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

September 2022

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.

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

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CHAPTER SUMMARY

This chapter presents proposed water quality objectives for mercury in Burrard Inlet, identified as a metal of primary concern by Tsleil-Waututh Nation in their Burrard Inlet Action Plan. These proposed objectives were developed using up-to-date research on relevant values and potential effects, sources and factors influencing mercury levels, benchmark screening, and historic and recent monitoring data for Burrard Inlet.

Mercury is toxic in its organic and inorganic forms and the most toxic form is methylmercury. Mercury bioaccumulates and biomagnifies through the food chain. The most sensitive values affected by mercury are protection of wildlife, and human consumption of shellfish and finfish.

The highest concentrations of mercury in marine sediments in Canada have been in industrial areas and harbours. Mercury can enter the marine environment from flooding, coal burning, smelting, chemical manufacturing and other industrial activities. Most of the anthropogenic mercury deposited in Canada comes from sources outside of the country via atmospheric transport. Mercury also enters Burrard Inlet through the Lions Gate Wastewater Treatment Plant, combined sewer overflows and stormwater discharges. Mobilization from marine sediments can also release mercury into the Inlet water column.

The water quality guideline from the Canadian Council of Ministers of the Environment(CCME) and BC working sediment quality guideline were used as benchmarks for an assessment of existing data on mercury in the water and sediment of Burrard Inlet, respectively. Tissue screening values protective of human consumption of finfish and shellfish were calculated and used as benchmarks for an assessment of mercury in tissue.

Elevated mercury levels in the water column, sediments and tissue have been observed across Burrard Inlet with noteworthy hotspots including the Central Harbour near Clark Drive and throughout Port Moody Arm, False Creek and Indian Arm South.

The proposed water quality objectives for mercury are as follows:

Proposed Water Quality Objectives for Mercury in Burrard Inlet

Sub-basin	Outer Harbour	False Creek	Inner Harbour	Central Harbour	Port Moody Arm	Indian Arm
Total Mercury in Water	0.016 µg/L mean[1]					
Total Mercury in Sediment	0.13 µg/g dry weight single-sample maximum[2]					
Total Mercury in Tissue	0.033 µg/g wet weight single-sample maximum[3]					

[1] Minimum of 5 samples in 30 days collected during the wet season.
[2] Based on at least 1 composite sample consisting of at least 3 replicates.
[3] Applies to all tissue types. Based on at least 1 composite sample consisting of at least 5 fish or 25 bivalves.
See Rao et al. (in prep) for additional details.

The water quality objective is intended to be protective of aquatic life and avian wildlife. The sediment quality objective is intended to be protective of aquatic life. The tissue objective is intended to be protective of marine wildlife and human subsistence consumers of wild finfish and shellfish but cannot be considered protective of marine mammals such as Southern Resident Killer Whales because it does not consider biomagnification in the food web.

Mercury monitoring programs in the inlet could be improved by increased monitoring of point and non-point sources, and of species harvested for consumption; as well as research guided at better understanding risks to human health.

Management options that could reduce anthropogenic inputs of mercury into Burrard Inlet include source controls and increased implementation of green infrastructure to prevent entry from stormwater, as well as mercury removal during wastewater treatment.

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ACRONYMS

BC	British Columbia
BIEAP	Burrard Inlet Environmental Action Program
CCME	Canadian Council of Ministers of the Environment
CSO	Combined sewer overflow
ENV	BC Ministry of Environment and Climate Change Strategy
EQOMAT	Environmental Quality Objectives and Monitoring Action Team
Hg	Mercury
ISMP	Integrated Stormwater Management Plan
ISQG	Interim sediment quality guideline
MeHg	Methylmercury
MOE	BC Ministry of the Environment
PEL	Probable effect level
SV	Screening value
TEL	Threshold effect level
TRV	Toxicological reference value
TWN	Tsleil-Waututh Nation
WWTP	Wastewater treatment plant

1. INTRODUCTION

This chapter proposes water quality objectives for mercury (Hg) in Burrard Inlet. Tsleil-Waututh Nation (TWN) has identified mercury as a metal of primary concern in their Burrard Inlet Action Plan (TWN 2017). This chapter includes relevant background information, an overview assessment of current status and trends in mercury levels in water, sediment and biota in Burrard Inlet in 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

Mercury is toxic in its organic and inorganic forms, and the most toxic form is organic methylmercury (MOE 2001). Methylmercury biomagnifies in the food web, is efficiently absorbed from diets and distributes into many bodily organs (Scheuhammer et al. 2015). The most sensitive values with respect to mercury levels in water and tissue are protection of aquatic life, wildlife, and human consumption of shellfish and finfish. Protection of aquatic life is the most sensitive value with respect to mercury in sediment, as mercury is lethal to benthic organisms (CCME 1999). Protection of human consumption of finfish and shellfish is the most sensitive value with respect to mercury in tissue. See the discussion of benchmarks below for details.

Human exposure to mercury generally tends to be through diet, in particular through consumption of fish. Trace amounts of mercury can be found in nearly all species of fish; however, levels in some are higher than in others. Fish at higher trophic levels tend to contain higher levels of total mercury, i.e., mercury biomaginifes through the aquatic food chain (Health Canada 2007).

2.2 Potential Sources of Mercury Pollution

Natural sources of mercury include forest fires, volcanoes and weathering. Approximately 70% of the sources of mercury in today's environment are anthropogenic air emissions from metal smelting, electricity generation including coal burning, waste incineration, and mining effluent (UNEP 2002). Other sources include chlor-alkali production, flooding due to dams and disposal and production of items containing mercury (ECCC 2016). Discharges from vessels are also a potential source of mercury input into Burrard Inlet. Vessel exhaust gas cleaning systems, also called scrubbers, have been found to discharge wash water that contains contaminants including mercury (ICCT 2019, 2020).

Metallic mercury is used for chemical manufacturing, electrical equipment, power generation, dental amalgams and metallurgical gold. Mercury compounds are used in paint, drywall, scientific supplies, pharmaceuticals and pesticides (MOE 2001).

Natural background concentrations of mercury in BC waters are low. Elevated mercury concentrations have been recorded in BC waters contaminated by industrial activity (MOE 2001). The highest concentrations of mercury in marine sediments in Canada has been in industrial areas and harbours, with most studies measuring concentrations of total mercury (CCME 1999).

In the 1990 BC Water Quality Objectives for Burrard Inlet, mercury in water, sediment and/or tissue was identified as a parameter of concern in False Creek, the Outer Harbour, the Inner Harbour and the Central Harbour (Nijman and Swain 1990). Objectives and monitoring for mercury in Port Moody Arm, and monitoring of mercury in fish muscle in Indian Arm were also recommended for comparison to other areas. Known sources included combined sewer overflows (CSOs), stormwater discharges, mobilization from marine sediments, the Lions Gate Wastewater Treatment Plant and the Premier

Street Landfill in North Vancouver (which has since had its leachate diverted to the municipal sewer system and has been converted into a recreational park). Mercury levels in Inner Harbour sediments suggested that mercury sources were anthropogenic (Nijman and Swain 1990).

2.3 Factors Influencing Mercury Levels in Burrard Inlet

There are three forms of mercury that are particularly notable environmentally. Elemental mercury, also referred to as Hg(0), is volatile and can be airborne over long distances. Divalent mercury, also referred to as Hg(II), can form compounds that are water-soluble or reactive in the air. Methylmercury (MeHg) is the most toxic and most prevalent in animal tissue (ECCC 2016).

The main mechanism of Hg(0) distribution is likely via atmospheric transport, resulting in long distance global transport (ECCC 2013). Environment Canada has estimated that 95% of the anthropogenic mercury deposited in Canada comes from sources outside of the country (ECCC 2016). Mercury deposited from the atmosphere via precipitation into terrestrial environments binds to organic matter and can be transported to the marine environment through groundwater runoff (Krabbenholt and Babiarz, 1992), wetlands (Mierle and Ingram 1991; St. Louis et al. 1994; Branfireun et al. 1998; Babiarz et al. 1998), reservoir creation (Porvari and Verta 1995; Tremblay et al. 1998a) and riparian soils (Bishop et al. 1995a).

Mercury may form complexes with organic and suspended solids in water, making it biologically unavailable. This unavailability may be temporary, however, as certain environmental conditions can enable its release into available forms (MOE 2001). High mercury levels in water may be transient, as low solubility, affinity to organic matter and adsorption to suspended solids enable it to settle into the sediment (Nijman and Swain 1990).

Factors influencing the behaviour and bioavailability of mercury in sediments, as well as its methylation and demethylation rates, include pH, redox potential and temperature. Particle size, organic matter content, metal oxide concentration and sulphide concentration, as well as individual organisms' behaviour and physiology, also affect its bioavailability (CCME 1999).

2.4 1990 Provisional Water Quality Objectives for Mercury

The 1990 Burrard Inlet water quality objectives for mercury in water, sediment and tissue are summarized in Table 1. They were set for protection of marine aquatic life, as well as for human consumption of finfish and shellfish. They were based on water quality criteria for mercury developed by the Province of BC in 1989 (Nagpal 1989, Nijman and Swain 1990). The 1989 criteria were derived from an assembly of toxicology data prepared by the United States Environmental Protection Agency in 1985.

Table 1: 1990 Provisional Water Quality Objectives for Mercury.

Sub-basin	False Creek	Outer Harbour	Inner Harbour	Central Harbour	Port Moody Arm	Indian Arm
Water	0.02 µg/L mean and 2 µg/L maximum				N/A	
Sediment	0.15 µg/g dry weight maximum					N/A
Tissue	0.5 µg/g weight wet maximum (fish tissue)				N/A	

Detection limits for mercury in water in 1990 were 0.05 µg/L, which is higher than the 1990 water quality objective for mercury in water (Nijman and Swain 1990).

3. WATER QUALITY ASSESSMENT

3.1 Benchmarks Used in this Assessment

Benchmarks were chosen to screen available data for potential acute and chronic effects and to inform the derivation of proposed objectives for mercury in Burrard Inlet. Based on a comparison of available benchmarks and a calculation of screening values using Health Canada toxicological reference values and risk assessment methodologies (Health Canada 2010a,b,c, 2012a; Richardson 1997, Richardson and Stantec 2013), protection of aquatic life is the value most sensitive to mercury levels in water and sediment, and human health and wildlife are the values most sensitive to mercury levels in tissue. The screening benchmarks chosen for the data assessment are summarized in Table 2.

BC water quality guidelines for mercury were updated in 2001 to protect aquatic life from chronic effects of mercury and account for bioaccumulation, although this update did not change the 1989 guideline of 0.02 µg/L. These guidelines followed updates to the Canadian Council of Ministers of the Environment (CCME) guidelines for mercury in the water column to protect aquatic life and wildlife. BC aquatic guidelines for mercury were also updated in consideration of human diets based primarily on fish (MOE 2001). The aquatic life guideline for water reflects the similar bioaccumulation potential of mercury in marine and freshwater food webs and is based on the 1999 CCME tissue residue guideline. The water quality guideline is based on total mercury, but decreases when the proportion of methylmercury is higher. It is intended to protect birds (MOE 2001).

The CCME guidelines for total mercury in water were later updated in 2003 to 0.016 µg/L (CCME 2003). These consider chronic toxicity, but not bioaccumulation potential. Although the CCME (2003) guideline does not address exposure through food or bioaccumulation to higher trophic levels, the guideline suggests that, to protect all wildlife consumers of aquatic life, methylmercury concentrations should be below 0.007 ng/L (0.000007 µg/L). The CCME estimates that methylmercury concentrations over 0.2 ng/L (0.0002 µg/L) could pose a risk to wildlife, and concentrations between those two figures could be hazardous to some wildlife depending on their preferred prey and bioaccumulation factors of those prey, and their trophic level. In this report, the CCME guideline was used as the screening benchmark for water samples for three reasons: 1) the CCME guideline reflects updates that are more recent than the BC Approved Water Quality Guidelines; 2) data for methylmercury in Burrard Inlet marine waters are lacking; and 3) the CCME guideline is established for total mercury in the absence of available data for methylmercury in water.

The CCME (1999) sediment guideline has been adopted as the BC working sediment quality guideline. It is based on total mercury concentration in the top 5 cm of sediment. Based on available toxicological data, the CCME concluded that the Canadian interim sediment quality guideline (ISQG) for total mercury of 0.13 mg/kg dry weight appears to be lower than the level at which biological effects would occur in benthic invertebrates.

A risk-based approach was used to calculate human health-based screening values for fish and shellfish tissue (Thompson and Stein 2021). The approach considers: the contaminant *receptors* (people who are exposed to the contaminant, in this case subsistence/Indigenous fisher, recreational fisher, and general BC populations[1], with screening values (SVs) calculated for the most sensitive life stage within each population), *exposure* to the contaminant (how much fish the receptors consume), and the contaminant *toxicity* (what is known about the contaminant and how it affects different receptors). Receptor characteristics were defined from Richardson and Stantec (2013), exposure was calculated through fish

[1] These populations are defined/differentiated by their fish ingestion rates, which are further defined based on age/life stage. Details are provided in Thompson and Stein (2021).

ingestion rates from Richardson (1997) and Health Canada (2010c), and toxicity was defined through toxicological reference values (TRVs) prescribed by Health Canada (2010a) or other international agencies (i.e., United States Environmental Protection Agency and the World Health Organization).

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 (Thompson and Stein 2021). Fish and shellfish tissue in this report refer to country foods, that is, foods produced in an agricultural (not for commercial sale) backyard setting or harvested through hunting, gathering or fishing activities (Health Canada 2010b). SVs 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 SV may indicate that further investigation to assess human health risk at a particular site is warranted; however, exceeding a SV does not imply an immediate risk to human health (Thompson and Stein 2021). SVs were calculated by Thompson and Stein (2021) using equations from Health Canada (2012).

The SV calculated for total Hg in fish and shellfish tissue is 0.035 µg/g wet weight for the most sensitive receptor (a toddler from a subsistence fishing population; Thompson and Stein 2021[2]), and the approved BC water quality guideline is 0.033 µg methylmercury/g wet weight in the diet of wildlife (ENV 2001). It is recommended that the SVs be compared against total mercury because it is total mercury that is measured in the laboratory (Thompson and Stein 2021). For the purpose of deriving SVs, it is assumed that 100% of total Hg in fish is methylmercury (MeHg) (Health Canada 2007). As low levels of mercury are present in most fish, exceedances of the mercury SV can also be compared against background concentrations compiled in Appendices I to III of Health Canada's Human Health Risk Assessment of Mercury in Fish (Health Canada 2007), or additional lab analysis could be used to determine the proportion of methylmercury to total mercury, with the SV adjusted accordingly (Thompson and Stein 2021). It would be easier, cheaper and more conservative, however, to assume all mercury in tissue is methylmercury.

Beckvar et al. (2005) suggest that a tissue concentration of 0.02 µg/g whole body (wet weight) could be protective of juvenile fish, based on sublethal endpoints; however, they advise that further studies are needed to validate this suggestion, as it is based on limited data. The federally-led work addressing the impacts of contamination on Southern Resident Killer Whales has included this concentration among its recommended Environmental Quality Guidelines for the protection of Chinook salmon, with the caveat that this value does not consider biomagnification in the food web and is likely not protective of Southern Resident Killer Whales (ECCC 2021). This benchmark was not included in the data assessment below due to the limitations as stated above.

[2] The tissue screening values used in this report are based on the raw calculations used by Thompson and Stein (2021) and include more significant digits than what is reported in that paper, for better comparison with other benchmarks.

Table 2: Screening Benchmarks for Mercury in Water, Sediment, and Tissue Used in this Assessment

Sample Type	Screening Benchmark	Value	Reference
Water	0.016 µg/L mean (chronic)	Aquatic life and avian wildlife	CCME (2003)
Sediment	0.13 µg total Hg/g dry weight mean (TEL)[1] 0.70 µg total Hg/g dry weight maximum (PEL)	Aquatic life	ENV 2021 (CCME 1999)
Tissue	The following in µg total Hg/g wet weight maximum[2]: Wildlife: 0.033 Subsistence fisher - toddler: 0.035 Subsistence fisher - woman of child-bearing age: 0.063 Subsistence fisher - other adult: 0.163 Recreational fisher - other adult: 0.324	Finfish and shellfish consumption	ENV 2001 (CCME 2001) Thompson and Stein 2021 (Health Canada 2010c)

[1] The threshold effect level (TEL) defines the level at which adverse effects rarely occur. The probable effect level (PEL) defines the level above which adverse effects are expected to occur frequently. Between PEL and TEL represents the range within which adverse effects occasionally occur. Interim sediment quality guidelines (ISQGs) are often set at the PEL when detailed data are not available. Note that the TEL & PEL do not consider biomagnification.
[2] Calculated screening values for which mercury concentrations in tissue can be compared and assessed for potential risks to human health. This is a single benchmark for all tissue types (e.g., fish muscle, bivalves, crustaceans) as data are not available to resolve to the level of objectives for different tissue types at this time. It should be noted that the values included in this table are based on the raw calculations used by Thompson and Stein (2021) and include more significant digits than what is reported in that paper, for better comparison with other benchmarks.

3.2 Data Sources

Data for mercury levels in Burrard Inlet were gathered from several studies and monitoring programs. A summary of the datasets used for this assessment is presented in Table 3. Although other datasets containing mercury sampling data may exist, the priority datasets were found to be the best available data for assessing the status of mercury in Burrard Inlet within the constraints of the project.
Maps showing the distribution of sampling sites for each of the post-1990 studies or monitoring programs are provided in Figure 1 through Figure 4.

Table 3: Studies and Monitoring Programs Contributing Data Used for the Assessment

Source	Study/Monitoring Program, Years	No. of Obs.	No. of Sites	Sampling Frequency	Parameters Sampled
BC ENV	Monitoring Data for Burrard Inlet, 1971–1989	212 water	16 water	Irregular	Total and dissolved mercury in water
Environment Canada	Benthic Contaminants Study, 1985–1987	Not listed	48 sediment 11 tissue	6 surveys	Total mercury in sediment by dry weight Total mercury in Dungeness Crab, Pandalid Shrimp, and English sole tissue by dry weight
Burrard Inlet Environmental Action Program (BIEAP) Environmental Quality Objectives and Monitoring Action Team (EQOMAT)	Sediment Quality in Burrard Inlet Using Various Chemical and Biological Benchmarks, 1998	45	15 sediment	3 samples per site in October 1995	Total mercury in sediment by dry weight
BC ENV	Provincial Water Quality Objectives Attainment Monitoring, 1990–2009	198 water, 49 sediment, 14 tissue	9 water, 12 sediment, 7 tissue	1–10 samples/year, irregular Water samples generally reported as maximum values and mean of 5 samples in 30 days	Total mercury in water Total mercury in sediment by dry weight Total mercury in English sole tissue by dry or wet weight
Metro Vancouver	Burrard Inlet Ambient Monitoring Program, 2007–2016	710 water, 210 sediment, 88 tissue	7	5 water samples/year, at both top and bottom of water column, regular. Reported as maximum values and mean of 5 samples in 30 days 5 sediment samples/2 years, regular Tissue samples in 2007 and 2012	Total mercury in water Total and extractable mercury in sediment by dry weight Total mercury and methylmercury in English sole tissue by wet weight
Ocean Wise	Pollution Tracker, 2015–2016	37 sediment, 30 tissue	15 sediment, 8 tissue	3 sediment samples and 50–200 mussels per site on a single day in October 2015, December 2015 and April 2016	Total and extractable mercury, and methylmercury in sediment by dry weight Total mercury and methylmercury in mussel tissue by wet and dry weight

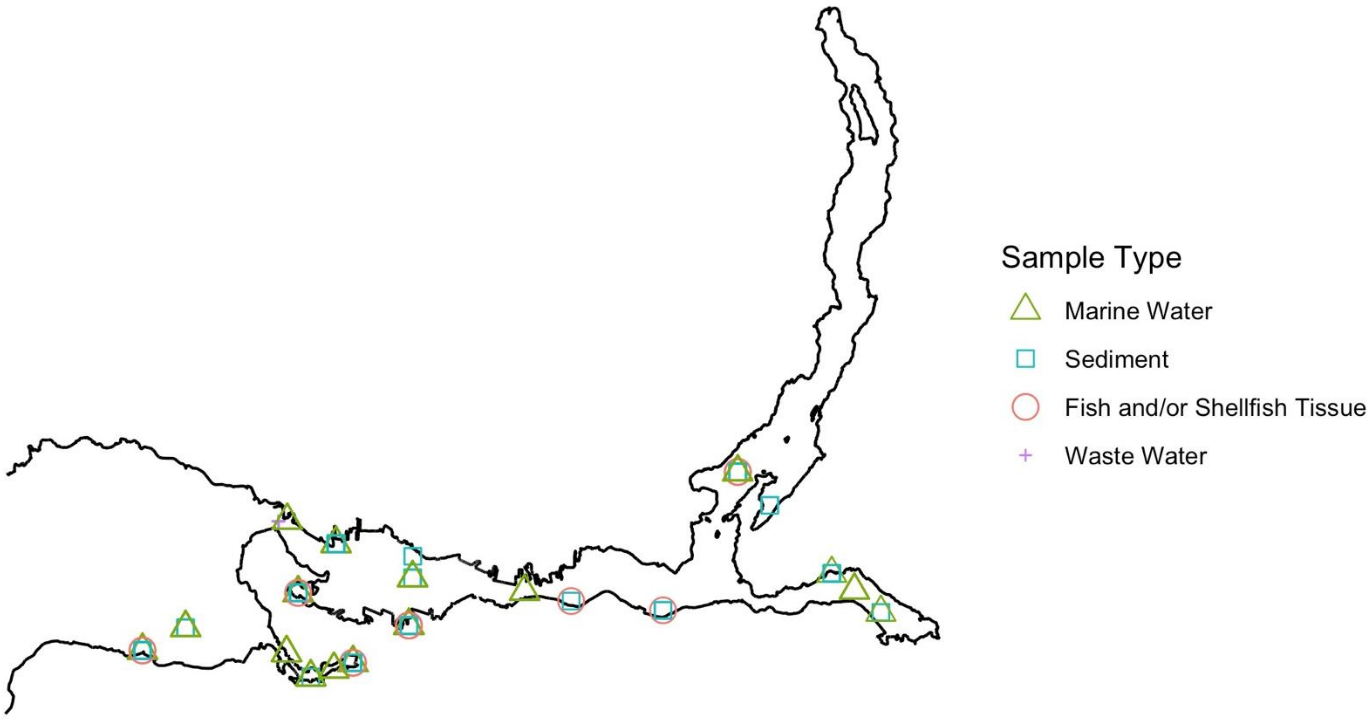

Figure 1: BC ENV sampling stations for mercury in Burrard Inlet (1990 to 2009)

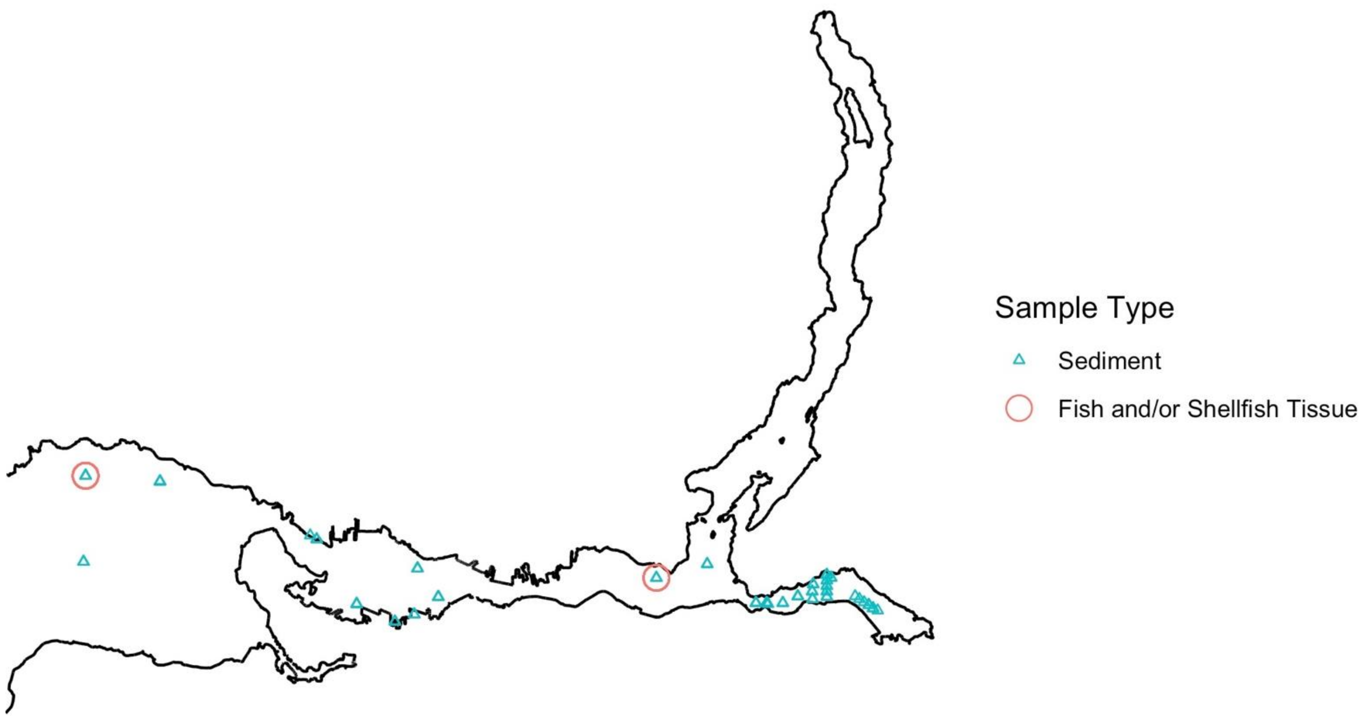

Figure 2: Environment Canada sampling stations in Burrard Inlet (1985 to 1987)

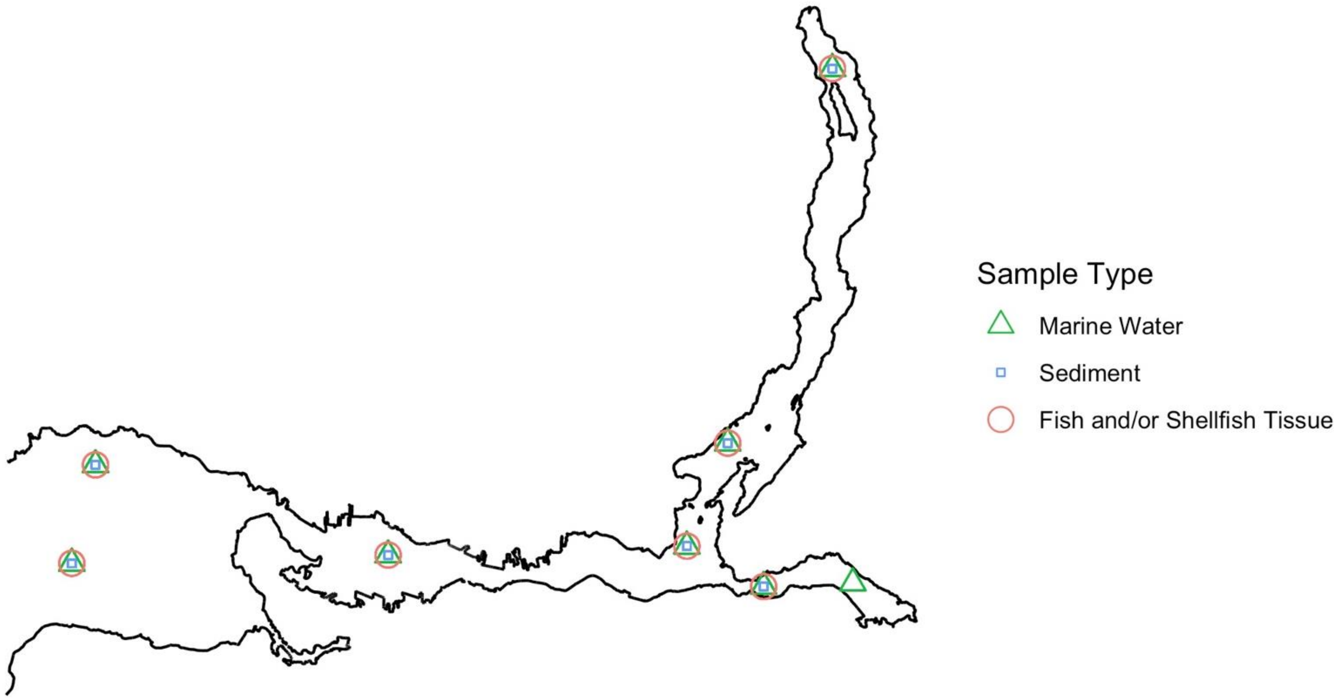

Figure 3: Metro Vancouver sampling stations for mercury in Burrard Inlet (2007 to 2016)

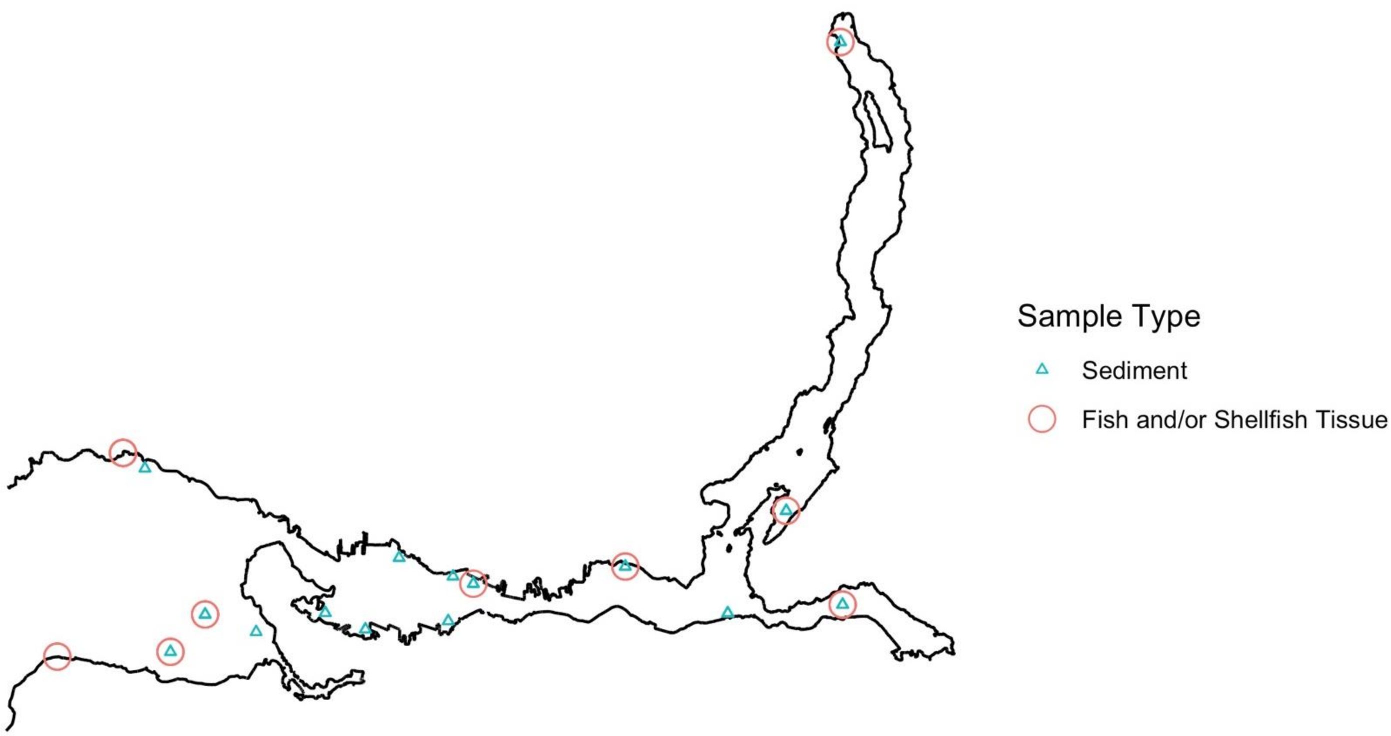

Figure 4: Pollution Tracker sampling stations for mercury in Burrard Inlet (2015 to 2016)

3.3 Assessment Results

Monitoring data were compared to screening benchmarks and temporal and spatial observations are presented by sub-basin, where appropriate. Because of variation in the sampling and analytical methods and distribution of sites, results from each monitoring program are discussed separately. Programs that collect samples at sites close to the shore are expected to produce different results compared to programs that collect samples offshore and at depth for ambient conditions. Therefore, there are limitations on comparing results between the monitoring programs.

Where mercury levels were below detection limits, values were plotted at the detection limit value in Figure 6 through Figure 13. Samples that were below detection limits were excluded from the evaluation of mean and maximum levels at the sample locations. Key observations for detection frequency, exceedances, and maximum observed mercury levels are described by monitoring program. Overall summaries of status and observations for water, sediment and tissue are provided alongside the rationale for the proposed water quality objectives in Section 4.2. All data presented are for total mercury levels, unless indicated. The only methylmercury data in Burrard Inlet is for sediment and fish tissue.

Data for constituents that impact mercury toxicity and bioavailability were also collected in the majority of these monitoring programs.

Pre-1990 Data

- 1985 –1987 – The Environment Canada Benthic Contaminants Study (Goyette and Boyd 1989) observed mean mercury levels in sediment that exceeded the estimated natural reference level for the study area of 0.2 µg/g at 39 (81%) of the 48 monitoring stations, and exceeded the PEL benchmark (0.7 µg/g) at 2 (4%) of the 48 monitoring stations. Mercury levels averaged 0.48 µg/g in the Inner Harbour and 0.32 µg/g in Port Moody Arm. The highest single sample maximum mercury levels were observed near the Burrard Yarrows Shipyard (6.4 µg/g), Inner Harbour South Shore (4.6 µg/g) and Inner Harbour North Shore (2.2 µg/g). The Inner Harbour South Shore location was adjacent to a combined sewer overflow outfall. Vancouver Shipyards and Vancouver Wharves were also identified as hot spots for mercury. Mercury levels in English sole (*Parophrys vetulus*) fish muscle tissue ranged from 0.19 to 0.50 µg/g dry weight, (equivalent to 0.048 to 0.125 µg/g wet weight, assuming 75% moisture content) which was similar to mercury levels in fish tissue reported for unpolluted coastal areas of BC (Harding and Goyette 1989).

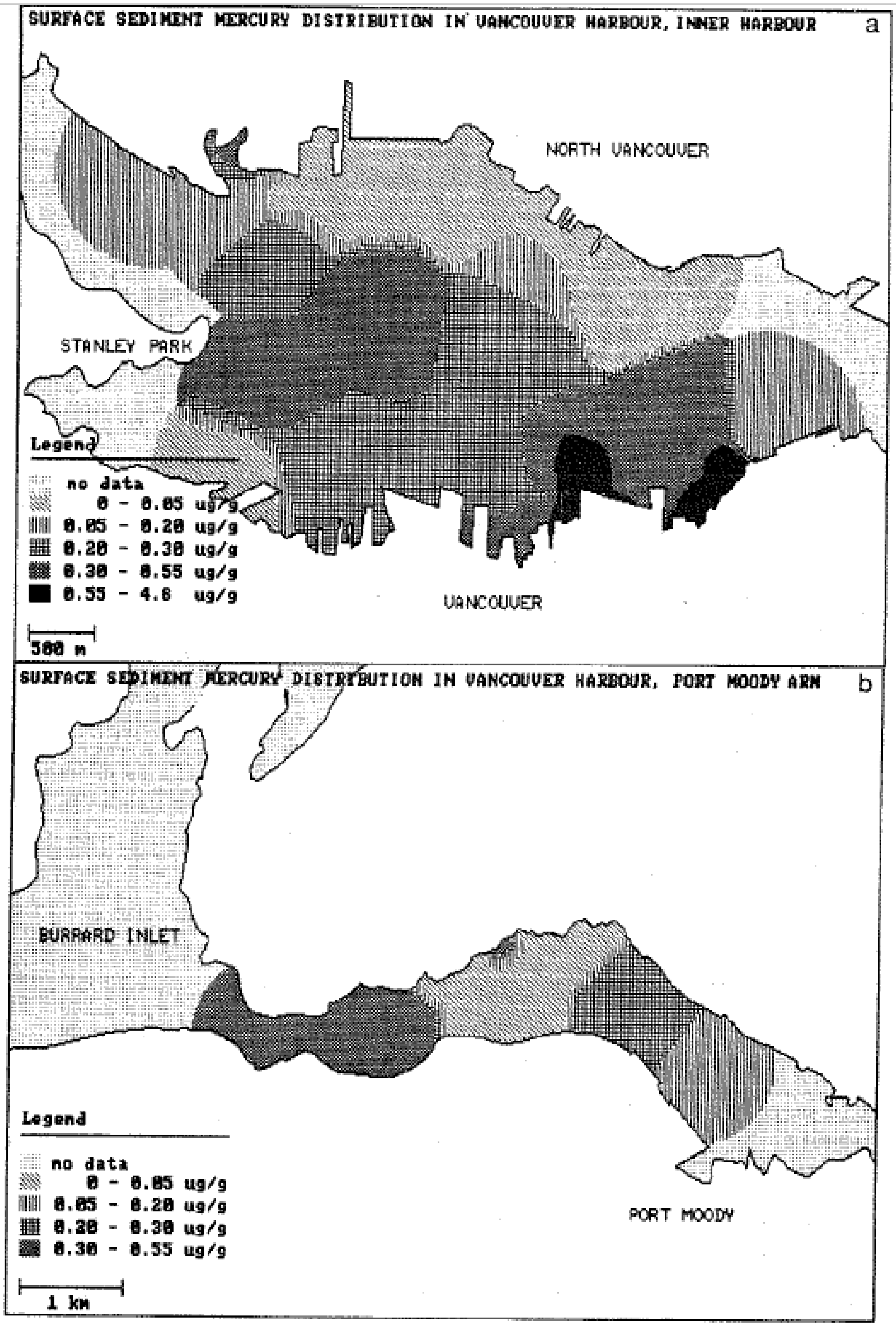

Figure 5: Surface sediment mercury distribution in Burrard Inlet (from 1985 to 1986)
(a) Inner Harbour and (b) Port Moody Arm (from Goyette and Boyd, 1989)

- 1971–1989 – BC Ministry of Environment and Climate Change Strategy (ENV) monitoring samples collected between 1971 and 1989 were above mercury detection limits in 59 (28%) of 212 water samples (refer to Figure 6). There were no data for sediment or fish tissue samples collected prior to 1990.
    - Detection limits for water samples were 0.05 µg/L (200 cases), 5 µg/L (1 case) and 50 µg/L (11 cases. In the 12 cases where the detection limit was above 0.05 µg/L, all measurements were below their respective detection limits. These 12 samples were all recorded in the 1970s and were excluded from the figures as they caused significant compression of the data that is above detection limits (range: 0.05 µg/L to 0.68 µg/L). There was one outlier: a value in 1973 at False Creek Cambie St (Station 300082) that was recorded as 60 µg/L. This outlier is not displayed in Figure 6 to keep the other data visible.
    - 147 samples were tested for dissolved mercury and 65 samples were tested for total mercury.
    - Excluding the potentially mislabelled value from 1973, the highest mercury levels were observed for dissolved mercury in water samples collected in 1977 at English Bay (Station 300076; maximum 0.68 µg/L) and False Creek Cambie St (Station 300082; maximum 0.49 µg/L). The lowest detection limit (0.05 µg/L) is higher than the chronic benchmark (0.016 µg/L), so it is not possible to accurately determine the extent of exceedances. Given that 28% of the samples were above the detection limit, it is understood that at least 28% of the samples exceeded the benchmark during this period. The actual frequency of exceedances is likely higher given the large difference between the benchmark and detection limits and given the high percentage of measurements of dissolved mercury, which would be lower than concentrations of total mercury.

Post-1990 Data

- 1998 – The BIEAP Sediment Quality Study (EQOMAT, 1998) observed total mercury concentrations above the detection limit in all 45 surface sediment samples. None of the samples exceeded the PEL (0.70 µg/g). However, all except for one sample in the Outer Harbour and one sample in Port Moody Arm exceeded the TEL (0.13 µg/g). The highest mercury levels were detected in False Creek (0.294 µg/g to 0.572 µg/g) and Port Moody Arm (0.279 µg/g to 0.375 µg/g). High variation was observed between replicate samples in two instances – one station in Indian Arm (0.328, 0.086, and 0.087 µg/g) and one station in Port Moody Arm (0.029, 0.111, and 0.090 µg/g).
- 1990–2009 – BC ENV water quality objectives attainment monitoring samples collected between 1990 and 2009 were above mercury detection limits for 75 (38%) of 198 water samples, 82 (99%) of 83 sediment samples, and 3 (21%) of 14 tissue samples. Thirty-four of the 83 sediment samples were volume-based (recorded in µg/L) and were excluded from the analysis as they were not directly comparable with mass-based measurements. This left a remaining 48 (98%) of 49 sediment samples above detection limits. Detection limits ranged from 0.00001 µg/L to 0.05 µg/L for water samples, 0.05 µg/g for fish tissue and were not listed for sediment samples in the database. The wide range of detection limits for mercury in water samples impacts the interpretation of results, particularly because the detection limit was above the chronic benchmark (0.016 µg/L) for 110 (56%) of the 198 water samples. The following key points summarize the monitoring results:
    - In water samples, the highest total mercury levels were measured at Vancouver Clark Drive (Station E207818, 0.1 µg/L to 0.2 µg/L) in 1991, Coal Harbour – South Shore Near Bayshore Hotel (Station E207813, 0.06 µg/L to 0.13 µg/L) in 1991 and Vancouver Harbour Vancouver Wharves (Station E207816, 0.06 µg/L to 0.12 µg/L) in 1991. Of the 75 total mercury samples that

exceeded detection limits, 29 samples (39%) exceeded the chronic benchmark (0.016 µg/L). An illustration of mercury levels in the BC ENV water samples is provided in Figure 6.

- Sediment samples exceeded the PEL benchmark (0.7 µg/g) at two stations in the Inner Harbour including Vancouver Harbour Clark Drive (Station E207818, maximum 2.69 µg/g) and Coal Harbour – South Shore near Bayshore Hotel (Station E207813, maximum 1.00 µg/g). The Vancouver Harbour Clark Drive sampling site is close to the combined sewer overflows at Clark Drive/Vernon Relief, which supports the observation from Goyette and Boyd (1989) that sewer overflows are a source of mercury in Burrard Inlet. Samples have exceeded the TEL benchmark (0.13 µg/g) in every sub-basin throughout the early 1990s and early 2000s. An illustration of total mercury levels in the BC ENV sediment samples is provided in Figure 7.
- Mercury levels are reported as 0.01 µg/g wet weight in one English sole whole body fish tissue sample collected from Vancouver Harbour Clark Drive (Station E207818) and equal to 0.02 µg/g wet weight in one English sole whole body fish tissue sample collected from Vancouver Harbour Shellburn (Station E207822), both in 2003. However, these values are suspect as the mercury detection limit listed for this dataset is 0.05 µg/g, which exceeds the recorded values. If the values are accurate, they would be below the most conservative screening benchmarks (subsistence toddler, 0.035 µg/g and wildlife, 0.033 µg/g). An illustration of total mercury levels in the BC ENV tissue samples is provided in Figure 8.

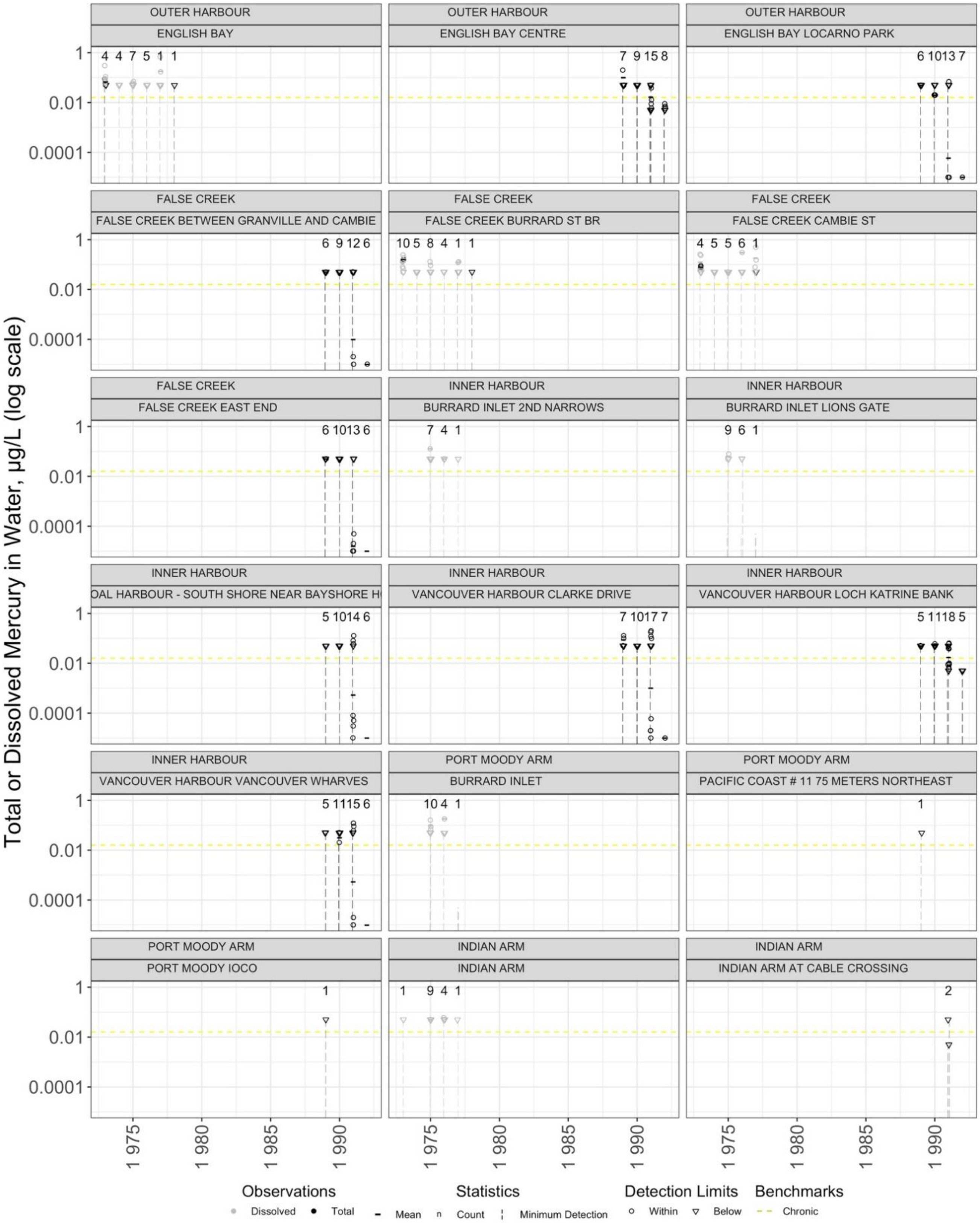

Figure 6: Mercury levels in BC ENV water samples (1971 to 1992) in µg/L (log scale).
The outlier in 1973 at False Creek Cambie St (60 µg/L) is not displayed to keep the other data visible.

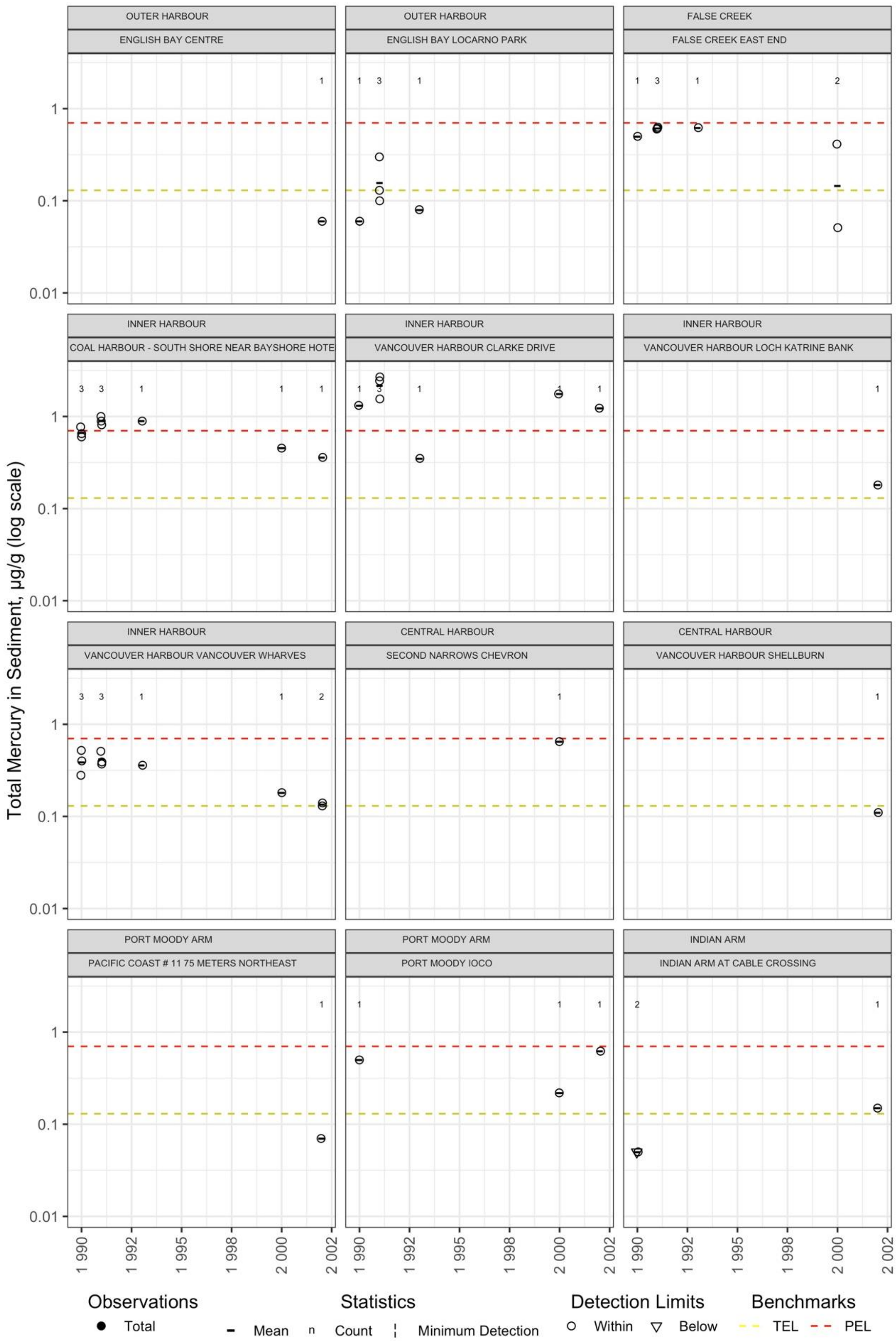

Figure 7: Mercury levels in BC ENV sediment samples (1990 to 2002) in µg/g (log scale)

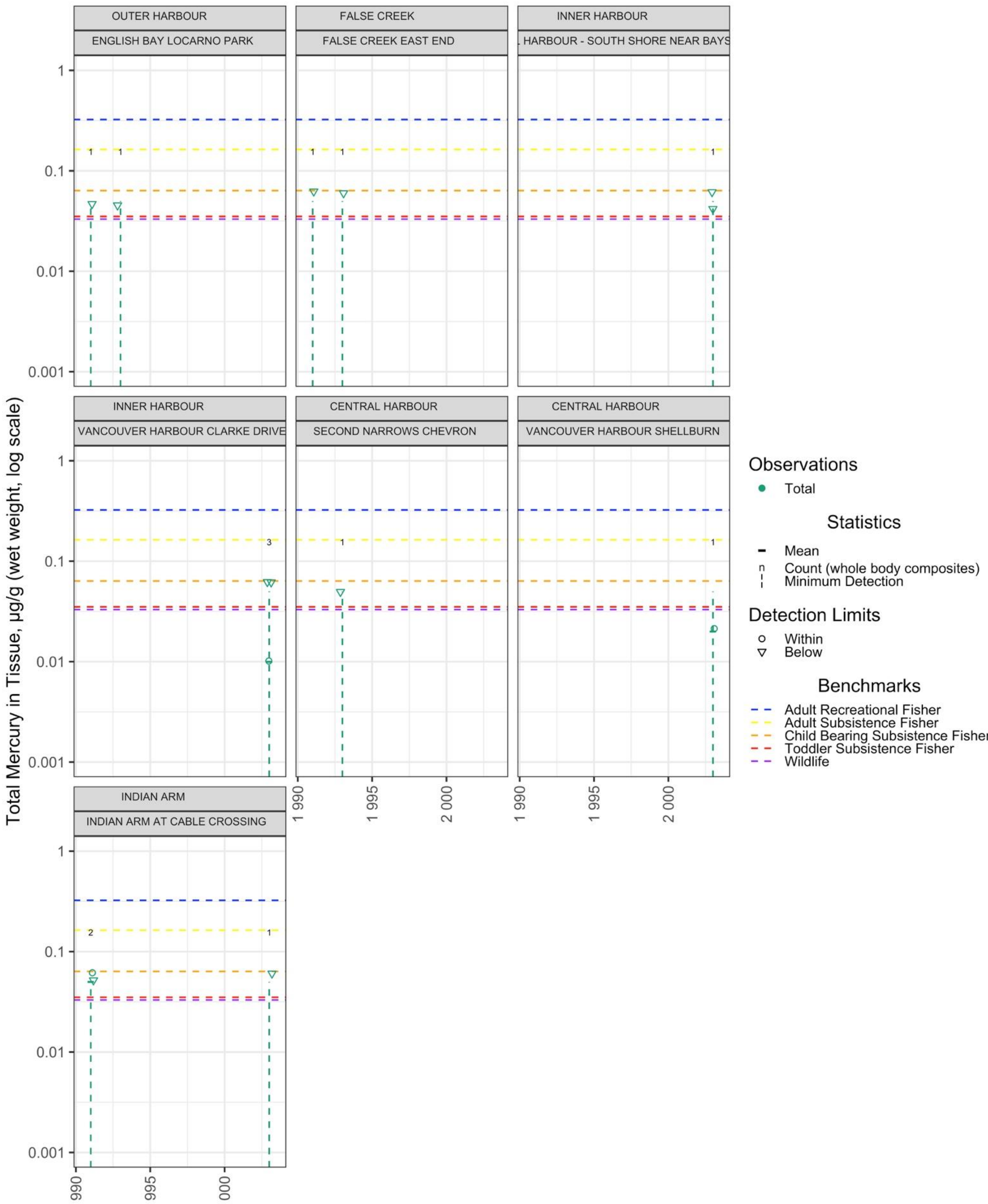

Figure 8: Mercury levels in BC ENV English sole fish tissue samples (1990 to 2002) in µg/g wet weight (log scale)

- 2007–2016 – As part of the Burrard Inlet Ambient Monitoring Program, Metro Vancouver has monitored mercury levels at the top and bottom of the water column annually (Figure 9) and in sediment every 2 to 3 years (Figure 10) since 2008. Mercury levels in English sole tissue (whole body, muscle, and liver) samples were measured in 2007 and 2012 (Figure 11). Between 2007 and 2016, total mercury levels were above detection limits for 203 (29%) of 710 water samples, 105 (100%) of 105 sediment samples, and 73 (100%) of 73 tissue samples. All extractable[3] mercury sediment samples were below detection limits (105 samples, 0.01 µg/g detection). All methylmercury tissue samples were above detection limits (15 samples of whole body tissue in 2012 only, detection limit not listed in database). Detection limits were between 0.00005 µg/L and 0.002 µg/L for total mercury in water samples, 0.005 µg/g for total mercury and 0.01 µg/g for extractable mercury in sediment samples, and 0.002 µg/g to 0.01 µg/g for total mercury in fish tissue samples. Because of the lower detection limits and the resulting greater detection frequency, greater emphasis has been placed on the Metro Vancouver monitoring data compared to the BC ENV monitoring data. The following points summarize the Metro Vancouver monitoring program results:
  - For marine water, five samples exceeded the chronic benchmark (0.016 µg/L) – one from the top of the water column at Outer Harbour North in 2012 (0.2 µg/L), one from the bottom of the water column at Port Moody Arm in 2012 (0.0288 µg/L), one each from the top and the bottom of the water column at Indian Arm South (0.0206 µg/L and 0.027 µg/L, respectively) and one from the bottom of the water column at Inner harbour (0.0181 µg/L) (Figure 9).
  - Metro Vancouver analyzed both total and extractable mercury levels in sediment samples; however, all extractable mercury samples were below detection limits and were excluded from analysis (see Figure 10). Mercury levels have not exceeded the PEL benchmark for mercury (0.7 µg/g) in this monitoring program. Mercury levels exceeded the TEL benchmark (0.13 µg/g) in at least one sample at all stations except for Indian Arm North. Trends are difficult to interpret with the limited data available. Mercury levels exceeded the TEL benchmark in every sample collected from both Port Moody Arm and Indian Arm South.
  - Total mercury levels in English sole fish whole body tissue samples were above the SV for a toddler from a subsistence fishing population (0.035 µg/g wet weight) at Outer Harbour North, Inner Harbour, and Indian Arm North, all in 2007 only. Total mercury levels in English sole fish muscle tissue samples were above the SV for a toddler from a subsistence fishing population at Outer Harbour North, Outer Harbour South, Inner Harbour, Port Moody Arm and Indian Arm North, all in 2007 only. Total mercury levels in English sole fish liver tissue samples were above SV for a toddler from a subsistence fishing population in all samples except for those collected at Central Harbour and Port Moody Arm. The highest measurements were recorded from liver samples collected from Outer Harbour North (0.7 µg/g). The highest mercury levels measured in whole body samples, which are more indicative of human and wildlife consumption of shellfish than liver, were 0.04 µg/g at Outer Harbour North, Inner Harbour, and Indian Arm North in 2007. For samples taken in 2012, both methylmercury and total mercury were analyzed. Methylmercury levels in whole body samples ranged in value from 0.010 µg/g at Port Moody Arm (with total mercury of 0.013 µg/g) to 0.040 µg/g at Outer Harbour North (with total mercury of 0.028 µg/g, which is lower than the methylmercury measurements and could be due

[3] Metro Vancouver analyzes Simultaneously Extractable Metals (SEM) in sediment by looking at the ratio of SEM/Acid Volatile Sulphide (AVS). If ∑SEM/∑AVS < 1 then metals are not expected to be bioavailable (as they would be predicted to be bound). The individual metal concentrations from the SEM method are summed and then compared with AVS. Total SEM is compared with AVS to assess potential bioavailability/toxicity; individual metals by SEM are not compared with guidelines (Metro Vancouver, *pers. comm.* March 2021).

to differences in compositing techniques and molar mass conversion; this requires further verification, which is outside of the scope of this data assessment). These results indicate that methylmercury constitutes a high proportion of the total mercury in English sole (see Figure 11).

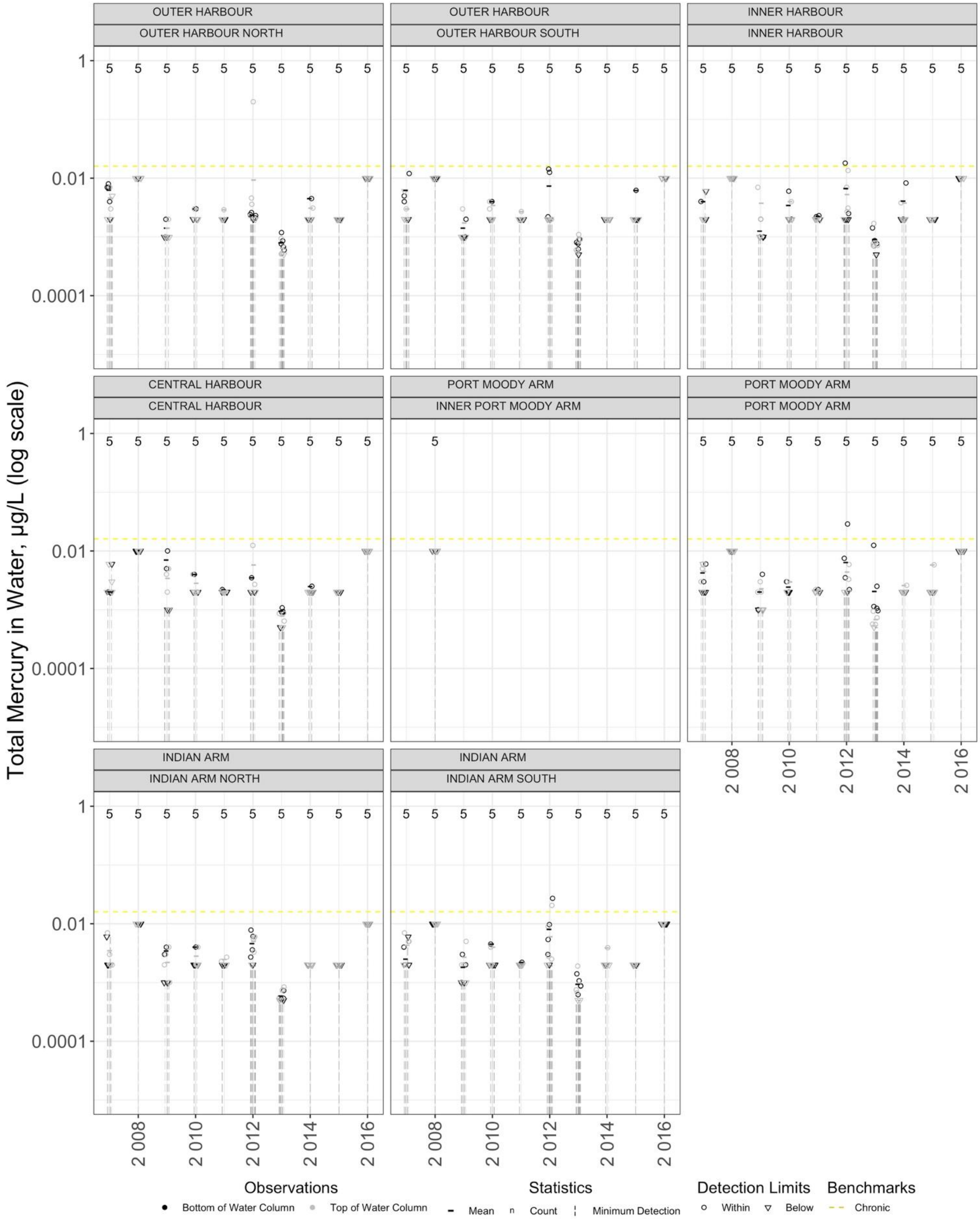

Figure 9: Mercury levels in Metro Vancouver water column samples (2007 to 2016) in µg/L (log scale)

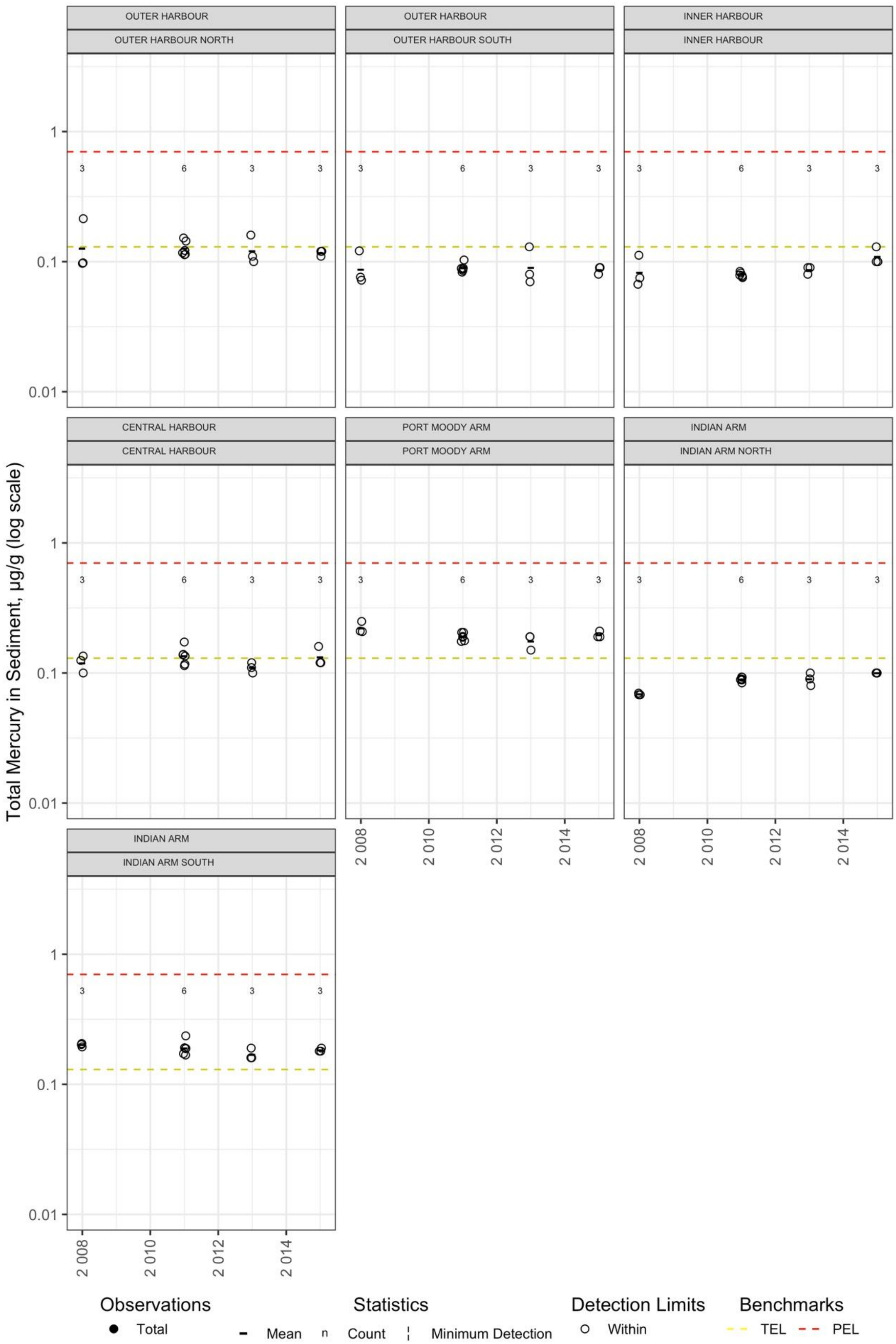

Figure 10: Mercury levels in Metro Vancouver sediment samples (2008 to 2016) in µg/g (log scale)

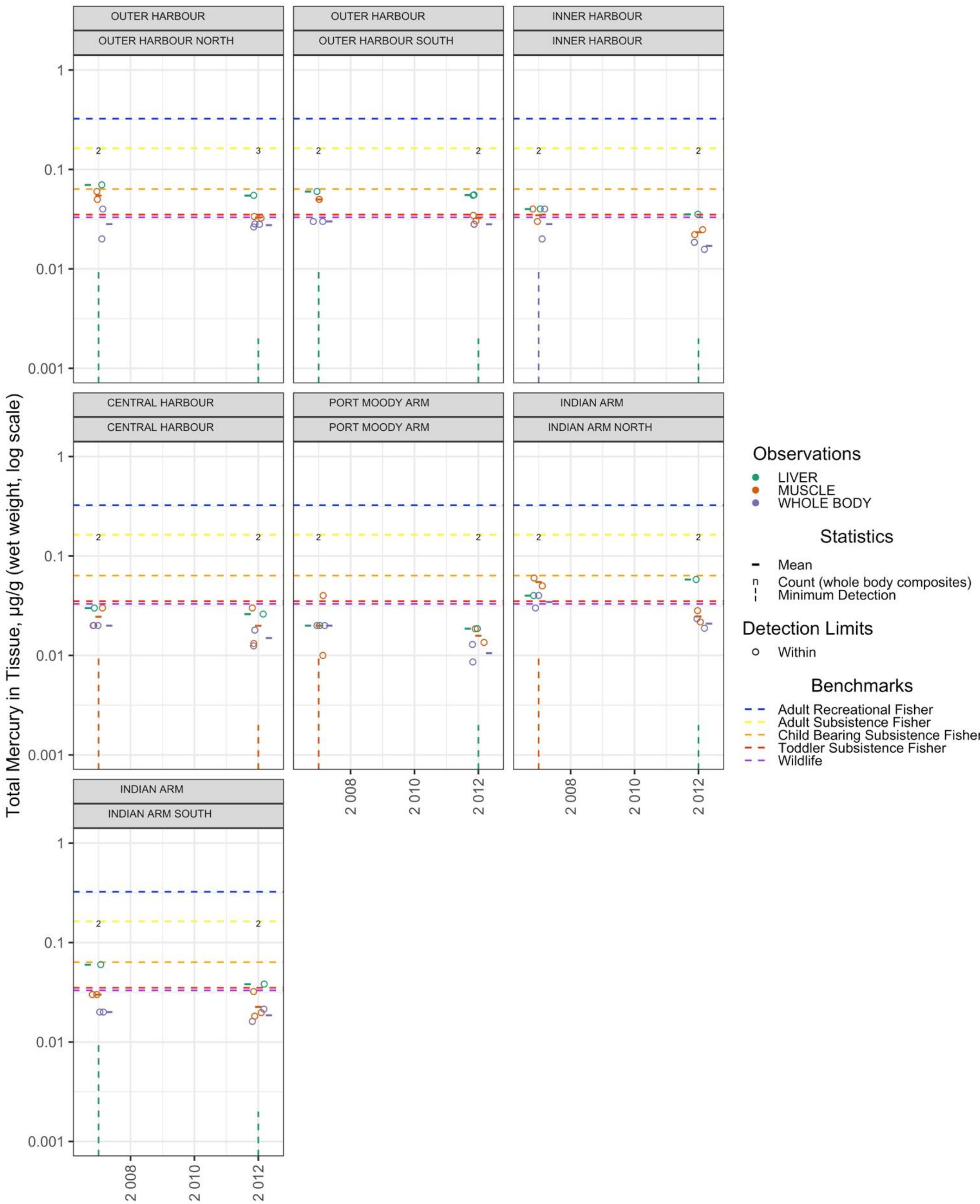

Figure 11: Mercury levels in Metro Vancouver English sole fish tissue samples (2007 to 2012) in µg/g (log scale)

- 2015–2016 – Pollution Tracker measured total mercury, extractable mercury, and methylmercury levels in sediment by dry weight and total mercury and methylmercury levels in Blue Mussel shellfish tissue by dry and wet weight in October 2015 and April 2016. Twenty-four (83%) of 29 sediment samples and 30 (100%) of 30 tissue samples were above detection limits (including total, extractable, and methyl measurements by dry and wet weight). For consistency with other monitoring programs and screening benchmarks, only dry weight values were analyzed for sediment and only wet weight values were analyzed for tissue. In sediment, dry weight detection limits were 0.005 µg/g for total mercury, 0.01 for µg/g for extractable mercury, and 0.00005 µg/g for methylmercury. In tissue, wet weight detection limits were 0.001 µg/g for both total mercury and methylmercury.
    - For sediment, there were no exceedances of the PEL benchmark (0.7 µg/g). Total mercury levels exceeded the TEL benchmark (0.13 µg/g) at the Outer Harbour, Inner Harbour, Central Harbour and Port Moody Arm stations. The highest single sample maximum for total mercury was measured at Inner Harbour (0.29 µg/g, Burrard Inlet 14). Total mercury levels ranged from 0.021 µg/g to 0.29 µg/g. Methylmercury levels ranged from <0.00005 µg/g to 0.00096 µg/g, representing about 2% or less of the total mercury measurements. All six samples analyzed for extractable mercury were below detection limits (see Figure 12).
    - Mercury levels in Blue Mussel samples did not exceed any of the screening benchmarks for human health or wildlife consumption of shellfish. The highest single sample maximum was measured at the Outer Harbour station (0.015 µg/g wet weight, Burrard Inlet 15; see Figure 13). Methylmercury levels ranged from 0.0013 to 0.0054 µg/g wet weight, representing about 15 to 50% of the total mercury measurements.

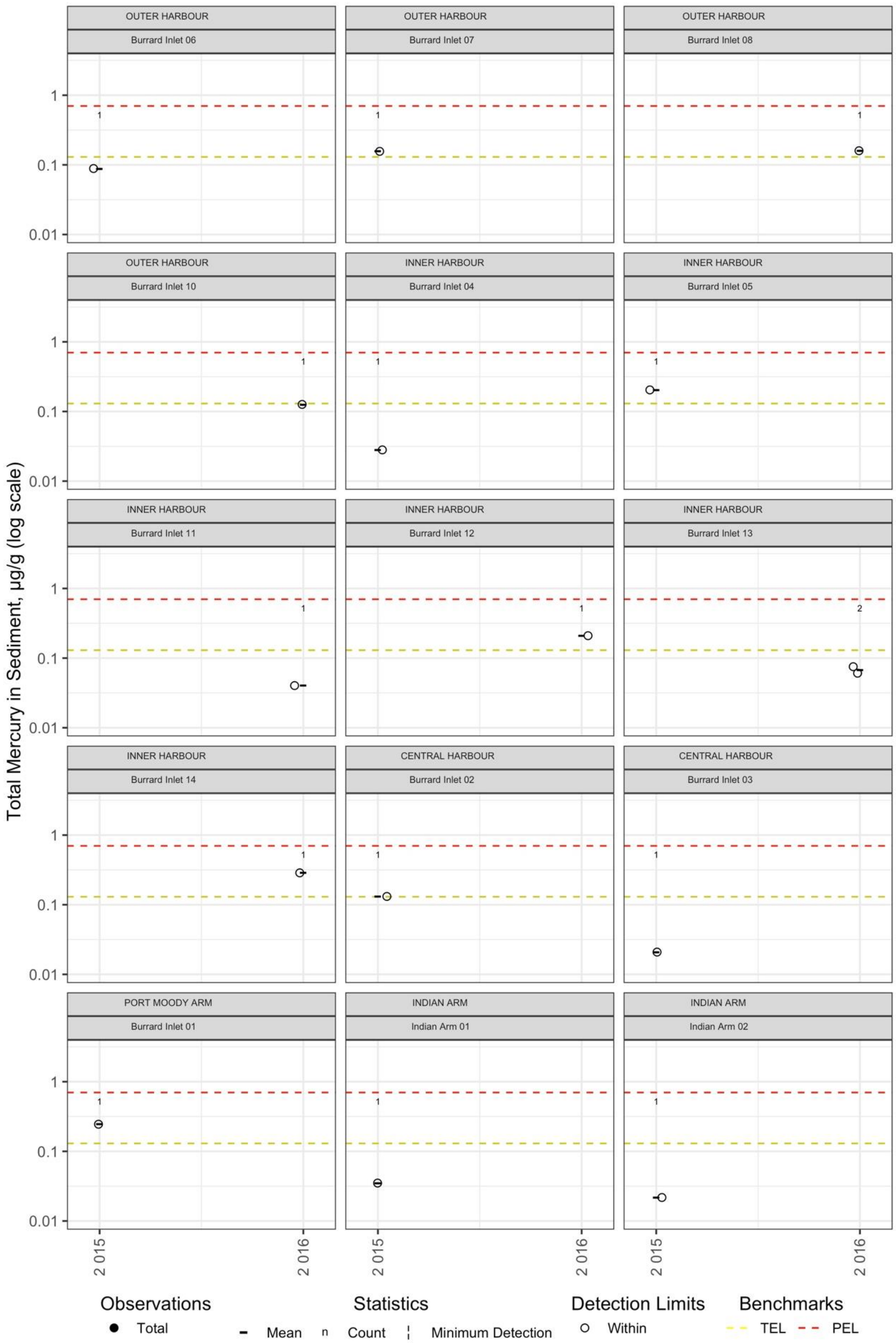

Figure 12: Mercury levels in Pollution Tracker sediment samples (2015 to 2016) in µg/g (log scale)

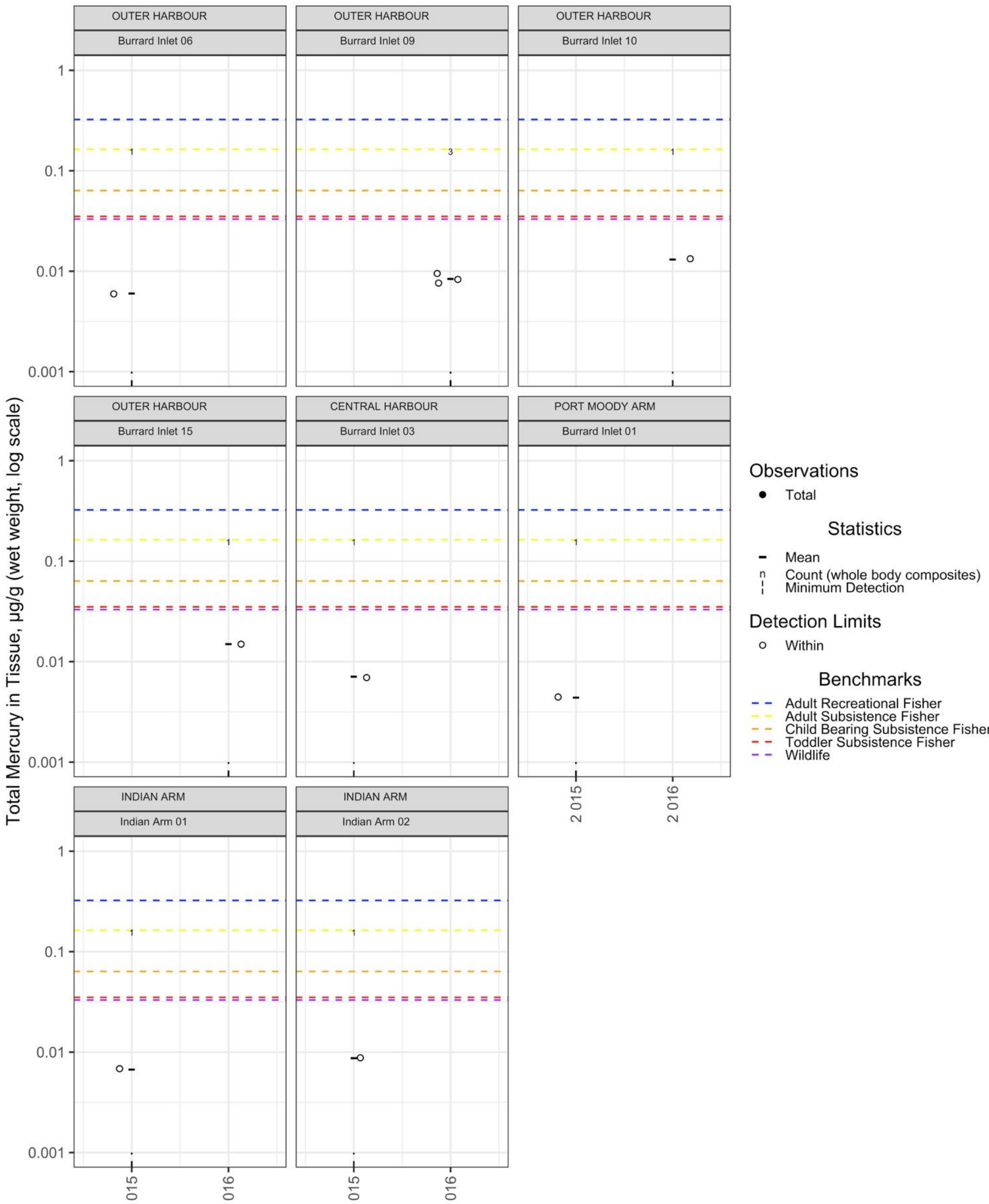

Figure 13: Mercury levels in Pollution Tracker blue mussel tissue samples (2015 to 2016) in µg/g (log scale)

3.4 Knowledge Gaps and Research Needs

The assessment of available mercury data, key monitoring programs, and previous reports identified the following knowledge gaps and research needs, which are addressed in the recommendations sections of this chapter:

- Further examination is required of the BC ENV attainment monitoring sediment samples recorded in µg/L between 1990-2009, for example to determine if the units or medium were mislabelled.
- Because of differences in sampling methodologies, reporting, and detection limits between years and programs, it is difficult to identify temporal trends with any confidence.
- Further study is required to derive objectives for mercury in tissue that are protective of marine mammals, particularly Southern Resident Killer Whales.
- There are no data available for methylmercury in the water column.
- "Cocktail effects" and synergistic interactions of a mixture of metals and other toxicants would require further examination. Some chemicals can enhance the effect of other chemicals, so that the combined effect is larger than predicted from the toxicity of individual chemicals (see for example Singh et al. 2017). This is a concern as chemicals are regulated and deemed "safe" on a single compound basis. Chemical uptake and accumulation in additional species, particularly intertidal species which are currently harvested by people (e.g., crabs), also needs further investigation, as existing studies have been limited to a few species.
- There has been little to no monitoring of sites influenced by permitted discharges, stormwater discharges or combined sewer overflow outfalls since 2009.
- CSOs have historically been a significant source of mercury pollution in Burrard Inlet (Nijman and Swain 1990); however, the extent of contaminated sediment has not been monitored.
- There has been little monitoring of mercury in Burrard Inlet in all media, including in the water column, sediment and tissue, and little monitoring intended at understanding potential human health risks.

4. PROPOSED OBJECTIVES FOR MERCURY IN BURRARD INLET

4.1 Proposed Objectives

Proposed objectives for mercury are presented in Table 4. The water objective is intended to be protective of aquatic life and avian wildlife. The sediment objective is intended to be protective of aquatic life. The tissue objective is intended to be protective of wildlife and human subsistence consumers of wild finfish and shellfish.

Table 4: Proposed Water Quality Objectives for Mercury

Sub-basin	Outer Harbour	False Creek	Inner Harbour	Central Harbour	Port Moody Arm	Indian Arm
Total Mercury in Water	0.016 µg/L mean					
Total Mercury in Sediment	0.13 µg/g dry weight single-sample maximum[2]					
Total Mercury in Tissue	0.033 µg/g wet weight single-sample maximum[3]					

[1] Minimum of 5 samples in 30 days collected during the wet season.
[2] Based on at least 1 composite sample consisting of at least 3 replicates.
[3] Applies to whole body. Based on at least 1 composite sample consisting of at least 5 fish or 25 bivalves.
See Rao et al. (in prep) for additional details.

4.2 Rationale

The proposed objective for total mercury in water is based on the 2003 CCME guideline for mercury in marine water, which is established for total mercury in the absence of available data for methylmercury in water. This is preferable to the 1990 water quality objectives for mercury in Burrard Inlet because it is based on updated toxicology data. It is preferable to the BC Approved Water Quality Guidelines because it is more reflective of the type of data available for Burrard Inlet (absence of methylmercury data).

The proposed objective for total mercury in sediment is BC's lower Working Sediment Quality Guideline – a concentration that will protect aquatic life from adverse effects in most situations.

The proposed objective for mercury in tissue is based on the tissue guideline for total mercury in wildlife which is similar to, and slightly more conservative than, the screening value for the most sensitive human receptor, i.e., a toddler from a subsistence fishing (or Indigenous) population. This value could be changed in future if research demonstrates that a lower value would protect Southern Resident Killer Whales and their prey. If continued monitoring shows that mercury concentrations exceed this proposed objective, discussions with health experts will be required to interpret monitoring data to understand implications on human consumption of seafood from Burrard Inlet.

As mercury levels have exceeded at least some benchmarks in all sub-basins in recent years, these objectives are proposed to apply across all sub-basins. Increased monitoring is required to better understand the extent and frequency of exceedances.

5. MONITORING RECOMMENDATIONS

The following are recommendations for future mercury monitoring in Burrard Inlet:

- Increase coordination of efforts between the ENV, Metro Vancouver, and Pollution Tracker programs to avoid duplication and increase monitoring coverage of areas that have not been monitored or have been monitored inconsistently, such as False Creek.
- Design future monitoring programs to capture seasonal variation and collect five marine water samples in 30 days.

- Increase monitoring of mercury in species that are harvested for human consumption.
- Perform a short term study to derive a relationship between the proportion of methylmercury and total mercury in the water column. Apply results to refine the objective for marine water and assess the bioavailability of mercury in Burrard Inlet.
- Investigate the extent of mercury contamination around major CSOs, including Clark Drive and Victoria Drive.
- Identify sources and focus remediation efforts through the following:
    - Measure mercury in water and sediment near outfalls and at discharge points, correlate this data to ambient conditions, and incorporate this monitoring into Metro Vancouver and Pollution Tracker's monitoring programs.
    - Collect discharge data that can inform mercury loading to prioritize the largest sources for mitigation, remediation, and source control efforts.
    - Determine the relative importance of current sources versus existing concentrations in marine sediment that may be at risk of re-suspension to understand whether elevated fish tissue concentrations are driven by current discharges or historical contamination in the sediment.
- Monitor mercury in water and sediment in False Creek and incorporate this monitoring into the programs run by Metro Vancouver, Pollution Tracker, and BC ENV.
- Work is needed to understand and minimize or eliminate the contaminants released into Burrard Inlet with vessel scrubber discharge water (ICCT 2020).

6. MANAGEMENT OPTIONS

The following initiatives are planned or underway and will help reduce mercury levels in Burrard Inlet:

- Tsleil-Waututh Nation's ongoing work to restore the health of the Inlet through implementation of the Burrard Inlet Action Plan;
- Development and implementation of Integrated Stormwater Management Plans (ISMPs) for all developed watersheds that flow into Burrard Inlet; and
- Development of source controls, including green stormwater infrastructure such as swales, rain gardens, and tree trenches.

The following management options that have the potential to further reduce anthropogenic sources of mercury to Burrard Inlet are recommended for consideration, although this is not an exhaustive list of tools and actions:

- Prioritize the implementation of source controls to reduce the volume of stormwater discharges into Burrard Inlet;
- Encourage or require more widespread adoption of green infrastructure and other design criteria that provide water quality treatment for stormwater runoff prior to discharge to Burrard Inlet; and
- Ensure that the upgrade of the Lions Gate Wastewater Treatment Plant from primary to tertiary treatment includes measures to remove mercury prior to discharge.

Given the current exceedances of mercury throughout the inlet, including in areas from which fish or shellfish are harvested, jurisdictions responsible for openings and closures of harvesting areas should engage with Indigenous and non-Indigenous communities with respect to guidelines for safe levels of consumption of fish, crustaceans and bivalve shellfish.

As a general management option, conversion of these water quality objectives from policy into regulation would increase their strength and efficacy for pollution reduction in Burrard Inlet.

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