure 2b). Mean HPAH levels were 3,610 and 3,070 µg/kg dry weight for these sampling depths. Total benzofluoranthenes, pyrene, and fluoranthene were the 3 most abundant HPAHs.

Only levels of 2-methylnaphthalene and naphthalene were significantly greater in 0-10 cm samples than in 0-2 cm samples.

Table 4. Summary statistics for levels of PAHs in 18 paired sediment samples.

The 0-2 cm results were provided by MSMP staff. Reporting limits were used when no contaminant was detected. Bold font shows results that were significant at alpha <0.05.

Contaminant (µg/kg dry weight)	Detection Frequency		Paired T-test	Median		Mean		Minimum		Maximum	
Sample depth (cm):	0-2	0-10		0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
Naphthalene	0.89	1.00	**0.05**	158	148	193	251	5.0UJ	3.5	796	961
Acenaphthylene	1.00	1.00	0.96	72	84	117	116	25	2.6	513	708
Acenaphthene	1.00	1.00	0.32	27	28	44	65	1.1	0.9J	224	447
Fluorene	1.00	1.00	0.61	43	45	75	88	1.9	1.8	409	515
Phenanthrene	1.00	1.00	0.63	207	207	324	288	5.2	6.7	1740	882
Anthracene	1.00	1.00	0.61	108	113	263	231	3.5	4.6	1320	1420
2-Methyl naphthalene	1.00	0.94	**0.04**	51	55	68	80	2.6	1.6	307	380
Total LPAH	1.00	1.00	0.90	649	724	1010	1040	21	20	5000	3450
Fluoranthene	1.00	1.00	0.90	298	301	482	498	9.9	10	1980	2240
Pyrene	1.00	1.00	0.97	363	372	613	609	9.8	10	2880	3600
Benzo(a) anthracene	1.00	1.00	0.47	131	135	221	187	3.4	4.7	1000	770
Chrysene	1.00	1.00	0.50	222	226	423	370	5.1	5.3	1920	2080
Total Benzo-fluoranthenes	1.00	1.00	0.32	377	383	659	615	13	16	3160	3400
Benzo(b) fluoranthene	0.94	1.00	0.26	277	267	497	433	8.9	11	2340	2290
Benzo(k) Fluoranthene	1.00	1.00	0.87	103	114	190	183	3.7	4.9	815	1110
Benzo(a)pyrene	0.94	1.00	0.18	204	209	406	332	4.9	6.0	1890	1750
Indeno(1,2,3-cd) pyrene	0.94	1.00	0.32	135	164	259	229	4.0	5.8	1300	976
Dibenzo(a,h) anthracene	1.00	1.00	0.67	38	43	52	48	1.0	1.0	211	132
Benzo(ghi) perylene	1.00	1.00	0.33	147	135	228	179	4.3	5.2	947	873
Total HPAH	1.00	1.00	0.38	2200	2050	3610	3070	55	72	13800	15800
Dibenzofuran	0.94	1.00	0.54	47	55	82	108	3.2	2.8	353	829
cPAH TEQ	1.00	1.00	0.17	300	290	630	440	10	10	2400	2300

J = Analyte identified, estimated value given.
UJ = Analyte was not detected; however, the detection limit may or may not represent the actual limit of quantification.

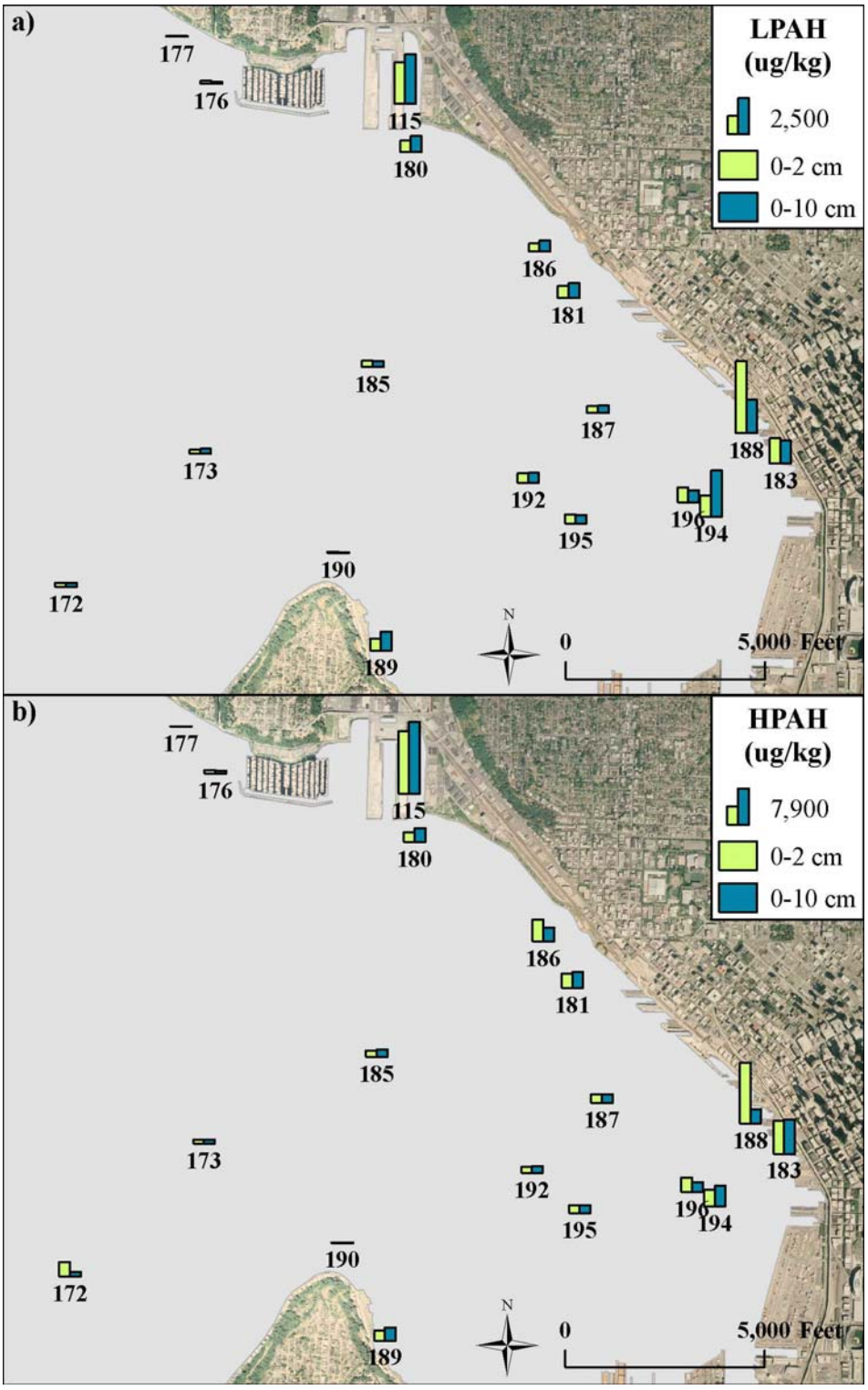

Figure 2. Levels of low and high molecular weight PAHs (LPAH and HPAH) in 0-2 cm and 0-10 cm sediment samples.

Bar graphs show levels of contaminants. The tall bar in the legend equals one-half the maximum level measured. (For example the maximum LPAH value is 5,000 µg/kg and the darker bar represents 2,500 µg/kg).

Aroclors 1254 and 1260 were the only Aroclor PCBs consistently detected (Table 5). PCB-1242 was measured near detection limits in over one-half of the 0-2 cm samples, but not found (same detection limits) in the 0-10 cm samples. All other Aroclors were undetected, most at the level of approximately 10 µg/kg dry weight. The maximum level measured was often 2-3 times the minimum level. Median levels for the total PCBs in the 0-2 and 0-10 cm samples were nearly the same (Figure 3). However, the mean levels were significantly different. The mean levels in 0-2 and 0-10 cm samples were 88 and 119 µg/kg (dry weight), respectively.

Table 5. Summary statistics for levels of Aroclor PCBs in 18 paired sediment samples.

The 0-2 cm results were provided by MSMP staff. Reporting limits were used when no Aroclor was detected. Bold font shows results that were significant at alpha <0.05.

Aroclor (µg/kg dry weight)	Detection Frequency		Paired T-Test	Median		Mean		Minimum		Maximum	
Sample depth (cm):	0-2	0-10		0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
PCB - 1016	0.00	0.00	-	10	10	10	11	9.0U	9.4U	11U	18U
PCB - 1221	0.00	0.00	-	10	10	10	10	9.0U	9.4U	11U	11U
PCB - 1232	0.00	0.00	-	10	10	11	10	9.0U	9.4U	21UJ	11U
PCB - 1242	0.56	0.00	-	10	11	11	13	9.0U	9.4U	15U	23UJ
PCB - 1248	0.00	0.00	-	20	19	22	23	9.8U	9.4U	40UJ	43UJ
PCB - 1254	0.89	0.89	**0.01**	30	34	39	58	9.8U	9.4U	90	150
PCB - 1260	0.83	0.83	**0.03**	29	30	44	62	9.8U	9.4U	109	204J
PCB - 1262	0.00	0.00	-	27	22	34	38	9.8U	9.4U	74UJ	102UJ
PCB - 1268	0.00	0.00	-	10	10	10	13	9.0U	9.4U	11U	51UJ
Total PCBs[3]	0.89	0.89	**0.01**	65	63	88	119	9.8	9.4	195	317

J = Analyte identified, estimated value given.
UJ = Analyte was not detected; however, the detection limit may or may not represent the actual limit of quantification.

Levels of dioxins/furans ranged over more than 4 orders of magnitude, congeners with the greatest number of chlorine atoms being the most abundant (octachloro-, heptachloro-, and hexachloro-dibenzodioxins/furans) (Table 6). Converted to Toxic Equivalents (TEQ), the range of values for surface sediments was 0.67 - 97.6 ng/kg (dry weight). The maximum level was found in 0-10 cm sediment collected from Station 188 (Figure 3).

The mean total TEQ level in 0-10 cm samples (15.1 ng/kg) was greater than for 0-2 cm sediments (8.85 ng/kg), but the paired t-test was not statistically significant. Mean total TEQ values were also greater than the median values, especially for 0-10 cm samples, because of high levels at just a few stations (Figure 3). Median TEQ values representing the 2 sampling depths were very similar.

[3] Total Aroclor PCBs were calculated as per the SMS (Ecology, 1995) with the highest detection limit used if all aroclors were undetected.

Table 6. Summary statistics for levels of dioxins/furans in 18 paired sediment samples**.**

Reporting limits were used when no congener was detected. Bold font shows results of paired t-test that were significant at alpha <0.05. Rows showing results as TEQ are highlighted.

Congener (or Sum) (ng/kg dry weight)	Detection Frequency		Paired T-Test	Median		Mean		Minimum		Maximum	
Sample Depth:	0-2	0-10		0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
2,3,7,8-TCDD	0.78	0.39	0.47	0.297	0.200	0.335	0.408	0.20U	0.20U	0.710	1.64
1,2,3,7,8-PeCDD	0.78	0.72	0.24	1.27	1.13	1.60	3.98	0.50U	0.50U	3.98	30.5
1,2,3,4,7,8-HxCDD	0.67	0.56	0.17	0.773	0.945	1.34	3.58	0.50U	0.50U	4.23	27.3
1,2,3,6,7,8-HxCDD	0.89	0.89	0.18	4.97	5.76	8.29	11.4	0.50U	0.50U	24.5	64.9
1,2,3,7,8,9-HxCDD	0.89	0.83	0.17	2.12	1.88	2.88	4.75	0.50U	0.50U	7.49	26.6
1,2,3,4,6,7,8-HpCDD	1.00	1.00	0.28	135	143	276	203	3.24	3.38	1220	832
OCDD	1.00	1.00	0.18	1440	1380	2780	1950	27.4B	29.9B	11300	7440
Total Dioxins			0.20	1580	1540	3070	2180	3.20	3.40	12600	8100
Dioxins[4] (TEQ)	-	-	0.50	3.76	4.12	6.69	8.83	0.461	0.463	23.3	53.4
2,3,7,8-TCDF	0.89	0.89	0.25	0.860	1.11	1.51	2.14	0.20U	0.20U	9.04	9.53
1,2,3,7,8-PeCDF	0.78	0.72	0.20	0.937	0.805	1.54	3.92	0.50U	0.50U	5.86	26.7
2,3,4,7,8-PeCDF	0.78	0.72	0.16	0.829	0.980	1.28	5.21	0.50U	0.50U	4.24	42.1
1,2,3,4,7,8-HxCDF	0.89	0.89	0.17	3.96	3.39	5.04	11.62	0.50U	0.50U	14.1	77.3
1,2,3,6,7,8-HxCDF	0.83	0.83	0.18	1.19	1.19	1.95	7.71	0.50U	0.50U	6.50	63.1
2,3,4,6,7,8-HxCDF	0.83	0.83	0.19	2.38	1.67	2.91	12.47	0.50U	0.50U	8.95	104
1,2,3,7,8,9-HxCDF	0.39	0.56	0.17	0.500	0.540	0.964	4.84	0.50U	0.50U	2.82	40.1
1,2,3,4,6,7,8-HpCDF	0.94	0.94	0.36	31.6	29.6	45.4	62.1	0.70UJ	0.70U	129	365
1,2,3,4,7,8,9-HpCDF	0.83	0.72	0.22	2.54	2.52	3.54	6.96	0.70U	0.70U	9.23	46.4
OCDF	1.00	1.00	0.67	112	102	170	157	2.22	1.60	472	487
Total Furans			0.46	160	147	233	273	2.20	1.60	623	1160
Furans [4] (TEQ)	-	-	0.18	1.41	1.62	2.16	6.25	0.20	0.20	5.56	44.1
Dioxins/furans [4] (TEQ)	-	-	0.31	5.15	5.87	8.85	15.1	0.67	0.67	26.6	97.6

U = Analyte was tested for, but not detected above, the reporting limit.
B = Analyte detected in blank and result <10 times the level in the blank.
UJ = Analyte was not detected; however, the detection limit may or may not represent the actual limit of quantification.

[4] For TEQ calculations, one-half the reporting limit was used if a congener was not detected.

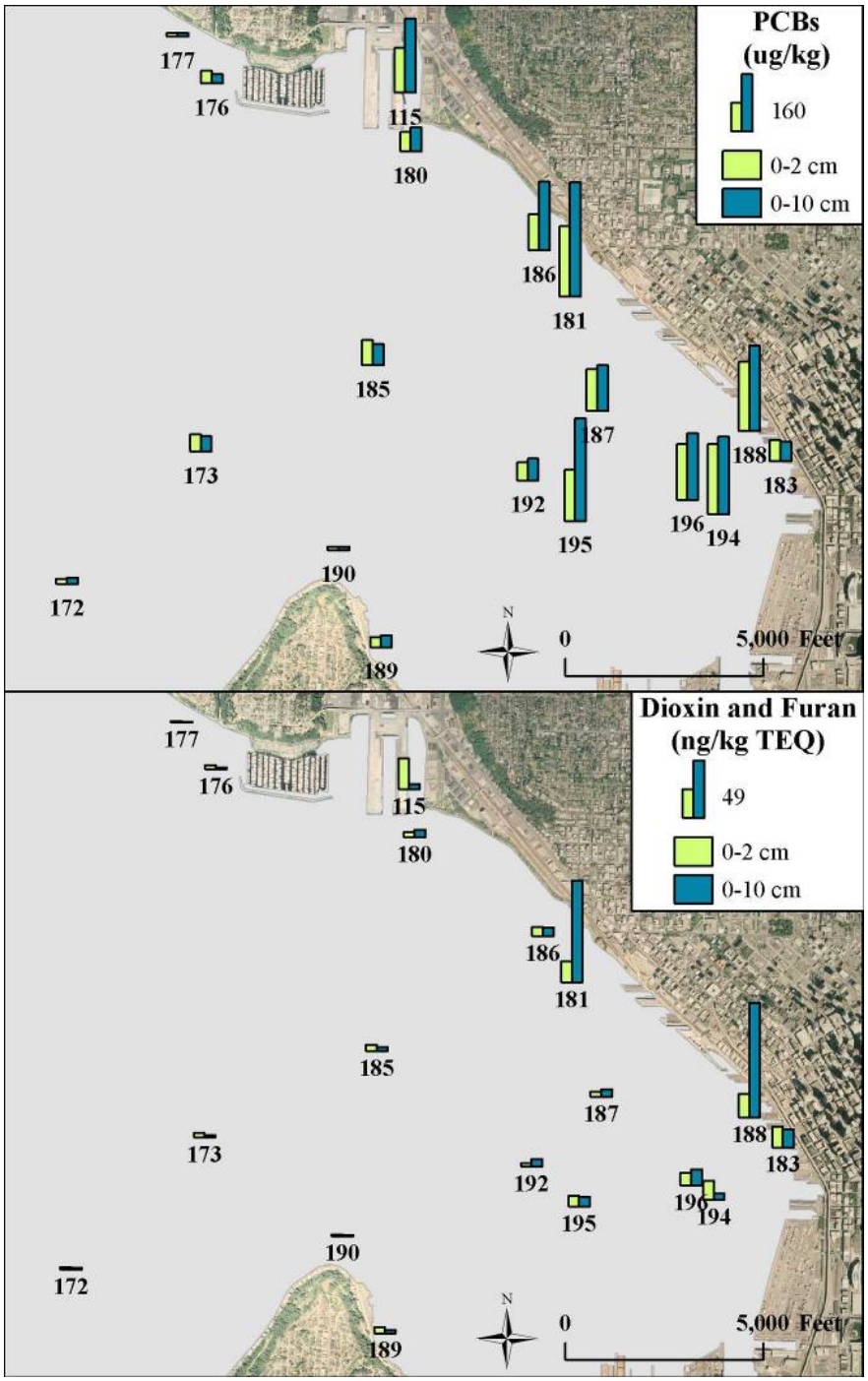

Figure 3. Levels of PCBs and dioxins/furans in 0-2 and 0-10 cm sediment samples.

Bar graphs show levels of contaminants. The tall bar in the legend equals one-half the maximum level measured. (For example the maximum PCBs value is 320 µg/kg and the darker bar represents 160 µg/kg). For TEQ calculations, one-half the detection limit was used for congeners not detected. Total Aroclor PCBs were calculated as per the SMS (Ecology, 1995) with the highest detection limit used if no Aroclors were detected.

Total dioxins/furans measured in all 30 of the 0-2 cm sediment samples ranged from 0.67-26.6 ng/kg TEQ (See Tables A-6 & A-7 in the Appendix). The maximum level was found at Station 115. Mean and median total dioxin/furan levels were 9.70 and 7.67 ng/kg TEQ, respectively. These results are summarized in Table 7 and are discussed more in a report prepared by the MSMP staff (Dutch et al., 2008).

Table 7. TEQs for dioxins/furans in all 30 of the 0-2 cm sediment samples.

TEQs were calculated by multiplying a toxic equivalency factor by each individual result and summing. One-half the reporting limit was used in TEQ calculations if a congener was not detected.

Summary Statistics	Total Dioxins (ng/kg TEQ)	Total Furans (ng/kg TEQ)	Total Dioxin/Furan (ng/kg TEQ)
Mean	7.36	2.33	9.70
Median	5.84	1.81	7.67
Minimum	0.465	0.200	0.665
Maximum	23.3	5.56	26.6
90% CI Upper	9.16	2.85	11.9
90% CI Lower	5.56	1.82	7.44

CI – confidence interval

Finally, levels of contaminants in the 0-10 cm sediment samples were compared to the sediment quality standards (SQS). Table 8 shows that 15 sample results, representing 8 stations, exceeded the SQS. Stations 183 and 194 had the most exceedances (3 each).

Table 8. Organic contaminants in 0-10 cm sediment samples that exceeded the SQS.

Results are only for 0-10 cm samples and are reported in units of mg/kg total organic carbon.

Station ID	Acenaphthene	Fluorene	Chrysene	Indeno[1,2,3-c,d]pyrene	Dibenzo[a,h]anthracene	Benzo[g,h,i]perylene	Dibenzofuran	Total PCBs
115				46.5		41.6		
180				36.1			15.5	
181								23.0
183			118	58.4	13.2			
186				34.2				20.9
189							15.2	
194	20.4	23.5					37.9	
195								15.4
SQS	16	23	110	34	12	31	15	12

Fish Tissue Chemistry

The 3 whole fish composite samples had a mean level of dioxins/furans of 1.35 ng/kg TEQ and a mean lipid content of 1.9% (Table 9). The only other study to measure dioxins/furans in English sole from Elliott Bay was conducted by Science Application International Corporation (SAIC) for the DMMP agencies (SAIC, 2008a). They used the same test methods to measure dioxins/furans in 3 composite tissue samples, each prepared from 5 whole fish. The mean level of dioxins/furans for that study was 0.68 ng/kg TEQ, somewhat lower than the mean of 1.35 ng/kg TEQ reported here.

Table 9. Dioxins/furans in whole body and skinless fillets of English sole.

Sample ID	TCDD (ng/kg wet weight)	Total TEQ (ng/kg wet weight) ND = RL/2	Lipid (%)
Whole Body Samples			
EBW01	0.030UJ	1.710	1.7
EBW02	0.066	1.340	2.3
EBW03	0.088	0.989	1.7
Mean (n = 3)	0.061	1.346	1.9
Median	0.066	1.340	1.7
Skinless Fillet Samples			
EBSF01	0.06	0.407	0.7
EBSF02	0.030UJ	0.573	0.5
EBSF03	0.073	0.285	0.7
EBSF04	0.030UJ	0.315	0.6
EBSF05	0.05J	0.398	0.6
EBSF06	0.036J	0.405	0.6
Mean (n = 6)	0.047	0.397	0.6
Median	0.043	0.402	0.6
DUSF01	0.030UJ	0.331	1.0
DUSF02	0.07	0.290	0.8
DUSF03	0.030UJ	0.260	0.7
DUSF04	0.030UJ	0.289	0.7
DUSF05	0.076	0.305	0.7
DUSF06	0.030UJ	0.350	0.7
Mean (n = 6)	0.044	0.304	0.8
Median	0.030	0.298	0.7

ND = analyte not detected in sample, RL = analytical reporting limit, EB = Elliott Bay nearshore trawl sites (see Figures 1 and 4), SF = skinless fillets, DU = Duwamish River trawl site (near Kellogg Island), W = whole body. TCDD = 2,3,7,8-tetrachlorodibenzodioxin.

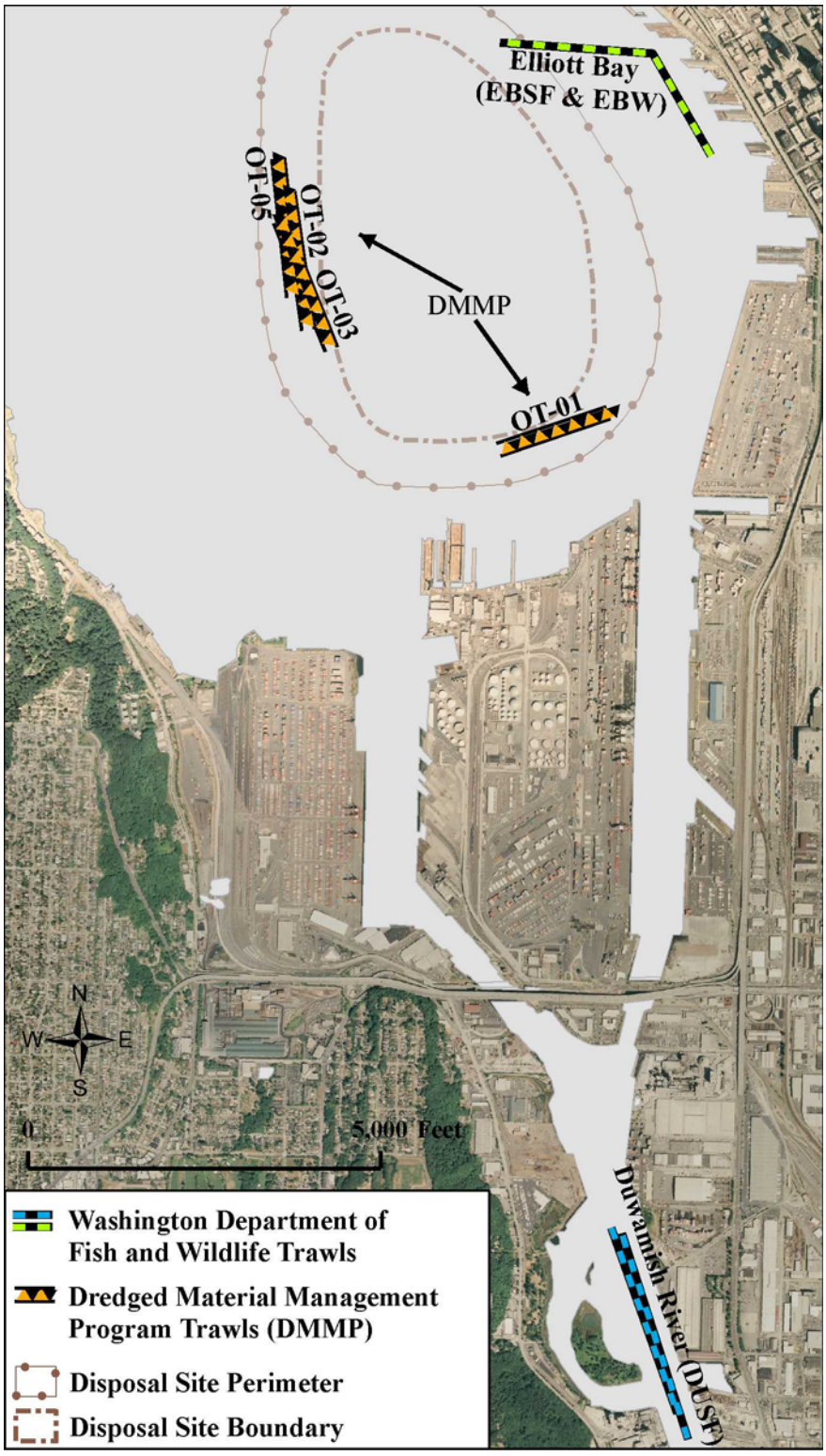

Figure 4. Locations where trawl samples were collected during summer 2007.

This study also measured levels of dioxins, furans, and lipids in skinless English sole fillets. The 6 fillets composited from fish collected near the Seattle waterfront trawl averaged 0.40 ng/kg TEQ and 0.6% lipids. The fillet samples from fish collected in the Lower Duwamish Waterway trawls averaged 0.30 ng/kg TEQ and 0.8% lipids.

We explored potential differences between the mean levels of dioxins/furans in different types of samples (whole fish vs. skinless fillets) and in like samples prepared using fish collected from different areas.

The following is a summary of findings. Sample sizes were not large enough to compare statistically; therefore, only qualitative comparisons were made.

- % lipids in whole body samples were greater than % lipids in skinless fillet samples collected for this study.
- Levels of dioxins/furans in whole body tissue samples were greater than levels in skinless fillet samples.
- Levels of dioxins/furans in skinless fillets prepared from fish collected at 2 sites in greater Elliott Bay did not differ.
- Levels of dioxins/furans in whole fish samples prepared from fish collected during 2 separate 2007 studies did not differ.

Levels of dioxins/furans were compared to the National Toxics Rule (NTR) threshold level for 2,3,7,8-tetrachlorodibenzodioxin (TCDD) of 0.07 ng/kg. In no case did the mean level of TCDD in composite samples exceed the NTR threshold (Appendix Table A-7). Consequently, levels of TCDD would not result in these areas receiving a Category 5 listing in Ecology's Section 303(d) list of impaired waterbodies.

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Discussion

Comparison of contaminants in 0-2 and 0-10 cm sediments

The purpose of measuring contaminant levels in 0-2 and 0-10 cm sediment samples was to see if they were statistically different. If not different, regulators might be justified in using 0-2 cm sediment sample results to supplement 0-10 cm data for making decisions.

Mean levels of contaminants in 0-2 and 0-10 cm samples were compared using a paired t-test. The null hypothesis was that the 2 levels did not differ. Assumptions were that sediments were homogeneous at each sampling location and that the mean differences between paired results did not deviate substantially from zero. These assumptions appeared to be true in most cases. Results of future comparisons, based on a larger number of samples, may not differ even for cases where these assumptions were not true. This is because the t-test is known to be relatively robust.

We found little reason to reject the null hypothesis for most conventional parameters. However, there was a significant increase in % silt with depth. This may have been due to recent inputs of sandy sediments. Natural processes may also have resuspended fine particles from recent deposits and transported them to other areas of Elliott Bay or beyond. However, this explanation is not supported by % clay in 0-2 and 0-10 cm samples that was indistinguishable.

Individual and summed PAHs, and dioxins/furans did not differ between the 0-2 and 0-10 cm samples. One explanation for this might be that the sources of these contaminants and their transport pathways to surface sediments have not declined.

Levels of most trace metals, Aroclors 1254 and 1260, and Total Aroclor PCBs were significantly greater in the 0-10 cm samples than in the 0-2 cm samples. The implication is that recent sediments have lower levels of contaminants than deeper deposits: accumulation of these contaminants is slowing. This finding is consistent with results from sediment cores that have shown levels of metals declining over past decades (Crecelius et al., 1999; Lefkovitz et al., 1997; Valette-Silver, 1993). Temporal trends in sediment quality at 10 long-term monitoring locations tell a similar story (Partridge et al., 2005).

We did not test for significant differences between the median levels measured in the 0-2 and 0-10 cm samples.

Defining area background

We evaluated whether any of the locations sampled for the MSMP might represent area background. *Background* is defined as:

"The concentration of hazardous substances that are consistently present in the environment in the vicinity of a site, and are the results of human activities unrelated to releases from that site" (Ecology, 1990).

For this, we weighed the following factors:

- Contamination, especially exceedances of SQS, reported by previous studies.
- Distance from contaminant sources (pathways), especially the LDW cleanup site.

After considering these factors, results for 5 stations (Figure 5) were pooled for analysis.

Area background locations were selected prior to reviewing results. Stations selected were removed from direct sources of contamination of PCBs, dioxins/furans, cPAHs, and arsenic. Sampling stations 172, 173, and 185 were distant from urban sources and in deep water. Sediments at these locations had relatively high % silt and % TOC. While stations 176, 177, and 190 were also distant from urban sources, they were in relatively shallow, highly dynamic environments. These stations had sandy sediments with relatively low % TOC (Table 10). We excluded station 176 from consideration as representing area background because 0-2 cm sediment there has been shown to exceed multiple sediment quality standards in 1998 (Long et al., 2000). Therefore, stations 172, 173, 177, 185, and 190 were selected as representing area background.

Table 10. Water depth and conventional parameters for stations that may represent area background.

Locations 172, 173, and 185 are in deep water and contain relatively high % fines total organic carbon (TOC) compared to locations 177 and 190.

Station ID	Water Depth (feet, MLLW)	Sands (%)	Fines (%)	TOC (%)
172	497.8	13.7	86.2	2.27
173	445.7	39.2	60.9	1.67
177	12.6	97.2	2.8	0.16
185	519.0	13.2	86.9	2.19
190	19.2	96.9	3.0	0.14

MLLW Mean lower low water

Results for Stations 115, 180, 186, 181, 188, and 183 did not appear to represent area background conditions because they exceeded at least 1 SQS in 1998 (Long et al., 2000), or they were close to contaminant sources. Results for Stations 192, 194, 195, 196, and 187 did not represent area background because they were located within the Elliott Bay dredge disposal site perimeter (Figure 1). Finally, Station 189 likely could not represent area background because it was relatively protected from exchange with the rest of Puget Sound and likely to receive contaminated sediment from local sources (McLaren and Ren, 1994).

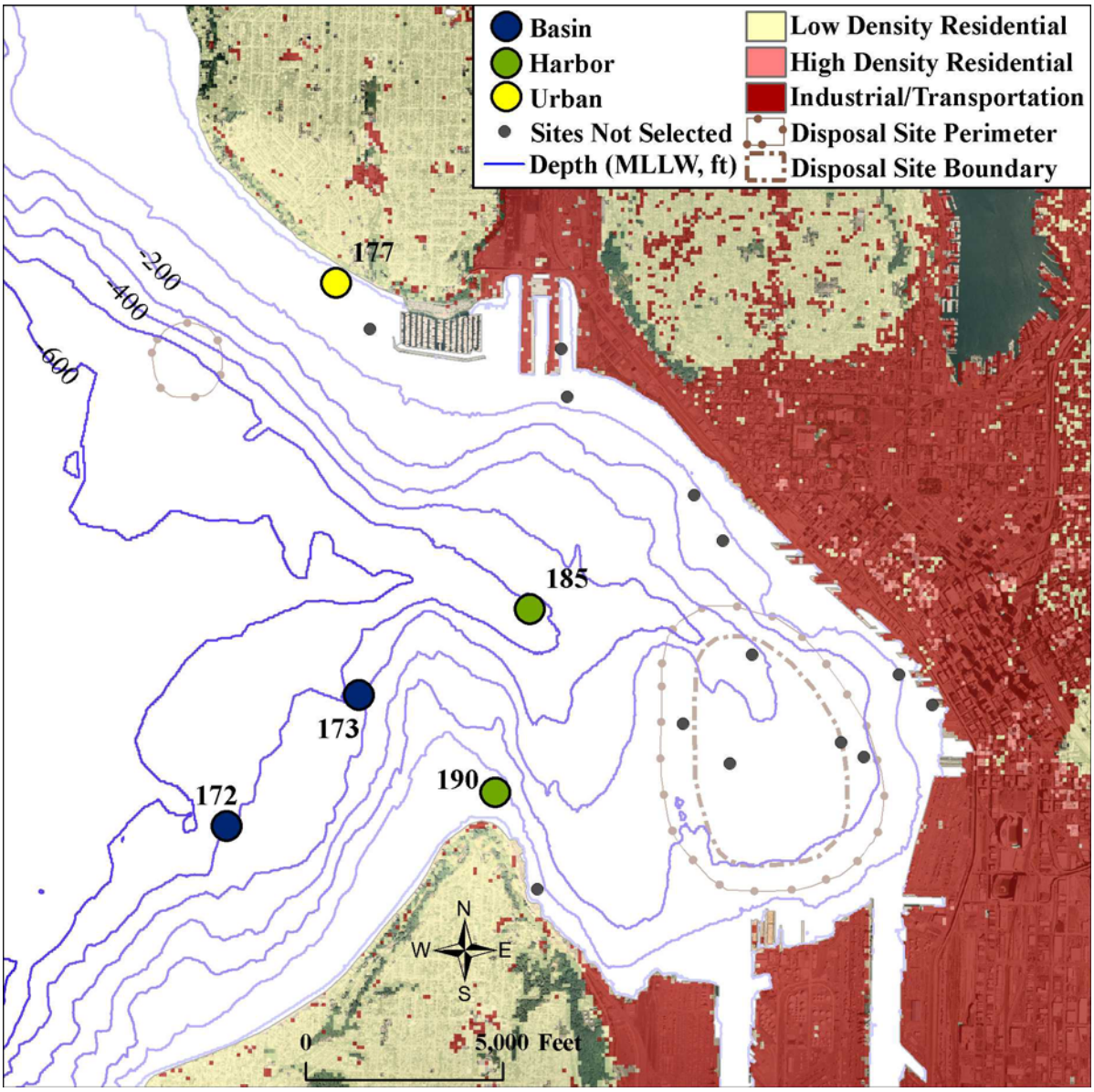

Figure 5. Locations of 0-10 cm sediment samples that may represent *area background*.

Levels of key contaminants measured in all 18 of the 0-10 cm samples, shown in Figure 6, are listed in Table 11. Results for just the 5 area background stations, listed separately in the same table, show levels of arsenic obviously lower only at the 2 sandy area background stations. The levels of cPAHs, dioxins/furans, and total Aroclor PCBs at the 5 area background stations were substantially lower than the mean or median levels for all 18 of the 0-10 cm stations. Contaminant levels at the silty locations (172, 173, and 185) were higher than those at sandy locations (177 and 190).

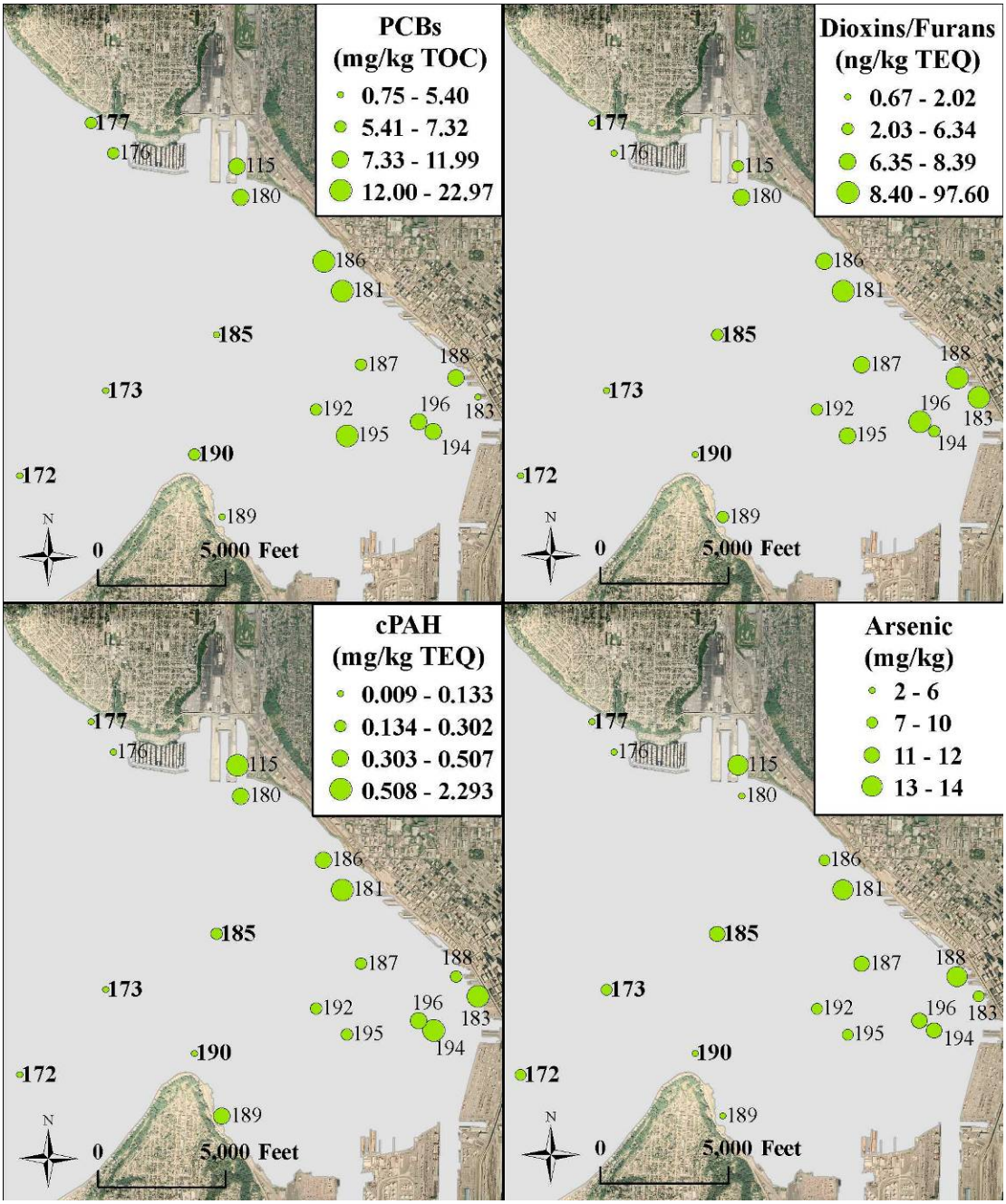

Figure 6. Levels of the contaminants of most concern in 0-10 cm sediment samples.

Concentration ranges reflect an equal number of sample results. Except the highest concentration range for Aroclor PCBs, that was set to start at the SQS (12 mg/kg of TOC). One-half the detection limit was used when a contaminant or congener was not detected. Zero was used when an individual Aroclor was not detected. Stations in bold may represent area background levels of contamination (see Discussion).

Table 11. Summary of chemistry results for 0-10 cm sediment samples.

Descriptive statistics for all 18 of the 0-10 cm sediment samples. Separate results for 5 locations used to evaluate area background levels of arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), total chlorinated dioxins/furans, total chlorinated dioxins, total chlorinated furans, and total Aroclor polychlorinated biphenyls (PCBs).

Summary Statistics / Station ID	Arsenic	cPAHs	PCBs [1]	Dioxins/ Furans	Dioxins	Furans
	mg/kg	µg/kg TEQ[2]	µg /kg	ng/kg TEQ [2]		
Descriptive statistics for 18 0-10 cm samples						
Mean	8.55	440	119	15.1	8.83	6.25
Median	8.96	290	63	5.87	4.12	1.62
Minimum	2.04	10	9.4	0.67	0.46	0.200
Maximum	13.7	2300	317	97.6	53.4	44.1
90% UCL	10.1	660	160	26.8	15.0	11.8
90% LCL	7.01	220	77	3.43	2.66	0.720
Results for 5 locations representing area background						
172	10.4	133	17	1.59	1.10	0.396
173	9.82	130	43	2.02	1.23	0.793
177	3.20	11	9.4	0.67	0.463	0.200
185	10.9	239	59	3.50	0.940	2.46
190	2.04	9	10	0.76	0.550	0.210
Mean	7.27	104	28	1.67	0.857	0.811
Median	9.82	130	17	1.50	0.940	0.396
Minimum	2.04	9	9.4	0.66	0.463	0.200
Maximum	10.9	239	59	3.40	1.23	2.46

[1] Total Aroclor PCBs were calculated as per the SMS (Ecology, 1995) with the highest detection limit used if all aroclors were undetected.
[2] One half the detection limit was used in place of results where no contaminate was found in TEQ calculations. TEQs represent the relative toxicity of the group of chemicals.
UCL = Upper confidence level. LCL = Lower confidence level.

According to MTCA, cleanup levels based on area background levels are determined by the lower of the 90th percentile value and 4 times the 50th percentile value for a dataset. However, a dataset based on 5 area background stations did not warrant calculating these values. Using mean and median levels for these 5 locations, area background levels in Elliot Bay would be 17-28 µg/kg PCBs, 1.6-1.7 ng/kg TEQ dioxins/furans, 100-130 µg/kg TEQ cPAHs, and 7.3-9.8 mg/kg arsenic. The mean levels of PCBs, dioxins/furans, and cPAHs in the remaining 13 0-10 cm samples were significantly greater ($p<0.03$) 5.5 times, 9.5 times, and 17 times greater, respectively. This indicates that suspended sediment from the LDW and nearshore sites did not accumulate at these area background locations or were diluted first.

The LDWG evaluated contaminant levels reported by previous sediment studies to suggest different levels that might represent area background (LDWG, 2008). The datasets used were:

- All post-1990 Elliott Bay sediment results.
- Elliott Bay results, excluding certain cleanup site locations.
- Results within the cleanup site (river miles 4.0-4.75).
- Results from locations upstream of the cleanup site (river miles 5.1-6.1).

Table 12 compares mean and median levels of contaminants that might represent area background, as suggested by LDWG and by this study. Arsenic levels for the different data sets all suggest 5-10 mg/kg for area background. Dioxins/furans in Puget Sound sediments well-removed from known point sources have seldom been measured. Therefore, mean and median values for the 5 results that we suggest represent area background (1.7 and 1.6 ng/kg TEQ, respectively) provide a new line of evidence for area background levels of dioxins/furans.

Table 12. Levels of selected contaminants surface sediments that *may* represent area background for Elliott Bay.

Results from this study (last row) are based on 0-10 cm samples only. Other results are from analysis sponsored by the Lower Duwamish Work Group (LDWG) and are based on different data sources and sample depths.

Location	Arsenic (mg/kg)		cPAH (µg/kg TEQ)		Total PCB[5] Aroclors (µg/kg dry wt.)		Dioxins/furans (ng/kg TEQ)	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Elliott Bay, all (LDWG)	8	7	990	280	160	22	-	-
Elliott Bay with exclusions[6] (LDWG)	7	6	460	210	140	46	-	-
River mile 4-4.75 (LDWG)	9.5	9.1	180	120	60	30	-	-
Upstream River mile 5.1-6.1 (LDWG)	6.7	5.4	51	9	17	5.6	-	-
Outer Elliott Bay 5 locations (This study)	7.3	9.8	100	130	28	17	1.71	1.59

MTCA recommends using the lower of the 90th percentile value and 4 times the 50th percentile value to set cleanup levels. LDWG reported these statistics, but only mean and median values are used here for comparison because the dataset suggested by this current study was limited to only 5 stations.

Generally, the levels of cPAHs and PCBs declined as follows:

- Levels based on past Elliott Bay results (greatest levels).
- Levels suggested by results for river mile 4.0-4.75 sediments.
- Levels suggested by results of this study.
- Levels measured upstream of the LDW cleanup site (lowest levels).

Defining area background conditions based on past sediment quality results from throughout Elliott Bay is not appropriate. Those data appear to include results influenced by point sources that can be reduced or eliminated. And sediment quality within river mile 4-4.75 can be influenced by downstream sediments within the cleanup site.

[5] Total Aroclor PCBs were calculated as per the SMS (Ecology, 1991) with the highest detection limit used if all Aroclors were undetected.
[6] Certain waterfront cleanup sites were excluded.

Defining area background conditions based only on current results for upstream sediment quality may not be appropriate either. Current upstream results may be problematic because they:

- Represent levels of contaminants associated with mainly sandy, not silty, sediments.
- Include contaminants from the LDW cleanup site that have been transported upstream.
- May not capture additional loading of contaminants from sources between the sampling station and the cleanup site.

We believe that results for the 5 stations identified in this discussion may represent area background levels for the LDW and Elliott Bay. Levels at these stations reflect:

- Distance from point and nonpoint (diffuse) sources resulting in major dilution of contaminants that might be derived from the cleanup site.
- Highly dynamic/sandy areas that do not readily accumulate contaminants

Contaminants in English sole tissues

The type of tissue sample prepared, whole fish vs. skinless fillet, was a major determinant of the levels of dioxins/furans measured. This was expected. Whole fish tend to have a higher fat content (% lipid) than skinless fillets, and so can accumulate more fat-soluble contaminants.

It was not initially surprising to find no significant difference between levels of dioxins/furans in whole fish or fillets from 2 Elliott Bay studies (SAIC, 2008a and our samples). Trawling for these 2 studies occurred only 3 months apart, and the fish could easily have come from the same population. However, levels of PCBs in tissues of English sole caught near Harbor Island have differed substantially from levels in fish from trawls along the Seattle waterfront (West, 2008). Reasons for this difference are unknown but may involve:

- A more even distribution of dioxins/furans in sediment or prey species than PCBs.
- Differences in trawl locations.

Although not significant, there was a slight difference in levels of dioxins/furans in the skinless fillets from the 2 trawl areas. A larger sample size might show Duwamish River (Kellogg Island) fish to have lower levels of tissue dioxins/furans than Seattle waterfront fish. This would be more analogous to results for PCBs in English sole from these areas and could reflect separate populations of fish exposed to different contaminant loads (West, 2008).

These are very small sample sizes, and conclusions drawn from these results should be considered exploratory. Given the limited size of the data set, we did not evaluate differences between gender, maturity, length, and age that can influence levels of contamination in each individual fish and composite sample.

Dioxins/furans levels in whole fish composites of English sole from various locations in Puget Sound ranged from 0.172-1.029 ng/kg TEQ (Table 13). Our whole body composites ranged from 0.989 to 1.710 ng/kg TEQ. This implies that fish sampled in Elliott Bay are at the top of the range for samples collected in Puget Sound. Whole body composite samples from this study had the highest mean value of all the studies.

In no case did the mean level of TCDD in composite samples exceed the NTR threshold. The Washington State Department of Health may, however, choose to evaluate these mean TEQ levels to determine if a seafood consumption warning is warranted. Ecology, EPA, and others may also use results of this study to see if dioxins/furans in English sole tissues represent human health risks. These activities are beyond the scope of this study.

Table 13. Summary of dioxin/furan levels in English sole and starry flounder in Puget Sound.

All studies collected fish in 2007.

Location	Sponsor/ Laboratory	Species	Preparation	Number of Fish per Composite	Number of Samples	Mean Dioxins/ Furans (ng/kg TEQ[7])	Range Dioxins/ Furans (ng/kg TEQ[7])
Elliott Bay[8]	Ecology/ PRL	English sole	Whole Fish	10	3	1.340	0.989-1.71
Budd Inlet[9]	SAIC/ Axys	English sole	Whole Fish	5	3	0.87	0.80-0.92
Elliott Bay	SAIC/ Axys	English sole	Whole Fish	5	3	0.680	0.413-1.03
Commencement Bay	SAIC/ Axys	English sole	Whole Fish	5	3	0.659	0.491-0.981
Port Gardner	SAIC/ Axys	English sole	Whole Fish	5	3	0.438	0.278-0.573
Bellingham Bay	SAIC/ Axys	English sole	Whole Fish	5	1	0.292	0.292
Anderson-Ketron Island	SAIC/ Axys	English sole	Whole Fish	5	3	0.286	0.172-0.345
Elliott Bay[8]	Ecology/ PRL	English sole	Skinless Fillet	20	6	0.397	0.285-0.573
Duwamish River[8]	Ecology/ PRL	English sole	Skinless Fillet	20	6	0.304	0.260-0.350
Budd Inlet[9]	SAIC/ Axys	Starry Flounder	Whole Fish	1-10	13	0.58	0.16-1.8
Bellingham Bay	SAIC/ Axys	Starry Flounder	Whole Fish	5	3	0.098	0.071-0.140

Axys = Axys Environmental Laboratory
PRL = Pacific Rim Laboratories, Ltd.
SAIC = Science Application International, Corp.

[7] One-half the reporting limit was used for undetected congeners.
[8] Results from this study.
[9] Results from SAIC, 2008b.

Conclusions

Area background conditions, if defined by mean or median levels of sediment contaminants measured at 5 outer Elliott Bay stations, would be approximately:

- Arsenic - 5-10 mg/kg
- cPAHs - 100-130 µg/kg
- Aroclor PCBs - 17-28 µg/kg
- TEQ dioxins/furans - 1.6-1.7 ng/kg

These are generally lower than mean and median levels calculated using results from past Elliott Bay studies or from river mile 4-4.75 of the Lower Duwamish Waterway. Our results are similar to levels suggested by results upstream of the cleanup site.

The current levels of dioxins/furans in surface sediment, if based on the larger dataset of 0-2 cm sample results, are in the 0.67-25.6 ng/kg TEQ range. The mean and median levels are 9.70 and 7.67 ng/kg TEQ, respectively. The 90% confidence interval of the mean is 7.5-12.0 ng/kg TEQ.

Samples of 0-2 cm sediment collected for this study contained significantly lower levels of most metals and Aroclor PCBs than their 0-10 cm sample counterparts. However, levels of dioxins/ furans, and almost all PAHs in 0-2 and 0-10 cm samples were not distinguishable. Consequently, levels of dioxins, furans, and PAHs might be pooled to make regulatory decisions.

Results of this study add to the very limited body of data available for dioxins/furans in Puget Sound biota. Levels of dioxins/furans in samples prepared from whole fish were greater than those measured in skinless fillet samples collected in approximately the same area at approximately the same time. The difference between skinless fillets collected from 2 areas in greater Elliott Bay was not significant ($p<0.10$).

Levels of 2,3,7,8-tetrachlorodibenzodioxin (TCDD) in fish tissues did not exceed the National Toxics Rule (NTR) threshold. Consequently, TCDD levels could not be a basis for listing greater Elliott Bay as impaired according to Section 303(d) of the federal Clean Water Act.

Recommendations

Following are the main recommendations from this study:

- Levels of contaminants in 5 surface sediment samples collected from outer Elliott Bay should be considered an independent line of evidence for defining area background values. If this approach proves useful, levels of contaminants should be measured at a larger number of random outer bay stations.

- Levels of metals and Aroclor PCBs in 0-2 cm Elliott Bay sediments should not be used for regulatory purposes. These parameters were found to be significantly lower in 0-2 cm sediment samples than in the 0-10 cm, biologically-active zone. However, lacking 0-10 cm results for dioxins/furans and PAHs in sediment, regulators may be justified in using 0-2 cm sediment sample results to make decisions. Levels of these parameters in the 2 depth intervals were statistically indistinguishable.

- Ecology's Marine Sediment Monitoring Program should measure dioxins/furans in 0-2 cm sediment samples to be collected at the same greater Elliott Bay locations in 2012. Results will help document any change in levels of dioxins/furans since this 2007 study.

- Levels of dioxins/furans measured for this study should be evaluated by the Washington State Department of Health or other health agencies to assess human health risk.

- Dioxins/furans should be measured in more biota, especially long-lived species occupying high trophic levels (top predators), throughout the Puget Sound basin. Results might inform (1) efforts to define natural and area background, (2) model food web contaminant storage and transport, (3) loading studies, and (4) levels of risk to different receptors of concern, including humans.

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Appendix

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Table A-1. Locations in greater Elliott Bay where sediment and English sole tissue samples were collected.

Final sampling location coordinates, water depth, and distance from target sampling locations are listed. Target locations for sediment sampling were selected prior to field work. There were no predetermined target locations for trawl samples. Trawl paths were linear from the start to end coordinates except the Elliott Bay Seattle Waterfront trawl had a mid-course direction change.

Sample Type / Location	Strata	Latitude (NAD83 HARN)	Longitude (NAD83 HARN)	Depth (ft) MLLW	Distance From Target (ft)
114	Urban	47.5754	122.3607	64.3	1.56
115	Urban	47.6281	122.3793	39.3	4.46
172	Basin	47.5944	122.4127	497.8	2.77
173	Basin	47.6037	122.3994	445.7	4.85
174	Basin	47.6248	122.3100	-	-
176	Urban	47.6291	122.3991	34.7	2.02
177	Urban	47.6324	122.4028	12.6	1.35
178	Urban	47.6258	122.3936	69.7	1.90
180	Urban	47.6248	122.3787	73.0	2.08
181	Harbor	47.6150	122.3623	119.9	2.53
182	Urban	47.6049	122.3442	118.8	2.84
183	Urban	47.6040	122.3404	39.6	2.57
184	Urban	47.6047	122.3410	36.2	2.76
185	Harbor	47.6100	122.3820	519.0	3.00
186	Harbor	47.6182	122.3654	124.7	3.23
187	Harbor	47.6072	122.3590	337.9	1.65
188	Harbor	47.6060	122.3439	112.4	2.35
189	Harbor	47.5905	122.3805	48.4	3.40
190	Harbor	47.5972	122.3851	19.2	2.41
192	Harbor	47.6023	122.3660	227.3	2.25
194	Harbor	47.6003	122.3473	222.3	2.68
195	Harbor	47.5996	122.3610	255.8	2.36
196	Harbor	47.6012	122.3496	237.6	2.66
197	Urban	47.5864	122.3637	30.7	2.35
199	Urban	47.5867	122.3650	44.7	2.76
200	Urban	47.5846	122.3458	56.1	1.84
201	Urban	47.5826	122.3434	47.0	1.61
202	Urban	47.5743	122.3433	48.4	2.18
203	Urban	47.5614	122.3474	13.2	2.70
204	Urban	47.5609	122.3451	16.8	6.18
205	Urban	47.5451	122.3369	23.3	2.17
Elliott Bay Trawl Seattle Waterfront	Start Pivot End	47.6038 47.6077 47.6080	122.3424 122.3467 122.3546	18.3 (min) 54.9 (max)	-
LDW Trawl A	Start End	47.5621 47.5550	122.3468 122.3428	6.9 (min) 8.4 (max)	-
LDW Trawl B	Start End	47.5620 47.5540	122.3462 122.3421	7.5 (min) 8.2 (max)	-

MLLW=Mean lower low water.
LDW = Lower Duwamish Waterway.

Table A-2. Summary of Quality Assurance/Quality Control review findings.

Parameter	Methods	Holding/ handling	Calibrations	Blanks	Reporting Limits	RPD/ RSD	LCS	Matrix spike recovery/ MSD	Decision
Total Solids (%)	SM2540G	Acceptable	Acceptable	<0.5	0.5	1	100	-	Acceptable
QAPP	PSEP	7d., 6mo.	-	-	0.1	<20	-	-	
Grain size (%)	PSEP	Acceptable	Acceptable	-		0-16.63	-	-	Acceptable
QAPP	PSEP	6mo.	-	<RL	1	<20	-	-	
TOC (%)	PSEP-TOC PSEP-TOCM	Acceptable	Acceptable	<0.1	0.1	1, 13	83	-	Acceptable
QAPP	PSEP (70°C), EPA 9060	14d., 6mo.	≥0.995, 90-110%rec	<RL	0.1	<20	80-120	75-125	
Trace Metals As, Cd, Cr, Cu, Pb, Ni, Se, Ag, Sn, Zn (mg/kg)	EPA 200.8	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
QAPP	EPA 200.8 or EPA 200.7	6mo., 2yrs.	≥0.995, 90- 110%rec	<0.5RL	0.1-5.0	<20	80-120	75-125	
PAHs (mg/L)	EPA SW8270	Acceptable	Acceptable	Acceptable			Acceptable		Acceptable
QAPP	8270D w/isotope dilution	14d., 1yr., 40d.	See Method	<0.5RL	0.5-2.0	<50	50-150	50-150	
PCB Aroclors (µg/kg)	EPA 8082 modified	Acceptable	Acceptable, 1 result qualified	Acceptable	9.4	Acceptable	89, 96	91,70, 49, 113	Acceptable
QAPP	EPA 8082	1yr., 40d.	See Method	<0.5RL	6-10	<50	50-150	50-150	
Dioxins/furans (ng/kg)	EPA 1613B	Acceptable	Acceptable	0.2-4.87	0.2-1.0	<30	Acceptable	80-121	Acceptable
QAPP	EPA 1613B	1yr.	See Method	<0.5RL	1.0-5.0	<50	Varies	-	
Dioxins/furans (Tissue)(ng/kg)	EPA 1613B	Acceptable	Acceptable	0.030-0.230	0.030-0.230	<40	Acceptable	92-125	Acceptable
QAPP	EPA 1613B	1yr.	See Method	<0.5RL	0.05-0.3	<50	Varies	-	
Lipids (% wet wt)	EPA 1613B	Acceptable	Acceptable	-	-	-	94.4, 107	-	Acceptable
QAPP	Sloan et al., 2004	1yr.	See Method	<0.5RL	0.1	<50	65-135	-	

QAPP = quality assurance project plan. RPD = relative percent difference. RSD = relative standard deviation. LCS = laboratory control sample. MSD= matrix spike duplicate.

Table A-3. Summary of results for levels of conventionals (%), by depth interval (cm).

Station ID	Grain Size Coarse		Grain Size Fines		Total Organic Carbon (70°C)		Total Organic Carbon (104°C)	
Depth (cm)	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	63.9	53.7	36.2	46.3	1.83	2.10	1.83	2.10
172	15.3	13.7	84.7	86.2	2.22	2.26	2.25	2.27
173	46.1	39.2	53.9	60.9	1.91	1.66	1.92	1.67
176	90.7	90.3	9.3	9.7	0.40	0.35	0.40	0.35
177	96.4	97.2	3.6	2.8	0.17	0.16	0.17	0.16
180	74.7	73.5	25.2	26.5	0.69	0.71	0.69	0.71
181	53.9	41.6	42.4	58.6	1.30	1.38	1.30	1.38
183	82.8	85.7	17.1	14.2	1.85	1.00	1.86	1.00
185	16.8	13.2	83.3	86.9	2.25	2.18	2.27	2.19
186	68.0	64.5	31.6	35.5	0.92	0.91	0.92	0.91
187	17.8	19	81.6	80.9	1.96	2.00	1.96	2.01
188	30.6	32.7	69.5	67.4	2.43	2.65	2.44	2.66
189	74.8	75.7	25.2	24.3	0.65	0.77	0.65	0.77
190	96.8	96.9	3.2	3.0	0.15	0.14	0.16	0.14
192	77.8	74.5	22.1	25.4	0.84	0.82	0.85	0.82
194	18.8	16.5	81.3	83.5	2.13	2.18	2.13	2.19
195	42.1	44.6	58.0	55.7	2.07	1.84	2.07	1.84
196	18.8	17.7	81.3	82.3	1.99	2.18	2.00	2.19

Table A-4. Summary of results for levels of metals (mg/kg dry weight), by depth interval (cm).

Site Number	Silver		Arsenic		Cadmium		Chromium		Copper	
Depth (cm):	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	0.79	0.91	13.70	13.70	0.57	0.71	33.0	46.2	59.1	75.5
172	0.32	0.33	9.13	10.40	0.29	0.32	42.2	53.8	41.1	49.3
173	0.28	0.30	9.01	9.82	0.25	0.37	38.1	45.7	35.3	39.6
176	0.18	0.19	3.56	3.49	0.11	0.13	21.6	26.7	17.1	25.0
177	0.01U	0.01U	3.13	3.20	0.14	0.17	27.9	29.9	6.5	7.5
180	0.34	0.40	5.97	5.79	0.14	0.19	23.8	30.5	19.8	24.6
181	1.04	1.26	11.10	13.30	0.31	0.40	49.9	69.4	49.5	59.7
183	0.28	0.43	9.29	6.58	0.17	0.20	22.0	26.1	36.6	33.0
185	0.39	0.41	9.90	10.90	0.28	0.31	42.9	52.1	45.6	53.8
186	0.62	0.73	6.84	7.59	0.21	0.25	28.6	36.5	23.6	31.6
187	0.29	0.48	7.74	11.20	0.18	0.36	22.4	47.1	32.3	57.5
188	1.31	1.34	10.80	12.80	0.43	0.49	38.3	49.2	64.8	75.8
189	0.12	0.13	4.55	3.74	0.1U	0.13	24.6	30.2	25.5	27.2
190	0.01U	0.01U	1.74	2.04	0.1U	0.10	18.5	21.0	5.7	6.8
192	0.17	0.22	7.71	8.10	0.19	0.15	29.4	29.8	18.8	25.9
194	1.13	1.14	10.20	11.60	0.41	0.45	39.6	49.8	74.2	76.2
195	0.32	0.31	7.80	7.59	0.41	0.49	28.8	32.6	40.0	42.3
196	0.77	0.81	10.80	12.10	0.33	0.38	38.5	50.5	94.6	83.5
SQS	6.1		57		5.1		260		390	

U = Analyte was tested for, but not detected above, the reporting limit.

Table A-4 continued

Site Number	Nickel		Lead		Selenium		Tin		Zinc	
Depth (cm):	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	64.0	37.1	48.8	82.1	0.55	0.71	130.00	132.00	111.0	136.0
172	36.2	43.6	26.9	30.8	0.99	1.30	2.42	2.96	90.6	111.0
173	33.9	39.5	22.0	29.0	0.70	1.00	2.70	2.80	83.5	120.0
176	20.7	25.2	16.8	20.8	0.50U	0.50U	1.60	1.60	51.4	48.0
177	20.5	23.0	7.0	8.0	0.50U	0.50U	0.76	0.70	32.0	33.0
180	22.2	26.7	19.4	26.3	0.50U	0.50U	2.41	2.71	47.0	51.6
181	43.2	57.3	47.0	74.2	0.50U	0.58	5.94	9.60	110.0	135.0
183	20.7	20.1	26.4	28.6	0.50U	0.50U	3.19	3.00	82.6	83.9
185	35.0	41.5	28.2	39.5	0.83	1.10	3.14	3.58	98.8	115.0
186	24.2	31.9	24.5	34.7	0.50U	0.50U	2.77	2.92	54.5	64.0
187	16.9	37.1	27.2	45.6	0.50U	0.94	3.69	3.97	82.4	112.0
188	29.6	37.3	82.5	86.0	0.59	0.79	9.00	9.07	110.0	124.0
189	23.5	27.8	25.8	29.6	0.50U	0.50U	2.27	2.47	49.0	51.7
190	16.9	20.2	6.8	7.5	0.50U	0.50U	0.48	1.20	27.0	26.0
192	24.9	27.4	31.0	29.9	0.50U	0.50U	1.50	20.90	54.5	59.8
194	31.3	39.1	79.0	75.9	0.67	0.88	6.69	7.78	130.0	134.0
195	22.7	24.9	25.7	32.1	0.52	0.55	2.78	2.62	82.1	83.9
196	29.3	28.2	44.4	67.8	0.65	0.88	5.41	5.86	110.0	125.0
SQS	-		450		-		-		410	

U = Analyte was tested for, but not detected above, the reporting limit.

Table A-5. Summary of results for levels of organic contaminants (µg/kg dry weight), by depth interval (cm).

Station ID	Naphthalene		Acenaphthylene		Acenaphthene		Fluorene		Phenanthrene		Anthracene		2-Methylnaphthalene		Total LPAH	
Depth (cm):	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	293	341J	353	708	104	119	231	214	749	645	1160	1420	113	83J	2890	3447
172	50	61	27	27	6.5	6.5	23	23	118	109	41	40	47	50	266	266.5
173	73	102	28	39	12	13	21	24	101	117	43	48	41	52	278	343
176	31J	26	26J	16	4.5	3.7	8.5	6.9	71	44	33	30	9.6J	9.1	174	126.6
177	5UJ	3.5	43J	2.6	1.1	0.88J	1.9	1.8	5.2	6.7	3.5	4.6	2.6	1.6	21	20.08
180	183	282J	84	184	40	43	53	72	234	276	184	265	61	75J	778	1122
181	197	294	83	122	30	37	47	55	290	333	188	210	71	100	835	1051
183	105J	112	363	184	71	57	108	118	463	577	659	563	45J	47	1769	1611
185	112	81	37	41	16J	14	33	32	163	157	67	81	53	50	428	406
186	151J	152J	70	82	23	23	32	36	185	334	115	129	45J	45J	576	756
187	95	116	55	49	22	22	39	38	178	180	97	103	48	56	486	508
188	796	961	513	131	224	210	409	217	1740	539	1320	291	307	380	5002	2349
189	245J	468J	73	157	35J	54	52	62	293	369	150	212	54	91J	848	1322
190	32UJ	18	25J	4.7	7.1J	1.4	8.1J	2.9	13	12	8.8	6.1	10J	4UJ	94	45.1
192	249	253	75	85	19J	25	28	33	193	205	95	90	45	53	659	691
194	388	821	102	108	95	447	115	515	495	882	278	436	119	178	1473	3209
195	164	143	51	51	40	31	62	52	221	208	101	107	64	74	639	592
196	306J	280	94	101	48	55	76	84	325	198	184	118	81J	98	1033	836

Table A-5 continued

Station ID	Fluoranthene		Pyrene		Benzo[a]anthracene		Chrysene		Total Benzofluoranthenes		Benzo[b]fluoranthene		Benzo[k]fluoranthene	
Depth (cm):	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	1450	2240J	2880	3600J	770	770	1920	2080J	3155	3400	2340	2290J	815	1110
172	165	174	186	174	64	64	100	107	50	177	E	121	50	56
173	146	156	188	202	58	64	83	103	153	172	111	125	42	47
176	138	94	134	100	62	45	100	73	140	117	102	86	38J	31
177	9.9	10	9.8	10	3.4	5.2	5.1	6.6	12.6	20	8.9	14	3.7	6.1
180	319	437	433	513	152	206	278	373	408	585	293	431	115	154
181	461	502	537	610	207	224	354	368	632	751	464	540	168	211
183	1160	1270	880	1080	513	526	1270	1180	1640	1733	1210	1290	430	443
185	227	255	250	288	93	109	143	174	264	330	193	239	71	91
186	284	470J	342	576J	132	195	245	314	397	569	277	456J	120	113
187	281	271	343	321	129	126	199	222	370	378	268	264	102	114
188	1980	852	2220	793	1000	188	1680	336	2400	387	1600	269	800	118
189	386	632	537	647	142	168	247	301	384	469	281	337	103	132
190	17	16	18	19	4.7	4.7	6.7	5.3	13.9	16	9.9	11	4	4.9
192	270	268	354	354	83	96	114	130	200	241	142	175	58	66
194	586	715	746	928	244	303	372	469	703	922	475	631	228	291
195	311	297	372	376	122	126	193	196	316	295	226	203	90	92
196	477	304	598	367	200	143	313	230	620	513	444	303	176	210

Table A-5 continued

Station ID	Benzo[a]pyrene		Indeno[1,2,3-c,d]pyrene		Dibenzo[a,h]anthracene		Benzo[g,h,i]perylene		Total HPAH		Dibenzofuran		cPAH (TEQ)	
Depth (cm):	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	1890	1750J	766	976J	149J	73	784	873	13764	15762	149	237	2393	2293
172	96	97	94	86	18	23	97	92	3211	994	20	23	354	133
173	87	95	72	86	17	19	76	89	880	986	22	23	118	130
176	82	66	60	54	22	13	56	47	794	609	9.30	7.40	111	90
177	4.9	7.9	4	5.8	1J	1J	4.5	5.2	55.20	71.80	3.20	2.80	7	11
180	249	335	135	256	33	75	154	200	2161	2980	47	110	325	451
181	341	390	297	325	67	56	258	289	3154	3515	46	58	465	529
183	871	847	424J	584	77	132	397	109	7232	7461	184	74	1149	1156
185	147	173	132	158	36	43	123	143	1415	1673	39	35	201	239
186	E	392	E	311J	44	47	157	149J	4793	3023	51	59	2081	507
187	204	201	166	169	47	49	151	162	1890	1899	41	38	277	275
188	1600	215	1300	140	211	122	947	126	13338	3159	353	115	2108	302
189	205	263	164	193	40	42	143	167	2248	2882	90	117	280	353
190	5.8	6	4	5.8	1J	1.1J	4.3	5.7	75.40	79.50	11UJ	6.40	8	9
192	118	142	102	120	15	28	101	115	1357	1494	41	52	159	192
194	447	577	274	333	57	30	270	340	3699	4617	158	829	579	740
195	165	204	106	136	25	39	118	123	1728	1792	63	48	224	266
196	385	214	303	180	69	73	258	182	3223	2206	151	106	507	307

Table A-5 continued

Station ID	Aroclor PCB - 1016		Aroclor PCB - 1221		Aroclor PCB - 1232		Aroclor PCB - 1242		Aroclor PCB - 1248		Aroclor PCB - 1254		Aroclor PCB - 1260		Aroclor PCB - 1262		Aroclor PCB - 1268		Total PCBs	
Depth (cm)	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	9.8U	13UJ	9.8U	10U	9.8U	10U	10J	17UJ	39UJ	36UJ	61	122	54	83	40UJ	52UJ	9.8U	22UJ	125	205
172	11U	11U	11U	11U	11U	11U	11U	11U	11UJ	11U	14J	17J	11U	11U	11UJ	11U	11U	11U	14	17
173	10U	10U	10U	10U	10U	10U	10U	10U	16UJ	21UJ	26	26J	22	17J	41U	10U	10U	10U	48	43
176	10U	9.7U	10U	9.7U	10U	9.7U	10U	9.7U	11UJ	9.7U	22	14	13	11	11UJ	9.7U	10U	9.7U	35	25
177	10U	9.4U	10U	9.4U	10U	9.4U	10U	9.4U	10U	9.4U	10U	9.4U	10U	9.4U	10U	9.4U	10U	9.4U	10*	9.4*
180	9.9U	9.8U	9.9U	9.8U	9.9U	9.8U	9.9U	9.8U	12UJ	9.8U	28	35	25	31	21UJ	23UJ	9.9U	9.8U	53	66
181	9.9U	10U	9.9U	10U	20UJ	10U	10J	12UJ	31UJ	43UJ	90	150	95	167	72UJ	102UJ	9.9U	51UJ	195	317
183	9U	10U	9U	10U	9U	10U	9U	10U	18UJ	10U	31	27	28	27	21UJ	19UJ	9U	10U	59	54
185	10U	10U	10U	10U	10U	10U	13J	10U	21UJ	17UJ	28	30	29	29	21UJ	20UJ	10U	10U	70	59
186	10U	10U	10U	10U	10U	10U	11J	19UJ	22UJ	32UJ	46	122	42	68J	33UJ	43UJ	10U	10U	99	190
187	10U	10U	10U	10U	10U	10U	15J	10U	27UJ	29UJ	44	59	57	68	40UJ	45UJ	10U	10U	116	127
188	10U	10U	10U	10U	10U	10U	15J	22UJ	28UJ	36UJ	77	124	101	112	71UJ	72UJ	10U	10U	193	236
189	10U	10U	10U	10U	10U	10U	10U	10U	12UJ	10U	16	20	12	13	10U	10U	10U	10U	28	33
190	9.8U	10U	9.8U	10U	9.8U	10U	9.8U	10U	9.8U	10U	9.8U	10U	9.8U	10U	9.8U	10U	9.8U	10U	9.8*	10*
192	9.7U	11U	9.7U	11U	9.7U	11U	10J	11U	15UJ	16UJ	21	33	18	27	13UJ	17UJ	9.7U	11U	49	60
194	10U	10U	10U	10U	10U	10U	11J	21UJ	37UJ	37UJ	73	88	109	126	74UJ	74UJ	10U	10U	193	214
195	10U	18UJ	10U	10U	10U	10U	12J	23UJ	40UJ	38UJ	54J	80	75	204J	48UJ	99UJ	10U	10U	141	284
196	11U	11U	11U	11U	21UJ	11U	15J	17UJ	30UJ	35UJ	59	79	79	105	57UJ	64UJ	11U	11U	153	184

J = Analyte identified, estimated value given.
E = Result exceeded the known calibration range; however, the sample was not diluted and re-analyzed.
U = Analyte was tested for but not detected above the reporting limit.
UJ = Analyte was not detected; however, the detection limit may or may not represent the actual limit of quantification.
* = All Aroclors undetected. Value is highest detection limit.

Table A-6. Summary of results for levels of dioxins/furans in surface sediment samples (ng/kg dry weight), by depth interval (cm).

Station ID	Total TEQ ng/kg dry weight					
	ND = 0		ND = DL/2		ND = DL	
Depth (cm):	0-2	0-10	0-2	0-10	0-2	0-10
115	26.60	4.45	26.60	4.47	26.60	4.50
172	1.06	1.41	1.50	1.59	1.93	1.78
173	4.21	1.62	4.23	2.02	4.26	2.43
176	2.37	1.01	2.86	1.49	3.34	1.98
177	0.04	0.04	0.67	0.67	1.29	1.29
180	4.40	6.35	4.52	6.45	4.65	6.55
181	18.10	87.00	18.10	87.00	18.10	87.00
183	17.60	15.20	17.60	15.20	17.60	15.20
185	5.30	3.17	5.30	3.50	5.30	3.82
186	8.11	7.62	8.13	7.62	8.16	7.62
187	4.65	6.41	4.70	6.41	4.75	6.41
188	19.80	97.60	19.80	97.60	19.80	97.60
189	4.98	2.66	5.01	2.89	5.03	3.11
190	0.09	0.14	0.71	0.76	1.33	1.38
192	2.75	6.21	2.80	6.34	2.85	6.46
194	16.30	5.30	16.30	5.40	16.30	5.50
195	9.41	8.29	9.41	8.39	9.41	8.49
196	11.00	13.90	11.00	13.90	11.00	13.90

ND = Analyte not detected.
DL = Detection limit.

Table A-6 continued

Station ID	2,3,7,8-TCDF		1,2,3,7,8-PeCDF		2,3,4,7,8-PeCDF		1,2,3,4,7,8-HxCDF		1,2,3,6,7,8-HxCDF	
Depth (cm):	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	0.59	1.16	2.47	0.64	1.56	0.87	6.84	2.69	3.17	0.84
172	0.55	0.94	0.5UJ	0.5UJ	0.5UJ	0.5UJ	1.18	0.99	0.5UJ	0.5UJ
173	1.03	0.46	0.556J	0.5UJ	0.544J	0.66J	1.77	2.36	0.71	0.632J
176	0.53	0.41	0.5UJ	0.5UJ	0.5UJ	0.5UJ	1.85	1.56	0.76	0.83
177	0.2U	0.2U	0.5UJ	0.5U	0.5UJ	0.5U	0.5UJ	0.5U	0.5UJ	0.5U
180	1.21	0.70	0.70	0.81	0.67	1.09	2.26	3.39	1.18	2.17
181	2.99	7.42	3.37	24.6	2.38	42.1	14.1	70	6.5	54.1
183	9.04	5.33	5.86	1.83	4.24	1.61	5.9	4.01	2.59	1.79
185	1.54	3.20	0.89	2.88	0.75	4.22	4.54	5.26	1.00	0.78
186	1.25	1.09	1.41	0.80	0.53	0.76	5.12	2.17	1.89	1.24
187	0.459	0.94	0.983	1.64	0.916	1.39	3.38	4.92	1.01	1.14
188	2.22	9.53	2.09	26.70	2.25	32.30	13.30	77.30	3.67	63.10
189	0.485	0.865	0.83	0.665	0.907	0.5U	2.2	1.28	1.19	0.768
190	0.2U	0.2U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U
192	0.79	1.12	0.55	1.18	0.61	0.788	2.09	4.63	0.504	1.26
194	0.82	1.24	2.49	0.75	2.56	1.17	11.20	3.38	4.25	1.52
195	0.90	1.42	1.39	3.25	0.93	2.70	5.37	10.90	2.09	4.04
196	2.39	2.34	2.06	2.32	2.22	1.71	8.56	13.3	3.01	3.02

Table A-6 continued

Station ID	2,3,4,6,7,8-HxCDF		1,2,3,7,8,9-HxCDF		1,2,3,4,6,7,8-HpCDF		1,2,3,4,7,8,9-HpCDF		OCDF		Total Furans	
Depth (cm):	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	5.74	2.14	1.06	0.64	82.3	21.8	5.24	3.57	219.0	66.1	327.97	100.45
172	0.5UJ	0.5UJ	0.5UJ	0.5UJ	7.2	3.9	0.7UJ	0.7UJ	29.0	10.4	37.93	16.23
173	0.80	0.93	0.5UJ	0.5UJ	15.5	10.3	0.78	1.29	44.9	27.6	66.59	44.23
176	0.75	1.12	0.5UJ	0.5UJ	31.7	6.3	2.58	0.7U	107.0	15.8	145.17	26.02
177	0.5UJ	0.5U	0.5UJ	0.5U	0.7UJ	0.7U	0.7UJ	0.7U	2.22	1.6	2.20	1.60
180	2.52	1.72	0.5U	0.89	19.60	31.5	1.51	1.95	80.9	88.6	110.55	132.82
181	8.95	89.7	2.45	34.1	102	284	8.24	38.5	472	386	622.98	1030.52
183	3.16	2.52	0.5U	0.68	61.3	76.8	5.34	5.46	214	471	311.43	571.03
185	2.24	0.72	0.572J	0.5UJ	31.4	7.2	2.50	0.7UJ	86.1	23.7	131.53	47.96
186	2.68	1.62	0.5U	0.52	42.3	35.9	3.69	2.64	116.0	125.0	174.87	171.74
187	1.51	2.30	0.5UJ	1.15	21.3	35	1.43	3.05	60	116	90.99	167.53
188	5.13	104.00	2.02	40.10	129.0	365.0	8.32	46.40	434.0	394.0	602.00	1158.43
189	1.19	0.884	0.5U	0.5U	28.2	16.6	2.02	1.93	144	53	181.03	76.00
190	0.5U	0.5U	0.5U	0.5U	1.2	1.28	0.7U	0.7U	5.71	4.65	6.90	6.00
192	0.89	1.19	0.5U	0.5U	14.4	53.2	0.96	2.96	64.9	258	85.69	324.33
194	8.30	2.63	2.82	0.56J	86.3	27.7	9.23	2.39	400.0	120.0	527.97	161.34
195	2.62	4.52	0.92	1.57	70.1	47.7	3.00	5.45	265.0	176.0	352.32	257.55
196	4.36	6.98	2.01	2.85	72.7	92.2	6.81	6.19	314	487	418.12	617.91

Table A-6 continued

Station ID	2,3,7,8-TCDD		1,2,3,7,8-PeCDD		1,2,3,4,7,8-HxCDD		1,2,3,6,7,8-HxCDD		1,2,3,7,8,9-HxCDD		1,2,3,4,6,7,8-HpCDD		OCDD		Total Dioxins	
Depth (cm):	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10	0-2	0-10
115	0.35	0.20	3.98	0.80	3.42	0.5UJ	24.50	1.77	6.17	1.25	1,220.0	144.0	11,300	1,330	12558.42	1478.02
172	0.23	0.2U	0.5UJ	0.518J	0.5UJ	0.5UJ	1.46	1.27	0.56	0.527J	30.8	22.7	239	159	272.05	184.02
173	0.36	0.2U	1.53	0.5UJ	0.73	0.5UJ	4.15	2.22	2.21	1.53	63.8	36.2	602	395	674.78	434.95
176	0.2U	0.2U	0.5U	0.5U	0.5U	0.5U	3.99	1.39	0.81	0.84	93.3	25.6	659	231	757.10	258.83
177	0.2U	0.2U	0.5UJ	0.5U	0.5UJ	0.5U	0.5UJ	0.5U	0.5UJ	0.5U	3.24	3.38	27.4B	29.9B	3.20	3.40
180	0.2U	0.2U	0.87	1.55	0.72	1.39	4.30	7.63	1.25	1.92	133.0	163.0	1320	1580	1460.14	1755.49
181	0.523	1.64	3.12	25.1	1.65	18.4	15	64.9	2.97	26.6	525	543	5,780	5,290	6328.26	5969.64
183	0.396	0.28	2.04	1.42	3.04	3.60	15.7	11.30	5.23	4.94	664	639	6,170	7,440	6860.41	8100.54
185	0.26	0.2U	1.29	0.5UJ	0.96	0.5UJ	4.90	1.70	2.47	0.5UJ	99.7	28.0	1,060	299	1169.58	328.70
186	0.47	0.35	1.66	2.04	1.09	0.87	10.00	6.68	3.27	4.58	206.0	207.0	2,320	2,040	2542.49	2261.52
187	0.333	0.396	1.24	1.12	0.5UJ	1.73	4.89	5.81	2	3.59	91.3	142	975	1,440	1074.76	1594.65
188	0.42	1.60	3.09	30.50	4.23	27.30	19.50	64.80	7.49	23.60	630.0	832.0	6,510	4,780	7174.73	5759.80
189	0.253	0.2U	0.974	0.789	0.736	0.5U	5.04	1.45	2.02	0.774	136	74.6	1,560	1,010	1705.02	1087.61
190	0.2U	0.2U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	0.5U	6.09	9.97	49.5	83.1	56.10	93.00
192	0.20	0.2U	0.75	1.21	0.5U	1.02	2.18	5.97	1.00	2.15	50.7	189	570	1,560	624.83	1759.35
194	0.71	0.2U	2.94	1.21	2.47	1.17	14.70	5.70	7.19	1.83	435.0	121.0	4,180	1,210	4643.01	1340.91
195	0.215	0.2U	1.22	1.14	0.81	1.80	8.10	7.12	1.50	2.83	335.0	161.0	4,200	2,080	4546.85	2253.89
196	0.518	0.673	2.15	1.75	1.29	3.18	9.82	14.9	4.63	7.04	237	318	2,590	4,170	2845.41	4515.54

B = Analyte detected in blank and result <10 times the level in the blank, J = Analyte identified, estimated value given, ND = Analyte not detected in sample, RL = analytical reporting limit, U = Analyte not detected above the reporting limit, UJ = Analyte not detected; however, the detection limit may or may not represent the actual limit of quantification.

Table A-7. Summary of results for levels of dioxins/furans (ng/kg dry weight) for stations where only 0-2 cm sediment was collected.

Station ID	Total TEQ		
	ND = 0	ND = RL/2	ND = RL
114	17.60	17.70	17.80
178	0.75	1.28	1.82
182	19.10	19.20	19.30
184	3.10	3.26	3.42
197	11.00	11.00	11.00
199	7.11	7.21	7.31
200	18.20	18.20	18.20
201	15.20	15.20	15.20
202	19.60	19.60	19.60
203	6.89	6.89	6.89
204	9.73	9.73	9.73
205	9.40	9.40	9.40

TEQ = toxic equivalent quotient (or concentration).
ND = Analyte not detected in sample.
RL = Analytical reporting limit.

Table A-7. continued

Station ID	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD
114	1.69	0.64	1.23	4.19	1.77	1.59	0.66	34.9	3.08	147	0.22	1.33	1.37	6.9	2.89	168	2,490
178	0.389	0.5U	0.5U	0.776	0.5U	0.5U	0.5U	6.21	0.7U	17.4	0.2U	0.5U	0.5U	1.24	0.68	29	267
182	0.92	0.99	2.01	8.92	2.92	5.89	1.61	187	9.71	794	0.2U	2.35	2.98	23.3	3.43	671	7,300
184	1.07	0.5UJ	0.594	1.95	0.5UJ	0.568J	0.5UJ	13.5	0.834	41.3	0.2U	1.03	0.553J	3.33	3.32	47.1	625
197	0.364	0.5U	0.5U	2.86	0.791	1.00	0.5U	52.1	2.42	93.6	0.2U	0.5U	0.5U	2.95	0.558	162	1,800
199	0.45	0.91	0.96	4.48	1.45	1.84	0.89	52.6	2.72	188	0.2U	0.71	0.74	6.9	2.15	271	2,890
200	2.14	1.99	2.32	7.5	2.97	5.6	1.37	58	4.88	225	0.53	3.65	3.11	15.3	5.26	637	6,160
201	2.83	1.49	2.93	7.93	3.95	5	1.23	64.9	4.58	207	0.86	3.9	4.73	12.1	5.54	343	3,290
202	2.39	2.31	2.44	9.45	3.95	5.56	3.01	78.5	7.51	255	0.47	4.07	3.11	20	7.44	619	5,430
203	0.97	0.86	1.17	4.06	1.2	2.42	0.61	40.3	2.9	151	0.41	1.48	2.39	10.3	3.71	321	2,920
204	1.48	2.03	2.44	11.1	3.72	4.96	1.69	112	7.61	475	0.2U	2.74	3.25	16.6	7.47	552	7,210
205	1.28	0.51J	1.01	3.23	1.4	2.58	0.72	133	3.49	554	0.2	0.986	1.72	10.8	3.89	318	3,170

J = Analyte identified, estimated value given.
ND = Analyte not detected in sample.
RL = Analytical reporting limit.
U = Analyte not detected above the reporting limit.
UJ = Analyte not detected; however, the detection limit may or may not represent the actual limit of quantification.

Table A-8. Summary of results for levels of dioxins/furans for fish tissue (ng/kg wet weight) collected in Elliott Bay and the Duwamish River.

Composite ID	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
Whole Body Tissue Samples										
EBW01	4.01	5.7	0.682	1.28	0.471	3.49	0.060UJ	0.979	0.33	1.88
EBW02	2.77	3.44	0.461	0.71	0.403	1.78	0.060UJ	0.739	0.146J	2.11
EBW03	1	2.87	0.506	0.953	0.47	1.69	0.111J	0.606	0.085UJ	1.79
Skinless Fillet Tissue Samples										
EBSF01	0.676	0.945	0.239J	0.455	0.229J	0.521	0.129J	0.565	0.186J	1.4
EBSF02	0.229	1.18	0.052J	0.35	0.154J	0.788	0.131J	0.385	0.085UJ	1.03
EBSF03	0.291	0.784	0.129J	0.3	0.148J	0.165J	0.063J	0.31	0.274	1.25
EBSF04	0.572	0.87	0.251J	0.209	0.097J	0.572	0.071J	0.459	0.209J	0.956
EBSF05	0.441	0.766	0.079J	0.291	0.098J	0.391	0.060UJ	0.288	0.192J	0.974
EBSF06	0.323	0.679	0.12J	0.272	0.084J	0.402	0.060UJ	0.333	0.144J	0.982
DUSF01	0.303	1.31	0.241J	0.298	0.127J	0.858	0.060UJ	0.302	0.168J	0.974
DUSF02	0.178	0.739	0.153J	0.348	0.075UJ	0.461	0.060UJ	0.375	0.204J	1.1
DUSF03	0.197	0.805	0.137J	0.341	0.075UJ	0.696	0.060UJ	0.353	0.153J	1.15
DUSF04	0.157	1.07	0.142J	0.394	0.091J	0.504	0.060UJ	0.339	0.085UJ	1.13
DUSF05	0.15	1.07	0.08J	0.315	0.113J	0.657	0.060UJ	0.317	0.14J	1.22
DUSF06	0.217	0.769	0.156J	0.528	0.213J	0.421	0.060UJ	0.651	0.204J	1.22

Table A-8. continued.

Composite ID	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD
Whole Body Tissue Samples							
EBW01	0.03UJ	0.259J	0.121J	0.777	0.209J	1.11	5.52
EBW02	0.066	0.372	0.1UJ	0.465	0.113J	1.25	4.91
EBW03	0.088	0.152J	0.133J	0.487	0.06UJ	1.51	6.41
Skinless Fillet Tissue Samples							
EBSF01	0.06	0.050UJ	0.100UJ	0.080UJ	0.060UJ	0.085UJ	1.04
EBSF02	0.030UJ	0.325	0.100UJ	0.080UJ	0.060UJ	0.085UJ	0.230UJ
EBSF03	0.073	0.050UJ	0.100UJ	0.108J	0.060UJ	0.249J	0.362J
EBSF04	0.030UJ	0.050UJ	0.100UJ	0.080UJ	0.060UJ	0.271J	0.514J
EBSF05	0.05J	0.147J	0.100UJ	0.133J	0.060UJ	0.249J	0.423J
EBSF06	0.036J	0.182J	0.100UJ	0.080UJ	0.060UJ	0.261J	0.87
DUSF01	0.030UJ	0.050UJ	0.100UJ	0.080UJ	0.060UJ	0.085UJ	0.230UJ
DUSF02	0.07	0.050UJ	0.100UJ	0.080UJ	0.060UJ	0.336	0.230UJ
DUSF03	0.030UJ	0.050UJ	0.100UJ	0.080UJ	0.060UJ	0.666	0.909
DUSF04	0.030UJ	0.063J	0.100UJ	0.080UJ	0.060UJ	0.282	0.553
DUSF05	0.076	0.050UJ	0.100UJ	0.080UJ	0.060UJ	0.459	0.526
DUSF06	0.030UJ	0.101J	0.100UJ	0.080UJ	0.060UJ	0.264J	0.338

J = Analyte was identified, estimated value given.
U = Analyte not detected above the reporting limit.
UJ = Analyte not detected; however, the detection limit may or may not represent the actual limit of quantification.

Table A-9. Individual fish characteristics for fish in EBW samples.

Fish Number	Composite Number	Total Length (mm)	Weight (grams)	Gender (M/F)	Age (interopercle)	Amount of fish in mixture (g)	Comments / Observations
1	1	234	95.9	M	8	30.3	Ground 3x, refroze, then reground
2	1	244	102.7	M	8	29.9	Question on age, tip of opercle cut off
3	1	270	111.5	M	9	30.1	
4	1	252	153.3	F	5	30.1	
5	1	312	196.2	M	9	30.1	
6	1	269	132.4	M	7	29.9	
7	1	251	115.5	M	6	30.1	Ground 4X
8	1	252	100.1	M	6	30.1	Extra water from rinse of equipment
9	1	247	94.3	M	7	29.8	
10	1	238	97.3	M	4	30.1	
11	2	254	108.3	M	5	35.1	
12	2	244	117.8	M	6	35.1	Removed both pre-opercle due to one being torn slightly
13	2	231	87.9	M	4	34.9	
14	2	263	118	F	6	35.2	
15	2	291	202.9	M	7	35	
16	2	265	140.2	M	11	35	
17	2	254	117.9	M	5	35	
18	2	230	87.1	F	6	35.1	
19	2	249	101.4	M	7	35	
20	2	251	109.8	M	6	35	
21	3	238	89.8	M	8	35.1	
22	3	252	105	F	8	34.9	Question on age, tip of opercle cut off
23	3	264	127.1	F	8	35	
24	3	215	73.7	M	5	35	
25	3	234	106.1	F	10	34.9	
26	3	218	78.5	F	7	35.1	
27	3	227	84	F	6	35.1	
28	3	201	61.1	M	7	34.9	
29	3	226	88.5	M	7	35.1	
30	3	271	144.3	M	4	35	

EBW = Elliot Bay whole body fish.