Lower Duwamish Waterway Group

City of Seattle/King County/The Boeing Company

DATA REPORT: 2023 PERIODIC MONITORING OF FISH, CRAB, CLAM, AND SURFACE WATER IN THE LOWER DUWAMISH WATERWAY

FINAL

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ABBREVIATIONS

95CI	95% confidence interval
95UCL	95% upper confidence limit (on the mean)
Alpha	Alpha Analytical Laboratories, Inc.
ALS	ALS Environmental-Kelso
AOC	Administrative Order on Consent
ARL	Analytical Resources, LLC
Brooks Applied	Brooks Applied Labs
Cape Fear	Cape Fear Analytical
CARB	California Air Resources Board
COC	contaminant of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CV	coefficient of variation
DO	dissolved oxygen
DQO	data quality objective
EAA	early action area
EPA	U.S. Environmental Protection Agency
GC/HRMS	gas chromatography/high-resolution mass spectrometry
GC/MS	gas chromatography/mass spectrometry
HpCDD	heptachlorodibenzo-*p*-dioxin
HpCDF	heptachlorodibenzofuran
HRGC/HRMS	high-resolution gas chromatography/high-resolution mass spectrometry
HxCDD	hexachlorodibenzo-*p*-dioxin
HxCDF	hexachlorodibenzofuran
IC-ICP-CRC-MS	ion chromatography-inductively coupled plasma-collision reaction cell-mass spectrometry
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
LDW	Lower Duwamish Waterway
OCDD	octachlorodibenzo-*p*-dioxin
OCDF	octachlorodibenzo-*p*-dioxin
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PeCDD	pentachlorodibenzo-*p*-dioxin
PeCDF	pentachlorodibenzofuran

ppt	parts per thousand
PRC	performance reference compound
PSEP	Puget Sound Estuary Program
QAPP	quality assurance project plan
RARE	Regional Applied Research Effort
RBTC	risk-based threshold concentration
RM	river mile
ROD	Record of Decision
SD	standard deviation
SE	standard error
SIM	select ion monitoring
SGS-Axys	SGS-Axys Analytical Services, Ltd.
SOP	standard operating procedure
SVOC	semivolatile organic compound
T-117	Terminal 117
TBT	tributyltin
TCDD	tetrachlorodibenzo-*p*-dioxin
TCDF	tetrachlorodibenzofuran
TEQ	toxic equivalent
TTL	target tissue level
UCT-KED	universal cell technology-kinetic energy discrimination
Windward	Windward Environmental LLC
ww	wet weight

Executive Summary

This document presents the periodic monitoring data collected in 2023 for contaminant of concern (COC) concentrations in fish, crab, and clam tissues and freely dissolved polychlorinated biphenyl (PCB) concentrations in surface water in the Lower Duwamish Waterway (LDW). The purposes of the monitoring were as follows:

1) To evaluate current concentrations of human health risk driver chemicals (i.e., PCBs, dioxins/furans, carcinogenic polycyclic aromatic hydrocarbons [cPAHs], and arsenic) in fish and shellfish

2) To track these chemicals in fish and shellfish and PCBs in surface water using a trend analysis

The following subsections provide a high-level synopsis of the 2023 collection efforts and results for fish/crab tissue, clam tissue, and surface water (from passive samplers).

Fish and Crab Tissue

Benthic fish (English sole), pelagic fish (shiner surfperch), and crab (graceful and Dungeness crab) were collected from the LDW from August 21 to 25, 2023. English sole and crab tissue samples were collected from two distinct reaches of the LDW, whereas shiner surfperch samples were collected from four subreaches (Table ES-1). Fish and crabs were collected primarily using a high-rise otter trawl; crabs were also collected using crab traps. Target numbers of fish and crabs specified in the periodic monitoring quality assurance project plan (QAPP) (Windward and Anchor QEA 2023) were met or exceeded for all species in each reach or subreach, except for graceful crab in Reach 2, where two fewer were collected than targeted (Table ES-1). A total of 12 composites for each target fish and crab species were analyzed for the human health risk drivers; a subset of samples was also analyzed for other non-risk driver COCs (vanadium, tributyltin [TBT], select semivolatile organic compounds [SVOCs], and select organochlorine pesticides).

Table ES-1
Overview of Fish and Crab Sampling

Species	Tissue Type(s)	Sampling Areas[1]	No. of Individuals Collected (Target Number)	Individuals Per Composite	Total No. of Composites
English sole	fillet, remainder	2 reaches	Reach 1: 70 (60) Reach 2: 70 (60)	10	12
Shiner surfperch	whole body	4 subreaches	Subreach 1a: 60 (45) Subreach 1b: 60 (45) Subreach 2a: 60 (45) Subreach 2b: 60 (45)	15	12

Species	Tissue Type(s)	Sampling Areas[1]	No. of Individuals Collected (Target Number)	Individuals Per Composite	Total No. of Composites
Graceful crab	edible meat, hepatopancreas	2 reaches	Reach 1: 50 (42) Reach 2: 40 (42)	6–7	12
Dungeness crab[2]	edible meat, hepatopancreas	2 reaches	Reach 1: 2 (na) Reach 2: 40 (na)	5	4

Notes:
1. Sampling areas included Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8). The four subreaches for shiner surfperch included subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).
2. Dungeness crab were collected, as available, for analysis of contaminants with TTLs (i.e., PCBs and dioxins/furans) to help communicate information regarding potential health risks to the public.
PCB: polychlorinated biphenyl
RM: river mile
TTL: target tissue level

Fish and crab tissue data were evaluated relative to two data quality objectives (DQOs): (1) comparison of the 95% upper confidence limits (on the mean) (95UCLs) with target tissue levels (TTLs) provided in the LDW Record of Decision and (2) evaluation of trends using average site-wide concentrations. Results from these evaluations include:

- **Total PCBs** – 95UCLs were above the corresponding TTLs for all species. When comparing the 2017 and 2023 datasets, there was a statistically significant decrease in total PCB concentrations for shiner surfperch and graceful crab. There was no statistically significant change in concentrations for English sole.
- **Dioxin/furan toxic equivalent (TEQ)** – 95UCLs were above the corresponding TTLs for benthic fish and whole-body crab; the 95UCL was equal to the TTL for crab edible meat. When comparing the 2017 and 2023 datasets, there was a statistically significant decrease in dioxin/furan TEQs for English sole and shiner surfperch. There was no statistically significant change in concentrations for graceful crab.

Clam Tissue

Clams (Eastern softshell) were hand collected from specified clam tissue collection areas throughout the LDW during low tides from June 4 to 6, 2023. Sufficient clams were collected in 10 of the 11 tissue collection areas and used to create composites for the analysis of inorganic arsenic and other risk drivers (i.e., PCBs, dioxins/furans, and cPAHs). Clam samples were analyzed as shown in Table ES-2.

Table ES-2
Clam Tissue Compositing Approach

Analyte	Tissue Type(s)	Composite Approach	Total Number of Composites
PCBs, dioxins/furans, cPAHs	Whole body	One composite (each consisting of 10 clams) was collected from 10 of the 11 clam tissue collection areas.	10
Inorganic arsenic	Siphon skin, remainder of whole body	Two composites (each consisting of 3 clams) were collected from 10 of the 11 clam tissue collection areas. Siphon skin was analyzed separately because inorganic arsenic has been shown to accumulate preferentially in *M. arenaria* siphon skin.	20 for each tissue type
Non-risk driver chemicals	Whole body	Three segment-wide composites were created by combining equal aliquots (by weight) of whole-body clam samples from each area within a given segment.	3

Notes:
cPAH: carcinogenic polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl

Clam tissue data were evaluated relative to two DQOs: (1) comparison of 95UCLs with TTLs and (2) an evaluation of trends using average, site-wide concentrations. Results from these evaluations include:

- **Total PCBs** – The site-wide 95UCL was above the TTL for clams. Total PCBs in clam tissue were similar in 2018 and 2023, but on average they decreased by more than a factor of four between 2004/2007 and 2023, likely as a result of early action area (EAA) remediation at the two areas where concentrations of PCBs in clams were highest in 2004 and 2007 (some uncertainty exists regarding the comparison of pre-and post-remediation data; see Section 5.2.2.1), source control, and/or natural recovery.
- **cPAH TEQ** – The site-wide 95UCL was above the TTL for clams. cPAH TEQs in clam tissue were similar in 2018 and 2023, but they decreased by more than a factor of three between 2004 and 2023. However, the use of a more sensitive analytical method in 2018 and 2023 may have contributed to this observed decrease in cPAH TEQs.
- **Dioxin/furan TEQ** – The site-wide 95UCL was above the TTL for clams. Dioxin/furan TEQs in clam tissue were similar in 2018 and 2023; no older data were available to evaluate longer-term trends.
- **Inorganic arsenic** – The site-wide 95UCL was above the TTL for clams (both including and excluding siphon skin). Inorganic arsenic concentrations in clam tissue were similar in older data (2004 and 2007), as well as in 2018 and 2023. Concentrations have been consistently highest at area C11 (RM 3.8E), which is known to have elevated sediment arsenic concentrations.

Surface Water (Passive Samplers)

Passive samplers are used to measure the freely dissolved PCB concentration, which is the fraction of the whole-water concentration not associated with particulates or colloidal organic particles (< 45 µm) in LDW surface waters. The passive samplers were deployed for approximately one month from August 3 to September 5, 2023, at two locations in the LDW: RM 3.3E and RM 1.9W. Nine passive samplers—which are low-density polyethylene strips—were deployed at each location, each attached to a frame such that it was suspended approximately 1 m above the sediment. Upon retrieval, a random number generator was used to select five of these samplers for analysis.

Passive sampler data were evaluated relative to the following DQO: an assessment of trends for PCBs in water as sediment remediation and source control continue. Results from this evaluation include:

- **Comparison across 2023 replicates** – There was little variability among the replicates analyzed for each location, and results for the two sampling locations were not significantly different.
- **Comparison with baseline data** – The 2023 PCB freely dissolved concentrations were significantly higher than the 2017 and 2018 concentrations. Deployment conditions (e.g., rainfall and river flow) and conventional parameters (e.g., water temperature) were similar across all three years. The different results among the three sampling years may reflect the inherent environmental variability in the dynamic water column of the LDW.

Next Steps

Periodic monitoring of COC concentrations in fish, crab, and clam tissue, as well as freely dissolved concentrations of PCBs in surface water, will be conducted again in 2028.

1 Introduction

This document presents the periodic monitoring data collected in 2023 for contaminant of concern (COC) concentrations in fish, crab, and clam tissues and freely dissolved polychlorinated biphenyl (PCB) concentrations in surface water in the Lower Duwamish Waterway (LDW) under the Fourth and Fifth Amendments to the Administrative Order on Consent (AOC). These data were collected in accordance with the quality assurance project plan (QAPP) for the periodic monitoring effort (Windward and Anchor QEA 2023). The purposes of the monitoring were to evaluate current concentrations of human health risk driver chemicals[1] in fish and shellfish, and to track these chemicals in fish and shellfish and PCBs in surface water using a trend analysis. The next periodic monitoring event is anticipated to occur in 2028, based on the long-term maintenance and monitoring plan that will be drafted in 2025. The evaluation of trends over time in tissue (fish, crab, and clams) and in surface water will continue in the future using the 2017/2018 baseline data, these 2023 monitoring data, and data from future monitoring events.

The remainder of this data report is organized into the following sections:

- Section 2 – Sample Collection and Processing
- Section 3 – Analytical Methods
- Section 4 – Results of Chemical Analyses
- Section 5 – Data Interpretation
- Section 6 – References

The main text of this report is supported by the following appendices:

- Appendix A – Data Tables
- Appendix B – Field Forms, Field Notes, Field Photos, and Chain of Custody Forms
- Appendix C – Compositing Plans
- Appendix D – Laboratory Tissue Preparation Notes
- Appendix E – *In situ* Water Quality Data
- Appendix F – Passive Sampler Supporting Documentation
- Appendix G – Statistical Analyses

[1] Risk driver chemicals, which the U.S. Environmental Protection Agency (EPA) refers to as COCs in the Record of Decision (ROD) (EPA 2014b), include PCBs, dioxins/furans, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and arsenic.

2 Sample Collection and Processing

This section summarizes results of the field sample collection, sample processing and compositing, and sample identification.

Additional sample collection and processing details are provided in the periodic monitoring QAPP (Windward and Anchor QEA 2023). Copies of field logbooks, tissue sample collection forms, and chain of custody forms are presented in Appendix B.

2.1 Fish and Crab Tissue

Fish and crab sampling took place in 2023 over three days, from August 21 to 23, and additional crab sampling was conducted on August 24 and 25. Species targeted for collection were English sole (*Parophrys vetulus*),[2] shiner surfperch (*Cymatogaster aggregate*), and graceful crab (*Metacarcinus gracilis*). Dungeness crabs (*Metacarcinus magister*) were also collected,[3] as available, for analysis of contaminants with LDW target tissue levels (TTLs)[4] to help communicate information regarding potential health risks to the public. Hereinafter, the term "target species" refers to English sole, shiner surfperch, graceful crab, and Dungeness crab.

English sole and crab tissue samples were collected from two distinct sampling areas of the LDW (Reach 1 [river mile (RM) 0 to RM 2.9] and Reach 2 [RM 2.9 to RM 4.8]), as described in the periodic monitoring QAPP (Windward and Anchor QEA 2023) (Map 2-1). The periodic monitoring QAPP also describes how both reaches were divided into two subreaches (a and b, for a total of four subreaches) for the purpose of collecting shiner surfperch (Map 2-2). These subreaches include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).

2.1.1 Fish and crab collection

Fish and crabs were collected using a high-rise otter trawl. Crabs were also collected using crab traps. The rationale for the field collection procedures is described in detail in the periodic monitoring QAPP (Windward and Anchor QEA 2023).

[2] During the remedial investigation and baseline sampling effort, starry flounder was identified as an alternate for English sole. Given that sufficient English sole had been collected during past efforts, starry flounder were not retained for this monitoring effort.

[3] Based on the results of the stable isotope evaluation (presented in Appendix I of the pre-design studies data evaluation report (Windward 2020), graceful and Dungeness crab occupy similar trophic positions. Thus, as was done during 2017 baseline sampling, graceful crab were collected as the target crab species for evaluation (insufficient numbers of Dungeness crab were available).

[4] TTLs are those presented in the 2014 ROD (EPA 2014b) or the explanation of significant differences for cPAHs (EPA 2021). As described in the ROD, TTLs are intended to be used to measure progress toward achieving Remedial Action Objective 1 (seafood consumption). TTLs are not cleanup levels; rather, they are to be used for informational purposes in assessing ongoing risks associated with the consumption of resident LDW fish and shellfish.

2.1.1.1 High-rise Otter Trawl

Trawling was conducted over four days, from August 21 through 24, 2023.[5] All trawling was conducted on the research vessel *Kittiwake*, captained by Eric Loss (University of Washington Friday Harbor Laboratories), per the specifications in the periodic monitoring QAPP (Windward and Anchor QEA 2023). Trawling was first conducted within subreaches until sufficient shiner surfperch had been collected. After the target number of shiner surfperch had been collected, all subsequent trawls were conducted throughout a reach. The numbers of trawls conducted in each reach/subreach are presented in Table 2-1, and trawling locations are shown on Map 2-3.

Table 2-1
Number of Trawls Conducted in each LDW Sampling Reach or Subreach

Sampling Area[1]	Number of Trawls	Notes
Reach 1	13	Trawls included 8 trawls in Reach 1a, 3 trawls in Reach 1b, and 2 reach-wide trawls.
Reach 2	24	Trawls included 7 trawls in Reach 2a, 2 trawls in Reach 2b, and 15 reach-wide trawls (the 10 reach-wide trawls on August 24, 2023, were focused only on collecting crabs).

Notes:
1. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8). The four subreaches for shiner surfperch include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).
LDW: Lower Duwamish Waterway
RM: river mile

2.1.1.2 Crab traps

From August 21 through 25, 2023, 113 crab traps were deployed (25 in Reach 1 and 88 in Reach 2). Traps used were Ladner© 30-inch rubber-wrapped stainless steel crab traps, each baited[6] inside the trap, to prevent the contents from being consumed. At any one time, 10 to 11 traps were dispersed throughout the sampling reaches, and deployment times typically ranged from approximately 2 to 4 hours. Crab trap locations are shown on Map 2-4.

2.1.1.3 Catch results

A total of 512 individual fish and crab were retained from 37 trawls and 113 crab trap deployments. Target numbers of fish and crabs specified in the periodic monitoring QAPP (Windward and Anchor QEA 2023) were met or exceeded for all species in each reach or subreach, except for graceful crabs in Reach 2 (Table 2-2).

[5] All targeted fish were caught during the first three days (August 21 through 23, 2023) of trawling; efforts on the fourth day (August 24, 2023) of trawling focused only on collecting additional crabs.
[6] A combination of chicken parts, fish heads and tails, and/or cat food was used as bait.

Table 2-2
Target and Actual Numbers of Target Species Retained by Reach

Species	Size (cm)	Reach 1[1]		Reach 2[1]	
		Target	Actual	Target	Actual
English sole	≥ 20	60	70[2]	60	70[2]
Shiner surfperch	≥ 8	90[2,3]	120[2,3]	90[2,3]	120[2,3]
Graceful crab	≥ 9	42	50[2]	42	40
Dungeness crab	≥ 9	NA	2	NA	40

Notes:
1. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8). The four subreaches for shiner surfperch include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).
2. English sole, shiner surfperch, and crab were archived individually (as whole organisms) if they were not included in composite samples (see Section 2.1.3). Extra individuals were retained when possible to provide additional options for compositing.
3. Each reach contained two subreaches, each with a target of 45 individuals. Within each subreach, 60 shiner surfperch were collected.
NA: not applicable
RM: river mile

Non-target fish and crab species captured in trawls or crab traps were identified, recorded, and released. A total of 12 species of fish and 17 types of invertebrates were caught and classified to the lowest taxonomic level practicable, including both target and non-target species. The numbers of each species caught using each collection method are presented in Table 2-3 for fish and Table 2-4 for invertebrates.

Table 2-3
Numbers and Types of Fish Species Caught in the LDW using Trawls and Crab Traps

Species	Scientific Name	Number of Individuals Caught[1]		
		Otter Trawl	Crab Trap	Total
Crescent gunnel	*Pholis laeta*	7	1	8
English sole	*Parophrys vetulus*	612	0	612
Longfin smelt	*Spirinchus thaleichthys*	688	0	688
Pacific herring	*Clupea pallasii*	106	0	106
Pacific sand sole	*Psettichthys melanostictus*	15	0	15
Pacific tomcod	*Microgadus proximus*	77	0	77
Pile perch	*Rhacochilus vacca*	41	0	41
Rock sole	*Lepidopsetta bilineata*	36	0	36
Shiner surfperch	*Cymatogaster aggregata*	7,447	0	7,447
Snake prickleback	*Lumpenus sagitta*	245	0	245

Species	Scientific Name	Number of Individuals Caught[1]		
		Otter Trawl	Crab Trap	Total
Staghorn sculpin	*Leptocottus armatus*	253	0	253
Starry flounder	*Platichthys stellatus*	333	0	333
Total		**9,860**	**1**	**9,861**

Notes:
1. Numbers of individuals include target species retained for compositing and archiving.
LDW: Lower Duwamish Waterway

Table 2-4
Numbers and Types of Invertebrate Species Caught in the LDW using Trawls and Crab Traps

Species	Scientific Name	Number of Individuals Caught[1]		
		Otter Trawl	Crab Trap	Total
Anemone	*Metridium* sp.	58	0	58
Cockle	Family: Cardiidae	8	0	8
Dock shrimp	*Pandalus danae*	7	0	7
Dungeness crab	*Metacarcinus magister*	32	33	65
Graceful crab	*Metacarcinus gracilis*	161	66	227
Jellyfish	Phylum: Cnidaria	1	0	1
Kelp crab	*Pugettia productus*	16	0	16
Moon snail	Family: Naticidae	2	0	2
Mussel	*Mytilus* sp.	37	0	37
Nudibranch	Order: Nudibranchia	54	0	54
Polychaete	Class: Polychaeta	1	0	1
Red rock crab	*Cancer productus*	9	11	20
Sea pen	Order: Pennatulacea	2	0	2
Sea star	*Pisaster* sp.	12	0	12
Shore crab	*Hemigrapsus* sp.	1	0	1
Shrimp	*Crangon* sp.	565	0	565
Snail	Class: Gastropoda	38	0	38
Total		**1,004**	**110**	**1,114**

Notes:
1. Numbers of individuals include target species retained for compositing and archiving.
LDW: Lower Duwamish Waterway

2.1.2 Fish and crab processing

Organisms caught were processed following the procedure described in the periodic monitoring QAPP (Windward and Anchor QEA 2023), which is summarized below.

All organisms captured in trawls were placed in containers filled with site water and sorted by species. All crabs captured were sorted upon removal from the crab traps. Non-target species were identified to the lowest practical taxonomic level, counted (or estimated if a species was present in large numbers), and released to the LDW as quickly as possible. Non-target species data were recorded on non-target species tally forms (Appendix B). Target fish and crab species that did not meet size requirements were counted and returned to the LDW. Target fish and crab species that met size requirements were rinsed with site water, inspected to ensure that the skin or exoskeleton was undamaged and intact, and retained for additional processing.

All target organisms were weighed and measured according to procedures in the periodic monitoring QAPP (Windward and Anchor QEA 2023), either on the boat after collection or on the dock at the end of each sampling day. Fish were measured with a measuring board to determine total length to the nearest millimeter, weighed to the nearest 0.5 g, and wrapped in aluminum foil. In addition, the gender of each English sole was determined, when possible, by an external visual examination of the gonads.[7] Crabs were measured with calipers to determine carapace width to the nearest millimeter, weighed to the nearest 0.5 g, examined to determine the individual crab's gender, and then each wrapped in two layers of aluminum foil. All measurements were recorded on target species tally forms (Appendix B). A label containing the project number, sampling personnel, date, time, and organism identification (ID) was placed in the outer bag of each double-bagged organism. All organisms were stored in coolers containing wet ice and delivered to Analytical Resources, LLC (ARL) within one day of collection. Tissue samples were stored, frozen, at ARL pending EPA approval of the compositing plan. After plan approval, Windward Environmental LLC (Windward) staff organized all samples into composite groups and had the samples transferred via courier to Alpha Analytical Laboratories, Inc. (Alpha) for homogenization.

2.1.3 Fish and crab compositing

Post-approval of the compositing plan, fish and crab were composited following the procedure described in the periodic monitoring QAPP (Windward and Anchor QEA 2023), which is summarized below.

Fish and crab tissue samples were chemically analyzed as composite samples, which were created by homogenizing individual fish or crab. The compositing plan (Appendix C) was developed in consultation with EPA. Most of the fish and crab retained for analysis were included in composite samples; the numbers and types of composite samples created and chemically analyzed are presented in Table 2-5. The remaining target organisms were archived individually (Table 2-6). Fish and crab composite samples were created using comparable organism sizes from the same sampling

[7] English sole were sexed by examining the size and shape of the gonads. The gonads of larger sole were sometimes visible when individual fish were held up to the sunlight. When it was not possible to determine gender externally, the gender was designated as indeterminate.

reach or subreach, as much as possible. Additional compositing details—including the ID, length, and weight of each target organism included in the composite samples—are provided in the compositing plan (Appendix C).

Table 2-5
Numbers of Fish and Crab Composite Tissue Samples Collected from the LDW

Species Name	Sample Type	No. of Individuals/ Composite Sample[1]	No. of Composite Samples	
			Reach 1[2]	Reach 2[2]
English sole	fillet (skin on)	10	6	6
	remainder	10	6	6
Shiner surfperch	whole body	15	Reach 1a: 3 / Reach 1b: 3	Reach 2a: 3 / Reach 2b: 3
Graceful crab	edible meat	6–7	6	6
	hepatopancreas	13–14	3[3]	3[3]
Dungeness crab	edible meat	5	0	4
	hepatopancreas	10	0	2[3]

Notes:
1. Equal mass from each individual was included in the composite sample, except where noted.
2. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8). The four subreaches for shiner surfperch include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).
3. To obtain sufficient mass for analysis, each hepatopancreas composite contained tissue from the 13 to 14 crabs represented in the corresponding 2 edible meat composites. In addition, the entire hepatopancreas sample mass from each individual crab was included in a composite.
LDW: Lower Duwamish Waterway
RM: river mile

Table 2-6
Numbers of Archived Individual Fish and Crab

Species	No. of Individuals Archived by Sampling Reach or Subreach[1]	
	Reach 1[2]	Reach 2[2]
English sole	10	10
Shiner surfperch	Reach 1a: 15 / Reach 1b: 15	Reach 2a: 15 / Reach 2b: 15
Graceful crab	8	0
Dungeness crab	2	20

Notes:
1. Per the periodic monitoring QAPP, archived individuals will be held frozen for up to one year from collection.
2. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8). The four subreaches for shiner surfperch include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).
QAPP: quality assurance project plan
RM: river mile

All fish and crab tissue preparation, including the filleting of fish, dissection of crabs, and homogenization of tissues, was conducted by Alpha following standard operating procedures (SOPs) provided in Appendix D of the periodic monitoring QAPP (Windward and Anchor QEA 2023). English sole were filleted (skin on), and the fillet and remainder (i.e., all tissue remaining after removal of fillet) were homogenized separately. Shiner surfperch were homogenized whole. Crabs were dissected, and the hepatopancreas and edible meat tissues[8] were homogenized separately. Laboratory notes for tissue preparation are presented in Appendix D.

Frozen subsamples of homogenized composite tissue samples were delivered via FedEx to ARL, ALS Environmental-Kelso (ALS-Kelso), Brooks Applied Labs (Brooks Applied), and Cape Fear Analytical (Cape Fear) for analysis.

2.2 Clam Tissue

Clams were hand collected from the specified clam tissue collection areas throughout the LDW (Map 2-5) during low tide from June 4 to 6, 2023. Clams were collected using a shovel and following the level-of-effort guidance and sampling and processing methods described in the periodic monitoring QAPP (Windward and Anchor QEA 2023).

2.2.1 Clam collection

To meet the number of clams needed for the various clam tissue analyses, a minimum of 16 Eastern softshell clams (*Mya arenaria*) were targeted for each clam tissue collection area. Sufficient clams were collected in 10 of the 11 tissue collection areas for the creation of composites for the analysis of inorganic arsenic and other risk drivers (i.e., PCBs, dioxins/furans, and cPAHs). As anticipated from results of baseline monitoring in 2018, clam abundance was low in clam tissue collection area 7 (Slip 4), an early action area (EAA) remediated in 2012. With the exception of two small (0.5-cm-wide) clams that were less than the target size of 2 cm in width, no clams were found in this area during the allocated maximum level of effort. With the exception of clam tissue collection area 7, five extra clams (more than the target number) were retained from each tissue collection area to provide additional options for compositing.

Details regarding the clam sampling level of effort in each sampling area and the total numbers of clams collected are provided in Table 2-7. In addition, Maps 2-6a through 2-6i present the locations where individual clams were collected within each of the identified clam tissue collection areas. Copies of field logbooks, clam collection forms, and chain of custody forms are provided in Appendix B.

[8] Crab edible meat includes muscle tissue from the upper body, legs, and claws.

Table 2-7
Summary of Clam Collection Efforts by Clam Tissue Collection Area

Clam Tissue Collection Area	Sampling Date (2023)	Level of Effort (person-hrs.[1])		No. of Clams Collected (target)[3]	Sufficient Clams Collected for Analysis?		Notes
		Actual	Max.[2]		Inorganic Arsenic Composite	Other Risk Driver Composite	
Intertidal Segment 1							
1 (RM 0.2W)	June 4	3.2	9	21 (16)	✓	✓	None
2 (RM 0.6–0.9W; Kellogg Island)	June 4	7	12	21 (16)	✓	✓	None
3 (RM 0.6–0.7W)	June 4	6.8	9	21 (16)	✓	✓	None
Intertidal Segment 2							
4 (RM 1.4–1.5W)	June 6	7.1[4]	6	21 (16)	✓	✓	None
5 (RM 1.8E; Slip 2)	June 5	3.3	6	21 (16)	✓	✓	None
6 (RM 2.1W)	June 6	4.6	6	21 (16)	✓	✓	None
Intertidal Segment 3							
7 (RM 2.8E; Slip 4)	June 6	9.3[4]	9	0 (16)	no	no	No clams collected; max level of effort reached[5]
8 (RM 2.8W)	June 5–6	5	6	21 (16)	✓	✓	None
9 (RM 2.9–3.35W)	June 5–6	15.3[4]	12	21 (16)	✓	✓	None
10 (RM 3.6–4.0W)	June 5	5.8	12	21 (16)	✓	✓	None
11 (RM 3.8E)	June 4–5	9.2[4]	6	21 (16)	✓	✓	None

Notes:
1. A person-hour is defined as the level of effort spent searching by 1 individual for 1 hour.
2. The maximum level of effort specified in the periodic monitoring QAPP was based on a 3-person field team (Windward and Anchor QEA 2023). When a different size field team was utilized during field collection efforts, the total number of person-hours was the same as a 3-person team would have expended.
3. In addition to the target numbers of clams specified (16 for each area), up to 5 additional clams were retained from each collection area to provide additional options for compositing.
4. The level of effort in these areas exceeded the maximum, because it was necessary for the field crew to wait for additional intertidal area to be exposed at a slightly lower tide.
5. Two small (0.5-cm-wide) clams that were less than the target size of 2 cm in width were found during tissue collection efforts. These clams were not retained due to their small size.
RM: river mile

2.2.2 Clam processing

Once collected, individual clams were evaluated for acceptability, measured valve-to-valve, processed, and given a unique identifier in accordance with the periodic monitoring QAPP (Windward and Anchor QEA 2023). Each unbroken (i.e., intact) clam ≥ 2 cm retained for compositing and analysis was rinsed with site water to remove excess sediment, wrapped in aluminum foil, and placed in a resealable plastic bag with an individual ID label. Bagged and labeled clams were held on

ice in a cooler for delivery to ARL at the end of each day. Clam samples were stored, frozen, at ARL before further processing.

2.2.3 Clam compositing

Clams selected for compositing were thawed in the refrigerator overnight prior to processing. Windward staff shucked clams and dissected them for inorganic arsenic siphon and remainder (i.e., whole-body without the siphon skin) analyses; samples were then homogenized by ARL following ARL SOP 3328S rev 000.

The numbers and types of composite samples created for each chemical analysis are presented in Table 2-8 (Maps 2-6a through 2-6i). Additional compositing details, including the ID and length of each clam included in the composite samples, are provided in the compositing plan (Appendix C), which was developed in consultation with EPA.

Table 2-8
Numbers of Clam Composite Tissue Samples

Clam Tissue Composite Type	Sample Type	No. of Individuals per Composite Sample[1]	No. of Composite Tissue Samples
Inorganic arsenic composites	Siphon skin	3	20
	Remainder	3	20
PCBs, dioxins/furans, and cPAH composites	Whole body	10	10
Segment-wide composites[2]	Whole body	30–40[3]	3

Notes:
1. Composites were created using the entire clam for each composite sample.
2. Segment-wide composites were analyzed for vanadium, TBT, SVOCs, and organochlorine pesticides.
3. Segment-wide composites were created by combining equal aliquots (by weight) of homogenized whole-body clam samples from each clam tissue collection area within a given segment.
cPAH: carcinogenic polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
SVOC: semivolatile organic compound
TBT: tributyltin

Frozen subsamples of homogenized composite tissue samples were shipped via UPS to Brooks Applied, ALS-Kelso, and Cape Fear for analysis.

2.3 Passive Samplers

Passive samplers—which consisted of stainless steel mesh envelopes containing low-density polyethylene strips used to determine freely dissolved PCB (PCB C_{free}) concentrations[9]— were

[9] The freely dissolved PCB concentration is the fraction of the whole-water concentration that is not associated with particulates or colloidal organic particles (< 45 µm).

deployed for approximately one month at two locations in the LDW (Table 2-9 and Map 2-7). Deployment and retrieval methods are summarized below; detailed methods are described in the periodic monitoring QAPP (Windward and Anchor QEA 2023).

Table 2-9
Passive Sampler Locations

Passive Sampler Location ID	Location Name	RM	Coordinates[1]		Sample Depth
			Easting (X)	Northing (Y)	
PS1	South Park Bridge	3.3E[2]	1274652	196653	Near-bottom
PS2	Lineage Logistics	1.9W[3]	1269066	201789	Near-bottom

Notes:
1. North American Datum 1983. Easting/Northing in U.S. Survey feet.
2. Passive samplers were deployed along the northern wing wall upstream of the base of South Park Bridge at RM 3.3E.
3. Passive samplers were deployed along Lineage Logistics (former Sea-Freeze Cold Storage) pier dock pilings at RM 1.9W.
ID: identification
RM: river mile

2.3.1 Deployment

On August 3, 2023, nine passive samplers were attached (approximately 1 foot apart) across two sampling frames at each location (PS1 and PS2) to increase the likelihood that five passive samplers would still be available for analysis at each location at the end of the deployment period.[10] A multi-parameter data logger was also deployed at each location, attached to one of the frames at the same depth as the passive samplers, to collect *in situ* water quality data (i.e., conductivity [which is used to determine salinity], temperature, dissolved oxygen [DO], and pH) for the duration of the sampling period; water quality data measurements were taken every 15 minutes.

2.3.2 Retrieval

After the one-month deployment period, the passive sampler frames were retrieved from each site on September 5, 2023. Each passive sampler within its mesh envelope was detached from the frame and wrapped in aluminum foil, double-bagged in resealable plastic bags, and labeled with an appropriate sample ID. The labeled bags containing the passive samplers were placed on ice in a cooler for shipment to SGS-Axys Analytical Services, Ltd. (SGS-Axys). The multi-parameter data loggers were detached from the frames and water quality data were downloaded off site; these *in situ* data are provided in Appendix E.

[10] As described in the periodic monitoring QAPP (Windward and Anchor QEA 2023), five replicate passive samplers per location were targeted for analysis. The four additional passive samplers were deployed in case any samplers were lost during the deployment period.

Five passive samplers from each location were selected for analysis using a random number generator. The remaining passive samplers were archived at SGS-Axys.

2.4 Sample Identification

This section presents sample ID information for individual fish, crabs, and clams and their respective composite samples, as well as for the passive sampler replicates.

2.4.1 Fish and crab

Unique alphanumeric IDs were assigned to each individually wrapped fish or crab in the field and recorded on the target fish and crab species form. The sample IDs for individual fish and crab included the following:

- Project area ID (LDW) and two-digit year (23)
- Tissue sampling area (R1 or R2 for English sole, Dungeness crab, and graceful crab; R1A, R1B, R2A, or R2B for shiner surfperch)
- Two-letter species code (ES, SS, DC, or GC, representing English sole, shiner surfperch, Dungeness crab, or graceful crab, respectively) and three-digit number indicating the sequential number of the organism captured during the sampling event.

Composite samples were identified using a similar convention. Their IDs included the following:

- Project area ID (LDW) and two-digit year (23)
- Tissue sampling area (R1 or R2 for English sole, Dungeness crab, and graceful crab; R1A, R1B, R2A, or R2B for shiner surfperch)
- Two-letter species code (ES, SS, DC, or GC) and two-letter tissue type code (WB, FL, RM, EM, or HP representing whole body, skin-on fillet, remainder [after removal of the fillet], edible meat, or hepatopancreas samples, respectively)
- Composite ID ("comp" and a two-digit sequential composite number)

2.4.2 Clams

A unique alphanumeric ID was assigned to each individual clam in the field and recorded on the target clam species form. The sample ID for each individual clam included the following:

- Project area ID (LDW) and two-digit year (23)
- Clam tissue collection area (C01 through C11)
- Two-letter species code (CL for clam) and three-digit number indicating the sequential number of the organism captured during the sampling effort.

Composite clam samples were identified using a similar convention; their IDs included the following:

- Project area ID (LDW) and two-digit year (23)
- Clam tissue collection area (C01 through C11)
- Species code (CL for clam) and a two-letter tissue type code (WB, SP, or RM for whole body, siphon skin, or remainder [after removal of the siphon skin], respectively)
- Composite ID ("comp" and a one-digit sequential composite number).

For the segment-wide intertidal composite samples analyzed for non-risk driver chemicals, the composite IDs were similar to those of the clam composites, except that the clam tissue collection area portion of the ID was replaced by an intertidal segment ID (S1, S2, or S3 for segment 1 RM 0.0 to RM 1.3], segment 2 [RM 1.3 to RM 2.6], or segment 3 [above RM 2.6], respectively).

2.4.3 Passive samplers

Unique alphanumeric IDs were assigned to each passive sampler replicate and included the following:

- Project area ID (LDW) and two-digit year (23)
- Passive sampler location ID (PS1 or PS2)
- One-digit sequential replicate number.

2.5 Field Deviations from the Periodic Monitoring QAPP

There was one field deviation from the periodic monitoring QAPP (Windward and Anchor QEA 2023) that involved minor modifications to the processing methods for graceful crabs. Specifically, the targeted total catch of 42 graceful crabs for each reach was not met for Reach 2 after 4 days of trawling and crab trap deployment/retrieval (only 40 crab were collected). This outcome was accepted by EPA after repeated attempts to collect the targeted number. In consultation with EPA, four of the six proposed edible meat composites from Reach 2 were prepared with tissue from the target of seven crabs, and the remaining two composites were prepared with tissue from six crabs. Similarly, 1 of the 3 proposed hepatopancreas composites from Reach 2 was prepared with tissue from the target of 14 crabs, and 2 composites were prepared with tissue from 13 crabs.

3 Analytical Methods

The methods and procedures used to prepare and chemically analyze the composite tissue samples are described briefly in this section and in detail in the periodic monitoring QAPP (Windward and Anchor QEA 2023). This section also discusses laboratory deviations from the periodic monitoring QAPP.

3.1 Fish and Crab Tissue

ARL performed semivolatile organic compound (SVOC), vanadium, lipid, and percent solids analyses; Cape Fear performed PCB congener and dioxin/furan analyses; Brooks Applied performed inorganic arsenic analyses; and ALS-Kelso performed organochlorine pesticide and cPAH analyses. Tissue samples were analyzed according to the methods presented in Table 3-1. Specific analytes analyzed in each tissue type are summarized in Table 3-2.

Table 3-1
Analytical Methods for Fish, Crab, and Clam Tissue Analyses

Analyte	Method	Reference	Laboratory
PCB congeners	HRGC/HRMS	Soxhlet extraction; EPA 1668C	Cape Fear
Inorganic arsenic	IC-ICP-CRC-MS	Lab SOP; BAL4100-001e	Brooks Applied
cPAHs	HRGC/HRMS	GC/HRMS; Isotope Dilution[1]	ALS-Kelso
Dioxins/furans	HRGC/HRMS	soxhlet extraction; EPA 1613B	Cape Fear
SVOCs	GC/MS	EPA 3350-C Mod; EPA 8270E	ARL
TBT	GC/MS	EPA 3350-C Mod; EPA 8270E-SIM	ARL
Vanadium	ICP-MS	EPA 6020B; UCT-KED	ARL
Organochlorine pesticides	GC/MS	EPA 3541 EPA; 8270E/1699 Mod	ALS-Kelso
Lipids	Gravimetric extraction	Bligh and Dyer (1959 mod)	ARL
Percent solids	Drying oven	PSEP (1986)	ARL

Notes:
1. The ALS-Kelso cPAH method is based on Reference Method 429 from the CARB.
ALS-Kelso: ALS Environmental-Kelso
ARL: Analytical Resources, LLC.
Brooks Applied: Brooks Applied Labs
Cape Fear: Cape Fear Analytical
CARB: California Air Resources Board
cPAH: carcinogenic polycyclic aromatic hydrocarbon
EPA: U.S. Environmental Protection Agency
GC/HRMS: gas chromatography/high-resolution mass spectrometry
GC/MS: gas chromatography/mass spectrometry
HRGC/HRMS: high-resolution gas chromatography/high-resolution mass spectrometry
IC-ICP-CRC-MS: ion chromatography-inductively coupled plasma-collision reaction cell-mass spectrometry
ICP-MS: inductively coupled plasma-mass spectrometry
PAH: polycyclic aromatic hydrocarbon

PCB: polychlorinated biphenyl
PSEP: Puget Sound Estuary Program
SIM: select ion monitoring
SOP: standard operating procedure
SVOC: semivolatile organic compound
TBT: tributyltin
UCT-KED: universal cell technology-kinetic energy discrimination

Table 3-2
Numbers of Composite Samples Analyzed for Each Analyte Group for Fish and Crab

Analyte	English Sole		Shiner Surfperch	Graceful Crab		Dungeness Crab[1]	
	Remainder	Fillet	Whole Body	Edible Meat	Hepatopancreas	Edible Meat	Hepatopancreas
PCB congeners	12	12	12	12	6	4	2
Inorganic arsenic	12	12	12	12	6	-	-
cPAHs	NA[2]	NA[2]	NA[2]	12	6	-	-
Dioxins/furans	12	12	12	12	6	4	2
Selected SVOCs	2	2	2	2	1	-	-
TBT	2	2	2	2	1	-	-
Vanadium	2	2	2	2	1	-	-
Selected organochlorine pesticides	2	2	2	2	1	-	-

Notes:
1. As described in the periodic monitoring QAPP (Windward and Anchor QEA 2023), Dungeness crab samples were analyzed for PCB congeners and dioxins/furans to help communicate information regarding potential health risks to the public.
2. cPAHs were not analyzed in fish tissue because they are metabolized (Collier et al. 2013). No cPAH TTLs were developed in the ROD (EPA 2014a) for fish and crab tissue.
cPAH: carcinogenic polycyclic aromatic hydrocarbon
NA: not applicable
PCB: polychlorinated biphenyl
QAPP: quality assurance project plan
ROD: Record of decision
SVOC: semivolatile organic compound
TBT: tributyltin
TTL: target tissue level

3.2 Clam Tissue

ARL performed SVOC, vanadium, lipid, and percent solids analyses; Cape Fear performed PCB congener and dioxin/furan analyses; Brooks Applied performed inorganic arsenic analyses; and ALS-Kelso performed organochlorine pesticide and cPAH analyses. Tissue samples were analyzed according to the methods presented in Table 3-1. The number of composite samples analyzed for each analyte is provided in Table 3-3.

Table 3-3
Numbers of Clam Tissue Composite Samples Analyzed for Each Analyte

Analyte	Number of Clam Tissue Composites		
	Clams (Whole Body)	Clams (Siphon Skin)	Clams (Remainder)
Human Health Risk Driver Chemicals			
PCB Congeners	10	-	-
Dioxins/furans	10	-	-
cPAHs	10	-	-
Inorganic arsenic	-	20	20
Non-risk Driver Chemicals			
Vanadium	3	-	-
TBT	3	-	-
Selected SVOCs	3	-	-
Organochlorine pesticides	3	-	-
Conventionals			
Lipid	10	-	-
Percent solids	10	3	3

Notes:
cPAH: carcinogenic polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
SVOC: semivolatile organic compound
TBT: tributyltin

3.3 Passive Samplers

SGS-Axys performed PCB congener analyses on the passive samplers via high-resolution gas chromatography/high-resolution mass spectrometry (HRGC/HRMS) following EPA method 1668c. Per the periodic monitoring QAPP (Windward and Anchor QEA 2023), five replicates from each location were analyzed.

3.4 Laboratory Deviations from the Periodic Monitoring QAPP

Laboratory deviations from the periodic monitoring QAPP (Windward and Anchor QEA 2023) are as follows:

- The standard reference material and matrix spike/matrix spike duplicate for organochlorine pesticide analysis were not analyzed due to an oversight by the laboratory. A laboratory control sample/laboratory control sample duplicate was used to assess precision and accuracy.
- Vanadium and total solids analyses in fish and crab samples were performed past holding times.

4 Results of Chemical Analyses

This section summarizes the results of the chemical analyses and data validation of the periodic monitoring samples. Data management practices are presented in Appendix C of the Pre-Design studies work plan (Windward and Integral 2017).

4.1 Fish and Crab Tissue Chemistry Results

This section summarizes fish and crab tissue chemistry results for human health risk drivers and conventional parameters (i.e., total solids and lipids) data for the various tissue types analyzed:

- English sole – Tissue was analyzed as fillet and remainder tissue samples; whole-body concentrations were calculated from fillet and remainder concentrations.
- Shiner surfperch – Tissue was analyzed as whole-body tissue samples.
- Crab – Tissue was analyzed as edible meat and hepatopancreas tissue samples; whole-body concentrations were calculated from edible meat and hepatopancreas concentrations.

The equations to calculate these concentrations and the supporting data used are presented in Appendix A1.

Results for each analyte are summarized by tissue type in Tables 4-1 through 4-5 for PCBs, dioxins/furans, cPAH toxic equivalent (TEQ), inorganic arsenic, and conventional parameters. The complete chemistry dataset is provided in Appendix A1. Laboratory reports and the data validation report are provided as part of the data package (available on ldwg.org). Interpretation of these results (i.e., comparison to TTLs and an evaluation of trends) is presented in Section 5.1.

Table 4-1
Total PCB Congener Data Summary for Fish and Crab Tissue

Sampling Reach/ Subreach[1]	Detection Frequency		Total PCB Concentrations[2] (µg/kg ww)		
	Ratio	%	Minimum	Maximum	Mean
English Sole (Fillet with Skin)					
R1	6/6	100	361.8 J	813.7 J	520.6
R2	6/6	100	158.9 J	318.6 J	269.1
English Sole (Whole Body [Calculated])					
R1	6/6	100	740.4 J	1,052 J	910.9
R2	6/6	100	292 J	911.6 J	605
Shiner Surfperch (Whole Body)					
R1a	3/3	100	235.3 J	314.8 J	278.2
R1b	3/3	100	286.4 J	368.3 J	328.5
R2a	3/3	100	336 J	560.8 J	468.3

Sampling Reach/ Subreach[1]	Detection Frequency		Total PCB Concentrations[2] (µg/kg ww)		
	Ratio	%	Minimum	Maximum	Mean
R2b	3/3	100	341.4 J	530.3 J	405.5
Graceful Crab (Edible Meat)					
R1	6/6	100	54.51 J	120.6 J	93.24
R2	6/6	100	34.79 J	62.28 J	49.58
Graceful Crab (whole body [calculated])					
R1	6/6	100	207.9 J	312 J	256
R2	6/6	100	140.2 J	185.2 J	169
Dungeness Crab (Edible Meat)					
R2	4/4	100	16.47 J	38.74 J	27.87
Dungeness Crab (Whole Body [Calculated])					
R2	4/4	100	380.2 J	485.8 J	431.9

Notes:
1. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8). The four subreaches for shiner surfperch include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).
2. Total PCB concentrations are the sum of PCB congeners. Previously, PCBs were measured as the sum of Aroclors and the sum of congeners. The total PCB concentrations calculated as sum of Aroclors and the sum of congeners for the same samples were compared in Appendix B of the *Pre-Design Studies Data Evaluation Report* (Windward 2020); the results were comparable.
J: estimated concentration
PCB: polychlorinated biphenyl
RM: river mile
ww: wet weight

Table 4-2
Dioxin/furan TEQ Data Summary for Fish and Crab Tissue

Sampling Reach/Subreach[1]	Detection Frequency		Dioxin/Furan TEQ (ng/kg ww)			RL or Range of RLs for Non-detected Results
	Ratio	%	Minimum	Maximum	Mean	
English Sole (Fillet With Skin)						
R1	4/6	67	0.239 J	0.360 J	0.281	0.254–0.255
R2	4/6	67	0.233 J	0.272 J	0.25	0.195–0.219
English Sole (Whole Body [Calculated])						
R1	6/6	100	0.479 J	0.710 J	0.584	NA
R2	6/6	100	0.362 J	0.523 J	0.453	NA
Shiner Surfperch (Whole Body)						
R1a	3/3	100	0.677 J	0.708 J	0.696	NA
R1b	3/3	100	0.599 J	1.08 J	0.767	NA
R2a	3/3	100	0.486 J	0.663	0.577	NA
R2b	3/3	100	0.484 J	0.767 J	0.585	NA

Sampling Reach/Subreach[1]	Detection Frequency		Dioxin/Furan TEQ (ng/kg ww)			RL or Range of RLs for Non-detected Results
	Ratio	%	Minimum	Maximum	Mean	
Graceful Crab (Edible Meat)						
R1	6/6	100	0.206 J	0.290 J	0.238	NA
R2	6/6	100	0.169 J	1.26 J	0.389	NA
Graceful Crab (Whole Body [Calculated])						
R1	6/6	100	0.721 J	1.12 J	0.875	NA
R2	6/6	100	0.487 J	4.57 J	1.83	NA
Dungeness Crab (Edible Meat)						
R2	2/4	50	0.170 J	0.191 J	0.181	0.175–0.176
Dungeness Crab (Whole Body [Calculated])						
R2	4/4	100	1.20 J	1.56 J	1.36	NA

Notes:
1. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8). The four subreaches for shiner surfperch include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).
J: estimated concentration
NA: not applicable
RL: reporting level
RM: river mile
TEQ: toxic equivalent
ww: wet weight

Table 4-3
cPAH TEQ Graceful Crab Data Summary

Sampling Reach[1, 2]	Detection Frequency		cPAH TEQ (µg/kg ww)			RL or Range of RLs for Non-detected Results
	Ratio	%	Minimum	Maximum	Mean	
Graceful Crab (Edible Meat)						
R1	4/6	67	0.120 J	0.233 J	0.172	0.0838–0.096
R2	0/6	0	ND	ND	ND	0.0491–0.114
Graceful Crab (Whole Body [Calculated])						
R1	6/6	100	0.188 J	0.390 J	0.314	NA
R2	6/6	100	0.0970 J	0.131 J	0.112	NA

Notes:
1. As described in Section 3.1, fish tissue was not analyzed for PAHs.
2. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8).
cPAH: carcinogenic polycyclic aromatic hydrocarbon
J: estimated concentration
NA: not applicable
ND: not detected
PAH: polycyclic aromatic hydrocarbon
RL: reporting limit
RM: river mile
TEQ: toxic equivalent
ww: wet weight

Table 4-4
Inorganic Arsenic Data Summary for Fish and Crab Tissue

Sampling Reach/Subreach[1]	Detection Frequency		Inorganic Arsenic (mg/kg ww)		
	Ratio	%	Minimum	Maximum	Mean
English Sole (Fillet With Skin)					
R1	6/6	100	0.0115	0.0724	0.0234
R2	6/6	100	0.00506 J	0.0519	0.0163
English Sole (Whole Body [Calculated])					
R1	6/6	100	0.0429	0.0760	0.0629
R2	6/6	100	0.0362 J	0.0557 J	0.0474
Shiner Surfperch (Whole Body)					
R1a	3/3	100	0.0216	0.0313	0.026
R1b	3/3	100	0.0308	0.0514	0.041
R2a	3/3	100	0.176	0.214	0.201
R2b	3/3	100	0.0528	0.0733	0.0648
Graceful Crab (Edible Meat)					
R1	6/6	100	0.0220	0.0292	0.025
R2	6/6	100	0.0169	0.0391	0.0249
Graceful Crab (Whole Body [Calculated])					
R1	6/6	100	0.0300	0.0375	0.034
R2	6/6	100	0.0287	0.0521	0.037

Notes:
1. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8). The four subreaches for shiner surfperch include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).
J: estimated concentration
RM: river mile
ww: wet weight

Table 4-5
Conventional Parameters Data Summary for Fish and Crab Tissue

Parameter	Detection Frequency		Result (%)		
	Ratio	%	Minimum	Maximum	Mean
English Sole (Fillet With Skin)					
Lipid	4/4	100	1.8	6.4	2.9
Total solids	4/4	100	20.75	22.45	21.58
English Sole (Whole Body [Calculated])					
Lipid	4/4	100	5.0	9.5	6.8
Total solids	4/4	100	23.36	26.58	25.25

Parameter	Detection Frequency		Result (%)		
	Ratio	%	Minimum	Maximum	Mean
Shiner Surfperch (Whole Body)					
Lipid	4/4	100	3.5	6.2	4.6
Total solids	4/4	100	23.82	27.55	25.40
Graceful Crab (Edible Meat)					
Lipid	4/4	100	0.42	0.65	0.56
Total solids	4/4	100	13.12	20.23	17.34
Graceful Crab (Whole Body [Calculated])					
Lipid	4/4	100	1.0	1.6	1.2
Total solids	4/4	100	12.93	19.82	16.71
Dungeness Crab (Edible Meat)					
Lipid	4/4	100	0.30	0.44	0.37
Total solids	4/4	100	16.25	19.70	17.97
Dungeness Crab (Whole Body [Calculated])					
Lipid	4/4	100	2.1	2.4	2.2
Total solids	4/4	100	16.15	19.03	17.59

4.2 Clam Tissue Chemistry Results

This section summarizes clam tissue chemistry results for human health risk drivers and conventional parameters (i.e., total solids and lipids) data. For clams, tissue was analyzed as whole-body samples for all chemicals except inorganic arsenic, for which tissue was analyzed as siphon skin and remainder samples.[11] Whole-body concentrations of arsenic were then calculated from these two concentrations.

The equations and supporting data used to calculate whole body concentrations are presented in Appendix A2. Results are summarized in Table 4-6 for inorganic arsenic and Table 4-7 for other risk driver chemicals and conventional parameters. In addition, the complete chemistry dataset for clams (including non-risk driver chemicals) is provided in Appendix A2. Among non-risk driver chemicals, only vanadium, tributyltin (TBT), and DDTs[12] were detected in clam tissue samples. Concentrations of these chemicals were similar to or lower than those in the baseline dataset. Laboratory reports and the data validation report are provided as part of the data package (available on ldwg.org). Interpretation of the clam tissue results (i.e., comparison to TTLs and an evaluation of trends) is presented in Section 5.2.

[11] Remainder clam tissue is whole-body tissue with the siphon skin removed.
[12] Dichlorodiphenyltrichloroethanes are better known by their acronym, DDTs.

Table 4-6
Inorganic Arsenic Results for Clam Tissue Composite Samples

Location ID	Siphon Skin			Remainder			Calculated Whole Body[1]		
	Composite ID (LDW23-)	Inorganic Arsenic (mg/kg ww)	Percent Solids (%)	Composite ID (LDW23-)	Inorganic Arsenic (mg/kg ww)	Percent Solids (%)	Composite ID (LDW23-)	Inorganic Arsenic (mg/kg ww)	Percent Solids (%)
C01	C01-CLSP-Comp1	4.70	15.05	C01-CLRM-Comp1	0.0693	10.25	C01-CLWB-Comp1	0.406	10.60
	C01-CLSP-Comp2	5.18	20.55	C01-CLRM-Comp2	0.0755	8.51	C01-CLWB-Comp2	0.411	9.30
C02	C02-CLSP-Comp1	10.1	19.98	C02-CLRM-Comp1	0.0668	9.66	C02-CLWB-Comp1	0.988	10.60
	C02-CLSP-Comp2	5.82	17.70	C02-CLRM-Comp2	0.0690	9.46	C02-CLWB-Comp2	0.730	10.40
C03	C03-CLSP-Comp1	6.31	19.45	C03-CLRM-Comp1	0.0770	11.06	C03-CLWB-Comp1	0.682	11.88
	C03-CLSP-Comp2	9.58	14.22	C03-CLRM-Comp2	0.110	9.74	C03-CLWB-Comp2	0.962	10.10
C04	C04-CLSP-Comp1	21.3	15.16	C04-CLRM-Comp1	0.144	10.08	C04-CLWB-Comp1	2.49	10.64
	C04-CLSP-Comp2	92.1	14.73	C04-CLRM-Comp2	0.205	9.22	C04-CLWB-Comp2	8.66	9.73
C05	C05-CLSP-Comp1	8.14	9.89	C05-CLRM-Comp1	0.0994	8.95	C05-CLWB-Comp1	0.743	9.03
	C05-CLSP-Comp2	2.17	10.90	C05-CLRM-Comp2	0.0859	9.79	C05-CLWB-Comp2	0.309	9.91
C06	C06-CLSP-Comp1	9.29	13.35	C06-CLRM-Comp1	0.0841	8.94	C06-CLWB-Comp1	1.12	9.43
	C06-CLSP-Comp2	9.90	12.74	C06-CLRM-Comp2	0.0883	11.05	C06-CLWB-Comp2	1.11	11.23
C08	C08-CLSP-Comp1	8.25	12.94	C08-CLRM-Comp1	0.0652	10.51	C08-CLWB-Comp1	0.759	10.71
	C08-CLSP-Comp2	2.29	10.77	C08-CLRM-Comp2	0.0730	9.17	C08-CLWB-Comp2	0.284	9.32
C09	C09-CLSP-Comp1	53.4	11.86	C09-CLRM-Comp1	0.0945	8.69	C09-CLWB-Comp1	5.24	9.00
	C09-CLSP-Comp2	15.7	10.83	C09-CLRM-Comp2	0.0717	9.79	C09-CLWB-Comp2	1.70	9.90
C10	C10-CLSP-Comp1	10.1	12.49	C10-CLRM-Comp1	0.0648	9.31	C10-CLWB-Comp1	1.21	9.67
	C10-CLSP-Comp2	11.1	14.02	C10-CLRM-Comp2	0.0530	10.16	C10-CLWB-Comp2	1.21	10.57
C11	C11-CLSP-Comp1	222 J	11.71	C11-CLRM-Comp1	0.373	9.86	C11-CLWB-Comp1	24.5 J	10.10
	C11-CLSP-Comp2	117	12.45	C11-CLRM-Comp2	0.328	10.44	C11-CLWB-Comp2	13.0	10.66

Notes:
1. The equations and supporting data used to calculate whole-body concentrations are presented in Appendix A2.
ID: Identification
J: estimated concentration
ww: wet weight

Table 4-7
PCB, Dioxin/Furan, and cPAH Chemistry and Conventional Parameter Results for Whole-body Clam Tissue Composite Samples

Location ID	Whole-body Composite ID	Total PCB Congeners (µg/kg ww)	PCB TEQ (ng/kg ww)	Dioxin/Furan TEQ (ng/kg ww)	Total TEQ (ng/kg ww)	cPAH TEQ (µg/kg ww)	Conventionals	
							Percent Solids (%)	Lipids (%)
C01	LDW23-C01-CLWB-Comp3	10.632 J	0.119 J	0.276 J	0.396 J	3.68 J	10.58	0.54
C02	LDW23-C02-CLWB-Comp3	16.39 J	0.190 J	0.363 J	0.553 J	2.20 J	10.32	0.52
C03	LDW23-C03-CLWB-Comp3	30.33 J	0.295 J	0.364 J	0.658 J	5.15 J	10.34	0.53
C04	LDW23-C04-CLWB-Comp3	30.16 J	0.215 J	2.52 J	2.73 J	6.99 J	11.39	0.52
C05	LDW23-C05-CLWB-Comp3	35.88 J	0.246 J	0.401 J	0.648 J	11.9 J	9.69	0.46
C06	LDW23-C06-CLWB-Comp3	35.84 J	0.291 J	0.375 J	0.666 J	3.75 J	10.81	0.62
C08	LDW23-C08-CLWB-Comp3	24.77 J	0.227 J	0.248 J	0.475 J	3.70 J	9.50	0.44
C09	LDW23-C09-CLWB-Comp3	25.31 J	0.241 J	0.273 J	0.514 J	3.18 J	8.78	0.45
C10	LDW23-C10-CLWB-Comp3	27.65 J	0.262 J	0.198 J	0.460 J	3.46 J	9.75	0.51
C11	LDW23-C11-CLWB-Comp3	22.65 J	0.179 J	0.257 J	0.436 J	4.39 J	9.65	0.54

Notes:
cPAH: carcinogenic polycyclic aromatic hydrocarbon
ID: Identification
J: estimated concentration
PCB: polychlorinated biphenyl
TEQ: toxic equivalent
ww: wet weight

4.3 Passive Samplers Chemistry Results

Passive samplers were used to estimate PCB C_{free} in LDW surface water. The PCB C_{free} data presented in this section reflect a 30-day average concentration during August and September to represent dry season conditions. This approach is consistent with sampling conducted in 2017 and 2018 (i.e., also in August and September). A concentration from this sampling period was selected for trend analysis because it is expected to have less variance than a concentration reflecting a wet season or individual whole-water samples. PCB C_{free} is expected to be lower than PCB concentrations in whole-water samples, which include freely dissolved PCBs and PCBs associated with particles and colloidal particles (< 0.45 µm). Freely dissolved PCBs are used to evaluate bioavailability trends over time, whereas whole-water data are used to assess applicable or relevant and appropriate requirements compliance.[13]

Table 4-8 presents a summary of PCB C_{free} results calculated from passive sampler data. The methods used to calculate the PCB C_{free} values are described in Appendix F. The equilibrium calculation methods used for the 2023 dataset differed from the method used in 2017 and 2018. The changes in methods and the associated effects on calculated PCB C_{free} values are also discussed in Appendix F. The PCB C_{free} concentrations calculated using the two calculation methods were very similar to each other, with an average difference of 4.2% for the 2017 data and an average difference of -6.5% for the 2018 data, when the total PCB C_{free} values were calculated using the 2023 equilibrium methods compared to the original total PCB C_{free} values. The average differences observed between the two calculation methods are much lower than the analytical variability associated with the analysis of the passive samplers.

Table 4-8
Summary of Freely Dissolved Total PCBs Data Calculated from Passive Samplers

Location	Detection Frequency	PCB C_{free} (pg/L)		
		Minimum	Maximum	Mean
PS1 (South Park Bridge) – RM 3.3	5/5	1,797 J	2,514 J	2,068
PS2 (Lineage Logistics) – RM 1.9	5/5	1,909 J	2,308 J	2,173

Notes:
The complete dataset is provided in Appendix A3.
J: estimated concentration
PCB: polychlorinated biphenyl
RM: river mile

Table 4-9 presents a summary of the conventional parameter data recorded by the data loggers deployed with the passive samplers. Full results for conventional parameters are presented in

[13] Whole-water data were collected during the 2017/2018 baseline sampling. Sampling will be repeated following sediment remediation per the future long-term monitoring and maintenance plan.

Appendix E. The conventional parameters recorded for PS1 were unusual and may reflect an issue with the data logger (e.g., flawed calibration or sensor errors). Specifically, the salinity at PS1 (RM 3.3) was higher than both the salinity at PS2 and salinity ranges expected in the LDW; the differences in pH between stations were unexpected.

Table 4-9
Summary of *In situ* Conventional Parameter Values Recorded during Passive Sampler Deployment

Parameter	Average Parameter Values (Range of 10th to 90th Percentile)[1]	
	PS1 – South Park Bridge (RM 3.3)[2]	PS2 – Lineage Logistics (RM 1.9)
DO (mg/L)	6.36 (5.54–7.17)	7.09 (6.34–7.84)
pH	6.21 (5.99–6.35)	7.85 (7.76–7.94)
Salinity (ppt)	34.9 (31.9–37.3)	26.3 (23.5–28.1)
Temperature (°C)	13.6 (12.9–14.3)	14.2 (13.4–15.1)
Total dissolved solids (mg/L)	34,400 (31,800–36,600)	26,700 (24,100–28,400)

Notes:
1.Parameter values were recorded by a data logger attached to a passive sampler frame at each location; values were recorded every 15 minutes during the passive sampler deployment. The range of the 10th to 90th percentile was used in this table (rather than minimum and maximum values) to avoid the inclusion of data identified as being of questionable quality.
2. Differences between the conventional parameter values reported for PS1 and PS2 in 2023 likely reflect an issue with the data logger (e.g., flawed calibration or sensor errors) at PS1.
DO: dissolved oxygen
ppt: parts per thousand
RM: river mile

4.4 Data Validation Results

Independent data validation on all analytical results was performed by Ecochem, Inc. Full validation was performed on a minimum of 10% of the data or a single sample delivery group, as specified in the periodic monitoring QAPP (Windward and Anchor QEA 2023). A summary-level validation review was conducted on the remaining data.

All data were determined to be acceptable for use as qualified. No data were rejected. The data validation report, which includes detailed information regarding all data qualifiers, is provided as part of the data package (available on ldwg.org).

5 Data Interpretation

As described in the periodic monitoring QAPP (Windward and Anchor QEA 2023), the data quality objectives (DQOs) for the 2023 periodic monitoring effort are based largely on the DQOs established in the QAPPs developed for baseline monitoring in 2017/2018. The three periodic monitoring DQOs are as follows:

- **DQO 1**: Calculate site-wide 95% upper confidence limit (on the mean) (95UCL) concentrations of human health risk drivers in fish, crabs, and clams in 2023 for comparison to TTLs.[14]
- **DQO 2**: Calculate site-wide mean concentrations of contaminants with TTLs in fish, crab, and clam tissues in 2023, for use in trends assessment as sediment remediation and source control continue.
- **DQO 3**: Calculate freely dissolved PCB concentrations in surface water, for use in trends assessments as sediment remediation and source control continue.

The subsections that follow present the data interpretation related to these three DQOs as applicable for each medium. As part of DQO 2, the 2023 data are compared with the 2017/2018 baseline dataset, as well as with older data from the remedial investigation (when available).

5.1 Fish and Crab Tissue

This section presents an interpretation of the fish and crab tissue data collected in 2023 relative to DQOs 1 and 2.

5.1.1 Comparison with TTLs

Site-wide 95UCL concentrations in fish and crab tissue were calculated for comparison with TTLs to address DQO 1. Details regarding the calculation of 95UCLs are presented in Appendix G. Note that for arsenic and cPAHs, TTLs were developed for only clam tissue, thus no comparison is presented here.

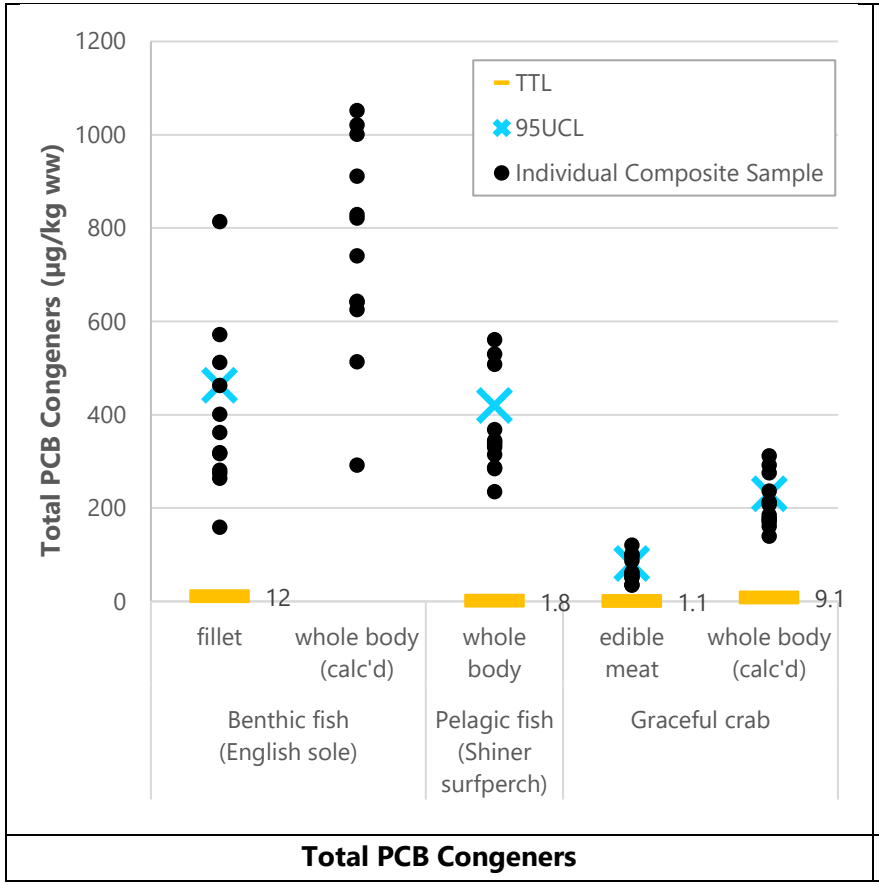
For total PCBs, the 95UCLs were above the TTL for all four tissue types for which TTLs were available (Table 5-1). For dioxin/furan TEQ, the site-wide 95UCLs for whole-body English sole and whole-body crab were greater than the respective TTLs, whereas the site-wide 95UCL for crab edible meat was equal to the TTL (Table 5-1). These data are presented graphically in Figure 5-1.

[14] TTLs are those presented in the 2014 ROD (EPA 2014a) or the explanation of significant differences for cPAHs (EPA 2021).

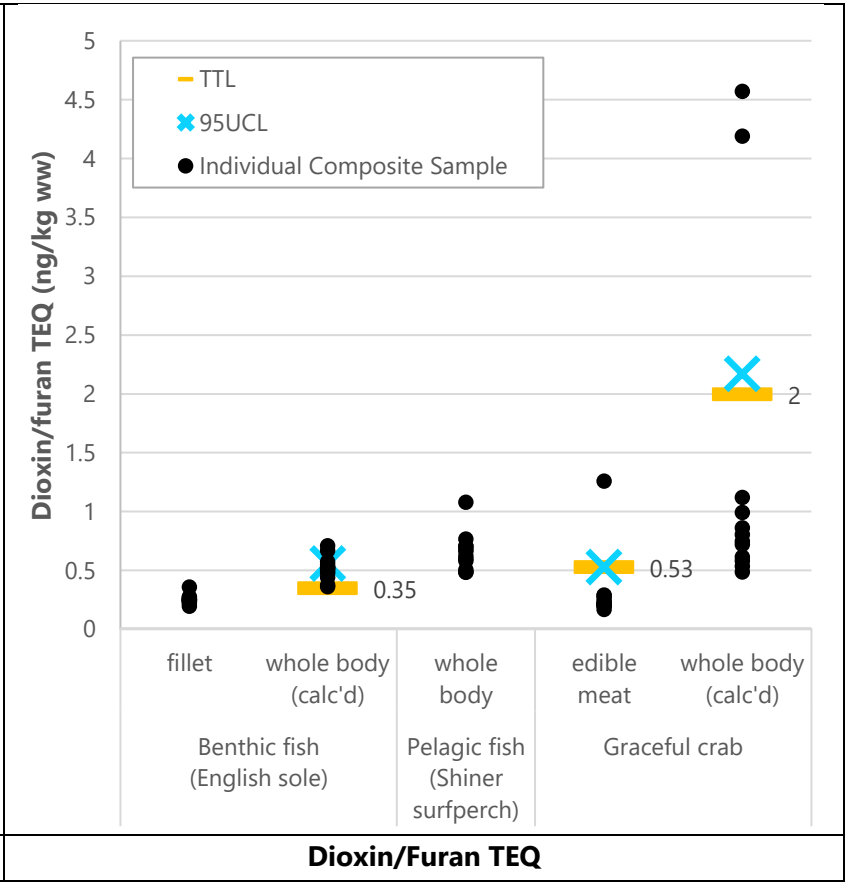
Table 5-1
Comparison of 2023 Fish and Crab Tissue Data with TTLs

ROD Species Group and Tissue Type	Baseline Species	Summary Statistics for 2023 Dataset				ROD TTL[2]	ROD TTL Basis	95UCL < TTL
		Detection Frequency	Mean Value	Range of Values	95UCL[1]			
Total PCB Congeners (µg/kg ww)								
Benthic fish – fillet	English sole[3]	12/12	394.9	158.9 J–813.7 J	463	12	Non-urban background	no
Pelagic fish – whole body	Shiner surfperch	12/12	370.1	253.3 J–560.8 J	420	1.8	Species-specific RBTC	no
Crab – edible meat	Graceful crab[4]	12/12	71.41	34.79 J–120.6 J	81	1.1	Non-urban background	no
Crab – whole body	Graceful crab[4]	12/12	212.4	140.2 J–312.0 J	231	9.1	Non-urban background	no
Dioxin/Furan TEQ (ng/kg ww)								
Benthic fish – whole body	English sole[3]	12/12	0.518	0.362 J–0.710 J	0.560	0.35	Non-urban background	no
Crab – edible meat	Graceful crab[4]	12/12	0.313	0.169 J–1.26 J	0.53	0.53	Non-urban background	**equal**
Crab – whole body[5]	Graceful crab[4]	12/12	1.35	0.487 J–4.57 J	2.27	2.0	Non-urban background	no

Notes:
1. The 95UCL was calculated using the equations for Welch's t-interval for normally distributed data for a stratified population (see Appendix G).
2. TTLs are as presented in Table 21 of the ROD (EPA 2014a). TTLs are not available for every species-chemical combination.
3. The TTL for benthic fish in ROD Table 21 (EPA 2014a) was based on non-urban background concentrations in a combination of species available in the Puget Sound tissue dataset, including English sole, rock sole, and starry flounder.
4. The TTL for crab in ROD Table 21 (EPA 2014a) was based on Dungeness crab; the LDW data are for graceful crab because sufficient numbers of Dungeness crab were not available (Windward and Anchor QEA 2023).
5. The crab whole-body dataset included two samples identified as statistical outliers (95% confidence; see Appendix G). The 95UCL calculated without these values would be 0.781 ng/kg ww.
95UCL: 95% upper confidence limit (on the mean)
J: estimated concentration
LDW: Lower Duwamish Waterway
PCB: polychlorinated biphenyl
RBTC: risk-based threshold concentration
ROD: record of decision
TEQ: toxic equivalent
TTL: target tissue level
ww: wet weight



Total PCB Congeners



Dioxin/Furan TEQ

Note: TTLs were not developed in the ROD for every species-chemical combination (EPA 2014a). For completeness, data are shown for the same species/tissue types for both chemicals, but no TTL is available for whole-body benthic fish for total PCBs or for benthic fish fillet and whole-body pelagic fish for dioxins/furans. 95UCLs are also not shown for these species-chemical combinations.

Figure 5-1 Comparison of Fish and Crab Tissue Concentrations with TTLs

5.1.2 Comparison with Baseline and Older Data

Fish and crab tissue data from the 2023 periodic monitoring effort were compared with baseline data (collected in 2017) and other older data from the LDW to address DQO 2.

A comparison of mean values—along with the results of the statistical evaluation conducted to determine whether there was a statistically significant difference among mean values from 2017 to 2023—is presented in Table 5-2. Details of this evaluation are presented in Appendix G. As shown in this table, there was a statistically significant decrease in total PCB congener concentrations for shiner surfperch and graceful crab (both for edible meat and whole-body concentrations). For dioxins/furans, there was a statistically significant decrease in the TEQ for English sole (both fillet and whole body) and for shiner surfperch. Other species-chemical combinations were not found to be statistically different among years. The subsections that follow present a comparison, by year and sampling reach, for total PCBs and dioxin/furan TEQ.

Table 5-2
Comparison Between 2017 and 2023 Fish and Crab Tissue Results

Species and Tissue Type	2017 Results			2023 Results			Comparison of 2017 vs. 2023[1]	
	n	Mean	SE	n	Mean	SE	Difference of Means [95CI for Difference]	Statistically Significant Difference?
Total PCB Congeners (µg/kg ww)								
Benthic fish – English sole – fillet	6	319.5	35.7	12	394.9	35.2	75.4 [-38.0, 189]	No
Benthic fish – English sole – whole body	6	808.1	53.7	12	758.0	48.9	-50.2 [-210, 109]	No
Pelagic fish – shiner surfperch – whole body	8	446.1	16.2	12	370.1	24.5	-76.0 [-145, -6.71]	**Yes (decrease)**
Crab – graceful crab – edible meat	8	113.1	6.91	12	71.4	5.08	-41.6 [-60.1, -23.2]	**Yes (decrease)**
Crab – graceful crab – whole body	6	257.1	14.0	12	212.5	9.42	-44.6 [-82.3, -7.09]	**Yes (decrease)**
Dioxin/furan TEQ (ng/kg ww)								
Benthic fish – English sole – fillet[2]	12	0.428	0.0250	12	0.216[2]	0.0241	-0.214 [-0.284, -0.144]	**Yes (decrease)**
Benthic fish – English sole – whole body	12	1.18	0.0383	12	0.518	0.0231	-0.658 [-0.752, -0.564]	**Yes (decrease)**
Pelagic fish – shiner surfperch – whole body	12	0.952	0.0759	12	0.656	0.0471	-0.295 [-0.500, -0.0905]	**Yes (decrease)**
Crab – graceful crab – edible meat	12	0.406	0.0219	12	0.313	0.0878	-0.0932 [-0.287, 0.100]	No

Species and Tissue Type	2017 Results			2023 Results			Comparison of 2017 vs. 2023[1]	
	n	Mean	SE	n	Mean	SE	Difference of Means [95CI for Difference]	Statistically Significant Difference?
Crab – graceful crab – whole body	12	1.21	0.0571	12	1.35	0.405	0.141 [-0.739, 1.02]	No

Notes:
1. A comparison of 2017 and 2023 results was conducted using a confidence interval on the mean of the 2023 data minus the mean of the baseline data and Welch's approximate t-interval. Blue shading indicates statistically significant differences. A positive value for the difference indicates an increase in concentration over time, whereas a negative value indicates a decrease in concentration over time. When the 95CI excludes zero, the difference is statistically significant (two-tailed alpha = 0.05). Details of this evaluation, including comparisons by sampling reach, are presented in Appendix G.
2. The 2023 results for dioxin/furan TEQ in English sole fillets included values less than the detection level, so the mean and SE were calculated using Kaplan-Meier.
95CI: 95% confidence interval
PCB: polychlorinated biphenyl
SE: standard error
TEQ: toxic equivalent
ww: wet weight

5.1.2.1 Total PCB Congeners

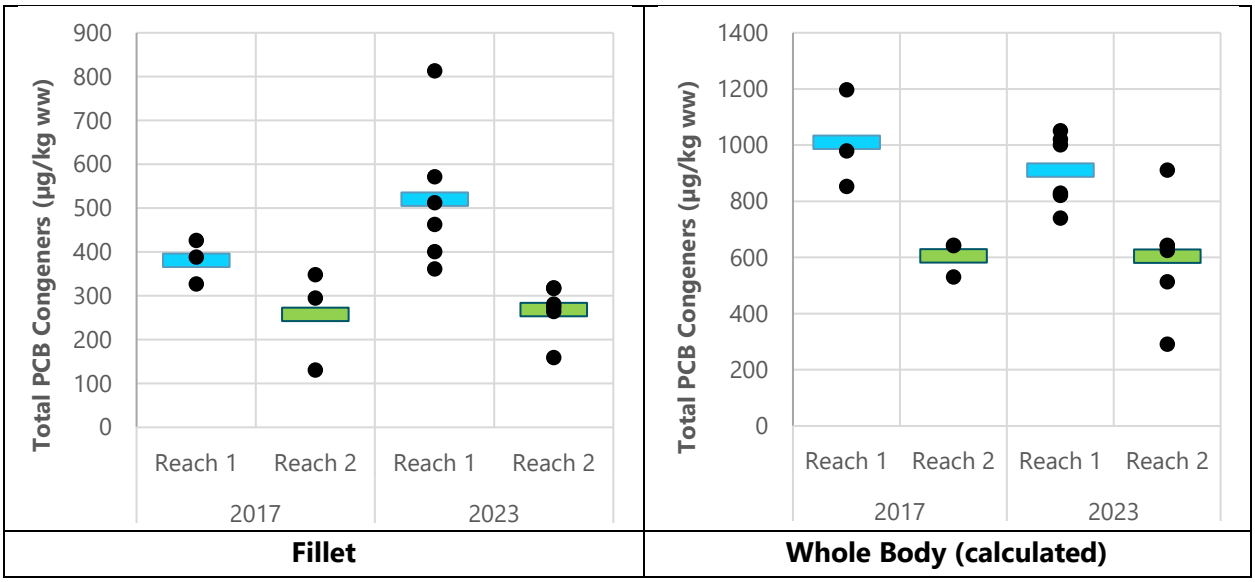
This section presents comparisons of data by sampling area and year for total PCB congeners. A summary of these comparisons is presented below by species:

- **English sole** (Figures 5-2 and 5-3) – Concentrations in English sole tissue were not significantly different in 2023 as compared with 2017 (Table 5-2). PCB concentrations in English sole collected from Reach 2 were lower than those from Reach 1 for both 2017 and 2023.

- **Shiner surfperch** (Figures 5-4 and 5-5) – Concentrations in shiner surfperch tissue were significantly different (lower) in 2023 as compared with 2017 (Table 5-2). This difference appears most pronounced in fish collected from Reach 1.

- **Graceful crab** (Figures 5-6 and 5-8) – Concentrations in graceful crab tissue were significantly different (lower) in 2023 as compared with 2017 (Table 5-2). As with English sole, PCB concentrations for crabs collected in Reach 2 were lower than those from Reach 1 for both years.

- **Dungeness crab** (Figures 5-7 and 5-8) – Because of the small sample size, a statistical comparison was not conducted for Dungeness crab. Total PCB concentrations appeared lower for edible meat tissue in 2023 (as compared with 2017), whereas whole-body concentrations were similar between the two years.



Note: Black dots indicate individual composite samples; green/blue bars indicate averages by reach. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8).

Figure 5-2 Total PCB Congeners in English Sole Tissue by Sampling Area and Year

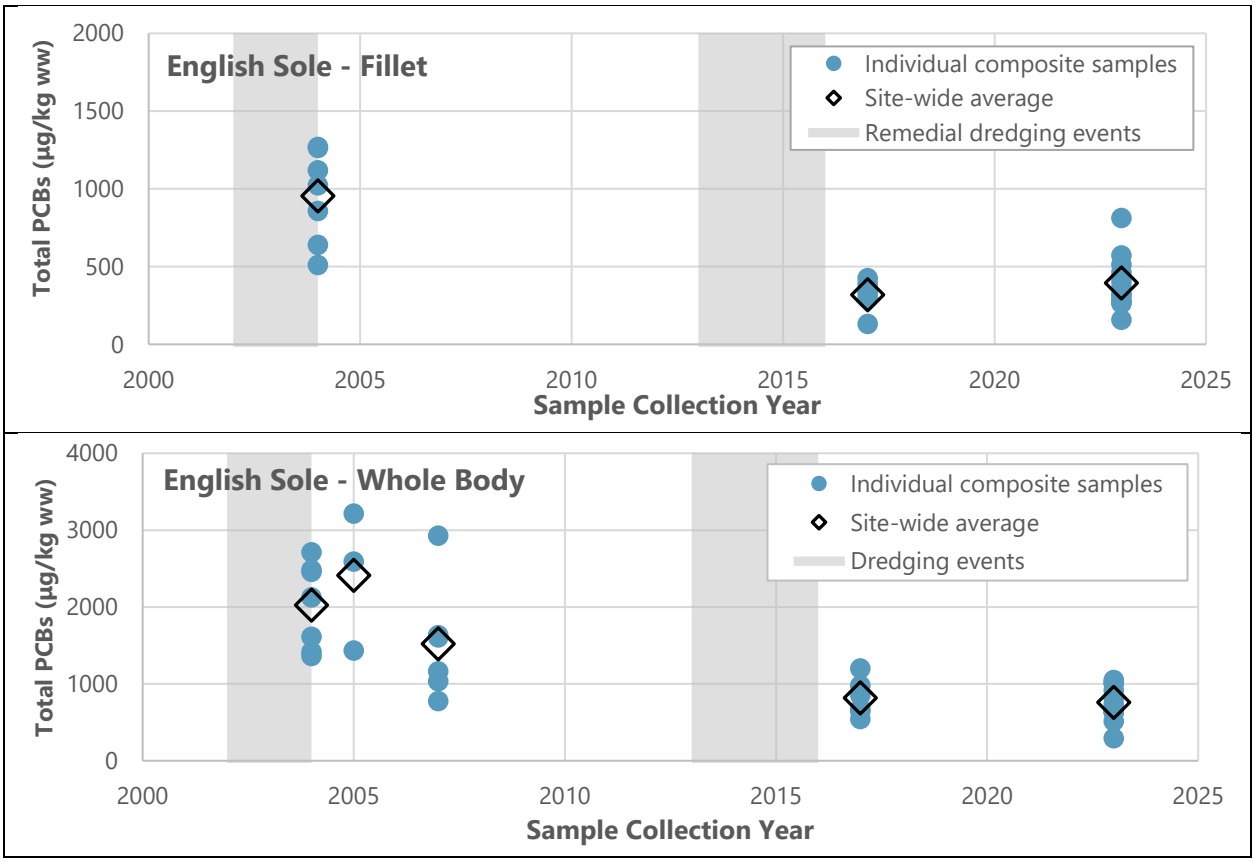
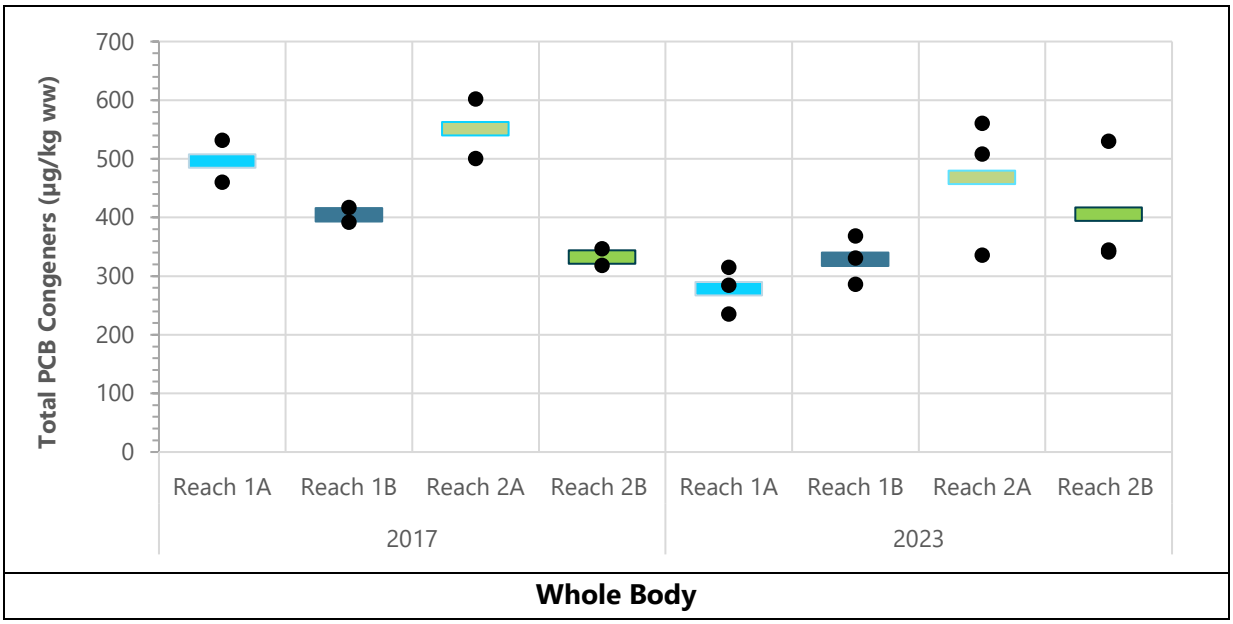


Figure 5-3 Total PCB Congeners in LDW English Sole Tissue Over Time

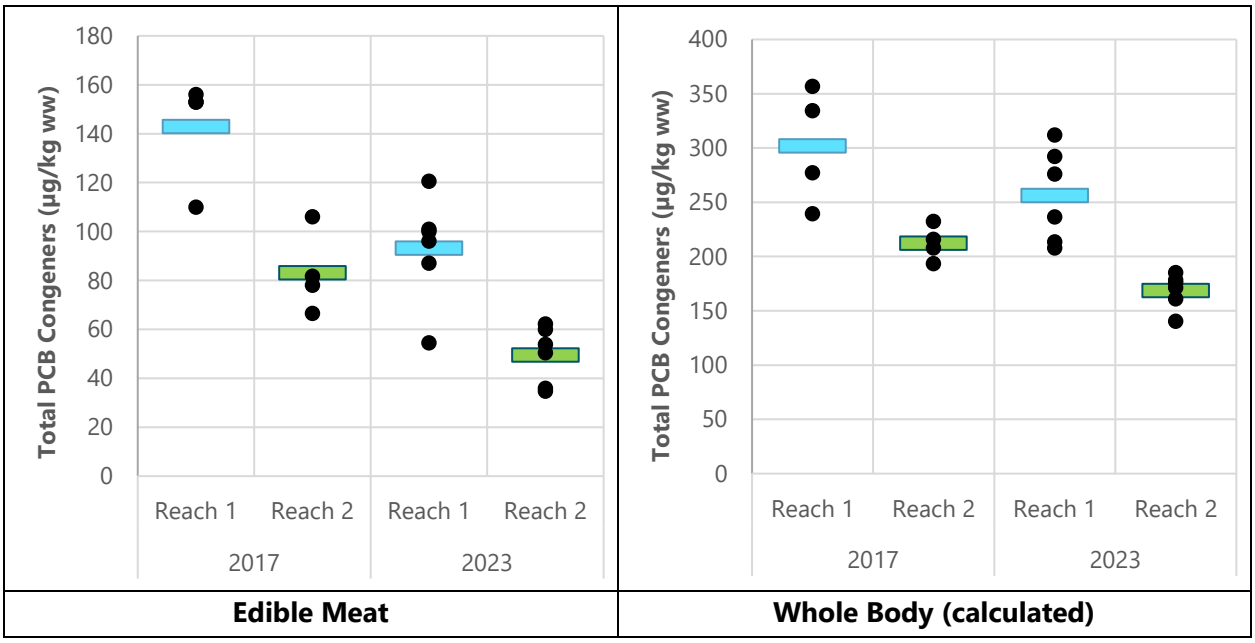


Note: Black dots indicate individual composite samples; green/blue bars indicate averages by subreach. Sampling areas include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).

Figure 5-4 Total PCB Congeners in Shiner Surfperch Tissue by Sampling Area and Year

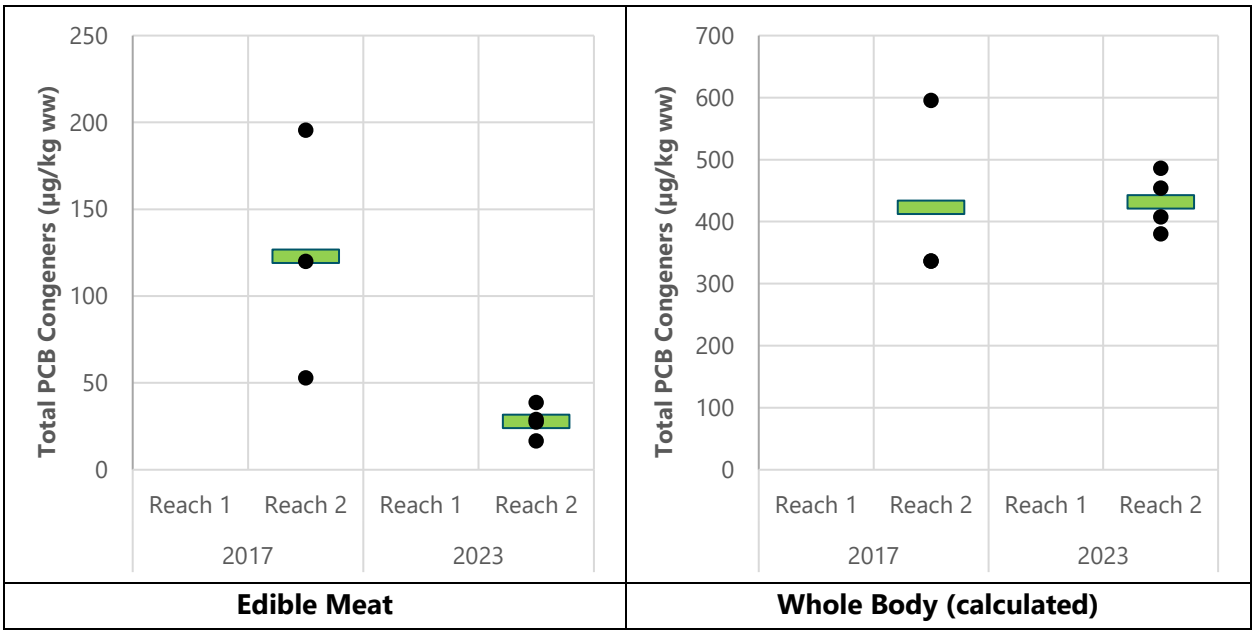
Note: Two highest values from 2004 (8,010 and 12,200 µg/kg ww) are not shown on this figure, but are included in the site-wide average.

Figure 5-5 Total PCB Congeners in LDW Shiner Surfperch Tissue Over Time



Note: Black dots indicate individual composite samples; green/blue bars indicate averages by reach. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8).

Figure 5-6 Total PCB Congeners in Graceful Crab Tissue by Sampling Area and Year



Note: One composite from 2017 contained crab from both Reach 1 and Reach 2. Black dots indicate individual composite samples; green bars indicate averages by reach. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8).

Figure 5-7 Total PCB Congeners in Dungeness Crab Tissue by Sampling Area and Year

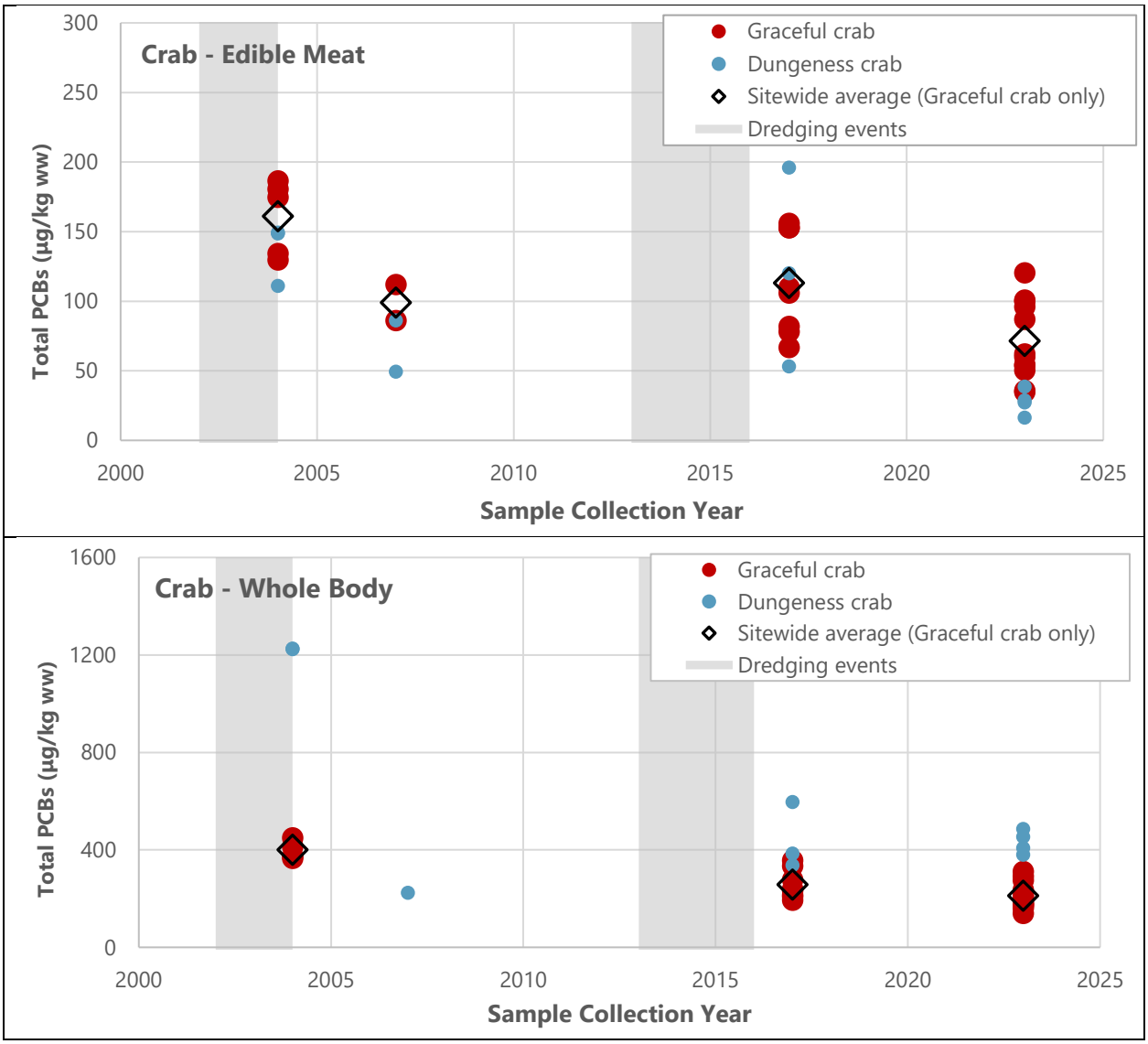


Figure 5-8 Total PCB Congeners in LDW Crab Tissue Over Time

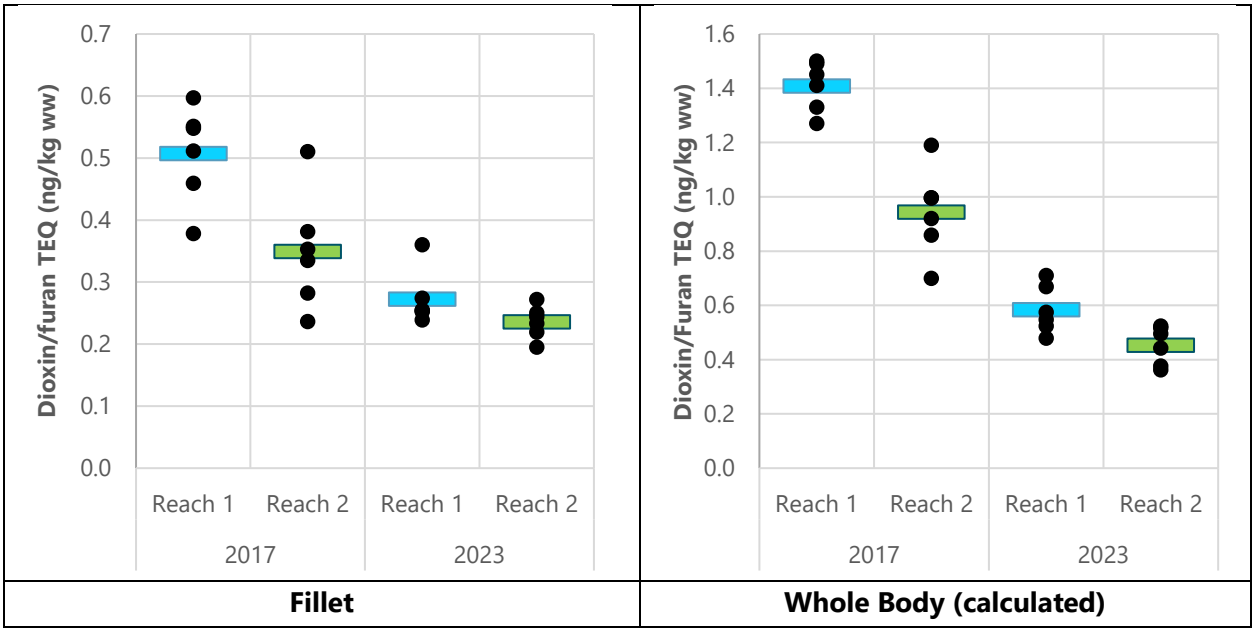
5.1.2.2 Dioxin/furan TEQs

This section presents comparisons of data by sampling area and year for dioxins/furans. A summary of these comparisons is presented below by species:

- **English sole** (Figure 5-9) – Dioxin/furan TEQs in English sole tissue were significantly different (lower) in 2023 as compared with 2017 (Table 5-2). TEQs between the two reaches were similar in 2023, whereas TEQs were generally lower in Reach 2 in the 2017 dataset.
- **Shiner surfperch** (Figure 5-10) – Dioxin/furan TEQs in shiner surfperch tissue were significantly different (lower) in 2023 as compared with 2017 (Table 5-2). TEQs were more consistent across subreaches in 2023 than in 2017.

- **Graceful crab** (Figure 5-11) – Dioxin/furan TEQs in graceful crab tissue were not significantly different between 2023 and 2017 (Table 5-2). However, with the exception of one high value in the crab edible meat Reach 2 dataset and two high values in the crab whole-body Reach 2 dataset in 2023 that influenced this result,[15] TEQs in 2023 generally appeared lower than those in 2017.

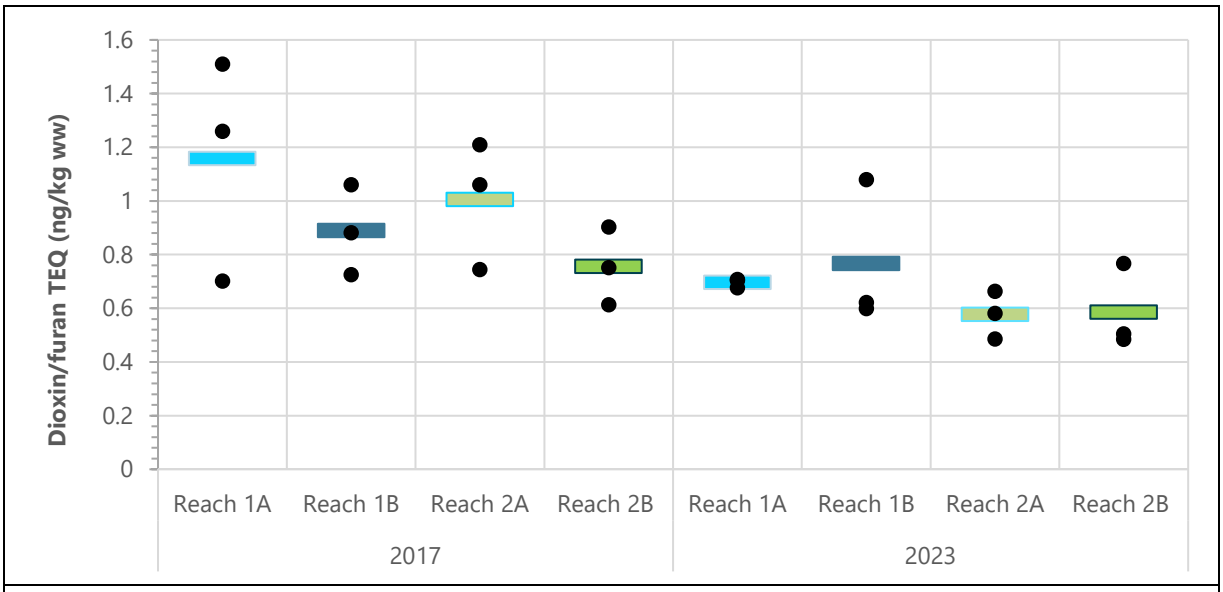
- **Dungeness crab** (Figure 5-12) – Because of the small sample size, a statistical comparison was not conducted for Dungeness crab. As with PCBs, dioxin/furan TEQs appeared lower for edible meat tissue in 2023 (as compared with 2017), whereas whole-body concentrations were similar between the two years.



Note: Black dots indicate individual composite samples; green/blue bars indicate averages by reach. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8).

Figure 5-9 Dioxin/furan TEQs in English Sole Tissue by Sampling Area and Year

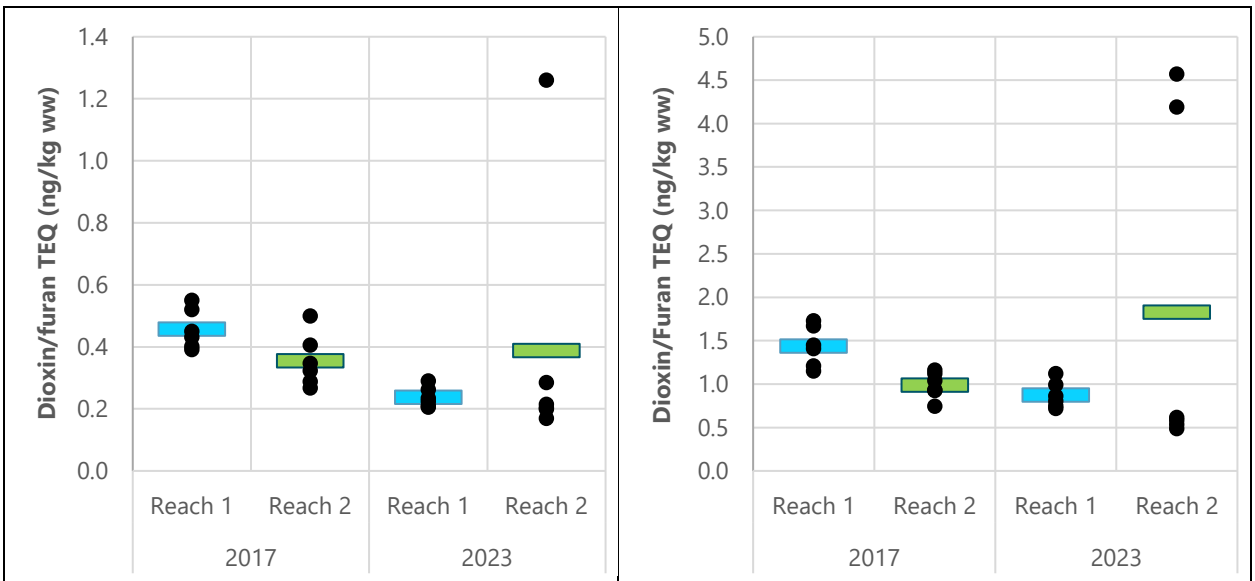
[15] As described in Appendix G, the crab edible meat dataset for dioxins/furans included one sample identified as a statistical outlier (99% confidence). Similarly, the crab whole-body dataset for dioxins/furans included two samples identified as statistical outliers (95% confidence).



Whole Body

Note: Black dots indicate individual composite samples; green/blue bars indicate averages by subreach. Sampling areas include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).

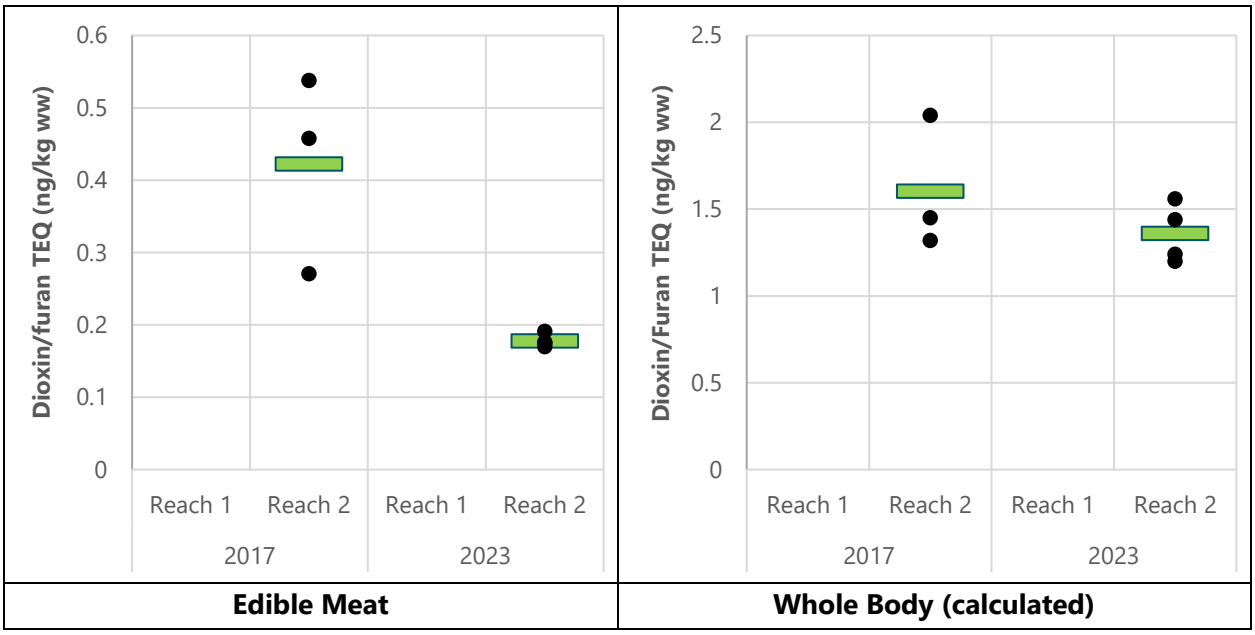
Figure 5-10 Dioxin/furan TEQs in Shiner Surfperch Tissue by Sampling Area and Year



Edible Meat | **Whole Body (calculated)**

Note: Black dots indicate individual composite samples; green/blue bars indicate averages by reach. Sampling areas include subreach 1a (RM 0 to RM 1.3), subreach 1b (RM 1.3 to RM 2.9), subreach 2a (RM 2.9 to RM 3.95), and subreach 2b (RM 3.95 to RM 4.8).

Figure 5-11 Dioxin/furan TEQs in Graceful Crab Tissue by Sampling Area and Year



Note: Black dots indicate individual composite samples; green bars indicate averages by reach. Sampling areas include Reach 1 (RM 0 to RM 2.9) and Reach 2 (RM 2.9 to RM 4.8).

Figure 5-12 Dioxin/furan TEQs in Dungeness Crab Tissue by Sampling Area and Year

5.2 Clam Tissue

This section presents an interpretation of the clam tissue data collected in 2023 relative to DQOs 1 and 2.

5.2.1 Comparison with TTLs

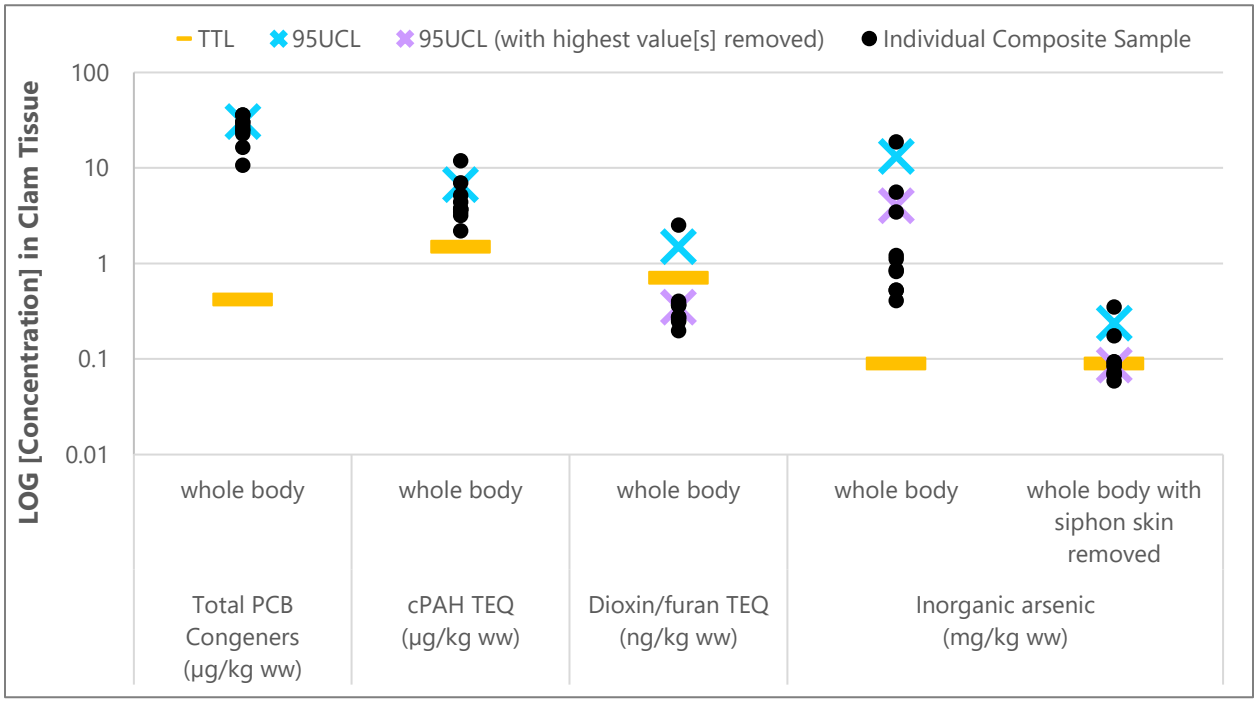
Site-wide 95UCL concentrations in clam tissue were calculated for comparison with TTLs to address DQO 1. Details regarding the calculation of 95UCLs are presented in Appendix G. As with the baseline dataset (i.e., clam tissue collected in 2018) (Windward 2020), the 95UCLs for all four risk drivers were above their respective TTLs (Table 5-3). Results for each composite sample are shown, along with the TTL and 95UCL for each of the risk drivers, in Figure 5-13.

Table 5-3
Comparison of 2023 Clam Tissue Data with TTLs

Dataset	Detection Frequency	Mean Value	Minimum Detect	Maximum Detect	95UCL[1]	TTL	95UCL < TTL?
Total PCB Congeners (µg/kg ww)							
Whole body, all data	10/10	25.96	10.632 J	35.88 J	30.6	0.42	No
cPAH TEQ (µg/kg ww)							
Whole body, all data	10/10	4.84	2.20 J	11.9 J	6.71	1.5	No

Dataset	Detection Frequency	Mean Value	Minimum Detect	Maximum Detect	95UCL[1]	TTL	95UCL < TTL?
Dioxin/Furan TEQ (ng/kg ww)							
Whole body, all data	10/10	0.528	0.198 J	2.52 J	1.50	0.71	No
Inorganic Arsenic (mg/kg ww)[2]							
Whole body, all data	20/20	3.33	0.409	18.8 J	13.2	0.09	No
Whole body without siphon skin, all data	20/20	0.115	0.0589	0.351	0.237	0.09	No

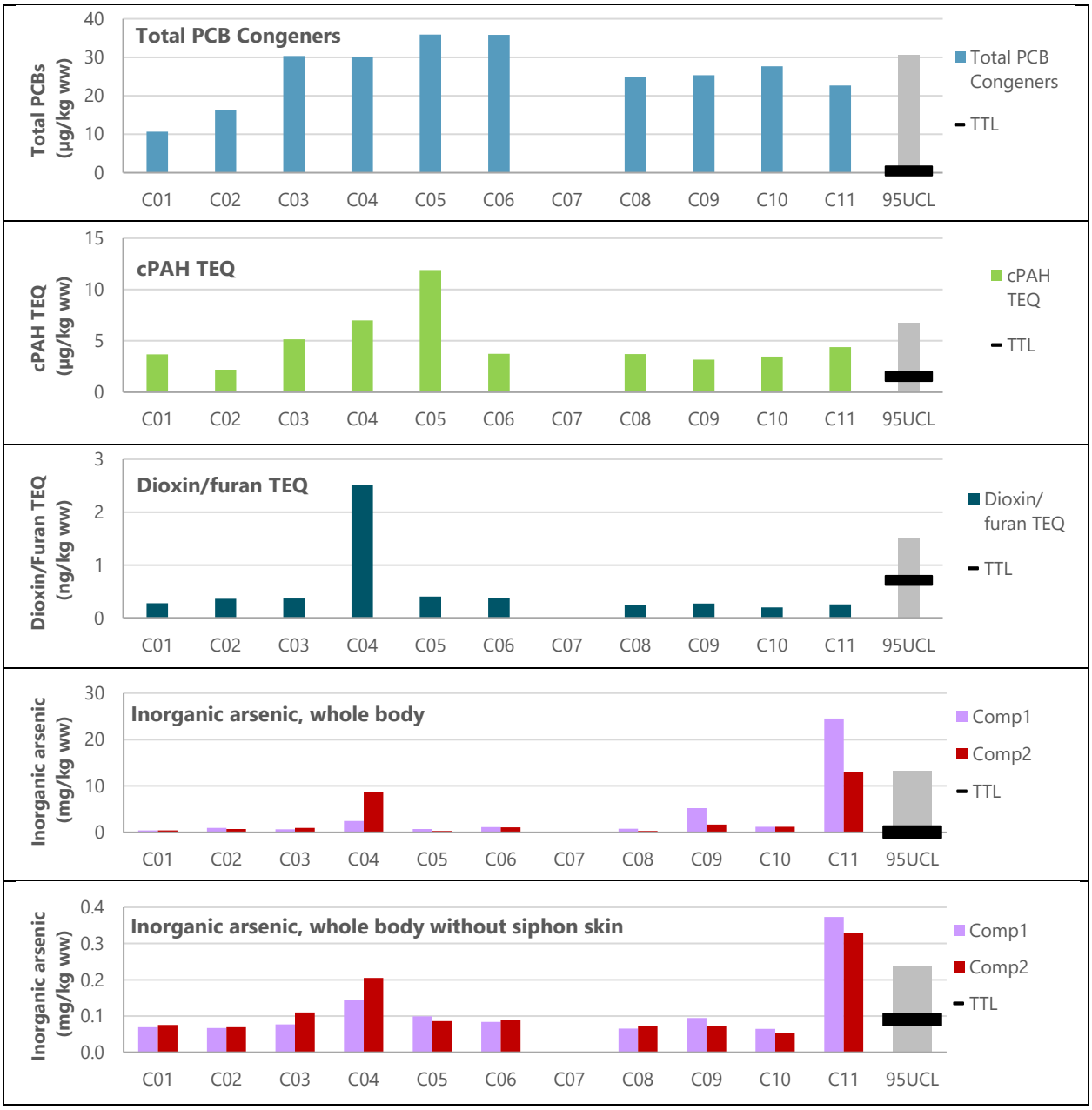
Notes:
1. The 95UCL was calculated using the equation for normal, lognormal, or gamma distribution, or Chebyshev's inequality for a non-parametric estimate, as determined by the data. See Appendix G for details.
2. Summary statistics for inorganic arsenic (including the 95UCL) were calculated by first averaging the concentrations for the two composite samples collected from each clam collection area. Calculating site-wide summary statistics based on each individual value (i.e., without initial averaging) would have suggested that each area had the same mean and variance. Since the data show that this is not a reasonable assumption, the initial averaging step was necessary to more accurately reflect variance across the site.
95UCL: 95% upper confidence limit (on the mean)
cPAH: carcinogenic polycyclic aromatic hydrocarbon
J: estimated concentration
PCB: polychlorinated biphenyl
TEQ: toxic equivalent
TTL: target tissue level
ww: wet weight



Note: Consistent with the summary statistics presented in Table 5-3, concentrations presented for inorganic arsenic reflect the averages for each clam tissue collection area.

Figure 5-13 Comparison of Clam Tissue Concentrations and TTLs

In addition to the site-wide comparison of TTLs, it is useful to look at concentrations in each of the clam tissue collection areas (Map 2-5). Figure 5-14 provides spatial comparisons of clam tissue concentrations for the risk driver chemicals (tables with concentrations are presented in Section 4.2).



Note: As described in Section 2.2, no clams were found in area C07 during the 2023 periodic monitoring effort.

Figure 5-14 Risk Driver Concentrations in Clam Tissue Composites by Area

5.2.2 Comparison with Baseline and Older Data

Clam tissue data from the 2023 periodic monitoring effort were compared with baseline data (collected in 2018) and other older data from the LDW to address DQO 2. As was done with fish and crab tissue, a statistical evaluation was conducted to determine whether there was a statistically significant difference among mean values from 2018 to 2023; the results of this evaluation are presented in Table 5-4. As shown, there is no statistically significant difference among concentrations in the baseline dataset (2018) and those in the 2023 periodic monitoring dataset. The subsections that follow present comparisons by year and sampling reach for the four risk driver chemicals.

Table 5-4
Statistical Comparison of 2018 and 2023 Clam Tissue Results

Dataset	2018 Results			2023 Results			Comparison of 2018 vs. 2023[1]		
	n	Mean	SE	n	Mean	SE	Difference of Means	95CI for the Difference	Statistically Significant Difference?
Total PCB Congeners (µg/kg ww)									
Whole body, all data	6	22.3	1.68	10	26.0	2.53	3.65	[-2.87, 10.2]	No
Whole body, same locations both years[2]	6	22.3	1.68	6	23.4	3.72	1.09	[-8.57, 10.8]	No
cPAH TEQ (µg/kg ww)									
Whole body, all data	9	4.29	0.734	10	4.84	0.883	0.554	[-1.87, 2.98]	No
Whole body, same locations both years[2]	9	4.29	0.734	9	5.02	0.966	0.739	[-1.85, 3.33]	No
Dioxin/furan TEQ (ng/kg ww)									
Whole body, all data	9	0.869	0.586	10	0.528	0.222	-0.342	[-1.73, 1.05]	No
Whole body, same locations both years[2]	9	0.869	0.586	9	0.556	0.247	-0.313	[-1.72, 1.09]	No
Inorganic arsenic (mg/kg ww)									
Whole body (calculated), all data	10	5.53	3.56	10	3.33	1.79	-2.20	[-10.8, 6.38]	No
Whole body excluding siphon skin, all data	10	0.0872	0.0159	10	0.115	0.0281	0.0277	[-0.042, 0.097]	No

Notes:
1. A comparison of 2017 and 2023 results was conducted using a confidence interval on the mean of the 2023 data minus the mean of the baseline data and Welch's approximate t-interval. Blue shading indicates statistically significant differences. A positive value for the difference indicates an increase in concentration over time, whereas a negative value indicates a decrease in concentration over time. When the 95CI excludes zero, the difference is statistically significant (two-tailed alpha = 0.05). Details of this evaluation are presented in Appendix G.
2. The dataset used for comparison was limited to those areas with data for both 2018 and 2023 for a given chemical.
95CI: 95% confidence interval
cPAH: carcinogenic polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
SE: standard error

TEQ: toxic equivalent
ww: wet weight

5.2.2.1 Total PCBs

Mean concentrations for total PCBs are presented by year in Table 5-5 and shown by area in Figure 5-15. Total PCB data are available for total PCB Aroclors for 2004, 2007, and 2018 and for total PCB congeners for 2018 (subset of samples) and 2023. On average, total PCB concentrations in clam tissue decreased by more than a factor of four; averages decreased from more than 100 µg/kg wet weight (ww) in 2004 and 2007 to less than 26 µg/kg ww in 2018 and 2023. A key factor in this decrease is that two of the areas from which clams were collected in 2004 and 2007 have since been remediated: area C07, which is in the Slip 4 EAA (remediation completed in 2012), and area C10, which includes the Terminal 117 (T-117) EAA (sediment remediation completed in 2015) (Map 2-5). Thus, although individual tissue composite concentrations (as well as 95UCLs) for all areas remain well above the TTL (0.42 µg/kg ww), average concentrations of total PCBs in clam tissue have decreased, likely as a result of EAA remediation at the two areas where concentrations of PCBs in clams were highest in 2004 and 2007,[16] source control, and/or natural recovery.

Table 5-5
Overview of Available LDW Clam Tissue Data for Total PCBs by Year

Year[1]	Total PCB Aroclors (µg/kg ww)		Total PCB Congeners (µg/kg ww)		Notes
	Count	Mean (±SD)	Count	Mean (±SD)	
2004	14	140 (± 165)	-	-	Includes pre-remediation data for Slip 4 and T-117. Samples were not analyzed for PCB congeners.
2007	6	105 (± 107)	-	-	Includes pre-remediation data for Slip 4 and T-117. Samples were not analyzed for PCB congeners.
2018	10	13.1 (± 3.13)	6	22.3 (± 4.11)	All samples were analyzed for PCB Aroclors, and a subset were also analyzed for PCB congeners.
2023	-	-	10	25.96 (± 7.99)	Samples were not analyzed for PCB Aroclors.

Notes:
1. With the exception of three composite samples from 2004 (which included 2 to 3 small *Macoma nasuta* individuals in addition to *M. arenaria*), all clam tissue data are for *M. arenaria* clams (Eastern softshell).
LDW: Lower Duwamish Waterway
PCB: polychlorinated biphenyl
SD: standard deviation
T-117: Terminal 117
ww: wet weight

[16] There is uncertainty regarding the impact of these EAA cleanups on clam tissue concentrations, based on both the locations where clams were collected and other non-sediment factors that influence PCB bioaccumulation. Concentrations of total PCBs in clams were above 150 ug/kg ww in area C07 (Slip 4 EAA) and area C10 (T-117 EAA) in both 2004 and 2007. In Area C07 (remediation completed in 2012), insufficient clams were found for PCB analysis following remediation. In area C10 (remediation completed in 2015), sufficient clams were collected for PCB analysis in 2018 and 2023, but the exact sampling locations of the pre-remediation clams included in the composites were not recorded, thus creating some uncertainty regarding the comparison of pre- and post-remediation clam data.

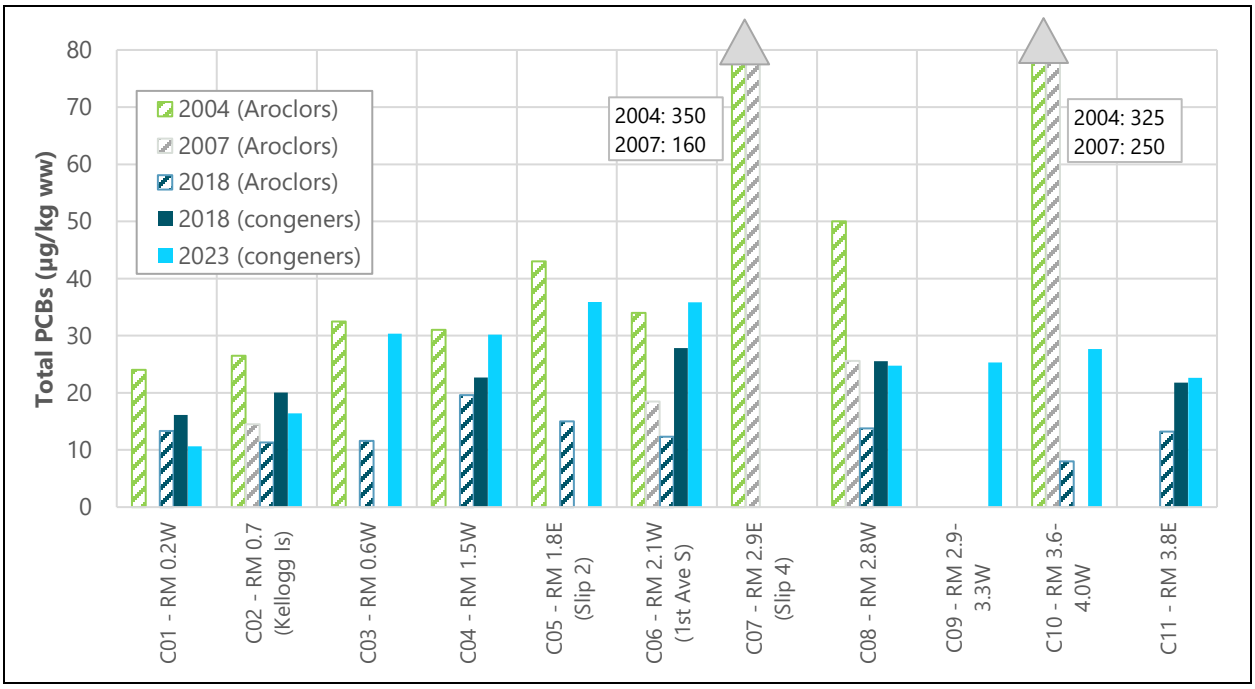


Figure 5-15 Comparison of Total PCB Concentrations in Clam Tisue over Time

5.2.2.2 cPAH TEQ

Mean cPAH TEQs for clam tissue are presented by year in Table 5-6 and are shown by area in Figure 5-16. On average, cPAH TEQs in clam tissue decreased by more than a factor of three from 2004 to 2018/2023. However, the different analytical methods (i.e., EPA 8720-select ion monitoring [SIM] in 2004 as compared with the more sensitive analytical method used in 2018 and 2023) may have contributed to observed decreases in the cPAH TEQs. As with total PCBs, the area with the highest cPAH TEQ in 2004 was area C07 (Map 2-5), which is in the Slip 4 EAA, where remediation was completed in 2012. Thus, although individual tissue composite concentrations (as well as 95UCLs) at clam tissue collection areas remain well above the TTL (1.5 µg/kg ww), concentrations of cPAHs in clam tissue appear to have decreased since 2004.

Table 5-6
Overview of Available LDW Clam Tissue Data for cPAH TEQ by Year

Year[1]	cPAH TEQ (µg/kg ww)		Notes
	Count	Mean (±SD)	
2004[2]	14	15.1	Includes pre-remediation data for Slip 4 and T-117.
2018[2]	9	4.29 (± 2.20)	-
2023[2]	10	4.84 (± 2.79)	-

Notes:
1. With the exception of three composite samples from 2004 (which included 2 to 3 small *M. nasuta* individuals in addition to *M. arenaria*), all clam tissue data are for *M. arenaria* clams (Eastern softshell).

2. In 2004, the cPAH analytical method used was EPA 8270-SIM. In 2018 and 2023, a more sensitive analytical method (GC/HRMS with isotope dilution) was used. The different analytical methods may have contributed to observed decrease in the cPAH TEQ.
cPAH: carcinogenic polycyclic aromatic hydrocarbon
EPA: U.S. Environmental Protection Agency
GC/HRMS: gas chromatography/high-resolution mass spectrometry
LDW: Lower Duwamish Waterway
SD: standard deviation
SIM: selection ion monitoring
TEQ: toxic equivalent
T-117: Terminal 117
ww: wet weight

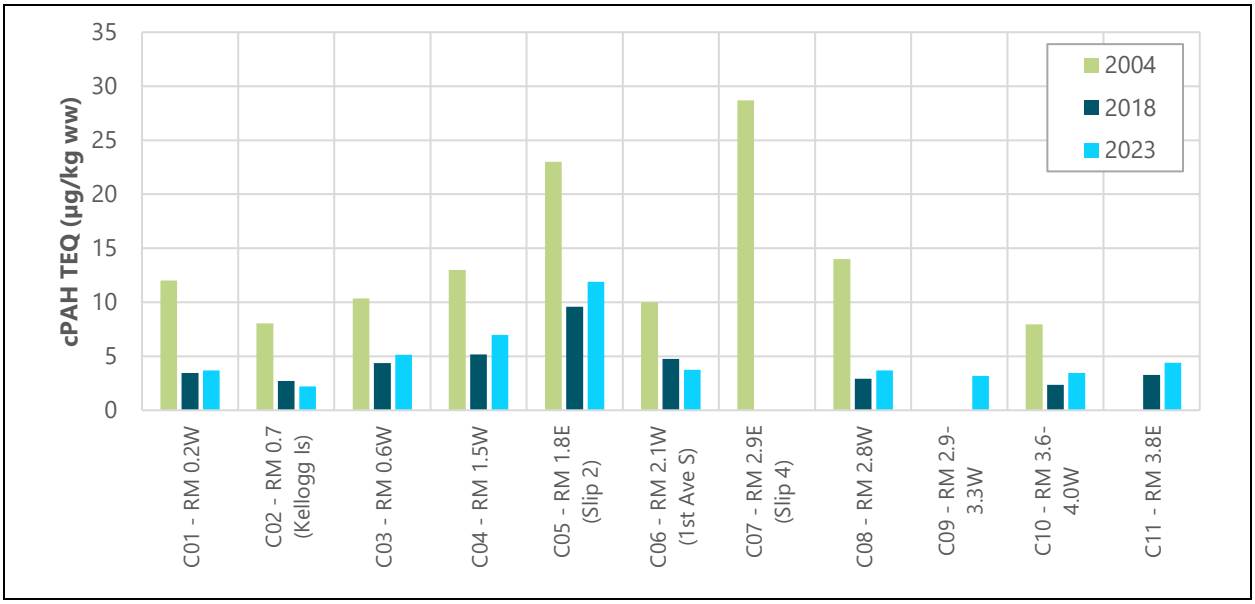


Figure 5-16 Comparison of cPAH TEQ in Clam Tisue over Time

5.2.2.3 Dioxin/furan TEQ

Mean dioxin/furan TEQs are presented by year in Table 5-7 and are shown by area in Figure 5-17. Dioxin/furan data are only available for 2018 and 2023, so an evaluation of longer-term trends is not possible currently. Dioxin/furan TEQs for all individual areas, except C04, were below the TTL (0.71 ng/kg ww) in both 2018 and 2023. The existing sediment data for the C04 area shows higher dioxin/furan TEQs compared to other areas of the LDW.

Table 5-7
Overview of Available LDW Clam Tissue Data for Dioxin/Furan TEQ by Year

Year[1]	Dioxin/Furan TEQ (ng/kg ww)	
	Count	Mean (±SD)
2018	9	0.87 (± 1.76)
2023	10	0.528 (± 0.70)

Notes:
1. All clam tissue data are for *M. arenaria* clams (Eastern softshell).
2. SDs denoted by ±.

LDW: Lower Duwamish Waterway
SD: standard deviation
TEQ: toxic equivalent
ww: wet weight

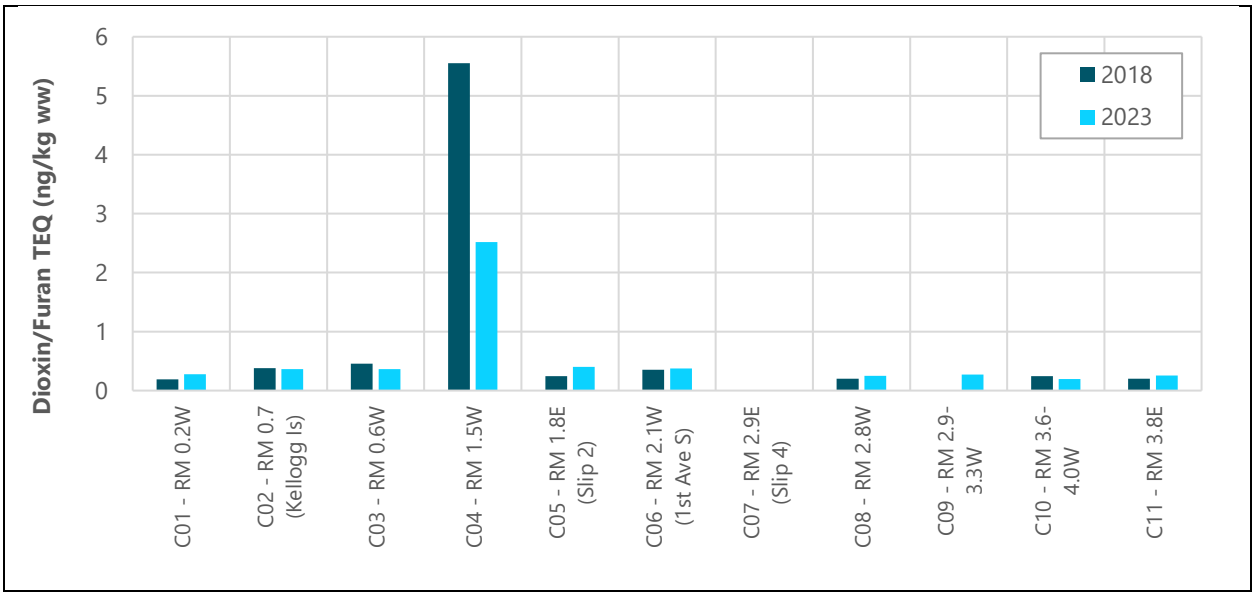


Figure 5-17 Comparison of Dioxin/Furan TEQ in Clam Tissue over Time

5.2.2.4 Inorganic arsenic

Mean inorganic arsenic concentrations in clam tissue are presented by year in Table 5-8 and are shown by area in Figure 5-18. Inorganic arsenic data are available for 2004, 2007, 2018, and 2023; for 2018 and 2023, tissue excluding the siphon skin was also analyzed for each composite because *M. arenaria* are known to accumulate arsenic in siphon skin tissue as described in the Regional Applied Research Effort (RARE) study (Kerns et al. 2017). No major changes were observed in concentrations of inorganic arsenic in clam tissue over time; concentrations were consistently highest in area C11 (RM 3.8E; Map 2-5), which is known to have elevated levels of arsenic in sediment. Concentrations also appear somewhat elevated in clam tissue collected from area C04 (Map 2-5). The relationship between concentrations of inorganic arsenic in siphon skin and remainder tissue was also evaluated. While higher concentrations in remainder tissue are associated with higher concentrations in siphon skin tissue, the relationship between these tissue types is not consistent (Figure 5-19).

Table 5-8
Overview of Available LDW Clam Tissue Data for Inorganic Arsenic by Year

Year[1,2]	Inorganic Arsenic (mg/kg ww)				Notes
	Whole Body		Whole Body Excluding Siphon Skin		
	Count	Mean (±SD)	Count	Mean (±SD)	
2004	14	1.2	-	Not analyzed	No samples were collected in 2004 from area C11 (RM 3.8E), which has been the area with the highest inorganic arsenic concentrations in all other years
2007	16	2.7	-	Not analyzed	-
2018	11	5.4 (± 11)	11	0.09 (± 0.05)	Whole-body values (i.e., soft tissue including siphon skin) were calculated based on data for siphon skin and data for whole body excluding siphon skin.
2023	20[3]	3.33 (± 5.7)	20[2]	0.115 (±0.089)	

Notes:
1. With the exception of three composite samples from 2004 (which included 2 to 3 small *M. nasuta* individuals in addition to *M. arenaria*), all clam tissue data are for *M. arenari*a clams (Eastern softshell). Composites from 2004 and 2007 generally included 20 to 30 individual clams, whereas composites from 2018 and 2023 each included 3 clams.
2. Data from the 2015 RARE study conducted by EPA and the US Army Corps of Engineers (Kerns et al. 2017) were not included in this summary, because that study evaluated commercially harvested clams exposed to conditions in test plots in the LDW (located at RM 3.7 and RM 3.9), rather than field-collected clams collected from areas throughout the LDW.
3. Two composites per area were collected in 2023; concentrations were averaged prior to calculation of summary statistics.
EPA: U.S. Environmental Protection Agency
LDW : Lower Duwamish Waterway
RARE: Regional Applied Research Effort
RM: river mile
SD: standard deviation
ww: wet weight

Figure 5-18 Comparison of Inorganic Arsenic Concentrations in Clam Tissue over Time

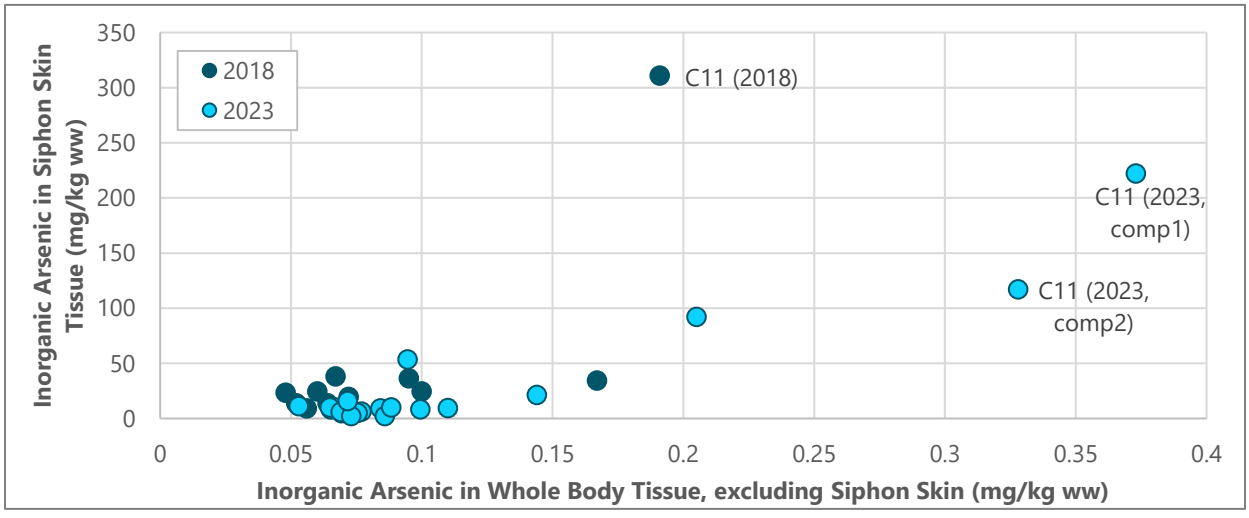


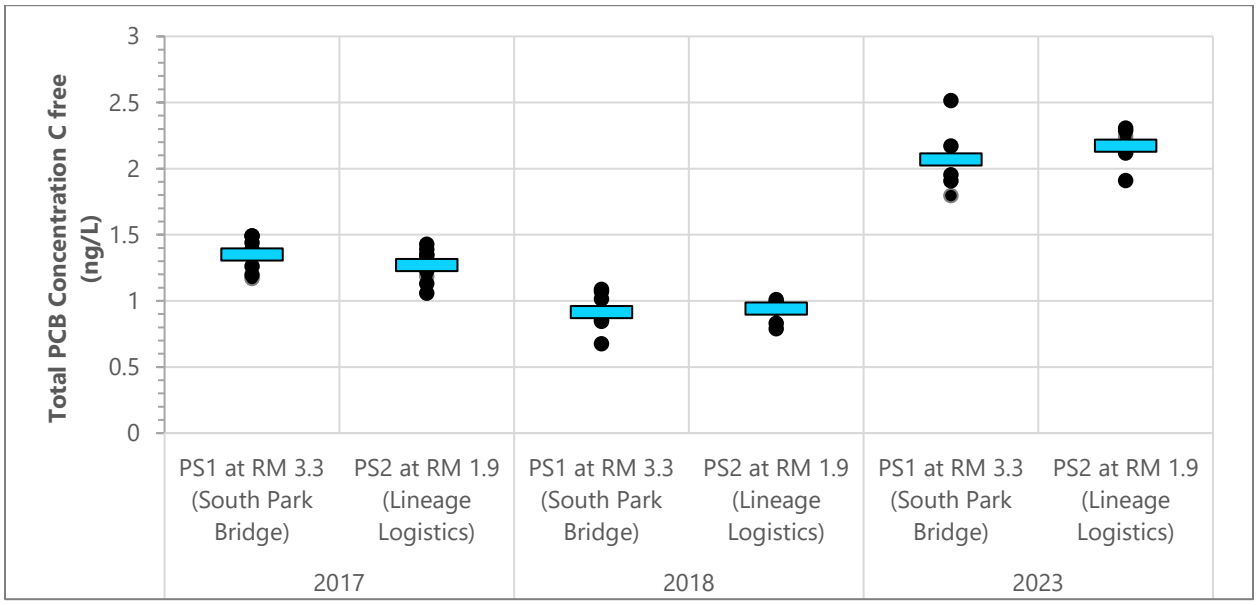
Figure 5-19 Relationship between concentrations of inorganic arsenic in siphon skin and whole-body excluding siphon skin tissue

5.3 Passive Samplers

Passive samplers were used to calculate PCB C_{free} in LDW surface water. In 2023, data from a total of 10 passive samplers were analyzed: 5 replicates at each of 2 locations (PS1 at RM 3.3 and PS2 at RM 1.9). In 2017 and 2018, nine replicates were analyzed at each of the locations. The PCB C_{free} in surface water calculated from the passive sampler data from all three sampling events is presented in Figure 5-20. For 2023, concentrations at PS1 and PS2 were not significantly different ($p = 0.49$). This is consistent with the results of comparisons between the two stations in 2017 and 2018, which showed no statistically significant differences between the locations ($p = 0.45$). However, the 2023 PCB C_{free} concentrations were significantly different (higher) than the concentrations for 2017 and 2018 ($p < 0.001$). The PCB C_{free} concentrations in 2017 and 2018 were also significantly different from one another ($p < 0.001$).[17] The difference between the 2023 concentrations and the baseline concentrations is greater than the difference between the two baseline events. The mean concentrations from 2023 are approximately twice the mean concentrations from 2018.

The difference between the 2023 results and the 2017 and 2018 results is not attributable to the difference in the calculation methods described in Appendix F. The PCB C_{free} concentrations shown in Figure 5-20 were all calculated using the 2023 method. The equilibration of the performance reference compounds (PRCs) in the samplers was similar in all sampling events. The same analytical laboratory prepared the passive samplers for deployment and analyzed the samplers in all three years. The differences among the three sampling years may reflect inherent environmental variability in the dynamic water column of the LDW. Results of future monitoring events will be useful to understand both the inherent environmental variability and long-term trends.

[17] Statistical comparisons were done using a two-factor analysis of variance design, with sampling location crossed with sampling year (Appendix G).



Note: Black dots indicate individual results; blue bars indicate averages by location.

Figure 5-20 PCB C_{free} calculated from Passive Samplers

The two passive sampler deployment locations (PS1 at South Park Bridge [RM 3.3] and PS2 at Lineage Logistics [RM 1.9]) had nearly identical means and variances (Table 5-9). The results for the two locations were the same in each of the three years. The year-to-year variability was statistically significant for all three years. The two locations provide redundant information about average PCB C_{free} concentrations.

Table 5-9
Summary Statistics for PCB C_{free} Data based on LDW Passive Samplers

Summary Statistic	2017[1]		2018[1]		2023	
	PS1 (RM 3.3)	PS2 (RM 1.9)	PS1 (RM 3.3)	PS2 (RM 1.9)	PS1 (RM 3.3)	PS2 (RM 1.9)
Detection frequency	9/9	9/9	8/8[2]	9/9	5/5	5/5
PCB C_{free} – mean value (ng/L)	1.25	1.26	1.03	0.96	2.07	2.17
PCBs C_{free} – SD[2] (ng/L)	0.115[3] (0.101 at PS1; 0.128 at PS2)		0.101[3] (0.115 at PS1; 0.086 at PS2)		0.232[3] (0.284 at PS1; 0.165 at PS2)	
CV = SD/mean	9.2%[4]		10.1%[4]		11.0%[4]	

Notes:
1. The results for 2017 and 2018 are from the 2020 data evaluation report (Windward 2020) and were calculated using the 2017/2018 calculation methods. The results for 2023 using the 2017/2018 calculation methods are provided in Appendix F, Table F-1 and Attachment F-3. The results are very similar to the 2023 results presented herein, with an average percent difference of -4%.
2. The results for one replicate sample at location PS1 (South Park Bridge) in 2018 were rejected due to issues with the PRC for this sample (Windward 2019).
3. The CVs reported for Pre-Design Studies baseline data use the values combined across the two stations.

4. The combined SD values reported for the Pre-Design Studies baseline samples are the residual SEs across both stations within each sampling year.
CV: coefficient of variation
LDW: Lower Duwamish Waterway
PCB: polychlorinated biphenyl
PRC: performance reference compound
RM: river mile
SD: standard deviation
SE: standard error

Deployment conditions and *in situ* conventional parameters recorded during the three passive sampler events are provided in Table 5-10. The deployment conditions and conventional parameters were generally similar across all three sampling events. The conventional parameters for the two stations used in 2023 were not as similar to one another, as they had been in previous years. The conventional parameters recorded for PS1 were unusual and may have reflected an issue with the data logger (e.g., flawed calibration or sensor errors). Specifically, the salinity and pH at PS1 (RM 3.3) were quite different than the values recorded at PS2; they were also outside of the ranges that would be expected in the LDW. No statistical evaluation was conducted for the conventional parameter data.

Table 5-10
Summary of Deployment Conditions and *in situ* Conventional Parameter Values during Passive Sampler Deployment

Parameter	Parameter Values					
	Passive Sampler Event 1 (2017)		Passive Sampler Event 2 (2018)		Passive Sampler Event 3 (2023)	
	PS1 – South Park Bridge (RM 3.3)	PS2 – Lineage Logistics (RM 1.9)	PS1 – South Park Bridge (RM 3.3)	PS2 – Lineage Logistics (RM 1.9)	PS1 – South Park Bridge (RM 3.3)	PS2 – Lineage Logistics (RM 1.9)
Deployment Conditions						
Deployment period	31 days (August 25 to September 25)		30 days (July 30 to August 29)		33 days (August 3 to September 5)	
Total rainfall[1]	0.92 inches (the majority of which [0.68 inches] fell during a 27-hour period		0.14 inches		0.52 inches (about half of which [0.26 inches] fell on a single day)	
Flow rate (Howard Hanson)[2]	340 cfs (314–439 cfs)		276 cfs (256–298 cfs)		319 cfs (281–381 cfs)	
Flow rate (Auburn)[2]	364 cfs (327–504 cfs)		275 cfs (258–306 cfs)		280 cfs (246–347 cfs)	
Average Conventional Parameters (Range of 10th to 90th Percentile)[3]						
DO (mg/L)	5.4 (4.9–5.9)	5.4 (5.1–5.7)	6.2 (4.8–7.4)	6.8 (5.8–7.8)	6.4 (5.5-7.2) [4]	7.1 (6.3-7.8)
pH	7.5 (7.4–7.6)	7.7 (7.6–7.7)	7.8 (7.6–7.9)	7.9 (7.8 – 8.0)	6.2 (6.0-6.4) [4]	7.9 (7.8-7.9)
Salinity (ppt)	31.4 (28.3–32.7)	31.9 (29.0–33.6)	26.2 (23.9–28.3)	25.5 (21.9–27.5)	34.9 (31.9-37.3) [4]	26.3 (23.5-28.1)
Temperature (°C)	13.7 (13.3–14.3)	13.7 (13.2–14.3)	14.1 (13.6–14.9)	14.2 (13.5–15.4)	13.6 (12.9-14.3) [4]	14.2 (13.4-15.1)
Total dissolved solids (mg/L)	31,200 (28,500–32,400)	31,800 (29,100–33,300)	26,600 (24,500–28,500)	25,900 (22,600–27,800)	34,400[4] (31,800-36,600)	26,700 (24,100-28,400)

Notes:
1. Total rainfall was based on measurements taken at the Hamm Creek gauge (HAU2).
2. Flow rates are those measured at the U.S. Geological Survey gauges just below the Howard Hanson Dam (Gauge 12105900) and at Auburn (Gauge 12113000).
3. Parameter values were recorded by a data logger attached to one of the passive sampler frames at each location every 15 minutes during passive sampler deployment. The range of the 10th to 90th percentile was used in this table (rather than minimum and maximum values) to avoid the inclusion of data identified as being of questionable quality.
4. Differences between the conventional parameter values reported for PS1 and PS2 in 2023 likely reflect an issue with the data logger (e.g., flawed calibration or sensor errors) at PS1.
cfs: cubic feet per second
DO: dissolved oxygen
RM: river mile
ppt: parts per thousand

5.4 Summary

A high-level overview of key conclusions from a review of the periodic monitoring data for fish and crab tissue, clam tissue, and passive sampler data is presented in Table 5-11. An overview of the 2023 results is presented in Table 5-12.

Table 5-11
Summary Key Conclusions

Media	Key Conclusions
Fish and crab tissue	• **Total PCBs** – 95UCLs were above the corresponding TTLs for all species. When comparing the 2017 and 2023 datasets, there was a statistically significant decrease in total PCB concentrations for shiner surfperch and graceful crab. • **Dioxin/furan TEQ** – 95UCLs were above the corresponding TTLs for benthic fish and whole-body crab; the 95UCL was equal to the TTL for crab edible meat. When comparing the 2017 and 2023 datasets, there was a statistically significant decrease in the dioxin/furan TEQs for English sole and shiner surfperch.
Clam tissue	• **Total PCBs** – The site-wide 95UCL was above the TTL for clams. Concentrations of total PCBs in clam tissue were similar in 2018 and 2023, but on average they decreased by more than a factor of four between 2004/2007 and 2023, likely as a result of EAA remediation at the two areas where concentrations of PCBs in clams were highest in 2004 and 2007 (some uncertainty exists regarding the comparison of pre-and post-remediation data; see Section 5.2.2.1), source control, and natural recovery.[1] • **cPAH TEQ** – The site-wide 95UCL was above the TTL for clams. cPAH TEQs in clam tissue were similar in 2018 and 2023, but they decreased by more than a factor of three between 2004 and 2023. However, the use of a more sensitive analytical method in 2018 and 2023 may have contributed to this observed decrease in cPAH TEQs.[1] • **Dioxin/furan TEQ** – The site-wide 95UCL was above the TTL for clams. Dioxin/furan TEQs in clam tissue were similar in 2018 and 2023; no older data were available to evaluate longer-term trends. • **Inorganic arsenic** – The site-wide 95UCL was above the TTL for clams (both including and excluding siphon skin). No major changes were observed in concentrations of inorganic arsenic in clam tissue over time.[2] Concentrations are consistently highest at area C11 (RM 3.8E), which is known to have elevated levels of arsenic in sediment.
Passive samplers	• There was little variability in the replicates analyzed for each location, and 2023 results for the two sampling locations did not differ significantly from one another. • The 2023 PCB C_{free} concentrations were significantly different than the 2017 and 2018 concentrations, with increases of 92.8% from 2017 results and 106% from 2018 results (concentrations in 2018 differed significantly from those in 2017, with a decrease of 26% in 2018). • Deployment conditions (e.g., rainfall and river flow) and conventional parameters (e.g., water temperature) were similar across all three years. The different results among the three sampling years may reflect the inherent environmental variability in the dynamic water column of the LDW.

Notes:
1. Differences in sampling design (e.g., locations sampled and clams per composite) and analytical improvements may have contributed to these observed decreases in concentrations.
2. Most previous sample data available for inorganic arsenic is for whole-body clams (i.e., siphon skins were not analyzed separately).
95UCL: 95% upper confidence limit (on the mean)
cPAH: carcinogenic polycyclic aromatic hydrocarbons
EAA: early action area PCB: polychlorinated biphenyl
LDW: Lower Duwamish Waterway

RM: river mile
TEQ: toxic equivalent
TTL: target tissue level

Table 5-12
Overview of 2023 Periodic Monitoring Results

Media	Total PCBs		Dioxin/Furan TEQ		cPAH TEQ		Inorganic Arsenic	
	TTL	Vs. 2017/ 2018[1]	TTL	Vs. 2017/ 2018[1]	TTL	Vs. 2017/ 2018[1]	TTL	Vs. 2017/ 2018[1]
Benthic fish	ABOVE	——	ABOVE	▼	NA	NA	NA	NA
Pelagic fish	ABOVE	▼	NA	▼	NA	NA	NA	NA
Crab edible meat	ABOVE	▼	EQUAL	——	NA	NA	NA	NA
Crab whole body	ABOVE	▼	ABOVE	——	NA	NA	NA	NA
Clam	ABOVE	——	ABOVE	——	ABOVE	——	ABOVE	——
Passive samplers	na	▲	NA	NA	NA	NA	NA	NA

Notes:
1. The trend evaluation is a comparison of 2023 results with baseline results (2017/2018). Result categories include statistically significant decreases (▼), no change (——), and statistically significant increases (▲).
95UCL: 95% upper confidence limit (on the mean)
cPAH: carcinogenic polycyclic aromatic hydrocarbons
NA: not applicable
PCB: polychlorinated biphenyl
TEQ: toxic equivalent
TTL: target tissue level

6 References

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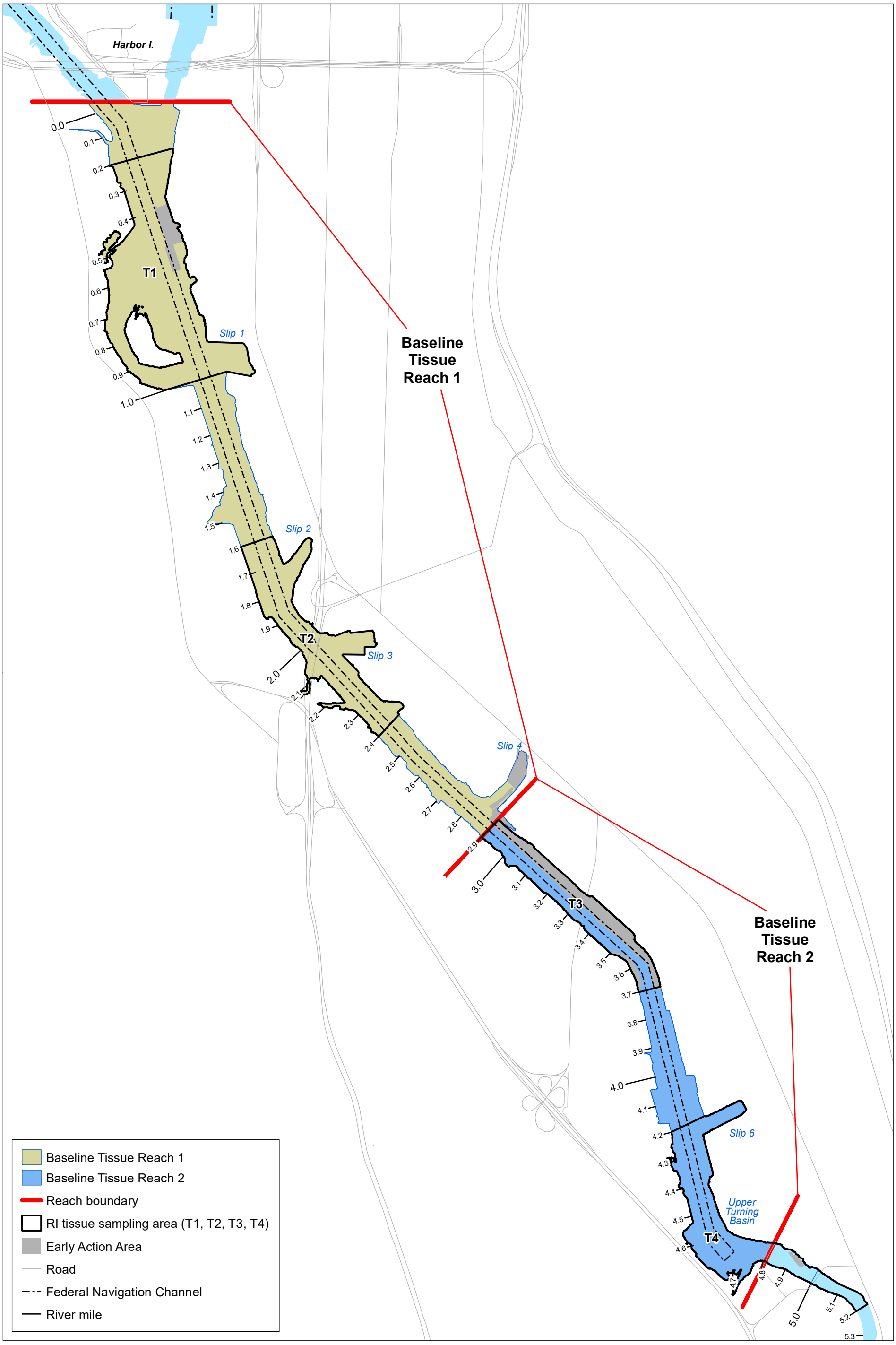
FINAL

Maps



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Map 2-1. Sampling reaches for English sole and crab tissue collection

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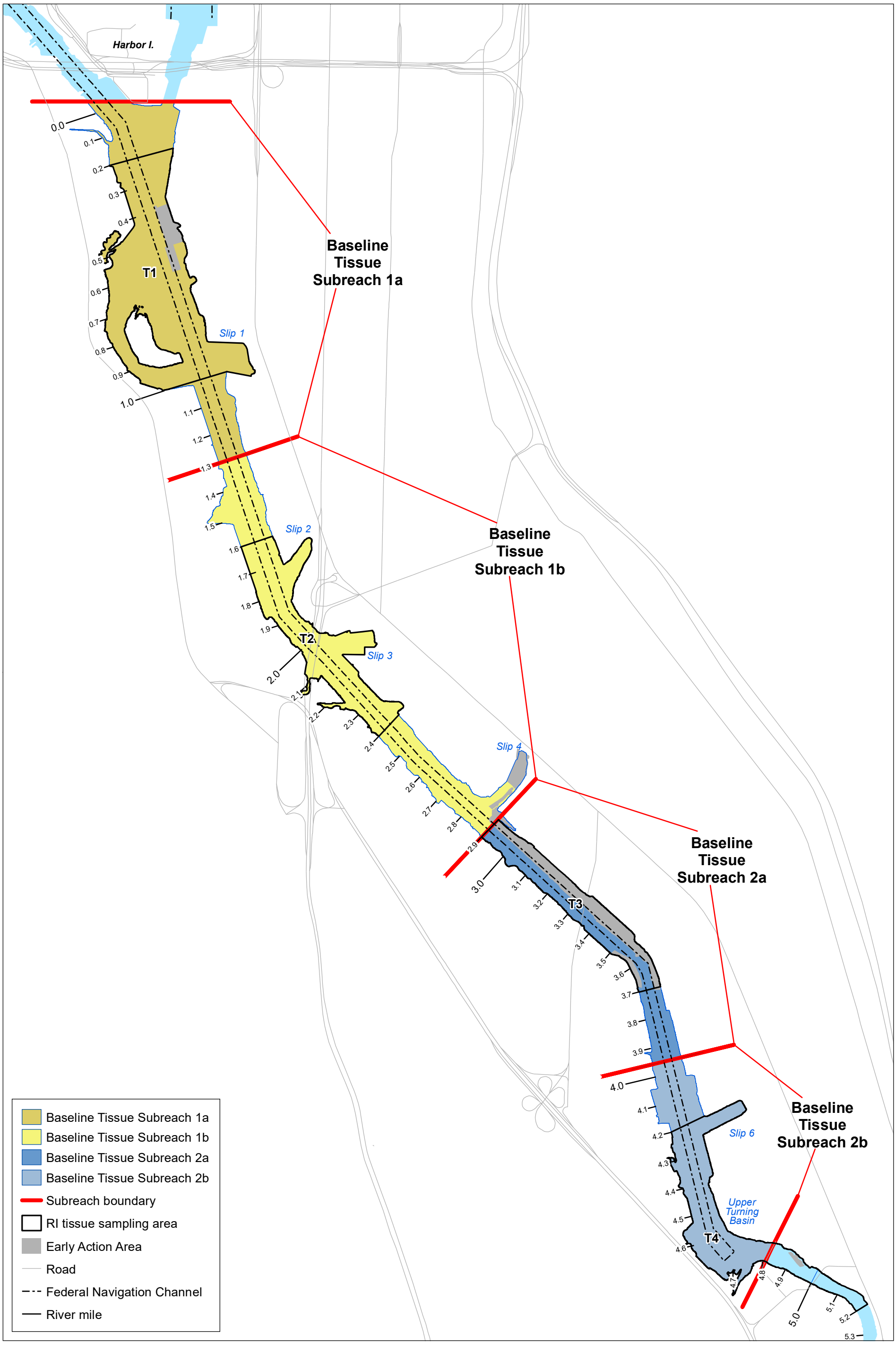

Prepared by craigh, 12/12/2024; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Periodic Monitoring\Data Report 2024\Map 2-2 6520 Shiner surfperch sampling plan.mxd

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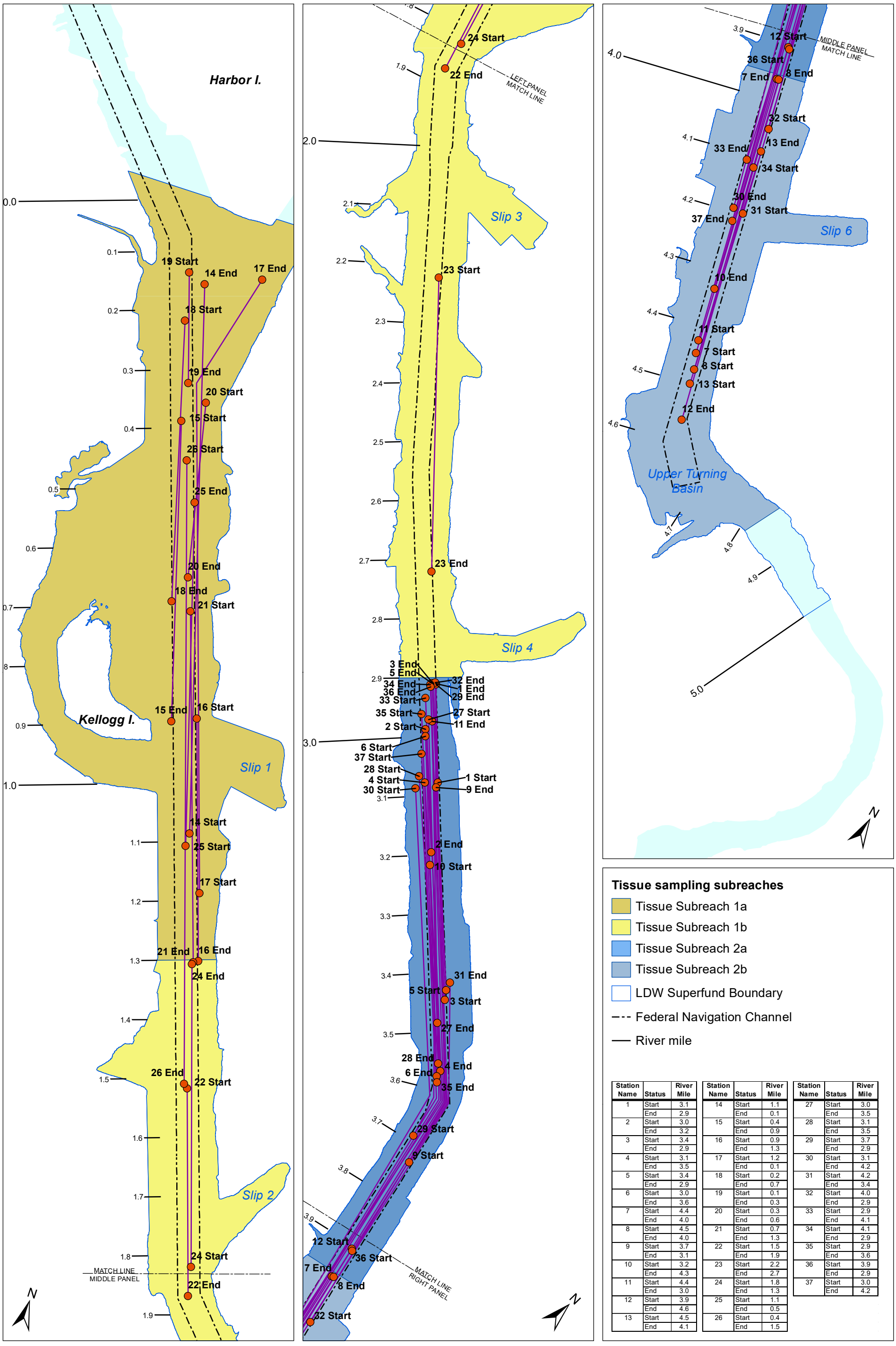
Map 2-2. Sampling subreaches for shiner surfperch tissue collection



Tissue sampling subreaches

- Tissue Subreach 1a
- Tissue Subreach 1b
- Tissue Subreach 2a
- Tissue Subreach 2b
- LDW Superfund Boundary
- Federal Navigation Channel
- River mile

Station Name	Status	River Mile
1	Start	3.1
	End	2.9
2	Start	3.0
	End	3.2
3	Start	3.4
	End	2.9
4	Start	3.1
	End	3.5
5	Start	3.4
	End	2.9
6	Start	3.0
	End	3.6
7	Start	4.4
	End	4.0
8	Start	4.5
	End	4.0
9	Start	3.7
	End	3.1
10	Start	3.2
	End	4.3
11	Start	4.4
	End	3.0
12	Start	3.9
	End	4.6
13	Start	4.5
	End	4.1

Station Name	Status	River Mile
14	Start	1.1
	End	0.1
15	Start	0.4
	End	0.9
16	Start	0.9
	End	1.3
17	Start	1.2
	End	0.1
18	Start	0.2
	End	0.7
19	Start	0.1
	End	0.3
20	Start	0.3
	End	0.6
21	Start	0.7
	End	1.3
22	Start	1.5
	End	1.9
23	Start	2.2
	End	2.7
24	Start	1.8
	End	1.3
25	Start	1.1
	End	0.5
26	Start	0.4
	End	1.5

Station Name	Status	River Mile
27	Start	3.0
	End	3.5
28	Start	3.1
	End	3.5
29	Start	3.7
	End	2.9
30	Start	3.1
	End	4.2
31	Start	4.2
	End	3.4
32	Start	4.0
	End	2.9
33	Start	2.9
	End	4.1
34	Start	4.1
	End	2.9
35	Start	2.9
	End	3.6
36	Start	3.9
	End	2.9
37	Start	3.0
	End	4.2

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0 0.1 0.2 Miles

0 0.1 0.2 Kilometers

Scale is the same for each inset map

Map 2-3. Trawling locations for 2023 periodic monitoring for fish and crab

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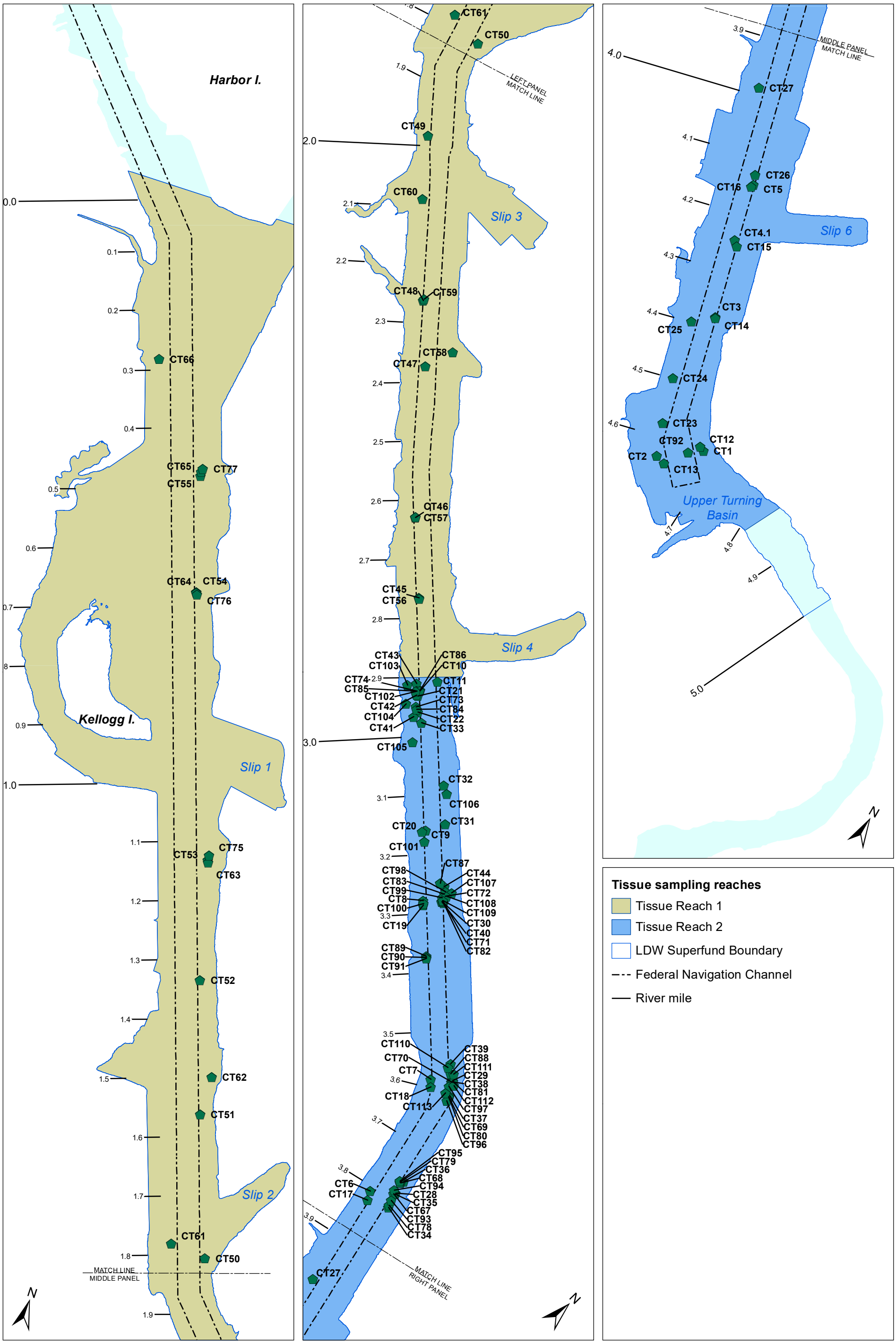

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Map 2-4. Crab trap locations for 2023 periodic monitoring for fish and crab

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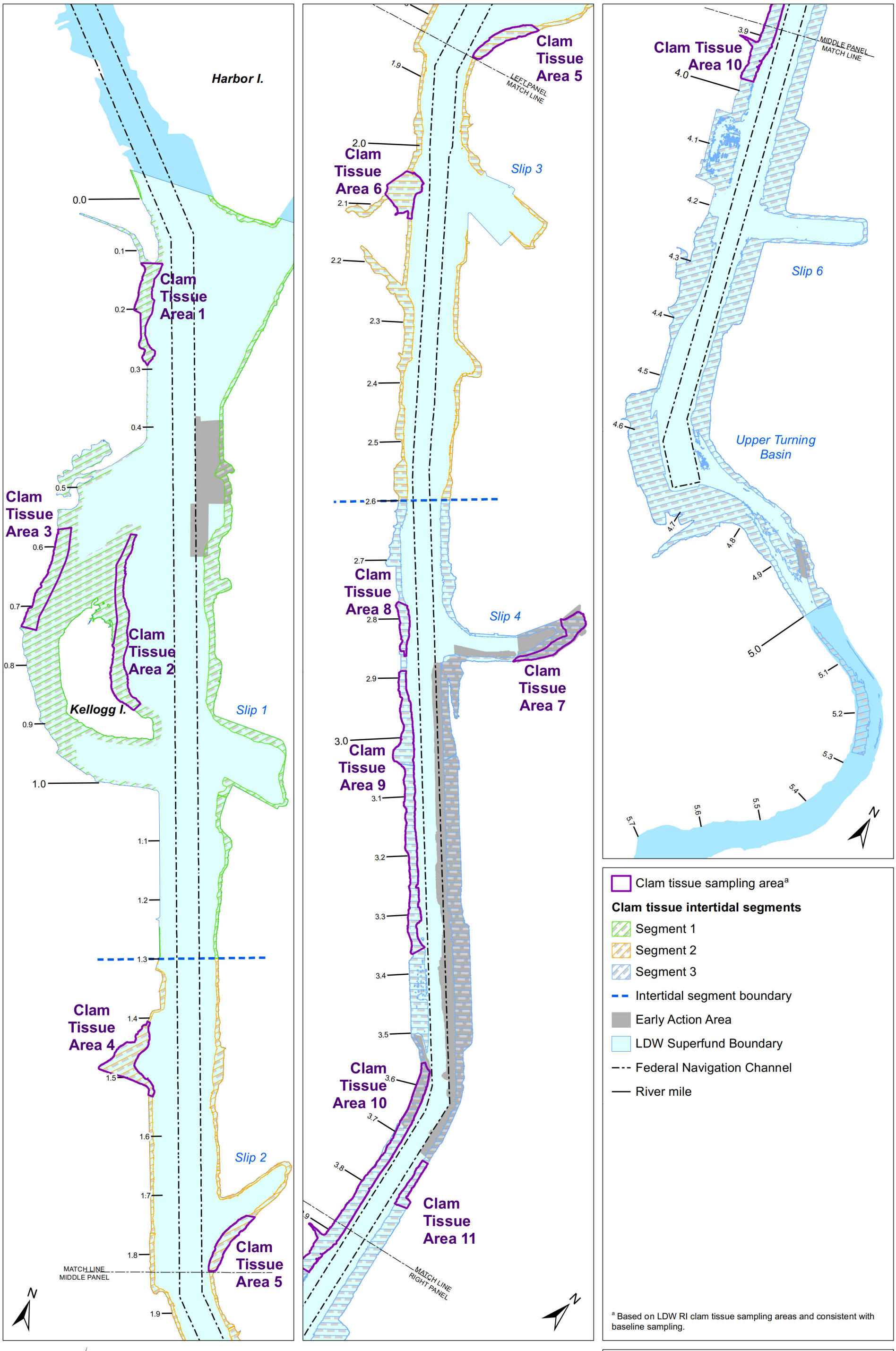

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0 0.1 0.2 Miles

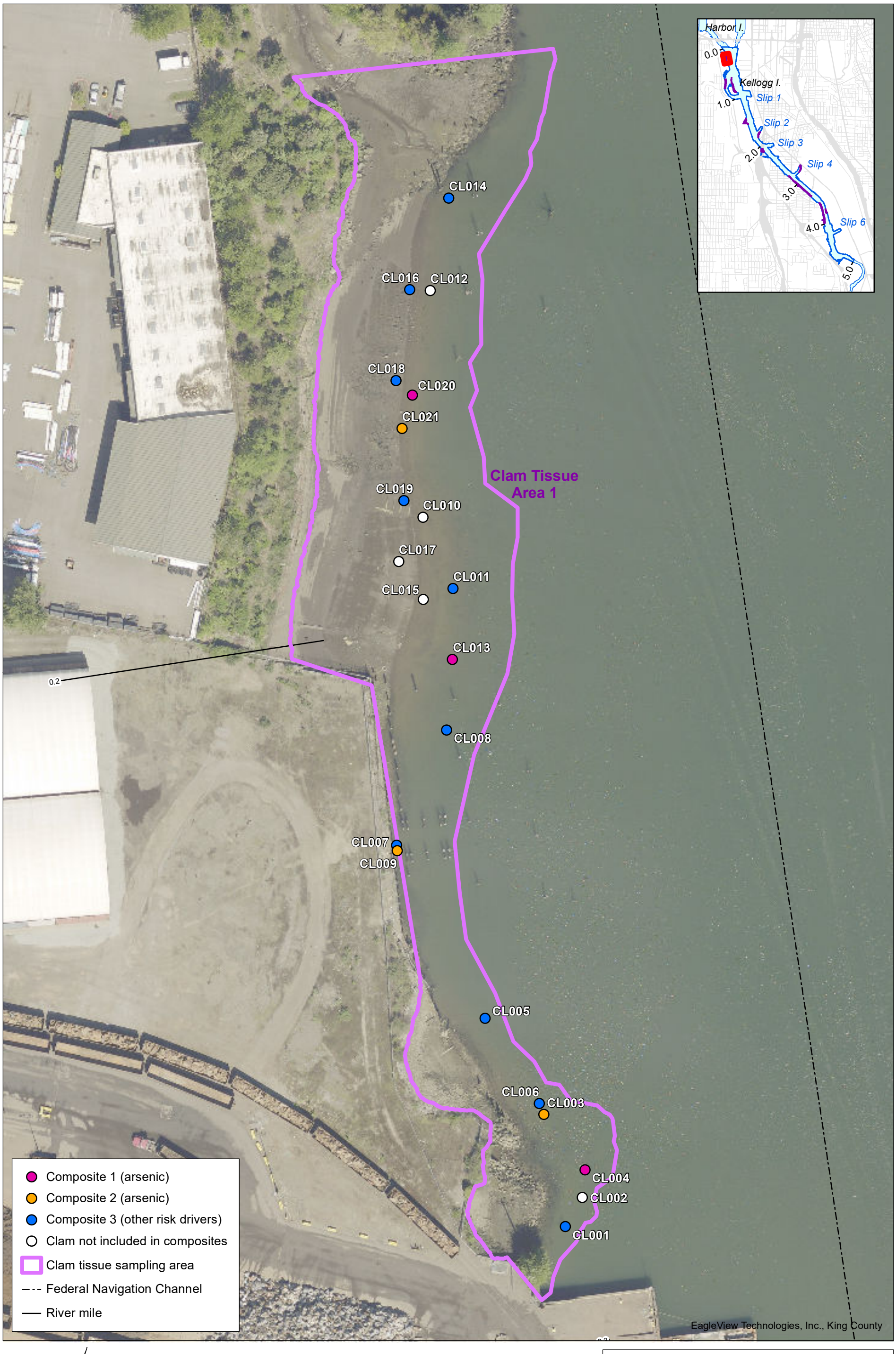
0 0.1 0.2 Kilometers

Scale is the same for each inset map

Map 2-5. Clam tissue sampling areas and intertidal segments

FISH, CRAB, CLAM AND SURFACE WATER PERIODIC MONITORING DATA REPORT FOR THE LDW DECEMBER 23, 2024

Prepared by craigh, 12/27/2024. W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Periodic Monitoring\Data Report 2024\Map 2-5 6523 Clam sampling plan.mxd



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N

0 50 100 Feet

0 10 20 Meters

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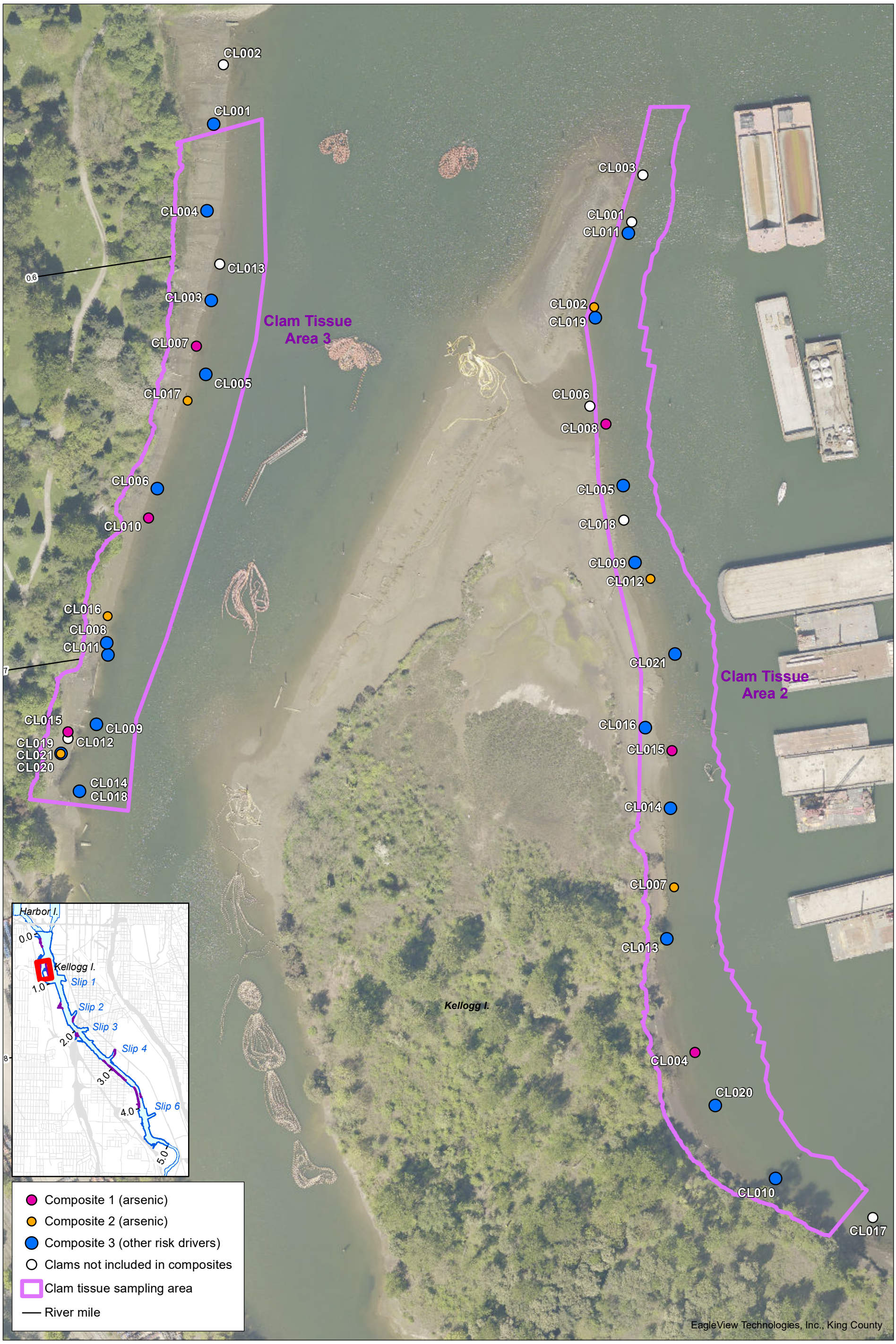
Map 2-6a. Individual clam tissue collection locations for area 1 (RM 0.2W)

Prepared by craigh, 12/12/2024; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Periodic Monitoring\Data Report 2024\Map 2-6a 7536 Clam composite assignments for area 1.mxd



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Map 2-6b. Individual clam tissue collection locations for area 2 (RM 0.6-0.9W) and area 3 (RM 0.6-0.7W)

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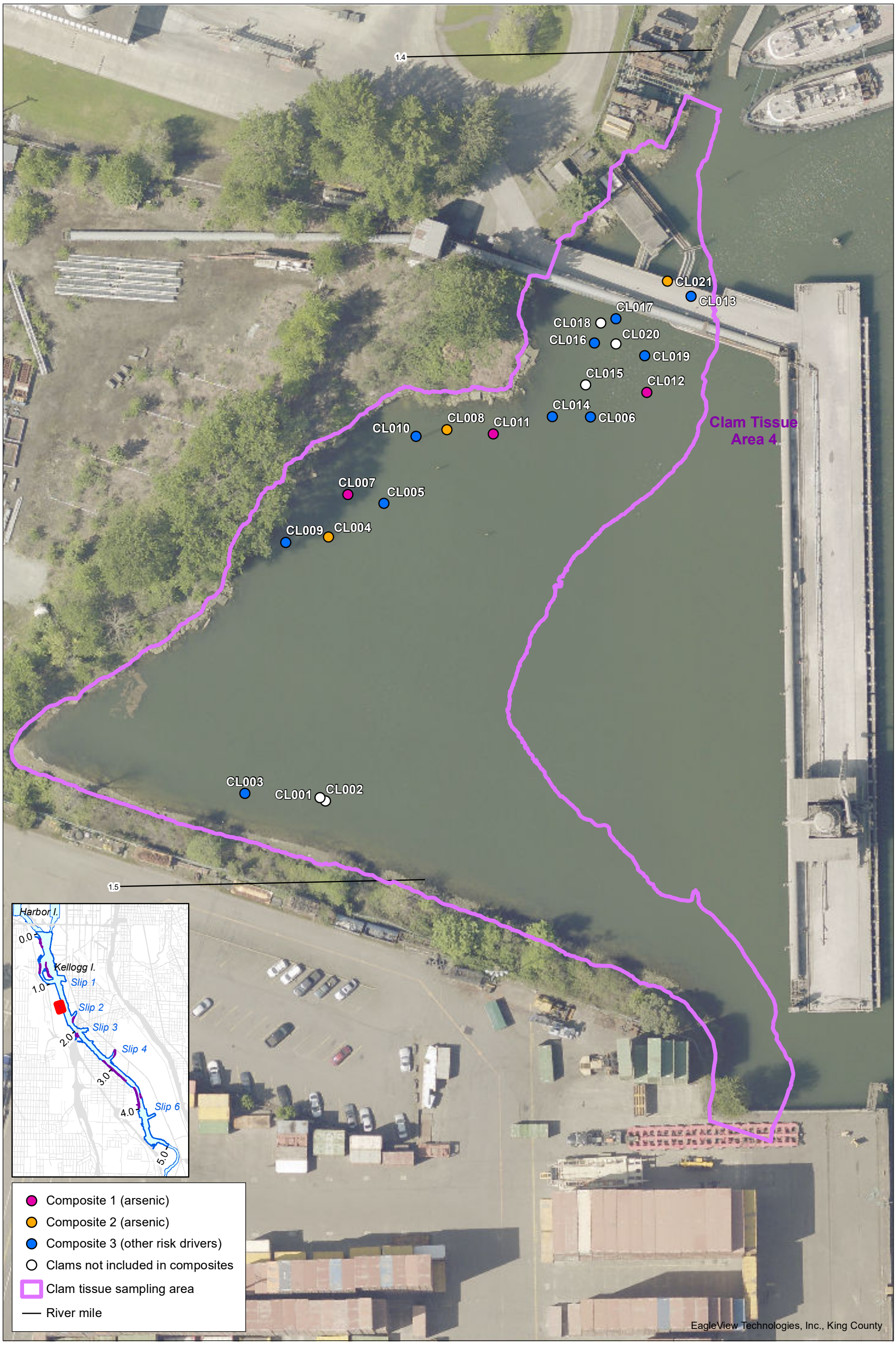
Prepared by craigh, 12/12/2024; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Periodic Monitoring\Data Report 2024\Map 2-6b7536 Clam composite assignments for area 2 and 3.mxd



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N

0 50 100 Feet

0 10 20 Meters

Map 2-6c. Individual clam tissue collection locations for area 4 (RM 1.4-1.5W)

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N

0 50 100 Feet

0 10 20 Meters

Map 2-6d. Individual clam tissue collection locations for area 5 (RM 1.8E)

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PERIODIC MONITORING DATA REPORT FOR THE LDW DECEMBER 23, 2024

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Clam Tissue
Area 6

CL019
CL018
CL021
CL017
CL014
CL016
CL013
CL008
CL011
CL006
CL020
CL001
CL015
CL009
CL003
CL007
CL002
CL012
CL005
CL010
CL004

Harbor I.
0.0
Kellogg I.
Slip 1
1.0
Slip 2
Slip 3
2.0
Slip 4
3.0
Slip 6
4.0
5.0

- Composite 1 (arsenic)
- Composite 2 (arsenic)
- Composite 3 (other risk drivers)
- Clams not included in composites
- Clam tissue sampling area
- Federal Navigation Channel

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N

0 40 80 Feet

0 10 20 Meters

Map 2-6e. Individual clam tissue collection locations for area 6 (RM 2.1W)

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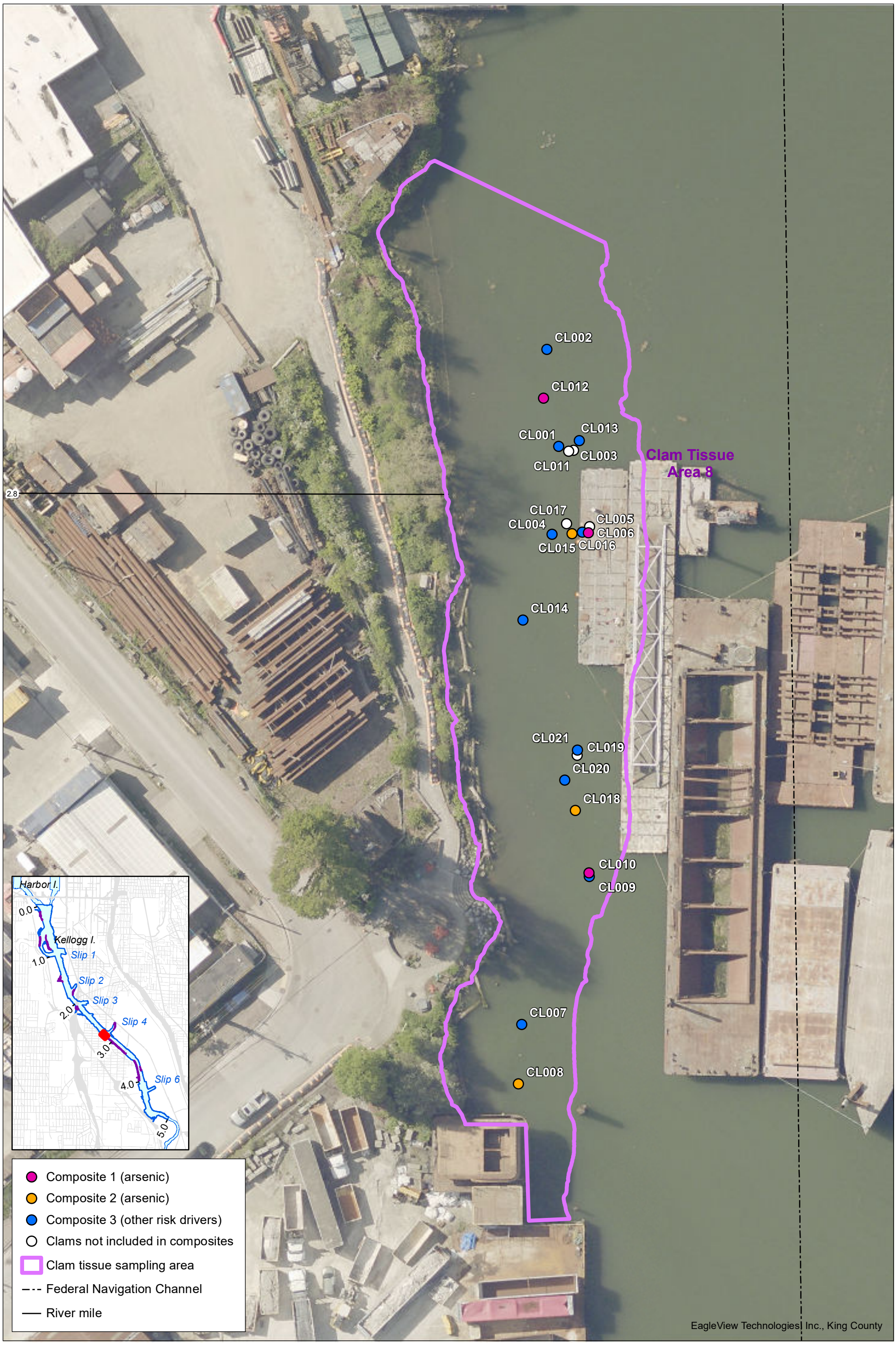

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0 50 100 Feet

0 10 20 Meters

Map 2-6f. Individual clam tissue collection locations for area 8 (RM 2.8W)

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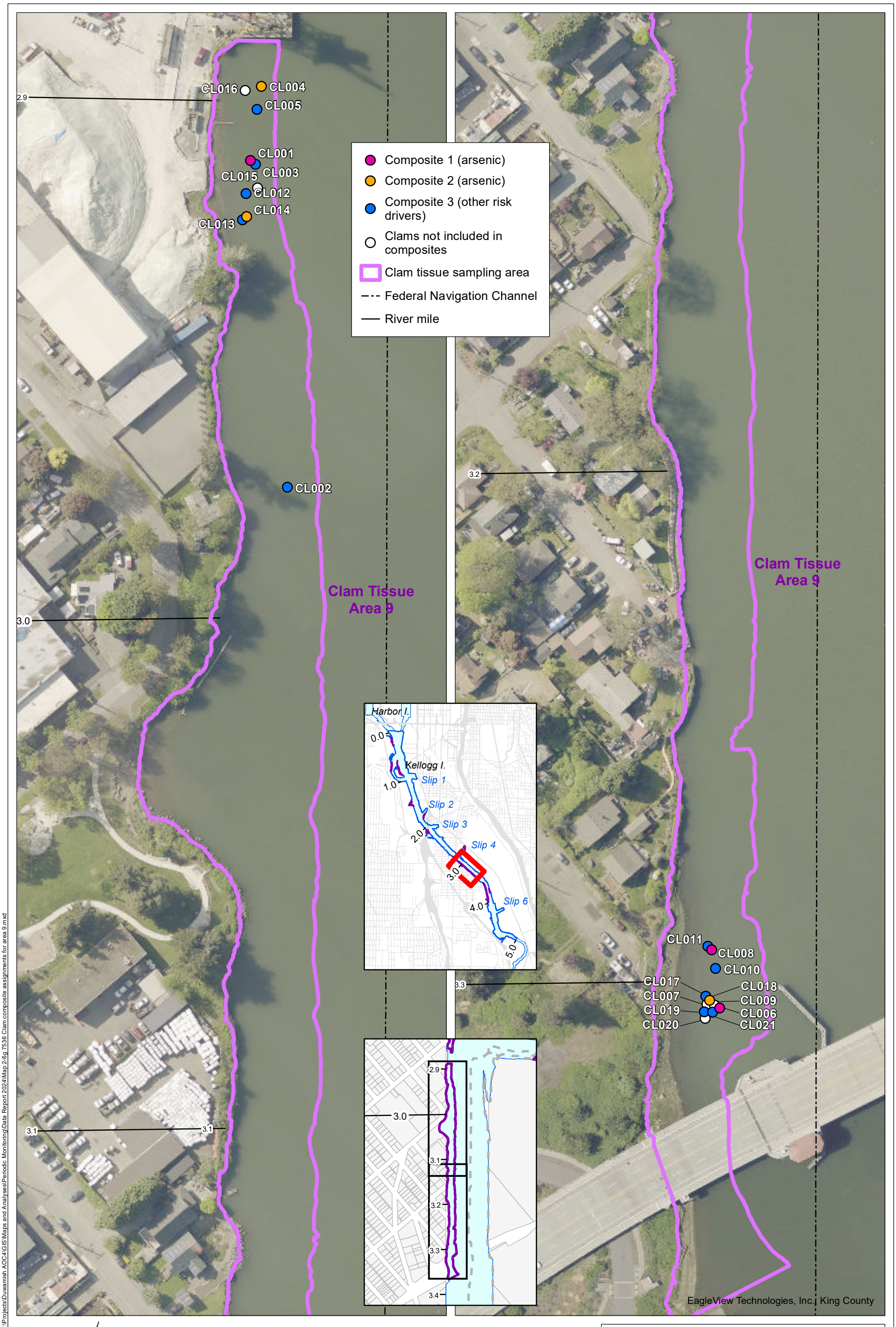

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0 50 100 Feet

0 20 40 Meters

Scale is the same for each inset map

Map 2-6g. Individual clam tissue collection locations for area 9 (RM 2.9-3.35W)

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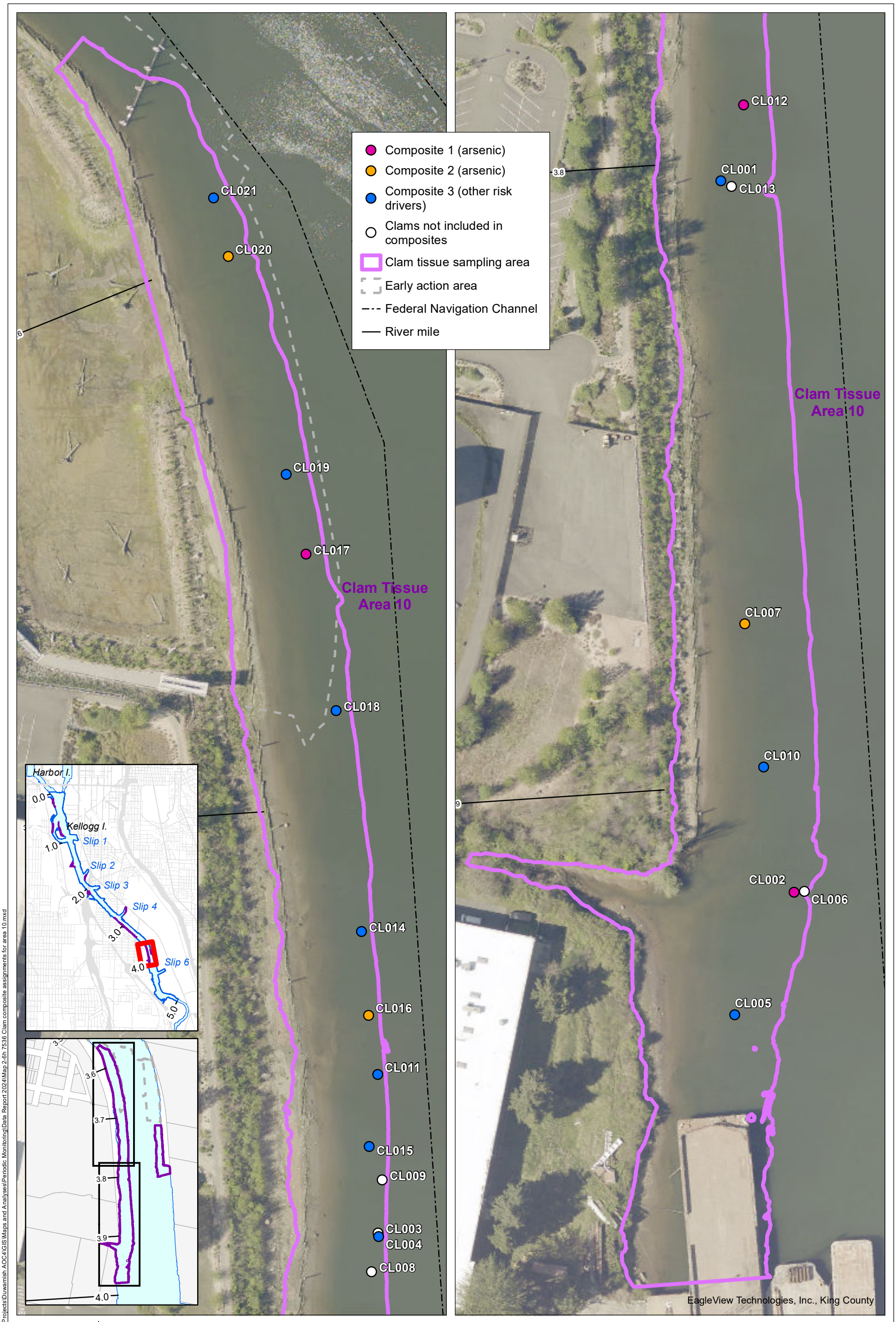

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N

0 50 100 Feet

0 20 40 Meters

Scale is the same for each inset map

Map 2-6h. Individual clam tissue collection locations for area 10 (RM 3.6-4.0W)

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PERIODIC MONITORING DATA REPORT FOR THE LDW DECEMBER 23, 2024

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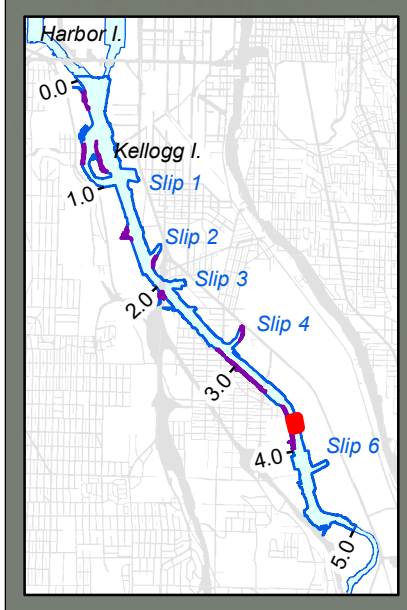
CL010
CL015
CL004
CL013
CL021
CL003
CL017
CL008
Clam Tissue Area 11
CL020
CL005
CL012
CL002
CL016
CL006
CL018
CL014
CL019
CL001
CL007
CL009
CL011



- Composite 1 (arsenic)
- Composite 2 (arsenic)
- Composite 3 (other risk drivers)
- Clams not included in composites
- Clam tissue sampling area
- Federal Navigation Channel

EagleView Technologies, Inc., King County

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N

0 25 50 Feet

0 5 10 Meters

Map 2-6i. Individual clam tissue collection locations for area 11 (RM 3.8E)

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Prepared by craigh, 12/12/2024; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Periodic Monitoring\Data Report 2024\Map 2-6i 7536 Clam composite assignments for area 11.mxd

Harbor I.

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9

Slip 1

Slip 2

Slip 3

Slip 4

LDW-PS2

Lineage Logistics dock

2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.0

LDW-PS1

South Park Bridge

Slip 6

Upper Turning Basin

Baseline passive sampler location

Early Action Area

LDW Superfund Boundary

Road

Federal Navigation Channel

River mile

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N

0 0.2 0.4 Miles

0 0.2 0.4 Kilometers

Map 2-7. Passive sampler deployment locations

FISH, CRAB, CLAM AND SURFACE WATER
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Prepared by craigh, 12/12/2024; W:\Projects\Duwamish AOC4\GIS\Maps and Analyses\Periodic Monitoring\Data Report 2024\Map 2-7 6522 Surface water sampling plan.mxd