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

September 2022

Tsleil-Waututh Nation
səlilwətaɬ

BRITISH COLUMBIA

This Technical Report forms part of a series of water quality parameter reports whose purpose is to inform updates to the 1990 Provincial Water Quality Objectives for Burrard Inlet. This report and others in the series assess the current state and impacts of contamination in Burrard Inlet; incorporate new scientific research and monitoring of water quality; and reflect a broader understanding of goals and values, including those of First Nations, to improve the health of the marine waters of Burrard Inlet. Updating the 1990 Provincial Water Quality Objectives is a priority action identified in the Tsleil-Waututh Nation's Burrard Inlet Action Plan which has been an impetus for this work.

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

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## CHAPTER SUMMARY

This chapter presents proposed water quality objectives for arsenic in Burrard Inlet. Arsenic has been identified as a metal of primary concern in Tsleil-Waututh Nation's Burrard Inlet Action Plan (TWN 2017). The proposed objectives were developed using up-to-date research on relevant values and potential effects, sources and factors influencing arsenic levels, benchmark screening, and historic and recent monitoring data for Burrard Inlet.

Arsenic is a ubiquitous element in the marine environment found in various chemical forms. It is a carcinogen, and accumulates in aquatic species, but does not biomagnify in the food web. Certain forms, or species, of arsenic are more toxic than others. The values most sensitive to arsenic pollution are aquatic life and human consumption of shellfish and finfish.

Anthropogenic sources of arsenic include smelting and refining industries, wood preservation facilities, pesticide application, fossil fuel combustion, waste incineration, and various manufacturing industries. Arsenic can enter Burrard Inlet via provincially authorized discharges, stormwater outfalls, and combined sewer overflows.

Screening benchmarks for arsenic in water and sediment were developed using BC Approved Water Quality Guidelines and BC Working Sediment Quality Guidelines, which were updated in 2002 and 2020, respectively. BC's current water quality guidelines are based on Canadian Environmental Quality Guidelines published in 2001 (water) and 1999 (sediment) by the Canadian Council of Ministers of the Environment. Human-health based screening benchmarks were calculated and used to assess arsenic in tissue.

The most recent ambient monitoring data analyzed indicate that arsenic levels are generally higher than the benchmark levels for marine water, sediment and tissue quality in all sub-basins. It is likely, however, that the widely elevated arsenic levels are due to the high naturally occurring levels of arsenic eroding from surrounding rock and soil. In addition, screening benchmarks and guidelines are available for speciated arsenic (As III, a known carcinogen) in water and tissue whereas available monitoring data measure total arsenic. Measuring speciated arsenic to evaluate the ratio of As (III) to total arsenic is recommended to refine the proposed interim objectives for water and tissue as these were prepared using conservative estimates for the ratio between As (III) and total arsenic.

The proposed water quality objectives for total arsenic are as follows:

| Sub-basin | Outer Harbour | False Creek | Inner Harbour | Central Harbour | Port Moody Arm | Indian Arm |
|---|---|---|---|---|---|---|
| **Total Arsenic in Water (Interim)** | 2.4 µg/L mean[1] | | | | | |
| **Total Arsenic in Sediment** | 7.24 µg/g dry weight single-sample maximum[2] | | | | | |
| **Total Arsenic in Tissue (Interim)** | 0.0258 µg/g wet weight single-sample maximum (all tissue types)[3] | | | | | |
| [1] Minimum of 5 samples in 30 days collected during the wet season. No more than 20% of samples > 2.4 µg/L.<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. See Rao et al. (in prep) for additional details. Assumes that 10% of total arsenic is present as inorganic arsenic. | | | | | | |

The tissue objective is a conservative value proposed to protect the most sensitive receptor (an adult from a subsistence fishing population). Because recent data showed that arsenic levels have exceeded this objective, health experts should be engaged to advise on safe limits for consumption of seafood from Burrard Inlet.

The understanding of arsenic levels in Burrard Inlet would be improved through monitoring coordination and consistency, as well as monitoring in the vicinity of likely sources and discharge locations for arsenic. Improved understanding of the relative proportions of organic and inorganic arsenic species would help to refine the objectives.

Management recommendations to reduce arsenic pollution in Burrard Inlet include green infrastructure to improve the quality and decrease the volume of stormwater entering the Inlet, and encourage adequate controls for runoff and erosion from arsenic-impacted soils.

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## ACRONYMS

| | |
|---|---|
| BC | British Columbia |
| BC ENV | BC Ministry of Environment and Climate Change Strategy |
| BIEAP | Burrard Inlet Environmental Action Programme |
| CCA | Chromated copper arsenate |
| CCME | Canadian Council of Ministers of the Environment |
| EQOMAT | Environmental Quality Objectives and Monitoring Action Team |
| ISMP | Integrated Stormwater Management Plan |
| ISQG | Interim Sediment Quality Guideline |
| OSF | Oral slope factor |
| PEL | Probable effects level |
| SV | Screening value |
| TEL | Threshold effect level |
| TRV | Toxicological reference value |
| TWN | Tsleil-Waututh Nation |
| US | United States |
| US EPA | United States Environmental Protection Agency |
| WQO | Water Quality Objective |

# 1. INTRODUCTION

This chapter proposes water quality objectives for arsenic in Burrard Inlet. Arsenic has been identified as a metal of primary concern in Tsleil-Waututh Nation's Burrard Inlet Action Plan (TWN 2017). This chapter includes relevant background information, an overview assessment of current status and trends in arsenic 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. Detailed context for this work and the Burrard Inlet area is provided by Rao et al. (2019).

# 2. BACKGROUND

## 2.1 Values and Potential Effects

Arsenic is a naturally abundant element found in the atmosphere, aquatic environment, sediments, and organisms. High concentrations of arsenic can be toxic to humans and aquatic life. Classified as a human carcinogen, human exposure to elevated arsenic levels, especially inorganic arsenic, has been associated with increased risk of cancer in the skin, lung, bladder, liver, and kidneys (Health Canada 2006, ATSDR 2007). Other adverse health effects associated with chronic exposure to inorganic arsenic include developmental effects, diabetes, neurological effects, and cardiovascular disease (World Health Organization 2001). The primary form of human exposure to arsenic is through consumption of contaminated water or food. Seafood generally contains higher arsenic concentrations than other foods (ATSDR 2007).

Marine organisms such as phytoplankton, algae, and bacteria easily take up arsenic from water and sediments, as some species of arsenic have chemical similarities to biologically important forms of nitrogen and phosphorus (ATSDR 2007, Francesconi 2010). The degree of accumulation of arsenic in marine organisms varies with water concentration, the chemical form of arsenic present, trophic level, and diet (McIntyre and Linton 2011). Although arsenic and its metabolites bioaccumulate in aquatic organisms (e.g., exoskeleton of invertebrates and livers of fish), arsenic does not biomagnify in the aquatic food chain; rather, concentrations decrease through increasing trophic levels (US EPA 1998, 2003, World Health Organization 2001, Chen and Folt 2000, Mason et al. 2000, Farag et al. 2003, ATSDR 2007, Baeyens et al. 2007, Ikemoto et al. 2008, Culioli et al. 2009).

Aquatic plants have been observed to be more sensitive than invertebrates or fish to arsenic levels (CCME 2001). In fish, chronic exposure to elevated arsenic levels can lead to decreased food intake and depressed energy and reproduction (McGeachy and Dixon 1990, McIntyre and Linton 2011).

The most sensitive values guiding water quality objectives for arsenic in Burrard Inlet are marine aquatic life and human consumption of shellfish and finfish. The goal of the objectives is to maintain arsenic levels below values which would be toxic to aquatic life and to humans who consume seafood at rates relevant to coastal Indigenous peoples.

## 2.2 Potential Sources of Arsenic Pollution

In Canada, the main natural sources of arsenic include weathering of rocks and soils. Anthropogenic sources include smelting and refining industries, wood preservation facilities, application of arsenical pesticides, fossil fuel combustion, and waste incineration, as well as use of arsenic in the manufacturing of pharmaceuticals and glass (CCME 2001, Wang and Mulligan 2006).

Potential sources of arsenic into Burrard Inlet include historical discharges, combined sewer overflows, and stormwater discharges. High arsenic levels have been identified in the Central Harbour, particularly in the Maplewood mudflats (Rao et al. 2019). In 1990, algae east of the Seymour River estuary and invertebrates at the Canadian Occidental Petroleum site (now Chemtrade Electrochem Inc.) contained high arsenic concentrations, although sources were not identified at that time (Nijman and Swain 1990). Elevated arsenic levels were identified in algae and sediments in Port Moody Arm in 1990, likely due to the historical timber processing, steel manufacturing, and log storage facilities. Arsenic was also identified in 1990 as being of concern in False Creek due to a large number of historic discharges, and in Inner Harbour sediments due to unknown anthropogenic sources. Monitoring of arsenic levels in the Outer Harbour was recommended in 1990 for comparison to other sub-basins (Nijman and Swain 1990).

Urban surface runoff has been identified as the major pathway for arsenic loading into Puget Sound (Ecology and King County 2011). Elevated arsenic concentrations have been found in soils surrounding treated wood such as at piers or playgrounds, indicating that arsenic can leach from wood treated with chromated copper arsenate (CCA) (Wang and Mulligan 2006, ATSDR 2007). Until 2004, CCA was the most common wood preservative used in deck and patio construction, playground equipment, landscaping, and fence posts. In 2003, CCA was withdrawn from use for residential applications in Canada and the US and can currently only be used for industrial wood products (ECCC 2013). Results from a contaminant loading study in Puget Sound indicated that leaching from CCA-treated wood, asphalt shingle roofs, and agricultural arsenic fertilizers, accounted for only 2–4% of the surface runoff loads of arsenic. These findings suggest that a high proportion of the arsenic load in Puget Sound is likely due to historical releases or natural sources (Ecology and King County 2011). The US National Urban Runoff Program detected arsenic in 58% of urban runoff samples from eight of the fifteen cities surveyed (Cole et al. 1984).

## 2.3 Factors Influencing Arsenic Levels in Burrard Inlet

Arsenic can be found in the water column and adsorbed to suspended solids. Concentrations in natural coastal and ocean waters range between 1–3 µg/L with a mean concentration of 1.7 µg/L (Neff 1997). These levels can be much higher in urban coastal areas due to anthropogenic activity and riverine inputs.

In the marine environment, dissolved arsenic exists in four oxidation states (-III, 0, +III and +V) as numerous organic and inorganic species, predominantly as arsenate (V) and arsenite (III) (Cullen and Reimer 1989, Neff 1997). The toxicity and bioavailability of arsenic depend on its chemical form and oxidation state. Trivalent species such as arsenite are more acutely toxic to aquatic organisms than pentavalent species like arsenate (Abdelghani et al. 1980, McGeachy and Dixon 1989, Suhendrayatna et al. 2002, Borak and Hosgood 2007, McIntyre and Linton 2011), and inorganic arsenic species are more toxic than organic species. Arsenic speciation is influenced by temperature, nutrient availability, oxidation potential, pH, salinity, and biological activities (ATSDR 2007, Kalia and Khambholja 2015). In oxygenated marine water with a normal pH of 8.1, arsenic exists primarily as arsenate (Neff 1997, Francesconi 2010).

Arsenate and phosphate have similar chemical properties and compete for sorption sites in marine phytoplankton, bacteria, and algae resulting in toxic effects (Kalia and Khambholja 2015). To prevent toxicity, aquatic organisms convert arsenate to methylated arsenic species, such as arsenosugars in algae (Francesconi 2010). Phosphate concentrations in seawater appear to regulate methylation of arsenic in marine waters (Kalia and Khambholja 2015).

In marine animals, the predominant form of arsenic is arsenobetaine, an organoarsenic compound, which typically accounts for over 80% of the total arsenic content, particularly in finfish and seafood consumed by humans (Lorenzana et al. 2009). The origin of arsenobetaine in marine animals remains unknown but is likely related to the similar chemical properties of arsenic and nitrogen (Francesconi 2010). Arsenobetaine is largely inert, nontoxic, and rapidly excreted by marine organisms and humans (Cullen and Reimer 1989, Borak and Hosgood 2007). The occurrence of aresenobetaine in seafood is not considered to pose a human health concern (Francesconi 2010). The toxicity of other organoarsenic compounds present in marine animals such as arsenosugars or arsenolipids is also limited.

### 2.4 1990 Provisional Water Quality Objectives for Arsenic

The 1990 Burrard Inlet objectives for arsenic in water and sediment are presented in Table 1. In 1990, limited water quality sampling suggested that all water samples tested for total arsenic in Burrard Inlet were below the detection limit at the time (5 µg/L) but sediment and algae had high concentrations of total arsenic (Nijman and Swain 1990).

The BC marine aquatic life criteria for arsenic (III) in water at the time was a 4-day sample average of 36 µg/L and a 1-hour average of 69 µg/L. Since total arsenic concentrations in the water column were low, a provisional objective of 10 µg/L total arsenic was adopted for the Inner and Central harbours where potential loading sources were identified.

Measured arsenic levels in sediment were highest in the Inner Harbour, Central Harbour, and Port Moody Arm, with a maximum concentration of 483 µg/g in one sample in the Inner Harbour. Sediment data for False Creek was not available but due to historical discharges, arsenic concentrations were expected to be high. A provisional sediment quality objective of a single-sample maximum of 20 µg/g was adopted for all sub-basins except for Indian Arm. This objective was selected because it was the median for ambient data from the Outer Harbour and was below the apparent effects threshold relative to reference sites in Puget Sound (Nijman and Swain 1990).

Although high arsenic concentrations were detected in algae and mussel tissue, a tissue objective was not proposed at the time, a rationale for this was not provided in the technical appendix to the 1990 objectives (Nijman and Swain 1990).

*Table 1: 1990 Provisional Water Quality Objectives for Arsenic.*

<table>
<tr><th>Sub-basin</th><th>False Creek</th><th>Outer Harbour</th><th>Inner Harbour</th><th>Central Harbour</th><th>Port Moody Arm</th><th>Indian Arm</th></tr>
<tr><td>Water</td><td>N/A</td><td>N/A</td><td colspan="2">10 µg/L maximum</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Sediment</td><td colspan="5">20 µg/g dry weight maximum</td><td>N/A</td></tr>
</table>

## 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 arsenic levels in Burrard Inlet. Based on the available literature, human consumption of seafood and protection of aquatic life are the most sensitive values for arsenic levels in the water column and protection of aquatic life is the most sensitive value for arsenic in sediments. Finfish and shellfish consumption by humans may be the most sensitive values for arsenic 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; and
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 were used.

Benchmarks selected for screening and assessing available data are summarized in Table 2: Screening Benchmarks for Total Arsenic in Water, Sediment, and Tissue Used in this Assessment . All concentrations are for total arsenic levels. Water benchmarks are used to screen for protection of aquatic life, sediment benchmarks are used to screen for protection of aquatic life while fish and mussel tissue benchmarks are used to screen for human health.

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

| Sample Type | Screening Benchmark | Value | Reference |
|---|---|---|---|
| Water | 12.5 µg/L (chronic benchmark) | Marine aquatic Life | ENV 2002 |
| Sediment | 7.24 µg/g dry weight (TEL[1])<br>41.6 µg/g dry weight (PEL[1]) | Marine aquatic life | ENV 2020 (CCME 1999) |
| Tissue[2] | 0.0258 µg/g wet weight (adult subsistence fisher)<br>0.0510 µg/g wet weight (adult recreational fisher) | Human consumption of finfish and shellfish | Thompson and Stein 2021 |

[1] The threshold effect level (TEL) defines the level at which adverse effects rarely occur. The probable effect level (PEL) defines the level above which adverse effects are expected to occur frequently. Between PEL and TEL represents the range within which adverse effects occasionally occur. Interim sediment quality guidelines (ISQGs) are often set at the PEL when detailed data are not available.
[2] Based on a calculated screening value for which arsenic concentrations in tissue can be compared and assessed for potential risks to human health. The screening benchmark assumes that only 10% of total arsenic is present as inorganic arsenic. 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.

Benchmarks for arsenic levels in water are based on current approved BC water quality guidelines for protection of aquatic life. The approved BC water quality guideline for total arsenic at 12.5 µg/L is based on chronic toxicity for the most sensitive marine aquatic organism to arsenic, the diatom (algae) *Skeletonema costatum* (CCME 2001).

Benchmarks for arsenic levels in sediment are based on the BC Working Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture (ENV 2020) as there are no published approved BC guidelines for arsenic in sediment. These working guidelines are for total arsenic levels for the protection of marine aquatic life. They adopt the Environmental Quality Guidelines from the CCME (1999), with the Interim Sediment Quality Guideline (ISQG) as the lower threshold and the Probable Effects Level (PEL) as the upper threshold. These guidelines are based on studies of field-collected sediments that measured concentrations of arsenic and other chemicals, and associated biological effects (CCME 1999).

BC does not currently have guidelines for arsenic in fish or shellfish tissue that are protective of consumption rates relevant to coastal Indigenous consumers of 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). Thus, a risk-based approach was used to calculate human-health based screening values (SVs) for fish and shellfish tissue using Health Canada's toxicological reference values (TRVs) and risk assessment methodologies (Thompson and Stein 2021, using Health Canada 2010a,b,c, 2011, 2012a; Richardson 1997, Richardson and Stantec 2013). A risk-based approach considers: the contaminant *receptors* (subsistence fisher, recreational fisher, the general BC population, pregnant woman, child and toddler); *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 (2011), and toxicity was defined through TRVs prescribed by Health Canada (2010a, 2011). SVs were calculated by Thompson and Stein using equations from Health Canada (2012) and an oral slope factor (OSF) of 1.8 (mg/kg BW-day)-1 for inorganic arsenic (Health Canada, 2010a). Consistent with Health Canada (2012, 2021) policy, non-threshold carcinogenic health impacts were assessed independently of background exposure. In this case, an incremental lifetime cancer risk of $1x10^{-5}$ was intended to represent a negligible increase in cancer risk from exposure to Burrard Inlet seafood.

Two SVs were selected to capture a range of potential fishers, with the most sensitive receptor being an adult from a subsistence fishing population. A toddler from a subsistence fishing population was not considered for the proposed tissue objective since arsenic is a carcinogen, and the tissue screening value used to derive the objective was based on a lifetime of exposure to a carcinogen, estimated at 60 years (Thompson and Stein 2021). Thus, the more conservative SV is for an adult from a subsistence fisher population and the less conservative SV is for an adult recreational fisher. The resulting SVs for inorganic arsenic are 0.00258 µg/g wet weight for an adult subsistence fisher and 0.00510 µg/g wet weight for an adult recreational fisher[1]. Further details on the methodology and equations used are provided in Thompson and Stein (2021).

Available data in Burrard Inlet for arsenic in tissue were for total arsenic rather than inorganic arsenic, however. Arsenic speciation data is crucial for deriving accurate estimates of inorganic arsenic uptake in marine organisms and understanding arsenic bioavailability and toxicological effects (Wang and Mulligan 2006, Schoof and Yager 2007). Inorganic arsenic quantification is expensive, however, and technically demanding due to very low quantification limits (Schoof and Yager 2007, Francesconi 2010). The general consensus in the literature is that less than 10% of total arsenic found in the edible portions of seafood is likely to be inorganic arsenic (Goessler et al. 1997, US EPA 1998, 2003, De Gieter et al. 2002, ATSDR 2007, Schoof and Yager 2007, Lorenzana et al. 2009). Because the OSF was applied for inorganic arsenic and available monitoring data was for total arsenic only, a scaling factor of 10 was applied to the SVs calculated by Thompson and Stein (2021) to account for the general and conservatively accepted ratio between total arsenic and inorganic arsenic in finfish and shellfish, resulting in the screening benchmarks of 0.0258 µg/g wet weight for an adult subsistence fisher and 0.0510 µg/g wet weight for an adult recreational fisher.

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, as defined above. Fishers refer to consumers of seafood, including fish and shellfish (including both bivalve and other shellfish). 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

[1] Based on the raw calculations used by Thompson and Stein (2021), which include more significant digits than what has been published in that paper.

or a screening benchmark derived from a SV may indicate that further investigation to assess human health risk at a particular site is warranted; however, this does not imply an immediate risk to human health (Thompson and Stein, 2021).

## 3.2 Data Sources

Data for arsenic 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 arsenic sampling data may exist, these datasets were prioritized as the best available data for assessing the status of arsenic in Burrard Inlet within the constraints of the project.

Maps showing the distribution of sampling sites for each of the post-1990 studies or monitoring programs are provided in Figure 1 through Figure 4.

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

| Source | Study/Monitoring Program, Years | No. of Obs. | No. of Sites | Sampling Frequency | Parameters Sampled |
|---|---|---|---|---|---|
| BC ENV | Monitoring Data for Burrard Inlet, 1971–1989 | 15 water, 8 sediment | 16 water, 6 soil | Irregular | Total arsenic in water<br>Total arsenic in sediment |
| Environment Canada | Benthic Contaminants Study, 1985–1987 | Not listed | 48 sediment, 11 tissue | 6 surveys | Total arsenic in sediment by dry weight<br>Total arsenic in Dungeness Crab, Pandalid Shrimp, and English sole tissue by dry weight |
| Burrard Inlet Environmental Action Program (BIEAP) Environmental Quality Objectives and Monitoring Action Team (EQOMAT) | Sediment Quality in Burrard Inlet Using Various Chemical and Biological Benchmarks, 1998 | 45 | 15 | 3 samples per site in October 1995 | Total arsenic in sediment by dry weight |
| BC ENV | Provincial Water Quality Objectives Attainment Monitoring, 1990–2009 | 175 water, 47 sediment, 17 tissue | 12 water, 13 sediment, 9 tissue | 1–10 samples/year, irregular<br>Water samples generally reported as maximum values and mean of 5 samples in 30 days | Total arsenic in water<br>Total arsenic in sediment by dry weight<br>Total arsenic in English sole tissue by dry or wet weight |
| Metro Vancouver | Burrard Inlet Ambient Monitoring Program, 2007–2016 | 710 water, 105 sediment, 73 tissue | 7 | 5 water samples/year, at both top and bottom of water column, regular Reported as maximum values and mean of 5 samples in 30 days<br>5 sediment samples/2 years, regular<br>Tissue samples in 2007 and 2012 | Total arsenic in water<br>Total arsenic in sediment by dry weight<br>Total arsenic in English sole tissue by wet weight |
| Ocean Wise | PollutionTracker, 2015–2016 | 16 sediment, 15 tissue | 15 sediment, 8 tissue | 3 sediment samples and 50–200 mussels per site on a single day in October 2015, December 2015 and April 2016 | Total arsenic in sediment by dry weight<br>Total arsenic mussel tissue by wet and dry weight |

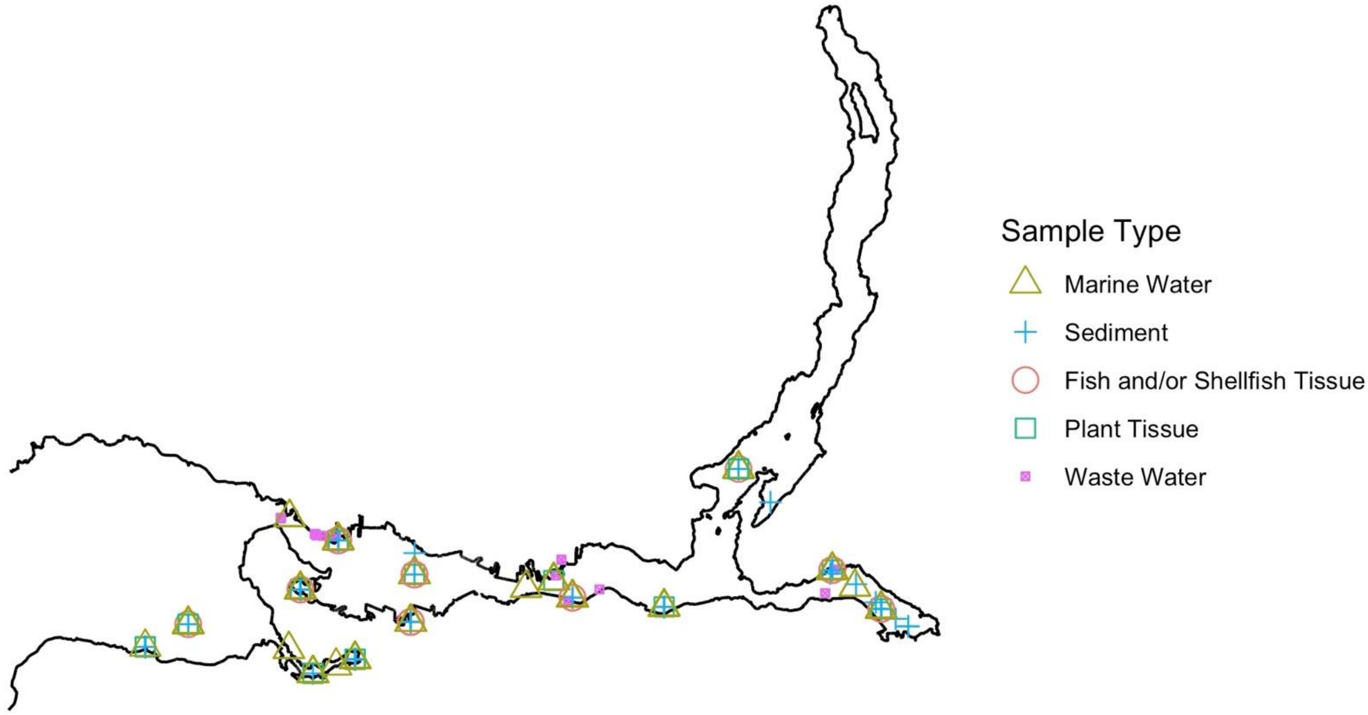


*Figure 1: BC ENV sampling stations for arsenic in Burrard Inlet (1990 to 2009)*

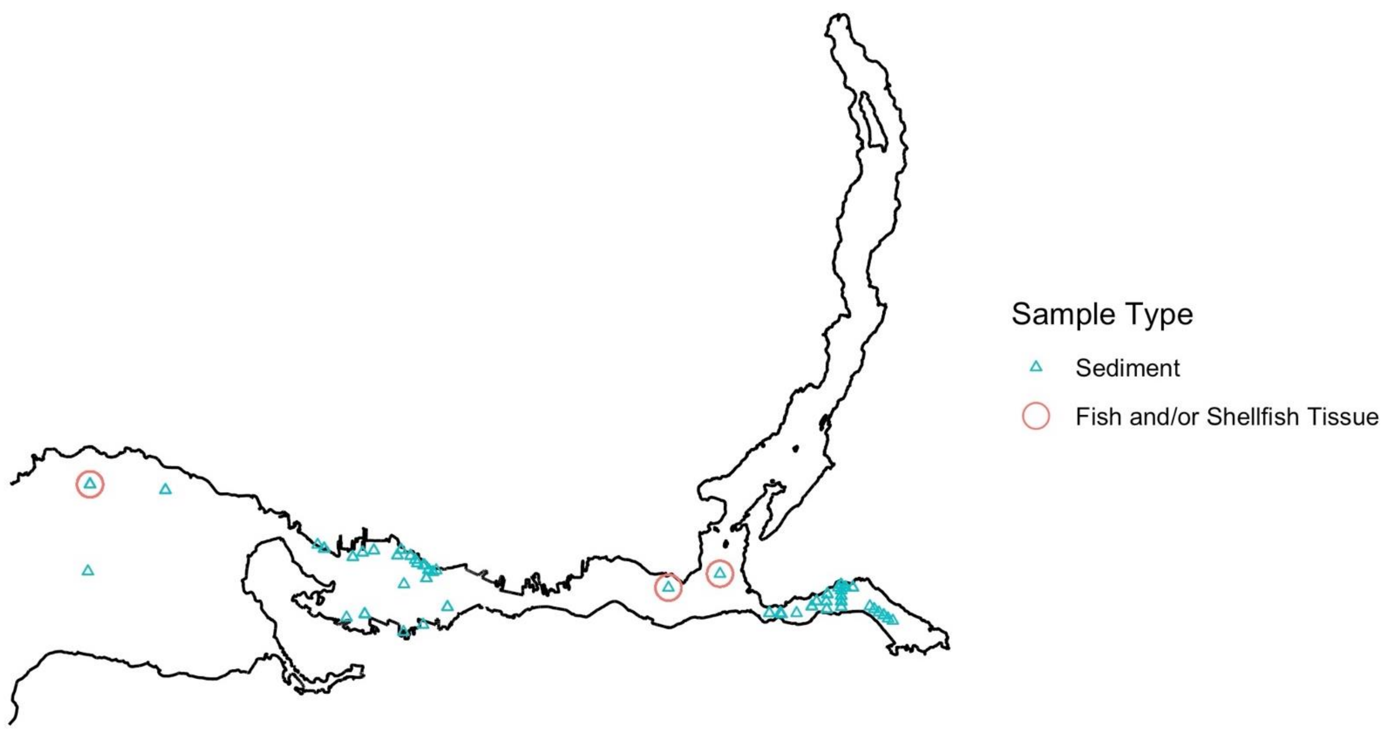


*Figure 2: Environment Canada sampling stations in Burrard Inlet (1985 to 1987)*

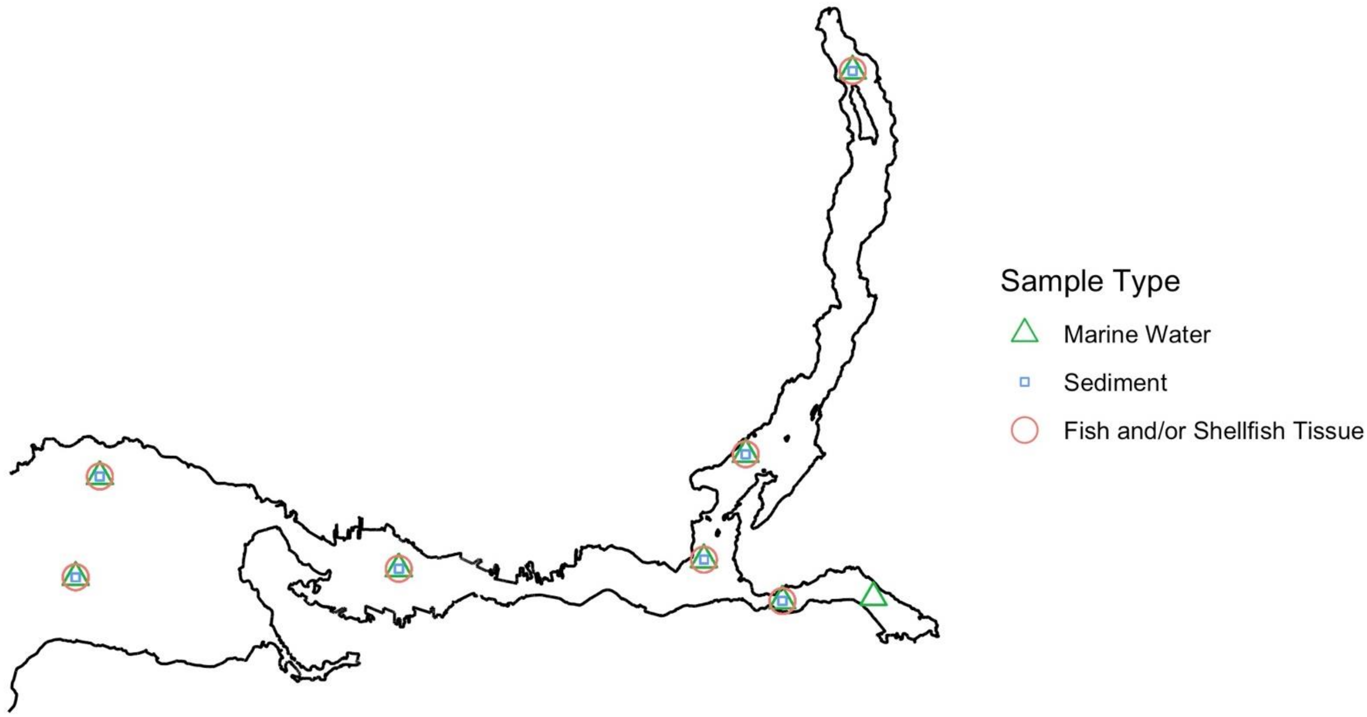


*Figure 3: Metro Vancouver sampling stations for arsenic in Burrard Inlet (2007 to 2016)*

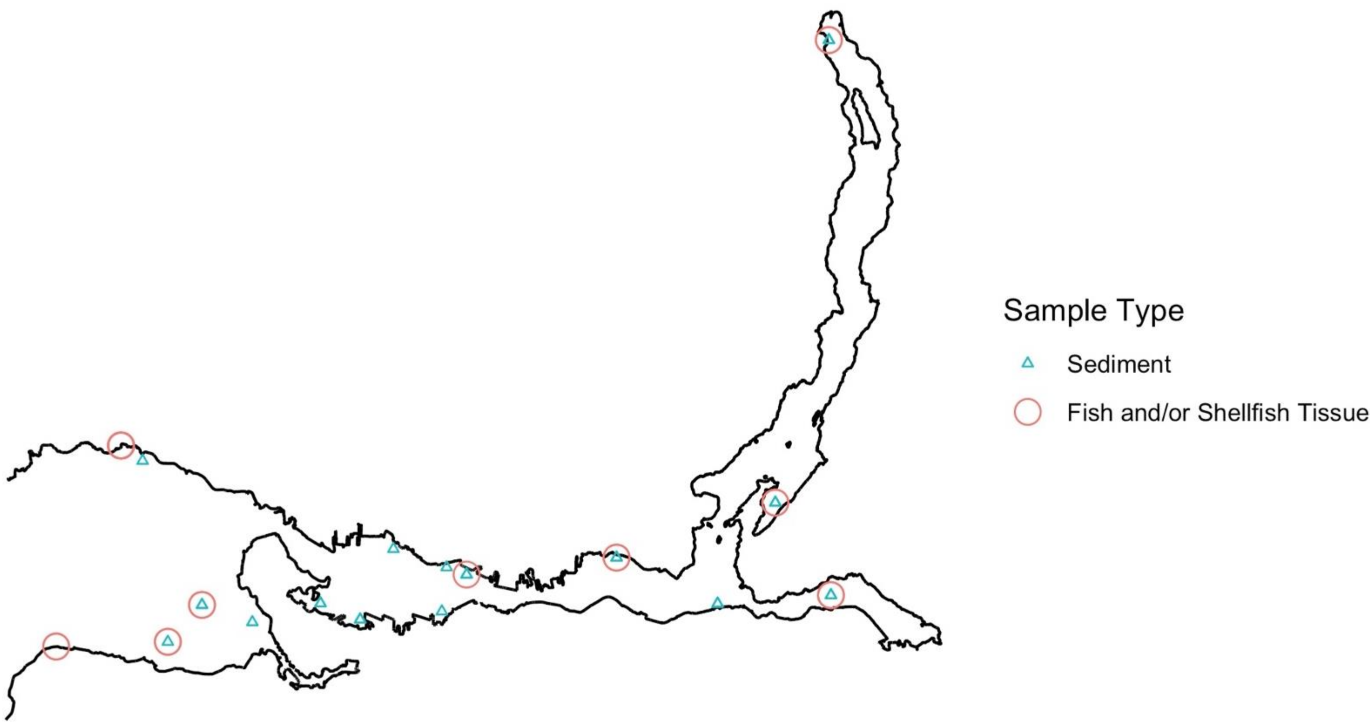


*Figure 4: PollutionTracker sampling stations for arsenic in Burrard Inlet (2015 to 2016)*

## 3.3 Assessment Results

Monitoring data were compared to screening benchmarks and temporal and spatial observations are presented by sub-basin, where appropriate. Because of the 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 arsenic levels were below detection limits, values were plotted at the detection limit value in Figure 5 through Figure 12. Samples that were below detection limits were excluded from the evaluation of mean and maximum levels at the sample locations. Key observations for detection frequency, exceedances, and maximum observed arsenic levels are described by monitoring program. Overall summaries of status and observations for water, sediment, and tissue are provided alongside the rationale for the proposed water quality objectives in Section 4.2. All data presented are for total arsenic levels, unless indicated. There is comparably little data for dissolved arsenic or speciated arsenic levels in Burrard Inlet.

Data for constituents that impact arsenic 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.

A summary of observations follows.

**Pre-1990 Data**

- 1985–1987 – The Environment Canada Benthic Contaminants Study (Goyette and Boyd 1989) observed arsenic concentrations in English sole (*Parophrys vetulus*) fish muscle tissue ranging from 17 to 93 µg/g dry weight, which was similar to arsenic levels in fish tissue reported for unpolluted coastal areas of BC (Harding and Goyette 1989).
- 1971–1989 – BC ENV monitoring samples collected between 1971 and 1989 were above arsenic detection limits in 23 (33%) of 70 water samples and 1 (12%) of 8 sediment samples. The following key points summarize the monitoring results:
    - Detection limits for water samples were 1 µg/L (32 cases), 5 µg/L (15 cases), and not listed (22 cases). In the 15 cases where the detection limit was 5 µg/L, all measurements were below detection limits. These 15 samples were all recorded in 1975. There was one recorded value in 1975 that was 8000 µg/L at Burrard Inlet Lions Gate (Station 300077) and one value in 1989 at Vancouver Harbour Clark Drive (Station E207818) that was recorded as 37 µg/L. These measurements were excluded from the figures as they compressed all other data and may be outlier values or laboratory errors, though verification was outside the scope of this report.
    - Excluding the two exceedingly high measurements in 1975 and 1989, the arsenic levels were measured as either 1 µg/L or 2 µg/L across Burrard Inlet, which is lower than the benchmark for the protection of aquatic life (12.5 µg/L).
    - There was one sediment sample that exceeded detection limits and measured 28 µg/g at Pacific Coast # 12 175 Meters Northeast (Station E207699). This exceeds the TEL benchmark (7.24 µg/g).

**Post-1990 Data**

- 1998 – The BIEAP Sediment Quality Study (EQOMAT 1998) observed total arsenic concentrations above the detection limit (8 µg/g) in 40 of 45 surface sediment samples. None of the samples exceeded the PEL (41.6 µg/g). However, all samples that exceeded the detection limit also exceeded the TEL (7.24 µg/g). The highest arsenic levels were detected in Port Moody Arm (≤ 23 µg/g) followed by the Inner Harbour (≤ 20 µg/g).
- 1990–2009 – BC ENV water quality objectives attainment monitoring samples collected between 1990 and 2009 were above arsenic detection limits for 133 (65%) of 205 water samples, 15 (32%) of 47 sediment samples, and 17 (100%) of 17 tissue samples. Detection limits ranged from 0.02 µg/L to 200 µg/L for water samples, 8 µg/g to 25 µg/g for sediment samples, and were 0.2 µg/g for English Sole whole body fish tissue samples. The wide range of detection limits for arsenic in water and sediment samples may impact the interpretation of results, particularly because the detection limits are frequently above the screening benchmarks. The following key points summarize the monitoring results:
    - In water samples, the highest total arsenic levels were measured at False Creek Between Granville and Cambie (Station E207815, 4 µg/L) in 2009, Vancouver Harbour Vancouver Wharves (Station E207816, 3.5 µg/L) in 2009, and English Bay Centre (Station 300076, 3.2 µg/L) in 2009. Of the 133 total arsenic samples that exceeded detection limits, no samples exceeded the benchmark for protection of aquatic life (12.5 µg/L). An illustration of arsenic levels in the BC ENV water samples is provided in Figure 5.
    - Sediment samples exceeded the TEL benchmark (7.24 µg/g) in all but two samples; they did not exceed the PEL benchmark (41.6 µg/g) in any samples. The highest measurements that exceeded detection limits were recorded at False Creek East End (Station E207814, 29 µg/g) in 1993 and Coal Harbour – South Shore near Bayshore Hotel (station E207813, 16 µg/g) in 2000. False Creek East End also had elevated levels in 2000 (14 µg/g) though this is lower than the measurement recorded in 1993. An illustration of total arsenic levels in the BC ENV sediment samples is provided in Figure 6.
    - Arsenic levels measured in English sole fish tissue are several orders of magnitude above the highest tissue screening benchmark (adult recreational fisher, 0.051 µg/g). The highest measurements were at Vancouver Harbour Vancouver Wharves (Station E207816, 18.7 µg/g) in 2003, Vancouver Harbour Clark Drive (Station E207818, 10.2 µg/g) in 2003, and Indian Arm at Cable Crossing (Station 300080, 6.7 µg/g) in 2003. An illustration of total arsenic levels in the BC ENV tissue samples is provided in Figure 7.

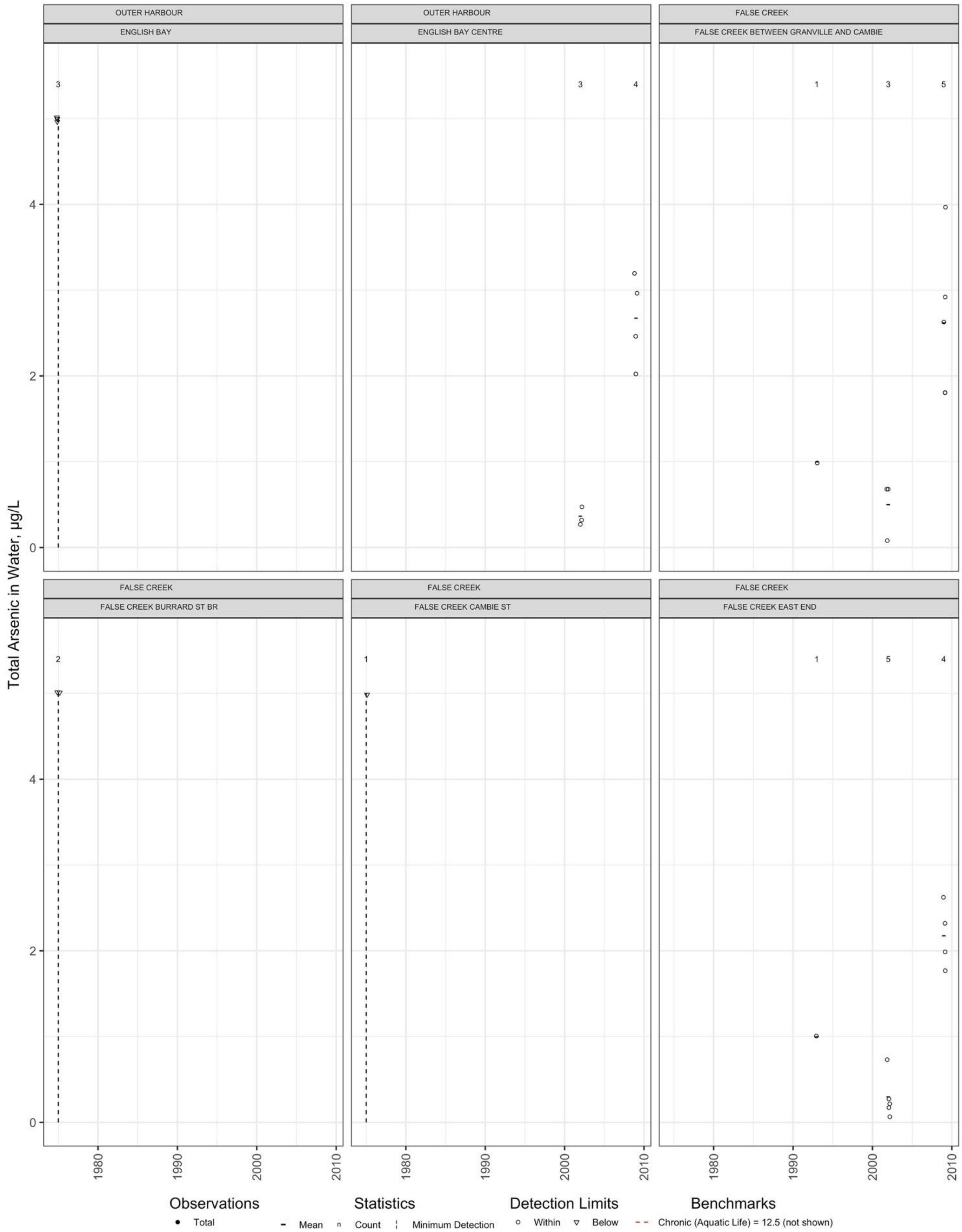


*Figure 5: Arsenic levels in BC ENV water samples (1975 to 2009) in µg/L*

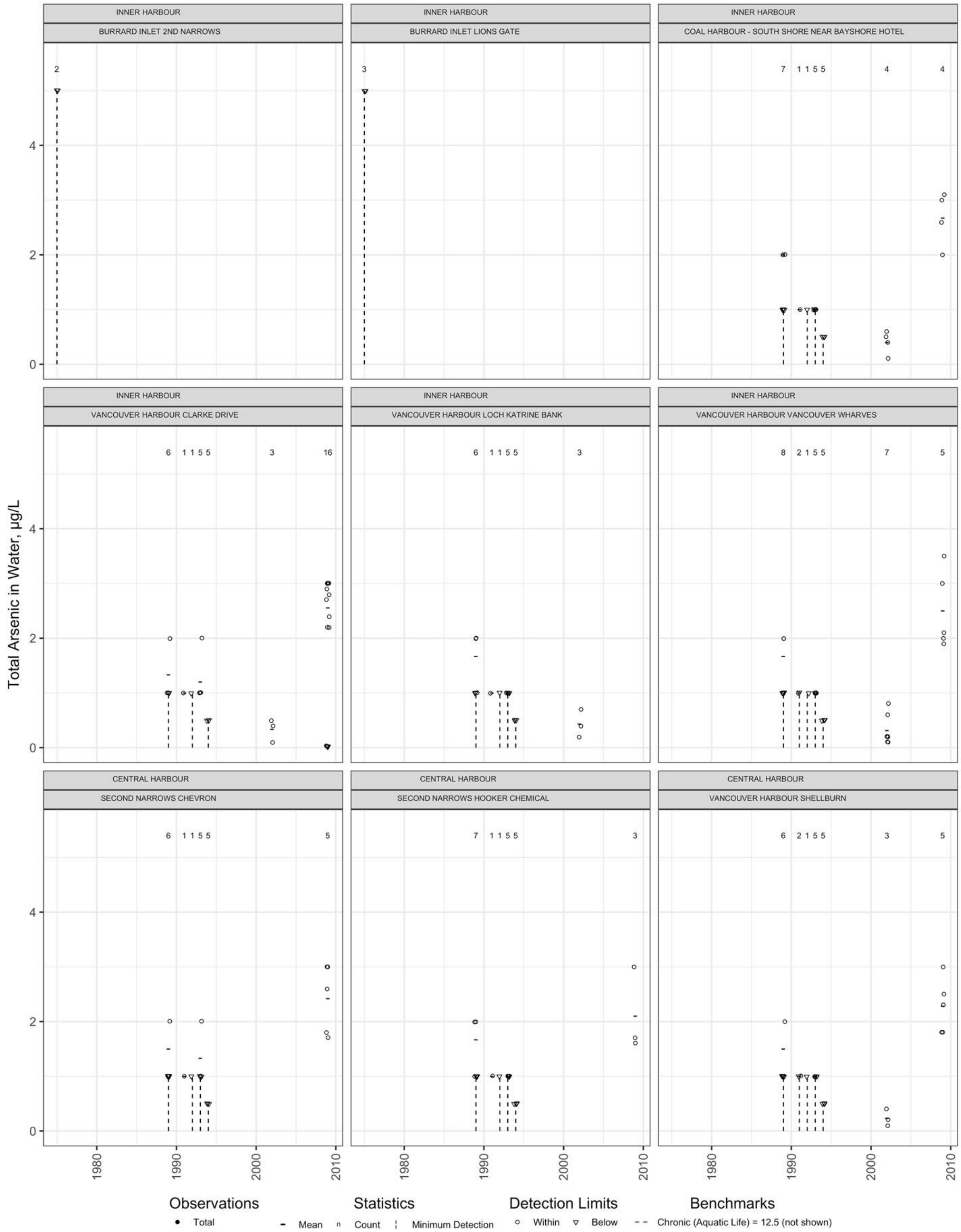


*Figure 5: Arsenic levels in BC ENV water samples (1975 to 2009) in µg/L (continued)*

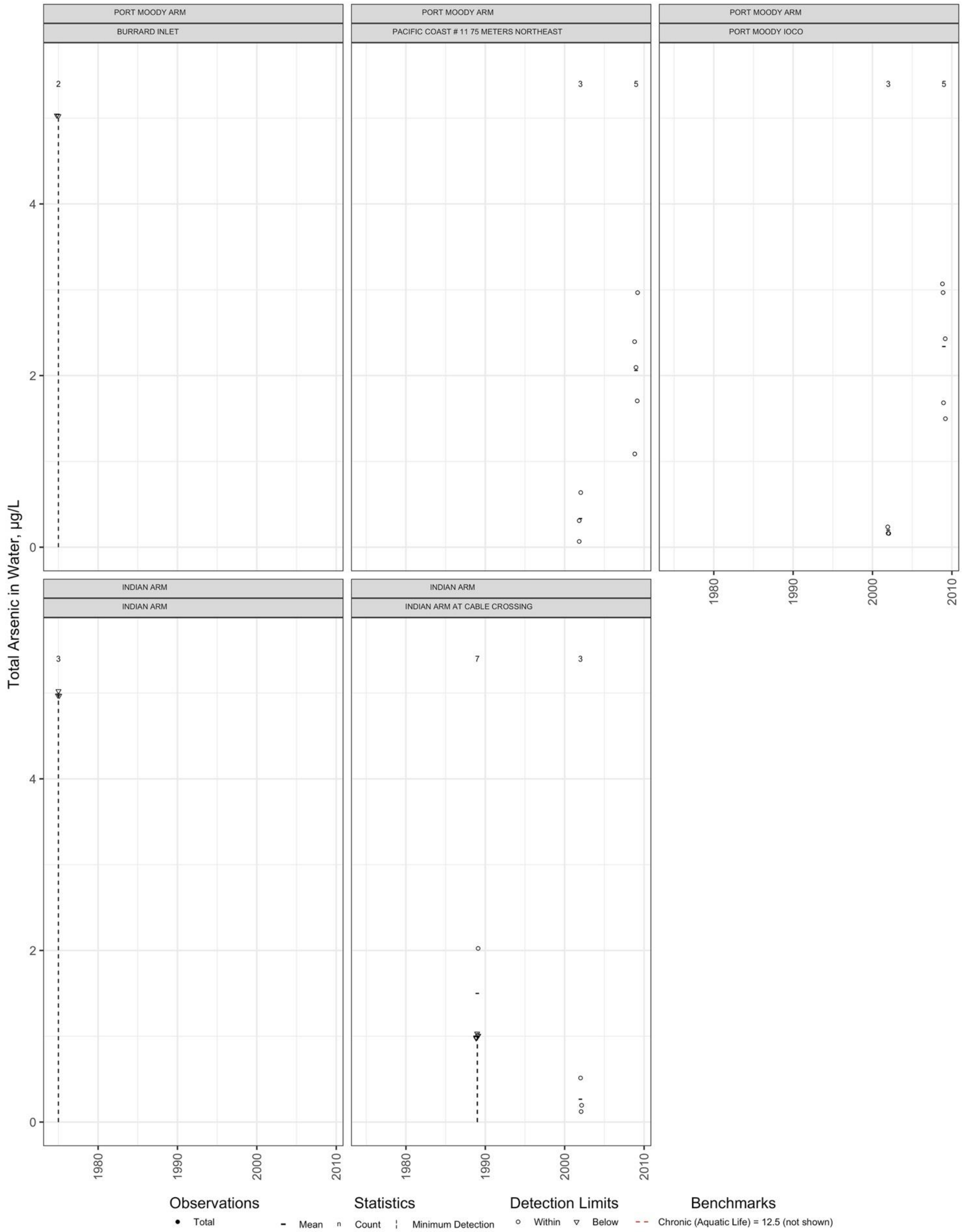


*Figure 5: Arsenic levels in BC ENV water samples (1975 to 2009) in µg/L (continued)*

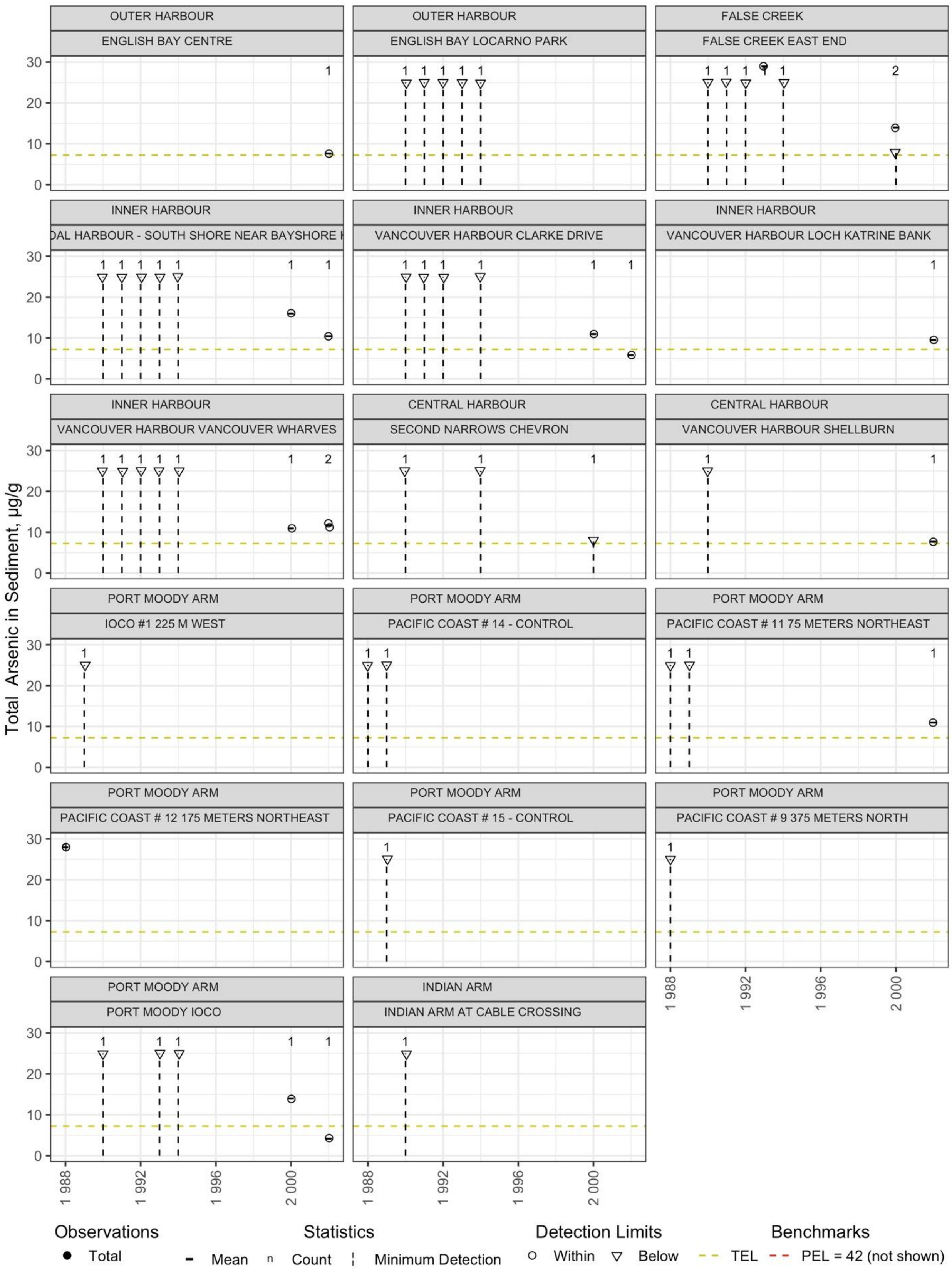


*Figure 6: Arsenic levels in BC ENV sediment samples (1988 to 2003) in µg/g*

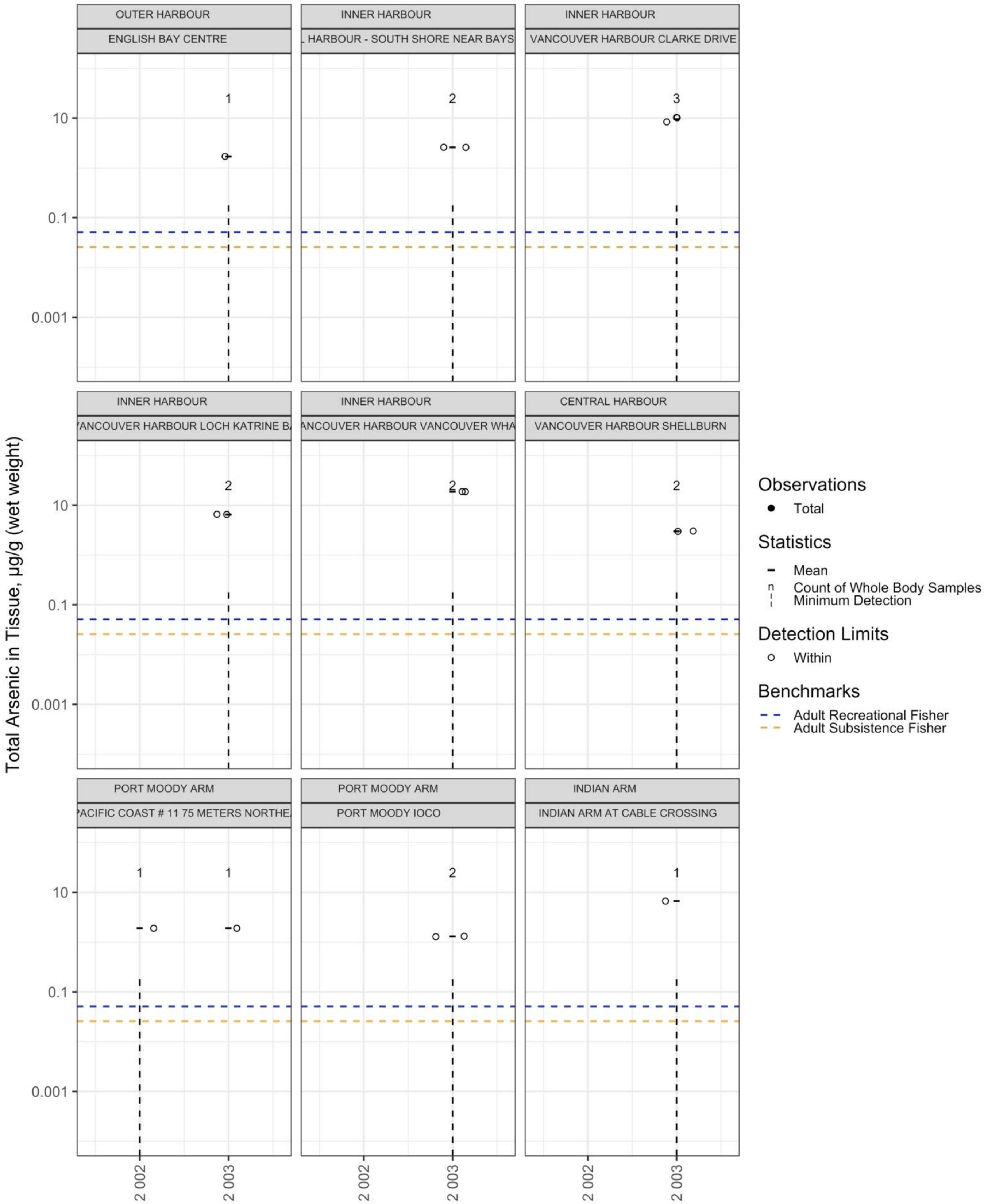


*Figure 7: Arsenic levels in BC ENV English sole fish tissue samples (2002 and 2003) in µg/g wet weight (log scale)*

- 2007–2016 – As part of the Burrard Inlet Ambient Monitoring Program, Metro Vancouver has monitored arsenic levels at the top and bottom of the water column annually (Figure 8) and in sediment every 2 to 3 years (Figure 9) since 2008. The “top” water sample was collected 1 m below the water surface and the “bottom” sample was taken 3 m above the ocean floor. Arsenic levels in English Sole tissue (whole body, muscle, and liver) samples were measured in 2007 and 2012 (Figure 10). Between 2007 and 2016, total arsenic levels were above detection limits for 700 (99%) of 710 water samples, 105 (100%) of 105 sediment samples, and 73 (100%) of 73 tissue samples. Detection limits were between 0.2 µg/L and 0.5 µg/L for total arsenic in water samples, 0.05 µg/g and 0.20 µg/g for total arsenic in sediment samples, and 0.01 µg/g for total arsenic in fish tissue samples. Because of the lower detection limits and the resulting greater detection frequency, greater emphasis has been placed on the Metro Vancouver monitoring data compared to the BC ENV monitoring data. The following key points summarize the Metro Vancouver monitoring program results:
    - For marine water, there were no exceedances of the benchmark for protection of aquatic life (12.5 µg/L). The highest values were measured in 2008 at Central Harbour (3.42 µg/L), Inner Harbour (3.03 µg/L), and Outer Harbour South (2.89 µg/L) (see Figure 8). In general, higher arsenic concentrations were found in the top of the water column compared to the bottom; however, reasons for this difference are unclear.
    - Arsenic levels exceeded the TEL benchmark for arsenic in sediment (7.24 µg/g) in all but three samples in this monitoring program but did not exceed the PEL benchmark for arsenic in sediment (41.6 µg/g). The highest values were measured in 2011 at Port Moody Arm (19.1 µg/g), in 2013 at Outer Harbour North (14.9 µg/g), and in 2015 at Indian Arm North (12.7 µg/g) (see Figure 9).
    - Total arsenic levels in English sole whole body fish tissue samples, ranging from 1.88 to 31.6 µg/g, were orders of magnitude above the screening benchmarks for human consumption of fish and shellfish (0.051 µg/g for adult recreational fisher). The highest values have consistently been measured in Indian Arm North and Indian Arm South (4.7 µg/g to 31.6 µg/g) (see Figure 10).

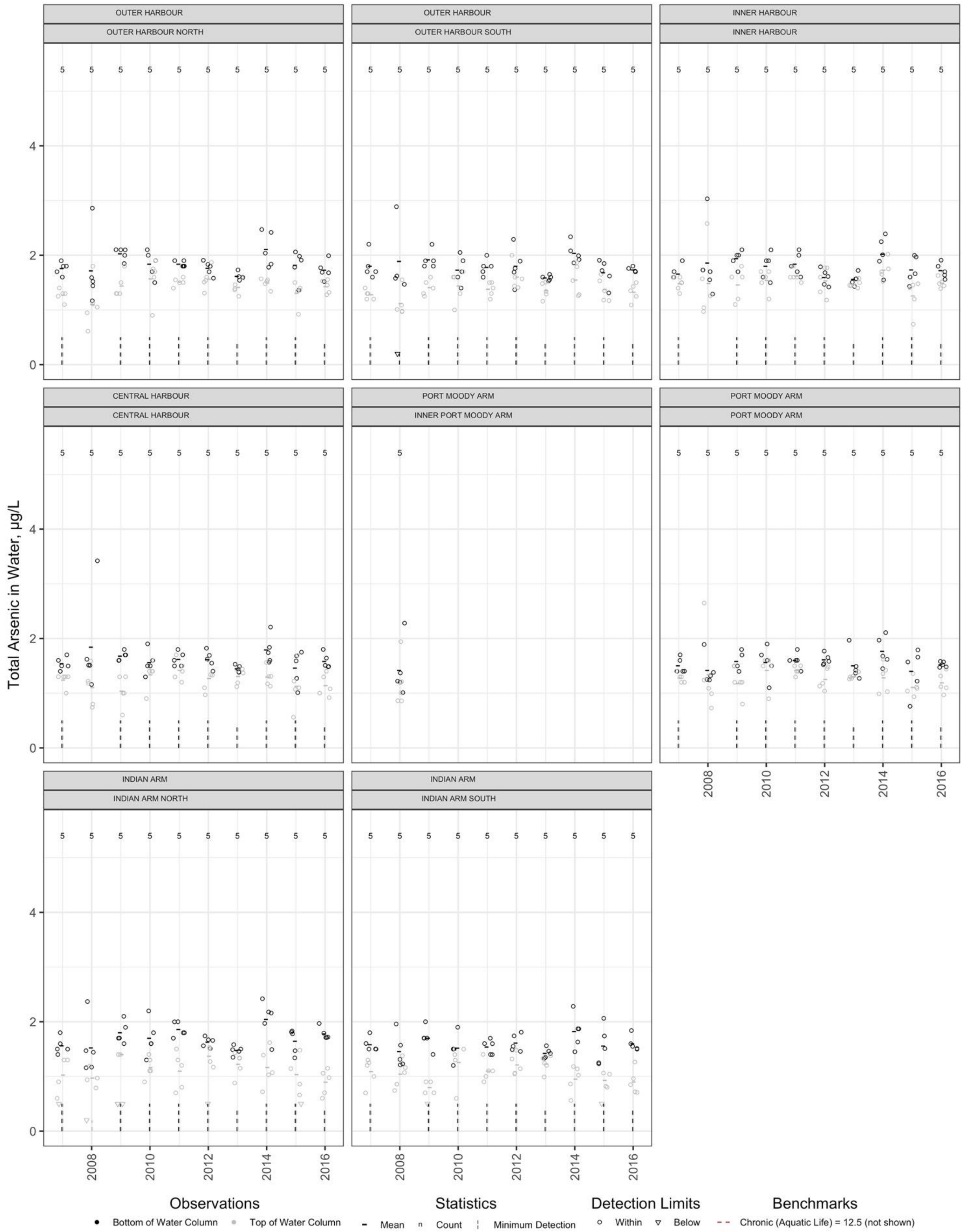


*Figure 8: Arsenic levels in Metro Vancouver water column samples (2007 to 2016) in µg/L*

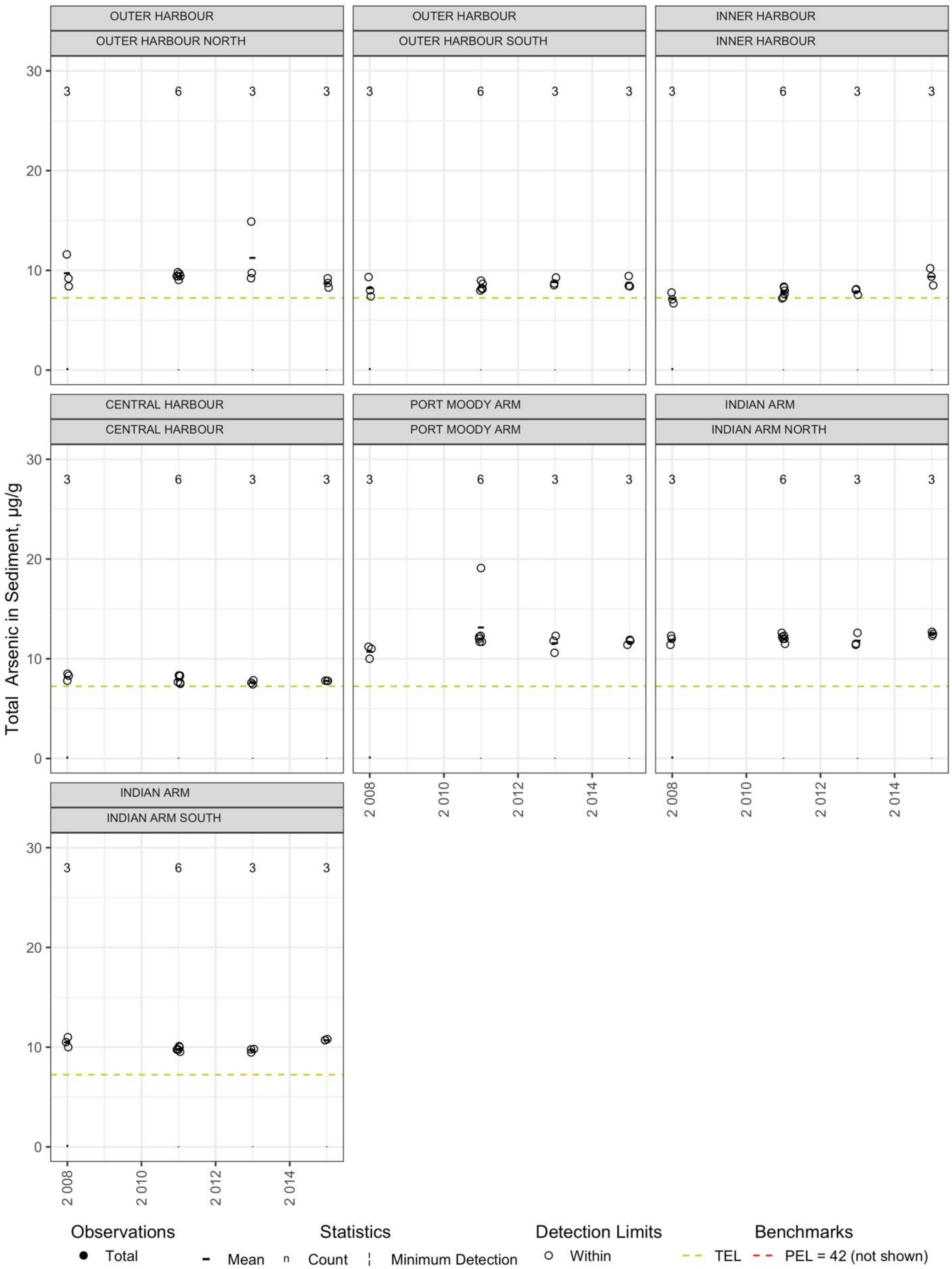


*Figure 9: Arsenic levels in Metro Vancouver sediment samples (2008 to 2016) in µg/g*

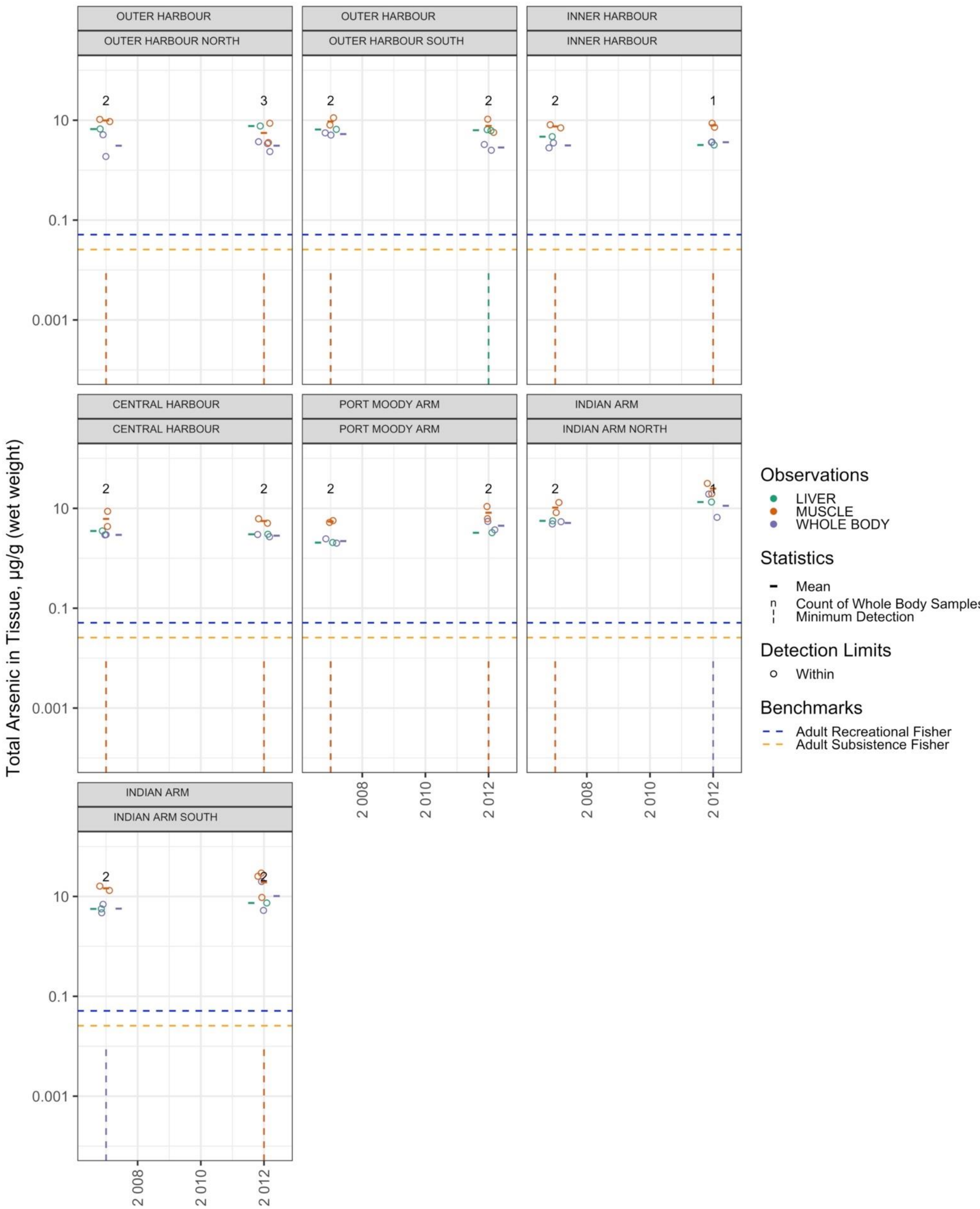


*Figure 10: Arsenic levels in Metro Vancouver English sole fish tissue samples (2007 and 2012) in µg/g (log scale)*

- 2015–2016 – The PollutionTracker program measured total arsenic in sediment by dry weight and total arsenic in blue mussel (*Mytilus edulis*) tissue by dry and wet weight in October 2015 and April 2016. All measurements were above detection limits. For consistency with other monitoring programs and screening benchmarks, only dry weight values were analyzed for sediment and only wet weight values were analyzed for tissue. In sediment, dry weight detection limits were 0.1 µg/g for total arsenic. In tissue, wet weight detection limits were 0.004 µg/g for total arsenic. The following key points summarize the PollutionTracker monitoring program results:
    - For sediment, 9 (56%) of 16 samples exceeded the TEL benchmark (7.24 µg/g) and no samples exceeded the PEL benchmark (41.6 µg/g). The highest single sample maximum for total arsenic was measured at Port Moody Arm (14 µg/g, Burrard Inlet 01) (Figure 11).
    - Arsenic levels in blue mussel samples ranged from 0.947 to 1.66 µg/g wet weight, which is orders of magnitude above the screening benchmarks for human consumption of shellfish (0.051 µg/g for adult recreational fisher). The highest single sample maximum was measured in the Outer Harbour (1.66 µg/g wet weight, Burrard Inlet 09) (Figure 12).

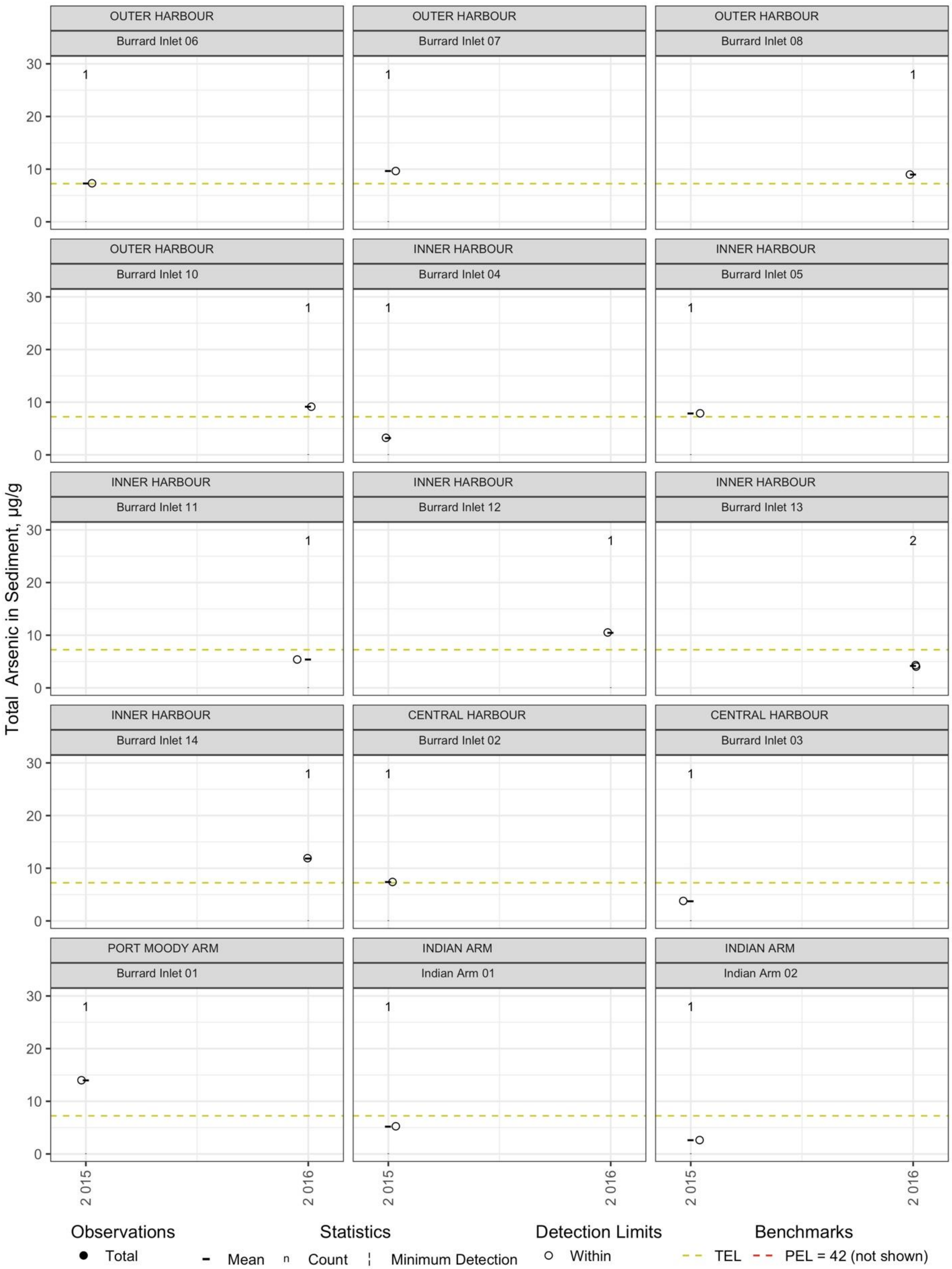


*Figure 11: Arsenic levels in PollutionTracker sediment samples (2015 and 2016) in µg/g*

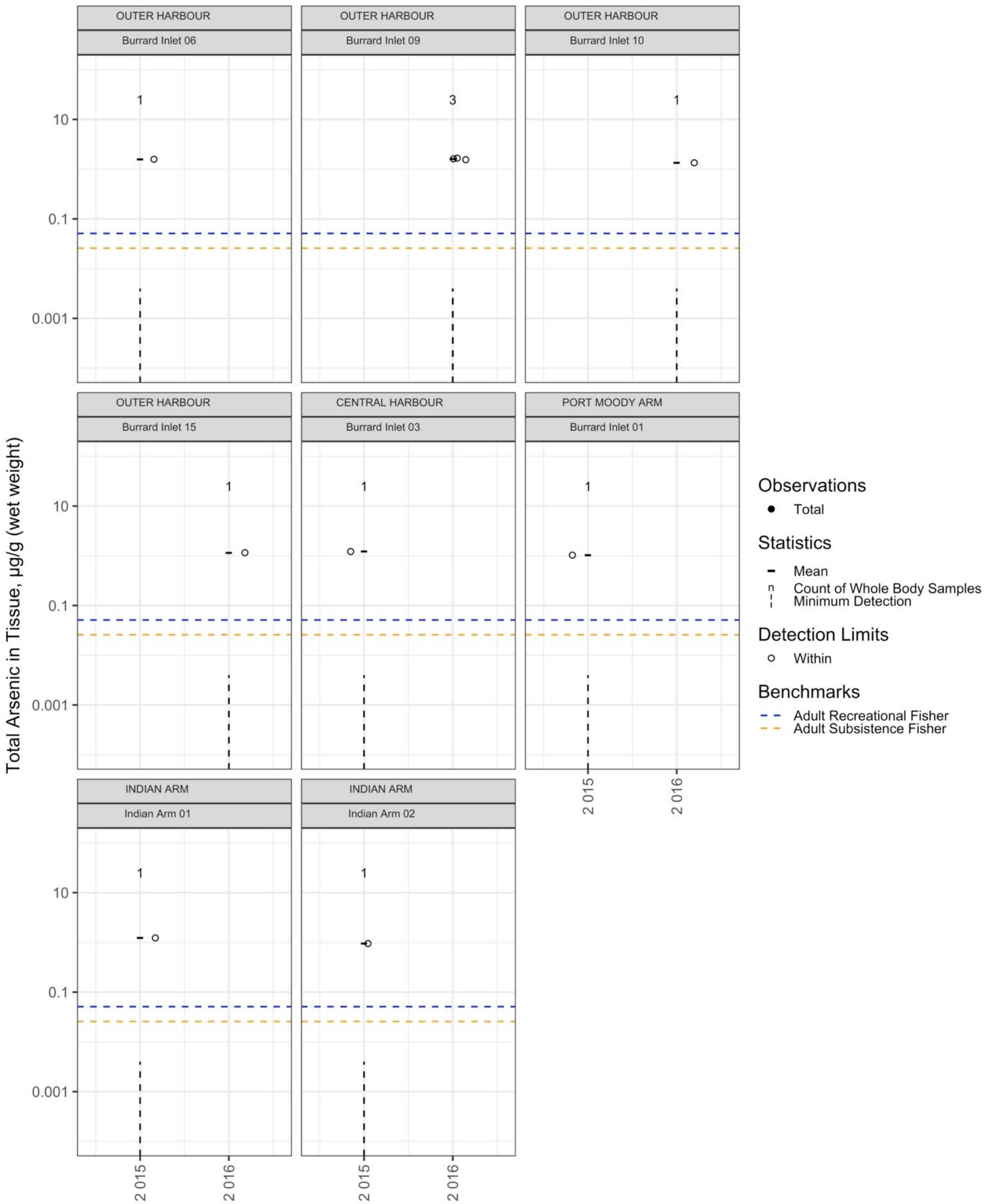


*Figure 12: Arsenic levels in PollutionTracker blue mussel tissue samples (2015 and 2016) in µg/g (log scale)*

## 3.4 Knowledge Gaps and Research Needs

The assessment of available arsenic 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:

- The toxicity of arsenic 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.
- Monitoring indicates that arsenic levels in Burrard Inlet English sole and blue mussel tissue have consistently been orders of magnitude above the tissue benchmarks for human consumption of finfish and shellfish. Some of the highest arsenic levels have been measured in tissue samples from Indian Arm, the sub-basin in which shellfish harvesting is most likely to occur. Further research is needed to identify the sources of these elevated levels, and the proportions that represent 'background' levels, historical inputs and current inputs. Further analysis of arsenic speciation to assess potentially carcinogenic risks would add clarity to the assessment performed here.
- Speciation of arsenic in marine seafood is critical as total arsenic determination is not sufficient to accurately assess environmental impacts or human health risks (Wang and Mulligan 2006); however, there is no single commonly accepted way of determining inorganic arsenic in foods. A validated analytical method is needed for inorganic arsenic with the intent of understanding human health risks associated with arsenic in seafood.
- If further analysis on arsenic speciation indicates that human health risks are present, this may warrant further source monitoring and assessment of arsenic sources to prioritize areas for management efforts.
- There has been little monitoring of arsenic in sediment or the water column in False Creek since 2009.

# 4. PROPOSED OBJECTIVES FOR ARSENIC IN BURRARD INLET

## 4.1 Proposed Objectives

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

*Table 4: Proposed Water Quality Objectives for Total Arsenic*

| Sub-basin | False Creek | Outer Harbour | Inner Harbour | Central Harbour | Port Moody Arm | Indian Arm |
|---|---|---|---|---|---|---|
| **Water** | 2.4 µg/L mean[1] | | | | | |
| **Sediment** | 7.24 µg/g dry weight single-sample maximum[2] | | | | | |
| **Tissue** | 0.0258 µg/g wet weight single-sample maximum (all tissue types)[3] | | | | | |

[1] Minimum of 5 samples in 30 days collected during the wet season. No more than 20% of samples > 2.4 µg/L.
[2] Based on at least 1 composite sample consisting of at least 3 replicates.
[3] Applies to all tissue types. Based on at least 1 composite sample consisting of at least 5 fish or 25 bivalves. See Rao et al. (in prep) for additional details. Assumes that 10% of total arsenic is present as inorganic arsenic.

## 4.2 Rationale

The 1990 provisional water quality objectives for Burrard Inlet 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 approved water quality guideline for total arsenic in water, adopted from the CCME, is set to protect aquatic life against chronic toxicity; however, it is higher than the 1990 Water Quality Objectives (WQOs) for Burrard Inlet and measured arsenic levels in Burrard Inlet have been consistently lower than this benchmark. To see no further degradation from current conditions, an interim numerical objective has been calculated using the 95% 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. Only measurements that were above detection limits were used to calculate these statistics (representing 99% of 710 data points) and all measurements were given equal weight. BC ENV's practice in this situation is to calculate the objective as 20% higher than the 95$^{th}$ percentile to account for the dynamic nature of water chemistry and the accuracy and precision of laboratory results (ENV 2021); hence the proposed objective for water is 2.4 µg/L. The qualifier that 'no more than 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. After further studies on arsenic speciation in Burrard inlet have been conducted, a more appropriate estimate may be developed and the objective may be revised.

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

| Summary Statistic | Count | Minimum | 25$^{th}$ Percentile | Median (50$^{th}$ Percentile) | Mean | 75$^{th}$ Percentile | 95$^{th}$ Percentile | Maximum |
|---|---|---|---|---|---|---|---|---|
| Value in µg/L | N = 710<br>N > DL*<br>= 700 | 0.56 | 1.3 | 1.5 | 1.5 | 1.7 | 2.0 | 3.4 |

**DL = detection limit*

The proposed objective for total arsenic in sediment of 7.24 µg/g dry weight was selected to be consistent with BC's lower working sediment quality guideline for the protection of marine aquatic life (ENV 2020).

The proposed objective for total arsenic in tissue of 0.0258 µg/g wet weight is protective of the most sensitive receptor, i.e. an adult from a subsistence fishing population. A toddler from a subsistence fishing population was not considered for the proposed tissue objective since arsenic is a carcinogen, and the tissue screening value used to derive the objective was based on a lifetime of exposure to a carcinogen (Thompson and Stein 2021). As described in Section 3.1, because the OSF was applied for inorganic arsenic (the more toxic form) and available monitoring data was for total arsenic only, a scaling factor of 10 was applied to the SVs calculated by Thompson and Stein (2021) to account for the general and conservatively accepted ratio between total arsenic and inorganic arsenic in finfish and shellfish. This approach is based on risk assessment relevant to subsistence consumption of country foods and results in a very conservative objective intended to protect water values, identify potential risks and flag contamination issues requiring further examination. Because arsenic levels measured in fish and shellfish tissue have greatly exceeded this proposed objective in recent years, further assessment and discussions with health experts are required, as a priority, to set safe consumption limits for seafood harvested from Burrard Inlet.

## 5. MONITORING RECOMMENDATIONS

Monitoring recommendations help refine the existing monitoring programs and inform future assessments to determine whether the water quality objectives for arsenic are attained. The following are recommendations for future arsenic 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 µg/g dry weight and tissue values in µg/g wet weight.
- Monitor the vicinity of areas known to be sources of arsenic, such as near stormwater and combined sewer overflow outfalls, areas with high historical contamination such as False Creek and the Inner Harbour, and areas with large amounts of treated wood. Undertake loading analyses to inform prioritization of sources to control and/or remediate.
- Conduct further monitoring of arsenic levels in fish and shellfish tissue, particularly in preferred seafood species, around current or potential harvesting sites, and including the following:
    - Conduct preliminary work to determine an adequate methodology and sample size to have sufficient arsenic speciation data to determine an appropriate percent for speciated inorganic arsenic in Burrard Inlet water and tissue samples. Once defined, conduct a one-time study to confirm or refine the assumption that approximately 10% of the total arsenic content is inorganic arsenic. The percentage assumption may need to be re-confirmed every 5 to 10 years according to the most current literature and data.
    - If speciation data warrants a human health risk assessment, perform a study to assess safe levels of seafood consumption given current arsenic levels in finfish and shellfish. This may include additional sampling of preferred seafood species.

## 6. MANAGEMENT OPTIONS

The following initiatives are planned or underway or should be adopted to help reduce arsenic levels in Burrard Inlet:

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

Based on the data assessment above, the following management options that have the potential to further reduce anthropogenic sources of arsenic to Burrard Inlet are recommended for consideration:

- Ensure that mercury discharges are not authorized, e.g. through provincial wastewater discharge authorizations;
- Since stormwater plays a role in transporting contaminants to Burrard Inlet, prioritize the implementation of source controls to reduce the volume and improve the water quality of stormwater discharges, with a special focus on areas containing treated wood;
- Encourage more widespread adoption of green infrastructure and other design criteria that provide water quality treatment for stormwater runoff prior to discharge to Burrard Inlet; and
- Encourage adequate controls for runoff and erosion from urban development to prevent soil that may be highly contaminated with arsenic from historical uses from entering Burrard Inlet.

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