OCEAN WISE POLLUTION TRACKER: Nine Years of Research Along the British Columbia Coast

Final Technical Report

OCEAN WISE

TABLE OF CONTENTS

ACKNOWLEDGMENT

We would like to extend our gratitude to the dedicated staff members who took the time and effort to prepare this report, including:

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- Dr. Joseph Kim, Research Scientist
- Emily Anderson, *Manager, Microplastics and Ocean Pollution*

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ABSTRACT

Ocean Wise launched Pollution Tracker in 2015 to generate high quality contaminant data for sediment and mussel samples collected along the entire coast of British Columbia (BC). Phase 1 was completed in 2017, Phase 2 completed in 2020, and Phase 3 completed in 2023. Pollution Tracker sites were selected to represent both remote and industrialized coastal areas and to address the interests of various partners. Sediment and mussels (*Mytilus sp.*) were collected in collaboration with First Nations communities, port authorities, government agencies, and community groups and submitted to accredited laboratories for contaminant analysis.

During Phases 1 to 3, our partners' support enabled collection and analysis of sediment from a total of 89 sites and mussels from 49 sites across the south, central and north coasts. However, this technical report presents 41 sediment and 20 mussel sites, as data for these sites exist across all three phases. Samples were analyzed for the following contaminant classes including polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), metals, polycyclic aromatic hydrocarbons (PAHs) (Tier 1); perfluorinated compounds (PFCs), alkylphenols, organochlorine (legacy) pesticides, dioxins and furans (Tier 2); tetrabromobisphenol A (TBBPA), hexabromocyclododecane (HBCD), current use pesticides, and pharmaceuticals and personal care products (PPCPs) (Tier 3). A subset of these results is presented in this technical report.

Phase 1 to 3 data for each site are categorized into regions and presented graphically.

BACKGROUND

Pollution Tracker was developed to provide a consolidated, comparable, and sustainable pollution assessment framework for coastal BC. Pollution Tracker has helped inform source identification, pollution priorities, best practices, and natural resource management. Pollution Tracker includes i) a coast-wide distribution of sampling sites in BC, ii) high resolution contaminant analyses in sediment and mussel samples, and iii) the interpretation of contaminant signatures from resulting profiles.

Pollution Tracker has been supported by a network of partners and uses a common data-sharing platform and common protocols for sample collection and analysis. Results are available on our website (pollutiontracker.org), in the form of partner reports, and in scientific publications.

Pollution Tracker's baseline dataset and network of monitoring sites provide:

- A foundation for an early warning platform for new contaminants in coastal British Columbia.
- An opportunity for additional research projects, such as the evaluation of risks to southern resident killer whales (SRKW) and other aquatic biota from contaminant exposure.

- Insight into the levels of contaminants in traditional seafoods for coastal First Nations.
- A foundation for more detailed, site, contaminant, or species-specific assessments to inform priority setting and management initiatives for ecosystem function and health, threats to fish health, recovery strategies/plans for SARA-listed species, and cumulative stressors.
- An opportunity to bring together a network of partners that are responsible for, concerned with, or expert in coastal contamination.

Data generated from Phase 1, 2 and 3 have been added to the coast-wide Pollution Tracker dataset. A summary of coast-wide results from Phase 1, 2 and 3 is presented on pollutiontracker.org.

METHODS

SAMPLE COLLECTION

During Phases 1, 2 and 3, Pollution Tracker partners' support enabled collection and analysis of sediment from a total of 89 sites, with mussels collected from 49 sites across the south, central and north coasts. This technical report includes data from 41 sediment sites and 20 mussel sites, which have been consistently monitored across all three phases. This consistency allows for a meaningful comparison of data over time. To make the data easier to visualize and interpret, these sites have been grouped into nine regions along the coast (Figures 1, 2 and 3, and detailed in Table 1). Specifically, the 41 sediment sites are categorized into nine regions, while the 20 mussel sites are grouped into seven regions (Table 1).

Table 1. Pollution Tracker samples collected across Phases 1, 2 and 3

Region	Location Name	Sample ID	Coordinates		Region Specific	
			Latitude (DD[1])	Longitude (DD)	Sediment	Mussels
West Vancouver Island	Dixon Island	DIX	48.8525	-125.1167	√	
	Grice Bay	WCVI1	49.114472	-125.791	√	
	Lemmens Inlet	WCVI2	49.1755	-125.891389	√	
Victoria Harbour	Victoria Harbour 1	VH1	48.4331	-123.3767	√	
	Victoria Harbour 2	VH2	48.4295	-123.3724	√	

Region	Location Name	Sample ID	Coordinates		Region Specific	
			Latitude (DD[1])	Longitude (DD)	Sediment	Mussels
	Victoria Harbour 3	VH3	48.4230	-123.3721	√	
	Victoria Harbour 4	VH4	48.4239	-123.3832	√	√
	Albert Head 1	AH1	48.3778	-123.4699		√
Gulf Islands	Patricia Bay	PB	48.6580	-123.4600	√	√
	Saturna Island	SAT	48.7800	-123.0800	√	√
	Fulford Harbour 1	GINP1	48.7523	-123.4278	√	
	Fulford Harbour 2	GINP2	48.7656	-123.4525	√	√
Fraser River	Fraser River 2	SBA1	49.232912	-123.288115	√	
	Fraser River 3	SBA2	49.154484	-123.290883	√	
	Fraser River 4	Site 5-2	49.102617	-123.168251	√	
	Fraser River 5	Site 7-2	49.212782	-123.180996	√	
	Fraser River 1	FR1	48.4574	-123.2267	√	
Burrard Inlet	Burrard Inlet 8	SOA4	49.335881	-123.202851	√	√
	Burrard Inlet 10	SOA5	49.281346	-123.190995	√	√
	Burrard Inlet 11	SOA6	49.30393	-123.062383	√	
	Burrard Inlet 12	SOA7	49.309446	-123.08696	√	
	Burrard Inlet 13	SOA8	49.288169	-123.10227	√	
	Burrard Inlet 14	SOA9	49.290634	-123.064566	√	
	Burrard Inlet 1	PMV1	49.2955	-122.8853	√	√

Region	Location Name	Sample ID	Coordinates		Region Specific	
			Latitude (DD[1])	Longitude (DD)	Sediment	Mussels
	Burrard Inlet 2	PMV2	49.2930	-122.9373	√	
	Burrard Inlet 3	PMV3	49.3069	-122.9840	√	
	Burrard Inlet 4	PMV4	49.3018	-123.0530	√	
	Burrard Inlet 5	PMV5	49.2930	-123.1210	√	
	Burrard Inlet 6	PMV6	49.2925	-123.1750	√	
	Burrard Inlet 7	PMV7	49.2874	-123.1521	√	
	Burrard Inlet 9	MSL2	49.340458	-123.212572		√
	Burrard Inlet 15	MSL5	49.279828	-123.242508		√
Howe Sound	Howe Sound 1	LG61	49.572	-123.291733	√	
	Howe Sound 3	SOA3	49.345032	-123.271821	√	√
	Howe Sound 2	HS1	49.3593	-123.4836	√	√
Indian Arm	Indian Arm 1	IA1	49.4628	-122.8858	√	√
	Indian Arm 2	IA2	49.3209	-122.9122	√	√
North Coast	Prince Rupert Harbour 1	NWC1	54.3135	-130.3331	√	√
	Metlakatla	NWC2	54.3212	-130.4821	√	√
Haida Gwaii	Armentieres Channel	HG1	-	-	√	√
	Louscoone Inlet	HG2	-	-	√	√
	Haswell Bay	HG4	-	-	√	√
	Bischof Islands	HG5	-	-	√	√

Region	Location Name	Sample ID	Coordinates		Region Specific	
			Latitude (DD[1])	Longitude (DD)	Sediment	Mussels
	Wiah Point	HG6	-	-	√	

[1] DD = decimal degree, '-' = not available

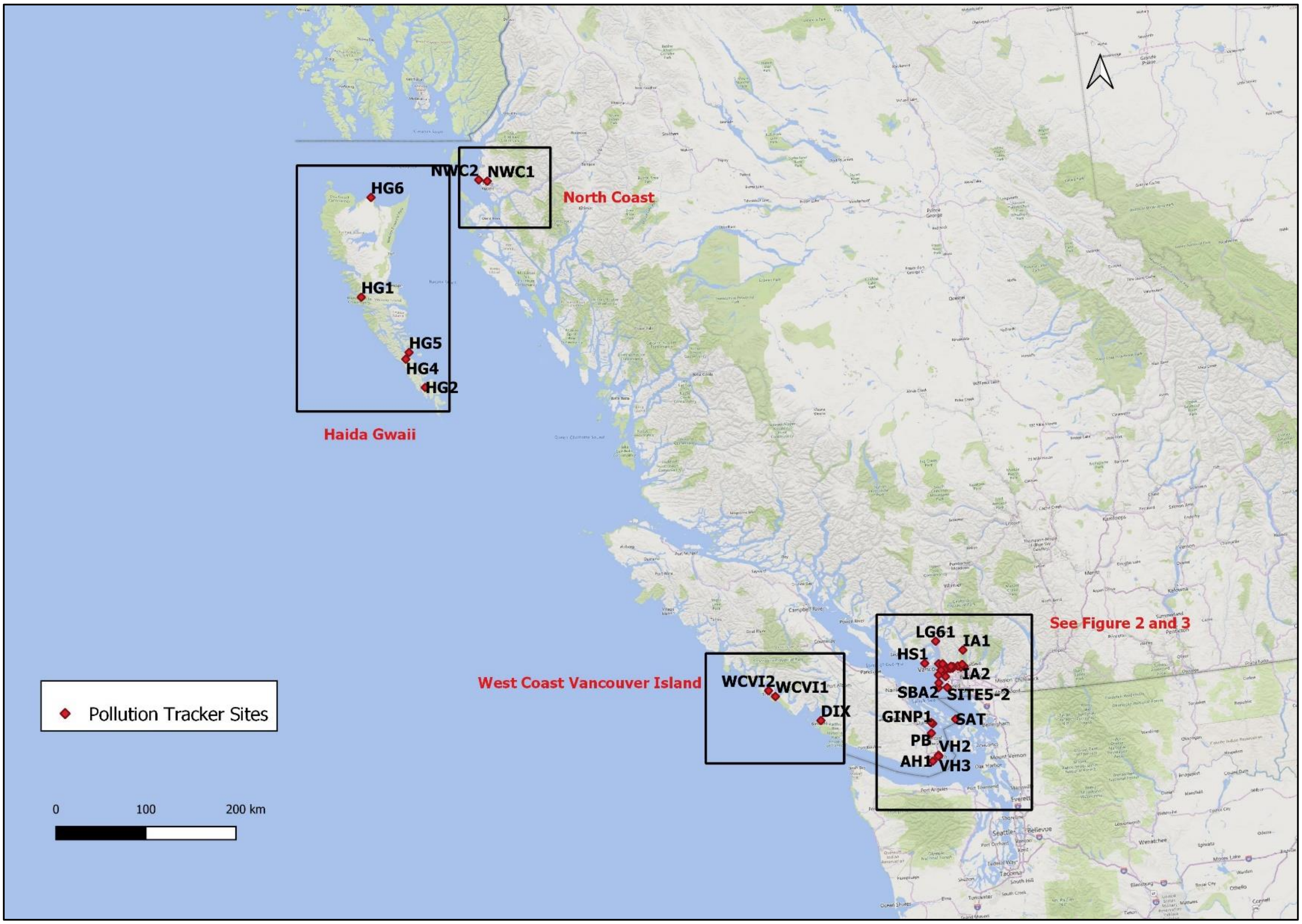

Figure 1: Pollution Tracker sites divided into the North Coast, Haida Gwaii, West Coast Vancouver Island and further south coast regions (see Figures 2 and 3).

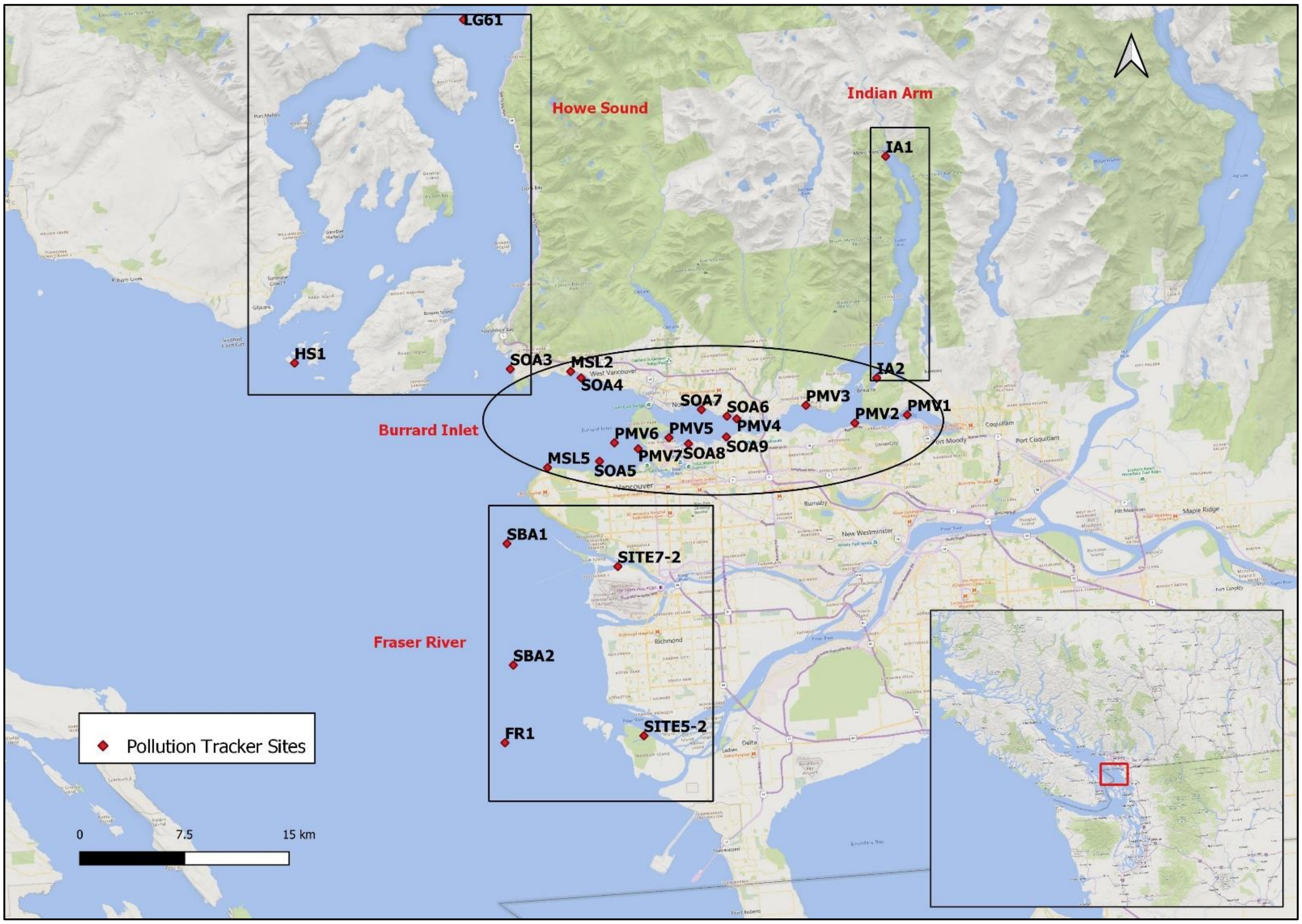

Figure 2: Pollution Tracker sites divided into the Howe Sound, Indian Arm, Burrard Inlet, and Fraser River regions.

Figure 3: Pollution Tracker sites showing the Victoria Harbour and Gulf Island regions.

Sample collection across all three phases are shown in Appendix A. Sediment samples were collected from a small vessel using a Petite Ponar. A minimum of three grabs were collected at each site, with sampling depths ranging from 6 to 25 meters. From each grab, the top 2 to 5 cm was collected and combined to create a composite sample for each site. Blue mussels were collected by hand within 2 km of the sediment sampling location. Approximately 50 to 100 mussels were collected at each site, depending on their size.

Samples were submitted to analytical laboratories (SGS AXYS Analytical Services, ALS Environmental, Pacific Rim Laboratories, and the University of British Columbia) for specialized analyses.

Depending on level of funding and partner interests, Pollution Tracker samples were submitted for Tier 1, 2, or 3 analyses, where Tier 3 is the most comprehensive (Figure 4).

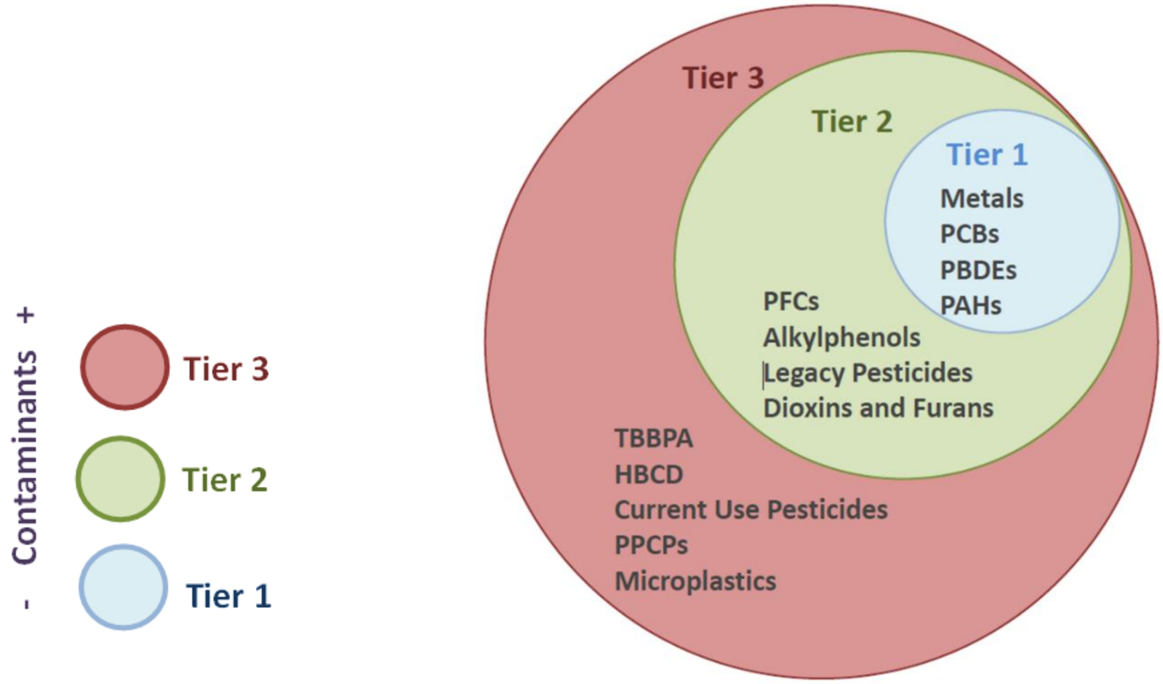

Figure 4: The Pollution Tracker tiered approach to sample analysis.

DATA ANALYSIS AND REPORTING

An evaluation of data quality was conducted by examining recoveries, blanks, detection limits, and resultant data profiles. Results were tabulated in support of a technical summary report across Phases 1, 2 and 3, and an internet-based report for the entire coast.

An overview of regional results for select contaminants are presented in this section. The contaminants included in this report are not exhaustive. To see the results for all contaminant classes analyzed, please refer to the histograms on our website at pollutiontracker.org. The contaminants included in this report (PAHs, PCBs, PBDEs, Metals [Cadmium, Methylmercury, Mercury, and Lead], PPCPs, DX/DFs, Legacy Pesticides, Current Use Pesticides, Alkylphenols) were selected based on the following criteria:

- their persistent, bioaccumulative, and toxic nature,

i) their carcinogenic potential, or

ii) their pseudo-persistence in the marine environment

Raw data can be provided as a separate attachment upon request.

Contaminant concentrations are reported on a wet weight (ww) tissue basis for mussels, while sediment data are provided on a dry weight (dw) basis. Therefore, reported concentrations are not directly comparable between sediment and tissues. The data presented below are blank-corrected, meaning that any contaminant concentrations measured in the laboratory 'blank' sample has been subtracted from the concentration measured in each sample. Note that values presented below may not exactly match the raw data provided.

Results are evaluated against environmental quality guidelines (Canadian Council of Ministers of the Environment [CCME]; Environment and Climate Change Canada [ECCC]; BC Ministry of Environment and Climate Change Strategy [MOE]). CCME guidelines for sediment quality include interim sediment quality guidelines (ISQGs), concentrations below which adverse biological effects are expected to occur rarely, and probable effects levels (PELs), concentrations above which adverse effects are expected to occur frequently. BC MOE has analogous guideline values, termed the Lower Working Sediment Quality Guideline (WSQG) and the Upper WSQG.

It is important to note that the sediment guidelines are largely based on toxicity endpoints for invertebrates and are not necessarily relevant to higher trophic level organisms (e.g., marine mammals). Regulatory guidelines protective of marine mammals are not yet available for most contaminants but are currently under development in Canada for certain priority chemicals. Working sediment quality guidelines for PCBs and PBDEs that are protective of marine mammals have recently been adopted by BC (BC MOE 2021). BC's 'working' guidelines provide benchmarks for substances that do not have formally approved guidelines.

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) have both natural and anthropogenic sources. Forest fires, agricultural burning, and fossil fuels are the major sources of PAHs. They are often byproducts of petroleum processing and combustion, but spilled oil from vessel transport or pipeline ruptures are major marine concerns. Thousands of different PAH compounds exist in the environment, with individual PAHs varying in behaviour and toxicity.

Total PAHs reported here are based on an analysis of 76 different compounds. The United States Environmental Protection Agency (EPA) has identified 16 priority PAHs that are thought to be carcinogenic through multiple routes of exposure and affect the immune, reproductive, nervous, and endocrine systems (EPA, 2014). The CCME provides guidelines for some key PAHs, but there are currently no guidelines for total PAHs in sediment or tissues. For simplicity and consistency, only total PAH concentrations are used in this analysis to facilitate comparison across regions and phases, allowing for a clearer identification of regional differences. Total PAH concentrations measured in sediments and tissue are shown in Figures 5 and 6.

Results:

- Regional detections - PAHs were detected in sediments and mussels across all regions from Phases 1 to 3 (Figures 5 and 6). The highest average concentrations of total PAHs in sediment were observed on the North Coast (45,591 µg/kg dw), while the lowest average concentrations were observed on the West Coast of Vancouver Island (WC Van Isld) (248 ± 108 µg/kg dw). Across all regions, levels of total PAHs in sediments and in mussels were not significantly different between Phase 1 and Phase 3 (Wilcoxon Test, $p > 0.05$), indicating minimal variation over time coastwide.

- Regional Hotspots – Throughout Phases 1, 2, and 3, average levels of total PAHs in sediments from the North Coast (Prince Rupert Harbour 1 – upper values) (45,591 µg/kg dw), Victoria Harbour (26,994 ± 3,566 µg/kg dw), and Burrard Inlet (6082 ± 892 µg/kg dw), regions were significantly higher than levels of PAHs in the other six regions (Wilcoxon Test, $p < 0.05$), establishing these three regions as PAH hotspots. The high PAH levels in these regions are consistent with harbour activities such as high vessel traffic and historical operations.

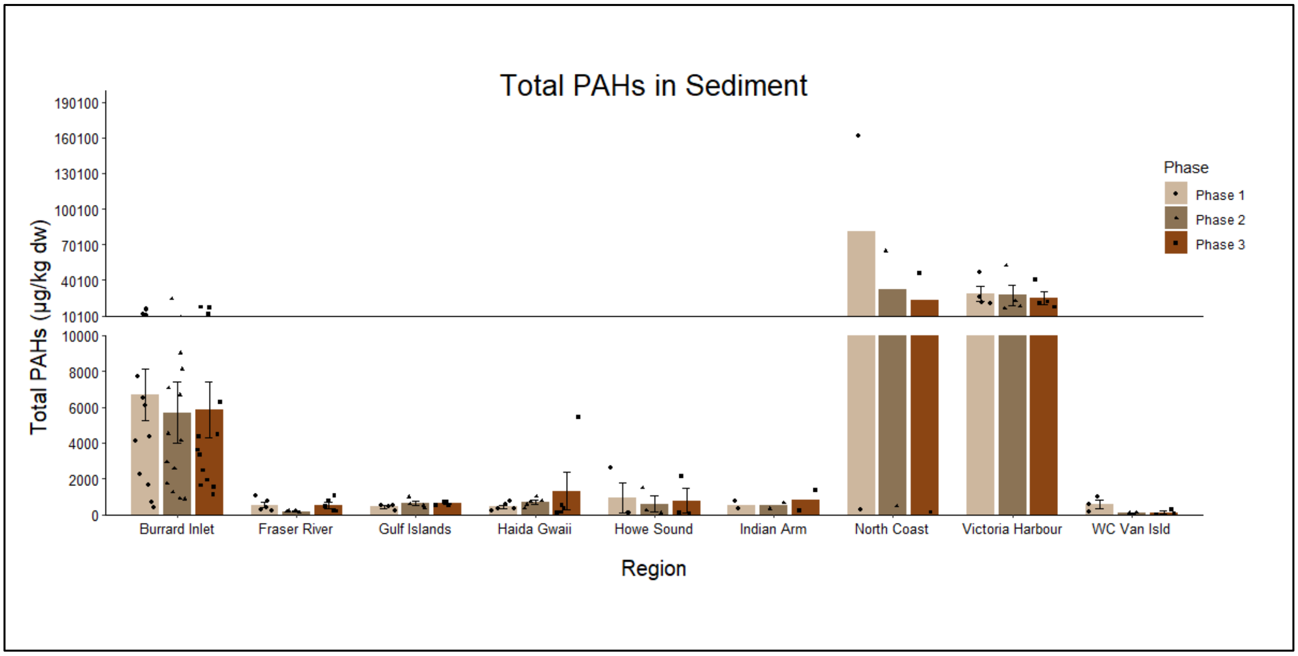

Figure 5. Total concentrations of polycyclic aromatic hydrocarbons (PAHs) in sediment across regions for Phases 1, 2 and 3.

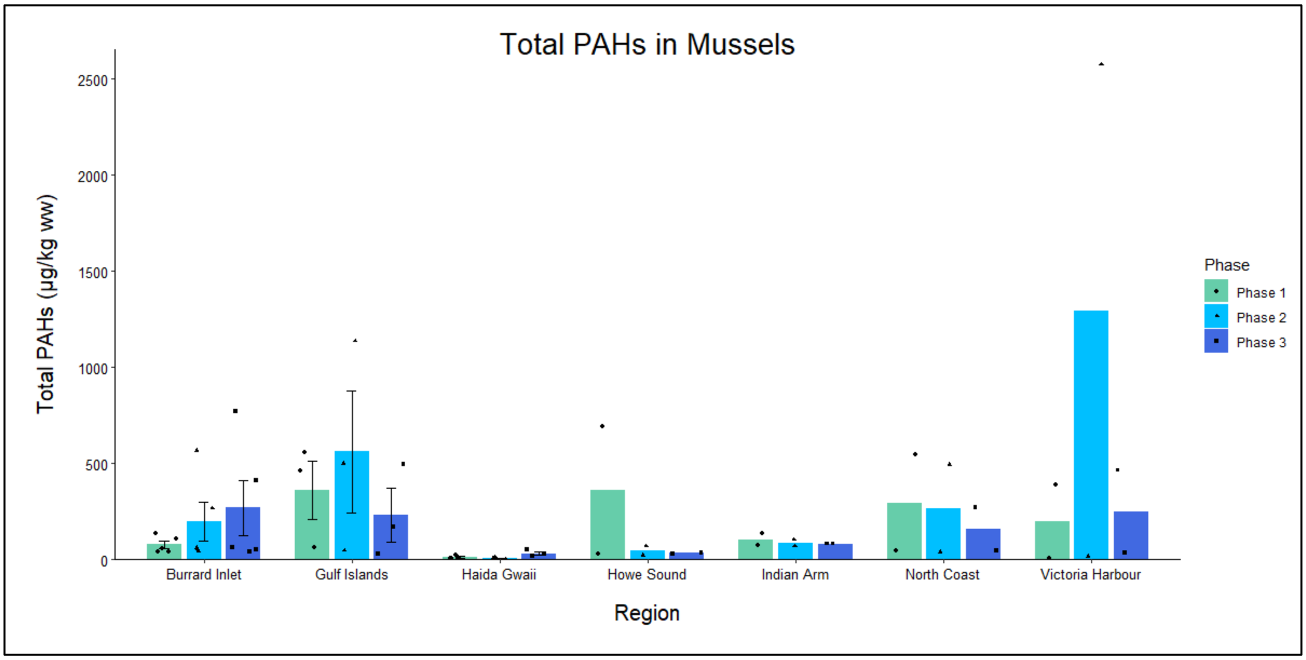

Figure 6. Total concentrations of polycyclic aromatic hydrocarbons (PAHs) detected in mussels across regions for Phases 1, 2 and 3.

Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) have been used extensively as stable, heat-resistant oils in electrical transformers and capacitors, heat exchange fluids, and as additives in paint, carbonless copy paper, and plastics. The import, manufacture, and sale of PCBs were made illegal in Canada in 1977, and release of PCBs to the environment was made illegal in 1985. However, PCB equipment can continue to be used until the end of its service life, and PCBs are still found in air, water, sediments, and biota. PCBs are a major legacy contaminant of concern in SARA-listed killer whales (*Orcinus orca*) in British Columbia (Ross et al. 2000, Ross 2006). There are 209 different PCB compounds. Concentrations of all 209 PCBs can be summed to give a total PCB concentration. For more information on PCB hotspots identified along the coast of British Columbia, please see our publication “Characterization and interpolation of sediment polychlorinated biphenyls and polybrominated diphenyl ethers in resident killer whale habitat along the coast of British Columbia, Canada,” (Kim et al., 2022).

Results:

- **Regional Hotspots** - The highest average concentrations of total PCBs in sediments were observed in Victoria Harbour (331 ± 105 µg/kg dw), the North Coast (158 ± 112 µg/kg dw), and Burrard Inlet (17.5 ± 5 µg/kg dw) across phases (Figure 7). Throughout Phases 1, 2, and 3, levels of PCBs in these three regions were significantly higher than levels of PCBs in the other six regions (Wilcoxon Test, $p < 0.05$) establishing Victoria Harbour, the North Coast, and Burrard Inlet as PCB hotspots.

- **PCB increase in Burrard Inlet mussels** – While levels of PCBs in mussels across regions were generally lower than those in sediments, concentrations in Burrard Inlet mussels increased from Phase 1 to Phase 3 (Figure 8) and this increase was significant (t-test, $p > 0.05$).

- **CCME PEL/BC Upper WSQG exceedances** – Levels of total PCBs in Victoria Harbour sediments consistently exceeded the CCME PEL/BC Upper WSQG of 189 µg/kg dw throughout all phases. Additionally, during Phase 3, levels of total PCBs in Prince Rupert Harbour (upper North Coast values) sediments also exceeded the CCME PEL/BC Upper WSQG. This guideline is protective of invertebrates, and an exceedance of the CCME PEL/BC Upper WSQG indicates adverse effects to marine invertebrates are expected to occur frequently.

- **CCME ISQG/BC Lower WSQG exceedances** – Levels of total PCBs in Victoria Harbour and Prince Rupert Harbour (upper North Coast values) sediments consistently exceeded the CCME ISQG/BC Lower WSQG of 21.5 µg/kg dw across all phases. In addition, one site in the Burrard Inlet region (PMV5 – Burrard Inlet 5) also consistently exceeded the CCME ISQG/BC Lower WSQG throughout all phases. The CCME ISQG/BC Lower WSQG is protective of invertebrates, and concentrations below 21.5 µg/kg dw indicate adverse effects to marine invertebrates are expected to occur rarely.

- **Additional BC Lower WSQG exceedances** - Total PCB levels in sediments throughout all regions and across all sampling phases exceeded the new BC Lower WSQG at 0.0037 µg/kg dw protective of marine mammals. This guideline is not shown in Figure 7 due to scale. However, on average, across all regions and phases total PCB levels were ~ 10,000 x over this guideline, indicating the potential for adverse effects to marine mammals that reside along the British Columbia coast.

- **Tissue Residue Guideline exceedances** - For comparison to available CCME tissue residue guidelines, mussel data are expressed on a toxicity equivalent (TEQ) basis. TEQs incorporate a measure of the toxicity of individual PCB compounds relative to the most toxic dioxin compound: 2,3,7,8-TCDD. TEQ values calculated for mussels from all regions were below tissue residue guidelines protective of mammalian wildlife receptors (0.79 ng TEQ/kg ww) (Figure 9). However, mussels from one site, VH4-M (Victoria Harbour 4), contained concentrations that were consistantly above the tissue residue guideline protective of avian wildlife receptors (2.4 ng TEQ/kg ww) throughout Phases 1 to 3 (Figure 10).

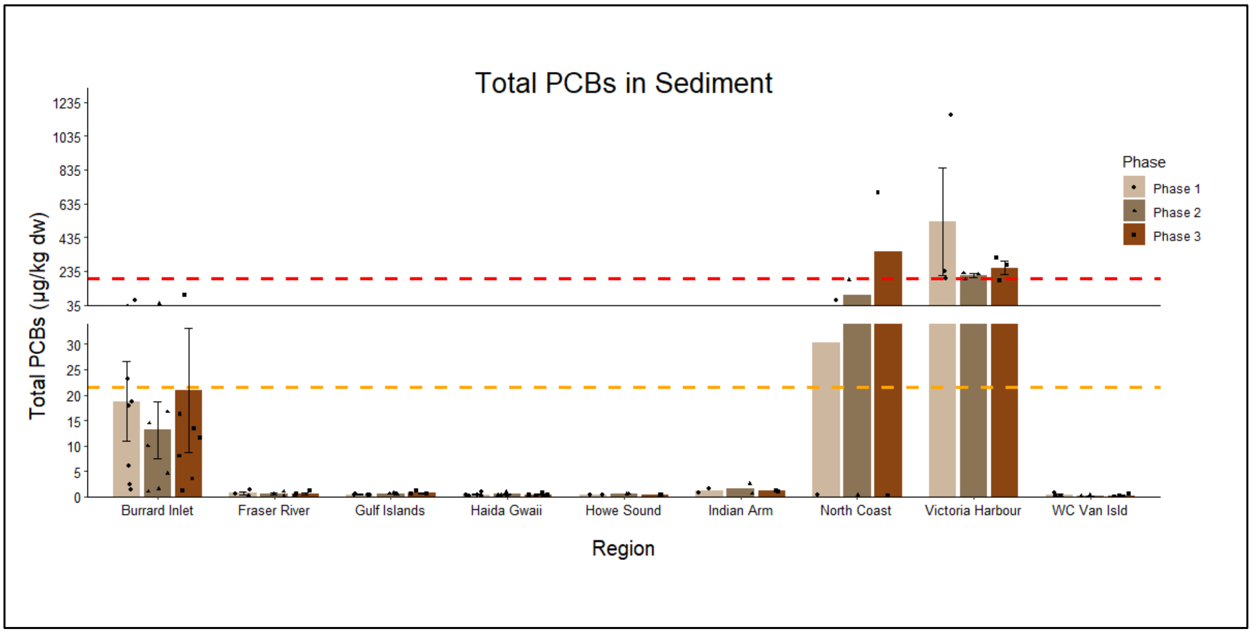

Figure 7. Total concentrations of polychlorinated biphenyls (PCBs) in sediment across regions for Phases 1, 2 and 3. The orange broken line represents the CCME ISQG/BC Lower WSQG of 21.5 µg/kg dw, while the red broken line represents the CCME PEL / BC Upper WSQG of 189 µg/kg dw.

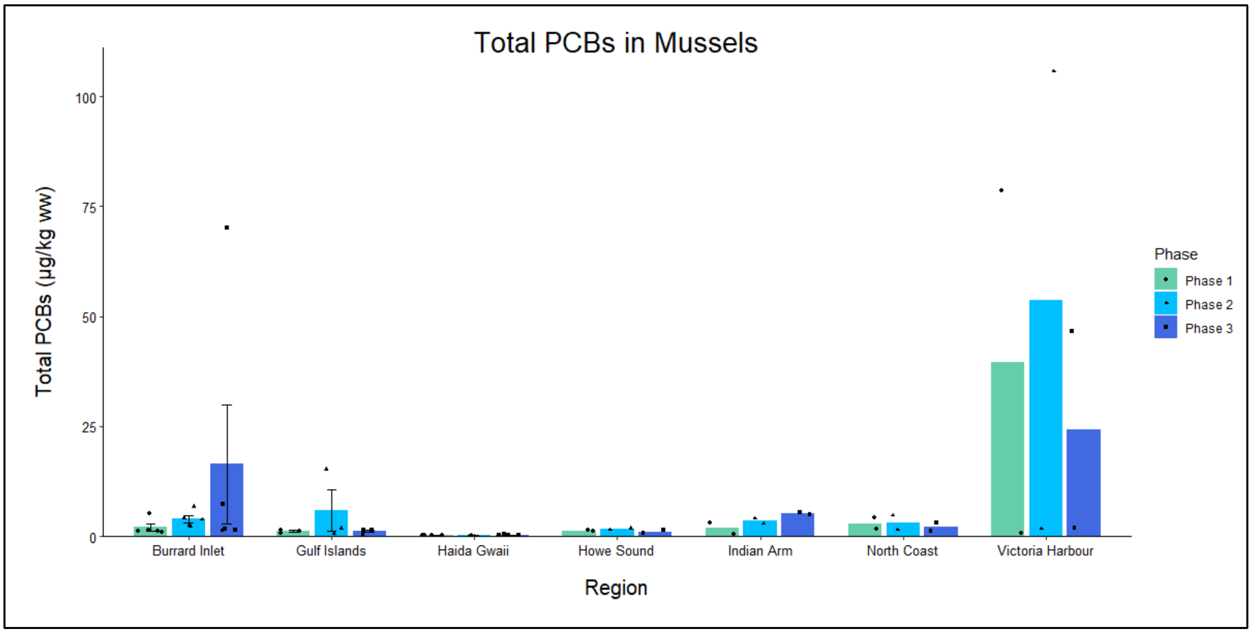

Figure 8. Total concentrations of polychlorinated biphenyls (PCBs) in mussels across regions for Phases 1, 2 and 3.

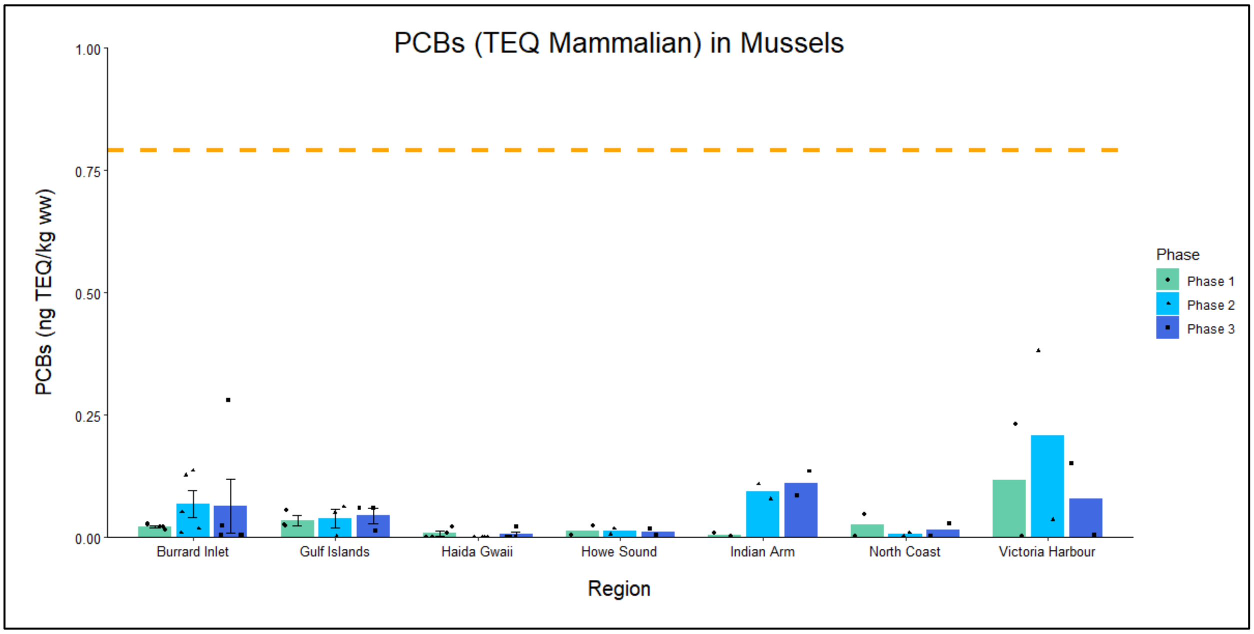

Figure 9. Toxic equivalents (TEQs) of polychlorinated biphenyls (PCBs) calculated for mussels across regions for Phases 1, 2 and 3. The orange broken line represents the tissue residue guideline protective of mammalian wildlife receptors (0.79 ng TEQ/kg diet ww).

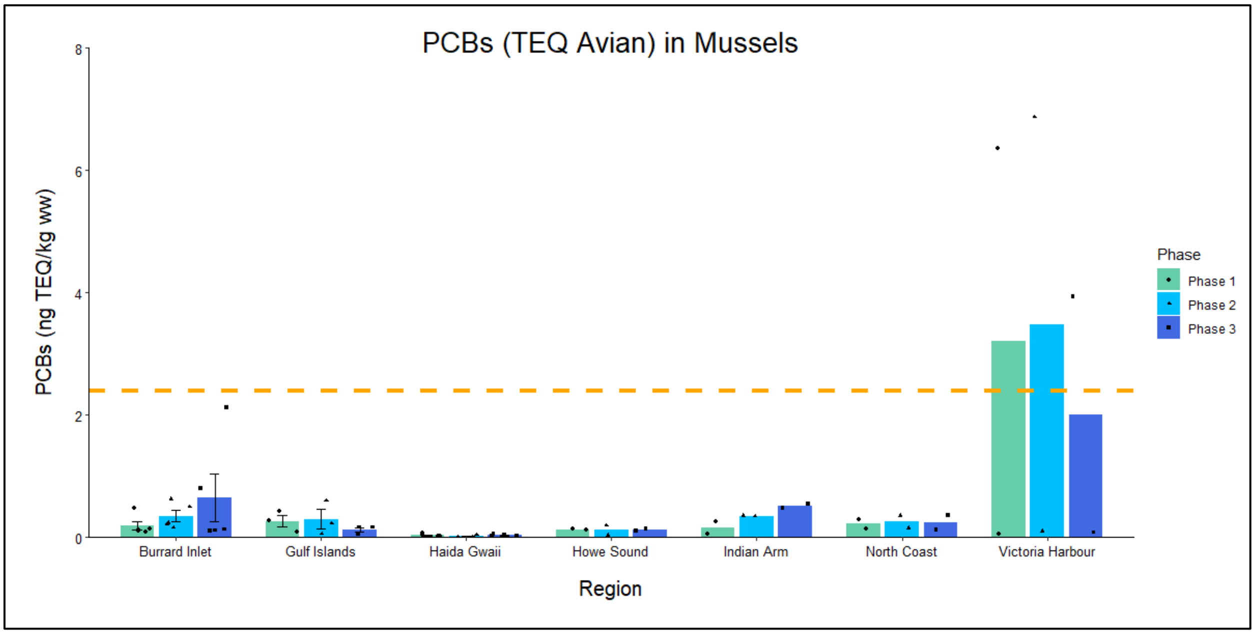

Figure 10. Toxic equivalents (TEQs) of polychlorinated biphenyls (PCBs) calculated for mussels across regions for Phases 1, 2 and 3. The orange broken line represents the tissue residue guideline protective of avian receptors (2.4 ng TEQ/kg diet ww).

Polybrominated Diphenyl Ethers (PBDEs)

Polybrominated diphenyl ethers (PBDEs) are a class of flame retardants widely used in furniture, electronics, and vehicles. There are up to 209 different possible types of PBDEs. Canadian regulations prohibit the manufacture of all PBDEs and restrict the use of and sale of certain PBDEs in commercial mixtures. PBDEs can travel long distances through the atmosphere and bioaccumulate in marine food webs. They are endocrine disrupting compounds, and exposure can lead to long-term developmental effects on the neurological, reproductive, and immune systems (Akortia et al., 2016). Like PCBs, PBDEs have been found in BC's killer whales (Rayne et al. 2004). In BC harbour seals, PBDEs have declined since 2004 when Canadian regulations were put in place (Ross et al. 2013). For more information on PBDE hotspots identified along the coast of British Columbia, please see our publication "Characterization and interpolation of sediment polychlorinated biphenyls and polybrominated diphenyl ethers in resident killer whale habitat along the coast of British Columbia, Canada," (Kim et al., 2022).

Federal environmental quality guidelines (FEQGs) have been developed for PBDEs in water, sediment, fish tissue, and bird eggs (EC 2013). FEQGs are based on different PBDE groupings, rather than total PBDE concentrations (Table 2). Guideline concentrations are based on 1% total organic carbon (TOC) and are adjusted based on actual TOC levels. British Columbia has recently adopted a working sediment quality guideline for total PBDEs considered protective of killer whales, based on the work of Alava et al., 2016 (BC MOE 2021). This guideline is shown in Figure 11.

Table 2: Federal Environmental Quality Guidelines for PBDEs.PBDE Group	Guideline Concentration (μg/kg)		
	Sediment	Wildlife Diet	Fish Tissue
Tri-BDE	44	-	120
Tetra-BDE	39	44	88
Penta-BDE	0.4	3 (mammals) 13 (birds)	1
BDE-99		3	
BDE-100		-	
Hexa-BDE	440	4	420
Hepta-BDE	-	64	-
Octa-BDE	5600	63	-
Non-BDE	-	78	-
Deca-BDE	19	9	-

Notes: Guideline concentrations are expressed on a dry weight basis for sediment and a wet weight basis for wildlife diet and fish tissue. FEQGs for sediment are normalized to 1% organic carbon. Site-specific TOC levels were considered when comparing sample concentrations to guidelines. If '-' = guideline not available.

Results:

- **Regional Hotspots** – the highest average concentrations of total PBDEs in sediments were observed in Victoria Harbour (47 ± 17 μg/kg dw), the North Coast (9 ± 6 μg/kg dw), and Burrard Inlet (3.7 ± 0.6 μg/kg dw) across phases (Figure 11). Levels of PBDEs in these three regions consistently exceeded the BC WSQG protective of killer whales (1 ug/kg dw). Additionally, levels of PBDEs throughout all phases were significantly higher in these three regions when compared to the other six (Wilcoxon Test, $p < 0.05$), establishing Victoria Harbour, the North Coast, and Burrard Inlet as PBDE hotspots.

- **FEQG exceedances in sediments** –when corrected for site-specific total organic carbon (TOC), PBDE concentrations in all sediment samples were below the applicable FEQGs except for the Victoria Harbour region. During Phase 1, site VH2 (Victoria Harbour 2) exceeded the FEQG for penta-BDE, while sites VH1 (Victoria Harbour 1), and VH3 (Victoria Harbour 3) exceeded the FEQG for deca-BDE. Additionally, during Phase 2, sites VH3 and VH4 exceeded the FEQG for deca- BDE and penta-BDE, respectively. There were no exceedances during Phase 3.

- **FEQG exceedances in mussels** – PBDE concentrations in mussels from all sites across phases were below the respective FEQG tissue guidelines, except for the Victoria Harbour region. During Phase 1, penta-PBDEs in mussels collected from site VH2 (Victoria Harbour 2) exceeded the FEQG protective of fish; however, there were no exceedances in this region during Phase 2 and Phase 3.

- **Apparent PBDE increase** – while average PBDE concentrations in sediment increased in the Haida Gwaii region from Phase 2 to Phase 3 (causing the overall average to exceed the BC WSQG), this increase was not significant (t-test, $p > 0.05$). Higher levels were observed during Phase 3 due to an increase in concentration at site HG1 (Armentieres Channel) from 0.03 µg/kg dw (Phase 2) to 4.9 µg/kg dw (Phase 3), and an increase at site HG6 (Wiah Point) from 3.5 µg/kg dw (Phase 2) to 10.7 µg/kg dw (Phase 3).

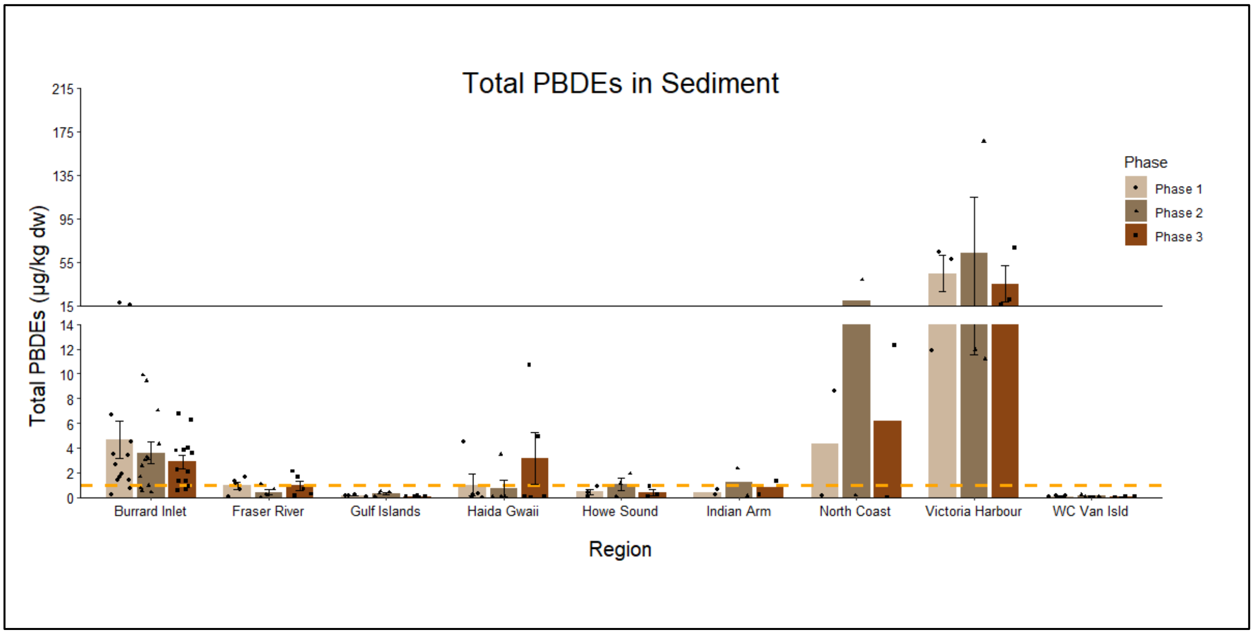

Figure 11. Total concentrations of polybrominated diphenyl ethers (PBDEs) in sediment across regions for Phases 1, 2 and 3. The orange broken line represents the BC WSQG protective of killer whales (1 µg/kg dw).

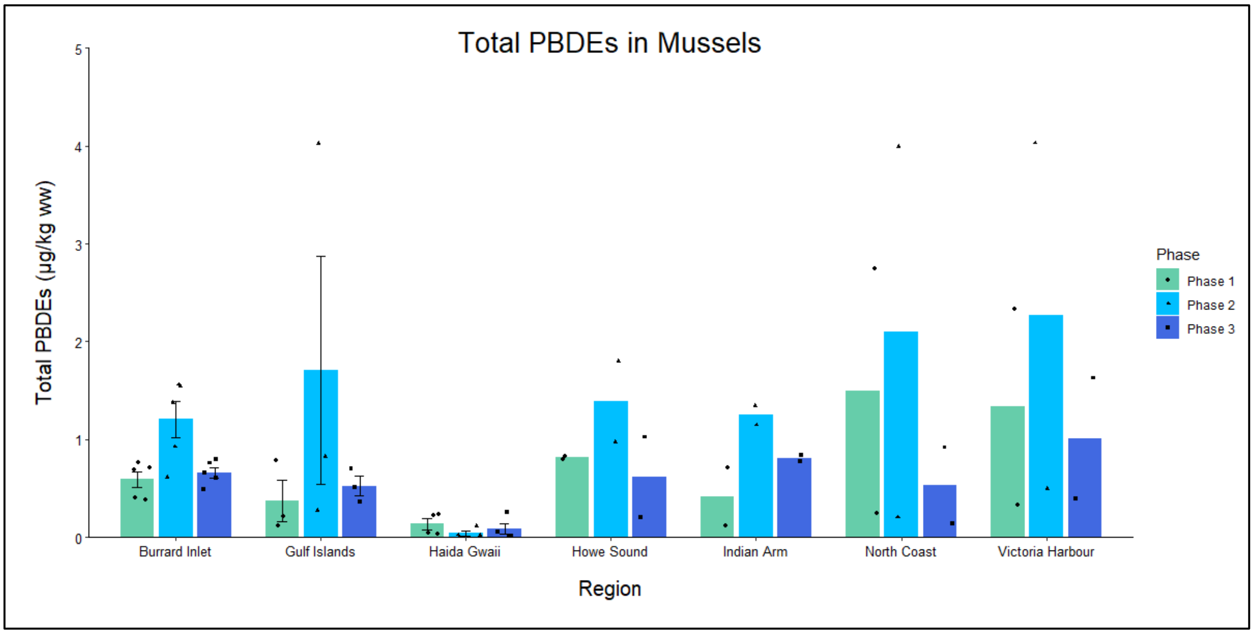

Figure 12. Total concentrations of polybrominated diphenyl ethers (PBDEs) in mussels across regions for Phases 1, 2 and 3.

Metals

Trace metals occur naturally but are also products or by-products of human activities. Common anthropogenic sources of metals include mining and industrial wastes, vehicle emissions, lead-acid batteries, fertilizers, paints, and treated woods. Metals do not break down in the environment but exist in a variety of forms depending on environmental variables such as pH, dissolved oxygen, water hardness, salinity, and organic carbon. The mobility, bioavailability, and toxicity of a metal vary. Typical toxic effects of metals include neurotoxicity, oxidative stress, and carcinogenicity (Jaishankar et al., 2014). Several metals, including inorganic cadmium, lead, and mercury have been defined as 'toxic' under the *Canadian Environmental Protection Act* (CEPA 1999). For more information on metal hotspots identified along the coast of British Columbia, please see our publication "Sediment Spatial Distribution and Quality Assessment of Metals in Chinook Salmon and Resident Killer Whale Marine Habitat in British Columbia, Canada," (Kim et al., 2023).

Results:

Cadmium

- Regional Hotspots – Across phases, the highest average concentrations of total cadmium in sediments were observed in the Haida Gwaii (4.6 ± 1.5 mg/kg dw), North Coast (3 ± 1.7

mg/kg dw), Victoria Harbour (1.2 ± 0.1 mg/kg dw), and West Coast of Vancouver Island (0.71 ± 0.3 mg/kg dw) regions (Figure 13). Levels of cadmium in these four regions consistently exceeded the CCME ISQG / BC Lower WSQG for cadmium (0.7 mg/kg dw) across all phases. Additionally, levels of cadmium across all phases were significantly higher in these four regions when compared to the other five (Wilcoxon Test, $p < 0.05$), establishing Haida Gwaii, the North Coast, Victoria Harbour, and the West Coast of Vancouver Island as cadmium hotspots.

- CCME PEL guideline exceedances – average concentrations of total cadmium in sediments from both the North Coast region and Haida Gwaii region exceeded the CCME PEL (4.2 mg/kg dw) during Phase 1. In addition, average concentrations in the Haida Gwaii region also exceeded the CCME PEL during Phase 2. Concentrations of cadmium in sediments from sites HG4 (Haswell Bay) and HG5 (Bischof Islands) in the Haida Gwaii region consistently exceeded the CCME PEL across all phases.
- Potential sources of cadmium – include recycling plants, paper mills, and industrial activities (Mariko, 2013). The active recycling plant operating in Victoria Harbour, and the historical operation of a paper mill in Prince Rupert Harbour (upper North Coast values in Figure 13) could be contributing to the high levels of cadmium observed in these regions. Additionally, marine disposal of mine tailings may be contributing to the high cadmium levels observed in the Haida Gwaii region (Johannessen et al., 2007). For further discussion on cadmium sources in British Columbia, please see our publication (Kim et al., 2023).

Mercury

- Regional Hotspots – Across phases, the highest average concentrations of total mercury in sediments were observed in the Victoria Harbour (0.6 ± 0.07 mg/kg dw), North Coast (0.17 mg/kg dw), Haida Gwaii (0.15 mg/kg dw), and Burrard Inlet (0.14 ± 0.01 mg/kg dw) regions (Figure 14). Levels of mercury in these regions almost always exceeded the CCME ISQG / BC Lower WSQG for mercury (0.13 mg/kg dw). Additionally, levels of mercury across all phases were significantly higher in these four regions when compared to the other five (Wilcoxon Test, $p < 0.05$), establishing Victoria Harbour, the North Coast, Haida Gwaii, and Burrard Inlet as mercury hotspots.
- CCME PEL guideline exceedances – average concentrations of total mercury in sediments from the Victoria Harbour region exceeded the CCME PEL for mercury (0.7 mg/kg dw) during Phase 1. Additionally, site VH3 (Victoria Harbour 3) consistently exceeded the CCME PEL across all phases.

Methylmercury

- **Tissue Residue guideline** – average concentrations of methylmercury detected in mussels across all regions (Figure 18) were below the CCME tissue guideline protective of wildlife consumers of aquatic biota (0.033 mg/kg ww).

- **Apparent Increase -** While levels of methylmercury appear to increase in mussels from Phase 1 to Phase 3 across most regions, this increase was not significant (Wilcoxon Test, $p > 0.05$).

Lead

- **Regional Hotspots** – Across phases, the highest average concentrations of total lead in sediments were observed in the North Coast (135 ± 104 mg/kg dw) and Victoria Harbour (119 ± 11 mg/kg dw) regions (Figure 15). Levels of lead in these regions consistently exceeded the CCME ISQG / BC Lower WSQG for lead (30.2 mg/kg dw). Additionally, levels of lead across all phases were significantly higher in these two regions when compared to the other seven (Wilcoxon Test, $p < 0.05$), establishing the North Coast and Victoria Harbour as lead hotspots.

- **CCME PEL guideline exceedances** – average concentrations of total lead in sediments from the North Coast and Victoria Harbour regions exceeded the CCME PEL for lead (112 mg/kg dw) during Phase 1. Additionally, the Victoria Harbour region exceeded the CCME PEL for lead during Phase 3. Sites VH1 (Victoria Harbour 1) and VH3 (Victoria Harbour 3) consistently exceeded the CCME PEL across all phases.

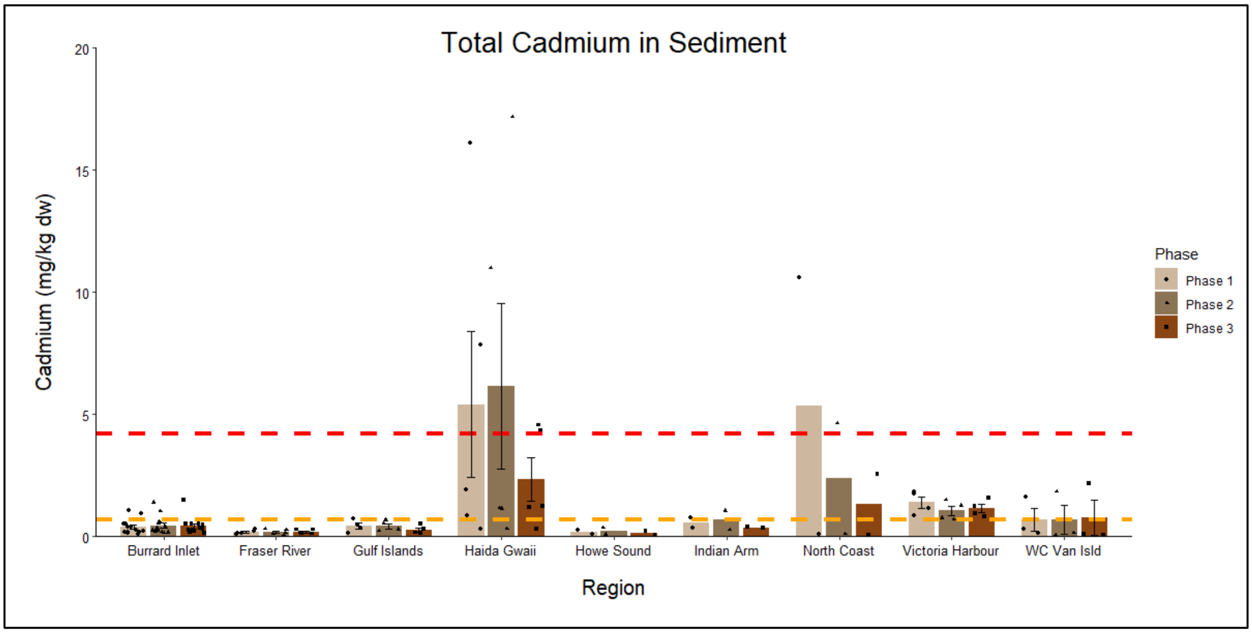

Figure 13. Total concentrations of cadmium detected in sediment across regions for Phases 1, 2 and 3. The orange broken line represents the CCME ISQG / BC Lower WSQG for cadmium (0.7 mg/kg dw), while the red broken line represents the CCME PEL for cadmium (4.2 mg/kg dw).

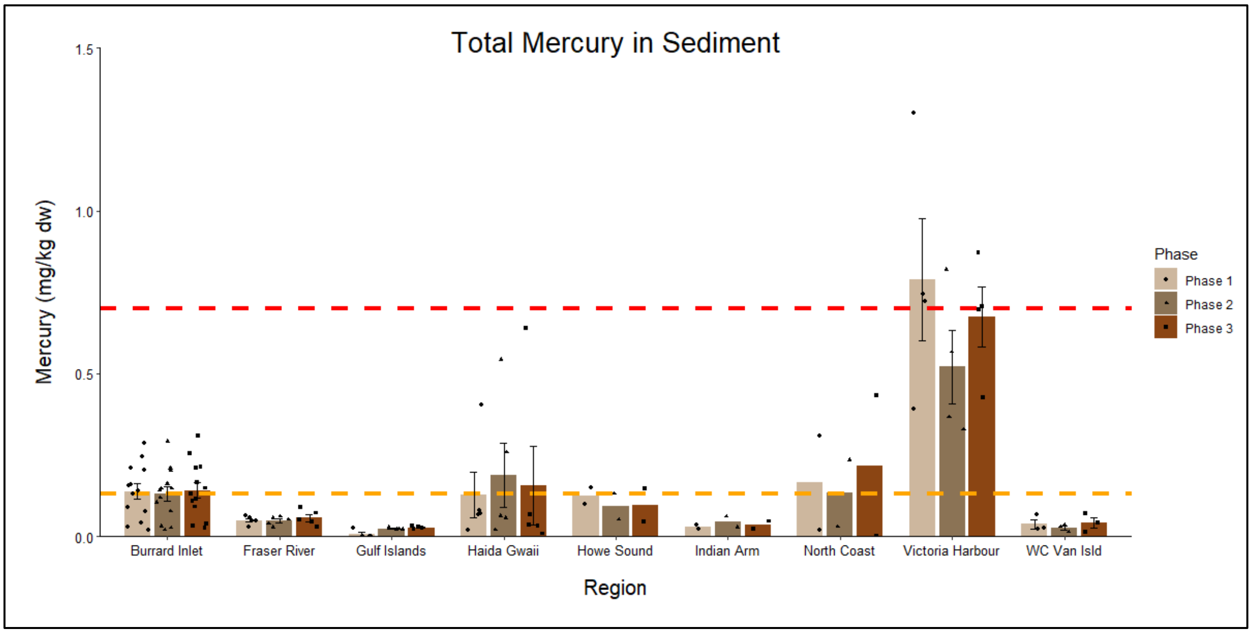

Figure 14. Total concentrations of mercury detected in sediment across regions for Phases 1, 2 and 3. The orange broken line represents the CCME ISQG / BC Lower WSQG for mercury (0.13 mg/kg dw), while the red broken line represents the CCME PEL for mercury (0.7 mg/kg dw).

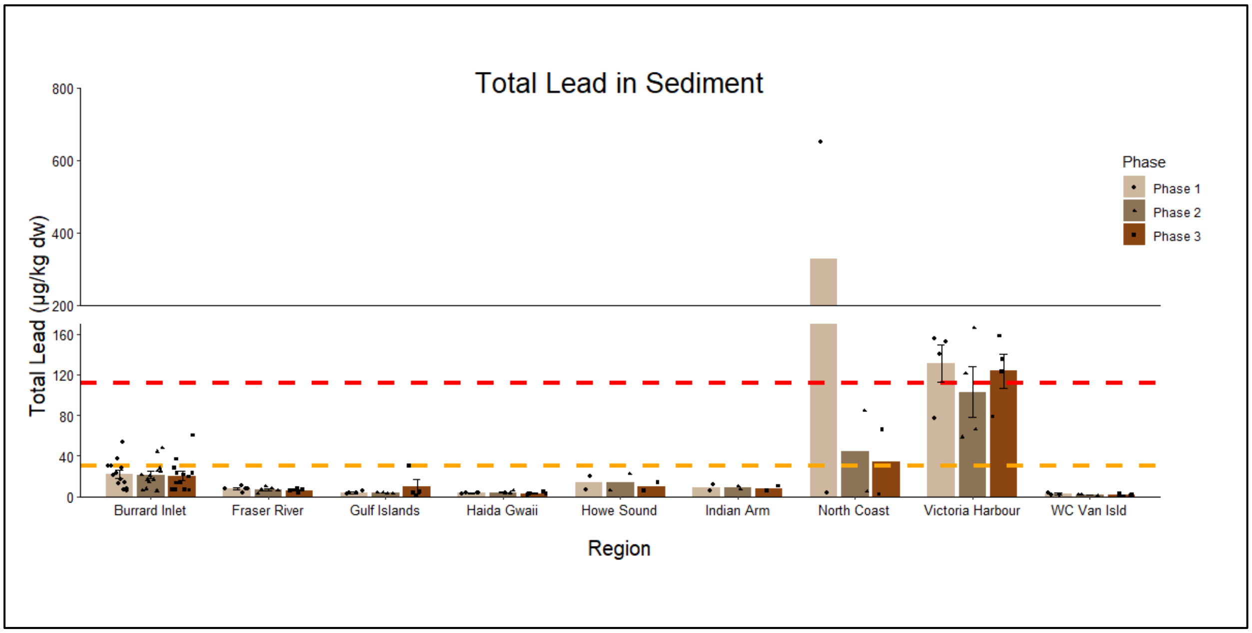

Figure 15. Total concentrations of lead detected in sediment across regions for Phases 1, 2 and 3. The orange broken line represents the CCME ISQG / BC Lower WSQG for lead (30.2 mg/kg dw), while the red broken line represents the CCME PEL for lead (112 mg/kg dw).

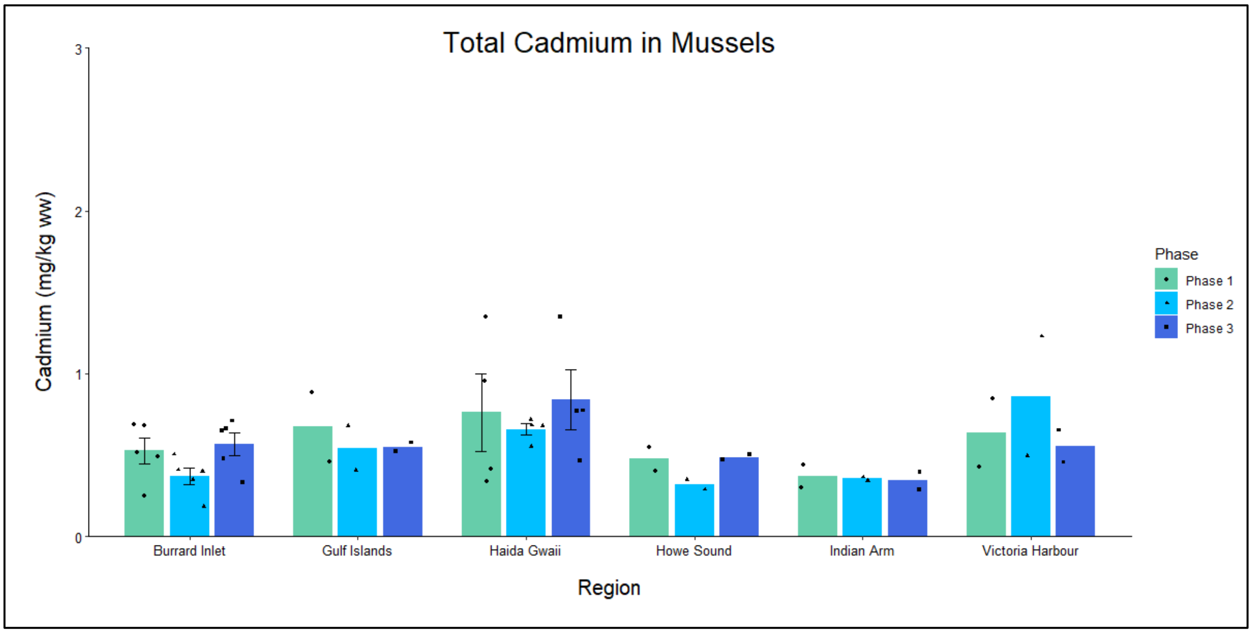

Figure 16. Total concentrations of cadmium detected in mussels across regions for Phases 1, 2 and 3.

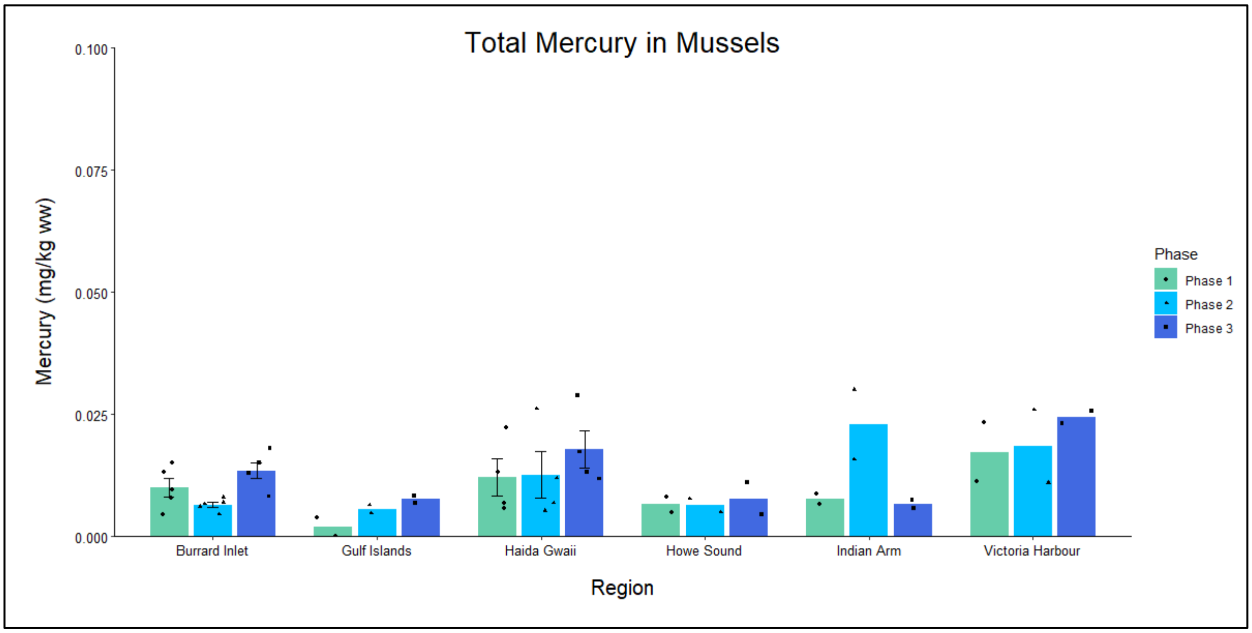

Figure 17. Total concentrations of mercury detected in mussels across regions for Phases 1, 2 and 3.

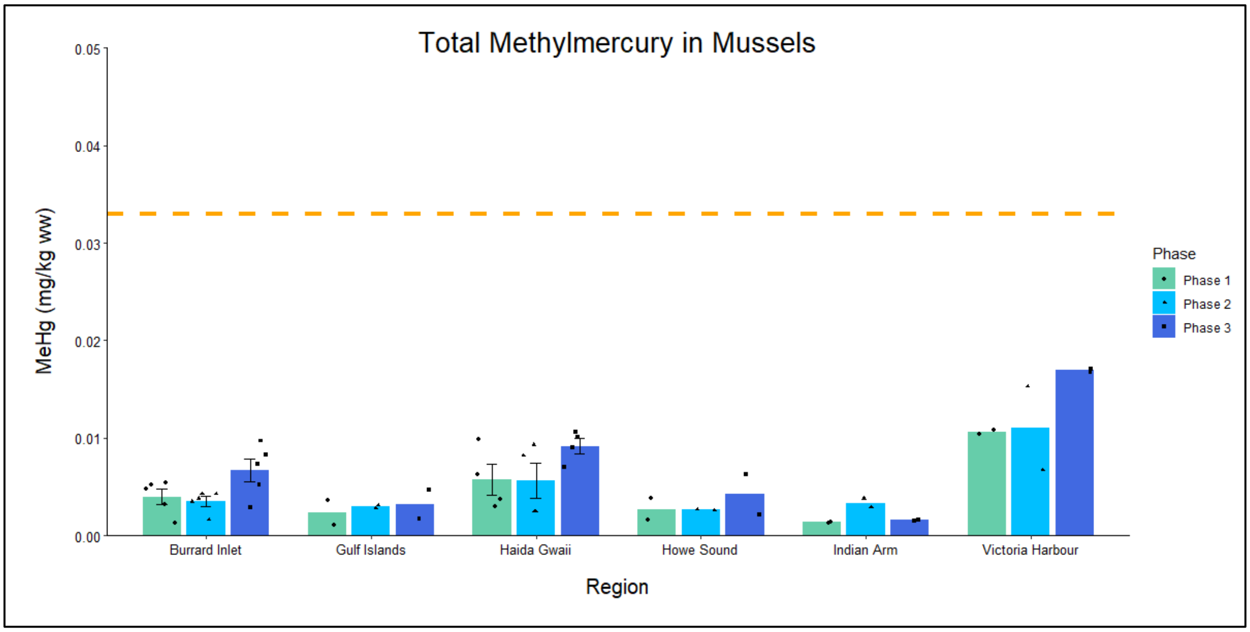

Figure 18. Total concentrations of methylmercury (MeHg) detected in mussels across regions for Phases 1, 2 and 3. The orange broken represents the CCME tissue guideline protective of wildlife consumers of aquatic biota (0.033 mg/kg ww).

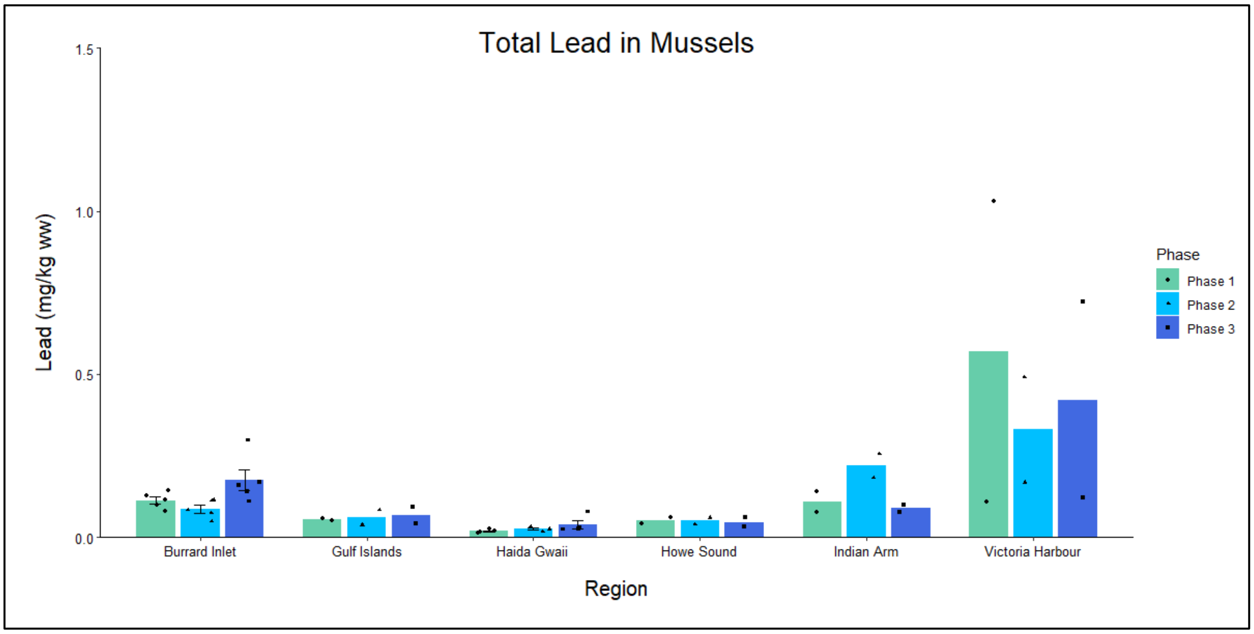

Figure 19. Total concentrations of lead detected in mussels across regions for Phases 1, 2 and 3.

Pharmaceuticals and Personal Care Products (PPCPs)

Pharmaceuticals and personal care products (PPCPs) include cosmetics, soaps, medications, and supplements used for both humans and animals. PPCPs enter the marine environment via wastewaters. While some PPCPs degrade quickly, they are considered pseudo-persistent in the environment because of continual inputs. The ability of many PPCPs to bioaccumulate is affected by their ionization state in different environmental conditions. PPCPs can have a variety of toxic effects in biota. Samples were analyzed for twelve PPCPs during Phase 1 - including the compounds bisphenol A and triclocarban, while during Phases 2 and 3 samples were analyzed for ninety PPCPs. Therefore, we cannot compare total PPCP levels amongst all three sampling phases, and the graphs below reflect that.

Sediment and Mussel Results:

- Regional Hotspots – the highest average concentrations of total PPCPs in sediments were observed in the Howe Sound (834 ± 490 µg/kg dw), Burrard Inlet (66 ± 46 µg/kg dw), and Victoria Harbour (37 ± 14 µg/kg dw) regions, across both sampling phases (Figure 20). Levels of total PPCPs throughout Phases 2 and 3 were significantly higher in these three regions when compared to the other five (Wilcoxon Test, $p < 0.05$), establishing Howe Sound, Burrard Inlet, and Victoria Harbour as PPCP hotspots.

- Increasing levels in sediments – total levels of PPCPs in sediments increased from Phase 2 to Phase 3 in seven of the eight coastal regions, and this overall increase was significant (Wilcoxon Test, $p < 0.05$).

- Apparent decreasing levels in mussels – while total levels of PPCPs in mussels appear to have decreased from Phase 2 to Phase 3 in five of the seven coastal regions, this overall decrease was not significant (Wilcoxon Test, $p > 0.05$).

- Guidelines - Marine environmental quality guidelines are not available for most PPCPs in Canada. However, Federal Environmental Quality Guidelines (FEQGs) exist for bisphenol A and triclocarban in sediment.

- Bisphenol A - Bisphenol A (BPA), a compound used to produce epoxy resins and polycarbonate plastics is a known endocrine disrupting chemical associated with adverse effects on the human reproductive system (ECCC and HC, 2018). While BPA is restricted in Canada, and banned from consumer products such as baby bottles, a commonly reported replacement Bisphenol S (BPS), has been shown to be similarly toxic to the reproductive system (Thoene et al., 2020).

- During Phase 3, bisphenol A was detected in sediment across five of the eight coastal regions including the Fraser River (site FR1- Fraser River 1), West Coast of Vancouver Island (DIX - Dixon Island), North Coast (NWC1 – Prince Rupert Harbour 1, NWC2 - Metlakatla), Burrard Inlet (PMV5 - Burrard Inlet 5, SOA4 - Burrard Inlet 8, SOA6 - Burrard Inlet 11, SOA7 - Burrard Inlet 12, SOA9 - Burrard Inlet 14), Gulf Islands (SAT - Saturna Island), and Victoria Harbour (VH1 – Victoria Harbour 1, VH2 – Victoria Harbour 2, VH3 – Victoria Harbour 3, VH4 – Victoria Harbour 4). However, levels of bisphenol A in sediment at all sites were below the FEQG/BC Lower WQG of 25 µg /kg dw when corrected for site-specific total organic carbon. Interestingly, bisphenol A was not detected in sediment from any region during Phases 1 and 2.

- Triclocarban - Triclocarban is an antibacterial agent commonly used in soaps. Triclocarban is toxic to aquatic organisms and has been found to be more effective in inhibiting or killing algae, crustaceans, and fish than in killing microbes (Halden et al., 2014).

- During Phase 3, triclocarban was detected in sediment across six of the eight coastal regions including the Gulf Islands (GINP1 – Fulford Harbour 1, SAT – Saturna Island), North Coast (NWC1 – Prince Rupert Harbour 1), Burrard Inlet (PMV1 - Burrard Inlet 1, PMV2 - Burrard Inlet 2, PMV5 - Burrard Inlet 5, PMV7 - Burrard Inlet 7, SOA4 – Burrard Inlet 8, SOA5 – Burrard Inlet 10, SOA6 – Burrard Inlet 11, SOA7 – Burrard Inlet 12, SOA8 –Burrard Inlet 13, SOA9 – Burrard Inlet 14), Fraser River (Site 5-2 – Fraser River 4,) Howe Sound (SOA3 – Howe Sound 3), and Victoria Harbour (VH1 – Victoria

Harbour 1, VH2 – Victoria Harbour 2, VH3 – Victoria Harbour 3, VH4 – Victoria Harbour 4). However, levels of triclocarban in sediment at all sites across phases were below the FEQG of 90 μg /kg dw (0.09 mg/kg dw) when corrected for site-specific total organic carbon. Triclocarban was also detected at many of these sites during Phases 1 and 2.

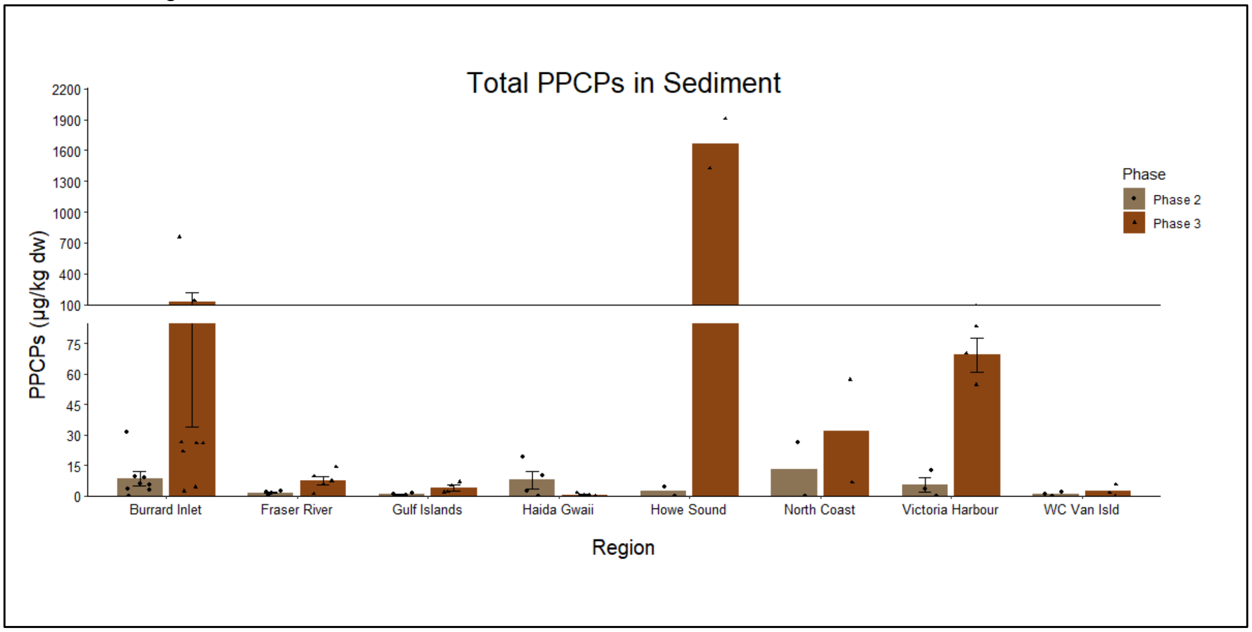

Figure 20. Total concentrations of pharmaceuticals and personal care products (PPCPs) detected in sediment across regions for Phases 2 and 3.

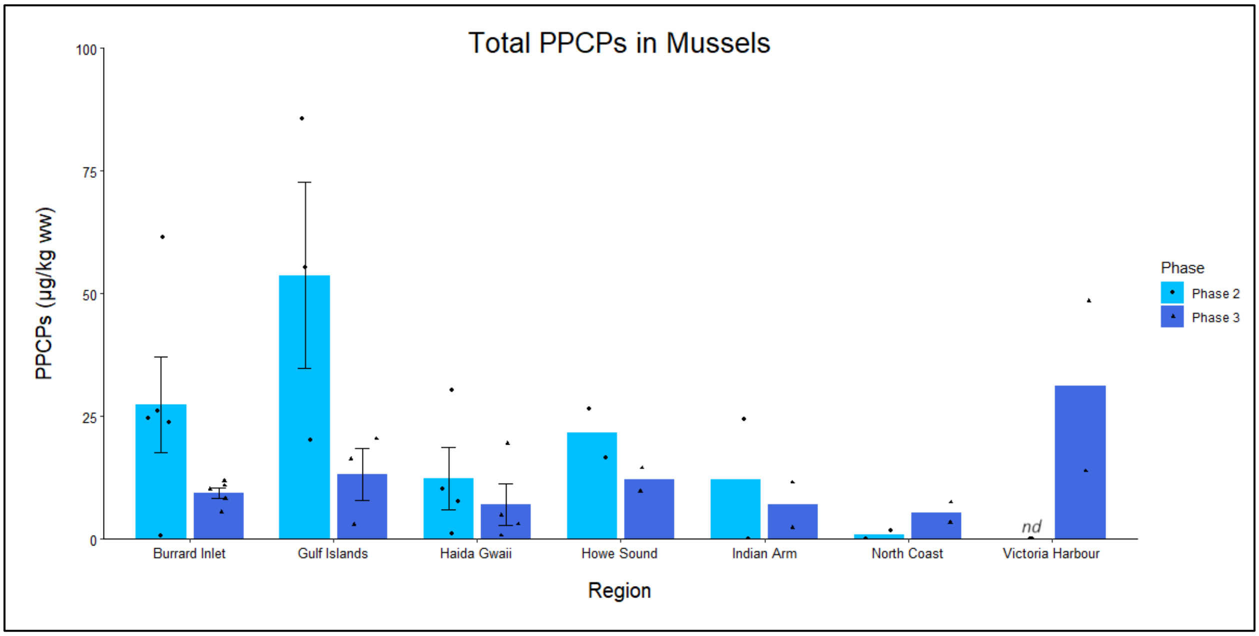

Figure 21. Total concentrations of pharmaceuticals and personal care products (PPCPs) detected in mussels across regions for Phases 2 and 3. Note *nd* = not detected.

Table 3: Individual PPCPs detected in sediment and mussels during Phases 2 and 3.

PPCP	Description
Amitriptyline	Antidepressant used to treat depression and pain
Benztropine	Medication to treat symptoms of Parkinson's disease
Bisphenol A (BPA)	Used in the manufacturing of polycarbonate plastic
Caffeine	Stimulant
Carbamazepine	Anti-epileptic drug and treatment of trigeminal neuralgia
Clarithromycin	Antibiotic used to treat various bacterial infections
Cocaine	Stimulant most frequently used as a recreational drug
DEET	Most common active ingredient in insect repellants
Diltiazem	Drug used to treat high blood pressure, angina

Diphenhydramine	Antihistamine used to treat allergies, colds
Enrofloxacin	Antibiotic used to treat bacterial infections in domestic animals
Erythromycin-H_2O	Metabolite of erythromycin, an antibiotic used to treat bacterial infections
Flumequine	Antibiotic used primarily to treat bacterial infections in food animals
Furosemide	Medication to treat high blood pressure
Gemfibrozil	Medication used to help lower fats (triglycerides) in the bloodstream
Ibuprofen	Non-steroidal anti-inflammatory drug used to relieve pain
Lomefloxacin	Antibiotic used to treat bacterial infections in humans
Miconazole	Antifungal medication used to treat ringworm, yeast infections
Naproxen	Non-steroidal anti-inflammatory drug used to treat pain and inflammatory diseases
Norfloxacin	Antibiotic used to treat a variety of bacterial infections
Norverapamil	Calcium channel blocker used for hypertension treatment
Ofloxacin	Antibiotic used to treat a variety of bacterial infections in humans
Sertraline	Antidepressant
Simvastatin	Medication used to lower cholesterol
Sulfadimethoxine	Antimicrobial used to treat infections in dogs and cats
Sulfamerazine	Antibacterial agent for various infections
Thiabendazole	Fungicide and parasiticide
Trenbolone acetate	Steroid used to promote muscle growth in livestock
Triclocarban	Antibacterial agent commonly used in soaps
Triclosan	Antibacterial and antifungal agent present in some consumer products
Verapamil	Drug used to treat high blood pressure, angina
Virginiamycin M1	Antibiotic used in livestock; occasionally used to prevent microbial contamination in ethanol fuels
Warfarin	Anticoagulant used to treat and prevent blood clots

Dioxins and Furans (DX/DFs)

Dioxins and furans (DX/DFs) are produced unintentionally during incomplete combustion, as well as during the manufacture of pesticides and other chlorinated substances. Pulp and paper mills in Canada released large amounts of dioxins and furans into the marine environment prior to regulations restricting the use of elemental liquid chlorine. Following these restrictions rapid declines were observed after 1989 (Hagen et al., 1997). There are 75 different dioxins, seven of which are of concern for detrimental health effects. There are 135 different types of furans, with varied toxicity. For comparison to CCME sediment quality guidelines and tissue residue guidelines, DX/DF data are expressed on a TEQ basis (Figures 22, 23, 24). TEQs report the toxicity-weighted concentrations of mixtures of DX/DF and incorporate a measure of the toxicity of individual compounds relative to the most toxic DX/DF compound (2,3,7,8 TCDD).

Sediment and Mussel Results

- **Regional Hotspots** – when expressed on a TEQ basis, the highest average levels of dioxins and furans in sediments across phases were observed in the Victoria Harbour (21.8 ± 2.8 ng TEQ/kg dw) region (Figure 22). Levels of dioxins and furans across all phases were significantly higher in Victoria Harbour when compared to the other regions (Wilcoxon Test, $p < 0.05$), establishing Victoria Harbour as a dioxin and furan hotspot.

- **Sediment Quality Guideline Exceedances** – average concentrations in Victoria Harbour sediments exceeded the **CCME PEL** (21.5 ng TEQ/kg dw) protective of fishthroughout Phases 1 and 2, while site VH3 (Victoria Harbour 3) exceeded this guideline throughout all phases (Figure 23). An exceedance of this CCME PEL indicates that adverse effects to fish are expected to occur frequently. Due to the high capacity of DX/DFs to accumulate in biological tissues, there is also the potential for wildlife that consume these fish to be impacted.

- Average concentrations in sediments from the Victoria Harbour, North Coast, and Burrard Inlet regions exceeded the **CCME ISQG/BC Lower WSQG** (0.85 ng TEQ/kg dw) protective of fish throughout all three phases. The Howe Sound and Indian Arm regions also exceeded this guideline during Phase 2, and Phases 1 and 2, respectively. Concentrations below 0.85 ng TEQ/kg dw indicate adverse effects to fish are expected to occur rarely.

- **Tissue Residue Guideline Exceedances** – mussels collected from site VH4 (Victoria Harbour 4) in the Victoria Harbour region exceeded the **tissue residue guideline protective of mammalian wildlife receptors** (0.71 ng TEQ/kg diet ww) throughout all three sampling phases. Site IA2 (Indian Arm 2) from the Indian Arm region also exceeded this guideline during Phase 2, while site MSL2 (Burrard Inlet 9) from the

Burrard Inlet region and site SOA3 (Howe Sound 3) from the Howe Sound region exceeded this guideline during Phase 1 (Figure 23).

- Across all regions and phases, levels of dioxins and furans did not exceed the tissue residue guideline protective of avian receptors at 4.75 ng TEQ/kg ww (Figure 24).

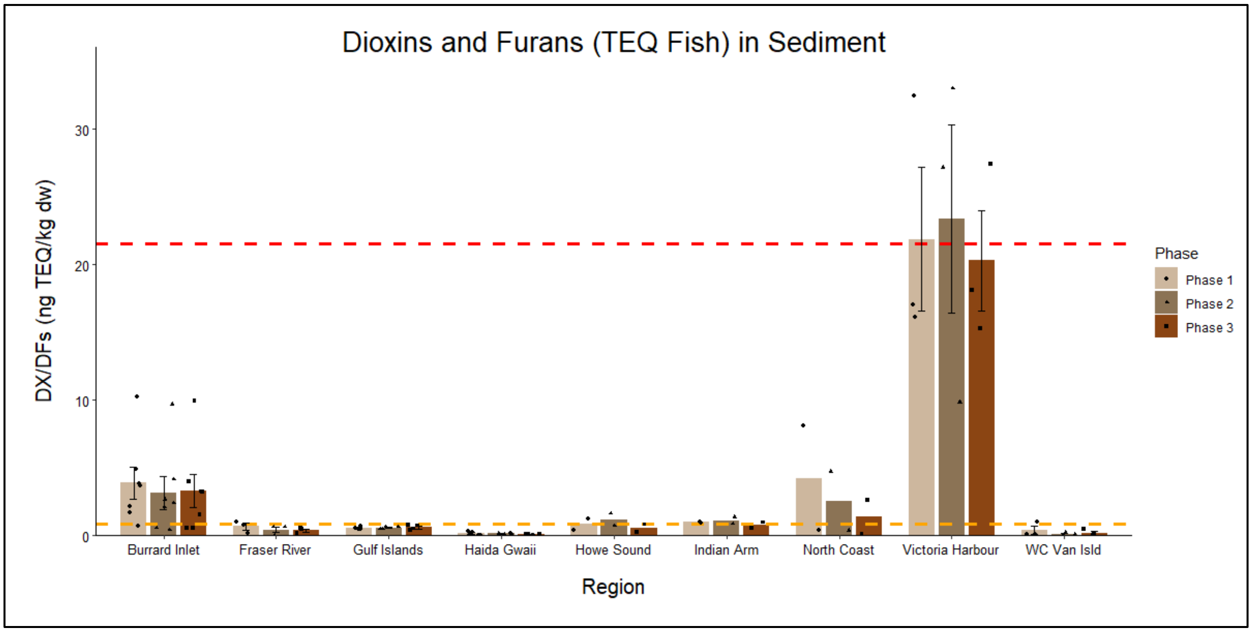

Figure 22. Toxic equivalents (TEQs) of dioxins and furans (DX/DFs) detected in sediment across regions for Phases 1, 2 and 3. The orange broken line represents the CCME ISQG/BC Lower WSQG (0.85 ng TEQ/kg dw) protective of fish while the red broken line represents the CCME PEL (21.5 ng TEQ/kg dw) protective of fish.

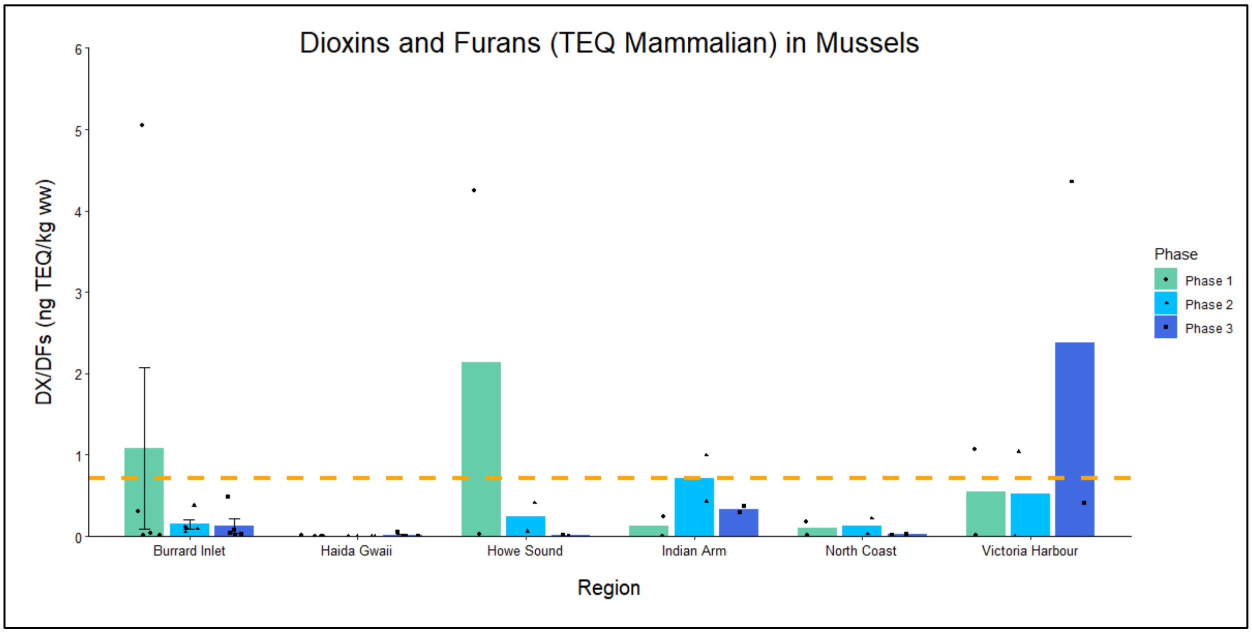

Figure 23. Toxic equivalents (TEQs) of dioxins and furans (DX/DFs) detected in mussels across regions for Phases 1, 2 and 3. The orange broken line represents the CCME tissue residue guideline protective of mammalian receptors (0.71 ng TEQ/kg ww).

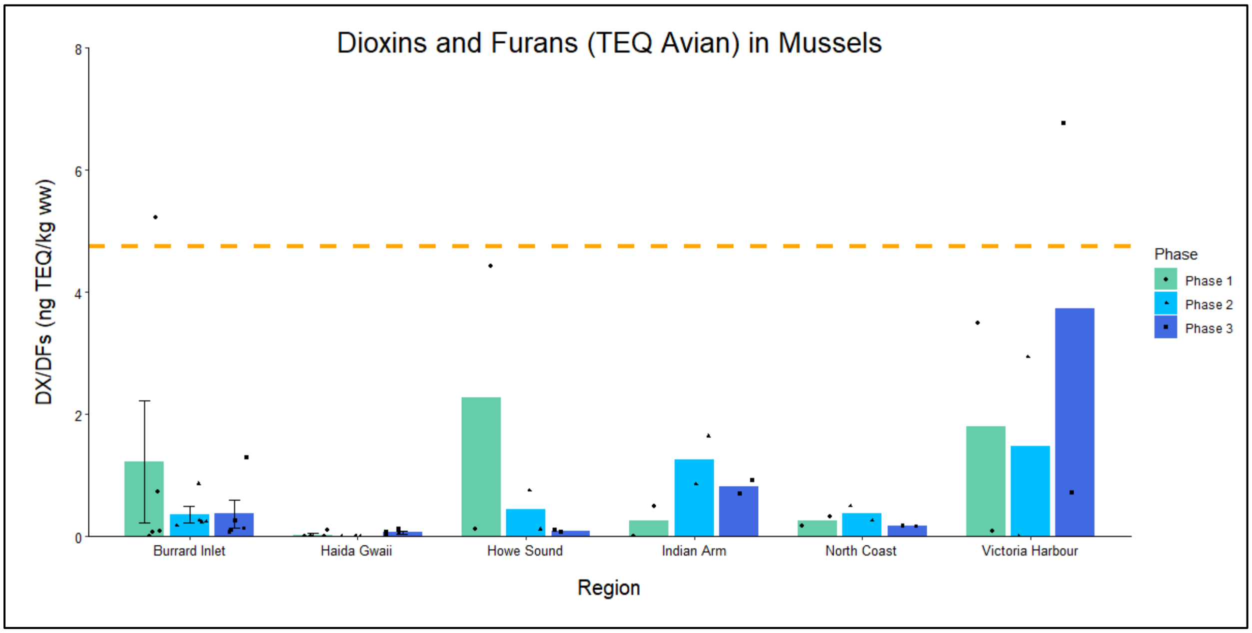

Figure 24. Toxic equivalents (TEQs) of dioxins and furans (DX/DFs) detected in mussels across regions for Phases 1, 2 and 3. The orange broken line represents the CCME tissue residue guideline protective of avian receptors (4.75 ng TEQ/kg ww).

Legacy Pesticides

Organochlorine pesticide use was restricted or banned in the 1970s and 1980s. Nine of the 12 most hazardous persistent organic pollutants targeted by the Stockholm Convention in 2001 are organochlorine pesticides, including dichlorodiphenyltrichloroethane (DDT). Toxicity includes damage to reproductive and neurological systems, carcinogenesis, and endocrine disruption (Garrett and Ross, 2010). All legacy pesticides detected have been banned in Canada and most other countries, although some like hexachlorocyclohexane (HCH), endosulphan, and DDT are still used in some parts of the world to control malaria carrying mosquitos (ATSDR, 2017). Hexachlorobenzene (HCB) continues to enter the environment in small amounts as a by-product of some industrial processes.

Sediment and Mussel Results

- Regional Levels – the highest average total legacy pesticide concentrations were observed in Victoria Harbour (sediment 5.7 ± 0.5 µg/kg dw; mussels 3.458 µg/kg ww), followed by Burrard Inlet (sediment 2.8 ± 1.6 µg/kg dw; mussels 0.6 ± 0.1 µg/kg ww) and the North Coast (sediment 2.1 µg/kg dw; mussels 0.7 µg/kg ww) (Figures 25 and 26). Individual legacy pesticides detected in sediments and mussels across regions and phases are described in Table 5.

- Guideline exceedances - some legacy pesticides detected in sediment exceeded available marine CCME ISQG and BC Working Sediment Quality Guidelines for DDD, DDT, and Hexachlorocyclohexane (HCH) across various regions and phases. These are shown in Table 4.

- There is one available marine CCME tissue residue guideline for legacy pesticides, which is for the total of DDT and its metabolites, DDD and DDE (14 µg/kg diet ww), (CCME, 1999). However, levels of DDT, DDD, and DDE in mussels across all regions and phases did not exceed this guideline.

Table 4. Total legacy pesticide exceedances across regions and phases.

Phase	Regional exceedances			Marine Guideline
	Victoria Harbour	Burrard Inlet	North Coast	
1	No exceedances	SOA7 SOA9	NWC1	CCME ISQG/ BC Working Sediment Quality Guideline for DDT: 1.19 µg/kg dw
		SOA9		CCME PEL for DDT: 4.77 µg/kg dw

		PMV5		CCME ISQG/ BC Working Sediment Quality Guideline for DDD: 1.22 µg/kg dw
2	VH1	No exceedances		CCME ISQG/ BC Working Sediment Quality Guideline for DDT: 1.19 µg/kg dw
	VH1 VH2 VH4			BC Working Sediment Quality Guideline for HCH: 0.32 µg/kg dw
	VH1 VH2 VH3 VH4		NWC1	CCME ISQG/ BC Working Sediment Quality Guideline for DDD: 1.22 µg/kg dw
3	VH1	No exceedances	No exceedances	CCME ISQG/ BC Working Sediment Quality Guideline for DDT: 1.19 µg/kg dw
	VH1 VH2 VH4			BC Working Sediment Quality Guideline for HCH: 0.32 µg/kg dw
	VH1 VH2 VH3 VH4			CCME ISQG/ BC Working Sediment Quality Guideline for DDD: 1.22 µg/kg dw

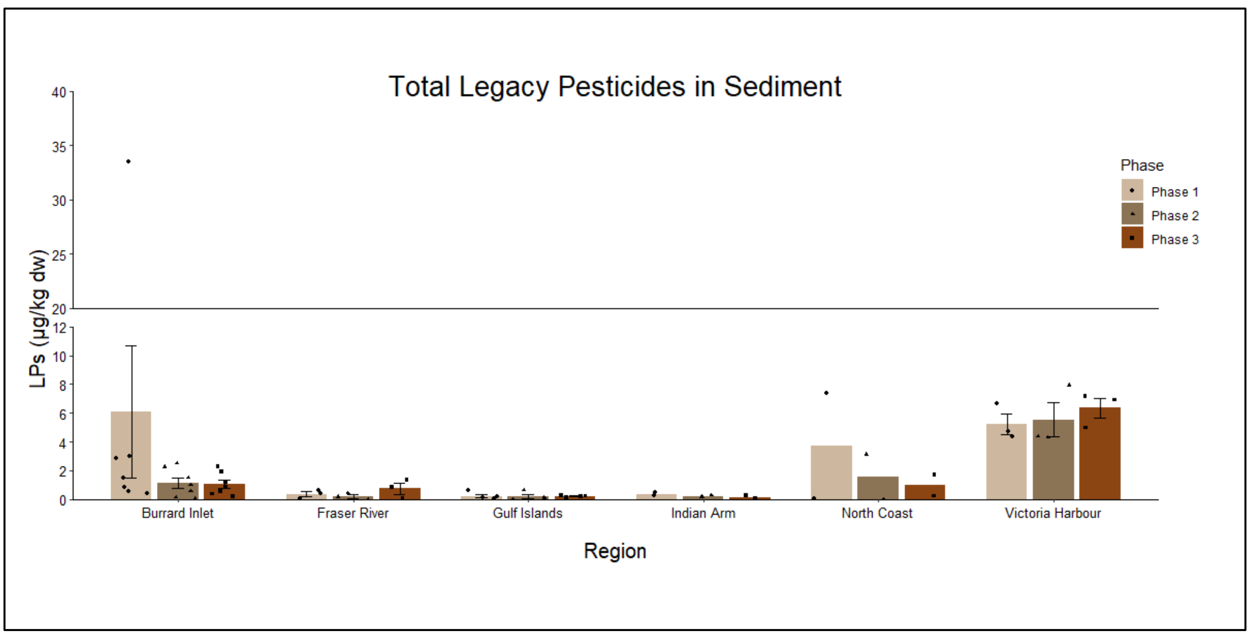

Figure 25. Total concentrations of legacy pesticides (LPs) detected in sediment across regions for Phases

1, 2 and 3.

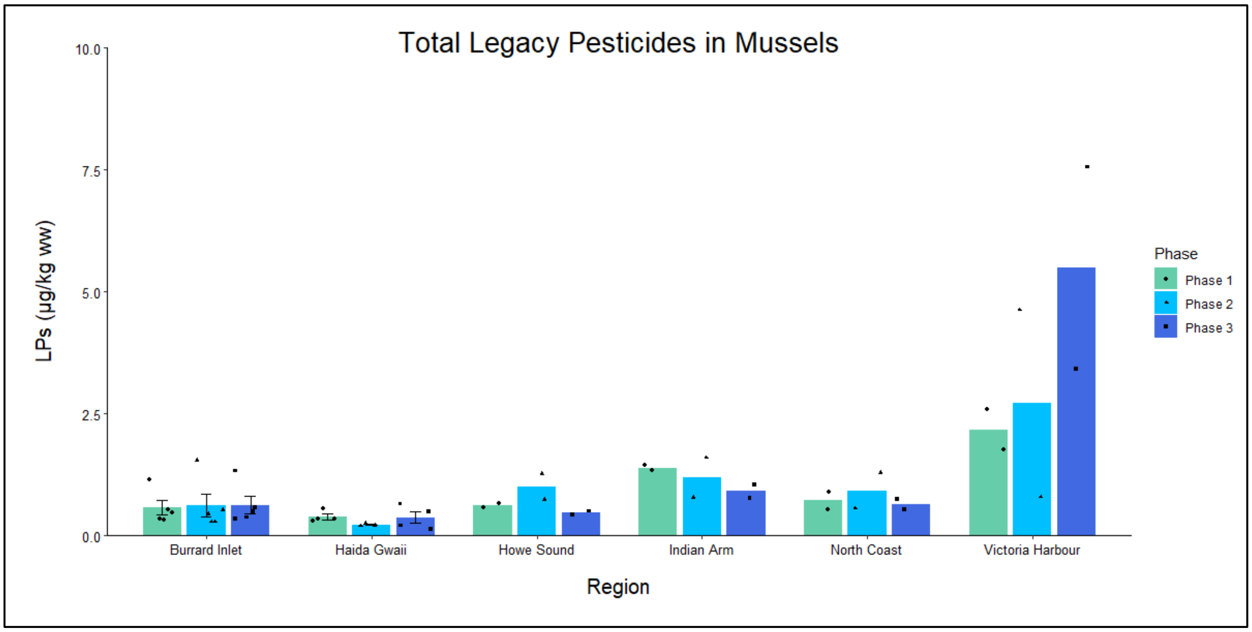

Figure 26. Total concentrations of legacy pesticides (LPs) detected in mussels across regions for Phases 1, 2 and 3.

Table 5: Description and status of legacy pesticides detected in sediments and mussels across all phases.

Pesticide	Use (Health Canada, 2020 and ATSDR, 2017)	Status (Health Canada, 2020; ATSDR, 2017; Stockholm Convention, 2017)	Guidelines (BC MOECCS, 2021 and CCME 2022)
Aldrin	Insecticide to control termites and other insect pests	Banned in Canada and most other countries. Rapidly converts to dieldrin.	BC Working Sediment Quality Guideline (marine): 0.005 µg/g dw
Chlordane	Insecticide to control termites and agricultural insect pests.	Banned in Canada and most other countries.	CCME and BC Working Sediment Quality Guideline (marine): 0.00226 µg/g dw
Dichlorodiphenyl-trichloroethane (DDT) Dichlorodiphenyl-dichloroethylene (DDE)	DDT is a broad-spectrum pesticide, widely used for insects on crops. DDE and DDD are metabolites of DDT. DDE has no	Banned in Canada and most other countries, but still used in some parts of the world for control of malaria-carrying mosquitoes.	DDT: CCME ISQG* and BC Working Sediment Quality Guideline (marine): 1.19 µg/kg dw; 4.77 µg/kg dw (PEL**) DDE: BC Working Sediment Quality

Dichlorodiphenyl-dichloroethane (DDD)	commercial use while DDD was also used as a pesticide.		Guideline (marine): 2.07 µg/kg dw DDD: CCME ISQG and BC Working Sediment Quality Guideline (marine): 1.22 µg/kg dw; 7.81 µg/kg dw (CCME PEL)
Dieldrin	Insecticide used to control termites, textile pests, insect-borne diseases, and insects in agricultural soils.	Banned in Canada and most other countries.	CCME ISQG and BC Working Sediment Quality Guideline (marine): 0.71 µg/kg dw;
Endosulfan	Insecticide to control crop pests, tsetse flies, cattle ectoparasites; wood preservative.	Banned in Canada. Banned/restricted in most countries. Still used in some countries for control of malaria-carrying mosquitoes.	No Sediment Quality Guidelines available; CCME and BC Working Water Quality Guidelines (marine): 0.0016 µg/L
Endrin	Insecticide sprayed on crops and for control of rodents.	Banned in Canada and banned or restricted in most other countries.	CCME ISQG and BC Working Sediment Quality Guideline (marine): 2.67 µg/kg dw; 62.4 µg/kg dw (PEL)
Heptachlor	Insecticide for soil insects and termites, crop pests, and malaria-carrying mosquitoes. The metabolite heptachlor epoxide is more likely to be found in the environment than heptachlor.	Banned in Canada and banned or restricted in most other countries. May still be used in the United States for control of fire ants in underground power transformers.	CCME ISQG and BC Working Sediment Quality Guidelines (marine): 0.6 µg/kg dw; 2.74 µg/kg dw (PEL)
Hexachlorobenzene (HCB)	Gamma-HCH (lindane): Broad-spectrum insecticide for seed and soil treatment, tree and wood applications, veterinary and human applications for ectoparasites (e.g. lice and scabies). Alpha-HCH, Beta-HCH: Insecticides	Gamma-HCH: Still used in some parts of the world for mosquito/malaria control but largely banned and restricted elsewhere. Alpha-HCH, Beta-HCH: Still produced unintentionally as by-products of gamma-HCH.	BC Working Sediment Quality Guideline (marine): 0.00032 µg/g

Hexachlorocyclohexane (HCH)	Gamma-HCH (lindane): Broad-spectrum insecticide for seed and soil treatment, tree and wood applications, veterinary and human applications for lice and scabies. Alpha-HCH, Beta-HCH: Insecticides	Gamma-HCH: Still used in some parts of the world for mosquito/malaria control but largely banned or restricted elsewhere. Alpha-HCH, Beta-HCH: Still produced unintentionally as by-products of gamma-HCH.	BC Working Sediment Quality Guideline (marine): 0.00032 µg/g dw
Heptachlor	Insecticide for soil insects and termites, crop pests, and malaria-carrying mosquitoes. The metabolite heptachlor epoxide is more likely to be found in the environment than heptachlor.	Banned in Canada and banned or restricted in most other countries. May still be used in the United States for control of fire ants in underground power transformers.	CCME ISQG and BC Working Sediment Quality Guidelines (marine): 0.6 µg/kg dw; 2.74 µg/kg dw (PEL)
Hexachlorobenzene (HCB)	Fungicide to treat seeds of food crops. Produced unintentionally as a byproduct of the manufacture of certain industrial chemicals.	Banned in Canada and most other countries but continues to enter the environment in small amounts as a by-product of some industrial processes. Was never manufactured in Canada.	CCME ISQG and BC Working Sediment Quality Guidelines (marine): 0.0038 µg/g dw; 0.023 µg/g dw (PEL)
Mirex	Insecticide for ants and termites; fire retardant in plastics, rubber, and electrical goods.	Banned or restricted in Canada and most other countries. Was never registered for use as a pesticide in Canada.	No marine guidelines available

*Note: *ISQG = interm sediment quality guideline; **PEL = probable effects level*

Current Use Pesticides (CUPs)

Current use pesticides (CUPs) are generally more target-specific and less persistent than legacy pesticides but may be more acutely toxic. CUPs include a wide range of chemicals with different modes of action (Garrett and Ross, 2010). CUPs typically enter the aquatic environment via surface runoff from treated areas, stormwater discharges, groundwater infiltration, and atmospheric deposition. Complex mixtures of pesticides are present in urban, agricultural, and remote areas of British Columbia (Garrett and Ross, 2010). The CUPs detected in Pollution Tracker samples across regions and phases are described in Table 8.

Sediment and Mussels Results

- Regional detections – CUPs were detected in sediment and mussels sporadically along the British Columbia coast, consistent with their physicochemical properties which allow them to be less persistent in the environment than the legacy pesticides. CUP detections in sediment and mussels across regions are described in Tables 6 and 7, respectively.

- High levels of pendimethalin –The highest average concentrations of CUPs detected in sediments were observed in Burrard Inlet (129 ± 51 μg/kg dw). This was due to the high amount of pendimethalin detected in Burrard Inlet sites SOA4 (Burrard Inlet 8), SOA5 (Burrard Inlet 10), SOA6 (Burrard Inlet 11), SOA7 (Burrard Inlet 12), SOA8 (Burrard Inlet 13), and SOA9 (Burrard Inlet 14) during Phase 1, where concentrations ranged from 121 μg/kg dw to 932 μg/kg dw. However, during Phases 2 and 3, pendimethalin was not analyzed in sediments collected from these same sites, perhaps accounting for the apparent decrease in CUP totals from Phase 1 to Phase 3 as shown in Figure 27. Similarly, a high amount of pendimethalin (830 μg/kg dw) was detected at site NWC1 (Prince Rupert Harbour 1) in the North Coast region during Phase 3 but went undetected in sediment at the same site during Phases 1 and 2. This accounts for the increase in CUP totals from Phase 1 to Phase 3 for the North Coast region (Figure 27). The high levels of CUPs observed in sediment from both the Burrard Inlet and North Coast regions were not reflected in mussels (Figure 28). Pendimethalin is a selective herbicide used to control grasses and weeds but also used on crops such as garlic and dry bulb shallots.

- Guideline - One marine guideline is available for a current use pesticide: chlorpyriphos in sediment, at 8 μg/kg dw (BC MOE and Climate Change Strategy, 2021). Detected levels of chlorpyriphos in sediments throughout all regions and phases were well below this guideline.

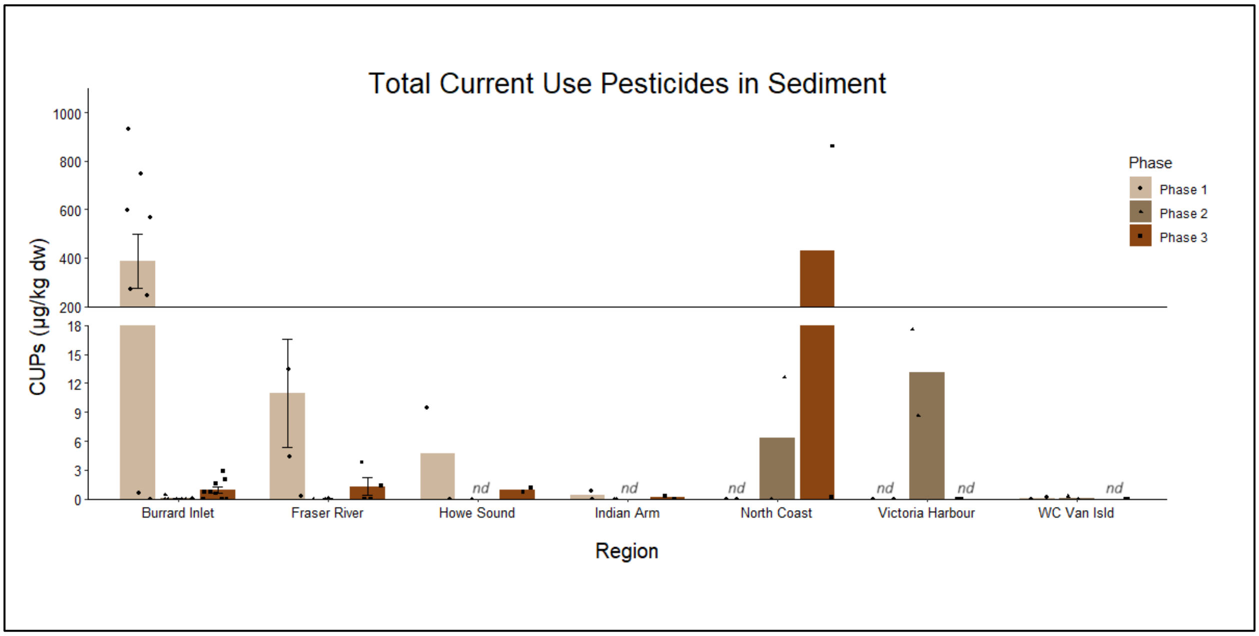

Figure 27. Total concentrations of current use pesticides (CUPs) detected in sediment across regions for Phases 1, 2 and 3. Note: *nd* = not detected.

Table 6. Total current use pesticides detected in sediments across regions and phases.

Phase	Region						
	Burrard Inlet	Fraser River	Howe Sound	Indian Arm	North Coast	Victoria Harbour	West Coast of Vancouver Island
1	Alachlor Octachlorostyrene Pendimethalin Permethrin	Alachlor Pendimethalin	Alachlor Octachlorostyrene Pendimethalin	Alachlor	Not detected	Not detected	Alachlor
2	Chlorpyrifos Octachlorostyrene Permethrin	Alachlor Chlorpyrifos Metolachlor	Not detected	Not detected	Flutriafol	Alachlor Diazinon Flutriafol	Metolachlor
3	Dinotefuran Flutriafol	Alachlor Chlorpyrifos Diazinon-Oxon Flutriafol	Dinotefuran	Alachlor Flutriafol Perthane	Alachlor Chlorpyrifos Desethylatrazine Flutriafol Pendimethalin Permethrin	Cypermethrin Octachlorostyrene Permethrin Tebuconazole	Not detected

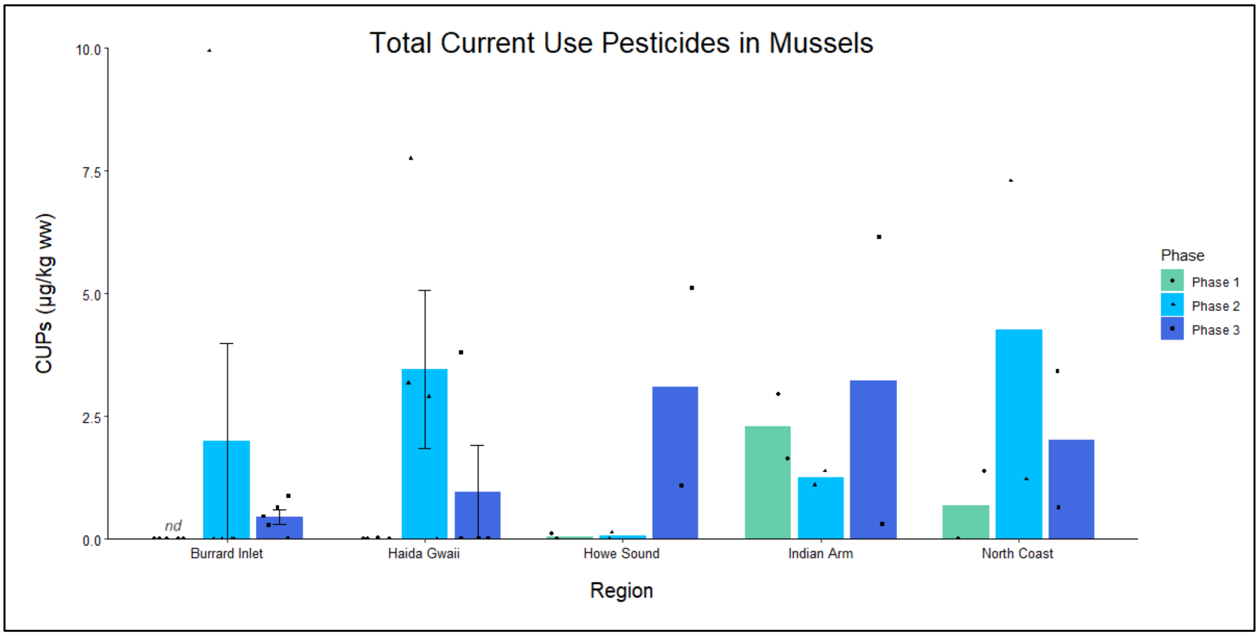

Figure 28. Total concentrations of current use pesticides (CUPs) detected in mussels across regions for Phases 1, 2 and 3. Note: *nd* = not detected.

Table 7. Total current use pesticides detected in mussels across regions and phases.

Phase	Region				
	Burrard Inlet	Haida Gwaii	Howe Sound	Indian Arm	North Coast
1	Trifluralin	Ametryn Trifluralin Turbufos	Trifluralin	Permethrin Trifluralin	Chlorpyriphos Metribuzin Trifluralin
2	Butylate Octachlorostyrene Permethrin	Butylate	Butylate	Butylate Metribuzin	Butylate Metribuzin Permethrin
3	Butylate Chlorpyriphos Tebuconazole	Butylate Chlorpyriphos Diazinon-Oxon Flutriafol Permethrin Quintozene Tebuconazole Trifluralin	Butylate Chlorpyrifos Chlorothalonil Dacthal Permethrin Quintozene	Ametryn Chlorpyrifos Permethrin Terbufos	Ametryn Butylate Metribuzin Metolachlor Turbufos

Table 8. Description and status of CUPs detected in sediments and mussels across regions and phases.

Pesticide	Use	Status	Guidelines

Alachlor	Aniline herbicide used to control grasses and broad-leafed weeds by interfering with protein synthesis and root growth in plants. In Canada, historically used on corn and soybean crops.	Banned in Canada in 1985 due to its carcinogenic potential and a lower risk alternative (metolachlor).	No marine guidelines available
Ametryn	Triazine herbicide used to control broadleaf weeds and grasses. Inhibits photosynthesis and other enzyme processes.	Used in Canada.	No marine guidelines available
Butylate	Selective thiocarbamate herbicide used to control grassy weeds and some broadleaf weeds at the germination stage. Used on corn crops.	Used in Canada (ECCC, 2011).	No marine guidelines available
Chlorpyrifos	Broad spectrum organophosphate insecticide that interferes with the nervous system upon contact.	Restricted use in Canada; banned or restricted in other countries (Health Canada, 2020).	BC Working Water Quality Guidelines (marine): 0.002 µg/L (BC MOECCS, 2021); sediment quality guideline 8 µg/kg dw.
Chlorothalonil	Broad spectrum organochlorine fungicide; wood protectant; insecticide.	Restricted use in Canada (Health Canada, 2016). Although most organochlorine pesticides have been banned in North America, chlorothalonil is still in use.	BC Working Water Quality Guidelines (marine): 0.36 µg/L (BC MOECCS, 2021)
Cypermethrin	Insecticide used for both large scale agricultural and domestic purposes.	Used in Canada.	No marine guidelines available
Dacthal	Herbicide used to control annual grasses and broadleaf weeds.	Not sold, distributed or applied in Canada. (Health Canada PMRA, 2025).	No marine guidelines available
Desethylatrazine	A metabolite of atrazine; a systemic herbicide which is a known endocrine disruptor.	Atrazine has restricted use in Canada; banned in the European Union since 2004 (Health Canada PMRA, 2023).	No marine guidelines available
Diazinon/ Diazinon-Oxon	Used to control pest insects in soil, on plants, and fruit and vegetable crops.	Used in Canada. Banned for residential use in the U.S., but still approved for agricultural uses.	No marine guidelines available
Dinotefuran	Broad-spectrum neonicotinoid insecticide used to control various	Used in Canada (Health Canada, 2019)	No marine guidelines available

	insect pests in agriculture, pest control and veterinary medicine.		
Flutriafol	Fungicide used to control fungal disease on grapes, apples, strawberries, and soybeans.	Used in Canada (Health Canada, 2015).	No marine guidelines available
Metolachlor	Herbicide used to control broadleaf weeds and grasses.	Used in Canada	BC Working Water Quality Guidelines for (freshwater) is 7.8 µg/L
Metribuzin	Selective triazine herbicide for broadleaf and grass weed control.	Used in Canada (Health Canada, 2019).	No marine guidelines available
Octachlorostyrene	Not a pesticide but highly toxic and persistent; produced during incineration and combustion processes involving chlorinated compounds (Chu et al., 2003).	Included here because it is analyzed along with structurally similar chlorinated pesticides and continues to be a byproduct of industrial activities.	Not a pesticide but highly toxic and persistent; produced during incineration and combustion processes involving chlorinated compounds (Chu et al., 2003).
Pendimethalin	Selective herbicide used on garlic and dry bulb shallots.	Used in Canada (Health Canada, 2012).	No marine guidelines available
Permethrin	Broad-spectrum pyrethroid insecticide used to control pests on crops and home gardens, as well as fleas and ticks on animals, biting flies, and cockroaches.	Used in Canada but currently under review for specific uses (Health Canada, 2017). Most frequently used pyrethroid in the United States.	No marine guidelines available
Perthane	Organochlorine insecticide used for pest control.	Used in Canada	No marine guidelines available
Quintozene	Organochlorine fungicide used in soils and seeds.	Restricted use in the United States, and still in use in other parts of the world. As of 2015, quintozene is no longer used in Canada (Health Canada, 2016).	No marine guidelines available
Tebuconazole	Systemic fungicide used to control fungal diseases on plants.	Used in Canada (Health Canada PMRA, 2021)	No marine guidelines available
Terbufos	Organophosphate insecticide used to control insects in soil. Primarily used on corn, sugar beets, rutabagas.	Used in Canada (Health Canada 2015; 2019).	No marine guidelines available
Trifluralin	Herbicide used to control grasses and broadleaf weeds in a variety of crops.	Used in Canada (Health Canada, 2012).	No marine guidelines available

Alkylphenols

Alkylphenols (APs) are used to make alkylphenol ethoxylates (APEs), used mainly as surfactants in detergents and cleaning products. They are also used as antioxidants, oil additives, and in cosmetics and pesticides. Alkylphenols can take months or longer to degrade in surface waters and sediments. They are endocrine disruptors, mimicking estrogen (EC and HC 2001). Nonylphenol (NP) and nonylphenol ethoxylates (NPEs) are the most widely used AP/APEs (Garrett and Ross 2010). Canada has banned the use of nonylphenol ethoxylates (NPEs) in detergents. Environmental quality guidelines are available for total NP and NPEs in sediment but not available for NP and NPEs in tissues.

Sediment and Mussel Results

- Regional Hotspots – Across phases, the highest average concentrations of NP and NPEs in sediments were observed in the Victoria Harbour (112.8 ± 15.8 µg/kg dw) and Burrard Inlet (60.8 ± 6.8 µg/kg dw) regions. Levels of NP and NPEs in sediment were significantly higher in these two regions when compared to the other seven (Wilcoxon Test, $p < 0.05$), establishing Victoria Harbour and Burrard Inlet as NP and NPE hotspots.

- Guidelines - Total NP and NPEs in sediment were expressed on a toxic equivalency basis (Figure 29). During Phase 3, site specific sediment guidelines based on percent total organic carbon (TOC) were calculated for all sites, and all levels were below Federal Environmental Quality Guidelines (FEQGs).

- Decreasing levels in mussels – Across regions, levels of NP and NPEs in mussels decreased from Phase 1 to Phase 3 (Figure 30) and this decrease was significant (Wilcoxon Test, $p < 0.05$). While levels of NP and NPEs in sediments from most regions also appear to be decreasing from Phase 1 to Phase 3, this decrease was not significant (Wilcoxon Test, $p > 0.05$).

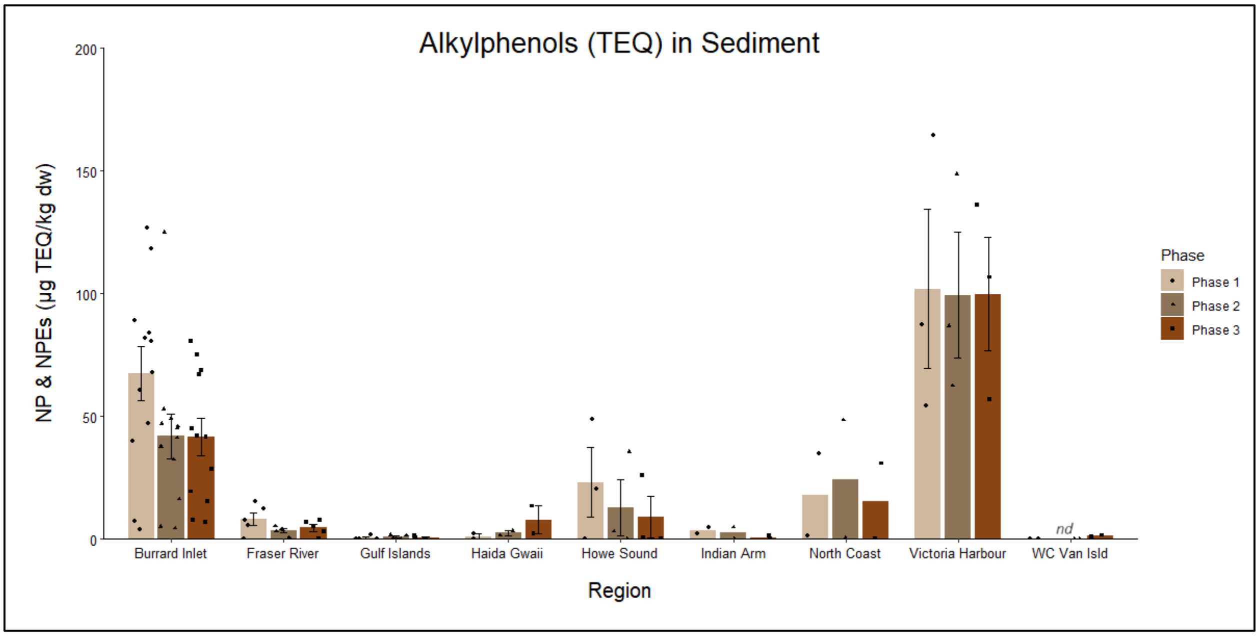

Figure 29. Toxic equivalents (TEQs) of alkylphenols (NP & NPEs) calculated for sediment across regions for Phases 1, 2 and 3. Note: *nd* = not detected.

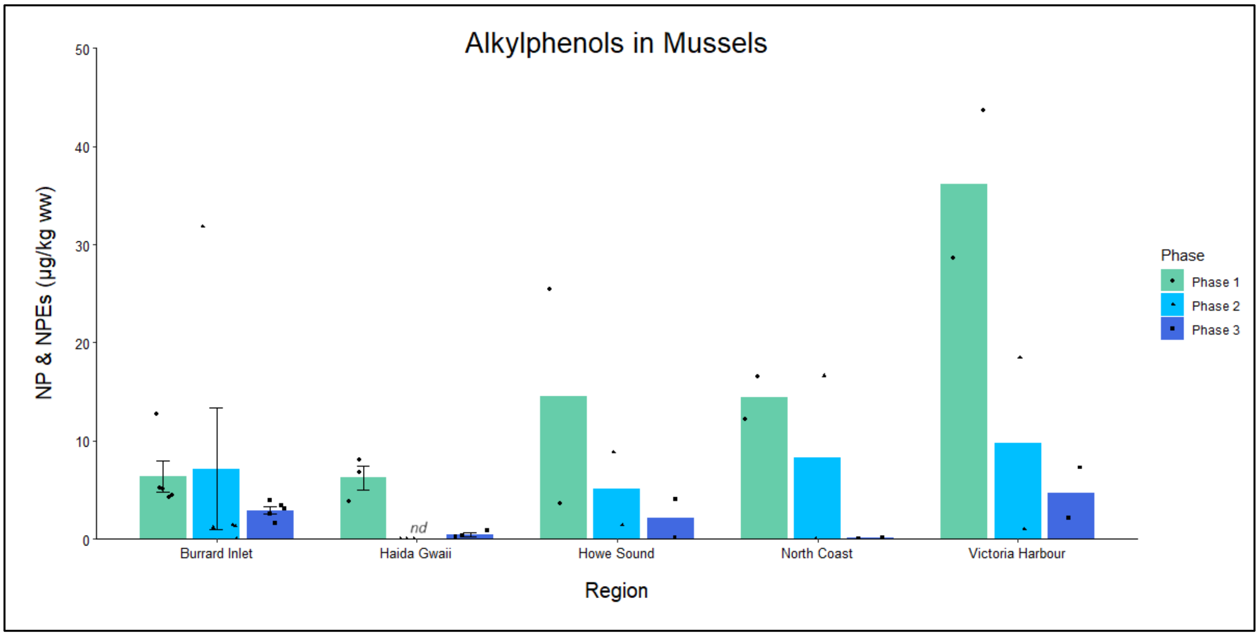

Figure 30. Concentrations of alkylphenols (NP & NPEs) detected in mussels across regions for Phases 1, 2 and 3. Note: *nd* = not detected.

Isotopes

Isotopes are atoms with different atomic weights, differing in their number of neutrons. Isotopes of carbon and nitrogen both naturally occur in two stable isotopic forms, and the ratios of heavy to light isotopes can be used to track sources of carbon- and nitrogen-containing substances, as well as where they end up (e.g., in the marine food chain). Raw isotope data are provided for sediments and mussels in Appendix B1-2 and may be used in future studies.

SUMMARY

The contaminants measured across regions in sediment and mussel samples reflect a variety of factors, including local inputs to the marine environment such as stormwater runoff, discharges from wastewater treatment plants, industrial waste and agricultural runoff. Other factors include historical operations, external inputs (e.g., contaminants carried from other places via oceanic and atmospheric transport and deposition), and oceanographic factors such as currents, water depth, and total organic carbon content in sediments.

Victoria Harbour was the most contaminated region coast-wide, identified as a hotspot for PAHs, PCBs, PBDEs, cadmium, mercury, lead, PPCPs, dioxins and furans, and lastly, NP and NPEs. The second most contaminated regions coast-wide were the North Coast and Burrard Inlet. The North Coast (in particular, Prince Rupert Harbour) was identified as a hotspot for PAHs, PCBs, PBDEs, cadmium, mercury, and lead, while Burrard Inlet was identified as a hotspot for PAHs, PCBs, PBDEs, mercury, PPCPs, and lastly NP and NPEs. These findings are consistent with enclosed or semi-enclosed bodies of water such as harbours and inlets that are associated with highly urbanized and densely populated cities. A summary of guideline exceedances per region is shown in Table 9 below.

Pollution Tracker's high quality, comparable, and accessible contaminant data are a vital and valuable tool for long-term chemical monitoring and ecosystem management. These data improve our understanding of the health of BC's coast and assist in the identification of contaminant hotspots.

Table 9. Summary of regional guideline exceedances across Phase 1, 2 and 3

Contaminant Class	Medium	Region*	Guideline Exceeded
PCBs	Sediment	Victoria Harbour, Prince Rupert Harbour	CCME PEL (189 mg/kg dw)
		Victoria Harbour, Prince Rupert	CCME ISQG / BC Lower WSQG (21.5 µg/kg dw)

		Harbour, Burrard Inlet	
		All Regions	BC Lower WSQG protective of marine mammals (0.0037 µg/kg dw)
PBDEs	Sediment	Victoria Harbour	BC Lower WSQG protective of killer whales (1 µg/kg dw)
Metals (Cadmium)	Sediment	North Coast, Haida Gwaii	CCME ISQG / BC Lower WSQG (0.7 mg/kg dw)
Metals (Lead)	Sediment	North Coast, Victoria Harbour	CCME ISQG / BC Lower WSQG (30.2 mg/kg dw)
Metals (Mercury)	Sediment	Victoria Harbour	CCME ISQG / BC Lower WSQG (0.13 mg/kg dw)
DXDFs	Sediment	Victoria Harbour, North Coast, Burrard Inlet, Howe Sound, Indian Arm	CCME ISQG / BC Lower WSQG protective of fish (0.85 ng TEQ/kg dw)

** At least one site in the region exceeded the guideline over at least one phase.*

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APPENDIX

APPENDIX A: POLLUTION TRACKER SITES SAMPLED FOR SEDIMENT AND MUSSELS DURING PHASE 1, 2 AND 3.

Sample ID	Phase 1		Phase 2		Phase 3	
	Sediment	Mussels	Sediment	Mussels	Sediment	Mussels
DIX	√		√		√	√
WCVI1	√		√		√	
WCVI2	√		√		√	
VH1	√		√	√	√	
VH2	√		√		√	√
VH3	√		√		√	
VH4	√	√	√	√	√	√
PB	√	√	√	√	√	√
AH1	√		√	√		√
SAT	√	√	√	√	√	√
GINP1	√	√	√	√	√	√
GINP2	√	√	√	√	√	√
SBA1	√		√		√	
SBA2	√		√		√	
Site 5-2	√		√		√	
Site 7-2	√		√		√	
FR1	√	√	√		√	
SOA3	√	√	√	√	√	√
SOA4	√	√	√	√	√	√
SOA5	√	√	√	√	√	√

Sample ID	Phase 1		Phase 2		Phase 3	
	Sediment	Mussels	Sediment	Mussels	Sediment	Mussels
SOA6	√		√		√	
SOA7	√		√		√	
SOA8	√		√		√	
SOA9	√		√		√	
West Bay/MSL2		√		√		√
Acadia/MSL5		√		√		√
PMV1	√	√	√	√	√	√
PMV2	√		√		√	
PMV3	√	√	√	√	√	
PMV4	√	√	√	√	√	
PMV5	√		√		√	
PMV6	√	√	√	√	√	
PMV7	√		√		√	√
LG61	√		√		√	√
HS1	√	√	√	√	√	√
IA1	√	√	√	√	√	√
IA2	√	√	√	√	√	√
NWC1	√	√	√	√	√	√
NWC2	√	√	√	√	√	√
HG1	√	√	√	√	√	√
HG2	√	√	√	√	√	√

Sample ID	Phase 1		Phase 2		Phase 3	
	Sediment	Mussels	Sediment	Mussels	Sediment	Mussels
HG4	√		√	√	√	√
HG5	√	√	√	√	√	√
HG6	√	√	√		√	√

APPENDIX B1: STABLE ISOTOPE AND BIOGENIC SILICA IN SEDIMENT FOR PHASE 1, 2 AND 3.

Phase	Site	δ15N (‰)	δ 13C (‰)	Biogenic Silica (%)	%Opal
Phase 1	PTP-DIX	7.7	-21.54	1.511	3.628
	PTP-HG1	5.0	-25.77	1.391	3.339
	PTP-HG2	6.1	-23.83	1.473	3.536
	PTP-HG4	5.8	-22.05	1.702	4.086
	PTP-HG5	7.1	-20.00	2.121	5.089
	PTP-HG6	6.9	-19.80	2.042	4.901
	PTP-HS1	8.0	-23.22	1.003	2.408
	PTP-IA2	5.7	-24.02	0.817	1.961
	PTP-NWC1	7.9	-24.58	1.086	2.606
	PTP-NWC2	8.7	-21.70	1.045	2.508
Phase 2	PTP2-GINP1	6.79	-20.77	2.777	NA
	PTP2-GINP2	5.32	-22.51	2.984	NA
	PTP2-PB	6.96	-20.59	2.569	NA
	PTP2-VH1	4.87	-24.71	6.28	NA

Phase	Site	δ15N (‰)	δ 13C (‰)	Biogenic Silica (%)	%Opal
	PTP2-VH2	5.46	-24.73	2.699	NA
	PTP2-VH3	4.87	-23.23	8.59	NA
	PTP2-VH4	5.33	-23.51	5.398	NA
	PTP2-PMV1	4.64	-23.22	5.462	13.108
	PTP2-PMV2	4.38	-24.62	3.084	7.402
	PTP2-PMV3	4.92	-24.30	1.098	2.636
	PTP2-PMV4	3.60	-25.79	1.938	4.651
	PTP2-PMV5	4.57	-24.53	2.096	5.030
	PTP2-PMV6	4.18	-24.35	3.165	7.596
	PTP2-PMV7	4.73	-24.00	3.019	7.245
	PTP2-HS1	7.62	-21.38	1.170	2.808
	PTP2-IA1	1.31	-26.59	2.045	4.908
	PTP2-IA2	5.12	-23.67	1.043	2.503
	PTP2-WCVI 1	7.26	-19.13	2.020	4.848
	PTP2-WCVI 2	6.40	-21.63	1.185	2.843
	PTP2-NWC1	5.10	-23.96	2.278	5.467
	PTP2-NWC2	6.32	-20.59	0.619	1.485
	PTP2-FR1	2.35	-25.15	2.296	5.510
	PTP2-SAT	5.14	-23.21	2.806	6.735
	PTP2-HG1	4.47	-24.88	2.545	6.107
	PTP2-HG2	4.32	-20.20	2.275	5.460

Phase	Site	δ15N (‰)	δ 13C (‰)	Biogenic Silica (%)	%Opal
	PTP2-HG4	6.11	-19.85	3.754	9.009
	PTP2-HG5	5.68	-24.92	4.306	10.335
	PTP2-DIX	7.77	-17.19	NA	NA
	PTP2-HG6	5.97	-18.83	3.598	8.634
Phase 3	PTP3 DIX	7.14	-21.99	1.055	2.532
	PTP3 FR1	1.67	-25.66	1.274	3.058
	PTP3 HG5	6.27	-19.36	1.842	4.422
	PTP3 HG6	6.05	-19.59	4.064	9.754
	PTP3 IA1	1.84	-26.53	1.407	3.376
	PTP3 IA2	5.56	-23.77	0.791	1.9
	PTP3 SAT	6.3	-23.15	1.469	3.527
	PTP3 -WCVI2	7.2	-8.14	0.777	1.864
	PTP3 -HG1	4.28	-25.83	2.033	4.739
	PTP3 -HG2	5.09	-25.15	2.19	5.257
	PTP3 HG4	6.8	-20.86	1.426	3.422
	PTP3 HG1	4.19	-25.66	1.542	3.700
	PTP3 NWC1	5.24	-24.68	1.675	4.020
	PTP3 WCVI1	7.48	-20.13	0.867	2.081
	PTP3 GINP1	6.64	-8.83	1.494	3.586

NA = Not analyzed.

APPENDIX B2: STABLE ISOTOPE IN MUSSELS FOR PHASE 1, 2 AND 3.

Phase	Site	δ15N (‰)	δ 13C (‰)
Phase 1	DIX	8.01	-18.51
	HG1	9.64	-18.34
	HG2	10.01	-18.12
	HG4	7.67	-18.94
	HG5	7.20	-17.93
	HG6	8.09	-18.23
	HS1	7.09	-19.65
	IA2	7.62	-20.30
	NCW1	6.81	-19.05
	NCW2	7.51	-18.17
Phase 2	PMV1	7.15	-19.2
	PMV3	6.38	-17.73
	PMV4	7.00	-19.20
	PMV6	6.44	-19.36
	HS1	7.07	-19.43
	IA1	7.57	-20.98
	IA2	7.47	-18.04
	WCVI5	8.40	-17.96
	NWC1	7.28	-17.38
	NWC2	8.23	-16.48
	SAT	7.25	-19.38

Phase	Site	δ15N (‰)	δ 13C (‰)
	HG1	7.77	-17.06
	HG4	8.09	-16.81
	HG5	7.35	-17.86
	GINP1	7.27	-17.68
	GINP2	6.73	-18.29
	PB	7.16	-19.12
	VH1	8.06	-20.16
	VH4	7.82	-18.71
	DIX	7.77	-17.19
Phase 3	DIX	8.07	-19.24
	1A1	9.12	-20.39
	1A2	8.85	-20.61
	HG2	8.10	-18.10
	HG1	8.08	-19.40
	HG4	9.02	-18.28
	HG5	9.35	-18.91
	HS1	7.73	-20.64
	WCVI5	7.66	-17.03
	NWC1	7.2	-18.8
	SOA5	6.7	-21.0
	SOA4	6.7	-21.3

Phase	Site	δ15N (‰)	δ 13C (‰)
	SOA3	6.2	-21.4
	MSL5	6.5	-20.5
	MSL2	6.7	-21.3