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

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Tsleil-Waututh Nation
səlilwətaɬ

British Columbia

This Technical Report forms part of a series of water quality parameter reports prepared with the purpose of informing 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. Photo Credit: Tsleil-Waututh Nation.

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CHAPTER SUMMARY

This chapter presents proposed water quality objectives for zinc in Burrard Inlet. These proposed objectives were developed using up-to-date research on relevant values and potential effects, sources and factors influencing zinc levels, benchmark screening, and historic and recent monitoring data for Burrard Inlet.

Zinc is an essential element that can be toxic to aquatic biota at elevated concentrations in both its dissolved and particulate forms. The water values most sensitive to zinc pollution are aquatic life and human consumption of shellfish and finfish. Toxicity of zinc is affected by factors that influence bioavailability such as particle size, hardness, pH, salinity, organic matter, metal oxide and sulphide levels, feeding behaviour, and uptake rates.

Most zinc discharged into the environment is from human activities, with stormwater runoff as a primary source of zinc entry into the marine environment. Sources of zinc include biocides, tires, brakes, oil and gas, galvanized metal surfaces, marine anodes and electronics. Zinc is also a component of several pharmaceuticals and personal care products and can therefore enter the sanitary sewer system.

BC water quality guidelines for zinc in water and sediment have been updated since 1990 (BC ENV 2017, 2019, 2020) and were used as benchmarks for screening zinc levels in water and sediment samples. Human health-based benchmarks were calculated and used to screen zinc levels in tissue samples (Thompson and Stein 2021).

Historic data indicate that zinc levels have been elevated near the vicinity of zinc sources, such as at Vancouver Wharves, where source controls for material handling were historically inadequate, and in False Creek, where there is a high concentration of stormwater outfalls and urban activity. Recent ambient monitoring indicates that zinc levels are generally lower than the benchmark levels.

The proposed marine water quality objectives for zinc are as follows:

Proposed Water Quality Objectives for Total Zinc

Sub-basin	Outer Harbour	False Creek	Inner Harbour	Central Harbour	Port Moody Arm	Indian Arm
Total Zinc in Marine Water	10 µg/L mean (no more than 20% of samples above 10 µg/L)[1] 55 µg/L maximum[2]					
Total Zinc in Marine Sediment	124 µg/g dry weight single-sample maximum[3]					
Total Zinc in Tissue	17 µg/g wet weight single-sample maximum (all tissue types)[4]					

[1] Minimum of 5 samples in 30 days collected during the wet season. No more than 20% of samples > 10 µg/L.
[2] Level not to be exceeded at any time.
[3] Based on at least 1 composite sample consisting of at least 3 replicates.
[4] 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.

Excessive zinc is toxic to humans and aquatic species, so continued monitoring of zinc in water, sediment, fish and mussel tissue is recommended. Further monitoring is recommended in the vicinity of:

- known sources of zinc, e.g., stormwater and combined sewer outfalls and permitted discharges;
- areas with elevated zinc levels due to historical practices such as Vancouver Wharves; and
- sub-basins with little recent data such as False Creek.

The primary management options to reduce the entry of zinc into Burrard Inlet include reducing the entry of zinc into the stormwater system and implementing green infrastructure that can absorb and treat stormwater prior to its discharge.

CONTENTS

FIGURES

TABLES

ACRONYMS

BC	British Columbia
BC ENV	British Columbia Ministry of Environment and Climate Change Strategy
BIEAP	Burrard Inlet Environmental Action Program
CCME	Canadian Council of Ministers of the Environment
EQOMAT	Environmental Quality Objectives and Monitoring Action Team
ISMP	Integrated Stormwater Management Plan
ISQG	Interim Sediment Quality Guideline
PEL	Probable effect level
TEL	Threshold effect level
TWN	Tsleil-Waututh Nation
US EPA	United States Environmental Protection Agency
US FDA	United States Food and Drug Administration
WQG	Water Quality Guideline
WQO	Water Quality Objective

1. INTRODUCTION

This chapter presents proposed water quality objectives for zinc in Burrard Inlet. This chapter includes relevant background information, an overview assessment of zinc levels in water, sediment, fish, and shellfish in Burrard Inlet, including a comparison to benchmarks, and a scientific rationale for the proposed objectives. Recommendations for future monitoring as well as management options to help achieve these proposed objectives are also included. Detailed context for this work and the Burrard Inlet area is provided in Rao et al. 2019.

2. BACKGROUND

2.1 Values and Potential Effects

Zinc is an essential element for plants and animals, including humans, in trace amounts (Nagpal 1999); however, it can be toxic to aquatic biota at elevated concentrations (CCME 1999). Zinc has been identified as one of the top five pollutants of concern in Puget Sound by the Puget Sound Toxics Loading Assessment (Bookter 2017). Both dissolved and particulate zinc are of concern. Zinc binds to particles and can be deposited into sediments; benthic organisms are therefore particularly vulnerable to zinc exposure (CCME 1999). Zinc exposure has been observed to decrease diversity and abundance, increase mortality and change behaviour of freshwater and marine benthic invertebrates. Toxicity varies with factors that influence bioavailability such as particle size, hardness, organic matter, metal oxide and sulphide levels, pH, salinity, feeding behaviour, and uptake rates (Environment Canada 1998, Nagpal 1999). The form of zinc that is most toxic to aquatic organisms is Zn2+ (ANZECC and ARMCANZ 2000).

Zinc has been found to be toxic to juvenile rainbow trout, with increased zinc toxicity at lower hardness values (stormwater typically has low hardness; Bailey 1999). It has also been observed to be toxic to water flea and fathead minnow (Tobiason and Logan 2000). Zinc can affect fish via disruption of respiratory and osmoregulatory functions (Niyogi and Wood 2004), and can bioaccumulate in aquatic organisms, particularly in crustaceans and bivalves (Nagpal 1999).

A Seattle-based study suggested that aquatic biota could be at risk from chronic exposure to zinc in stormwater, but that this risk was attenuated by removal, dilution and reduced bioavailability downstream from the points of discharge (Brix et al. 2010).

BC has adopted the Health Canada recreational water quality guidelines, which do not consider exposure to zinc and other inorganic chemical contaminants to be a significant health risk for recreational water users (BC ENV 2017, Health Canada 2012b).

With reference to the values described in Rao et al. 2019, the most sensitive values guiding water quality objectives for zinc in Burrard Inlet are aquatic life and human consumption of shellfish and finfish. The goal of the WQOs is to maintain zinc levels below values which would be toxic to aquatic life, and to humans who consume seafood at rates relevant to coastal Indigenous peoples.

2.2 Potential Sources of Zinc Pollution

Most zinc discharged into the environment is from human activities (Nagpal 1999). It can enter aquatic systems as a result of surface runoff or aerial deposition (CCME 1999).

Known and potential loading sources for zinc in Burrard Inlet identified in 1990 included combined sewer overflows, stormwater discharges, bulk ore handling facilities at Vancouver Wharves, leachate from the Premier Street landfill, provincially authorized discharges from the Electric Reduction Company of Canada[1], stormwater discharges from Pacific Coast Terminals and Imperial Oil, and effluent from Petro-Canada (Nijman and Swain 1990).

Surface runoff was identified as the major pathway for the entry of zinc into Puget Sound (Bookter 2017). Zinc is used as a rust-resistant coating for iron and steel products (Nagpal 1999). Zinc has been found in stormwater in both urban environments and at sawmill operations; sources include moss control products, wear of tires and brake linings, motor oil, diesel fuel, road surfaces, and runoff from galvanized metal surfaces such as roofs, gutters, downspouts, siding, turbines, equipment boxes, fences, light poles, steps, storm sewer pipes and truck trailer panels (Bailey et al. 1999, Bookter 2017, DOE 2008, Ozaki et al. 2004). In a contaminant loading study of 17 toxic chemicals in Puget Sound, it was estimated that more than 80% of zinc releases come from roofing materials; stormwater was described as a key pathway for transport (DOE 2011).

Zinc is also present in varnishes, linoleum, screens, batteries, electrical appliances, cement and concrete, preserved wood, agricultural chemicals, and chemicals used in firefighting exercises (Nagpal 1999). Zinc is used in marine anodes (PPRC 2019) and is present (e.g. as the biocide zinc pyrithione) in marine anti-fouling paints that are used as substitutes for tributyltin paint. Zinc pyrithione can photo-degrade to less toxic compounds but persists in shaded areas including under docked marine vessels (Bao et al. 2008).

Zinc can enter the sanitary sewer system, as it is available for ingestion as an over-the-counter supplement and is found in a variety of personal care products.

2.3 Factors Influencing Zinc Levels in Burrard Inlet

Zinc is believed to be most bioavailable when dissolved (Campbell and Tessier 1996). In aquatic environments, zinc forms complexes with dissolved organic matter (Florence and Batley 1977) and is adsorbed to organic matter, mineral particles, clays and hydrous oxides of manganese, iron, and silicon (Spear 1981 in Nagpal 1999). Zinc found in sediments is present as precipitated zinc, ferric and manganic hydroxides, and insoluble organic complexes and sulphides. The zinc released from sediments can become oxidized. The bioavailability of zinc in sediment is variable, depending on its speciation. In marine water, zinc is found in solution, as solid precipitate or adsorbed to particulates. At pH 8.1, most zinc is present as zinc hydroxide, followed by free ion, monochloride ion ($ZnCl^+$) and zinc carbonate. As pH decreases, the proportion of free ion zinc increases (U.S. EPA 1987 in Nagpal 1999). The relative proportions of the various forms of zinc also change with salinity, with zinc sulfate ($ZnSO_4$) and $ZnCl^+$ dominant at lower salinity (Spear 1981 in Nagpal 1999).

There is no definitive trend with respect to the toxicity effects of zinc in combination with other contaminants. The availability, sorption or binding of zinc to tissues, and therefore its toxicity, are affected by environmental factors such as calcium, magnesium and phosphate levels, dissolved oxygen, hardness, salinity, pH and temperature. Some organisms may acclimate over time to a higher level of zinc (Nagpal 1999). At pH levels below 8, zinc toxicity decreases with decreasing pH (Holcombe and Andrew 1978, Bradley and Sprague 1985, Harrison et al. 1986, Everall et al. 1989, Roy and Campbell 1995). Zinc pyrithione may be combined with copper in antifouling paints; their synergistic effects can result in increased toxicity of zinc pyrithione to marine invertebrates (Bao et al. 2008).

2.4 1990 Provisional Water Quality Objectives for Zinc

The 1990 provisional water quality objectives for zinc are outlined in Table 1. The 1990 objectives were set based on US national criteria derived by the US Environmental Protection Agency in 1985. The 1990 objectives for sediment were set for all sub-basins except for Indian Arm. The 1990 sediment quality

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[11] Currently ERCO Worldwide, a division of Superior Plus LP

objective for zinc was determined to be below the lowest measured Apparent Effects Threshold numbers from Puget Sound at the time, and no larger than three times the mean concentrations of reference sites in B.C., which included Boundary Bay and the Fraser River. There were no 1990 objectives for zinc in tissue (Nijman and Swain 1990).

Table 1: 1990 Provisional Water Quality Objectives for Zinc in Burrard Inlet

Sub-basin	False Creek	Outer Harbour	Inner Harbour	Central Harbour	Port Moody Arm	Indian Arm
Water	≤ 86 µg/L mean 95 µg/L maximum					
Sediment	150 µg/g dry weight maximum					N/A
Tissue	None					
All values are for total zinc levels.						

3. <u>WATER QUALITY ASSESSMENT</u>

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 proposed objectives for zinc levels in Burrard Inlet. Based on the available literature, aquatic life is the value most sensitive to zinc levels in the water column and sediments. Finfish and shellfish consumption by humans may be the most sensitive values for zinc levels in tissue, though limited data is available. Water and sediment benchmarks were used to screen for protection of aquatic life while fish and mussel tissue benchmarks were used to screen for human health.

The screening benchmarks chosen for the data assessment in this report are summarized in Table 2. All values are for total zinc levels. Canadian guidelines for the protection of these values were used as benchmarks, where available. 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 2019);
2. BC working water quality guidelines published by BC ENV (BC ENV 2020); 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).

Guidelines for zinc in tissue were not available, so human-health based screening values for fish and shellfish tissue were derived from Health Canada toxicological reference values and risk assessment methodologies (Health Canada 2010a,b,c, 2012a; Richardson 1997, Richardson and Stantec 2013). Details about the methods used are described below, with more details available in Thompson and Stein (2021).

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

Sample Type	Screening Benchmark	Status	Value	Reference
Water	10 µg/L mean (chronic benchmark) 55 µg/L maximum (acute benchmark)	Approved	Marine aquatic life	BC Water Quality Guideline, from Nagpal 1999
Sediment	124 µg/g dry weight mean (TEL)[a] 271 µg/g dry weight maximum (PEL)[a]	Working	Marine aquatic life	BC Working Water Quality Guidelines, BC ENV 2020 and CCME 1999
Tissue[b]	17 µg/g wet weight (toddler subsistence fisher benchmark) 40 µg/g wet weight (adult subsistence fisher benchmark) 79 µg/g wet weight (adult recreational fisher benchmark)	N/A	Human consumption of finfish and shellfish	Screening value calculated from Health Canada 2010c

[a] 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.
[b] Calculated screening value for which zinc 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.

The science on the effects of zinc has progressed since 1990, and BC water and sediment quality guidelines for zinc have since been updated (Nagpal 1999; BC ENV 2017, 2019, 2020). Therefore, the 1990 objectives were not used as screening benchmarks.

Benchmarks for zinc levels in water are based on the BC Approved Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture (ENV 2017). The mean screening benchmark (chronic) for water is based on the long-term mean (chronic)[2] BC water quality guideline of 10 µg/L, which was developed using the lowest observable effect level, (19-19.6 µg/L zinc for the marine algae *S. schroederi* and *S. constatum*) with a safety factor of 0.5 incorporated (Nagpal 1999). There is no current national marine water quality guideline for zinc (CCME 2018) and no published federal environmental quality guideline for zinc (Government of Canada 2019). The maximum screening benchmark (acute) for water is based on the short-term maximum (acute)[3] BC water quality guideline of 55 µg/L, which was developed using the lowest observable acute effect levels (112-168 µg/L for Arctic grayling [*Thymallus arcticus*] and 119 to 310 µg/L for Pacific oyster [*Crassostrea gigas*]), with a safety factor of 0.5 incorporated.

Benchmarks for zinc 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 zinc in sediment. The working B.C. sediment guideline of 124 µg/g dry

[2] According to BC ENV (2016), "Long-term average (i.e. chronic) WQGs are intended to protect the most sensitive species and life stage against sub-lethal and lethal effects for indefinite exposures. An averaging period approach is used for these WQGs. This approach allows concentrations of a substance to fluctuate above and below the guideline provided that the short-term maximum is never exceeded and the long-term average is met over the specified averaging period (e.g. 5 samples in 30 days). Averaging periods are chosen as reasonable and practical durations to address long-term effects and to fit into monitoring timetables."
[3] According to BC ENV (2016), "A short-term maximum (i.e. acute) WQG is a level that should never be exceeded in order to meet the intended protection of the most sensitive species and life stage against severe effects such as lethality over a defined short term exposure period (e.g. 96 hrs). Short-term maximum WQGs are intended to assess risks associated with infrequent exposure events such as spills."

weight (interim sediment quality guideline, ISQG, based on the threshold effect level, TEL) and 271 µg/g dry weight (probable effect level, PEL) is based on the CCME guideline for zinc from 1998 (BC ENV 2020). This CCME guideline was developed using a modification of the National Status and Trends Program approach described in the CCME's 1995 Protocol for the Derivation of Sediment Quality Guidelines for the Protection of Aquatic Life (CCME 1999).

There were no BC or CCME tissue guidelines for zinc at the time of writing. There was no Canadian Food Inspection Agency guideline for human consumption of zinc in tissue at the time of writing. The US EPA has derived a human health ambient water quality criterion for zinc of 26,000 µg/L for the consumption of organisms (US EPA 2002) and a criterion of 5000 µg/L for organoleptic effects (US EPA 1986). Washington State's water quality criterion applicable for human consumption of organisms is 2900 µg/L zinc, based on a fish consumption rate of 175 g/day (Washington State Legislature 2019). There is no US Food and Drug Administration action level for zinc in fish or shellfish (US FDA 2000).

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 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, recreational, and general BC populations, with screening values 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 (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).

Tissue screening values 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). Screening values provide general guidance to environmental managers and represent a suggested safe level of a contaminant in fish tissue based on a conservative estimate of a person's fish consumption per day; they do not provide advice regarding consumption limits or constitute a fishing advisory. Exceedances of a screening value may indicate that further investigation to assess human health risk at a particular site is warranted; however, exceeding a screening value does not imply an immediate risk to human health (Thompson and Stein, 2021).

Tissue screening values 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 zinc assumed to come from country foods (in this case, wild seafood). Three screening values were selected to capture a range of potential fishers. The most conservative screening value is protective of a toddler from a subsistence fisher population while the less conservative screening values are protective of adult subsistence fishers and adult recreational fishers. Three benchmarks were selected for tissue in order to provide more reference points for the data assessment.

3.2 Data Sources

Data on zinc levels in Burrard Inlet were gathered from several recent and historic studies and monitoring programs. A summary of the datasets used for this assessment is presented in Table 3. Although other datasets containing zinc sampling data may exist, these priority datasets were found to contain the best available data for assessing the status of zinc within Burrard Inlet within the constraints of the project. Maps showing the distribution of sampling sites for the recent 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	614 water 8 sediment	19 water 6 sediment	Irregular	Total and dissolved zinc in water Total zinc in sediment by dry weight
Environment Canada	Benthic Contaminants Study, 1985–1987	Not listed	73 sediment 11 tissue	6 surveys	Total zinc in sediment by dry weight Total zinc 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 zinc in sediment by dry weight
BC ENV	Provincial Water Quality Objectives Attainment Monitoring, 1990–2009	965 water 78 sediment 17 tissue	14 water 12 sediment	1–10 samples/year, irregular Water samples generally reported as maximum values and mean of 5 samples in 30 days	Total and dissolved zinc in water Total zinc in sediment by dry weight Total zinc in English sole tissue, dry or wet weight not stated
Metro Vancouver	Burrard Inlet Ambient Monitoring Program, 2007–2016	710 water 210 sediment 73 tissue	7	5 water samples/year, regular. Reported as maximum values and mean of 5 samples in 30 days 3-6 sediment samples/site/2 years, regular Tissue samples in 2007 and 2012	Total and dissolved zinc in water Total and extractable zinc in sediment by dry weight Total zinc in English sole tissue by wet weight
Ocean Wise	Pollution Tracker, 2015–2016	18 sediment 15 tissue	13 sediment 9 tissue	3 sediment samples and 50–200 mussels per site on a single day in October 2015, December 2015 or April 2016	Total zinc in sediment by dry weight Total zinc in mussel tissue by wet weight

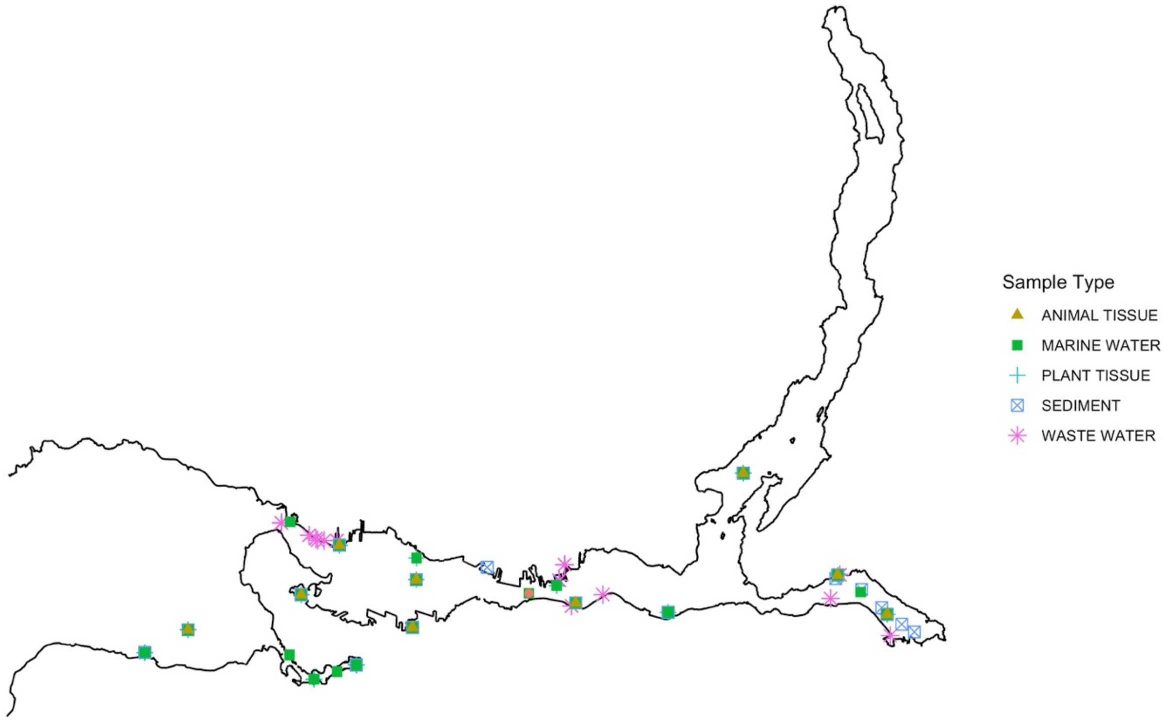

Figure 1: BC ENV sampling stations in Burrard Inlet (1971 to 2009)

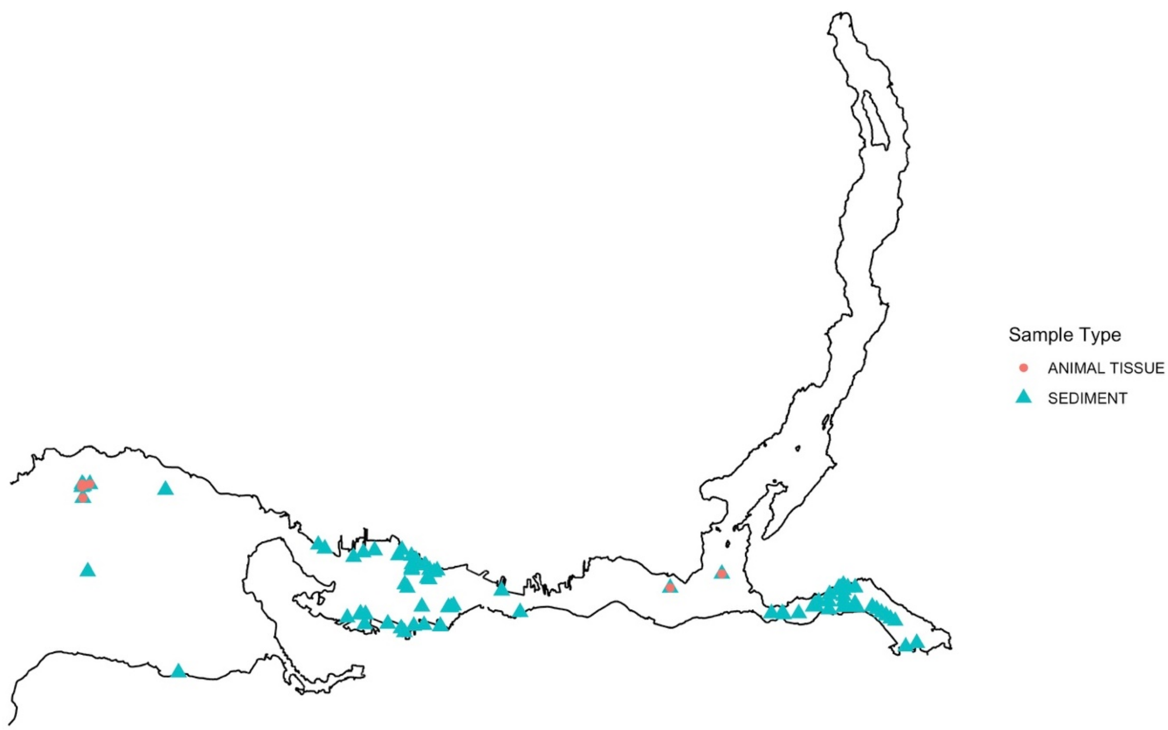

Figure 2: Environment Canada sampling stations in Burrard Inlet (1985 to 1987)

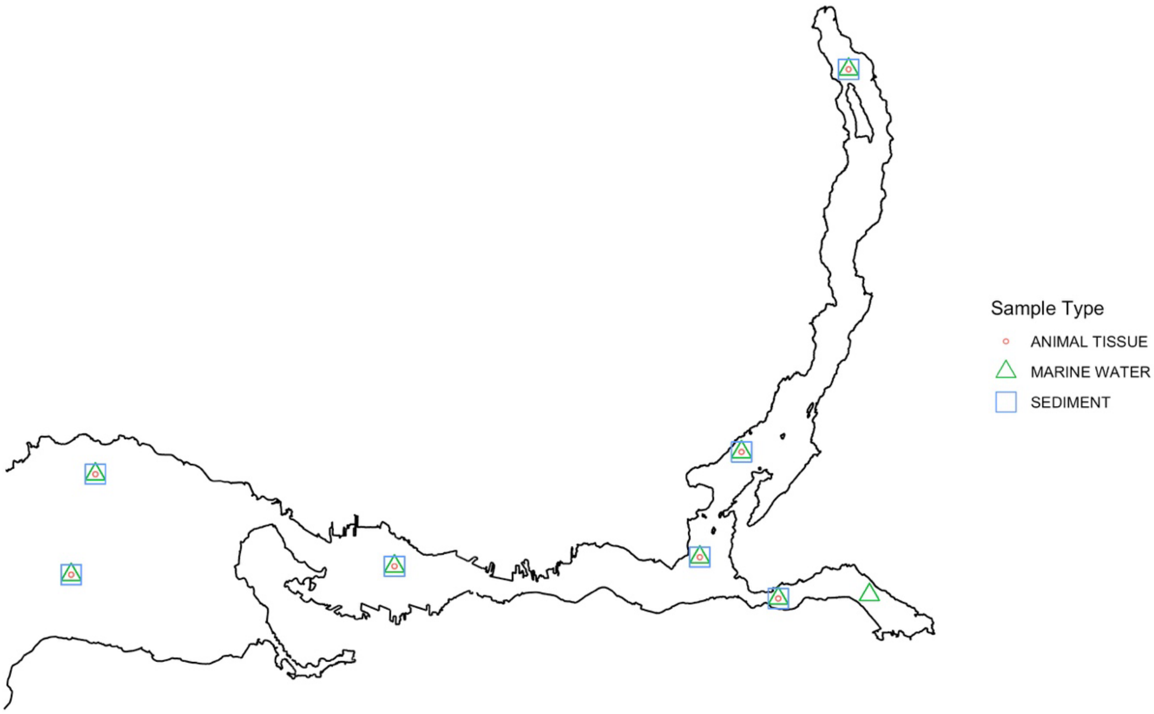

Figure 3: Metro Vancouver sampling stations in Burrard Inlet (2007 to present)

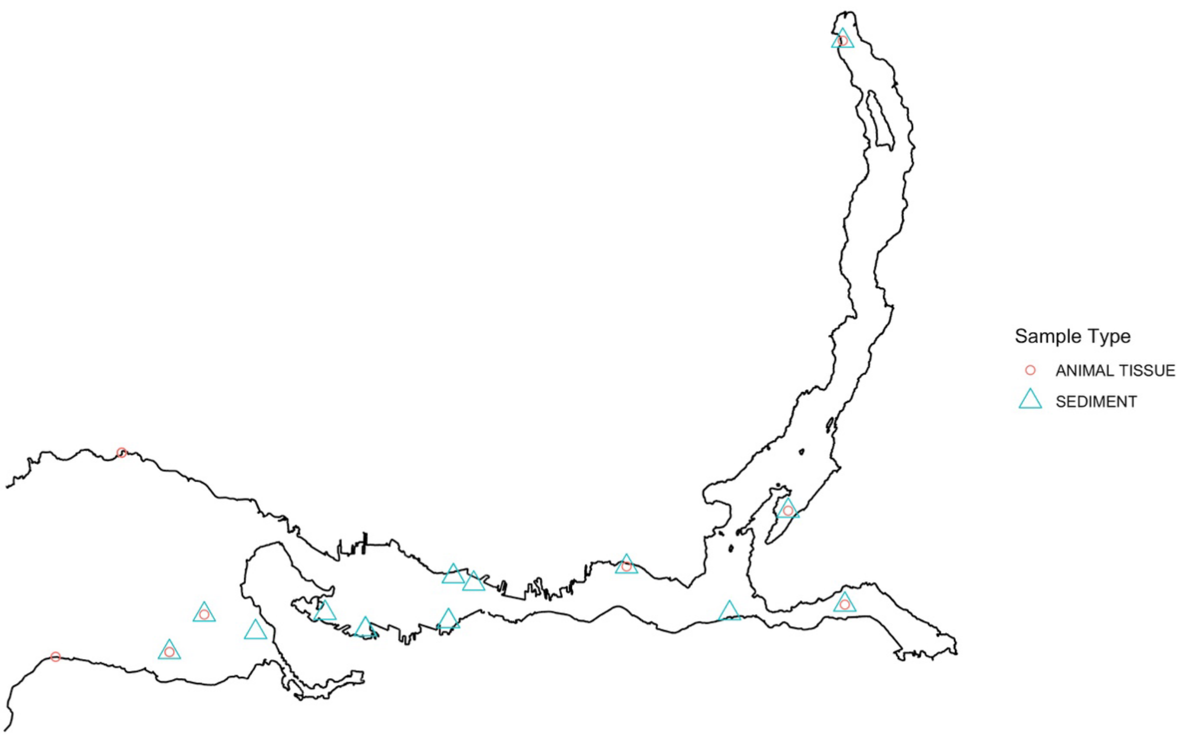

Figure 4: Pollution Tracker sampling stations in Burrard Inlet (2015 to 2016)

3.3 Assessment Results

The results of the data assessment for zinc 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 zinc levels were below detection limits, values were plotted at the detection limit value and identified with a triangle marker in Figure 6 through Figure 12. Detection limits in the database for the key monitoring programs range from 0.005 µg/L to 20 µg/L for total zinc in marine water, from 0.5 µg/g to 2 µg/g for total zinc in sediment, and from 0.04 µg/g to 0.5 µg/g for total zinc in animal tissue. Older data frequently have higher detection limits due to improvements in analytical methods over the past 50 years. Detection frequency was calculated and is noted throughout the assessment for each monitoring program. 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. All data presented are for total zinc levels, unless indicated.

Heat maps illustrating the distribution of zinc 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 while historic data may indicate that zinc levels in parts of Burrard Inlet may have been higher prior to 2002 than at present, differences in sampling frequency and method detection limits do not allow for direct comparison of historic data with recent data. Nagpal (1999) warns that historical records of zinc concentrations may be artificially high as a result of contamination during measurement and poorer detection methods. Instead, the heat maps may be used to illustrate the best understanding of potential areas where zinc levels may be relatively high in comparison to the rest of Burrard Inlet.

Historic Data (pre-1990)

- 1985–1987 – The Environment Canada Benthic Contaminants Study (Goyette and Boyd, 1989) observed zinc in surface sediment samples above the detection limit at all stations. Mean zinc levels in sediment exceeded the TEL benchmark (124 µg/g) at 56 of 73 (77%) of the monitoring stations. The highest maximum zinc levels were above the PEL benchmark (271 µg/g) and were observed on the northern side of Inner Harbour near Vancouver Wharves (average 417 µg/g, range 113 to 2276 µg/g). The largest source of zinc in Burrard Inlet was thought to be the concentrate loading area at Vancouver Wharves due to zinc concentrate spillage during vessel loading and unloading. The distribution of zinc in sediment measured in the study is illustrated in Figure 5. Zinc levels in English sole (*Parophrys vetulus*) fish tissue ranged from 5.1 to 39.8 µg/g, which is similar to zinc levels in fish tissue reported for unpolluted coastal areas of BC (Harding and Goyette, 1989).

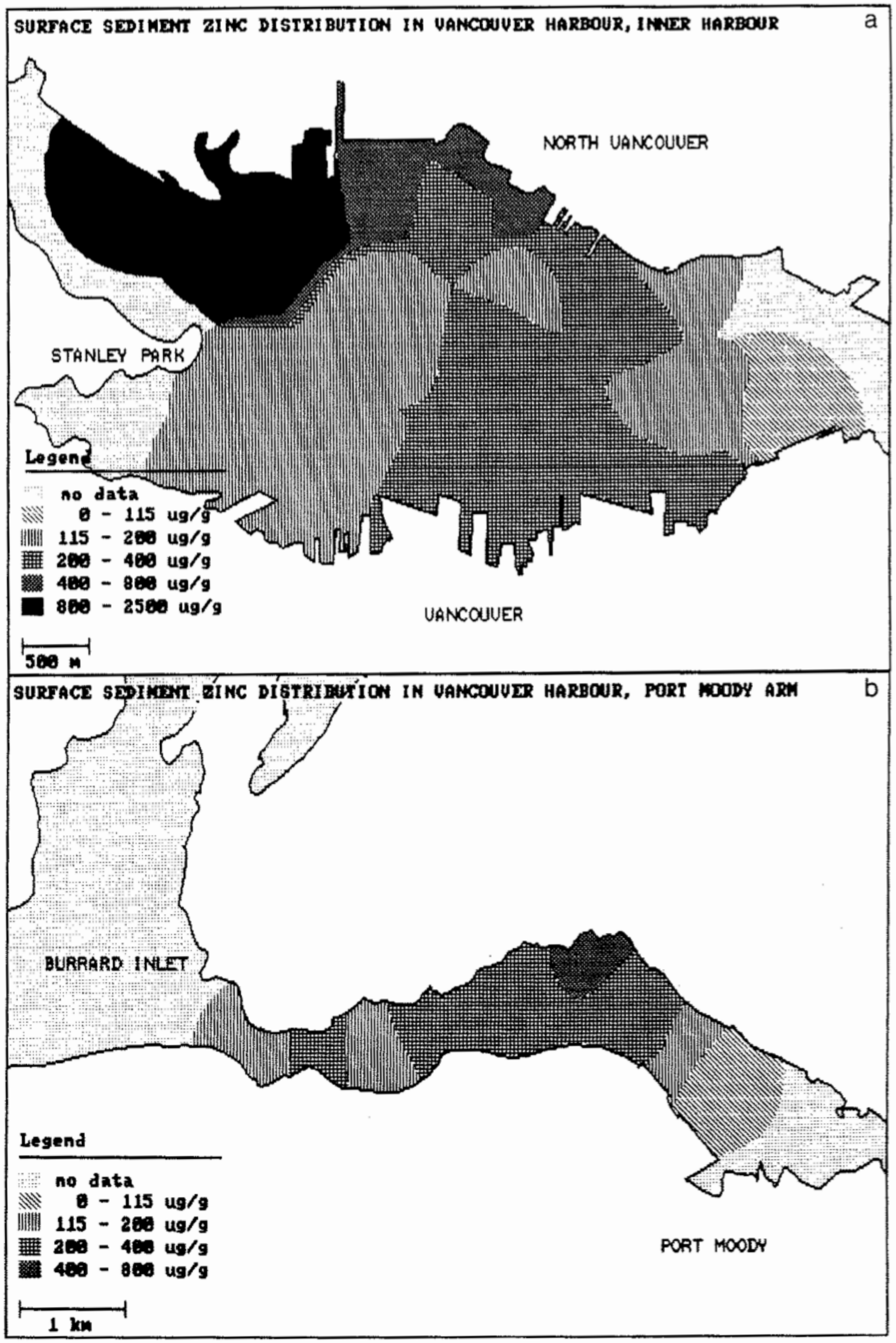

Figure 5: Surface sediment zinc distribution in Burrard Inlet (from 1985 to 1986) (a) Inner Harbour and (b) Port Moody Arm (from Goyette and Boyd, 1989)

- 1971–1990 – BC ENV monitoring samples collected between 1971 and 1990 for zinc were above detection limits for 66% 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 5 and 20 µg/L, creating some uncertainty in the interpretation of potential patterns and comparison to benchmarks given that the chronic benchmark is 10 µg/L.
    - Annual mean zinc levels in water samples were frequently above the acute benchmark (55 µg/L) in all sub-basins, except for Port Moody Arm where no sampling was conducted. The highest zinc levels were observed in water samples collected at False Creek 'Burrard St Br' (Station 300081; mean 41 µg/L, maximum 410 µg/L), and False Creek Cambie St (Station 300082; mean 69 µg/L, maximum 380 µg/L).
    - Zinc levels in sediment ranged from 176 µg/g at Port Moody Arm near Pacific Coast Terminal #11 (station E207702) in 1988 to 678 µg/g at Port Moody Arm near Pacific Coast Terminal #14 (station E207701) in 1988.

Recent Data (post-1990)

- 1998 – The BIEAP Sediment Quality Study (EQOMAT, 1998) observed zinc in surface sediments above the detection limit in all 45 samples. The highest zinc levels were detected in the Inner Harbour where samples at location 3A, slightly east of Vancouver Wharves, measured between 519 and 981 µg/g and exceeded the PEL benchmark of 271 µg/g. Elevated zinc levels were also recorded in False Creek (221 to 235 µg/g) and in Port Moody Arm (202 to 215 µg/g) with levels exceeding the TEL benchmark (124 µg/g). The lowest zinc levels were recorded in Indian Arm where levels of zinc in sediment were between 48 and 51 µg/g.
- 1990–2009 – BC ENV water quality objectives attainment monitoring samples collected between 1990 and 2009 were above zinc detection limits for 38% of water samples, 100% of sediment samples, and 100% of tissue samples. Detection limits ranged from 1 to 5 µg/L for water samples, were not listed for sediment samples and were 0.5 µg/g for fish tissue. The wide range of detection limits for zinc in water samples may impact the interpretation of the water sample results. The following key points summarize the monitoring results:
    - Of the 38% of values that were above detection limits in water samples, there were frequent exceedances of the acute benchmark (55 µg/L) with maximum levels reaching 271 µg/L in the Inner Harbour at Vancouver Wharves (Station E207816). An illustration of zinc levels in BC ENV's water samples is provided in Figure 6.
    - Sediment samples exceeded the PEL benchmark (271 µg/g) at several stations prior to 2002 including English Bay at Locarno Park (Station E207812), False Creek East End (Station E207814), Coal Harbour South Shore (Station E207813), Vancouver Harbour Clarke Drive (Station E207818), Vancouver Wharves (Station E207816), Port Moody Arm Pacific Coast #14 (Station E207701) and Port Moody Arm #11 (Station E207698). Vancouver Wharves had frequent and high levels of zinc in sediment in the early 1990s with maximum levels of 1780 µg/g. Measured 2002 levels ranged from 92 µg/g at English Bay Centre (Station 300076) to 398 µg/g at Vancouver Wharves. These levels would be high enough to designate Vancouver Wharves as contaminated with zinc under the BC Contaminated Sites Regulation 13/2019, since the levels are above 330 µg/g, which is the generic numerical sediment criteria for typical marine and estuarine conditions. Zinc levels in BC ENV sediment samples are illustrated in Figure 7.
    - From samples collected in 2003, English sole tissue samples ranged from 3.4 µg/g to 6 µg/g, which is below the screening benchmark of 17 µg/g.

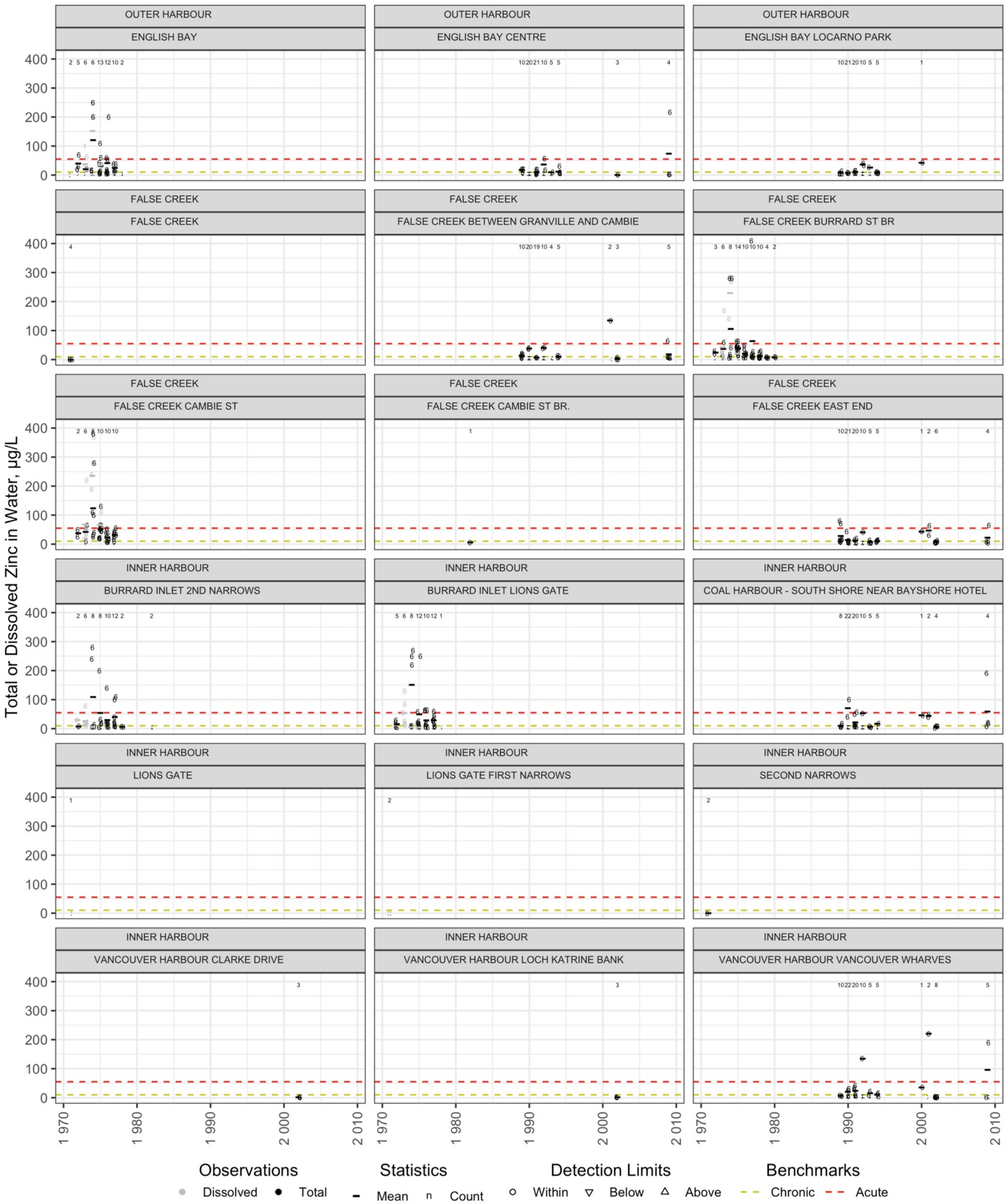

Figure 6: Zinc levels in BC ENV water samples (1970 to 2009) in µg/L

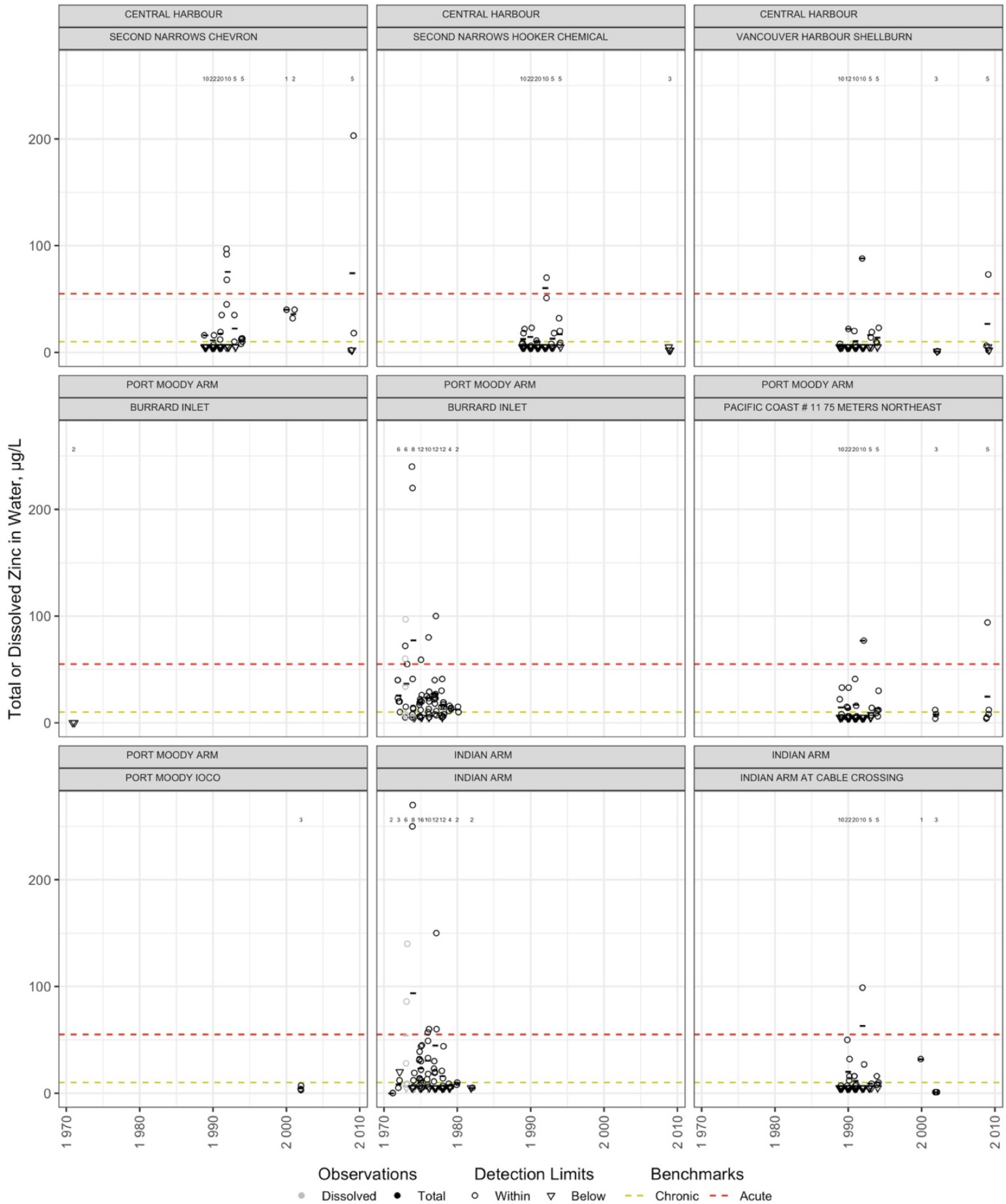

Figure 6: Zinc Levels in BC ENV water samples (1970 to 2009) in µg/L (continued)

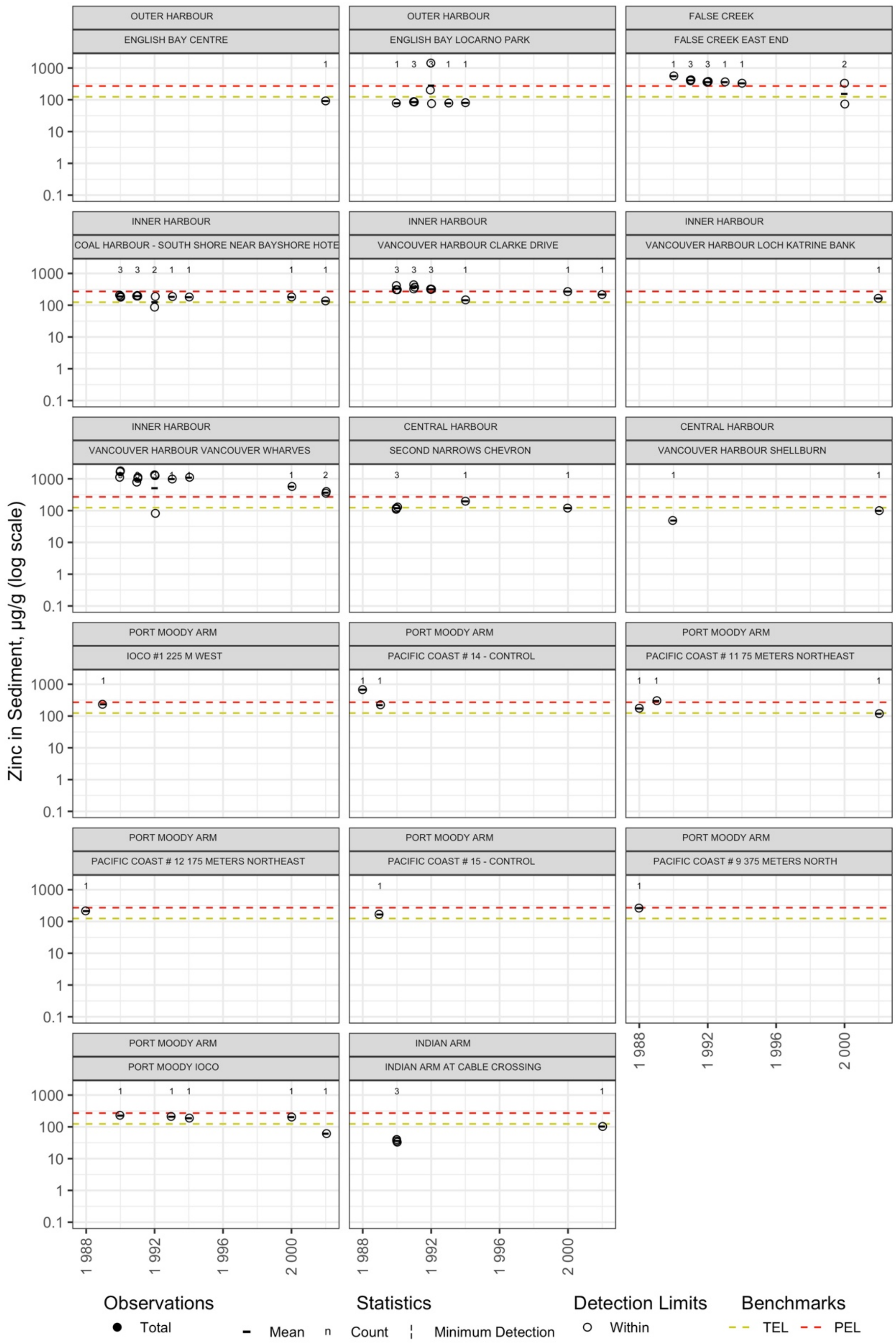

Figure 7: Zinc levels in BC ENV sediment samples (1988 to 2009) in µg/g

- 2007–2016 – As part of the Burrard Inlet Ambient Monitoring Program, Metro Vancouver has monitored zinc levels in the water column annually (Figure 8) and in sediment every 2 to 3 years (Figure 9) since 2008. English sole tissue (whole body, muscle, and liver) samples were measured in 2007 and 2012 (Figure 10). Between 2007 and 2016, zinc levels were above detection limits for 92% of water samples, 100% of sediment samples, and 100% of tissue samples. Detection limits were between 0.5 µg/L and 0.8 µg/L for water samples, 0.5 µg/g to 1 µg/g for sediment samples, and 0.01 µg/g to 0.1 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 than on the BC ENV monitoring data. The following key points summarize the Metro Vancouver monitoring results:
    - Mean zinc levels in the water samples exceeded the chronic benchmark at Outer Harbour South in 2007, in this program (Figure 8). The highest zinc level measured was at Outer Harbour South (44.8 µg/L) in 2007. Across all locations, mean levels of 5 samples collected over 30 days range from <1 µg/L to 23 µg/L.
    - Metro Vancouver analyzed both total and extractable zinc levels in sediment samples but only total zinc levels were part of this scope (Figure 9). Mean and maximum zinc levels in the sediment samples exceeded the PEL benchmark only at Port Moody Arm in 2016 but frequently exceed the TEL benchmark, especially in Port Moody Arm and Indian Arm South. The highest zinc level measured was at Port Moody Arm (366 µg/g) in 2016.
    - English Sole fish tissue samples exceeded the screening benchmark for adults in a subsistence fishing population (40 µg/g wet weight) for liver samples at all monitoring locations. Whole body samples exceeded the screening benchmark for toddlers in a subsistence fishing population (17 µg/g wet weight) at Port Moody Arm in 2007. There were no exceedances of the screening benchmark for adults in a recreational fishing population (79 µg/g wet weight) and no muscle tissue samples exceeded any of the benchmarks. The highest value recorded value for liver tissue (72.6 µg/g wet weight) was measured in Indian Arm South in 2007. The highest value recorded for whole body tissue (18.6 µg/g wet weight) was measured in Port Moody Arm in 2007. The highest value recorded in muscle tissue (5.8 µg/g wet weight) was measured in Port Moody Arm in 2007 (Figure 10).

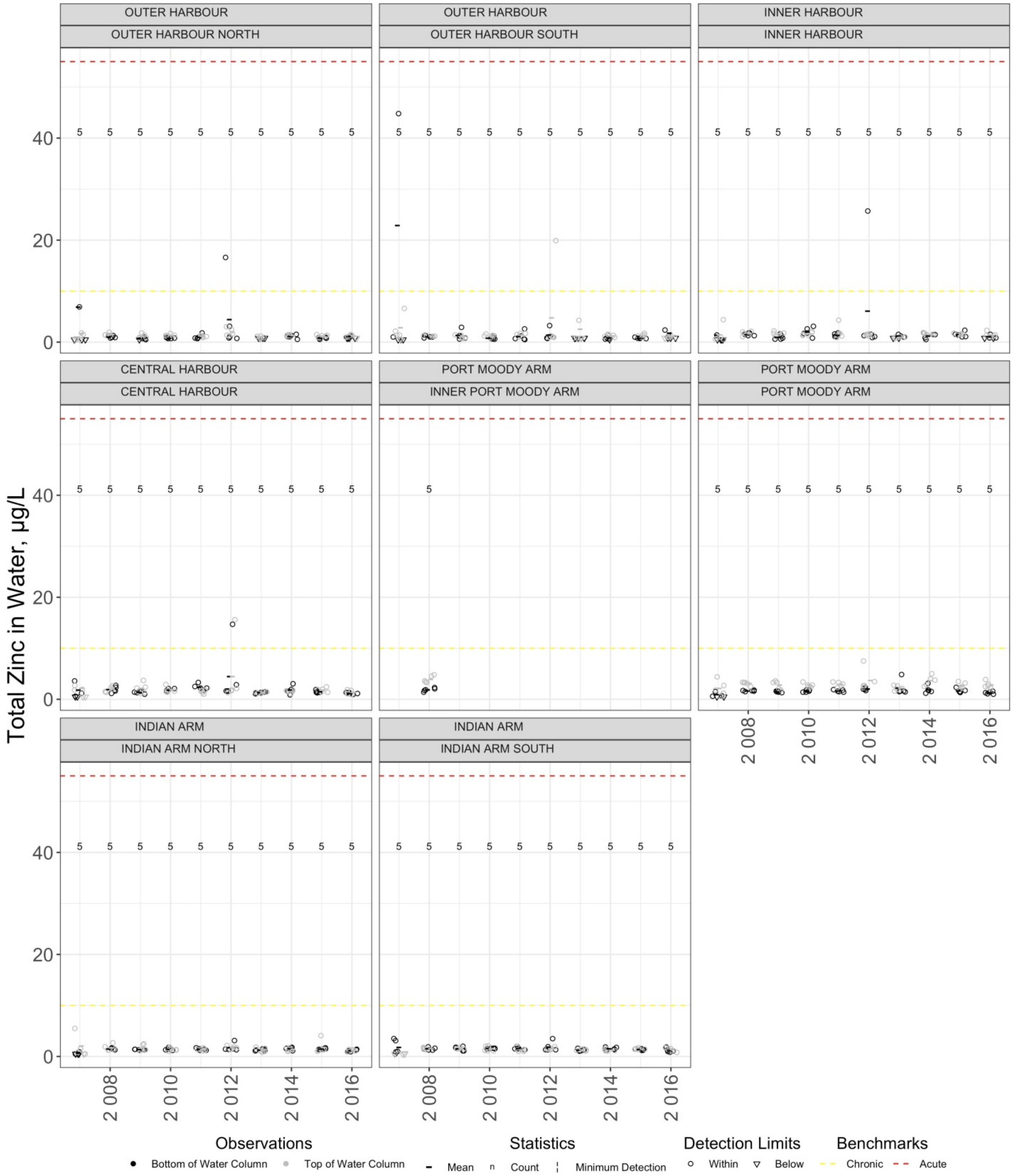

Figure 8: Zinc levels in Metro Vancouver water column samples (2007 to 2016) in µg/L

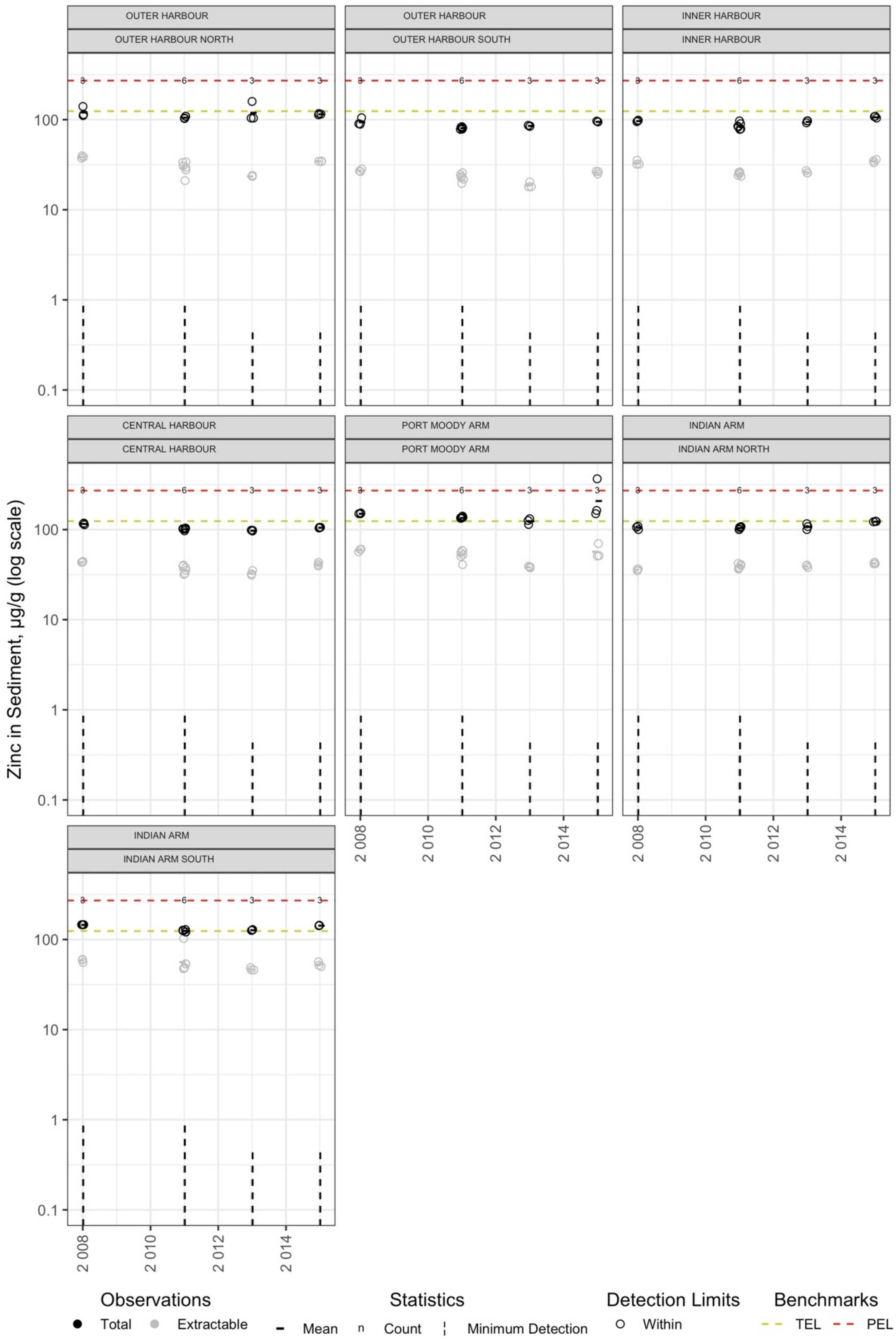

Figure 9: Zinc levels in Metro Vancouver sediment samples (2008 to 2016) in µg/g

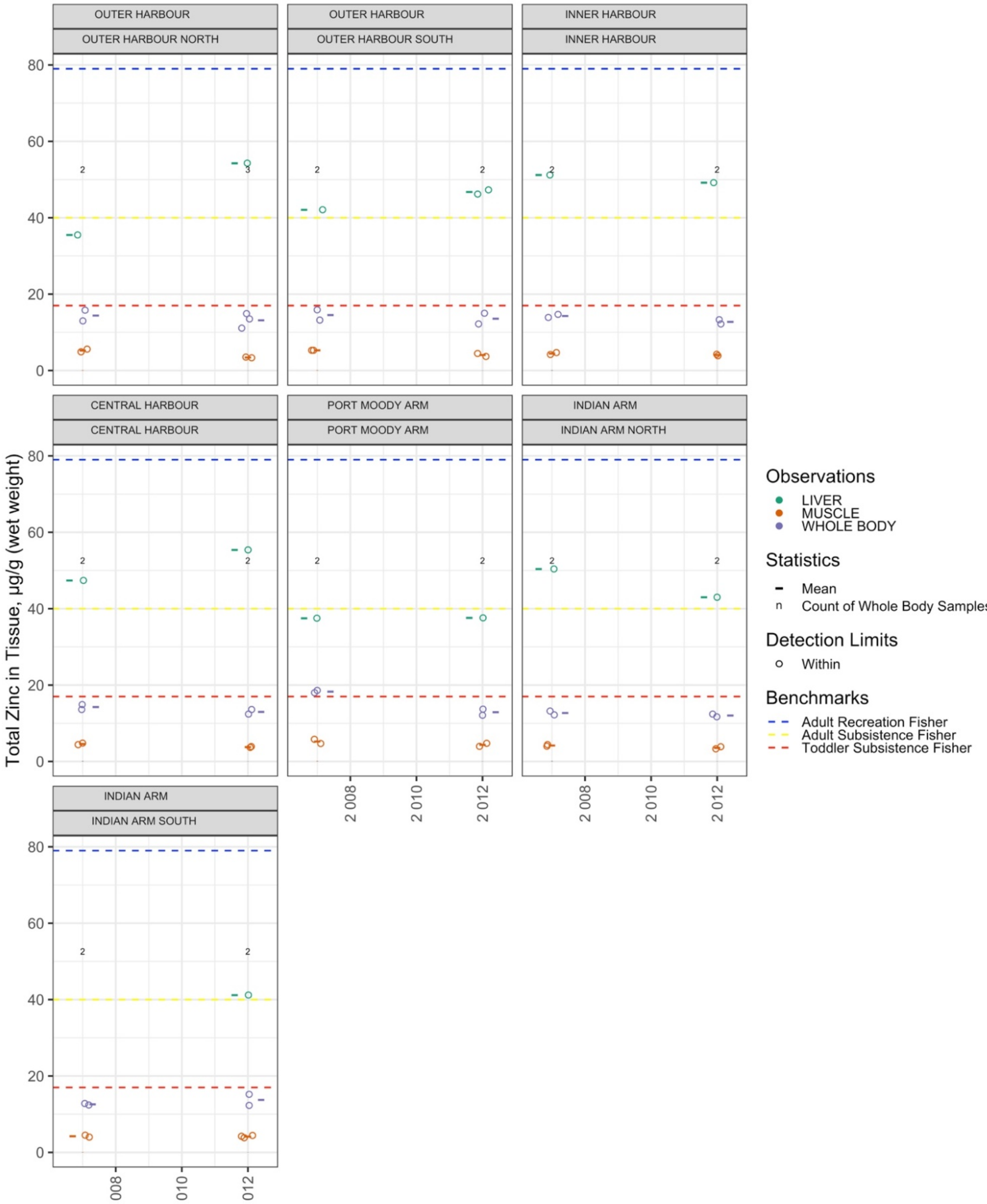

Figure 10: Zinc levels in Metro Vancouver English sole fish tissue samples (2007 to 2012) in µg/g

- 2015–2016 – Pollution Tracker monitoring of zinc levels in sediment (Figure 11) and mussel tissue (Figure 12) occurred in October 2015 and April 2016. Pollution Tracker results are summarized as follows:
    - Mean zinc levels in the sediment samples exceeded the TEL benchmark at the Port Moody Arm monitoring location (Figure 11). The highest zinc levels in sediment were recorded in Port Moody Arm (138 µg/g), the Outer Harbour (101 µg/g) and the Inner Harbour (88.8 µg/g).
    - Zinc levels in the mussel samples were above the subsistence toddler benchmark (17 µg/g wet weight) in one sample collected from Port Moody Arm but did not exceed the subsistence adult or recreational adult screening benchmarks (Figure 12). The highest zinc levels were observed in Port Moody Arm (22.4 µg/g wet weight) and Outer Harbour (16.2 µg/g wet weight).

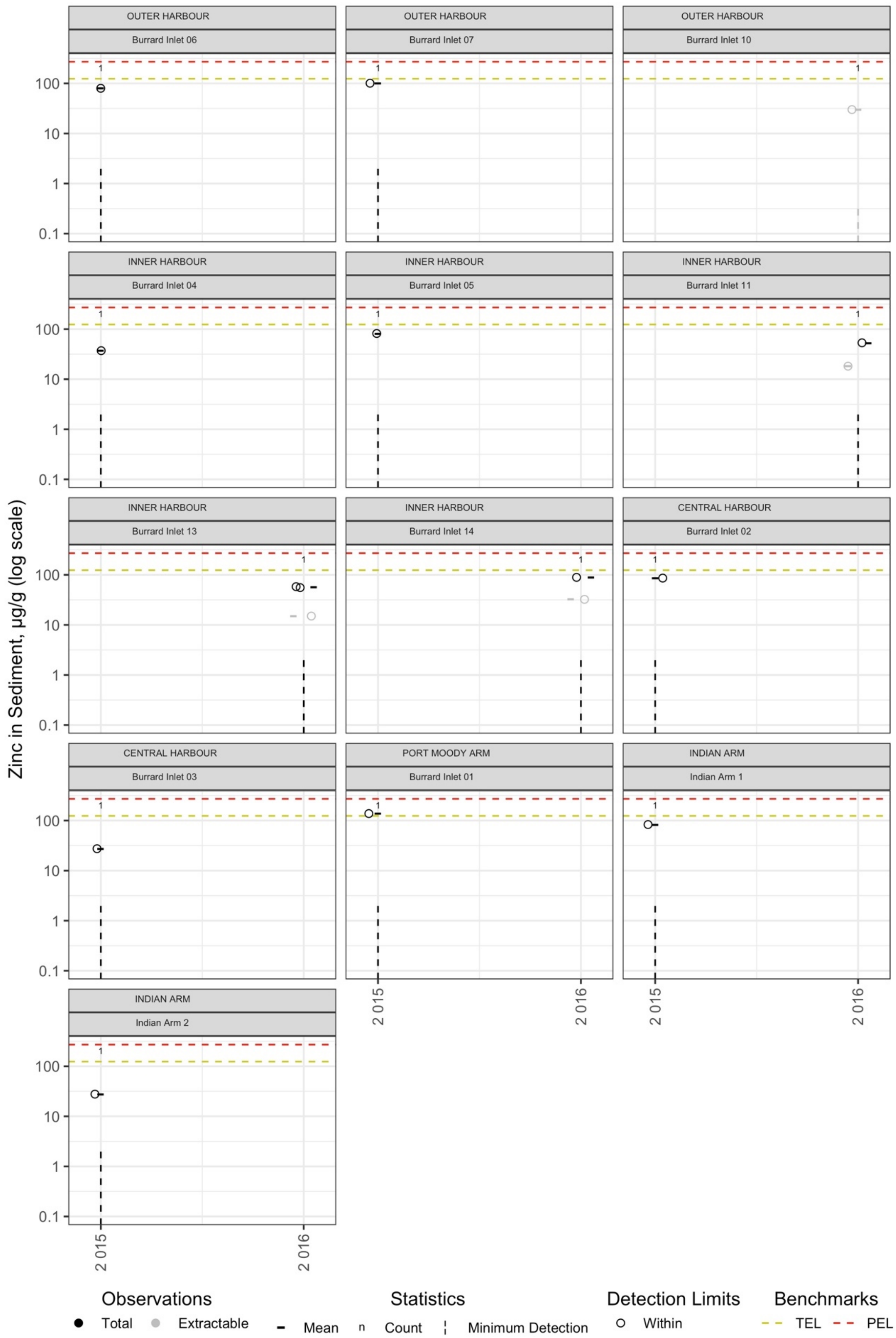

Figure 11: Zinc levels in Pollution Tracker sediment samples (2015 to 2016) in µg/g

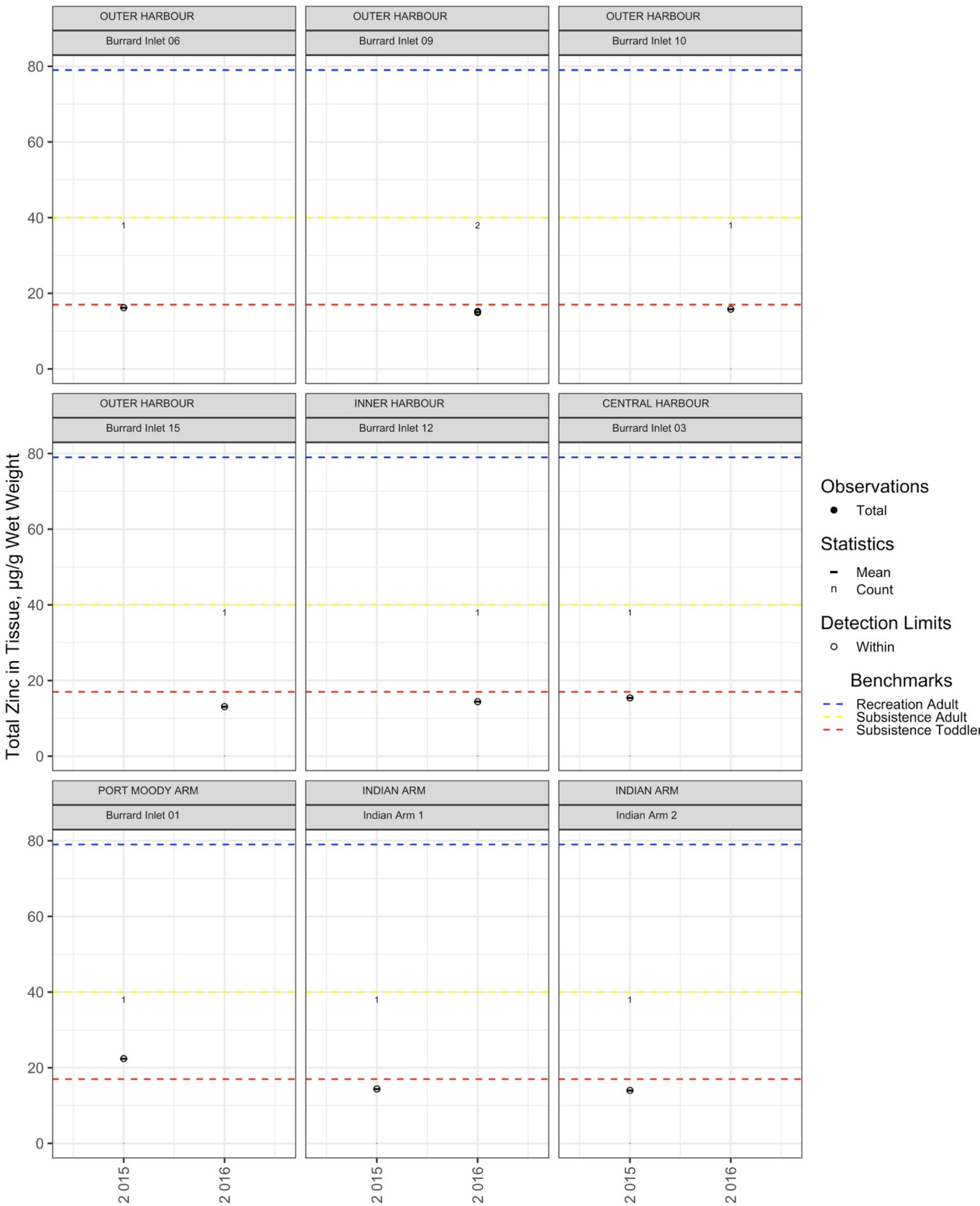

Figure 12: Zinc levels in Pollution Tracker blue mussel tissue samples (2015 to 2016) in µg/g

3.4 Knowledge Gaps and Research Needs

The assessment of available zinc 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:

- Because of differences in sampling methodologies, reporting, and detection limits between years and programs, it is difficult to interpret whether observed temporal differences have resulted from actual changes in zinc levels in the environment or are a result of improvements or differences in the sampling methodology and/or analysis.
- Zinc is known to be toxic to microscopic species and arthropods, though research on species found in Burrard Inlet is limited.
- There is limited data and assessment available for dissolved zinc and bioavailability.
- Sediment toxicity due to accumulation of one or more trace metals, synergistic effects and uptake in other species – particularly those in the intertidal zone, requires further examination.
- There has been little to no monitoring of sites influenced by permitted discharges, stormwater discharges or combined sewer overflow outfalls since 2009.
- The linkage between permitted discharge monitoring data, including the Lions Gate WWTP, and ambient zinc levels has not been established.
- Vancouver Wharves has historically been a significant source of zinc pollution in Burrard Inlet. The extent of contaminated sediment has not been documented.
- There has been little monitoring of zinc in sediment or the water column in False Creek since 2009.
- Zinc levels in English Sole liver tissue frequently exceed the screening benchmark for a toddler from a subsistence fishing population, but there is limited data available to indicate the quantity of liver tissue that would traditionally be eaten.

4. PROPOSED OBJECTIVES FOR ZINC IN BURRARD INLET

4.1 Proposed Objectives

Proposed water, sediment and tissue objectives for zinc are presented in Table 4. The water and sediment objectives are set to protect marine aquatic life. The tissue objective is set to protect consumption of shellfish and finfish by humans.

Table 4: Proposed Water Quality Objectives for Total Zinc

Sub-basin	Outer Harbour	False Creek	Inner Harbour	Central Harbour	Port Moody Arm	Indian Arm
Total Zinc in Marine Water	10 µg/L mean (no more than 20% of samples above 10 µg/L)[1] 55 µg/L maximum[2]					
Total Zinc in Marine Sediment	124 µg/g dry weight single-sample maximum[3]					
Total Zinc in Tissue	17 µg/g wet weight single-sample maximum (all tissue types)[4]					

[1] Minimum of 5 samples in 30 days collected during the wet season. No more than 20% of samples > 10 µg/L.
[2] Level not to be exceeded at any time.
[3] Based on at least 1 composite sample consisting of at least 3 replicates.
[4] 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

The 1990 provisional objectives for zinc levels in Burrard Inlet are not recommended for use going forward because the science on the effects of zinc has progressed since 1990, the objectives were based on US EPA guidelines at that time, and more current BC guidelines now exist. In addition, detection limits have improved since 1990, allowing for assessment of zinc levels at lower thresholds. Both water and sediment quality objectives are proposed to be consistent with the BC approved (BC ENV 2019) and working (BC ENV 2020) water quality guidelines for the protection of marine aquatic life, respectively.

The proposed mean objective for total zinc in water represents a level below which there is low risk for effects to aquatic life based on long-term chronic exposure. The objective for short-term acute exposure is also proposed because of the infrequent exceedances that currently occur and to limit the exposure of marine aquatic life to levels above the guideline on a short-term basis.

The proposed objective for total zinc in sediment is the interim sediment quality guideline from the BC working guidelines. The proposed objectives are the same for all sub-basins as they are already achieved in all sub-basins based on recent ambient monitoring levels, although they have not always been achieved at all sites historically, especially at monitoring sites near potential sources of zinc.

With the exception of Metro Vancouver English sole liver tissue samples, measured levels of zinc in tissue were well below the screening benchmarks for adults from both recreational and subsistence fishing populations, and were infrequently above the screening benchmark for toddlers from a subsistence fishing population. The benchmark for a toddler from a subsistence fishing population is proposed as the objective for zinc in fish tissue because it is the most conservative for protecting human consumption of shellfish and finfish.

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 zinc objectives are attained. The following are recommendations for future zinc monitoring in Burrard Inlet:

- Increase coordination of efforts between BC ENV, Metro Vancouver and Pollution Tracker monitoring 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.
- Establish consistent methodologies for water column, sediment and tissue sampling, including consistent reporting of sediment values in µg/g dry weight and tissue values in µg/g wet weight.
- Continue to monitor dissolved zinc levels in water and sediment. Once adequate data is available, determine whether an additional assessment of zinc levels against bioavailability and toxicity is warranted.
- Monitor the vicinity of areas known to be sources of zinc, such as near stormwater and combined sewer outfalls and near permitted discharges.
- Monitor sediment in the area around Vancouver Wharves to establish the extent of elevated zinc levels.
- Monitor zinc in water and sediment in False Creek and incorporate this monitoring into the programs run by Metro Vancouver, Pollution Tracker or BC ENV.

- Sample tissue in species that are preferred for human consumption and compare results to those in indicator species.

6. MANAGEMENT OPTIONS

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

- Development and implementation of Integrated Stormwater Management Plans (ISMPs) for all developed watersheds that flow into Burrard Inlet;
- Development of source controls, including green stormwater infrastructure such as swales, rain gardens, and tree trenches;
- Inflow and infiltration reduction programs to reduce groundwater and stormwater into sanitary sewer pipes, thereby reducing untreated sewage discharges from sanitary and combined sewer overflows;
- Upgrading the Lions Gate Wastewater Treatment Plant, with anticipated completion in 2024;
- Existing pre-treatment requirements for waste discharge permittees; and
- Adoption of pollution prevention plans by Port of Vancouver tenants.

The following management options that have the potential to further reduce anthropogenic sources of zinc 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;
- Clean paved surfaces with vacuum assisted dry sweepers to remove debris that can sorb zinc in runoff and prevent this debris from entering the stormwater system;
- Requirements, for example through inclusion in ISMPs, for regular cleanout of catch basins and testing of the material for leachability (e.g., Greenland 1999);
- Replace, coat or paint galvanized surfaces and explore roof treatments to keep zinc out of runoff;
- Reduce the use of recycled tires for rubber crumb in artificial turf, tracks and playground surfaces around the Lower Mainland, and determine environmentally friendly options to recycle tires; and
- Public education, awareness and regulation towards the following:
    - Use of reduced zinc or zinc-free roofing materials;
    - Use of moss control and anti-fouling products that do not contain zinc;
    - Use of non-metal fencing and building materials;
    - Vehicle maintenance to prevent drips and leaks of motor oil; and
    - Proper disposal and recycling of marine anodes.

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

(see following pages)

Heat Map of Zinc in Sediment Samples Collected by All Monitoring Programs from 1985-1987

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

Burrard Inlet Catchment (Study Area) (BC Hydro 2005, KWL 2012, AECOM 2017, COC 2018/2019, BC 2019, COB 2019, COV 2019, CPM 2019, DNV 2019, DWV 2019)

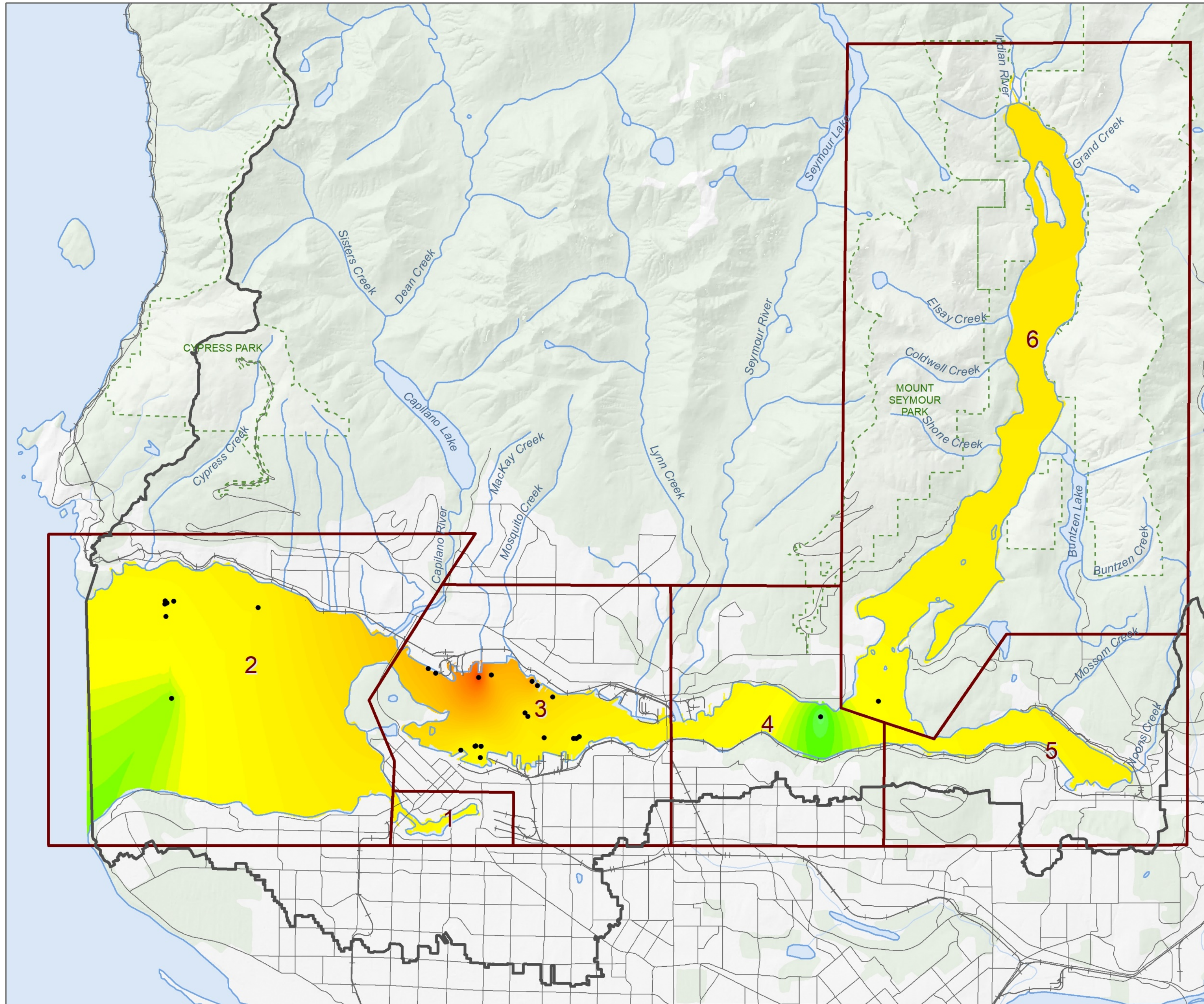
Burrard Inlet Sub-Basin

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

• 1985-1987 Zinc Sample Site

1985-1987 Total Zinc in Sediment (µg/g dry weight)

- 1167
- 124 (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

This map is a living document and is intended to be amended and refined over time. The data used to produce this map originate from many sources and are presented without prejudice. Heat map interpolations were prepared by Kerr Wood Leidal Associates Ltd. using methods available in ArcGIS.This map is the property of the Tsleil-Waututh Nation and may not be reproduced without written permission.

Data Sources for Study Area and Basemap: AECOM, Province of BC (BC), BC Hydro, City of Burnaby (COB), City of Coquitlam (COC), City of Vancouver (COV), City of Port Moody (CPM), District of North Vancouver (DNV), District of West Vancouver (DWV), Government of Canada (GOC), Kerr Wood Leidal (KWL).

Data Sources for Heat Map: Burrard Inlet Environmental Action Program (BIEAP) Environment Quality Objectives and Monitoring Action Team (EQOMAT), BC Ministry of Environment and Climate Change Strategy (ENV), Environment and Climate Change Canada (ECCC), Metro Vancouver (MV), Ocean Wise Pollution Tracker (OW), North Pacific Marine Science Organization (PICES).

Projection: NAD 1983 UTM Zone 10N | Map Scale: 1:125,000

Map produced April 2020 by the Tsleil-Waututh Nation

[1] Heat Map of Zinc Levels 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)

Burrard Inlet Sub-Basin

1 - False Creek

2 - Outer Harbour

3 - Inner Harbour

4 - Central Harbour

5 - Port Moody

6 - Indian Arm

• 1988-1992 Zinc Sample Site

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

- 1167
- 124 (Proposed Water Quality Objective)
- 27

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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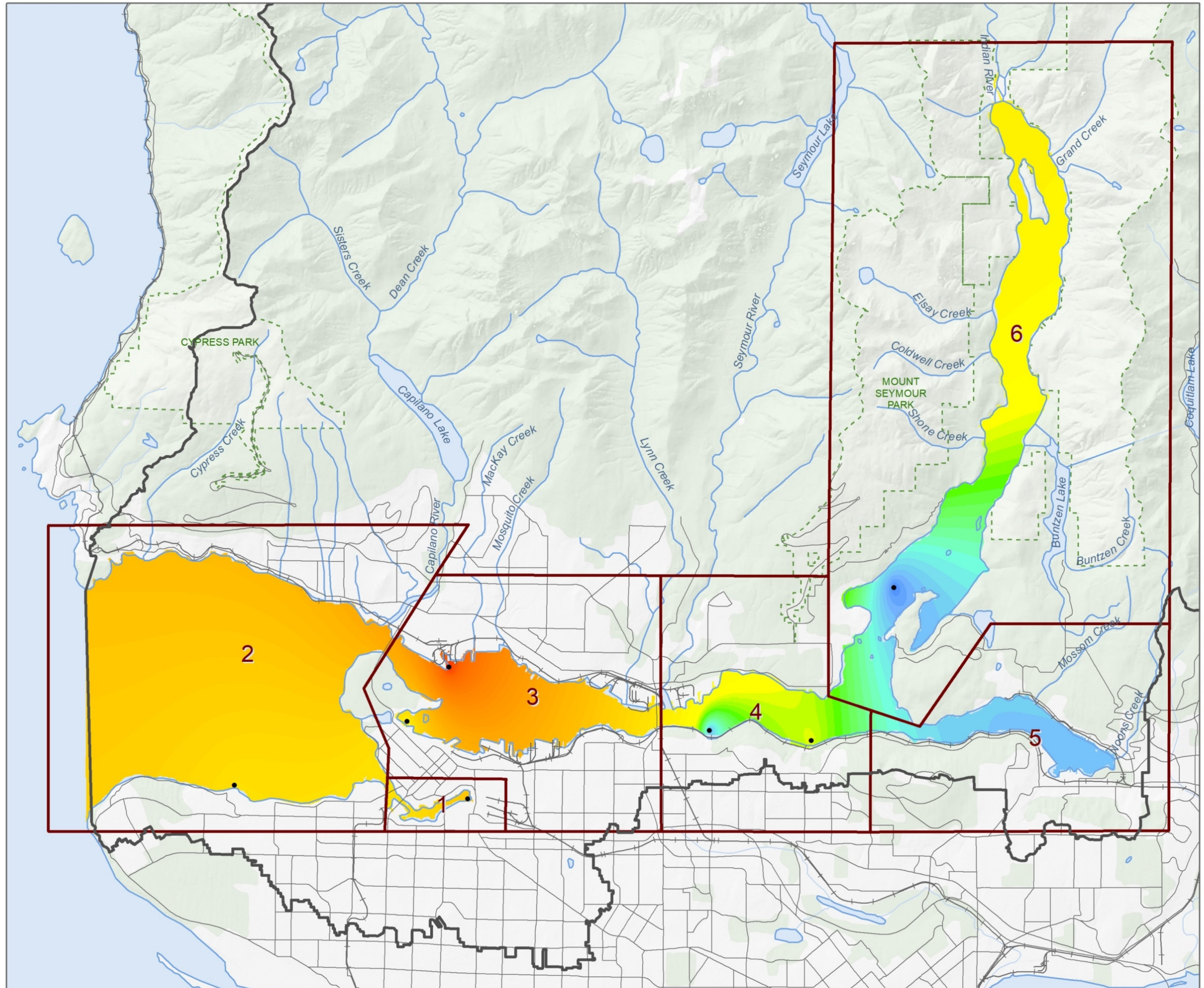

Projection: NAD 1983 UTM Zone 10N | Map Scale: 1:125,000

Map produced February 2020 by the Tsleil-Waututh Nation

Heat Map of Zinc Levels 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)

Burrard Inlet Sub-Basin

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

• 1993-1997 Zinc Sample Site

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

1167
124 (Proposed Water Quality Objective)
27

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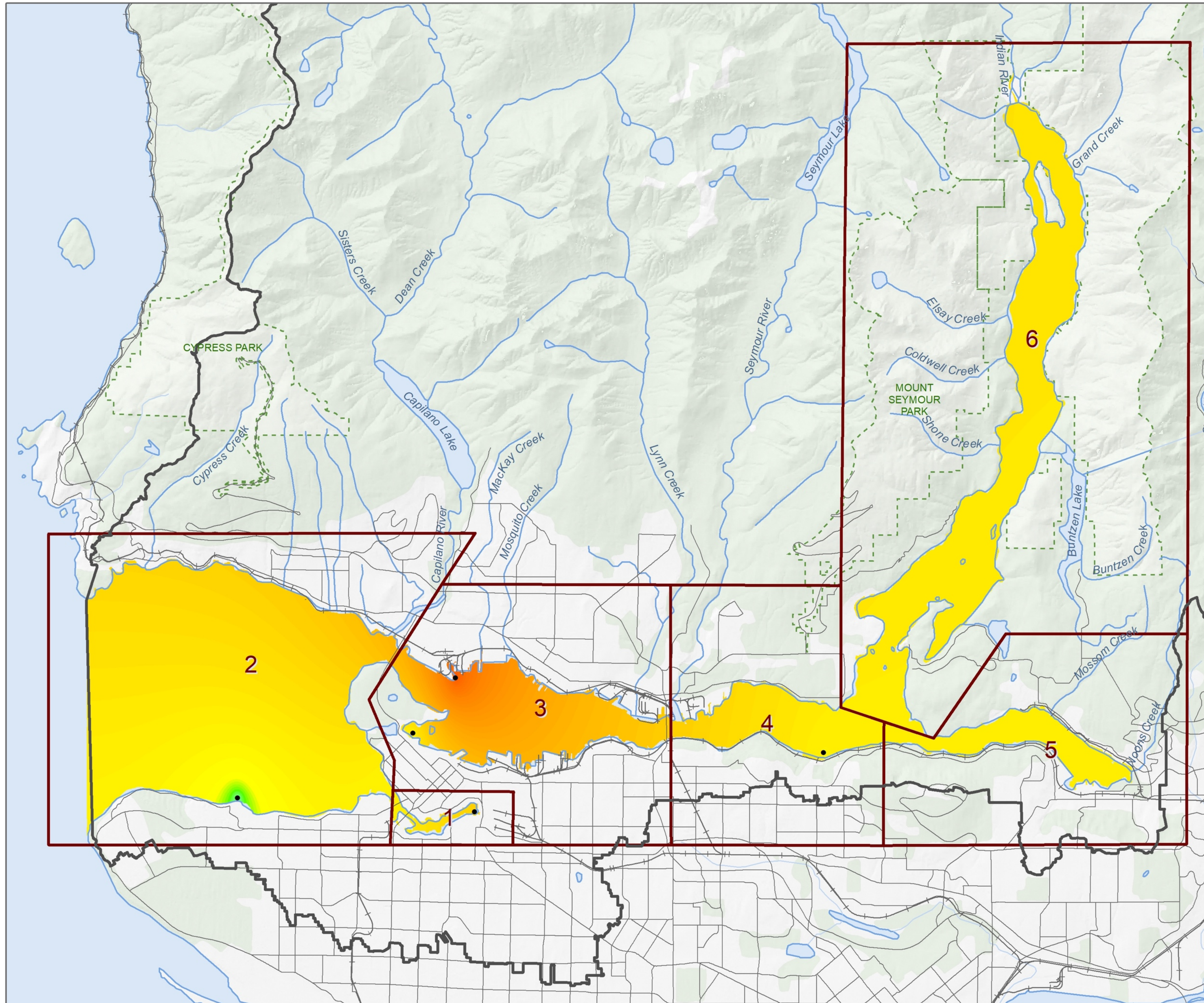

Projection: NAD 1983 UTM Zone 10N | Map Scale: 1:125,000

Map produced February 2020 by the Tsleil-Waututh Nation

Heat Map of Zinc Levels 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)

Burrard Inlet Sub-Basin

1 - False Creek

2 - Outer Harbour

3 - Inner Harbour

4 - Central Harbour

5 - Port Moody

6 - Indian Arm

• 1998-2002 Zinc Sample Site

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

1167

124 (Proposed Water Quality Objective)

27

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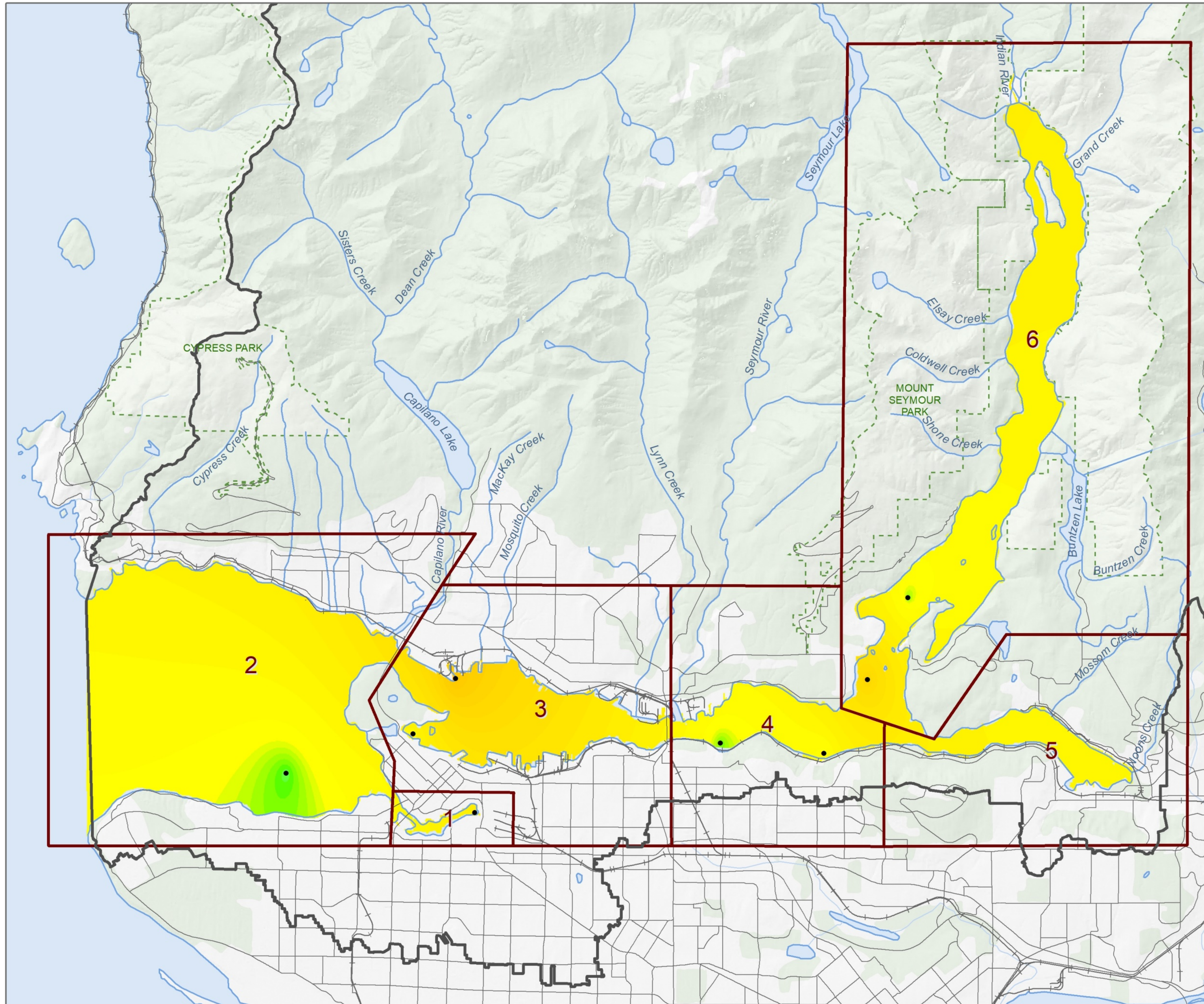

Projection: NAD 1983 UTM Zone 10N | Map Scale: 1:125,000

Map produced February 2020 by the Tsleil-Waututh Nation

Heat Map of Zinc Levels 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)

Burrard Inlet Sub-Basin

1 - False Creek

2 - Outer Harbour

3 - Inner Harbour

4 - Central Harbour

5 - Port Moody

6 - Indian Arm

• 2008-2012 Zinc Sample Site

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

1167

124 (Proposed Water Quality Objective)

27

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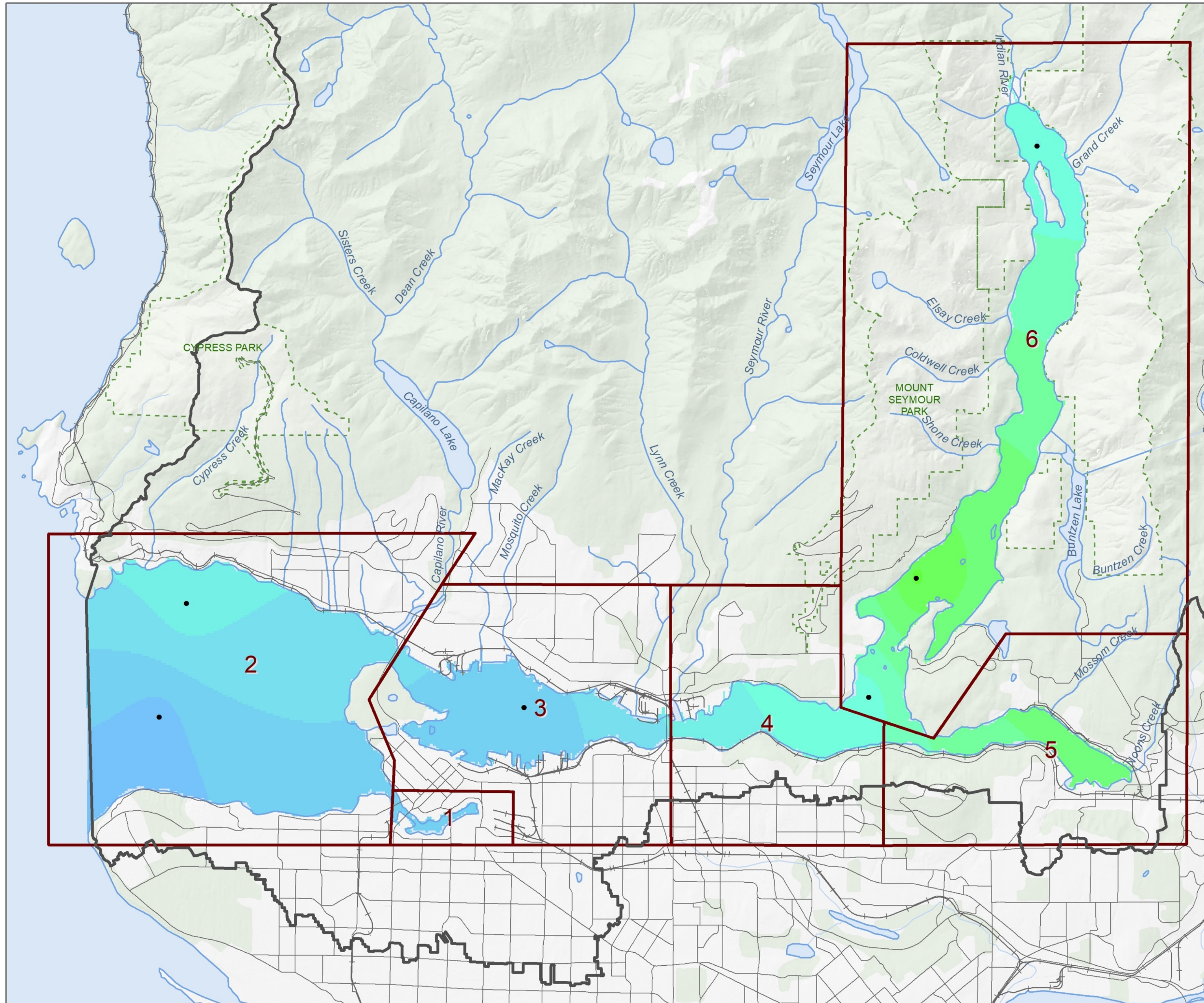

Projection: NAD 1983 UTM Zone 10N | Map Scale: 1:125,000

Map produced February 2020 by the Tsleil-Waututh Nation

Heat Map of Zinc Levels 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)

Burrard Inlet Sub-Basin

1 - False Creek

2 - Outer Harbour

3 - Inner Harbour

4 - Central Harbour

5 - Port Moody

6 - Indian Arm

• 2013-2017 Zinc Sample Site

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

- 1167
- 124 (Proposed Water Quality Objective)
- 27

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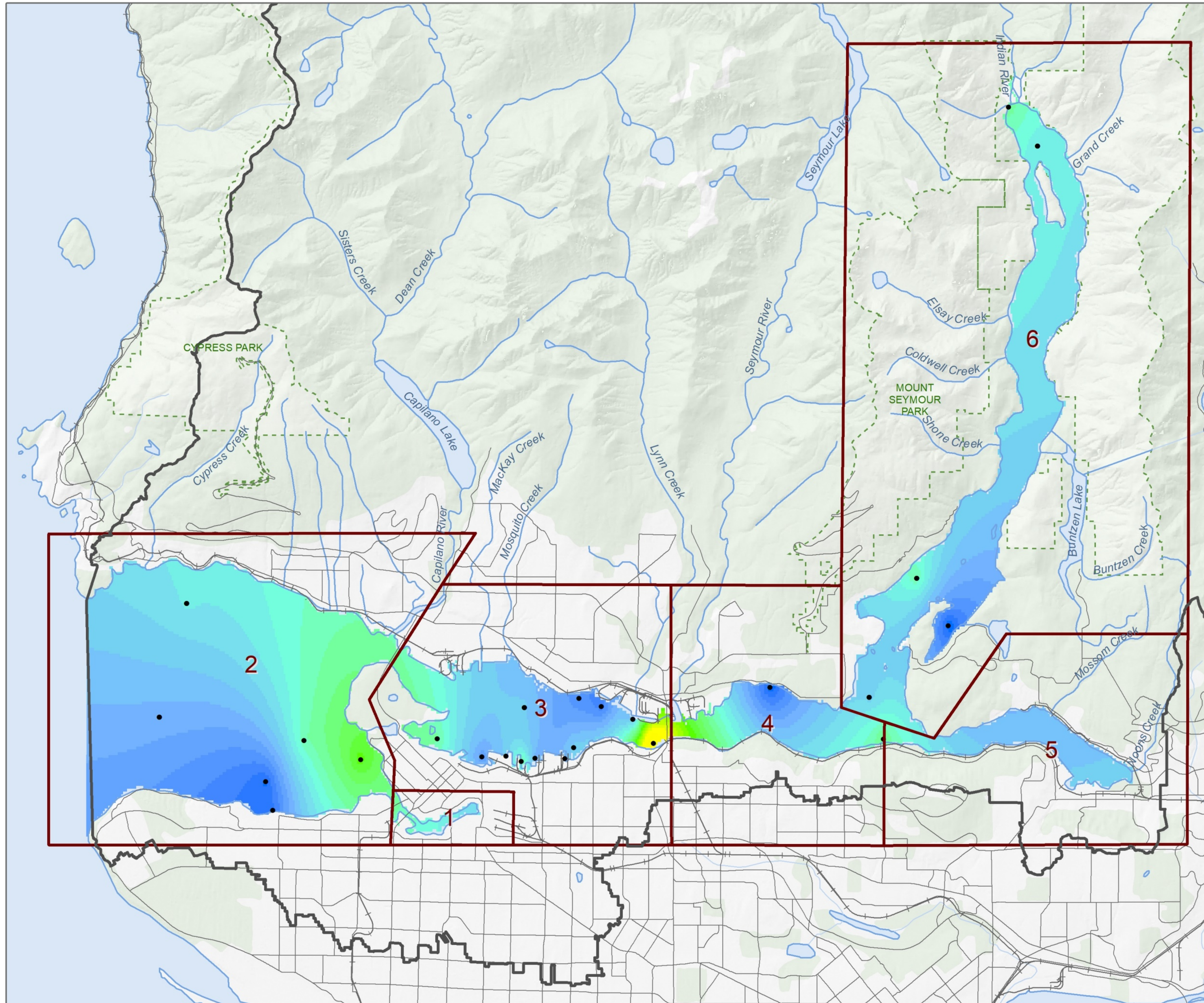

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