# Development of baseline data for long-term monitoring of sediment conditions at reference sites in Saint John Harbour, New Brunswick: benthic infaunal invertebrates and sediment contaminants 2011-2013

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# Development of baseline data for long-term monitoring of sediment conditions at reference sites in Saint John Harbour, New Brunswick: benthic infaunal invertebrates and sediment contaminants 2011-2013

by

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## Abstract

Seasonal and annual monitoring of infaunal invertebrates and sediment contaminants was done at reference sites known to have historically low metals and polycyclic aromatic hydrocarbons (PAHs) in the Saint John Harbour, New Brunswick between 2011 and 2013. The objectives of this study were to generate baseline data to be used to develop a long-term monitoring program in the Harbour. Total abundance, richness, and diversity of invertebrates varied seasonally, annually, and spatially, and habitat-specific assemblages were identified in the inner and outer harbour. All sediment contaminants (19 metals; 16 priority PAHs) showed little variability among sites, seasons or years (typically < 5-fold), and only 2 (arsenic and nickel) metals exceeded guidelines across sites. Results were used to design a long-term monitoring program that could be used to assess cumulative effects of additional development in the Harbour.

## Résumé

Le suivi saisonnier et annuel de l'endofaune et des contaminants sédimentaires a été effectué aux sites de référence reconnus pour leurs faibles concentrations en métaux et hydrocarbures aromatiques polycycliques (HAPs) dans le Port de Saint-Jean, au Nouveau-Brunswick, entre 2011 et 2013. Les objectifs de cette étude étaient d'établir une base de référence pouvant être utilisée dans le développement d'un programme de suivi à long terme dans le Port. L'abondance, la richesse spécifique, et la diversité de l'endofaune ont présenté des variations saisonnière, annuelle et spatiale et des assemblages spécifiques ont été identifié aux sites situés dans les portions intérieure et extérieure du Port. Tous les contaminants sédimentaires (19 métaux, 16 HAPs prioritaires) ont démontré très peu de variabilité entre sites, saisons ou années (typiquement < 5 fois plus) et seulement 2 métaux (arsenic et nickel) parmi les sites ont excédé les recommandations. Les résultats ont été utilisés pour concevoir un programme de suivi à long terme pouvant être utilisé pour évaluer les effets cumulatifs de développements additionnels dans le Port.

## Introduction

Saint John Harbour is one of Canada’s major ports and the largest natural harbour in New Brunswick and is situated at the mouth of the Saint John River where it enters the Bay of Fundy. The Harbour presents an estuarine environment influenced by strong tidal currents and with a seabed ranging from silt and mud to gravel and rock. Like many other coastal estuaries that have been important centres of human settlement, the Harbour has been subjected to a wide range of anthropogenic activities since the late 1800s. Saint John Harbour has major shipping traffic that is supported via a dredged channel; material from maintenance dredging is disposed of at the Black Point ocean disposal site, located in the Outer Harbour. Saint John Harbour also receives inputs of industrial effluents including those from oil refining, brewing, and pulp and paper production, as well as municipal effluents, from the surrounding concentration of major industries and urban development. Cumulative effects are likely to occur from the large number of human activities in estuaries like Saint John Harbour. However, monitoring programs and environmental impact assessments have traditionally focused on a single development and do not share common methodologies or a common framework, making it difficult to assess cumulative effects.

Researchers at the University of New Brunswick (UNB), in partnership with the Saint John Harbour – Environmental Monitoring Partnership (SJH-EMP; a consortium of industry, government and non-governmental organizations with interests in the Harbour), examined benthic invertebrate communities and sediment contaminants of the Inner and Outer Saint John Harbour. The goals were to provide the SJH-EMP with current baseline data on spatial and temporal variability in invertebrate communities and sediment contaminants and to integrate findings to assess relationships between infaunal organisms and sediment characteristics of the Harbour such as grain size, organic carbon, and the presence of contaminants. This research generated the information needed to develop a regional monitoring program, including an optimal sampling strategy (i.e., sites, times, and methods) and thresholds against which to assess changes. This will facilitate future monitoring of contaminants and biota and detection of cumulative effects of human activities in Saint John Harbour.

This report summarizes Phase 1 of the research on benthic infaunal invertebrate communities and sediment contaminants in the Saint John Harbour. This phase focused on characterizing spatial and temporal variability at reference sites from 2011-2013 (Years 1-2). Reference sites were identified on the basis of being removed from any known point sources of contaminants and on their low concentrations of contaminants measured in past studies (e.g. Parrott et al. 2002). The current results will form the baseline for comparison of data from Phase 2 (future publications), which focused on identifying potential “hotspots” of sediment contamination and whether benthic communities were considered to be impaired at those sites of potential concern (Years 2-3). The overall objective of this report is to summarize and identify the range of conditions at reference sites in Saint John Harbour.

## BENTHIC COMMUNITIES

In the development of a cumulative effects monitoring program for Saint John Harbour, information about benthic marine invertebrates is crucial. Benthic invertebrates are ecologically important in marine habitats as they 1) are an important component of marine food webs, serving as a food source for many larger organisms, including commercially fished species, and 2) impact major ecological processes such as cycling of elements, water column processes, pollutant distribution and fate, and transport and stability of sediments (Snelgrove, 1997). Studies often use benthic infaunal invertebrates as indicators of anthropogenic impacts because they can respond relatively quickly to disturbances as most are small, have relatively short life spans, have limited mobility after settlement, can show measurable responses to environmental stress or change, and can be sampled quantitatively (Clarke and Warwick, 2001; Bacci, 2009). Distributions of infaunal organisms are also related to a variety of characteristics of their habitat (sediment characteristics, flow regime, food supply) (Snelgrove and Butman 1994) and habitat-specific invertebrate assemblages can be identified.

A number of studies have examined benthic infaunal communities in Saint John Harbour since the 1960’s, particularly in the Outer Harbour, including an extensive survey in 2001 to monitor the impacts of dredged material disposal at the Black Point ocean disposal site (Envirosphere, 2002). This 2001 survey reported a characteristic benthic infaunal community throughout the Outer Harbour, with abundance and species richness increasing towards seaward areas and in proximity to the disposal site. The community consisted of deposit-feeding organisms, dominated by the small bivalve *Nucula proxima* and several species of polychaete worms (including *Tharyx* sp., *Nephtys incisa*, *Ninoe nigripes*, *Cossura longocirrata*, and *Ophelina acuminata*), but also included several species of suspension feeders (e.g., the clam *Arctica islandica* and the tunicate *Bostrichobranchus pilularis*) (Envirosphere, 2002). The community was considered to be similar to natural communities in other coastal areas of eastern North America with similar substrates and was not indicative of typical ‘disturbed’ communities. Little information exists on the infaunal communities of the Inner Saint John Harbour.

Although spatial characterization of benthic infaunal communities was extensive in some past studies, there is little information on their temporal variation. Additionally, sampling at individual sites has not been extensive enough to characterize the degree of small-scale spatial variability and sample sizes needed to detect significant changes at a given study site. Data from the 2011-2013 surveys in the present study will build upon the infaunal data which have been collected in previous studies. Specifically, the present research on benthic infaunal communities at reference sites will:

1. describe seasonal, annual, and spatial variability of infaunal communities at reference sites and their relationship to sediment characteristics;
2. examine the effect of sample size on ability to detect change in infaunal communities;

3. determine the taxonomic resolution of identification sufficient for detecting spatial and temporal variability in infaunal benthic invertebrate communities; and,
4. begin to define thresholds for a regional monitoring framework against which future changes can be assessed to determine if further monitoring or management is required.

## CONTAMINANTS IN SEDIMENT

A number of studies on the Saint John Harbour over the past three decades have revealed higher concentrations of some metals in the Inner Harbour in comparison to the Outer Harbour and other sites in the Inner Bay of Fundy. These “hotspots” were likely related to localized anthropogenic activities. For example, an extensive survey by Ray and McKnight (1984) showed that mean concentrations of copper, lead, cadmium, and zinc in Courtenay Bay (Inner Harbour) were 1.2-2.8-times higher than all other sites in the Inner and Outer Harbour. Other metals (nickel, manganese, molybdenum, mercury) were not different across the >100 sites that were sampled in that study. Metal concentrations throughout the Harbour were low, but there was a trend of decreasing concentrations from Courtenay Bay in a seaward direction, indicating a small, but detectable anthropogenic input in the Courtenay Bay area. Inner Harbour sediments were measured again in 1992 (31 stations) (Tay et al., 1997) and mean concentrations of copper, lead, mercury, and zinc were similar to previous results, but cadmium concentrations were found to be lower than the previous study. Monitoring of the Harbour in 2001 showed that some of the highest concentrations of chromium, copper, nickel, lead, and zinc (21, 43, 20, 43, and 227 mg/kg dw, respectively) in Inner Harbour sediments were located in shallow waters near East Saint John, an area that receives sediment from the Little River which flows past industrialized sites. Elevated concentrations of these metals also occurred near the shipyards at the mouth of the Saint John River and south of Partridge Island (Parrott et al., 2002). However, metal concentrations of most sediment sampled throughout the Harbour were below Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines (ISQGs) for arsenic, chromium, copper, lead, and zinc (7.2, 52, 19, 30, and 124 mg/kg dw, respectively; CCME, 1999), with the exception of only 1 or 2 samples. More recent analyses of a limited number of sites showed that sediment concentrations of aluminum, copper, manganese, nickel, and zinc at two locations (Red Head and Hazen Creek) in the Inner Harbour were up to 2-times higher compared to two sites (Ducks Cove and Saints Rest) further removed from human activities, while concentrations of cadmium and lead were similar between all four sites (Doyle et al., 2011). Some of the differences in concentrations among studies may be related to differences in analytical techniques.

Some organic contaminants have also been measured in sediments from the Saint John Harbour. Polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) were measured in sediments collected from Inner and Outer Harbour sites in 1992 (Tay et al., 1997). Most stations (n = 21/31 Inner Harbour and 17/18 Outer Harbour) had below detectable concentrations for PCBs (<10 µg/kg dw total Arochlor), some sites had measurable PCB concentrations (19-73 µg/kg) and two samples exceeded Disposal at Sea guidelines of 100 µg/kg dw (Canada Gazette, 2001; i.e., 134 and 348 µg/kg). Disposal at Sea guidelines for total PAHs (2.5 mg/kg dw; Canada Gazette, 2001) were also exceeded at 6 sites in the Inner Harbour, with concentrations ranging from 0.5 to 19 mg/kg dw. In a 2001 survey, concentrations of PCBs in Outer Harbour sediments ranged from <10 µg/kg dw at most sites (n = 55/64) to 35 µg/kg dw and PAH concentrations ranged from <0.05 mg/kg dw at half of the sites (n = 31/64) to 1.6 mg/kg (Land and Sea 2001). More recent data for these contaminants in the Harbour are relatively sparse or remain unreported.

Despite the range of studies that have been done on the Saint John Harbour, little current information exists on sediment contaminants and none have generated the information needed to identify appropriate reference sites and the degree of natural variation at these sites that are critical for setting thresholds and triggers for a regional monitoring framework. To address this, the present research on contaminants in sediment at reference sites in the Harbour will:

1. examine spatial and temporal (seasonal and annual) variability of a suite of sediment contaminants (metals, PAHs and PCBs (spatial only));
2. establish reference, baseline concentrations; and,
3. refine the critical effects size needed to define a warning level against which future changes can be assessed and further monitoring or management is required.

## Materials and Methods

### LONG TERM REFERENCE SITES

Existing data from studies conducted in Saint John Harbour (e.g., Parrott et al., 2002; Envirosphere, 2003) and consultations with the SJH-EMP were used to choose reference sites for sampling in Year 1. Six reference sites were chosen for the first year of grab sampling (2011-2012) - three in the Inner Saint John Harbour and three in the Outer Saint John Harbour (Figure 1, Table 1). For the purpose of this report, the Inner Harbour is defined as the area north of Black Point (eastern shore) and Sheldon Point (western shore); none of the reference sites were located in the very innermost part of the Inner Harbour. The references sites were selected based on:

- presence of soft substrate (as defined with known maps of the Harbour bottom);
- being removed from any known point sources of contaminants (least developed sites); and
- known, low concentrations of metals, PCBs, and PAHs.

Sampling was conducted on the following timeline to examine seasonal (Year 1) and interannual variability (Years 1-2):

Year 1: August 2011, October 2011, April 2012, and June 2012
Year 2: October 2012 and June 2013

In the first sampling event, grabs at one of the sites selected in the Outer Harbour (Site 05: 45°11.529N, 66°05.735W; data not included in report) did not capture much sediment and a different site (Site 13; Figure 1; Table 1) was selected for later sampling events.

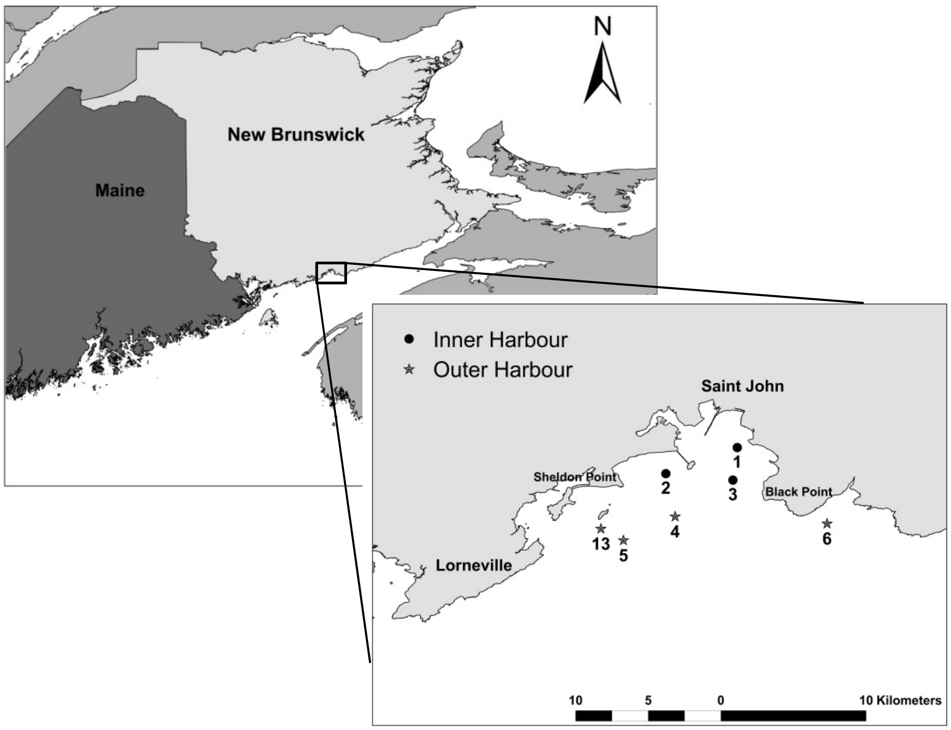


Figure 1. Locations of reference sites in the Inner and Outer Saint John Harbour, New Brunswick, 2011-2013.

Table 1. Locations and descriptions of reference sites in the Inner and Outer Saint John Harbour, New Brunswick, 2011-2013, including depth below mean low water (MLW).

| Site | # sample events | GPS coordinates (WGS 84) | Depth below MLW (m) | Description |
|---|---|---|---|---|
| Inner Harbour | | | | |
| 01 | 6 | 45º14.957N, 66º01.506W | 3.6 | South of sewage outfall, near Red Head. Fine sediment with patches of sand, presence of pebble and shell hash. |
| 02 | 6 | 45º13.989N, 66º04.160W | 7.7 | Southwest of Partridge Island. Fine sediment, slightly anoxic. |
| 03 | 6 | 45º13.748N, 66º01.670W | 8.0 | North of dredging disposal site near Black Point. Fine sediment, presence of organic debris. |
| Outer Harbour | | | | |
| 04 | 6 | 45º12.412N, 66º03.815W | 12.6 | Midway between Manawagonish Island and the dredging disposal site. Fine to sandy sediment. |
| 06 | 6 | 45º12.151N, 65º58.172W | 37.5 | Southeast of Canaport LNG ship loading area. Dense fine sediment, presence of pebble, cobble, organic debris and shell hash. |
| 13 | 5[a] | 45º11.958N, 66º06.572W | 12.6 | Southeast of Manawagonish Island. Fine sediment, usually anoxic, presence of shell hash and organic debris. |

[a] Site 13 replaced Site 05 in October 2011 due to lack of suitable substrate for sampling

## SAMPLE SIZE REQUIREMENTS

Sampling for benthic invertebrates, sediment characteristics and contaminants was done concurrently so that the relationships between them could be examined; however, in some cases the number of replicates per site varied between the approaches. For both contaminants and infaunal invertebrates, ten replicates were originally taken at each site in August 2011 (except Site 05).

**Sediment chemistry sampling: Power analyses of the most variable sediment chemistry results from the initial samples indicated that a minimum of 5 replicate samples were required to achieve 80% power with an alpha of 0.05 and an effects size of 2 standard deviations (SD).**

For contaminants, 6-10 replicates per site were collected in October 2011, and only 5 replicates per site were taken thereafter. For the benthic invertebrate communities, time constraints and sampling difficulties limited the number of samples collected at some sites on some dates. As a result, 6 replicates were collected at each site in October

2011 (but 5 at Site 01), 10 replicates at each in April 2012 (but 5 at Site 01 and 8 at Site 06) and June 2012, and 8 replicates at each site in October 2012 and June 2013 (Appendix B, Table B-2). Strong tidal currents and waves were the main reason for the reduced number of replicate samples as it was difficult to successfully deploy the grab (i.e., sampler hit the bottom at an angle and did not penetrate or capture sediment).

## FIELD SAMPLING PROTOCOL

A ~0.1 $m^2$ Smith McIntyre grab (SMG) sampler (Smith and McIntyre, 1954; Wildish and Wilson, 1976) attached by a cable to the winch of a 50' converted offshore lobster boat was used to collect quantitative samples of surface sediment for physical, chemical, and infaunal analysis (Appendix A; Figure A-1). The SMG grab was lowered vertically from the stationary boat to collect sediment. After the grab was triggered, it was slowly pulled up onto the deck of the boat and placed on the hopper, and penetration depth and sample width were measured.

Due to the large tides in the Bay of Fundy and the Saint John River flowing into the Harbour, currents in the Harbour are strong and make grab sampling difficult. Best results were obtained when Inner Harbour sites were sampled during or just after high tide, as currents in this portion of the Harbour are at their minimum 2 hours after high tide (Jeff Melanson, UNB Ocean Mapping Group, pers. comm.). Due to their greater depth (Table 1), Outer Harbour sites were sampled at low tide to minimize water depth.

To obtain representative benthic samples, sediment penetration depth must be at least 5 cm (Stubbs et al., 1987). For Saint John Harbour sediment - composed mostly of fine sand, silt, and clay - a penetration depth of 7 to 9 cm was usually obtained, with occasional samples reaching a depth of up to 14 cm. The depth of penetration for each grab was determined by insertion of a ruler vertically along the grab midline. The sediment in the grab was separated into two halves (Appendix A; Figure A-2). One side of the grab was sampled for physicochemical analysis and the other side was used for infaunal analysis. Acceptability of the grab samples was based upon a minimum depth of penetration of 5 cm. Sampling was repeated until the sufficient number of acceptable grab samples was obtained; however, in some cases (<2% of samples) samples less than 5 cm in depth were accepted due to time constraints and difficulty penetrating the sediment.

For the infaunal half of the grab, the volume of sediment sampled for each replicate was estimated using a MatLab (v. R2011a) program (written by P. Riley of the UNB Dept. of Engineering). An arc with a 23-cm radius was used to closely match the curvature of the sampler. The surface area was limited by the maximum jaw width (27.9 cm) of the sampler and was estimated to be 321 $cm^2$. Volume was calculated using the arc of the sampler, and measured width and depth of the sample. For bulging samples (10 to 14 cm deep), the arc of the bulging surface was modelled using a parabolic equation to estimate and add the additional volume above that of a flat upper surface. The volume of sediment sampled for infauna ranged from approximately 0.5 L to 4 L.

At each sampling site and for each replicate, GPS coordinates and observations were recorded. When samples appeared anoxic (based on colour change with sediment depth and sulfidic smell) and contained considerable debris, a description of the sediment was noted (Appendix B; Table B-1), including:

- Texture: shell hash, cobble, pebble, gravel, sand, or mud (silt and/or clay);
- General sediment colours (e.g., black, green, brown, red, yellow) and colour change with depth as a possible indicator of redox state;
- Smell: none, sulfidic ($H_2S$), or humic (musty, organic odor);
- Other (e.g., occurrence of concretions, organic debris, epifaunal organisms, etc.).

Slightly less than half of the sediment (infaunal portion) in the grab was then scooped out with a trowel and sieved through a 0.5-mm mesh, large, plastic sieve in a tub filled with seawater. Organisms were then gently rinsed from the sieve with seawater from a squirt bottle, and placed directly into labeled, 8 or 16 oz. polypropylene jars. Organisms and any remaining sediment (>0.5 mm) were immediately preserved with ethanol (95% v/v purity).

A subsample (top 5 cm) from the remaining portion of the grab (physicochemical portion) was collected using a new pre-cleaned plastic corer at each site and placed into labeled, 250 mL pre-cleaned glass amber containers (purchased certified pre-cleaned for semivolatile, pesticide/PCB, and metal analyses; Fisher Scientific, Canada). The corer was labelled with a 5 cm depth mark and was 6.4 cm in diameter, which gave a typical sample volume of ~160 mL. In cases where grab samples were less than 5 cm in depth (<2% of samples), the same volume of sediment was collected from a larger surface area of the grab for the physicochemical analyses. In Oct. 2011 when there were difficulties getting the grab to penetrate well at Sites 01, 04, and 06, samples from some grabs were collected for physiochemical analyses but not benthic invertebrates due to insufficient sediment for the invertebrate analysis. All sediment samples were kept on ice in coolers until they were brought to the laboratory at UNB-Saint John. Samples for sediment chemistry were then frozen until needed for analysis.

## PROCESSING AND ANALYSIS OF BENTHIC INVERTEBRATE SAMPLES

### <u>SAMPLE PROCESSING AND IDENTIFICATION</u>

All benthic invertebrate samples collected in August 2011 (n = 10 replicates per site) were processed and thereafter, a subset of preserved infauna samples collected on other dates were processed (Appendix B; Table B-2). Benthic samples from sediment grabs with less than 5 cm sediment depth typically were not processed unless there were fewer than 5 replicates with sediment depth greater than 5 cm (see below for details).

Preserved benthic samples were processed by sieving (0.5-mm mesh, stainless steel sieve) them gently with freshwater to remove any remaining fine sediment. Pebbles, cobbles, broken shell pieces, and debris were removed and the sample portion greater than 0.5 mm was poured into small glass petri dishes and covered with 95% ethanol to prevent desiccation during sorting and identification. Samples were examined under a dissecting microscope using a magnification between 10x and 100x. A compound microscope was also used to look at finer features necessary for the identification of most organisms. Due to some damage during the sieving process, many organisms (mostly polychaetes) were found in sections. To avoid overestimating organism density, only head portions were counted for the groups that were found in larger numbers (e.g., *Cossura longocirrata*). For less common species, all heads and tails were gathered and the greater of the two numbers was recorded. Bryozoans and foraminiferans were not included in the count as they were most likely drifting dead organisms at the time of sampling.

All organisms were identified to the species level whenever possible, using at least two peer-reviewed sources as guides. Each new organism identified was catalogued (in a glass vial with 95% ethanol) and pictures were taken. This catalogue was sent to the Atlantic Reference Centre (St. Andrews, NB) for confirmation of species identification. Some organisms could not be identified to the species level because of damage or missing features. These organisms were grouped into their genus or family or even larger groups like phylum. Data in this study uses the highest taxonomic resolution possible, but some groups are better described than others (species versus family). For lower taxonomic resolution groups (e.g., family), the organisms were separated and added to the individuals already identified to species within that group according to percentage of each species within the group. This was done to avoid possible duplication of the number of taxa studied (see Appendix B; Table B-3 for species list). Some species were merged and presented as families or genera if there was uncertainty about the identification of each species (e.g., *Eudorella* spp.). A few individuals were also eliminated from the database because damage during sieving or handling resulted in a lack of characteristics necessary for identification to at least the family level (e.g., missing shells, heads, or tails). The World Register of Marine Species (WoRMS, 2014) and the Integrated Taxonomic Information System (ITIS) online databases were used to verify and update each taxonomic entry (i.e., authoritative taxonomic names).

Data on species abundance (# individuals/m$^2$) and occurrence were entered into a database created for this project, which could later be queried to generate spreadsheets for input into statistical packages.

## DATA ANALYSIS

Benthic community data were analysed from 10 replicates per site for August 2011 (except Site 13 not sampled on this date) and 5 replicates per site for all dates thereafter. Data from samples with a 4 to 5 cm sediment depth were only included when necessary to achieve a minimum of 5 replicates (1 sample at Site 01 in Oct. 2011, and 2 samples at Site 01 and 1 at Site 03 in April 2012; Appendix B; Table B-2). Species abundance was normalized to the ‘expected’ surface area of sediment sampled for invertebrates (27.9 cm x 11.5 cm = 321 cm$^2$), which was less than half of the measured opening of the grab sampler. Species abundance per volume of the grab was not used because most of the species were found in the top few cm of sediment. Data were grouped by major taxonomic group and averaged across replicates and sampling dates for general discussion of species composition of benthic samples. The Shannon diversity index (H') was calculated as: $H' = \sum_i p_i \, x \, log(p_i)$, where $p_i$ is the proportion of the total individuals from the $i^{th}$ species.

Both seasonal and interannual variability have the potential to influence trends in benthic communities within the Saint John Harbour. Therefore, to evaluate this potential variability at reference sites in the present study, total organism abundance, species richness, and Shannon diversity index (H') were compared across sites and sampling dates. To examine seasonal variation of organism abundance, species richness, and diversity (H') at reference sites, data were compared between the four sampling dates in Year 1 (August 2011, October 2011, April 2012, and June 2012). To examine interannual variation, data were compared between October 2011 and October 2012 and between June 2012 and June 2013.

To determine whether there was an interaction between sampling date and site on mean organism abundance, species richness, and diversity (H') at these reference sites, a two-way analysis of variance (ANOVA) was conducted with all Inner and Outer Harbour sites. Factors (date, site) and the interaction (date x site) were considered significant at an alpha of 0.05. The Kolmogorov-Smirnov test of normality and Levene's Median test of equal variance were used prior to all ANOVAs. Data were transformed using various methods (i.e., log, squared) to meet the assumption of normality and equal variance, where possible. The Holm-Sidak method was used for all pairwise multiple comparisons (SigmaStat 3.5). Since Site 13 was not sampled in August 2011, this created an unbalanced design for the two-way ANOVA; therefore the analysis was run twice, once excluding all August 2011 and once excluding Site 13 data.

Multivariate analyses of the benthic invertebrate community were done using PRIMER 6.0. Differences in assemblages among sites and dates were visually represented using non-parametric multidimensional scaling (MDS) plots based on Bray-Curtis similarity matrices. Prior to creation of the similarity matrices, abundance data were square-root transformed to down-weight the importance of numerically dominant animals. The main patterns were unchanged when data were analysed using untransformed data or following log or presence/absence transformations (data not presented). Following these multivariate graphical representations, two-way permutational multivariate analysis of variance (PERMANOVA) was used to assess the effect of site and sampling date on the invertebrate assemblages in the grab samples. As for the univariate analyses described above, data analyses for the seasonal comparisons were run twice, once excluding August 2011 and once excluding Site 13 data.

Linear models were used to examine relationships between mean values of organism abundance, species richness, or diversity (H') for each combination of site and sampling date (n=35 data points) and mean sediment % moisture, % total organic carbon, % loss on ignition at 950°C, and average grain size (*Mz*). The best fitting model out of all possible combinations of the sediment parameters and a null model (intercept only) was determined using the Akaike Information Criterion (AICc).

The PRIMER Biota-Environmental matching and Stepwise (BEST) procedure (Clarke and Warwick, 2001) was used to determine the highest correlation between spatial and temporal patterns of square-root transformed infaunal abundance data and combinations of the following sediment parameters: % moisture, % total organic carbon, % loss on ignition at 950°C, and average grain size (*Mz*). The BEST procedure estimated Spearman correlation ($\rho_s$) values between Bray-Curtis community similarity matrices and the Euclidean distance similarity matrices derived from different subsets of the normalized abiotic data for the same grab samples.

To determine how altering the level of taxonomic resolution would affect the results of the multivariate analyses, abundances were aggregated to the levels of genus, family, suborder, order, infraclass and class and separate Bray-Curtis similarity matrices were obtained for untransformed, square-root transformed, log-transformed, and presence/absence transformed abundance data for each of these different resolutions. Taxonomic sufficiency was tested by calculating Spearman rank correlations ($\rho_s$) between species and lower taxonomic resolution similarity matrices using the RELATE procedure in PRIMER (Clarke and Warwick 2001).

Since some infaunal invertebrate species were spatially clumped at a site, an index of dispersion was calculated to determine which species were less spatially clustered within a site and might therefore have a lower variance for future monitoring. In PRIMER 6, the index of dispersion (D), which corresponds to a “clumping” measure, was calculated as: $D = \sigma^2/\mu$, where $\sigma^2$ is the variance and $\mu$ the mean (Clarke et al., 2006). Out of the 149 species, 5 relatively abundant and well-distributed species ($D < 3$) were selected as potentially good discriminating species and power analyses were done for these individual species.

## PHYSICAL/CHEMICAL ANALYSES OF SEDIMENT

Frozen sediment samples were thawed prior to analyses and macroinvertebrates or debris (pieces of wood, fibres or plastic) were manually removed. The wet sample was homogenized and aliquots (see Table 2) were removed for determination of loss on ignition (LOI) and % moisture. The remainder of the sample was freeze-dried for a minimum of three days and then homogenized using a dried, acid washed glass mortar and pestle. Aliquots of the dried sample were removed for determination of grain size, elements, total mercury (Hg), PAHs, and PCBs. Sample requirements and methods for the different physicochemical analyses are summarized in Table 2 and described in detail in subsequent sections.

Table 2. Summary of physicochemical analyses of sediment samples.

| Test | Mass of sample | Unit Reported | Method Used |
|---|---|---|---|
| $LOI_{550/950}$ | 20 g wet | % | Gravimetric |
| TOC | Calculated from $LOI_{550}$ | % | Calculated from linear regression<br>% TOC = (0.255 x % $LOI_{550}$) - 0. 111, $R^2$ = 0.882 |
| Moisture | 15 g wet | % | Gravimetric |
| Grain Size | 20 g dry | % | Gravimetric |
| Elemental (Metals) | 0.5 g dry | mg/kg dw | Digestion and ICP-OES quantification based on US EPA 3051, 200.7, and 6010C methods |
| Total Hg | 0.03 g dry | µg/kg dw | DMA-80 based on US EPA 7473 methods |
| PAHs | ≥10 g dry | mg/kg dw | ASE extraction, GPC cleanup and GC/MS quantification based on US EPA 3545, 3640A and 8270C methods |
| PCBs | ≥10 g dry | µg/kg dw | ASE extraction, GPC and Florisil cleanup and GC/ECD quantification based on US EPA 3545, 3640A, 3620C, and 8082 methods |

MOISTURE CONTENT

An empty container was weighed (Sartorius CP323S balance) and then reweighed once ~15 g of homogenized, wet sample was added. The container was covered with a Kimwipe and then placed in the freeze dryer (Labconco FreezeZone[12]) for a minimum of three days. The container was re-weighed and the percent moistures were calculated as follows:

$$\%\ Moisture = \left(1 - \left[\frac{(weight\ of\ container\ + dry\ sample) - weight\ of\ container}{(weight\ of\ container\ + wet\ sample) - weight\ of\ container}\right]\right) x100\%$$

GRAIN SIZE

Approximately 20 g of homogenized, dried sediment was weighed into a tared, clean 150 mL beaker. Using a series of sieves stacked from largest to smallest mesh size (4, 1, 0.500, 0.250, 0.125, and 0.063 mm) with a piece of paper under the last sieve to catch the finest grain fraction, the sample was dumped into the top sieve and the stack was manually shaken for 10 minutes. The empty beaker was re-weighed to determine the actual weight of the sample used. The contents of the 4-mm sieve were carefully transferred to a piece of paper and then into a tared beaker and the mass recorded. This was repeated for each of the remaining sieves and the percent of each grain size fraction was determined gravimetrically as follows:

$$\%Grain\ size\ fraction = \frac{weight\ of\ sediment\ fraction\ in\ sieve}{total\ weight\ of\ sample} x100\%$$

Grain size fractions were classified as follows based on the Wentworth scale are listed in Table 3.

Table 3: Grain size Wentworth size class and reported categories.

| Grain size (mm) | Wentworth size class | Reported category |
|---|---|---|
| >4 | Pebble | Gravel |
| 1 to <4 | Very coarse sand and granule | |
| 0.5 to <1 | Coarse sand | Coarse sand |
| 0.250 to <0.5 | Medium sand | Fine and medium sand |
| 0.125 to <0.250 | Fine sand | |
| 0.063 to <0.125 | Very fine sand | Silt and clay |
| <0.063 | Silt and clay | |

Average grain size (*Mz*) was determined as: $Mz\ (mm) = \sum (f_i m_i)/100$ , where $m_i$ is the size of grade *i* (i.e., 4, 2, 1, 0.5, 0.25, 0.125, 0.063 mm) and $f_i$ is its percentage.

<u>LOSS ON IGNITION AND TOTAL ORGANIC CARBON</u>

Loss on ignition (LOI), which is a measure of all organic matter, is a common alternative to the dry combustion measurement of total organic carbon (TOC) due to the reduced cost and labour for LOI and the ability to estimate TOC based on a relationship between these two parameters.

Approximately 20 g of homogenized, wet sample was weighed into a tared, clean, pre-weighed ceramic dish and the wet weight of the sample recorded. The sample was dried for 16 hours at 105°C in an oven (Fisher Scientific Isotemp), cooled in a desiccator and then weighed. The sample was then heated to 550°C (Barnstead Thermolyne 30400 Furnace) and held at that temperature for 3.5 hours, cooled, and then weighed. Then the sample was heated to 950°C and held for 1.5 hours, cooled, and weighed. Estimates of loss on ignition (LOI) at 550 and 950°C were determined gravimetrically as follows:

*Dry weight (DW) = (weight of dish + dry sample at specific temperature) – weight of dish*

$$\%LOI_{550} = \frac{(DW_{105} - DW_{550})}{DW_{105}} x100\% \qquad \%LOI_{950} = \frac{(DW_{550} - DW_{950})}{DW_{105}} x100\%$$

Total organic carbon was calculated based on the results of LOI. Initially, 20 samples were sent to Research Productivity Council (RPC; Fredericton, NB) for measurement of TOC using a LECO combustion/infrared method (based on Strobel et. al., 1995). The TOC content from RPC and the $LOI_{550}$ content from UNB were fit with a linear regression model in the form TOC = slope x LOI ± intercept, which was not forced through the origin. The resulting equation was used to convert the % $LOI_{550}$ to % TOC (± SE for slope and intercept).

$\%\ TOC = (0.255 \pm 0.022 \times \%\ LOI_{550}) - 0.111 \pm 0.073$, $R^2 = 0.882$

The Min and Max TOC values used in the regression were 0.4 and 1.3% respectively. A total 5.2% of the samples fell outside the regression range (22/423 samples). As a quality control for the higher TOC samples, we determined the LOI of certified reference material (CRM) 1941b (n=2, target of 2.99 ± 0.24% organic content) and calculated the TOC using the same regression shown above. The TOC was determined to be 2.17% and 2.44% TOC (average recovery of 77.0% based on the CRM target value).

ELEMENTS

Sample digestion and analysis of metals followed a test method based on US Environmental Protection Agency (US EPA) standard testing protocols 3051A (US EPA, 2007a), 200.7 (US EPA, 1994a), and 6010C (US EPA, 1998a). A 0.5 g aliquot of homogenized, dried sample was digested using a microwave digestion (CEM Mars 5) and 10 mL of metal grade nitric acid (Fisher Scientific, Canada). (This is considered to be a soft digestion that provides information on the more bioavailable/leachable fraction of metals rather than a vigorous digestion (using hydrofluoric acid) that extracts all metals in the sample.) Then 40 mL of Milli-Q water and known standardized amount of Yittrium (Y) (SCP Science, QC) was added as an internal standard after the digestion process. Samples were filtered using Millex syringe filters (0.45 µm) and disposable syringes with polyethylene barrels and polypropylene plungers (Fisher Scientific) into polypropylene test tubes (Fisher Scientific) for analysis. The following 22 elements were quantified using an inductively coupled plasma-optical emissions spectrophotometer (ICP-OES, iCAP 6500 Duo, Thermo Fisher Scientific) using an internal standard calibration method. Limit of quantification (LOQ; see below) and wavelengths used for quantification are listed in Table 4.

Table 4: Summary of LOQ and wavelength for individual elements reported.

| Element | Symbol | LOQ (mg/kg dw) | Wavelength (λ ) |
|---|---|---|---|
| aluminum | Al | <2.7 | 396.1 |
| arsenic | As | <1.6 | 189.0 |
| cadmium | Cd | <0.08 | 228.8, 214.4 |
| chromium | Cr | <0.12 | 267.7 |
| cobalt | Co | <0.15 | 228.6 |
| copper | Cu | <0.19 | 324.7 |
| iron | Fe | <0.64 | 259.9 |
| lanthanum | La | <1.0 | 333.7 |
| lead | Pb | <0.77 | 220.3 |
| magnesium | Mg | <4.3 | 279.0 |
| manganese | Mn | <0.03 | 257.6 |
| nickel | Ni | <0.13 | 221.6 |
| phosphorus | P | <0.67 | 177.4 |
| rubidium | Rb | <0.86 | 780.0 |
| selenium | Se | <1.1 | 196.0 |
| silver | Ag | <0.22 | 328.0 |

Table 4 (continued)

| Element | Symbol | LOQ (mg/kg dw) | Wavelength (λ ) |
|---|---|---|---|
| strontium | Sr | <0.004 | 407.7 |
| sulphur | S | <1.1 | 180.7 |
| thallium | Tl | <0.55 | 190.8 |
| uranium | U | <6.4 | 409.0 |
| vanadium | V | <0.15 | 292.4 |
| zinc | Zn | <0.04 | 202.5, 206.2, 213.8 |

Quality assurance/quality control (QA/QC) procedures included the following: each batch of 11 samples included a method blank (MB), CRM [National Institute of Standards & Technology (NIST) Standard Reference Material (SRM) 2702 Inorganics in Marine Sediment], and sample duplicate (see Table K-1 for recoveries). The MB consisted of Ottawa sand (Fisher Scientific, Ottawa, ON) which was run through the entire testing process. The target MB value was equal to or less than the LOQ. For instances where the MB was greater than the LOQ, the LOQ was increased to the level found in the blank. CRM and calibration check results were reported as percent recovery based on the certificate's certified and calculated target values. The duplicate samples were reported as relative percent difference. Instrument blanks and calibration checks were routinely done throughout the analysis. All standards (SCP Science, QC), calibration checks (SCP Science, QC), and reference materials were certified with a certificate of analysis. Instrument detection limits (IDL) were determined by running 20 repeats of a blank ($IDL = average_{blanks} + 3 \times SD_{blanks}$; based on US EPA 200.7). The LOQs were determined to be 5 times the IDL (Montaser and Golightly, 1992).

## TOTAL MERCURY

Sample preparation and analysis of total mercury followed a test method based on US EPA standard testing protocol 7473 (US EPA, 1998b). A 0.03 g aliquot of homogenized, dried sample was run on a direct mercury analyzer (Milestone DMA-80). Quality assurance/quality control procedures included the following. Each batch of 10 samples included an instrument blank, method blank, CRM (NIST SRM 2702 Inorganics in Marine Sediment; see Table K-1 for recoveries), calibration standard checks, and sample duplicate. The QA/QC procedures for the MB, CRMs, standard checks and sample duplicates followed those for analysis of other metals. All standards (Ultra Scientific, N. Kingstown, RI, USA), calibration checks, and reference materials were certified with a certificate of analysis. The limit of detection (LOD) was determined by averaging all the method blanks run in the batch and adding 3 times the SD of the method blanks (LOD 2.8-4.9 µg/kg dw total Hg).

## POLYCYCLIC AROMATIC HYDROCARBONS

Sample extraction and analysis of PAHs followed a test method based on US EPA standard testing protocols 3545A (US EPA, 2007b), 3640A (US EPA, 1994b), and 8270C (US EPA, 1996c). A minimum 10 g aliquot of homogenized, dried sample was extracted using an Accelerated Solvent Extractor (Dionex ASE 300) with distilled in glass (DIG) grade, 50:50 dichloromethane (DCM):hexane (Caledon Laboratories, Georgetown, ON). Extracted samples were concentrated to 6 mL of 50:50 DCM:Hexane using a Büchi rotavapor (R-200) and nitrogen evaporator (N-EVAPTM112, Organomation Associates Inc.). Samples were run through a gel permeation column (J2 Scientific Automated Gel Permeation System) using 50:50 DCM:hexane to remove heavier contaminant that may interfere with the quantification of PAHs. The sample was then concentrated into 1.0 mL isooctane (pesticide grade, Fisher Scientific) using the same techniques mentioned above. A known standardized amount of internal standard solution (naphthalene-d8, acenaphthene-d10, phenanthrene-d10, chrysene-d12 and perylene-d12) was added to each sample prior to quantification. The concentrated extracts were run on a gas chromatograph-mass spectrometer (Agilent 6890/5975B GC-MS) and quantified using an internal standard calibration and single ion monitoring mode.

Quality assurance/quality control procedures included the following. Each batch of 8 samples included a MB, MS, CRM (NIST SRM 1941b Organics in Marine Sediments; see Table K-1 for recoveries), and sample duplicate. Individual sample recoveries were verified by adding a known amount of three surrogates (nitrobenzene-d5, 2-fluorobiphenyl, p-Terphenyl; certified standards, SPEX Certiprep, Metuchen, NJ, USA) to each sample, MB, MS, CRM, and sample duplicate prior to the extraction. The surrogates were reported as percent recovery based on the calculated target concentration. In addition, instrument performance was verified by running tune check standards, and calibration check standards for both the target and surrogate compounds. All calibration standards, calibration check standards, tune standards, surrogates standards, and internal standards were certified (SPEX Certiprep, Metuchen, NJ, USA). Method detection limits (MDLs) were determined by running 8 low level spike samples (5x higher than the expected MDL) through the entire process. The t-value (n = 8, 95%) was multiplied by the standard deviation of the 8 runs to determine the MDL for each PAH. The MDL of the total PAHs was determined by taking the square root of the sum of squares of the individual PAH MDLs.

Analyses included quantification of 16 PAHs using the quantification ions listed in Table 5. The MDL was <0.01 mg/kg dw for individual PAHs. For the purpose of this report, data were summed and reported as total PAHs (MDL <0.04 mg/kg).

Table 5: Quantification ion used for quantifying the individual PAHs.

| PAH | Quantification Ion |
|---|---|
| acenaphthene | 153 |
| acenaphthylene | 152 |
| anthracene | 178 |
| benzo[a]anthracene | 228 |
| benzo[a]pyrene | 252 |
| benzo[b]fluoranthene | 252 |
| benzo[k]fluoranthene | 252 |
| benzo[g,h,i]perylene | 276 |
| dibenzo[a,h]anthracene | 278 |
| chrysene | 228 |
| fluoranthene | 202 |
| fluorene | 166 |
| indeno[1,2,3-cd]pyrene | 276 |
| naphthalene | 128 |
| phenanthrene | 178 |
| pyrene | 202 |

## POLYCHLORINATED BIPHENYLS

PCBs were only measured in the October 2011 samples of the present study. Sample extraction and analysis of PCBs followed a test method based on US EPA standard testing protocols 3545A (US EPA, 2007b), 3660B (US EPA, 1996a), 3640A (US EPA, 1994b), and 8082 (US EPA, 1996b). A minimum 10 g aliquot of homogenized, dried sample was spiked with a surrogate solution containing PCB 30 and PCB 204 (Accustandard, New Haven, CT, USA) and then extracted using an ASE 300 with DIG grade, 50:50 DCM:hexane (Caledon Laboratories, Georgetown, ON. Sulphur was removed using activated copper. Extracted samples were concentrated to 6.0 mL of 50:50 DCM:Hexane using a Büchi rotavapor (R-200) and nitrogen evaporator (N-EVAPTM112, Organomation Associates Inc.) and were run through a gel permeation column (J2 Scientific Automated Gel Permeation System) to remove contaminants that may interfere with the quantification of PCBs. Samples were re-concentrated to 1.0 mL of isooctane. Each sample was spiked with a known amount of internal standard containing PCB 103 and PCB 198 (AccuStandard, New Haven, CT, USA). The final extracts were run on a gas chromatograph-electron capture detector (Agilent 6890 GC-ECD) and quantified using an internal standard calibration.

Quality assurance/quality control procedures included the following. Each batch of 8 samples included a MB, MS, CRM (NIST SRM 1941b Organics in Marine Sediments; see Table K-1 for recoveries), and sample duplicate. The QA/QC procedures for the MB, CRMs, standard checks and sample duplicates followed those listed for PAH analysis. MDLs were determined by running 8 low level spike samples (5x higher than the expected MDL) through the entire process. The t-value (n = 8, 95%) was multiplied by the standard deviation of the 8 runs to determine the MDL for each PCB congener. The reporting limit (RL) for PCBs was based on the amount of the lowest calibration standard and determined to be 0.12 µg/kg dw for each individual congener, when two congeners co-eluted the RL was 0.24 µg/kg. The MDLs were equal to or less than the RL. All calibration standards, calibration check standards, surrogates standards, and internal standards were certified (AccuStandard, New Haven, CT, USA). Tune standards were also certified (SPEX Certiprep, Metuchen, NJ, USA).

Analyses included quantification of the following 88 individual PCBs congeners, some of which co-eluted. For the purpose of this report, congener data were summed and reported as total PCBs (RL <2.9 to <3.7 µg/kg dw).

| | | | | |
|---|---|---|---|---|
| PCB 4/10 | PCB 31 | PCB 74 | PCB 119 | PCB 172 |
| PCB 5 | PCB 33/53 | PCB 76 | PCB 123/149 | PCB 174 |
| PCB 6 | PCB 37/42 | PCB 77/110 | PCB 126/178 | PCB 180 |
| PCB 8 | PCB 44 | PCB 81/87 | PCB 128/167 | PCB 187 |
| PCB 9/7 | PCB 45 | PCB 83 | PCB 131 | PCB 190 |
| PCB 12/13 | PCB 47 | PCB 85 | PCB 132/105 | PCB 194 |
| PCB 17/15 | PCB 48 | PCB 91 | PCB 135/144 | PCB 199 |
| PCB 16/32 | PCB 49 | PCB 92/84 | PCB 146 | PCB 201 |
| PCB 18 | PCB 52 | PCB 97 | PCB 151 | PCB 202 |
| PCB 19 | PCB 56/60 | PCB 99 | PCB 153 | PCB 204[a] |
| PCB 22 | PCB 64/41 | PCB 100 | PCB 163/138 | PCB 205 |
| PCB 26 | PCB 66/95 | PCB 101/89 | PCB 169 | PCB 206 |
| PCB 28 | PCB 70 | PCB 114 | PCB 170 | PCB 207 |
| PCB 30[a] | PCB 71 | PCB 118 | PCB 171/156 | |

[a] spiked surrogates

## DATA ANALYSIS

Analytical results for chemical parameters that were less than the corresponding detection limits (i.e., < LOD, MDL, or RL; % of samples reported in Table 6) were replaced with a random value below the detection limit. Overall summary statistics were calculated based on all samples (i.e., all replicates for all sites on all sampling dates) for general comparison to sediment quality guidelines. Summary statistics were also calculated for each sampling date (5-10 samples/date) at individual sites in the Inner and Outer Harbour.

Both seasonal and interannual variations have the potential to influence long-term trends in sediment contaminant concentrations within Saint John Harbour. Therefore, to evaluate this potential variability at references sites in the present study, arsenic, lead, zinc, and total PAHs were selected as representative chemical parameters because these compounds represent both metal and organic groups, and have ISQGs and considerable historical data. To examine seasonal variation of sediment concentrations at reference sites, data were compared between the four sampling dates in Year 1 (August 2011, October 2011, April 2012, and June 2012). To examine interannual variation data were compared between October 2011 and October 2012 and between June 2012 and June 2013. It should be noted that some of the within-site differences between seasons and years may also be due to spatial heterogeneity, as samples were not always collected in the exact same location over time due to winds and strong tides.

To determine the effects of sampling date and site on mean sediment concentrations at reference sites, a two-way analysis of variance (ANOVA) was conducted for select chemical parameters, with all Inner and Outer Harbour sites. Factors (date, site) and factor interaction (date x site) were considered significant at an alpha of 0.05. When interactions were significant ($p<0.05$), date and site were split and analyzed separately within factors. The Kolmogorov-Smirnov test of normality and Levene's Median test of equal variance were used prior to all ANOVAs to test data assumptions. Data were transformed using various methods (i.e., log, reciprocal) to meet the assumption of normality and equal variance, where possible. The Holm-Sidak method was used for pairwise multiple comparisons after 2-way ANOVAs (SigmaStat 3.5 or Minitab 16.2.3). Since Site 13 was not sampled in August 2011, this created an unbalanced design for the two-way ANOVA for the Outer Harbour; therefore the analysis was run twice, once excluding all August 2011 and once excluding Site 13 data.

## Results and Discussion

### BENTHIC COMMUNITIES

A number of groups of organisms dominated the benthic infaunal communities at reference sites in the Saint John Harbour. The most abundant group of organisms at Inner Harbour sites were polychaete worms, which ranged from 74-93% of individuals, on average (Figure 2). Polychaetes at Inner Harbour sites were predominantly *Cossura longocirrata*, a deposit-feeding species which represented 36-77% of individuals at Inner Harbour sites. Infaunal invertebrates at the Outer Harbour sites were dominated by both polychaetes (40-67%) and bivalves (30-54%; Figure 2). *Cossura longocirrata* comprised a much smaller fraction of the total polychaetes at Outer Harbour sites when compared to Inner Harbour sites. Bivalves were more common at Outer Harbour sites than Inner Harbour sites; the most common species was the deposit feeder *Nucula proxima* (21-51% of individuals). Nematodes were abundant in a number of samples from Site 01 in the Inner Harbour, comprising 15% of the infaunal individuals at this site. However, the relative abundance of nematodes at Site 01 varied considerably both between sampling dates (1-37%; see data by date in Appendix B; Table B-4) and among replicates collected on the same date (replicate-specific data not shown). The abundance of nematodes may have been underestimated because most are <0.5 mm and would not have been retained by the sieve. Crustaceans, primarily amphipods and cumaceans (hooded or comma shrimp), comprised 12% of the benthic community at Site 06 in the Outer Harbour, but were less abundant at other sites. Abundance of these 2 groups may have also been underestimated due to the high mobility of the organisms. Other taxonomic groups (e.g., Bryozoa, Chordata, Cnidaria, Echinodermata, Nemertea, Sipuncula) represented ≤ 2% of the infaunal community at all sites.

Infaunal assemblages in the size range (meiofauna) of those found at the reference sites in Saint John Harbour are characteristically found in the top 5 centimeters of estuarine fine muddy sediments (Kennish 1986). The spatial distribution of benthic invertebrates is affected by a variety of environmental factors (salinity, sediment characteristics, water depth). In addition to those physicochemical factors, predation and competition for space and food among infaunal species may be responsible for the difference in species composition observed between the Inner and Outer Harbour.

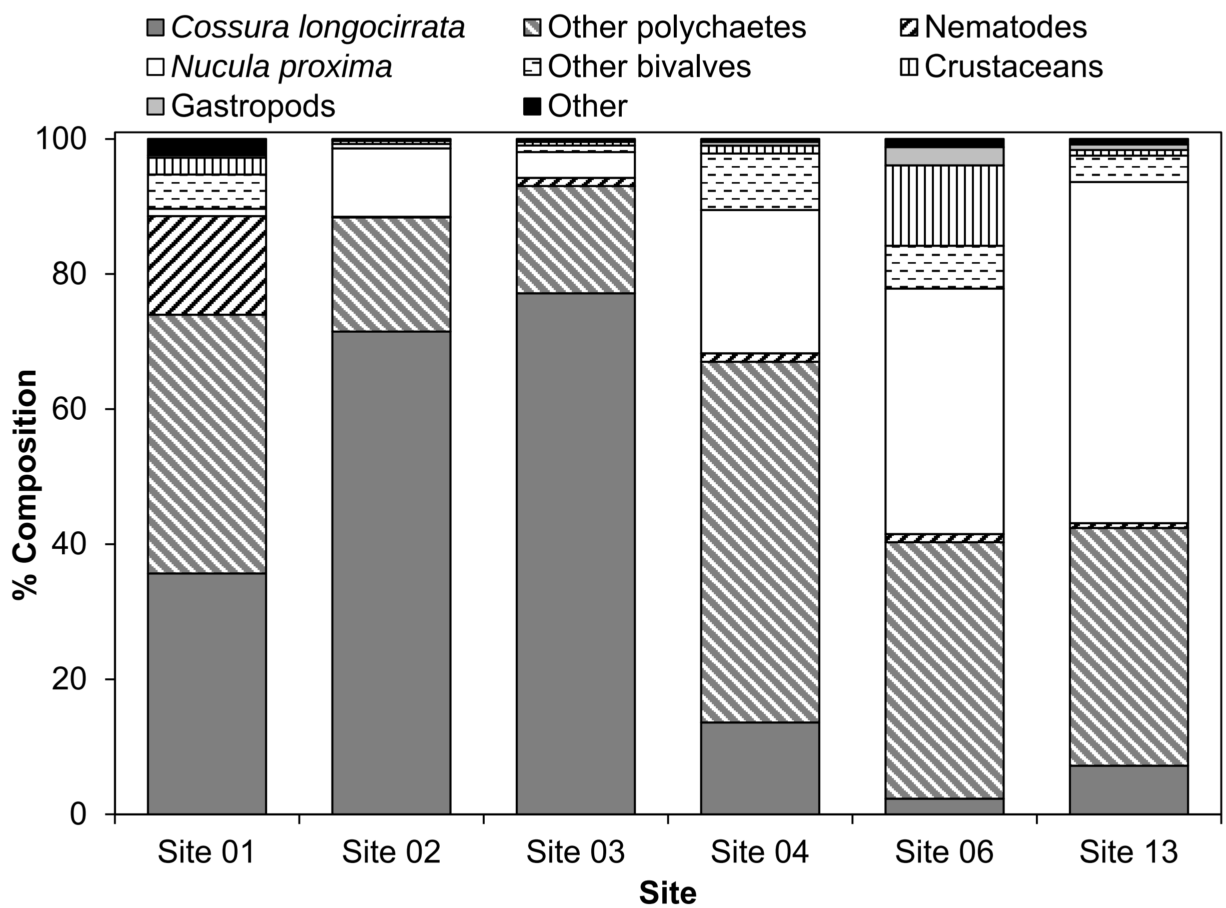


Figure 2. Percentage composition of individuals by major groups of infaunal invertebrates in sediment grab samples from reference sites in the Inner (Sites 01, 02, 03) and Outer (Sites 04, 06, 13) Saint John Harbour. Data are means of n = 5-10 samples on each of 5-6 sampling dates in 2011-2013 (see Appendix B; Table B for data by date).

SEASONAL AND INTERANNUAL VARIATION

Total abundance of benthic invertebrates varied widely across sites and dates, ranging from 5 individuals $m^{-2}$ at Site 01 in June 2012 to 1466 individuals $m^{-2}$ at Site 02 in August 2011 (Figure 3). There was a statistically significant interaction between date and site for total invertebrate abundance at reference sites in Saint John Harbour (Appendix C; Table C-1); therefore, seasonal variation was assessed on a site-specific basis. At Site 02, abundance was significantly higher in August 2011 and October 2011 than April 2012 and June 2012 (Figure 3). At Site 03, abundance in October 2011 was significantly higher than June 2012. For Site 01 in the Inner Harbour and Sites 04, 06, and 13 in the Outer Harbour, there were no significant among-date differences in total invertebrate abundance. In addition, abundance at Sites 02 and 03 were significantly higher than at other sites in both August 2011 and October 2011 (Appendix C; Table C-1).

Mean species richness ranged from 2.6 at Site 01 in June 2012 to 22.9 at Site 06 in August 2011 (Figure 4). There was a significant interaction between date and site for species richness of invertebrates so temporal analyses were done within site (Appendix C; Table C-1). At Site 01, richness was significantly higher in August 2011 and October 2011 than April 2012 and June 2012 (Figure 4). At Site 02, richness was significantly higher in October 2011 than on other dates. At Site 04, richness in August 2011 was significantly higher than June 2012. For Sites 03, 06, and 13, there were no significant among-date differences in species richness. In addition, species richness was lowest at Site 01 across all dates and was significantly lower than some of the other sites (Appendix C; Table C-1).

Mean diversity (H') ranged from 0.24 at Site 02 in August 2011 to 2.4 at Site 06 in October 2011 (Figure 5). There was a significant interaction between date and site for diversity (H') of invertebrates so temporal comparisons were done within site (Appendix C; Table C-2). At Site 02, diversity was significantly higher in April 2012 and June 2012 than in August 2011 (Figure 5). At Site 03, diversity was significantly higher in October 2011 than in August 2011. Diversity at Site 04 was significantly higher in August 2011 than June 2012. At Site 06 diversity was significantly higher in October 2011 and June 2012 than in August 2011. For Sites 01 and 13, there were no significant among-date differences in diversity.

There were some interannual differences in total invertebrate abundance among and between sites. For comparisons of total invertebrate abundance between October 2011 and October 2012, both date and site were significant factors but there was no significant interaction between date and site (Appendix D; Table D-1). Abundance at Sites 02 and 03 was significantly higher than at all other sites and was significantly higher in October 2011 than October 2012 (Appendix D; Figure D-1). For June 2012 and June 2013, there was a significant interaction between date and site so analyses were done within site (Appendix D; Table D-1). At Sites 01 and 04, abundance was significantly higher in June 2013 than June 2012 (Appendix D; Figure D-1). For Sites 02, 03, 06, and 13 there were no significant differences in abundance between dates.

Abundance at Site 01 was significantly lower than at other sites in both June 2012 and June 2013 (Appendix D; Table D-1).

For comparisons of richness between October 2011 and October 2012, date and site were both significant factors, but there was no significant interaction between date and site (Appendix D; Table D-1). Species richness was significantly higher in October 2011 than October 2012, but there was only a 12% difference between mean estimates of richness (Appendix D; Figure D-2). Species richness at Site 01 was significantly lower than at other sites, except Site 13 (Appendix D; Figure D-2). For comparisons of richness between June 2012 and June 2013, only site was a significant factor (Appendix D; Table D-1). Species richness at Site 06 was significantly higher than at other sites, which did not differ significantly from one another (Appendix D; Figure D-2).

For comparisons of diversity (H') between October 2011 and October 2012, only site was a significant factor (Appendix D; Table D-2). Diversity at Sites 04, 06, and 13 in the Outer Harbour was significantly higher than at Inner Harbour sites (01, 02, 03), which did not differ significantly from one another (Appendix D; Figure D-3). Diversity at Site 06 was significantly higher than at Site 13. For comparisons of diversity between June 2012 and June 2013, there was a significant interaction between date and site so analyses were done within site (Appendix D; Table D-2). At Site 01 diversity was significantly higher in June 2013 than in June 2012 (Appendix D; Figure D-3). For all other sites (02, 03, 04, 06, and 13), there were no significant differences in diversity between dates.

In MDS plots examining multivariate similarity in the benthic invertebrate community between samples for the seasonal (Figure 6) and inter-annual comparisons (Figure 7), Sites 02 and 03 in the Inner Harbour grouped together and separately from the Outer Harbour sites, and Site 01 was more variable than the other sites. For the seasonal comparison, there was a significant interaction between site and date (PERMANOVA, Appendix C, Table C-3). For Site 01, within-site similarity of replicate samples on a given date ranged from 25-60% and average similarity between dates ranged from 12-44% (Appendix C; Table C-3). For all other reference sites, average similarity of invertebrate assemblages both within and between dates was higher and ranged from 45-80% (Appendix C; Table C-3). For the interannual comparison, there was again a significant interaction between site and date (PERMANOVA, Appendix D, Table D-3). For Site 01, within-site similarity of replicate samples on a given date ranged from 31-55% and average similarity between dates ranged from 14-42% (Appendix D; Table D-3). For all other reference sites, average similarity of invertebrate assemblages both within and between dates was higher and ranged from 41-72% (Appendix D; Table D-3).

Overall, the results indicated that there was significant spatial and temporal variability in both univariate (total abundance, species richness, and diversity) and multivariate metrics of the infaunal invertebrate community at reference sites in Saint John Harbour. A high degree of spatial (e.g. Ysebaert and Herman, 2002, Boesch et al., 1976), seasonal (e.g. Chainho et al., 2007), and interannual (e.g. Ysebaert and Herman, 2002) variability of infaunal invertebrate communities is typical of temperate estuaries. Spatial variation in abundance and distribution of infaunal species is often related to variation in sediment characteristics (Snelgrove and Butman, 1994) and physical gradients in the estuary (salinity, depth), as well as biotic interactions among species. Some of the seasonal and annual variation in infauna at reference sites in Saint John Harbour may be attributed to changes in sediment characteristics (see section 3.2). However, temporal variation is likely also related to temporal variation in recruitment patterns of different infaunal species.

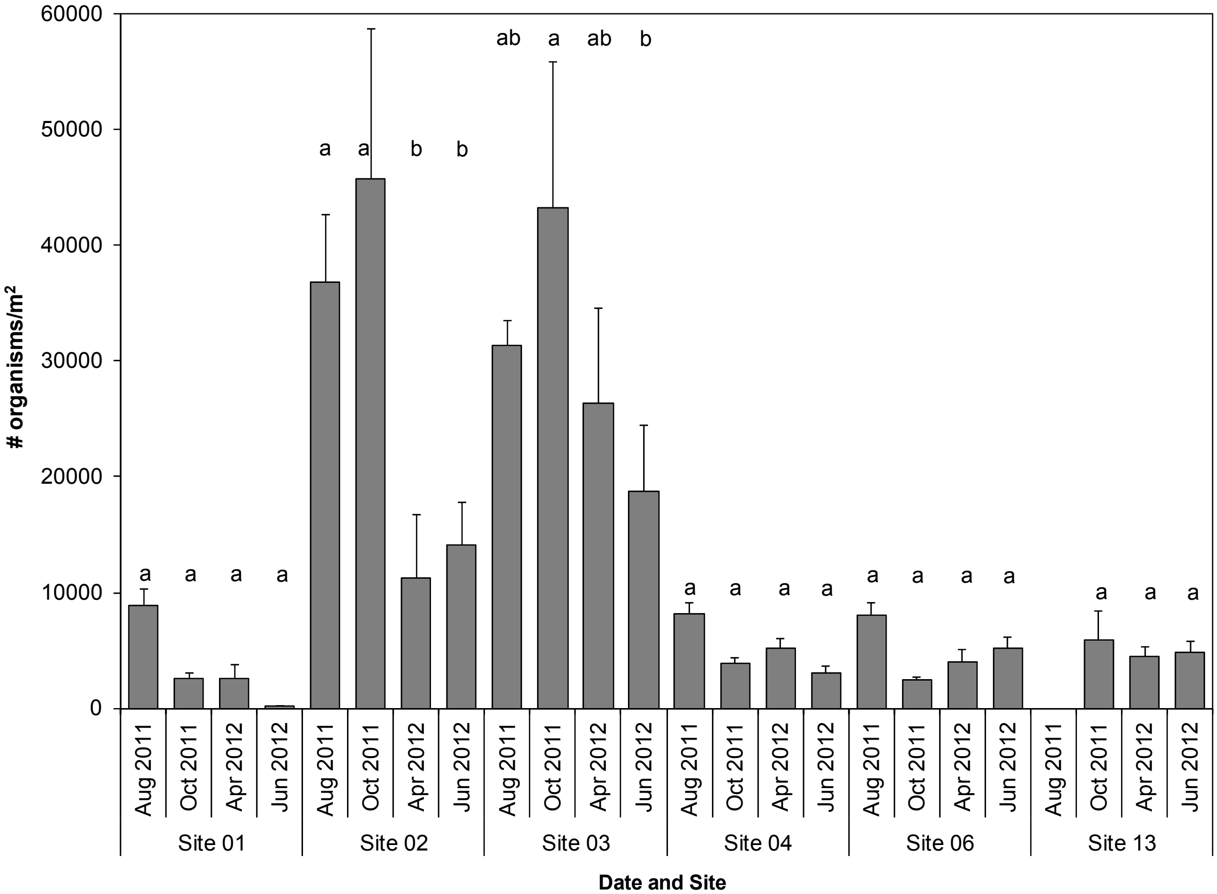


Figure 3. Seasonal variation of total benthic invertebrate abundance in sediments from Saint John Harbour reference sites, 2011-2012. Different letters indicate significantly different means for post-hoc comparisons (Holm-Sidak test, p <0.050) of dates within each site following the detection of a significant date x site interaction. Data are means (± SE) of n = 5-10 samples on each sampling date per site.

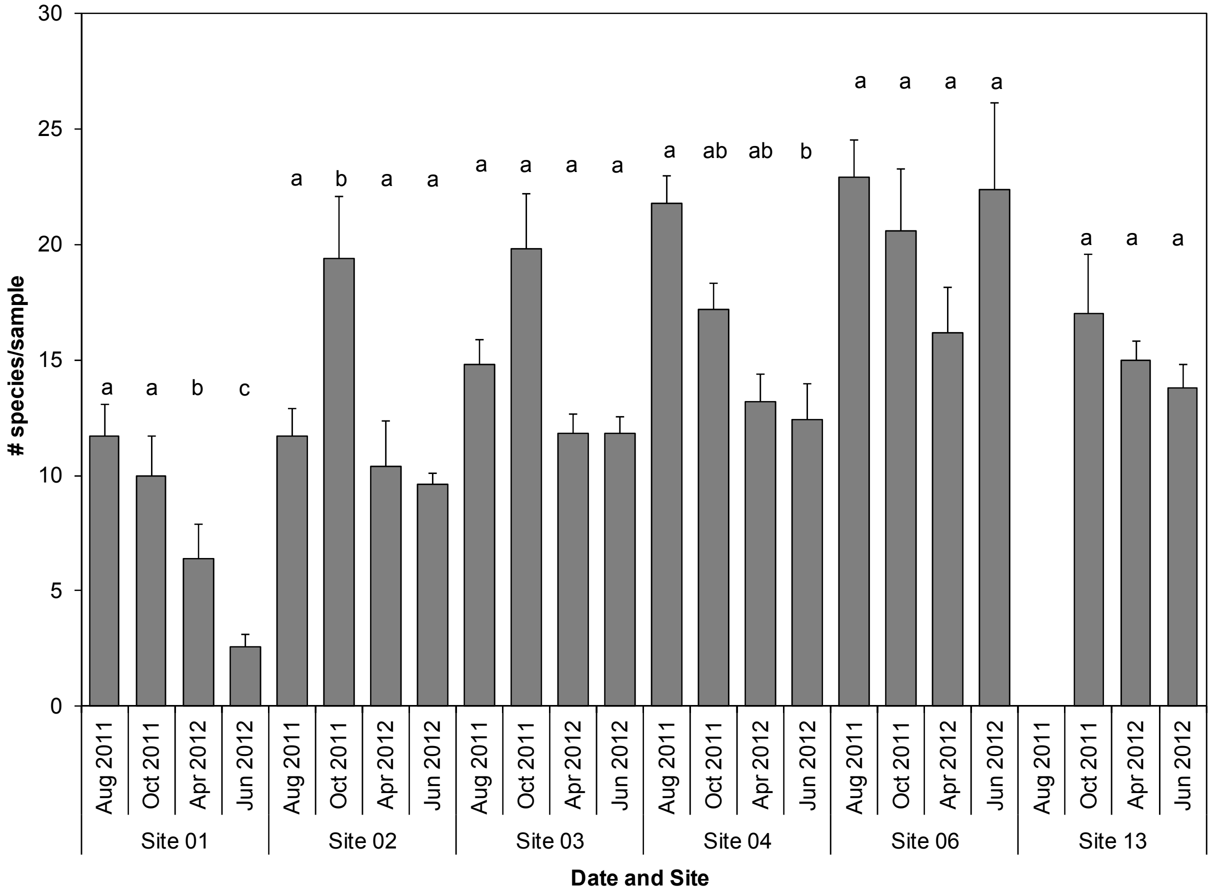


Figure 4. Seasonal variation of infaunal invertebrate species richness in sediments from Saint John Harbour reference sites, 2011-2012. See Figure 3 for description.

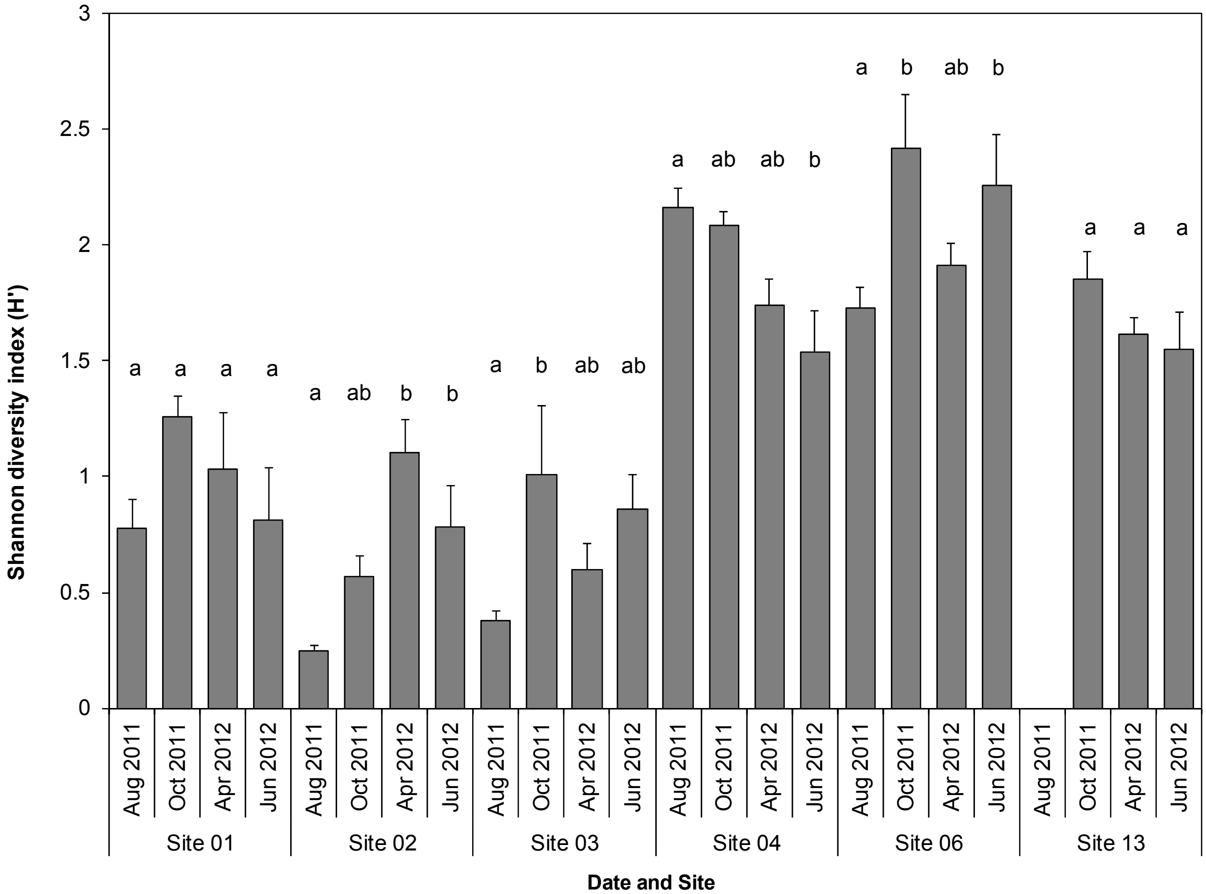


Figure 5. Seasonal variation of Shannon diversity index (H') of benthic invertebrates in sediments from Saint John Harbour reference sites, 2011-2012. See Figure 3 for description.

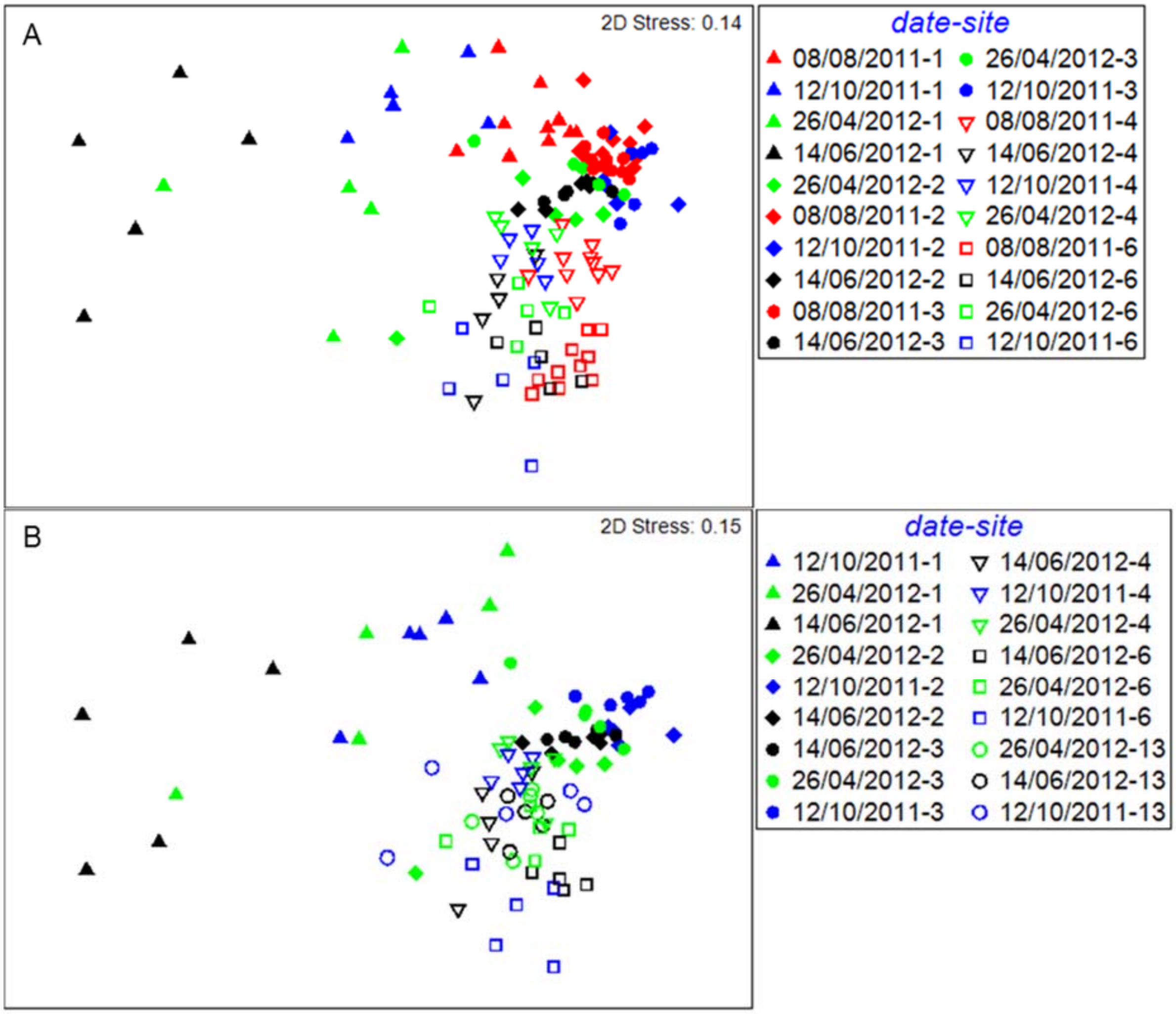


Figure 6. MDS plot of multivariate similarity in invertebrate assemblages among Saint John Harbour reference sites and dates (dd/mm/yyyy) based on Bray-Curtis similarity of square root transformed data for Year 1. Seasonal comparison for Year 1 with A) Site 13 excluded because it was not sampled in August 2011, and B) August 2011 data excluded because Site 13 not sampled at that time. Solid symbols are Inner Harbour sites and open symbols are Outer Harbour sites.

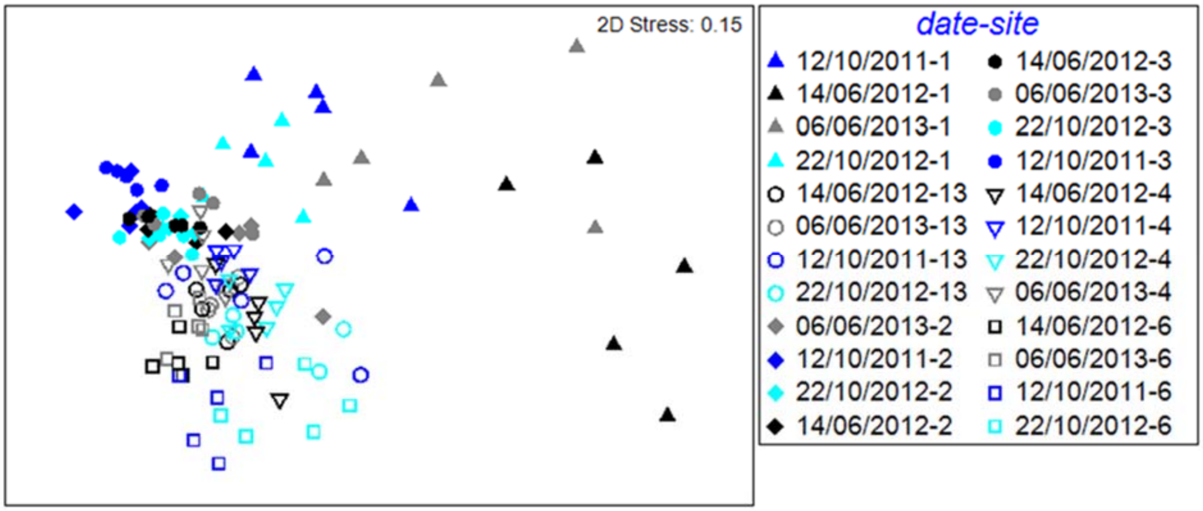


Figure 7. MDS plot of interannual differences (dates indicated as dd/mm/yyyy) and variation among sites for invertebrate assemblages at Saint John Harbour reference sites based on Bray-Curtis similarity of square root transformed data. Solid symbols are Inner Harbour sites and open symbols are Outer Harbour sites.

## SEDIMENT PHYSICAL CHARACTERISTICS

Sediments collected from reference sites in the Inner Harbour were predominantly silt-clay (~80% on average) and contained varying proportions of fine-medium sand (~16% on average; Figure 8). Sediments from the Outer Harbour were also predominantly silt-clay (~56-80% on average), but typically contained a greater proportion of fine-medium sand (~20-35% on average) than Inner Harbour sediments. Coarse sand and gravel typically comprised less than 10% of the sediment, on average, with the exception of two sampling events (see data by date in Appendix E; Table E-1). In three of five replicates collected at Site 01 in April 2012, coarse material comprised 25-90% of the samples, and in three of seven replicates collected at Site 06 in October 2011 coarse material comprised ~30% of the samples (replicate-specific data not shown). On previous sampling dates, these stations were characterized by ≤ 10% coarse material, suggesting an uncovering event at each station between sampling events. In all subsequent sampling these two sites were characterized by ≤ 10% coarse material. In general, grain size of sediment samples collected in the present study was similar to that reported in other studies of Saint John Harbour (Parrott et al., 2002; Envirosphere, 2003). A number of sediment samples appeared to be lightly anoxic based on the general description of sediment colour at the time of sampling (see Appendix B; Table B-2). This typically occurred in samples with the greatest penetration depth and was most evident at the bottom of the samples, which is not expected to affect the benthic infaunal community present.

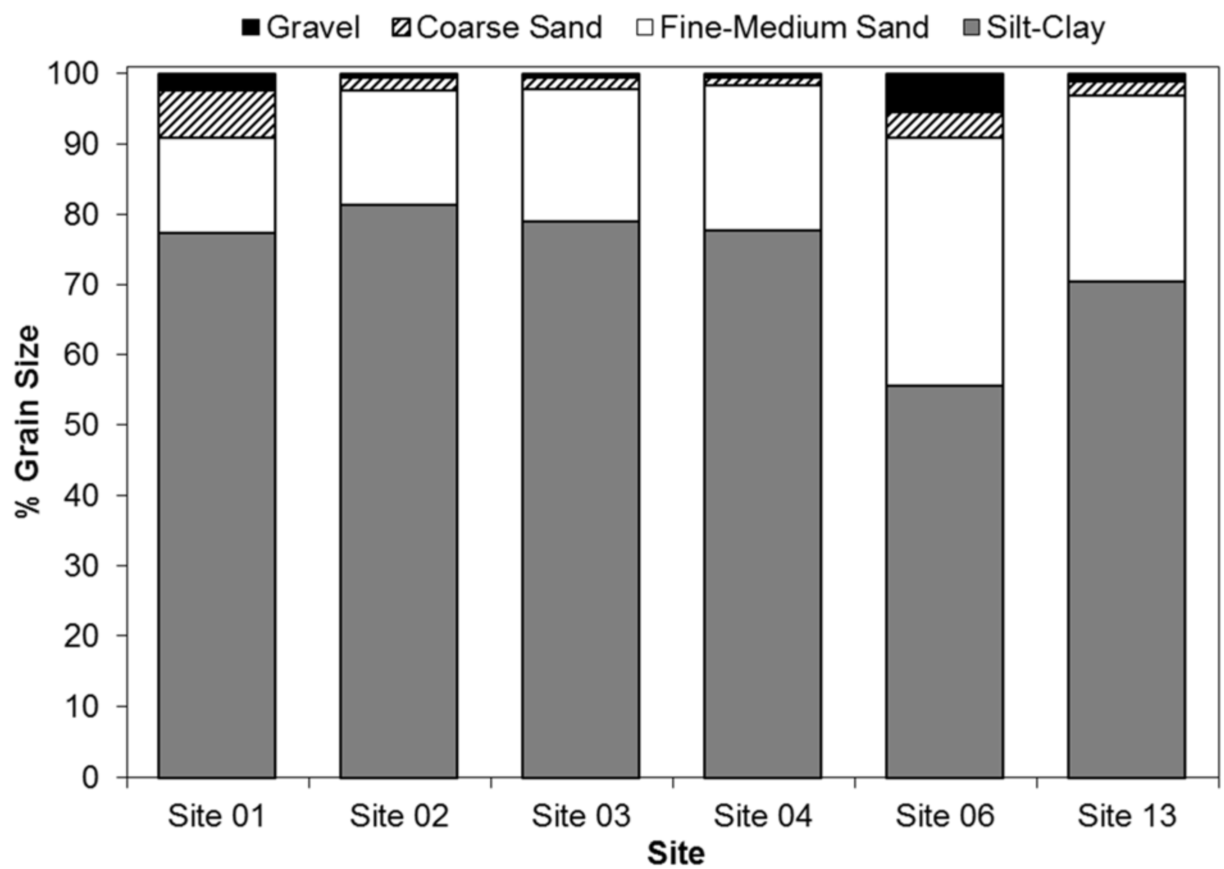


Figure 8. Grain size distribution of sediment at reference sites in the Inner (Sites 01, 02, 03) and Outer (Sites 04, 06, 13) Saint John Harbour. Data are means of n = 5-10 samples on each of 5-6 sampling dates in 2011-2013 (see Appendix E; Table E-1 for data by date).

Total organic carbon was low in sediments collected from Saint John Harbour reference sites, ranging from 0.21 to 1.7%. On average, TOC ranged from 0.66-0.88% at Inner Harbour sites and from 0.54-0.71% at Outer Harbour sites (Figure 9). These data are within the range of sediment TOC values reported in other studies of Saint John Harbour (Parrott et al., 2002; Envirosphere, 2003).

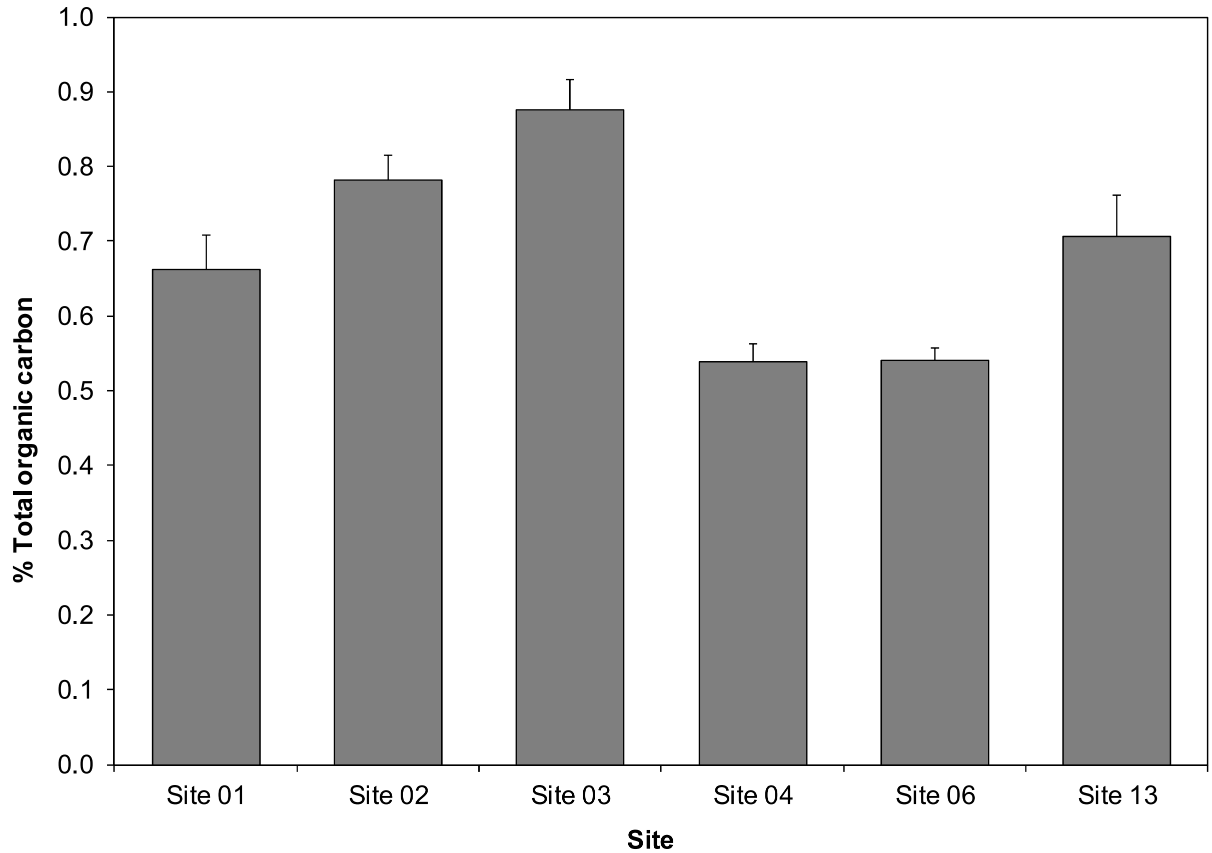


Figure 9. Total organic carbon content of sediment at reference sites in the Inner (Sites 01, 02, 03) and Outer (Sites 04, 06, 13) Saint John Harbour. Data are means (± SE) of n = 5-10 samples on each of 5-6 sampling dates in 2011-2013 (see Appendix E; Table E-1 for data by date).

RELATIONSHIP BETWEEN INFAUNAL INVERTEBRATES AND SEDIMENT CHARACTERISTICS

Linear models were used to determine if sediment parameters (% moisture, % TOC, % $LOI_{950}$, and *Mz*) explained the variation in mean abundance, richness, and diversity of benthic invertebrates among sites and sampling dates. The best fit model for mean total abundance included only sediment % moisture, to which it was positively related and explained 33% of the variance in abundance ($F_{1,33}$=16.3, p=0.0003, $r^2$=0.33), while the best model for mean Shannon diversity index (H') was a negative relationship to sediment % moisture, which explained 42% of the variance in diversity ($F_{1,33}$=24.3, p=2.26x$10^{-5}$, $r^2$=0.42). In contrast, for species richness, the best fit model included only the intercept, indicating no significant relationship to sediment parameters.

To examine the relationship of sediment characteristics to the multivariate measures of the benthic community, the BEST procedure was used to determine the set of abiotic factors whose similarity matrix best correlated to that of the similarity matrix of the biological data. This analysis indicated that for the seasonal comparison, the best fit model of sediment characteristics to the benthic community included % moisture and *Mz* ($\rho_s$ = 0.477) when site 13 was excluded and only *Mz* ($\rho_s$ = 0.357) when August 2011 was excluded (due to unbalanced design). For the interannual comparisons, correlation of the community similarity matrices to those of sediment characteristics demonstrated that the best fit model for October 2011 versus October 2012 included % moisture and *Mz* ($\rho_s$ = 0.331) and that for June 2012 versus June 2013 included % TOC and *Mz* ($\rho_s$ = 0.242).

Correlations between sediment type and infaunal invertebrate distributions have been documented in many studies (reviewed by Snelgrove and Butman, 1994). At the Saint John Harbour reference sites, this study's analyses detected some relationships between the benthic infaunal community and sediment characteristics. However, because the sediment was relatively similar at all of the reference sites (primarily silt/clay with relatively low organic matter content), there was not a large range of values of sediment characteristics over which to examine these relationships, and the infaunal species found at all of the reference sites were characteristic of muddy habitats. Consequently, characteristics of the benthic infauna community at the reference sites in Saint John Harbour were not strongly correlated with sediment parameters.

## SEDIMENT CHEMISTRY

Several metals, PAHs, and PCBs were measured in the sediments collected from reference sites in the Saint John Harbour. Of the 22 elements analyzed in sediment, 19 were measured at concentrations above the LOQ in all or most sediment samples (see Table 6). Silver, thallium, and uranium were below the LOQ in the majority of sediment samples and have not been reported. Phenanthrene, fluoranthene, and pyrene were the dominant PAHs in Saint John Harbour sediments, on average each comprising between 15-24% of the total PAHs (data not shown). PCBs 8, 22, 26, and 28 were the dominant congeners, on average each comprising 11-19% of the total PCBs (data not shown). Sediment concentrations of metals and organics typically varied by less than a factor of 10 between maximum and minimum measured values of all samples (across sites and over time), and in most cases by less than a factor of 5. The exceptions were copper and total PAHs for which concentrations varied by factors of ~85 and ~15-40, respectively, across all samples. In general, sediment concentrations (based on the averages of all data) were similar between the Inner and Outer Harbour reference sites (Table 6).

Concentrations of metals and organics in sediments were compared to Canadian Council of Ministers of the Environment (CCME) – Interim Sediment Quality Guidelines (ISQG), established for the protection of marine life. These numerical guidelines are equivalent to threshold effect levels (TEL), which represent the concentration of a chemical below which adverse biological effects are expected to occur rarely (CCME, 1999). Where ISQG-TELs for select parameters did not exist, sediment concentrations were compared to existing U.S. National Oceanic and Atmospheric Administration (NOAA) – Screening Quick Reference Tables (SQuiRT) TELs (Buchman, 2008). Surveys conducted in 2001 reported that almost all metal concentrations in Saint John Harbour sediments were below the ISQG-TELs for arsenic, cadmium, chromium, copper, lead, and zinc (mercury, PAHs, and PCBs were not measured; Parrott et al., 2002). In the present study, arsenic and nickel were the only chemicals to exceed sediment quality guidelines. Arsenic exceeded the ISQG-TELs of 7.2 mg/kg dw in 39% of Inner Harbour samples and 13% of Outer Harbour samples, by up to a factor of 2. Nickel exceeded the SQuiRT-TEL of 16 mg/kg in 72% of Inner Harbour samples and 50% of Outer Harbour samples, by up to a factor of 2. Arsenic and nickel did not exceed the CCME and SQuiRT probable effect levels (PEL) of 42 and 43 mg/kg dw, respectively; PEL is the sediment concentration above which adverse effects to benthic invertebrates are expected to occur frequently (CCME, 1999). Arsenic is naturally elevated in rock, soil, and sediment of some areas of Atlantic Canada with natural ranges reported from 4-15 mg/kg for the Bay of Fundy and 9-27 mg/kg in Passamaquoddy Bay, NB (Loring, 1982; Loring et al., 1988).

Table 6. Concentrations of metals and organics in sediment collected from reference sites in Saint John Harbour, 2011-2013. Data are based on n = 5-10 samples from each of 6 sampling sites on 6 sampling dates between August 2011 and June 2013 (except only 1 sampling date for PCBs).

| Metals and Organics (mg/kg-dw) | CCME ISQG[a] | Limit of Quantification | Inner Harbour | | | | | Outer Harbour | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | SE | n | Min | max | Mean | SE | n | min | max |
| Al | na | 2.7 | 19000 | 500 | 112 | 8400 | 30000 | 18000 | 500 | 101 | 8900 | 32000 |
| As | 7.2 | 1.6 | 6.9 | 0.1 | 112[d] | 3.9 | 11 | 6.0 | 0.2 | 101[d] | 3.9 | 15 |
| Cd | 0.70 | 0.08 | 0.08 | 0.004 | 112[c] | <0.08 | 0.21 | 0.09 | 0.004 | 101[c] | <0.08 | 0.21 |
| Co | na | 0.15 | 9.2 | 0.2 | 112 | 5.6 | 14 | 8.7 | 0.2 | 101 | 5.9 | 16 |
| Cr | 52 | 0.12 | 27 | 1 | 112 | 13 | 40 | 24 | 1 | 101 | 14 | 43 |
| Cu | 19 | 0.19 | 7.7 | 0.2 | 112[c] | <0.19 | 16 | 5.6 | 0.4 | 101[c] | <0.19 | 17 |
| Fe | na | 0.64 | 21000 | 400 | 112 | 13000 | 34000 | 21000 | 500 | 101 | 15000 | 43000 |
| La | na | 1.0 | 21 | 0.3 | 112 | 13 | 35 | 20 | 0.3 | 101 | 12 | 27 |
| Mg | na | 4.3 | 6500 | 100 | 112 | 3500 | 9500 | 5900 | 130 | 101 | 3600 | 12000 |
| Mn | na | 0.03 | 460 | 7 | 112 | 300 | 680 | 390 | 5 | 101 | 280 | 520 |
| Ni | 16[b] | 0.13 | 18 | 0.4 | 112[d] | 9.0 | 30 | 16 | 0.4 | 101[d] | 7.9 | 31 |
| P | na | 0.67 | 690 | 9 | 112 | 490 | 1000 | 540 | 10 | 101 | 330 | 920 |
| Pb | 30 | 0.77 | 9.4 | 0.2 | 112 | 4.9 | 16 | 8.8 | 0.2 | 101 | 5.0 | 17 |
| Rb | na | 0.86 | 51 | 2 | 112 | 8.3 | 110 | 43 | 2 | 101 | 7.9 | 110 |
| S | na | 1.1 | 1700 | 50 | 112 | 610 | 3600 | 1800 | 80 | 101 | 570 | 4900 |
| Se | na | 1.1 | 1.3 | 0.07 | 112[c] | <1.1 | 3.2 | 1.4 | 0.08 | 101[c] | <1.1 | 3.1 |
| Sr | na | 0.004 | 49 | 1 | 112 | 26 | 72 | 45 | 1 | 101 | 29 | 100 |
| V | na | 0.15 | 41 | 1 | 112 | 21 | 68 | 39 | 1 | 101 | 23 | 64 |
| Zn | 124 | 0.04 | 47 | 1 | 112 | 27 | 78 | 43 | 1 | 101 | 27 | 89 |
| Total Hg (µg/kg-dw) | 130 | 2.8-4.9 | 12 | 1 | 112[c] | 4.1 | 41 | 7.7 | 0.3 | 101[c] | <3.2 | 25 |
| Total PAHs | 1.7[b] | 0.04 | 0.18 | 0.02 | 112[c] | <0.04 | 1.5 | 0.14 | 0.01 | 101[c] | <0.04 | 0.60 |
| Total PCBs (µg/kg-dw) | 22 | 2.9-3.7 | 8.2 | 0.89 | 22[c] | <2.9-3.7 | 18 | 3.8 | 0.5 | 22[c] | <2.9-3.7 | 9.0 |

na – no marine sediment quality guideline exists, [a] Canadian Council of Ministers of the Environment (CCME), 1999 – Interim Sediment Quality Guidelines (ISQG) threshold effect level (TEL) for the Protection of Aquatic Life – Marine, [b] Buchman, 2008: US National Oceanic and Atmospheric Administration (NOAA) – Screening Quick Reference Tables (SQuiRT) TEL, [c] # samples < DL: Cd – 50 (Inner), 48 (Outer); Cu – 1 (Inner), 15 (Outer); Se – 47 (Inner), 41 (Outer); Total Hg – 2 (Inner), 9 (Outer); Total PAHs – 9 (Inner), 16 (Outer); Total PCBs – 1 (Inner), 9 (Outer) and [d] # samples exceeding ISQG-TEL: As – 44 (Inner), 13 (Outer) and SQuiRT-TEL: Ni – 81 (Inner), 52 (Outer)

SEASONAL AND INTERANNUAL VARIATION

Seasonal differences were found for some metals and PAHs among reference sites in the Saint John Harbour. There was a significant interaction between date and site for arsenic, lead, zinc, and PAHs (Appendix F; Table F-1); therefore, seasonal variation of sediment concentrations was assessed on a site-specific basis. At Site 01, concentrations of arsenic, lead, and zinc in sediment collected in October 2011 were significantly lower than in other seasons (Figure F-1 to Figure F-4). For Site 02, Pb and Zn concentrations in April 2012 were significantly lower than in some other seasons. Significant differences among sites were detected for arsenic and lead in August and October 2011 (Table F-1). Although there was a significant interaction between site and date for PAHs, post-hoc tests did not detect any significant differences between the combinations of sites and dates. Sediment concentrations at any one particular reference site did not appear to be consistently different than at other reference sites and there were no consistent differences in contaminant concentrations between Inner and Outer Harbour reference sites (Appendix F; Table F-1).

In general, over a 10-month period there was no consistent evidence of significant seasonal variation of sediment concentrations of metals and PAHs at reference sites in the Saint John Harbour. Seasonal differences in sediment quality have been investigated in studies of other estuarine environments. In a coastal wetland of Hong Kong, there was significant temporal variation in metal concentrations (Cd, Cu, Ni, Zn) between four seasons; however, this differed across metals and there was no general trend for the contaminants studied (Lau, 2000). In an estuary of eastern England, sediments collected every 2 months over a 22-month period showed significant seasonal differences in metal concentrations. Three select metals (Cd, Hg, Zn) showed similar temporal trends at three sites representing upper, middle, and lower reaches of the estuary, with maximum concentrations measured during the winter (December-February) and minima during the summer (July-September) (Wright and Mason, 1999).

No significant between-year differences were found for sediment contaminant concentrations in Saint John Harbour. For sediments collected in October 2011 and 2012, there was a significant interaction between date and site for arsenic, zinc, and total PAHs (Appendix G; Table G-1); therefore, interannual variation of sediment concentrations was assessed on a site-specific basis. No significant differences were detected between October 2011 and October 2012 at any of the sites (Figure G-4). Arsenic and zinc concentrations were highest at Sites 06 and 02, respectively, in October of 2012 (Figure G-1 to Figure G-4). Contaminant concentrations of sediment samples collected in June 2012 and 2013 showed a significant interaction between site and date only for As, but post-hoc comparisons did not detect any differences between years at any of the sites. For Zn, Pb, and total PAHs, concentrations did not vary significantly by date or site and there was no significant interaction between these two factors (Appendix G; Table G-1). In October 2011, metal and PAHs concentrations at Sites 02 and 03 were consistently higher than those at Sites 01 and 04; however, there were no between-site differences in sediment concentrations in October 2012, June 2012, and June 2013 (Appendix G; Table G-1).

In general, in the two years of this study there was no consistent evidence of significant interannual variation of sediment concentrations of metals and PAHs at reference sites in Saint John Harbour. Monitoring of another historically contaminated harbour in Atlantic Canada, Sydney Harbour, Nova Scotia, over a four year period (2009-2012; baseline and 3 years remediation) showed little temporal variability in sediment concentrations of metals (As, Cd, Cu, Pb, Hg, Zn); however, concentrations of total PAHs, the major contaminant of concern, increased compared to baseline during the onset of local remediation activities (Walker et al., 2013).

## SOURCES OF UNCERTAINTY

Potential sources of uncertainty during sampling in the field and processing in the laboratory include:

1) Sampling in repeated locations: wind and strong tidal currents during some of the sampling events led to some drifting in between grab samples and, therefore, to a wider distribution of the samples within certain sites and sampling dates, potentially increasing spatial variability for some sites. The estimated maximum extent of the sampled area at a site was 100-400 m.

2) External factors: sediment movement (deposition, resuspension, and transport) occurs within the Harbour and changes in sediment distribution during storm events could contribute to temporal variation in sediment chemistry and the benthic community, particularly at certain sites (e.g., changes in sediment grain size at Site 01 between sampling dates).

3) Sediment chemistry analyses: certified reference materials, method blanks, surrogates, method spikes, and duplicate samples were included as part of a QA/QC program to quantify measurement variability and error and address uncertainty. Relative percent difference (RPD) was used to determine the precision of the duplicate samples.

4) Variation in condition of preserved organisms: the delicate nature of marine invertebrates makes them susceptible to damage during sieving and processing. Despite being preserved rapidly while still in the field, condition of organisms upon identification varied temporally, most likely due to seasonal variation in body condition and size.

To address the question of the taxonomic resolution necessary to detect spatial and temporal variability in the benthic invertebrate community, a taxonomic sufficiency assessment, using second-stage MDS, was done in which abundances were aggregated to the levels of genus, family, suborder, order, infraclass and class (note that many polychaetes worms are not classified by orders but by infraclasses) and the correlation between similarity matrices for the data at different taxonomic resolutions was determined (Appendix H, Table H-1). The analyses suggest that multivariate patterns of temporal (seasonal and interannual) and spatial variability can still be detected at higher taxonomic resolution. For example, Spearman's rank correlations, $\rho_s$, were ≥0.98 at the family level compared to species level. Transformation also had effects on the patterns detected at the different levels of taxonomic resolution (Appendix H, Table H-1).

Due to spatial and temporal variability in the data, power analyses were conducted to determine if the number of samples collected was adequate to detect a range of expected effect sizes for sediment contaminants. Power analyses conducted based on site-specific mean concentrations of arsenic demonstrated that with 5 to 6 samples there was ≥ 80% power to detect a critical effect size equivalent to 2-times the SD (Vanderbilt University PS: Power and Sample Size Calculation v 3.0, 2009; t-test $\alpha$ = 0.05, Table 7). Analyses conducted with the other select metals (Pb, Zn) and total PAHs gave very similar results.

For benthic invertebrates, power analyses (Vanderbilt University PS: Power and Sample Size Calculation v 3.0, 2009; t-test $\alpha$ = 0.10, power = 90%) were done to determine the number of samples necessary to detect changes in total abundance, species richness, and diversity (H'). $\alpha$ = 0.10 and power = 90% were used for the invertebrate power analyses following the approach used in the Environmental Effects Monitoring (EEM) program for the pulp and paper industry (Environment Canada, 2010). These calculations indicated that for total abundance, species richness, and diversity, a minimum of 5 replicate samples were required to detect an effect size of 2 SD, and 18 replicate samples were required to detect an effect size of 1 SD. Because the variability (SD) differed between the population metrics (abundance, richness, and diversity) as well as across sites and dates, when the effect size was expressed in terms of % of the mean, the number of samples needed to detect differences of 75 and 100% of the mean varied among sites and dates (Oct 2011 and 2012 and June 2011 and 2012, Table 8). In general, there was higher power to detect differences in species richness and diversity than total abundance due to the greater variability in abundance. To determine if abundance of individual species was less variable than total abundance and would require fewer samples to detect changes over time, 5 species were selected based on having a dispersion value <3 (D=1.46-2.35) and total abundance across all samples >150 individuals (abundance 152-1500). The species selected were two species of polychaetes, *Ninoe nigripes* and *Nephtys incisa,* two bivalves *Arctica islandica* and *Nucula delphinodonta,* and a gastropod *Ilyanassa trivittata* (Figure D-4). Power analyses for these species with low intra-site variability indicated that an extremely large number of samples would be needed to detect changes in abundance of *A. islandica, N. delphinodonta*, and *I. trivittata* equal to 100% of the mean (Table 8). The number of samples needed to detect effects of this size for *N. nigripes* was quite variable among sites and dates, while effects of this magnitude would more easily be detected for the polychaete *N. incisa* (Table 8). However, detection of changes of 100% of the mean generally required lower sample size for total abundance than for any of the individual species.

Table 7. Power (%) based on site-specific mean concentrations of arsenic in sediments collected from reference sites in Saint John Harbour, 2011-2013. Standard deviation (SD) based on grand mean of n = 5-6 sampling dates for each site.

| Site | n | SD (σ) | Power (%) at critical effect size[a] | | |
|---|---|---|---|---|---|
| | | | 1x SD | 2x SD | 3x SD |
| 01 | 6 | 1.27 | 32 | 88 | 99 |
| 02 | 6 | 0.73 | 32 | 88 | 99 |
| 03 | 6 | 0.52 | 32 | 88 | 99 |
| 04 | 6 | 0.54 | 32 | 88 | 99 |
| 06 | 6 | 1.17 | 32 | 88 | 99 |
| 13 | 5 | 1.23 | 25 | 79 | 98 |

[a] Vanderbilt University PS: Power and Sample Size Calculation v 3.0: t-test, $\alpha = 0.050$, $\sigma$ = SD, critical effect size $\delta$ = 1-, 2-, or 3x SD

Table 8. Sample size needed to detect a difference of 75% and 100% of mean of total abundance, abundance of 5 individual species, species richness, and diversity (H') of benthic invertebrates at reference sites in Saint John Harbour, with power of 0.90 and α = 0.10, in October 2011 and 2012, and June 2012 and 2013.

| | Site | Number of replicates (n) at critical effect size (δ)[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | October | | | | June | | | |
| | | 2011 | | 2012 | | 2012 | | 2013 | |
| | | 75% | 100% | 75% | 100% | 75% | 100% | 75% | 100% |
| Total abundance | 01 | 7 | 5 | 19 | 11 | 28 | 16 | 13 | 8 |
| | 02 | 13 | 8 | 9 | 5 | 12 | 7 | 32 | 18 |
| | 03 | 14 | 8 | 7 | 4 | 15 | 9 | 23 | 13 |
| | 04 | 3 | 2 | 3 | 2 | 7 | 4 | 6 | 4 |
| | 06 | 3 | 2 | 8 | 5 | 7 | 4 | 3 | 2 |
| | 13 | 29 | 16 | 16 | 9 | 6 | 4 | 4 | 3 |
| Abundance *Ninoe nigripes* | 01 | - | - | 155 | 88 | - | - | 68 | 39 |
| | 02 | 18 | 11 | 4 | 3 | 6 | 4 | 48 | 27 |
| | 03 | 28 | 16 | 9 | 5 | 8 | 5 | 24 | 14 |
| | 04 | 12 | 7 | 16 | 10 | 36 | 21 | 4 | 3 |
| | 06 | 4 | 3 | 15 | 9 | 5 | 3 | 9 | 5 |
| | 13 | 12 | 7 | 13 | 8 | 8 | 5 | 6 | 4 |
| Abundance *Nephtys incisa* | 01 | 29 | 17 | 11 | 7 | 68 | 39 | 152 | 86 |
| | 02 | 5 | 3 | 2 | 2 | 3 | 2 | 32 | 18 |
| | 03 | 4 | 2 | 5 | 3 | 12 | 7 | 24 | 14 |
| | 04 | 5 | 3 | 9 | 6 | 10 | 6 | 20 | 12 |
| | 06 | 12 | 7 | 9 | 5 | 4 | 3 | 6 | 4 |
| | 13 | 10 | 6 | 19 | 11 | 6 | 4 | 12 | 7 |
| Abundance *Arctica islandica* | 01 | - | - | 155 | 88 | - | - | - | - |
| | 02 | 26 | 15 | 68 | 39 | - | - | 155 | 88 |
| | 03 | 31 | 18 | 26 | 15 | - | - | 58 | 33 |
| | 04 | 9 | 5 | 10 | 6 | 28 | 16 | 10 | 6 |
| | 06 | - | - | - | - | - | - | - | - |
| | 13 | 115 | 65 | 58 | 33 | 155 | 88 | 26 | 15 |
| Abundance *Nucula delphinodonta* | 01 | - | - | 155 | 88 | - | - | - | - |
| | 02 | 68 | 39 | 58 | 33 | 58 | 33 | 34 | 20 |
| | 03 | - | - | 13 | 8 | 34 | 20 | 107 | 60 |
| | 04 | 55 | 31 | 22 | 12 | 24 | 14 | 10 | 6 |
| | 06 | 155 | 88 | 155 | 88 | 152 | 86 | 81 | 46 |
| | 13 | 66 | 37 | 155 | 88 | 68 | 39 | 21 | 12 |
| Abundance *Ilyanassa trivittata* | 01 | - | - | 58 | 33 | - | - | - | - |
| | 02 | 155 | 88 | 18 | 10 | 58 | 33 | 155 | 88 |
| | 03 | 26 | 15 | 62 | 35 | 68 | 39 | 68 | 39 |
| | 04 | 155 | 88 | - | - | 58 | 33 | 26 | 15 |
| | 06 | 13 | 8 | 36 | 20 | 7 | 5 | 21 | 12 |
| | 13 | 68 | 39 | 34 | 20 | 58 | 33 | 68 | 39 |
| Richness | 01 | 5 | 4 | 3 | 2 | 7 | 4 | 7 | 4 |
| | 02 | 4 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 03 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | - |
| | 04 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 |
| | 06 | 4 | 3 | 2 | 2 | 5 | 3 | 3 | 2 |
| | 13 | 4 | 3 | 4 | 3 | 2 | 2 | 4 | 3 |
| Diversity | 01 | 2 | 2 | 4 | 3 | 13 | 8 | 3 | 2 |
| | 02 | 4 | 3 | 3 | 2 | 8 | 5 | 5 | 3 |
| | 03 | 14 | 8 | 5 | 3 | 6 | 4 | 6 | 4 |
| | 04 | - | - | 2 | 2 | 3 | 2 | - | - |
| | 06 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | - |
| | 13 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |

## DEFINITION OF REFERENCE CONDITIONS

Reference conditions at the sites were defined using the approach of Arcizewski (2014) in which normal ranges of natural variability are derived using thresholds (grand means ± 2SD). Once the expected range of natural variability is established, observation of a measurement outside of that "natural range" would trigger confirmation and further monitoring (see Table 9). In the early stages of monitoring, 2SD of the individuals in the first sample set are used to set a conservative normal range. Once the data from 3 or more sampling periods are available, the normal range can be calculated from 2SD of the means of samples; it is important to note that this estimate of the normal range will not stabilize until at least 8-12 sampling events (Arcisewski, 2014), and the initial conservative range can be used as an outer boundary for determining the level of concern.

Table 9. Tiers and decision triggers for regional environmental monitoring (Wrona and di Cenzo, 2011).

| **Level** | **Trigger** | **Consequence** |
|---|---|---|
| Effect | Significant statistical change | Seek confirmation |
| Warning Sign | Exceeds critical effect size, and is confirmed | Increase monitoring frequency to define extent and magnitude of change |
| Response Sign | Exceeds critical threshold effect size and is getting worse | Investigate cause |
| Action Level | Passes probable effects level or water quality criterion | Change in management strategy warranted |

Reference levels can be defined at multiple spatial scales (within-site, local reference sites, regional scale), and the data should be evaluated at multiple scales (Greig and Pickard 2014).

- Has the site changed?
- Has the site changed relative to local reference sites?
- Has the site changed relative to regional sites?

To define reference conditions for chemicals in sediment, average concentrations at a site on each sampling date (based on 5-10 replicate samples) were used to determine grand means and SDs on a site-specific basis, an area basis (i.e., Inner and Outer Harbour sites), and a regional basis (i.e., whole harbour). The range of reference conditions was defined as 2-times the SD of the grand mean for the site, area, or region (Appendix I; Table I-1). Values in this table can then be used to assess changes in mean values over time and can be applied to other harbour sites for which baseline data do not yet exist. An example with arsenic graphically shows how the mean concentrations at each site on each sampling date fall within the 2-times SD-range for the site, area, and region (Figure 10; see Table I-1 for specific values).

For benthic invertebrates, we determined the range of reference conditions (2-times the SD of the grand mean) for species richness (Figure 11), total abundance, and diversity for October for each site individually (based on 5 replicate samples), as well as for the Inner and Outer Harbour and the whole Harbour (Appendix J, Table J-1). It should be noted that this definition of reference conditions is based on only two years of sampling, and that 5 to 7 years of data will be required to truly define the range of reference conditions at these sites. The range of reference conditions varied due to the spatial and temporal variability in the invertebrate community. For species richness, the range of reference conditions was larger in the Outer Harbour (Sites 04-06) than in the Inner Harbour (Sites 01-03) (Figure 11). In contrast, for total abundance (Table J-1), the range of reference conditions was much greater in the Inner than the Outer Harbour due to the high variability in total abundance at Sites 02 and 03.

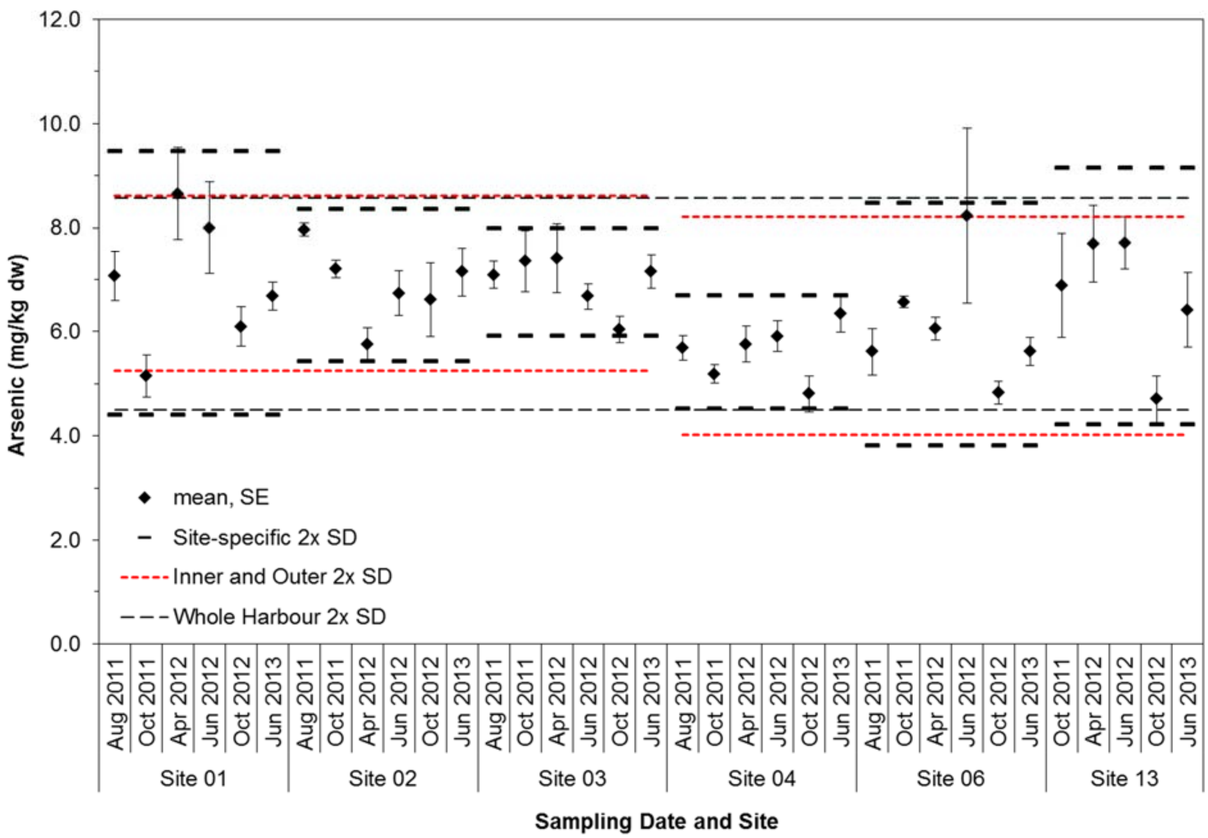


Figure 10. Range of reference site concentrations for arsenic (± 2x SD of grand mean; mg/kg dw) on the basis of site, area (Inner Sites 01, 02, 03 versus Outer Sites 04, 06, 13), and region (whole harbour) in sediment collected from reference sites in Saint John Harbour, 2011-2013.

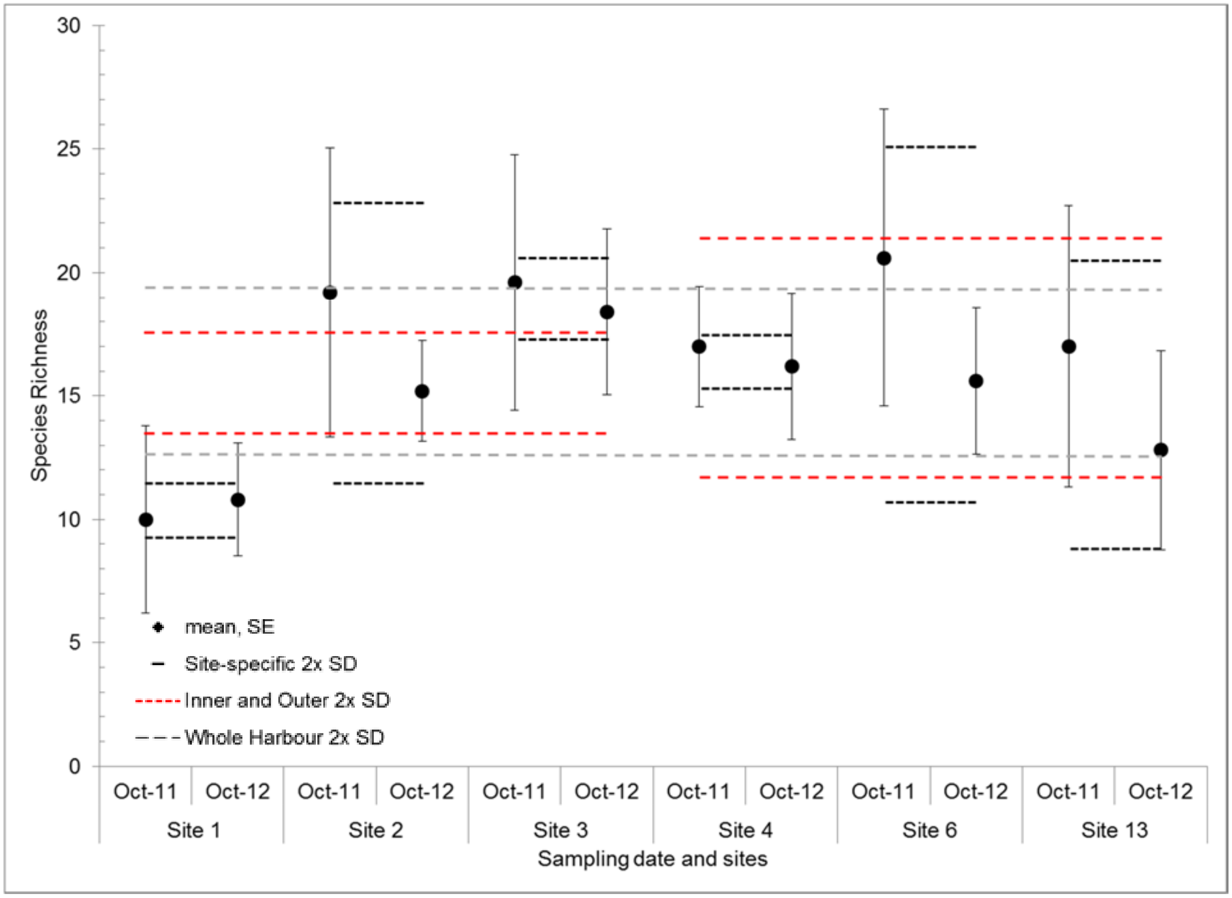


Figure 11. Range of site-specific reference conditions for species richness (± 2x SD of grand mean) of benthic invertebrate samples collected from reference sites in Saint John Harbour in October 2011 and 2012.

**RECOMMENDATIONS AND ADVICE FOR LONG TERM MONITORING AND SAMPLING IN SAINT JOHN HARBOUR**

Standardization of the sampling design is essential for being able to compare results from studies conducted by different groups. The following are recommendations for infaunal and sediment contaminant sampling in the Saint John Harbour.

Field Methods

1. Reference sites: Ongoing sampling of these six reference sites will allow for the detection of long-term, cumulative changes in the Harbour. These sites should be sampled as part of other monitoring programs to continue to provide baseline data on the overall status of the Harbour.

2. Sampling method: Sampling should be done using a grab, such as the Smith-McIntyre grab used in this study (sampled surface area of the grab of 0.089 $m^2$), of sufficient size and weight to penetrate the sediment despite strong tidal currents. Concurrent sampling of invertebrates, sediment characteristics, and

contaminants is recommended as it allows for an examination of the relationships between these variables at a small spatial scale (within-site), and the development of predictive relationships that can be applied to other sites.

3. Timing of sampling: Inner Harbour sites should be sampled during or just after high tide (minimum tidal currents approx. 2 hours after high tide) while the deeper Outer Harbour sites should be sampled during low tide.

4. Season of sampling: Community composition of benthic invertebrates changes seasonally and invertebrates tend to be more abundant and easily identified at certain times of the year (e.g. Reynoldson et al, 2003). Sediment sampling at reference sites in Saint John Harbour should be standardized to a single season of the year due to seasonal variability in the benthic invertebrate community. October is preferred due to higher species richness and total abundance at many of the sites, but June is also potentially a good time of year for sampling due to lower variability in abundance and richness at some sites (Figures 3 and 4). August is not recommended for sampling due to the small size of newly recruited individuals of many species at this time of year.

5. Replication: Based on power analyses (see section 3.4), a minimum of 5 samples per site is recommended for both sediment contaminants and benthic invertebrates.

6. Methods for sediment contaminants: The top 5 cm of sediment should be collected using a pre-cleaned corer, put in pre-cleaned glass jars, and frozen until processed. This allows for direct comparisons to the CCME ISQGs.

7. Methods for benthic invertebrates: A minimum penetration depth of 5 cm into the sediment is required. A sampled surface area of at least 0.03 $m^2$ (area sampled in this study) is needed to ensure adequate numbers of invertebrates are collected. The sample should be sieved on 500 μm mesh to retain the majority of large juveniles and adults of infaunal organisms without retaining too much sediment. A larger mesh size is not recommended due to the very small size of most of the individuals collected. Invertebrates should be preserved in 80% ethanol or buffered formalin.

Laboratory methods:

1. Sediment analysis for metals and PAHs: Sediments should be freeze-dried and macroinvertebrates and larger debris removed. Extraction, clean up and analyses should be done using standard US EPA methods and quality assurance procedures.

2. Sediment characteristics: Organic carbon content and grain size of the sediment should be measured using standard techniques.

3. Infaunal identification: Organisms should be identified to species level where possible. Taxonomic sufficiency analysis indicates that identification to family level would still retain most of the information about patterns across reference sites and dates (Appendix H, Table H-1). However, species-level identification will provide more detailed information for detection of impacts (e.g., pollution indicator species). For example, organically enriched sites in estuaries generally support only a few opportunistic or tolerant species (Rosenberg, 1978). Polychaetes in particular tend to be less diverse and abundant in contaminated estuaries heavily modified by anthropogenic activities involving contaminants (e.g., Johnston and Roberts, 2009). Identification at the species level (when possible) can also be important to monitor invasive or rare species.

Data interpretation:

1. Thresholds for assessing changes in sediment contaminants have been set at 2SDs calculated from site means, means of either the Inner or Outer Harbour data, or Harbour-wide means. These thresholds can be used to determine whether contaminant means of new samples fall within or outside these thresholds. If the latter, confirmation of the results is recommended using additional sampling.

2. Thresholds for assessing changes in infaunal invertebrates have been set at 2SDs calculated from site means because of the variability in invertebrate data among sites. As above, these thresholds can be used to assess changes of concern in the Harbour.

3. When data on reference sites for other harbours are missing, the 2SD values from reference sites in this study could be adopted as threshold criteria until such as time as sufficient data become available to design site specific criteria.

In conclusion, this report provides several seasons and years of baseline data for infaunal invertebrates and contaminants in sediments collected from reference sites in the Saint John Harbour. Results from these analyses were used to develop recommendations for a long-term monitoring program in the Harbour that would allow for assessment of cumulative effects of any new developments. In addition, this report provides some general approaches that could be applied to long-term monitoring programs in other harbours.

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**APPENDIX A.** Field sampling protocol supplemental information

Figures depicting specific aspects of sediment grab samples are shown below.

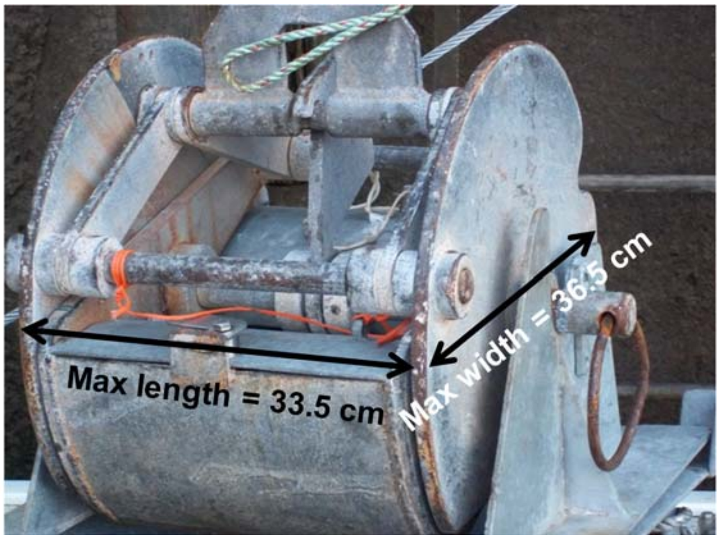



Figure A-1. Smith McIntyre grab sampler. Photo courtesy of L. LeBlanc, 2011.

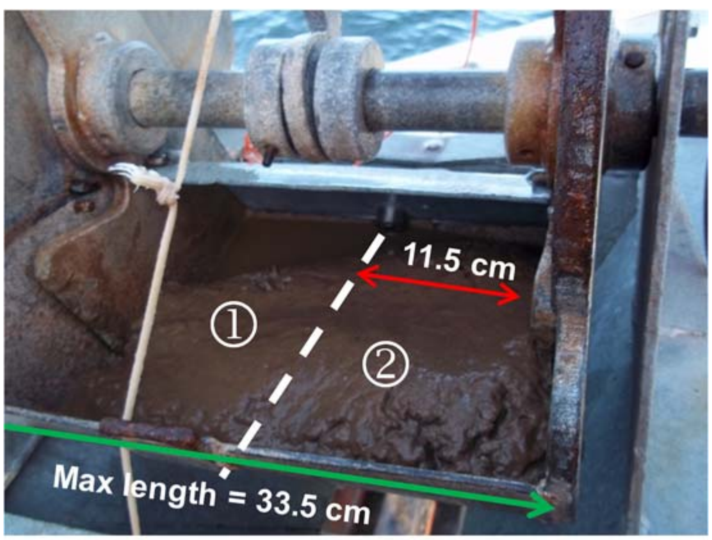



Figure A-2. Example of grab sample of sediment in a Smith McIntyre grab sampler and division of sample along grab midline into 1) physicochemical portion and 2) infaunal portion. Cut-off length for infaunal portion was 11.5 cm, not quite in the middle of the grab which would have been 16.75 cm.

## APPENDIX B. Benthic community data

Table B-1. General sediment descriptions noted during sample collection, including anoxia, of surface grab samples from six Saint John Harbour reference sites in 2011-2013.

| Date | Site | Sediment general description | Anoxic samples (replicate #, sediment depth shown for samples processed for benthos) |
|---|---|---|---|
| Aug 2011 | 01 | mud, some cores are sandy | |
| | 02 | fine mud, organic debris | |
| | 03 | fine mud, organic debris | |
| | 04 | fine mud, organic debris (shell hash, wood, plant) | |
| | 06 | mud, some rocks, shell hash, organic debris | |
| Oct 2011 | 01 | mostly sand but also some rocks, mud (some replicates), organic debris (plant, mud tubes) | 3 |
| | 02 | fine mud and organic debris (plants, wood) | |
| | 03 | fine mud, organic debris (wood, tube of polychaetes) | |
| | 04 | mud and sand, shell hash, organic debris | 6 (7 cm), 7 |
| | 06 | mud, pebbles, coarse sand, shells, and organic debris (hydroids, wood) | |
| | 13 | mud, rocks, shells, organic debris (wood) | 6 (12 cm) |
| Apr 2012 | 01 | sandy, some mud, some rocks, shells | 5 (4 cm); lightly anoxic |
| | 02 | clay, mud, some organic debris | |
| | 03 | clay, mud and organic debris (plant, wood) | |
| | 04 | clay, mud and some sand, lots of organic debris | 2, 3 (11 cm), 6 (5 cm), 7; all lightly anoxic |
| | 06 | mud, some rocks, shell hash, organic debris | |
| | 13 | mud and some rocks, shells, lots of debris (replicate #5) | |
| Jun 2012 | 01 | mostly sand, some mud and organic debris | |
| | 02 | mud, organic debris | 1, 3 (11 cm), 4 (10 cm), 5 (11 cm), 6, 7, 8 (10 cm), 9 (12 cm), 10; all lightly anoxic |
| | 03 | mud and organic debris | 1 (11 cm), 3 (9 cm), 4, 5 (10 cm), 6, 7 (11 cm), 8, 9 (10 cm), 10; all lightly anoxic |
| | 04 | clay, mud and some sand, lots of organic debris | 1 (8 cm), 2, 3, 4 (8 cm), 6, 7 (11 cm), 8, 9, 10 (9 cm); all anoxic at bottom only |

Table B-1. continued

| Date | Site | Sediment general description | Anoxic samples (replicate #, sediment depth shown for samples processed for benthos) |
|---|---|---|---|
| | 06 | mud, some rocks, shell hash, organic debris (wood) | |
| | 13 | mud, some rocks, lots of organic debris | 1 (12 cm), 8 (11 cm), 9 (8 cm), 10 (8 cm); all light anoxic at bottom |
| Date | Site | Sediment general description | Anoxic samples (replicate #, sediment depth shown for samples processed for benthos) |
| Oct 2012 | 01 | sand and mud, some pebbles, some organic debris | |
| | 02 | fine mud, lots of organic debris | |
| | 03 | clay, mud and organic debris (polychaete tubes) | |
| | 04 | fine mud, shell hash, organic debris (wood, plant) | |
| | 06 | mud and pebbles, shells | 6 (7 cm) |
| | 13 | mud, some sand, pebbles, shell hash, organic debris (wood) | |
| Jun 2013 | 01 | mud, some sand, organic debris | 6 (11 cm) |
| | 02 | fine mud, organic debris | |
| | 03 | mud, organic debris | |
| | 04 | fine mud, some shells, organic debris | |
| | 06 | mud, sand, pebbles, shells, some organic debris | |
| | 13 | mud, pebbles, shell hash, organic debris | |

Table B-2. Number of benthic infaunal invertebrate samples collected, processed, and used for data analysis from sediment collected as surface grab samples from six Saint John Harbour references sites in 2011-2013.

| Date | Inner Harbour | | | | Outer Harbour | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | collected | processed | data analysis | Site | collected | Processed | data analysis |
| Aug 2011 | 01 | 10 | 10 | 10 | 04 | 10 | 10 | 10 |
| Oct 2011 | | 5 | 5 | 5[a] | | 6 | 6 | 5 |
| Apr 2012 | | 5 | 5 | 5[b] | | 10 | 8 | 5 |
| Jun 2012 | | 10 | 5 | 5 | | 10 | 5 | 5 |
| Oct 2012 | | 8 | 5 | 5 | | 8 | 5 | 5 |
| Jun 2013 | | 8 | 5 | 5 | | 8 | 5 | 5 |

Table B-2. continued

| Date | Inner Harbour | | | | Outer Harbour | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | collected | processed | data analysis | Site | collected | processed | data analysis |
| Aug 2011 | 02 | 10 | 10 | 10 | 06 | 10 | 10 | 10 |
| Oct 2011 | | 6 | 5 | 5 | | 6 | 6 | 5 |
| Apr 2012 | | 10 | 9 | 5 | | 8 | 5 | 5 |
| Jun 2012 | | 10 | 5 | 5 | | 10 | 5 | 5 |
| Oct 2012 | | 8 | 5 | 5 | | 8 | 5 | 5 |
| Jun 2013 | | 8 | 5 | 5 | | 8 | 5 | 5 |
| Aug 2011 | 03 | 10 | 10 | 10 | 13 | ns | - | - |
| Oct 2011 | | 6 | 5 | 5 | | 6 | 6 | 5 |
| Apr 2012 | | 10 | 6 | 5[a] | | 10 | 6 | 5 |
| Jun 2012 | | 10 | 5 | 5 | | 10 | 5 | 5 |
| Oct 2012 | | 8 | 5 | 5 | | 8 | 5 | 5 |
| Jun 2013 | | 8 | 5 | 5 | | 8 | 5 | 5 |

ns - Site 13 not sampled August 2011
[a] 1 sample with <5 cm sediment depth used for data analysis to have a minimum of 5 replicates
[b] 2 samples with <5 cm depth used for data analysis

Table B-3. List of infaunal species identified in sediment collected as surface grab samples from six Saint John Harbour references sites in 2011-2013.

| Phylum - Order |
|---|
| Annelida - Polychaeta |
| *Alitta virens* (formerly *Nereis virens*) |
| *Ampharete spp.* |
| *Aphroditella hastata* |
| *Aricidea catherinae* |
| *Asabellides oculata* |
| *Bipalponephtys neotena* |
| *Brada villosa* |
| *Capitella capitata* |
| *Chaetozone setosa* |
| *Chone infundibuliformis* |
| *Cossura longocirrata* |
| *Dipolydora quadrilobata* |
| *Drilonereis longa* |
| *Drilonereis magna* |
| *Eteone longa* |
| *Flabelligera affinis* |
| *Glycera dibranchiata* |
| *Goniada maculata* |
| *Harmothoe spp. (H. extenuata/imbricata)* |
| *Hartmania moorei* |
| *Laonice cirrata* |
| *Levinsenia gracilis* |
| *Lumbrineris fragilis* |
| *Macrochaeta sp.* |
| *Maldanidae* (78% *Clymenella torquata*) |
| *Microphthalmus spp.* |
| *Nephtys picta* |
| *Nephtys caeca?* |
| *Nephtys ciliata* |
| *Nephtys incisa* |
| *Nereis pelagica* |
| *Ninoe nigripes* |
| *Ophelina acuminata* |
| *Owenia fusiformis* |
| *Pherusa spp.* |
| *Pholoe minuta* |
| *Phyllodoce mucosa* |
| *Polycirrus spp.* |
| *Polydora websteri* |
| *Prionospio steenstrupi* |
| *Sabellaria vulgaris* |
| *Scalibregma inflatum* |
| *Scoletoma tenuis* |
| *Scoletoma tetraura* |
| *Scoloplos acutus* |
| *Spiophanes bombyx* |
| *Sternaspis scutata* |
| *Sthenelais limicola* |
| *Syllidae* |
| *Terebellides stroemii* |
| *Tharyx spp.* |
| *Travisia carnea* |
| unknown polychaete - brown and green |
| Annelida – Oligochaeta |
| unknown oligochaete |
| Arthropoda – Amphipoda |
| *Ampelisca macrocephala* |
| *Ampelisca vadorum* |
| *Aoridae* |
| *Argissa hamatipes* |
| *Caprella septentrionalis* |
| *Casco bigelowi* |
| *Deflexilodes intermedius* |
| *Dyopedos monacantha* |
| *Gammarus sp.* |
| *Haploops fundiensis* |
| *Harpinia propinqua* |
| *Ischyrocerus anguipes* |
| *Leptocheirus pinguis* |
| *Melita dentata* |
| *Photis pollex* |
| *Phoxocephalus holbolli* |
| *Unciola irrorata* |
| *Unciola serrata* |

Table B-3. continued.

Phylum - Order

Arthropoda - Copepoda
- unknown Copepoda
- Harpacticoida

Arthropoda - Cumacea
- *Diastylis spp. (D. polita and D. scuulpta)*
- *Diastylis quadrispinosa*
- *Eudorella spp.*
- *Lamprops quadriplicata*
- *Leptostylis sp.?* (juvenile)
- *Oxyurostylis smithi*
- *Pseudoleptocuma sp.*

Arthropoda - Isopoda
- *Chiridotea coeca*
- *Chiridotea tuftsi*
- *Edotia triloba*
- *Idotea phosphorea*

Arthropoda - Nebaliacea
- *Nebalia bipes*

Arthropoda - Ostracoda
- unknown Ostracoda

Arthropoda - Sessilia
- *Balanus balanus*

Arthropoda - Trombidiformes
- *Halacaridae*

Bryozoa
- *Caberea ellisii*
- *Crisia eburnea*
- *Flustra foliacea*

Cephalorhyncha
- *Pycnophyes sp.*

Chordata
- *Dendrodoa carnea*
- *Didemnum albidum*
- *Molgula siphonalis?*
- *Molgula sp. 1*
- *Molgula sp.2*
- unknown right angle siphon tunicate

Cnidaria
- unknown Actiniaria sp.1 - brown
- unknown Actiniaria - short white
- *Clytia sp.*
- unknown Cnidaria - soft colony
- *Edwardsia sp. 1*
- *Edwardsiidae* (different than sp.1)

Echinodermata
- *Amphipholis squamata*
- *Ekmania barthii*
- *Mesothuria (Allantis) intestinalis?*

Mollusca – Bivalvia
- *Anomia simplex*
- *Arctica islandica*
- *Astarte undata*
- *Cyclocardia borealis*
- *Ensis directus*
- *Hiatella arctica*
- *Lyonsia hyalina*
- *Macoma balthica*
- *Modiolus modiolus*
- *Musculus sp.*
- *Mysella planulata*
- *Mytilus edulis/trossulus*
- *Nucula delphinodonta*
- *Nucula proxima*
- *Nucula tenius*
- *Nuculana tenuisulcata*
- *Pandora gouldiana*
- *Parvicardium pinnulatum*
- *Periploma aleuticum*
- *Solamen glandula*
- *Spisula solidissima*
- *Thraciidae*
- *Thyasira flexuosa*
- *Thyasira trisinuata?*
- *Yoldia limatula*
- *Yoldia myalis*
- *Yoldia sapotilla*

Table B-3. continued.

| Phylum - Order | |
|---|---|
| Mollusca - Gastropoda | Nematoda |
| *Crepidula fornicata* | unknown Nematoda |
| *Cylichna gouldii* | Nemertea |
| *Diaphana minuta* | *Cerebratulus lacteus* |
| *Ilyanassa trivittata* | unknown Nemertea |
| *Littorina saxatilis* | Oligochaeta |
| *Lunatia heros* | unknown Oligochaeta |
| *Nucella lapillus* | Phoronida |
| *Propebela concinnula?* | *Phoronis muelleri?* |
| *Retusa obtusa* | Platyhelminthes |
| Mollusca - Nudibranchia | unknown Trematoda – yellow |
| *Cuthona sp.* | Porifera |
| Mollusca - Scaphopoda | *Haliclona oculata* |
| *Antalis entalis* | Sipuncula |
| Mollusca - Solenogaster | *Golfingia sp.* |
| *Chaetoderma nitidulum* | *Phascolion (Phascolion) strombus strombus* |
| | unknown Sipuncula sp. 1 |

Table B-4. Benthic infaunal invertebrate community composition (by % of individuals) from sediment grab samples from six Saint John Harbour references sites in 2011-2013.

| | Inner Harbour – Site 01 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 5 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Composition – Major groups (%)* | | | | | | | | | | | | |
| Polychaetes | 92 | 4 | 95 | 2 | 65 | 18 | 52 | 17 | 93 | 3 | 47 | 12 |
| *Cossura longocirrata* | 78 | 5 | 36 | 15 | 20 | 17 | 4 | 4 | 63 | 9 | 14 | 6 |
| Other polychaetes | 14 | 3 | 59 | 14 | 46 | 19 | 48 | 18 | 30 | 6 | 34 | 6 |
| Nematodes | 6 | 4 | 0.9 | 0.7 | 31 | 17 | 10 | 6 | 2 | 1 | 37 | 8 |
| Bivalves | 1 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 28 | 12 | 2 | 1 | 5 | 5 |
| *Nucula proxima* | 0.6 | 0.2 | 0.2 | 0.2 | 0 | 0 | 0 | 0 | 0.8 | 0.5 | 5 | 5 |
| Other bivalves | 0.6 | 0.2 | 0 | 0 | 0.2 | 0.2 | 28 | 12 | 2 | 1 | 0 | 0 |
| Crustaceans | 0.7 | 0.2 | 3 | 2. | 0.8 | 0.5 | 5 | 5 | 2 | 1 | 3 | 3 |
| Gastropods | 0.04 | 0.04 | 0 | 0 | 1 | 1 | 0 | 0 | 0.7 | 0.5 | 0 | 0 |
| Other | 0.3 | 0.1 | 0.8 | 0.6 | 2 | 1 | 5 | 5 | 0 | 0 | 7 | 4 |
| *Total abundance (#/m$^2$)* | 8885 | 1438 | 2548 | 521 | 2523 | 1268 | 156 | 66 | 3688 | 1278 | 729 | 205 |
| *Richness (# species/sample)* | 12 | 1.4 | 10 | 1.7 | 6 | 1.5 | 3 | 0.5 | 11 | 1.0 | 7 | 1.5 |
| *Shannon diversity (H')* | 0.78 | 0.13 | 1.26 | 0.09 | 1.03 | 0.24 | 0.81 | 0.23 | 1.24 | 0.18 | 1.53 | 0.15 |

| | Inner Harbour – Site 02 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 5 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Composition – Major groups (%)* | | | | | | | | | | | | |
| Polychaetes | 99 | 0.1 | 97 | 0.8 | 77 | 12 | 95 | 1 | 92 | 1 | 70 | 16 |
| *Cossura longocirrata* | 96 | 0.4 | 89 | 2 | 55 | 13 | 79 | 6 | 69 | 4 | 41 | 13 |
| Other polychaetes | 3 | 0.4 | 8 | 1 | 22 | 3 | 16 | 5 | 23 | 3 | 30 | 11 |
| Nematodes | 0.04 | 0.02 | 0.07 | 0.04 | 0.3 | 0.3 | 0 | 0 | 0.08 | 0.05 | 0.2 | 0.1 |
| Bivalves | 0.5 | 0.1 | 3 | 0.8 | 23 | 12 | 5 | 1 | 5 | 0.5 | 29 | 16 |
| *Nucula proxima* | 0.3 | 0.07 | 2 | 0.7 | 22 | 13 | 4 | 0.9 | 5 | 0.5 | 28 | 16 |
| Other bivalves | 0.2 | 0.06 | 0.6 | 0.1 | 0.7 | 0.2 | 0.7 | 0.4 | 0.9 | 0.5 | 1 | 0.2 |
| Crustaceans | 0.03 | 0.02 | 0.1 | 0.04 | 0.1 | 0.1 | 0 | 0 | 2 | 0.8 | 0.3 | 0.2 |
| Gastropods | 0.1 | 0.05 | 0.08 | 0.02 | 0.3 | 0.2 | 0.1 | 0.08 | 0.8 | 0.2 | 0.05 | 0.05 |
| Other | 0.03 | 0.02 | 0.1 | 0.08 | 0 | 0 | 0 | 0 | 0.03 | 0.03 | 0.1 | 0.1 |
| *Total abundance (#/m$^2$)* | 36841 | 5760 | 45688 | 13019 | 11265 | 5488 | 14056 | 3766 | 12648 | 2890 | 9763 | 4398 |
| *Richness (# species/sample)* | 12 | 1.2 | 19 | 2.7 | 10 | 1.9 | 10 | 0.5 | 15 | 0.9 | 10 | 0.9 |
| *Shannon diversity (H')* | 0.25 | 0.02 | 0.57 | 0.09 | 1.10 | 0.14 | 0.78 | 0.18 | 1.20 | 0.12 | 1.13 | 0.19 |

Table B4. continued.

| | Inner Harbour – Site 03 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 5 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Composition – Major groups (%)* | | | | | | | | | | | | |
| Polychaetes | 99 | 0.2 | 95 | 3 | 93 | 4 | 97 | 0.8 | 86 | 6 | 89 | 4 |
| *Cossura longocirrata* | 93 | 0.9 | 73 | 9 | 86 | 4 | 79 | 5 | 62 | 10 | 69 | 7 |
| Other polychaetes | 6 | 0.8 | 22 | 6 | 7 | 1 | 18 | 5 | 24 | 8 | 19 | 4 |
| Nematodes | 0.01 | 0.01 | 0.2 | 0.1 | 4 | 3 | 0 | 0 | 0.03 | 0.03 | 3 | 2 |
| Bivalves | 1 | 0.1 | 3 | 2 | 4 | 1 | 3 | 0.5 | 12 | 6 | 6 | 1 |
| *Nucula proxima* | 0.4 | 0.07 | 1 | 0.6 | 3 | 1 | 2 | 0.4 | 11 | 6 | 5 | 1 |
| Other bivalves | 0.5 | 0.1 | 2 | 1 | 0.4 | 0.3 | 0.4 | 0.1 | 1 | 0.3 | 1 | 0.7 |
| Crustaceans | 0.03 | 0.01 | 1 | 0.6 | 0 | 0 | 0 | 0 | 1 | 0.5 | 1 | 0.5 |
| Gastropods | 0.1 | 0.05 | 0.2 | 0.2 | 0.04 | 0.04 | 0.3 | 0.2 | 0.5 | 0.2 | 0.2 | 0.09 |
| Other | 0.09 | 0.03 | 0.6 | 0.4 | 0.02 | 0.02 | 0.1 | 0.1 | 0.09 | 0.09 | 0.4 | 0.3 |
| *Total abundance (#/m$^2$)* | 31355 | 2109 | 43259 | 12630 | 26393 | 8139 | 18785 | 5706 | 14698 | 2988 | 13819 | 5246 |
| *Richness (# species/sample)* | 15 | 1.1 | 20 | 2.4 | 12 | 0.9 | 12 | 0.7 | 18 | 1.4 | 14 | 0.6 |
| *Shannon diversity (H')* | 0.38 | 0.04 | 1.01 | 0.30 | 0.60 | 0.11 | 0.86 | 0.15 | 1.27 | 0.18 | 1.20 | 0.22 |

| | Outer Harbour – Site 04 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 5 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Composition – Major groups (%)* | | | | | | | | | | | | |
| Polychaetes | 70 | 4 | 74 | 5 | 81 | 7 | 51 | 15 | 47 | 8 | 78 | 5 |
| *Cossura longocirrata* | 25 | 4 | 16 | 6 | 18 | 6 | 3 | 2 | 2 | 0.9 | 18 | 6 |
| Other polychaetes | 45 | 3 | 58 | 5 | 63 | 8 | 48 | 14 | 46 | 7 | 60 | 5 |
| Nematodes | 0.3 | 0.2 | 0.1 | 0.1 | 0.9 | 0.6 | 0.1 | 0.1 | 0.8 | 0.2 | 5 | 1 |
| Bivalves | 26 | 3 | 23 | 5 | 17 | 7 | 47 | 15 | 50 | 8 | 14 | 5 |
| *Nucula proxima* | 14 | 2 | 15 | 4 | 12 | 5 | 40 | 14 | 36 | 7 | 11 | 4 |
| Other bivalves | 12 | 2 | 8 | 2 | 5 | 3 | 7 | 2 | 14 | 2 | 4 | 0.9 |
| Crustaceans | 2 | 0.6 | 1 | 0.7 | 0.3 | 0.2 | 0.7 | 0.5 | 1 | 0.3 | 1 | 0.6 |
| Gastropods | 0.3 | 0.09 | 1 | 0.5 | 0.4 | 0.4 | 0.4 | 0.3 | 0.2 | 0.2 | 0.9 | 0.6 |
| Other | 1 | 0.2 | 0.3 | 0.2 | 0.1 | 0.1 | 0.2 | 0.2 | 0.7 | 0.6 | 0.07 | 0.07 |
| *Total abundance (#/m$^2$)* | 8171 | 885 | 3900 | 397 | 5190 | 887 | 3065 | 595 | 3433 | 426 | 8748 | 1513 |
| *Richness (# species/sample)* | 22 | 1.2 | 17 | 1.1 | 13 | 1.2 | 12 | 1.6 | 16 | 1.3 | 16 | 0.7 |
| *Shannon diversity (H')* | 2.16 | 0.08 | 2.08 | 0.06 | 1.74 | 0.11 | 1.54 | 0.17 | 1.86 | 0.09 | 1.86 | 0.02 |

Table B4. continued.

| | Outer Harbour – Site 06 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 5 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Composition – Major groups (%)* | | | | | | | | | | | | |
| Polychaetes | 28 | 3 | 43 | 9 | 45 | 6 | 40 | 6 | 42 | 6 | 43 | 6 |
| *Cossura longocirrata* | 2 | 0.6 | 2.2 | 2 | 5 | 2 | 2 | 0.4 | 0.7 | 0.7 | 3 | 1 |
| Other polychaetes | 27 | 3 | 41 | 8 | 40 | 6 | 38 | 6 | 41 | 6 | 40 | 5 |
| Nematodes | 0.3 | 0.2 | 0.3 | 0.3 | 0.8 | 0.4 | 0.6 | 0.5 | 0.7 | 0.7 | 4 | 2 |
| Bivalves | 63 | 4 | 35 | 10 | 49 | 5 | 35 | 6 | 31 | 4 | 43 | 6 |
| *Nucula proxima* | 56 | 4 | 29 | 8 | 42 | 5 | 28 | 6 | 25 | 5 | 38 | 6 |
| Other bivalves | 7 | 0.5 | 6 | 2 | 8 | 1 | 7 | 0.4 | 6 | 3 | 5 | 2 |
| Crustaceans | 6 | 3 | 13 | 3 | 4 | 1 | 22 | 3 | 18 | 4 | 8 | 1 |
| Gastropods | 0.8 | 0.2 | 4 | 1 | 0.2 | 0.2 | 2 | 0.4 | 8 | 3 | 1 | 0.5 |
| Other | 0.7 | 0.2 | 3 | 2 | 0.3 | 0.2 | 1 | 0.5 | 1 | 0.9 | 0.3 | 0.1 |
| *Total abundance (#/m$^2$)* | 8056 | 1031 | 2430 | 280 | 4050 | 1019 | 5140 | 995 | 1259 | 278 | 5695 | 577 |
| *Richness (# species/sample)* | 23 | 1.6 | 21 | 2.7 | 16 | 1.9 | 22 | 3.7 | 15 | 1.4 | 21 | 2.0 |
| *Shannon diversity (H')* | 1.73 | 0.09 | 2.42 | 0.23 | 1.91 | 0.09 | 2.26 | 0.22 | 2.34 | 0.11 | 2.05 | 0.08 |

| | Outer Harbour – Site 13 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | | | 5 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Composition – Major groups (%)* | | | | | | | | | | | | |
| Polychaetes | ns | - | 62 | 5 | 40 | 5 | 43 | 6 | 39 | 3 | 28 | 4 |
| *Cossura longocirrata* | ns | - | 9 | 5 | 9 | 3 | 7 | 3 | 3 | 1 | 8 | 4 |
| Other polychaetes | ns | - | 53 | 9 | 31 | 4 | 35 | 6 | 36 | 4 | 20 | 3 |
| Nematodes | ns | - | 1 | 0.3 | 1 | 0.6 | 0.2 | 0.2 | 0 | 0 | 0.8 | 0.4 |
| Bivalves | ns | - | 34 | 6 | 56 | 5 | 56 | 6 | 57 | 4 | 70 | 5 |
| *Nucula proxima* | ns | - | 28 | 7 | 53 | 5 | 53 | 7 | 52 | 6 | 67 | 4 |
| Other bivalves | ns | - | 6 | 1 | 3 | 1 | 3 | 0.8 | 6 | 2 | 3 | 0.5 |
| Crustaceans | ns | - | 1 | 0.8 | 0 | 0 | 0.9 | 0.2 | 1 | 0.9 | 0.8 | 0.2 |
| Gastropods | ns | - | 0.3 | 0.2 | 1 | 0.9 | 0.3 | 0.2 | 2 | 1 | 0.3 | 0.1 |
| Other | ns | - | 1 | 0.8 | 2 | 0.9 | 0.3 | 0.3 | 0.6 | 0.2 | 0.2 | 0.1 |
| *Total abundance (#/m$^2$)* | ns | - | 5863 | 2520 | 4492 | 824 | 4872 | 870 | 2872 | 893 | 6679 | 850 |
| *Richness (# species/sample)* | ns | - | 17 | 2.5 | 15 | 0.8 | 14 | 1.0 | 13 | 1.8 | 15 | 2.1 |
| *Shannon diversity (H')* | ns | - | 1.85 | 0.12 | 1.61 | 0.08 | 1.55 | 0.16 | 1.65 | 0.11 | 1.28 | 0.12 |

ns - Site 13 not sampled August 2011

## APPENDIX C. Analysis of seasonal variation in benthic community

Table C-1. Seasonal variation between benthic communities at Inner and Outer Saint John Harbour reference sites.

| Two-way ANOVA with date and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050. | | |
|---|---|---|
| | Abundance (# individuals) | Richness (# species) |
| *Site 13 data excluded because not sampled August 2011* | | |
| Transform | not improved | Log |
| Normality | Fail (<0.050) | Fail (<0.050) |
| Equal Variance | Fail (<0.050) | Pass (0.148) |
| Date | <0.001 | <0.001 |
| Site | <0.001 | <0.001 |
| Date x Site | 0.006 | <0.001 |
| *August 2011 data excluded because Site 13 not sampled* | | |
| Transform | not improved | None |
| Normality | Fail (<0.050) | Pass (0.179) |
| Equal Variance | Fail (<0.050) | Pass (0.318) |
| Date | 0.004 | <0.001 |
| Site | <0.001 | <0.001 |
| Date x Site | 0.007 | 0.085 |

| Date within Site - Dates with different letters are significantly different | | | | | | |
|---|---|---|---|---|---|---|
| Date | Abundance (# individuals) | | | | | |
| | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
| *Site 13 data excluded because not sampled August 2011* | | | | | | |
| Aug 2011 | a | a | ab | a | a | - |
| Oct 2011 | a | a | a | a | a | - |
| Apr 2012 | a | b | ab | a | a | - |
| Jun 2012 | a | b | b | a | a | - |
| *August 2011 data excluded because Site 13 not sampled* | | | | | | |
| Aug 2011 | - | - | - | - | - | - |
| Oct 2011 | a | a | a | a | a | A |
| Apr 2012 | a | b | b | a | a | A |
| Jun 2012 | a | b | b | a | a | A |

Table C-1. continued.

| Date within Site - Dates with different letters are significantly different | | | | | | |
|---|---|---|---|---|---|---|
| Date | Richness (# species) | | | | | |
| | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
| *Site 13 data excluded because not sampled August 2011* | | | | | | |
| Aug 2011 | a | a | a | a | a | - |
| Oct 2011 | a | b | a | ab | a | - |
| Apr 2012 | b | a | a | ab | a | - |
| Jun 2012 | c | a | a | b | a | - |
| *August 2011 data excluded because Site 13 not sampled* | | | | | | |
| Aug 2011 | - | - | - | - | - | - |
| Oct 2011 | a | a | a | a | a | A |
| Apr 2012 | ab | b | b | a | a | A |
| Jun 2012 | b | b | b | a | a | A |

| Site within Date - Sites with different letters are significantly different | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Site | Abundance (# individuals) | | | | Richness (# species) | | | |
| | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 |
| *Site 13 data excluded because not sampled August 2011* | | | | | | | | |
| Site 01 | a | a | a | a | a | a | a | A |
| Site 02 | b | b | ab | a | a | b | ab | B |
| Site 03 | b | b | b | a | ab | b | b | Bc |
| Site 04 | a | a | a | a | b | ab | b | Bc |
| Site 06 | a | a | a | a | b | b | b | C |
| Site 13 | - | - | - | - | - | - | - | - |
| *August 2011 data excluded because Site 13 not sampled* | | | | | | | | |
| Site 01 | - | a | a | a | - | a | a | A |
| Site 02 | - | b | ab | a | - | b | ab | Ab |
| Site 03 | - | b | b | a | - | b | ab | B |
| Site 04 | - | a | ab | a | - | ab | ab | B |
| Site 06 | - | a | a | a | - | b | b | C |
| Site 13 | - | a | a | a | - | ab | b | B |

Table C-2. Seasonal variation between benthic communities at Inner and Outer Saint John Harbour reference sites using Shannon Diversity Index (H').

| Two-way ANOVA with date and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050. | |
|---|---|
| *Site 13 data excluded because not sampled August 2011* | |
| Transform | not improved |
| Normality | Pass (0.082) |
| Equal Variance | Fail (<0.050) |
| Date | <0.001 |
| Site | <0.001 |
| Date x Site | <0.001 |
| *August 2011 data excluded because Site 13 not sampled* | |
| Transform | None |
| Normality | Pass (0.328) |
| Equal Variance | Pass (0.614) |
| Date | 0.04 |
| Site | <0.001 |
| Date x Site | 0.096 |

Date within Site - Dates with different letters are significantly different

| Date | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
|---|---|---|---|---|---|---|
| *Site 13 data excluded because not sampled August 2011* | | | | | | |
| Aug 2011 | a | a | a | a | a | - |
| Oct 2011 | a | ab | b | ab | b | - |
| Apr 2012 | a | b | ab | ab | ab | - |
| Jun 2012 | a | b | ab | b | b | - |
| *August 2011 data excluded because Site 13 not sampled* | | | | | | |
| Aug 2011 | - | - | - | - | - | - |
| Oct 2011 | a | a | a | a | a | A |
| Apr 2012 | a | a | a | a | a | A |
| Jun 2012 | a | a | a | a | a | A |

Site within Date - Sites with different letters are significantly different

| Site | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 |
|---|---|---|---|---|---|---|---|---|
| | *Site 13 data excluded because not sampled August 2011* | | | | *August 2011 data excluded because Site 13 not sampled* | | | |
| Site 01 | a | a | a | a | - | ad | ad | A |
| Site 02 | b | b | a | a | - | b | ab | A |
| Site 03 | b | ab | a | a | - | ab | a | A |
| Site 04 | c | c | b | b | - | c | bc | B |
| Site 06 | d | c | b | c | - | c | c | C |
| Site 13 | - | - | - | - | - | cd | cbd | B |

Table C-3. PERMANOVA of seasonal variation between benthic communities at Inner and Outer Saint John Harbour reference sites using Bray Curtis similarity matrices on square root transformed data.

| Two-way PERMANOVA with date and site as factors using Bray Curtis similarity matrices | | | | | | |
|---|---|---|---|---|---|---|
| Source | df | SS | MS | Pseudo-F | P(perm) | Unique perms |
| *Site 13 data excluded because not sampled August 2011* | | | | | | |
| Date | 3 | 17151 | 5717 | 7.0156 | 0.001 | 998 |
| Site | 4 | 86669 | 21667 | 26.589 | 0.001 | 996 |
| Date x Site | 12 | 36066 | 3005.5 | 3.6882 | 0.001 | 992 |
| Residual | 105 | 85564 | 814.9 | | | |
| Total | 124 | $2.3251 \times 10^5$ | | | | |
| *August 2011 data excluded because Site 13 not sampled* | | | | | | |
| Date | 2 | 6797.9 | 3398.9 | 3.3029 | 0.001 | 999 |
| Site | 5 | 68486 | 13697 | 13.31 | 0.001 | 996 |
| Date x Site | 10 | 22218 | 2221.8 | 2.159 | 0.001 | 997 |
| Residual | 72 | 74094 | 1029.1 | | | |
| Total | 89 | $1.716 \times 10^5$ | | | | |

| Average percent similarity between/within dates | | | | |
|---|---|---|---|---|
| | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 |
| *Site 01* | | | | |
| Aug 2011 | 60 | - | - | - |
| Oct 2011 | 44 | 51 | - | - |
| Apr 2012 | 27 | 29 | 25 | - |
| Jun 2012 | 12 | 17 | 22 | 31 |
| *Site 2* | | | | |
| Aug 2011 | 75 | - | - | - |
| Oct 2011 | 69 | 72 | - | - |
| Apr 2012 | 53 | 54 | 55 | - |
| Jun 2012 | 67 | 62 | 63 | 74 |
| *Site 3* | | | | |
| Aug 2011 | 80 | - | - | - |
| Oct 2011 | 63 | 65 | - | - |
| Apr 2012 | 69 | 59 | 64 | - |
| Jun 2012 | 72 | 61 | 68 | 75 |
| *Site 4* | | | | |
| Aug 2011 | 70 | - | - | - |
| Oct 2011 | 60 | 65 | - | - |
| Apr 2012 | 59 | 65 | 65 | - |
| Jun 2012 | 53 | 57 | 57 | 57 |
| *Site 6* | | | | |
| Aug 2011 | 64 | - | - | - |
| Oct 2011 | 47 | 49 | - | - |
| Apr 2012 | 51 | 48 | 59 | - |
| Jun 2012 | 54 | 49 | 58 | 62 |

Table C-3. continued.

| Average percent similarity between/within dates | | | | |
|---|---|---|---|---|
| | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 |
| *Site 13* | | | | |
| Aug 2011 | - | - | - | - |
| Oct 2011 | - | 45 | - | - |
| Apr 2012 | - | 54 | 65 | - |
| Jun 2012 | - | 53 | 65 | 66 |

## **APPENDIX D.** Analysis of interannual variation in benthic community

Table D-1. Interannual variation between benthic communities at Inner and Outer Saint John Harbour reference sites.

| Two-way ANOVA with data and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050. | | | | |
|---|---|---|---|---|
| | Abundance (# individuals) | | Richness (# species) | |
| | Oct 2011+2012 | Jun 2012+2013 | Oct 2011+2012 | Jun 2012+2013 |
| Transform | log | log | none | Squared |
| Normality | Pass (0.446) | Pass (0.257) | Pass (0.353) | Fail (<0.050) |
| Equal Variance | Pass (0.208) | Pass (0.257) | Pass (0.626) | Pass (0.060) |
| Date | 0.003 | 0.048 | 0.017 | 0.454 |
| Site | <0.001 | <0.001 | <0.001 | <0.001 |
| Date x Site | 0.132 | 0.006 | 0.562 | 0.655 |

| Date - Dates with different letters are significantly different | | |
|---|---|---|
| Date | Abundance (# individuals) | Richness (# species) |
| Oct 2011 | a | a |
| Oct 2012 | b | b |
| Jun 2012 | - | a |
| Jun 2013 | - | a |

| Site - Sites with different letters are significantly different | | | |
|---|---|---|---|
| Site | Abundance (# individuals) | Richness (# species) | |
| | Oct 2011+2012 | Oct 2011+2012 | Jun 2012+2013 |
| Site 01 | a | a | a |
| Site 02 | b | b | a |
| Site 03 | b | b | a |
| Site 04 | a | b | a |
| Site 06 | a | b | b |
| Site 13 | a | ab | a |

| Date within site - Dates with different letters are significantly different | | | | | | |
|---|---|---|---|---|---|---|
| Date | Abundance (# individuals) | | | | | |
| | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
| Jun 2012 | a | a | a | a | a | A |
| Jun 2013 | b | a | a | b | a | A |

Table D-1. continued.

| Site within date - Sites with different letters are significantly different | | |
|---|---|---|
| Site | Abundance (# individuals) | |
| | Jun 2012 | Jun 2013 |
| Site 01 | a | a |
| Site 02 | b | b |
| Site 03 | b | b |
| Site 04 | c | b |
| Site 06 | bc | b |
| Site 13 | bc | b |

Table D-2. Interannual variation between benthic communities at Inner and Outer Saint John Harbour reference sites using Shannon Diversity Index (H').

Two-way ANOVA with data and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050.

| | Oct 2011+2012 | Jun 2012+2013 |
|---|---|---|
| Transform | none | none |
| Normality | Pass (0.357) | Pass (0.317) |
| Equal Variance | Pass (0.316) | Pass (0.707) |
| Date | 0.496 | 0.038 |
| Site | <0.001 | <0.001 |
| Date x Site | 0.068 | 0.040 |

Date - Dates with different letters are significantly different

| Date | Abundance (# individuals) |
|---|---|
| Oct 2011 | a |
| Oct 2012 | a |

Site - Sites with different letters are significantly different

| Site | Oct 2011+2012 |
|---|---|
| Site 01 | a |
| Site 02 | a |
| Site 03 | a |
| Site 04 | bc |
| Site 06 | b |
| Site 13 | c |

Date within site - Dates with different letters are significantly different

| Date | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
|---|---|---|---|---|---|---|
| Jun 2012 | a | a | a | a | a | A |
| Jun 2013 | b | a | a | a | a | A |

Site within date - Sites with different letters are significantly different

| Site | Abundance (# individuals) | |
|---|---|---|
| | Jun 2012 | Jun 2013 |
| Site 01 | a | abc |
| Site 02 | a | a |
| Site 03 | a | ab |
| Site 04 | b | bc |
| Site 06 | c | c |
| Site 13 | b | ab |

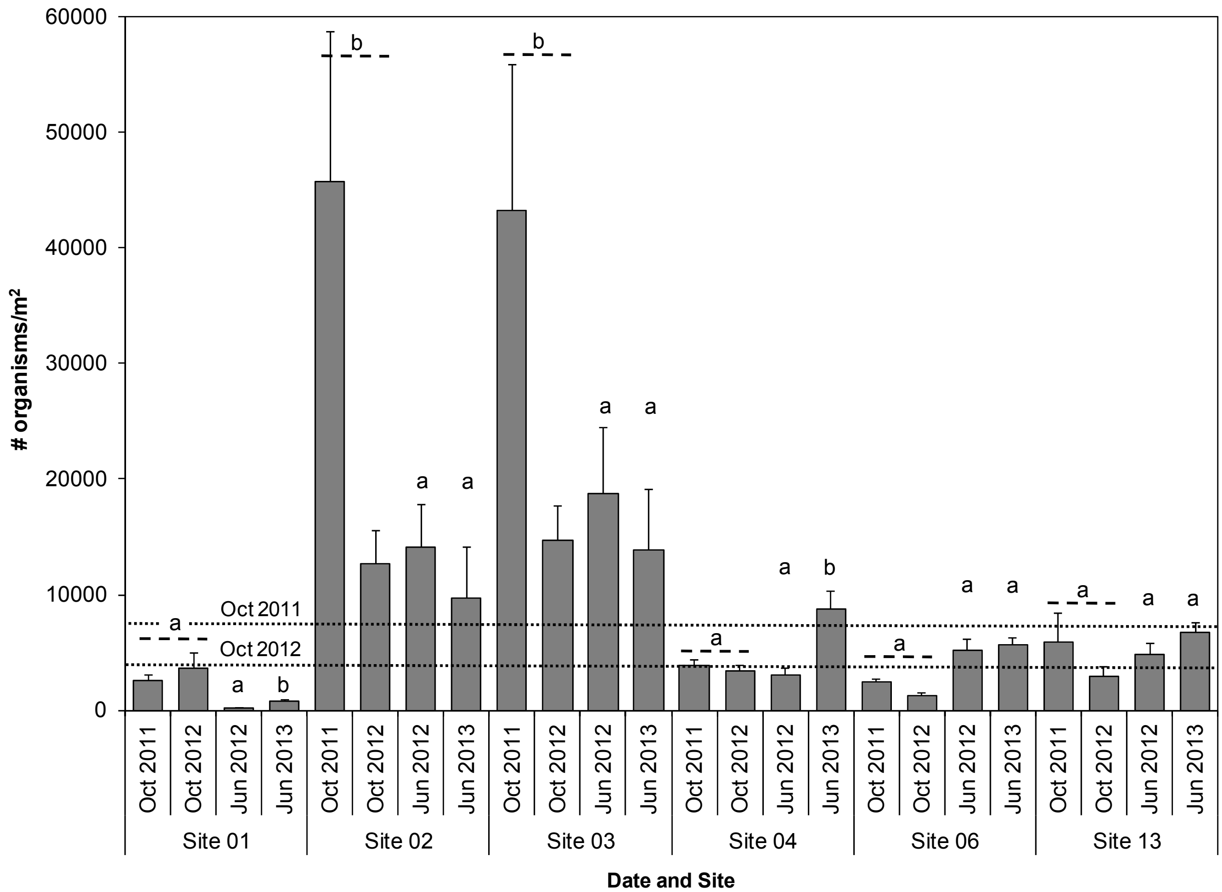



Figure D-1. Interannual variation of total organism abundance in sediments from Saint John Harbour reference sites, 2011-2013. Data are means (± SE) of n = 5 samples on each sampling date per site. Dotted lines are means across all sites that are significantly different. Different letters indicate significantly different means between sites for October 2011 and 2012 (dashed short lines) and between month-year pairing per site for June 2012 and 2013 (two-way ANOVA, Holm-Sidak test, p <0.050).

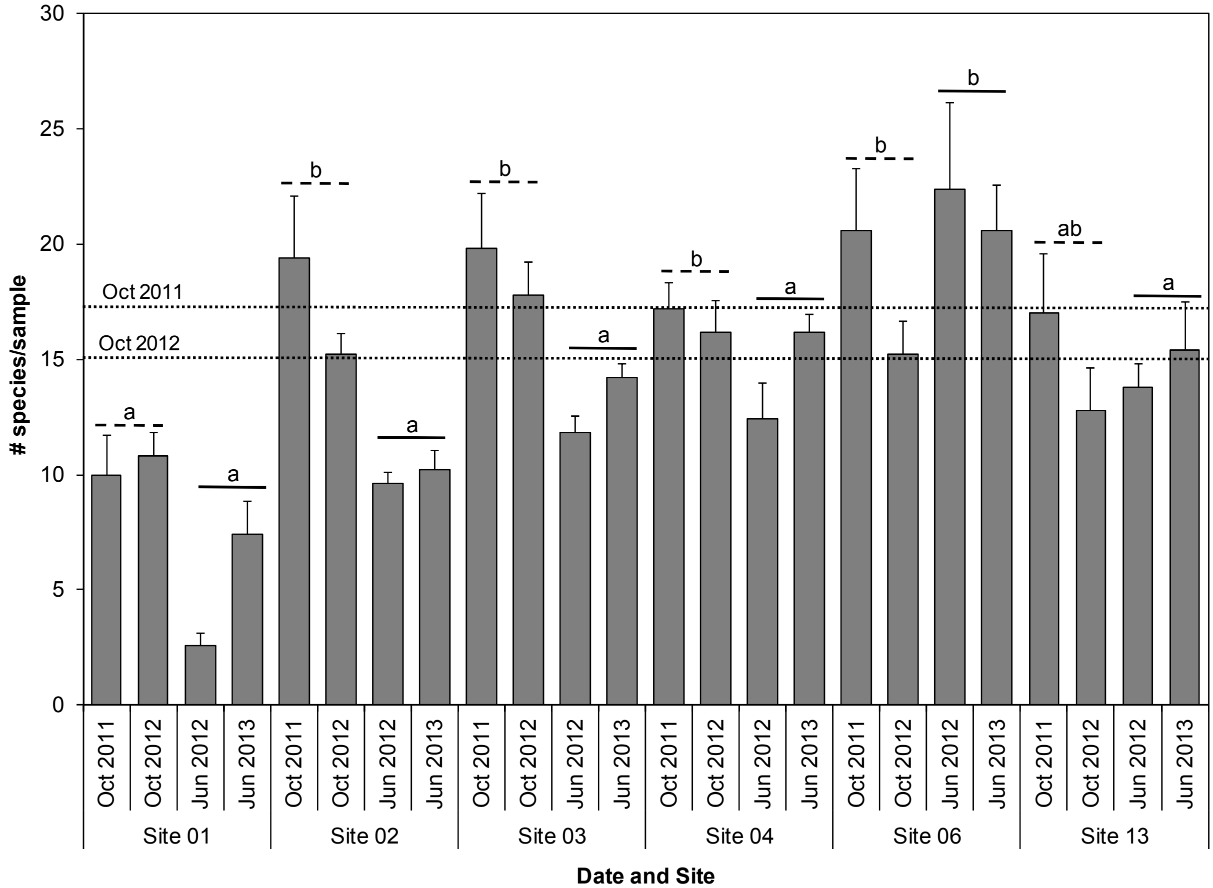



Figure D-2. Interannual variation of species richness in sediments from Saint John Harbour reference sites, 2011-2013. Data are means (± SE) of n = 5 samples on each sampling date per site. Dotted lines are means across all sites that are significantly different. Different letters indicate significantly different means between sites for October 2011 and 2012 (dashed short lines) and for June 2012 and 2013 (solid short lines; two-way ANOVA, Holm-Sidak test, $p < 0.050$).

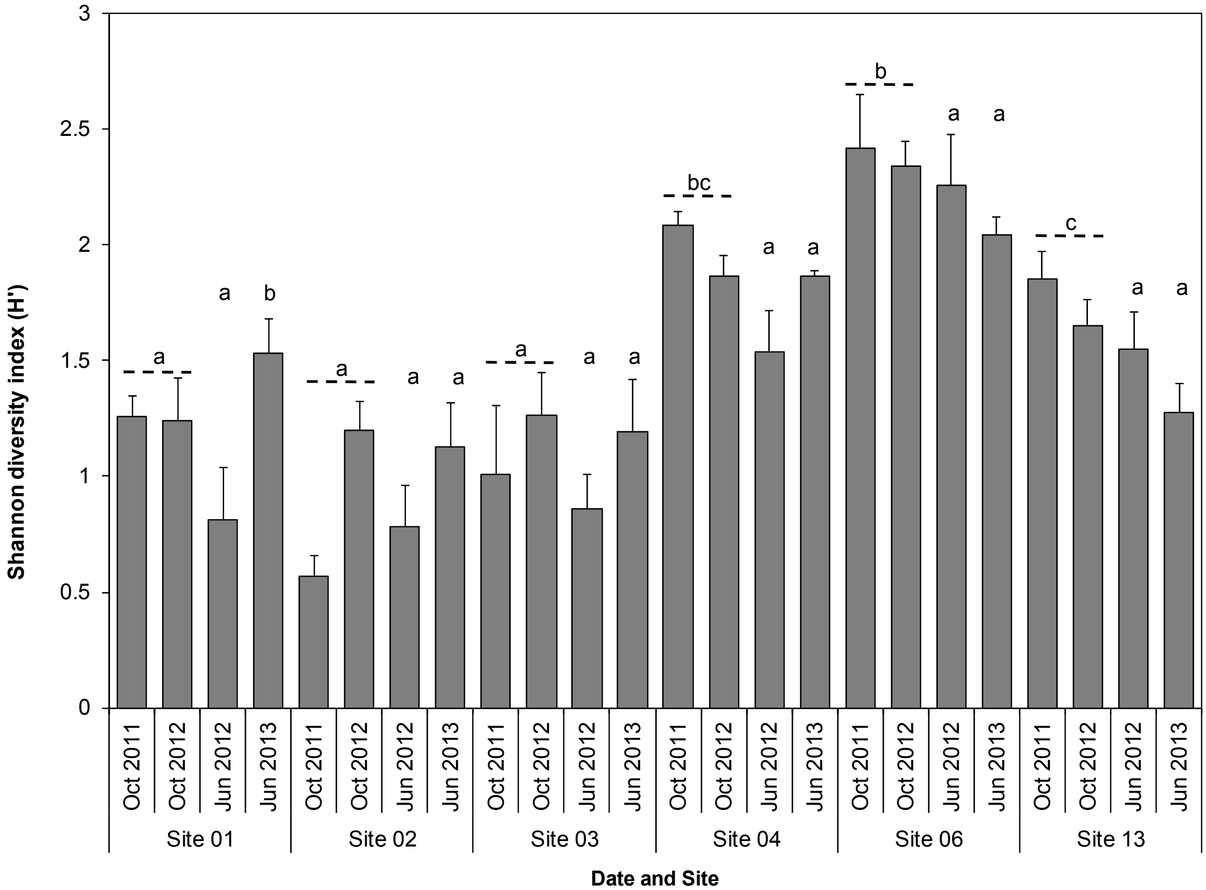



Figure D-3. Interannual variation of species diversity using Shannon diversity index (H') in sediments from Saint John Harbour reference sites, 2011-2013. Data are means (± SE) of n = 5 samples on each sampling date per site. Different letters indicate significantly different means between sites for October 2011 and 2012 (dashed short lines) and between month-year pairing per site for June 2012 and 2013 (two-way ANOVA, Holm-Sidak test, p <0.050).

Table D-3. PERMANOVA of interannual variation between benthic communities at Inner and Outer Saint John Harbour reference sites using Bray Curtis similarity matrices on square root transformed data.

| Two-way PERMANOVA with date and site as factors using Bray Curtis similarity matrices | | | | | | |
|---|---|---|---|---|---|---|
| Source | df | SS | MS | Pseudo-F | P(perm) | Unique perms |
| Date | 3 | 12273 | 4090.8 | 4.4751 | 0.001 | 999 |
| Site | 5 | 83415 | 16683 | 18.25 | 0.001 | 999 |
| Date x Site | 15 | 40318 | 2687.8 | 2.9403 | 0.001 | 996 |
| Residual | 96 | 87757 | 914.14 | | | |
| Total | 119 | $2.2376 \times 10^5$ | | | | |

| Average percent similarity between/within dates | | | | |
|---|---|---|---|---|
| | Oct 2011 | Jun 2012 | Jun 2013 | Oct 2012 |
| *Site 01* | | | | |
| Oct 2011 | 51 | - | - | - |
| Jun 2012 | 17 | 31 | - | - |
| Jun 2013 | 27 | 24 | 37 | - |
| Oct 2012 | 42 | 14 | 31 | 55 |
| *Site 02* | | | | |
| Oct 2011 | 72 | - | - | - |
| Jun 2012 | 62 | 74 | - | - |
| Jun 2013 | 48 | 59 | 53 | - |
| Oct 2012 | 62 | 71 | 57 | 76 |
| *Site 03* | | | | |
| Oct 2011 | 65 | - | - | - |
| Jun 2012 | 61 | 75 | - | - |
| Jun 2013 | 55 | 68 | 61 | - |
| Oct 2012 | 58 | 70 | 63 | 66 |
| *Site 04* | | | | |
| Oct 2011 | 65 | - | - | - |
| Jun 2012 | 57 | 56 | - | - |
| Jun 2013 | 61 | 54 | 73 | - |
| Oct 2012 | 59 | 59 | 56 | 60 |
| *Site 06* | | | | |
| Oct 2011 | 49 | - | - | - |
| Jun 2012 | 49 | 62 | - | - |
| Jun 2013 | 47 | 59 | 66 | - |
| Oct 2012 | 50 | 42 | 41 | 53 |
| *Site 13* | | | | |
| Oct 2011 | 45 | - | - | - |
| Jun 2012 | 53 | 66 | - | - |
| Jun 2013 | 53 | 67 | 71 | - |
| Oct 2012 | 49 | 58 | 57 | 54 |

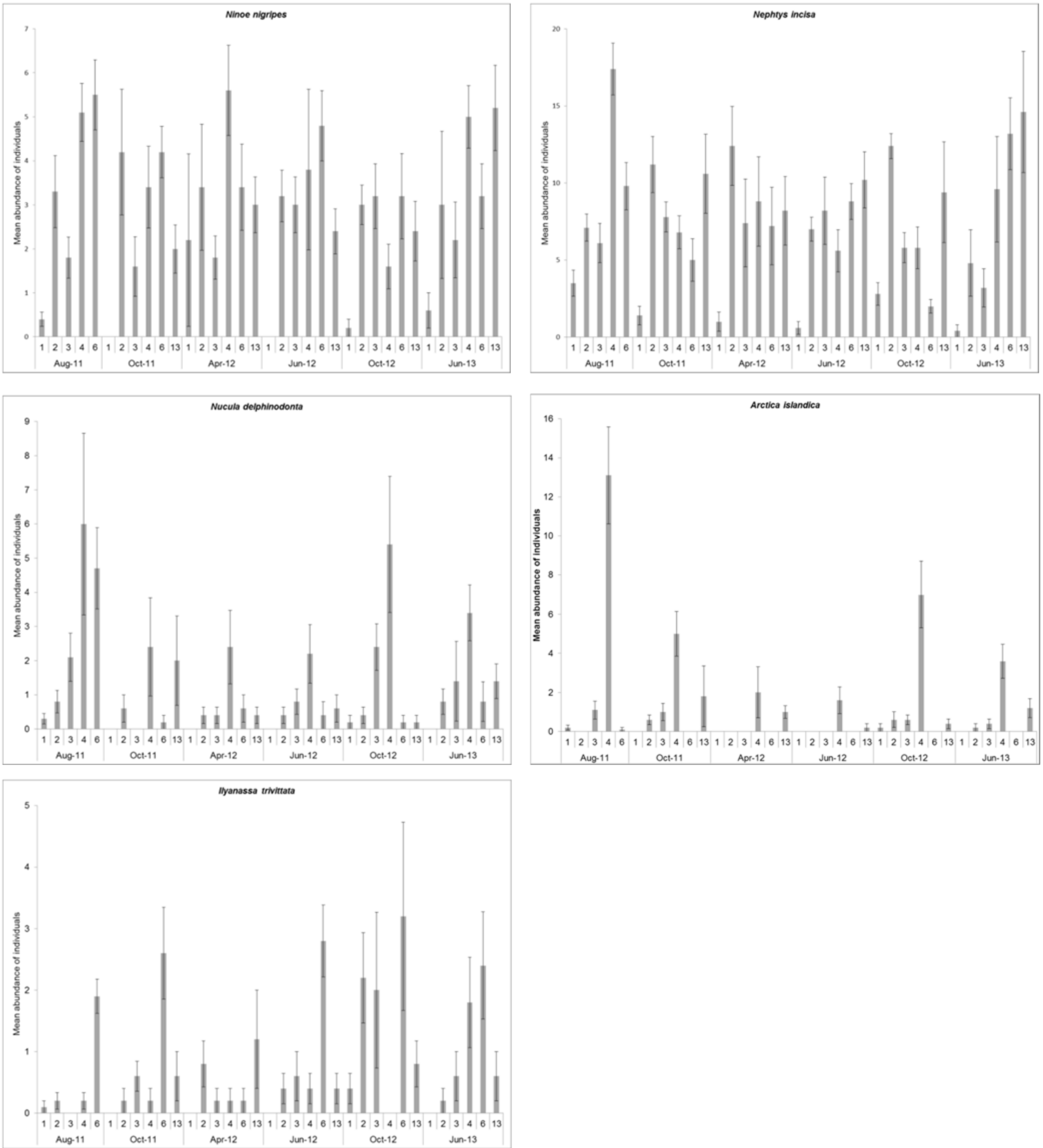



Figure D-4. Mean (+1SE) abundance of 2 species of polychaetes (*Ninoe nigripes* and *Nephtys incisa*), 2 bivalves (*Arctica islandica* and *Nucula delphinodonta*) and 1 gastropod (*Ilyanassa trivittata*) with dispersion (D) < 3.

## APPENDIX E. Sediment physical/chemical data

Table E-1. Physical and chemical properties of sediment collected as surface grab samples from six Saint John Harbour references sites in 2011-2013.

| | Inner Harbour – Site 01 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 10 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Physical Parameters (%)* | | | | | | | | | | | | |
| Moisture | 40 | 2 | 29 | 3 | 30 | 6 | 38 | 6 | 37 | 4 | 40 | 2 |
| TOC[a] | 0.75 | 0.06 | 0.41 | 0.08 | 0.64 | 0.1 | 0.56 | 0.1 | 0.74 | 0.1 | 1.0 | 0.09 |
| $LOI_{550}$ | 3.4 | 0.2 | 2.1 | 0.3 | 2.9 | 0.5 | 2.6 | 0.4 | 3.4 | 0.4 | 4.4 | 0.4 |
| $LOI_{950}$ | 1.9 | 0.09 | 1.3 | 0.1 | 1.6 | 0.1 | 1.8 | 0.06 | 1.6 | 0.2 | 1.7 | 0.1 |
| Silt-Clay | 79 | 3 | 84 | 2 | 43 | 20 | 71 | 10 | 90 | 4 | 89 | 2 |
| Fine-Med Sand | 15 | 1 | 12 | 2 | 19 | 6 | 17 | 5 | 9.2 | 4 | 9.9 | 1.9 |
| Coarse Sand | 4.5 | 1 | 3.8 | 0.5 | 25 | 10 | 12 | 8 | 0.81 | 0.08 | 1.0 | 0.1 |
| Gravel | 1.5 | 0.6 | 0.53 | 0.07 | 13 | 6 | 0.66 | 0.2 | 0.24 | 0.05 | 0.063 | 0.04 |
| Mz (mm)[b] | 0.21 | 0.02 | 0.19 | 0.01 | 0.65 | 0.18 | 0.26 | 0.08 | 0.12 | 0.01 | 0.12 | 0.01 |
| *Metals and Organics (mg/kg dw)* | | | | | | | | | | | | |
| Al | 18000 | 1000 | 12000 | 1000 | 20000 | 2000 | 21000 | 3000 | 11000 | 1000 | 20000 | 2000 |
| As | 7.1 | 0.5 | 5.2 | 0.4 | 8.7 | 0.9 | 8.0 | 0.9 | 6.1 | 0.4 | 6.7 | 0.3 |
| Cd | 0.059 | 0.02 | 0.077 | 0.01 | 0.13 | 0.02 | 0.12 | 0.02 | 0.062 | 0.006 | 0.089 | 0.002 |
| Co | 9.3 | 0.6 | 7.0 | 0.5 | 9.2 | 0.5 | 9.4 | 1.1 | 8.6 | 0.6 | 9.1 | 0.4 |
| Cr | 28 | 1 | 18 | 2 | 26 | 3 | 28 | 4 | 20 | 2 | 26 | 2 |
| Cu | 7.6 | 0.8 | 5.3 | 0.8 | 10 | 1 | 9.8 | 1.7 | 6.3 | 0.8 | 7.7 | 0.5 |
| Fe | 19000 | 1000 | 16000 | 900 | 22000 | 1000 | 23000 | 2000 | 21000 | 1000 | 22000 | 900 |
| La | 24 | 1 | 21 | 1 | 19 | 2 | 19 | 2 | 20 | 2 | 20 | 0.5 |
| Mg | 6200 | 300 | 4400 | 300 | 6800 | 500 | 6800 | 700 | 6000 | 400 | 6500 | 300 |
| Mn | 480 | 10 | 380 | 20 | 460 | 30 | 510 | 50 | 390 | 10 | 510 | 20 |
| Ni | 18 | 1 | 12 | 1 | 19 | 1 | 22 | 2 | 15 | 2 | 18 | 1 |
| P | 760 | 30 | 600 | 20 | 820 | 70 | 700 | 70 | 640 | 20 | 690 | 10 |
| Pb | 9.6 | 0.6 | 7.3 | 0.4 | 9.4 | 0.9 | 10 | 2 | 9.3 | 0.9 | 9.7 | 0.4 |
| Rb | 53 | 5 | 24 | 4 | 51 | 10 | 59 | 10 | 19 | 6 | 50 | 6 |
| S | 1600 | 200 | 1000 | 200 | 1600 | 500 | 1600 | 300 | 1700 | 200 | 1700 | 100 |
| Se | 1.4 | 0.1 | 1.0 | 0.2 | 0.46 | 0.09 | 0.44 | 0.1 | 2.8 | 0.09 | 0.50 | 0.09 |
| Sr | 49 | 2 | 34 | 3 | 49 | 4 | 52 | 6 | 42 | 2 | 50 | 3 |
| V | 41 | 2 | 28 | 2 | 39 | 3 | 46 | 6 | 35 | 2 | 43 | 3 |
| Zn | 50 | 4 | 34 | 3 | 53 | 5 | 51 | 7 | 42 | 4 | 48 | 2 |
| Total Hg (µg/kg) | 12 | 1 | 8.0 | 1 | 16 | 3 | 22 | 6 | 16 | 5 | 8.8 | 0.4 |
| Total PAHs[c] | 0.13 | 0.03 | 0.10 | 0.05 | 0.14 | 0.04 | 0.21 | 0.05 | 0.18 | 0.04 | 0.39 | 0.3 |
| Total PCBs[d] (µg/kg) | na | - | 6.4 | 1 | na | - | na | - | na | - | na | - |

Table E-1. continued.

| | Inner Harbour – Site 02 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 6 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Physical Parameters (%)* | | | | | | | | | | | | |
| Moisture | 45 | 0.5 | 45 | 1 | 31 | 2 | 38 | 3 | 40 | 2 | 43 | 2 |
| TOC[a] | 0.90 | 0.02 | 0.83 | 0.05 | 0.43 | 0.05 | 0.79 | 0.08 | 0.77 | 0.06 | 0.82 | 0.08 |
| $LOI_{550}$ | 4.0 | 0.07 | 3.7 | 0.2 | 2.1 | 0.2 | 3.5 | 0.3 | 3.5 | 0.2 | 3.6 | 0.3 |
| $LOI_{950}$ | 2.0 | 0.03 | 2.1 | 0.1 | 1.4 | 0.05 | 1.8 | 0.2 | 1.6 | 0.04 | 1.7 | 0.09 |
| Silt-Clay | 74 | 1 | 65 | 2 | 89 | 2 | 91 | 2 | 94 | 2 | 87 | 3 |
| Fine-Med Sand | 23 | 1 | 31 | 2 | 8.9 | 2.6 | 6.8 | 1.6 | 5.0 | 2.0 | 12 | 3 |
| Coarse Sand | 2.4 | 0.2 | 3.2 | 0.8 | 1.9 | 0.2 | 1.9 | 0.2 | 0.67 | 0.06 | 0.78 | 0.3 |
| Gravel | 0.57 | 0.04 | 0.37 | 0.07 | 0.52 | 0.08 | 0.54 | 0.08 | 0.16 | 0.03 | 0.072 | 0.02 |
| Mz (mm)[b] | 0.18 | 0.002 | 0.22 | 0.01 | 0.15 | 0.01 | 0.13 | 0.004 | 0.11 | 0.004 | 0.13 | 0.01 |
| *Metals and Organics (mg/kg dw)* | | | | | | | | | | | | |
| Al | 23000 | 800 | 22000 | 700 | 17000 | 1000 | 19000 | 1000 | 12000 | 1000 | 22000 | 1000 |
| As | 8.0 | 0.1 | 7.2 | 0.2 | 5.8 | 0.3 | 6.7 | 0.4 | 6.6 | 0.7 | 7.1 | 0.5 |
| Cd | 0.060 | 0.01 | 0.085 | 0.01 | 0.061 | 0.02 | 0.103 | 0.007 | 0.054 | 0.008 | 0.067 | 0.01 |
| Co | 11 | 0.1 | 10 | 0.2 | 7.1 | 0.4 | 8.5 | 0.6 | 8.8 | 0.5 | 9.5 | 0.7 |
| Cr | 33 | 0.8 | 29 | 1 | 24 | 1 | 26 | 2 | 22 | 2 | 28 | 2 |
| Cu | 9.0 | 0.2 | 9.0 | 0.5 | 6.6 | 0.8 | 7.7 | 0.7 | 6.0 | 0.7 | 8.2 | 0.9 |
| Fe | 22000 | 400 | 26000 | 800 | 17000 | 800 | 20000 | 1000 | 22000 | 1000 | 26000 | 2000 |
| La | 21 | 0.4 | 21 | 0.5 | 22 | 2 | 20 | 0.6 | 19 | 1 | 22 | 1 |
| Mg | 7400 | 100 | 7200 | 200 | 4800 | 300 | 5900 | 400 | 6400 | 400 | 7100 | 300 |
| Mn | 530 | 6 | 480 | 10 | 440 | 20 | 430 | 20 | 360 | 20 | 510 | 30 |
| Ni | 21 | 0.2 | 19 | 0.5 | 16 | 1 | 19 | 2 | 16 | 1 | 18 | 2 |
| P | 670 | 9 | 670 | 20 | 670 | 40 | 730 | 30 | 630 | 4 | 690 | 30 |
| Pb | 11 | 0.1 | 11 | 0.3 | 6.6 | 0.5 | 8.5 | 0.7 | 9.0 | 0.7 | 10 | 1 |
| Rb | 75 | 3 | 61 | 3 | 50 | 4 | 55 | 6 | 27 | 5 | 58 | 5 |
| S | 2000 | 40 | 2100 | 90 | 1100 | 80 | 1600 | 200 | 1700 | 200 | 1900 | 100 |
| Se | 1.6 | 0.05 | 1.8 | 0.1 | 0.70 | 0.1 | 0.58 | 0.2 | 2.3 | 0.5 | 0.76 | 0.09 |
| Sr | 60 | 1 | 53 | 1 | 46 | 2 | 51 | 3 | 45 | 3 | 54 | 2 |
| V | 49 | 1 | 43 | 1 | 34 | 2 | 43 | 3 | 37 | 3 | 48 | 3 |
| Zn | 55 | 1 | 51 | 1 | 36 | 2 | 41 | 3 | 44 | 3 | 48 | 4 |
| Total Hg (µg/kg) | 11 | 1 | 12 | 1 | 6.1 | 0.6 | 13 | 2 | 11 | 1 | 9.7 | 1 |
| Total PAHs[c] | 0.29 | 0.05 | 0.24 | 0.04 | 0.12 | 0.01 | 0.29 | 0.2 | 0.12 | 0.02 | 0.073 | 0.03 |
| Total PCBs[d] (µg/kg) | na | - | 11 | 2 | na | - | na | - | na | - | na | - |

Table E-1. continued.

| | Inner Harbour – Site 03 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 6 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Physical Parameters (%)* | | | | | | | | | | | | |
| Moisture | 45 | 1 | 44 | 3 | 35 | 2 | 38 | 1 | 40 | 1 | 45 | 1 |
| TOC[a] | 0.90 | 0.09 | 0.87 | 0.1 | 0.76 | 0.08 | 0.77 | 0.03 | 0.75 | 0.04 | 1.2 | 0.07 |
| $LOI_{550}$ | 4.0 | 0.3 | 3.8 | 0.4 | 3.4 | 0.3 | 3.5 | 0.1 | 3.4 | 0.1 | 5.1 | 0.3 |
| $LOI_{950}$ | 1.9 | 0.06 | 2.3 | 0.1 | 1.5 | 0.08 | 1.8 | 0.06 | 1.8 | 0.06 | 1.9 | 0.05 |
| Silt-Clay | 66 | 2 | 73 | 4 | 91 | 1 | 86 | 3 | 87 | 3 | 86 | 2 |
| Fine-Med Sand | 30 | 2 | 25 | 4 | 8.2 | 1 | 11 | 2 | 12 | 3 | 13 | 2 |
| Coarse Sand | 2.6 | 0.3 | 1.3 | 0.2 | 0.54 | 0.07 | 2.3 | 0.4 | 0.98 | 0.3 | 1.2 | 0.5 |
| Gravel | 0.85 | 0.2 | 0.61 | 0.2 | 0.19 | 0.06 | 0.63 | 0.1 | 0.046 | 0.01 | 0.17 | 0.05 |
| Mz (mm)[b] | 0.23 | 0.01 | 0.18 | 0.01 | 0.13 | 0.002 | 0.15 | 0.01 | 0.12 | 0.01 | 0.14 | 0.01 |
| *Metals and Organics (mg/kg dw)* | | | | | | | | | | | | |
| Al | 22000 | 1000 | 20000 | 2000 | 21000 | 2000 | 20000 | 1000 | 14000 | 1000 | 20000 | 2000 |
| As | 7.1 | 0.3 | 7.3 | 0.6 | 7.4 | 0.7 | 6.7 | 0.2 | 6.0 | 0.3 | 7.2 | 0.3 |
| Cd | 0.058 | 0.01 | 0.12 | 0.01 | 0.12 | 0.02 | 0.10 | 0.007 | 0.077 | 0.02 | 0.093 | 0.004 |
| Co | 10 | 0.3 | 9.7 | 0.6 | 9.1 | 0.8 | 8.8 | 0.4 | 9.1 | 0.6 | 9.6 | 0.4 |
| Cr | 31 | 1 | 28 | 2 | 29 | 3 | 27 | 1 | 24 | 1 | 26 | 1 |
| Cu | 8.1 | 0.4 | 4.1 | 1.1 | 9.5 | 0.9 | 7.6 | 0.5 | 6.3 | 0.3 | 9.6 | 0.6 |
| Fe | 23000 | 900 | 24000 | 2000 | 21000 | 2000 | 21000 | 800 | 23000 | 800 | 23000 | 800 |
| La | 25 | 1 | 19 | 1 | 26 | 3 | 22 | 1 | 20 | 1 | 18 | 0.5 |
| Mg | 7900 | 300 | 7100 | 500 | 5900 | 600 | 6000 | 300 | 6800 | 200 | 6800 | 300 |
| Mn | 480 | 10 | 440 | 30 | 500 | 50 | 430 | 4 | 370 | 8 | 490 | 20 |
| Ni | 18 | 1 | 20 | 1 | 19 | 2 | 18 | 1 | 16 | 1 | 19 | 1 |
| P | 710 | 10 | 640 | 30 | 750 | 60 | 800 | 10 | 610 | 30 | 730 | 10 |
| Pb | 10 | 0.4 | 11 | 1 | 9.4 | 0.9 | 9.0 | 0.5 | 8.9 | 0.3 | 11 | 0.4 |
| Rb | 60 | 4 | 56 | 8 | 61 | 8 | 59 | 5 | 30 | 3 | 51 | 5 |
| S | 1700 | 80 | 2100 | 200 | 1400 | 100 | 1500 | 100 | 1900 | 200 | 1900 | 70 |
| Se | 1.4 | 0.05 | 2.0 | 0.1 | 0.58 | 0.1 | 0.84 | 0.07 | 2.6 | 0.4 | 1.5 | 0.1 |
| Sr | 49 | 1 | 54 | 2 | 53 | 5 | 50 | 2 | 49 | 3 | 51 | 2 |
| V | 45 | 2 | 40 | 4 | 42 | 4 | 46 | 2 | 40 | 1 | 45 | 3 |
| Zn | 54 | 2 | 51 | 3 | 46 | 4 | 42 | 2 | 45 | 3 | 51 | 2 |
| Total Hg (µg/kg) | 13 | 1 | 15 | 2 | 9.7 | 0.6 | 11 | 2 | 10 | 0.3 | 11 | 0.8 |
| Total PAHs[c] | 0.16 | 0.06 | 0.27 | 0.07 | 0.19 | 0.02 | 0.12 | 0.03 | 0.15 | 0.007 | 0.10 | 0.01 |
| Total PCBs[d] (µg/kg) | na | - | 8.4 | 2 | na | - | na | - | na | - | na | - |

Table E-1. continued.

| | Outer Harbour – Site 04 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 8 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Physical Parameters (%)* | | | | | | | | | | | | |
| Moisture | 36 | 1 | 30 | 2 | 30 | 3 | 33 | 1 | 33 | 2 | 40 | 1 |
| TOC[a] | 0.57 | 0.04 | 0.41 | 0.03 | 0.58 | 0.09 | 0.48 | 0.04 | 0.51 | 0.04 | 0.72 | 0.04 |
| $LOI_{550}$ | 2.7 | 0.1 | 2.0 | 0.1 | 2.7 | 0.4 | 2.3 | 0.2 | 2.4 | 0.2 | 3.3 | 0.1 |
| $LOI_{950}$ | 1.5 | 0.1 | 1.4 | 0.1 | 1.1 | 0.1 | 1.5 | 0.07 | 1.4 | 0.03 | 1.6 | 0.05 |
| Silt-Clay | 80 | 1 | 73 | 3 | 86 | 1 | 72 | 4 | 79 | 3 | 77 | 2 |
| Fine-Med Sand | 18 | 1 | 25 | 3 | 13 | 1 | 24 | 4 | 21 | 3 | 22 | 2 |
| Coarse Sand | 1.5 | 0.2 | 1.1 | 0.2 | 0.59 | 0.3 | 2.7 | 0.5 | 0.50 | 0.1 | 0.83 | 0.1 |
| Gravel | 0.49 | 0.09 | 0.42 | 0.07 | 0.25 | 0.1 | 0.73 | 0.09 | 0.11 | 0.02 | 0.11 | 0.03 |
| Mz (mm)[b] | 0.17 | 0.003 | 0.17 | 0.003 | 0.14 | 0.004 | 0.18 | 0.01 | 0.14 | 0.004 | 0.14 | 0.01 |
| *Metals and Organics (mg/kg dw)* | | | | | | | | | | | | |
| Al | 17000 | 800 | 14000 | 1000 | 17000 | 2000 | 17000 | 1000 | 12000 | 1000 | 26000 | 1000 |
| As | 5.7 | 0.2 | 5.2 | 0.2 | 5.8 | 0.3 | 5.9 | 0.3 | 4.8 | 0.3 | 6.3 | 0.3 |
| Cd | 0.083 | 0.01 | 0.066 | 0.01 | 0.049 | 0.01 | 0.12 | 0.01 | 0.04 | 0.01 | 0.13 | 0.01 |
| Co | 8.4 | 0.2 | 7.3 | 0.4 | 7.7 | 0.6 | 8.2 | 0.4 | 7.1 | 0.5 | 9.2 | 0.3 |
| Cr | 24 | 1 | 20 | 1 | 23 | 2 | 22 | 2 | 20 | 2 | 26 | 1 |
| Cu | 5.7 | 0.3 | 0.076 | 0.01 | 6.5 | 1.0 | 5.8 | 0.5 | 3.6 | 0.7 | 9.3 | 0.4 |
| Fe | 17000 | 400 | 18000 | 800 | 18000 | 1000 | 18000 | 800 | 19000 | 1000 | 29000 | 1000 |
| La | 21 | 1 | 19 | 1 | 21 | 1 | 20 | 1 | 20 | 2 | 26 | 1 |
| Mg | 5500 | 80 | 5000 | 300 | 4900 | 500 | 4900 | 300 | 5800 | 400 | 6300 | 200 |
| Mn | 420 | 20 | 370 | 10 | 470 | 6 | 340 | 10 | 330 | 20 | 440 | 20 |
| Ni | 15 | 1 | 14 | 1 | 15 | 2 | 16 | 1 | 11 | 1 | 18 | 1 |
| P | 610 | 20 | 480 | 20 | 560 | 20 | 530 | 40 | 460 | 30 | 580 | 40 |
| Pb | 8.2 | 0.2 | 7.6 | 0.4 | 7.9 | 0.6 | 9.1 | 0.4 | 7.5 | 0.6 | 11 | 0.4 |
| Rb | 44 | 3 | 32 | 4 | 48 | 8 | 44 | 5 | 20 | 6 | 50 | 3 |
| S | 1400 | 200 | 1100 | 100 | 1100 | 200 | 1200 | 100 | 1100 | 100 | 1600 | 90 |
| Se | 1.5 | 0.1 | 1.6 | 0.07 | 0.66 | 0.1 | 0.58 | 0.1 | 2.9 | 0.04 | 1.7 | 0.05 |
| Sr | 48 | 6 | 37 | 2 | 44 | 3 | 43 | 2 | 38 | 3 | 46 | 2 |
| V | 37 | 1 | 30 | 2 | 36 | 3 | 40 | 2 | 35 | 3.0 | 45 | 1 |
| Zn | 44 | 1 | 35 | 2 | 36 | 4 | 40 | 2 | 35 | 2.6 | 47 | 2 |
| Total Hg (µg/kg) | 7.3 | 0.5 | 5.7 | 0.6 | 5.9 | 1.0 | 5.9 | 0.7 | 7.2 | 0.7 | 8.1 | 0.5 |
| Total PAHs[c] | 0.09 | 0.02 | 0.04 | 0.01 | 0.22 | 0.06 | 0.10 | 0.03 | 0.10 | 0.03 | 0.11 | 0.02 |
| Total PCBs[d] (µg/kg) | na | - | 3.8 | 0.9 | na | - | na | - | na | - | na | - |

Table E-1. continued.

| | Outer Harbour – Site 06 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| date | Aug 2011 | | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 10 | | 7 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Physical Parameters (%)* | | | | | | | | | | | | |
| Moisture | 31 | 1 | 29 | 1 | 30 | 1 | 31 | 1 | 30 | 1 | 32 | 2 |
| TOC[a] | 0.56 | 0.03 | 0.52 | 0.03 | 0.48 | 0.03 | 0.50 | 0.02 | 0.55 | 0.03 | 0.62 | 0.07 |
| $LOI_{550}$ | 2.6 | 0.1 | 2.5 | 0.1 | 2.3 | 0.1 | 2.4 | 0.08 | 2.6 | 0.1 | 2.9 | 0.3 |
| $LOI_{950}$ | 1.5 | 0.04 | 2.3 | 0.4 | 1.7 | 0.1 | 1.5 | 0.02 | 1.5 | 0.06 | 1.5 | 0.03 |
| Silt-Clay | 56 | 4 | 40 | 4 | 72 | 4 | 59 | 9 | 61 | 5 | 52 | 6 |
| Fine-Med Sand | 38 | 4 | 40 | 1 | 24 | 4 | 27 | 6 | 34 | 4 | 45 | 6 |
| Coarse Sand | 3.3 | 0.4 | 5.6 | 0.4 | 2.6 | 0.4 | 5.8 | 1 | 2.0 | 0.2 | 1.5 | 0.3 |
| Gravel | 2.8 | 0.4 | 15 | 4 | 2.1 | 1.0 | 7.7 | 3 | 3.1 | 1 | 0.76 | 0.3 |
| Mz (mm)[b] | 0.29 | 0.01 | 0.66 | 0.12 | 0.22 | 0.03 | 0.43 | 0.13 | 0.27 | 0.05 | 0.22 | 0.01 |
| *Metals and Organics (mg/kg dw)* | | | | | | | | | | | | |
| Al | 15000 | 2000 | 21000 | 900 | 18000 | 800 | 19000 | 800 | 15000 | 1000 | 17000 | 2000 |
| As | 5.6 | 0.4 | 6.6 | 0.1 | 6.1 | 0.2 | 8.2 | 2 | 4.8 | 0.2 | 5.6 | 0.3 |
| Cd | 0.05 | 0.01 | 0.09 | 0.002 | 0.08 | 0.005 | 0.16 | 0.01 | 0.05 | 0.01 | 0.10 | 0.01 |
| Co | 9.1 | 0.4 | 9.5 | 0.3 | 8.1 | 0.4 | 9.0 | 0.4 | 8.2 | 0.5 | 8.6 | 0.4 |
| Cr | 22 | 1 | 26 | 1 | 24 | 1 | 24 | 1 | 22 | 2 | 21 | 1 |
| Cu | 6.1 | 0.9 | 0.36 | 0.2 | 7.2 | 0.3 | 6.3 | 0.3 | 4.8 | 0.5 | 7.2 | 1 |
| Fe | 21000 | 3000 | 25000 | 600 | 19000 | 700 | 18000 | 900 | 23000 | 1600 | 22000 | 2000 |
| La | 18 | 1 | 20 | 0.3 | 19 | 0.4 | 18 | 0.4 | 20 | 1.1 | 14 | 0.7 |
| Mg | 6300 | 600 | 6800 | 200 | 5300 | 200 | 5100 | 200 | 7400 | 500 | 5400 | 300 |
| Mn | 360 | 8 | 390 | 9 | 410 | 6 | 330 | 8 | 360 | 20 | 390 | 7 |
| Ni | 16 | 1 | 18 | 1 | 17 | 1 | 18 | 1 | 14 | 1 | 16 | 1 |
| P | 530 | 40 | 470 | 7 | 620 | 20 | 600 | 80 | 400 | 20 | 490 | 30 |
| Pb | 8.6 | 0.4 | 7.9 | 0.3 | 7.2 | 0.3 | 8.8 | 0.2 | 6.9 | 0.7 | 8.7 | 0.6 |
| Rb | 33 | 3 | 50 | 3 | 50 | 4 | 49 | 3 | 24 | 3 | 34 | 4 |
| S | 2300 | 400 | 2500 | 200 | 1700 | 300 | 1800 | 300 | 2500 | 200 | 2300 | 300 |
| Se | 1.4 | 0.2 | 1.9 | 0.09 | 0.80 | 0.03 | 0.6 | 0.1 | 2.9 | 0.08 | 0.92 | 0.3 |
| Sr | 37 | 2 | 53 | 7 | 48 | 1 | 53 | 2 | 43 | 4 | 43 | 2 |
| V | 33 | 1 | 40 | 1 | 36 | 1 | 43 | 2 | 38 | 2 | 39 | 2 |
| Zn | 46 | 3 | 45 | 1 | 40 | 2 | 47 | 2 | 40 | 3 | 42 | 2 |
| Total Hg (µg/kg) | 7.1 | 0.6 | 5.5 | 0.8 | 7.9 | 0.9 | 5.7 | 0.5 | 9.2 | 2 | 6.5 | 0.9 |
| Total PAHs[c] | 0.07 | 0.02 | 0.08 | 0.04 | 0.27 | 0.08 | 0.14 | 0.04 | 0.20 | 0.05 | 0.17 | 0.02 |
| Total PCBs[d] (ug/kg) | na | - | 2.9 | 0.8 | na | - | na | - | na | - | na | - |

Table E-1. continued.

| | Outer Harbour – Site 13 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| date | Oct 2011 | | Apr 2012 | | Jun 2012 | | Oct 2012 | | Jun 2013 | |
| n | 6 | | 5 | | 5 | | 5 | | 5 | |
| | mean | SE | mean | SE | mean | SE | mean | SE | mean | SE |
| *Physical Parameters (%)* | | | | | | | | | | |
| Moisture | 35 | 4 | 38 | 4 | 39 | 2 | 35 | 3 | 38 | 4 |
| TOC[a] | 0.73 | 0.1 | 0.90 | 0.2 | 0.49 | 0.05 | 0.68 | 0.07 | 0.71 | 0.1 |
| $LOI_{550}$ | 3.3 | 0.5 | 4.0 | 0.6 | 2.4 | 0.2 | 3.1 | 0.3 | 3.2 | 0.5 |
| $LOI_{950}$ | 2.1 | 0.3 | 1.5 | 0.2 | 3.0 | 0.3 | 1.7 | 0.2 | 1.6 | 0.1 |
| Silt-Clay | 68 | 4 | 74 | 2 | 64 | 4 | 73 | 4 | 74 | 3 |
| Fine-Med Sand | 29 | 4 | 24 | 2 | 28 | 3 | 26 | 4 | 25 | 3 |
| Coarse Sand | 2.3 | 0.5 | 1.6 | 0.2 | 4.9 | 0.6 | 0.46 | 0.2 | 0.76 | 0.1 |
| Gravel | 0.78 | 0.1 | 0.36 | 0.08 | 3.2 | 2 | 0.57 | 0.4 | 0.07 | 0.01 |
| Mz (mm)[b] | 0.20 | 0.01 | 0.16 | 0.005 | 0.29 | 0.08 | 0.16 | 0.01 | 0.14 | 0.01 |
| *Metals and Organics (mg/kg dw)* | | | | | | | | | | |
| Al | 19000 | 3000 | 24000 | 2000 | 22000 | 2000 | 13000 | 1000 | 20000 | 3000 |
| As | 6.9 | 1 | 7.7 | 0.7 | 7.7 | 0.5 | 4.7 | 0.4 | 6.4 | 0.7 |
| Cd | 0.11 | 0.02 | 0.12 | 0.02 | 0.17 | 0.01 | 0.05 | 0.01 | 0.07 | 0.02 |
| Co | 9.5 | 1 | 10 | 1 | 11 | 0.7 | 7.3 | 0.6 | 9.9 | 0.8 |
| Cr | 26 | 3 | 32 | 3 | 28 | 3 | 21 | 2 | 27 | 3 |
| Cu | 5.1 | 3 | 11 | 1 | 9.0 | 1 | 4.2 | 0.9 | 8.6 | 1 |
| Fe | 22000 | 2000 | 23000 | 2000 | 20000 | 1000 | 21000 | 2000 | 22000 | 2000 |
| La | 21 | 1 | 21 | 1 | 19 | 1 | 23 | 1 | 17 | 0.5 |
| Mg | 6100 | 700 | 6700 | 600 | 5400 | 400 | 6900 | 700 | 6300 | 700 |
| Mn | 380 | 20 | 470 | 20 | 350 | 10 | 330 | 20 | 430 | 5 |
| Ni | 18 | 3 | 21 | 2 | 22 | 2 | 12 | 1 | 19 | 2 |
| P | 560 | 40 | 580 | 20 | 600 | 20 | 460 | 20 | 580 | 20 |
| Pb | 9.2 | 2 | 11 | 1 | 12 | 1 | 8.1 | 0.9 | 11 | 1 |
| Rb | 48 | 10 | 78 | 10 | 57 | 9 | 19 | 5 | 55 | 10 |
| S | 1900 | 500 | 2200 | 300 | 1900 | 200 | 1500 | 200 | 2400 | 400 |
| Se | 1.8 | 0.2 | 0.52 | 0.09 | 0.82 | 0.1 | 2.9 | 0.04 | 0.60 | 0.1 |
| Sr | 46 | 4 | 51 | 3 | 52 | 1 | 39 | 3 | 44 | 2 |
| V | 39 | 5 | 47 | 4 | 47 | 4 | 36 | 3 | 47 | 5 |
| Zn | 49 | 8 | 52 | 4 | 55 | 5 | 36 | 4 | 50 | 5 |
| Total Hg (µg/kg) | 8.8 | 3 | 12 | 2 | 11 | 2 | 8.7 | 1 | 10 | 1 |
| Total PAHs[c] | 0.10 | 0.04 | 0.25 | 0.05 | 0.22 | 0.09 | 0.16 | 0.06 | 0.19 | 0.03 |
| Total PCBs[d](µg/kg) | na | - | 4.5 | 1 | na | - | na | - | na | - |

na – not analyzed, [a] total organic carbon (TOC) calculated from loss on ignition at 550°C ($LOI_{550}$)
[b] average grain size $Mz = \Sigma (f_i m_i)/100$, where $m_i$ is the size of grade $i$ (i.e., 4, 2, 1, 0.5, 0.25, 0.125, 0.063 mm) and $f_i$ is its percentage, [c] sum of 16 individuals PAHs: acenaphthene, acenaphthylene, anthracene, benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[g,h,i]perylene, chrysene, dibenzo[a,h]anthracene, fluoranthene, fluorine, indeno[1,2,3-cd]pyrene, naphthalene, phenanthrene, pyrene and
[d] sum of 88 individual PCB congeners

## APPENDIX F. Analysis of seasonal variation in sediment chemical concentrations

Table F-1. Seasonal variation between sediment concentrations for select chemical parameters at Saint John Harbour reference sites.

Two-way ANOVA with date and site as factors with Holm-Sidak post-hoc comparisons for all pairwise multiple comparisons. P-value reported, alpha = 0.050.

| | As | Pb | Zn | Total PAHs |
|---|---|---|---|---|
| *Site 13 data excluded because not sampled August 2011* | | | | |
| Transform | reciprocal | reciprocal | None work | None work |
| Normality | Pass (0.087) | Pass (>0.150) | Pass (0.095) | Fail (<0.050) |
| Equal Variance | Pass (0.132) | Fail (<0.050) | Pass (0.255) | Pass (0.883) |
| Date | 0.047 | <0.001 | <0.001 | 0.568 |
| Site | <0.001 | 0.002 | <0.001 | 0.016 |
| Date x Site | <0.001 | <0.001 | <0.001 | 0.033 |
| *August 2011 data excluded because Site 13 not sampled* | | | | |
| Transform | reciprocal | reciprocal | None work | None work |
| Normality | Pass (0.131) | Pass (>0.150) | Fail (<0.050) | Fail (<0.050) |
| Equal Variance | Pass (0.093) | Pass (0.148) | Pass (0.524) | Pass (0.809) |
| Date | 0.010 | 0.028 | 0.611 | 0.177 |
| Site | 0.001 | 0.002 | 0.001 | 0.374 |
| Date x Site | <0.001 | <0.001 | 0.002 | 0.045 |

Date within site - Dates with different letters are significantly different

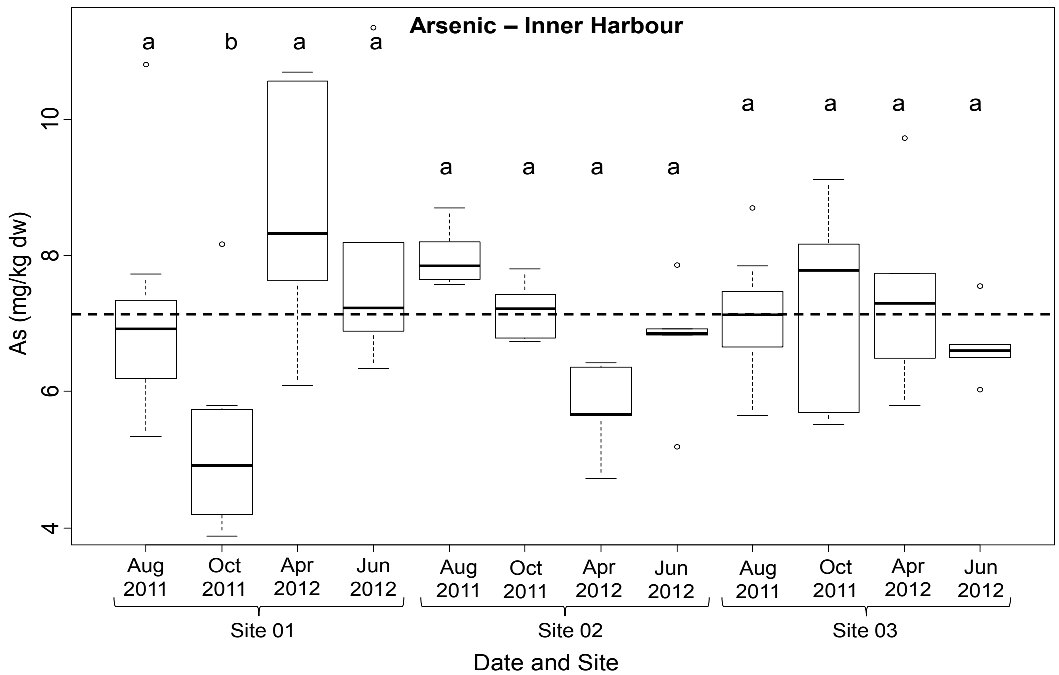
| Date | As | | | | | | Pb | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
| Aug 2011 | a | a | a | a | a | - | a | b | a | a | a | - |
| Oct 2011 | b | a | a | a | a | a | b | b | a | a | a | a |
| Apr 2012 | a | a | a | a | a | a | ab | a | a | a | a | a |
| Jun 2012 | a | a | a | a | a | a | ab | ab | a | a | a | a |
| **Date** | **Zn** | | | | | | **Total PAHs** | | | | | |
| | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
| Aug 2011 | a | a | a | a | a | - | a | a | a | a | a | - |
| Oct 2011 | b | ab | a | a | a | a | a | a | a | a | a | a |
| Apr 2012 | a | b | a | a | a | a | a | a | a | a | a | a |
| Jun 2012 | a | ab | a | a | a | a | a | a | a | a | a | a |

Table F-1. continued.

Site within date - Sites with different letters are significantly different

| Site | As | | | | Pb | | | |
|---|---|---|---|---|---|---|---|---|
| | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 |
| Site 01 | abc | a | a | a | ab | a | ab | a |
| Site 02 | a | c | a | a | b | b | a | a |
| Site 03 | ab | bc | a | a | ab | ab | ab | a |
| Site 04 | bc | ab | a | a | a | ab | ab | a |
| Site 06 | c | bc | a | a | ab | ab | ab | a |
| Site 13 | - | abc | a | a | - | ab | b | a |

| Site | Zn | | | | Total PAHs | | | |
|---|---|---|---|---|---|---|---|---|
| | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 | Aug 2011 | Oct 2011 | Apr 2012 | Jun 2012 |
| Site 01 | a | a | a | a | a | a | a | a |
| Site 02 | a | a | a | a | a | a | a | a |
| Site 03 | a | a | a | a | a | a | a | a |
| Site 04 | a | a | a | a | a | a | a | a |
| Site 06 | a | a | a | a | a | a | a | a |
| Site 13 | - | a | a | a | - | a | a | a |



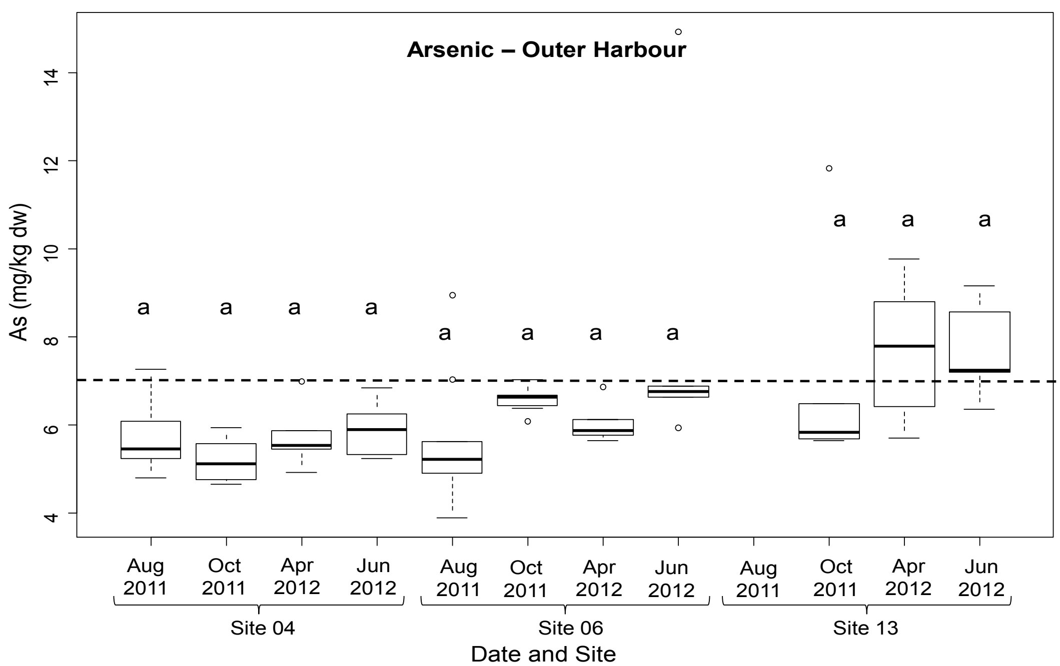
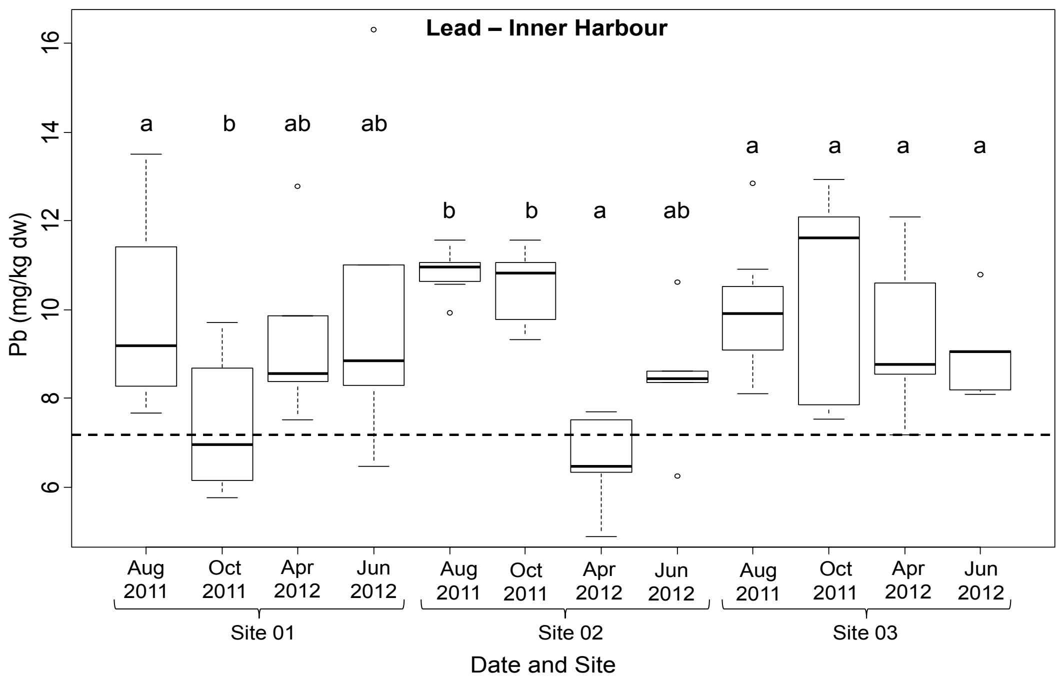




Figure F-1. Seasonal variation of arsenic concentrations in sediments from Saint John Harbour reference sites, 2011-2012. Dashed line is CCME-ISQG. Boxplot whiskers are minimum and maximum values. Different letters indicate significantly different mean concentrations within each site (two-way ANOVA, Holm-Sidak test, $p < 0.050$). n = 5-10 samples on each sampling date per site.



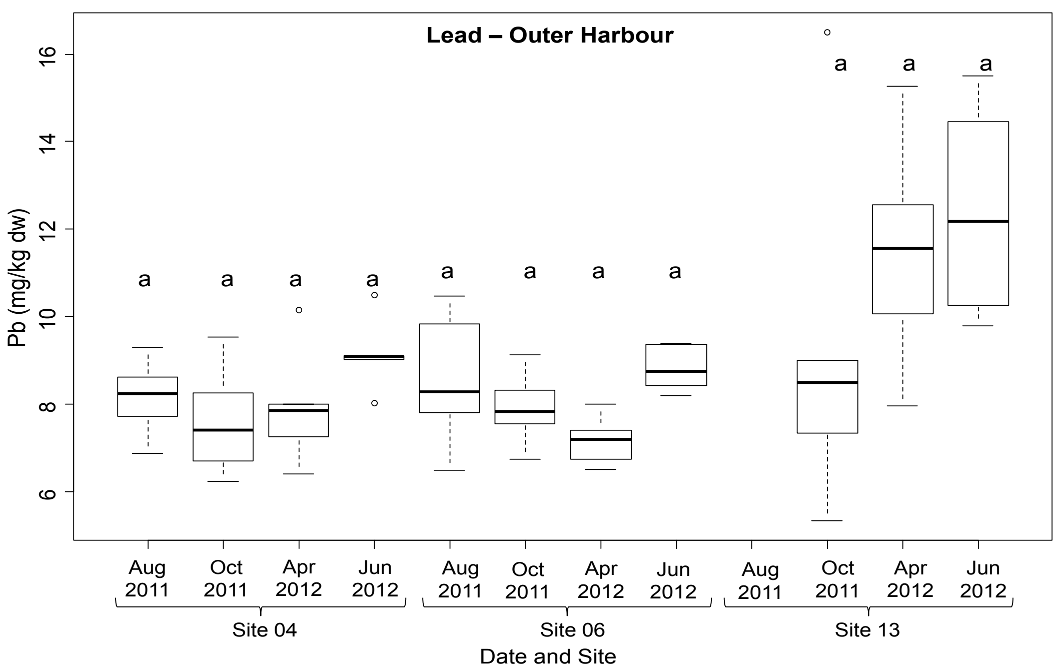
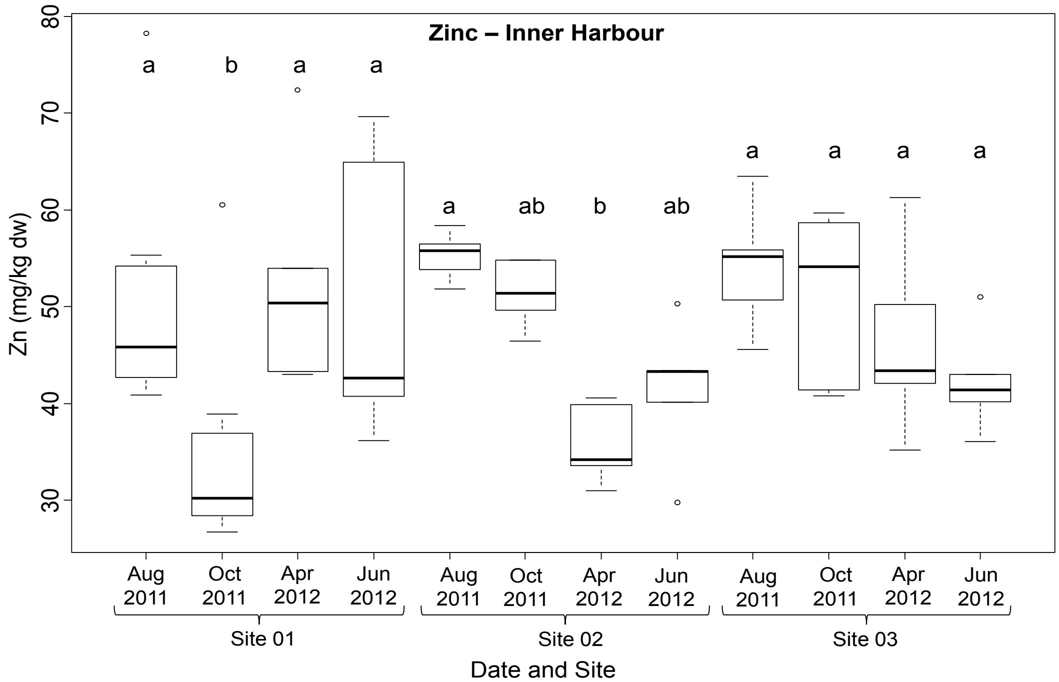




Figure F-2. Seasonal variation of lead concentrations in sediments from Saint John Harbour reference sites, 2011-2012. See Figure F-1 for description.



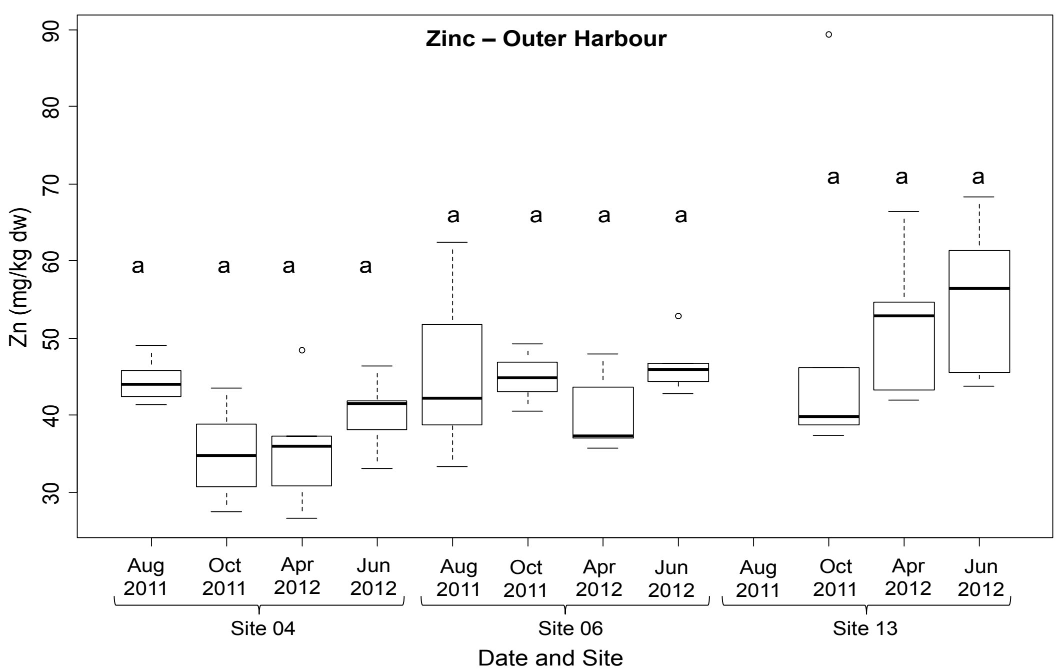
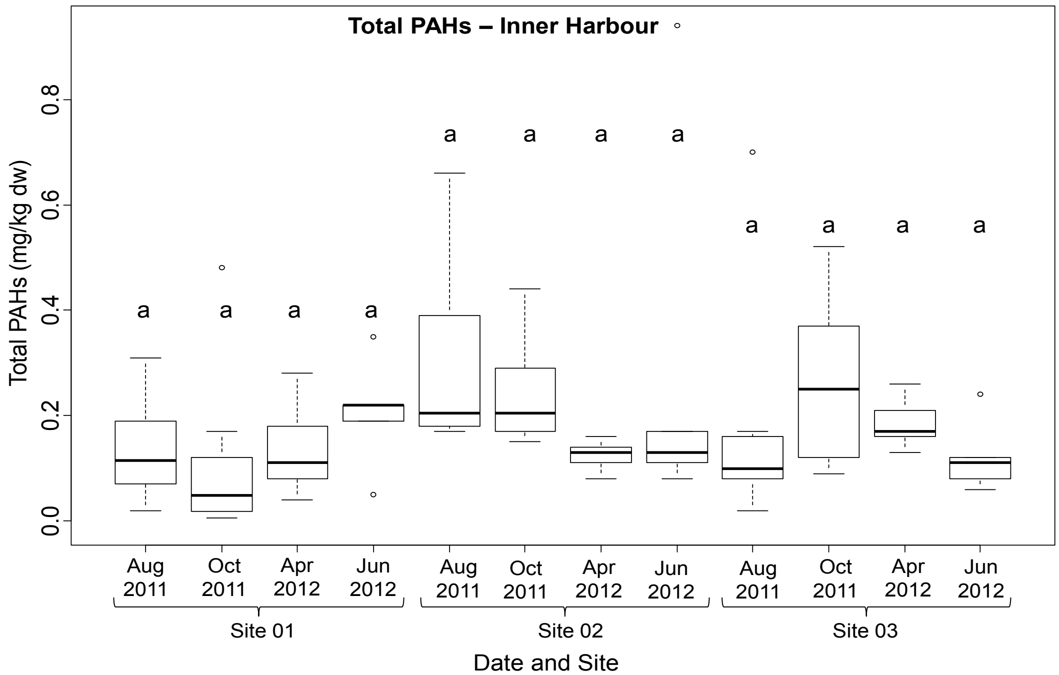




Figure F-3. Seasonal variation of zinc concentrations in sediments from Saint John Harbour reference sites, 2011-2012. See Figure F-1 for description.



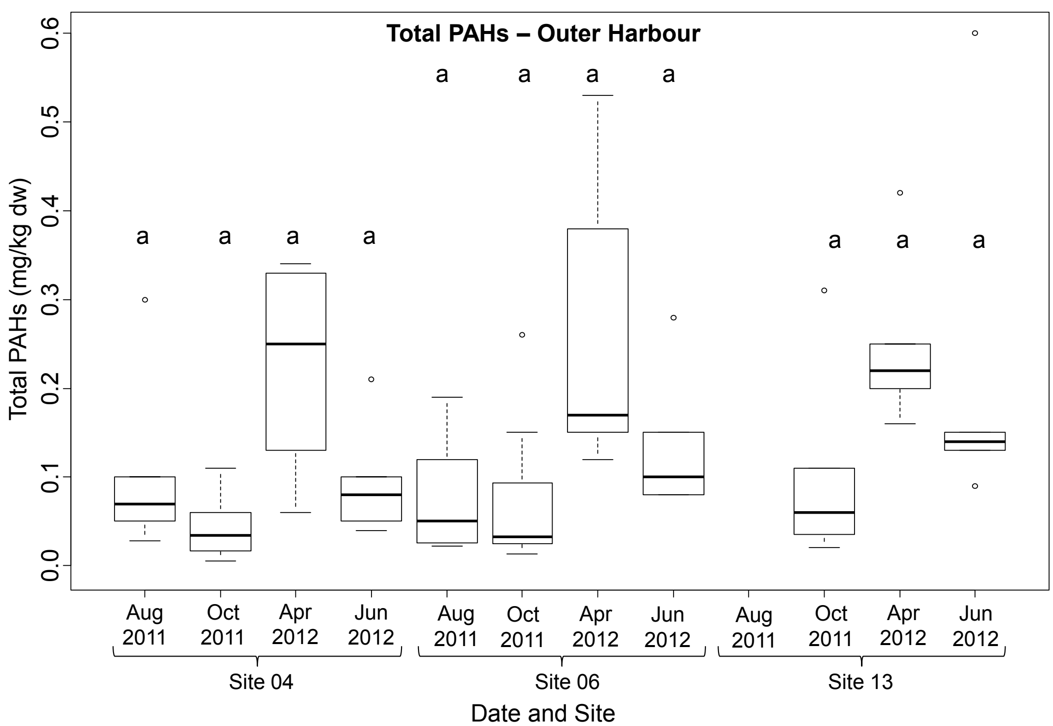




Figure F-4. Seasonal variation of total PAH in sediments from Saint John Harbour reference sites, 2011-2012. See Figure F-1 for description.

## APPENDIX G. Analysis of interannual variation in sediment chemical concentrations

Table G-1. Interannual variation between sediment concentrations for select chemical parameters at Saint John Harbour reference sites.

Two-way ANOVA with date and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050.

| | As | Pb | Zn | Total PAHs |
|---|---|---|---|---|
| *October 2011 and 2012* | | | | |
| Transform | none work | log | reciprocal | none work |
| Normality | Fail (<0.050) | Pass (>0.150) | Pass (>0.150) | Fail (0.047) |
| Equal Variance | Pass (0.626) | Pass (0.543) | Pass (0.589) | Pass (0.050) |
| Date | 0.002 | 0.240 | 0.150 | 0.008 |
| Site | 0.001 | 0.002 | <0.001 | 0.009 |
| Date x Site | 0.018 | 0.087 | 0.025 | 0.012 |
| *June 2012 and 2013* | | | | |
| Transform | reciprocal | log | reciprocal | log |
| Normality | Pass (>0.150) | Pass (0.116) | Pass (0.106) | Pass (0.145) |
| Equal Variance | Pass (0.695) | Pass (0.169) | Pass (0.613) | Pass (0.761) |
| Date | 0.080 | 0.297 | 0.220 | 0.465 |
| Site | 0.229 | 0.052 | 0.247 | 0.188 |
| Date x Site | 0.039 | 0.305 | 0.133 | 0.150 |

Date within site - Dates with different letters are significantly different

| Date | As | | | | | | Pb |
|---|---|---|---|---|---|---|---|
| | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 | All Sites |
| Oct 2011 | a | a | a | a | a | a | no posthoc test |
| Oct 2012 | a | a | a | a | a | a | |

| Date | Zn | | | | | | Total PAHs | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
| Oct 2011 | a | a | a | a | a | a | a | a | a | a | a | a |
| Oct 2012 | a | a | a | a | a | a | a | a | a | a | a | a |

Table G-1. continued

Site within date - Sites with different letters are significantly different

| Site | As Oct 2011 | As Oct 2012 | Pb All Dates | Zn Oct 2011 | Zn Oct 2012 | Total PAHs Oct 2011 | Total PAHs Oct 2012 |
|---|---|---|---|---|---|---|---|
| Site 01 | b | ab | abc | b | a | b | a |
| Site 02 | ab | ab | a | a | a | a | a |
| Site 03 | a | ab | ab | a | a | a | a |
| Site 04 | ab | ab | bc | b | a | b | a |
| Site 06 | ab | ab | c | ab | a | ab | a |
| Site 13 | ab | b | abc | ab | a | ab | a |

June Comparisons.

Date within site - Dates with different letters are significantly different

| Date | As Site 01 | As Site 02 | As Site 03 | As Site 04 | As Site 06 | As Site 13 | Pb All Sites |
|---|---|---|---|---|---|---|---|
| Jun 2012 | a | a | a | a | a | a | no posthoc test |
| Jun 2013 | a | a | a | a | a | a | |

| Date | Zn All Sites | Total PAHs All Sites |
|---|---|---|
| Jun 2012 | no posthoc test | no posthoc test |
| Jun 2013 | | |

Site within date - Sites with different letters are significantly different

| Site | As Jun 2012 | As Jun 2013 | Pb All Dates | Zn All Dates | Total PAHs All Dates |
|---|---|---|---|---|---|
| Site 01 | a | a | no posthoc test | no posthoc test | no posthoc test |
| Site 02 | a | a | | | |
| Site 03 | a | a | | | |
| Site 04 | a | a | | | |
| Site 06 | a | a | | | |
| Site 13 | a | a | | | |

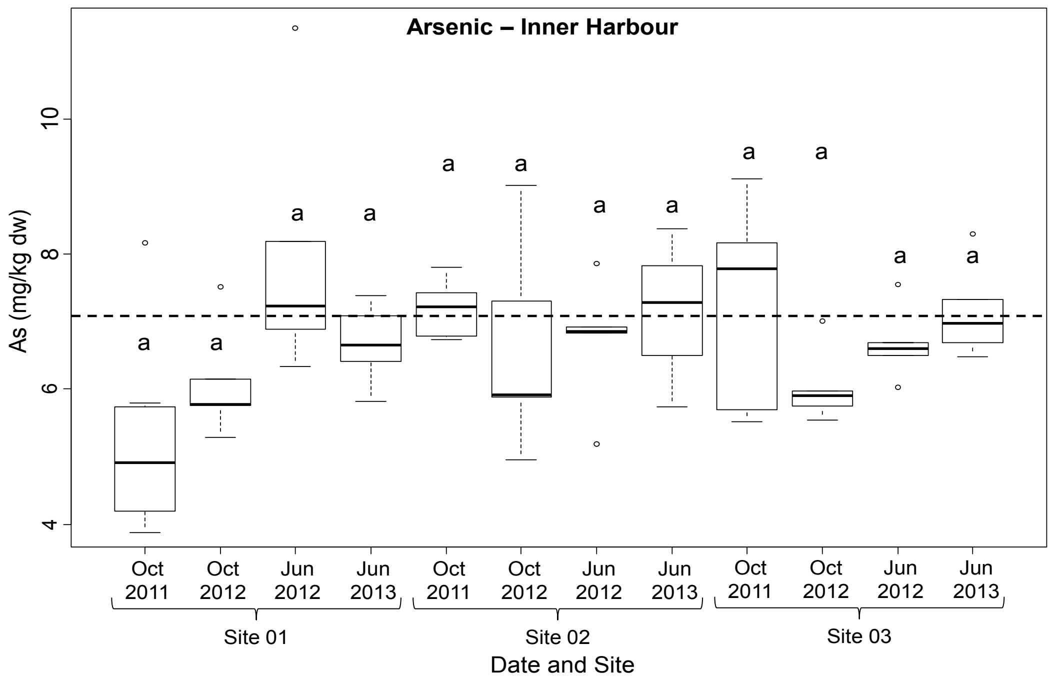
Table G-1. continued

Date within site - Dates with different letters are significantly different

| Date | As | | | | | | Pb |
|---|---|---|---|---|---|---|---|
| | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 | All Sites |
| Jun 2012 | a | a | a | a | a | a | no posthoc test |
| Jun 2013 | a | a | a | a | a | a | |
| **Date** | **Zn** | | | | | | **Total PAHs** |
| | All Sites | | | | | | All Sites |
| Jun 2012 | no posthoc test | | | | | | no posthoc test |
| Jun 2013 | | | | | | | |

Site within date - Sites with different letters are significantly different

| Site | As | | Pb | Zn | Total PAHs |
|---|---|---|---|---|---|
| | Jun 2012 | Jun 2013 | All Dates | All Dates | All Dates |
| Site 01 | a | a | no posthoc test | no posthoc test | no posthoc test |
| Site 02 | a | a | | | |
| Site 03 | a | a | | | |
| Site 04 | a | a | | | |
| Site 06 | a | a | | | |
| Site 13 | a | a | | | |



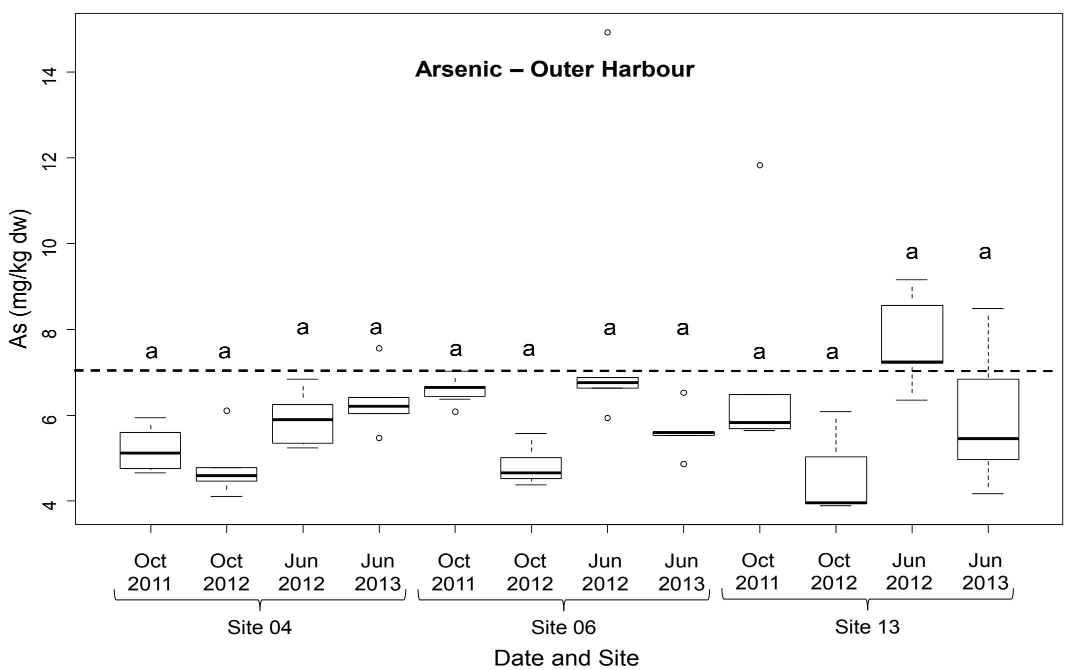
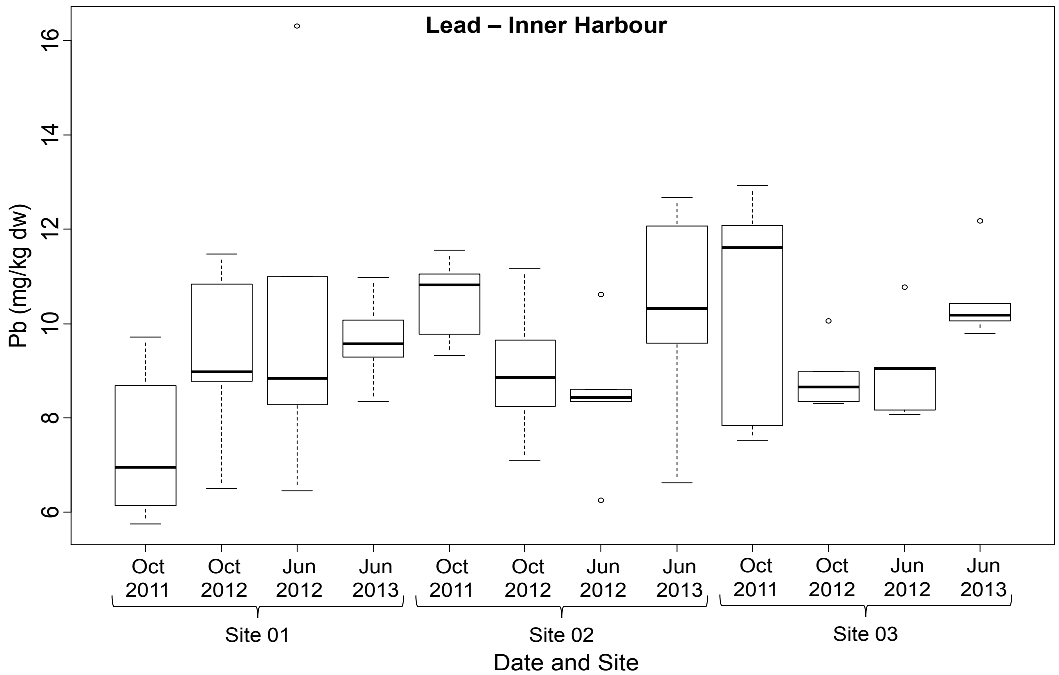




Figure G-1. Interannual variation of arsenic concentrations in sediments from Saint John Harbour reference sites, 2011-2013. Dashed line is CCME-ISQG. Boxplot whiskers are minimum and maximum values. Different letters indicate significantly different mean concentrations between month-year pairing per site (two-way ANOVA, Holm-Sidak test, $p < 0.050$). n = 5-10 samples on each sampling date per site.



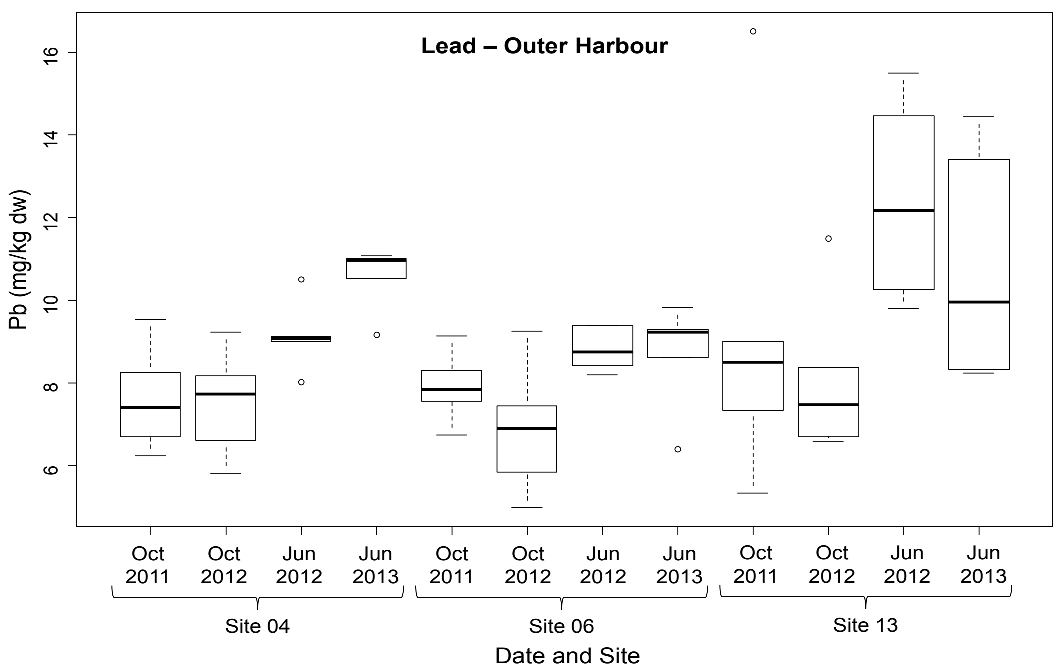
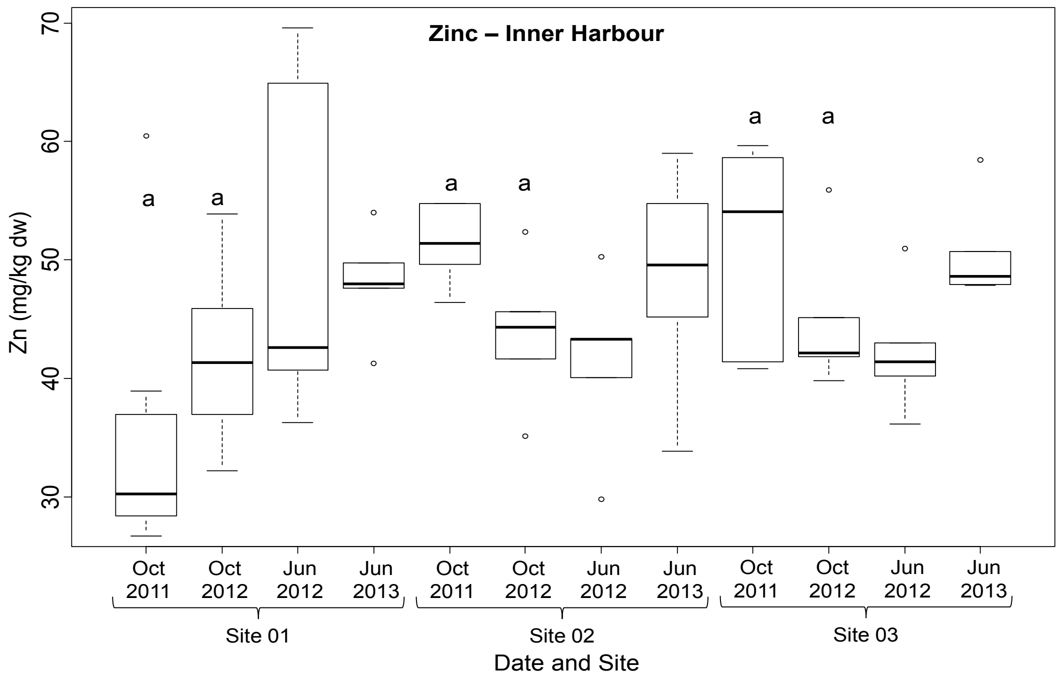




Figure G-2. Interannual variation of lead concentrations in sediments from Saint John Harbour reference sites, 2011-2013. See Figure G-1 for description.



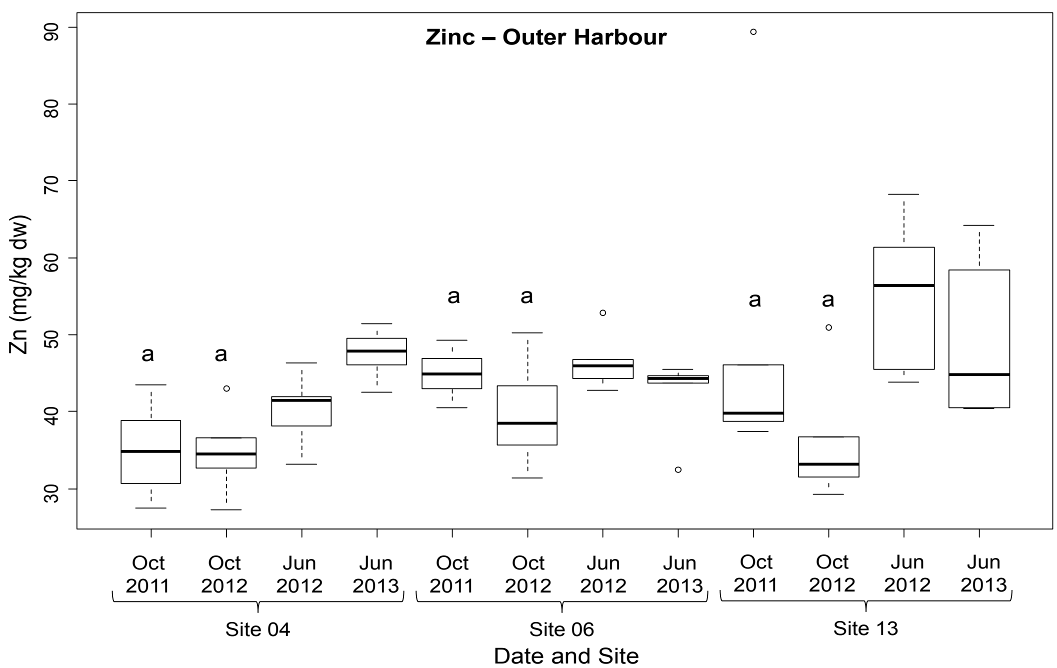
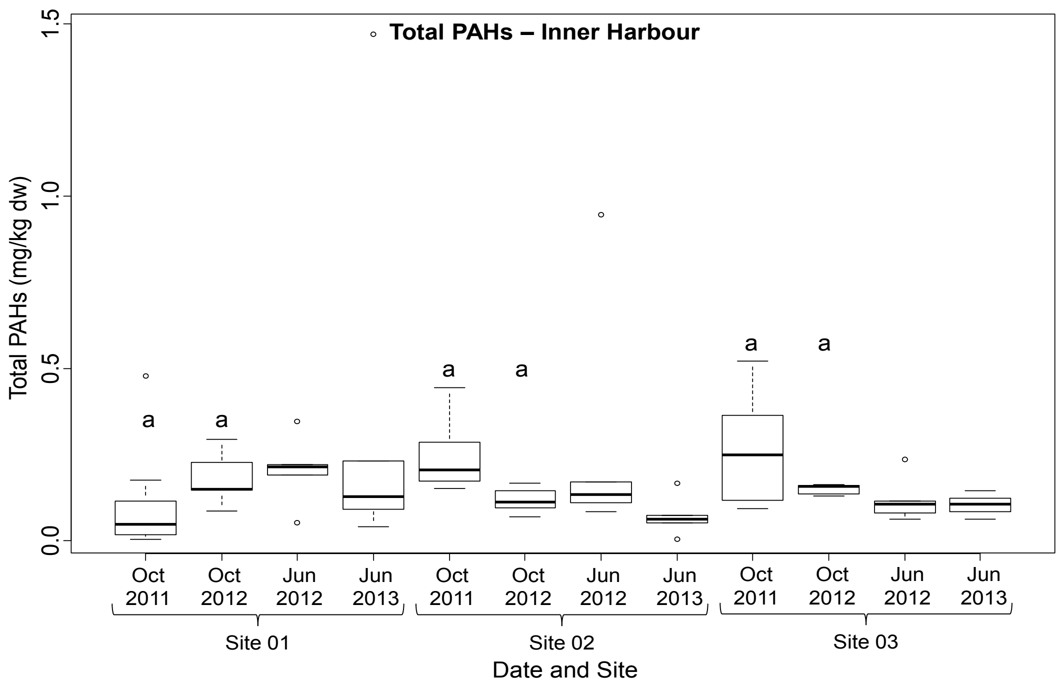




Figure G-3. Interannual variation of zinc concentrations in sediments from Saint John Harbour reference sites, 2011-2013. See Figure G-1 for description.



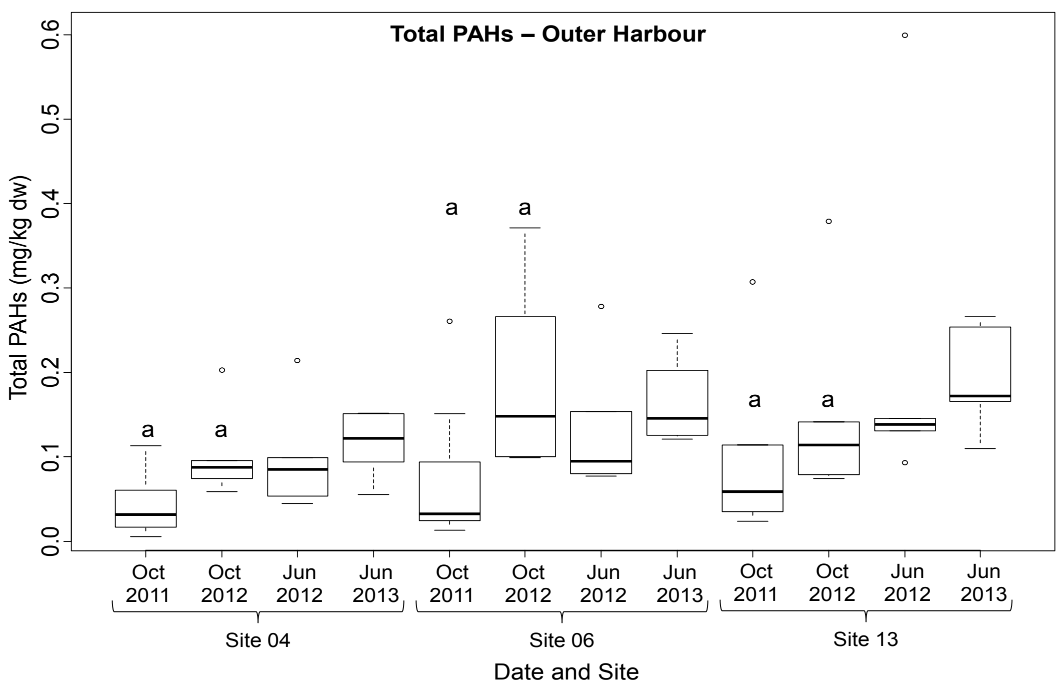




Figure G-4. Interannual variation of zinc concentrations in sediments from Saint John Harbour reference sites, 2011-2013. See Figure G-1 for description.

## APPENDIX H. Taxonomic sufficiency

Table H-1.Taxonomic sufficiency, using second-stage MDS. Abundances were aggregated to the levels of species, genus, family, suborder, order, infraclass and class (note that many polychaetes worms are not classified to orders but to infraclass) and untransformed or transformed (square-root, logarithmic or presence/absence). Correlations ($\rho_s$) are expressed as the correlation between the similarity matrix for the species level for a given transformation to that of each of the taxonomic resolutions.

Interannual comparison – October 2011 and 2012

| **Spearman's Rank Correlation ($\rho_s$)** | Species | Genus | Family | Suborder | Order | Infraclass | Class |
|---|---|---|---|---|---|---|---|
| Untransformed | 1 | 0.99887 | 0.99590 | 0.93654 | 0.92968 | 0.92027 | 0.85222 |
| Square-root | 1 | 0.99306 | 0.98266 | 0.90896 | 0.87793 | 0.80671 | 0.72132 |
| Logarithmic | 1 | 0.99168 | 0.98117 | 0.90923 | 0.88007 | 0.81336 | 0.67498 |
| Presence/Absence | 1 | 0.96685 | 0.91504 | 0.75038 | 0.66536 | 0.39284 | 0.28297 |

Interannual comparison – June 2012 and 2013

| **Spearman's Rank Correlation ($\rho_s$)** | Species | Genus | Family | Suborder | Order | Infraclass | Class |
|---|---|---|---|---|---|---|---|
| Untransformed | 1 | 0.99958 | 0.99672 | 0.98238 | 0.9821 | 0.98039 | 0.95391 |
| Square-root | 1 | 0.99603 | 0.99248 | 0.9634 | 0.95772 | 0.939 | 0.90827 |
| Logarithmic | 1 | 0.99465 | 0.99009 | 0.94908 | 0.93967 | 0.90903 | 0.8758 |
| Presence/Absence | 1 | 0.97177 | 0.95418 | 0.86613 | 0.85154 | 0.75404 | 0.48178 |

Seasonal comparison for all sites without Aug. 2011

| **Spearman's Rank Correlation ($\rho_s$)** | Species | Genus | Family | Suborder | Order | Infraclass | Class |
|---|---|---|---|---|---|---|---|
| Untransformed | 1 | 0.99931 | 0.99655 | 0.95567 | 0.95433 | 0.95193 | 0.91331 |
| Square-root | 1 | 0.99589 | 0.99051 | 0.94744 | 0.93685 | 0.90257 | 0.85494 |
| Logarithmic | 1 | 0.99370 | 0.98690 | 0.93684 | 0.92329 | 0.87639 | 0.81425 |
| Presence/Absence | 1 | 0.97312 | 0.94391 | 0.83993 | 0.80985 | 0.61204 | 0.40090 |

Seasonal comparison for all 4 dates without site 13

| **Spearman's Rank Correlation ($\rho_s$)** | Species | Genus | Family | Suborder | Order | Infraclass | Class |
|---|---|---|---|---|---|---|---|
| Untransformed | 1 | 0.99927 | 0.99568 | 0.95532 | 0.95297 | 0.94923 | 0.90211 |
| Square-root | 1 | 0.9961 | 0.98993 | 0.94587 | 0.93052 | 0.89059 | 0.83376 |
| Logarithmic | 1 | 0.99516 | 0.98859 | 0.94237 | 0.92630 | 0.88226 | 0.80872 |
| Presence/Absence | 1 | 0.97539 | 0.94508 | 0.82977 | 0.79969 | 0.62208 | 0.41639 |

## APPENDIX I. Range of reference concentrations for metals and PAHs

Table I-1. Range of reference concentrations for metals and PAHs (± 2x SD of the grand mean) on the basis of site, area (Inner-Sites 01, 02, 03 vs Outer-Sites 04, 06, 13), and region (whole harbour) in sediment collected from reference sites in Saint John Harbour, 2011-2013.

| Metals and Organics (mg/kg dw) | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
|---|---|---|---|---|---|---|
| n | 6 | 6 | 6 | 6 | 6 | 5 |
| Al | 8000-25000 | 11000-27000 | 14000-25000 | 8100-26000 | 12000-22000 | 11000-27000 |
| As | 4.4-9.5 | 5.4-8.4 | 5.9-8 | 4.5-6.7 | 3.8-8.5 | 4.2-9.2 |
| Cd | 0.03-0.15 | 0.03-0.11 | 0.05-0.15 | 0.01-0.16 | 0.01-0.17 | 0.01-0.19 |
| Co | 6.9-11 | 6.5-12 | 8.4-10 | 6.4-9.5 | 7.6-9.9 | 6.9-12 |
| Cr | 16-33 | 19-35 | 22-32 | 17-28 | 19-27 | 18-35 |
| Cu | 3.9-12 | 5.3-10 | 3.4-12 | 0-11 | 0.1-11 | 1.9-13 |
| Fe | 15000-26000 | 15000-29000 | 19000-25000 | 11000-28000 | 16000-26000 | 20000-24000 |
| La | 17-24 | 18-24 | 15-28 | 18-23 | 14-23 | 15-25 |
| Mg | 4300-7900 | 4500-8500 | 5200-8300 | 4300-6500 | 4200-7900 | 5500-7200 |
| Mn | 340-560 | 340-580 | 350-550 | 290-500 | 310-430 | 280-510 |
| Ni | 10-24 | 14-22 | 16-21 | 10-19 | 13-20 | 11-26 |
| P | 540-860 | 610-750 | 560-850 | 420-660 | 350-690 | 440-670 |
| Pb | 7.2-11 | 6-13 | 8.2-11 | 6.1-11 | 6.4-9.7 | 6.9-14 |
| Rb | 9.3-76 | 23-86 | 30-76 | 17-63 | 18-62 | 9.3-94 |
| S | 1000-2100 | 1000-2400 | 1300-2300 | 830-1700 | 1500-2900 | 1200-2700 |
| Se | 0-3 | 0-2.7 | 0.02-3 | 0-3.2 | 0-3.1 | 0-3.4 |
| Sr | 33-60 | 41-62 | 47-55 | 34-52 | 33-59 | 35-57 |
| V | 26-52 | 31-54 | 38-48 | 27-47 | 31-45 | 33-54 |
| Zn | 32-60 | 32-60 | 39-57 | 29-50 | 38-49 | 34-63 |
| THg | 3.4-24 | 5.6-15 | 7.6-15 | 4.7-8.6 | 4.2-9.8 | 7.4-13 |
| TPAHs | 0-0.4 | 0-0.38 | 0.05-0.28 | 0-0.23 | 0-0.3 | 0.07-0.3 |

Table I-1. continued.

| Metals and Organics (mg/kg dw) | Inner Harbour | Outer Harbour | Whole Harbour |
|---|---|---|---|
| n | 18 | 17 | 35 |
| Al | 11000-26000 | 11000-25000 | 11000-25000 |
| As | 5.2-8.6 | 4-8.2 | 4.5-8.6 |
| Cd | 0.03-0.14 | 0.01-0.17 | 0.02-0.15 |
| Co | 7.2-11 | 6.6-11 | 6.9-11 |
| Cr | 19-34 | 17-31 | 18-33 |
| Cu | 4.3-11 | 0.5-11 | 1.9-11 |
| Fe | 16000-27000 | 15000-27000 | 16000-27000 |
| La | 17-25 | 16-24 | 16-25 |
| Mg | 4700-8200 | 4400-7400 | 4500-7900 |
| Mn | 350-560 | 300-480 | 300-540 |
| Ni | 13-22 | 11-22 | 12-22 |
| P | 570-820 | 400-670 | 410-820 |
| Pb | 7.2-12 | 5.7-12 | 6.4-12 |
| Rb | 20-80 | 14-73 | 17-77 |
| S | 1100-2300 | 770-2800 | 910-2600 |
| Se | 0-2.8 | 0-3.1 | 0-3 |
| Sr | 39-61 | 34-56 | 36-59 |
| V | 31-52 | 29-49 | 30-51 |
| Zn | 35-59 | 31-56 | 33-58 |
| THg | 4.8-19 | 3.9-11 | 2.5-17 |
| TPAHs | 0.01-0.35 | 0-2.8 | 0-1.9 |

## APPENDIX J. Range of reference conditions for benthic invertebrates

Table J-1. Range of reference conditions (± 2 x SD of the grand mean) for total abundance, richness and diversity for benthic invertebrates on the basis of site, area (Inner-Sites 01, 02, 03 vs Outer-Sites 04, 06, 13), and region (whole harbour) in marine invertebrates collected from reference sites in Saint John Harbour, in October 2011 and 2012.

| | Site 01 | Site 02 | Site 03 | Site 04 | Site 06 | Site 13 |
|---|---|---|---|---|---|---|
| *n* | 5 | 5 | 5 | 5 | 5 | 5 |
| Total abundance ($m^{-2}$) | 1505.46-4726.29 | -17535.50-75809.40 | -11360.30-69273.27 | 3008.61-4311.42 | 211.36-3486.00 | 115.28-8636.39 |
| Species richness | 9.27-11.53 | 11.54-22.86 | 17.30-20.70 | 15.47-17.73 | 11.03-25.17 | 8.96-20.84 |
| Diversity | 1.22-1.27 | -0.01-1.78 | 0.74-1.56 | 1.67-2.27 | 2.33-2.45 | 1.45-2.07 |

| | Inner Harbour | Outer Harbour | Whole Harbour |
|---|---|---|---|
| *n* | 15 | 15 | 30 |
| Total abundance ($m^{-2}$) | -8056.51-48862.38 | 1111.75-5477.94 | -3472.38-27170.16 |
| Species richness | 13.46-17.61 | 11.82-21.25 | 12.64-19.43 |
| Diversity | 0.67-1.52 | 1.82-2.26 | 1.47-1.67 |

## APPENDIX K. Certified reference material recoveries

Table K-1. Mean ± standard deviation of CRM recoveries for THg, various elements and PAHs for SJH reference sites from August 2011 to June 2013.

| | CRM 2702 | CRM 1941b |
|---|---|---|
| TPAHs | - | 88.2 ± 15.1 |
| TPCBs | - | 98.9 ± 28.4 |
| THg | 91.6 ± 4.6 | - |
| Ag | <DL | - |
| Al | 53.7 ± 3.4 | - |
| As | 78.0 ± 6.5 | - |
| Cd | 100.6 ± 28.4 | - |
| Co | 87.2 ± 6.8 | - |
| Cr | 74.6 ± 13.1 | - |
| Cu | 88.3 ± 6.6 | - |
| Fe | 73.2 ± 5.9 | - |
| La | 57.6 ± 8.0 | - |
| Mg | 69.0 ± 3.8 | - |
| Mn | 82.0 ± 4.5 | - |
| Ni | 81.1 ± 7.0 | - |
| P | 89.4 ± 11.5 | - |
| Pb | 78.2 ± 6.5 | - |
| Rb | 107.7 ± 9.0 | - |
| S | 98.0 ± 5.4 | - |
| Se | 105.6 ± 24.7 | - |
| Sr | 45.1 ± 2.5 | - |
| Tl | <DL | - |
| U | 83.8 ± 13.9 | - |
| V | 77.1 ± 4.6 | - |
| Zn | 85.4 ± 6.0 | - |