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

August 2021

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 interim water quality objectives for lead in Burrard Inlet, identified as a metal of primary concern in the science-based Tsleil-Waututh Nation (TWN) led Burrard Inlet Action Plan. These proposed objectives were developed using up-to-date research on relevant values and potential effects, sources and factors influencing lead levels, benchmark screening, and monitoring data for Burrard Inlet. These objectives are considered interim because benchmarks for lead currently do not account for bioaccumulation into higher trophic levels such as marine mammals.

Lead is a metal that is toxic to humans and wildlife, including aquatic life. The water values most sensitive to lead pollution are human consumption of finfish and shellfish, and aquatic life. Toxicity and bioavailability of lead are affected by factors such as water hardness, salinity, chemical speciation and partitioning, redox potential, pH and concentrations of iron, metal oxides, organic carbon, sulphide and phosphate. Organic lead compounds synthesized by humans are more toxic than inorganic lead compounds.

Sources of lead contamination in Burrard Inlet have included specific industrial discharges, landfill leachate, spent ammunition, combined sewer overflows and stormwater runoff. Lead can enter stormwater from industrial and household products, artificial surfaces made from shredded rubber, and leaching from contaminated sites and/or older buildings and structures.

British Columbia's (BC) working water quality guidelines for lead in water and sediment were used as benchmarks for screening lead levels in water and sediment samples. Due to a lack of recent updates, additional research is needed to evaluate bioaccumulation of lead at higher trophic levels as BC's benchmarks are not protective of marine birds or mammals. Human health-based screening values were calculated and used as benchmarks for lead levels in tissue samples.

Elevated lead levels have been observed across Burrard Inlet with noteworthy hotspots including the Inner Harbour near Vancouver Wharves, English Bay at Locarno, False Creek East, throughout Port Moody Arm, Indian Arm North and Indian Arm South.

The proposed interim water quality objectives for lead are as follows:

Sub-basin	False Creek	Outer Harbour	Inner Harbour	Central Harbour	Port Moody Arm	Indian Arm
Total Lead in Water	2 µg/L mean AND no more than 20% of samples above 2 µg/L[1]					
Total Lead in Sediment	30.2 µg/g dry weight single-sample maximum[2]					
Lead in Tissue	Short-term (by 2025): 0.139 µg/g wet weight single-sample maximum [3] Long-term (by 2050): 0.07 µg/g wet weight single-sample maximum [3]					

[1] Minimum of 5 samples in 30 days collected during the wet season. No more than 20% of samples > 2 µg/L.
[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.

In addition, an overall qualitative objective is proposed that lead levels be as low as reasonably achievable, as there is no lead threshold for health effects.

Because elevated lead levels have been observed in many parts of Burrard Inlet, continued monitoring in water, sediment, fish tissue and shellfish tissue is recommended. Increased coordination, pollutant source tracking, and further study of lead effects due to bioaccumulation are also recommended.

Several management actions have been, or are being, undertaken that have the potential to reduce marine lead pollution, including bans on lead in paint and gasoline (occurred in the early 1990s in Canada) as well as development of source controls, green infrastructure and management plans to reduce pollution from stormwater.

Further management options could include banning lead in ammunition and fishing tackle, preventing industrial and domestic discharges of lead, avoiding the use of rubber crumb in artificial surfaces, more widespread adoption of green infrastructure and remediation of historically contaminated areas.

CONTENTS

FIGURES

TABLES

ACRONYMS

BC	British Columbia
BIEAP	Burrard Inlet Environmental Action Program
CCME	Canadian Council of Ministers of the Environment
CFIA	Canadian Food Inspection Agency
DOC	Dissolved organic carbon
ENV	British Columbia Ministry of Environment and Climate Change Strategy
EQOMAT	Environmental Quality Objectives and Monitoring Action Team
IQ	Intelligence quotient
ISQG	Interim sediment quality guideline
PEL	Probable effect level
SV	Screening value
TEL	Threshold effect level
TWN	Tsleil-Waututh Nation
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

1. INTRODUCTION

This chapter presents updated water quality objectives for lead in Burrard Inlet, identified as a metal of primary concern in the science-based, Tsleil-Waututh Nation (TWN) led Burrard Inlet Action Plan (TWN 2017). It includes relevant background information, an overview assessment of current status and trends for lead levels in water, sediment, and biota in Burrard Inlet, including a 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

Lead is a toxic metal that can affect every organ system because it can mimic and inhibit the action of calcium and interact with proteins (Zabka et al. 2006). There is no safe level of lead exposure in humans (CDC 2012) and human ingestion of lead is of particular concern (ECCC 2013). Lead ingestion is also known to be toxic to other animals (Haig et al. 2014).

Considerable research has been done on the effects of lead on birds. The most important route of lead exposure in birds is direct ingestion of lead, or consumption of animals that were shot with lead ammunition or ingested lead fishing tackle (Ocean Wise 2019). Other aquatic organisms are exposed to lead through overlying and interstitial waters, as well as sediments, which are major routes of exposure (CCME 1999).

The toxicity of lead to aquatic organisms depends on its bioavailability, which is governed by factors such as dissolved organic carbon (DOC), pH, alkalinity, water hardness and salinity. Generally, increasing DOC levels have the most significant effect on decreasing lead bioavailability (ANZECC 2000).

Transfer of lead into food webs and biota depends on the chemical speciation of lead in the water, chemical partitioning of lead in sediment, biology of the particular organism, redox potential, pH and concentrations of iron, metal oxide, organic carbon, sulphide and phosphate (Nagpal 1987, CCME 1999). Human activities have led to the synthesis of organic lead compounds, which tend to be more toxic than inorganic lead, with increased alkylation resulting in increased toxicity (CCME 1999).

The most sensitive values guiding water quality objectives for lead are human consumption of shellfish and finfish, as well as aquatic life. The goal of the objectives is to maintain lead levels below values which would be toxic to aquatic life and to humans who consume seafood at rates relevant to coastal Indigenous peoples such as Tsleil-Waututh Nation.

2.2 Potential Sources of Lead Pollution

Lead can enter the environment naturally from the weathering of rocks, and can enter the ocean through atmospheric and direct deposition, ultimately ending up in marine sediments.

Anthropogenic sources of lead include mining and smelting, and products such as batteries (especially automotive batteries), dyes, paints, pipes, alloys, ammunition and weights (ECCC 2013, Ocean Wise 2019). It is also used during the manufacture of pipes, circuit boards, sheeting, electrical components, polyvinyl chloride, radiation shields, paint primers and yacht keels. Lead use has been phased out in gasoline (in 1990), household paints (from the early 1990s) and food cans (from the early 1980s) (ECCC 2013). Lead can enter stormwater during the manufacture and use of industrial and household products such as those listed above, and the leaching of paints from older structures and soils that have been contaminated with leaded gasoline or other products, and artificial surfaces made from shredded rubber (US EPA 2019). Discharges from vessels are also a potential source of lead input into Burrard Inlet. Vessel exhaust gas cleaning systems, also called scrubbers, have been found to discharge wash water that contains contaminants including lead (ICCT 2019, 2020).

Elevated levels of lead have been recorded in all sub-basins of Burrard Inlet and lead bioaccumulation has also been observed in the Inlet (Nijman and Swain 1990, Rao et al. 2019). The sources of lead into Burrard Inlet include stormwater runoff into all sub-basins, combined sewer overflows, lead ore loading at the Vancouver Wharves terminal in the Inner Harbour, historical discharges from Canadian Occidental Petroleum[1] in the Central Harbour, Imperial Oil and Allied Chemical[2] in Port Moody Arm (Nijman and Swain 1990), and ammunition historically used for bird hunting in Port Moody Arm (City of Port Moody EPC 2018). Historically, the Premier Street landfill was also a source of lead loading into the Inner Harbour (Nijman and Swain 1990). In the Central Harbour, elevated lead levels were observed in the Maplewood mudflats during a study of wood waste and contamination hotspots (Teranis 2017).

2.3 Factors Influencing Lead Levels in Burrard Inlet

Lead quickly falls out of the water column into the sediment by forming complex molecules with organic matter such as humic substances (Nagpal 1987). It is also deposited in association with particulates such as iron and manganese oxides, or precipitates with carbonate or sulphide (CCME 1999). It adsorbs to suspended material such as clay, iron, aluminum and manganese (oxy)hydroxides. In marine water, speciation of lead is influenced by chloride complexation. In its dissolved form, lead is often complexed with dissolved organic matter (ANZECC 2000).

2.4 1990 Provisional Water Quality Objectives for Lead

The 1990 objectives for lead in water, sediment, and tissue in Burrard Inlet are summarized in Table 1, and were set for the protection of aquatic life. The 1990 objective for water was based on CCME guidelines that were partially adapted from the US EPA, which applied the US 'Guidelines for Deriving Numerical Water Criteria for the Protection of Aquatic Organisms and Their Uses' to acute lead values that were available for thirteen saltwater animal species at the time. The 1990 objective for sediment was set to be 0.1 times the lowest measured Apparent Effects Threshold (AET) in Puget Sound at the time (Malins et al. 1980), which is also equal to the Puget Sound reference site concentration for lead. However, it was noted that this objective had a high degree of uncertainty due to unknown background levels of lead in sediments around Burrard Inlet. More detail can be found in Nijman and Swain (1990). The 1990 objective for fish tissue was identified as an 'alert level' and refers to research that was published by ENV in 1987 (Nagpal 1987).

Table 1: 1990 Provisional Water Quality Objectives for Lead, for the Protection of Aquatic Life

Sub-basin	False Creek	Outer Harbour	Inner Harbour	Central Harbour	Port Moody Arm	Indian Arm
Water	≤ 2 µg/L mean and 140 µg/L maximum					
Sediment	30 µg/g dry weight maximum					N/A
Tissue	0.8 µg/g wet weight maximum (fish muscle)					
All values are for total lead levels.						

[1] Previous holders of ENV permit PE-18, which has since undergone several changes in ownership and permit amendments. PE-18 is currently held by Chemtrade Electrochem Inc. (Rao et al. 2019).
[2] Former holders of ENV permit PE-1133, which has since undergone changes in ownership and permit requirements, and is currently held by Chemtrade Chemicals Ltd. (Rao et al. 2019).

3. WATER QUALITY ASSESSMENT

3.1 Benchmarks Used in this Assessment

Benchmarks were used to screen available data for potential acute and chronic effects and to inform the derivation of updated objectives for lead levels in Burrard Inlet. Based on the available literature, aquatic life is the most sensitive value for lead levels in the water column and sediments. Finfish and shellfish consumption by humans are the most sensitive values for lead levels in tissue, though limited evidence is available.

Canadian guidelines for the protection of these values were used as screening benchmarks, where available. In general, potential sources of screening benchmarks were prioritized as follows:

1. BC approved water quality guidelines published by the BC Ministry of Environment and Climate Change Strategy (BC ENV; BC ENV 2019);
2. BC working water quality guidelines published by BC ENV (2017); and
3. Canadian Environmental Quality Guidelines published by the Canadian Council of Ministers of the Environment (CCME; CCME 2014).

If no benchmarks were available from the above sources, then guidelines or benchmarks available from other sources or jurisdictions were used. If appropriate, multiple benchmarks were selected (e.g., chronic and acute, upper and lower).

The screening benchmarks chosen for the data assessment in this report are summarized in Table 2. All values are for total lead levels. Water and sediment benchmarks are used to screen for protection of aquatic life; fish and mussel tissue benchmarks are used to screen for human health. Guidelines for lead in tissue were not available, so human-health based tissue screening values (SVs) for fish and shellfish tissue were derived from Health Canada toxicological reference values and risk assessment methodologies (Health Canada 2010a,b, 2012a, 2021; Richardson 1997, Richardson and Stantec 2013, Thompson and Stein 2021).

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

Sample Type	Screening Benchmark	Status	Value	Reference
Water	≤ 2 µg/L mean (chronic) 140 µg/L maximum (acute)	Approved	Marine aquatic life	BC Approved Water Quality Guidelines (ENV 2017, Nagpal 1987)
Sediment	30.2 µg/g dry weight mean (threshold effect level; chronic) [1] 112 µg/g dry weight maximum (probable effect level; acute)[1]	Working	Marine aquatic life	BC Working Sediment Quality Guidelines, BC ENV 2017b and CCME 1999
Tissue[2]	0.070 µg/g wet weight (toddler subsistence fisher) 0.139 µg/g wet weight (adult subsistence fisher) 0.276 µg/g wet weight (adult recreational fisher)	N/A	Human consumption of finfish and shellfish	Screening value calculated from Health Canada 2010b (Thompson and Stein 2021)

Sources and notes:
[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 TEL when detailed data are not available.
[2] Calculated screening value for which lead concentrations in tissue can be compared and assessed for potential risks to human health. This is a single benchmark for whole body and muscle samples (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.

There have been few updates to water and sediment quality guidelines for lead since the 1990 objectives for lead levels in Burrard Inlet were developed, therefore, these benchmark levels are similar to the 1990 objective levels for water and sediment.

Benchmarks for lead levels in water are based on the BC Approved Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture (ENV 2017), which are consistent with the 1990 water quality objectives for lead in Burrard Inlet. The guideline was derived by the US EPA in the 1980s using toxicity studies for 13 marine species (Nagpal 1987). The BC water quality guidelines for lead in marine water have not been updated since the 1980s, and there is no federal environmental quality guideline for lead in marine water (ECCC 2019). Washington State's water quality standards for the dissolved fraction of lead in marine surface waters for the protection of aquatic life are from 1980 and predate the water quality objectives for Burrard Inlet (US EPA 2016, 2018).

Benchmarks for lead levels in sediment are based on the BC working sediment quality guidelines threshold effect and probable effect levels (ENV 2017) because there is no published BC approved sediment quality guideline for lead in sediment. BC working Sediment Quality Guidelines are also from the 1980s and were based on CCME sediment quality guidelines for lead. The same guideline values have been maintained in the current CCME sediment quality guidelines for lead, published in 1999 (CCME 1999). The CCME guidelines are based on toxicity to benthic invertebrates, from the Biological Effects Database for Sediments. In marine and estuarine sediments, 94% of adverse biological effects were observed at concentrations higher than the interim sediment quality guideline (ISQG). These guidelines do not account for bioaccumulation, however, and are not protective of birds and marine mammals (Ocean Wise 2019). It can be concluded that the sediment guidelines are also not necessarily protective of human consumers of seafood.

There are currently no BC tissue guidelines for lead, although Nagpal (1987) recommended that total lead levels of 0.8 µg/g (wet weight) in the edible portions of fish be considered an alert level. In 2003, the World Health Organization (WHO) recommended that human consumption of lead not exceed a daily tolerable limit of 3.5 µg/kg of body weight (WHO 2003). This limit was reviewed in 2011, however, and it was concluded that it was not possible to establish a weekly tolerable intake level that would be considered protective of human health (JECFA 2011). A 2002 study found that among all ages and genders, the average daily dietary exposure to lead in Vancouver was 0.11 µg/kg of body weight (JECFA 2011).

In the absence of relevant guidelines for human consumption of fish and shellfish tissue, a risk-based approach was used to calculate human health-based tissue SVs 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, recreational, and general BC populations, with 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 ingestion rates from Richardson (1997) and Health Canada (2010b), and toxicity was defined through toxicological reference values (TRVs) prescribed by Health Canada (2021) or other international agencies (i.e., United States Environmental Protection Agency and the World Health Organization).

Tissue 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 2010a). 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).

Tissue SVs were calculated by Thompson and Stein (2021) using equations from Health Canada (2012). An allocation factor of 0.2 was used in the calculation to reflect the fraction of lead assumed to come from country foods (in this case, wild seafood). The lead total daily intake was obtained from Health Canada's (2019) lead guideline for Canadian drinking water quality and is for a toddler receptor, based on the endpoint of IQ loss. Three tissue SVs were selected to capture a range of potential fishers (i.e., receptors). The most conservative value is protective of a toddler from a subsistence fisher population while the less conservative values correspond with adult subsistence fishers and adult recreational fishers. These three SVs were used in the data assessment to provide multiple reference points.

3.2 Data Sources

Data on lead levels in Burrard Inlet were gathered from several studies and monitoring programs from 1971 to 2016. A summary of the datasets used for this assessment is presented in Table 3. Although other datasets containing lead sampling data may exist, the priority datasets were found to be the best available data for assessing the status of lead within 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 Figures 1 through 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	496 water 8 sediment	32 water 6 sediment	Irregular	Total and dissolved lead in water Total lead in sediment by dry weight
Environment Canada	Benthic Contaminants Study, 1985–1987	Not listed	73 for sediment 11 for tissue	6 surveys	Total lead in sediment by dry weight Total lead 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	3 samples per site in October 1995	Total lead in sediment by dry weight
BC ENV	Provincial Water Quality Objectives Attainment Monitoring, 1990–2009	748 water 74 sediment 68 tissue	14 water 12 sediment	1–10 samples/site and year, irregular Water samples generally reported as maximum values and mean of 5 samples in 30 days	Total and dissolved lead in water Total lead in sediment by dry weight Total lead in English Sole dry or wet weight not stated
Metro Vancouver	Burrard Inlet Ambient Monitoring Program, 2007–2016	709 water 210 sediment 73 tissue	7	5–10 water samples/site and year, regular. Reported as maximum values and mean of 5 samples in 30 days 3–6 sediment samples/site every 2 years, regular Tissue samples in 2007 and 2012	Total lead in water Total and extractable lead in sediment by dry weight Total lead in English sole tissue by wet weight
Ocean Wise	Pollution Tracker, 2015–2016	22 sediment, 15 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 lead in sediment by dry weight Total lead in mussel tissue by wet weight

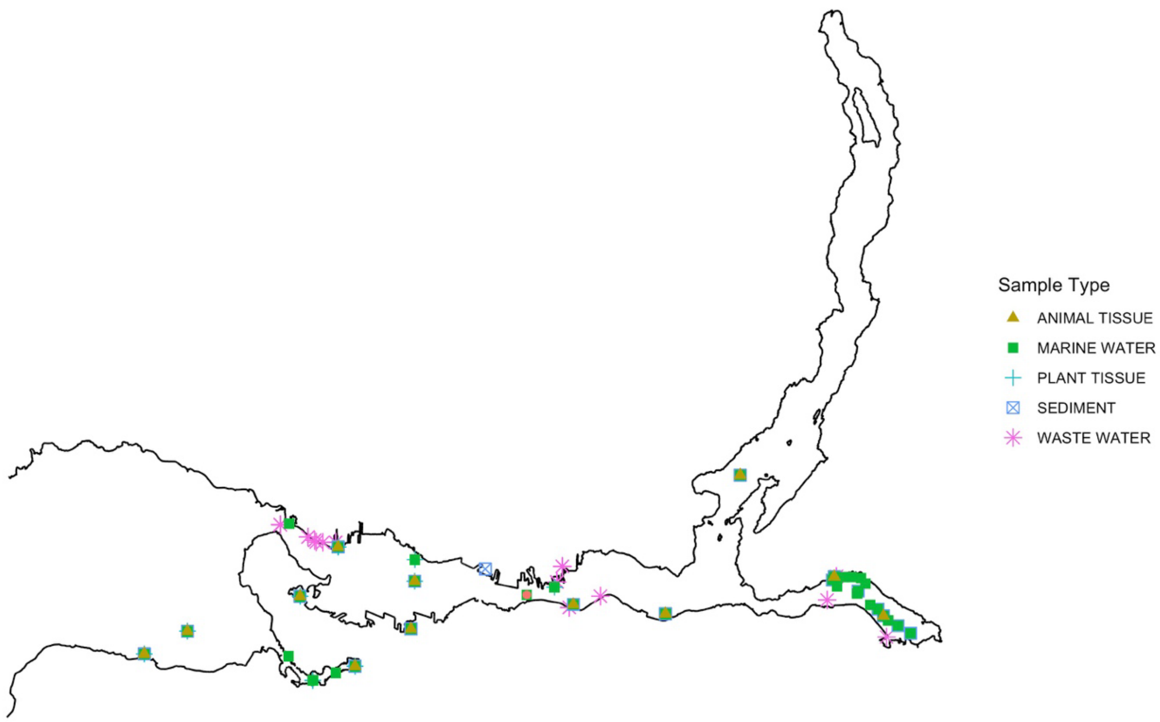

Figure 1: BC ENV sampling stations in Burrard Inlet (1971 to 2009)

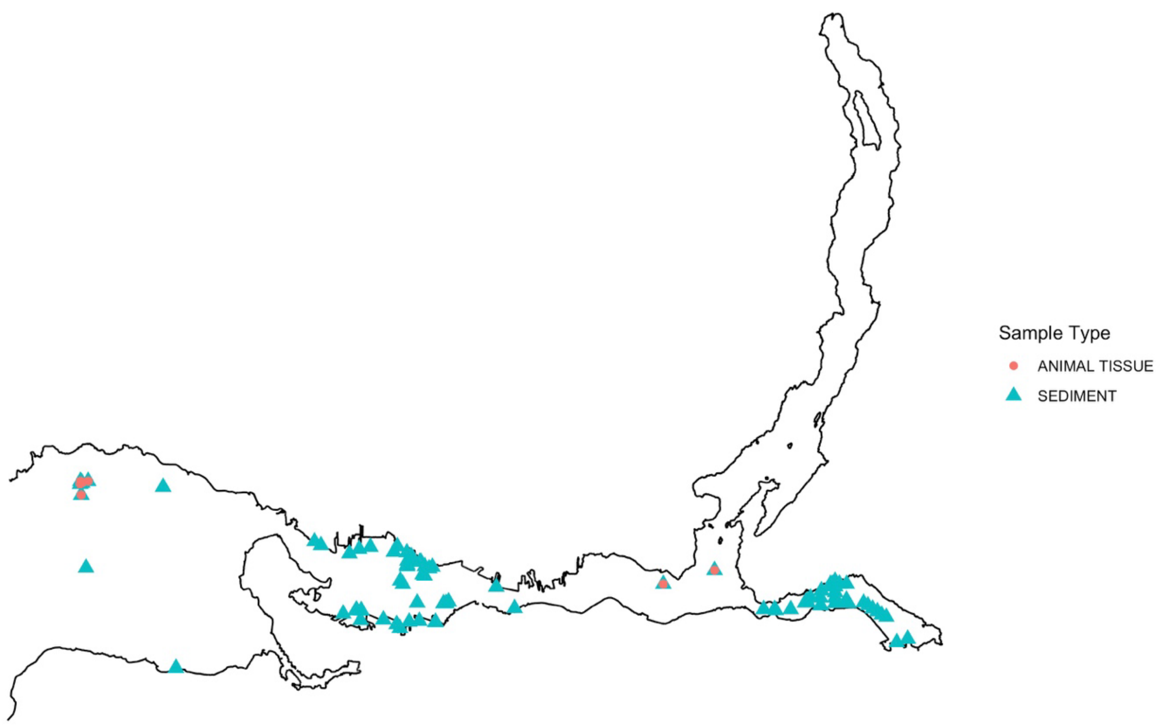

Figure 2: Environment Canada sampling stations in Burrard Inlet (1985 to 1987)

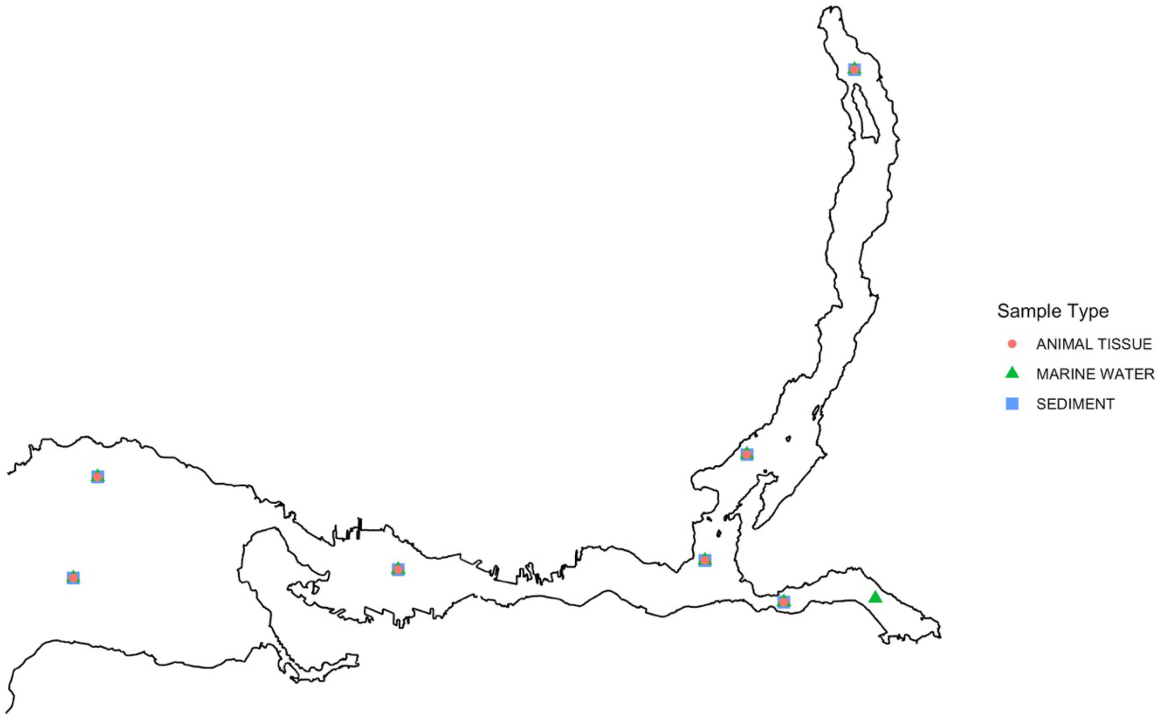

Figure 3: Metro Vancouver sampling stations in Burrard Inlet (2007 to 2016)

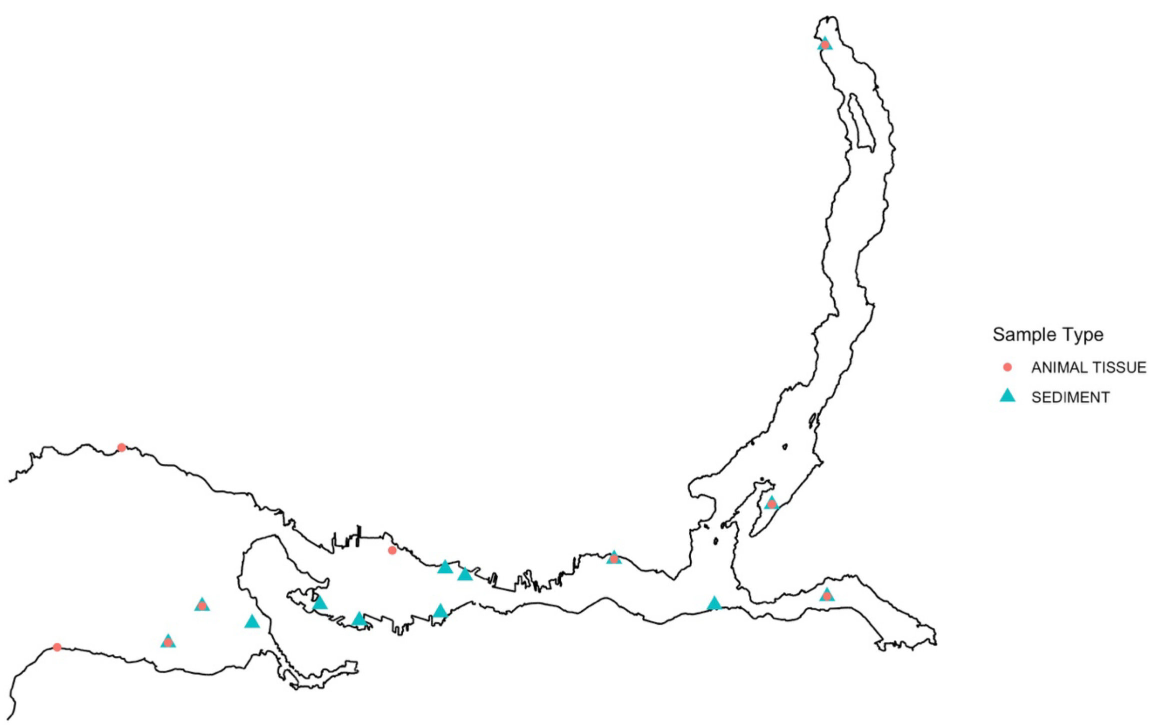

Figure 4: Pollution Tracker sampling stations in Burrard Inlet (2015 to 2016)

3.3 Assessment Results

The results of the data assessment for lead are summarized below. Monitoring data were compared to 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 at depth for ambient conditions. Therefore, there are limitations on comparing results between the monitoring programs. Where lead levels were below detection limits, values were plotted at the detection limit value in Figure 6 through Figure 12. Because detection limits can be quite variable between monitoring programs and between years, for consistency across chapters, samples that were below detection limits were excluded from the evaluation of mean and maximum levels at the sample locations. 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 lead levels collected from surface grab or composite samples, unless indicated. There is comparably little data for dissolved lead levels in Burrard Inlet. All sediment data presented are in dry weight.

Data for constituents that impact lead toxicity and bioavailability were also collected in the majority of these monitoring programs; however, an assessment of potential bioavailability or toxicity due to environmental conditions was outside of the scope of this assessment. Additional analyses would be required for confirmation.

Heat maps illustrating the distribution of lead levels in sediment in 5-year increments across all monitoring programs and years where data is present are provided in Appendix A. It is important to recognize that differences in sampling frequency and method detection limits do not allow for direct comparison of historic data with more recent data. Instead, the heat maps may be used to illustrate the best understanding of potential areas where lead levels may be relatively high in comparison to the rest of Burrard Inlet.

Pre-1990 Data

- 1985–1987 – The Environment Canada Benthic Contaminants Study (Goyette and Boyd, 1989) observed mean lead levels in sediment that exceeded the threshold effect level (TEL) benchmark (30.2 µg/g) at 95% of the 73 monitoring stations and exceeded the probable effect level (PEL) benchmark (112 µg/g) at 14% of the of the 73 monitoring stations. The highest single sample maximum lead levels were observed on the northern side of Inner Harbour near Vancouver Wharves (average 468 µg/g, range 39 to 5,420 µg/g). Other areas with elevated lead levels were the Vancouver Shipyards (5 to 624 µg/g), Burrard Yarrows Shipyard (3 to 1710 µg/g), the Clarke Drive/Vernon Relief combined sewer overflow (241 to 342 µg/g) and the Ioco Refinery (maximum level of 182 µg/g in 1985/1986 and 298 µg/g in 1986/1987). The distribution of lead in sediment measured in the study is illustrated in Figure 5. Lead levels in English sole (*Parophrys vetulus*) fish muscle tissue ranged from 0.08 to 1.59 µg/g dry weight, which was similar to lead levels in fish tissue reported for unpolluted coastal areas of BC (Harding and Goyette, 1989).

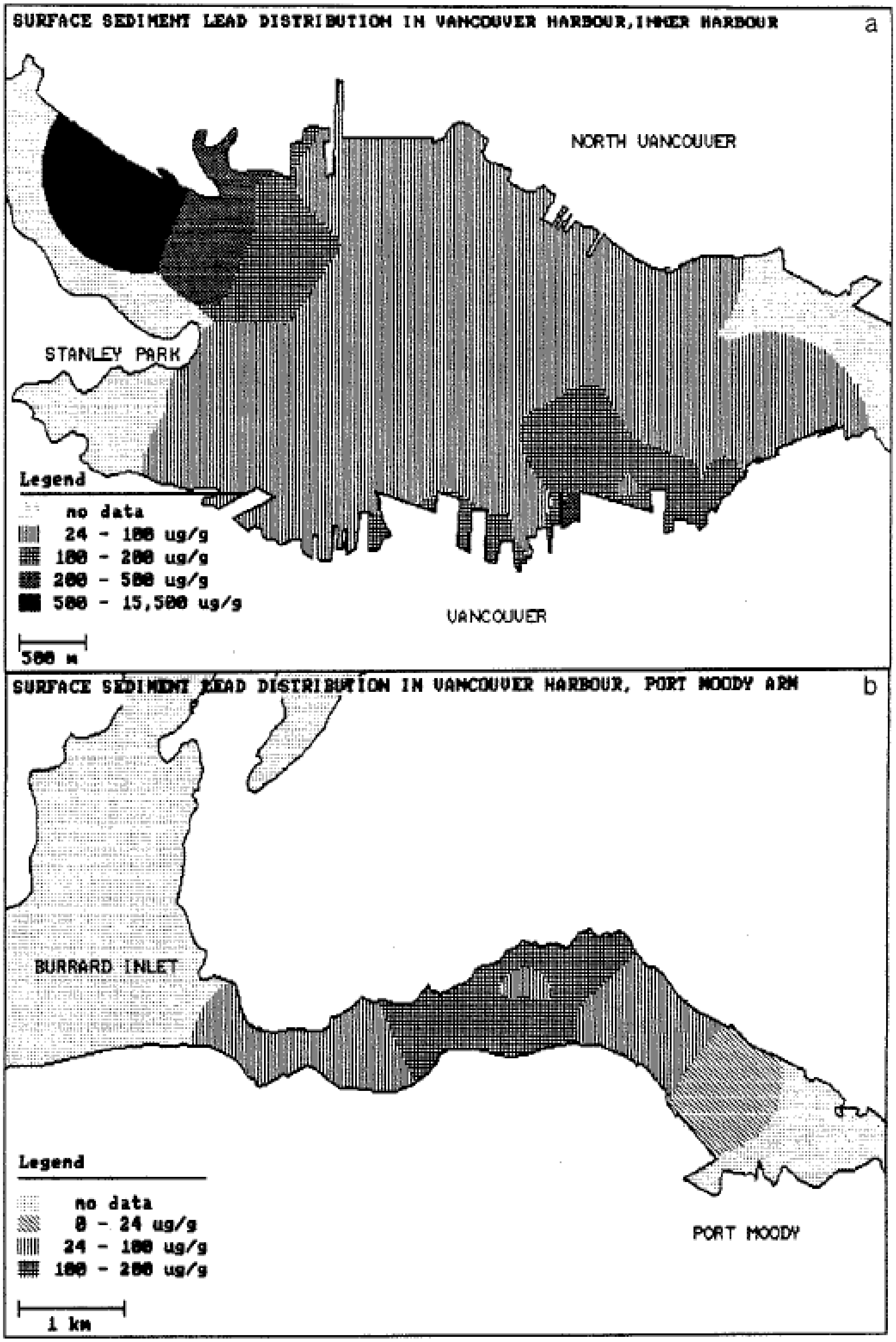

Figure 5: Surface sediment lead distribution in Burrard Inlet (from 1985 to 1986) (a) Inner Harbour and (b) Port Moody Arm (from Goyette and Boyd, 1989)

- 1971–1990 – BC ENV monitoring samples collected between 1971 and 1990 were above lead detection limits for 60% of water samples and 100% of sediment samples. There was no data for fish tissue samples collected prior to 1990. Detection limits for water samples ranged between 0.001 and 1 µg/L, creating some uncertainty in the interpretation of potential patterns and comparison to benchmarks.
    - Annual mean lead levels in water samples were frequently above the chronic benchmark (2 µg/L) in all sub-basins. The highest single-sample maximum lead levels were observed in water samples collected at Vancouver Harbour Vancouver Wharves (Station E207816; maximum 75 µg/L), Vancouver Harbour Shellburn (Station E207822; maximum 50 µg/L) and Pacific Coast #11 75 M North East (Station 207698; maximum 49 µg/L). There were no exceedances of the acute benchmark (140 µg/L).
    - Lead levels in sediment ranged from 15 µg/g at Port Moody Arm near Pacific Coast Terminal #11 (station E207702) in 1988 to 90 µg/g at Port Moody Arm near IOCO #1 (station E207688) in 1989.

Post-1990 Data

- 1998 – The BIEAP Sediment Quality Study (EQOMAT, 1998) observed lead in surface sediments above the detection limit in all 45 samples. The highest lead levels were detected in the Inner Harbour at location 3A, slightly east of Vancouver Wharves, where samples exceeded the TEL benchmark of 121 µg/g (range 110 to 140 µg/g, mean 123 µg/g). Lead levels exceeded the PEL benchmark (30.2 µg/g) in all sub-basins except for Indian Arm.
- 1990–2009 – BC ENV water quality objectives attainment monitoring samples collected between 1990 and 2009 were above lead detection limits for 53% of water samples, 95% of sediment samples, and 0% of tissue samples. Detection limits ranged from 0.1 to 60 µg/L for water samples, were 10 µg/g for sediment samples and ranged from 0.1 to 10 µg/g for fish tissue. The wide range of detection limits for lead in water samples and tissue samples may impact the interpretation of the water sample results and does not allow for an assessment of the tissue samples. The following key points summarize the monitoring results:
    - In water samples, the highest single-sample maximum lead levels were measured at False Creek Between Granville and Cambie Street (Station E207815, 170 µg/L) and Pacific Coast #11 75 m North East (Station E207698, 160 µg/L). These were the only two stations where lead levels exceeded the acute benchmark (140 µg/L); however, 219 samples had lead levels that exceeded the chronic benchmark (2 µg/L), excluding 15 samples that had a detection limit of 60 µg/L. An illustration of lead levels in BC ENV's water samples is provided in Figure 6.
    - Single-sample maximum lead levels in sediment samples exceeded the PEL benchmark (112 µg/g) at three stations prior to 2002 including Vancouver Wharves (Station E207816), English Bay at Locarno Park (Station E207812), and False Creek East End (Station E207814). Vancouver Wharves had frequent and high levels of lead in sediment (range 20 to 1190 µg/g, mean 498 µg/g). Measured lead levels in 2002 ranged from 18.6 µg/g at English Bay Centre (Station 300076) to 92.3 µg/g at Vancouver Wharves. Lead concentrations at Vancouver Wharves were considerably lower in 2002 than levels observed 10 years earlier. An illustration of lead levels in BC ENV's sediment samples is provided in Figure 7.
    - All English sole tissue samples were below detection limits.

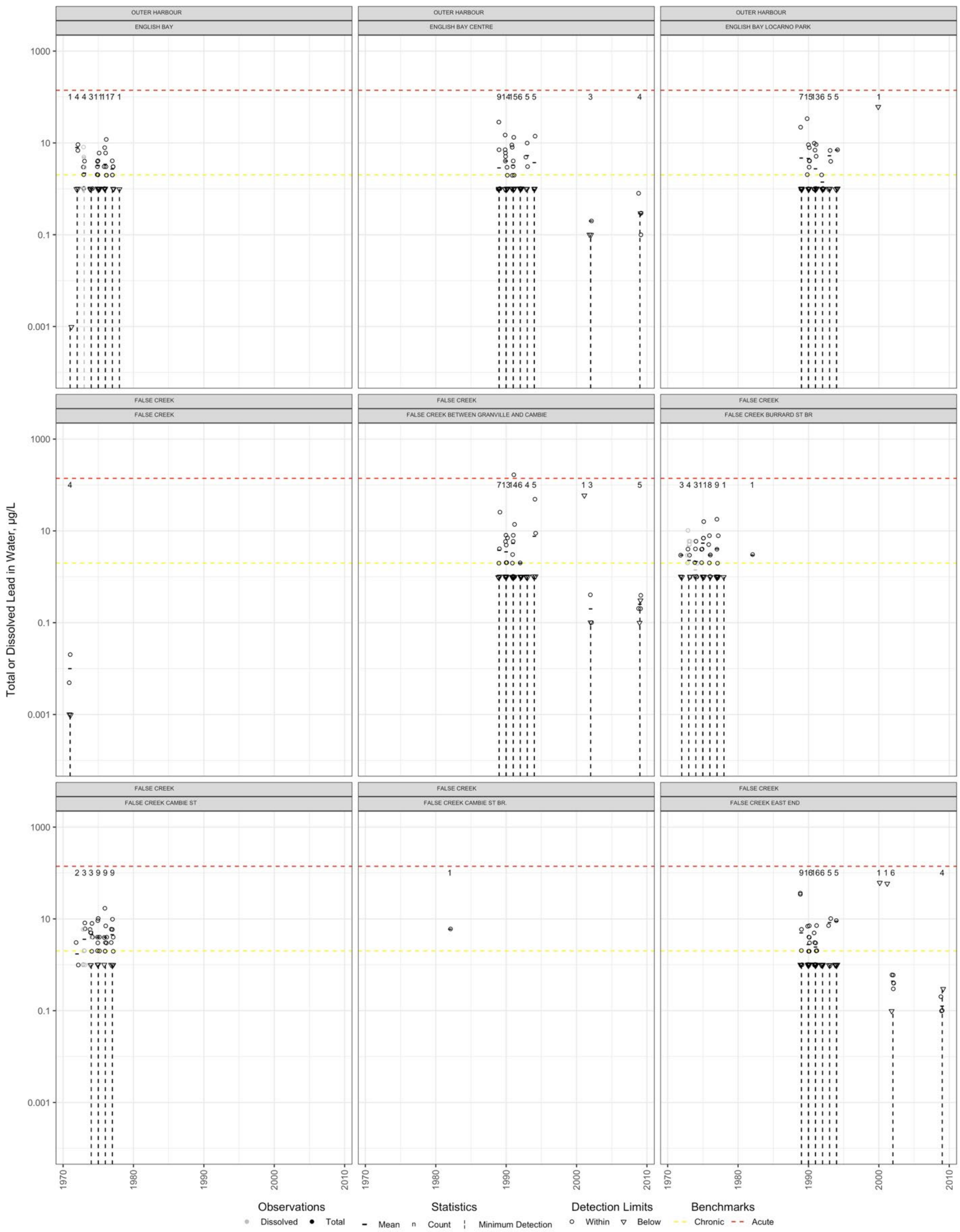

Figure 6: Lead levels in BC ENV water samples (1970 to 2009) in µg/L (log scale)

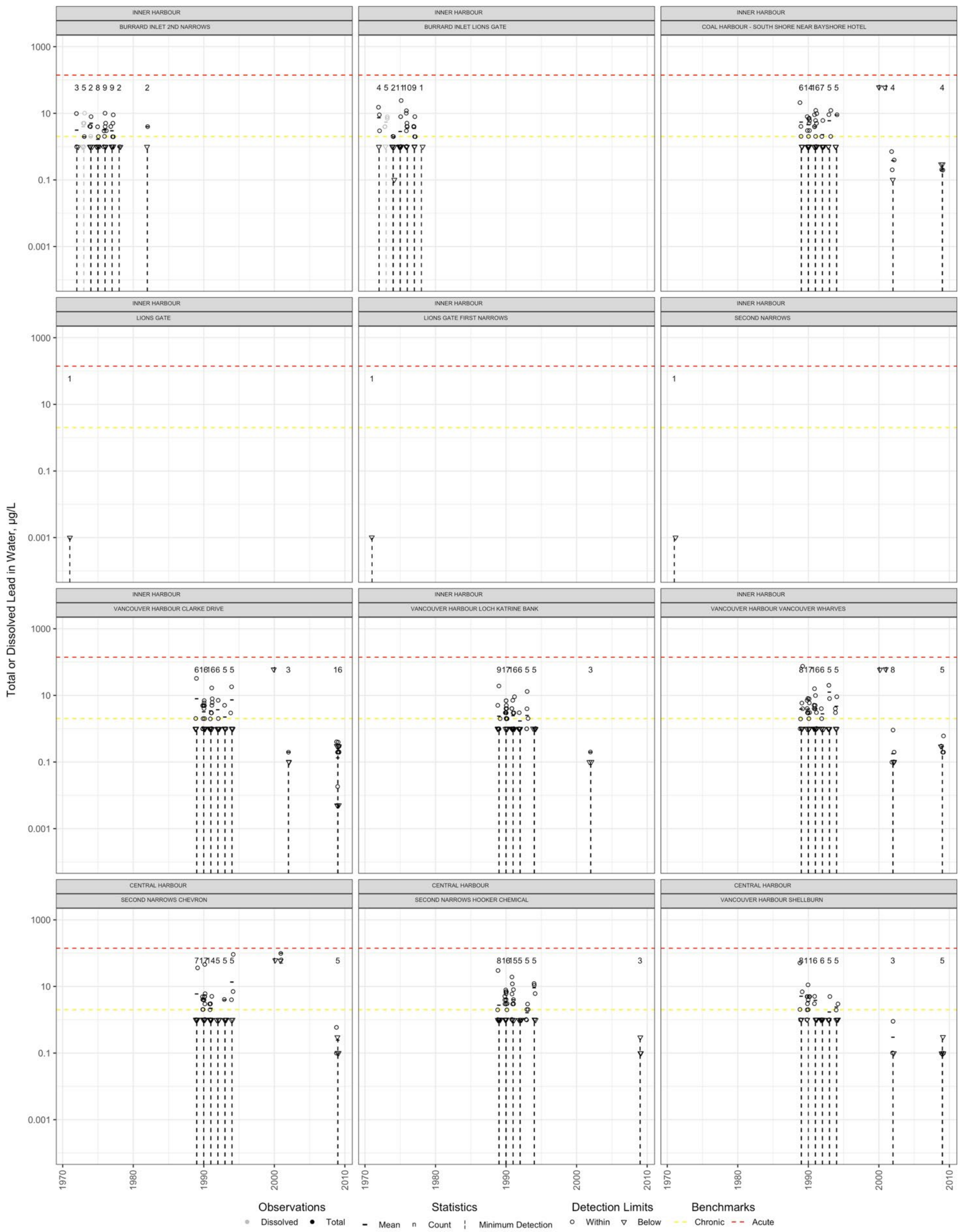

Figure 6: Lead levels in BC ENV water samples (1970 to 2009) in µg/L (log scale, continued)

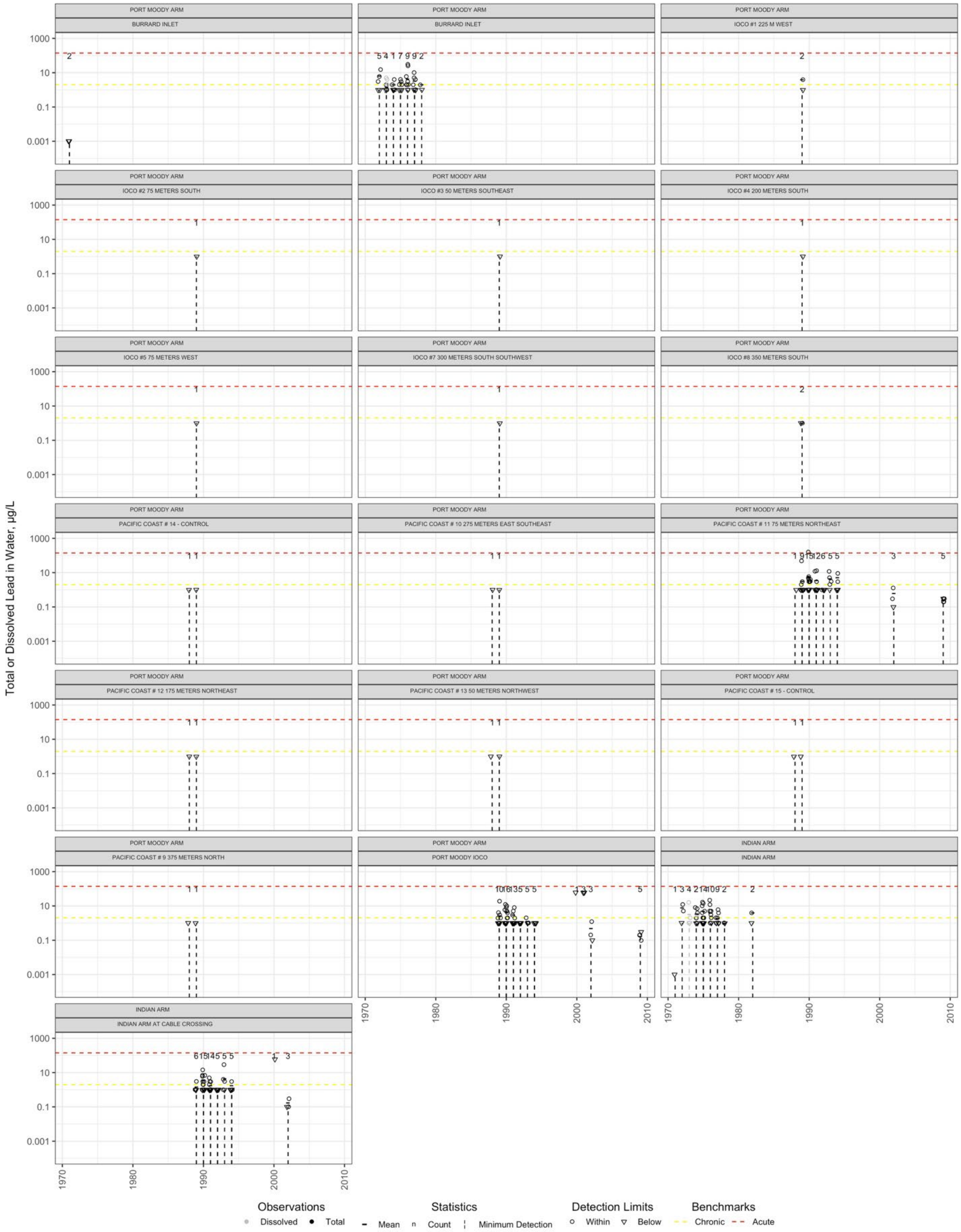

Figure 6: Lead levels in BC ENV water samples (1970 to 2009) in µg/L (log scale, continued)

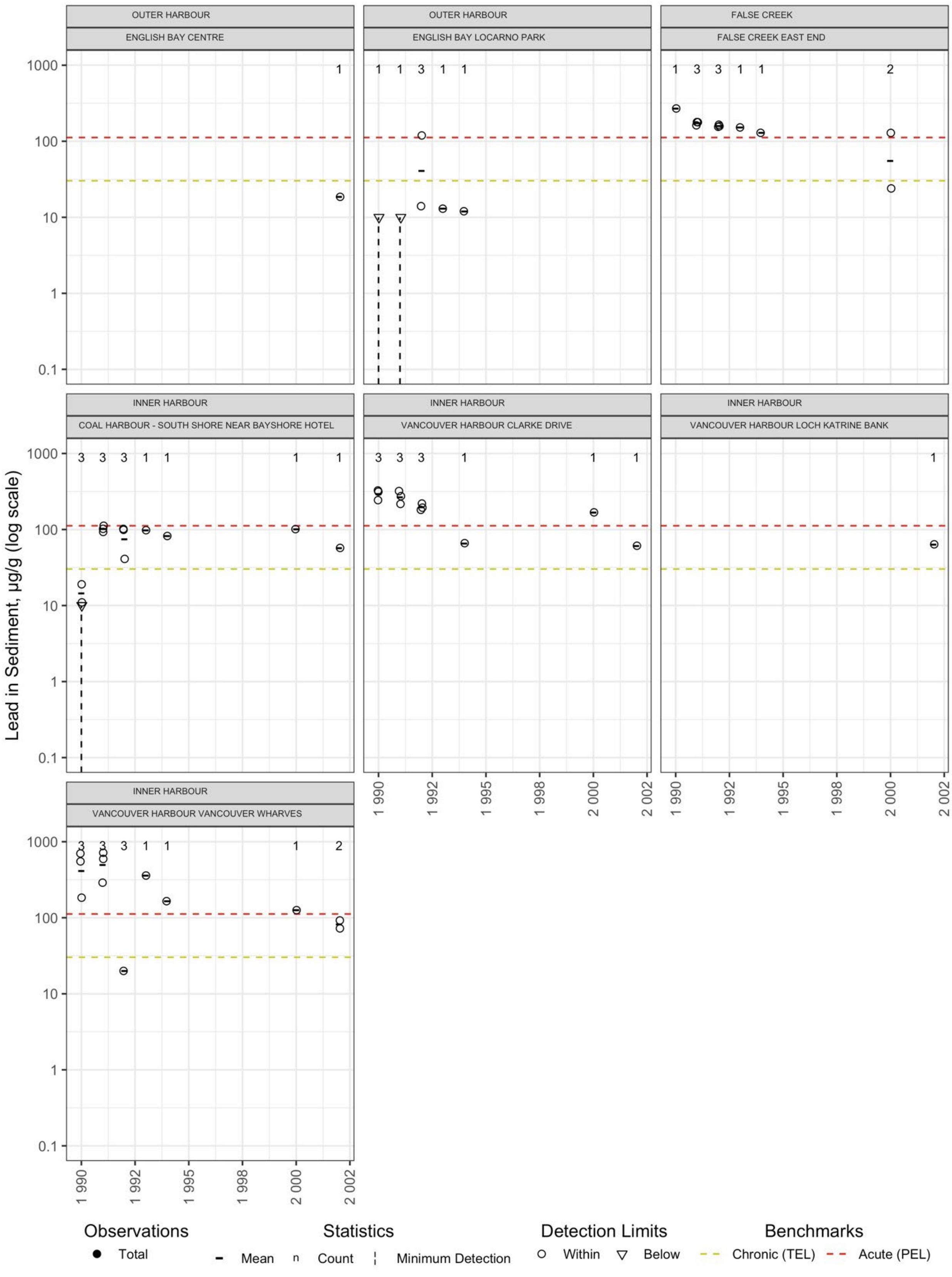

Figure 7: Lead levels in BC ENV sediment samples (1988 to 2002) in µg/g dry weight (log scale)

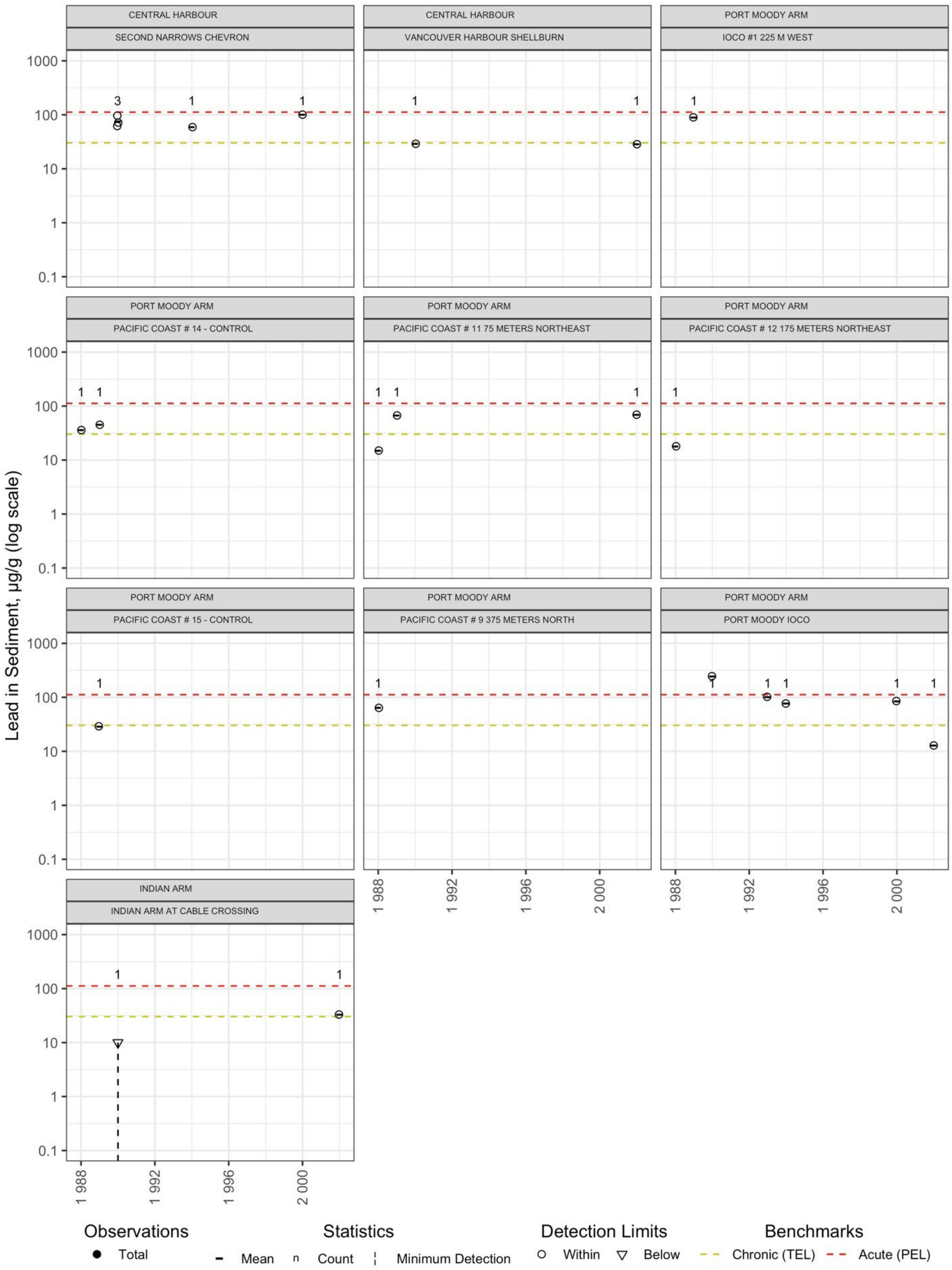

Figure 7: Lead levels in BC ENV sediment samples (1988 to 2002) in µg/g dry weight (log scale, continued)

- 2007–2016 – As part of the Burrard Inlet Ambient Monitoring Program, Metro Vancouver has monitored lead levels in the water column annually (Figure 8) and in sediment every 2 to 3 years (Figure 9) since 2008. Lead levels in English Sole tissue (whole body, muscle, and liver) samples were measured in 2007 and 2012 (Figure 10). Between 2007 and 2016, lead levels were above detection limits for 91% of water samples, 100% of sediment samples, and 99% of tissue samples. Detection limits were between 0.007 µg/L and 0.05 µg/L for water samples, 0.020 µg/g to 4.144 µg/g for sediment samples, and 0.002 µg/g to 0.01 µg/g for 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 key points summarize the Metro Vancouver monitoring results:
  - Metro Vancouver collected water samples from two depths at each site; the "top" sample was collected 1 m below the water surface and the "bottom" sample was taken 3 m above the ocean floor. No single-sample maximum lead levels exceeded the acute benchmark (140 µg/L) and no mean lead levels exceeded the chronic benchmark (2 µg/L). Single sample maximum lead levels in the water samples exceeded the chronic benchmark (2 µg/L) at Inner Harbour in 2015 at the top of the water column (3.19 µg/L) and at Indian Arm North in 2014 at the bottom of the water column (2.21 µg/L) (Figure 8). Lead concentrations were generally similar in the top and bottom samples.
  - Metro Vancouver analyzed total lead levels in sediment samples (Figure 9). No samples exceeded the PEL benchmark for lead (112 µg/g). Lead levels did exceed the TEL benchmark (30.2 µg/g) in most samples across all years in samples that were collected from Port Moody Arm and Indian Arm South, and in one sample from Inner Harbour. The highest lead level was measured at Indian Arm South in 2011 (66.7 µg/g).
  - English Sole liver tissue samples exceeded the screening benchmark for adult recreational fishers (0.276 µg/g wet weight) at all monitoring locations, and whole body tissue samples exceeded the screening benchmark for adult recreational fishers at all monitoring locations except for Outer Harbour South and Central Harbour (Figure 10). English Sole muscle samples did not exceed the screening benchmark for adult recreational fishers at any monitoring location, but were above the toddler subsistence fisher screening benchmark (0.070 µg/g wet weight) at Outer Harbour North, Outer Harbour South and Port Moody Arm. The highest value recorded for liver tissue (2.65 µg/g wet weight) was measured in Indian Arm North in 2012. The highest value recorded for whole body tissue (0.67 µg/g wet weight) was measured in Inner Harbour in 2007. The highest value recorded in muscle tissue (0.116 µg/g wet weight) was measured in Outer Harbour South in 2012. While the liver samples have the highest lead levels, they are likely of lesser relevance for human consumption compared to muscle and whole body samples because finfish liver tissue is not expected to be consumed in high quantities.

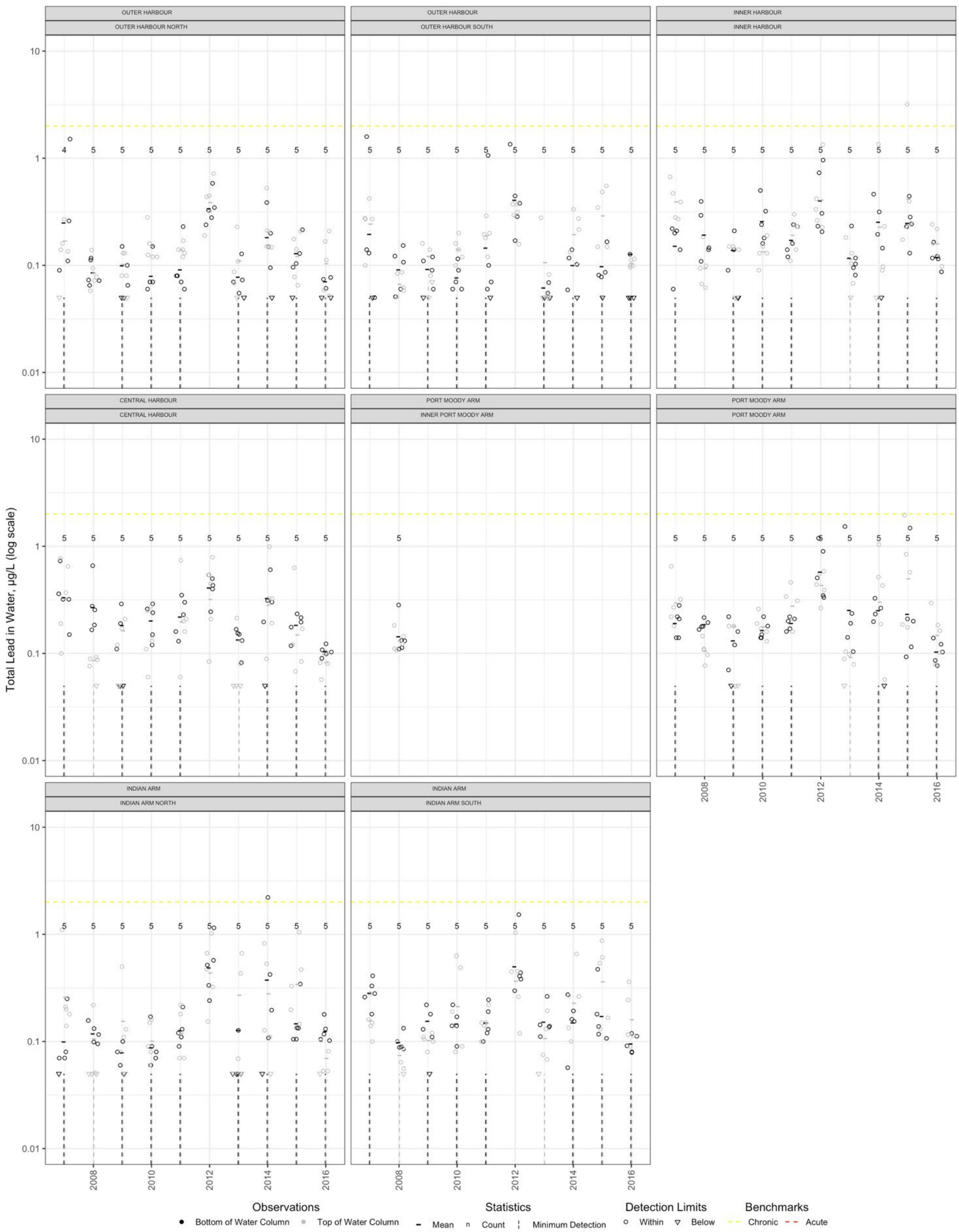

Figure 8: Lead levels in Metro Vancouver water column samples (2007 to 2016) in µg/L (log scale)

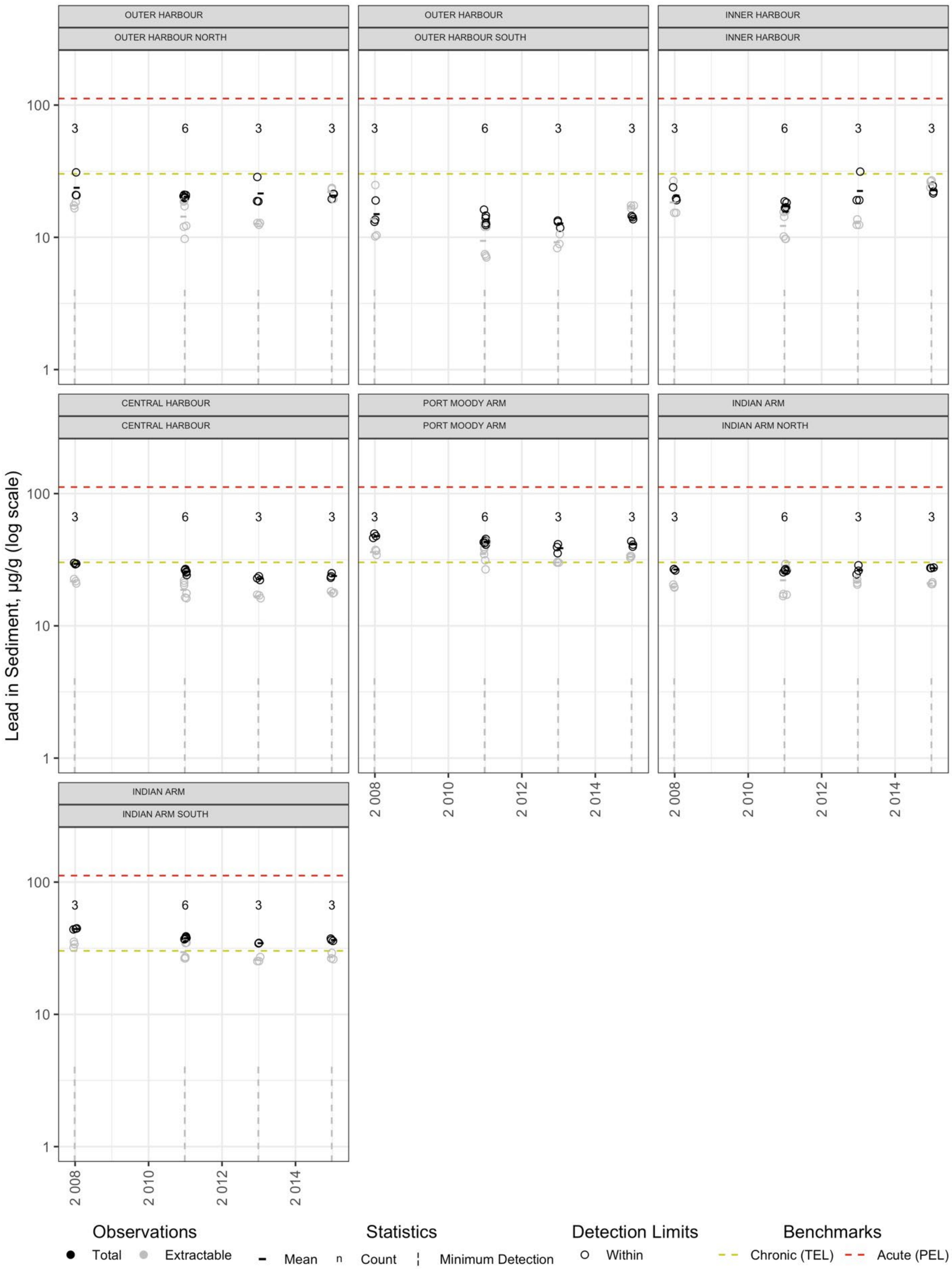

Figure 9: Lead levels in Metro Vancouver sediment samples (2008 to 2016) in µg/g dry weight (log scale)

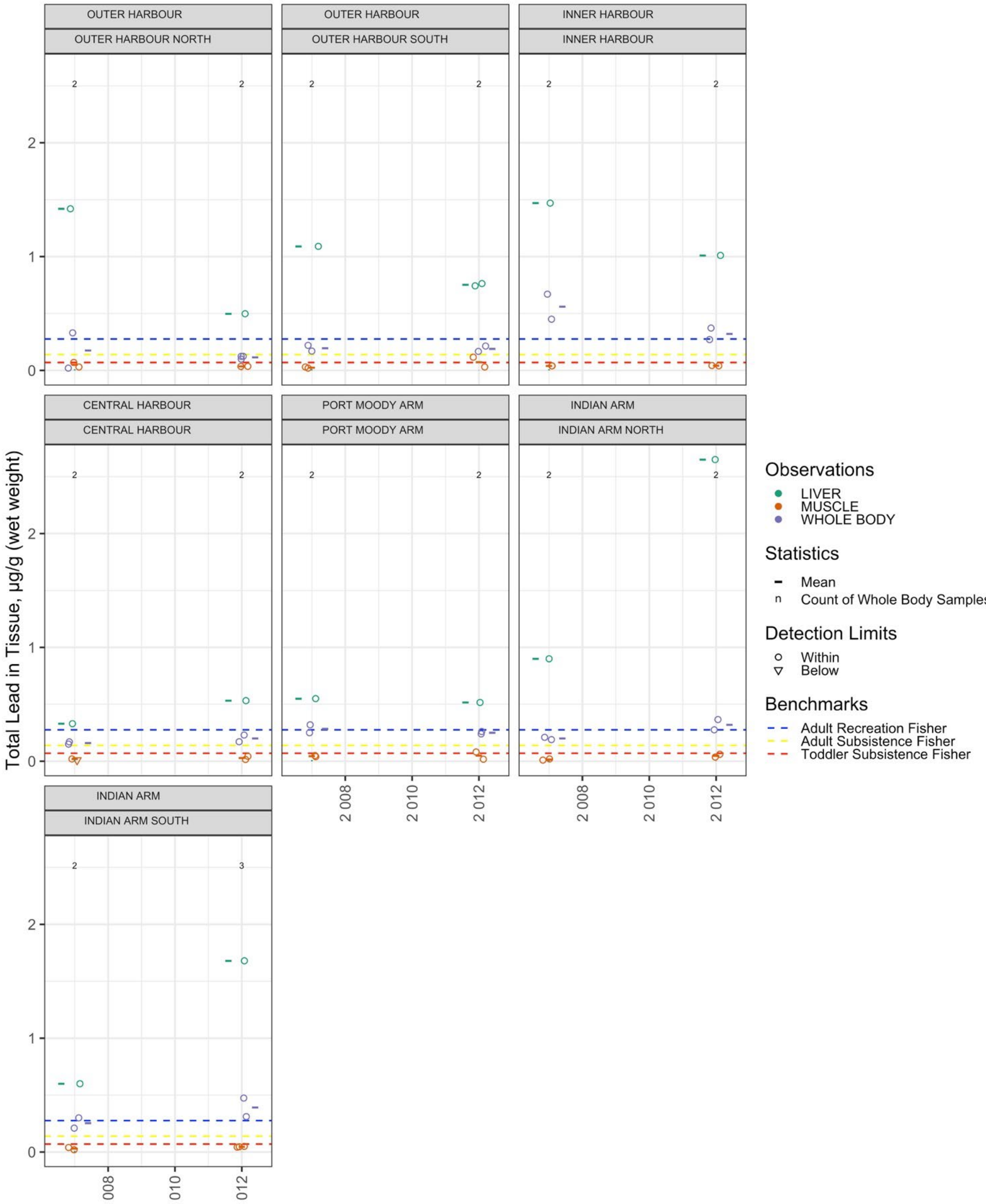

Figure 10: Lead levels in Metro Vancouver English Sole fish tissue samples (2007 to 2012) in µg/g

- 2015–2016 – Pollution Tracker monitoring of lead levels in sediment (Figure 11) and mussel tissue (Figure 12) occurred in October 2015 and April 2016. All samples measured were above detection limits (0.5 µg/g dry weight for sediment and 0.004 µg/g wet weight for tissue). Pollution Tracker results are summarized as follows:
  - Mean lead levels in the sediment samples exceeded the TEL, or chronic benchmark (30.2 µg/g) at the Port Moody Arm monitoring location. The highest lead levels in sediment were recorded in Port Moody Arm (54 µg/g) and the Inner Harbour (30 µg/g, 28.2 µg/g) (Figure 11).
  - Lead levels in the mussel tissue samples did not exceed the adult recreational fisher screening benchmark (0.276 µg/g wet weight), exceeded the adult subsistence fisher benchmark (0.139 µg/g wet weight) at Central Harbour, Port Moody Arm and Indian Arm, and exceeded the toddler subsistence fisher benchmark at all monitoring locations. The highest lead levels in blue mussel tissue were recorded in Central Harbour (0.147 µg/g wet weight), Port Moody Arm (0.143 µg/g wet weight) and Indian Arm (0.141 µg/g wet weight) (Figure 12).

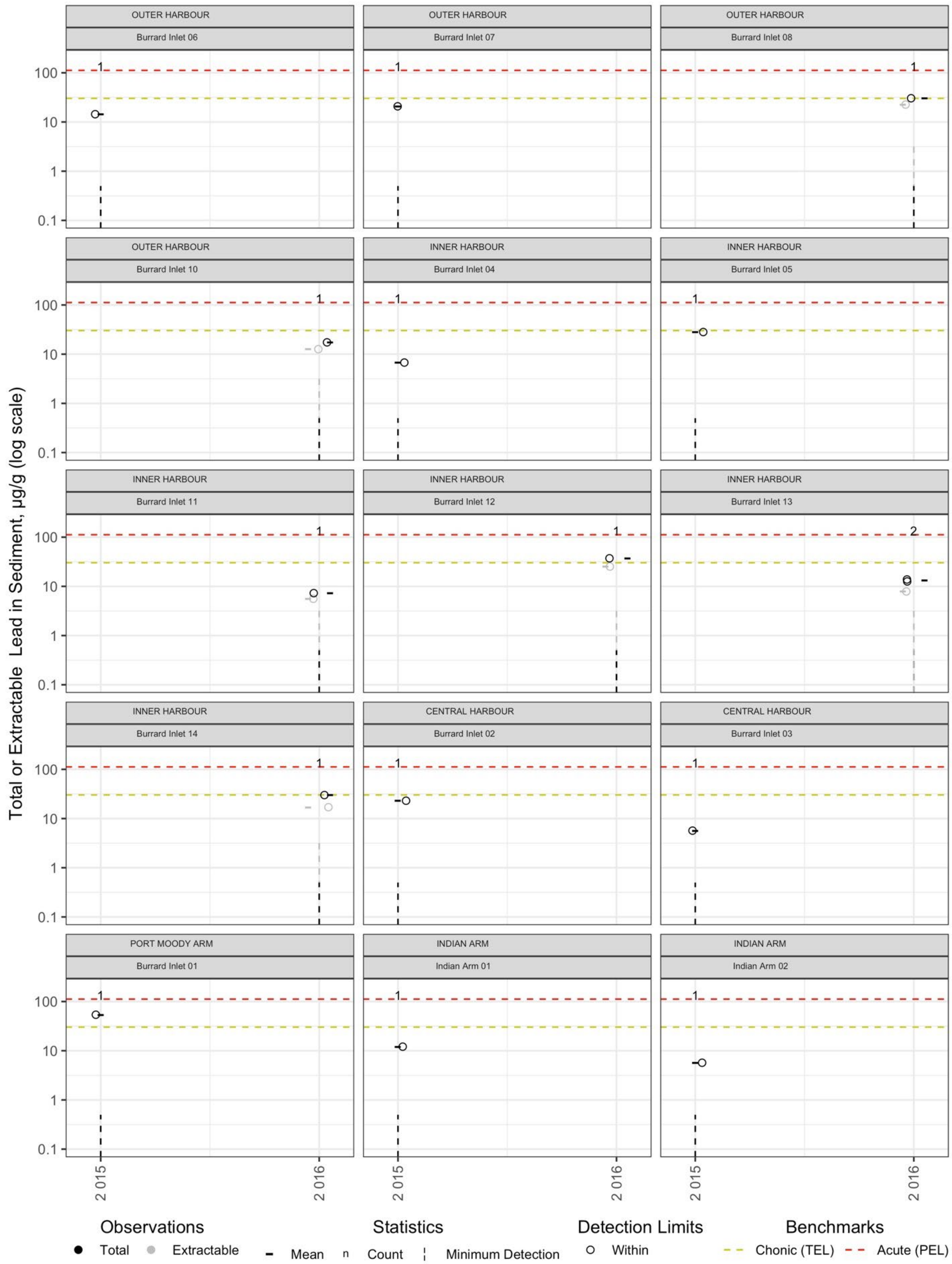

Figure 11: Lead levels in Pollution Tracker sediment samples (2015 to 2016) in µg/g dry weight (log scale)

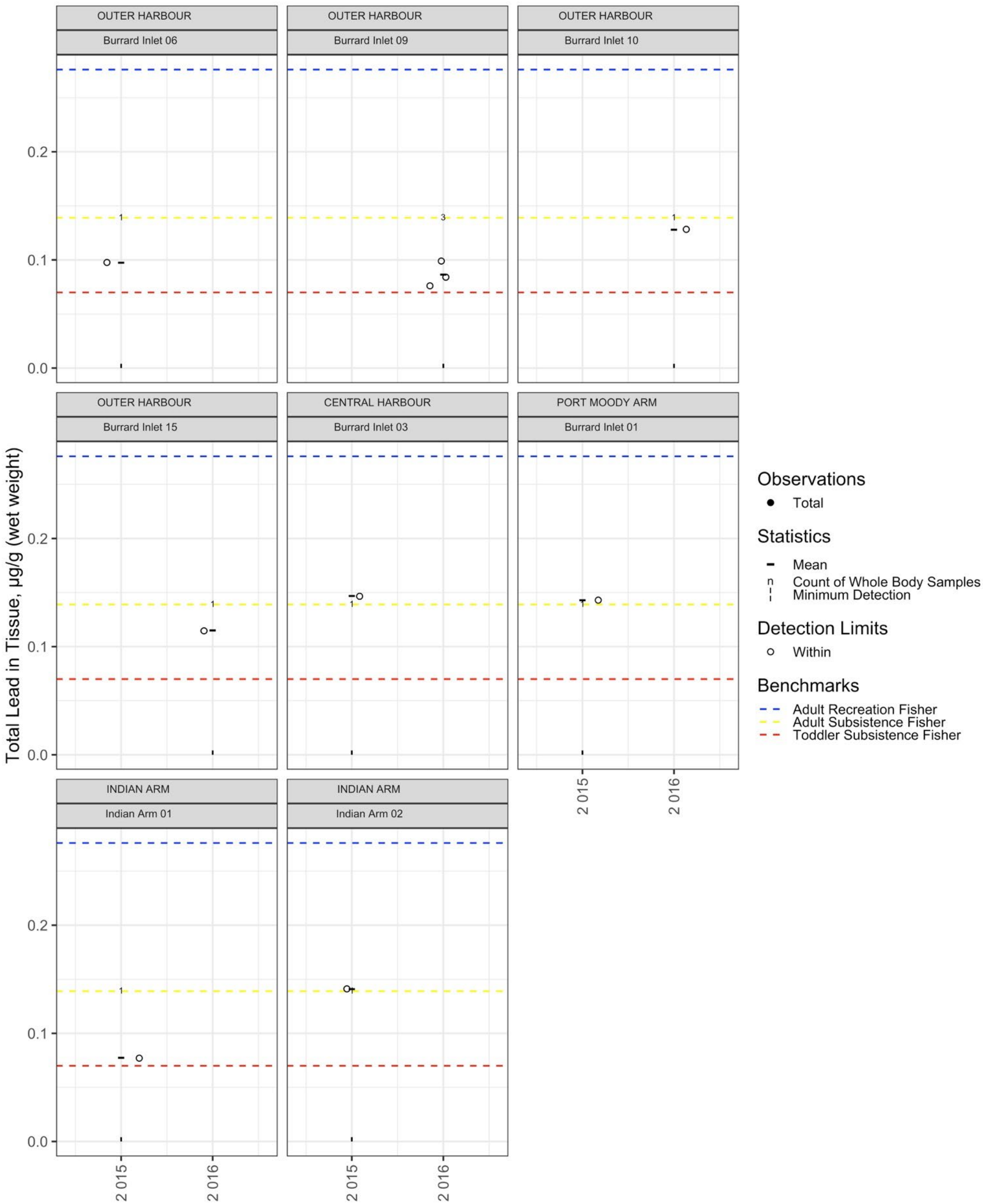

Figure 12: Lead levels in Pollution Tracker blue mussel tissue samples (2015 to 2016) in µg/g

3.4 Knowledge Gaps and Research Needs

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

- BC guideline values for lead in water and sediment have not been updated since the 1980s, and do not account for bioaccumulation (Ocean Wise 2019); a better understanding is needed of lead toxicity at higher trophic levels (e.g., birds and marine mammals).
- Species-specific chronic and acute effects levels for lead for aquatic species present in Burrard Inlet, and for marine waters generally, are not well understood.
- Past sediment transport studies have determined that Port Moody Arm and Indian Arm are areas of net sediment deposition (McLaren 1994). Effects of sediment deposition in Indian Arm and Port Moody Arm and the potential accumulation of heavy metals, including lead, have not been established. From the Metro Vancouver and Pollution Tracker monitoring programs, it appears that lead levels are consistently elevated in Port Moody Arm and the south end of Indian Arm. This may be a concern for aquatic species that inhabit these basins and for humans who regularly consume fish or shellfish gathered from these basins.
- Recent decisions to open shellfish harvesting in a small portion of Indian Arm are based on data from a very small area. There is a lack of data for lead levels in finfish and shellfish tissue in Indian Arm more broadly or in other areas of Burrard Inlet. Because shellfish in these areas may be accumulators of lead due to sediment transport, a more detailed human health risk assessment may be warranted.
- There has been little, or no monitoring of sites influenced by permitted discharges, stormwater discharges, or combined sewer overflow outfalls since 2009.
- There has been little monitoring of lead in sediment or the water column in False Creek since 2009.
- The seasonality of lead in the water column is not well understood.
- The bioavailability of lead has not been taken into consideration in previous monitoring studies. However, the effect of abiotic factors, including DOC, on the bioavailability and toxicity of lead to marine aquatic species is not entirely known. Bioavailability predictions based on DOC and other factors need to be developed.

4. PROPOSED OBJECTIVES FOR LEAD IN BURRARD INLET

4.1 Proposed Objectives

Proposed interim objectives for lead are presented in Table 4. An overall qualitative objective is proposed that lead levels be as low as reasonably achievable.

Table 4: Proposed Interim Water Quality Objectives for Lead

Sub-basin	False Creek	Outer Harbour	Inner Harbour	Central Harbour	Port Moody Arm	Indian Arm
Total Lead in Water	2 µg/L mean AND no more than 20% of samples above 2 µg/L[1]					
Total Lead in Sediment	30.2 µg/g dry weight single-sample maximum[2]					
Lead in Tissue	Short-term (by 2025): 0.139 µg/g wet weight single-sample maximum [3] Long-term (by 2050): 0.07 µg/g wet weight single-sample maximum [3]					

[1] Minimum of 5 samples in 30 days collected during the wet season. No more than 20% of samples > 2 µg/L.
[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.

4.2 Rationale

Objectives are proposed for lead in water and sediment to protect marine aquatic life, and for lead in tissue to protect human consumption of finfish and shellfish. Due to a lack of benchmarks for lead levels in water and sediment that account for bioaccumulation into higher trophic levels, these proposed water quality objectives are considered interim and may be revised if further research becomes available.

The proposed mean objective for total lead in water should be set to a level below which there is low risk for effects to aquatic life based on long-term chronic exposure. The existing BC water quality guidelines for lead are based on limited information, however, and are only protective of fish and invertebrates (Nagpal 1987), and do not consider bioaccumulation to higher trophic levels such as marine mammals. At this time, therefore, the objective may not be sufficiently protective of these higher trophic levels. The qualifier that no more than 20% of samples exceed the BC water quality guideline (as per BC ENV 2019) is proposed to prevent the observed infrequent exceedances from being offset by generally low concentrations, to limit the exposure of marine aquatic life to levels above the objective until more research is available. This qualifier is a condition of attaining the objective. The 1990 maximum water quality objective of 140 µg/L has been omitted because only two of 2,094 total samples considered in the data assessment for this report exceeded 140 µg/L (in 1990 and 1992). The highest lead level in water recorded in Burrard Inlet since 2000 was 3.19 µg/L in 2015.

Boyette and Goyd (1989) cite estimated reference levels for lead in marine sediments ranging from 7.8 µg/g in the Fraser River Estuary to 24 µg/g in Vancouver Harbour and Puget Sound; they used 24 µg/g as a benchmark to assess lead levels in Vancouver Harbour. The objective for total lead in sediment is proposed to be consistent with the interim sediment quality guideline from the BC working guidelines, which is 30.2 µg/g and is considered a TEL.

Measured levels of lead in English Sole tissue (liver, muscle, whole body) were frequently above the toddler subsistence fisher screening benchmark and blue mussel shellfish tissue (whole body) samples were above the toddler subsistence fisher screening benchmark in all cases. While blue mussel samples did not exceed the other screening benchmarks, English Sole liver and whole body samples were also frequently above the adult subsistence fisher screening benchmark and the adult recreational fisher screening benchmark. English Sole liver samples likely spike the results, due to the higher accumulation rate of lead into liver tissue. To consider potential risk in the absence of adequate data for human consumption rates of different tissue types, the objectives are proposed to apply to whole body samples.

Tsleil-Waututh Nation has a goal of obtaining 10% of their diet from Burrard Inlet. Thus, the short-term objective is intended to protect an adult consumer from a subsistence fishing population. Currently no shellfish tissue considered in this data assessment had lead levels below 0.07 µg/g wet weight, which is the SV protective of a toddler consumer from a subsistence fishing population. The SV protective of a toddler is proposed as the long-term objective for lead in tissue because it is the most conservative value for protecting human consumption of shellfish and finfish at rates relevant to coastal Indigenous peoples. Timelines for the short- and long-term objectives are set to coincide with timelines for meeting proposed water quality objectives for microbiological indicators in Burrard Inlet. The intent of these tissue objectives is to flag elevated lead levels as they are recorded, and work towards restoring Burrard Inlet back to conditions where they can meet Tsleil-Waututh Nation's goals.

The overall objective of lead being as low as reasonably achievable is proposed because there is no lead threshold for health effects (CDC 2012). TRVs for lead are based on the lowest measurable population-level health effects, which is less than 1 point decrease in population IQ (Health Canada 2021).

To meet the water quality goals for Burrard Inlet as outlined in Rao et al. (2019), these objectives are proposed to extend across all sub-basins.

5. MONITORING RECOMMENDATIONS

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

- As any exposure to lead is considered to pose some risk for harmful effects, lead should be included in fish and shellfish monitoring programs if there is any evidence that it may be present in fish tissue (Thompson and Stein 2021).
- As additional information and research on lead toxicity and bioaccumulation becomes available, incorporate this data to develop updated screening benchmarks and objectives for lead in Burrard Inlet.
- Use knowledge of sediment transport patterns in Burrard Inlet (McLaren 1994) to guide sediment sampling locations since the nearest vicinity of lead sources are not necessarily the locations of highest lead levels in sediment. That is, while there may be a greater density of lead sources in the Inner Harbour and the Central Harbour, lead from these sources may accumulate in Port Moody Arm or Indian Arm. When dredging must be conducted, conduct sediment monitoring to ensure that higher lead levels from layers below the sediment surface are not re-exposed. These findings and recommendations are consistent with the findings and recommendations for cadmium.

- Monitor lead in fish, clam, prawn, and crab tissue samples from locations in Burrard Inlet where these species are actively harvested or were traditionally harvested. Consider performing both species-specific and human health risk assessments if this monitoring indicates that lead levels are elevated above objective levels.
- Measure lead in water and sediment near outfalls and discharge points, correlate this data to ambient conditions, and incorporate this monitoring into Metro Vancouver and Pollution Tracker's monitoring programs.
- Monitor lead in water and sediment in False Creek and incorporate this monitoring into the programs run by Metro Vancouver, Pollution Tracker or BC ENV.
- 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 and Indian Arm.
- Design future monitoring programs to capture seasonal variation, and collect five samples in 30 days, to help address the knowledge gap regarding seasonality of lead in the water column, and determine the worst-case scenario for lead levels.
- Perform an assessment to determine the bioavailable fraction of lead in water samples.
- Collect supporting water chemistry data (e.g. hardness, DOC, pH) for every site on every sampling occasion, so that these can be used for more advanced assessments in the future, including predictions of lead bioavailability.
- More 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

Management actions that have been or are being undertaken to reduce marine lead pollution include the following:

- Tsleil-Waututh Nation's ongoing work to restore the health of the Inlet through implementation of the Burrard Inlet Action Plan;
- A ban on lead in products such as leaded gasoline in Canada and the United States (Ocean Wise 2019);
- A ban on lead shot for waterfowl hunting in Canada (Ocean Wise 2019);
- Development and implementation of Integrated Stormwater Management Plans for all developed watersheds that flow into Burrard Inlet;
- Development of source controls, including green stormwater infrastructures such as swales, rain gardens, and tree trenches;
- Inflow and infiltration reduction programs to reduce groundwater and stormwater entry into sanitary sewer pipes, thereby reducing untreated sewage discharges from sanitary and combined sewer overflows; and
- Adoption of pollution prevention plans by Port of Vancouver tenants.

Proposed management actions that have the potential to reduce the amount of lead in Burrard Inlet include, but are not limited to, the following:

- Banning lead ammunition in all forms of hunting, as has been done in Sweden and Denmark (Ocean Wise 2019);
- Ban lead fishing tackle, as has been done in Denmark and the United Kingdom (Ocean Wise 2019);
- Use alternatives to rubber crumb for artificial turf and playgrounds;
- Ensure that BC ENV permit holders and other Port of Vancouver tenants are preventing the discharge of lead into waterways;
- Improve public education, awareness, and regulation to ensure responsible replacement and disposal of lead-containing materials;
- Prioritize the implementation of source controls to reduce stormwater discharges into Burrard Inlet;
- Encourage more widespread adoption of green infrastructure and other design criteria that provide water quality treatment for stormwater runoff prior to discharge;
- Remediation of historically contaminated areas and hotspots to ensure that lead and other heavy metals cannot become suspended or made bioavailable. Vancouver Wharves, Vancouver Shipyard and Burrard Yarrows Shipyard have historically had lead levels that were elevated in sediment, which could become resuspended or surficial if dredging occurs; and
- Ensure that vessels comply with the Vessel Pollution and Dangerous Chemicals Regulation, for example to be in accordance with the International Maritime Organization Guidelines for Exhaust Gas Cleaning Systems (Government of Canada 2014) and minimize or eliminate contamination via discharge water.

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APPENDIX A: HEAT MAP ILLUSTRATIONS OF LEAD LEVELS IN BURRARD INLET SEDIMENT

Heat Map of Lead in Sediment Samples Collected by All Monitoring Programs from 1983-1987

Please note the data presented on this map may not be complete in all areas

Burrard Inlet Catchment (Study Area) (POBC2017)

Burrard Inlet Sub-Basin

- 1 - False Creek
- 2 - Outer Harbour
- 3 - Inner Harbour
- 4 - Central Harbour
- 5 - Port Moody Arm
- 6 - Indian Arm
- • 1983-1987 Lead Sample Site

1983-1987 Total Lead in Sediment (µg/g dry weight)

- 1972
- 30.2 (Proposed Water Quality Objective)
- 0

This heat map is based on interpolations from limited data obtained from specific sites, and is for illustrative purposes only. This map should not be used to infer actual values at particular sites. The map was developed through a combination of different interpolation methods in ArcGIS. Values were assigned to cells in between the points at which real data were taken, based on the relationship and distance between sample points, to produce a clean surface/gradient across the map. For more details refer to desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/how-topo-to-raster-works.htm

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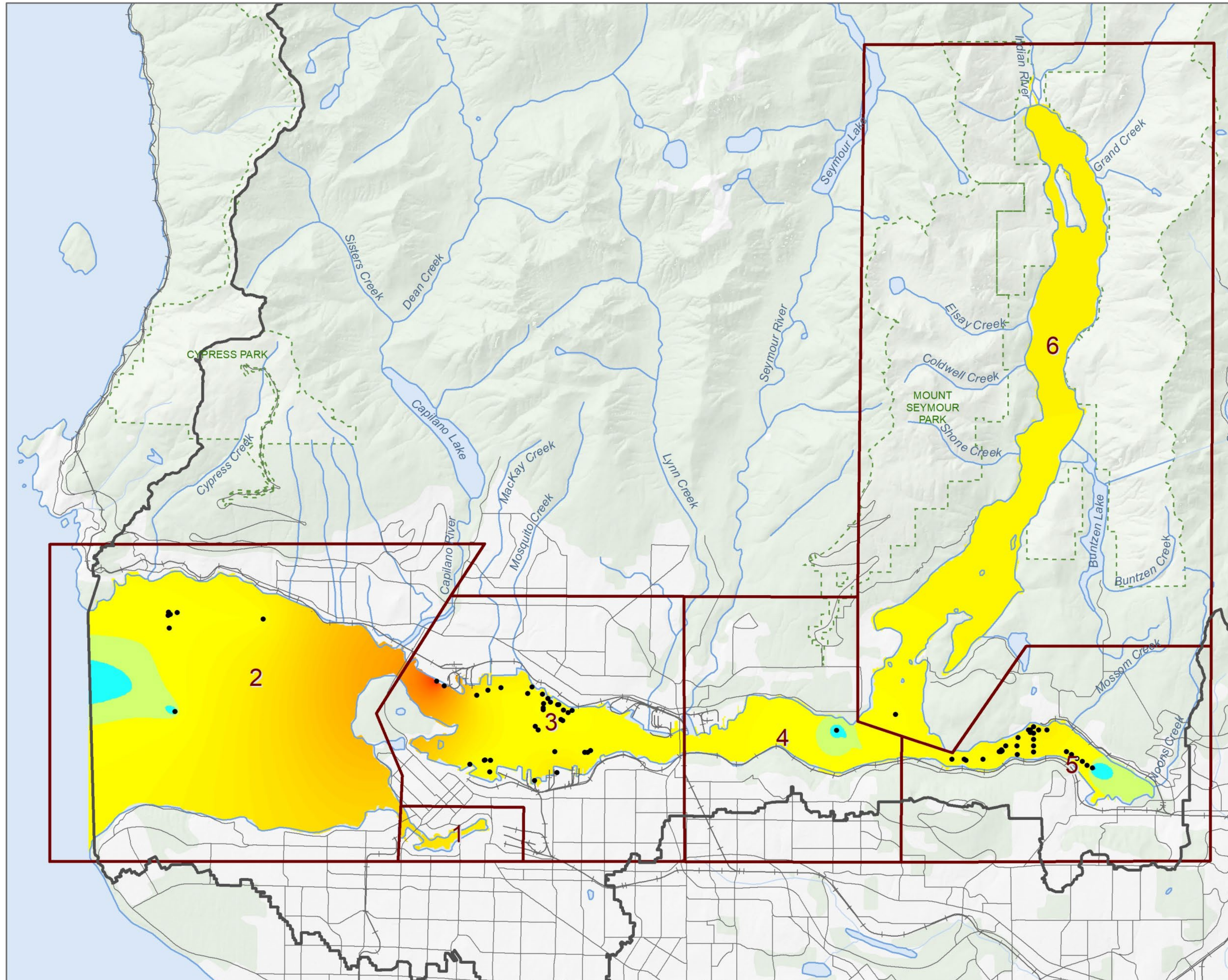

Heat Map of Lead in Sediment Samples Collected by All Monitoring Programs from 1988-1992

Please note the data presented on this map may not be complete in all areas

Burrard Inlet Catchment (Study Area) (POBC2017)

Burrard Inlet Sub-Basin

- 1 - False Creek
- 2 - Outer Harbour
- 3 - Inner Harbour
- 4 - Central Harbour
- 5 - Port Moody Arm
- 6 - Indian Arm
- • 1988-1992 Lead Sample Site

1988-1992 Total Lead in Sediment (µg/g dry weight)

1972

30.2 (Proposed Water Quality Objective)

0

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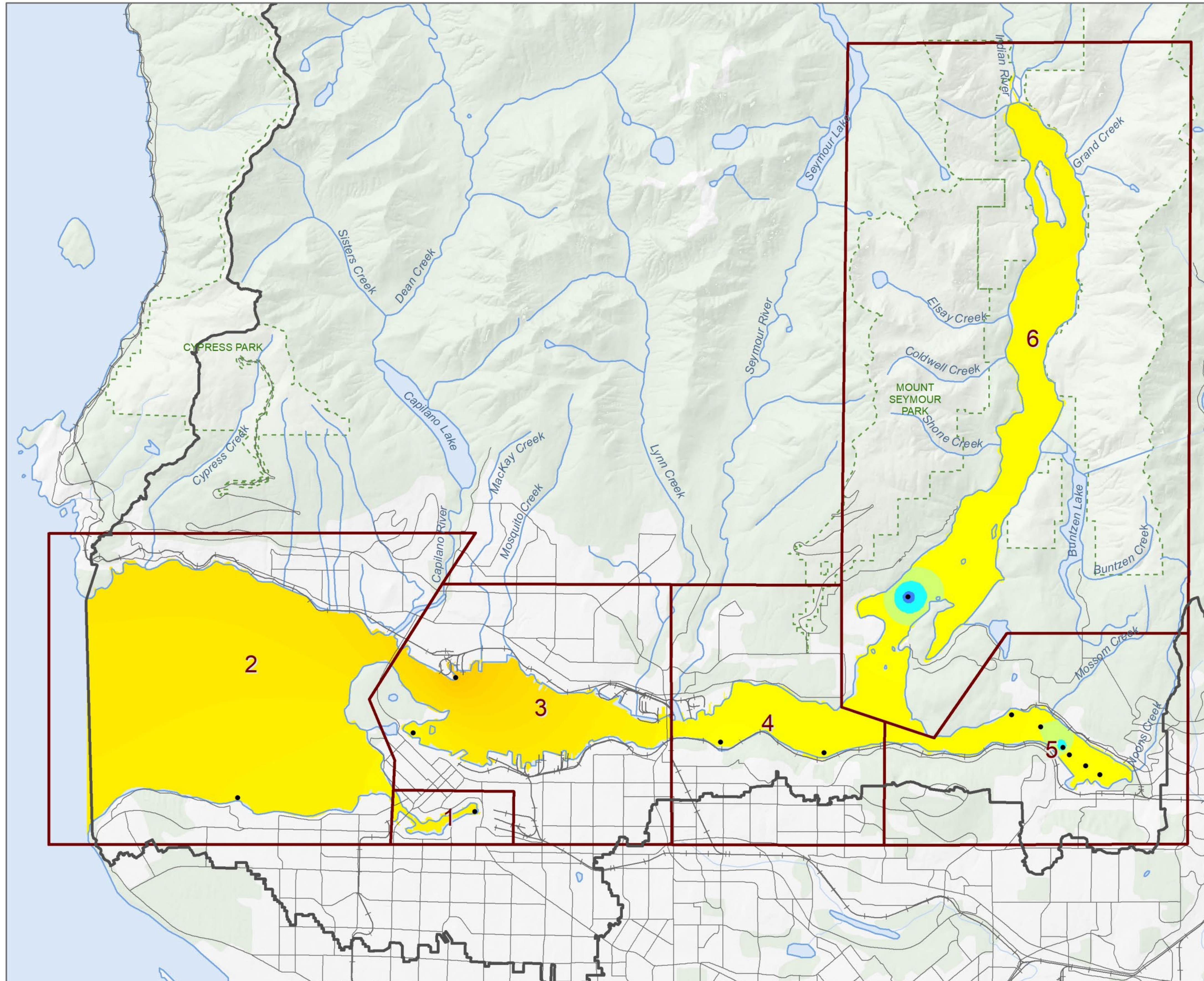

Heat Map of Lead in Sediment Samples Collected by All Monitoring Programs from 1993-1997

Please note the data presented on this map may not be complete in all areas

Burrard Inlet Catchment (Study Area) (POBC2017)

Burrard Inlet Sub-Basin

- 1 - False Creek
- 2 - Outer Harbour
- 3 - Inner Harbour
- 4 - Central Harbour
- 5 - Port Moody Arm
- 6 - Indian Arm

• 1993-1997 Lead Sample Site

1993-1997 Total Lead in Sediment (µg/g dry weight)

- 1972
- 30.2 (Proposed Water Quality Objective)
- 0

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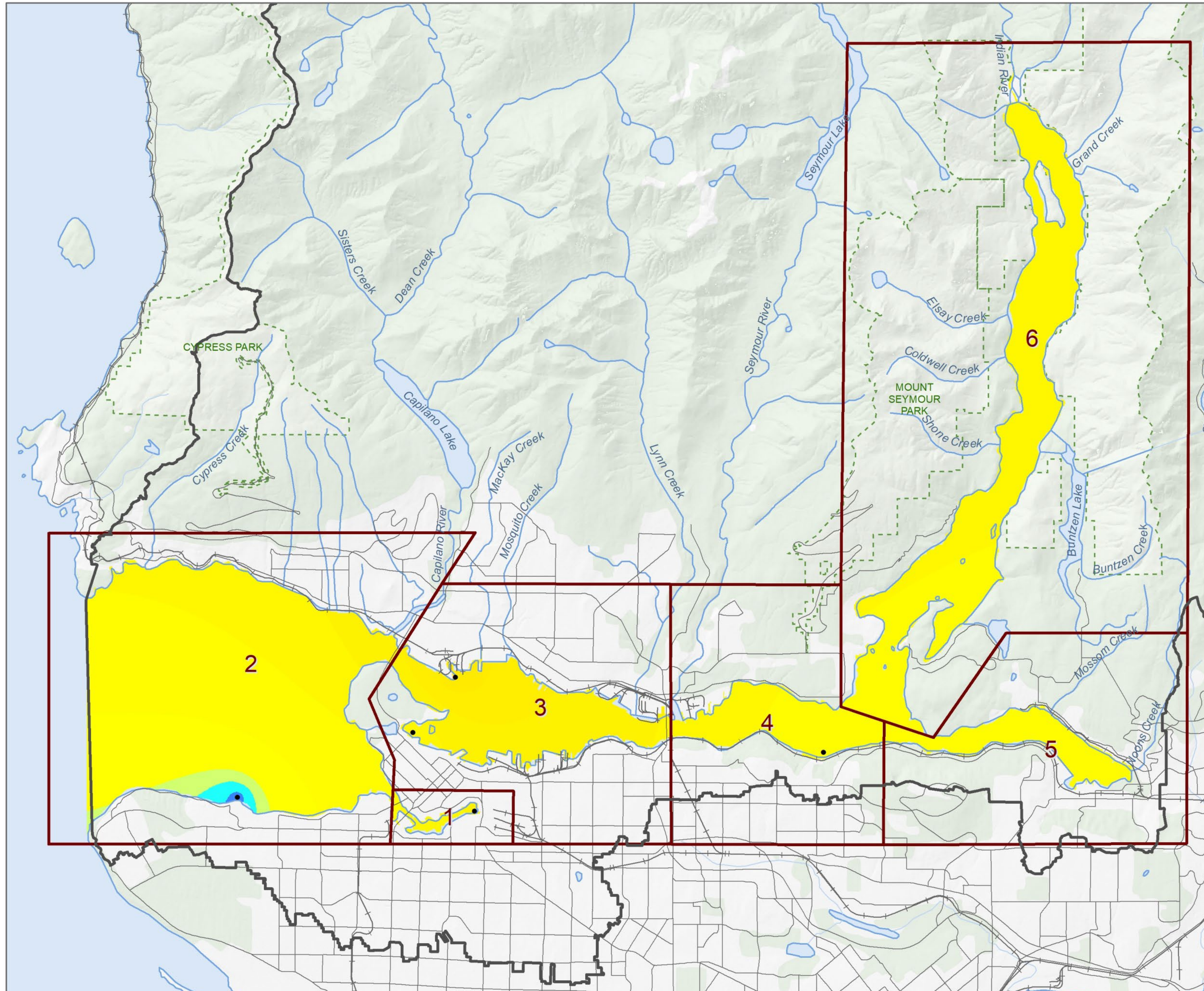

Heat Map of Lead in Sediment Samples Collected by All Monitoring Programs from 1998-2002

Please note the data presented on this map may not be complete in all areas

Burrard Inlet Catchment (Study Area) (POBC2017)

Burrard Inlet Sub-Basin

- 1 - False Creek
- 2 - Outer Harbour
- 3 - Inner Harbour
- 4 - Central Harbour
- 5 - Port Moody Arm
- 6 - Indian Arm
- • 1998-2002 Lead Sample Site

1998-2002 Total Lead in Sediment (µg/g dry weight)

- 1972
- 30.2 (Proposed Water Quality Objective)
- 0

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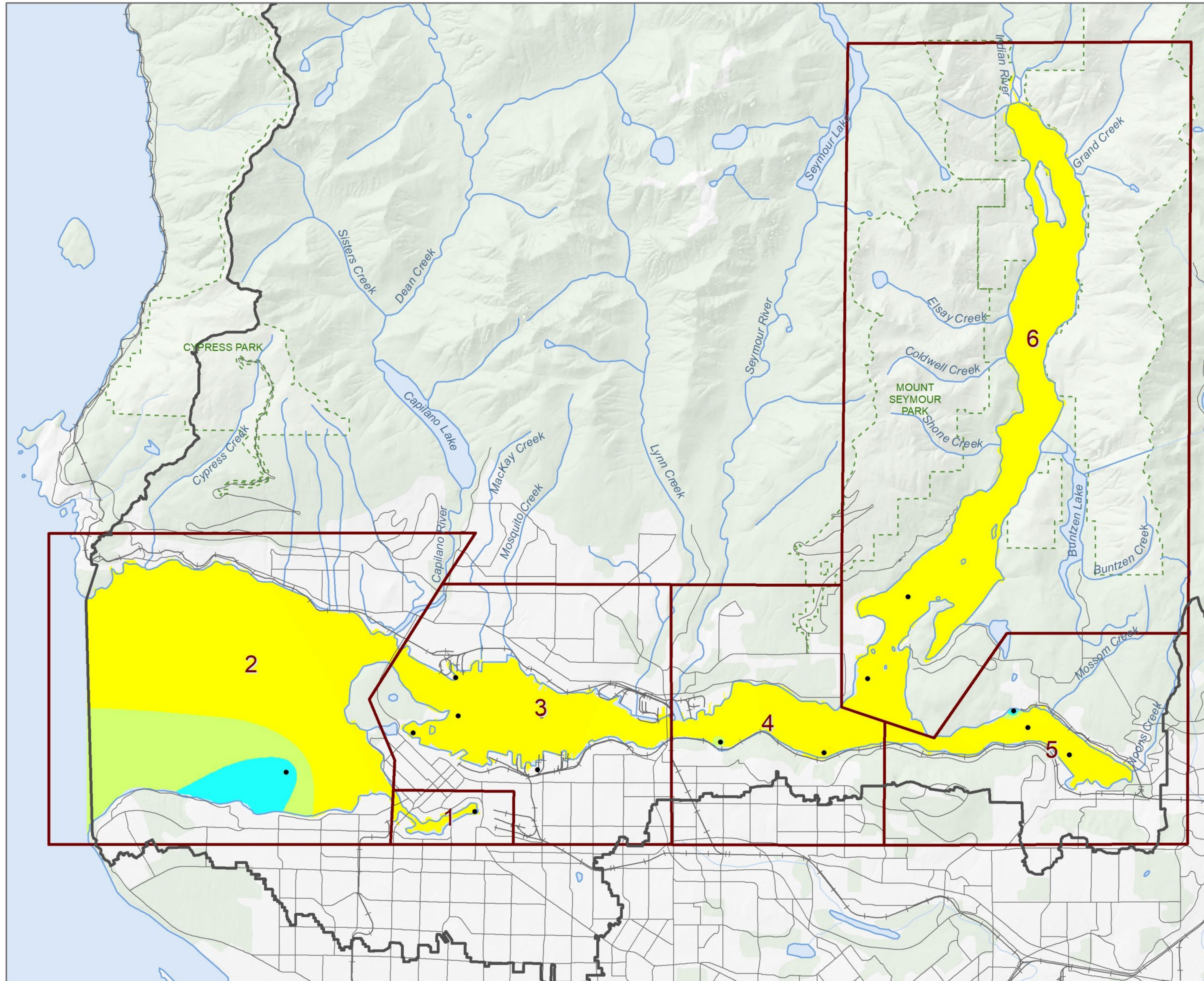

1

Heat Map of Lead in Sediment Samples Collected by All Monitoring Programs from 2008-2012

Please note the data presented on this map may not be complete in all areas

Burrard Inlet Catchment (Study Area) (POBC2017)

Burrard Inlet Sub-Basin

- 1 - False Creek
- 2 - Outer Harbour
- 3 - Inner Harbour
- 4 - Central Harbour
- 5 - Port Moody Arm
- 6 - Indian Arm

• 2008-2012 Lead Sample Site

2008-2012 Total Lead in Sediment (µg/g dry weight)

- 1972
- 30.2 (Proposed Water Quality Objective)
- 0

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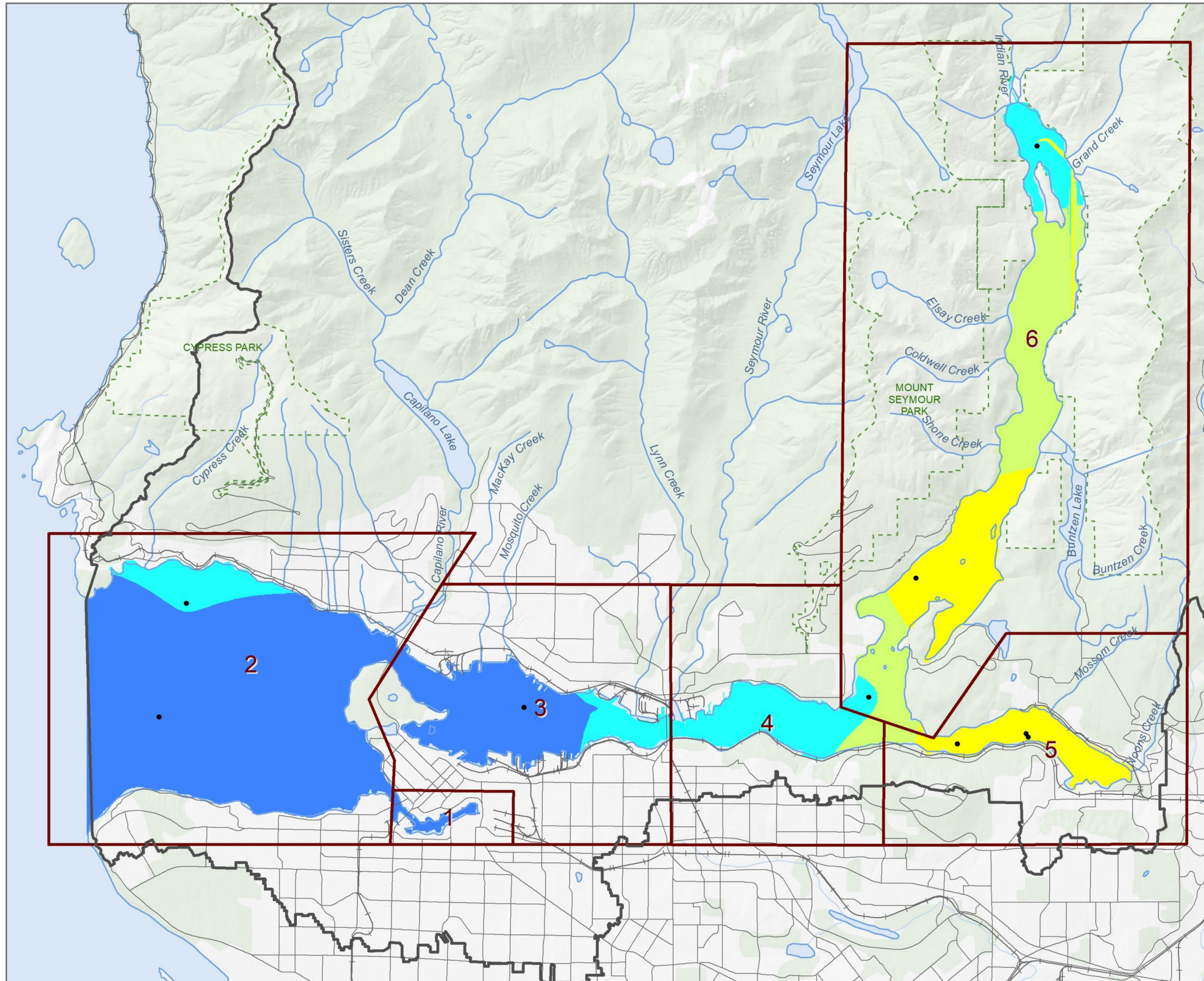

Heat Map of Lead in Sediment Samples Collected by All Monitoring Programs from 2013-2017

Please note the data presented on this map may not be complete in all areas

- Burrard Inlet Catchment (Study Area) (POBC2017)

Burrard Inlet Sub-Basin

- 1 - False Creek
- 2 - Outer Harbour
- 3 - Inner Harbour
- 4 - Central Harbour
- 5 - Port Moody Arm
- 6 - Indian Arm
- • 2013-2017 Lead Sample Site

2013-2017 Total Lead in Sediment (µg/g dry weight)

- 1972
- 30.2 (Proposed Water Quality Objective)
- 0

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