Water Quality Assessment and Proposed Objectives for Burrard Inlet: Pesticides Technical Report

July 2024

Tsleil-Waututh Nation
səlilwətaɬ

British Columbia

This Technical Report forms part of a series of water quality parameter reports whose purpose is to inform updates to the 1990 Provincial Water Quality Objectives for Burrard Inlet. This report and others in the series assess the current state and impacts of contamination in Burrard Inlet; incorporate new scientific research and monitoring of water quality; and reflect a broader understanding of goals and values, including those of First Nations, to improve the health of the marine waters of Burrard Inlet. Updating the 1990 Provincial Water Quality Objectives is a priority action identified in the Tsleil-Waututh Nation's Burrard Inlet Action Plan which has been an impetus for this work.

ISBN:978-1-0399-0033-2

Citation:
Braig, S., LeNoble, J., and Delisle, K. 2024 Water Quality Assessment and Proposed Objectives for Burrard Inlet: Pesticides Technical Report. Prepared for Tsleil-Waututh Nation and the Province of BC.

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Cover Photograph:
Underwater monitoring equipment is installed from the Tsleil-Waututh Nation boat in Burrard Inlet.

Acknowledgements

Work to update the Burrard Inlet Water Quality Objectives is being led by the Tsleil-Waututh Nation (TWN), in collaboration with the BC Ministry of Environment and Climate Change Strategy (ENV) and Ministry of Water, Land and Resource Stewardship (WLRS). Progress on this work and production of this Technical Report have been supported by the following:

The project Coordination Team including: Anuradha Rao and Kate Menzies (TWN), Diane Sutherland and Kristy Gabelhouse (ENV), Nicole Obee (WLRS) and Patrick Lilley (Kerr Wood Leidal, consultant to TWN).

Multi-agency advisory bodies: Burrard Inlet Water Quality Technical Working Group and Roundtable (representatives of First Nations; local, provincial and federal governments; health authorities; industry; academics and NGOs).

Staff, specialists and consultants including:

- Adrienne Hembree, Andrew George, Bridget Doyle, Carleen Thomas, Ernie George, Gabriel George, Graham Nicholas, Jessica Steele, John Konovsky, Melany Sanchez, Sarah Dal Santo and Stormy MacKay (TWN), Allison Hunt and Anne Sheridan (Inlailawatash)
- Kevin Rieberger and Heather Thompson (WLRS), and Dan Stein (BC Ministry of Health [HLTH]).
- Grace Nijdam, Jack Lau, Karin Bjorklund (Kerr Wood Leidal)

We would also like to acknowledge financial support from: the Government of Canada, BC Ministry of Environment and Climate Change Strategy, Sitka Foundation and Vancity Credit Union, and in-kind contributions by Water Quality Roundtable member organizations.

CHAPTER SUMMARY

This chapter presents data analysis and proposed water quality objectives for pesticides in Burrard Inlet. Objectives are proposed for twenty-three legacy and seven current use pesticides (CUPs) using up-to-date research on values to protect (particularly aquatic life, and human consumption of finfish and shellfish), potential effects, sources and factors influencing pesticide levels, benchmark screening, and historic and recent monitoring data for Burrard Inlet. Tsleil-Waututh Nation (TWN) has identified pesticides as contaminants of concern in their Burrard Inlet Action Plan (TWN, 2017).

There are many different types of pesticides, such as herbicides, insecticides, fungicides, and vertebrate toxicants, originally developed to target specific classes of biota. They have been formulated into thousands of products that are available worldwide to target fungi, insects, herbaceous plants, and vertebrates, and are applied to forests, rangelands, wetlands, cultivated crops, cities, and towns. Most of these are applied on field crops and terrestrial habitats where the chemicals often drift or translocate into non-target aquatic systems and can cause unintentional impacts on non-target species.

For this chapter, a list of legacy pesticides and CUPs has been selected based on frequent and recent exceedances of benchmarks in water, sediment and/or tissue in Burrard Inlet. These pesticides are listed in Table 1 along with their corresponding chemical grouping, uses, and associated legislation.

Legacy pesticides are compounds that were once used but are now banned due to adverse effects to humans and the environment. Organochlorines, which make up a large proportion of legacy pesticides, are structurally diverse persistent organic pollutants (POPs) that have a range of toxic effects in humans and other organisms, including damage to reproductive and neurological functions, ability to cause cancer, and hormone disruption. The carbamate pesticide aldicarb, which is persistent in groundwaters, exerts acute and chronic toxicity to fish and aquatic invertebrates, and acts by primarily disrupting the nervous system function. Organophosphate pesticides (e.g., diazinon) and organochlorines are highly persistent and are easily dissolved in fats and oils which can then accumulate in species at higher trophic levels. Their low water solubility and low vapour pressure allows them to be transported over great distances and persist, bioaccumulate and biomagnify within biological systems, posing particular health risks for higher trophic level species.

In general, CUPs are more target-specific and less persistent than legacy pesticides, but some CUPs (e.g., the organophosphate chlorpyrifos) are more acutely toxic. The sublethal effects of some CUPs on marine species include endocrine disruption, impaired immune function, abnormal development, altered behaviours, reduced growth, and reproductive impairment. CUPs are produced in high volumes and are used widely. There is still limited data indicating the bioaccumulation of CUPs in biota, with the exception being *gamma*-hexachlorocyclohexane (lindane), which has been found in seals, beluga (*Delphinapterus leucas*) and other wildlife, indicating that lindane bioaccumulates in marine food webs.

Benchmarks from existing sources were used for the protection of aquatic life, and in some cases human health, in water and sediment. Screening values were calculated for pesticide levels in tissue to protect human consumption of finfish and shellfish at rates relevant to coastal Indigenous consumers.

The benchmarks for pesticide levels in sediment and water are based on the BC Working Sediment Quality Guidelines (WSQGs) and the BC Working Water Quality Guidelines (WWQGs). These benchmarks have been adopted from the Canadian Council for Ministers of the Environment Environmental Quality Guidelines and other scientific literature. Other benchmarks used include the US EPA Freshwater Sediment Screening Benchmarks and the Water Quality Standards for Surface Waters of the State of Washington. Benchmarks for the protection of aquatic life are based on BC's WWQGs and the

Contaminated Sites Regulation for diazinon. Benchmarks that screen for the protection of human health are based on ENV and HLTH (2021).

Of the pesticides covered in this report (see Appendix C Data Sources), only chlorophenols have been measured in Burrard Inlet marine water samples and among these, tri-, tetra- and pentachlorophenols were detected but at concentrations below applicable benchmarks.

Fifty-nine pesticides have been monitored in sediments in Burrard Inlet (see Appendix C for sampling years) and 23 of these were found in concentrations above the various detection limits. Detected pesticides include the legacy pesticides: chlordanes, dichlorodiphenyltrichloroethane (DDT) and metabolites, dieldrin, endosulfans, endrins, methoxychlor, as well as the CUPs hexachlorocyclohexanes, permethrin and chlorophenols. Among the legacy pesticides, one chlordane isomer (*trans*-chlordane), two DDT compounds (2,4-DDT and 4,4-DDT), and dieldrin exceeded the sediment benchmarks. Of the CUPs, the isomers *alpha*- and *gamma*-hexachlorocyclohexane exceeded the sediment benchmarks. No sediment benchmarks were available for endosulfans, methoxychlor, permethrin, and chlorophenols.

Thirty-three pesticides have been monitored in Burrard Inlet fish and mussel tissue (see Appendix C for sampling years), with 19 of these measured above the various detection limits. Pesticides found in tissue include the legacy pesticides: chlordanes, DDT and metabolites, dieldrin, endosulfans, endrin, hexachlorobenzene, and mirex, as well as the currently used hexachlorocyclohexanes, permethrin and trifluralin. Concentrations of certain pesticides in tissue were summed based on parameter types, and then total concentrations were screened against the most conservative tissue benchmark for human consumption, i.e., for either a toddler from a subsistence fisher population (for non-carcinogens) or an adult subsistence fisher (for carcinogens). The sum of DDT and metabolites as well as hexachlorocyclohexanes and chlordanes exceeded the tissue benchmarks among the monitored legacy pesticides.

Summary of Pesticides Monitoring Data	Water	Sediment	Tissue
Number of Monitored Parameters	18	59	33
Number of Detected Parameters	3	23	19
Number of Parameters Exceeding Benchmarks	0	6 (cis- & trans-chlordanes; 2,4-DDT; 4,4-DDT; Dieldrin; *alpha*-hexachlorobenzene; *gamma*-hexachlorobenzene)	3 (sum of chlordanes; sum of DDEs and DDTs; sum of hexachlorocyclohexane)

Proposed objectives for water, sediment and tissue were drawn from the most protective existing benchmarks, and are tabulated in Appendix A. Where there was no detection of a given pesticide, the proposed objective is ‘do not detect, when using best available detection limits, and/or decrease in current levels’. In addition to these objectives, an overall objective is for a decreasing trend in levels of legacy pesticides and CUPs in all media. These Burrard Inlet-specific objectives are proposed in the interest of understanding trends and ultimately reducing pesticide loadings and levels in Burrard Inlet.

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ACRONYMS

AChE	Acetylcholinesterase
BC	British Columbia
BW	Body weight
CCME	Canadian Council of Ministers of the Environment
CEC	Contaminant of emerging concern
CUPs	Current Use Pesticides
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DL	Detection Limit
df	Detection Frequency
ENV	Ministry of Environment and Climate Change Strategy
EqP	Equilibrium Partitioning
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
HLTH	Ministry of Health
MVN	Metro Vancouver
n	Sample Count
OSF	Oral Slope Factor
OW	Ocean Wise Conservation Association
PICES	North Pacific Marine Organization
POPs	Persistent Organic Pollutants
SRKW	Southern Resident Killer Whale
SV	Screening Value
TRV	Toxicological Reference Values
TWN	Tsleil-Waututh Nation
WLRS	Ministry of Water, Land and Resource Stewardship
WSQG	Working Sediment Quality Guideline
WWQG	Working Water Quality Guideline
WQO	Water Quality Objective

1. INTRODUCTION

Tsleil-Waututh Nation (TWN) has identified pesticides as contaminants of concern in their Burrard Inlet Action Plan (TWN, 2017). This Pesticides Technical Report proposes water quality objectives (WQOs) for both legacy and current use pesticides (CUPs) in Burrard Inlet. It includes relevant background information, an overview assessment of current status and trends in pesticide levels in water, sediment, and biota in Burrard Inlet, comparison to benchmarks, and a rationale for the proposed objectives. Recommendations for future monitoring as well as management options to help achieve these objectives are also included.

2. BACKGROUND

2.1 Values and Potential Effects

Pesticides, such as herbicides, insecticides, fungicides, and vertebrate toxicants were originally developed to target specific classes of biota (Environment Canada, 2011). They have been formulated into thousands of products that are available worldwide to target fungi, insects, herbaceous plants, and vertebrates, and are applied to forests, rangelands and wetlands, cultivated crops, cities and towns. Most pesticides are applied to field crops and terrestrial habitats where the chemicals can drift or translocate into non-target aquatic systems, where they can cause unintentional impacts on non-target species (Hoffman et al., 2003).

Coastal and inland water systems, such as Burrard Inlet, are permanent or temporary habitats for many commercial and culturally important fish species and crustacea. While protection of aquatic life remains important, WQOs should also protect human consumption of finfish and shellfish, a value of concern with respect to pesticides. The goal of a WQO is to maintain pesticide levels below concentrations which would be toxic to aquatic life and to humans who consume seafood for subsistence (i.e., consumption rates relevant to coastal Indigenous peoples such as Tsleil-Waututh Nation).

Priority legacy pesticides and CUPs in this assessment have been selected (Table 1) based on pesticides of concern including those with frequent and recent exceedances of benchmarks in water, sediment and/or tissue in Burrard Inlet, and are presented with their corresponding chemical groupings, uses, and associated legislation.

Table 1: Priority Legacy and Current Use Pesticides Covered in this Assessment, and their Primary Metabolites of Environmental Relevance.

Legacy Pesticides	Chemical Group	Uses	Legislation
Aldicarb Metabolites: Aldicarb sulfone, aldicarb sulfoxide	Carbamate	Broad-spectrum, systemic insecticide used to control a variety of insects, mites and nematodes	Used in Canada from 1975 to 1996; registered uses in Canada were discontinued in 1996 (CCME, 1999b)
Aldrin	Organochlorine	Insecticide to control termites and other insect pests	Banned in Canada in 1990 (ECCC, 2017) and most other countries
Chlordane (including its isomers *cis*- and *trans*-chlordane) and its components *cis*- and *trans*-nonachlor Metabolite: Oxy-chlordane	Organochlorine	Insecticide to control termites and other insect pests	Banned in Canada in 1998 (ECCC, 2017) and most other countries
Dichlorodiphenyltrichloroethane (DDT) Metabolites: Dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyldichloroethane (DDD)	Organochlorine	DDT is a broad-spectrum pesticide, widely used for insects on crops; DDE has no commercial use while DDD was also used as a pesticide	Banned in Canada in 1985 (ECCC, 2017) and most other countries; still used in other countries for mosquito control
Diazinon Metabolite: Diazinon-oxon	Organophosphate	Insecticide used to control cockroaches, aphids, scales, mites, ants, crickets, and other insects	Banned and phased out in Canada in 2013 (Carex, 2020 and Health Canada, 2013); banned in most other countries
Dieldrin (isomer of endrin)	Organochlorine	Insecticide used to control termites, textile pests, insect-borne diseases, and insects in agricultural soils; also a breakdown product of aldrin	Banned in Canada in 1990 (ECCC, 2017) and most other countries
Endosulfan (including its isomers *alpha*- and *beta*-endosulfan) Metabolite: Endosulfan sulfate	Organochlorine	Insecticide to control crop pests, tsetse flies, cattle ectoparasites; wood preservative	Banned in Canada in 2016 (ECCC, 2017) and most other countries
Endrin (isomer of dieldrin) Metabolites: Endrin aldehyde, endrin ketone	Organochlorine	Insecticide sprayed on crops and for control of rodents	Banned in Canada in 1990 (ECCC, 2017) and most other countries

Legacy Pesticides	Chemical Group	Uses	Legislation
Heptachlor Metabolite: Heptachlor epoxide	Organochlorine	Insecticide for soil insects and termites, crop pests, and malaria-carrying mosquitoes; heptachlor epoxide is more likely to be found in the environment than heptachlor	Banned in Canada in 1985 (ECCC, 2017) and most other countries
Hexachlorobenzene (HCB)	Organochlorine	Fungicide to treat seeds of food crops; Produced unintentionally as a by-product in the manufacture of certain industrial chemicals	Banned in Canada in 1999 (ECCC, 2017) and most other countries
Methoxychlor	Organochlorine	Insecticide used for agricultural, household pests, and parasites on cattle; has relatively low toxicity and short persistence in biological systems relative to other organochlorine pesticides	Banned in Canada in 2005 (ECCC, 2021) and in most other countries
Mirex	Organochlorine	Insecticide for ants and termites; fire retardant in plastics, rubber, and electrical goods	Banned and never allowed for use in Canada (ECCC, 2017)
Toxaphene	Organochlorine	Insecticide used primarily for cotton in the US in the 60s and 70s	Banned in Canada and USA since 1982 (CIRNAC, 2022)
Current Use Pesticides (CUPs)	**Chemical Group**	**Uses**	**Legislation**
Atrazine	Triazine	Selective herbicide used to control grass and broadleaf weeds in crops (corn and sorghum in Canada)	Currently allowed for use in Canada and the USA (Health Canada, 2017a); Banned in the European Union
Carbaryl	Carbamate	Used mainly as an insecticide	Currently allowed for use in Canada; Registered to control a wide range of arthropod pests (Health Canada, 2016)
Chlorophenols (19 congeners, mono, di-, tetra, and pentachlorophenols)	Chlorophenols	Widely used in pesticides and wood preservatives	No longer manufactured in Canada. As of 2022 Health Canada's Pest Management Regulatory Agency (PMRA) indicated that all penta products are being phased out within one year (including

			prohibition on import) (Health Canada, 2022).
Current Use Pesticides (CUPs)	**Chemical Group**	**Uses**	**Legislation**
Chlorpyrifos	Organophosphate	Used to control insects in agricultural, residential, and commercial settings	The existing stocks of all chlorpyrifos products in Canada are being phased out by the end of 2023 (Health Canada, 2021a)
Imidacloprid	Neonicotinoid	One of the most widely used insecticides to control sucking, chewing and soil insects as well as fleas on pets	Health Canada concluded in 2021 that a complete ban on neonicotinoids is not warranted but certain restrictions and risk-reduction measures apply (Health Canada, 2021c)
Hexachlorocyclohexane, (including its isomers *alpha*-, *beta*-, *gamma*-, and *delta*-hexachlorocyclohexane; *gamma*-hexachlorocyclohexane is also known as **lindane**)	Organochlorine	Lindane is an insecticide used for treatment of scabies and pediculosis (Costa, 2015)	Only current allowed use in Canada is for control of head lice and scabies (Environment Canada, 2015); Health Canada de-registered hexachlorocyclohexane pesticides in the late 1990s
Malathion	Organophosphate	Broad-spectrum insecticide in the agricultural and domestic sector	Registered for use in Canada (CAREX, 2023a).
Permethrin	Pyrethroid	Widely used insecticide product for domestic use and agricultural crops	Used in Canada (Health Canada, 2020 and Ocean Wise, 2021).
Simazine	Triazine	Herbicide used to control broadleaf weeds and annual grasses	Currently registered for a wide variety of uses in Canada (e.g., fruits, corn, shelter belts, woodlots) (Health Canada, 2016a).
Trifluralin	Dinitroaniline	Herbicide used to control broadleaf weeds and annual grasses	Currently registered in Canada for use on ornamentals, shelterbelts, terrestrial food/feed crops, oil seed and fibre production crops (Health Canada, 2015).

2.1.1 Legacy Pesticides

Legacy pesticides are compounds that were once used but are now banned due to adverse effects to humans and the environment. The legacy pesticides that will be assessed in this report are listed in Table 1. With the exception of aldicarb (carbamate pesticide) and diazinon (an organophosphate), legacy pesticides fall under the organochlorine class of pesticides, a large group of structurally diverse persistent organic pollutants (POPs). These legacy pesticides, along with some of their breakdown products, are listed as probable human carcinogens (Stockholm Convention, 2019). Further details are provided in Appendix E.

2.1.2 Current Use Pesticides

As a result of bans and restrictions on most legacy pesticides, CUPs were developed to generally have lower persistence and bioaccumulative potential, as well as a higher water solubility. This was expected to result in reduced negative environmental impacts (Kannan et al., 2005). However, the number and diversity of CUPs have greatly expanded, with many being detected in various environmental media, and in locations far from potential sources, making them difficult to monitor. Additional data is required regarding toxic effects of CUPs, such as the potential environmental and human adverse impacts (Degrendele et al., 2016).

The CUPs discussed in this report include atrazine, carbaryl, chloropyrifos, chlorophenols (19 congeners, mono, di-, tetra, and pentachlorophenols), imidacloprid, hexachlorocyclohexanes (including its isomers *alpha*-, *beta*-, *gamma*- [also known as lindane], and *delta*-hexachlorocyclohexane), malathion, permethrin, simazine, and trifluralin (Table 1). Further details are provided in Appendix E.

2.2 Potential Sources of Pesticide Pollution

2.2.1 Legacy Pesticides

In the case of legacy pesticides that are not currently authorized for use in Canada and the USA, volatilization and wind erosion of soil particles are relevant emission pathways into the marine environment. Legacy pesticides may still exist in some local media due to their high persistence, or they may be transported from other countries where their use continues. In those countries, following their use to control pests and vector-borne diseases, these pesticides can disperse through air and water and redistribute on a global scale (Alam et al., 2014 and European Union, 2021). Residues of legacy pesticides such as organochlorines have been detected in the atmosphere, snow, vegetation, runoff, aquatic amphipods, and lake trout from various western Canadian mountains (Gillian et al., 2007). Long-range atmospheric transport of POPs across the Pacific Ocean, via the rapid movement of westerly air masses, provides a mechanism for the delivery of pollutants to North America from Asia (Noël et al., 2009), where many legacy-type pesticides are potentially still being used (European Union, 2021). Toxaphenes can still be produced unintentionally during the chlorination processes in some manufacturing (CCME, 2002).

2.2.2 Current Use Pesticides

CUPs can enter marine waters such as Burrard Inlet through urban discharges (residential use and grass management on golf courses[1] and parks), and industry. In agricultural settings, pesticides can be directly

[1] A total of 37 golf course inspections in BC (representing 12% of golf courses in BC, which include golf courses located in the Lower Mainland, Southern Interior, Vancouver Island, and in the Kootenays), conducted by the Ministry of Environment and Climate Change Strategy (2017) revealed a total annual usage of 27,901 kg of active ingredient (comprised of 95% fungicide and 5% herbicide) applied by licensed golf courses in BC, with 7925.5 kg of those used in the Lower Mainland. (ENV 2017).

washed into sewage systems from field sprayer filling and cleaning activities on paved surfaces, or during application processes (Munz et al., 2017). Pesticides that are transported into the surrounding waterways adjacent to agricultural fields, can flow into the Fraser River. Once in the Fraser River, these pesticides can be transported into Burrard Inlet through the dispersal of the Fraser River sediment plume, which is largely modulated by wind, followed by river flow conditions and tides (Halverson and Pawlowicz, 2016; Pawlowicz et al., 2017). During agricultural application, a significant portion of the pesticide spray can also enter the atmosphere (Cabrerizo et al., 2011). Once airborne, pesticides can be carried by wind and deposited through wet or dry deposition into Burrard Inlet. In addition, CUPs can repeatedly re-volatilize from plants, soils and surface waters and travel long distances, contaminating areas far from their original source (Cabrerizo et al., 2011).

Waterways which are close to agricultural lands are most likely to be contaminated by pesticides (Pinto et al., 2016). This was observed in a study that analyzed pesticides in surface waters around agricultural sites in the Lower Fraser Valley of BC between 2003 and 2005 (Woudneh et al., 2009). In this study, 51 pesticides were detected, including atrazine and permethrin. For pyrethroid pesticides, which includes permethrin, their wide range of uses in both agriculture and household pest control also contribute to the influx of pesticides into the marine environment. Atrazine, commonly found in marine waters, was detected in agricultural ditches that flow into the Fraser River in the Lower Fraser Valley in 2006 (at 0.1 to 0.6 µg/L) (Solomon et al., 1996).

Pesticides used in non-agricultural settings, such as golf courses, parks, industrial and residential areas, can enter the storm sewer systems and conventional wastewater treatment plants, which are often not equipped to remove these compounds and, therefore, pesticides are directly discharged into the marine environment (Munz et al., 2017).

For chlorophenols, most of the pollution can be sourced back to specific anthropogenic activity (Scow et al., 1982). Pollution sources may originate from surface runoff from wood-treatment facilities, manufacturing plant and municipal waste discharges (Allen, 1989), and from the disinfection of drinking water (WHO, 1996). For example, using chlorine to treat humic matter and/or the formation of natural carboxylic acids during the chlorination of municipal drinking water is responsible for incidental chlorophenol production and input into the environment (ENV, 2021b). Chlorophenols are also present in pesticides and insecticides (Igbinosa et al., 2013). Other sources of chlorophenols could include textiles, leather products, refineries, pulp and paper factories, domestic preservatives, and petrochemical facilities (Igbinosa et al., 2013). They may also be present due to the degradation of other chemicals in the environment (Government of Canada, 1987a).

2.3 Factors Influencing Pesticide Levels in Burrard Inlet

2.3.1 Legacy Pesticides

Organochlorine pesticides are all structurally similar, in that they contain chlorine atoms that are bounded to the carbon structure by a covalent attachment. They are highly lipophilic and have low vapour pressure, resulting in persistence and potential for bioaccumulation in the marine environment. Organochlorine half-lives range from 60 days to several decades (Jayaraj et al., 2016; Blus, 2002), while the half-lives of carbamate pesticides (e.g., aldicarb) range anywhere from a few days to years (Moore et al., 2009). Various factors can influence their persistence in marine systems including temperature, light, pH, and the presence of microorganisms. For example, aldicarb is only persistent at low pH and temperature conditions (e.g., groundwaters) (Government of Canada, 1987b). In addition, metabolism by higher trophic organisms can also break down these compounds into metabolites that are often more persistent and toxic than the parent compounds (Blus, 2002). Examples of this are heptachlor and aldrin, which are relatively short-lived compounds in organisms, but their metabolites heptachlor epoxide and dieldrin are far more persistent and toxic (Blus, 2002). Many legacy pesticides that reach the marine environment leave the superficial mixed waters and settle in sediments, where they can be stored for a long time. Therefore, sediments in coastal waters, and in particular those on the continental shelf, represent an important reservoir of legacy pesticides and are estimated to contain thousands of tons of POPs globally (Gioia et al., 2011).

A study conducted in the Tajan River (located in the southern basin of the Caspian Sea in Iran), measured concentrations of the organophosphate diazinon and used the AQUATOX[2] model to simulate the fate of this compound in the water system. The results indicated that diazinon underwent several degradation processes including hydrolysis, photolysis, sedimentation and microbial metabolism (Ahmadi-Mamaqani et al., 2011).

Like organochlorines, toxaphene is also persistent and bioaccumulates in the marine environment. Once in aquatic environments, toxaphene does not dissolve well, but rather partitions into sediments and tissues, with a half life of up to 14 years (Indian and Northern Affairs Canada, 2010). For nonachlor (cis, trans), the half life is between 10 and 20 years and therefore can persist and bioaccumulate in the food chain. Polar regions have found chlordane related compounds in fish and marine levels that are comparable to PCBs and DDT isomers (Bondy, 2000).

2.3.2 Current Use Pesticides

Even though CUPs generally degrade faster than legacy pesticides, they have been found in waterbodies, which allows them to potentially transfer into the aquatic food chain. Occurrence of lindane (an organochlorine pesticide) has been reported across the Canadian Arctic Archipelago, with concentrations ranging between 0.19 and 0.45 ng/L (Bidleman et al., 2007 and Strachan et al., 2000). Pyrethroids, such as permethrin, are as hydrophobic as some organochlorine pesticides (log K_{ow} between 4.8 and 7.0), hence can sorb onto organic particles and sediments, which are then consumed by filter feeders (Méjanelle et al., 2020). Alternatively, these pesticides can also persist in sediments where their biodegradability is greatly reduced (Méjanelle et al., 2020).

Many factors will determine the persistence of CUPs in Burrard Inlet, some of which include location, and biotic and abiotic characteristics of the water column. For example, two of the most notable parameters of influence on chlorophenols are pH and temperature, which can affect their breakdown, transport, and toxicity; higher water temperatures and more acidic pH correspond to increased volatility and toxicity (WHO, UN Environment Programme, & International Labour Organisation, 1989). Through both biotic and abiotic transformation and degradation, some CUPs may also be converted into other compounds, which creates intermediate or end products that may be more harmful than the original compound. Such is the case for chlorophenols (Michalowicz & Duda, 2007). Variations in water properties can also affect the breakdown of CUPs by microorganisms, where water properties are a function of location and temperature, influencing pesticide persistence by affecting the role of microbial degradation (Bondarenko et al., 2004). For example, malathion and carbaryl are considered non-persistent under most conditions, suggesting that surface water contamination by these CUPs would be transient. In contrast, chloropyrifos and trifluralin microbial degradation is reduced when in seawater and therefore results in longer persistence of these CUPs in seawater (Bondarenko et al., 2004).

Chlorophenol levels in Burrard Inlet can also be predicted by the congener. An increase in chlorination increases the size and electrophilicity and thus decreases the water solubility of the compound. This results in higher partitioning to sediments and lipids amongst the larger chlorophenols, causing a greater

[2] AQUATOX is a simulation model for aquatic systems and predicts the fate of various pollutants and their effect on the ecosystem (US EPA, 2021).

bioavailability and bioconcentration in organisms; pentachlorophenol (PCP) being the most persistent (Government of Canada, 1987a; Warrington, 1997; Czaplicka, 2004).

Overall, there is still limited data indicating the bioaccumulation of CUPs in biota. Data exist for lindane, which has been found in seals, belugas (*Delphinapterus leucas*) and other wildlife, indicating that lindane is able to bioaccumulate in marine food webs (Hoferkamp et al., 2010). Chlorpyrifos and permethrin have also been found to bioaccumulate (Vorkamp et al., 2014).

2.4 1990 Provisional Water Quality Objectives for Pesticides

There were no WQOs developed in 1990 for pesticides in Burrard Inlet except for chlorophenols in water (maximum 0.2 µg/L), sediment (maximum 0.01 µg/g dry weight), and tissue (maximum 0.1 µg/g wet weight in fish).

3. WATER QUALITY ASSESSMENT

3.1 Benchmarks Used in this Assessment

Benchmarks were used to screen available data for potential acute and chronic effects of pesticides, and to inform the derivation of proposed objectives for pesticide levels in Burrard Inlet. These benchmarks are tabulated in Appendix A. Benchmarks for the protection of aquatic life, and in some cases human health, in both water and sediment were taken from existing benchmarks from BC, Canadian and U.S. jurisdictions. Screening values were calculated for pesticide levels in tissue to protect human consumption of finfish and shellfish. While there are multiple values (designated uses) identified for Burrard Inlet (Rao et al., 2019), the most conservative benchmark protective of the most sensitive of those values were used for screening purposes, as available.

Some water benchmarks were used to screen for human consumption of seafood and protection of aquatic life. Benchmarks for pesticide levels in water were based on US EPA water quality criteria for human consumption of seafood and water (US EPA, 2019), and the Washington State Water Quality Standards (2019), which also provides benchmarks for the protection of aquatic life. Benchmarks that screen for the protection of aquatic life are based on BC's working water quality guidelines (WWQGs), taken from the Canadian Council of the Ministers of the Environment (CCME, 2010 and CCME, 2006). The Contaminated Sites Regulation (Province of BC, 2013) also provides a water quality guideline for diazinon.

Benchmarks for pesticide levels in sediment are based on BC Working Sediment Quality Guidelines (WSQGs) (ENV, 2021). These working guidelines adopt the Environmental Quality Guidelines from the Canadian Council for Ministers of the Environment (CCME, 1998) and other sources (Long and Morgan, 1990) with the Interim Sediment Quality Guideline (ISQG) as the lower threshold and the Probable Effects Level (PEL) as the upper threshold. Diazinon and atrazine benchmarks are based on the US EPA (2006) Freshwater Sediment Screening Benchmarks but can be adopted as marine sediment guidelines. For aldrin and diazinon, these benchmarks are derived from the equilibrium partitioning (EqP) method with Region III (mid-Atlantic region) Biological Technical Assistance Group (BTAG) freshwater values, and log K_{ow} values between 2 and 6.

The tissue benchmarks were derived by ENV and HLTH (2021). Tissue Screening Values (SVs) are defined as conservative threshold values against which contaminant concentrations in fish tissue can be compared and assessed for potential risks to human health (ENV and HLTH, 2021). Fish and shellfish tissue in this report refer to country foods, that is, foods produced in an agricultural backyard setting (not for commercial sale) or harvested through hunting, gathering or fishing activities (Health Canada, 2021d). Screening values provide general guidance to environmental managers and represent a suggested safe level of a contaminant in fish tissue based on a conservative estimate of a person's fish consumption per day; they do not provide advice regarding consumption limits or constitute a fishing advisory. Exceedances of a screening value may indicate that further investigation to assess human health risk at a particular site is warranted; however, exceeding a screening value does not imply an immediate risk to human health (ENV and HLTH, 2021). Calculations for screening values for human fish consumption are provided in Appendix B.

BC recommends using a risk-based approach (ENV and HLTH, 2021; WLRS, 2023). A risk-based approach considers:

- the contaminant *receptors* (subsistence fisher, recreational fisher, the general BC population, pregnant woman, child and toddler);
    - In the present assessment, three screening values were selected to capture a range of potential fishers. The most conservative is protective of a toddler from a subsistence fisher demographic while the screening values protective of adult subsistence fishers and adult recreational fishers are less conservative.
- *exposure* to the contaminant (how much fish the receptors consume) calculated through fish ingestion rates from Richardson (1997); and,
- the contaminant *toxicity* (what is known about the contaminant and how it affects different receptors) defined through toxicological reference values TRV, prescribed by Health Canada (2021e), or other international agencies (i.e., United States Environmental Protection Agency and the World Health Organization).
    - For noncarcinogenic contaminants, the TRV is the daily dose that is deemed to be tolerable or acceptable (i.e., the dose that is "safe"). This is a dose above which toxic effects are expected to occur. Non-carcinogenic TRVs for oral ingestion are identified by Health Canada as tolerable daily intakes (TDIs).
    - For substances that are carcinogenic, the TRV represents an upper bound estimate of the slope between exposure and the occurrence of cancer. For ingestion of contaminants, the slope of the dose-response relationship is referred to as an oral slope factor (OSF) (Health Canada, 2021d). Carcinogenic fish tissue SVs for Burrard Inlet are based on a negligible increase in incremental lifetime cancer risk of 1 in 100,000, mean human receptor body weight (BW), OSF, life expectancy, fish consumption rates, frequency of consumption, and the years exposed to the contaminant (USEPA, 2000; Health Canada, 2021d).

Benchmarks for human health could not be derived for the following parameters because of insufficient toxicological information:

- Marine water: aldicarbs, carbaryl, 2,4,6-tri-, 2,4-di- and 2,3,4,6-tetrachlorophenol, mirex, oxy-chlordane, simazine, toxaphene, and trifluralin.
- Sediment: aldicarbs, carbaryl, chlorophenols, endosulfans, imidacloprid, malathion, methoxychlor, mirex, oxy-chlordane, permethrins, simazine, and trifluralin.

3.2 Data Sources

Data for pesticide levels in Burrard Inlet were gathered from several studies and monitoring programs and a summary of the priority datasets used for this assessment is presented in Appendix C. Although other datasets containing pesticide sampling data exist, the priority datasets were found to contain the best available data for assessing the status of pesticides within Burrard Inlet within the constraints of the project. Maps outlining the sample sites for pesticides in Burrard Inlet are provided in Figure 1 through Figure 5.

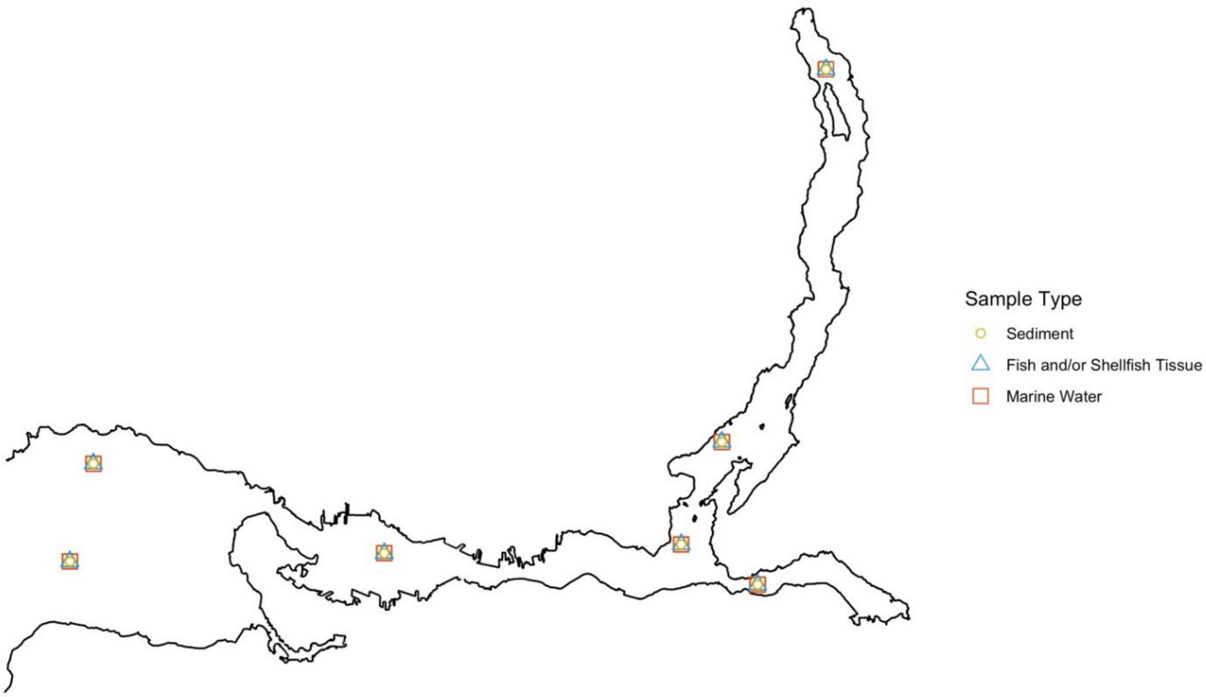

Figure 1. Metro Vancouver ambient sampling stations in Burrard Inlet (2007 to 2016)

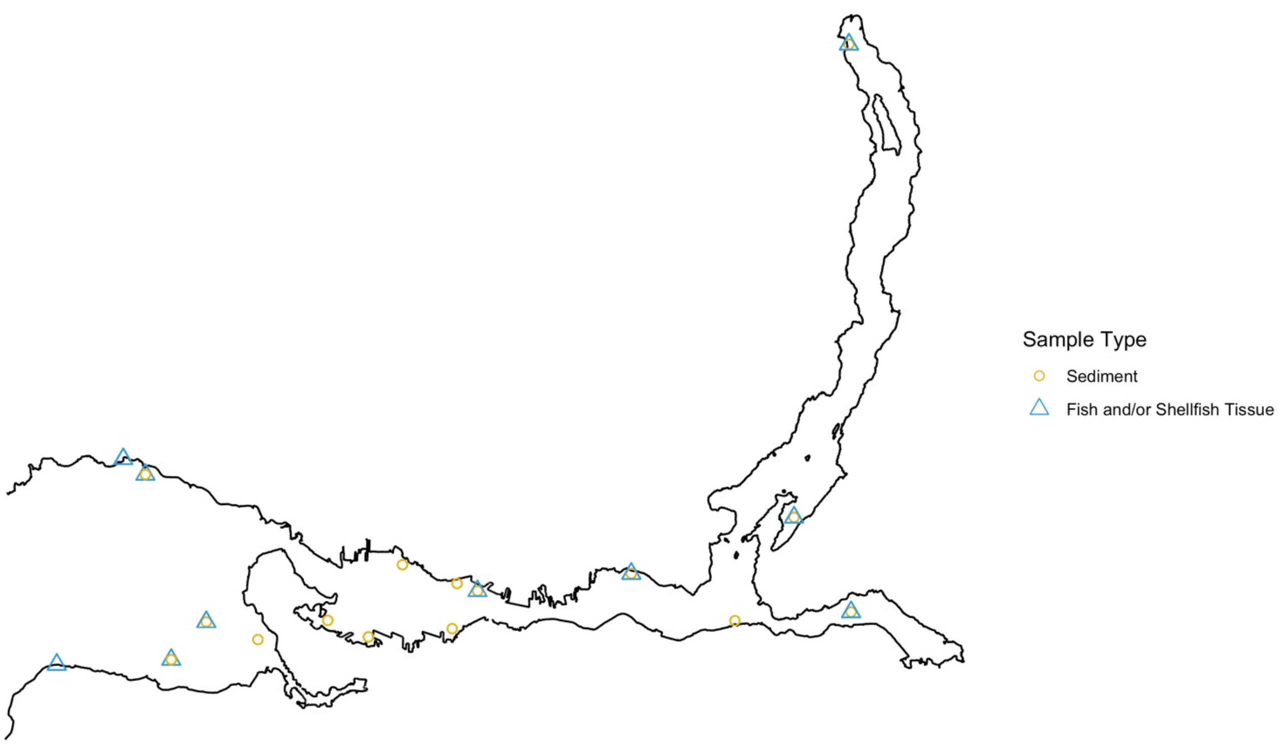

Figure 2. Ocean Wise (Pollution Tracker) sampling stations in Burrard Inlet (2015 to 2019)

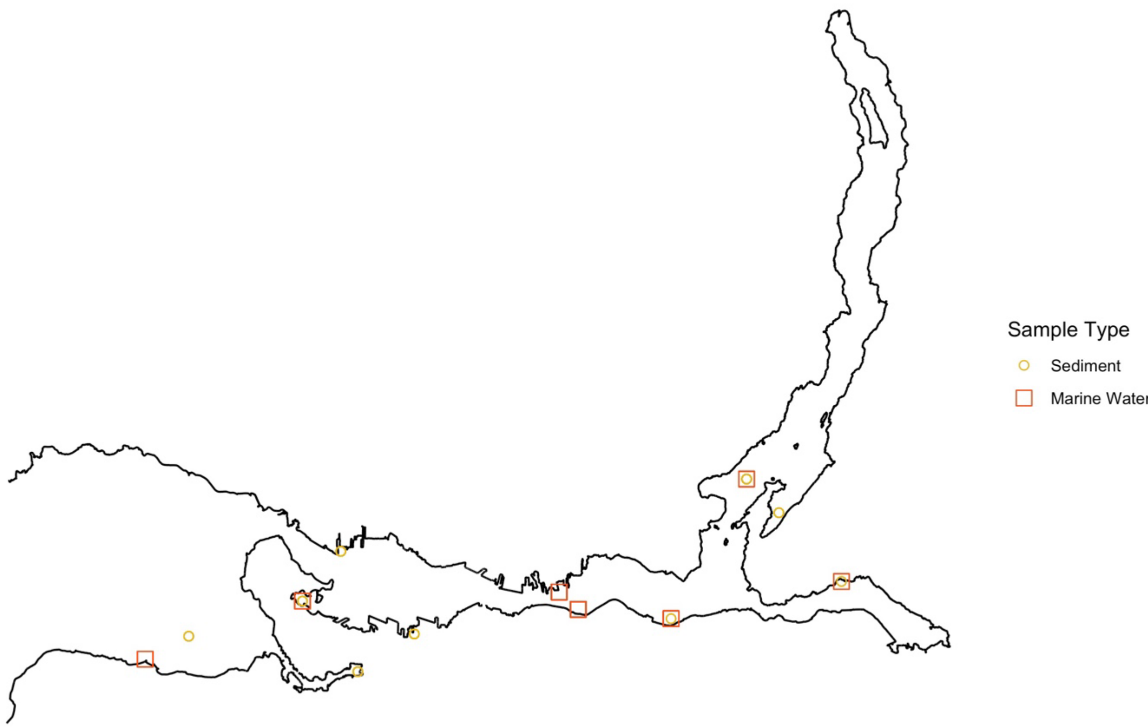

Figure 3. ENV sampling stations in Burrard Inlet (1992 to 2020)

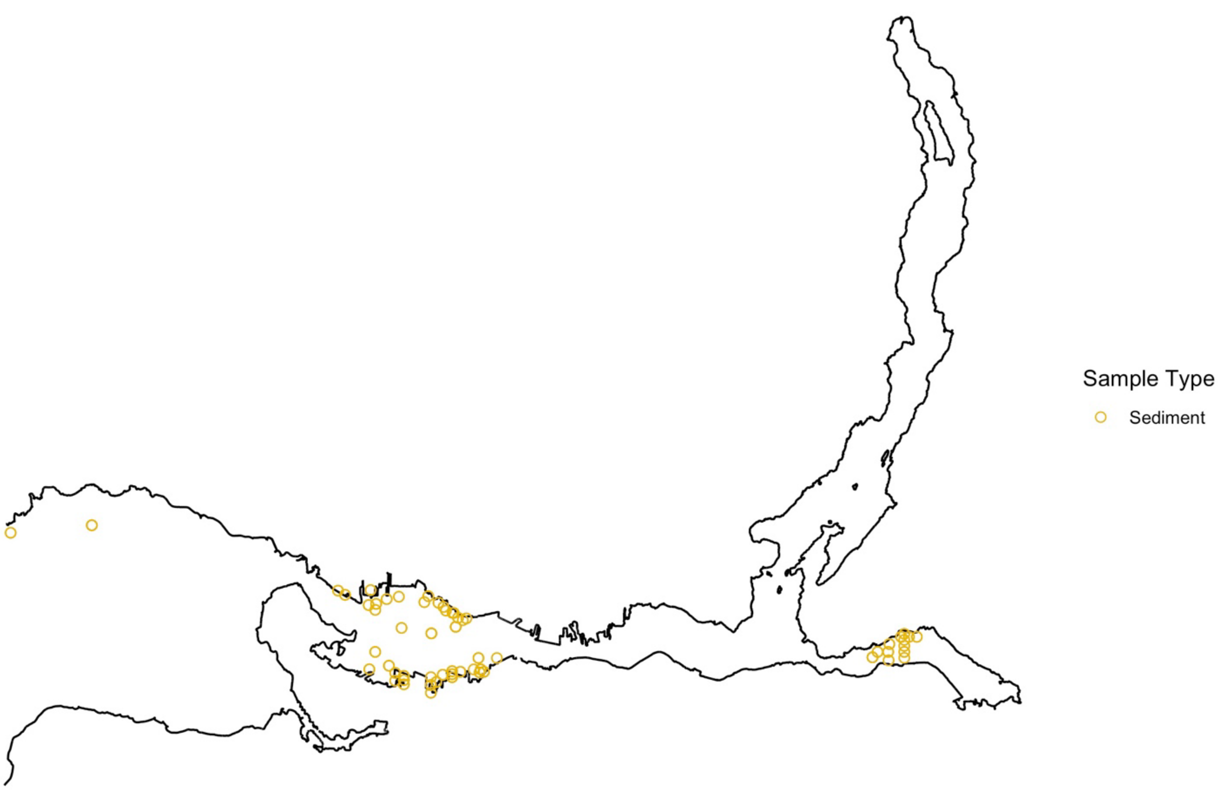

Figure 4. ECCC sampling stations in Burrard Inlet (1985 to1986)

Figure 5. PICES sampling stations in Burrard Inlet (1999)

3.3 Assessment Results

Available monitoring data were compared to screening benchmarks, with summaries provided in Table 2 and Table 3, and more details provided in Appendix D. Because of the large number of reviewed compounds, observations are presented for Burrard Inlet as a whole, and not for each sub-basin. Because of variations in the sampling and analytical methods and distribution of sites, results from each monitoring program are presented separately in Appendix D.

Detection limits were variable and frequently above the screening benchmarks, which created challenges for providing comparisons. Where the highest detection limit within a dataset for a pesticide was greater than a screening benchmark, this was noted as a limitation. As a conservative approach, analytical data were not blank corrected.

Because of the wide range of detection limits, samples that were below detection limits were excluded from the summary of mean, minimum, and maximum concentrations. Field replicates were averaged prior to the assessment. Key observations for detection frequency, exceedances, and maximum observed pesticide concentrations are described in the monitoring program in Appendix D. Overall summaries of status and observations for marine water, sediment and tissue are provided below.

Table 2. Summary of Detected Pesticides in Media of Burrard Inlet and Exceeded Benchmarks

Detected Parameters	Detected in (Media)	Exceeded Benchmark(s)
Legacy Pesticides		
***cis-* & *trans-*Chlordane**	Sediment Tissue	Sediment Tissue (sum of chlordanes)
2,4-DDE	Sediment Tissue	Tissue (sum of DDEs + DDTs)
4,4-DDE	Sediment Tissue	Tissue (sum of DDEs + DDTs)
2,4-DDT	Sediment Tissue	Sediment Tissue (sum of DDEs + DDTs)
4,4-DDT	Sediment Tissue	Sediment Tissue (sum of DDEs + DDTs)
Dieldrin	Sediment Tissue	Sediment
Endosulfan I & II	Sediment Tissue	(no sediment benchmark)
Endrin	Sediment Tissue	
Endrin aldehyde & ketone	Sediment	
Hexachlorobenzene	Tissue	
Methoxychlor	Sediment	(no sediment benchmark)
Mirex	Tissue	
***cis-* & *trans-*Nonachlor**	Sediment Tissue	Tissue (sum of chlordanes)
Current Use Pesticides		
Tri-, tetra- & pentachlorophenol	Marine Water Sediment	(no sediment benchmark)
***alpha-*Hexachlorocyclohexane**	Sediment Tissue	Sediment Tissue (sum of hexachlorocyclohexanes)
***beta-*Hexachlorocyclohexane**	Sediment Tissue	(no sediment benchmark) Tissue (sum of hexachlorocyclohexanes)
***delta-*Hexachlorocyclohexane**	Sediment	(no sediment benchmark)
***gamma-*Hexachlorocyclohexane**	Sediment Tissue	Sediment Tissue (sum of chlordanes)
Permethrin	Sediment Tissue	(no sediment benchmark)
Trifluralin	Tissue	(no benchmarks)

Table 3. Compounds Measured but Not Detected in Media of Burrard Inlet

Non-Detected Parameters	Below Detection Limit in (Media)
Legacy Pesticides	
Aldicarb, incl. sulfone & sulfoxide	Sediment
Aldrin	Sediment Tissue
Diazinon	Sediment Tissue
Diazinon-oxon	Tissue
Endosulfan sulfonate	Sediment Tissue
Endrin aldehyde & ketone	Tissue
Heptachlor	Sediment Tissue
Methoxychlor	Tissue
Mirex	Sediment
Oxy-chlordane	Sediment Tissue
Toxaphene	Tissue
Current Use Pesticides	
Atrazine	Sediment Tissue
Carbaryl	Sediment
Other chlorophenol congeners	Sediment Marine Water
Chlorpyrifos	Sediment Tissue
Imidacloprid	Sediment
***delta*-Hexachlorocyclohexane**	Tissue
Malathion	Sediment Tissue
Simazine	Sediment Tissue
Trifluralin	Sediment

3.4 Knowledge Gaps and Research Needs

Knowledge gaps and research needs that need to be addressed for both legacy and CUPs – in general and specifically within Burrard Inlet – were identified as follows:

- Gaps in the understanding of the sub-lethal toxicity, species sensitivity distributions, environmental fate, and surface water concentrations for each pesticide need to be addressed. Toxicity data are even more limited for marine organisms than freshwater biota.
- More extensive baseline/current condition studies of pesticide concentrations are needed for fish and fish habitat data (Anderson et al., 2021).

- Sufficiently low detection limits need to be developed to detect pesticides; this would allow for a better characterization of pesticides in surface waters and investigation of ecologically and toxicologically relevant concentrations (Anderson et al., 2021; De Solla et al, 2012).
- Environmental monitoring data available for use are skewed toward more freshwater than marine samples. As a result, the risk for marine species is often compared to pesticide concentrations measured in freshwater habitats. This aspect should be further investigated since the fate of pesticides may differ with salinity, pH, dissolved organic carbon, and other physicochemical differences between freshwater and marine systems (DeLorenzo and Fulton, 2012).
- Further pesticide monitoring efforts in the marine environment of Burrard Inlet would improve the accuracy of pesticide risk assessments for coastal habitats (DeLorenzo and Fulton, 2012).
- While many pesticides are additive in toxicity, some have been shown to exhibit synergistic effects (Belden et al., 2000; DeLorenzo and Serrano, 2006); therefore, the examination of pesticide mixtures would allow for further assessment of potential risks to the marine environment of Burrard Inlet.
- Predictions of risk will also be enhanced by including toxicity data for early life stages of coastal species, which are often more sensitive than the adult forms and reside in estuarine areas in closest proximity to sources of pesticide exposure (DeLorenzo and Fulton, 2012).
- There is limited knowledge about pesticide adjuvants that are added to enhance a pesticide's performance and/or to facilitate application. Examples of adjuvant types include solvents, odour masking agents, propellants, defoaming agents, deposition agents, drift control agents, and thickeners. Adjuvants can be toxic, and several negative effects have been reported in humans and on the environment (Mesnage and Antoniou, 2018). Some pesticide adjuvants are identified contaminants of emerging concern (CECs), for example nonylphenol ethoxylates used as surfactants; other adjuvants are suspected CECs for which environmental occurrence and toxicity are unknown (CECs in Burrard Inlet are addressed in Björklund and LeNoble 2024).
- Novel pesticides are continuously developed as legacy and CUPs are being replaced due to identified harmful effects and subsequent restrictions, but general knowledge about these novel compounds is lacking.

4. PROPOSED OBJECTIVES FOR PESTICIDES IN BURRARD INLET

The most conservative and protective benchmarks, based on recent research and where exceeded in samples collected by the assessed monitoring programs, are proposed as WQOs for Burrard Inlet. In addition to these numeric objectives, an overall objective is a decreasing trend in the levels of legacy pesticides and CUPs in all media. For pesticides that are yet to be sampled in Burrard Inlet, the most conservative benchmarks that exist are also proposed objectives. Where there have been no detections of a given pesticide, the objective proposed is 'do not detect, when using best available detection limits'. Proposed WQOs are presented in Appendix A. These site-specific objectives are proposed for pesticides in Burrard Inlet in the interest of understanding trends and ultimately reducing pesticide loading and concentrations in the inlet.

The proposed WQOs based on BC working water quality guidelines for pesticides in water are set to protect aquatic life against acute toxicity; however, they are not appropriate for assessing chronic exposure effects or risks to human health from the consumption of finfish and shellfish. The benchmarks that have been adopted from the US EPA criteria for pesticide levels in water are based on water quality criteria for human consumption of seafood developed by the US EPA as well as the Washington State Water Quality Standards (2019).

Where there is insufficient toxicological information, a qualitative objective is proposed for a decreasing trend in the concentration of each of the pesticides in all media over time.

5. MONITORING RECOMMENDATIONS

Monitoring recommendations help refine existing monitoring programs and inform future assessments to determine whether the pesticide objectives are attained. The following are recommendations for pesticide monitoring in Burrard Inlet:

- Analyses are complicated by the wide range of detection limits among the monitoring programs. Maintaining a standardized detection limit, where possible, as part of any monitoring program for pesticides would be beneficial to the analysis. It is recognized that commercial laboratories may not be able to achieve detection limits that are significantly lower than some of the proposed objectives. Where this is the case, the limitations for the monitoring program, assessment, and conclusions should be noted.
- Due to the influence of temperature, light and pH, monitoring of both legacy and CUPs in water should occur year-round to determine seasonal effects on pesticide concentrations.
- Monitoring is needed at stormwater outfalls to help identify hotspots.
- Monitoring should be conducted to determine which pesticides are entering Burrard Inlet from tributaries and discharge points within its watershed, versus from Fraser River sediment.
- All monitoring data should become open data and be made available to Indigenous governments, regulatory agencies, municipalities, and the public on a timely basis.
- CUPs such as glyphosate (US EPA, 2022), s-metolachlor (US EPA, 1995) and 2,4-dichlorophenoxyacetic acid (2,4-D) (US EPA, 2023) should be considered for inclusion in future monitoring programs because they are high production volume chemicals with proven toxic effects on humans and/or aquatic organisms including plants and animals.
- Monitoring should include pesticides for which there are approved or working BC marine WQGs, but which are currently not monitored in Burrard Inlet. Examples include monochlorobenzene, chlorothalonil, and imidacloprid.
- With any improvement in detection limits, concentrations of pesticides that were previously not detected or below detection limits should be compared to the screening benchmarks to understand their potential effects.

6. MANAGEMENT OPTIONS

Key management options that should be applied throughout the Fraser River watershed and Burrard Inlet basin to help reduce pesticide levels in Burrard Inlet include the following:

- Source controls such as phasing out the use of pesticides for residential and cosmetic use.
- Educational and outreach campaigns that promote Integrated Pest Management (IPM) in agricultural and residential settings. An example is to implement crop rotations to reduce pests in agricultural fields, or the use of biocontrols (a method of controlling pests with other organisms), both of which result in a reduced need for pesticides.
- Support continued compliance verification activities of all pesticide use sectors to determine if they are compliant with current IPM practices (ENV, 2005 and 2017) and any additional requirements expressed by Indigenous Nations.

- Development and implementation of Integrated Stormwater Management Plans (ISMPs) for all developed watersheds that flow into Burrard Inlet.
- Since urban stormwater plays a role in transporting pesticides to Burrard Inlet (e.g. Levin et al, 2020), prioritize the implementation of source controls to reduce the input of pesticides and improve the water quality of stormwater discharges.
- Conduct a pollutant load study to help identify the sources of pesticides (and other contaminants) to Burrard Inlet.
- Encourage more widespread adoption of green infrastructure and other design criteria that provide water quality treatment for stormwater runoff prior to discharge to Burrard Inlet.
- Encourage adequate controls for runoff and erosion from urban development to prevent soil that may be highly contaminated with pesticides from entering Burrard Inlet.

LITERATURE CITED

Ahmadi-Mamaqani, Y., Khorasani, N., Talebi,K., Hashemi, S, H., Rafiee, G., Bahadori-Khosroshahi, B. 2011. Diazinon fate and toxicity in the Tajan River (Iran) ecosystem. Env. Eng. Science. Vol 28, pp, 1-10.

Alam, J., Daoxian, Y., Jiang, Y, J., Yuchuan, S., Yong, Li., Xin, Xu. 2014. Source and transport of organochlorine pesticides in the Nanshan underground river, China. Env. Earth Sciences. Vol 71, pp. 1977-1987.

Allen, R. J. 1989. An Overview of Pollution of the Fraser River Estuary by Chlorinated Phenolic Compounds, Burlington, ON: National Water Research Institute.

Anderson, J.C., Marteinson, S,C., Prosser, R.S. 2021. Prioritization of Pesticides for Assessment of Risk to Aquatic Ecosystems in Canada and Identification of Knowledge Gaps. Rev Environ Contam Toxicol. Doi: 10.1007/398_2021_81. Epub ahead of print. PMID: 34625837.

Awkerman, J.A., Lavelle, C.W., Henderson, W.M., Hemmer, B, L., Lilavois, C.R., Harris, P., Zielinski, N., Hoglund, M.D., Glinski, D.A., MacMillan, D., Ford, J., Seim, R.F., Moso, E., Raimondo, S. 2020. Cross-Taxa Distinctions in Mechanisms of Developmental Effects for Aquatic Species Exposed to Trifluralin. Env. Tox and Chem. Vol 39(9), pp. 1797-1812.

Belden, J.B., Hofelt, C, S,.Lydy, M, J. 2000. Analysis of multiple pesticides in urban storm water using solid-phase extraction. Arch. Env. Contam. Toxicology. Vol. 38, pp. 7-10.

Bidleman T.F., Kylin H, Jantunen LM, Helm PA, Macdonald RW. Hexachlorocyclohexanes (HCHs) in the Canadian Archipelago. 1. Spatial distribution and pathways of α-, βand γ-HCHs in surface water. Environ Sci Technol 2007;41:2688–95.

Björklund, K., and LeNoble, J. 2024 (in prep.). Water Quality Assessment and Proposed Objectives for Burrard Inlet: Contaminants of Emerging Concern Technical Report. Prepared for Tsleil-Waututh Nation and the Province of B.C.

Blus, L. J. 2002. Organochlorine Pesticides. *Handbook of Ecotoxicology*, 2nd Ed. Edited by Hoffman, D.J., Rattner, B.A., Burton, A.G., Cairns, J. Lewis Publishers, USA. Pp. 313

Bondarenko, S., Gan, J., Haver, D.L., Kabashima, J.N. 2004. Persistence of selected organophosphate and carbamate insecticides in waters from coastal watershed. Env. Tox. And Chem. Vol 23(11), pp. 2649.

Brain, R. A., Anderson, J, C., Hanson, M, L. 2021. Acute and early life-stage toxicity of atrazine in sheepshead minnow (*Cyprinodon variegatus*). Ecotox. And Env. Safety. Vol 218. Pp, 112303.

Brown, M.T., Takada, H. 2017. Indicators of marine pollution in the North Pacific ocean. Arch. Env. Toxicol. Vol 73, pp, 171-175.

Cabrerizo, A., Dachs, J., Moechel, M., Ojeda, M., Caballera, G., Barcelo, D., Jones, K. 2011. Ubiquitous net volatilization of polycyclic aromatic hydrocarbons from soils and parameters influencing their soil-air partitioning. Env. Sc and Tech. Vol. 45, pp, 4740-4747.

CAREX Canada. 2020. Diazinon Profile. https://www.carexcanada.ca/profile/diazinon/ (accessed Oct, 2021).

CAREX Canada. 2023a. Malathion Profile. Malathion – CAREX Canada (accessed March 2023).

CAREX Canada. 2023b. Chlorothalonil Profile. Chlorothalonil – CAREX Canada (accessed March 2023).

CCME (Canadian Council of Ministers of the Environment). 1998. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg. http://ceqg-rcqe.ccme.ca/en/index.html#void

CCME (Canadian Council of Ministers of the Environment). 1999a. Canadian environmental quality guidelines, Canadian Council of Ministers of the Environment, Winnipeg. http://ceqg-rcqe.ccme.ca/en/index.html#void

CCME (Canadian Council of Ministers of the Environment). 1999b. Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses: Aldicarb. https://ccme.ca/en/res/aldicarb-canadian-water-quality-guidelines-for-the-protection-of-agricultural-water-uses-en.pdf

CCME (Canadian Council of Ministers of the Environment). 1999c. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life: Toxaphene. https://ccme.ca/en/res/toxaphene-canadian-sediment-quality-guidelines-for-the-protection-of-aquatic-life-en.pdf.

CCME (Canadian Council of Ministers of the Environment). 1999d. Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses: Simazine. https://ccme.ca/en/res/simazine-en-canadian-water-quality-guidelines-for-the-protection-of-aquatic-life.pdf (accessed Oct 2022).

CCME (Canadian Council of Ministers of the Environment). 2002.Canadian sediment quality guidelines for the protection of aquatic life: Toxaphene. Updated. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment. https://ccme.ca/en/res/toxaphene-canadian-sediment-quality-guidelines-for-the-protection-of-aquatic-life-en.pdf (accessed Nov 2022).

CCME (Canadian Council of Ministers of the Environment). 2007. Canadian water quality guidelines for the protection of aquatic life: Imidacloprid. Canadian Council of Ministers of the Environment, Winnipeg. https://ccme.ca/en/res/chlorpyrifos-en-canadian-water-quality-guidelines-for-the-protection-of-aquatic-life.pdf.

CCME (Canadian Council of Ministers of the Environment). 2008. Canadian water quality guidelines for the protection of aquatic life: Chloropyrifos. Canadian Council of Ministers of the Environment, Winnipeg. https://ccme.ca/en/res/chlorpyrifos-en-canadian-water-quality-guidelines-for-the-protection-of-aquatic-life.pdf.

CCME (Canadian Council of Ministers of the Environment). 2009. Canadian water quality guidelines for the protection of aquatic life: Carbaryl. Canadian Council of Ministers of the Environment, Winnipeg. https://ccme.ca/en/res/2009-carbaryl-cwqg-scd-1436-en.pdf.

CCME (Canadian Council of Ministers of the Environment). 2010. Canadian water quality guidelines for the protection of aquatic life: Endosulfan. Canadian Council of Ministers of the Environment, Winnipeg. http://ceqg-rcqe.ccme.ca/download/en/327

Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC). 2022. Persistent Organic Pollutants. Persistent organic pollutants (rcaanc-cirnac.gc.ca) (accessed March, 2023)

Costa, L, C. 2015. The neurotoxicity of organochlorine and pyrethroid pesticides. Handbook of Clinical Neurology. Vol 131, pp.135-148.

Czaplicka, M. 2004. Sources and transformations of chlorophenols in the natural environment. Science of the Total Environment, Volume 322, pp. 21-39.

Degrendele, C., Okonski, K., Melymuk, L., Landlova, L., Kukucka, P., Audy, O., Kohoutek, J., Cupr, P., Klanova, J. 2016. Pesticides in the atmosphere: a comparison of gas-particle partitioning and particle size distribution of legacy and current-sue pesticides. Atmos. Chem. Phys. Vol. 16, pp. 1531-1544.

DeLorenzo, M., Fulton, M, H. 2012. Comparative risk assessment of permethrin, chlorothalonil, and diuron to coastal aquatic species. Marine Poll. Bull. Vol 64, pp. 1291-1299.

DeLorenzo, M., Serrano, L. 2006. Mixture Toxicity of the Antifouling Compound Irgarol to the Marine Phytoplankton Species *Dunaliella tertiolecta*. Journal of Environmental Science and Health. Vol 41, Isssue 6. pp. 1349-1360.

DeLorenzo, M., Scott, G.I., Ross, P.E. 2001. Toxicity of pesticides to aquatic microorganisms: A review. Env. Tox. And Chem. Vol 20, pp. 84-98.

De Solla, S., Struger, J., McDaniel, T.V. 2012. Detection limits can influence the interpretation of pesticide monitoring data in Canadian surface waters. Chemosphere. Vol.86, pp. 565-571.

Edmunds, J,S., McCarthy, R, A., Ramsdell, J, S. 2000. Permanent and functional male-to-female sex reversal in d-rR strain medaka (Oryzias latipes) following egg microinjection of o,p'-DDT. Env health Perspect. Vol 108. Pg, 219-224.

Environment and Climate Change Canada (ECCC). 2017.Part I- Canada's Draft National Implementation Plan for the Stockholm Convention. https://ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=C164ACE6-1 (accessed Oct, 2021).

ECCC (Environment and Climate Change Canada). 2021. Substances with pesticidal uses. https://www.canada.ca/en/health-canada/services/chemical-substances/other-chemical-substances-interest/substances-pesticidal-uses.html (accessed Oct, 2021).

ENV (BC Ministry of Environment and Climate Change Strategy). 2005. Survey of pesticide use in British Columbia: 2003. Ministry of Environment, Government of British Columbia.

ENV (BC Ministry of Environment and Climate Change Strategy). 2017. Integrated Pest Management Act Golf Course Compliance Audit. https://www2.gov.bc.ca/assets/gov/environment/pesticides-and-pest-management/pesticide-use/reports/2017_golf_course_audit_report.pdf (accessed Oct 2021).

ENV (BC Ministry of Environment and Climate Change Strategy). 2021a. British Columbia working Water Quality Guidelines: aquatic life, wildlife & agriculture. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/bc_env_working_water_quality_guidelines.pdf (accessed Oct 2021).

ENV (BC Ministry of Environment and Climate Change Strategy). 2021b. Ambient Water Quality Guidelines for Chlorophenols. First Update. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-guidelines/approved-wqgs/bc_env_chlorophenols_waterqualityguideline_technical.pdf (accessed Nov 2022).

ENV (BC Ministry of Environment and Climate Change Strategy) and HLTH (BC Ministry of Health). 2021. Tissue Quality Objectives recommendations for Burrard Inlet. Prepared for Tsleil-Waututh Nation and the Province of BC. https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/water-quality-objectives/burrard_inlet_water_quality_objectives_methods_tissue_rec_june_3-_2021.pdf

Environment Canada. 2011. Presence and Levels of Priority Pesticides in Selected Canadian Aquatic Ecosystems. Water Science and Technology Directorate. https://www.canada.ca/content/dam/eccc/migration/main/eaudouce-freshwater/5eef7087-5907-4e79-8efe-37e6541e6fcf/presenceandlevelsofprioritypesticidesinselectedcanadianaquaticecosystems-20final-s.pdf (Accessed September 2021).

Environment Canada. 2015.Update to Canada's National Implementation Plan under the Stockholm Convention on Persistent Organic Pollutants. https://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=FDB6031D-1&offset=4 (Accessed Oct 2021).

European Union. 2021. The use of pesticides in developing countries and their impact on health and the right of food. https://www.europarl.europa.eu/cmsdata/219887/Pesticides%20health%20and%20food.pdf (accessed Oct 2021).

Fulton, M.H., Key, P.B., DeLorenzo, M.E. 2013. Insecticide toxicity in fish. Organic Chemical Toxicology of Fishes. Pp 309-368.

Ge, T. Han, J., Qi, Y., Gu, X., Ma, L., Zhang, C., Naeem, S., Huang, D. 2017. The toxic effects of chlorophenols and associated mechanisms in fish. Aquatic Toxicology, Volume 184, pp. 78-93.

Gillian, L.D., Lei, Y.D., Teixeira, C., Muir, D.C.G., Wania, F. 2007. Pesticides in western Canadian mountain air and soil. Env. Sci. Technol. Vol 41, pp 6020-6025.

Gioia, R., Dachs, J., Nizzetto, L., Berrojalbiz, N., Galbán, C., Del Vento, S., Mejanelle, L., Jones, K. C. 2011. Sources, Transport and Fate of Organic Pollutants in the Oceanic Environment. Persistent Pollution – Past, Present and Future. Doi:10.1007/978-3-642-17419-3_8 . Pp. 111–139.

Government of Canada, 1987a. Water Chlorophenols. https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/publications/healthy-living-vie-saine/water-chlorophenols-eau/alt/water-chlorophenols-eau-eng.pdf (accessed Oct 2022).

Government of Canada, 1987b. Aldicarb. https://publications.gc.ca/Collection/H48-10-1-5-1995E.pdf (accessed March 2023).

Greymore, M., Stagnitti, F., Allinson, G. 2001. Impacts of atrazine in aquatic ecosystems. Env. International. Vol. 26, pp. 483-495.

Halverson, M. Pawlowicz, R. 2016. Tide, Wind, and River Forcing of the Surface Currents in the Fraser River Plume, Atmosphere-Ocean, 54:2, 131-152, DOI: 10.1080/07055900.2016.1138927Health Canada. 2022. Re-evaluation Note REV2022-02, Update on the Special Review of Pentachlorophenol. Re-evaluation Note REV2022-02, Update on the Special Review of Pentachlorophenol – Canada.ca (accessed April 2022).

Health Canada. 2010a. Federal contaminated site risk assessment in Canada. Supplemental guidance on human health risk assessment for country foods (HHRA $_{Foods}$). Contaminated Sites Division. Safe Environments Directorate. Ottawa, ON (CA): Health Canada. http://publications.gc.ca/collections/collection_2012/sc-hc/H128-1-11-641-eng.pdf (Accessed July 2020)

Health Canada. 2010b. Use of Malathion in Mosquito Control Programs. https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/fact-sheets-other-resources/malathion-mosquito-control-programs.html (accessed Oct 2022).

Health Canada. 2013. Diazinon Risk Management Plan Re-evaluation Note REV2013-01. https://www.hc-sc.gc.ca/cps-spc/alt_formats/pdf/pubs/pest/decisions/rev2013-01/rev2013-01-eng.pdf (accessed Nov 2021).

Health Canada. 2015. Re-evaluation Note REV2015-12, Special Review of Trifluralin: Proposed Decision for Consultation. https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/consultations/re-evaluation-note/2015/special-review-trifluralin/document.html#t1 (accessed Oct 2022).

Health Canada. 2016. Re-evaluation Decision RVD2016-02, Carbaryl. https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/reevaluation-decision/2016/document-carbaryl-rvd2016-02.html (accessed Oct 2022).

Health Canada. 2015. Re-evaluation Note REV2016-09, Special Review of Simazine: Proposed Decision for Consultation. Re-evaluation Note REV2016-09, Special Review of Simazine: Proposed Decision for Consultation – Canada.ca (accessed March 2023).

Health Canada. 2017a. Proposed re-evaluation decision PRVD2017-18, permethrin and its associated end-use products. https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/consultations/proposed-re-evaluation-decisions/2017/permethrin/document.html (accessed Oct 2021).

Health Canada. 2017b. Re-evaluation Note REV2017-09, Special Decision: Atrazine. https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/reevaluation-note/2017/atrazine-rev-2017-09.html (accessed Oct 2021).

Health Canada. 2019. Re-evaluation Decision RVD2019-06, Imidacloprid and Its Associated End-use Products: Pollinator Re-evaluation. https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/reevaluation-decision/2019/imidacloprid.html (accessed Oct 2022).

Health Canada. 2021a. Re-evaluation Note REV2021-04, Cancellation of remaining chlorpyrifos registrations under paragraph 20(1)(a) of the Pest Control Products Act. (https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/reevaluation-note/2021/cancellation-remaining-chlorpyrifos-registrations.html (accessed Oct 2022).

Health Canada. 2021b. Guidelines for Canadian Drinking Water Quality. Malathion. https://www.canada.ca/content/dam/hc-sc/documents/programs/consultation-malathion-drinking-water/pub1-eng.pdf (accessed Nov 2022).

Health Canada. 2021c. Re-evaluation Decision RVD2021-05, Imidacloprid and Its Associated End-Use Products. Re-evaluation Decision RVD2021-05, Imidacloprid and Its Associated End-use Products – Canada.ca (accessed March, 2023).

Health Canada. 2021d. Federal contaminated site risk assessment in Canada. Part I: Guidance on human health preliminary quantitative risk assessment (PQRA), Version 3.0. Ottawa, ON (CA): Health Canada. http://publications.gc.ca/collections/collection_2018/sc-hc/H128-1-11-632-eng.pdf (Accessed May 2023)

Health Canada. 2021e. Federal contaminated site risk assessment in Canada. Toxicological Reference Values (TRVs). Version 3.0. Ottawa, ON (CA) Health Canada. https://publications.gc.ca/collections/collection_2021/sc-hc/H129-108-2021-eng.pdf.

Health Canada. 2022. Update on the Special Review of Pentachlorophenol. https://www.canada.ca/content/dam/hc-sc/documents/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/reevaluation-note/2022/update-special-review-pentachlorophenol/update-special-review-pentachlorophenol.pdf (accessed May, 2022).

Hoferkamp, L., Hermanson, M, H., Muir, D, C, G. 2010. Current use pesticides in arctic meadia; 2000-2007. Science of the Tot Env. Vol 403, pp.2985-2994.

Hoffman, D,J,. Barnett, R,A., Burton, A, G., Cairns, J.J. 2003. Introduction. *Handbook of Ecotoxicology*, 2nd Ed. Edited by Hoffman, D.J., Rattner, B.A., Burton, A.G., Cairns, J. Lewis Publishers, USA. Pp. 1-17.

Igbinosa, E.O., Odjadjare, E.E., Chigor, C.N., Igbinosa, I.H., Emoghene, A.O., Ekhaise, F.O., Igiehon, N.O., Idemudia, O.G. 2013. Toxicological Profile of Chlorophenols and Their Derivatives in the Environment: The Public Health Perspective. Scientific World Journal. Vol 2013, Article ID 460215. https://doi.org/10.1155/2013/460215

Indian and Northern Affairs Canada. 2010. Persistent Organic Pollutants (POPs) Fact Sheet. Toxaphene. https://publications.gc.ca/collections/collection_2015/aadnc-aandc/R73-2-0-2010-eng.pdf (accessed Nov 2022).

Jayaraj, R., Megha, P., Sreedev, P. Organochlorine pesticides, their toxic effects on living organisms and their fate in the environment. Inter. Tox. Vol. 9, pp. 90-100.

Kannan, K., Ridal, J., Struger, J. 2005. Pesticides in the Great Lakes. Handbook of Env Chem. Vol 5, pp. 151-199.

Koshlukova, S.E., Reed, N.R. 2014. Chlordane. Encyclopedia of Toxicology (Third Edition). Pp. 841-845.

Levin, P.S., Howe, E.R., Robertson, J.C. 2020. Impacts of stormwater on coastal ecosystems: the need to match the scales of management objectives and solutions. Philos Trans R Soc Lond B Biol Sci. Vol 375, pp 1814. Doi: 10.1098/rstb.2019.0460

Long, E.R., and L.G. Morgan. 1990. The potential for biological effects of sediment sorbed contaminants tested in the national status and trends program, National Oceanic and Atmospheric Administration, Seattle, Washington.

Méjanelle, L., Jara, B., Dachs, J. 2020. Fate of pyrethroids in freshwater and marine environments. Pyrethroid Insecticides, 2020, ff10.1007/698_2019_433ff. ffhal-02933589f

Menzie, C.M. 1980. Metabolism of Pesticides-Update III. Special Scientific Report- Wildlife No. 232. Washington, DC: U.S.Department of the Interior, Fish and Wildlife Service, 1980., p. 136

Mesnage, R. and Antoniou, MN. 2018. Ignoring Adjuvant Toxicity Falsifies the Safety Profile of Commercial Pesticides. Front. Public Health 5:361. Doi: 10.3389/fpubh.2017.00361.

Michalowicz, J. & Duda, W., 2007. Phenols – Sources and Toxicity. Polish Journal of Environmental Science, 16(3), pp. 347-362.

Munz, R., Hannemann, C., Orlinskiy, P, Gunold, R., Paschke, A., Foit, K., Becker, J., Kaske, O., Paulsson, E., Peterson, M., Jernstedt, H., Kreuger, J., Schuurmann G., Liess, M. 2017. Pesticides from wastewater treatment plant effluents affect invertebrate communities. Sc of the Tot Env. Pp. 387-399.

Moore, D,R,J.,Thompson, R.P., Rodney, S.I., Fischer, D., Ramanarayanan, T., Hallz, T. 2009. Refined Aquatic Risk Assessment for Aldicarb in the United States. Integrated Environmental Assessment and Management. Vol. 6 (1), pp. 102–118.

Noël, M., Dangerfield, N., Hourston, R, A,S.,Belze, W., Shaw, P., Yunker, M, B., Ross, P, S. 2009. Do trans-Pacific air masses deliver PBDEs to coastal British Columbia, Canada? Env. Poll. Vol 157, pp. 3404-3412.

Pawlowicz, R. Di Costanzo, R. Halverson, M. Devred, M. Johannessen, S. 2017. Advection, Surface Area, and Sediment Load of the Fraser River Plume Under Variable Wind and River Forcing, Atmosphere-Ocean, 55:4-5, 293-313, DOI: 10.1080/07055900.2017.1389689

Perez-Rodrigues, V., Wu, N., de-la Cova, A., Schmidt, J., Denslow, N.D., Martyniuk, C.J. 2019. The organochlorine pesticide toxaphene reduced non-mitochondrial respiration and induces heat shock protein in early-staged zebrafish (Danio rerio). Comparative Biochem. And Physiol. Part C: doi:10.1016/j.cbpc.2019.108669

Pinto, M.I., Vale, C., Sontag, G., Noronha, J.P. 2016. Pathways of priority pesticides in sediments of coastal lagoons: The case study of Obidos Lagoon, Portugal. Marine Poll. Bull. Vol 106, pp. 335-340.

Poleksic, V., and Karan, V. 1999. Effects of Trifluralin on Carp: Biochemical and Histological Evaluation. Ecotoxicology and Environmental Safety. Vol 43, pp. 213-221.

Province of BC. 2013. BC reg. 375/96. Environmental Management Act. Contaminated Sites Regulation. http://www.bclaws.ca/civix/document/id/loo89/loo89/375_96_08 (accessed Oct 2021).

Rao, A., Sanchez, M., Sutherland, D. and P. Lilley. 2019. Water Quality Assessment and Updated Objectives for Burrard Inlet: Introduction. Prepared for Tsleil-Waututh Nation and the Province of BC.

Richardson, G.M and Stantec Consulting Ltd. 2013. 2013 Canadian Exposure Factors Handbook Life Expectancy, Body Dimensions, Inhalation, Time-Activity, and Soil Ingestion. https://www.usask.ca/toxicology/docs/cef (Accessed July 2020)

Richardson, G.M. 1997. Compendium of Canadian Human Exposure Factors for Risk Assessment. Ottawa: O'Connor Associates Environmental Inc.

Sandoval-Herrera, N., Freylan, M., Espinoza, M., Romero, A., 2019. Neurotoxicity of organophosphate pesticide could reduce the ability of fish to escape predation under low does of exposure. Scientific Reports 9, 10530. https://doi.org/10.1038/s41598-019-46804-6.

Sang, S., Petrovic, S., Cuddeford, V. 1999. Lindane: A review of toxicity and environmental fate. Prepared for World Wildlife Fund's Toxicology Program. https://www.researchgate.net/profile/Vijay-Cuddeford/publication/242513937_LINDANE__A_REVIEW_OF_TOXICITY/links/568d40f808aef987e565e348/LINDANE-A-REVIEW-OF-TOXICITY.pdf (accessed Oct, 2022).

Scholz, N. L., Fleishman, E., Brown, L., Werner, I., Johnson, M.L., Brooks, M. L., Mitchelmore, C.L., Schlenk, D. A perspective on modern pesticides, palagic fish declines, and unknown ecological resilience in highly managed ecosystems. BioScience. Vol 62, pp. 428-434.

Scow, K. et al., 1982. An Exposure and Risk Assessment for Chlorinated Phenols, Washington, DC: United States Environmental Protection Agency.

Steinberg, C,E,W., Lorenz, R., Spieser, O, H., Effects of atrazine on swimming behaviour of zebrafish, *Brachydanio rerio*. Water Res. Vol 29(3), pp. 981-985.

Strachan WMJ, Fisk A, Texeira CF, Burniston DA, Norstron R. PCBs and organochlorine pesticide concentrations in the waters of the Canadian Archipelago and other Arctic regions. AMAP workshop on persistent organic pollutants (POPs) in the Arctic: human health and environmental concerns, Rovaniemi, Arctic Monitoring Assessment Program/University of the Arctic; 2000.

Stockholm Convention. 2019. All POPs listed in the Stockholm Convention. Available at: http://chm.pops.int/TheConvention/ThePOPs/ListingofPOPs/tabid/2509/Default.aspx (accessed Oct. 2021).

Solomon, K.R., Baker, D.D., Richards, P.R., Dixon, K.R., Klaine, S.J., La Point, T.W., Kendall, R.J., Weisskipf, C.P., Giddings, J.M., Giesy, J.P., Hall, L.W., Williams, M, W. 1996. Ecological risk assessment of atrazine in North America surface waters. Env. Tox. And Chem. Vol. 15, pp. 31-76.

Tišler,T., Jemec, A., Mozetic, B., Trebše, P. 2009. Hazard identification of imidacloprid to aquatic environment. Chemosphere. Vol 76, pp. 907–914.

Tsleil-Waututh Nation (TWN)_. 2017. Burrard Inlet Action Plan. Prepared by Kerr Wood Leidal Associates for Tsleil-Waututh Nation. 144 pp.

UNEP (United Nations Environmental Programme). 2006. Lindane. Risk Profile. Adopted by the Persistent Organic Pollutants Review Committee at its second meeting. Microsoft Word – POPRC-2 rep add4.doc (pops.int) (accessed March 2023).

US EPA (United States Environmental Protection Agency). 1995. R.E.D. Facts: Metalochlor. EPA-738-95-007. https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/fs_PC-108801_1-Apr-95.pdf (accessed August 2023)

US EPA (United States Environmental Protection Agency). 1986. Quality Criteria for Water. Office of Water Regulations and Standards. EPA 440/5-86-001. Pp. 477.https://www.epa.gov/sites/default/files/2018-10/documents/quality-criteria-water-1986.pdf (accessed Nov, 2022).

US EPA (United States Environmental Protection Agency). 2000. Guidance for assessing chemical contaminant data for use in fish advisories. Volume 2. Risk assessment and fish consumption limits. Third Edition. EPA 823-B-00-008. Washington, DC (US): U.S. Environmental Protection Agency, Office of Water.

US EPA (United States Environmental Protection Agency). 2006. Region III BTAG FRESHWATER SEDIMENT SCREENING BENCHMARKS. https://www.epa.gov/sites/production/files/2015-09/documents/r3_btag_fw_sediment_benchmarks_8-06.pdf (accessed Oct 2021).

US EPA (United States Environmental Protection Agency). 2015. Final updated ambient Water Quality Criteria for the protection of human health. https://www.regulations.gov/document?D=EPA-HQ-OW-2014-0135-0155

US EPA (United States Environmental Protection Agency). 2019. Reports and fact sheets about fish consumption and human health. https://www.epa.gov/fish-tech/reports-and-fact-sheets-about-fish-consumption-and-human-health

US EPA (United States Environmental Protection Agency). 2020. National recommended water quality criteria – human health criteria table. https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table

US EPA (United States Environmental Protection Agency). 2021. AQUATOX: Linking water quality and aquatic life. https://www.epa.gov/ceam/aquatox (accessed Oct 2021).

US EPA (United States Environmental Protection Agency). 2022. Glycophosphate. https://www.epa.gov/ingredients-used-pesticide-products/glyphosate (accessed August 2023).

US EPA (United States Environmental Protection Agency). 2023. 2,4-D. https://www.epa.gov/ingredients-used-pesticide-products/24-d#:~:text=2%2C4%2DD%20is%20a,the%20growth%20of%20citrus%20plants. (accessed August 2023).

Vajargah, M.F., Namin, J.I., Mohsenpour, R., Yalsuyi, A.M., Prokic, M.D., Faggio, C. 2021. Histological effects of sublethal concentrations of insecticide Lindane on intestinal tissue of grass carp (*Ctenopharyngodon idella*). Veterinary Research Communications. Vol 45, pp. 373-380.

Velisek, J., Kouba, A., Stara, A. 2013. Acute toxicity of triazine pesticides to juvenile signal crayfish (*Pacifastacus leniusculus*). Neuroendocrinology Letters. Vol 34, pp. 31-36.

Vorkamp, K., & Riget, F.F. 2014. A review of new and current-use contaminants in the Arctic environment: Evidence of long-range transport and indications of bioaccumulation. Chemosphere. Vol 111, pp. 379-395.

Warrington, P. D., 1997. Ambient Water Quality Guidelines for Chlorophenols – First Update, Victoria: British Columbia Ministry of Environment, Lands and Parks (Currently Ministry of Environment and Climate Change Strategy).

Washington State Department of Ecology (DoE). 2013. Sediment Management Standards. https://apps.ecology.wa.gov/publications/documents/1309055.pdf

Washington State Legislature. 2019. Chapter 173-201A. WAC Water quality standards for surface waters of the State of Washington. https://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A

WLRS (BC Ministry of Water, Land & Resource Stewardship). 2023. Derivation of screening values for contaminants in fish tissue. Prov. B.C., Victoria B.C.

World Health Organization (WHO), UN Environment Programme, & International Labour Organisation, 1989. Chlorophenols other than Pentachlorophenol. http://www.inchem.org/documents/ehc/ehc/ehc093.htm [Accessed July 2019].

World Health Organization (WHO). 1996. Chlorophenols in Drinking Water, Geneva: World Health Organization.

Woudneh, M,B., Ou, Z., Sekela, M., Tuominen, T., Gledhill, M. 2009. Pesticide multiresidue in waters of the Lower Fraser Valley, British Columbia, Canada. Part I. Surface water. J. Environ. Vol 38, pp. 940-947.

Xin, J., Liu, X., Liu, W., Jiang, L., Wang, J., Niu, J. 2011. Production and use of DDT containing antifouling paint resulting in high DDT residue in three paint factory sites and two shipyard sites, China. Chemosphere. Vol 84, pp. 342-347.

APPENDIX A: SCREENING BENCHMARKS AND PROPOSED WATER QUALITY OBJECTIVES (WQOS)

The screening benchmarks used (Table A1) are the most conservative benchmarks identified for each parameter in water, sediment and tissue. Benchmarks for water and sediment were sourced from Provincial, Federal, and U.S. environmental quality guidelines and standards, and screening levels were calculated for pesticide levels in tissue (see Section 3.1). Comments with respect to data analysis reflect guidance from BC HLTH (D. Stein, BC HLTH, pers. comm., 2021).

Benchmarks were not available for the following parameters because of insufficient toxicological information:

- Marine water: aldicarbs, 2,4,6-tri-, 2,4-di- and 2,3,4,6-tetrachlorophenol, mirex, oxy-chlordane, simazine, toxaphene, and trifluralin.
- Sediment: aldicarbs, carbaryl, chlorophenols, endosulfans, imidacloprid, malathion, methoxychlor, mirex, oxy-chlordane, permethrins, simazine, and trifluralin.

Table A1. Screening Benchmarks and Proposed WQOs for Legacy and Current Use Pesticides in Water, Sediment and Tissue Used in this Assessment.
**Any objective of 'do not detect' implies non-detection when using best available detection limits*

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
All pesticides	All		Decreasing trend in concentrations			
Legacy Pesticides						
Aldicarb	Water	Not available	Not available			
	Sediment	Not available	Not available			
	Tissue	0.0351 µg/g ww (toddler)	0.0351 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Sum concentrations of aldicarb, aldicarb sulfone, and aldicarb sulfoxide
Aldrin	Water	0.0000077 µg/L	0.0000077 µg/L; decreasing trend in concentrations	Human consumption of shellfish	US EPA 2015, 2020	Based on carcinogenicity of 10^{-6} risk
	Sediment	0.005 µg/g dw	Do not detect* and/or decrease in current levels	Aquatic life	ENV 2021a (Long and Morgan 1990)	EPA chronic marine EqP threshold; 0.0001 significantly toxic to *R. abronius* based on CoA[3]
	Tissue	0.00020 µg/g ww (adult subsistence fisher)	Do not detect* and/or decrease in current levels	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Carcinogen; Aldrin, dieldrin, heptachlor assessed together: add measured concentrations in tissue and compare to screening value

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
Chlordane	Water	0.000093 µg/L	0.000093 µg/L; decreasing trend in concentrations	Human consumption of finfish	Washington State 2019	Carcinogen; Based on an additional lifetime cancer risk of one-in-100,000 (1 x 10^{-5} risk level)
	Sediment	0.00226 µg/g dw	0.00226 µg/g dw; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 1998)	Canadian interim sediment quality guideline
	Tissue	0.0026 µg/g ww (adult subsistence fisher)	0.0026 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Carcinogen; Combine with other chlordane/nonachlor isomers, except oxy-chlordane which has a different mechanism of toxicity
2,4,6-Trichlorophenol	Tissue	0.161 µg/g ww (adult subsistence fisher)	0.161 (µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Carcinogen
2,4-Dichlorophenol	Tissue	3.471 µg/g ww (toddler)	3.47 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	
2,3,4,6-Tetrachlorophenol	Tissue	0.35 µg/g ww (toddler)	0.35 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	
Monochlorophenol	Water	0.1 µg/L	0.1 µg/L; decreasing trend in concentrations	Primary contact	ENV 1997	
Total Dichlorophenols	Water	0.3 µg/L	0.3 µg/L; decreasing trend in concentrations	Primary contact	ENV 1997	
Total Tetrachlorophenols	Water	1 µg/L	1 µg/L; decreasing trend in concentrations	Primary contact	ENV 1997	

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
Total Trichlorophenols	Water	2 µg/L	2 µg/L; decreasing trend in concentrations	Primary contact	ENV 1997	
DDE	Water	0.000018 µg/L	0.000018 µg/L; decreasing trend in concentrations	Human consumption of shellfish	US EPA 2015, 2020	Carcinogen; Based on carcinogenicity of 10^{-6} risk
	Sediment	0.00207 µg/g dw	0.00207 µg/g dw; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 1998)	Canadian interim sediment quality guideline
	Tissue	0.01 µg/g ww (adult subsistence fisher)	0.01 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Carcinogen
DDT	Water	0.000025 µg/L	0.000025 µg/L; decreasing trend in concentrations	Human consumption of finfish	Washington State 2019	Carcinogen; Based on an additional lifetime cancer risk of one-in-100,000 (1 x 10^{-5} risk level)
	Sediment	0.00119 µg/g dw	0.00119 µg/g dw; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 1998)	Canadian interim sediment quality guideline
	Tissue	0.01 µg/g ww (adult subsistence fisher)	0.01 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Carcinogen
DDD	Water	Not available	Not available			
	Sediment	0.00122 µg/g dw	0.00122 µg/g dw; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 1998)	Canadian interim sediment quality guideline
	Tissue	0.014 µg/g ww (adult subsistence fisher)	0.014 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Carcinogen

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
Diazinon	Water	0.03 µg/L[1]	0.03 µg/L; decreasing trend in concentrations	Aquatic life	Province of BC 2013	Protective of fish. Assumes minimum 1:10 dilution available; Standards for all organic substances are for total substance concentrations
	Sediment	0.00239 µg/g dw	Do not detect* and/or decrease in current levels	Aquatic life	US EPA 2006	Protective of fish; Value derived from the EqP method with Region III BTAG[4] freshwater values and log K_{ow} values between 2 and 6
	Tissue	0.70 µg/g ww (toddler)	Do not detect* and/or decrease in current levels	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Include diazinon-oxon
Dieldrin	Water	0.0000012 µg/L	0.0000012 µg/L; decreasing trend in concentrations	Human consumption of shellfish	US EPA 2015, 2020	Carcinogen; Based on carcinogenicity of 10^{-6} risk
	Sediment	0.00071 µg/g dw	0.00071 µg/g dw; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 1998)	Canadian interim sediment quality guideline
	Tissue	0.00020 µg/g ww (adult subsistence fisher)	0.00020 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Carcinogen; Aldrin, dieldrin, heptachlor assess together: add measured concentrations in tissue and compare to screening value
Endosulfan	Water	0.0016 µg active ingredient/L	0.0016 µg active ingredient/L; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 2010)	Long term exposure; Value calculated from low-effect data using lowest endpoint approach
	Sediment	Not available	Not available			

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
	Tissue	0.21 µg/g ww (toddler)	0.21 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Combine all endosulfan isomers and compare to this screening value
Endrin	Water	0.0023 µg/L	0.0023 µg/L; decreasing trend in concentrations	Aquatic life	Washington State 2019	Chronic value; more conservative than Washington or US EPA value for finfish / shellfish consumption
	Sediment	0.00267 µg/g dw	0.00267 µg/g dw; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 1998)	
	Tissue	0.011 µg/g ww (toddler)	0.011 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Endrin is either endrin aldehyde or endrin ketone; If both are being reported add them together, but otherwise just compare to endrin screening value
Heptachlor	Water	0.0000059 µg/L	0.0000059 µg/L; decreasing trend in concentrations	Human consumption of shellfish	US EPA 2015, 2020	Based on carcinogenicity of 10^{-6} risk
	Sediment	0.0006 µg/g dw	Do not detect* and/or decrease in current levels	Aquatic life	ENV 2021a (CCME 1998)	Canadian interim sediment quality guideline
	Tissue	0.00020 µg/g ww (adult subsistence fisher)	Do not detect* and/or decrease in current levels	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Carcinogen; Aldrin, dieldrin, heptachlor assessed together: add measured concentrations in tissue and compare to screening value
Hexachlorobenzene	Water	0.000079 µg/L	0.000079 µg/L; decreasing trend in concentrations	Human consumption of shellfish	US EPA 2015, 2020	Carcinogen; Based on carcinogenicity of 10^{-6} risk

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
	Sediment	0.0038 µg/g dw	0.0038 µg/g dw; decreasing trend in concentrations	Aquatic life	Washington State, 2013	
	Tissue	0.002 µg/g ww (toddler)	0.002 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Screening value for all potential receptors
Methoxychlor	Water	0.02 µg/L	0.02 µg/L; decreasing trend in concentrations	Human consumption of finfish and shellfish	US EPA 2015, 2020	Intended to be protective of the general adult population from noncarcinogenic effects due to chronic (up to a lifetime) exposure to methoxychlor from consuming fish and shellfish from inland and nearshore waters
	Sediment	Not available	Not available			
	Tissue	0.17 µg/g ww (toddler)	0.17 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Screening value for all potential receptors
Mirex	Water	Not available	Not available			
	Sediment	Not available	Not available			
	Tissue	0.007 µg/g ww (toddler)	0.007 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Screening value for all potential receptors
Oxy-chlordane	Water	Not available	Not available			
	Sediment	Not available	Not available			

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
	Tissue	0.021 µg/g ww (toddler)	Do not detect* and/or decrease in current levels	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Oxy-chlordane is a metabolite of chlordane, and generally seems much more toxic than chlordane itself, and also persistent in fat tissue and bioaccumulative. It should be evaluated separately from chlordane
Toxaphene	Water	Not available	Not available			
	Sediment	0.00011 µg/g dw	0.0001 µg/g dw; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 1999c, 2002)	Canadian interim sediment quality guideline
	Tissue	0.003 µg/g ww (adult subsistence fisher)	Do not detect* and/or decrease in current levels	Human consumption of finfish and shellfish	ENV and HLTH 2021e	
Current Use Pesticides (CUPs)						
Atrazine	Water	1.8 µg/L	1.8 µg/L; decreasing trend in concentrations	Aquatic life	CCME 1999	Highest trophic level protected = fish; guideline is for freshwater, but can be applied to marine (D. Spry (ECCC), per. communication)
	Sediment	0.00662 µg/g dw	Do not detect* and/or decrease in current levels	Aquatic life	US EPA 2006	Highest trophic level protected = fish; guideline is for freshwater sediment, but can be applied to marine (D. Spry (ECCC), per. communication)

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
	Tissue	0.018 µg/g ww (toddler)	Do not detect* and/or decrease in current levels	Human consumption of finfish and shellfish	ENV and HLTH 2021e	
Carbaryl	Water	0.29 µg/L	0.29 µg/L	Aquatic life	CCME 2009	May be refined when data available
	Sediment	Not available	Not available			
	Tissue	0.351 µg/g ww (toddler)	Do not detect* and/or decrease in current levels	Human consumption of finfish and shellfish	ENV and HLTH 2021e	
Chlorpyrifos	Water	0.002 µg/L	0.002 µg/L; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 2008)	
	Sediment	0.008 µg/g mean	Do not detect* and/or decrease in current levels	Aquatic life	New York State Department of Environmental Conservation (NYSDEC)	Interim sediment quality guideline
	Tissue	0.00597 µg/g ww (toddler)	Do not detect* and/or decrease in current levels	Human consumption of finfish and shellfish	ENV and HLTH 2021e	
Lindane (*gamma*-hexachlorocyclohexane (γ-HCH))	Water	0.010 µg/L	0.010 µg/L; decreasing trend in concentrations	Human consumption of finfish and shellfish	US EPA 2015, 2020	
	Sediment	0.00032 µg/g dw	0.00032 µg/g dw; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 1998)	Canadian interim sediment quality guideline

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
	Tissue	0.00289 µg/g ww (adult subsistence fisher)	0.00289 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Carcinogen; This is the screening value for *gamma*-HCH (lindane), since it is used as an agricultural insecticide; In the interim, recommendation from HLTH was to combine all HCH and compare to this screening value
Imidacloprid	Water	0.65 µg/L	0.65 µg/L; decreasing trend in concentrations	Aquatic life	ENV 2021a (CCME 2007)	
	Sediment	Not available	Not available			
	Tissue	2.11 µg/g ww (toddler)	2.11 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	
Malathion	Water	0.1 µg/L	0.1 µg/L; decreasing trend in concentrations	Aquatic life	US Environmental Protection Agency. 1986. Quality criteria for water 1986. (The Gold Book) Washington, DC (US): Office of Water Regulations and Standards. 477 p. EPA 440/5-86-001.	
	Sediment	Not available	Not available			
	Tissue	0.702 µg/g ww (toddler)	Do not detect* and/or decrease in current levels	Human consumption of finfish and shellfish	ENV and HLTH 2021e	

Parameter	Medium[2]	Screening Benchmark (dw = dry weight; ww = wet weight)	Proposed WQO	Value to protect	Reference	Comments
Permethrin	Water	0.001 µg/L	0.001 µg/L; decreasing trend in concentrations	Aquatic life	CCME 2006	Derived by multiplying the 96-h LC_{50} value of 0.02 µg a.i./L for *Mysidopsis bahia* by an acute application factor of 0.05 for nonpersistent substances; Highest trophic level protected = fish
	Sediment	Not available	Not available			
	Tissue	1.74 µg/g ww (toddler)	1.74 µg/g ww; decreasing trend in concentrations	Human consumption of finfish and shellfish	ENV and HLTH 2021e	Add all permethrin isomers and compare to this benchmark

[1] Any water sample to be analyzed for organic substances should not be filtered. Most other Contaminated Sites Regulations levels are at least an order of magnitude higher than WQGs, particularly for other pesticides, so may need to convert this value to an order of magnitude lower, particularly if actual levels in Burrard Inlet are much lower.

[2] For sediment guidelines that are expressed as µg/g, is based on the sediment as a whole and does not require adjustment for organic carbon content. Adjustments to guidelines are only required when they are expressed in terms of the sediment containing 1% organic carbon. For sediments with organic carbon other than 1%, an adjustment in guidelines should be made by multiplying the guideline by the % organic carbon content of the sediment.

[3] CoA = Co-Occurrence analysis.

[4] Region III BTAG = Mid-Atlantic region, Biological Technical Assistance Group (BTAG).

APPENDIX B: CALCULATIONS FOR SCREENING VALUES FOR HUMAN FISH CONSUMPTION

Human health-based tissue screening values for select pesticides were calculated from the following equations for non-carcinogen (Equation 1) and carcinogen pesticides (Equation 2) (see ENV and HLTH [2021] for details), with examples listed in the tables below (Tables A1 and A2). Screening values for non-carcinogens and carcinogens are calculated differently in consideration of the different approaches for each, as discussed in Section 3.1.

Non-carcinogen

(Equation 1)

$$SV_n = \frac{TDI \times BW \times AF}{IR_{Food} \times RAF_{Oral}}$$

Where:

- SV_n = screening value for a noncarcinogen (µg/g);
- TDI[3] = tolerable daily intake (µg/kg BW/day); the contaminant dose deemed safe or acceptable;
- BW = body weight (kg);
- AF = allocation factor; the fraction of the contaminant allocated to come from country foods; an AF of 0.2 was applied;
- IR_{Food} = ingestion rate of fish by humans (g/day); and
- RAF_{Oral} = relative absorption factor from the gastrointestinal tract for a contaminant.

Table A1. Example of tissue screening value calculation for a non-carcinogen pesticide, aldicarb

Receptor Population	Receptor Life Stage	Ingestion Rate (g/day)	Reference Dose (TDI) (µg/kg bw/day)	Standard Body Weight (kg)	Relative Absorption Factor (%)	Allocation Factor (unitless)	Screening Value (µg/g, wet weight)
Subsistence Fishers	Toddler	95	1	16.5	100%	0.2	0.0351

[3] For non-carcinogen pesticides, the Tolerable daily intakes (TDIs) were obtained from Health Canada (2021e) and from EPA (2016).

Carcinogen

(Equation 2)

$$SVc = \frac{\left(\frac{ILCR}{OSF}\right) \times BW \ \times LE}{IR_{Food} \ \times RAF_{Oral} \times ET}$$

Where:

- SV_c = screening value for a noncarcinogen (µg/g);
- ILCR = incremental lifetime cancer risk; 1/100,000;
- OSF = oral slope factor (µg/kg BW/day) $^{-1}$;
- BW = body weight (kg);
- LE = life expectancy (80 years);
- IR_{Food} = ingestion rate of fish by humans (g/day);
- RAF_{Oral} = relative absorption factor from the gastrointestinal tract for a contaminant;
- ET = exposure term (80 years); and
- LE = 80 years.

Table A2. Example of tissue screening value calculation for a carcinogen pesticide, DDT

Receptor Population	**Receptor Life Stage**	**Ingestion Rate (g/day)**	**Risk specific dose (RsD ug/kg/d) = [target cancer risk/oral slope factor]*1000**	**Standard Body Weight (kg)**	**D2 (total years exposed to contaminant)**	**LE (life expectancy)**	**Relative Absorption Factor (%)**	**Screening Value (µg/g, wet weight)**
Subsistence/ Recreational Fisher	Adult	Sed	0.03	70.7	80	80	100%	0.01

APPENDIX C: DATA SOURCES

Table C1: Data Sources for Pesticides in Burrard Inlet

Source	Program	Parameter	No. of Obs.	No. of Sites	Sampling Frequency	Years with Data
BC ENV	Provincial Water Quality Objectives Attainment Monitoring	2,4'-DDE	6 sediment	6	Single event	2020
		4,4'-DDE				
		2,4'-DDT				
		4,4'-DDT				
		Endrin				
		Methoxychlor				
		2-chlorophenol	6 sediment	5 sediment	Single event	2002, 2020
		3-chlorophenol	4 sediment	4 sediment	Single event	2002
		4-chlorophenol	4 sediment	4 sediment	Single event	2002
		2,3-Dichlorophenol	6 sediment	5 sediment	Single event	2002, 2020
		2,4,3,4-Dichlorophenol	4 sediment	4 sediment	Single event	2002
		2,5-Dichlorophenol	4 sediment	4 sediment	Single event	2002
		2,6-Dichlorophenol	4 sediment	4 sediment	Single event	2002
		3,4-Dichlorophenol	2 sediment	2 sediment	Single event	2020
		3,5-Dichlorophenol	6 sediment	5 sediment	Single event	2002, 2020
		2,3,4-Trichlorophenol	4 sediment	4 sediment	Single event	2002
		2,3,5-Trichlorophenol	4 sediment	4 sediment	Single event	2002
		2,3,6-Trichlorophenol	6 sediment	5 sediment	Single event	2002, 2020
		2,4,5-Trichlorophenol	4 sediment	4 sediment	Single event	2002
		2,4,6-Trichlorophenol	4 sediment	4 sediment	Single event	2002
		2,3,4,5-Trichlorophenol	4 sediment	4 sediment	Single event	2002
		3,4,5-Trichlorophenol	6 sediment	5 sediment	Single event	2002, 2020
		Trichlorophenol	17 marine water	3 marine water	Single sample in 1992, 4 or 5 samples in 30 days in 1993	1992, 1993

Source	Program	Parameter	No. of Obs.	No. of Sites	Sampling Frequency	Years with Data
		2,3,4,5-Tetrachlorophenol	5 marine water 7 sediment	5 marine water 6 sediment	Single sample in 2000 for marine water Single event for sediment	2000
		2,3,4,6-Tetrachlorophenol	5 marine water 7 sediment	5 marine water 6 sediment	Single sample in 2000 Single event for sediment	2000
		2,3,4,6,2,3,4,6-Tetrachlorophenol	4 sediment	4 sediment	Single event	2002
		Tetrachlorophenol	17 marine water	7 marine water	Single sample in 1992, 4 or 5 samples in 30 days in 1993	1992, 1993
		Pentachlorophenol	22 marine water 13 sediment	7 marine water 7 sediment	Single sample in 1992 and 2000, 4 or 5 samples in 30 days in 1993 Single event for sediment	1992, 1993, 2000, 2002, 2020
Metro Vancouver	**Burrard Inlet Ambient Monitoring Program**	*cis*-Chlordane	105 sediment	7	Single event Two events in 2011 Triplicate samples	2008, 2011, 2013, 2015
		trans-Chlordane				
		2,4'-DDE	105 sediment 58 fish tissue		Single event Two sediment events in 2011 Triplicate samples for sediment and duplicate samples for whole body and muscle tissue, single samples for liver tissue. Liver measured in 2007 only.	2007, 2008, 2011, 2012, 2013, 2015
		4,4'-DDE				
		2,4'-DDT				
		4,4'-DDT				
		DDT	21 sediment		Single event Triplicate samples	2015
		Endosulfan I	42 sediment		Two sediment events in 2011 with triplicate samples	2011
		Endosulfan II				
		Endosulfan sulfate				
		Endrin	105 sediment		Single event Two events in 2011	2008, 2011, 2013, 2015
		Endrin aldehyde				

Source	Program	Parameter	No. of Obs.	No. of Sites	Sampling Frequency	Years with Data
		Endrin ketone			Triplicate samples	
		alpha-Hexachlorocyclohexane	42 sediment		Two sediment events in 2011 with triplicate samples	2011
		beta-Hexachlorocyclohexane				
		delta-Hexachlorocyclohexane				
		gamma-Hexachlorocyclohexane				
		gamma-hexachlorocyclohexane	63 sediment		Single event Triplicate samples	2008, 2013, 2015
		Methoxychlor	105 sediment		Single event Two events in 2011 Triplicate samples	2008, 2011, 2013, 2015
		trans-Nonachlor	21 sediment		Single event Triplicate samples	2008
		Toxaphene	58 fish tissue		Single event Duplicate samples for whole body and muscle tissue, single samples for liver tissue. Liver measured in 2007 only.	2007, 2012
		3,4-chlorophenol	140 marine water	7 marine water	5 samples in 30 days at the top and bottom of the water column	2014, 2015
		2,3-Dichlorophenol				
		2,4 & 2,5-Dichlorophenol				
		2,6-Dichlorophenol				
		3,4-Dichlorophenol				
		3,5-Dichlorophenol				
		2,3,4-Trichlorophenol				
		2,3,5-Trichlorophenol				
		2,3,6-Trichlorophenol				
		2,4,5-Trichlorophenol				
		2,4,6-Trichlorophenol				
		3,4,5-Trichlorophenol				

Source	Program	Parameter	No. of Obs.	No. of Sites	Sampling Frequency	Years with Data
		2,3,4,5-Tetrachlorophenol				
		2,3,4,6-Tetrachlorophenol				
		2,3,5,6-Tetrachlorophenol				
		Pentachlorophenol				
Ocean Wise	**Pollution Tracker**	Aldicarb	6 sediment	6 sediment	Single composites of 200 mussel specimens Single event for sediment with sampling in single, duplicate, or triplicate	2016
		Aldicarb sulfone	6 sediment	6 sediment		2016
		Aldicarb sulfoxide	6 sediment	6 sediment		2016
		Atrazine	15 sediment 10 mussel tissue	12 sediment 8 mussel tissue		2015, 2016
		Carbaryl	6 sediment	6 sediment		2016
		Chlorpyrifos	11 sediment 30 mussel tissue	32 sediment 8 mussel tissue		2015, 2016
		cis-Chlordane	19 sediment 13 mussel tissue	15 sediment 9 mussel tissue		2015, 2016, 2018, 2019
		trans-Chlordane	20 sediment 13 mussel tissue	15 sediment 9 mussel tissue		2015, 2016, 2019
		2,4'-DDE	22 sediment 11 mussel tissue	15 sediment 8 mussel tissue		2015, 2016, 2019
		4,4'-DDE	27 sediment 18 mussel tissue	15 sediment 10 mussel tissue		2015, 2016, 2018, 2019
		2,4'-DDT	18 sediment 7 mussel tissue	15 sediment 7 mussel tissue		2015, 2016, 2019
		4,4'-DDT	23 sediment 13 mussel tissue	15 sediment 9 mussel tissue		2015, 2016, 2019
		Diazinon	18 sediment 10 mussel tissue	11 sediment 8 mussel tissue		2015, 2016, 2018, 2019
		Diazinon-Oxon	10 mussel tissue	8 mussel tissue		2015, 2016, 2018, 2019
		Endosulfan I	26 sediment 14 mussel tissue	15 sediment 9 mussel tissue		2015, 2016, 2018, 2019

Source	Program	Parameter	No. of Obs.	No. of Sites	Sampling Frequency	Years with Data
		Endosulfan II	18 sediment 13 mussel tissue	15 sediment 9 mussel tissue		2015, 2016, 2018
		Endrin	17 sediment 11 mussel tissue	15 sediment 8 mussel tissue		2015, 2016
		Endrin aldehyde	5 sediment 1 mussel tissue	5 sediment 1 mussel tissue		2015
		Endrin ketone	17 sediment 11 mussel tissue	15 sediment 8 mussel tissue		2015, 2016
		Imidacloprid	6 sediment	6 sediment		2016
		beta-hexachlorocyclohexane	44 sediment 32 mussel tissue	15 sediment 10 mussel tissue		2015, 2016, 2018, 2019
		delta-Hexachlorocyclohexane	17 sediment 11 mussel tissue	15 sediment 8 mussel tissue		2015
		gamma-Hexachlorocyclohexane	17 sediment 13 mussel tissue	15 sediment 9 mussel tissue		2015, 2016, 2018, 2019
		Malathion	11 sediment 10 mussel tissue	12 sediment 8 mussel tissue		2015, 2016, 2018, 2019
		Methoxychlor	17 sediment 11 mussel tissue	15 sediment 8 mussel tissue		2015
		cis-Nonachlor	17 sediment 15 mussel tissue	15 sediment 9 mussel tissue		2015, 2016, 2018, 2019
		trans-Nonachlor	17 sediment 13 mussel tissue	15 sediment 9 mussel tissue		2015, 2016, 2018, 2019
		oxy-Chlordane	19 sediment 11 mussel tissue	15 sediment 8 mussel tissue		2015, 2016, 2018
		Permethrin	12 sediment 14 mussel tissue	11 sediment 9 mussel tissue		2015, 2016, 2018, 2019
		Simazine	13 sediment 10 mussel tissue	12 sediment 8 mussel tissue		2015, 2016, 2018, 2019
		Trifluralin	13 sediment 5 mussel tissue	11 sediment 5 mussel tissue		2015, 2016, 2018, 2019

Source	Program	Parameter	No. of Obs.	No. of Sites	Sampling Frequency	Years with Data
ECCC	**Benthic**	Trichlorophenol	86 sediment	59 sediment	Single, duplicate, or triplicate samples	1985, 1986
		Tetrachlorophenol	174 sediment			
PICES	**PAH and Pesticide Study**	Aldrin	6 sediment 12 fish tissue	5 sediment 3 fish tissue	Single event at three sites for sediment and two sites for tissue, duplicate event at 1 site for sediment and tissue, triplicate tissue samples collected during each event	1999
		cis-Chlordane				
		trans-Chlordane				
		2,4'-DDE				
		4,4'-DDE				
		2,4'-DDT				
		4,4'-DDT				
		Dieldrin				
		Endosulfan I	12 fish tissue	3	Single event at two sites, duplicate event at 1 site, triplicate samples collected during each event	
		Endosulfan II				
		Endosulfan sulfate				
		Heptachlor	12 sediment 12 fish tissue	5 sediment 3 fish tissue	Single event at three sites for sediment and two sites for tissue, duplicate event at 1 site for sediment and tissue; duplicate sediment and triplicate tissue samples collected during each event	
		Hexachlorobenzene	12 fish tissue	3	Single event at two sites, duplicate event at 1 site, triplicate samples collected during each event	
		alpha-Hexachlorocyclohexane				
		beta-Hexachlorocyclohexane				
		gamma-Hexachlorocyclohexane	6 sediment 12 fish tissue	5 sediment 3 fish tissue	Single event at three sites for sediment and two sites for tissue, duplicate event at 1 site for sediment and tissue, triplicate tissue samples collected during each event	
		Mirex				
		cis-Nonachlor				
		trans-Nonachlor				
		oxy-Chlordane				

APPENDIX D: KEY OBSERVATIONS FOR DETECTION FREQUENCY, BENCHMARK EXCEEDANCES, AND MINIMUM/MAXIMUM/AVERAGE OBSERVED PESTICIDE CONCENTRATIONS IN BURRARD INLET MEDIA

Notes:

- Observations are presented for Burrard Inlet as a whole, and not for each sub-basin.
- Results from different monitoring programs are not directly comparable as variations exist in the sampling and analytical methods as well as the distribution of sites.
- Used benchmarks are found in**Error! Reference source not found.**
- An asterisk (*) in the tissue benchmark exceedance column indicates that concentrations of several individual compounds or isomers have been summed together, as the benchmarks were based on parameter types (as opposed to individual compound/isomers) (D. Stein, BC HLTH, *pers. comm.* 2021). The summed concentrations and benchmark comparison are found at the end of the table.
- Samples below DLs were excluded from the summary of mean, minimum, and maximum concentrations.

Table D1: Summary of Pesticide Observations in Burrard Inlet Media. (OW = Ocean Wise Conservation Association; PICES =North Pacific Marine Organization; MVN = Metro Vancouver; ENV = BC Ministry of Environment and Climate Change Strategy)

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum	Maximum	Mean
					µg/L or µg/g			µg/L or µg/g	µg/L or µg/g	µg/L or µg/g
Aldicarb	Sediment	OW	6	0%	0.0000736 to 0.000116	NA	NA	NA	NA	NA
Aldicarb sulfone	Sediment	OW	6	0%	0.000147 to 0.000693	NA	NA	NA	NA	NA
Aldicarb sulfoxide	Sediment	OW	6	0%	0.0000736 to 0.000116	NA	NA	NA	NA	NA
Aldrin	Sediment	PICES	6	0%	0.00021 to 0.00053	0.005	NA	NA	NA	NA
	Tissue	PICES	12	0%	0.00058 to 0.0011	0.00020	NA	NA	NA	NA
Atrazine	Sediment	OW	15	0%	0.000239 to 0.000855	0.00662	NA	NA	NA	NA
	Tissue	OW	10	0%	0.000401 to 0.000953	0.018	NA	NA	NA	NA
Carbaryl	Sediment	OW	6	0%	0.0000736 to 0.000116	NA	NA	NA	NA	NA
***cis*-Chlordane**	Sediment	MVN	105	12%	0.000016 to 0.0005	0.00226	0%	0.000012	0.00057	0.00010

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits µg/L or µg/g	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum µg/L or µg/g	Maximum µg/L or µg/g	Mean µg/L or µg/g
		OW	19	37%	0.0000087 to 0.000061	0.00226	0%	0.000009	0.000064	0.000033
		PICES	6	17%	0.00026 to 0.00043	0.00226	0%	NA	0.00017	NA
	Tissue	OW	13	46%	0.000012 to 0.000071	0.0026	*	0.00003	0.00011	0.000065
		PICES	12	50%	0.00061 to 0.0011	0.0026	*	0.0013	0.0029	0.0022
***trans*-Chlordane**	Sediment	MVN	105	34%	0.000005 to 0.0005	0.00226	2%	0.000016	0.0041	0.00047
		OW	20	45%	0.000008 to 0.000065	0.00226	0%	0.000017	0.00012	0.000056
		PICES	6	17%	0.00017 to 0.00043	0.00226	0%	NA	0.00036	NA
	Tissue	OW	13	62%	0.000012 to 0.00004	0.0026	*	0.000036	0.000052	0.000088
		PICES	12	8%	0.00023 to 0.0011	0.0026	*	NA	0.0015	NA
Chlorpyrifos	Sediment	OW	11	0%	0.000019 to 0.000233	0.008	NA	NA	NA	NA
	Tissue	OW	30	0%	0.0000352 to 0.000188	0.00597	NA	NA	NA	NA
2,4’-DDE	Sediment	ENV	6	0%	0.002 to 0.25	0.00207	NA	NA	NA	NA
		MVN	105	7%	0.000006 to 0.007	0.00207	0%	0.000005	0.00013	0.000029
		OW	22	14%	0.0000039 to 0.000143	0.00207	0%	0.000009	0.000016	0.000012
		PICES	6	0%	0.00019 to 0.00047	0.00207	NA	NA	NA	NA
	Tissue	MVN	58	41%	0.0001 to 0.004	0.01	*	0.00011	0.0053	0.00078
		OW	11	0%	0.0000046 to 0.0000237	0.01	NA	NA	NA	NA
		PICES	12	75%	0.00024 to 0.00033	0.01	*	0.00066	0.0016	0.00096
4,4’-DDE	Sediment	ENV	6	0%	0.002 to 0.25	0.00207	NA	NA	NA	NA

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits µg/L or µg/g	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum µg/L or µg/g	Maximum µg/L or µg/g	Mean µg/L or µg/g
		MVN	105	62%	0.000008 to 0.000774	0.00207	0%	0.000085	0.0019	0.00045
		OW	27	19%	0.0000362 to 0.000787	0.00207	0%	0.000066	0.00032	0.00020
		PICES	6	50%	0.00032 to 0.00045	0.00207	0%	0.00029	0.00052	0.00039
	Tissue	MVN	58	79%	0.0001 to 0.002	0.01	*	0.0020	0.015	0.0062
	Tissue	OW	18	17%	0.0000517 to 0.000512	0.01	*	0.00029	0.00040	0.00035
	Tissue	PICES	12	100%	Unknown	0.01	*	0.017	0.073	0.038
2,4’-DDT	Sediment	ENV	6	0%	0.002 to 0.25	0.00119	NA	NA	NA	NA
	Sediment	MVN	105	12%	0.000025 to 0.007	0.00119	0%	0.000013	0.0011	0.00028
	Sediment	OW	18	17%	0.0000268 to 0.00011	0.00119	6%	0.00012	0.0020	0.00088
	Sediment	PICES	6	0%	0.00028 to 0.0007	0.00119	NA	NA	NA	NA
	Tissue	MVN	58	34%	0.0001 to 0.004	0.01	*	0.00011	0.0020	0.00051
	Tissue	OW	12	25%	0.0000204 to 0.000383	0.01	*	0.000023	0.000041	0.000032
	Tissue	PICES	12	100%	Unknown	0.01	*	0.00083	0.0045	0.0030
4,4’-DDT	Sediment	ENV	6	0%	0.002 to 0.25	0.00119	NA	NA	NA	NA
	Sediment	MVN	105	43%	0.000033 to 0.005	0.00119	17%	0.000057	0.0090	0.0017
	Sediment	OW	23	61%	0.0000259 to 0.000118	0.00119	9%	0.000031	0.0085	0.00084
	Sediment	PICES	6	0%	0.00029 to 0.00074	0.00119	NA	NA	NA	NA
	Tissue	MVN	58	38%	0.0001 to 0.004	0.01	*	0.00010	0.0046	0.00074
	Tissue	OW	13	46%	0.0000197 to 0.000758	0.01	*	0.00005	0.00018	0.00010
	Tissue	PICES	12	92%	0.00058	0.01	*	0.0022	0.013	0.0092

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits	Benchmark	% Benchmark	Minimum	Maximum	Mean
					µg/L or µg/g	µg/L or µg/g	Exceedance	µg/L or µg/g	µg/L or µg/g	µg/L or µg/g
Diazinon	Sediment	OW	18	0%	0.0000077 to 0.000416	0.00239	NA	NA	NA	NA
	Tissue	OW	10	0%	0.000161 to 0.000298	0.70	NA	NA	NA	NA
Diazinon-Oxon	Tissue	OW	10	0%	0.000137 to 0.000376	0.70	NA	NA	NA	NA
Dieldrin	Sediment	PICES	6	50%	0.00019 to 0.00035	0.00071	17%	0.00032	0.00077	0.00053
	Tissue	PICES	12	17%	0.00058 to 0.0011	0.00020	*	0.0040	0.0040	NA
Endosulfan I	Sediment	MVN	42	5%	0.0000152 to 0.000315	NA	NA	0.00018	0.00025	0.00022
		OW	26	4%	0.0000095 to 0.000526	NA	NA	NA	0.000063	NA
	Tissue	OW	14	7%	0.000114 to 0.000295	0.21	*	NA	0.000028	NA
		PICES	12	0%	0.0017 to 0.0033	0.21	NA	NA	NA	NA
Endosulfan II	Sediment	MVN	42	0%	0.0000156 to 0.000164	NA	NA	NA	NA	NA
		OW	18	6%	0.0000097 to 0.000499	NA	NA	NA	0.000024	NA
	Tissue	OW	13	15%	0.000108 to 0.000416	0.21	NA	NA	NA	NA
		PICES	12	0%	0.0017 to 0.0033	0.21	NA	NA	NA	NA
Endosulfan sulfate	Sediment	MVN	42	0%	0.0000201 to 0.000295	NA	NA	NA	NA	NA
	Tissue	PICES	12	0%	0.00059 to 0.0012	0.21	NA	NA	NA	NA
Endrin	Sediment	ENV	6	0%	0.005 to 0.25	0.00267	NA	NA	NA	NA
		MVN	105	13%	0.000002 to 0.0005	0.00267	NA	NA	NA	NA
		OW	17	6%	0.0000087 to 0.0000932	0.00267	0%	0.000002	0.00090	0.00048
	Tissue	OW	11	45%	0.0000115 to 0.000028	0.011	*	NA	0.000009	NA
Endrin aldehyde	Sediment	MVN	105	5%	0.0000016 to 0.0005	0.00267	0%	0.00020	0.00030	0.00025

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits µg/L or µg/g	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum µg/L or µg/g	Maximum µg/L or µg/g	Mean µg/L or µg/g
		OW	5	0%	0.0000087 to 0.0000097	0.00267	NA	NA	NA	NA
	Tissue	OW	1	0%	0.0000118	0.011	NA	NA	NA	NA
Endrin ketone	Sediment	MVN	105	10%	0.000001 to 0.0005	0.00267	0%	0.00050	0.00110	0.00070
		OW	17	0%	0.0000097 to 0.000229	0.00267	NA	NA	NA	NA
	Tissue	OW	11	0%	0.0000127 to 0.0000991	0.011	NA	NA	NA	NA
Heptachlor	Sediment	PICES	12	0%	0.00011 to 0.00053	0.0006	NA	NA	NA	NA
	Tissue	PICES	12	0%	0.00058 to 0.0011	0.00020	NA	NA	NA	NA
Hexachlorobenzene	Tissue	PICES	12	100%	Unknown	0.002	0%	0.00074	0.0012	0.00099
Imidacloprid	Sediment	OW	6	0%	0.000147 to 0.000233	NA	NA	NA	NA	NA
***alpha*-Hexachlorocyclohexane**	Sediment	MVN	42	2%	0.00003 to 0.00116	0.00032	2%	NA	0.00058	NA
	Tissue	PICES	12	50%	0.00023 to 0.0011	0.00289	*	0.00071	0.00094	0.00084
***beta*-Hexachlorocyclohexane**	Sediment	MVN	42	0%	0.0000711 to 0.000901	0.00032	NA	NA	NA	NA
		OW	44	64%	0.0000032 to 0.000095	0.00032	0%	0.000007	0.00016	0.00004
	Tissue	OW	32	88%	0.0000043 to 0.000053	0.00289	*	0.000013	0.00015	0.000061
		PICES	12	100%	Unknown	0.00289	*	0.0017	0.0048	0.0034
***gamma*-Hexachlorocyclohexane**	Sediment	MVN	42	12%	0.0000801 to 0.00118	0.00032	10%	0.00021	0.0016	0.00074
		OW	17	12%	0.0000062 to 0.000033	0.00032	0%	0.000008	0.000050	0.000029
		PICES	6	33%	0.00028 to 0.00046	0.00032	17%	0.00018	0.00057	0.00038
	Tissue	OW	13	31%	0.0000071 to 0.000021	0.00289	*	0.000010	0.000029	0.000023
		PICES	12	0%	0.00058 to 0.0011	0.00289	NA	NA	NA	NA

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits µg/L or µg/g	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum µg/L or µg/g	Maximum µg/L or µg/g	Mean µg/L or µg/g
***delta*-Hexachlorocyclohexane**	Sediment	MVN	42	2%	0.0000183 to 0.000971	0.00032	0%	NA	0.000074	NA
		OW	17	0%	0.0000072 to 0.0000272	0.00032	NA	NA	NA	NA
	Tissue	OW	11	0%	0.000006 to 0.0000111	0.00289	NA	NA	NA	NA
***gamma*-Hexachlorocyclohexane**	Sediment	MVN	63	24%	0.000004 to 0.0005	0.00032	2%	0.000006	0.00040	0.00011
Malathion	Sediment	OW	12	0%	0.000341 to 0.000917	NA	NA	NA	NA	NA
	Tissue	OW	10	0%	0.000218 to 0.00179	NA	NA	NA	NA	NA
Methoxychlor	Sediment	ENV	6	0%	0.02 to 2.5	NA	NA	NA	NA	NA
		MVN	105	32%	0.000012 to 0.006	NA	NA	0.00004	0.0079	0.0014
		OW	17	0%	0.0000253 to 0.00118	NA	NA	NA	NA	NA
	Tissue	OW	11	0%	0.0000221 to 0.00515	0.17	NA	NA	NA	NA
Mirex	Sediment	PICES	6	0%	0.00025 to 0.00066	NA	NA	NA	NA	NA
	Tissue	PICES	12	100%	Unknown	0.007	0%	0.00078	0.0022	0.0012
Oxy-chlordane	Sediment	OW	19	0%	0.0000039 to 0.000074	NA	NA	NA	NA	NA
		PICES	6	0%	0.00013 to 0.00033	NA	NA	NA	NA	NA
	Tissue	OW	11	0%	0.0000094 to 0.000048	0.021	NA	NA	NA	NA
		PICES	12	0%	0.0006 to 0.0012	0.021	NA	NA	NA	NA
***cis*-Nonachlor**	Sediment	OW	17	18%	0.0000068 to 0.0000783	0.00226	NA	0.000011	0.000025	0.000019
		PICES	6	0%	0.00017 to 0.00042	0.00226	NA	NA	NA	NA
	Tissue	OW	15	33%	0.0000116 to 0.000101	0.0028	*	0.000029	0.000039	0.000032

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits µg/L or µg/g	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum µg/L or µg/g	Maximum µg/L or µg/g	Mean µg/L or µg/g
		PICES	6	50%	0.00063 to 0.0011	0.0028	*	0.0012	0.0032	0.0024
***trans*-Nonachlor**	Sediment	MVN	21	14%	0.007	0.00226	0%	0.000008	0.000013	0.000011
		OW	17	24%	0.0000089 to 0.000053	0.00226	0%	0.000013	0.000052	0.000029
		PICES	6	17%	0.00014 to 0.00022	0.00226	0%	NA	0.00013	NA
	Tissue	OW	13	92%	0.0000065 to 0.000031	0.0028	*	0.00003	0.00009	0.00006
		PICES	12	92%	0.00079	0.0028	*	0.0017	0.0046	0.0030
Permethrin	Sediment	OW	12	17%	0.00011 to 0.000713	NA	NA	0.00022	0.00062	0.00042
	Tissue	OW	14	14%	0.00209 to 0.013	1.74	*	0.0016	0.0029	0.0023
Simazine	Sediment	OW	12	0%	0.000159	NA	NA	NA	NA	NA
	Tissue	OW	10	0%	0.000191 to 0.000391	NA	NA	NA	NA	NA
Trifluralin	Sediment	OW	12	0%	0.0000284 to 0.0000917	NA	NA	NA	NA	NA
	Tissue	OW	5	60%	0.0000496 to 0.0000499	NA	0%	0.00011	0.00018	0.00029
Toxaphene	Tissue	MVN	58	0%	0.0005 to 0.2	0.003	NA	NA	NA	NA
CHLOROPHENOLS										
2-chlorophenol	Sediment	ENV	6	0%	0.02 to 0.5	NA	NA	NA	NA	NA
3-chlorophenol	Sediment	ENV	4	0%	0.25 to 0.5	NA	NA	NA	NA	NA
4-chlorophenol	Sediment	ENV	4	0%	0.25 to 0.5	NA	NA	NA	NA	NA
3,4-chlorophenol	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
2,3-Dichlorophenol	Sediment	ENV	6	0%	0.02 to 0.05	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits µg/L or µg/g	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum µg/L or µg/g	Maximum µg/L or µg/g	Mean µg/L or µg/g
2,4 & 2,5-Dichlorophenol	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
	Sediment	ENV	4	0%	0.025 to 0.05	NA	NA	NA	NA	NA
2,5-Dichlorophenol	Sediment	ENV	4	0%	0.025 to 0.05	NA	NA	NA	NA	NA
2,6-Dichlorophenol	Sediment	ENV	4	0%	0.025 to 0.05	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
3,4-Dichlorophenol	Sediment	ENV	2	0%	0.02 to 0.04	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
3,5-Dichlorophenol	Sediment	ENV	6	0%	0.02 to 0.05	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
2,3,4-Trichlorophenol	Sediment	ENV	4	0%	0.025 to 0.05	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
2,3,5-Trichlorophenol	Sediment	ENV	4	0%	0.025 to 0.05	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
2,3,6-Trichlorophenol	Sediment	ENV	6	0%	0.02 to 0.05	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
2,4,5-Trichlorophenol	Sediment	ENV	4	0%	0.025 to 0.05	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
2,4,6-Trichlorophenol	Sediment	ENV	4	0%	0.025 to 0.05	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
2,3,4,5-Trichlorophenol	Sediment	ENV	4	0%	0.025 to 0.05	NA	NA	NA	NA	NA

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits µg/L or µg/g	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum µg/L or µg/g	Maximum µg/L or µg/g	Mean µg/L or µg/g
3,4,5-Trichlorophenol	Sediment	ENV	4	0%	0.02 to 0.05	NA	NA	NA	NA	NA
	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
Trichlorophenol	Sediment	ECCC	86	38%	0.0003	NA	NA	0.0007	0.060	0.0073
	Marine Water	ENV	17	6%	0.1	2	0%	NA	0.2	NA
2,3,4,5-Tetrachlorophenol	Sediment	ENV	7	0%	0.0005	NA	NA	NA	NA	NA
	Marine Water	ENV	5	0%	0.005	NA	NA	NA	NA	NA
		MVN	140	0%	0.1	NA	NA	NA	NA	NA
2,3,4,6-Tetrachlorophenol	Sediment	ENV	7	0%	0.0005	NA	NA	NA	NA	NA
	Marine Water	ENV	5	0%	0.002	NA	NA	NA	NA	NA
		MVN	140	0%	0.1	NA	NA	NA	NA	NA
2,3,4,6,2,3,4,6-Tetrachlorophenol	Sediment	ENV	4	0%	0.025 to 0.05	NA	NA	NA	NA	NA
2,3,5,6-Tetrachlorophenol	Marine Water	MVN	140	0%	0.1	NA	NA	NA	NA	NA
Tetrachlorophenol	Sediment	ECCC	174	98%	0.001	NA	NA	0.0002	0.15	0.014
	Marine Water	ENV	17	6%	0.1	1	0%	NA	0.3	NA
Pentachlorophenol	Sediment	ENV	13	23%	0.0002 to 0.05	NA	NA	0.0006	0.0008	0.0007
	Marine Water	ENV	22	14%	0.005 to 0.1	NA	NA	0.2	0.6	0.4
	Marine Water	MVN	140	4%	0.1	NA	NA	0.11	0.71	0.26
SUMMED PARAMETERS FOR TISSUE BENCHMARK ASSESSMENT										
Sum of aldrin, dieldrin, heptachlor	Tissue	PICES	2	NA	NA	0.00020	0%	0.004	0.004	NA

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits µg/L or µg/g	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum µg/L or µg/g	Maximum µg/L or µg/g	Mean µg/L or µg/g
Sum of *cis*-chlordane, *trans*-chlordane, *a*-chlordane, *g*-chlordane, *cis*-nonachlor, *trans*-nonachlor, nonachlor	Tissue	OW	9	NA	NA	0.0026	100%	0.00003	0.0002	0.0001
	Tissue – Liver	PICES	4	NA	NA	0.0026	100%	0.0077	0.0088	0.0084
Sum of 2,4'-DDE, 4,4'-DDE, 2,4'-DD", 4,4'-DDT	Tissue - Liver	MVN	14	NA	NA	0.01	29%	0.002	0.021	NA
	Tissue - Muscle	MVN	3	NA	NA	0.01	0%	0.002	0.002	NA
	Tissue – Whole Body	MVN	27	NA	NA	0.01	4%	0.002	0.015	NA
	Tissue	OW	3	NA	NA	0.01	0%	0.000045	0.00022	NA
	Tissue – Whole Body	OW	4	NA	NA	0.01	0%	0.000078	0.00040	NA
	Tissue - Liver	PICES	4	NA	NA	0.01	100%	0.042	0.060	NA
Sum of endosulfan I, endosulfan II, endosulfan sulfate	Tissue	NA	0	NA	NA	0.21	NA	NA	NA	NA
Sum of *alpha-*, *beta-*, *gamma-*, and *delta-*hexachlorocyclohexane,	Tissue	OW	9	NA	NA	0.00289	0%	0.000028	0.00012	NA
	Tissue – Whole Body	OW	5	NA	NA	0.00289	0%	0.000048	0.00010	NA
	Tissue – Liver	PICES	4	NA	NA	0.00289	50%	0.0026	0.0053	NA
Sum of *cis*-permethrin, *trans*-permethrin, permethrin	Tissue	OW	2	NA	NA	0.018	0%	0.0016	0.0029	NA

Parameter	Media	Source	Sample Count	% Detection	Range of Detection Limits µg/L or µg/g	Benchmark µg/L or µg/g	% Benchmark Exceedance	Minimum µg/L or µg/g	Maximum µg/L or µg/g	Mean µg/L or µg/g
Sum of endrin, endrin aldehyde, endrin ketone	Tissue	OW	4	NA	NA	0.011	0%	0.000014	0.000020	NA
Sum of diazinon, diazinon-oxon	Tissue	NA	0	NA	NA	0.70	NA	NA	NA	NA

Marine Water

Of the pesticides covered in this report, only chlorophenols have been measured in water samples collected by the key monitoring programs (Appendix C). Individual congeners and/or the sum of tri-, tetra- and pentachlorophenols have been monitored in marine waters. Only the sum of tri-, tetra- and pentachlorophenol congeners have been detected.

- **Trichlorophenol** (6% detection frequency [df], sample count [n] = 17, ENV) was detected at a concentration of 0.2 µg/L, which is below the benchmark of 2 µg/L.
- **Tetrachlorophenol** (6% df, n = 17, ENV) was detected at a concentration of 0.3 µg/L, which is below the benchmark of 1 µg/L.
- **Pentachlorophenol** (ENV: 14% df, n = 22; MVN: 4% df, n = 140) concentrations varied between 0.20 and 0.37 µg/L in the ENV samples and between 0.11 and 0.27 µg/L in the samples collected in the Metro Vancouver monitoring program. No benchmark was identified for pentachlorophenol in marine water.

Sediment

The assessed data set (Appendix C) included 59 different parameters monitored in sediment and 23 of these have been detected in samples collected by the key monitoring programs; these include the legacy pesticides chlordanes, DDT and metabolites, dieldrin, endosulfans, endrins, methoxychlor, as well as the CUPs hexachlorocyclohexanes, permethrin and chlorophenols (Table 2 and Table 3). Below follows a summary of legacy and current use pesticides that have been detected in sediment.

<u>Legacy Pesticides</u>

- **Chlordanes**
    - *cis*-Chlordane has been detected in sediment samples collected by the Metro Vancouver (12% df, n = 105), Pollution Tracker (37% df, n = 19), and PICES (17% df, n = 6) monitoring programs, at concentrations ranging from 0.000009 to 0.00057 µg/g dw; all concentrations are at least one order of magnitude below the benchmark of 0.00226 µg/g dw.
    - *trans*-Chlordane has been detected in sediment samples collected by the Metro Vancouver (34% df, n = 105), Pollution Tracker (45% df, n = 20), and PICES (17% df, n = 6) monitoring programs, at concentrations ranging from 0.000016 to 0.0041 µg/g dw. Two percent of the samples collected by Metro Vancouver exceeded the benchmark of 0.00226 µg/g dw.
    - *cis*-Nonachlor has been detected in sediment samples collected by the Pollution Tracker (18% df, n = 17) monitoring program, at concentrations ranging from 0.00004 to 0.0079 µg/g dw; all concentrations are below the benchmark of 0.00226 µg/g dw.
    - *trans*-Nonachlor has been detected in sediment samples collected by the Metro Vancouver (14% df, n = 21), Pollution Tracker (24% df, n = 17), and PICES (17% df, n = 6) monitoring programs, at concentrations ranging from 0.000008 to 0.00013 µg/g dw; all concentrations are at least one order of magnitude below the benchmark of 0.00226 µg/g dw.
- **DDT and Metabolites**
    - 2,4'-DDE has been detected in sediment samples collected by the Metro Vancouver (7% df, n = 105) and Pollution Tracker (14% df, n = 22) monitoring programs, at concentrations ranging from 0.000009 to 0.00013 µg/g dw; all concentrations are at least one order of magnitude below the benchmark of 0.00207 µg/g dw.

- 4,4'-DDE has been detected in sediment samples collected by the Metro Vancouver (62% df, n = 105), Pollution Tracker (19% df, n = 27), and PICES (50% df, n = 6) monitoring programs, at concentrations ranging from 0.000066 to 0.0019 µg/g dw; all concentrations are below the benchmark of 0.00207 µg/g dw.
    - 2,4'-DDT has been detected in sediment samples collected by the Metro Vancouver (12% df, n = 105) and Pollution Tracker (17% df, n = 18) monitoring programs, at concentrations ranging from 0.000013 to 0.0020 µg/g dw. Six percent of the samples collected by the Pollution Tracker program exceeded the benchmark of 0.00119 µg/g dw.
    - 4,4'-DDT has been detected in sediment samples collected by the Metro Vancouver (43% df, n = 105) and Pollution Tracker (61% df, n = 23) monitoring programs, at concentrations ranging from 0.000031 to 0.0090 µg/g dw. Seventeen percent of the samples collected by Metro Vancouver and 9% of the Pollution Tracker samples exceeded the benchmark of 0.00119 µg/g dw.
- **Dieldrin** has been detected in sediment samples collected by the PICES (50% df, n = 6) monitoring program, at concentrations ranging from 0.00032 to 0.00077 µg/g dw. One of the samples, or 17%, exceeded the benchmark of 0.00071 µg/g dw.
- **Endosulfans**
    - Endosulfan I has been detected in two sediment samples collected by Metro Vancouver (5% df, n = 42) and one sample by Pollution Tracker (4% df, n = 26) monitoring programs, at concentrations ranging from 0.00006 to 0.00025 µg/g dw. No benchmark was identified for endosulfan I in sediment.
    - Endosulfan II has been detected in one sediment sample collected by the Pollution Tracker (6% df, n = 18) monitoring program at 0.000024 µg/g dw. No benchmark was identified for endosulfan II in sediment.
- **Endrins**
    - Endrin has been detected in sediment samples collected by the Metro Vancouver (13% df, n = 105) and Pollution Tracker (6% df, n = 17) monitoring programs, at concentrations ranging from 0.000002 to 0.00090 µg/g dw; all concentrations are at least one order of magnitude below the benchmark of 0.00267 µg/g dw.
    - Endrin aldehyde has been detected in sediment samples collected by the Metro Vancouver (5% df, n = 105) monitoring program, at concentrations ranging from 0.00020 to 0.00030 µg/g dw; all concentrations are at least one order of magnitude below the benchmark of 0.00267 µg/g dw.
    - Endrin ketone has been detected in sediment samples collected by the Metro Vancouver (10% df, n = 105) monitoring program, at concentrations ranging from 0.00050 to 0.0011 µg/g dw; all concentrations are below the benchmark of 0.00267 µg/g dw.
- **Methoxychlor** has been detected in sediment samples collected by the Metro Vancouver (32% df, n = 105) monitoring program, at concentrations ranging from 0.000011 to 0.000025 µg/g dw. No benchmark was identified for methoxychlor in sediment.

In summary, one chlordane isomer (*trans*-chlordane), two DDT compounds (2,4-DDT and 4,4-DDT), and dieldrin exceeded the sediment benchmarks among legacy pesticides.

Current Use Pesticides

- **Hexachlorocyclohexanes**
  - *alpha*-Hexachlorocyclohexane has been detected in one sediment sample collected by the Metro Vancouver (2% df, n = 42) monitoring program, at 0.00058 µg/g dw, which exceeds the benchmark of 0.00032 µg/g dw.
  - *beta-Hexachlorocyclohexane* has been detected in sediment samples collected by the Pollution Tracker (64% df, n = 44) monitoring program, at concentrations ranging from 0.000007 to 0.00016 µg/g dw; all concentrations are below the benchmark of 0.00032 µg/g dw.
  - *gamma*-Hexachlorocyclohexane has been detected in sediment samples collected by the Metro Vancouver (20% df, n = 105), Pollution Tracker (12% df, n = 17), and PICES (33% df, n = 6) monitoring programs, at concentrations ranging from 0.000006 to 0.0016 µg/g dw. Eight percent of the samples collected by Metro Vancouver and 17% of PICES samples exceeded the benchmark of 0.00032 µg/g dw.
  - *delta*-Hexachlorocyclohexane has been detected in one sediment sample collected by the Metro Vancouver (2% df, n = 42) monitoring program, at 0.00007 µg/g dw, which is one order of magnitude below the benchmark of 0.00032 µg/g dw.
- **Permethrin** has been detected in sediment samples collected by the Pollution Tracker (17% df, n = 12) monitoring program, at concentrations ranging from 0.00022 to 0.00062 µg/g dw. No benchmark was identified for permethrin in sediment.
- **Chlorophenols**
  - Trichlorophenol (38% df, n = 86, ECCC) was detected in concentrations from 0.0007 to 0.060 µg/g dw.
  - Tetrachlorophenol (98% df, n = 174, ECCC) concentrations varied between 0.0002 and 0.15 µg/g dw.
  - Pentachlorophenol (23% df, n = 13, ENV) showed concentrations between 0.0006 and 0.0008 µg/g dw.
  - No benchmarks were identified for chlorophenols in sediment.

In summary, *alpha*- and *gamma*-hexachlorocyclohexane exceeded the sediment benchmarks among the monitored CUPs.

Animal Tissue

The assessed data set (Appendix C) included 33 different parameters monitored in tissue and 19 of these have been detected in samples collected by the key monitoring programs; these include the legacy pesticides chlordanes, DDT and metabolites, dieldrin, endosulfans, endrin, hexachlorobenzene, and mirex, as well as the currently used hexachlorocyclohexanes, permethrin and trifluralin (Table 2 and Table 3). A summary of legacy and current use pesticides that have been detected in animal tissue is provided below.

For the data assessment against benchmarks, concentrations of certain pesticides in tissue were summed based on parameter types following the guidance of BC HLTH (D. Stein, BC HLTH, *pers. comm.*, 2021). Parameters with similar chemistry and toxicity pathway were summed together, such as the cyclodienes aldrin, dieldrin, and heptachlor. Tissue concentrations were screened against the most conservative tissue benchmark in Appendix A, i.e., for either a toddler from a subsistence fisher population in the case of non-carcinogens, and an adult subsistence fisher or adult recreational fisher in the case of carcinogens.

Legacy Pesticides

- **Chlordanes**
  - *cis*-Chlordane has been detected in mussel samples collected by the Pollution Tracker (46% df, n = 13) and PICES (50% df, n = 12) monitoring programs, at concentrations ranging from 0.00003 to 0.0029 µg/g ww.
  - *trans*-Chlordane has been detected in mussel samples collected by the Pollution Tracker (62% df, n = 13) and PICES (8% df, n = 12) monitoring programs, at concentrations ranging from 0.00004 to 0.0015 µg/g ww.
  - *cis*-Nonachlor has been detected in mussel samples collected by the Pollution Tracker (33% df, n = 15) and PICES (50% df, n = 6) monitoring programs, at concentrations ranging from 0.000029 to 0.0032 µg/g ww.
  - *trans*-Nonachlor has been detected in mussel samples collected by the Pollution Tracker (92% df, n = 13) and PICES (92% df, n = 12) monitoring programs, at concentrations ranging from 0.00003 to 0.0046 µg/g ww.
  - The sum of *cis*-chlordane, *trans*-chlordane, a-chlordane, g-chlordane, *cis*-nonachlor, *trans*-nonachlor, and nonachlor in each sample was screened against the adult subsistence fisher benchmark of 0.0026 µg/g ww. The mussel samples collected by Pollution Tracker in 2015/2016 did not exceed the benchmark. However, four fish liver samples collected by PICES in 1999 exceeded the benchmark (maximum 0.0088 µg/g).
- **DDT and Metabolites**
  - 2,4'-DDE has been detected in fish tissue samples collected by the Metro Vancouver (41% df, n = 58) and PICES (75% df, n = 12) monitoring programs, at concentrations ranging from 0.00011 to 0.0053 µg/g ww.
  - 4,4'-DDE has been detected in fish tissue samples collected by the Metro Vancouver (79% df, n = 58), mussel samples by Pollution Tracker (17% df, n = 18), and fish tissue samples by PICES (100% df, n = 12) monitoring programs, at concentrations ranging from 0.0002 to 0.073 µg/g ww.
  - 2,4'-DDT has been detected in fish tissue samples collected by the Metro Vancouver (34% df, n = 58), mussel samples by Pollution Tracker (25% df, n = 12), and fish tissue samples by PICES (100% df, n = 12) monitoring programs, at concentrations ranging from 0.00002 to 0.0045 µg/g ww.
  - 4,4'-DDT has been detected in fish tissue samples collected by the Metro Vancouver (38% df, n = 58), mussel samples by Pollution Tracker (46% df, n = 13), and fish tissue samples by PICES (92% df, n = 12) monitoring programs, at concentrations ranging from 0.00005 to 0.013 µg/g dw.
  - In Metro Vancouver's program, both whole fish body and liver tissue samples were monitored. DDE and DDT concentrations in whole body tissue samples were up to one order of magnitude lower than levels found in liver tissue.
  - The sum of 2,4'-DDE, 4,4'-DDE, 2,4'-DD", 4,4'-DDT in each sample was screened against the adult subsistence fisher benchmark of 0.01 µg/g ww. The benchmark was exceeded in 29% of the liver and 4% of the whole-body fish tissue samples collected by Metro Vancouver, and in 100% of the fish liver samples collected by the PICES program.
- **Dieldrin** has been detected in two fish tissue samples (17% df, n = 12) collected by the PICES monitoring program, both at 0.0040 µg/g ww. The detected dieldrin concentrations did not exceed the adult subsistence fisher benchmark of 0.0002 µg/g ww for the sum of aldrin (all < DL), dieldrin, and heptachlor (all < DL).

- **Endosulfans**
  - Endosulfan I has been detected in one mussel tissue sample (7% df, n = 14) collected by the Pollution Tracker monitoring program at 0.000028 µg/g ww.
  - Endosulfan II has been detected in two mussel tissue samples (15% df, n = 13) collected by the Pollution Tracker monitoring program at 0.00006 and 0.00024 µg/g ww.
  - The endosulfans were detected in three individual samples and did not exceed the subsistence fisher benchmark of 0.21 µg/g ww for the sum of endosulfan I, endosulfan II, and endosulfan sulfate (all < DL).
- **Endrin** has been detected in mussel tissue samples collected by the Pollution Tracker (45% df, n = 11) monitoring program, at concentrations ranging from 0.000014 to 0.000021 µg/g ww. The detected endrin concentrations did not exceed the subsistence fisher benchmark of 0.011 µg/g ww for the sum of endrin, endrin aldehyde (all < DL), and endrin ketone (all < DL).
- **Hexachlorobenzene** has been detected in fish tissue samples collected by the PICES (100% df, n = 12) monitoring program, at concentrations ranging from 0.00066 to 0.0013 µg/g ww, which is below the toddler benchmark of 0.002 µg/g ww.

<u>Current Use Pesticides</u>

- **Hexachlorocyclohexanes**
  - *alpha*-Hexachlorocyclohexane has been detected in fish tissue samples collected by the PICES (50% df, n = 12) monitoring program, at concentrations ranging from 0.00071 to 0.00094 µg/g ww.
  - *beta*-Hexachlorocyclohexane has been detected in mussel tissue samples collected by the Pollution Tracker (88% df, n = 32) monitoring program, at concentrations ranging from 0.000031 to 0.00015 µg/g ww.
  - *gamma*-Hexachlorocyclohexane has been detected in mussel tissue samples collected by the Pollution Tracker (31% df, n = 13) monitoring program, at concentrations ranging from 0.00078 to 0.0022 µg/g ww.
  - *delta*-Hexachlorocyclohexane has been detected in fish tissue samples collected by the PICES (100% df, n = 12) monitoring program, at concentrations ranging from 0.00071 to 0.00094 µg/g ww.
  - The sum of *alpha*-hexachlorocyclohexane, *beta*-hexachlorocyclohexane, *gamma*-hexachlorocyclohexane, and *delta*-hexachlorocyclohexane in each sample was screened against the adult subsistence fisher benchmark of 0.00289 µg/g ww. The benchmark was exceeded in two fish samples collected by the PICES program.
- **Permethrin** has been detected in two mussel tissue samples collected by the Pollution Tracker (14% df, n = 14) monitoring program at 0.0016 and 0.0029 µg/g ww, which is below the adult subsistence fisher benchmark of 1.74 µg/g ww for the sum of *cis*-permethrin, *trans*-permethrin, and permethrin.
- **Trifluralin** has been detected in three mussel tissue samples collected by the Pollution Tracker (60% df, n = 5) monitoring program at concentrations ranging from 0.00011 to 0.000029 µg/g ww, which is considerably lower than the toddler benchmark of 0.263 µg/g ww.

In summary, the sum of DDT and metabolites as well as hexachlorocyclohexanes and chlordanes exceeded the tissue benchmarks among the monitored legacy pesticides.

APPENDIX E: FURTHER DETAILS ABOUT THE PESTICIDES CONSIDERED IN THIS TECHNICAL REPORT

Legacy Pesticides

The use of organochlorine pesticides, such as dichlorodiphenyltrichloroethane (DDT), in controlling human health pests, and subsequently agricultural pests, helped to exponentially increase their use following World War II (Blus, 2002). Organochlorine pesticides were also used extensively in antifouling paints on ship hulls, in which DDT was used as an additive (Xin et al., 2011). Prior to a ban of these pesticides, applications would often result in visible fish kills and were linked to eggshell thinning in bird populations, clutch failure and declines of eagles, osprey, pelicans and other piscivorous birds (Sholz et al., 2012).

The discovery that many organochlorine pesticides were having widespread adverse effects on non-target organisms and evidence related to their toxicity, persistence, and lipophilic characteristics, brought about their ban in the 1970s and 1980s in North America and many other countries (Blus, 2002). The Stockholm Convention also placed aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, toxaphene and mirex on the POPs list, with methoxychlor currently under review (Stockholm Convention, 2019). The US Environmental Protection Agency (USEPA) also classified DDT and hexachlorocyclohexane (HCH) isomers as POPs. The classified HCH isomers are *alpha*-HCH, *beta*-HCH, and *gamma*-HCH (lindane; classified as a CUP) which are the main constituents of HCH. However, even though most countries have now banned the use of these pesticides, many developing countries still continue to use them due to a lack of proper legislation and market regulations (Jayaraj et al., 2016).

Both organochlorine and organophosphate pesticides are slowly degraded, highly persistent and lipophilic and can accumulate in species at higher trophic levels. Their low water solubility and low vapour pressure allows them to be transported over great distances and persist and bioaccumulate within systems (Blus, 2002). Exposure and uptake in marine organisms can occur through various pathways, such as dermal, respiratory and oral routes, with oral ingestion being the main exposure pathway. Bioaccumulation of legacy pesticides into the tissues of organisms can elicit chronic forms of toxicity, notably those mediated through the disruption of endocrine processes (i.e., hormone mimics or endocrine disrupting substances) (Brown and Takada, 2017). Organochlorine pesticides can supress the endocrine system in aquatic animals (Scholz et al., 2012). In higher trophic species, organochlorine pesticides can also affect immune system functions (inhibiting the calcium ion flux and calcium-magnesium-ATPase, which cause a release of neurotransmitters), sex characteristics, and tumour growth (Jayaraj et al., 2016).

Estrogenic activity from exposure to organochlorine pesticides was observed in hatchling and juvenile American alligators (*Alligator mississipensis*) in Lake Apopka, Florida which exhibited gonadal abnormalities and altered concentrations of sex steroids in both male and female alligators (Blus, 2002). Some organochlorines can also act as estrogenic chemicals when fish are undergoing critical life stages of sex determination. This was observed when fish eggs (Japanese medaka, *Oryzius latipes*) were microinjected with o,p’-DDT, resulting in complete male and female sex reversal ten weeks after injection (Edmunds et al., 2000). DDT and dieldrin have been identified as contaminants of concern to Southern Resident Killer Whales (SRKW) and DDT is also recognized as a contaminant of concern to the Chinook salmon, the primary prey of SRKW (ECCC, 2020).

The carbamate pesticide aldicarb has been used in agricultural settings in Canada between 1975 and 1996 (discontinued use in Canada) (CCME, 1999b). This carbamate pesticide exerts acute and chronic toxicity to fish and aquatic invertebrates, and acts by primarily disrupting the nervous system function

(Bondarenko et al., 2004). Aldicarb can also have effects on population density of plankton (Bondarenko et al., 2004). Aldicarb exposure is associated with the inhibition of acetylcholinesterase (AChE) activities in the central nervous system, which can lead to inhibition of brain activity and behavioural endpoints, such as reductions in spontaneous swimming, feeding rates, swimming stamina and predator detection rates in fish (Moore et al., 2009).

Cis- and *trans*-nonachlor are among the major components of chlordane, which was previously used as an insecticide in agricultural and non-agricultural settings until late 1980s in North America (Bondy, 2000). Nonachlor has been shown to accumulate in edible fish tissue of some estuarine fish such as spot (*Leiostomus xanthuru*), when exposed under chronic conditions (Menzie, 1980). In rats, exposure to nonachlor indicated hepatic changes consistent with microsomal enzyme induction, and a decrease in kidney function (Bondy, 2000). Oxychlordane, a metabolite of chlordane is an insecticide that has been banned in Canada, USA, and the European Union (Koshlukova and Reed, 2014). These pesticides can cause hepatotoxicity, neurotoxicity and developmental toxicity in humans and aquatic life (Koshlukova and Reed, 2014).

Current Use Pesticides

Most of the CUPs listed in Table 1 belong to different chemical groups; however, overall, sublethal effects of some of these CUPs on aquatic species (zebra fish; *s*heepshead minnow, *Cyprinodon variegatus*; coho salmon, *Oncorhynchus kisutch*; and Chinook salmon, *Oncorhynchus tshawytscha)* may include endocrine disruption, impaired immune function, abnormal development, altered behaviours, reduced growth and feeding, and reproductive impairment (Sholz et al., 2012).

Triazine pesticides, which include atrazine and simazine, were both introduced in the 1950s and are both common in agricultural and forestry applications (Velisek et al., 2013). Triazine can affect aquatic ecosystems by impairing phytoplankton growth and succession, which can impact the growth of zooplankton species, and in turn affect the amount of food available to higher trophic level species (Degrendele et al., 2016). Zebra fish have also been shown to be directly affected by atrazine through reduced metabolic indicators and changes in behaviours at low concentrations (<6 µg/L) (Steinberg et al., 1995 and Greymore et al., 2001). The 96-hour lethal concentration to 50% of the organisms (LC50) for juvenile signal crayfish (*Pacifastacus leniusculus*), which can be used as a bio-indicator of environmental contamination, were 12. 1 mg/L for atrazine and 77.9 mg/L for simazine, indicating that atrazine has greater toxicity to crayfish than simazine (Velisek et al., 2013). The differential toxicity of simazine can be attributed to differences in susceptibility and tolerance related to its accumulation, biotransformation, and excretion. For atrazine, several chronic exposure studies have also been conducted in Atlantic salmon (*Salmo salar*) under freshwater and saltwater conditions, which indicated effects on ion regulation, growth, and endocrine responses at the 0.1 mg/L level. Reduced feeding was also observed in Atlantic salmon, which resulted in reduced growth; however, over three months, compensatory growth was observed indicating potential recovery (Brain et al., 2021). Atrazine, which was initially introduced in the 1950s, is common in agricultural and forestry applications and affects aquatic ecosystems by impairing phytoplankton growth and succession. This can result in a reduction of zooplankton species and in turn affect the amount of food available to higher trophic level species (Degrendele et al., 2016). Fish (zebra fish, *Danio rerio*) have also been shown to be directly affected by atrazine through reduced metabolic indicators and changes in behaviours at low concentrations (<6 µg/L) (Steinberg et al., 1995 and Graymore et al., 2001). Sheepshead minnow larvae were also found to be sensitive to atrazine, with larval length and wet weight being the most sensitive indicators of toxicity to early life-stages (Wan et al., 2006). A study with two anadromous salmonid species (coho and Chinook salmon) reported 24 h, 48 h, 72 h, and 96 h LC50 values ranging from 12 mg/L to 22 mg/L when exposed to atrazine under freshwater conditions (Wan et al., 2006). Several chronic exposure studies have also been conducted in Atlantic salmon (*Salmo salar*) under freshwater and saltwater conditions, which indicated effects on ion regulation, growth, and endocrine responses at the 0.1 mg/L level. Reduced feeding was also observed in Atlantic salmon, which resulted in reduced growth; however, over three months, compensatory growth was observed indicating potential recovery (Brain et al., 2021).

The organophosphate malathion and chlorpyrifos, have been used extensively as a broad-spectrum insecticide in agricultural and non-agricultural settings (Health Canada, 2021b). Although the use of chlorpyrifos is being phased out in Canada (Health Canada, 2021a), malathion is still being used. Both organophosphates can exert an effect on organisms by inhibiting the enzyme AchE, which is critical enzyme for the functioning of nerve impulses. When organisms are exposed to these organophosphates, this inhibition can result in respiratory arrest which reflects the pesticides high neurotoxicity. The neurotoxicity of organophosphates can also affect escape responses and detection avoidance in fish (*Astyanax aeneus* (Characidae)), which has been observed at low sublethal concentrations (Sandoval-Herrera et al., 2019).

Chlorophenols are organochlorinated ring compounds, with a hydroxyl (OH) group and varying levels of chlorination. There are 19 chlorophenol congeners, with toxicity related directly to the degree of chlorination (Health Canada, 2008). Chlorophenols are persistent, bioaccumulative, and toxic substances that may damage ecosystems, and despite Canada's lack of chlorophenol production, these compounds continue to be imported and used in Canada for industrial, agricultural, and domestic processes (Government of Canada, 1987a; Igbinosa et al., 2013). Chlorophenols pose a hazard[4] to human health and the environment based on its toxicity; and depending on exposure, can then pose a risk[5]. Exposure within aquatic life to chlorophenol compounds can inhibit an organism's ability to detoxify; affects immune system function; impedes the endocrine system; and can have deleterious effects on DNA (Ge et al., 2017). The International Agency for Research on Cancers and the World Health Organization (WHO) has categorized the higher chlorinated phenols as potential human carcinogen groups, which include the pentachlorophenols, tetrachlorophenols, and trichlorophenols (Igbinosa et al., 2013). For the lesser chlorinated phenols (chlorophenols and dichlorophenols), data is inadequate to classify them under potential carcinogens (Health Canada, 2008). Chlorophenols can also have detrimental effects to aquatic life by altering the flavour of shellfish (Warrington, 1997) (Australia & New Zealand Guidelines for Fresh & Marine Water Quality, 2000). This could become a concern when flavour impairment leads to a loss of appetite in adult wildlife or causes juveniles to refuse their mother's tainted milk (Warrington, 1997).

Imidacloprid was introduced into the market in 1991, which is part of the group of nicotine-related insecticides knows as neonicotinoids (Tišler et al., 2009). These act as agonists of the postsynaptic nicotinic acetylcholine receptors (nAChRs), resulting in the impairment of normal nerve function in organisms. Water fleas (*D. magna*) were shown to be the most sensitive to imidacloprid, after short term exposure (48-hour EC50 at 56.6 mg/L) and long term exposure (21 day NOEC at 1.25 mg/L), followed by zebrafish and algae (Tišler et al., 2009).

Trifluralin belongs to the dinitroaniline group. It is a commonly used herbicide that is highly toxic to aquatic organisms, since it is potentially genotoxic, mutagenic, carcinogenic and mitochondrial toxic through calcium ion dysregulation (Awkerman et al., 2020). Acute and subacute toxicity of trifluralin in fish (carp, *Cyprinus carpio*, L.) found a decrease in relative growth, and changes in the vital organs (the most affected organs being the gills and kidneys) (Poleksic and Karan, 1998).

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[4] Hazard is defined as the *potential* of a pesticide to cause harm.

[5] Risk is the *possibility* of the pesticide to cause harm.

Hexachlorocyclohexane is a technical mix of isomers, with *gamma*-hexachlorocyclohexane, or lindane, being the most commercially important. Other environmentally relevant isomers are *alpha*-, *beta*-, and *delta*-hexachlorocyclohexane. Lindane is in many ways a legacy pesticide that has been widely used since the 1940s as an insecticide, primarily for canola and corn crops in Canada (UNEP, 2006). The production of lindane has decreased rapidly in recent years and its use was restricted in Canada in 1999. It is currently found in low concentrations in non-prescription drugs for the treatment of lice and scabies. Lindane is persistent, bioaccumulates easily in the food chain and bioconcentrates rapidly. Lindane has been classified as a carcinogen and endocrine disrupter, and there is evidence for reproductive, developmental and immunotoxic effects in aquatic organisms.

Permethrin pesticides, which are part of the pyrethroid insecticides, can have serious toxicological impacts to fish, aquatic invertebrates, and sediment organisms. Several studies have examined the toxic effects of pyrethroids in fish reproduction and during early developmental stages. For instance, permethrin can cause developmental toxicities, abnormal vascular development, changed locomotor activities, and thyroid disruption in zebrafish, while abnormal swimming behaviour and reduced growth and increased predation risk were noted in larval fathead minnows (*Pimephales promelas*) in response to a sublethal exposure to pyrethroid insecticide (Fulton et al., 2013).

Lindane is very toxic to aquatic organisms, with variable differences within fish species. Fish with higher lipid content have been shown to be more resistant to lindane, since less of the compound is available to target organs when stored in fatty tissue; however, acute exposure to lindane in fish has shown to result in biochemical changes to the liver and brain tissues, as well as hyperglycemia (Sang et al., 1999). In amphipods (*Gammarus pulex*), lindane exposure results in a decrease in feeding activity. Chronic lindane exposure of more or equal to 0.25 ppm, was shown to decrease growth, reproduction and survival in water flea (Daphnia). Acute exposure to lindane in immature grass carp (*Ctenopharyngodon Idella*) also resulted in respiratory problems, changes in behaviours, intestinal functions and tissue lesions (Vajargah et al., 2021).

There is still limited data indicating the bioaccumulation of CUPs in biota. The exception is lindane, which has been found in seals, beluga (*Delphinapterus leucas*) and other wildlife, indicating that lindane is able to bioaccumulate in marine food webs (Hoferkamp et al., 2010). Due to lindane being able to bioaccumulate, and when coupled with the fact that there is still limited data on the bioaccumulation potential of other CUPs, the relevance of monitoring these contaminants in marine environments becomes apparent (Hoferkamp et al., 2010). CUPs have been identified as contaminants of concern to SRKW and their prey, Chinook salmon (ECCC, 2020).