

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



August 2021



Tsleil-Waututh Nation  
səlilwətəl



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 nickel in Burrard Inlet, identified in Tsleil-Waututh Nation’s Burrard Inlet Action Plan as one of the most problematic heavy metals in the Inlet. These proposed objectives were developed using up-to-date research on relevant values and potential effects, sources and factors influencing nickel levels, benchmark screening, and monitoring data for Burrard Inlet.

Nickel is an essential trace element but can be toxic at high concentrations. The water value most sensitive to nickel pollution in water and sediment is aquatic life, and to nickel in tissue is human consumption of finfish and shellfish.

Most nickel discharged into the environment is from human activities, with domestic wastewater discharges and stormwater runoff as primary sources of nickel entry into the marine environment. Sources of nickel include stainless steel and other alloys; computer components; chemical, iron and food processing; batteries; timber products; catalysts; pigments; paving; roofing; and tobacco products.

BC water quality guidelines for nickel in water and sediment have not been updated since 1990 and are based on a limited selection of studies that were conducted in the 1970s and 1980s. However, in the absence of guidelines based on more recent toxicity data, these guidelines were adopted as benchmarks for the assessment of nickel levels and observations in the water and sediment in Burrard Inlet. A human-health based screening value was used as a benchmark for nickel in tissue.

Data indicate that, in the marine environment of Burrard Inlet, there have been elevated nickel levels in areas near combined sewer and stormwater outfalls, such as at Clark Drive, and where there is a high concentration of sewer outfalls and urban activity, such as in False Creek. The most recent ambient monitoring data analyzed indicate that nickel levels are generally lower than the benchmark levels for marine water quality but generally higher than the benchmark levels for marine sediment quality, and higher than at least one of the tissue quality benchmarks.

The proposed water quality objectives for nickel are as follows:

| <b>Sub-basin</b>  | <b>False Creek</b>   | <b>Outer Harbour</b> | <b>Inner Harbour</b> | <b>Central Harbour</b> | <b>Port Moody Arm</b> | <b>Indian Arm</b> |
|---|--|----------------------|----------------------|------------------------|-----------------------|-------------------|
| <b>Total Nickel in Water</b>  | 0.8 µg/L mean <sup>1</sup>   |                      |                      |                        |                       |                   |
| <b>Total Nickel in Sediment</b>   | 30 µg/g dry weight single-sample maximum <sup>2</sup>                      |                      |                      |                        |                       |                   |
| <b>Total Nickel in Tissue</b>   | 0.42 µg/g wet weight single-sample maximum (all tissue types) <sup>3</sup> |                      |                      |                        |                       |                   |
| <sup>1</sup> Minimum of 5 samples in 30 days collected during the wet season. No more than 20% of samples > 0.8 µg/L.<br><sup>2</sup> Based on at least 1 composite sample consisting of at least 3 replicates.<br><sup>3</sup> 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. |  |                      |                      |                        |                       |                   |

Because excessive nickel is a known toxin to humans and aquatic species, continued monitoring of nickel in water, sediment, fish and mussel tissue is recommended. Additional monitoring is recommended in the vicinity of known sources of nickel, such as near stormwater and combined sewer outfalls; areas with elevated nickel 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 nickel into Burrard Inlet include reducing the entry of nickel into the stormwater system and implementing green infrastructure that can absorb and treat stormwater prior to its discharge into Burrard Inlet.

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## **ACRONYMS**

|          |  |
|----------|--|
| AET      | Apparent effects threshold   |
| AF       | Allocation factor  |
| BC       | British Columbia OR Background concentration                         |
| BC ENV   | British Columbia Ministry of Environment and Climate Change Strategy |
| BIEAP    | Burrard Inlet Environmental Action Program                           |
| BW       | Body weight  |
| CCME     | Canadian Council of Ministers of the Environment                     |
| EQOMAT   | Environmental Quality Objectives and Monitoring Action Team          |
| IR       | Ingestion rate   |
| ISQG     | Interim Sediment Quality Guideline                                   |
| PEL      | Probable effect level  |
| RAF      | Relative absorption factor   |
| SV       | Screening value  |
| TDI      | Tolerable daily intake   |
| TEL      | Threshold effect level   |
| TRV      | Toxicological reference value  |
| TWN      | Tsleil-Waututh Nation  |
| US EPA   | United States Environmental Protection Agency                        |
| USA NOAA | United States National Oceanic and Atmospheric Administration        |

## **1. INTRODUCTION**

This chapter proposes water quality objectives for nickel in Burrard Inlet, identified in Tsleil-Waututh Nation's Burrard Inlet Action Plan as one of the most problematic heavy metals in the Inlet (TWN 2017). This chapter includes relevant background information, an overview assessment of current status and trends in nickel levels in water, sediment, and biota in Burrard Inlet, comparison to benchmarks, and a rationale for the proposed objectives. Recommendations for future monitoring as well as management options to help achieve these objectives are also included.

## **2. BACKGROUND**

### **2.1 Values and Potential Effects**

Nickel is an essential trace element but can be toxic at high concentrations, particularly in the form  $Ni^{2+}$  (ANZECC & ARMCANZ 2000). Nickel can interfere with the metabolism of other essential metals. Water soluble forms of nickel, such as nickel sulphate, nickel chloride, and nickel hydroxide, are more readily absorbed. The first two are most common; nickel sulphate is more toxic than nickel chloride. Waterfowl feeding in areas contaminated with nickel are vulnerable due to accumulation of nickel into aquatic plants (Cempel and Nickel 2006, Eisler 1998).

The free ion of nickel can be taken up by fish through the gills. In aquatic animals, excess nickel can lead to impairment of gas exchange, inhibition of ion regulation and oxidative stress (Blewett and Leonard 2017).

Dietary intake of nickel, with gastrointestinal absorption, is considered a more important route of exposure in humans than via air and drinking water, although the presence of food in the stomach results in less nickel absorption. The kidney is the main target organ for nickel toxicity following oral exposure. Tests on laboratory animals have shown toxicity to fetuses following exposure to nickel (Cempel and Nickel 2006).

In the marine environment, the values most sensitive to nickel pollution in Burrard Inlet are aquatic life, and human consumption of finfish and shellfish at rates applicable to coastal Indigenous populations such as Tsleil-Waututh Nation.

### **2.2 Potential Sources of Nickel Pollution**

Natural sources of nickel include the weathering of rocks and minerals (ANZECC & ARMCANZ 2000). Anthropogenic sources of nickel include metal plating and finishing such as the production of stainless steel and other nickel alloys; manufacturing of computer components, chemicals and batteries; the processing of iron, and timber products; use as catalysts and pigments in metallurgical, chemical and food processing industries; paving and roofing; tobacco products; and metal water pipes (Cempel and Nickel 2006, Eisler 1998, Hunt et al 2002). Nickel can become airborne through coal, diesel and other fuel combustion; waste incineration; and tobacco smoking. Domestic wastewater and metal smelting are major sources of nickel pollution in marine and freshwater aquatic systems (Cempel and Nickel 2006).

Discharges from vessels are also a potential source of nickel input into Burrard Inlet. Vessel exhaust gas cleaning systems, also called scrubbers, have been found to discharge wash water that contains contaminants including nickel (ICCT 2019, 2020). Elevated nickel concentrations have been observed in aquatic plants and animals in the vicinity of heavily populated areas, sewage outfalls, nickel smelters, nickel-cadmium battery manufacturers, electroplating plants and coal ash disposal basins (Eisler 1998).

Sources for nickel in Burrard Inlet identified in 1990 included stormwater discharges in False Creek, the Inner Harbour and the Central Harbour; combined sewer overflows in False Creek and the Inner Harbour; the Vancouver Wharves terminal in the Inner Harbour and historical discharges from Canadian Occidental Petroleum<sup>1</sup> in the Central Harbour (Nijman and Swain 1990).

### 2.3 Factors Influencing Nickel Levels in Burrard Inlet

Most nickel in the aquatic environment is associated with sediments (ANZECC & ARMCANZ 2000). Precipitation, complexation and adsorption can lead to its deposition in sediments (Cempel and Nikel 2006).

Nickel bioavailability and toxicity can be reduced by the presence of other metals and major ions, such as Ca<sup>2+</sup> and Mg<sup>2+</sup> (hardness), as they can compete with nickel for uptake sites (Blewett and Leonard 2017).

Nickel toxicity decreases with increasing hardness, pH and salinity. At pH greater than 6, nickel adsorbs or co-precipitates with iron and manganese (oxy)hydroxides. Increased concentrations of dissolved organic matter, such as humic and fulvic acids, reduce the bioavailability of nickel in aquatic systems (ANZECC & ARMCANZ 2000). Uncertainty remains about the mechanism of nickel toxicity in aquatic environments (Brix et al. 2016).

### 2.4 1990 Provisional Water Quality Objectives for Nickel

The 1990 Burrard Inlet objectives for nickel in water and sediment are presented in Table 1. The 1986 U.S. Environmental Protection Agency (EPA) water quality criteria for marine aquatic life were adopted for water, but only in False Creek, the Inner Harbour and the Central Harbour, where potential loading sources and/or exceedances of the chronic criteria had been identified at the time. Due to limitations inherent to the equipment used at the time, detection limits were high, at 10 µg/L, potentially masking some exceedances. The objective for nickel in sediment (45 µg/g) was set to be higher than the lowest apparent effects threshold (AET) for Puget Sound (28 µg/g) but lower than the nickel level at the Puget Sound reference site (65 µg/g) and within the Burrard Inlet reference range at the time (38–52 µg/g; Nijman and Swain 1990).

Table 1: 1990 Provisional Water Quality Objectives for Nickel

| Sub-basin                               | False Creek                      | Outer Harbour | Inner Harbour                    | Central Harbour                  | Port Moody Arm | Indian Arm |
|---|----------------------------------|---------------|----------------------------------|----------------------------------|----------------|------------|
| <b>Water</b>                            | ≤ 8 µg/L mean<br>75 µg/L maximum | N/A           | ≤ 8 µg/L mean<br>75 µg/L maximum | ≤ 8 µg/L mean<br>75 µg/L maximum | N/A            | N/A        |
| <b>Sediment</b>                         | 45 µg/g dry weight maximum       |               |                                  |                                  |                | N/A        |
| All values are for total nickel 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 updated objectives for nickel levels in Burrard Inlet. Based on the available literature,

<sup>1</sup> Previous holders of ENV permit PE-18, which has since undergone several changes in ownership and permit amendments. PE-18 is currently held by Chemtrade Electrochem Inc. (Rao et al. 2019).

aquatic life is the most sensitive value for nickel levels in the water column and sediments. Finfish and shellfish consumption by humans may be the most sensitive values for nickel levels in tissue, though limited data is available.

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

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

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).

Table 2 outlines the benchmarks that were used for screening of nickel levels in this assessment. All concentrations are for total nickel levels. Water and sediment benchmarks are used to screen for protection of aquatic life while fish and mussel tissue benchmarks are used to screen for human health. Human-health based screening values (SVs) for fish and shellfish tissue were derived from Health Canada toxicological reference values and risk assessment methodologies (Health Canada 2010a,b, 2012, 2021; Richardson 1997, Richardson and Stantec 2013, Thompson and Stein 2021).

*Table 2: Screening Benchmarks for Nickel in Water, Sediment, and Biota Used in this Assessment*

| Sample Type         | Screening Benchmark  | Status   | Value                                      | Reference   |
|---------------------|--|----------|--|---|
| Water               | 8.3 µg/L mean (chronic benchmark)  | Working  | Marine aquatic life                        | US EPA 1986 <sup>1</sup>  |
| Sediment            | 30 µg/g dry weight (lower benchmark)<br>50 µg/g dry weight (upper benchmark) <sup>2</sup>  | Working  | Marine aquatic life                        | Long and Morgan 1990 <sup>3</sup>   |
| Tissue <sup>4</sup> | 0.42 µg/g wet weight (toddler subsistence fisher benchmark)<br>0.83 µg/g wet weight (adult subsistence fisher benchmark)<br>1.65 µg/g wet weight (adult recreational fisher benchmark) | Proposed | Human consumption of finfish and shellfish | Screening value calculated from Health Canada 2010b (Thompson and Stein 2021) |

<sup>1</sup>BC Working Water Quality Guidelines (US EPA 1986)  
<sup>2</sup>Effect levels based on US NOAA National Status and Trends Program Approach  
<sup>3</sup>BC Working Sediment Quality Guidelines (Long and Morgan 1990)  
<sup>4</sup>Calculated screening value for which nickel 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.

All values are for total nickel levels.  
Water and sediment benchmarks are used to screen for protection of aquatic life while fish and mussel tissue benchmarks are used to screen for human health.

Benchmarks for nickel levels in water and sediment are based on the BC Working Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture (ENV 2017) as there are no published approved BC guidelines for nickel. Because of limited knowledge on the mechanisms for nickel toxicity in marine



water, there are few recent guidelines established in Canada or elsewhere (Blewett and Leonard 2017). There are no guidelines for nickel in marine water or sediment from the CCME (2014), and there are no federal environmental quality guidelines for nickel (ECCC 2019). CCME marine water quality guidelines for nickel are due to be updated, but no work was planned at the time of writing this document (Azizishirazi 2020).

The BC Working Water Quality Guideline, based on a 1986 US EPA guideline (US EPA 1986), is based on acute toxicity testing of 18 invertebrates and 4 fish species as well as chronic toxicity testing of the mysid (a crustacean), *Mysidopsis bahia*<sup>2</sup>, which was the only species for which acceptable chronic toxicity test data was available at the time. Comparatively, chronic guidelines for other metals, including lead and copper, have been based on toxicity testing and literature using a wider pool of different species.

The final acute effects level was calculated to be 149.2 µg/L using the 22 species dataset while the chronic effects level for the mysid species was 92.47 µg/L. The acute effects level was divided by a Final Acute-Chronic Ratio of 17.99 to arrive at final chronic guideline of 8.3 µg/L (see US EPA 1986 for details). This guideline is 11 times lower than the chronic effects level determined for the mysid. Expanded chronic toxicity studies for nickel have since been published (e.g. DeForest and Schlekot 2013, European Chemicals Bureau 2008), but have not yet been used to update water quality nickel. There are no acute BC guidelines for nickel freshwater and no CCME guidelines for nickel in freshwater or marine water.

The BC Working Sediment Quality Guidelines, developed in 1990, are based on a compilation and assessment of a 'moderate amount of data available for sediments to estimate effects thresholds, however all of the data [were] from matching biological and chemical field samples' (Long and Morgan 1990). These guidelines were first published in the US National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program. With the available data at the time, effects were not observed at a nickel concentration of 21 µg/g. The lower effects level (30 µg/g) was developed using the 10<sup>th</sup> percentile of the recorded effect levels and the upper effects level (50 µg/g) was developed using the 50<sup>th</sup> percentile of the recorded effect levels.

Australia and New Zealand recommend a 99% protection level of 7 µg/L for slightly to moderately disturbed marine systems (ANZECC & ARMCANZ 2000).

The current US EPA recommended water quality criteria for nickel levels for the protection of aquatic life in saltwater are 74 µg/L (acute) and 8.2 µg/L (chronic), and were last updated in 1995 (US EPA 2020). The US EPA criteria are expressed in terms of dissolved nickel in the water column whereas the BC guidelines express values for total nickel, which is a more conservative approach. The highest nickel concentrations measured among all Burrard Inlet water samples were approximately 40 µg/L (measured by BC ENV in a few samples between 1971 and 1990). Therefore, it was deemed unnecessary to compare Burrard Inlet data against the US EPA acute benchmark for nickel in water.

There are currently no BC tissue guidelines for nickel and the Canadian Food Inspection Agency does not have a guideline for nickel for fish or shellfish exports to major markets such as the European Union or China (CFIA 2019). The US EPA human health criterion for nickel is 4600 µg/L for the consumption of organisms (US EPA 2002). The fish tissue bioconcentration factor is from the US EPA 1980 Ambient Water Quality Criteria document (US EPA 2002). Health Canada's upper limit for daily nickel intake in a male or female aged 14 and over is 1000 µg/day (Health Canada, 2001).

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

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<sup>2</sup> Since reclassified under the genus *Americamysis* (Price et al. 1994).

Stein 2021). The approach considers: the contaminant *receptors* (people who are exposed to the contaminant, in this case subsistence/Indigenous, recreational, and general BC populations, with SVs calculated for the most sensitive life stage within each population), *exposure* to the contaminant (how much fish the receptors consume), and the contaminant *toxicity* (what is known about the contaminant and how it affects different receptors). Receptor characteristics were defined from Richardson and Stantec (2013), exposure was calculated through fish ingestion rates from Richardson (1997) and Health Canada (2010b), and toxicity was defined through toxicological reference values (TRVs) prescribed by Health Canada (2021) or other international agencies (i.e., United States Environmental Protection Agency and the World Health Organization).

Tissue SVs are defined as conservative threshold values against which contaminant concentrations in fish tissue can be compared and assessed for potential risks to human health (Thompson and Stein, 2021). Fish and shellfish tissue in this report refer to country foods, that is, foods produced in an agricultural (not for commercial sale) backyard setting or harvested through hunting, gathering or fishing activities (Health Canada 2010a). SVs provide general guidance to environmental managers and represent a suggested safe level of a contaminant in fish tissue based on a conservative estimate of a person's fish consumption per day; they do not provide advice regarding consumption limits or constitute a fishing advisory. Exceedances of a SV may indicate that further investigation to assess human health risk at a particular site is warranted; however, exceeding a SV does not imply an immediate risk to human health (Thompson and Stein, 2021).

Tissue SVs were calculated by Thompson and Stein (2021) using equations from Health Canada (2012) and a TRV for nickel sulphate (Health Canada 2021), which is the more toxic of the two common forms of nickel. This TRV has been applied to develop the SVs in the absence of a TRV for soluble nickel. These SVs could be adjusted in future if necessary, based on more detailed analysis of the form of soluble nickel present. An allocation factor of 0.2 was used in the calculation to reflect the percentage of nickel assumed to come from country foods (in this case, wild seafood). Three tissue SVs were selected to capture a range of potential fishers (i.e., receptors). The most conservative value is protective of a toddler from a subsistence fisher population while the less conservative values correspond with adult subsistence fishers and adult recreational fishers. These three SVs were used in the data assessment to provide multiple reference points.

### **3.2 Data Sources**

Data for nickel levels in Burrard Inlet were gathered from several studies and monitoring programs. A summary of the datasets used for this assessment is presented in Table 3. Although other datasets containing nickel sampling data may exist, the priority datasets were found to be the best available data for assessing the status of nickel within Burrard Inlet within the constraints of the project.

Maps showing the distribution of sampling sites for each of the post-1990 studies or monitoring programs are provided in Figure 1 through Figure 3.

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   | 292 water, 8 sediment              | 17 water, 6 sediment            | Irregular  | Total and dissolved nickel in water<br>Total nickel in sediment 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 nickel in sediment by dry weight  |
| BC ENV  | Provincial Water Quality Objectives Attainment Monitoring, 1990–2009                     | 432 water, 70 sediment, 17 tissue  | 12 water, 12 sediment, 9 tissue | 1–10 samples/site and year, irregular<br>Water samples generally reported as maximum values and mean of 5 samples in 30 days   | Total and dissolved nickel in water<br>Total nickel in sediment by dry weight<br>Total nickel in Dungeness Crab, Pandalid Shrimp, and English sole tissue by dry weight |
| Metro Vancouver   | Burrard Inlet Ambient Monitoring Program, 2007–2016                                      | 710 water, 210 sediment, 73 tissue | 7                               | 5 water samples/site and year, regular. Reported as maximum values and mean of 5 samples in 30 days<br>3–6 sediment samples/site every 2 years, regular<br>Tissue samples in 2007 and 2012 | Total nickel in water<br>Total and extractable nickel in sediment by dry weight<br>Total nickel in English sole tissue by wet weight                                    |
| Ocean Wise  | PollutionTracker, 2015–2016  | 22 sediment, 15 tissue             | 15 sediment, 9 tissue           | 3 sediment samples and 50–200 mussels per site on a single day in October 2015, December 2015 and April 2016   | Total and extractable nickel in sediment by dry weight<br>Total nickel in mussel tissue by wet and dry weight   |

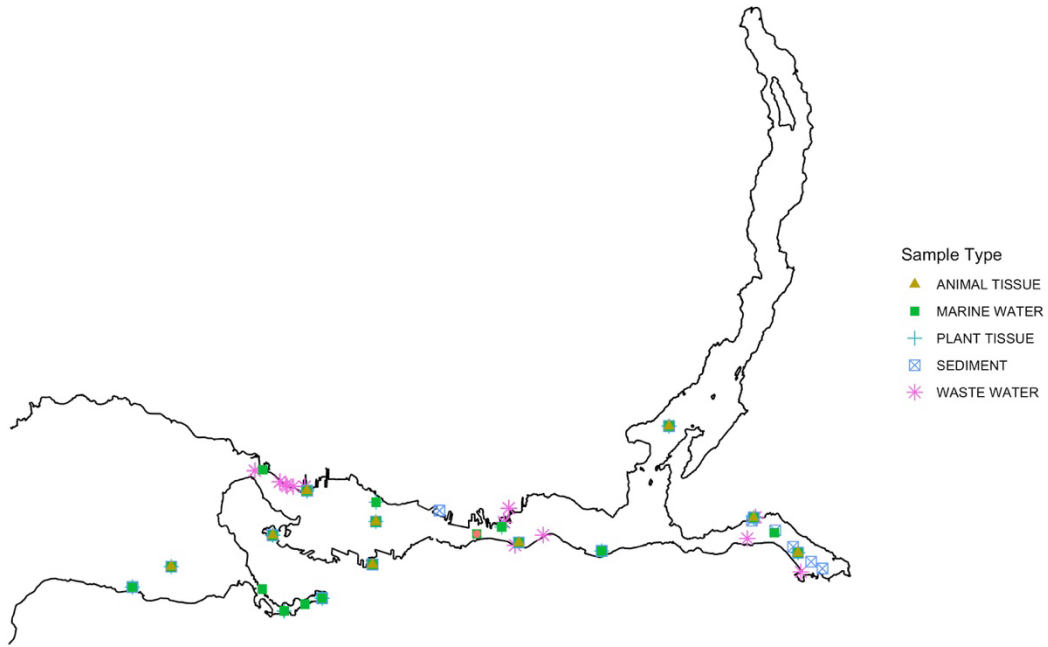


Figure 1: BC ENV sampling stations in Burrard Inlet (1971 to 2009)

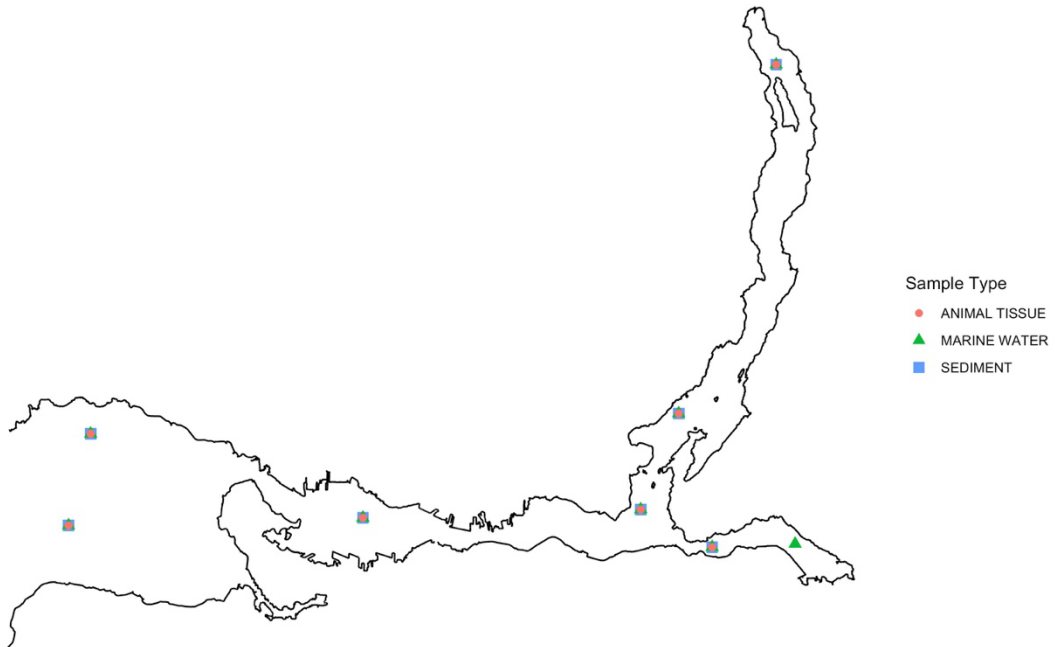


Figure 2: Metro Vancouver sampling stations in Burrard Inlet (2007 to 2016)

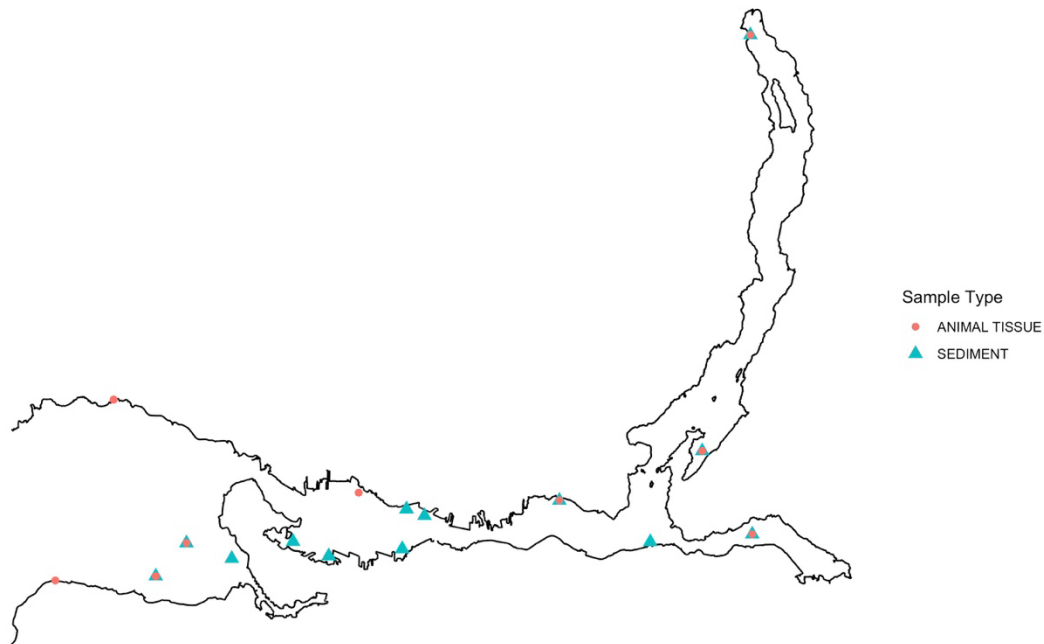


Figure 3: PollutionTracker sampling stations in Burrard Inlet (2015 to 2016)

### 3.3 Assessment of Monitoring Data

Monitoring data were compared to screening benchmarks and temporal and spatial observations are presented by sub-basin, where appropriate. Because of variation in the sampling and analytical methods and distribution of sites, results from each monitoring program are discussed separately. Programs that collect samples at sites close to the shore are expected to produce different results compared to programs that collect samples offshore and at depth for ambient conditions. Therefore, there are limitations on comparing results between the monitoring programs. Where nickel levels were below detection limits, values were plotted at the detection limit value in Figure 4 through Figure 10. 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 nickel levels collected from surface grab or composite samples, unless indicated. There is comparably little data for dissolved nickel levels in Burrard Inlet. Sediment data are all reported in dry weight. Tissue data are reported in wet or dry weight (see Table 3).

Data for constituents that impact nickel 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

- 1971–1990 – BC ENV monitoring samples collected between 1971 and 1990 were above nickel detection limits in 9% of 292 water samples and 100% of 8 sediment samples. There was no data for fish tissue samples collected prior to 1990 (refer to Figure 4 and Figure 5).
  - Detection limits for water samples ranged between 0.01 (9 cases), 1 (1 case) and 10 µg/L (282 cases), creating high uncertainty in the interpretation of potential patterns, particularly because

the detection limit is above the benchmark (8.3 µg/L) for a great majority of samples. The highest nickel levels were observed in water samples collected in 1972 at English Bay (Station 300076; maximum 40 µg/L) and Burrard Inlet (Station 300079; maximum 40 µg/L). Lions Gate (Station 300077), 2nd Narrows (Station 300078), Indian Arm (Station 300080), False Creek Burrard ST Bridge (Station 300081) and False Creek Cambie ST (Station 300082) each recorded nickel levels of 20 µg/L in 1974. No other observations were above 10 µg/L.

### Post-1990 Data

- 1998 – The BIEAP Sediment Quality Study (EQOMAT, 1998) observed nickel concentrations above the detection limit in all 45 surface sediment samples. The highest nickel levels were detected in the Outer Harbour at location PEI, which is located south of Godman Creek, (range 43 to 47 µg/g, mean 45 µg/g). Nickel levels exceeded the lower effects level sediment benchmark (30 µg/g) in all sub-basins except for Central Harbour and Indian Arm.
- 1990–2009 – BC ENV water quality objectives attainment monitoring samples collected between 1990 and 2009 were above nickel detection limits for 19% of 432 water samples, 99% of 70 sediment samples, and 12% of 17 tissue samples. Detection limits ranged from 0.02 to 20 µg/L for water samples, were 5 µg/g for sediment samples and 0.8 µg/g for fish tissue. The wide range of detection limits for nickel in water samples may impact the interpretation of results, particularly because the detection limit is above the benchmark (8.3 µg/L) for more than two thirds of the water samples. The following key points summarize the monitoring results:
  - In water samples, the highest nickel levels were measured at Vancouver Harbour Lock Katrine (Station E207819, 40 µg/L) in 1990 and Second Narrows Chevron (Station E207821, 27 µg/L) in 2009. Of the 84 samples that exceed detection limits, 24 samples (29%) exceed the screening benchmark (8.3 µg/L). Exceedances occur in all sub-basins except for Indian Arm. An illustration of nickel levels in BC ENV's water samples is provided in Figure 4.
  - Sediment samples exceeded the upper effects level benchmark (50 µg/g) at two stations prior to 2002 including Vancouver Wharves (Station E207816) and English Bay Locarno Park (Station E207812). Similar to the observations for other metals, including lead and zinc, Vancouver Wharves had frequent and high levels of nickel in sediment (range 29.5 to 136 µg/g, mean 72.4 µg/g). Nickel levels in 2002 ranged from 11.8 µg/g at Port Moody IOCO (Station E207823) to 38.4 µg/g at English Bay Centre (Station 300076). An illustration of nickel levels in BC ENV's sediment samples is provided in Figure 5.
  - Nickel levels were 1.5 µg/g in two English sole fish tissue samples collected from Vancouver Harbour Vancouver Wharves (Station E20716). There is no metadata in the dataset to indicate whether values were measured in dry weight or wet weight so the worst case (wet weight) concentration is assumed for screening purposes. These levels are above the screening benchmarks for adult and toddler subsistence fishers (0.83 and 0.42 µg/g wet weight, respectively) but below the benchmark for an adult recreational fisher (1.65 µg/g wet weight). All other English sole tissue samples (15 of 17 samples) were below detection limits.

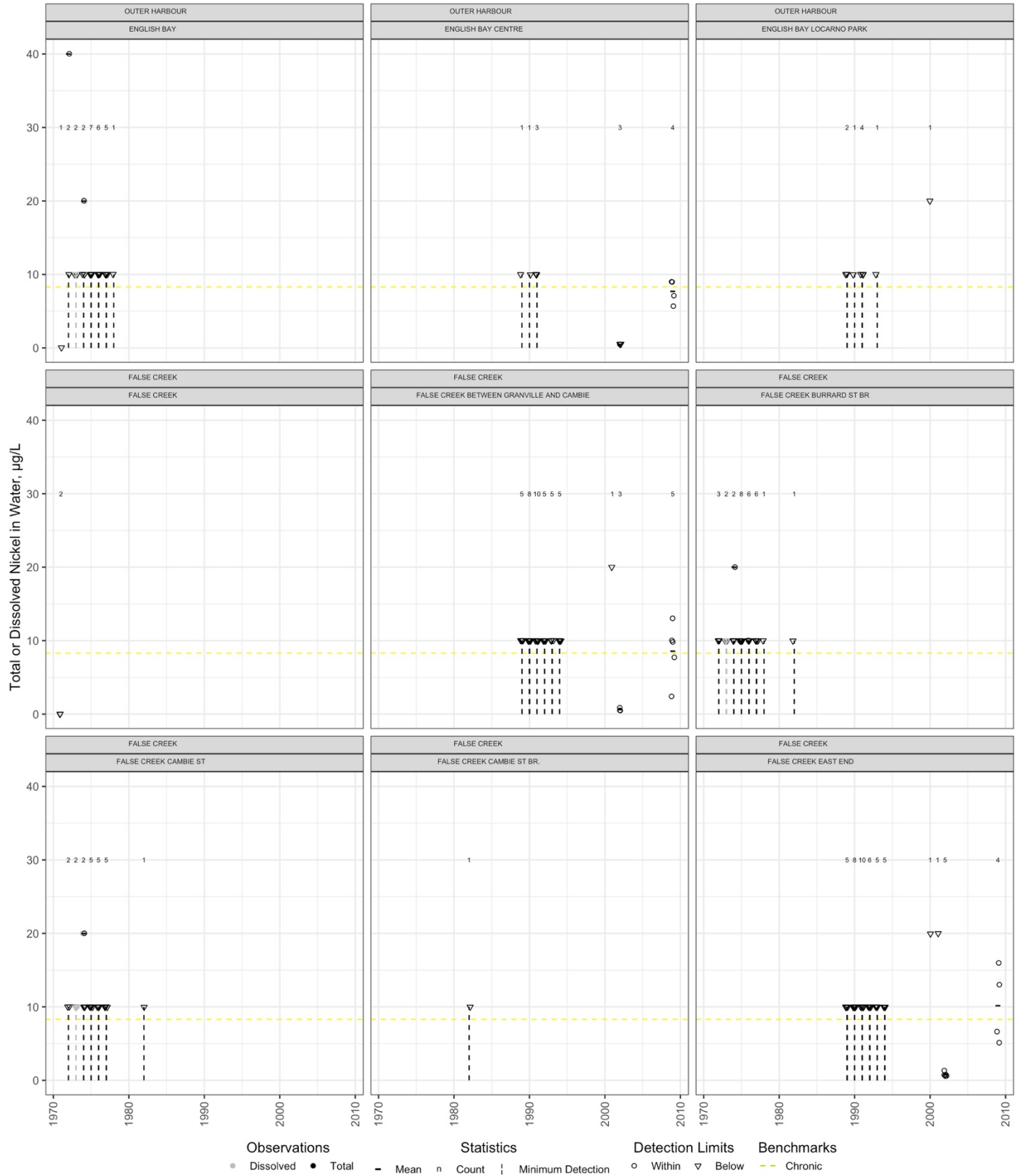


Figure 4: Nickel levels in BC ENV water samples (1971 to 2009) in µg/L

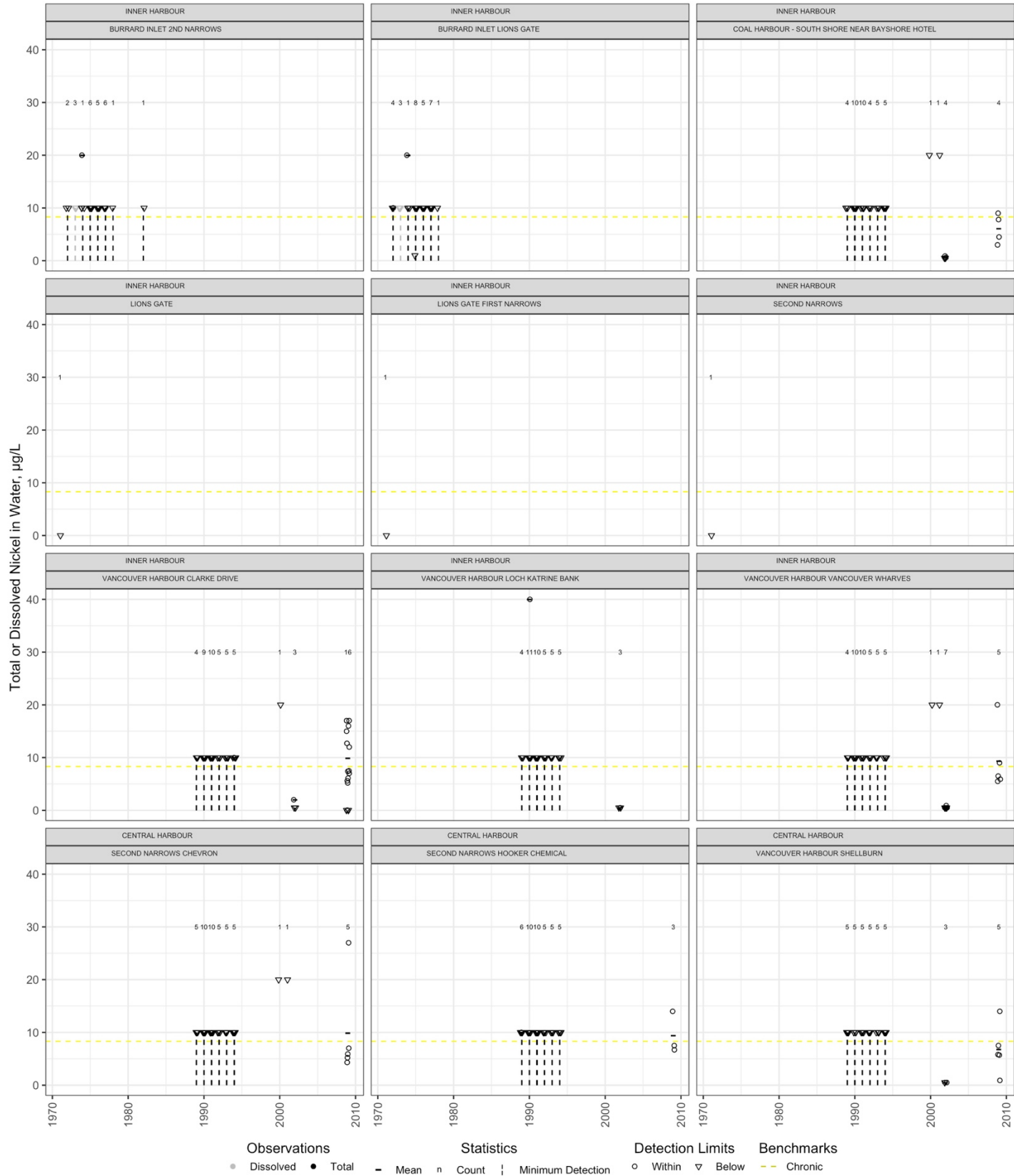


Figure 4: Nickel levels in BC ENV water samples (1971 to 2009) in µg/L (continued)



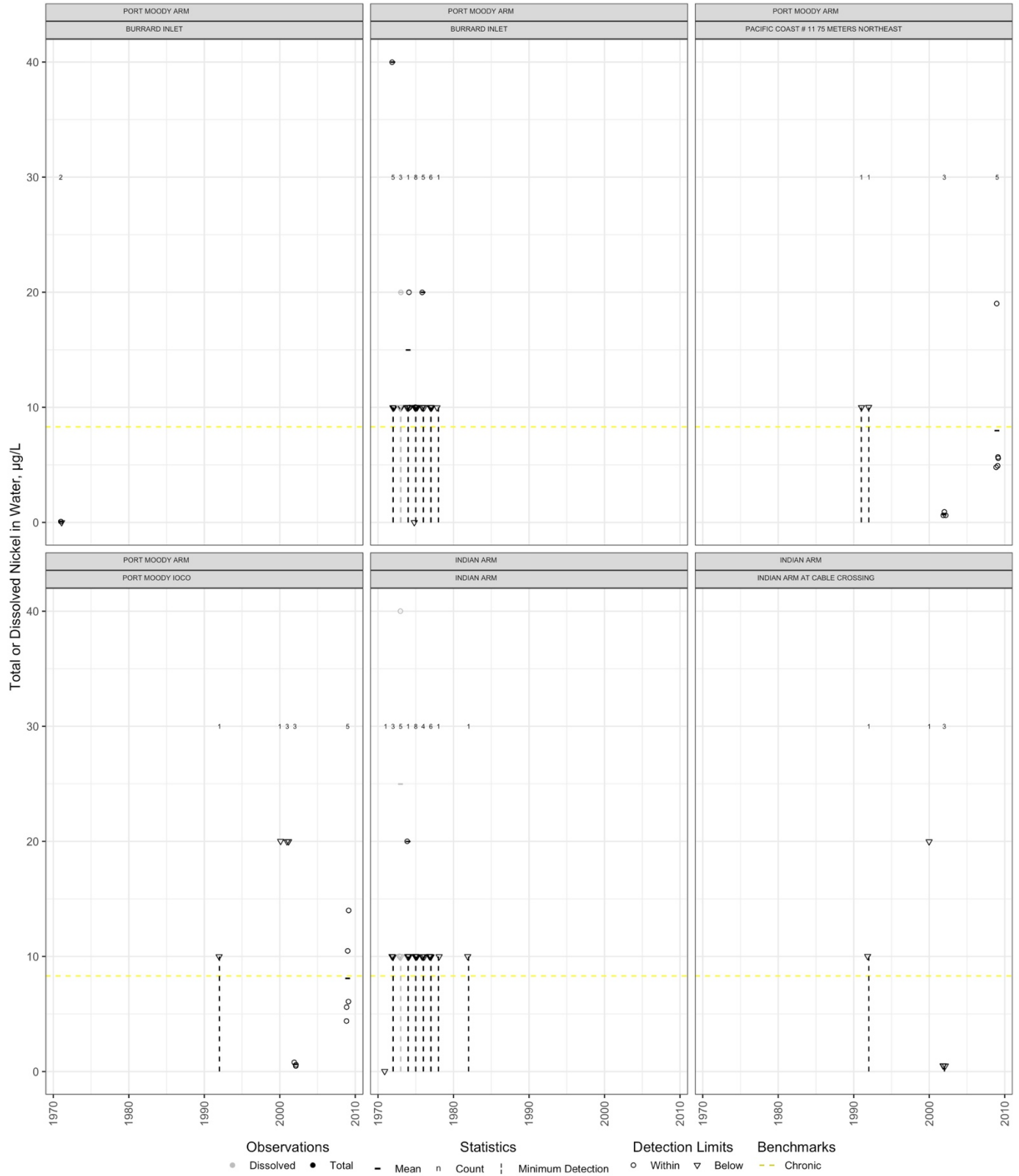


Figure 4: Nickel Levels in BC ENV water samples (1971 to 2009) in µg/L (continued)

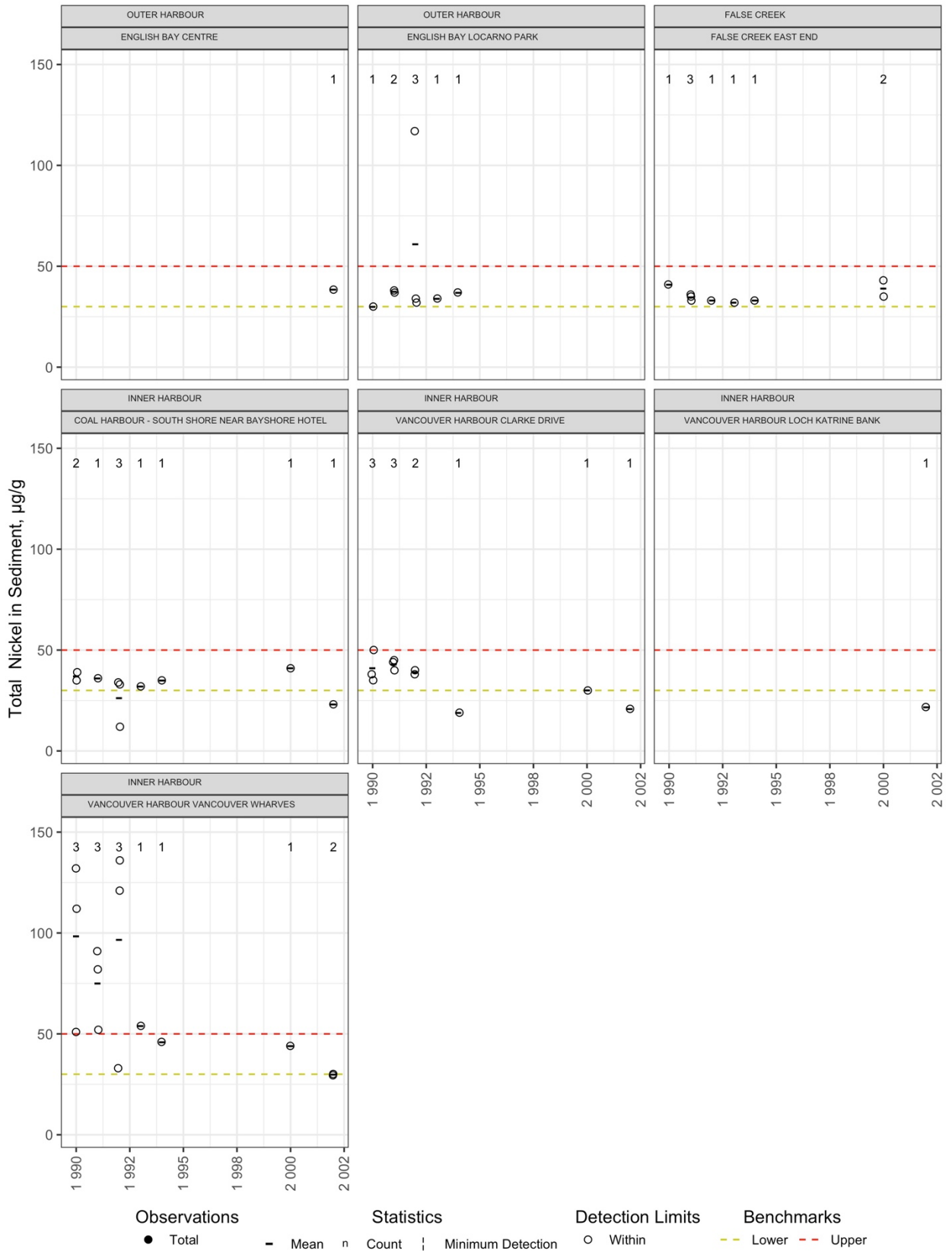


Figure 5: Nickel levels in BC ENV sediment samples (1988 to 2002) in µg/g dry weight

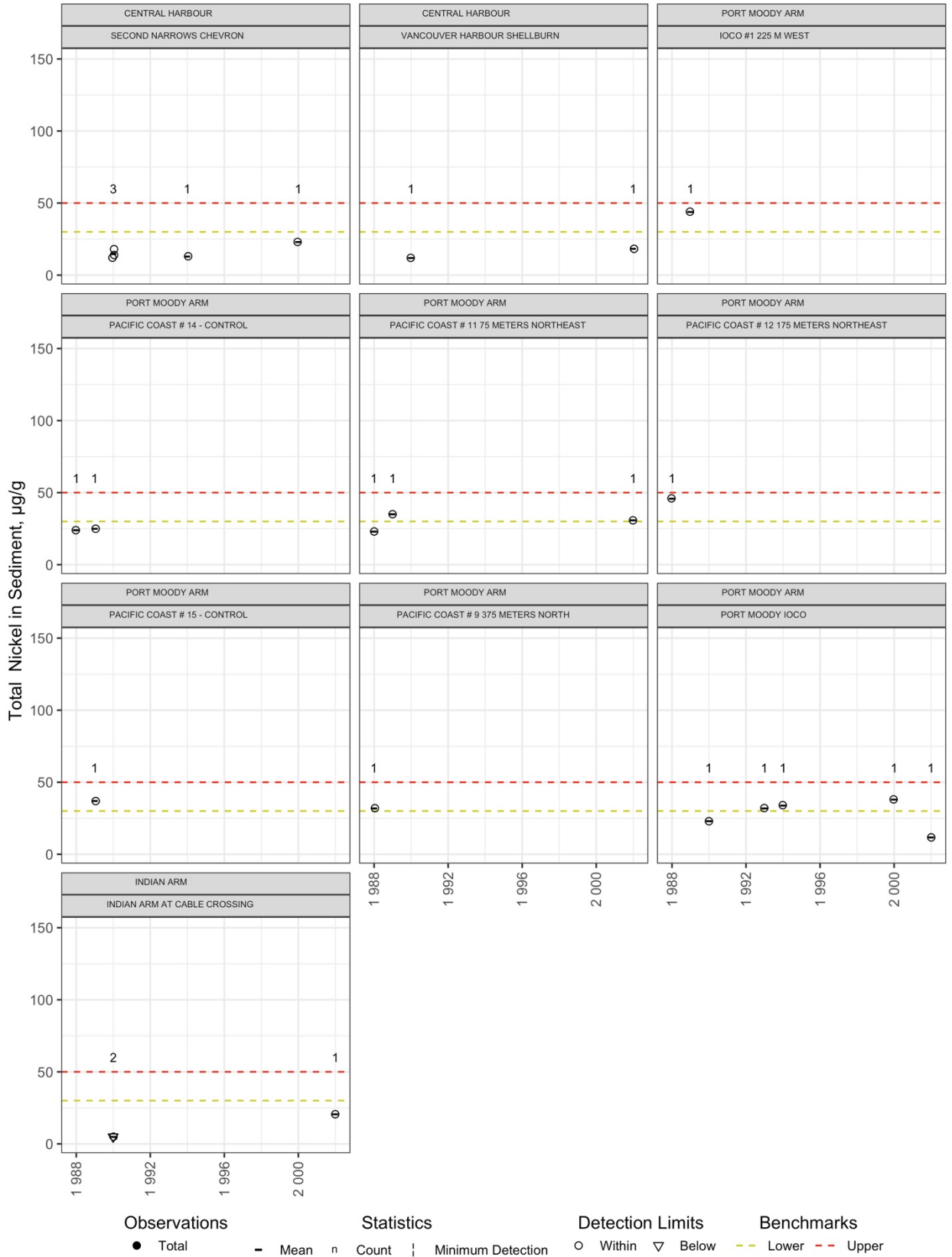


Figure 5: Nickel levels in BC ENV sediment samples (1988 to 2002) in µg/g dry weight (continued)

- 2007–2016 – As part of the Burrard Inlet Ambient Monitoring Program, Metro Vancouver has monitored nickel levels in the water column annually (Figure 6) and in sediment every 2 to 3 years (Figure 7) since 2008. Nickel levels in English sole tissue (whole body, muscle, and liver) samples were measured in 2007 and 2012 (Figure 8). Between 2007 and 2016, nickel levels were above detection limits for 100% of 710 water samples, 100% of 210 sediment samples, and 73% of 73 tissue samples. Detection limits were between 0.005 µg/L and 0.05 µg/L for water samples, 0.1 µg/g to 0.8 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 compared to the BC ENV monitoring data. The following key points summarize the Metro Vancouver monitoring program 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. The single sample maximum nickel level in water samples exceeded the benchmark (8.3 µg/L) at Outer Harbour South in 2007 at the bottom of the water column (10.4 µg/L) (see Figure 6). No other water samples exceed the screening benchmark. Lower nickel concentrations were generally found in the top samples, which could be a result of freshwater inputs with lower nickel levels.
  - Metro Vancouver analyzed both total and extractable nickel levels in sediment samples (Figure 7). In this assessment, only total nickel levels in sediment were considered. Samples exceed the upper benchmark for nickel (50 µg/g) at Outer Harbour North in 2013 (71.1 µg/g) and in 2008 (64.2 µg/g) and at Outer Harbour South in 2008 (56.5 µg/g). Nickel levels exceed the lower benchmark (30 µg/g) in 56 of 105 total nickel samples in the dataset. There were no exceedances in Central Harbour or Indian Arm North, though there are frequent exceedances in all other sub-basins.
  - English sole fish tissue samples were below the toddler subsistence fisher screening benchmark (0.42 µg/g wet weight) in all samples. The highest nickel levels were measured in Indian Arm North in 2012 (0.317 µg/g wet weight) and both Outer Harbour North and Outer Harbour South in 2007 (0.300 µg/g wet weight).

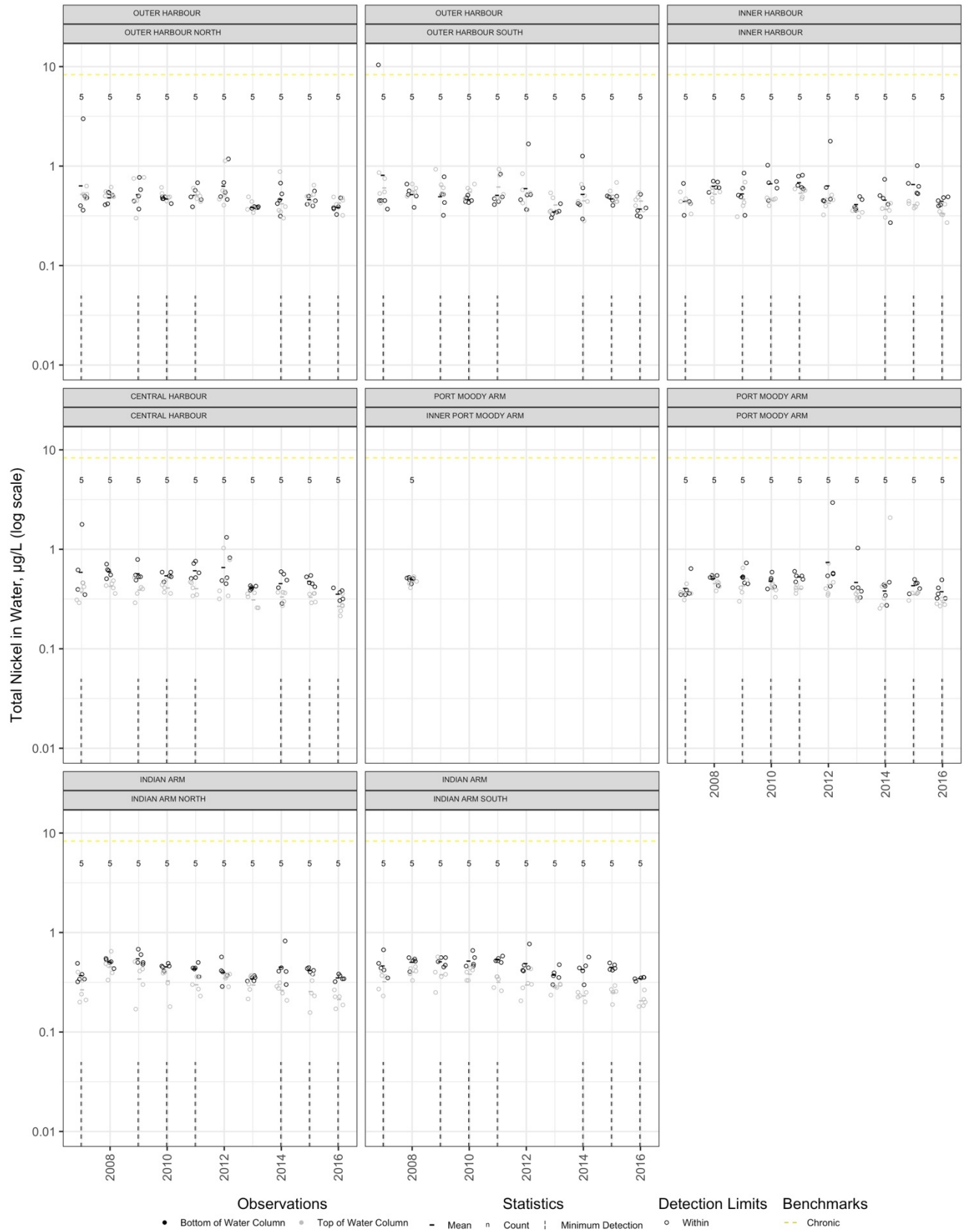


Figure 6: Nickel levels in Metro Vancouver water column samples (2007 to 2016) in µg/L (log scale)

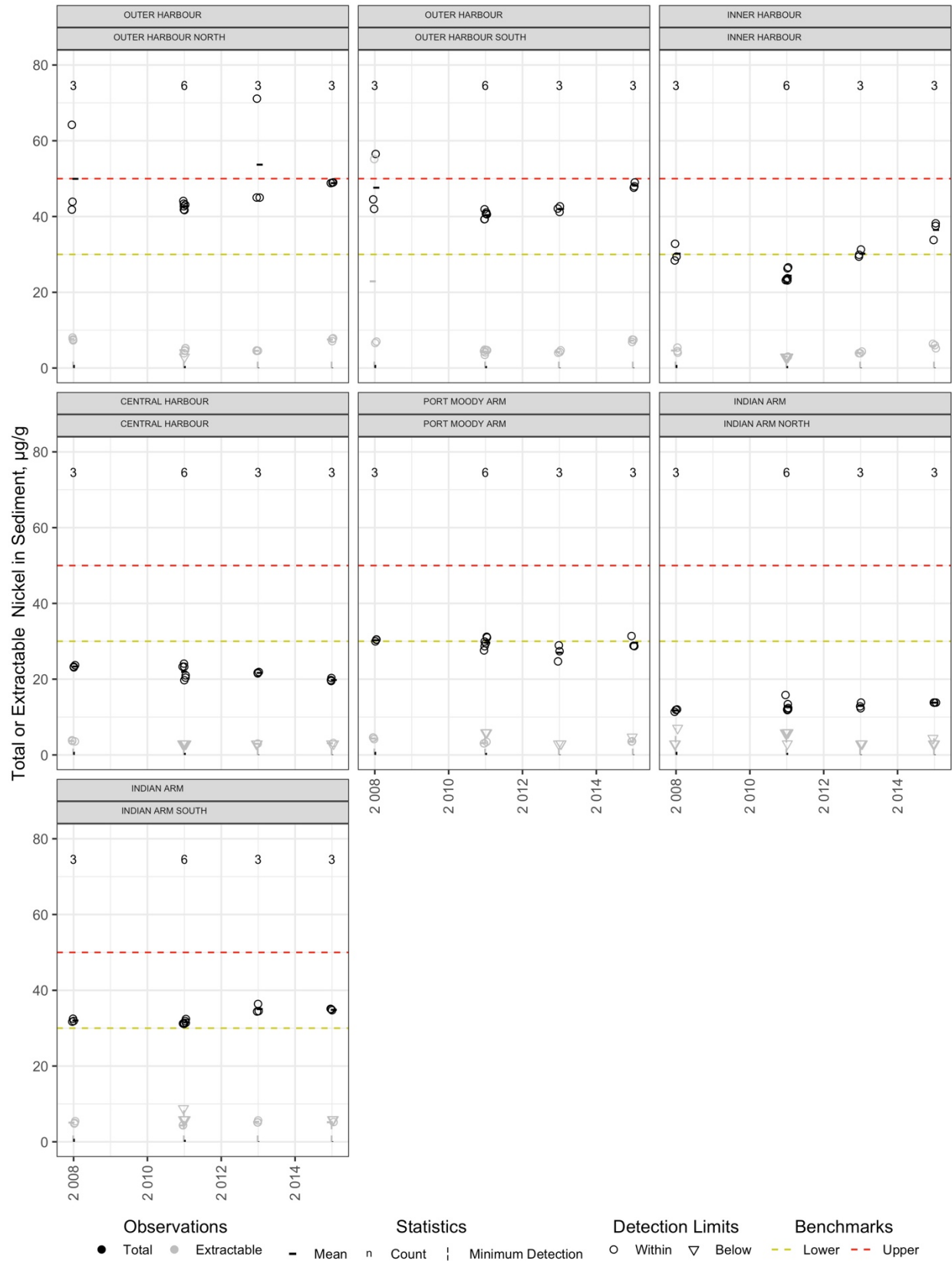


Figure 7: Nickel levels in Metro Vancouver sediment samples (2008 to 2016) in µg/g dry weight

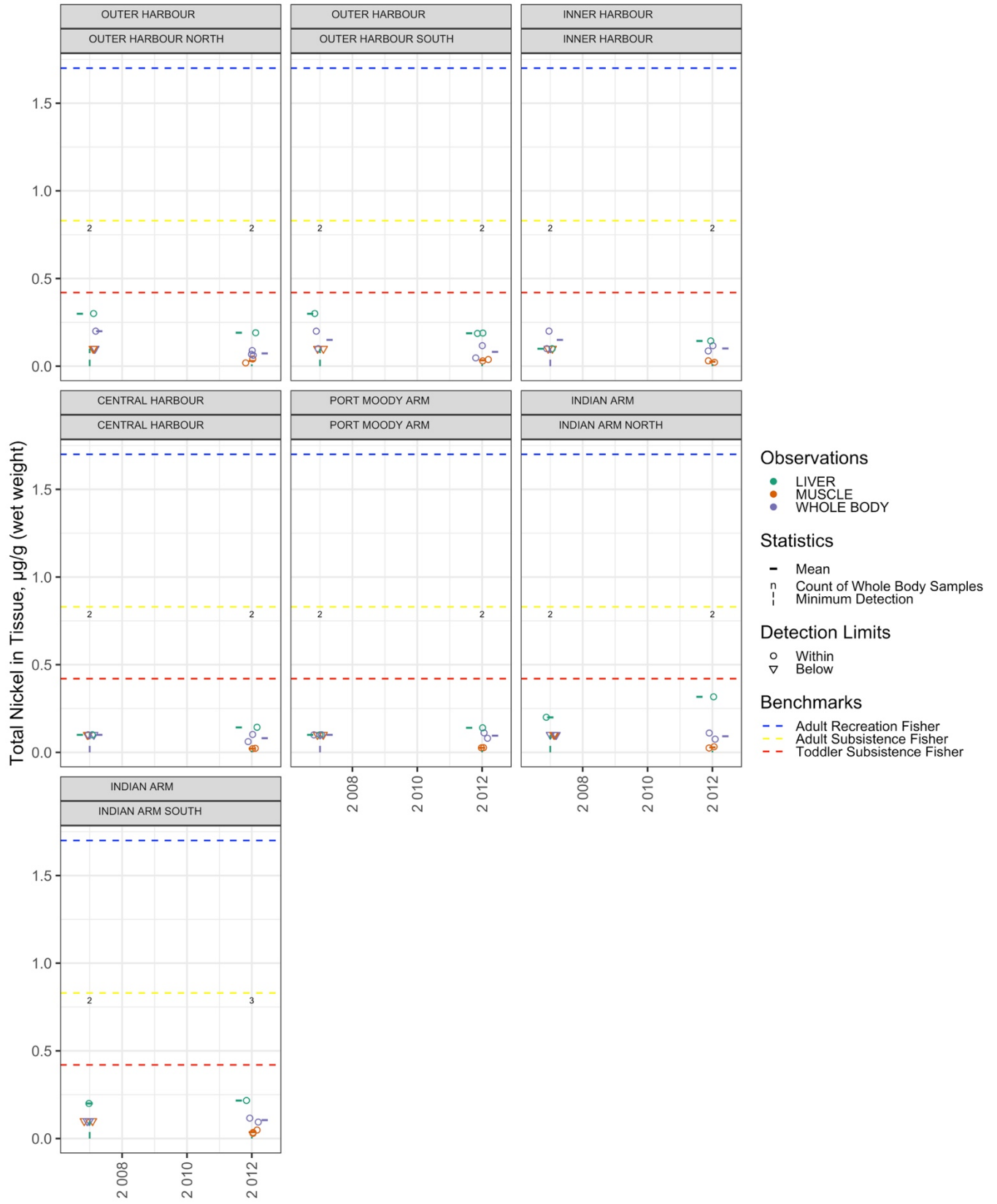


Figure 8: Nickel levels in Metro Vancouver English sole fish tissue samples (2007 to 2012) in µg/g

- 2015–2016 – PollutionTracker monitoring of nickel levels in sediment (Figure 9) and mussel tissue (Figure 10) occurred in October 2015 and April 2016. All samples measured above detection limits, which were 0.5 µg/g for sediment and 0.04 µg/g for tissue. PollutionTracker results are summarized as follows:
  - Mean nickel levels in the sediment samples exceeded the lower benchmark (30 µg/g) at all monitoring stations in the Outer Harbour (36.1–44.6 µg/g) as well as in Port Moody Arm (31.4 µg/g). There were no other exceedances of the upper or lower screening benchmarks.
  - Nickel levels in the mussel samples were above the subsistence toddler screening benchmark (0.42 µg/g wet weight) in two of 10 wet weight samples but did not exceed the subsistence adult or recreational adult screening benchmarks. The highest nickel levels were observed in the Central Harbour (0.641 µg/g wet weight) and Outer Harbour (0.512 µg/g wet weight).



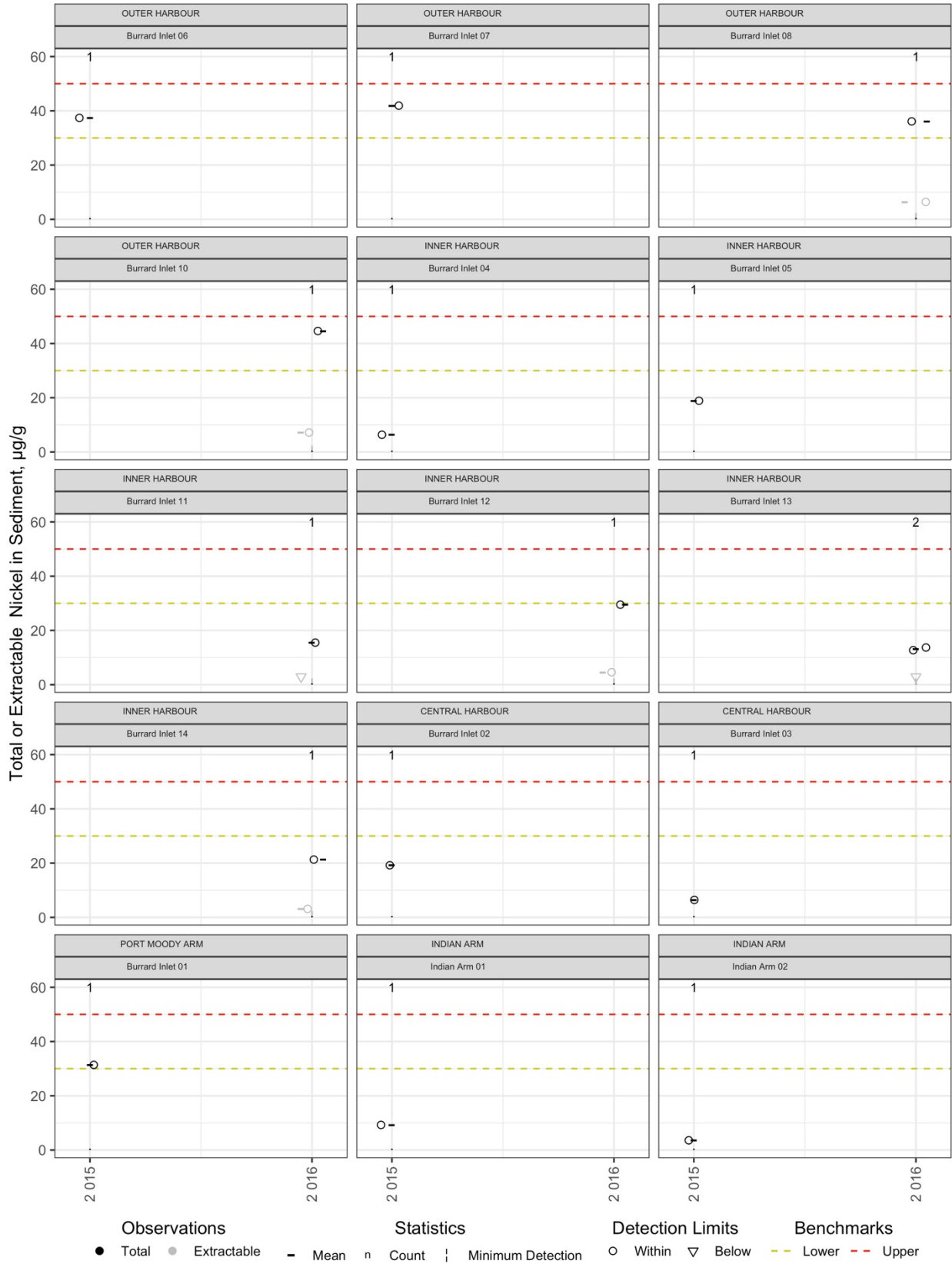


Figure 9: Nickel levels in PollutionTracker sediment samples (2015 to 2016) in µg/g dry weight

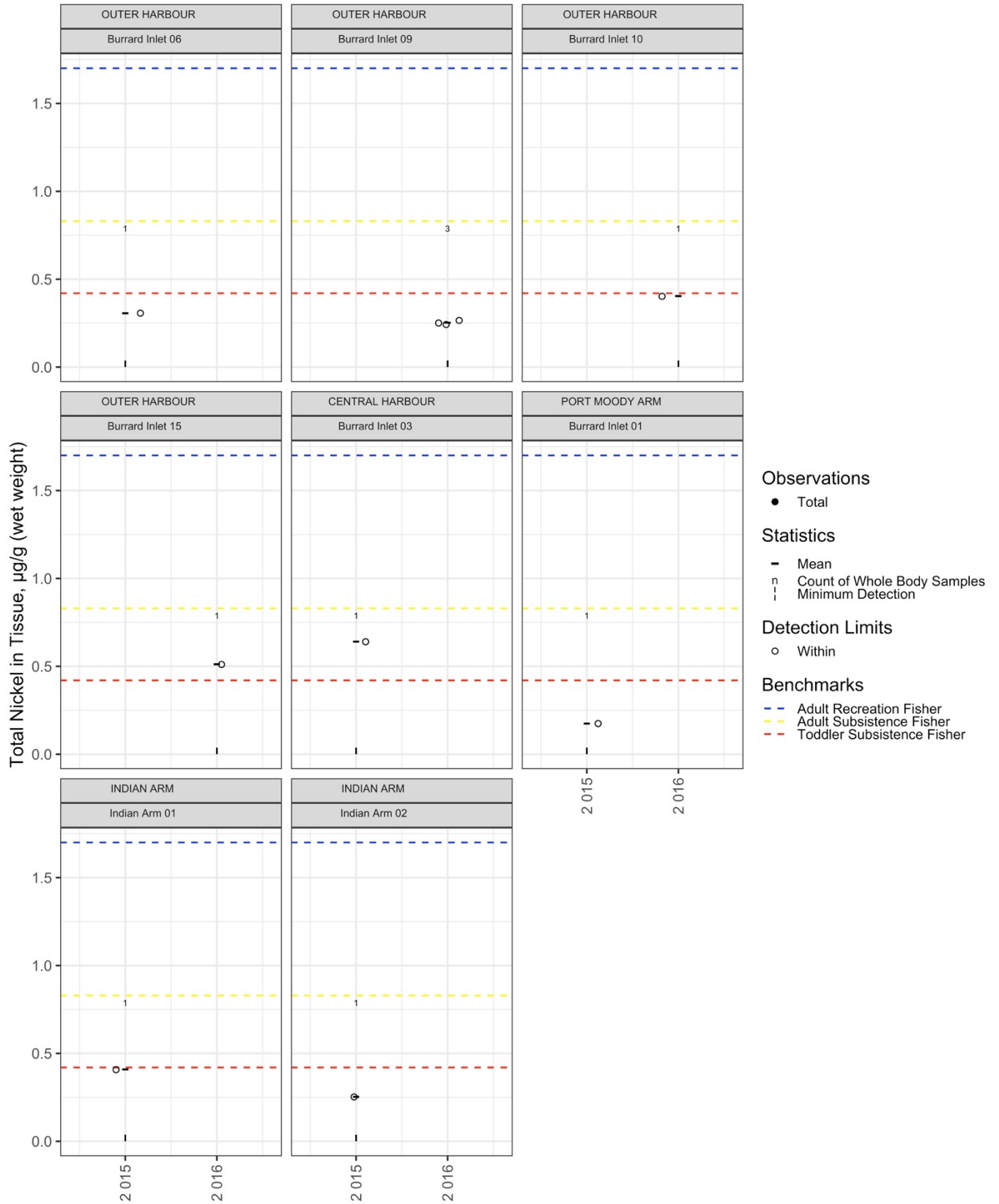


Figure 10: Nickel levels in PollutionTracker blue mussel tissue samples (2015 to 2016) in µg/g

### 3.4 Knowledge Gaps and Research Needs

The assessment of available nickel 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 nickel levels in the environment or are a result of improvements or differences in the sampling methodology and/or analysis.
- 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 or no monitoring of sites influenced by permitted discharges, stormwater discharges or combined sewer overflow outfalls since 2009. There are elevated nickel levels in False Creek and near Clark Drive, which both have relatively high influences from combined sewer overflows.
- There has been little monitoring of nickel in sediment or the water column in False Creek since 2009.
- Monitoring in the past 10 years indicate that nickel levels are below screening benchmarks for water quality but are above screening benchmarks for sediment quality. It is challenging to determine the extent of nickel contamination in the sediments of Burrard Inlet, in the absence of knowledge on expected background nickel levels.
- Existing guidelines for nickel in water and sediment are outdated and do not reflect potential effects on species that are local to Burrard Inlet.
- A draft biotic ligand model (Niyogi and Wood 2004) and expanded toxicity studies (DeForest and Schlegel 2013, European Chemicals Bureau 2008) are available for nickel in seawater. Although uncertainty remains regarding the mechanisms of nickel toxicity in aquatic environments (Brix et al. 2016), comparison of sample-specific HC5<sup>3</sup> values calculated using the nickel seawater biotic ligand model and consideration of expanded toxicity studies could validate or provide context for the proposed water quality objective and BC Water Quality Guideline for nickel (Section 4). This analysis was not possible within the scope of this report.

## 4. PROPOSED OBJECTIVES FOR NICKEL IN BURRARD INLET

### 4.1 Proposed Objectives

Proposed objectives for nickel are presented in Table 4. The water objective is set to maintain or improve existing levels of nickel in the water column. The sediment objective is set to protect marine aquatic life. The tissue objective is set to protect human consumption of shellfish and finfish.

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<sup>3</sup> Hazard Concentration 5% (HC5) is the toxicant concentration at which the most sensitive 5% of the tested species experience the toxic endpoint (NAS 2020).

Table 4: Proposed Water Quality Objectives for Nickel

| Sub-basin   | False Creek  | Outer Harbour | Inner Harbour | Central Harbour | Port Moody Arm | Indian Arm |
|---|--|---------------|---------------|-----------------|----------------|------------|
| <b>Total Nickel in Water</b>  | 0.8 µg/L mean <sup>1</sup>   |               |               |                 |                |            |
| <b>Total Nickel in Sediment</b>   | 30 µg/g dry weight single-sample maximum <sup>2</sup>                      |               |               |                 |                |            |
| <b>Total Nickel in Tissue</b>   | 0.42 µg/g wet weight single-sample maximum (all tissue types) <sup>3</sup> |               |               |                 |                |            |
| <sup>1</sup> Minimum of 5 samples in 30 days collected during the wet season. No more than 20% of samples > 0.8 µg/L.<br><sup>2</sup> Based on at least 1 composite sample consisting of at least 3 replicates.<br><sup>3</sup> 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. |  |               |               |                 |                |            |

## 4.2 Rationale

While the 1990 provisional objectives for nickel levels in Burrard Inlet were developed at a similar time to when the existing guidance documentation and studies were prepared for the current BC Working Water Quality Guidelines, the 1990 provisional objectives are not recommended for use going forward because they do not align with the current provincial guidelines and, in the absence of scientific data, there is not a strong case for this inconsistency.

The BC Working Water Quality Guideline for nickel was set at a level to protect a suite of marine aquatic species from toxicity effects of nickel. Although a high proportion of samples from Burrard Inlet were below this working guideline, levels in most sediment samples exceed levels safe for marine aquatic life and some tissue samples have exceeded guidelines. Therefore, stable or decreasing levels of nickel in the water column over time should be a management objective in order to reduce the potential deposition of nickel into sediments and uptake by organisms over time. To this end, a numerical objective has been calculated using the 95<sup>th</sup> percentile of individual sample values based on 10 years of existing monitoring data from Metro Vancouver’s Burrard Inlet Ambient Monitoring Program. Summary statistics are provided in Table 5 and refer to Figure 6 for an illustration of the measured values. All measurements in this dataset were above detection limits and were given equal weight for the calculation of summary statistics. BC ENV’s practice in this situation is to calculate the objective as 20% higher than the 95<sup>th</sup> percentile to account for the dynamic nature of water chemistry and the accuracy and precision of laboratory results; hence the proposed objective for water is 0.8 µg/L. This objective value was compared to Metro Vancouver’s ambient data for 5 samples in 30 days for existing conditions since this is considered to be the most reliable and consistent dataset, which demonstrates that the objective is reasonable given the frequency of exceedances (highlighted in red in Table 6). The qualifier that no more of 20% of samples are to exceed this value is a condition of attaining the objective, to prevent exceedances from being masked or offset by generally low concentrations.

Table 5: Summary Statistics for All Total Nickel Levels Recorded in Metro Vancouver Burrard Inlet Ambient Monitoring Program Samples between 2007 and 2016

| Summary Statistic | Count   | Minimum | 25 <sup>th</sup> Percentile | Median (50 <sup>th</sup> Percentile) | Mean | 75 <sup>th</sup> Percentile | 95 <sup>th</sup> Percentile | Maximum |
|-------------------|---------|---------|-----------------------------|--------------------------------------|------|-----------------------------|-----------------------------|---------|
| Value in µg/L     | N = 710 | 0.16    | 0.36                        | 0.43                                 | 0.48 | 0.52                        | 0.74                        | 10.4    |

Table 6: Mean ( $\mu\text{g/L}$ ) of 5 Water Samples Collected in 30 Days for Metro Vancouver's Ambient Monitoring with Exceedances of the Proposed Water Quality Objective Highlighted in Red

| Year                              | Outer Harbour North | Outer Harbour South | Inner Harbour | Central Harbour | Port Moody Arm | Indian Arm North | Indian Arm South |
|-----------------------------------|---------------------|---------------------|---------------|-----------------|----------------|------------------|------------------|
| <b>Top of the Water column</b>    |                     |                     |               |                 |                |                  |                  |
| 2007                              | 0.52                | 0.62                | 0.44          | 0.37            | 0.37           | 0.28             | 0.33             |
| 2008                              | 0.53                | 0.57                | 0.53          | 0.43            | 0.46           | 0.47             | 0.40             |
| 2009                              | 0.54                | 0.65                | 0.48          | 0.40            | 0.44           | 0.36             | 0.39             |
| 2010                              | 0.51                | 0.55                | 0.45          | 0.41            | 0.40           | 0.34             | 0.38             |
| 2011                              | 0.51                | 0.64                | 0.54          | 0.41            | 0.40           | 0.30             | 0.32             |
| 2012                              | 0.62                | 0.55                | 0.43          | 0.57            | 0.46           | 0.35             | 0.31             |
| 2013                              | 0.40                | 0.41                | 0.35          | 0.31            | 0.34           | 0.30             | 0.28             |
| 2014                              | 0.46                | 0.47                | 0.37          | 0.33            | 0.67           | 0.27             | 0.23             |
| 2015                              | 0.50                | 0.52                | 0.41          | 0.33            | 0.35           | 0.27             | 0.25             |
| 2016                              | 0.43                | 0.45                | 0.34          | 0.27            | 0.29           | 0.22             | 0.21             |
| <b>Bottom of the Water Column</b> |                     |                     |               |                 |                |                  |                  |
| 2007                              | 0.95                | 2.42                | 0.45          | 0.72            | 0.42           | 0.37             | 0.47             |
| 2008                              | 0.48                | 0.53                | 0.63          | 0.60            | 0.51           | 0.50             | 0.51             |
| 2009                              | 0.53                | 0.51                | 0.55          | 0.58            | 0.54           | 0.55             | 0.51             |
| 2010                              | 0.47                | 0.46                | 0.69          | 0.54            | 0.48           | 0.45             | 0.52             |
| 2011                              | 0.52                | 0.53                | 0.69          | 0.62            | 0.53           | 0.43             | 0.53             |
| 2012                              | 0.67                | 0.71                | 0.75          | 0.72            | 1.01           | 0.41             | 0.50             |
| 2013                              | 0.39                | 0.35                | 0.42          | 0.41            | 0.51           | 0.34             | 0.38             |
| 2014                              | 0.48                | 0.60                | 0.48          | 0.47            | 0.39           | 0.48             | 0.44             |
| 2015                              | 0.46                | 0.47                | 0.67          | 0.48            | 0.43           | 0.42             | 0.45             |
| 2016                              | 0.39                | 0.38                | 0.45          | 0.36            | 0.38           | 0.35             | 0.35             |

The sediment quality objective is proposed to be consistent with the BC working water quality guidelines for marine waters until further updates to the toxicity assessment of nickel are available.

Measured levels of nickel in tissue were well below the adult recreational fisher and adult subsistence fisher screening benchmarks in all cases but above the toddler subsistence fisher screening benchmark in 40% of the mussel samples from the 2015 and 2016 PollutionTracker samples. The toddler subsistence fisher SV is proposed as the objective for nickel in fish tissue because it is the most conservative value for protecting human consumption of shellfish and finfish at rates of relevance to Tseil-Waututh Nation.

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

- Increase coordination of efforts between BC ENV, Metro Vancouver and PollutionTracker 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.
- Establish consistent methodologies for water column, sediment and tissue sampling, including consistent reporting of sediment values in g/g dry weight and tissue values in µg/g wet weight.
- Monitor the vicinity of areas known to be sources of nickel, such as near stormwater and combined sewer outfalls.
- Monitor sediment in the area around Vancouver Wharves to establish the extent of elevated nickel levels.
- Support the development of approved water and sediment quality guidelines for marine aquatic life in British Columbia, using data on species that live in Burrard Inlet.
- More work is needed to understand and minimize or eliminate the contaminants released into Burrard Inlet with vessel scrubber discharge water (ICCT 2020).

## **6. MANAGEMENT OPTIONS**

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

- Tsleil-Waututh Nation's ongoing work to restore the health of the Inlet through implementation of the Burrard Inlet Action Plan;
- Development and implementation of Integrated Stormwater Management Plans for all developed watersheds that flow into Burrard Inlet;
- Development of source controls for stormwater, including green infrastructure such as swales, rain gardens, and tree trenches;
- Inflow and infiltration reduction programs to reduce groundwater and stormwater into sanitary sewers, thereby reducing untreated sewage discharges from sanitary and combined sewer overflows;
- Upgrading the Lions Gate Wastewater Treatment Plant from primary to tertiary treatment;
- 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 nickel to Burrard Inlet are recommended for consideration, although this is not an exhaustive list of tools and actions:

- Improve education, awareness, and regulation to ensure proper disposal of nickel alloy and nickel-plated materials, batteries and other nickel-containing materials;
- Advocate to reduce the use of nickel-containing metal coatings, galvanized metals, pipes, fittings, roofing, paving or other materials that come into contact with domestic wastewater or rainwater.

- Since stormwater plays a role in transporting contaminants to Burrard Inlet, prioritize the implementation of source controls to reduce the amount of stormwater being discharged 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.
- Ensure that vessels comply with the Vessel Pollution and Dangerous Chemicals Regulation, for example, to be in accordance with the International Maritime Organization Guidelines for Exhaust Gas Cleaning Systems (Government of Canada 2014) and minimize or eliminate contamination via discharge water.

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## **APPENDIX A: CALCULATIONS FOR SCREENING VALUES FOR HUMAN FISH CONSUMPTION**

Human health screening values were calculated from the following equation (see Thompson and Stein [2021] for details) and listed in the table below. Tolerable daily intake (TDI) was obtained from Health Canada (2021), and was the oral TDI used to derive a toxicological reference value based on a critical health endpoint of post-implantation perinatal lethality.

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

Where:

- $SV_n$  = screening value for a noncarcinogen ( $\mu\text{g/g}$ );
- $TDI$  = tolerable daily intake ( $\mu\text{g/kg BW/day}$ ); the contaminant dose deemed safe or acceptable;
- $BW$  = body weight (kg);
- $AF$  = allocation factor; the fraction of the contaminant allocated to come from country foods; an AF of 0.2 was applied;
- $IR_{Food}$  = ingestion rate of fish by humans (g/day);
- $RAF_{Oral}$  = relative absorption factor from the gastrointestinal tract for a contaminant; and
- $BC$  = background concentration ( $\mu\text{g/g}$ ); the naturally occurring background concentration in environmental media or tissue.

| Receptor Population  | Receptor Life Stage | Ingestion Rate (g/day) | Reference Dose (TDI) ( $\mu\text{g/kg bw/day}$ ) | Standard Body Weight (kg) | Relative Absorption Factor (%) | Allocation Factor (unitless) | Screening Value ( $\mu\text{g/g}$ , wet weight) |
|----------------------|---------------------|------------------------|--|---------------------------|--------------------------------|------------------------------|---|
| Subsistence Fishers  | Adult               | 220                    | 12   | 76.5                      | 100%                           | 0.2                          | 0.83  |
|                      | Toddler             | 94                     | 12   | 16.5                      | 100%                           | 0.2                          | 0.42  |
| Recreational Fishers | Adult               | 111                    | 12   | 76.5                      | 100%                           | 0.2                          | 1.65  |