

# Contaminant concentrations in juvenile Chinook salmon (*Oncorhynchus tshawytscha*) collected from Barkley Sound, West Coast Vancouver Island, British Columbia, in 2022

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CONTAMINANT CONCENTRATIONS IN JUVENILE CHINOOK SALMON  
(*ONCORHYNCHUS TSHAWYTSCHA*) COLLECTED FROM BARKLEY SOUND, WEST  
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by

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## ABSTRACT

Noël, M., Loseto, L.L., Colbourne, K., Bartlett, M., Bokvist, J., and Brown, T.M. 2025.

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Chinook salmon (*Oncorhynchus tshawytscha*) are a culturally, economically and ecologically important species in the Northeastern Pacific Ocean. With the marine environment being under tremendous anthropogenic pressure including overfishing, habitat degradation, shipping, climate change and contaminants, Chinook populations have been declining significantly over the past decades. In order to better understand threats associated with contaminant exposure, especially early in life, we collected juvenile Chinook samples in the nearshore marine waters of Barkley Sound on the West Coast of Vancouver Island, BC, in July 2022. Due to the low individual weight, multiple individuals were used to create two composite samples that were analysed for nitrogen and carbon stable isotopes as well as 12 contaminant classes: legacy and current use pesticides, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), dioxins and furans, per- and polyfluoroalkyl substances (PFAS), polycyclic aromatic hydrocarbons (PAHs), pharmaceutical and personal care products (PPCPs), alkylphenols, hexabromocyclododecane (HBCDD), polychlorinated paraffins, brominated and chlorinated flame retardants and metals including mercury. Metals, PAHs and PCBs were the top three contaminants detected with the highest concentrations. For the majority of contaminant classes (except PFCs and pesticides), sample RBC-22-01 had lower concentrations than RBC-22-02 potentially reflecting differences in fish weight and sampling location between the two composite samples. Comparing our results to established effects thresholds, juvenile Chinook salmon from Barkley Sound may be at low risk of exposure to contaminants, specifically PCBs, PBDEs, DDT, PAHs and mercury. However, given the small sample size and literature highlighting impacts of contaminants on juvenile Chinook growth and survival, additional analyses should be conducted to better assess individual and spatial variation in contaminant exposure in Barkley Sound juvenile Chinook.

## RÉSUMÉ

Noël, M., Loseto, L.L., Colbourne, K., Bartlett, M., Bokvist, J., and Brown, T.M. 2025. Contaminant concentrations in juvenile Chinook salmon (*Oncorhynchus tshawytscha*) collected from Barkley Sound, West Coast Vancouver Island, British Columbia, in 2022. Can. Tech. Rep. Fish. Aquat. Sci. 3655: vii + 31 p. <https://doi.org/10.60825/7pxg-md57>

Le saumon quinnat (*Oncorhynchus tshawytscha*) est une espèce importante sur les plans culturel, économique et écologique dans le Nord-Ouest Pacifique. L'environnement marin étant soumis à d'énormes pressions anthropiques, notamment la surpêche, la destruction de l'habitat, le transport maritime, les changements climatiques et les contaminants, les populations de saumon quinnat ont connu un déclin important au cours des dernières décennies. Afin de mieux comprendre les menaces liées à l'exposition aux contaminants, en particulier en début de vie, nous avons prélevé des échantillons de juvéniles dans les eaux côtières de la baie Barkley, sur la côte ouest de l'île de Vancouver, en Colombie-Britannique, en juillet 2022. En raison du faible poids individuel, plusieurs individus ont été utilisés pour créer deux échantillons composites qui ont été analysés pour les isotopes stables de l'azote et du carbone ainsi que 12 classes de contaminants : pesticides anciens et actuels, biphényles polychlorés (BPC), éthers diphényliques polybromés (PBDE), dioxines et furanes, substances per- et polyfluoroalkylées (PFAS), hydrocarbures aromatiques polycycliques (HAP), produits pharmaceutiques et de soins personnels (PPSP), alkylphénols, hexabromocyclododécane (HBCDD), paraffines polychlorées, retardateurs de flamme bromés et chlorés et métaux, dont le mercure. Les métaux, les HAP et BPC étaient les trois contaminants détectés avec les concentrations les plus élevées. Pour la majorité des classes de contaminants (à l'exception des PFC et des pesticides), l'échantillon RBC-22-01 présentait des concentrations plus faibles que RBC-22-02, ce qui reflète potentiellement des différences de poids de poisson et de lieu d'échantillonnage entre les deux échantillons composites. Nos résultats suggèrent que les saumons quinnats juvéniles de la baie Barkley présentent un faible risque lié à l'exposition aux contaminants, notamment aux BPC, PBDE, DDT, HAP et mercure. Cependant, compte tenu de la petite taille de l'échantillon et de la littérature soulignant les impacts des contaminants sur la croissance et la survie des saumons quinnats juvéniles, des analyses supplémentaires devraient être menées afin de mieux évaluer les variations individuelles et spatiales de l'exposition aux contaminants chez les saumons quinnats juvéniles de la baie Barkley.

## INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*), the largest of the Pacific salmon, are a culturally, economically and ecologically important species in the Northeastern Pacific Ocean. They play an important role in the culture and diet of coastal Indigenous communities (Marushka et al., 2019) and in commercial and recreational fisheries (Kristianson and Strongitharm, 2006). They are also the dominant prey for the *Endangered* Southern Resident Killer Whales (SRKW) and *Threatened* Northern Resident Killer Whales (NRKW) inhabiting the coastal waters of British Columbia (BC), Canada, and Washington State (WA), USA. SRKW and NRKW usually prefer older and larger Chinook salmon which comprise 80% of the annual SRKW diet and 87% of NRKW spring and summer diet (Ford et al., 2010; Ward et al., 2010a; Hanson et al., 2021). As prey availability and quality as well as contaminant exposure have been identified as two of the main threats to the recovery of these killer whale populations (Fisheries and Oceans, 2011), better understanding of contaminant concentrations in their preferred prey is key.

The marine environment is under significant anthropogenic pressures including overfishing, habitat degradation shipping, climate change and contaminants (Quinn, 2018). As a result, Chinook populations have been declining significantly over the past decades (Irvine et al., 2020) such that nine of the 17 populations of Chinook salmon in the USA are listed as *Endangered* or *Threatened*, and, 20 populations are assessed as *Endangered* or *Threatened* in Canada (COSEWIC, 2018 2020). Although declines in Chinook salmon abundance are thought to be linked to freshwater, estuarine and marine environmental conditions, contaminants may also play a role, especially exposure to contaminants during their early life stage. For example, exposure to contaminants in freshwater and/or estuaries have been shown to impact growth and survival of juvenile Chinook salmon (Lundin et al., 2019, 2023; Zabel et al., 2004; Meador et al., 2014).

A variety of contaminants have been detected in adult Chinook salmon collected from the West Coast of Vancouver Island (WCVI) (Holbert et al., 2024). Some of the highest concentrations (on a lipid weight basis) of alkylphenols (APs), total hexachlorocyclohexane (HCH), short chain chlorinated paraffins (SCCPs) and medium-chain chlorinated paraffins (MCCPs) have also been detected in WCVI adult Chinook relative to other stocks (Brown and Holbert, unpublished data). Juvenile salmon are exposed to a variety of contaminants during their seaward migration depending on the characteristics and anthropogenic activities of the watershed. In their study of hatchery-reared Chinook salmon, Meador et al. (2014) found that individuals transiting through contaminated estuaries had a survival rate that was 45% lower than for those transiting through uncontaminated estuaries. To better characterize contaminant levels and evaluate their potential impacts on the health of juvenile Chinook, we collected juvenile Chinook salmon throughout Barkley Sound on the WCVI in July 2022 in order to evaluate the levels of 12 different contaminant classes.

## MATERIALS AND METHODS

### STUDY DESIGN

Follow the Fish (FtF) is a research program funded under Fisheries and Oceans Canada's Pacific Salmon Strategy Initiative (PSSI) with the aim to investigate factors that may be limiting the survival of WCVI Chinook salmon. Projects under this program are investigating the distribution, health and condition of juvenile Chinook and the environments they reside in. Salmon surveys target juvenile Chinook salmon during their first year of life using various capture methods in rivers, estuaries and nearshore marine habitats. Efforts focus on sampling

Chinook originating from the Stamp River, Sarita River and Nitinat River populations in Barkley Sound as indicator populations of WCVI Chinook. Tissue samples are collected from fish to support research objectives of multiple projects under FtF, including the investigation of juvenile salmon exposure to contaminants.

## SURVEY LOCATION AND SAMPLE COLLECTION

In 2022, the FtF program carried out purse seine surveys to catch and sample juvenile Chinook in the nearshore marine waters of Barkley Sound. The Somass River, with a drainage basin of 1,412 square kilometers, supplies water to the head of the Alberni Inlet which then open into Barkley Sound on the southwest coast of Vancouver Island. Barkley Sound is roughly 24 km wide and 20 km long (Carter, 1973) and is an area well known for commercial and recreational fishing. Other anthropogenic activities in the area include logging and the presence of a pulp and paper mill in Port Alberni which discharges industrial effluents into the aquatic environment (Alderdice and Brett, 1957; Levings, 1980; Hagen et al., 1997). To investigate exposure of juvenile Chinook salmon to contaminants during the summer growth period, samples were collected on July 27 and 28, 2022. A 275 m long x 20 m deep purse seine net was deployed at 5 sampling locations (Figure 1). A subset of captured juvenile Chinook salmon were euthanized and had their fork length measured and a fin clip taken for genetic stock identification. Whole fish were frozen in the field using liquid nitrogen and sent to the Pacific Science Enterprise Center, West Vancouver, BC, where they were stored at -80 until further analyses.

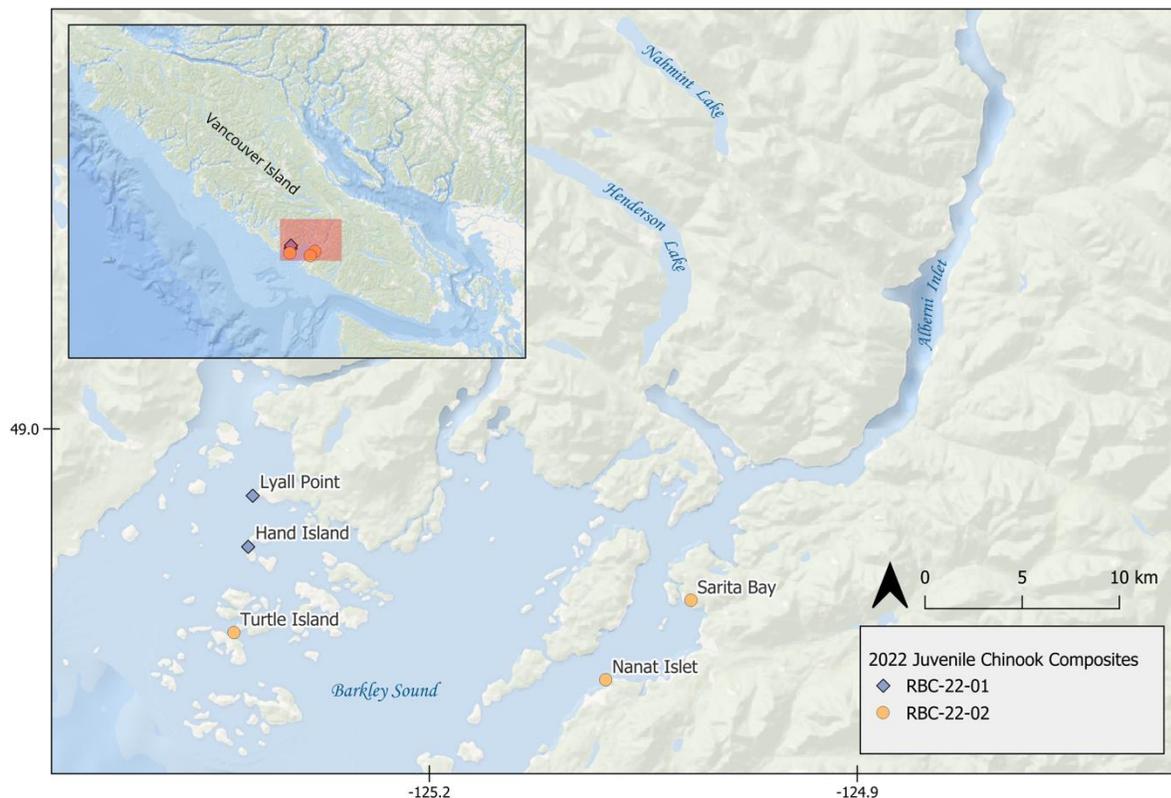


Figure 1. Juvenile chinook samples were collected at different sites within Barkley Sound, British Columbia, Canada, and pooled into two composite samples RBC-22-01 and RBC-22-02.

## LABORATORY ANALYSIS

### Genetic Stock Identification

Fin clips collected in the field were sent to the Molecular Genetics Lab to determine stock of origin of fish using genetic stock identification (GSI) and parentage-based tagging (PBT) methods (Beacham et al., 2018).

### Stable isotope and contaminant analyses

Due to the low individual weight, multiple individuals had to be pooled to create a composite sample with enough material for the whole suite of analyses (Table 1). Fish for each composite were selected based on their matching stock and collection site. Individually packaged whole fish were shipped to SGS AXYS Analytical Ltd for homogenization and processing. Unused material from each composite was returned to DFO and subsequently sent to the Freshwater Institute Biotracers Laboratory in Winnipeg, MB, for stable isotope analyses and ALS Canada Ltd. in Burnaby, BC, Canada for metal analyses.

Table 1: Weight, length and origin of the Robertson Creek juvenile Chinook salmon collected to create the two composite samples. (GSI: Genetic Stock Identification; PBT: Parentage-Based Tagging)

Sample ID	Composite ID	Collection Date	Site	Weight (g)	Fork length (mm)	Adipose Clip Status	GSI vs PBT
P8001	RBC-22-01	7/28/2022	Hand Island	14.7	108	Unmarked	GSI
P8011	RBC-22-01	7/28/2022	Hand Island	27.4	134	Unmarked	PBT
P8006	RBC-22-01	7/28/2022	Hand Island	5.5	85	Unmarked	GSI
P8016	RBC-22-01	7/28/2022	Hand Island	6.3	81	Unmarked	GSI
P8859	RBC-22-01	7/27/2022	Lyll Point	5.6	82	Unmarked	GSI
P8088	RBC-22-02	7/28/2022	Sarita Bay	6.7	83	Unmarked	GSI
P8089	RBC-22-02	7/28/2022	Sarita Bay	4.1	78	Unmarked	GSI
P8058	RBC-22-02	7/28/2022	Nanat Islet	6.9	88	Clipped	GSI
P8879	RBC-22-02	7/27/2022	Turtle Island	8.1	86	Unmarked	GSI
P8884	RBC-22-02	7/27/2022	Turtle Island	6.5	92	Unmarked	GSI
P8889	RBC-22-02	7/27/2022	Turtle Island	13.7	109	Unmarked	GSI
P8894	RBC-22-02	7/27/2022	Turtle Island	8.3	93	Unmarked	GSI

### Stable isotope analysis

Whole body composites were analyzed for carbon and nitrogen stable isotopes at the Freshwater Institute Biotracers Laboratory as described in Rosenberg et al. (2015). Briefly, subsamples were freeze dried and one mg of sample was loaded into tin capsules and analyzed using a Thermo Advantage V Plus continuous flow Isotope Ratio Mass Spectrometer coupled with a Costech 4010 Elemental Analyzer.

Carbon and nitrogen results were expressed using standard delta ( $\delta$ ) notation in units of *per mil* (‰). The delta values of carbon and nitrogen represent deviations from a standard such as

$$\delta_{\text{sample}} = [(R_{\text{sample}} / R_{\text{standard}}) - 1] \times 1000$$

where R is the  $^{13}\text{C}/^{12}\text{C}$  or  $^{15}\text{N}/^{14}\text{N}$  ratio in the sample and the standard. The standards used for carbon was Vienna PeeDee Belemnite (VPDB) and IAEA-N-1 (IAEA, Vienna) for nitrogen.

## Contaminant analyses

Composites were analyzed for 12 different contaminant classes: legacy and current use pesticides, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), dioxins and furans, per- and polyfluoroalkyl substances (PFAS), polycyclic aromatic hydrocarbons (PAHs), pharmaceutical and personal care products (PPCPs), alkylphenols, hexabromocyclododecane (HBCDD), polychlorinated paraffins, brominated and chlorinated flame retardants and metals including mercury (Table 2). Samples were run alongside reference samples and blanks to evaluate method performance.

*Table 2: Methods and laboratories used for the analyses of the 12 contaminant classes in the two juvenile Chinook salmon composite samples.*

<b>Analyte Group (where applicable published reference method indicated)</b>	<b>Laboratory</b>
Legacy and Current Use Pesticides by HRMS (EPA 1699)	SGS AXYS Analytical Ltd.
PCB Congeners by HRMS (EPA 1668C using SPB octyl coelution pattern)	SGS AXYS Analytical Ltd.
PBDE Congeners by HRMS (EPA 1614A)	SGS AXYS Analytical Ltd.
Dioxins and Furans by HRMS (EPA 1613B)	SGS AXYS Analytical Ltd.
PFAS by LC MS/MS Isotope Dilution (EPA 1633)	SGS AXYS Analytical Ltd.
PAHs, Alkylated PAHs, Alkylated PAH Groups by Isotope Dilution GC/MS (8270D modified by EPA 1625)	SGS AXYS Analytical Ltd.
PPCPs by LC MS/MS (Modified EPA 1694)	SGS AXYS Analytical Ltd.
Alkylphenols by Isotope dilution GC/MS or LC MS/MS	SGS AXYS Analytical Ltd.
HBCDD isomers by LC-MS/MS using LC MS/MS isotope dilution quantification	SGS AXYS Analytical Ltd.
Polychlorinated paraffins by LR-GC-MS	SGS AXYS Analytical Ltd.
Brominated and chlorinated flame retardants by isotope dilution GC-(ECNI)-MS	SGS AXYS Analytical Ltd.
Mercury by CVAAS, and metals by CRC ICPMS	ALS Canada Ltd.

## DATA ANALYSIS

All contaminant data were blank-corrected and levels were reported in both wet weight (ww) and lipid weight (lw) basis, when appropriate. Since not all congeners/compounds were detectable in both samples, substitutions had to be applied. For the calculations of totals, individual congener/compound concentrations below the detection limit were treated as zero (Vorkamp et al., 2011).

All data summaries and statistical analyses were conducted using RStudio version 2024.09.1. Since only two samples were available, limited statistical analyses were possible. T-tests were conducted to evaluate the differences in length and weight of the fish that were combined to create the two composite samples.

## RESULTS AND DISCUSSION

### BIOLOGICAL VARIABLES

All the Chinook sampled were from the Robertson Creek stock based on genetic stock information with a probability of assignment greater than 96% for all fish. Two fish were known to originate from Robertson Creek Hatchery: fish P8058 in RBC-22-02 had a clipped adipose fin while fish P8011 in RBC-22-01 had a PBT stock ID, both indicate hatchery-origin (Table 1). The remaining fish had stock information assigned with GSI which could mean that the fish is natural or hatchery-origin for this particular stock and brood year.

The average weight of the fish pooled in the two composite samples were  $11.9 \pm 9.5$  g and  $7.8 \pm 2.9$  g for RBC-22-01 and RBC-22-02, respectively. These weights were not significantly different between composite samples (t-test:  $p = 0.290$ ; Table 1) but it is important to note that the one hatchery fish (P8011) in the RBC-22-01 composite was much heavier than the other fish (27.4g). It had a PBT brood year of 2021, which means it was less than a year old (sub-yearling) and had migrated to the ocean after hatching in the spring of 2022, much like the other fish collected.

For fork length, the averages were  $98.0 \pm 22.9$  cm and  $89.6 \pm 9.9$  cm for the RBC-22-01 and RBC-22-02 samples, respectively. The average lengths were not different between the two composite samples (t-test:  $p = 0.416$ ; Table 1).

RBC-22-01 had higher lipids (1.09%) compared to 0.95% which may be attributed to the presence of a bigger fish in the pool.

Based on the fork length of fish and PBT results from fish P8011, all fish were presumed to be Chinook in their first year at sea. While the other fish caught were smaller in length and weight than P8011, we can assume that they were also sub-yearling.

### STABLE ISOTOPES

In marine organisms, the majority of contaminants are accumulated through the diet. Evaluating diet and trophic position is therefore useful when investigating contaminant levels in fish. Carbon and nitrogen stable isotope ratios (i.e.  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ) are used as ecological tracers that can provide insights into the structure of marine food webs (Boecklen et al., 2011). While carbon stable isotopes can provide information on the dietary origins of carbon sources (i.e., nearshore vs offshore or benthic/littoral vs pelagic (France, 1995), nitrogen stable isotopes provide information on trophic position in a food web (DeNiro and Epstein, 1978, 1981). The two composite samples had quite a different isotopic signature.

While nitrogen isotope was 12.9 ‰ for the RBC-22-01 sample, it was 10.8 ‰ for the RBC-22-02 sample. On average, the fish from the two composite samples were feeding within the same trophic level or combination of trophic levels (within 3 ‰, Cabana and Rasmussen, 1994). These results are in the higher range of  $\delta^{15}\text{N}$  reported for juvenile Chinook salmon collected at different sites within the Snohomish River (O’Neill et al., 2020).

For carbon, the RBC-22-01 sample had a value of -18.1 ‰ as opposed to -20.7 ‰ for RBC-22-02. Together with the difference observed in nitrogen isotopes, a difference of 2.6 ‰ in carbon isotopes could suggest a difference in trophic level as a small trophic enrichment (0.5–1 ‰) for carbon is usually described from predator to prey (Michener and Kaufman, 2007). These results could also suggest a higher contribution of terrestrial sources of carbon for the RBC-22-02 fish composite sample and may be due to the fish collected by Sarita Bay and Nanat Islet having a stronger freshwater influence being closer to the Albern Inlet where the Somass River discharges.

## OVERVIEW OF CONTAMINANT LEVELS



Figure 2: Total concentrations (ng/g wet weight (ww)) of each contaminant class analyzed in the two juvenile Robertson Creek Chinook salmon composite samples ranked from highest to lowest. \* indicates contaminants not detected

Out of the 12 contaminant classes investigated, metals, PAHs and PCBs were the top three contaminants detected. The rest of the contaminants ranked as follows PFAS > PPCPs > alkylphenols > pesticides > HFR > PCDD/Fs > chlorinated paraffins, HBCDD. Chlorinated paraffins and HBCDD were not detected in any of the samples (Figure 2).

For the majority of contaminant classes (except PFCs and pesticides), sample RBC-22-01 had lower levels than RBC-22-02 with the biggest difference being for PCBs (3.5x or 2x when expressed on lw basis), PPCPs (2.2x or 2.5x when expressed on lw basis) and PAHs (1.3x or 1.5x when expressed on a lw basis).

The lower concentrations reported in the RBC-22-01 sample was surprising and, while the reasons remain unclear, some of the following factors may have played a role:

- As presented above, this specific sample had two fish that were larger and heavier than all the other fish sampled for the study, potentially resulting in a dilution effect of contaminant concentrations. Previous studies have shown that fast growing salmon had lower concentrations of trace elements than slower growing individuals due to growth dilution (Ward et al., 2010b, c).
- Three fish of the RBC-22-02 composite were from Sarita Bay and Nanat Islet which are located in the Trevor Channel portion of Barkley Sound. Oceanographic settings in this channel only allows for intermediate water exchange between Alberni Inlet and the Pacific Ocean potentially trapping contaminants (Syvitski and Shaw, 1995; Carter, 1973) which may have contributed to the general higher levels of contaminants detected in this particular composite sample.

## **METALS**

Metals can be of both natural (bedrocks, volcanoes, forest fires) and anthropogenic sources such as mines, metal smelters and refineries, wastewater treatment plant effluents, urban runoff and landfill leachates (Grant and Ross, 2002).

The same number of metals were detected in both samples (27 metals for RBC-22-01 and RBC-22-02, out of 34 measured). As presented previously, total metal levels were higher in the RBC-22-02 sample (20,110 ug/g ww) compared to the RBC-22-01 sample (17,746 ug/g ww) (Figure 2, Appendix 1).

The same top 6 metals with the highest concentrations were present in both samples (phosphorus, calcium, potassium, sodium, magnesium and zinc, Table 3) and accounted for the majority of metals detected in the samples (>99%). These elements have been classified as essential metals as they are required for the correct functioning of organisms. They are involved in a variety of processes such as signalling, enzyme regulation, muscle contraction or osmotic pressure (Jomova et al., 2025).

Table 3: Top six metals with the highest concentrations (ug/g ww) measured in the two composites of juvenile Chinook salmon.

	RBC-22-01	RBC-22-02
	Phosphorus 5590	Calcium 7020
	Calcium 5570	Phosphorus 6020
	Potassium 3590	Potassium 3330
	Sodium 2300	Sodium 2790
	Magnesium 569	Magnesium 812
	Zinc 45.2	Zinc 58.1
<b>Sum Top 6</b>	17,664	20,030
<b>Percent contribution to total metals</b>	99%	99%

Metals of concern for toxic injury, copper, mercury, cadmium and lead are four metals that have been identified as of concern for Chinook salmon by the Contaminants Technical Working Group (ECCC, 2020).

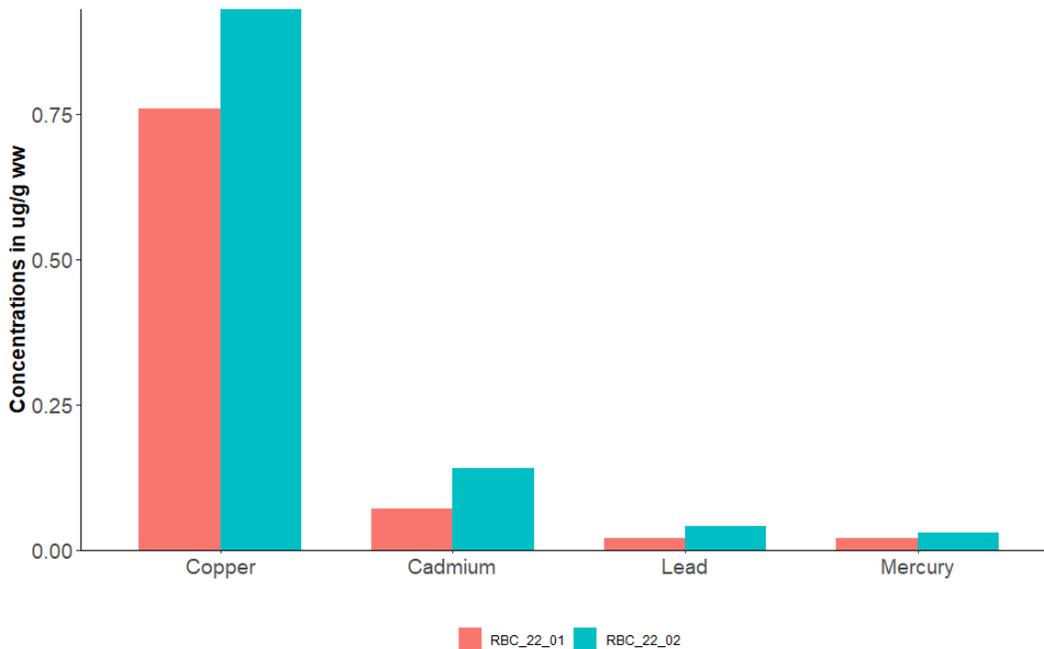


Table 4: Total concentrations (ug/g ww) of copper, cadmium, lead and mercury in the two juvenile Chinook salmon samples.

Copper had the highest concentrations out of the four metals of interest. The levels reported here were in the same range as those reported in juvenile Chinook from Puget Sound (gill tissue, O'Neill et al., 2015). Mercury had the lowest concentrations out of the four metals of interest with similar levels for the two composite samples (0.02 and 0.03 ug/g ww for RBC-22-01 and RBC-22-02, respectively).

A study investigating metal levels in sediment from Barkley Sound found higher levels of cadmium and lead closer to the port Alberni pulp mill as opposed to locations further downstream (Ikehata, 2013). The National Pollutant Release Inventory showed that the Port Alberni pulp and paper mill released 14.7 and 35.7 kg of cadmium and lead, respectively, in 2022 ([National Pollutant Release Inventory Map - Canada.ca](https://www23.ec.gc.ca/npri)). Of note, the mill also released 15 tonnes of phosphorus in 2022, an element that had one of the highest concentrations in our samples.

### PHARMACEUTICALS AND PERSONAL CARE PRODUCTS (PPCPs)

Pharmaceuticals and personal care products (PPCPs) encompass a wide variety of products, from prescription drugs, over the counter medication, dietary supplements, veterinary drugs to cosmetics and sunscreens or laundry and cleaning products (Osuoha et al., 2025). Concerns have grown over PPCPs over the past decade given their widespread release through landfill leaching, wastewater and sewage treatment plants, presence in a variety of environmental matrices and potential for adverse environmental effects (review in Osuoha et al., 2025).

Similar number of PPCPs were detected in both samples (2 and 4 for RBC-22-01 and RBC-22-02, respectively, out of 141 measured). Hydrocortisone was also detected in both samples but, since it was not possible to differentiate between natural cortisol and man-made hydrocortisone, we removed hydrocortisone from the calculations of total PPCPs.

As presented previously, PPCP levels were higher in the RBC-22-02 sample (2.2 ng/g ww or 230.8 ng/g lw) compared to the RBC-22-01 sample (1.3 ng/g ww or 122.8 ng/g lw) (Figure 2, Appendix 1).

*Table 5: Pharmaceutical and personal care products detected in the two juvenile Chinook salmon samples. Concentrations presented in ng/g wet weight with the lipid weight concentration in brackets. \*levels of hydrocortisone are presented just for information but not deemed reliable.*

RBC-22-01	RBC-22-02
Virginiamycin M1 0.71 (64.8)	Clinafloxacin 0.84 (88.4)
Ofloxacin 0.63 (58.1)	Ofloxacin 0.83 (87.6)
	Virginiamycin M1 0.51 (53.8)
	DEET 0.01 (1.1)
<i>Hydrocortisone*</i> 24.8 (2275.2)	<i>Hydrocortisone*</i> 54.8 (5768.4)

N,N-diethyl-meta-toluamide (DEET) is a widely used insect repellent. It was also detected in Puget Sound juvenile Chinook collected in 2013–2014 at higher levels (0.41–2.2 ng/g; Meador et al., 2016). Clinafloxacin, ofloxacin and virginiamycin are all antibiotics so that their detection in juvenile Robertson Creek Chinook clearly indicates anthropogenic sources that have been

discharged into their freshwater or marine environment. Virginiamycin, an antibiotic approved for large animals, was also detected in Puget Sound juvenile Chinook at higher levels (10 ng/g; Meador et al., 2016).

In a study on PPCPs in water from Barkley Sound and Puget Sound, Keil et al. (2011) found that overall levels in Barkley Sound were 10–100 times lower than those reported in Puget Sound. None of the compounds they detected in Barkley Sound water overlapped with the ones we detected in juvenile Chinook salmon in this study.

## POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

Polycyclic aromatic hydrocarbons (PAHs) can be of both natural or anthropogenic sources. In Canada, the dominant source of PAHs is forest fires while anthropogenic sources include residential wood heating, aluminum smelters, creosote-treated products, spills of petroleum products and metallurgical and coking plants (ECCC, 2022a; Health Canada, 2024; Marvin et al., 2021). PAHs can also enter the marine environment through atmospheric deposition, runoff and discharge from wastewater treatment plants (Morales-Caselles et al., 2017).

Similar number of PAHs were detected in both samples (40 and 42 for RBC-22-01 and RBC-22-02, respectively). As presented previously, PAH levels were higher in the RBC-22-02 sample (5.1 ng/g ww or 536.2 ng/g lw) compared to the RBC-22-01 sample (3.9 ng/g ww or 356.7 ng/g lw) (Figure 2, Appendix 1). These levels were lower than those reported for juvenile Chinook salmon collected from various sites in and around an industrial harbour in Oregon, WA (6–28.8 ng/g ww; whole body composite) (Lundin et al., 2021).

The top 6 PAHs with the highest concentrations accounted for just over 50% of total PAHs in both samples (53 and 56% for RBC-22-01 and RBC-22-02, respectively).

*Table 6: The predominant six PAHs with the highest concentrations. Concentrations presented in ng/g wet weight with the lipid weight concentration in brackets.*

	<b>RBC-22-01</b>	<b>RBC-22-02</b>
	C1-Naphthalenes 0.58 (52.9)	C1-Naphthalenes 0.66 (69.1)
	Naphthalene 0.53 (48.9)	C4-Naphthalenes 0.61 (63.7)
	2-Methynaphthalene 0.32 (29.3)	Naphthalene 0.44 (46.2)
	1-Methylnaphthalene 0.26 (23.6)	C2-Naphthalenes 0.36 (37.8)
	Phenanthrene 0.25 (23.1)	1-Methylnaphthalene 0.33 (34.7)
	C2-Fluorenes 0.25 (22.6)	Phenanthrene 0.33 (34.2)
<b>Sum top 6</b>	2.2 (200.4)	2.7 (285.7)
<b>Percent contribution of top 6 to total PAHs</b>	56%	53%

Since PAHs usually originate from multiple sources, ratios of specific PAHs have been used in a variety of matrices to help understand sources and differentiate between natural and anthropogenic sources (Yunker et al. 2002). Given the limited number of PAHs detected, the anthracene (Ant) /phenanthrene (Phe) ratio ( $\text{Ant} / (\text{Ant} + \text{Phe})$ ) and the fluoranthene (Fl) / pyrene (Py) ratio ( $\text{Fl} / (\text{Fl} + \text{Py})$ ) were the only two ratios that could be calculated.

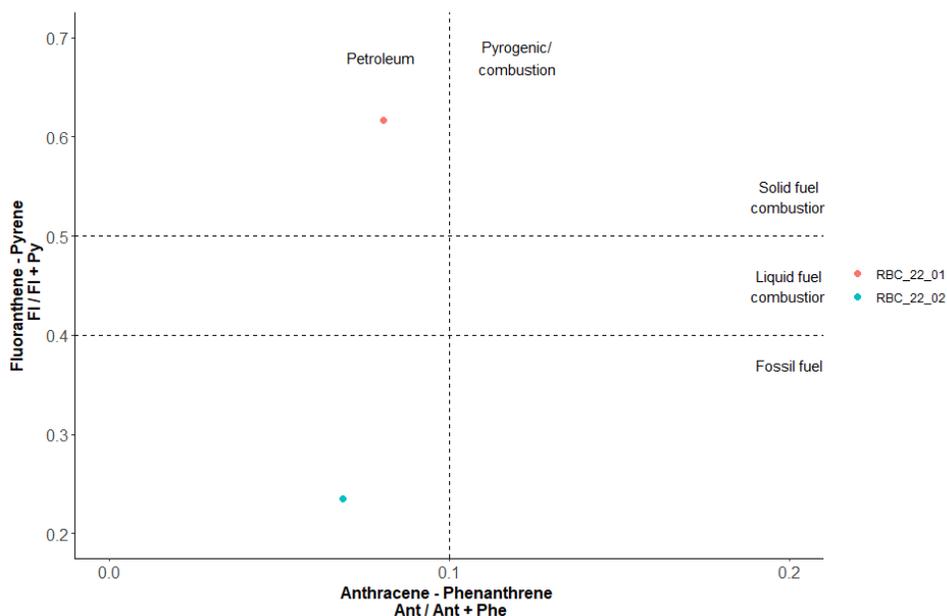


Figure 3: Diagnostic ratios for the two composites, based on PAH concentrations (wet weight) measured in the two juvenile Chinook samples. (Fl: fluoranthene, Py: pyrene, Ant: Anthracene, Phe: phenanthrene).

The two samples had Ant / (Ant + Phe) ratio < 0.1 (0.08 and 0.07 for RBC-22-01 and RBC-22-02, respectively, Figure 3), indicating that PAHs originated from petroleum sources in these samples. An Ant / (Ant + Phe) ratio at or just below 0.1 was characteristic of remote areas in a study looking at sediment in BC (Yunker et al., 2002). While RBC-22-02 had a Fl / (Fl + Py) ratio < 0.4 suggesting the additional contribution of petroleum products to PAHs found in this sample, RBC-22-01 had a Fl / (Fl + Py) ratio > 0.5 suggesting the additional contribution of solid fuel combustion (coal, wood or grass) to the source of PAHs for this particular sample. Given the location of sample collection and the similar life stages of the fish in the two composites, these results were surprising and we question what variability may look like in the region and across the fish samples collected. Wood burning for heating homes and wildfires are the major sources of PAHs in Canada (Berthiaume et al., 2021). In addition, biomass burning in Asia has been shown to also deliver PAHs through air masses travelling across the Pacific Ocean (Berthiaume et al., 2021). PAH contamination from solid fuel combustion is usually expected in more remote areas while a petroleum signature is usually associated with vehicle emissions in urban locations (Yunker et al., 2002).

## POLYCHLORINATED BIPHENYLS (PCBS)

Polychlorinated biphenyls (PCBs) are persistent organic pollutants (POPs) that were heavily used electrical and hydraulic equipment as well as paint additives, sealing and caulking compounds and inks, starting from 1929. Due to their persistence in the environment and their adverse health effects, they were banned in the 1970s. However, they remain among the top contaminant class of concern in marine food webs and is the dominant contaminant class

measured in adult Chinook salmon stocks and SRKW in the Northeastern Pacific (Ross et al., 2000; Holbert et al., 2024).

Similar number of PCB congeners were detected in both samples (138 and 137 for RBC-22-01 and RBC-22-02, respectively). As presented previously, PCB levels were higher in the RBC-22-02 sample (4.6 ng/g ww or 479.8 ng/g lw) compared to the RBC-22-01 sample (1.3 ng/g ww or 118.9 ng/g lw) (Figure 2, Appendix 1). These levels appeared higher, on a lw basis, than those reported for adult Chinook salmon also collected from WCVI ( $78.1 \pm 10.5$  ng/g lw; Holbert et al., 2024). PCB levels in our study were five times lower (on a lw basis) than those reported for juvenile salmon (composite sample without the gut and the brain) collected at more contaminated locations within the Snohomish River watershed, Puget Sound, Washington (21 ng/g ww or 1500 ng/g lw, O'Neill et al., 2020) and lower than levels reported juvenile Chinook salmon collected from various sites in and around an industrial harbour in Oregon, WA (27–59 ng/g ww; whole body composite) (Lundin et al., 2021).

The homologue group contribution was comparable between the two samples with a dominance of penta- (24.3 and 15.5% for RBC-22-01 and RBC-22-02, respectively), hexa- (42.2 and 41.3%) and hepta-PCBs (18.6 and 31.6%) (Figure 4) highlighting a PCB signature characterized by the more heavily chlorinated PCB homologue groups.

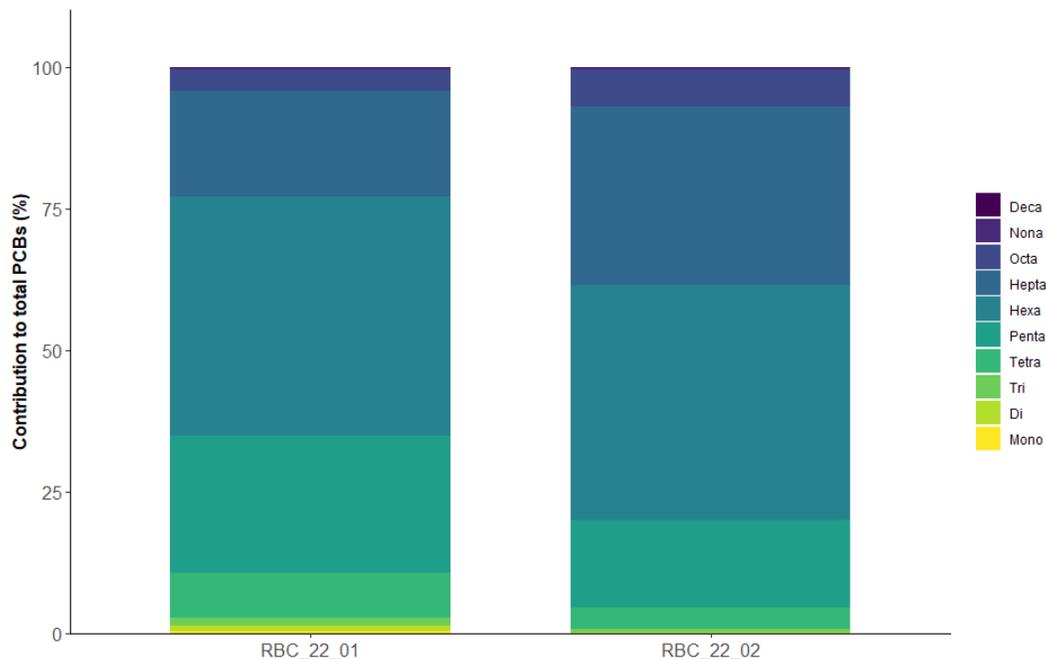


Figure 4: PCB homologue group contribution in the two juvenile Chinook salmon samples.

When looking at individual congeners, the top 6 PCB congeners with the highest concentrations accounted for just under 50% of total PCBs in both samples (44 and 45% for RBC-22-01 and RBC-22-02, respectively). The top 4 PCB congeners with the highest concentrations were the same in both samples: PCB-153+168, PCB-129+138+160+163, PCB-180+193 and PCB-187 (Table 7).

Table 7: Top 6 PCB congeners with the highest concentrations. Concentrations presented in ng/g wet weight with the lipid weight concentration in brackets.

	<b>RBC-22-01</b>	<b>RBC-22-02</b>
	PCB-153+168 0.19 (17.5)	PCB-153+168 0.64 (67.8)
	PCB-129+138+160+163 0.14 (12.8)	PCB-129+138+160+163 0.45 (47.7)
	PCB-180+193 0.06 (5.8)	PCB-180+193 0.36 (38.2)
	PCB-187 0.06 (5.8)	PCB-187 0.33 (34.8)
	PCB-90+101+119 0.06 (5.4)	PCB_147+149 0.14 (23.8)
	PCB-118 0.06 (5.4)	PCB-183+185 0.13 (16.6)
<b>Sum top 6</b>	0.57 (52.7)	2.1 (228.9)
<b>Percent contribution of top 6 to total PCBs</b>	44%	45%

The heavier signature observed in the two samples is usually more typical of a local source signal for PCBs as more chlorinated congeners are less volatile and therefore less likely to travel (Ross et al., 2004; Elliott et al., 1996). PCB-153, -138 and -101 were also reported as the dominant congeners in adult Chinook samples collected along the BC coast from 10 different stocks and reflect the ability of these congeners to bioaccumulate in the food chain (Holbert et al., 2024). However, the overall signature for the West Coast Vancouver Island (WCVI) adult Chinook was on the lighter side which differs from the present results and may reflect the different diet from WCVI adult Chinook going further at sea and therefore further away from potential local sources and juvenile chinook that are feeding close to shore at this stage of their lives.

## PER- AND POLYFLUOROALKYL SUBSTANCES (PFAS)

Per- and poly-fluoroalkyl substances (PFAS) are a large group (~15,000 compounds) of human made substances widely used in a variety of products such as non-stick cookware, clothing, cosmetics, food packaging, firefighting foams, lubricants and oil/water repellents. They are called ‘forever chemicals’ due to their persistence in the environment. PFAS can be released in the environment from the manufacturing plants, locations where firefighting foams have been used such as airports and military installations but also through consumer use and disposal of PFAS-containing products (ECCC and Health Canada, 2025).

A limited number of PFAS were detected in both samples (2 and 4 for RBC-22-01 and RBC-22-02, respectively, out of 40 measured). As presented previously, PFAS levels were similar in both samples (1.9 ng/g ww and 1.6 ng/g ww for RBC-22-01 and RBC-22-02, respectively) (Figure 2, Appendix 1).

While perfluorooctanesulfonic acid (PFOS) and N-ethyl perfluorooctane sulfanamide ethanol (N-EtFOSE) were detected in both samples, perfluoroundecanoic acid (PFUnA) and perfluorotridecanoic acid (PFTrA) were only detected in RBC-22-02. N-EtFOSE was, by far, the

dominant PFAS in each sample (Table 8). N-EtFOSE is attached to phosphate esters in protective paper coatings (Rhoads et al., 2008) and can be transformed into PFOS in the environment via various biotic and abiotic routes (Nguyen et al., 2013; Rhoads et al., 2008). While it is toxic (Vase et al., 2001), PFOS, the breakdown product, is more toxic and bioaccumulative (Lau et al., 2007). PFOS has been added to the list of persistent organic pollutants (POPs) regulated by the Stockholm Convention and the leading manufacturer of PFOS-based compounds ceased production in 2010. PFOS had been detected historically in water samples from Barkley Sound in 2009–2011 at levels that were surprisingly similar to the more industrial/urban Puget Sound (Dinglasan-Panlilio et al., 2014). A recent study suggested that paper mill processing discharge could be an underestimated source of PFAS to the aquatic environment (Chow and Foo, 2023) so the Port Alberni pulp and paper mill could be a potential local source for PFAS.

PFOS (along with PFOA) has been identified as major concern for Chinook salmon by the Contaminants Technical Working Group for the recovery of SRKW. In their study of Puget Sound juvenile Chinook, Meador et al., (2016) reported levels of PFOS (1.2–34 ng/g ww) significantly higher than those reported here.

*Table 8: PFAS analytes detected in the two Robertson Creek juvenile Chinook salmon composite samples. (N-ethyl perfluorooctane sulfonamide ethanol (N-EtFOSE), perfluorooctanesulfonic acid (PFOS), perfluoroundecanoic acid (PFUnA), perfluorotridecanoic acid (PFTrA)). Concentrations presented in ng/g wet weight.*

	RBC-22-01	RBC-22-02
N-EtFOSE	1.8	1.1
PFOS	0.19	0.14
PFUnA	na	0.15
PFTrDA	na	0.17

## ALKYLPHENOLS (AP)

Alkylphenols (APs) and, in particular, alkylphenol ethoxylates (APEs) are chemicals used as surfactants. Nonylphenol (NP) is the most commercially important AP as it is used to produce nonylphenol ethoxylate (NPEO) surfactants which are used in a wide variety of products such as paints, adhesives, washing agents, formulation of pesticides, textile and leather industry, personal care products, cleaner and detergents, etc (Priac et al., 2014). Nonylphenols and NPEs were added to the Canadian List of Toxic Substances as per Schedule 1 of CEPA in 2002. In 2022, the government of Canada released the *Performance Measurement Evaluation for Risk Management of Nonylphenol and its ethoxylates* and concluded that the risk management strategy in place was meeting its intended objectives with lower reported NP and NPE levels but recommended continued monitoring to expand the available dataset and monitor trends over time (ECCC, 2022b).

4-NP was the only AP detected in the two juvenile Chinook samples (Appendix 3) and levels were slightly higher in the RBC-22-02 (1.3 ng/g ww (or 133.4 ng/g lw)) compared to RBC-22-01 (1.1 ng/g ww (or 98.8 ng/g lw)) (Figure 2, Appendix 1). In their study of juvenile Chinook from Puget Sound, Meador et al. (2016) also detected 4-NP at higher levels (30–76 ng/g ww) than those reported here. In addition, they also detected the NPEO which were not detected here.

## PESTICIDES

Pesticides have a wide range of applications. They can be used in agriculture to prevent crop damage or plant disease but also in forestry, industry as well as in private backyards for lawn care or weed and insect control. In Canada, all pesticides used, sold or imported are regulated by Health Canada's Pest Management Agency (Health Canada, 2023a). Most pesticides are applied to terrestrial habitats but can reach the marine environment through overspray or drift during application, surface runoff or long-range atmospheric transport. It is estimated that 10% of pesticides applied to soil reach non-target areas (Schulz, 2004; Anderson et al., 2021). While organochlorine pesticides (OCP) have been restricted in the 1980s due to their persistence, toxicity and bioaccumulative properties, current-use pesticides (CUPs) have been widely applied in recent decades and tend to be more water soluble and more mobile in the aquatic environment (Ding et al., 2023; Harris et al., 2008).

Similar number of pesticide analytes were detected in both samples (22 and 17 for RBC-22-01 and RBC-22-02, respectively, out of 76 measured). As presented previously, total pesticide concentrations were higher in the RBC-22-01 sample (1.2 ng/g ww or 112.8 ng/g lw) compared to the RBC-22-02 sample (0.95 ng/g ww or 99.9 ng/g lw) (Figure 2, Appendix 1).

The top 6 pesticides with the highest concentrations accounted for the majority of total pesticide concentrations (82 and 89% for RBC-22-01 and RBC-22-02, respectively, Table 9). Five of the six pesticides were the same between the two samples: while flutriafol was detected in RBC-22-01 sample, it was not detected at all in RBC-22-02 sample and while cis-nonachlor was in the top 6 for the RBC-22-02 sample, it was detected at much lower concentrations in RBC-22-01.

The majority of pesticides detected in both samples were no longer in use at the time of sampling, therefore detection of these compounds likely reflected historical use nearby and/or deposition from long-range atmospheric transport.

*Table 9: The dominant six pesticides in the two Robertson Creek juvenile Chinook composite samples. Concentrations presented in ng/g wet weight with the lipid weight concentration in brackets.*

	<b>RBC-22-01</b>	<b>RBC-22-01</b>
	4,4' DDE 0.46 (42.0)	4,4' DDE 0.47 (49.3)
	Atrazine 0.24 (22.0)	Atrazine 0.21 (21.7)
	Flutriafol 0.12 (11.3)	Alachlor 0.07 (7.6)
	Alachlor 0.08 (7.7)	Hexachlorobenzene 0.05 (5.3)
	Hexachlorobenzene 0.06 (5.3)	Trans nonachlor 0.03 (2.9)
	Trans nonachlor 0.05 (4.1)	Cis nonachlor 0.02 (2.4)
<b>Sum top 6</b>	1	0.85
<b>Percent contribution to total pesticides</b>	82%	89%

The Contaminants Technical Working Group (ECCC, 2020) has identified current use pesticides and DDT and its metabolites as of concern for Chinook salmon.

Atrazine and flutriafol were the only two pesticides detected that are still in use in Canada. Atrazine is a herbicide used to control grass and broadleaf weeds in corn and sorghum crops. In light of potential human and environmental health risks, Health Canada initiated, in 2017, a special review of all registered products containing atrazine. A second special review of atrazine is currently underway (Health Canada, 2023b). Flutriafol is fungicide providing broad spectrum control of certain ascomycetes and rust fungi on a range of crops (Health Canada, 2015).

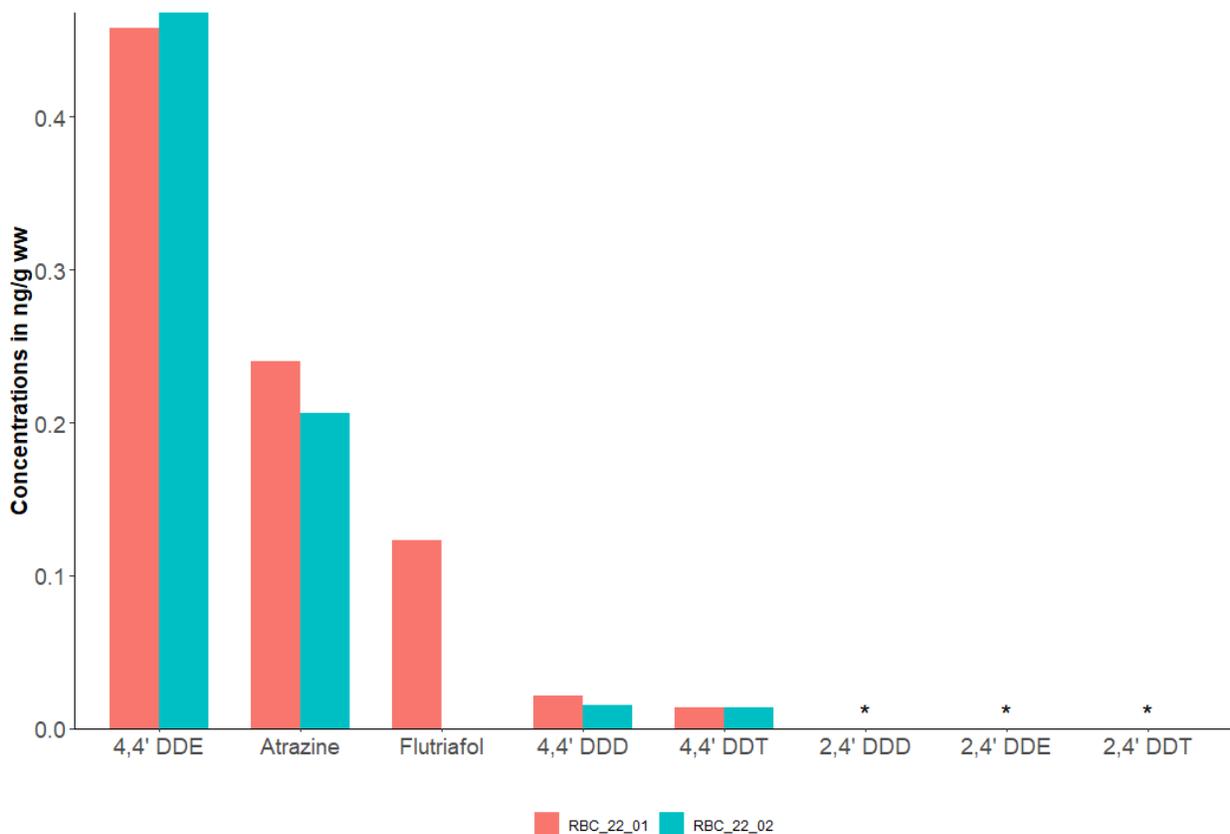


Figure X: Total concentrations (ug/g ww) of 4,4' DDE, atrazine, flutriafol, 4,4' DDD, 4,4' DDT, 2,4' DDD, 2,4' DDE and 2,4' DDT in the two Robertson Creek juvenile Chinook salmon samples. (\* indicates pesticides that were not detected).

DDT and its metabolites were also the most frequently detected pesticides in juvenile salmon from the Sacramento River with 4,4' DDE being dominant. Levels were one to two orders of magnitude higher (Anzalone et al., 2022) than those reported here. Sum DDT in our study (0.49 ng/g ww (or 45.2 ng/g lw) and 0.50 ng/g ww (or 52.3 ng/g lw) for RBC-22-01 and RBC-22-02, respectively) were four times lower (on a lw basis) than those reported for juvenile salmon (composite sample without the gut and the brain) collected at different locations within the Snohomish River watershed, Puget Sound, Washington (2.8 ng/g ww or 210 ng/g lw, O'Neill et al., 2020), with 4,4' DDE also being dominant.

### POLYBROMINATED DIPHENYL ETHERS (PBDES)

Polybrominated diphenyl ethers (PBDEs) were heavily used as flame retardants in a variety of products such as electronic devices, textiles, furniture, appliances or automotive parts.

Similar number of PBDE congeners were detected in both samples (49 and 41 for RBC-22-01 and RBC-22-02, respectively).

As presented previously, PBDE levels were higher in the RBC-22-02 sample (0.57 ng/g ww or 60.4 ng/g lw) compared to the RBC-22-01 sample (0.27 ng/g ww or 24.9 ng/g lw) (Figure 2, Appendix 1). These levels are in the same range, on a lipid weight basis, as those reported for adult Chinook salmon collected from 10 different stocks along the BC coast ( $5.1 \pm 1.2$  ng/g ww or  $53.1 \pm 12.9$  ng/g lw; Holbert et al., 2024). PBDE (sum BDE-47 and -99) levels in our study were 16 times lower (on a lw basis) than those reported for juvenile salmon (composite sample without the gut and the brain) collected at different locations within the Snohomish River watershed, Puget Sound, Washington (9.7 ng/g ww or 660 ng/g lw, O'Neill et al., 2020).

The homologue group contribution was very different between the two samples with a lighter PBDE pattern in the RBC-22-02 sample dominated by tetra- and penta-BDEs (43.9 and 45.4%, respectively) while RBC-22-01 sample had a heavier PBDE signature with nona- and deca-BDEs accounting for 9.5 and 26.8%, respectively (Figure 5).

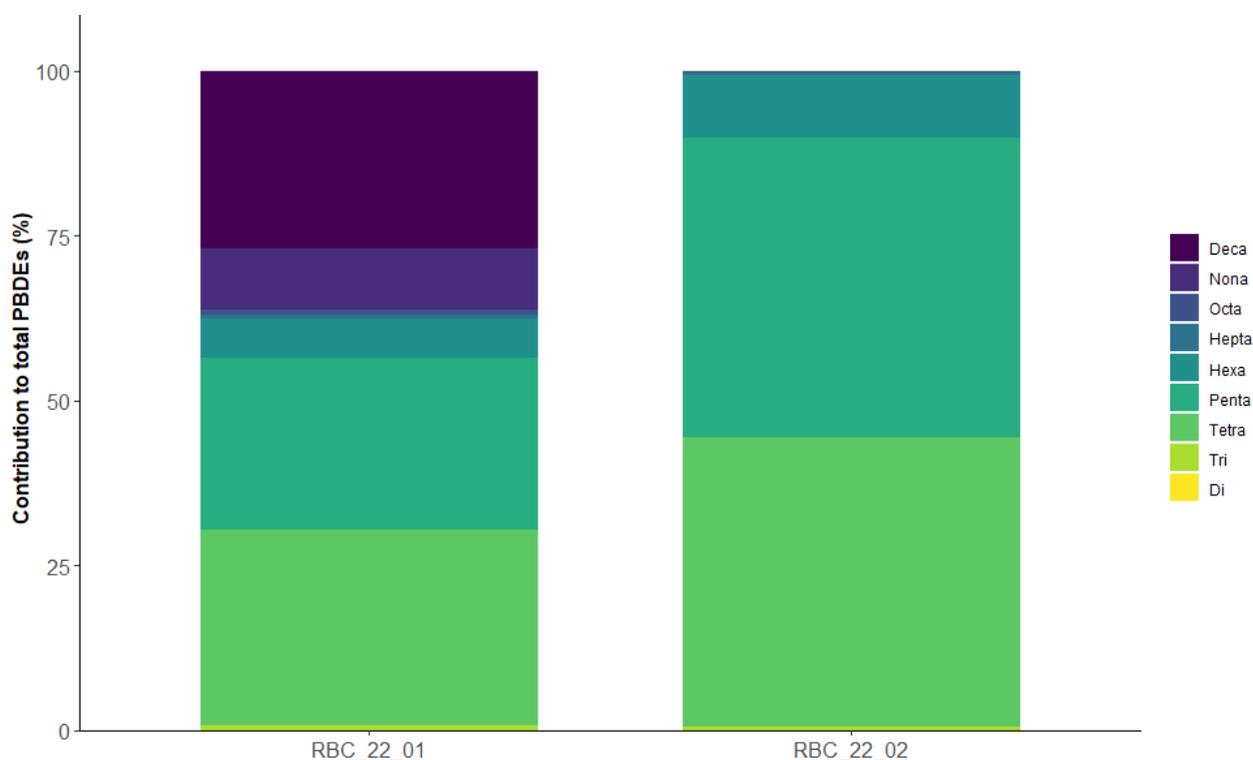


Figure 5: PBDE homologue group contribution in the two Roberston Creek juvenile Chinook salmon composite samples.

When looking at individual congeners, the top 6 PBDE congeners with the highest concentrations accounted for the majority of total PBDE concentrations (85 and 96% for RBC-22-01 and RBC-22-02, respectively). BDE-47, -99 and -100 were present in the top 6 of both samples. While RBC-22-01 had BDE-207, -208 and -209 in the top 6, RBC-22-02 had BDE-49, -153 and -154 (Table 10).

Table 10: Top 6 PBDE congeners with the highest concentrations. Concentrations presented in ng/g wet weight with the lipid weight concentration in brackets.

	<b>RBC-22-01</b>	<b>RBC-22-02</b>
	BDE-47 0.07 (6.7)	BDE-47 0.24 (24.9)
	BDE-209 0.07 (6.7)	BDE-99 0.19 (19.6)
	BDE-99 0.05 (4.2)	BDE-100 0.07 (7.6)
	BDE-100 0.02 (2.3)	BDE-154 0.02 (2.6)
	BDE-207 0.01 (1.2)	BDE-153 0.02 (2.6)
	BDE-208 0.01 (0.91)	BDE-49 0.008 (0.85)
<b>Sum top 6</b>	0.23 (22.0)	0.96 (58.2)
<b>Percent contribution to total PBDEs</b>	85%	96%

The differences observed may reflect variability in the region. The overall pattern was similar to what was observed in adult Chinook salmon from various BC and Washington State stocks where BDE-47 was consistently dominant likely due to the debromination of BDE-99 and BDE-100 into BDE-47 occurring in the food web (Holbert et al., 2024; Kelly et al., 2008; Lv et al., 2020). Holbert et al. (2024) also found that BDE-99 and BDE-100, which are both highly lipophilic and bioaccumulative congeners, were among the top six of the PBDEs detected in adult Chinook salmon. BDE-209 was detected in all stocks in the Holbert et al. (2024) study, except for individuals from the West coast Vancouver Island stock. Since BDE-209 is usually associated with urbanized areas and their contribution was high with samples exhibiting lower PBDE levels, they concluded that its detection was likely a result of lab contamination (Holbert et al., 2024). In the present study, the data was blank corrected but BDE-209 was detected in the blank with levels half of what was detected in RBC-22-01 and at the same levels of what was detected in RBC-22-02 so that its occurrence in the top 6 may also be due to lab contamination. Regarding the other nona-BDEs detected in high levels in RBC-22-01, results should be interpreted with caution as they were flagged by the laboratory and estimated maximum concentrations were reported. These congeners could also be the result of degradation of BDE-209 during the lab analysis procedures.

## **HALOGENATED FLAME RETARDANTS (HFRS)**

Halogenated flame retardants (HFRs) have been used in various products as flame retardants in replacement of PBDEs. They are used as additives so not chemically bound to polymers leading to their leakage during the various stages of the life cycle of products they are in (Birnbaum and Staskal, 2004, Staskal and Birnbaum, 2008).

A limited number of HFRs were detected in the two samples (1 and 2 for RBC-22-01 and RBC-22-02, respectively). As presented previously, total HFR levels were similar between the two samples (0.08 ng/g ww (or 7.6 ng/g lw) and 0.10 ng/g ww (or 10.1 ng/g lw) in RBC-22-01 and RBC-22-02, respectively) (Figure 2 and Table Appendix 1).

While tetrabromo-*o*-chlorotoluene (TBCT) was detected in both samples, 1,2,3,4,5-pentabromobenzene (PBBz) was only detected in RBC-22-01 (Table 11).

Table 11: Halogenated flame retardants detected in the two Robertson Creek juvenile Chinook salmon samples. Concentrations presented in ng/g wet weight with the lipid weight concentration in brackets.

	RBC-22-01	RBC-22-02
<b>PBBZ</b>	Not detected	0.004 (0.42)
<b>TBCT</b>	0.08 (9.7)	0.09 (9.7)
<b>Total HFR</b>	0.08 (7.6)	0.10 (10.1)

Limited information is available on HFRs in the marine environment. Significant trophic magnification has been reported for PBBz and TBCT in marine food webs from Bohai Sea, China and Lake Taihu, respectively (Liu et al., 2021; Zheng et al., 2018; review in Li et al., 2024).

## POLYCHLORINATED DIBENZO DIOXINS / FURANS (PCDD/FS)

Polychlorinated dibenzodioxins / dibenzofurans (PCDD/Fs) enter the environment through the large scale burning of municipal and medical waste. Other sources in Canada include the production of steel and iron, backyard burning of household waste, fuel burning, wood burning, pulp and paper process, electric power generation (Health Canada, 1990). They are highly persistent and have been found in a variety of matrices.

More PCDD/F congeners were detected in RBC-22-01 (n = 6) than in RBC-22-02 (n = 2).

As presented previously, PCDD/F levels were similar in both samples (0.85 ng/g ww (or 78.2 ng/g lw) and 0.91 ng/g ww (or 96.2 ng/g lw) for RBC-22-01 and RBC-22-02, respectively) (Figure 2 and Appendix 1).

There were no furans detected in the RBC-22-02 sample. Octa-CDD (OCDD) was detected in both samples. 2,3,7,8 TCDD and TCDF, the most toxic congeners of dioxins and furans were both detected in the RBC-22-01 sample (Table 12).

Table 12: PCDD and PCDF congeners detected in the two Robertson Creek juvenile Chinook salmon samples. Concentrations presented in ng/g wet weight with the lipid weight concentration in brackets.

RBC-22-01	RBC-22-02
OCDD 0.39 (35.7)	OCDD 0.71 (74.5)
1,2,3,4,6,7,8 HpCDF 0.11 (10.5)	1,2,3,4,6,7,8 HpCDD 0.21 (21.7)
2,3,7,8 TCDF 0.09 (8.7)	
2,3,7,8 TCDD 0.09 (7.8)	
1,2,3,6,7,8 HxCDF 0.09 (7.8)	
1,2,3,7,8 PeCDD	

RBC-22-01	RBC-22-02
0.08 (7.7)	

## EFFECTS

Juvenile Robertson Creek Chinook salmon contaminant concentrations were compared to established effects thresholds for fish to evaluate potential adverse health effects in this stock.

A salmon specific threshold has been developed for PCBs (2,400 ng/g lw; Table 13; Meador et al., 2002) based on various juvenile salmonids studies that reported different effects from enzyme induction to mortality. The levels reported in the present study were below this threshold. More recently, Berninger and Tillit (2019) developed a concentration-response threshold regression for PCB effects in fish based on the meta-analysis of mortality, growth and reproductive threshold responses available in the literature. However, their model was not deemed applicable for tissue concentrations below 100 ng/g ww and, in this study, levels were 1.3 and 4.6 ng/g ww.

For total DDTs, Beckvar et al. (2005) developed a threshold of 600 ng/g ww above which effects on growth, reproduction and survival may be observed in fish. This value was adjusted for lipid content to 6,000 ng/g lw (Johnson et al., 2007) and none of our samples surpassed this threshold (the highest level reported here was 52.3 ng/g lw, two orders of magnitude lower than this threshold). However, it is important to note that this threshold does not take into account sublethal effects such as endocrine disruption or immunotoxicity.

In their lab study, Arkoosh et al. (2010, 2017, 2018) fed juvenile Chinook salmon a diet that reflected the PBDE congeners found in the stomach content of wild juvenile Chinook collected from urban areas. Based on this study, O'Neill et al. (2015) derived a range of PBDE levels associated with increased disease susceptibility and altered thyroid levels (Table 13). Concentrations of total PBDEs in the two Robertson Creek juvenile Chinook composites were below these thresholds.

Finally, for mercury, Beckvar et al. (2005) developed a threshold of 200 ng/g ww above which effects on growth, reproduction and behaviour may be observed in fish. Concentrations of Hg in the two Robertson Creek juvenile Chinook composites were an order of magnitude lower than this threshold.

Table 13: Effects thresholds for fish reported in the literature for PCBs, PBDEs, DDT and mercury.

	Species	Effects observed	Threshold	Reference
<b>PCBs</b>	Various juvenile salmonids	Biochemical and immune system effects	2,400 ng/g lw	Meador et al., 2002
	Fish	Growth, reproduction, mortality	Concentration-response threshold regression	Berninger and Tillit, 2019
<b>PBDEs</b>	Juvenile Chinook salmon	Increased disease susceptibility	470 – 2,500 ng/g lw (BDE-47+99)	Arkoosh et al., 2017, 2018 ; O'Neill et al., 2015

	<b>Species</b>	<b>Effects observed</b>	<b>Threshold</b>	<b>Reference</b>
	Juvenile Chinook salmon	Altered thyroid	1,500 – 2,500 ng/g lw (BDE49+99)	Arkoosh et al., 2017; O'Neill et al., 2015
<b>Sum DDT</b>	Juvenile and adult fish	Effects on behaviour and growth, mortality	6000 ng/g lw	Beckvar et al., 2005; Johnson et al., 2007
<b>Mercury</b>	Juvenile and adult fish	Sublethal effects (growth, reproduction, behaviour)	200 ng/g ww	Beckvar et al., 2005

**CONCLUSION**

This data provides a comprehensive presentation of 12 contaminant classes in Robertson Creek juvenile Chinook salmon from the WCVI not previously available. Other studies reporting contaminant levels in juvenile Chinook samples have mostly been conducted in more urban areas in Puget Sound, WA as well as Oregon (O’Neil et al., 2020; Anzalone et al., 2022; Lundin et al., 2021). The present levels were generally lower than those measured in the aforementioned studies aligning with the fact that the West Coast of Vancouver Island is relatively remote from any major urban or industrial centers. Even though all fish were collected at the same time within Barkley Sound, some differences in concentrations and patterns for some contaminants were observed that may reflect variability of contaminant exposure related to the locations where they were collected in Barkley Sound or variability amongst individuals selected for each of the composite (influence of size).

When comparing our Robertson Creek juvenile Chinook concentrations in the present study to established effects thresholds for fish, results suggest that Robertson Creek juvenile Chinook salmon from Barkley Sound may be at low risk due to contaminants, specifically PCBs, PBDEs, DDT, PAHs and mercury. However, this was based on data for only two composite samples and comparisons with established effects thresholds for fish could only be done for three of the 12 contaminant classes measured, in addition to mercury. Given that both experimental and in the field studies have shown that exposure to contaminants can affect growth and survival of juvenile Chinook salmon (Lundin et al., 2019, 2023 Zabel et al., 2004; Meador et al., 2014), it is recommended that additional analyses be conducted to better evaluate contaminants and associated effects in juvenile Chinook from Barkley Sound.

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Appendix 1. Total concentrations of the 12 different contaminant classes analyzed in the two juvenile Chinook salmon composite samples. Concentrations were blank corrected and reported in ng/g wet weight and lipid weight (in italics). (nd: not detected)

	RBC-22-01	RBC-22-02
Metals	17746340 <i>na</i>	20110700 <i>na</i>
PPCPs	26.1 <i>2398.1</i>	56.9 <i>5999.3</i>
PAHs	3.9 <i>356.7</i>	5.1 <i>536.2</i>
PCBs	1.3 <i>118.9</i>	4.6 <i>479.8</i>
PFAS	1.9 <i>177.9</i>	1.6 <i>169.3</i>
Alkylphenols	1.1 <i>98.8</i>	1.3 <i>133.4</i>
Pesticides	1.2 <i>112.8</i>	0.95 <i>99.9</i>
PBDEs	0.27 <i>24.9</i>	0.57 <i>60.4</i>
HFRs	0.08 <i>7.6</i>	0.1 <i>10.1</i>
PCDD/Fs	0.0006 <i>0.05</i>	0.0009 <i>0.1</i>
Chlorinated paraffins	nd <i>nd</i>	nd <i>nd</i>

	<b>RBC-22-01</b>	<b>RBC-22-02</b>
HBCDD	nd	nd
	<i>nd</i>	<i>nd</i>

Appendix 2. Concentrations of individual metals measured in the two juvenile Chinook composite samples. Concentrations were blank corrected and reported in ug/g wet weight. (nd: not detected)

	RBC-22-01	RBC-22-02
Aluminum	27.4	2.16
Antimony	nd	nd
Arsenic	0.355	0.266
Barium	0.531	0.925
Beryllium	nd	nd
Bismuth	nd	nd
Boron	6.50	6.53
Cadmium	0.0673	0.136
Calcium	5570	7020
Cesium	0.0115	0.0088
Chromium	0.902	2.33
Cobalt	0.0117	0.0238
Copper	0.759	0.927
Iron	21.4	31.4
Lead	0.0166	0.0357
Lithium	nd	nd
Magnesium	569	812
Manganese	1.19	1.63
Mercury	0.0154	0.0295
Molybdenum	0.0412	0.0845
Nickel	0.044	0.670
Phosphorus	5590	6020
Potassium	3580	3330
Rubidium	0.894	0.957
Selenium	0.337	0.379
Sodium	2300	2790
Strontium	21.6	32.0
Tellurium	nd	nd
Thallium	0.00062	0.00076
Tin	0.032	0.051
Uranium	0.00305	0.00405
Vanadium	0.031	0.054
Zinc	45.2	58.1
Zirconium	nd	nd

Appendix 3. Concentrations of individual alkylphenols measured in the two juvenile Chinook composite samples. Concentrations were blank corrected and reported in ng/g wet weight and lipid weight (in italics). (nd: not detected)

	<b>RBC-22-01</b>	<b>RBC-22-02</b>
NP1EO	nd	nd
NP2EO	nd	nd
4-NP	1.1 <i>1.3</i>	98.8 <i>133.4</i>
4n-OP	nd	nd