

Mercury and arsenic concentrations in fish tissues and the influence of historic gold mines in Nova Scotia

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ABSTRACT

Mercury and arsenic concentrations in freshwater and anadromous fish were examined to determine the effects of historic gold mine tailings on the concentration of mercury (Hg) and arsenic (As) in fish in 19 water bodies from July 2006 to November 2007.

A total of 300 fish, representing 11 species were sampled and analyzed for total mercury and arsenic contamination in selected lakes associated with historic gold mining (n= 14) and morphologically similar lakes (controls) not associated with historic gold mining (n= 5). Hg concentrations were generally correlated with fish length in all sites while As concentrations were generally not correlated with fish length. Mean Hg concentrations in lakes associated with historic gold mining ($Hg^{conc}=0.62$ mg/kg) was generally higher than lakes not associated with historic gold mining ($Hg^{conc}=0.57$ mg/kg). However, there was insufficient evidence to suggest that for any fish species, mercury concentrations were elevated in lakes with gold mine tailings in the watershed. Conversely, there was evidence to suggest that arsenic concentrations in some fish species were elevated in lakes associated with historic gold mines.

Brook trout, smallmouth bass, white perch and yellow perch all had greater than 30% exceedance above the Canadian human health guideline for consumption of Hg in fish of 0.5 mg/kg. The lengths at which these species exhibited a 50% likelihood of exceeding the mercury guideline were 30.0, 32.1, 10.4 and 17.2 cm respectively. Only white sucker (n=4, 13% of sample) and yellow perch (n=1, 3% of sample) exhibited As concentrations above the Canadian human health guideline for fish tissue of 3.5 mg/kg. Zero brook trout exceeded the guideline in lakes associated with historic gold mining, however, one fish from Dollar Lake, a site not associated with historic gold mining, did.

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BACKGROUND

Mercury in aquatic environments poses a threat to most organisms. In water, mercury can be found in a form known as methyl-mercury (MeHg), a bioavailable version of elemental mercury (Weiner et al. 2003). This methylated form is mobile enough to be readily accumulated in exposed organisms yet once ingested it remains in the body, a process known as bioaccumulation. Through biomagnification, even relatively low levels of methyl-mercury can cause substantially elevated levels of MeHg in predators high in the trophic food web. In Nova Scotia, cyanobacteria and periphyton are the first organisms to assimilate MeHg. These primary producers are consumed by several trophic strata of zooplankton and aquatic invertebrates and are eventually consumed by either prey fish or omnivorous fishes. The fish are then preyed upon by piscivorous fishes. Because it is often these high trophic-level piscivorous fish which are most sought by humans, the risk of consuming fish with elevated levels of mercury is considerable even in environments with relatively low levels of mercury. Additionally, it has been documented that piscivorous birds, such as osprey and loons (Evers et al. 1998, Burgess et al. 2005), as well as some mammals (Weiner et al 2003) are particularly susceptible to MeHg poisoning through food web transfers. Sources of mercury can be categorized into three groups; natural sources, current human activity and past human activity (Weiner et al. 2003). Mercury is a naturally occurring element found in certain geological groupings. This mercury is also mined and processed for industrial use (Evers 2005). Anthropogenic sources of mercury in Nova Scotia are often associated with two major sources; atmospheric deposition of mercury and point source deposition of mercury. Atmospheric mercury is generally the by-product of fossil fuel usage in automobiles and industry, both within Canada and around the globe. One of the more common point sources of mercury is abandoned gold mines. Gold mine tailings left behind, often contain mercury and arsenic, by-products of gold extraction (Murdoch and Clair 1986). It has been previously documented that increased levels of mercury in aquatic systems and food webs may result from the presence of historic gold mine tailings (HGMT) within their drainages (Lane et al. 1989, Weiner et al 2003).

Similarly, elevated levels of arsenic have been linked to HGMT (Brooks et al. 1982, Dale and Freedman 1982, Murdoch and Clair 1986, Lane et al. 1989, Wong et al. 1999, Wong et al. 2002). Arsenic, like mercury is a fairly common element in the earth's upper crust. Until sequestered in soils and sediments, arsenic is bioavailable and readily assimilated by many organisms (Dale and Freedman 1982). Arsenic readily bio accumulates however unlike mercury, its associated organic metabolites do not readily bio magnify through trophic levels (US EPA 2003). With the understanding of mercury and arsenic toxicity pathways, fish are therefore fairly good indicators of both mercury and arsenic in the surrounding aquatic environment and may be useful in assessing residual effects of historical mining activities.

In Nova Scotia, over 65 000 anglers (Nova Scotia Department of Fisheries, 2010) actively pursue fish in freshwater every year. Many of these anglers retain and consume fish, thus the health of the fish and any potential contamination which may affect their suitability for human consumption is of continued importance. The Historic Gold Mines Advisory Committee (HGMAC) was established in 2005. A sub-committee of the HGMAC, the

Freshwater Working Group was established in 2006 to reassess the degree to which fish are contaminated with mercury and arsenic associated with historical gold mines in Nova Scotia. The primary objectives of this study were to: (1) examine the potential for mercury and arsenic contamination of fish living downstream from historic gold mine tailings, (2) assess the current levels of mercury and arsenic contamination against the recommended Canadian Guidelines for human consumption of fish tissue, and (3) to provide recommendations for fish consumption advisories. Several biological hotspots have been identified in northeastern North America where mercury concentrations are of concern in aquatic environments and include Kejimikujik National Park and central Nova Scotia (Evers, 2005).

STUDY AREA

The southern upland region of Nova Scotia is a geological formation lying south of a line extending from Digby to Canso. It is comprised mainly of hard igneous and metamorphic rocks, primarily slates, granites and greywacke, which are slow to degrade and provide few base cations to surficial waters. This area is generally low gradient with altitudes rarely exceeding 140 meters. Peat bogs and conifer forests dominate the landscape and contribute large amounts of organic acids and humic substances to lakes and rivers. Consequently, many surface waters are heavily tea-coloured and often acidic. Associated with these geological formations are sporadic gold deposits that have historically been commercially mined.

In an effort to assess the effects of HGMT on the level of mercury and arsenic contamination in fish, lakes were sampled based on the presence/ absence of HGMT. Lakes considered to be affected by HGMT are those where there is historical evidence of tailings either on the banks of the lake (immediate drainage) or in an upstream section of the watershed. Maps and sampling data were provided by the Nova Scotia Departments of Natural Resources and Environment. Figures 1A and 1B show the distribution of sample sites as well as the general assumed location of HGMT. Also, in an effort to reduce the confounding effects of differing geophysical and watershed water chemistry attributes, lakes were chosen such that lakes assumed to be affected by contamination from historic gold mines were paired with an unaffected lake from the same or a neighbouring watershed.

In recent years, population growth in the greater Halifax city area as well as the south shore of Nova Scotia has contributed to urban sprawl. As a result of the growing population, it is assumed that mercury and arsenic pollution in the area and an associated increase in deposition of mercury and arsenic in nearby lakes has occurred, primarily from increased automobile and industrial emissions. Proximity to urban areas was therefore also a consideration site selection for this project.

METHODS

Sampling design

In general, the analysis of fish tissue for biological indication of methyl-mercury contamination (and to an extent arsenic) should be restricted to either prey-fish (mainly cyprinidae in Nova Scotia) or to piscivorous fish of a high trophic position. Substantial variation in the diet of omnivorous fishes between lakes and in general omnivorous fish are not recommended as test subjects (Harris et al. 2007). In Nova Scotia, low fish species diversity and relatively unproductive habitats may permit the comparison of omnivorous fishes from similar local lakes, as has been done in previous studies (Drysedale et al. 2005). Several fish species, including both those important to angling and locally abundant, were therefore sampled, regardless of trophic status. Samples were obtained via gill nets, box (eel) traps, wire minnow traps and angling. Angling was aimed at obtaining larger individuals which more closely representative those encountered by anglers. The length and weight of all fish were recorded and scales were sampled for later aging. All samples were frozen within 24 hours. Water chemistry samples were taken from the surface, and where stratification occurred, from the hypolimnion. Samples were taken using acid-washed sample bottles. In many cases, the number of fish sampled was greater than the number of fish that could be analyzed. Fish were therefore selected to provide a representative sample across several ages and length classes. In some cases, as with smaller individuals (< 10cm), several fish were homogenized. Homogenized analysis represented the mean Hg or As concentration for 2, or occasionally 3 individuals. Also, in an effort to reduce the confounding effects of differing geophysical and water chemistry attributes, lakes were chosen such that lakes assumed to be affected by contamination from historic gold mines were paired with unaffected lakes from the same or a neighbouring watershed.

Water chemistry samples were taken from 0.5 m below the surface to minimize rain water influence, and where lake stratification occurred, from the hypolimnion. Samples were taken using acid-washed sample bottles.

Laboratory Processing

Fish samples were analyzed for total mercury and total arsenic. Generally, greater than 95% of total mercury in fish tissue is methyl-mercury (Grieb et al. 1990) as was determined in previous studies (Drysedale et al. 2005) in Nova Scotia. Samples were homogenized and portioned as per the individual requirements of each fish sample (whole fish and/or fillet and/or composite). The homogenates were prepared for analysis by microwave assisted digestion in nitric acid. The resulting solutions were analyzed for arsenic by inductively coupled plasma - mass spectrometry (ICP-MS) (EPA 200.8) and for mercury by cold vapour atomic absorption spectrometry (AAS) (EPA 245.6). Duplicates and sample spikes were utilized for quality control purposes as well as certified reference materials (Dogfish tissue - DORM-2 and oyster tissue - NIST 1566b).

Sediment samples were air dried and sieved at 2mm. Portions were digested according to EPA Method 3050B. The resulting solutions were diluted to volume for arsenic analysis by inductively coupled plasma - mass spectrometry (ICP-MS) (EPA 200.8). Mercury was determined by cold vapour atomic absorption spectrometry (AAS) (EPA 245.5). Duplicates and certified reference material were utilized for quality control purposes.

Statistical Analysis

Because the data was skewed and had outlier values, the concentration data were log-transformed. For concentration values where quality assurance (duplicates) were conducted, the mean value between the duplicate and initial reading was taken. For values which were below the lower detection limit (LDL), a random number generator was used to assign a value between 0 and the LDL rather than using 0.5 times the LDL which generates an artificially uniform rather than true distribution of values (Croghan et al, 2003). To test the effects of the presence of HGMT, analysis of co-variance (ANCOVA) was used with presence/absence of HGMT and fish species as factors and total length of the fish as the covariate. Similarly, to test for contamination differences between lakes, ANCOVA was used with lake and species as factors and total length of the fish as the covariate. To regress mean Hg and As concentration against water chemistry parameters, both white perch and yellow perch were length-adjusted for comparability among sample lakes.

RESULTS

A total of 226 samples were analyzed representing 300 individual fish as a result of homogenization/composition. Species distribution was not uniform across all lakes thus not all species were sampled from all lakes (Table 1). A total of 11 species were sampled from lakes with HGMT present and a total of 7 species were sampled in lakes without HGMT present (control) (Figure 2). In some lakes, too few individuals of some species were collected and thus not all analysis could be performed for all species.

The size of fish captured was representative of those which most anglers target with the exception of smallmouth bass where large bass were under represented (Table 2). Some species were underrepresented as a whole (American eel, chain pickerel, golden shiner, landlocked salmon and striped bass), therefore no statistical interpretation and limited inference of mercury or arsenic contamination for those species could be made (Table 1, Table 2).

Mercury in Fish Tissue

Mercury concentrations in fish varied and piscivorous fishes exhibited the highest mercury concentrations (with the exception of chain pickerel) (Table 2). American eel showed the highest concentrations of any species (mean=0.94 mg/kg, SD=0.81, n=6) while the omnivorous white sucker (mean=0.23 mg/kg, SD=0.10, n=37) and brown bullhead (mean=0.23 mg/kg, SD=0.08, n=23) exhibited the lowest level of contamination (Table 2).

Mercury concentration showed significant positive correlation with fish length for brook trout ($r^2=0.20$, $p=0.018$), smallmouth bass ($r^2=0.42$, $p=0.016$), white sucker ($r^2=0.16$, $p=0.015$) and yellow perch ($r^2=0.71$, $p<0.001$) (Table 3, Figure 3). No correlation with length was observed for brown bullhead ($r^2=0.02$, $p=0.554$) or white perch ($r^2=0.04$, $p=0.157$) (Table 3, Figure 3). Sample size was insufficient to test this correlation for the remaining species.

Weight, like length, showed significant correlation with mercury concentration for the same fish species however the correlation was generally less robust. The correlations were as follows: brook trout ($r^2=0.23$, $p=0.011$), brown bullhead ($r^2=0.00$, $p=0.749$), smallmouth bass ($r^2=0.26$, $p=0.07$), white perch ($r^2=0.02$, $p=0.277$), white sucker ($r^2=0.10$, $p=0.058$) and yellow perch ($r^2=0.72$, $p<0.001$) (Table 3).

Both brook trout (Figure 4) and yellow perch (Figure 8) had higher mean mercury concentrations in fish sampled from lakes associated with HGMT. When all samples across all sites (HGMT and control) are pooled the average Hg concentration was 0.62 mg/kg ($n=184$) in HGMT lakes and 0.57 mg/kg ($n=51$) in non-HGMT lakes. There was insufficient evidence to suggest that the presence of historic gold mine tailings significantly increased mercury contamination of any fish species ($p>0.16$) (Table 4 to Table 9). Of the five species tested by ANCOVA, the three species exhibiting the lowest P-values (brook trout, yellow perch and white perch) were those anticipated to reflect increased mercury concentrations (i.e. piscivorous fishes). Conversely, white perch exhibited higher mercury concentrations in fish sampled from lakes without HGMT in their drainage basins (Figure 6). It is important to note that the lack of significance may be primarily controlled by large sample variance, and that the trends observed in the analysis may approach significance with additional samples. Also of note are the ANCOVA results for yellow perch data (Table 9) from Fisherman's Harbour Lake (FHL), which contributed 7 of the 9 yellow perch samples from lakes without HGMT present (control lakes) and largely controlled the model. Mercury concentrations in yellow perch from FHL were unexpectedly high, the source of which warrants further investigation.

When samples were analyzed on a lake by lake basis, predatory fishes such as brook trout ($p=0.019$) (Table 11, Figure 4), white perch ($p<0.001$) (Table 13, Figure 6) and yellow perch ($p<0.001$) (Table 15, Figure 8) showed significant differences in mercury concentration between lakes. Brown bullheads ($p=0.170$) (Table 12, Figure 5) and white sucker ($p=0.126$) (Table 14, Figure 7) showed no significant differences between lakes. These significant differences were driven primarily by lakes of small sample size (often $n = 2$ or 3), therefore these results are not thought to be reliable. However, some general trends became evident and may suggest that additional sampling would show real statistical significance in mercury contamination. Brook trout sampled from Long Lake (HGMT present) had mercury concentrations higher than in the control samples of Dollar Lake and Northeast Lake (Figure 4). The highest level of mercury found in white perch were from lakes associated with HGMT, however the lake exhibiting the lowest level of mercury contamination was also a HGMT lake (Lake Charles) (Figure 6). Again,

Fisherman's Harbour Lake, a lake un-impacted by HGMT, exhibited the highest yellow perch mercury concentrations of all sites (Figure 8).

When samples were pooled by species, and were not site specific, many exhibited mercury contamination above the Canadian guidelines for fish and fish products (0.5 mg/kg FW). For all brook trout samples, 33% exceeded the guideline (Table 16) and the probability of exceeding the guideline was 50% at a length of 30.0 cm (Figure 9). For smallmouth bass, 31% of the samples were above the guideline (Table 16) and at a length of 32.1 cm; the probability of exceeding the guideline was 50% (Figure 10). Over 78% of white perch had mercury concentrations above the guideline (Table 16) and a 50% probability of exceeding the guideline occurred at a length of only 10.4cm (Figure 11). Finally, 48% of yellow perch samples were above the guideline (Table 16) and at a length of 17.2 cm, the probability of exceeding the guideline was 50% (Figure 12). No probabilistic model of mercury contamination was developed for brown bullhead or white sucker as all samples were below the guideline.

Mercury concentration was also correlated with several water chemistry parameters. The concentration of mercury in white perch was significantly positively correlated with conductivity ($r^2=0.72$, $p=0.02$) and alkalinity ($r^2=0.60$, $p=0.04$) (Table 18). Total dissolved solids (TDS) also showed some evidence, though non-significant, of a relationship with mercury contamination ($r^2=0.52$, $p=0.10$) (Table 18). Mercury in yellow perch was not significantly correlated with any water chemistry parameter, however total organic carbon (TOC) showed some indication of a relationship ($r^2=0.65$, $P=0.098$) (Table 19). A summary of water chemistry parameters is found in table 20. Other species were not assessed against water chemistry parameters.

Arsenic in Fish Tissue

Arsenic concentrations in fish exhibited greater variation than mercury contamination. However unlike mercury, no clear trends were observed with regards to feeding guilds. White Sucker exhibited the highest concentrations of any species (mean=1.31mg/kg, SD=2.29, n=37) while brook trout (mean=0.15 mg/kg, SD=0.19, n=27) and white perch (mean=0.17 mg/kg, SD=0.14, n=55) exhibited the lowest level of contamination (Table 2). The concentration of arsenic showed no significant relationship with the length of fish, however our data for brown bullhead did suggest a non-significant relationship ($r^2=0.17$, $p=0.053$) (Table 3). Arsenic concentration regressed on fish body weight showed similar trends with a significant positive relationship for brown bullhead ($r^2=0.27$, $p=0.01$) and no significant relationship for other species (Table 3).

There was evidence to suggest that arsenic concentration in several fish species was elevated in lakes with HGMT present. ANCOVA models testing the effect of HGMT presence/absence on arsenic concentration showed significant effects in brook trout ($p=0.027$) (Table 4, Table 5), white sucker ($p<0.001$) (Table 4, Table 8) and yellow perch ($p<0.001$) (Table 4, Table 9). Similar models for brown bullheads ($p=0.053$) (Table 4, Table 6) and white perch ($p=0.055$) (Table 4, Table 7) showed a strong though not significant relationship.

When analyzed based on location, arsenic concentrations were significantly different among lakes (Table 10). Brook trout ($p < 0.007$) (Table 11, Figure 14), brown bullhead ($p = 0.012$) (Table 12, Figure 15), white perch ($p = 0.012$) (Table 13, Figure 16), white sucker ($p = 0.023$) (Table 14, Figure 17) and yellow perch ($p < 0.001$) (Table 15, Figure 18) all showed significant differences between two or more sample lakes. However because sample sizes were small and the models driven primarily by lakes with 2 or 3 fish samples, we could not accurately and statistically determine what differences between lakes existed and the above results should be assessed with caution.

Arsenic contamination as analysed by species (pooled – not site specific) indicated that very few samples were above the Canadian guidelines for arsenic contamination in fish and fish products destined for human consumption, set at 3.5 mg/kg FW. For brook trout, only one fish (4% of total) was determined to be above the guideline, and this trout was sampled from Dollar Lake (control) (Table 17). A total of 4 white suckers (11% of total) also had arsenic concentrations above the guideline (Table 17). Finally, yellow perch sampling revealed only 1 individual (2% of total) with arsenic levels exceeding the guideline (Table 17). No other fish exceeded the guideline.

In some fish, the concentration of arsenic was correlated to several water chemistry parameters. For white perch, arsenic concentration was significantly correlated to pH ($r^2 = 0.68$, $p = 0.023$), TOC ($r^2 = 0.80$, $p = 0.016$) and colour ($r^2 = 0.64$, $p = 0.030$) (Table 18). Unlike white perch, data for yellow perch showed no significant relationship between arsenic concentration and water chemistry ($p > 0.492$) (Table 19).

Mercury and Arsenic in Sediment

Mercury concentration in sediment samples with lakes with HGMT present were higher a mean of 5.12 mg/kg (SD=11.28) and lakes without HGMT present in the same watersheds considerably lower, with a mean of 0.15 mg/kg (SD=0.13) (Table 21, Figure 19). This difference however was not statistically significant (ANOVA, $p = 0.285$) (Table 22). Mercury concentration in sediments showed no significant relationship to the mean mercury concentration in fish tissue (all fish species combined and not size-adjusted ($r^2 = 0.10$, $p = 0.201$) (Table 23, Figure 20).

Conversely, arsenic levels in sediment were variable and high in some lakes, with levels in lakes near HGMT (mean=621 mg/kg, SD=1140) higher than in lakes without HGMT in the watershed (mean=6 mg/kg, SD=2) (Table 21, Figure 19). This was statistically significant ($\alpha = 0.05$, ANOVA, $p = 0.035$) (Table 22). The maximum measured arsenic level was 3960 mg/kg. Unlike mercury, the concentration of arsenic in sediments was significantly related to the mean arsenic concentration in fish tissue (all fish species combined and not size-adjusted ($r^2 = 0.50$, $p = 0.001$) (Table 23, Figure 20).

DISCUSSION

Our initial results suggest that mercury concentrations in piscivorous and omnivorous fishes are generally higher in lakes affected by the presence of historical gold mine tailings (HGMT). However, statistical significance supporting these results was low and should not be accepted as strong evidence as low sample size may drive the ANCOVA results. Additional data should be collected and analyzed prior to firm conclusions about the impact of historical gold mine tailings. Arsenic data was affected by the presence of HGMT. While there was statistical significance in the tests, analysis is based on the same data set as mercury analysis and issue of low sample size may also affect the reliability of the results.

Separating lakes in to two groups (impacted and control sites) and weighting each accordingly may provide a tool for setting fish consumption advisories. However, analysis based on species (i.e. with no regard to sample origin) may also be a useful guideline. Sufficient caution should be used however when extrapolating the proportion of samples exceeding consumption guidelines across the province of Nova Scotia. Because the overall goal of this study was to test the potential effects of HGMT, lakes associated with HGMT were well represented in the samples and at a much higher proportion than they would occur in a random sample of lakes across the province. Perhaps a more appropriate approach would be to assume that this sample more closely represents lakes and fish in the Southern Upland region, where the vast majority of gold mining has occurred and thus where any potential effects associated with mining would be of concern to fish consumption. Therefore, consumption advisories could be assessed for fish more likely to be targeted and consumed by anglers in the Southern Uplands based on these results. Alternatively, lake specific advisories could be developed in areas of highest concern such as those impacted by HGMT.

These data suggest that in the locations sampled arsenic is of little concern for freshwater fish consumption. Mercury may be an issue and re-assessment of the current guidelines, based on these data may be prudent. For example, brook trout, the most preferred and arguably the most consumed fish in the province, exhibited relatively high levels of mercury. Advisories on the quantities of trout as well as suggesting a maximum size of trout and other species for consumption may be an effective method for reducing the threat of mercury-contaminated fish for human consumption.

The classification of acceptable control lakes should also be further examined as some reference lakes (i.e. Fisherman's Harbour Lake) unexpectedly had higher mercury concentrations and may indicate the presence of additional natural or anthropogenic sources of mercury such as soil erosion, ocean spray (Richardson et al. 2003, Beauchamp et al. 2002). Using samples from Fisherman's Harbour Lake has obviously severely skewed the ANCOVA analysis, particularly for yellow perch. When analyzed on a lake by lakes basis, there was evidence of statistically significant differences between lakes, some of which represented lakes with HGMT as well as reference lakes. Though samples were further segmented and sample sizes further reduced, there is evidence to suggest that further sampling be done in pairwise form, such that fish samples from lakes known to have HGMT in the watershed are compared only to lakes specifically chosen for comparison, preferable nearby and of similar size and water chemistry.

Aquatic organisms are affected by multiple sources of contamination, including historic anthropogenic sources, recent or current anthropogenic sources and natural sources (Harris et al. 2007). Of the anthropogenic sources, mercury can be transported in the atmosphere or deposited directly into the aquatic environment. The role of local point sources of deposition has been suggested to contribute a large portion of total mercury load a lake receives (Gilmour and Henry 1991). In our study sites, those lakes in the more urbanized areas may be more susceptible to increased atmospheric loading of mercury and thus comparison between lakes of differing proximity to urban areas may provide alternative results.

While few conclusions regarding the effects of HGMT are made from these data, the trend of a non-significant effect on mercury concentrations yet significant effect of arsenic concentration may provide insight to the role of contamination pathways for the two toxic metals. Mercury is primarily bioaccumulated and biomagnified (Harris et al. 2007, Driscoll et al. 2007), thus differences in foraging and diet selection, on an individual and population level, would contribute to variation in mercury contamination between lakes of similar mercury availability. Conversely, the pathway of arsenic contamination is primary through direct contact with environmental arsenic, either via porous surfaces (Spehar et al. 1980) or ingestion, and levels are elevated by bioaccumulation, but not biomagnification (U.S.EPA 2003). This is consistent with our findings of no clear relationship between feeding guild and arsenic concentration.

Drysdale et al (2005) sampled fish for mercury concentrations from lakes in Kejimikujik National Park. The mean mercury concentration for brook trout (mean length=26cm) was 0.31 mg/kg (SD=0.22), for white perch (mean length=29cm) 1.03 mg/kg (SD=0.45), and for yellow perch samples (mean length=12.0cm) 0.25 mg/kg (SD=0.14). If values in this study are size-adjusted for comparison to Drysdale et al. (2005), brook trout mercury levels were similar, white perch Hg levels were lower and yellow perch Hg levels were slightly higher than previously documented. The white perch sample in this study contained few large (>27cm) individuals, thus these data likely underestimates mean mercury concentrations.

Few studies have assessed arsenic concentrations in Nova Scotia fish. In a study of Mitchell Brook, a tributary to Lake William, it was found that the cyprinid *Fundulus diaphanus* (Banded killifish) had arsenic concentrations of between 0.63 and 3.2 ug/kg (Brooks et al 1982). Thus, little comparison could be made between these most recent values and historic values for Nova Scotian fishes. However, if we compare these data with those collected by Lowe et al. (1985) where several fish species were analyzed for arsenic across 112 stations in the United States, these Nova Scotian values were generally similar or slightly higher.

The effect of HGMT on fish species diversity cannot be adequately assessed based on the data presented here. Historical species distributions are often not well documented or have changed significantly due to the effect aquatic invasive species such as chain

pickerel (*Esox niger*) and smallmouth bass (*Micropterus dolomieu*) which have had negative impacts on species diversity, community composition and abundance (Mitchell et al. 2010). Additionally, the Shubenacadie-Grand Lake chain (i.e. Lake William, Lake Charles, Lake Thomas, Lake Fletcher, Powder Mill Lake, Second Lake and Muddy Pond), contains several populations of anadromous species including striped bass, Atlantic salmon, alewife (*Alosa pseudoharengus*), American Shad (*Alosa sapidissima*) and rainbow smelt (*Osmerus mordax*). Many of the inland lakes sampled in this study would not have historically contained these anadromous species.

Though only 8 individuals were sampled, chain pickerel exhibited significantly lower mercury levels than anticipated for such a highly piscivorous species. A potential explanation for lower than anticipated mercury levels for chain pickerel (and the 2 striped bass sampled) could be that these fish may feed largely on anadromous alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) in the lakes from which these fish were sampled. These anadromous fishes feed primarily on marine forage and would therefore have been exposed to different levels of mercury. Though these fish may only be seasonally available, their contribution to the diet of chain pickerel may be sufficient to decrease mercury intake. Alternatively, faster growth rates have been shown to be significantly correlated with lower mercury concentrations in fish tissues (Trudel et al. 2006, Simoneau et al. 2004) and possibly explain lower than expected results for higher trophic positioned predatory species.

CONCLUSIONS AND RECOMMENDATIONS

General trends were evident which indicated that mercury and arsenic concentrations in fish tissue in Nova Scotia may be site specific due to naturally occurring or anthropogenic sources of mercury and interactions with HGMT where mercury and arsenic contamination in fish occur. Mercury concentrations above the Canadian human health guideline for consumption of Hg in fish of 0.5 mg/kg were documented for individual fish in all sites regardless of site type for most species. However, no statistical significance could be drawn from this research. We recommended that additional sampling be conducted on these and additional sample lakes. Additional lakes should be chosen to provide a pairwise comparison for specific lakes such that they are morphologically/ limnologically similar and regionally close. To a large extent, the budget allocated for this project limited the number of fish for which heavy metal analysis could be conducted. Directed sampling in the future should further elucidate any influences of HGMT on mercury and arsenic contamination in Nova Scotia's freshwater fishes. Modelling influences of lake morphology (eg. volume), water chemistry (eg. DOC, pH), landscape features (eg. amount of wetlands, drainage area), trophic parameters and proximity to point sources of mercury could be useful to focus sampling efforts.

Additionally, recreational anglers often target predatory species such as brook trout, landlocked salmon, striped bass, smallmouth bass and chain pickerel. Also, it is generally the larger individuals of these species which are retained for consumption. Thus, the

higher levels of mercury observed for larger individuals suggests that caution and an understanding of which fish are consumed (mean size, age etc.) should form part of a sampling program to support fish consumption advisories.

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TABLES

Table 1 – Description of fish sampled from each lake; historic gold mine tailings (HGMT) and control sites (C). All fish analyzed for both mercury and arsenic.

	Site Type	American Eel	Brook Trout	Brown Bullhead	Chain Pickerel	Golden Shiner	Landlocked salmon	Smallmouth Bass	Striped Bass	White Perch	White Sucker	Yellow Perch	Total
Beaver Brook	HGMT	3		2		1					1	1	8
Lake Charles	HGMT						2	6		4	4		16
Charlotte Lake	HGMT	1	2	4		3	1			6	4	2	23
Dollar Lake	C		11	1									12
Fisherman's Hbr Lake	C	1										7	8
Lake Fletcher	HGMT			1	3			2		7			13
Long Lake	HGMT		7							7	6		20
Molega Lake	HGMT		1							2	5	5	13
Muddy Pond	HGMT										1	7	8
Northeast Lake	C		6										
Powder Mill Lake	HGMT			4	1			3			3		11
Ponhook Lake	HGMT			5						10	1		16
Rocky Brook Lake	C			3						7	3		13
Scraggy Lake	HGMT			2							3	6	11
Seal Hbr Lake	HGMT					2					3	11	16
Second Lake	C							1		5		2	8
Seven Mile Lake	C			1							3		4
Lake Thomas	HGMT									6			6
Lake William	HGMT	1			4		1	1	2	1		1	11

Table 2 – Summary of fish sample total length (cm), weight (g), mercury and arsenic contamination (mg/kg fish tissue FW).

Species	Sample Size	Mean Total Length (cm)	Range Total Length (cm)	Mean Weight (g)	Range Weight (g)	Mean Hg Conc. (mg/kg)	Standard Deviation Hg Conc.	Range Hg Conc.	Mean As Conc. (mg/kg)	Standard Deviation As Conc.	Range As Conc.	Mean Moisture Content (%)	Standard Deviation Moisture Content	Range Moisture Content
American Eel	6	43.9	33.4- 59.0	195.1	61- 382	0.94	0.81	0.43- 2.54	0.17	0.13	0.08- 0.43	75.5	6.7	64.5- 79.8
Brook Trout	27	25.1	18.1- 34.4	175.8	48- 418	0.42	0.35	0.10- 1.34	0.15	0.19	<0.05- 0.85	81.0	1.8	75.8- 83.7
Brown Bullhead	23	21.0	12.3- 34.0	156.6	24- 644	0.23	0.08	0.09- 0.39	0.54	1.37	0.06- 6.68	79.1	2.0	76.5- 83
Chain Pickerel	8	40.4	26.5- 56.0	507.6	110- 1202	0.36	0.15	0.15- 0.54	0.93	0.71	0.19- 2.14	81.2	1.0	79.6- 82.3
Golden Shiner	6	11.4	7.9- 13.7	17.0	6- 29	0.36	0.14	0.19- 0.58	0.66	0.64	0.24- 1.60	67.9	18.0	32.2- 82.8
Landlocked Salmon	4	38.1	31.2- 52.4	554	260- 1298	0.52	0.43	0.13- 0.95	0.10	0.05	0.06- 0.18	77.9	1.3	76.0- 78.8
Smallmouth Bass	13	23.5	11.0- 32.5	186	14- 442	0.44	0.20	0.13- 0.86	0.51	0.32	0.10- 1.11	79.6	1.1	78.5- 82.1
Striped Bass	2	36.4	35.4- 37.3	564	505- 622	0.36	0.11	0.28- 0.44	0.15	0.04	0.12- 0.18	76.7	1.3	75.7- 77.6
White Perch	55	20.7	9.0- 29.0	133.4	18- 384	0.87	0.46	0.08- 1.76	0.17	0.14	<0.05- 0.77	79.2	2.3	70.5- 86.2
White Sucker	37	28.4	9.4- 45.8	300.1	9- 992	0.23	0.10	0.07- 0.48	1.31	2.29	0.07- 11.00	78.0	2.6	72.1- 84.0
Yellow Perch	42	16.7	4.5- 28.1	79.7	2- 286	0.74	0.62	0.11- 2.67	0.53	0.83	<0.05- 4.10	77.5	4.0	70.4- 94.8

Table 3 – Regressions of mercury and arsenic concentrations on body length and body weight for all species with n>10. Data pooled from all lakes. Log-transformed data.

	<u>Mercury</u>				<u>Arsenic</u>			
	Length		Weight		Length		Weight	
	R ²	P-Value	R ²	P-Value	R ²	P-Value	R ²	P-Value
Brook Trout	0.20	0.018	0.23	0.011	0.05	0.281	0.01	0.634
Brown Bullhead	0.02	0.566	0.00	0.749	0.17	0.053	0.27	0.010
Smallmouth Bass	0.42	0.016	0.26	0.070	0.02	0.636	0.01	0.722
White Perch	0.04	0.157	0.02	0.277	0.03	0.186	0.00	0.691
White Sucker	0.16	0.015	0.10	0.058	0.02	0.429	0.01	0.584
Yellow Perch	0.71	<0.001	0.72	<0.001	0.01	0.610	0.01	0.643

Table 4 - ANCOVA table of mercury and arsenic concentrations with the presence/absence of HGMT as a factor. Log-transformed data. No smallmouth bass were sampled from control lakes thus this comparison could not be made and sample size was insufficient to test this relationship for all other species.

	<u>Mercury</u>				<u>Arsenic</u>			
	% Variation Explained by Model	P-Value	Significance	Effects	% Variation Explained by Model	P-Value	Significance	Effects
Brook Trout	27%	0.161	NS	None	25%	0.027	S	As Conc. higher in lakes with HGMT
Brown Bullhead	2%	0.559	NS	None	18%	0.053	NS	As Conc. higher in lakes with HGMT
White Perch	7%	0.334	NS	None	19%	0.055	NS	As Conc. higher in lakes with HGMT
White Sucker	16%	0.862	NS	None	30%	<0.001	S	As Conc. higher in lakes with HGMT
Yellow Perch	71%	0.449	NS	None	44%	<0.001	S	As Conc. higher in lakes with HGMT

Table 5 – Brook trout Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, presence of HGMT as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	0.631	1	0.631	6.629	0.017	0.084	1	0.084	1.426	0.245
Presence of HGMT	0.199	1	0.199	2.090	0.161	0.047	1	0.047	0.804	0.379
L*Presence of HGMT	n/a	n/a	n/a	n/a	n/a	0.328	1	0.328	5.564	0.027
Residuals	2.283	24	0.095	-	-		23	0.059	-	-

Table 6 – Brown bullhead Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, presence of HGMT as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	0.010	1	0.010	0.353	0.559	0.856	1	0.856	4.21	0.054
Presence of HGMT	0.000	1	0.000	0.007	0.936	0.022	1	0.022	0.107	0.747
Residuals	0.576	20	0.029	-	-	4.065	20	0.203	-	-

Table 7 – White perch Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, presence of HGMT as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	0.237	1	0.237	2.669	0.108	0.344	1	0.344	3.84	0.055
Presence of HGMT	0.085	1	0.085	0.953	0.334	0.719	1	0.719	8.02	0.007
Residuals		52	0.089			4.66	52	0.090	-	-

Table 8 – White sucker Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, presence of HGMT as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	0.244	1	0.244	6.245	0.018	0.024	1	0.024	0.875	0.356
Presence of HGMT	0.001	1	0.001	0.030	0.864	3.24	1	3.24	13.86	0.001
L*Presence of HGMT	0.000	1	0.000	0.007	0.933	n/a	n/a	n/a	n/a	n/a
Residuals	1.288	33	0.039	-	-	7.944	34	0.234	-	-

Table 9 – Yellow perch Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, presence of HGMT as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	3.391	1	3.391	96.276	0.000	0.058	1	0.058	0.450	0.506
Presence of HGMT	0.021	1	0.021	0.584	0.449	3.881	1	3.881	30.028	0.000
Residuals	1.376	39	0.035	-	-	5.041	39	0.129	-	-

Table 10 – Summary of Analysis of Covariance models with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, location (lake) as a factor and total body length as a covariate. No smallmouth bass were sampled from control lakes thus this comparison could not be made. Sample size was insufficient to test this relationship for all other species.

	<u>Mercury</u>				<u>Arsenic</u>			
	% Variation Explained by Model	P-Value	Significance	Effects	% Variation Explained by Model	P-Value	Significance	Effects
Brook Trout	67%	0.019	S	Not applicable due to sample size	68%	0.007	S	Not applicable due to sample size
Brown Bullhead	59%	0.170	NS	Not applicable due to sample size	93%	<0.001	S	Not applicable due to sample size
White Perch	77%	<0.001	S	Not applicable due to sample size	70%	0.012	S	Not applicable due to sample size
White Sucker	53%	0.126	NS	Not applicable due to sample size	92%	0.023	S	Not applicable due to sample size
Yellow Perch	87%	<0.001	S	Not applicable due to sample size	93%	<0.001	S	Not applicable due to sample size

Table 11 – Brook trout Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, location (lake) as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	0.691	1	0.691	12.111	0.003	0.084	1	0.084	2.633	0.122
Lake	0.658	4	0.164	2.883	0.052	0.620	4	0.155	4.854	0.008
L*Lake	0.737	3	0.246	4.303	0.019	0.537	3	0.179	5.602	0.007
Residuals	1.027	18	0.057	-	-	0.575	18	0.032	-	-

Table 12 – Brown bullhead Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, location (lake) as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	0.080	1	0.080	4.307	0.058	0.823	1	0.823	29.953	0.000
Lake	0.265	8	0.0331	1.783	0.170	3.763	8	0.470	17.124	0.000
Residuals	0.241	13	0.019	-	-	0.357	13	0.028	-	-

Table 13 – White perch Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, location (lake) as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	0.378	1	0.378	14.684	0.000	0.271	1	0.271	6.877	0.012
Lake	3.437	9	0.382	14.827	0.000	3.722	9	0.414	10.506	0.000
Residuals	1.133	44	0.026	-	-	1.731	44	0.039	-	-

Table 14 – White sucker Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, location (lake) as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	0.251	1	0.251	8.423	0.008	0.204	1	0.204	3.532	0.079
Lake	0.567	11	0.052	1.730	0.126	8.776	11	0.798	13.785	0.000
L*Lake	n/a	n/a	n/a	n/a	n/a	1.480	8	0.185	3.196	0.023
Residuals	0.715	24	0.030	-	-	0.926	16	0.058	-	-

Table 15 – Yellow perch Analysis of Covariance table with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, location (lake) as a factor and total body length as a covariate.

	<u>Mercury</u>					<u>Arsenic</u>				
Source of Variation	SS	df	MS	F	P	SS	df	MS	F	P
Length	3.391	1	3.391	173.031	0.000	0.688	1	0.688	29.359	0.000
Lake	0.767	8	0.096	4.893	0.001	6.722	8	0.840	35.863	0.000
L*Lake	n/a	n/a	n/a	n/a	n/a	0.960	6	0.160	6.833	0.000
Residuals	32	0.627	0.020	-	-	0.609	26	0.023	-	-

Table 16 – Percent of samples that exceed the Canadian health guideline for mercury in fish tissue (0.5 mg/kg).

Species	Lakes with no HGMT	Lakes with HGMT	Combined Samples
American Eel	0/1 = 0%	3/5 = 60%	3/6 = 50%
Brook Trout	4/17 = 24%	5/10 = 50%	9/27 = 33%
Brown Bullhead	0/5 = 0%	0/18 = 0%	0/23 = 0%
Chain Pickerel	N/S	2/8 = 25%	2/8 = 25%
Golden Shiner	NS	1/6 = 17%	1/6 = 17%
Landlocked Salmon	NS	2/4 = 50%	2/4 = 50%
Smallmouth Bass	NS	4/13 = 31%	4/13 = 31%
Striped Bass	NS	0/2 = 0%	0/2 = 0%
White Perch	11/12 = 92%	32/43 = 74%	43/55 = 78%
White Sucker	0/6 = 0%	0/31 = 0%	0/37 = 0%
Yellow Perch	4/9 = 44%	16/33 = 48%	20/42 = 48%

Table 17– Percent of samples that exceed the Canadian health guideline for Arsenic in fish tissue (3.5 mg/kg).

Species	Lakes with no HGMT	Lakes with HGMT	Combined Samples
American Eel	0/1 = 0%	0/5 = 0%	0/6 = 0%
Brook Trout	1/17 = 6%	0/10 = 0%	1/27 = 4%
Brown Bullhead	0/5 = 0%	0/18 = 0%	0/23 = 0%
Chain Pickerel	N/S	0/8 = 0%	0/8 = 0%
Golden Shiner	NS	0/6 = 0%	0/6 = 0%
Landlocked Salmon	NS	0/4 = 0%	0/4 = 0%
Smallmouth Bass	NS	0/13 = 0%	0/13 = 0%
Striped Bass	NS	0/2 = 0%	0/2 = 0%
White Perch	0/12 = 0%	0/43 = 0%	0/55 = 0%
White Sucker	0/6 = 0%	4/31 = 13%	4/37 = 11%
Yellow Perch	0/9 = 0%	1/33 = 3%	1/42 = 2%

Table 18 – Regression analysis of mercury and arsenic contamination in white perch in relation to selected water chemistry parameters. TOC = total organic carbon and TDS = total dissolved solids. Note ^A - Heavily influenced by Long Lake with high Hg and high pH.

<u>White Perch</u>												
	pH		Conductivity		Alkalinity		TOC		TDS		Colour	
	R ²	P-Value	R ²	P-Value	R ²	P-Value	R ²	P-Value	R ²	P-Value	R ²	P-Value
Log Hg	0.34 ^A	0.167 ^A	0.72	0.016	0.60	0.041	0.33	0.237	0.52	0.104	0.33	0.176
Log As	0.68	0.023	0.27	0.227	0.38	0.14	0.80	0.016	0.01	0.836	0.64	0.03

Table 19 – Regression analysis of mercury and arsenic contamination in yellow perch in relation to selected water chemistry parameters. TOC = total organic carbon and TDS = total dissolved solids

<u>Yellow Perch</u>												
	pH		Conductivity		Alkalinity		TOC		TDS		Colour	
	R ²	P-Value	R ²	P-Value	R ²	P-Value	R ²	P-Value	R ²	P-Value	R ²	P-Value
Log Hg	0.06	0.700	0.00	0.996	0.00	0.963	0.652	0.098	0.021	0.818	0.64	0.105
Log As	0.17	0.492	0.00	0.939	0.01	0.878	0.156	0.510	0.03	0.779	0.15	0.518

Table 20 – Summary of water chemistry parameters of the study lakes. Cond. = Conductivity, DOC = dissolved organic carbon, TOC = total organic carbon, TDS = total dissolved carbon, TCU = true colour units. Beaver Brook not sampled.

Lake	Date Sampled	pH	Cond. $\mu\text{S/cm}$	Alkalinity mg/l	DOC mg/l	TOC mg/l	Sulfate mg/l	TDS mg/l	Colour TCU	Phosphorus mg/l
<u>Lakes with H.G.M.T. Present</u>										
Charles	Oct-17	7.3	203	18		3.6	10	103	10	0.01
Charlotte	Oct-16	5.7	25.5	<3	8.2	8.4	<5	30	53	<0.005
Fletchers	Oct-03	7.1	136	11	5.2	5.2	6.9	60	25	<0.005
Long	Oct-19	6.7	27.5	5	4.5	4.6	<5	20	24	0.04
Molega	Nov-22	5.4	35.8	<3	8.6	8.8	<5	58	61	0.01
Muddy Pond	Oct-03	6.5	162	24	8	8.2	5.6	85	51	0.021
Ponhook	Nov-22	5.4	30.8	<3	10.8	11.7	<5	65	82	0.01
Powder Mill	Oct-03	7.4	207	24	4.3	4.3	8.8	90	14	<0.005
Scraggy	Oct-16	5.6	23.1	<3	8.8	9	<5	22	65	0.005
Seal Harbour	Oct-02	5.4	31.9	<3	15.3	15.7	<5	32	145	0.11
Thomas	Oct-03	6.9	159	15	4.6	4.6	7.9	73	21	<0.005
William	Oct-17	7.2	159	14	4.3	4.5	7.8	67	19	0.005
	Mean	6.38	100.05	9.84	7.51	7.38	5.17	58.75	47.5	0.018
	SD	0.82	76.53	8.99	3.44	3.65	2.97	27.33	38.53	0.03
	Range	5.4-7.3	23.1-207	<3-24	4.3-15.3	3.6-15.7	<5-10	20-103	10-145	<0.005-0.11
<u>Lakes with H.G.M.T. Absent (Controls)</u>										
Dollar		7	123	12		5.2	<5	75	21	0.005
FH	Oct – 2	5	33.9	<3	18.6	19.1	<5	38	186	0.008
NE	July - 30	4.9	31	<3		9.4	<5	20	87.5	0.005
Second		5.3	27	<3			<5		56	<0.005
Seven Mile	Nov-22	6	29.8	<3	5.6	6.1	<5	37	39	0.27
	Mean	5.64	48.94	n/a	12.1	9.95	<5	42.5	77.9	0.058
	SD	0.87	41.47	n/a	9.19	6.36	n/a	23.18	65.21	0.12
	Range	4.9-7	27-123	<3-12	5.6-18.6	5.2-19.1	n/a	20-75	21-186	<0.005-0.27

Table 21 - Summary of mercury and arsenic concentrations measured in sediment samples.

	<u>Mercury</u>				<u>Arsenic</u>			
	N	Mean	SD	Range	N	Mean	SD	Range
Lakes with HGMT	14	5.12	11.283	0.01 – 40.40	14	621.1	1140.2	0.5 – 3960.0
Controls	4	0.15	0.133	0.02 - 0.29	4	5.5	1.9	4.0 – 6.0

Table 22 – Analysis of Variance table for lake sediment samples with log-transformed mercury concentration and log-transformed arsenic concentration as the response variate, and the presence/absence of HGMT as a factor.

Source of Variation	<u>Mercury</u>					<u>Arsenic</u>				
	SS	df	MS	F	P	SS	df	MS	F	P
Presence of HGMT	1.394	1	1.394	1.226	0.285	4.922	1	4.922	5.332	0.035
Residuals	18.183	16	1.136	-	-	14.771	16	0.923	-	-

Table 23 – Summary of regression analysis of mercury and arsenic levels in sediment against mercury and arsenic levels in fish tissue.

	R ²	P-Value
Mercury	0.10	0.201
Arsenic	0.50	0.001

FIGURES

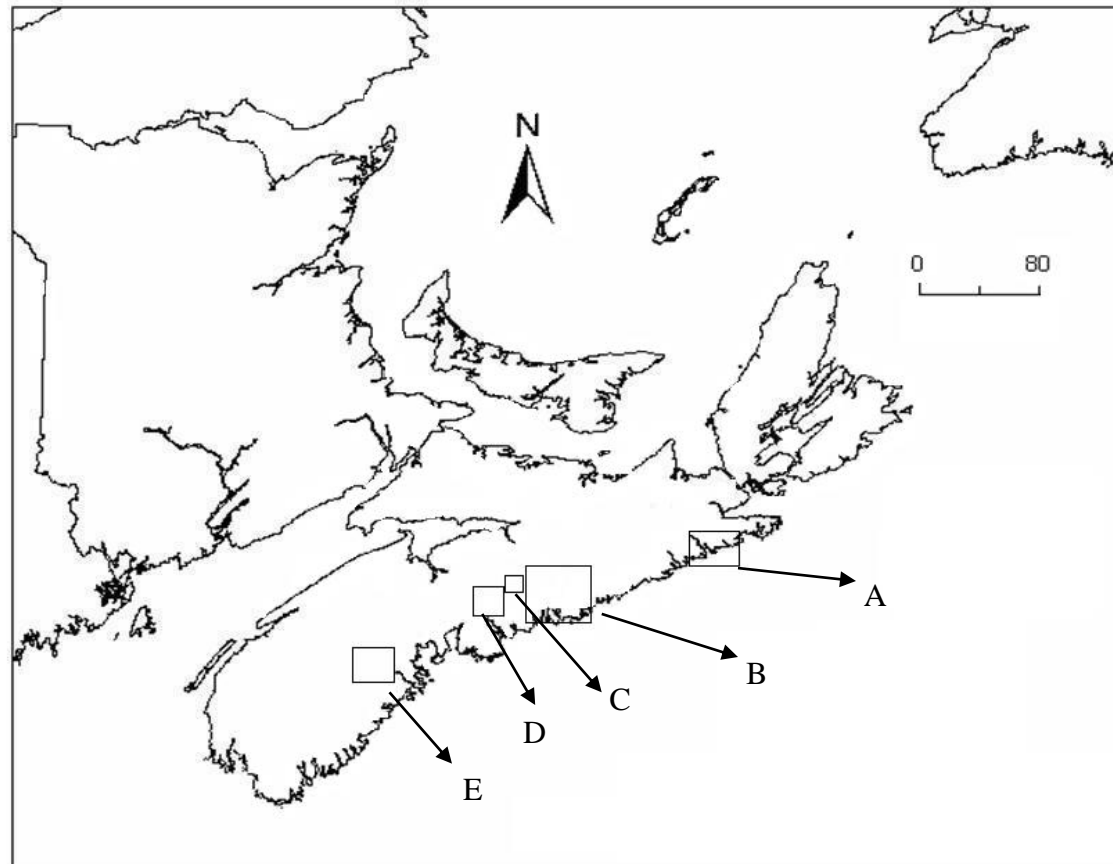


Figure 1A – Nova Scotia map indicating the location of study lakes.

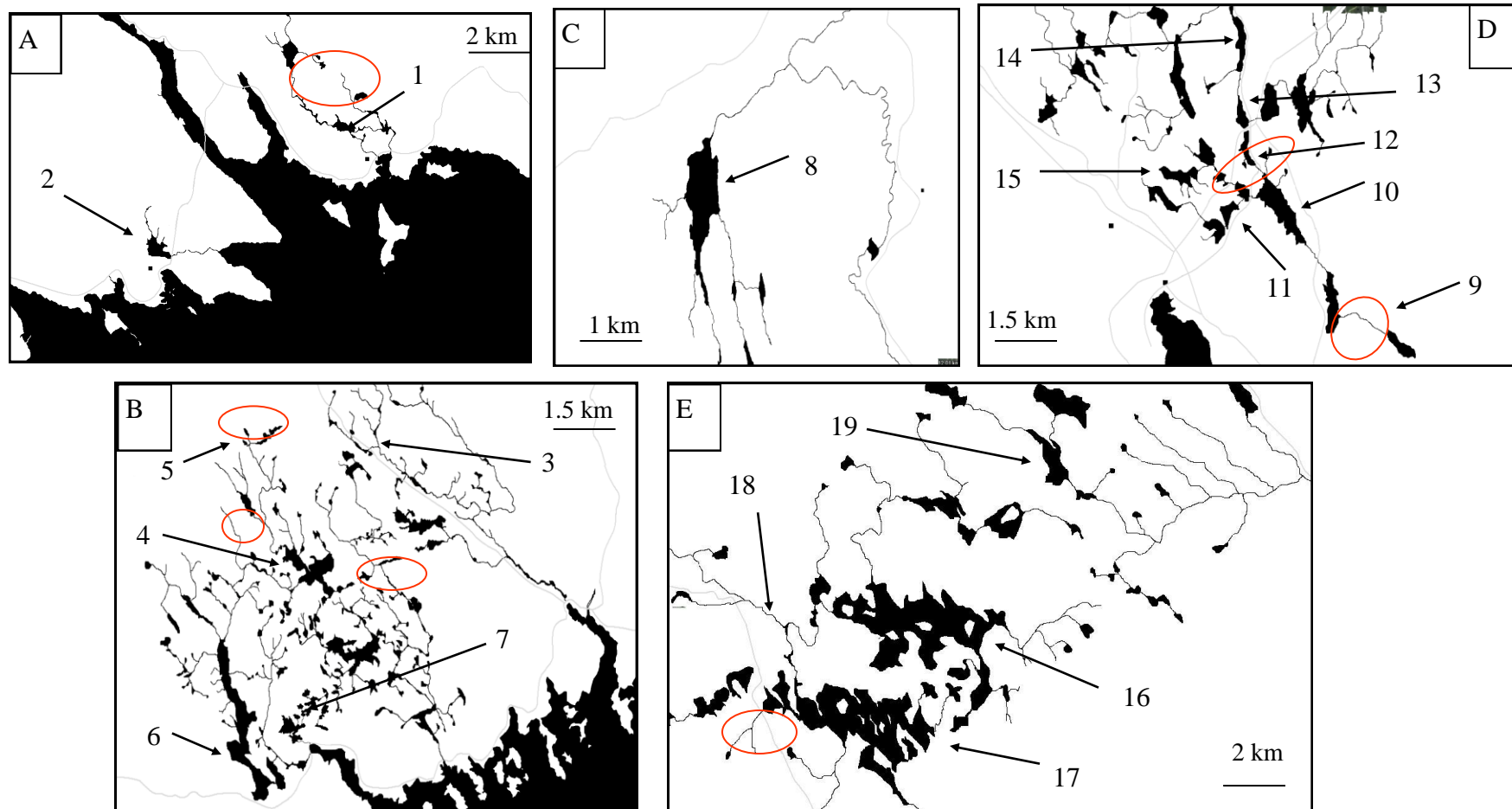


Figure 1B. Suspected locations of tailings from historic gold mines and lakes sampled: 1=Seal Harbour Lake, 2=Fishermans Harbour Lake, 3=Rocky Lake, 4=Scraggy Lake, 5=Long Lake, 6= Lake Charlotte, 7= Northeast Lake, 8= Dollar Lake, 9= Lake Charles, 10= Lake William, 11=Powder Mill Lake, 12= Muddy Pond, 13= Lake Thomas, 14= Lake Fletcher, 15= Second Lake, 16= Ponhook Lake, 17= Molega Lake, 18= Beaver Brook, 19= Seven Mile Lake.

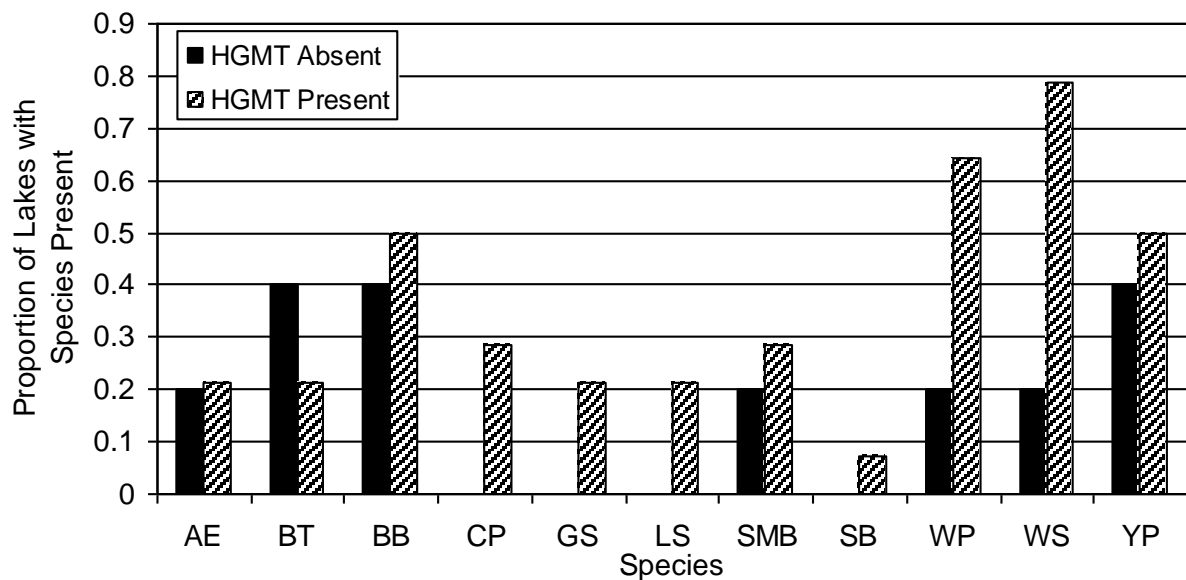


Figure 2 – Proportion of lakes where HGMT are present or absent where at least one specimen from each species was sampled. A total of 14 lakes affected by HGMT and 5 lakes unaffected by HGMT (control) were sampled. AE=American Eel, BT=Brook Trout, BB=Brown Bullhead, CP=Chain Pickerel, GS= Golden Shiner, LS=Landlocked Salmon, SMB=Smallmouth Bass, SB=Striped Bass, WP=White Perch, WS=White Sucker and YP=Yellow Perch.

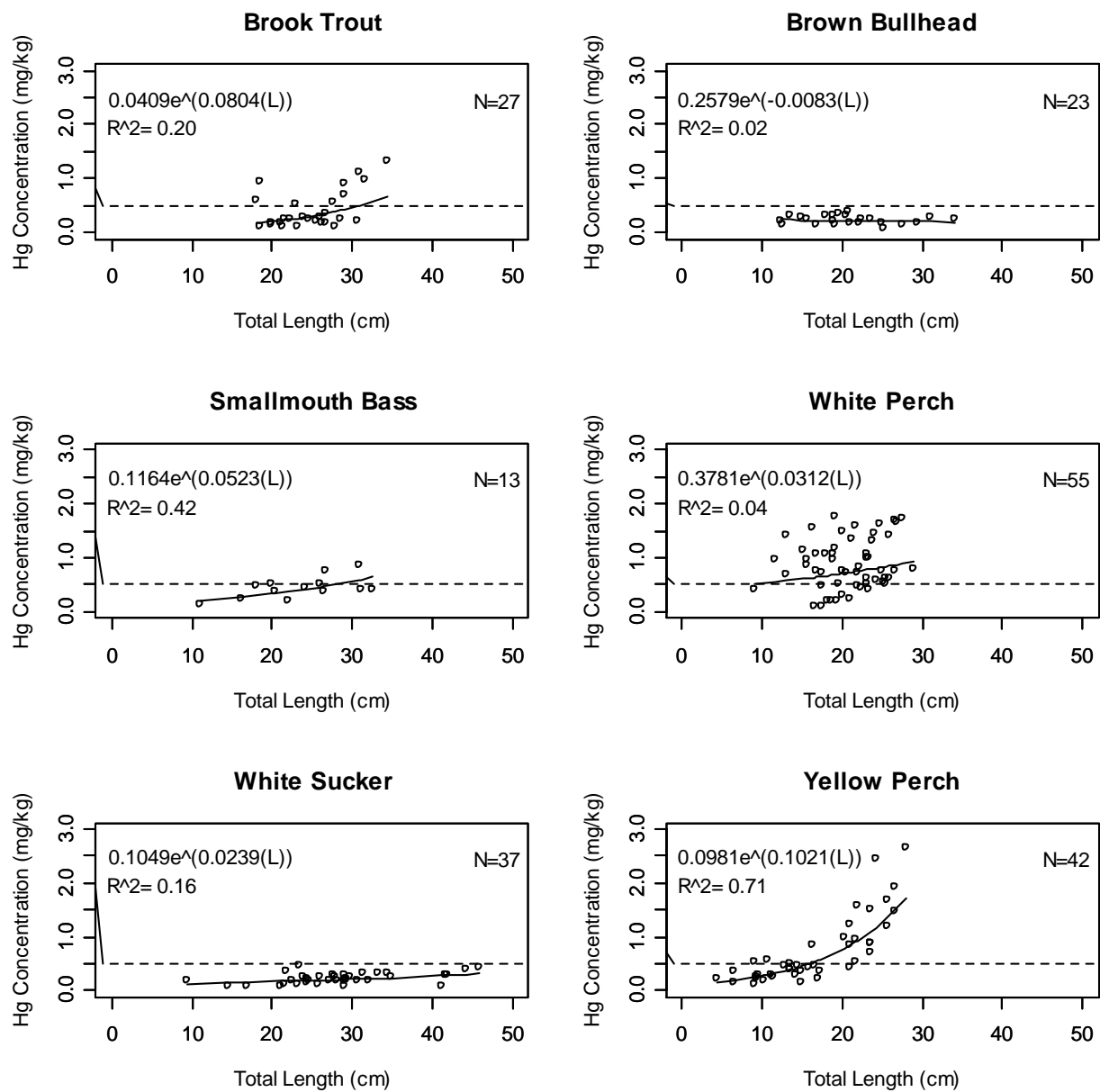


Figure 3 – Regressions of mercury concentration (mg/kg fish tissue FW) on total length for fish species with $N > 10$.

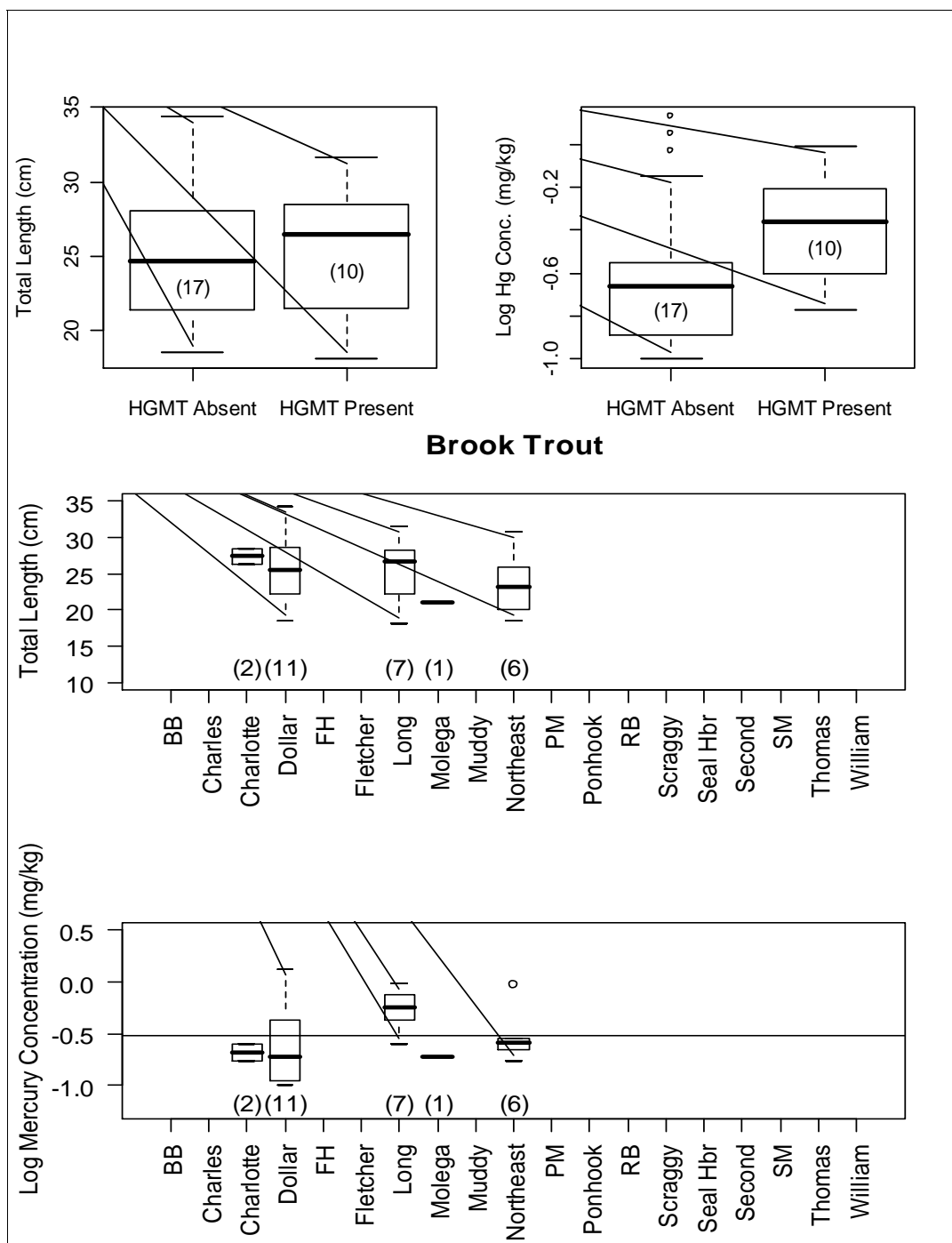


Figure 4 – Boxplots of brook trout length frequency and log mercury (Hg) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.

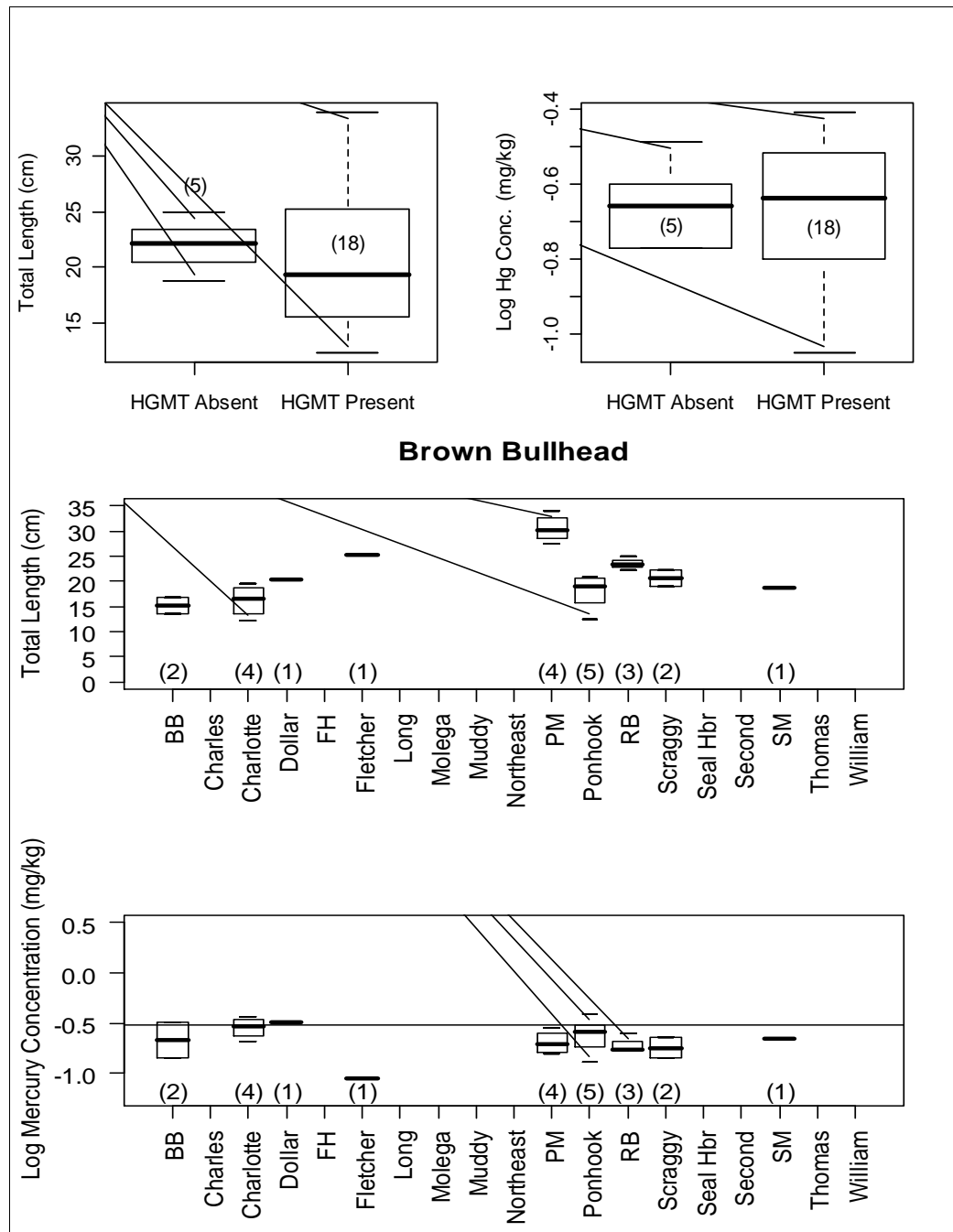


Figure 5 – Boxplots of brown bullhead length frequency and log mercury (Hg) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.

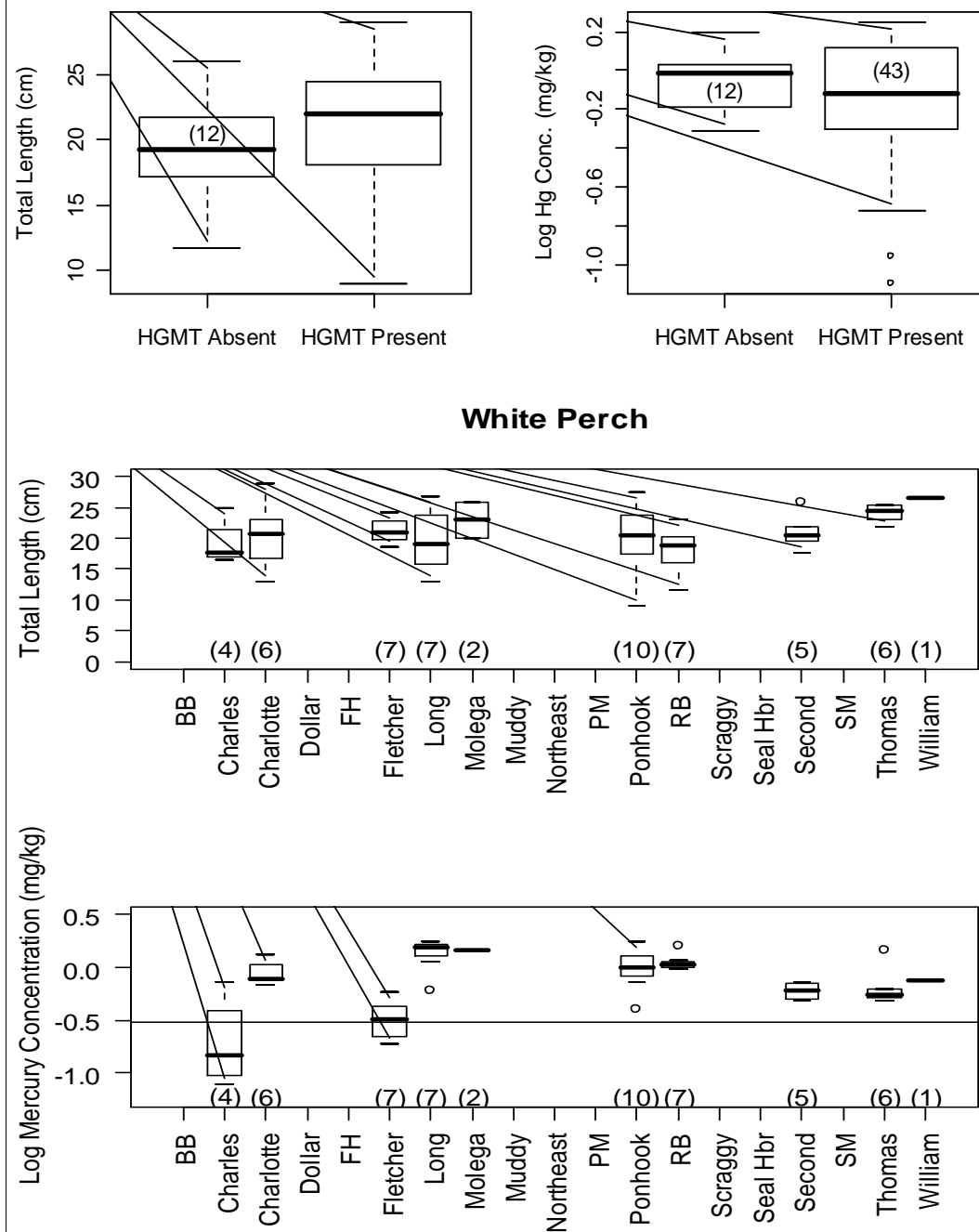


Figure 6 – Boxplots of white perch length frequency and log mercury (Hg) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.

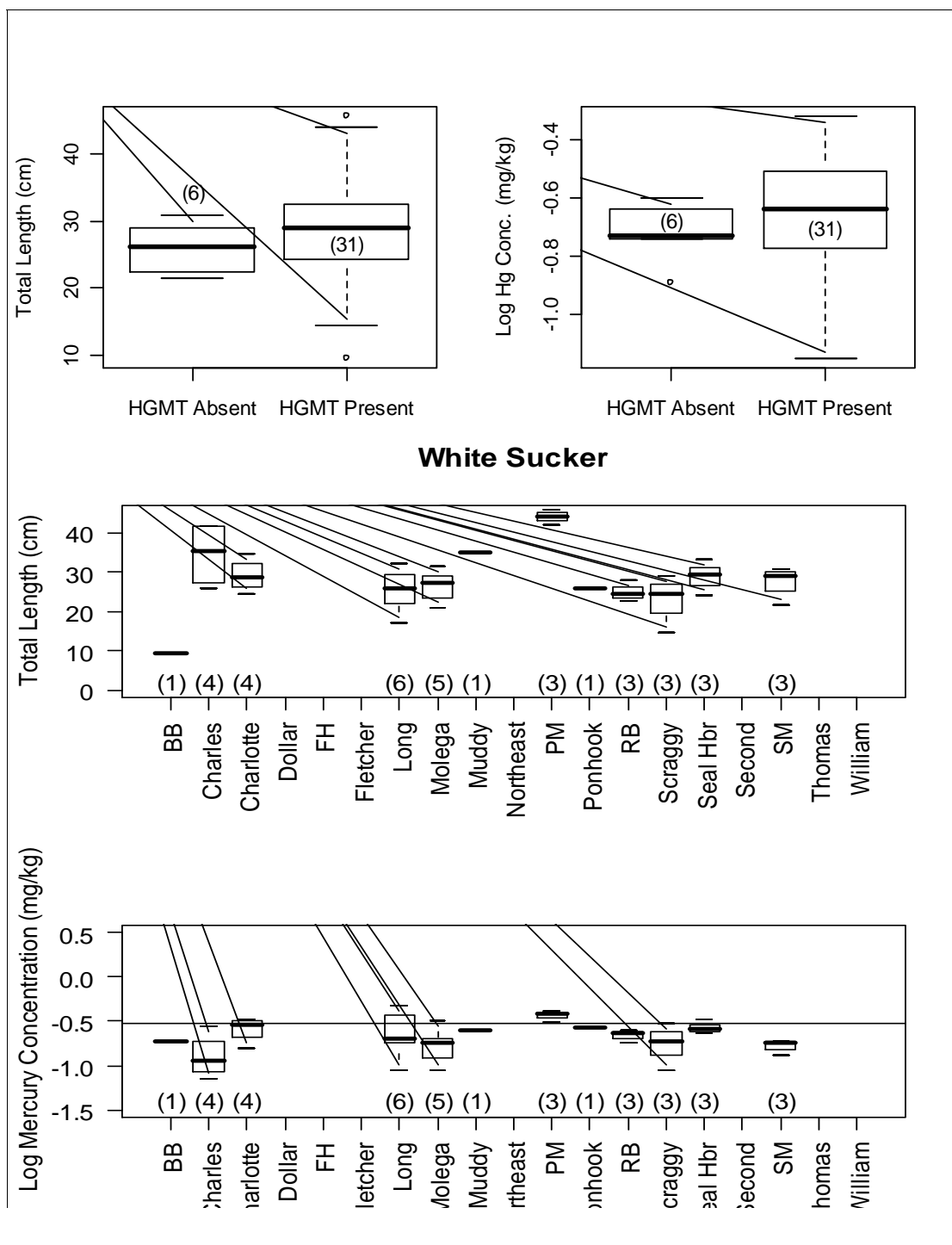


Figure 7 – Boxplots of white sucker length frequency and log mercury (Hg) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.

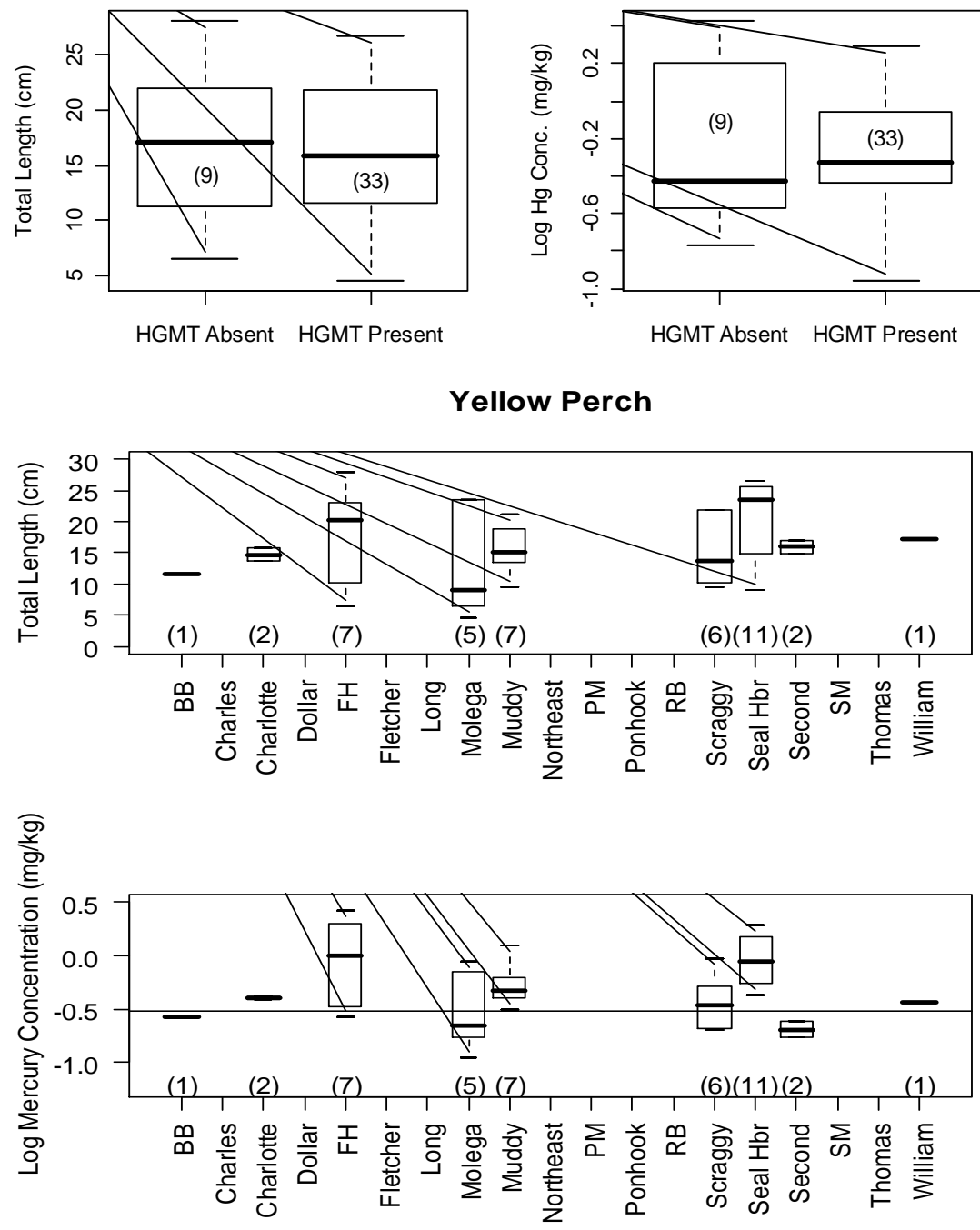


Figure 8 – Boxplots of yellow perch length frequency and log mercury (Hg) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.

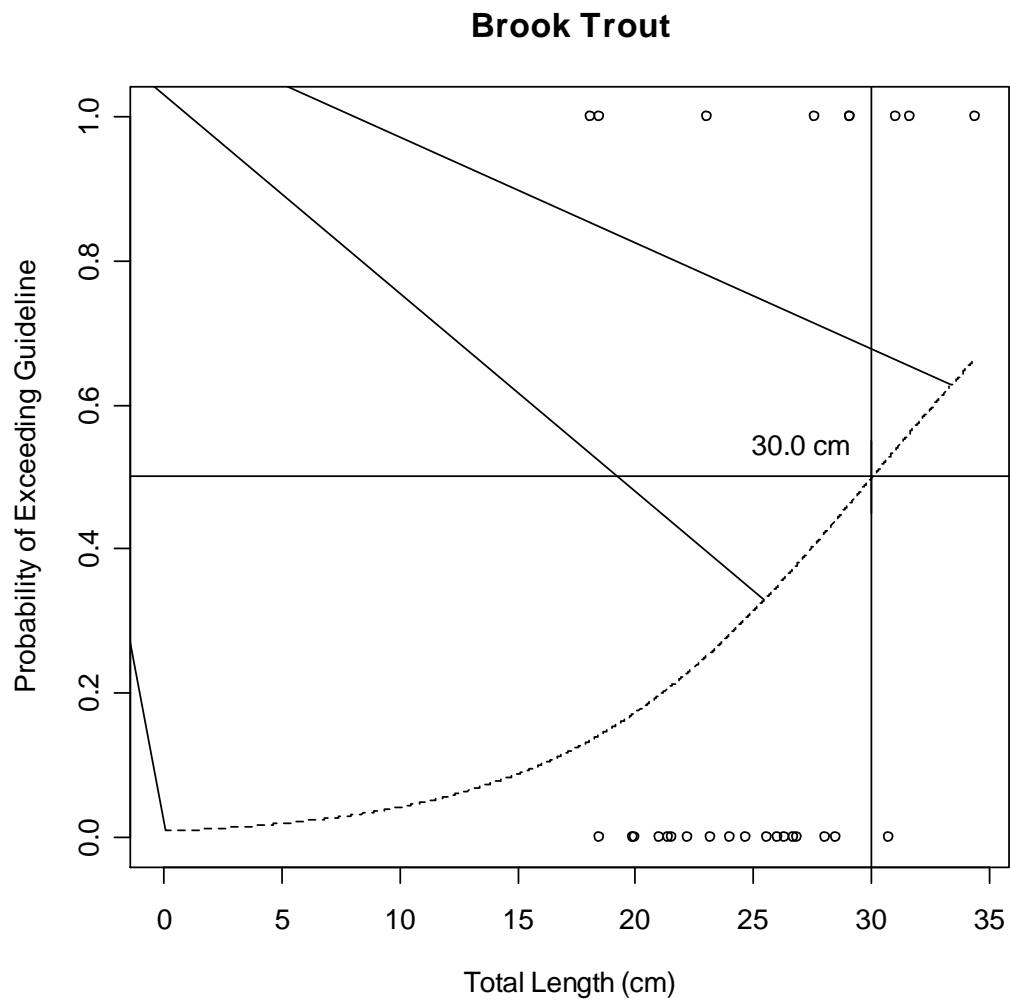


Figure 9 – Logistic regression model of the probability of brook trout tissue mercury concentration exceeding the Canadian consumption guideline based on total body length (cm).

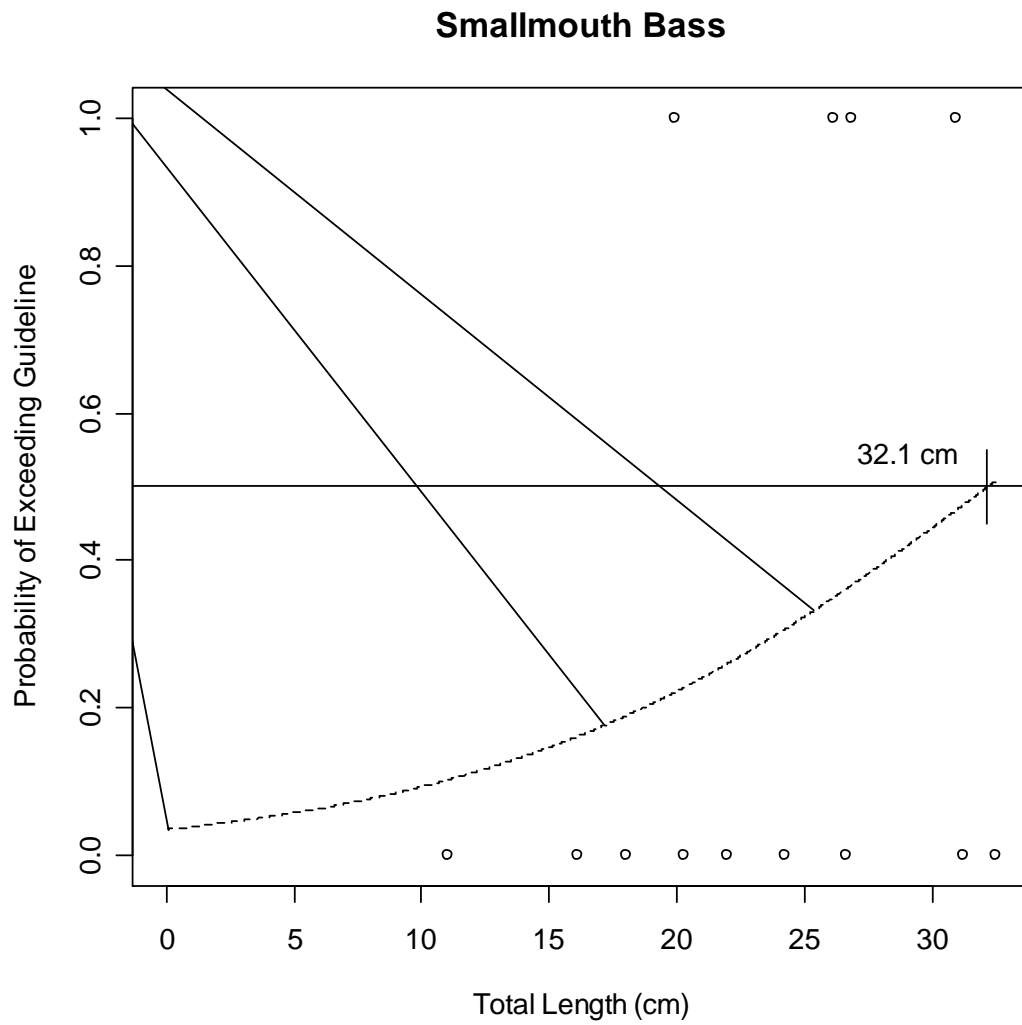


Figure 10 – Logistic regression model of the probability of smallmouth bass tissue mercury concentration exceeding the Canadian consumption guideline based on total body length (cm).

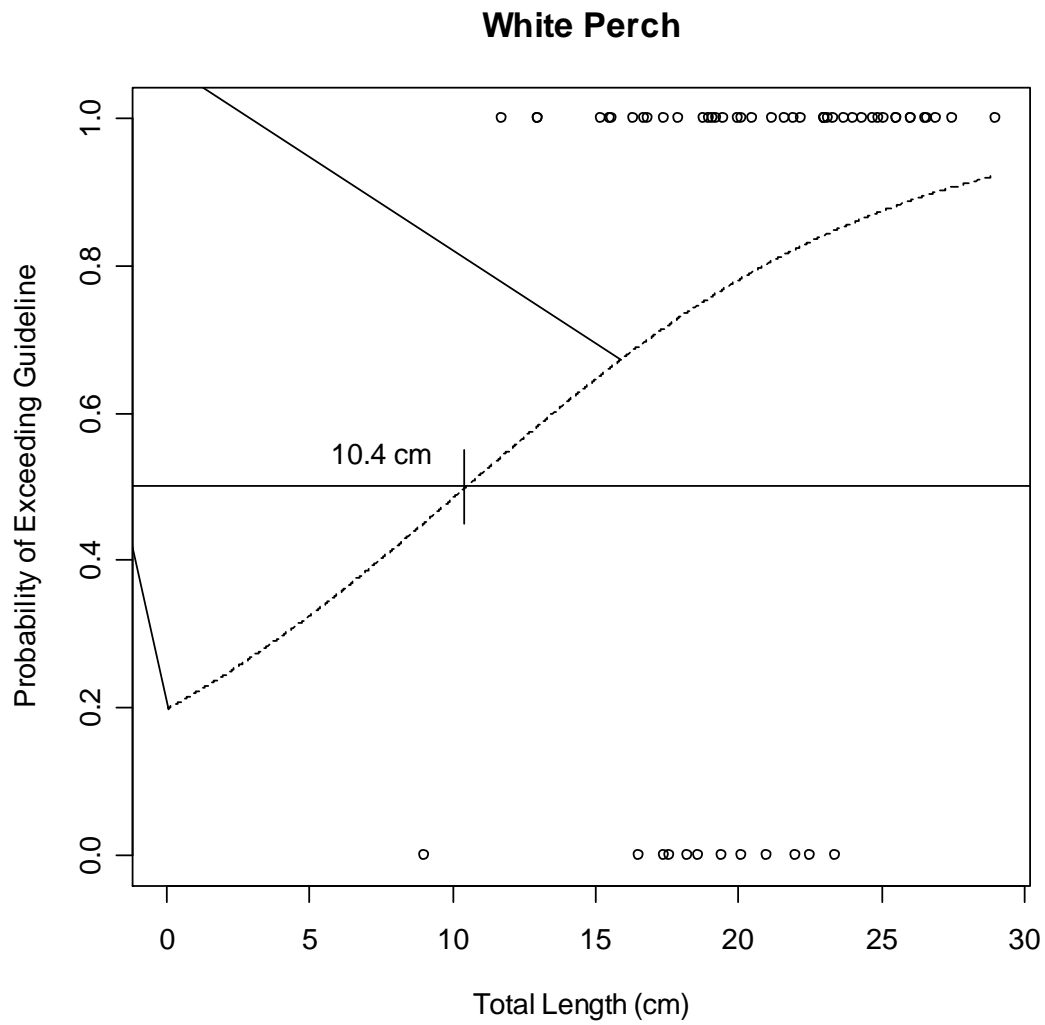


Figure 11– Logistic regression model of the probability of white perch tissue mercury concentration exceeding the Canadian consumption guideline based on total body length (cm).

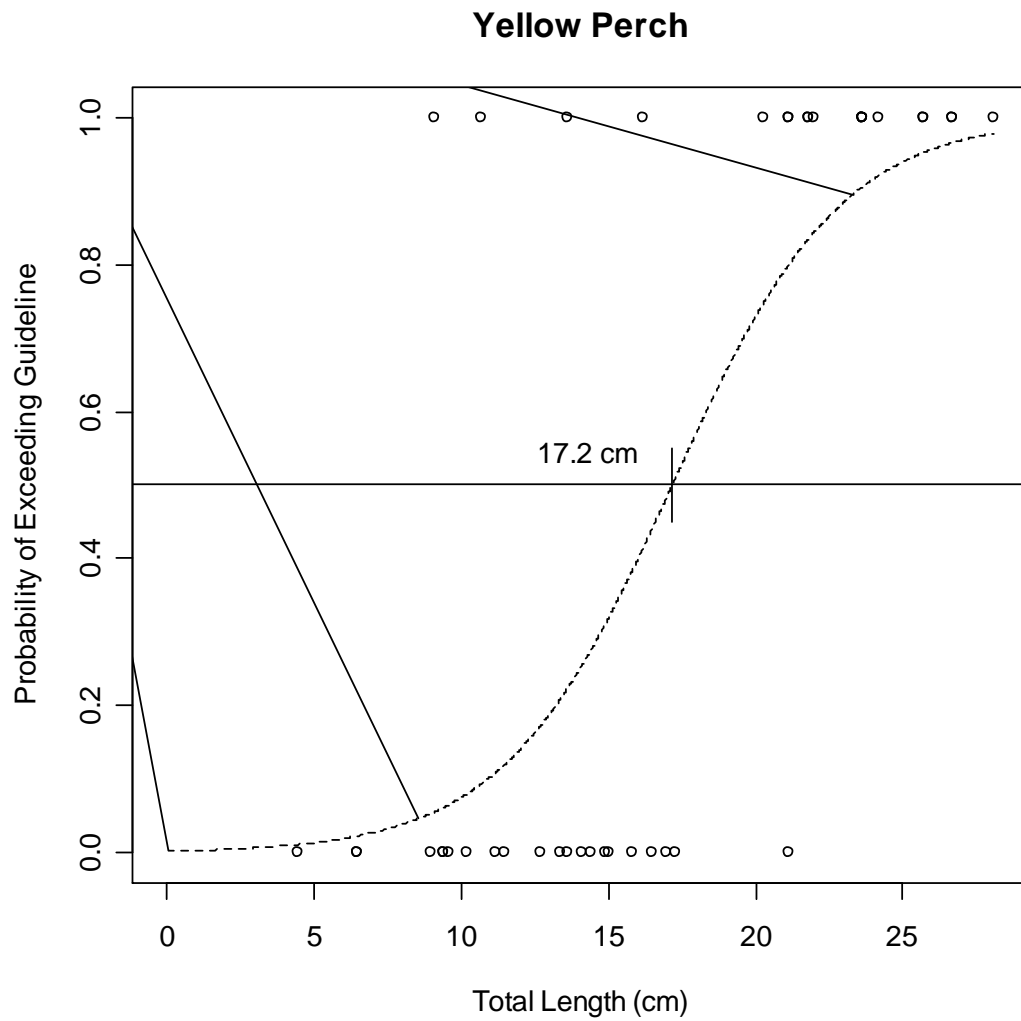


Figure 12 – Logistic regression model of the probability of yellow perch tissue mercury concentration exceeding the Canadian consumption guideline based on total body length (cm).

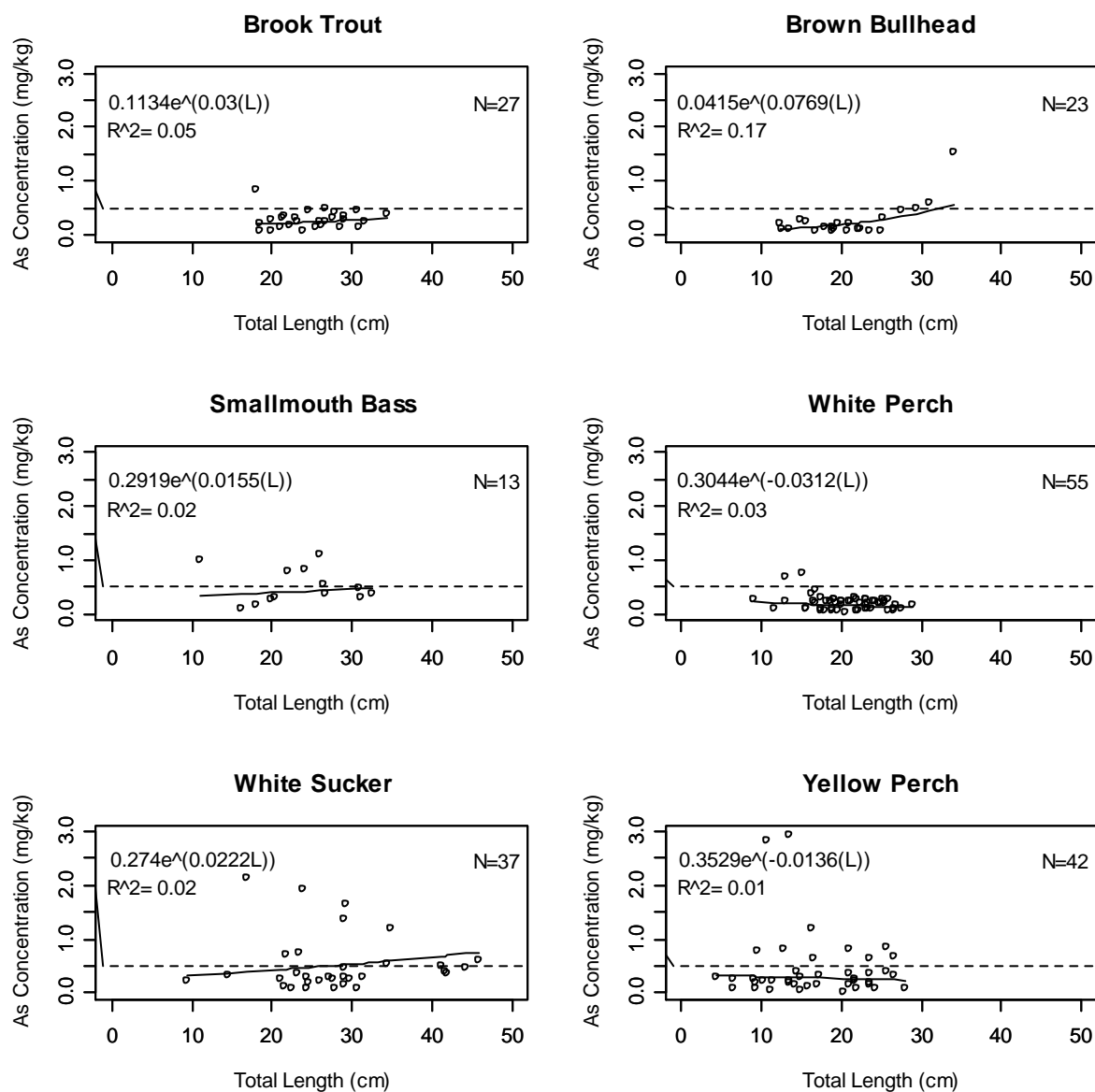


Figure 13 – Regressions of arsenic concentration (mg/kg fish tissue FW) on total length for fish species with $n > 10$.

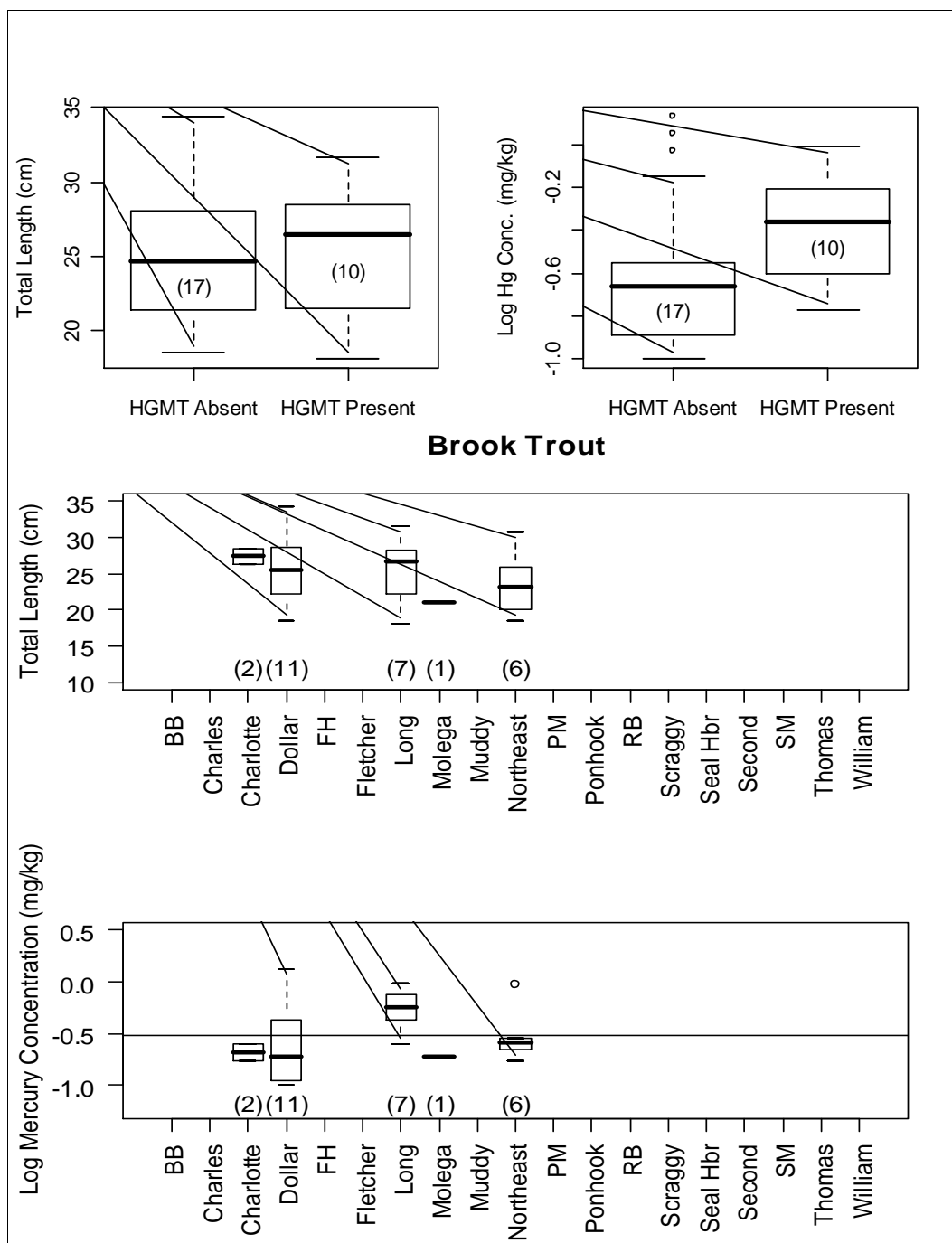
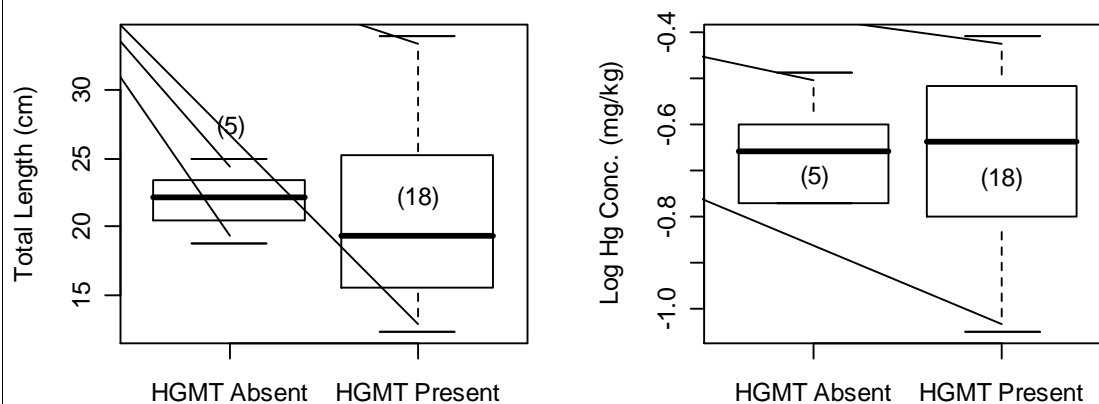


Figure 14 – Boxplots of brook trout length frequency and log arsenic (As) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.



Brown Bullhead

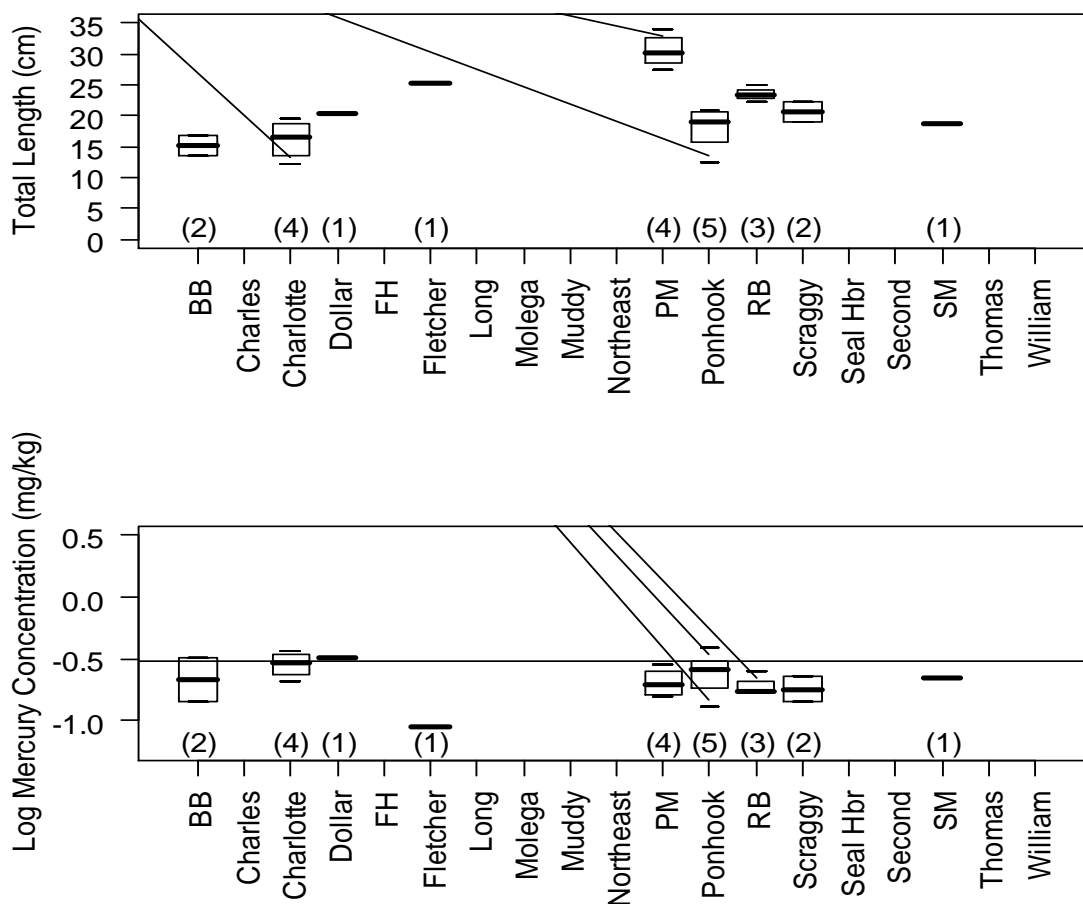


Figure 15 – Boxplots of brown bullhead length frequency and log arsenic (As) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.

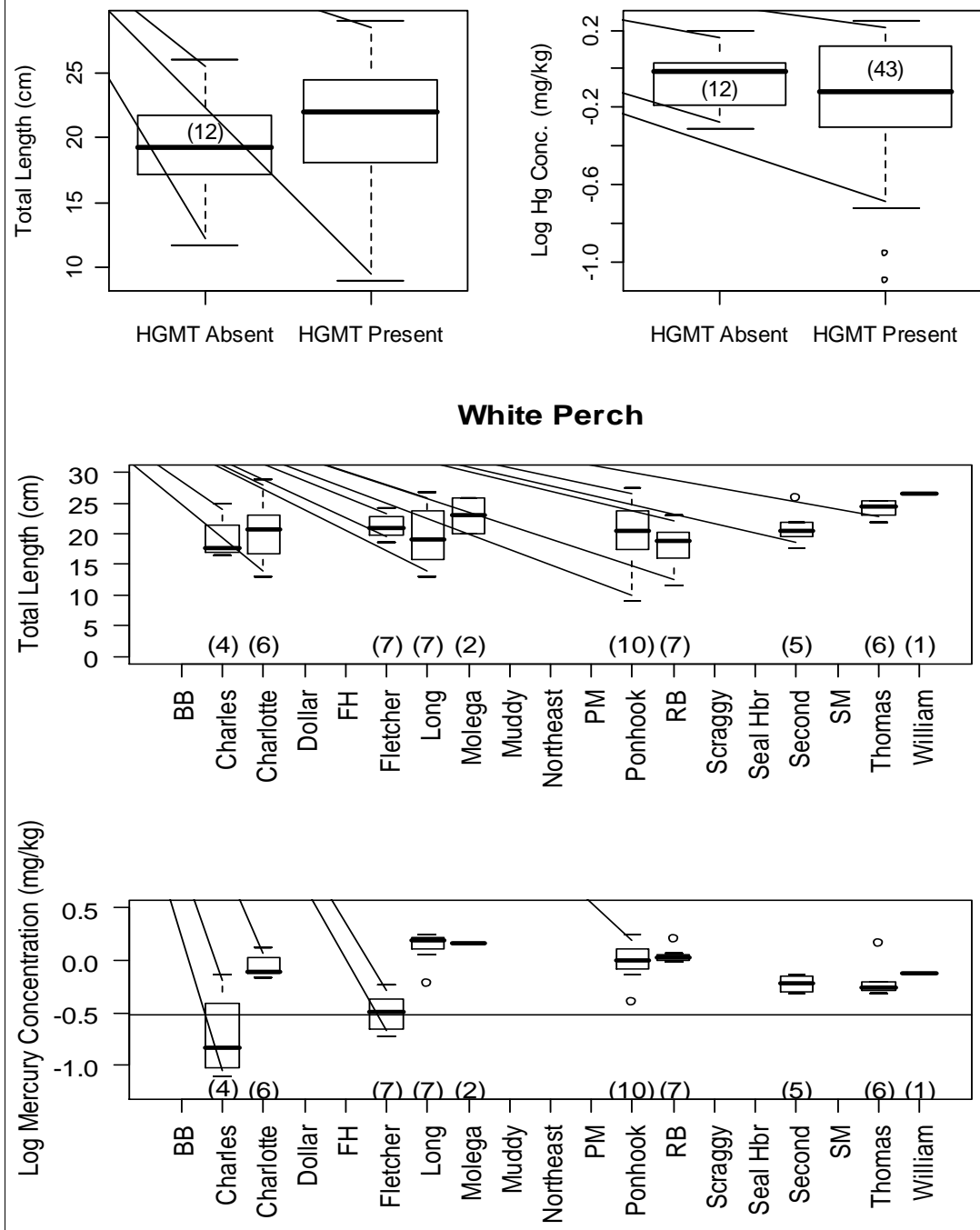


Figure 16 – Boxplots of white perch length frequency and log arsenic (As) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.

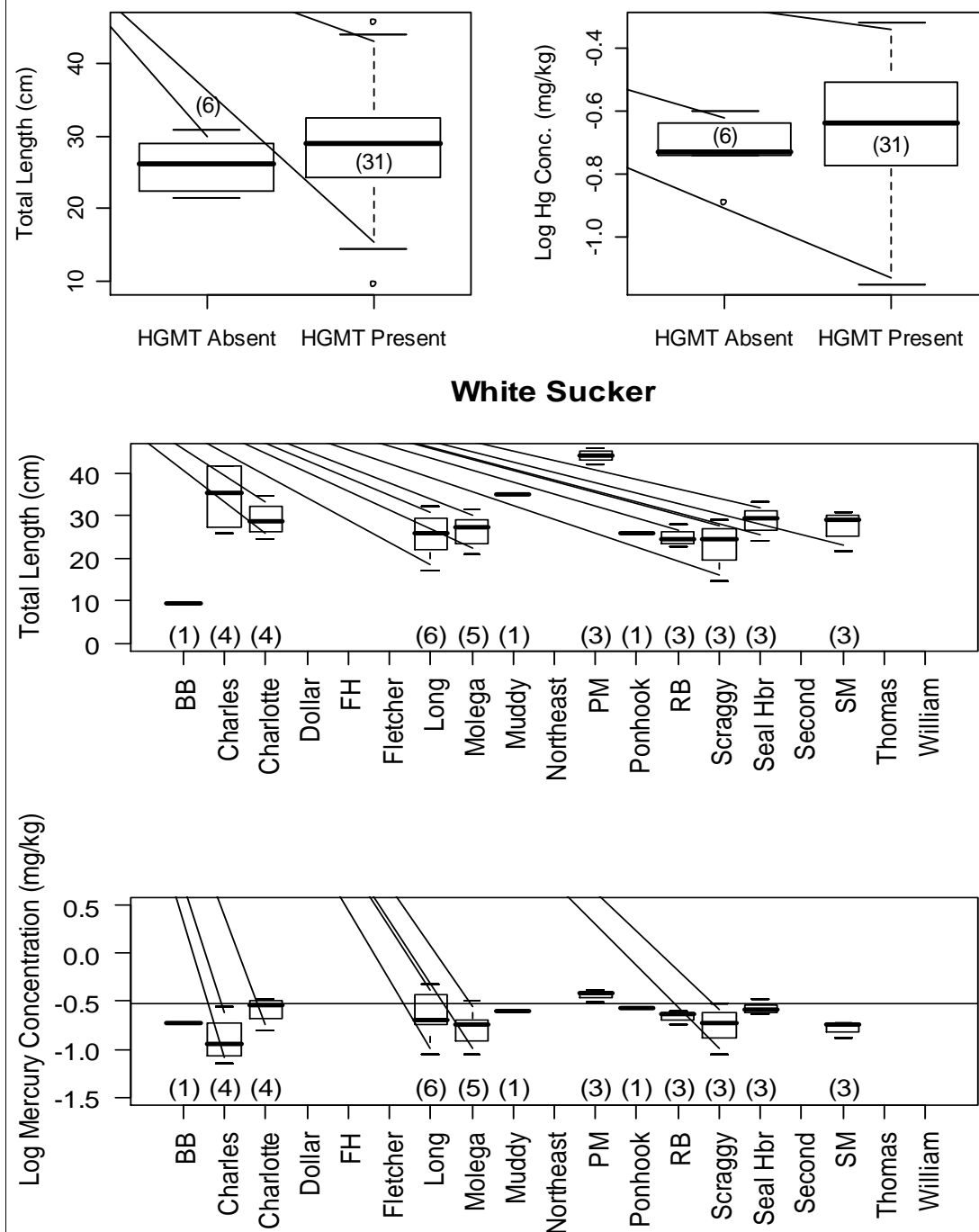
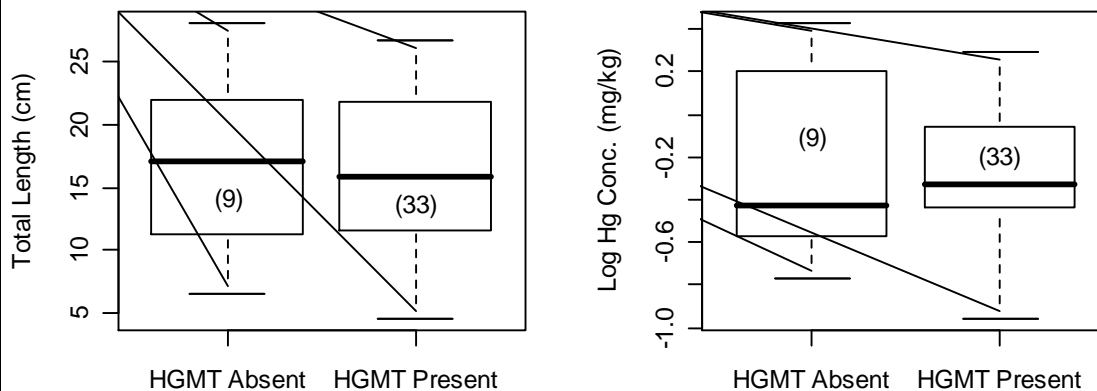


Figure 17 – Boxplots of white sucker length frequency and log arsenic (As) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.



Yellow Perch

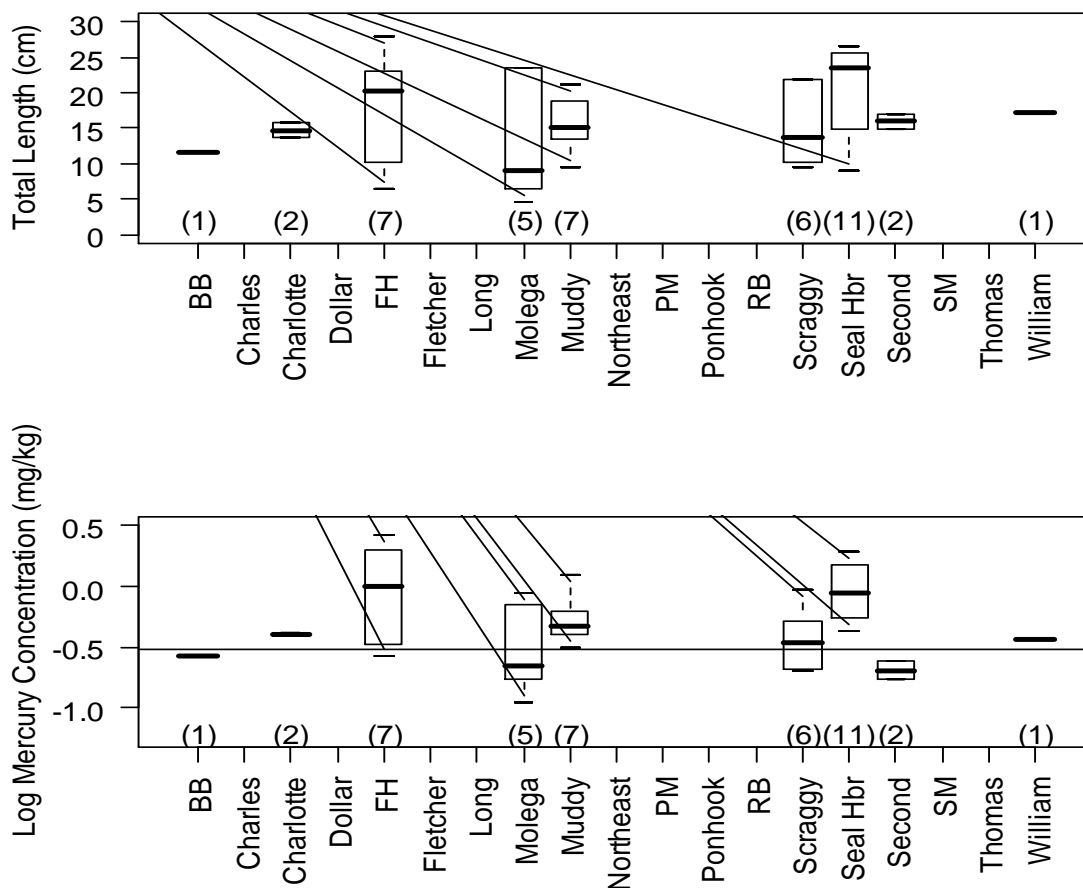


Figure 18 – Boxplots of yellow perch length frequency and log arsenic (As) concentration (mg/kg tissue FW) for lakes with HGMT absent / present and by individual lake. Boxes represents 25th percentile, median and 75th percentile data. Sample size represented in parenthesis. BB=Beaver Brook, FH=Fisherman's Harbour Lake, PM=Powder Mill Lake, RB=Rock Brook Lake and SM=Seven Mile Lake.

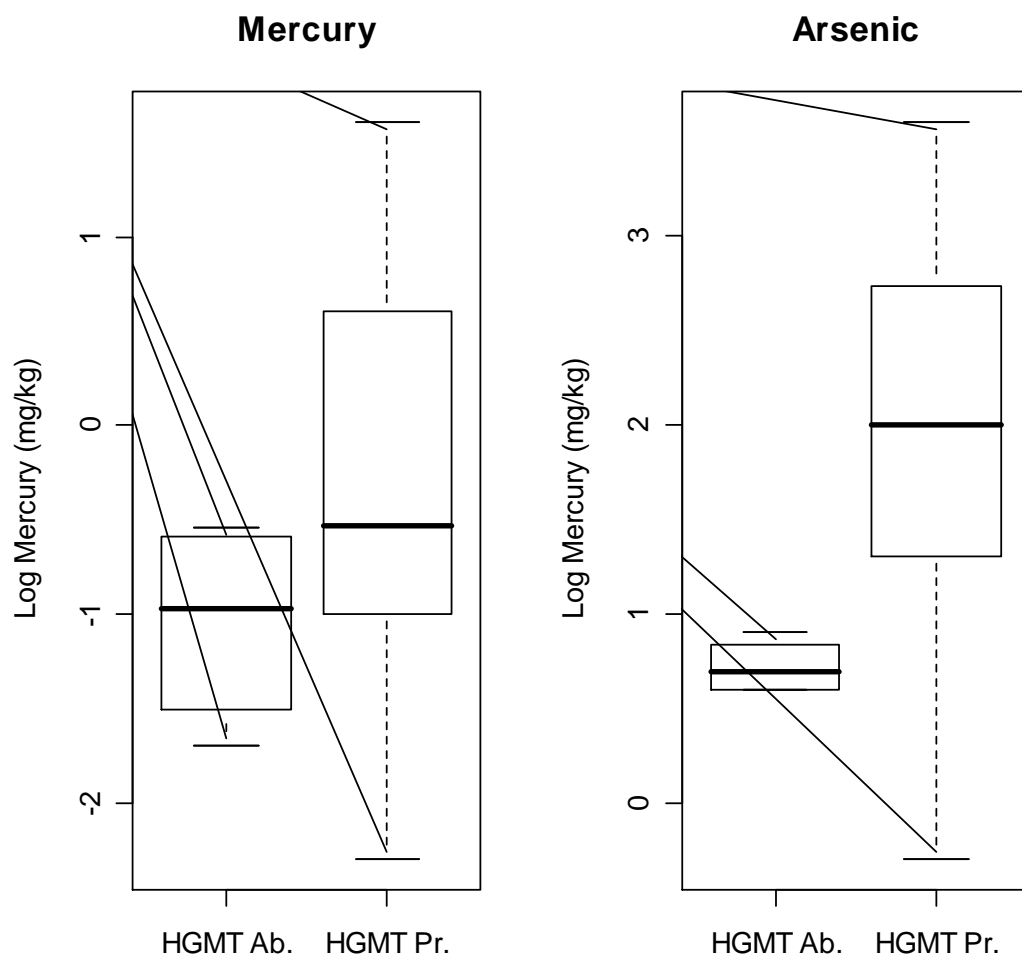


Figure 19 – Boxplots of sediment mercury and arsenic concentrations in lakes affected by HGMT and those not affected by HGMT. Concentrations are log-transformed.

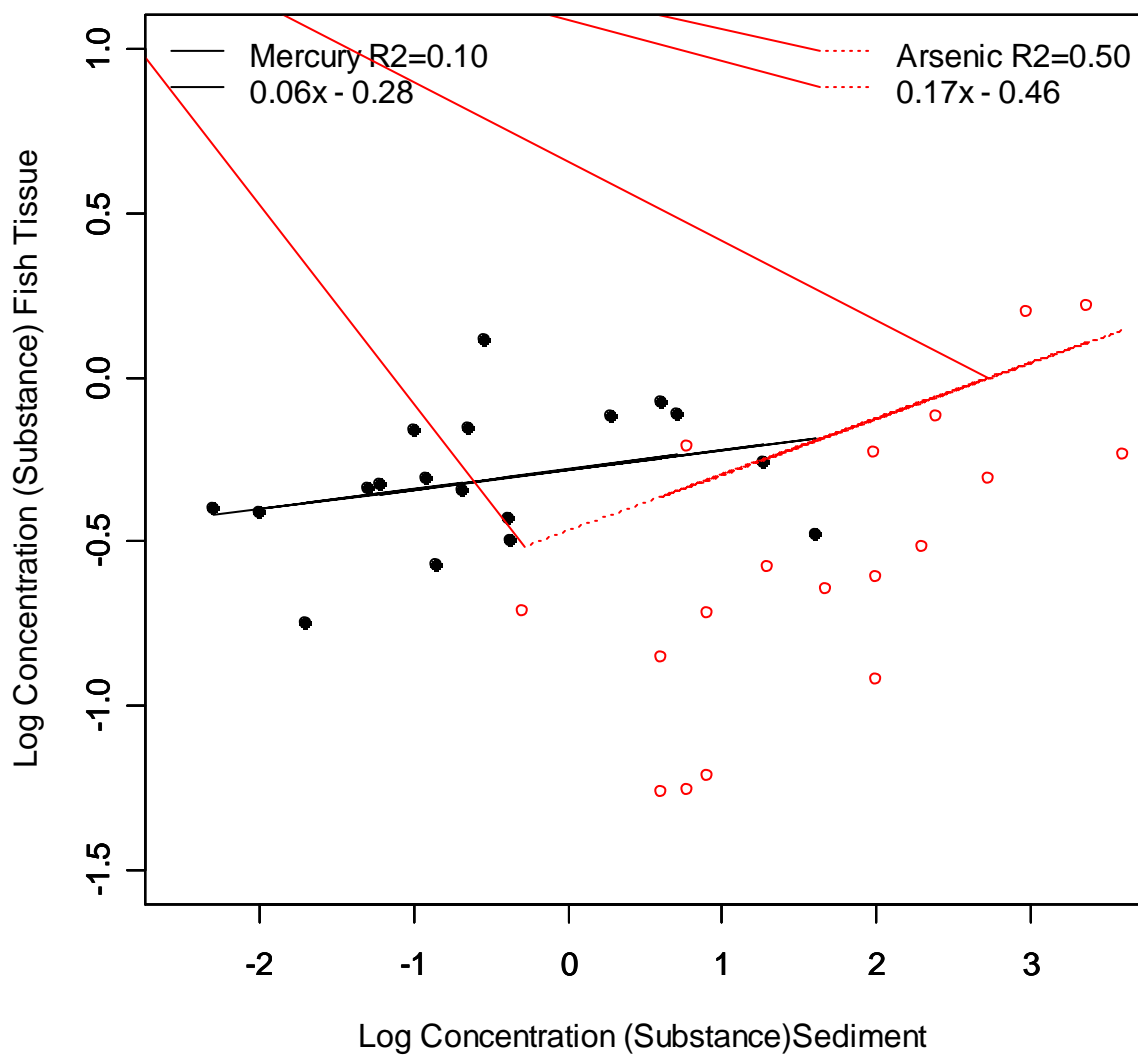


Figure 20 –Log-transformed mercury and arsenic concentrations in fish tissue (mean of all fish, not size adjusted) regressed on log-transformed mercury and arsenic concentration in lake sediment samples.