# Water Quality Assessment and Proposed Objectives for Burrard Inlet: Copper 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 water quality objectives for copper, identified as a metal of primary concern in the science-based, 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 copper levels, benchmark screening, and monitoring data for Burrard Inlet.

Copper is an essential trace element, but some marine fish and invertebrates are very sensitive to copper. Sensitive values considered for informing proposed water quality objectives included marine and estuarine aquatic life, as well as human consumption of finfish and shellfish.

Most dissolved copper is of anthropogenic origin and urban rainwater (stormwater) provides a major transport pathway. Sources of copper include marine anti-fouling paints and other biocides, electrical conductors, plumbing fixtures, pipes, pesticides, cooking utensils, vehicle brake pad and tire wear, oil and lubricant spills and roofing and other construction materials. Physical factors such as pH, alkalinity, and salinity as well as the presence of other contaminants can affect the bioavailability and toxicity of copper.

Benchmarks used for copper included guidelines from Australia/New Zealand for water, British Columbia (BC) working water quality guidelines for sediment and a calculated human health-based tissue screening value for tissue.

Elevated copper levels have been observed in water and sediment across Burrard Inlet with noteworthy hotspots including the Inner Harbour near Vancouver Wharves, English Bay at Locarno, False Creek, throughout Port Moody Arm, and Indian Arm South. There are numerous stormwater outfalls located in many of these areas.

The proposed water quality objectives for copper are as follows:

<table>
<tr><th>Sub-basin</th><th>Outer Harbour</th><th>False Creek</th><th>Inner Harbour</th><th>Central Harbour</th><th>Port Moody Arm</th><th>Indian Arm</th></tr>
<tr><td>Total Copper in Water</td><td colspan="6">1.3 µg/L mean[1]<br>AND<br>no more than 20% of samples above 1.3 µg/L</td></tr>
<tr><td>Total Copper in Sediment</td><td colspan="6">18.7 µg/g dry weight single-sample maximum[2]</td></tr>
<tr><td>Copper in Tissue</td><td colspan="6">15 µg/g wet weight single-sample maximum[3]</td></tr>
<tr><td colspan="7">[1] Minimum of 5 samples in 30 days collected during wet and dry seasons (until the peak season is identified).<br>[2] Based on at least 1 composite sample consisting of at least 3 replicates.<br>[3] Applies to all tissue types. Based on at least 1 composite sample consisting of at least 5 fish or 25 bivalves.<br>See Rao et al. (in prep) for additional details.</td></tr>
</table>

Monitoring for copper in water should occur year-round (in both wet and dry seasons), at least initially, due to the variety of potential sources. Monitoring can then be focused on the peak time of year once that timeframe has been determined. Monitoring results should be considered with other influencing factors. The primary management options to reduce the entry of copper into Burrard Inlet include rainwater management through source controls, green infrastructure and bio-filtration.

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## ACRONYMS

| | |
|---|---|
| ANZECC-ARMCANZ | Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand |
| BC | British Columbia |
| BIEAP | Burrard Inlet Environmental Action Program |
| CCME | Canadian Council of Ministers of the Environment |
| DW | Dry weight |
| ENV | British Columbia Ministry of Environment and Climate Change Strategy |
| EQOMAT | BIEAP Environmental Quality Objectives and Monitoring Action Team |
| 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 |
| WQO | Water Quality Objective |

# 1. INTRODUCTION

This chapter proposes updated water quality objectives for copper in Burrard Inlet, identified as a metal of primary concern in the science-based, TWN-led Burrard Inlet Action Plan (TWN 2017). It includes relevant background information, an overview assessment of current status and trends in copper levels in water, sediment, and fish tissue in Burrard Inlet, comparison to benchmarks, and a rationale for the proposed objectives. Recommendations for future monitoring as well as management options to help achieve these objectives are also included.

# 2. BACKGROUND

## 2.1 Values and Potential Effects

Although copper is an essential trace element for animal (including human) metabolism, excessive amounts can be toxic (Singleton 1987, Health Canada 2010a). Species vary in their sensitivity to copper; aquatic organisms are particularly sensitive to copper levels in water (Singleton 1987) and sediment (CCME 1999). Low levels of copper can cause neurotoxicity in juvenile salmon (McIntyre et al. 2012). Excessive amounts of copper may cause liver damage in living organisms (Singleton 1987). Exposure to copper can lead to decreased population density and abundance, increased mortality and changes in behaviour of benthic invertebrates (CCME 1999). Marine invertebrates are particularly sensitive to copper during larval stages and developmental stages that involve calcification (Singleton 1987). Research suggests that low levels of copper (5–20 µg/L over 3 hours) can disrupt the olfactory systems of juvenile Coho salmon, leading to reduced ability to avoid predators (McIntyre et al. 2012). The human body is generally able to regulate copper levels, but disruptions to this regulatory system can cause copper toxicity (Gaetke et al. 2014).

The most sensitive value guiding the setting of 1990 water quality objectives for copper was protection of marine and estuarine aquatic life. While protection of aquatic life remains important, the revised objectives should also protect human consumption of finfish and shellfish, which are values of concern with respect to copper. The goal of the water quality objective is to maintain copper levels below levels which would be toxic to aquatic life and to humans who consume seafood for subsistence (i.e.,consumption rates relevant to coastal Indigenous peoples such as Tsleil-Waututh Nation).

## 2.2 Potential Sources of Copper Pollution

Copper can enter aquatic systems via surface runoff or deposition from the air (CCME 1999), as well as discharges from point sources. Some of the sources of copper transport are through wastewater treatment plants or to the ocean directly via stormwater outfalls.

Natural sources of copper include weathering, oxidation and bacterial breakdown of rocks containing copper deposits (Singleton 1987). Background concentrations of copper in marine systems can range significantly, including to levels that exceed guidelines (CCME 1999).

Most dissolved copper is of anthropogenic origin, for example from industries such as mining, electroplating, petroleum refining, metal work, foundries, smelters, road-building and textile manufacturing; products such as marine anti-fouling paints and other biocides, electrical conductors, plumbing fixtures, pipes, pesticides, cooking utensils (Singleton 1987); vehicle brake pad and tire wear, oil and lubricant spills (Davis et al. 2001); and roofing and other construction materials (e.g. Chang et al. 2004, Pennington and Webster-Brown 2008).

Stormwater is likely a major pathway for the entry of copper into Burrard Inlet, with sources including brake pads and pipes. Discharge from vessels are also a potential source of copper input into Burrard

Inlet. Vessel exhaust gas cleaning systems, also called scrubbers, have been found to discharge wash water that contains contaminants including copper (ICCT 2019, 2020).

Discharges in Burrard Inlet authorized by the Province of BC under the *Environmental Management Act* with the potential to input copper include Kinder Morgan (Vancouver Wharves) in the Inner Harbour, and Chemtrade and Terrapure in the Central Harbour.

## 2.3 Factors Influencing Copper Levels in Burrard Inlet

In aquatic systems, copper may be dissolved as free ions or compounds, suspended as precipitates, or adsorbed onto other particles (e.g., iron, manganese oxides and organic matter) that may settle to the bottom. The form it takes depends on levels of bicarbonate/carbonate, phosphate, pH, water hardness, suspended particulate content and the presence of organic complexing agents (CCME 1999, Singleton 1987).

Physical factors and the presence of other contaminants can affect the bioavailability and toxicity of copper. The dissolved form of copper is the most bioavailable (CCME 1999).

Copper toxicity decreases with increased dissolved organic carbon concentration and shows moderate non-linear changes with changes in pH. Water hardness also affects toxicity via uptake because copper competes with calcium and magnesium for binding sites in biota. Bioavailability of copper decreases with alkalinity (carbonate concentration) because alkalinity affects copper speciation in solution (NIWA 2017). Salinity has also been found to protect marine organisms against copper toxicity; increased salinity increases the amount of inorganic ligand-copper complexation (Singleton 1987). Other influencing physical factors include redox potential, temperature, dissolved oxygen, and particle size. Finer sediments allow for increased adsorption of copper, and low dissolved oxygen content can increase copper toxicity (CCME 1999, Singleton 1987).

Biochemical factors include the presence of organic matter (organic matter in sediment or suspended organic solids may decrease the toxicity of copper), oxides of other metals (e.g., Fe, Mn) and sulphide (e.g., acid volatile sulphide can bind divalent metals and make them unavailable, depending on the presence of other factors and metals) (CCME 1999). Additive toxicity has been observed when copper is mixed with ammonia, nickel, nickel dieldrin and potassium pentachlorophenate, zinc and nickel, phenol, zinc and phenol, and zinc and cadmium. Toxicity of copper with zinc can be additive or synergistic, depending on other conditions. Decreased toxicity of copper has been observed when it is mixed with manganese, humic acids and substances, domestic sewage, lignosulphonate, nitrilotriacetic acid, ethylenediaminetetraacetic acid (EDTA) or spent sulphite liquor (Singleton 1987).

Runoff from terrestrial areas can lead to higher copper concentrations at the surface in nearshore areas. Copper also tends to accumulate in sediments due to its affinity for particulate matter including organic matter, and fractions of iron and manganese oxides (Campbell and Tessier, 1996). As a variety of organisms live in, or are in contact with bed sediments, sediments act as an important exposure route for aquatic organisms (CCME 1999). Copper levels in algae can be higher than those in the surrounding water (Singleton 1987).

## 2.4 1990 Provisional Water Quality Objectives for Copper

Water quality objectives were set in 1990 for copper in marine water and sediment in Burrard Inlet, as shown in Table 1. Objectives were set for the protection of marine aquatic life and were set the same for all sub-basins, with the exception that no sediment quality objective was set for Indian Arm. The water quality objective was based on toxicity studies of barnacle larvae and Pacific oyster (*Crassostrea gigas*) and blue mussel (*Mytilus edulis*) embryos, as per the 1987 approved BC Water Quality Guidelines for copper (Singleton 1987). The sediment quality objective was set as approximately one-third of the lowest measured apparent effects threshold in Puget Sound (Nijman and Swain 1990). No tissue quality objectives were set in 1990.

*Table 1: 1990 provisional water quality objectives for copper*

| Sub-basin | False Creek | Outer Harbour | Inner Harbour | Central Harbour | Port Moody Arm | Indian Arm |
|---|---|---|---|---|---|---|
| **Water** | ≤ 2 μg/L mean<br>3 μg/L maximum | | | | | |
| **Sediment** | 100 μg/g dry weight maximum | | | | | N/A |
| All values are for total copper levels. | | | | | | |

## 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 proposed objectives for copper levels in Burrard Inlet. Benchmarks for copper were available for the protection of aquatic life in water and sediment, and screening values (SVs) were calculated for copper levels in tissue to protect human consumption of finfish and shellfish. The tissue benchmarks were derived by Thompson and Stein (2021) from Health Canada toxicological reference values and risk assessment methodologies (Health Canada 2010 a,b, 2012a, 2021; Richardson 1997, Richardson and Stantec 2013). Benchmarks chosen for this data assessment are summarized in Table 2, with details and rationale described in the subsequent text. Water and sediment benchmarks are used to screen for protection of marine aquatic life while finfish and shellfish tissue benchmarks are used to screen for human health.

*Table 2: Screening benchmarks for total copper levels in water, sediment, and tissue used in this assessment*

| Sample Type | Screening Benchmark | Value to Protect | Reference |
|---|---|---|---|
| Water | 0.3 μg/L (99% protection level)[1]<br>1.3 μg/L (95% protection level)[1] | Aquatic life | ANZECC-ARMCANZ 2000 |
| Sediment | 18.7 μg/g dry weight mean (threshold effect level)[2]<br>108 μg/g dry weight maximum (probable effect level)[2] | Aquatic life | ENV 2020 (CCME 1998) |
| Tissue[3] | 15 μg/g wet weight (toddler subsistence fisher)<br>30 μg/g wet weight (adult subsistence fisher)<br>59 μg/g wet weight (adult recreational fisher) | Human consumption of finfish and shellfish | Screening value calculated from Health Canada 2010b (Thompson and Stein 2021) |
| [1] Protection levels refer to the percentage of species for which the benchmark value is protective (ANZECC-ARMCANZ 2000).<br>[2] 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 (CCME 1998).<br>[3] Calculated screening value for which copper 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. | | | |

BC Water Quality Guidelines (ENV 2017, 2019, 2020), US EPA (2016; 2018 a,b; no date) Water Quality Criteria and ANZECC-ARMCANZ (2000) Guideline Values were consulted as potential screening benchmarks.

The approved BC water quality guideline for copper in marine water[1] was set to avoid acute lethal effects and long-term sublethal effects but has not been updated since 1987 (ENV 2019, Singleton 1987).

The US EPA produced draft guidelines in 2016 proposing that Water Quality Criteria be set relative to water chemistry conditions, particularly temperature, pH, dissolved oxygen content (DOC) and salinity (US EPA 2016). Those draft criteria have since been archived, however, possibly due to concerns regarding the biotic ligand model that was used in their derivation. The biotic ligand model has been deemed reliable for the development of water quality guidelines for freshwater systems; however, it may not be directly applicable to marine and estuarine systems (Sander et al. 2015).

Discussions about appropriate methods to understand copper toxicity in marine waters are still unresolved among multiple jurisdictions including in Canada, due to influencing physical factors, which has stalled the development of national or provincial guidelines for copper in marine waters. A process for updating guideline values has been proposed in Australia and New Zealand, following an analysis of US EPA and European Union approaches (NIWA 2017).

A comparison of Canadian and international benchmarks conducted by Environment and Climate Change Canada to identify guidelines protective of endangered Southern Resident Killer Whales and their prey (ECCC 2021: section 1) concluded that the current ANZECC-ARMCANZ (2000) guidelines are the most protective benchmarks currently available for marine waters and are consistent with the species sensitivity distribution methodology used by CCME. These guidelines are based on the 95th percentile of a no observed effect concentration distribution (ECCC 2021)[2]. ANZECC-ARMCANZ (2000) determined that a copper value of 1.3 µg/L would protect 95% of species and 0.3 µg/L would protect 99% of species from which data were analyzed. The 70 data points used to derive these guidelines originated from 25 species in five taxonomic groups (fish, crustaceans, molluscs, annelids and algae), including species endemic to the Australian region as well as species from other areas of the world (ANZG 2000). This benchmark has been used in the data assessment for this chapter in the absence of recent site-specific benchmarks, and given its use for the federal initiative to protect Southern Resident Killer Whales as the most protective benchmark available.

Updated BC Water Quality Guidelines for primary contact recreation (ENV 2017) are based on Health Canada recreational guidelines, which state that exposure to inorganic chemical contaminants is not considered a significant health risk for recreational water users (Health Canada 2012b).

BC working sediment quality guidelines for copper were updated in 2017 and are based on the CCME (1998) Environmental Quality Guidelines (ENV 2020), which adopted the federal marine/estuarine interim sediment quality guideline (ISQG) and probable effects level (PEL). The BC working ISQG of 18.7 µg/g dry weight (dw) is based on copper concentrations at which adverse biological effects are occasionally associated with exposure in the top 5 cm of sediment (i.e., the threshold effect level, TEL).

[1] ≤ 2 µg/L long-term average – 30-day average concentration, based on a minimum of 5 weekly samples; 3 µg/L short-term maximum not to be exceeded at any time. Measuring total copper was considered to encompass all potentially toxic forms of copper (Singleton 1987).

[2] As part of the work of the Technical Working Group focusing on contaminants affecting Southern Resident Killer Whales and their prey.

The probable effect level (PEL) at 108 µg/g dw is based on levels where adverse biological effects will likely cause severe effects on aquatic life and are expected to occur frequently. The marine studies on which the ISQGs and PELs were based used 440 mostly field-collected samples containing a range of concentrations, sediment types and chemical mixtures. Sublethal effects were observed for clams when copper levels in sediment were 4.4 µg/g; however, these data were not statistically significant and hence not used for deriving guidelines (CCME 1999).

Guidelines for copper in tissue were not available, so human-health based SVs for fish and shellfish tissue were derived from Health Canada toxicological reference values and risk assessment methodologies (Health Canada 2010 a,b, 2012a, 2021; Richardson 1997, Richardson and Stantec 2013).

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 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).

SVs were calculated by Thompson and Stein (2021) using equations from Health Canada (2012) and using the tolerable daily intakes recommended in Health Canada (2021), with the health endpoint of hepatotoxicity and gastrointestinal effects. An allocation factor of 0.2 was used in the calculation to reflect the fraction of copper assumed to come from country foods (in this case, wild seafood). The SV used as a benchmark for tissue is the most conservative, as calculated for the most sensitive receptor, i.e., a toddler from a subsistence fisher or Indigenous population. 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.

The comparison of Canadian and international benchmarks conducted by Environment and Climate Change Canada to identify guidelines protective of endangered Southern Resident Killer Whales and their prey (ECCC 2021: section 1) did not identify any existing guidelines for copper in tissue that would be protective of aquatic life.

## 3.2 Data Sources

Data from sampling efforts that tested for copper were compiled for this assessment. A summary of the datasets that were analyzed for this assessment is presented in Table 3. Although other datasets containing copper sampling data may exist, these datasets were found to be the best available data for assessing the status of copper within Burrard Inlet within the constraints of the project. Maps outlining the sample sites for copper in Burrard Inlet are provided in Figure 1 through Figure 4.

*Table 3: Studies and/or monitoring programs contributing data used in this assessment*

| Source | Study/ Monitoring Program | Year(s) | No. of Obs. | No. of Sites | Sampling Frequency | Parameters Sampled |
|---|---|---|---|---|---|---|
| Environment Canada | Benthic Contaminants Study | 1985–1987 | Not listed | 73 sediment<br>11 tissue | 6 surveys | Total copper in sediment, µg/g dry weight<br>Total copper in Dungeness Crab, Pandalid Shrimp and English sole tissue by dry weight |
| 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 copper in sediment by dry weight |
| BC ENV | Monitoring Data for Burrard Inlet | 1971–1989 | 8 sediment<br>516 water | 6 sediment<br>12 water | Irregular | Total copper in sediment by dry weight<br>Total and dissolved copper in water |
| BC ENV | Provincial Water Quality Objectives Attainment Monitoring | 1990–2009 | 78 sediment<br>949 water<br>17 tissue | 14 water<br>12 sediment<br>9 tissue | 1–10 samples/ year, irregular<br>Water samples generally reported as maximum values and average of 5 samples in 30 days | Total copper in sediment by dry weight<br>Total copper in water<br>Total copper in English sole tissue by dry weight |
| Metro Vancouver | Burrard Inlet Ambient Monitoring Program | 2007–2016 | 710 water<br>210 sediment<br>73 tissue | 7 | 5–10 water samples/site and year, regular. Reported as maximum values and average of 5 samples in 30 days<br>3-6 sediment samples/site every 2 years, regular<br>Tissue samples in 2007 and 2012 | Total copper in water<br>Total and extractable copper in sediment by dry weight<br>Total copper in English sole tissue by wet weight |
| Ocean Wise | Pollution Tracker | 2015–2016 | 22 sediment<br>15 tissue | 15 sediment<br>8 tissue | 3 sediment samples and 50–200 mussels per site on a single day in Oct 2015, Dec 2015 or Apr 2016 | Total and extractable copper in sediment by dry weight<br>Total copper in mussel tissue by wet weight and dry weight |

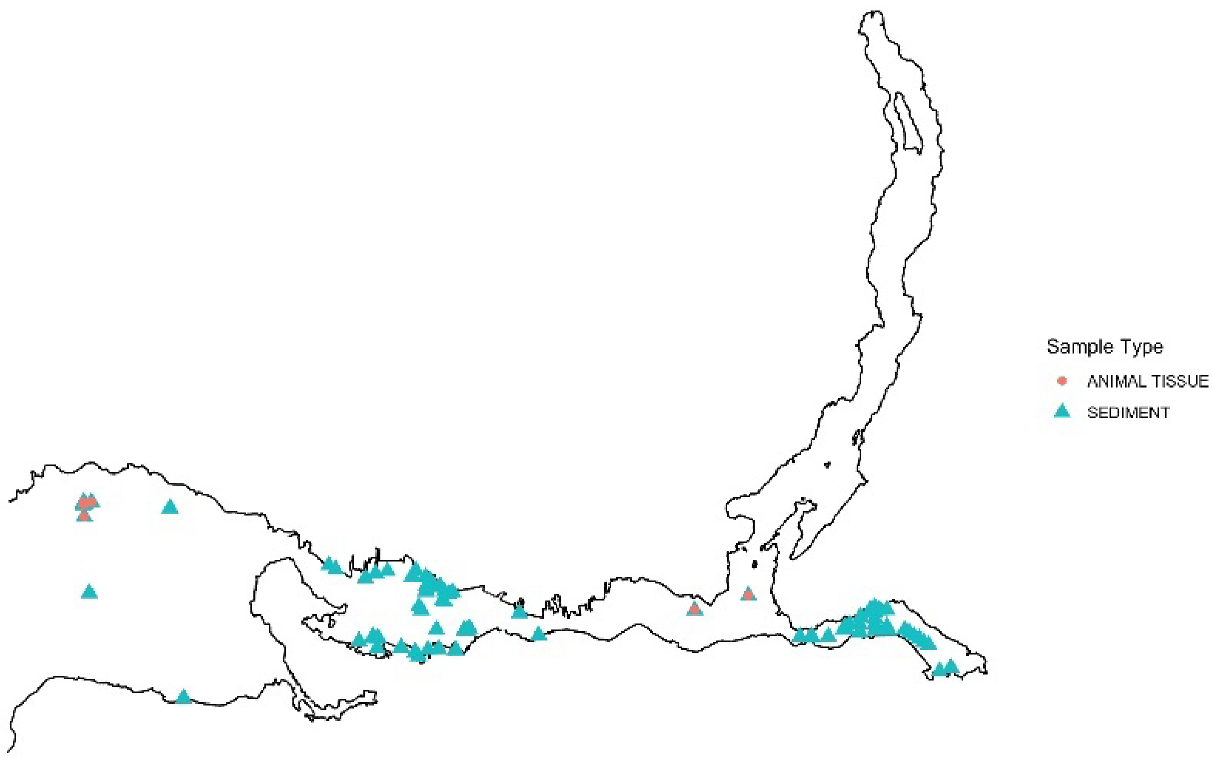


*Figure 1. Environment Canada sampling stations in Burrard Inlet (1985 to 1987).*

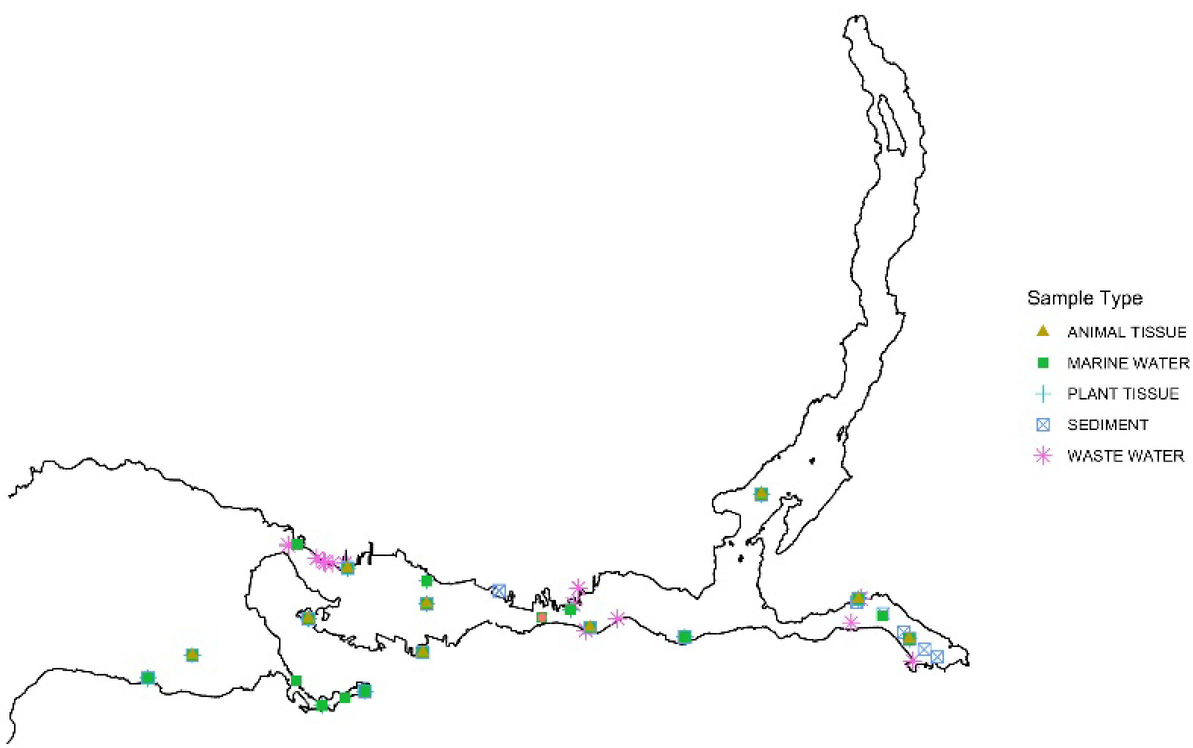


*Figure 2. ENV sampling stations in Burrard Inlet (1971 to 2009).*

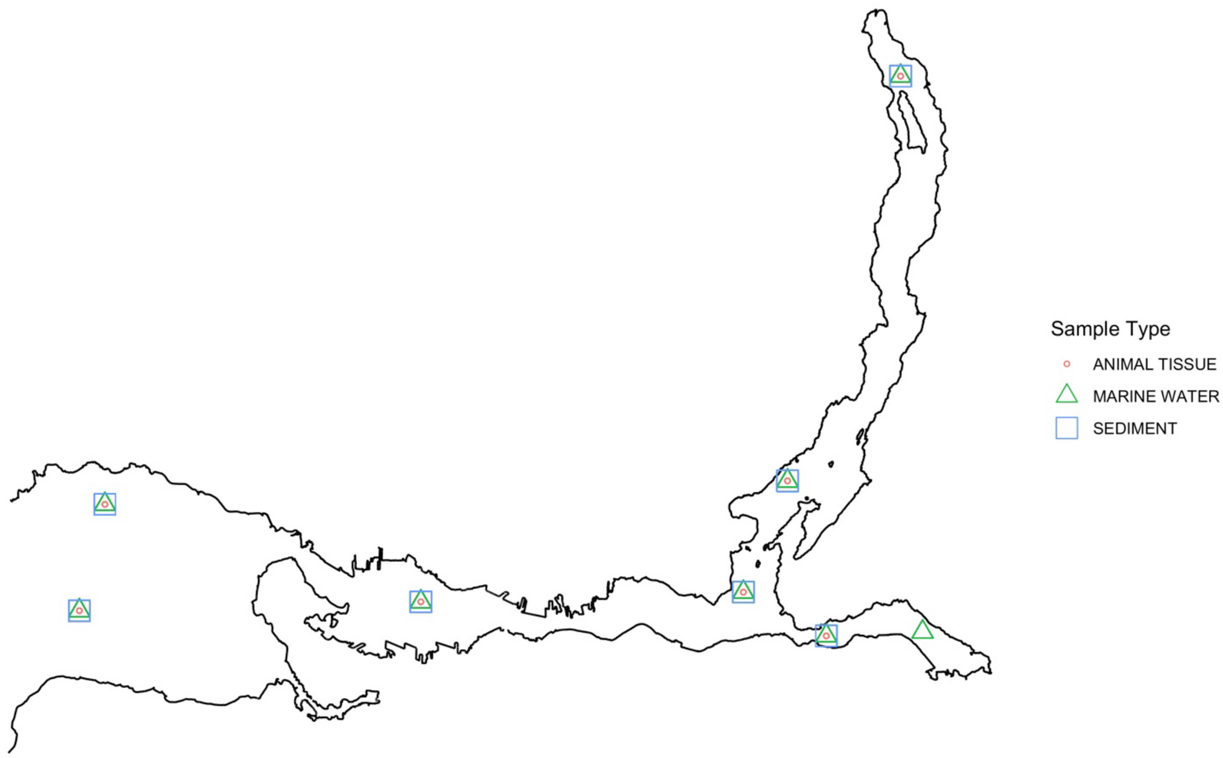


*Figure 3. Metro Vancouver sampling stations in Burrard Inlet (2007 to 2016).*

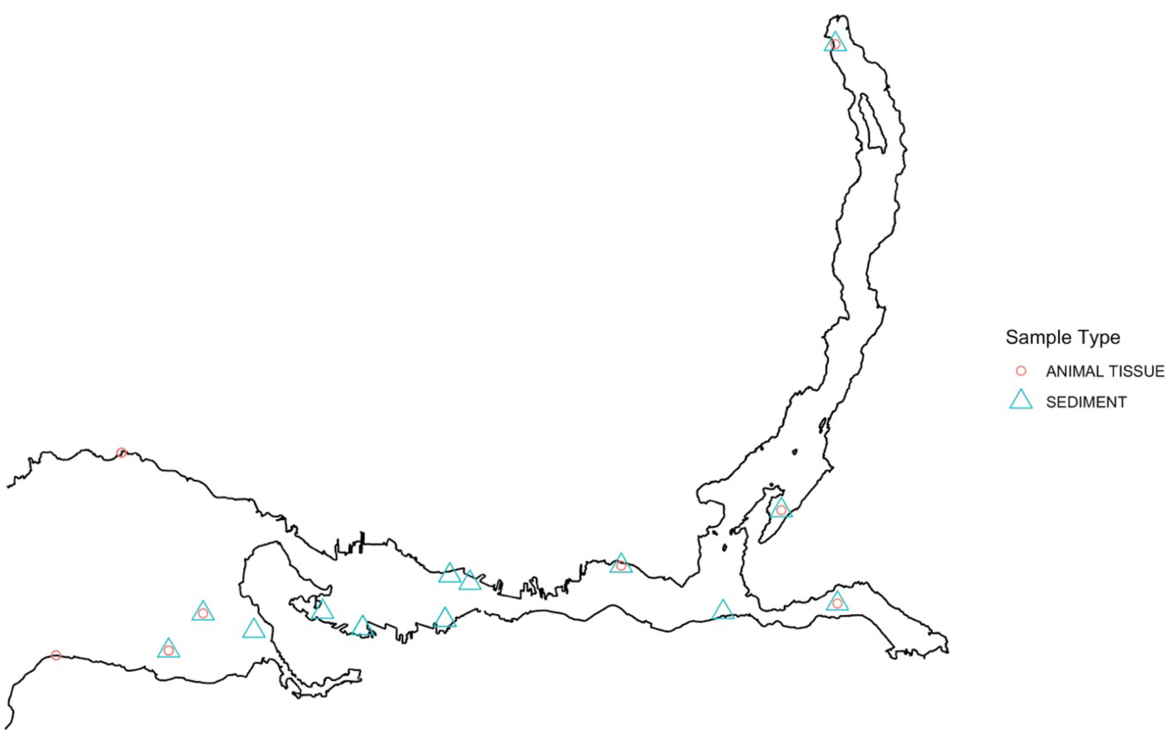


*Figure 4. PollutionTracker sampling stations in Burrard Inlet (2015 to 2016).*

## 3.3 Assessment Results

The results of the data assessment for copper 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 than programs that collect samples at depth for ambient conditions. Therefore, there are limitations on comparing results between the monitoring programs.

Where copper levels were below detection limits, values were plotted at the detection limit value in Figure 5 through Figure 13. 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 copper levels collected in surface grab or composite samples, unless indicated. There is comparably little data for dissolved copper levels in Burrard Inlet. All sediment data are presented in dry weight.

Data for constituents that impact copper 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.

**Pre-1990 Data**

- 1985–1987 – The Environment Canada Benthic Contaminants Study (Goyette and Boyd, 1989) included an assessment of copper levels in surface sediments and biota from six different surveys. Samples were generally collected in duplicates on individual dates. Mean sediment copper concentrations for the entire study area ranged from 47 to 9760 µg/g, with an average concentration of 305 µg/g. Historical sediment copper levels for Vancouver Harbour have been estimated to be <65 µg/g from 1985/86 results from Spanish Banks and Cates Park and a core sample from the Pacific Environment Institute (later the West Vancouver Laboratory) in 1988. Copper concentrations ranged from 62 µg/g at 14–16 cm to 40 µg/g at core depth 157 cm, reflecting historical levels below the contaminated surface layer. Generally, there was no evidence of metal uptake in the species examined during the study, despite the elevated metal levels in the surrounding sediments.
- 1970–1989 – BC ENV monitoring samples collected between 1971 and 1989 were above copper detection limits for 74% of water samples and 100% of sediment samples. Detection limits for water samples ranged between 0.001 and 3 µg/L, creating some uncertainty in the interpretation of potential patterns and comparison to benchmarks.
    - Detected water concentrations varied between 0.002 and 551 µg/L with an average at 10.2 µg/L; 63% of the samples exceeded the 1.3 µg/L benchmark (95% protection level) (Figure 7). High single-sample concentrations were found at the former Hooker Chemical (Station E207820) in the Central Harbour (551 µg/L), English Bay at Locarno Park (486 µg/L, Station E207812), in Indian Arm (427 µg/L, Station E207812), and at Burrard Bridge in False Creek (410 µg/L, Station 300081).
    - Sediment concentrations were measured at eight locations in Port Moody Arm in 1988 and 1989 (Figure 8). Concentrations varied between 46 and 129 µg/g dw.

Concentrations in all samples exceeded the TEL (18.7 µg/g) and one sample collected near IOCO #1 (Station E207688) also exceeded the PEL (108 µg/g).

**Post-1990 Data**

- 1995 – BIEAP Sediment Quality Study (EQOMAT, 1998) assessed surface sediment collected from fifteen stations. Samples were collected in triplicates on individual dates in October 1995. Replicated samples were averaged to determine the result at a given site on a given day. Sediment copper concentrations were above the background levels in Burrard Inlet (Goyette and Boyd 1989, Moore 1991, Boyd et al. 1997). In total, 11 of 15 stations exceeded the PEL benchmark of 108 µg/g dw and all stations exceeded the TEL benchmark of 18.7 µg/g dw. The highest concentration was recorded in the Inner Harbour at Station 3A at 1008 µg/g (mean of three replicates). The next highest concentration dropped to less than 200 µg/g.
- 1990–2009 – BC ENV water quality objectives attainment monitoring samples collected between 1990 and 2009 were above copper detection limits for 65% of water samples, 100% of surface sediment samples, and 0% of tissue samples. Detection limits ranged from 0.05 to 6 µg/L for water samples, was unknown for sediment samples and was 0.5 µg/g for fish tissue. The wide range of detection limits for copper in water samples may impact the interpretation of the water sample results. The following key points summarize the monitoring results:
    - Detected copper concentrations in water ranged from 0.08 to 2,471 µg/L (Figure 7). Among the detected concentrations, 99% of the samples showed levels above the lower benchmark at 0.3 µg/L and 44% of the samples were also above the higher benchmark at 1.3 µg/L. High copper concentrations ranging between 0.08 and 23 µg/L (average at 4.9 µg/L) were found at Clark Drive (Station E207818) in the Inner Harbour. The highest copper concentration at 2,471 µg/L was detected in waters near Vancouver Wharves; however, this sample appears to be an outlier, as concentrations in other samples from this location varied between 0.4 and 18 µg/L. Several sites showed considerably higher concentrations in a small number of the total samples, for example Shellburn in the Central Harbour (Station E207822) and Loch Katrine Bank in the Inner Harbour (Station E207819). At Shellburn, high concentrations were detected in one sample collected in 1990 (100 µg/L) and one sample collected in 2009 (85 µg/L) whereas considerably lower concentrations (≤ 10 µg/L) were found in the remaining 29 samples. This could indicate that high copper concentrations exist in pockets within the sediments and that multiple field replicates or composites are required to adequately capture the variability on the harbour floor. At Loch Katrine Bank, replicate samples collected in 1990 showed considerably different concentrations at 61 and 1 µg/L, respectively.
    - Copper concentrations in sediment varied largely by location (Figure 8). The highest concentrations were found close to Vancouver Wharves (Station E207816); concentrations ranged between 75 and 10,000 µg/g dw, with an average concentration at 4,230 µg/g dw. The second highest maximum (9,550 µg/g dw) and average (1,130 µg/g dw) concentrations were found next to Locarno Park in English Bay (Station E207812). The lowest concentrations were found in Indian Arm (Station 300080); this was the only monitored location where copper concentrations in some samples were below the TEL benchmark of 18.7 µg/g dw. Concentrations from several locations, e.g., Coal Harbour (Station E207813), False Creek (Station E207814), Vancouver Wharves (Station E207816), Clark Drive (Station E207818), and Port Moody Arm at IOCO (Station E207823), also exceeded the PEL benchmark of 108 µg/g dw.

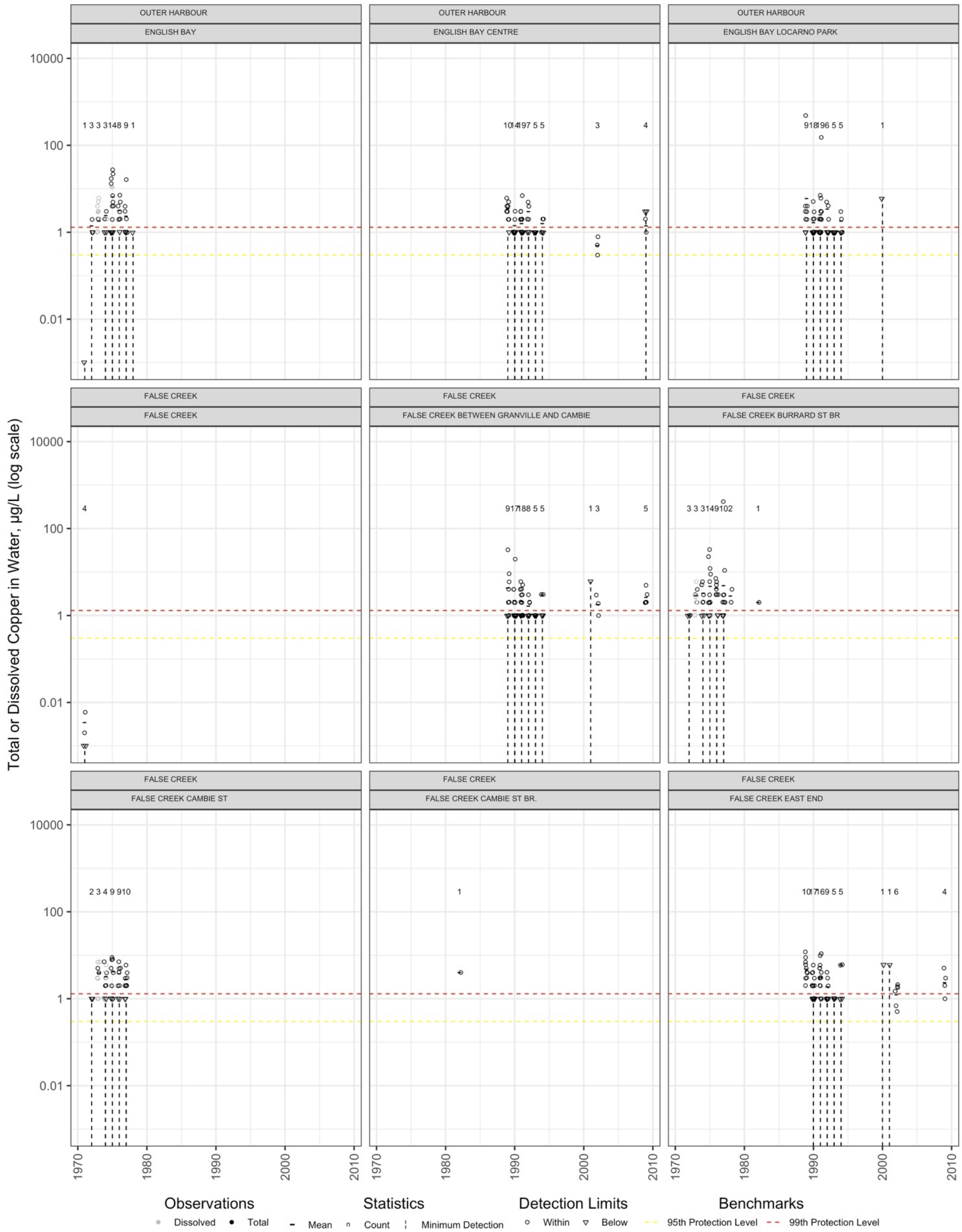


*Figure 5. Copper levels in ENV water samples (1971 to 2009) in µg/L (log scale)*

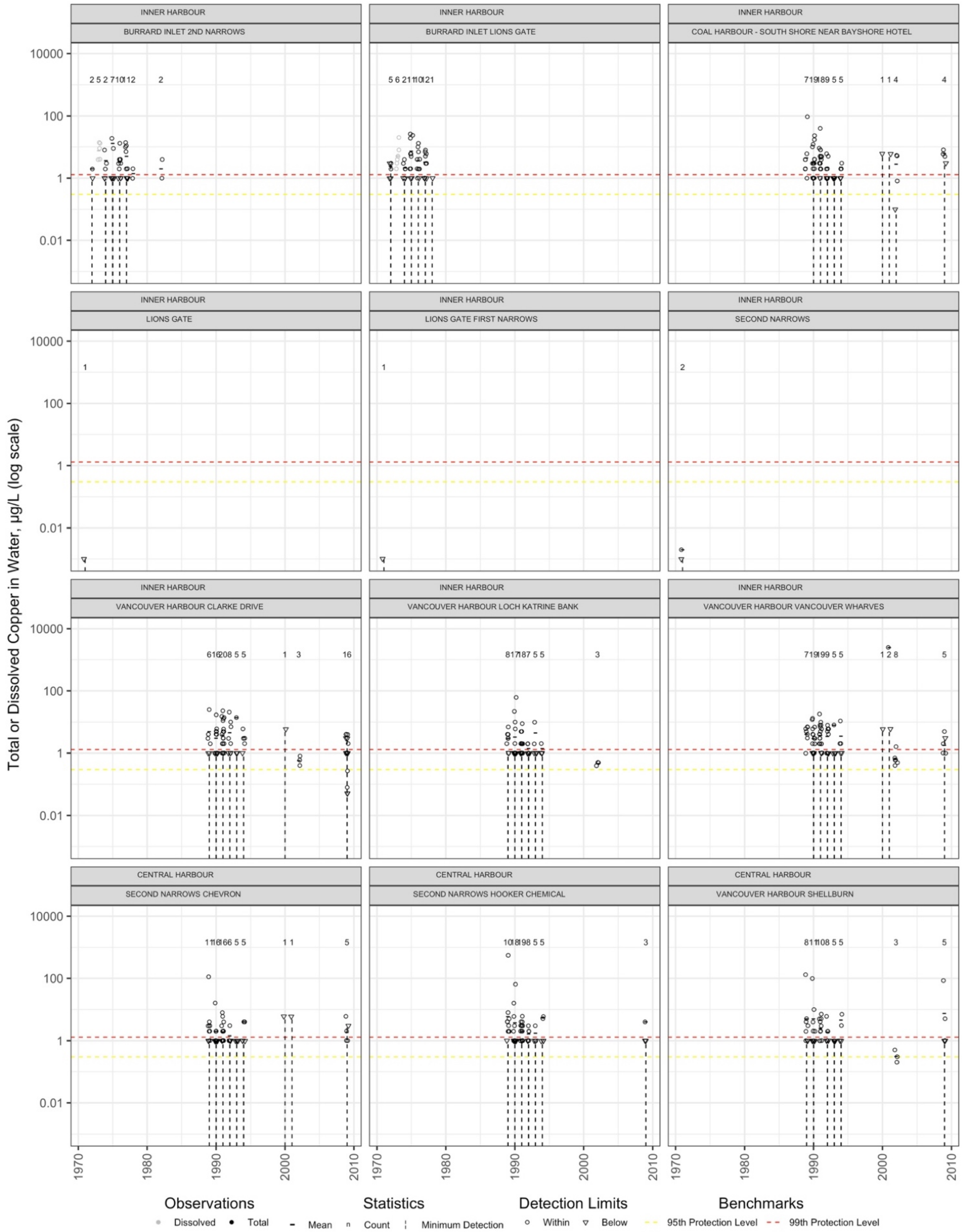


*Figure 6. Copper levels in ENV water samples (1971 to 2009) in µg/L (log scale, continued)*

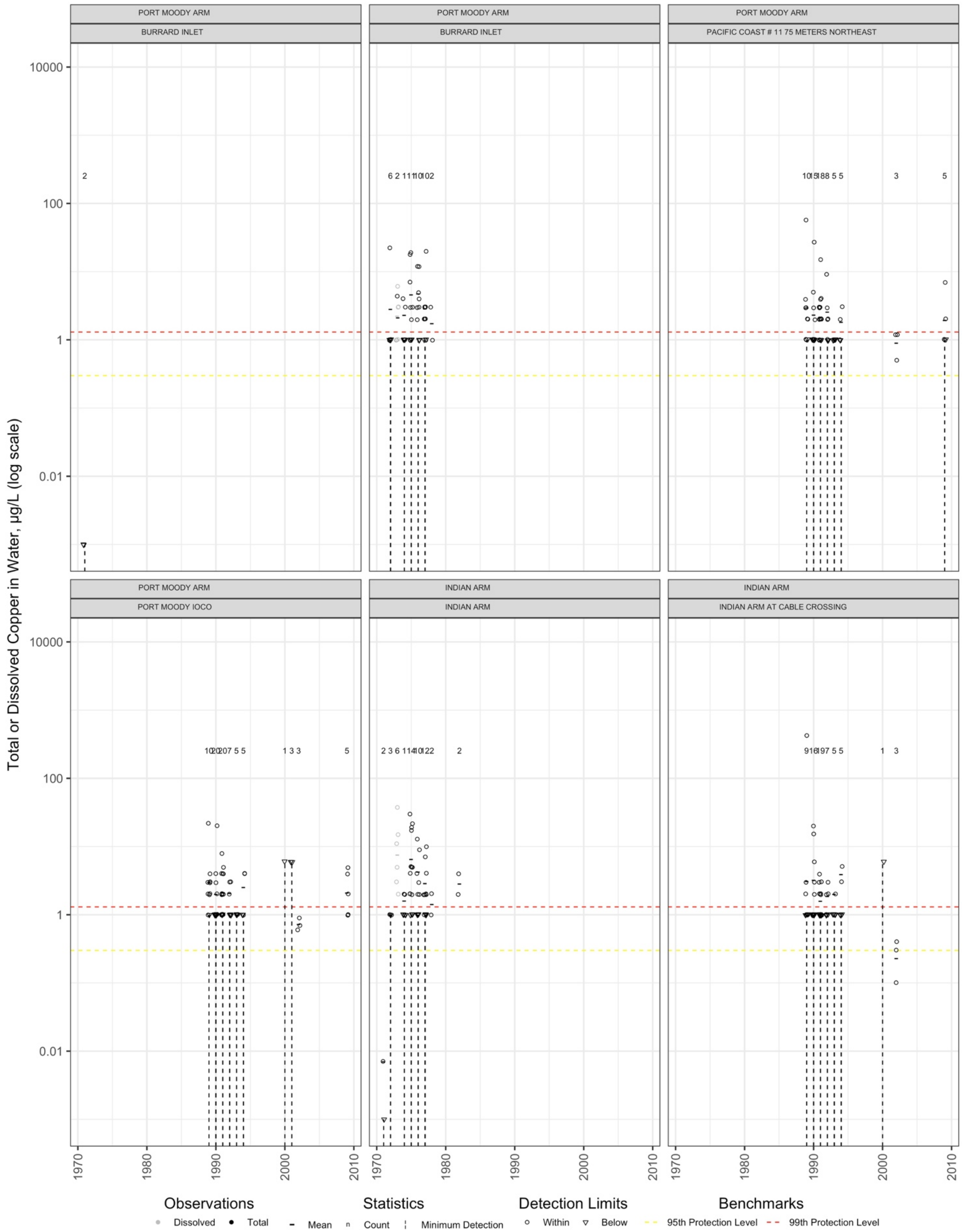


*Figure 7. Copper levels in ENV water samples (1971 to 2009) in µg/L (log scale, continued)*

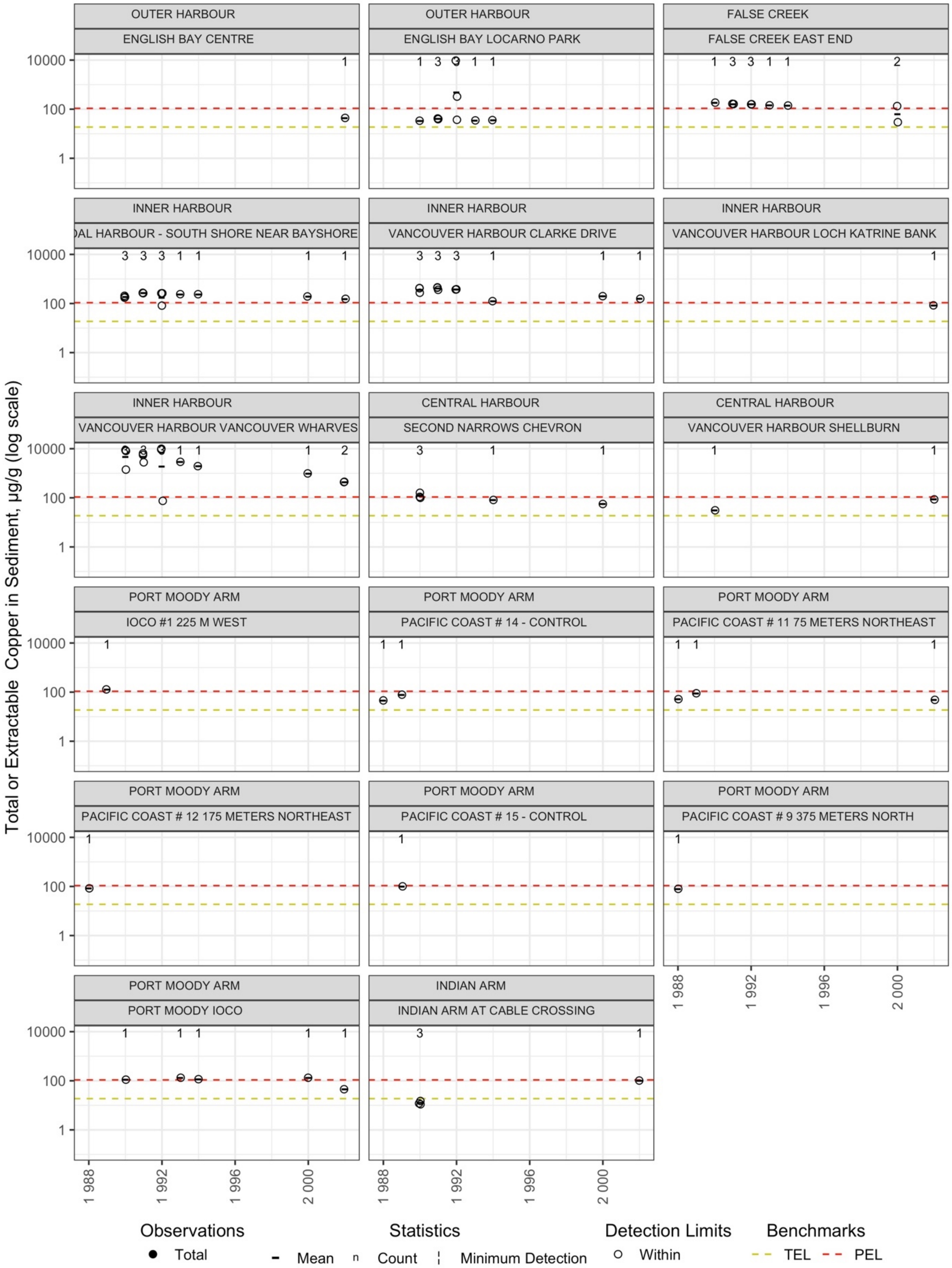


*Figure 8. Copper levels in ENV sediment samples (1988 to 2002) in µg/g dry weight (log scale)*

- 2007–2016 – As part of the Burrard Inlet Ambient Monitoring Program, Metro Vancouver has monitored copper levels in the water column annually (Figure 9) and in surface sediments every two to three years (Figure 10) since 2008. Copper levels in English sole tissue (whole body, muscle, and liver) samples were measured in 2007 and 2012 (Figure 11). Copper levels were above detection limits in all water and sediment samples and 81% of tissue samples. Detection limits were 0.05 µg/L for water samples, between 0.1 and 0.64 µg/g for sediment samples, and either 0.01 or 0.5 µg/g for fish tissue samples. 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 spatial or temporal trends were observed in water concentrations throughout the eight sub-basins between 2007 and 2016 (Figure 9). Copper concentrations in samples from all locations were generally between the 95 and 99% protection levels (i.e., between 0.3 and 1.3 µg/L). A few samples also exceeded 1.3 µg/L (95% protection level). The highest copper concentrations were generally measured in water samples from Port Moody Arm. The highest single concentration, however, was detected at 34 µg/L in one sample from Outer Harbour South in 2007.
    - There was no temporal trend in copper concentrations in sediment samples. Total concentrations exceeded the lower sediment (TEL) benchmark at 18.7 µg/g in samples from all locations (Figure 10). Some samples from Outer Harbour North and all samples from Port Moody Arm and Indian Arm South also exceeded the higher PEL benchmark at 108 µg/g. The highest average concentrations were found in the Port Moody Arm, and the lowest concentrations in Indian Arm North.
    - Concentrations of copper in female whole-body English sole composites from all seven sites were higher than the concentrations in male whole-body composites. Copper concentrations in tissue did not exceed the most conservative toddler subsistence fisher benchmark of 15 µg/g wet weight (ww). The highest copper levels were found in liver samples collected from Outer Harbour North and South (sites 1 and 2) at 14.2 µg/g ww and 11.4 µg/g ww, respectively. Copper concentrations in whole body and muscle tissue samples were generally one order of magnitude lower than in liver and were all below the most conservative tissue benchmark.

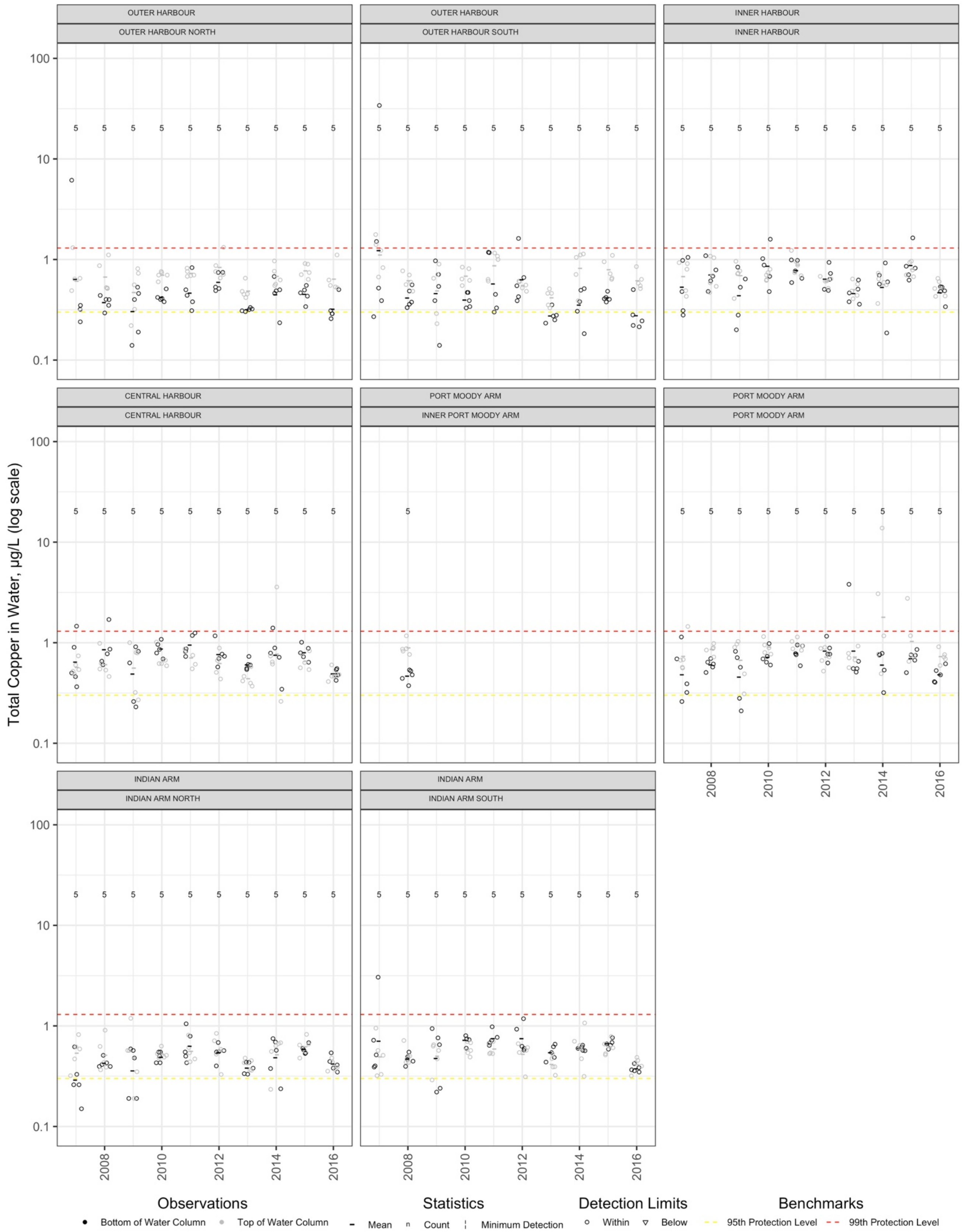


*Figure 9. Copper levels in Metro Vancouver water column samples (2007 to 2016) in µg/L (log scale)*

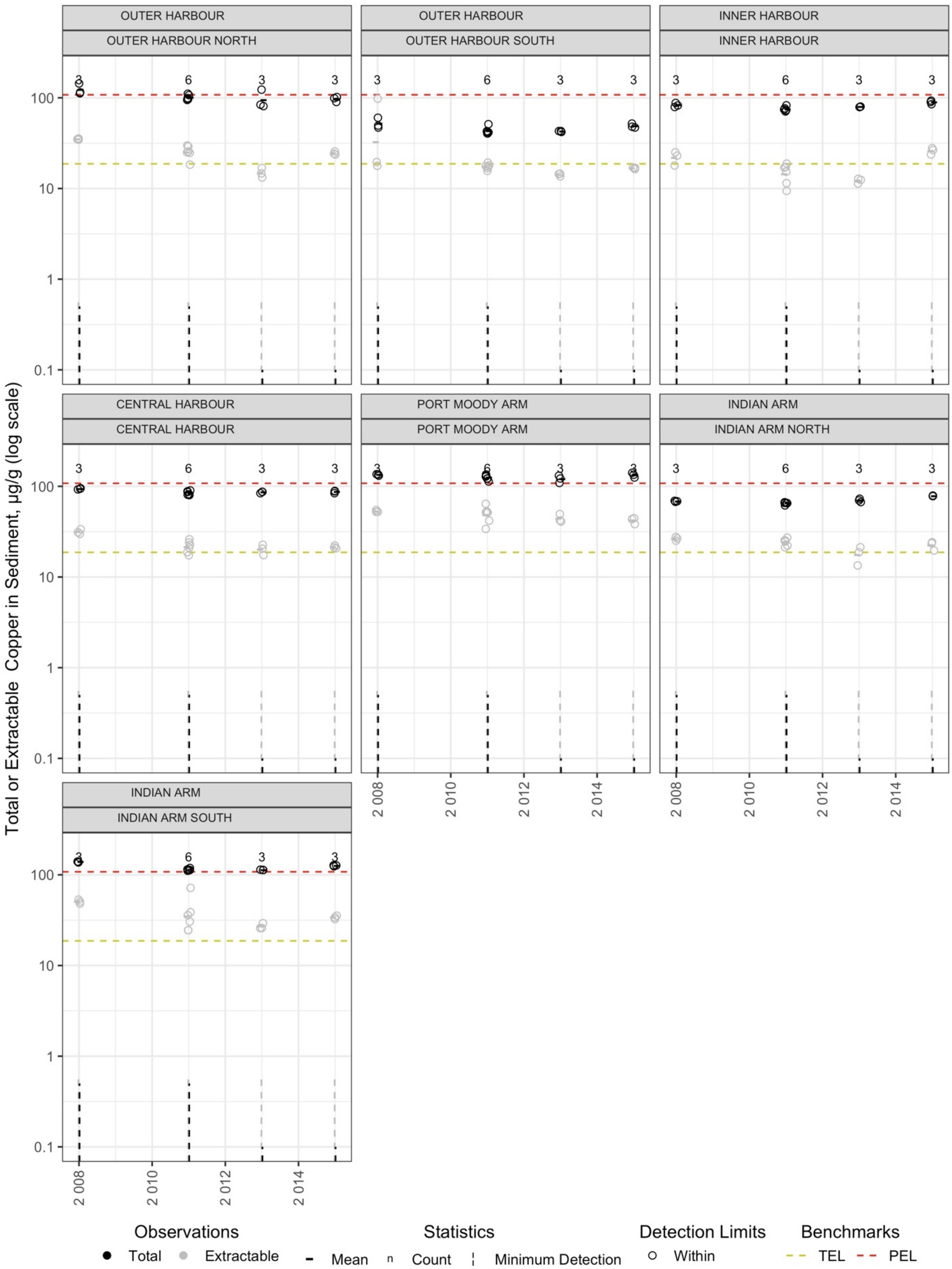


*Figure 10. Copper levels in Metro Vancouver sediment samples (2008 to 2015) in µg/g dry weight (log scale)*

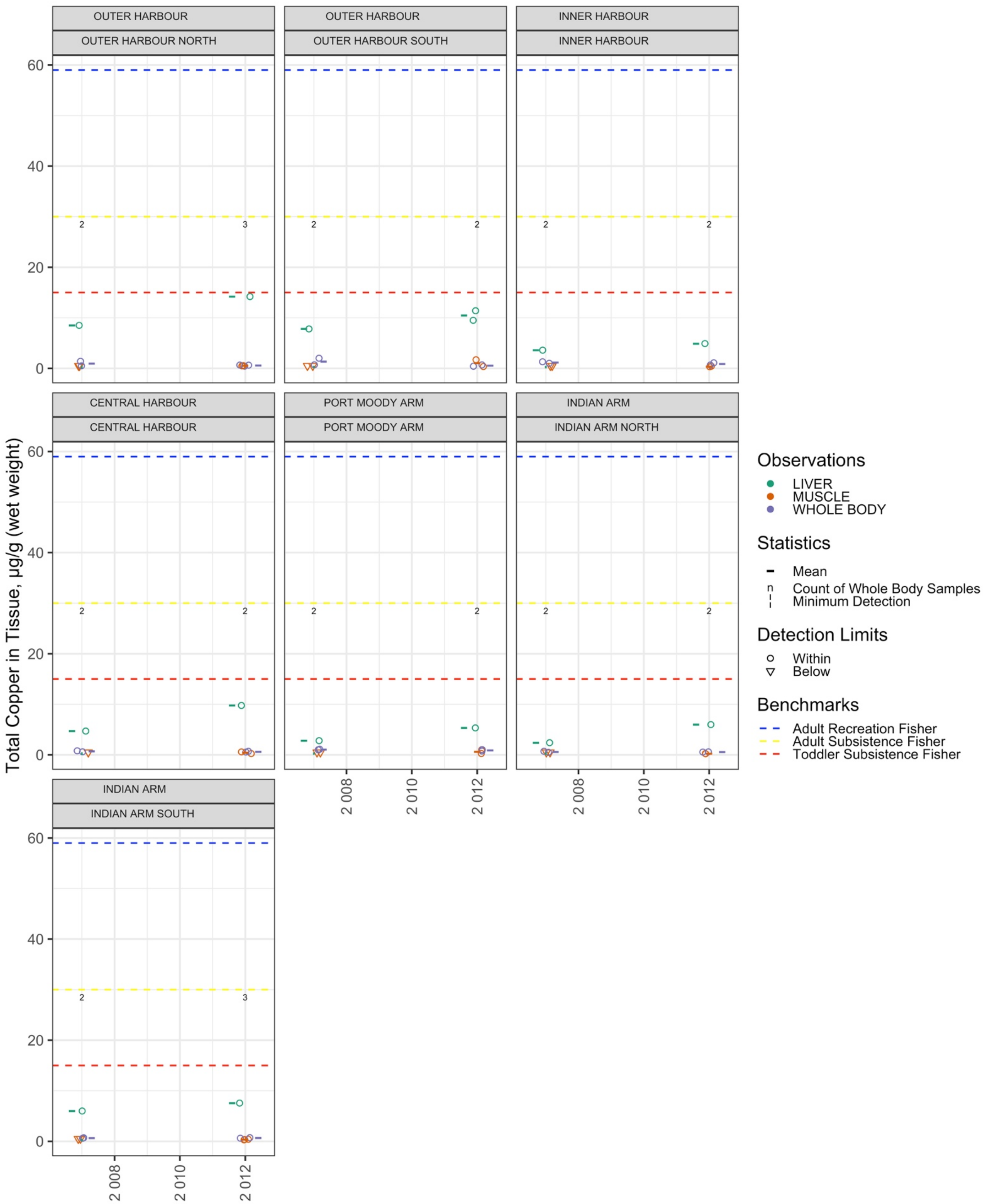


*Figure 11. Copper levels in Metro Vancouver English Sole tissue samples (2007 and 2012) in µg/g*

- 2015–present – Ocean Wise's PollutionTracker monitoring of copper levels in sediment (Figure 12) and mussel tissue (Figure 13) occurred in October 2015 and April 2016. Surface (top 2 to 5 cm) sediment samples were collected from 15 locations and mussels from 8 locations. Pollution Tracker results are summarized as follows:
  - The TEL sediment benchmark (18.7 µg/g dw) was exceeded in most samples for total copper, except samples from Indian Arm Site 2, Central Harbour Site 3, and Inner Harbour Site 4 (Figure 12). The extractable concentration of copper, measured at four sites, was above the TEL benchmark in one sample from Outer Harbour Site 14. The PEL (108 µg/g dw) was exceeded in the Outer Harbour (162 µg/g) and the Inner Harbour (156 µg/g).
  - Copper concentrations in mussels did not exceed the most conservative toddler subsistence fisher benchmark at 15 µg/g ww (Figure 13).

It is important to note that the data from the various monitoring programs (e.g. Figure 5 vs. Figure 9, Figure 8 vs. Figure 10) are not directly comparable due to differences in program design. Metro Vancouver sampled in the middle of sub-basins to understand ambient conditions (Figure 3), whereas ENV (Figure 2) and ECCC (Figure 1) sampled nearshore receiving environments closer to known point sources. Detection limits have also decreased over time. ENV data were collected from 1970-2009, and Metro Vancouver data were collected from 2007-2016. More samples of copper in water were below the detection limit in ENV samples compared to the Metro Vancouver samples, because the detection limits were generally higher for the ENV data (e.g., ≤ 3 µg/L ENV, 0.05 µg/L Metro Vancouver). The more recent ENV samples show fewer non-detects.

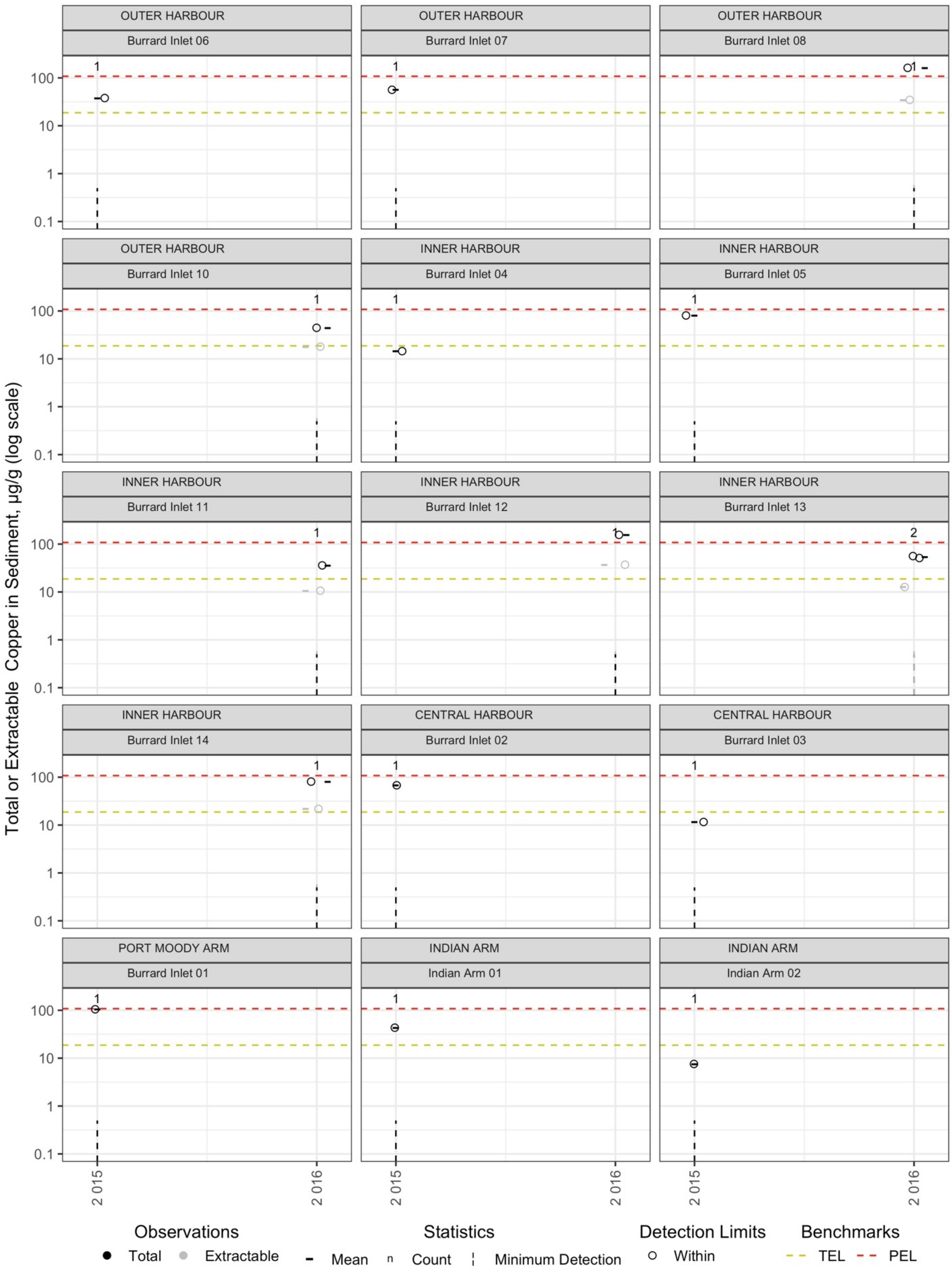


*Figure 12. Copper levels in Ocean Wise sediment samples (2015 and 2016) in µg/g dry weight (log scale)*

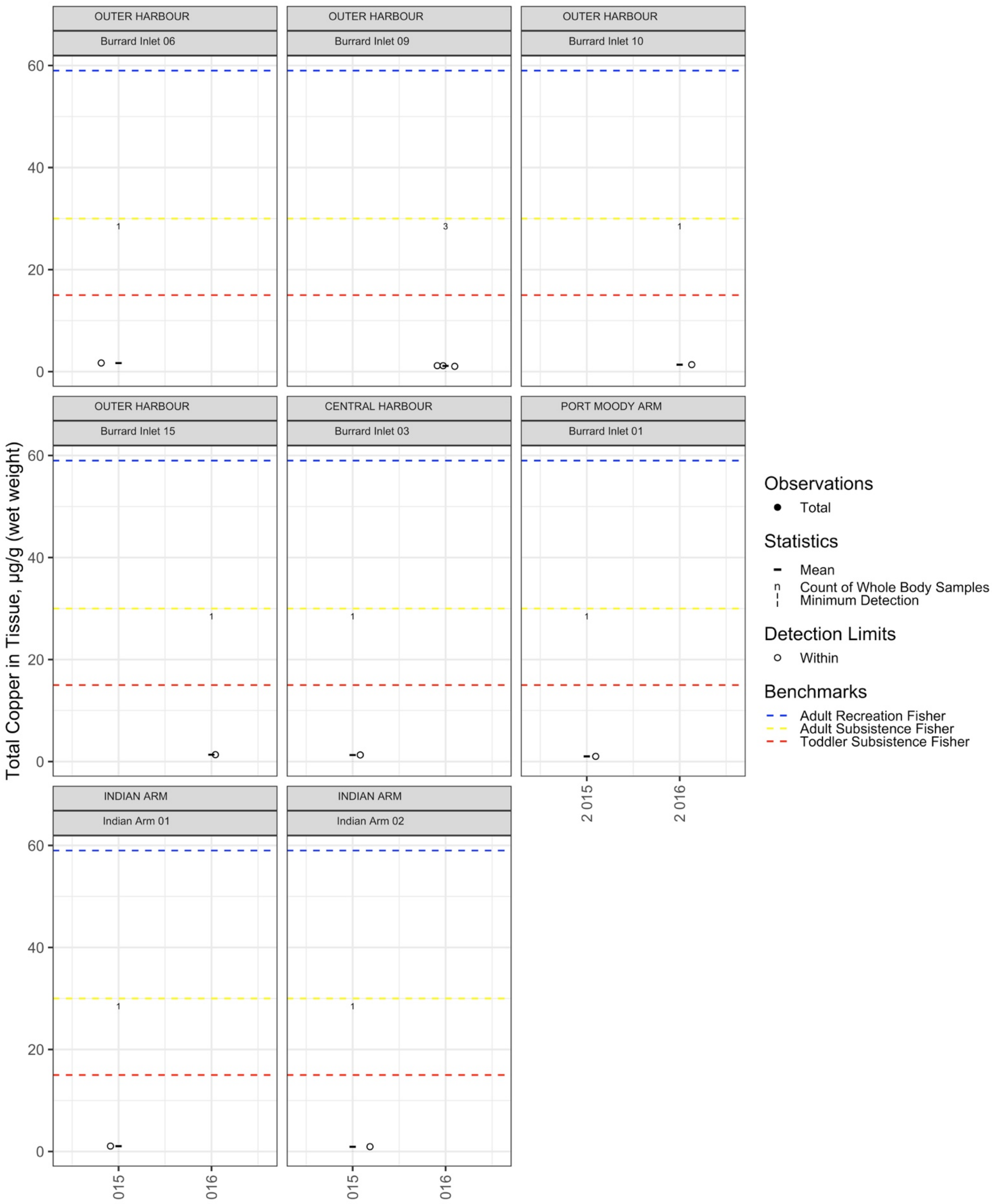


*Figure 13. Copper levels in Ocean Wise mussel tissue samples (2015 and 2016) in µg/g*

## 3.4 Knowledge Gaps and Research Needs

Priority knowledge gaps and research needs that were identified include:

- Whether there is any seasonal variability of copper levels in Burrard Inlet.
- In the cooling systems of some facilities with authorized discharges into Burrard Inlet (e.g., Canada Place), chlorine-based systems to prevent fouling of equipment were replaced with the installation of copper anodes. This was done to prevent pollution via chlorination to the receiving environment. It should be determined whether these copper anodes contribute a significant amount of copper into the receiving environment.
- There is a lack of information on copper concentrations in shellfish tissue. This information is key to understanding the effects on the organisms' health and human health upon consumption. Shellfish tissue sampling can also help determine the level of bioaccumulation throughout the food web.
- Differences in the seasonal or daily movements of individual fish could increase variability in replicated data and potentially explain year to year variability in tissue contaminant data or lack of correlation between tissue results and sediment contamination. It is therefore necessary to determine the residency or movement patterns of English sole in Burrard Inlet in order to determine whether this species is an acceptable indicator. Tagging and tracking studies might help to establish residency, although tracking for a year or more might be necessary. If it is not possible to demonstrate site fidelity in English sole, another sentinel species or a sedentary or sessile invertebrate species might be more suitable.
- The toxicity and bioavailability of copper is affected by other factors including the presence of other contaminants. Analysis of potential toxicity based on additive or synergistic factors, and development of criteria for chemical mixtures is still a topic of investigation. Improved understanding of the effects of chemical mixtures could help determine management options to reduce overall toxicity in areas of concern.

# 4. PROPOSED OBJECTIVES FOR COPPER IN BURRARD INLET

## 4.1 Proposed Objectives

Proposed objectives for copper are presented in Table 4.

Table 4: Proposed water quality objectives for copper in Burrard Inlet

| Sub-basin | Outer Harbour | False Creek | Inner Harbour | Central Harbour | Port Moody Arm | Indian Arm |
|---|---|---|---|---|---|---|
| **Total Copper in Water** | 1.3 µg/L mean[1]<br>AND<br>no more than 20% of samples above 1.3 µg/L | | | | | |
| **Total Copper in Sediment** | 18.7 µg/g dry weight single-sample maximum[2] | | | | | |
| **Copper in Tissue** | 15 µg/g wet weight single-sample maximum[3] | | | | | |

[1] Minimum of 5 samples in 30 days collected during wet and dry seasons (until the peak season is identified).
[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

The proposed Water Quality Objectives (WQOs) for copper in water and sediment in Burrard Inlet are adopted from benchmarks that are based on more recent research and are more stringent than the 1990 copper WQOs for Burrard Inlet. Although research to update guidelines for copper in marine waters is ongoing in several jurisdictions, these site-specific objectives are proposed for copper in Burrard Inlet in the interest of understanding trends and ultimately reducing copper loading and levels in the inlet.

The proposed objective for copper in water is 1.3 µg/L to be consistent with the Draft Recommended Environmental Quality Guidelines for the Protection of Southern Resident Killer Whales and their Prey (ECCC 2021). This value originates from a species sensitivity distribution model and is considered a marine high reliability trigger value appropriate for slightly to moderately disturbed systems (ANZG 2000). This type of model typically includes various assumptions and limitations. BC has its own approved species sensitivity distribution model, which may produce different trigger values; this proposed objective may be revisited and updated following any future analyses based on the BC model and updates to the BC Water Quality Guidelines for copper. The qualifier that no more than 20% of samples exceed 1.3 µg/L is also proposed to ensure that, overall, levels are consistently below the WQO and that exceedances are not masked by generally low concentrations.

The proposed objective for copper in sediment is 18.7 µg/g to be consistent with the BC working sediment quality guidelines (ENV 2020), derived from the Canadian Sediment Quality Guidelines for the Protection Of Aquatic Life (CCME 1999).

Existing guidelines were not available as benchmarks for copper in tissue, so toxicological information and human health risk assessment guidance from Health Canada was used to develop tissue SVs for protection of the most sensitive values in Burrard Inlet, and the most sensitive receptors within those values: consumption of finfish and shellfish by Indigenous toddlers (see Section 3.1.3). This SV is proposed as a WQO for copper in finfish and shellfish tissue.

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

# 5. MONITORING RECOMMENDATIONS

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

- Because of the influence of rainwater runoff on copper levels, monitoring of copper in water must occur year-round (in both wet and dry seasons), at least initially, to determine the time of year during which copper levels are highest. Monitoring can then be focused on collecting 5 samples in 30 days during that peak time of year.
- Monitoring at stormwater outfalls could help identify hotspots for source control.
- Monitoring methods to understand and address potential threats of copper to forage fish embryos should be considered, for example monitoring of metals such as copper in interstitial waters[3].
- More work is needed to understand and minimize or eliminate the contaminants released into Burrard Inlet with vessel scrubber discharge water (ICCT 2020).

[3] The water occupying the spaces between sediment particles

- All monitoring data should become open data and be made available to regulatory agencies, Indigenous governments, municipalities, and the public on timely basis.

## 6. MANAGEMENT OPTIONS

Key management options for reducing copper levels in Burrard Inlet include the following:

- Ensure land use planning includes improvements to rainwater management such as plant based bio-filtration and other green infrastructure to improve rainwater quality as a goal for all urban areas
- Reduction of impervious surfaces
- Motorized vehicle reduction strategies
- Examination of effluent permits under the *Environmental Management Act* as potential sources
- 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.
- Source controls such as phasing out the use of copper in automotive brake pads and shoes (TWN 2017), requiring non-biocide alternatives to copper-based anti-fouling paints and mechanisms.

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