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COMMUNITY-BASED MONITORING IN THE SAINT JOHN HARBOUR

REPORT FOR FISHERIES AND OCEANS CANADA'S COASTAL ENVIRONMENTAL BASELINE MONITORING PROGRAM 2018-2022

ACAP SAINT JOHN

Community-Based Monitoring in the Saint John Harbour

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Abstract

The goal of this project was to create a field program in the Saint John Harbour to collect aquatic environmental data on water quality, fish communities, and sediment PAHs in line with Fisheries and Oceans' Coastal Environmental Baseline Monitoring Program. The 2018 sampling season served as a pilot year for building the Harbour Baseline Monitoring Program, and there have been four full sampling seasons since. Water quality was analyzed at 22 sites, and of these sites, 13 were also sampled for sediment contaminants and eight sites were surveyed for nekton communities via beach seine and fyke net. There was generally good water quality at most Harbour sites, except for certain sites, especially those in Marsh Creek and Little River. Marsh Creek and Little River are two streams known to have historic contamination from industrial and municipal effluents. We collected a total of 41,715 fish and invertebrates, representing 38 species, in beach seines and fyke nets across the eight fishing sites

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1. Introduction

The Saint John Harbour is located at the mouth of the Wolastoq (St. John River) in New Brunswick, where it receives a mean annual discharge of 1,110 m^3/s of fresh water (Cunjak and Newbury 2004), including discharge from other watersheds. The Saint John Harbour is a dynamic system with an 8 m tidal influence in the Bay of Fundy (Trites and Garrett 1983); this system has a number of human influences, freshwater inputs, and other changing natural conditions. The Harbour contains a port with frequent shipping and dredging activities (Courtenay et al. 2002), as well as industrial (i.e., pulp and paper effluent, ballast water, and oil refinery effluent) and municipal discharges entering the aquatic ecosystem. The Coastal Environmental Baseline Program, a Canadian federal government environmental initiative, funded the development of an environmental monitoring program in 2016 for busy shipping ports in Canada to evaluate environmental indicators and baseline conditions. The Saint John Harbour was selected for this federal monitoring program because of its highly industrialized port. Identifying current baseline conditions in the Saint John Harbour will allow observations of significant changes in environmental indicators in future years or as new industrial or municipal developments occur.

Fish community monitoring has been used to detect anthropogenic changes in previous studies in watersheds around the Harbour (and for pre-design analysis for sentinel species monitoring programs; Arens et al. 2007; Casselman 2007; Vallieres et al. 2007; Methven 2003, unpublished data; Power 2012-2013, unpublished data). Mummichog (Fundulus heteroclitus), Atlantic silverside (Menidia menidia), and rock gunnel (Pholis gunnellus) have been investigated as sentinel species using previous fish community data collected in the Saint John Harbour and surrounding watersheds (Vallis et al. 2007; McMullin et al. 2010; Doyle et al. 2011). ACAP Saint John has historic fish community and water quality data dating back to the early 1990s for monitoring purposes in the Greater Saint John area and has used these data to aid cleanup initiatives such as Harbour Cleanup (the cessation of raw sewage entering the Harbour in 2014).

Municipal and industrial discharges into aquatic environments can carry contaminants that accumulate in nearshore and offshore substrates (Doyle et al. 2011). Among these contaminants are polycyclic aromatic hydrocarbons (PAHs). PAHs are a group of organic contaminants that are released into the environment from the incomplete combustion of wood, coal, and fossils fuels. Sources of PAHs include car exhaust, industrial emissions, marine traffic, and residential emissions, and they are also used in products like pesticides, asphalt, and creosote (a preservative used on wood products). These compounds are typically released in complex mixtures and can be easily transported from land to water through rain, urban runoff, and snowmelt (Stogiannidis and Laane 2015). Most PAHs bioaccumulate and are acutely toxic to animals, and medium to larger sized PAHs are also carcinogenic (Manzetti 2013). PAH sampling in the Saint John Harbour over the last 2 decades has identified considerable PAH contamination within the sediments (Zitko 1999; Van Geest at al. 2015). Within the Harbour area, Marsh Creek is also known to contain extreme PAH contamination due to creosote applications at a former lumber yard on the banks.

2. Objectives and Significance

The goal of this project was to develop a field program in the Saint John Harbour focused on collecting baseline environmental data on water quality, sediment PAHs, and biotic communities. To be concurrent with Eastern Charlotte Waterways (an environmental not-for profit organization overseeing the Charlotte County community), who have also collected baseline biological data in the region, sampling protocols were adapted from a Department of Fisheries and Oceans Canadian Technical Report (Ipsen 2016). ACAP Saint John's Harbour monitoring program serves to fill in data gaps in priority areas around the Harbour in line with Fisheries and Oceans' Coastal Environmental Baseline Monitoring Program.

Water quality monitoring is a key method for evaluating short- and long-term changes in aquatic ecosystem health. Monitoring fish communities can indicate a response to their habitat, i.e., a loss in species richness may indicate a negative change in the environment. Since PAHs are highly tied to oil and gas industries, vehicles, residential home heating, etc., they are an important parameter to examine in an industrialized area such as Saint John. The sites selected for this program are primarily concentrated around the most industrialized parts of the city's coastline, with some sites outside of the Harbour selected for comparative purposes. A continual baseline monitoring program in support of cumulative effects assessment (Duinker and Greig 2006) will be a crucial next step in determining the health of the Saint John Harbour.

3. Materials and Methods

3.1 Water Quality Sampling

Water sampling was generally completed within a two-hour window before or after low tide in the Saint John Harbour. There were 22 water quality sites (Table 1, Figure 1) sampled as part of this program. Water quality samples and measurements were collected bi-weekly or monthly between May and October each year, starting in September 2018, and ending in October 2022.

Table 1. *Sites sampled in the Saint John Harbour Baseline Monitoring Program with site codes and coordinates. Sediment sampling sites (for PAH analysis) and fishing sites (for biotic community analysis) are also identified. All sites are monitored for water quality.*

Site	Site Code	Latitude	Longitude	Sediment Site	Fishing Site
Black Beach	BB	45.154591	-66.229004	X	
Saints Rest Beach	SRB	45.222523	-66.126761	X	
Bayshore	BS	45.244895	-66.075821	X	
Digby Ferry Terminal	DFT	45.253016	-66.062025	X	X
Mill Creek	Mill	45.279310	-66.155487		
Kennebecasis Drive	KD	45.305689	-66.095746		
Spar Cove	SC	45.276147	-66.090295	X	X
Inner Harbour	IH	45.272068	-66.073478	X	X
Tin Can Beach	TCB	45.262244	-66.054578	X	X
Courtenay Bay	CB	45.276202	-66.047032	X	X
Marsh Creek 2	MC2	45.281834	-66.049478		X
Marsh Creek Downstream	MCDS	45.282676	-66.049784	X	
Marsh Creek 3	MC3	45.284826	-66.052373		
Marsh Creek 4	MC4	45.289029	-66.047363		
Marsh Creek 5	MC5	45.291050	-66.043541		
Marsh Creek 11	MC11	45.309737	-66.033974		
Marsh Creek Upstream	MCUS	45.321672	-66.015109		
Little River	LR	45.272416	-66.022299	X	X
Hazen Creek 2/Expansion	HC2	45.275821	-66.999035		
Hazen Creek Nearshore	HCNS	45.258105	-66.020075	X	X
Hazen Creek Mouth	HCM	45.260928	-66.015080	X	
Mispec Beach	MB	45.223043	-65.954639	X	

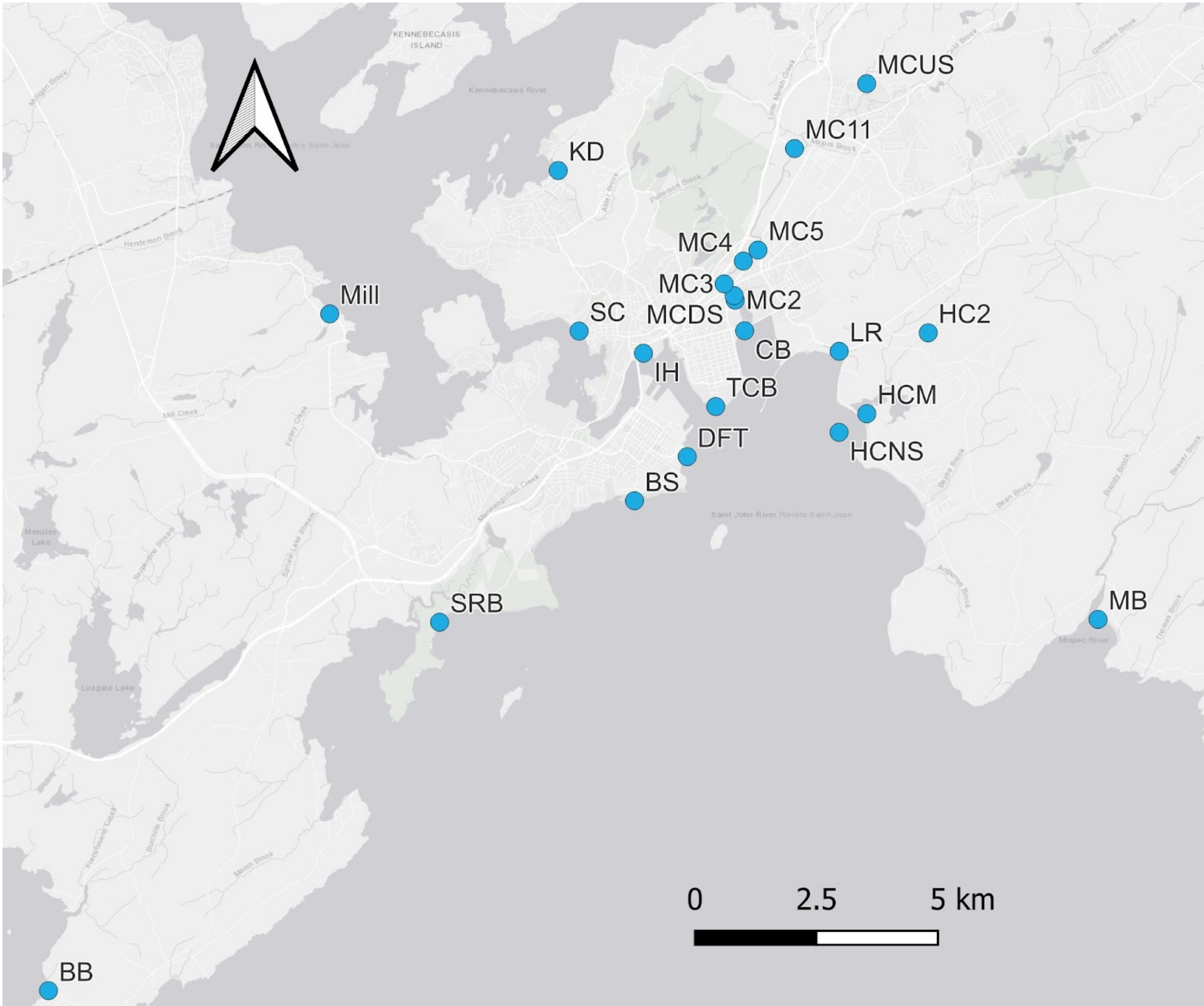

Figure 1. *Map of sites in and around the Saint John Harbour. Site names and geographic coordinates are provided in Table 1.*

A calibrated YSI multimeter was used to analyze *in-situ* water temperature (±0.1°C), dissolved oxygen (DO; ±0.01 mg/L and %), salinity (±0.01 ppt), conductivity (± 1 μS/cm) and pH (±0.01). A turbidity meter was used to measure turbidity in the water (±0.01 NTU) (n = 1/site per date; two sampling events in 2018, 10 in 2019, 6 in 2020, 11 in both 2021 and 2022). All reasonable efforts were made to remove measurements that were ecologically impossible or could not be validated. Due to the large amount of data, potential errors with equipment, the number of people that had a part in data collection and input, and the large amount of natural variability in conditions at many sites, some isolated datapoints within this dataset may be erroneous. All results are presented as a mean ± standard deviation (SD).

Figure 2. *Chemical Technology students collecting water quality data in Courtenay Bay.*

Starting in 2019, collected water samples were analyzed using a DR900 multiparameter colorimeter for total ammonia (±0.01 mg/L; blanks = 0.023 ± 0.054 mg/L, n = 46; duplicates within 36 ± 52 %, n = 43) and orthophosphate (±0.01 mg/L; blanks = 0.08 ± 0.19 mg/L, n = 45; duplicates within 38 ± 42 %, n = 45). In 2020 to 2022, orthophosphate (PO_4^{3-}) was further analyzed for phosphorus (P) in each sample (±0.01 mg/L; blanks = 0.03 ± 0.073 mg/L, n = 36; duplicates within 49 ± 56 %, n = 48). When access to the NBCC chemical technology lab was available from June to August 2019, total suspended solids, and fecal coliform content (± 1 cfu) were also analyzed.

Ammonia concentrations measured in 2021 were considerably higher than those measured in previous years. Blank samples with distilled water, which historically had concentrations around 0 mg/L, had concentrations around 0.07 mg/L. As a result, sample ammonia concentrations in 2021 were standardized to a new baseline concentration. However, ammonia concentrations in blank samples may have been even higher than 0.07 mg/L at some points in 2021, resulting in reported ammonia levels that are still elevated compared to previous years. Due to this uncertainty with the 2021 ammonia data, we also present ammonia results for each individual year in this report to better understand patterns in ammonia levels.

Laboratory analysis of fecal coliforms was conducted on water samples in 2019. Starting in 2020, fecal coliform analysis was replaced with analysis of *Escherichia coli*, a particular species of fecal bacteria. Concentrations of total coliforms and *E. coli* were estimated using the IDEXX Colilert incubation system (±0.1 MPN/100 mL). The Colilert-18 reagent was added to 100 mL of sample and incubated in standardized trays at 35°C for 18 hours, after which samples were removed from the incubator. The number of yellow and fluorescing trays corresponded to the total coliform and *E. coli* concentrations, respectively, measured as the most probable number/100 mL (MPN/100 mL). If a site exceeded 2 ppt salinity, the sample was analyzed in a 1:10 dilution so that the salinity would not interfere with bacterial growth, and results were multiplied by ten to achieve MPN/100 mL. Total coliform counts are unreliable outside of freshwater sites; for this reason, total coliforms are not presented in this report, though they were observed. All *E. coli* counts at or above the detection limit (2419.6 MPN/100 mL) were assigned the detection limit as a value. This method was used to allow for comparisons between undiluted freshwater sites and diluted tidal sites; the dilution and subsequent multiplication at higher salinity sites can result in *E. coli* counts over the detection limit, but undiluted sites cannot be given values higher than the detection limit. The total *E. coli* levels at several sites may be far higher than 2419.6 MPN/100 mL.

3.2 Sediment PAH Sampling

Sediment sampling for PAH analysis was conducted at 13 sites for this program (Table 1). Sampling occurred at low tide, typically at the same time as water quality sampling. A plastic corer was used to collect a standardized amount of sediment from each site (2018: n = 1/site, 2019-2020: n = 3/site, 2021: n = 4-6/site, 2022: n = 1-4/site). The corer was cleaned between sites with acetone and deionized water or 5% nitric acid (Figure 3). An operator wore clean powder-free nitrile gloves at each site, and the corer was rinsed in site water before each sample was collected. Each sediment sample was collected from the top 5 cm, placed into a clean glass jar, and frozen. Sediment samples were sent to the Research and Productivity Council of New Brunswick in Fredericton for PAH analysis (detection limit [DL]: 0.01-0.05 mg/kg).

Total PAHs were calculated from the addition of all individual PAHs (17 PAH analytes). Individual PAH values that were lower than the detection limit (0.01-0.05 mg/kg) were reported as half the DL (0.005-0.025 mg/kg). As a result, the lowest total PAH concentration possible in this report is 0.085 mg/kg. Blank samples (n=21) were all reported as lower than the DL for all of the PAHs tested, spike recovery was 97 ± 6.04% (n = 21), and duplicate samples were within 9 ± 16 % (n = 17).

Figure 3. *ACAP Saint John staff member collecting a sediment sample at Inner Harbour.*

3.3 Biotic Community Sampling

Nekton community sampling (i.e., fish and crustaceans) was conducted monthly at eight sites from May to October between October 2018 and October 2022 (Table 1). Sampling occurred within a two-hour window around low tide using fyke nets and seine nets (Figure 4a and b). Using two types of fishing gear facilitates a more thorough survey of the nekton community by targeting different species and individuals of different sizes. Seine tows were conducted parallel to the shoreline for three minutes at each site. The seine nets had dimensions of 9 x 1.5 m with 9 mm mesh and a central collection bag. All animals collected were identified and counted before being released (Figure 4c). Total body lengths (mm) were measured for up to 30 individuals of each species (Figure 4d). If more than 30 individuals of a species were caught, the remaining individuals were counted but not measured before being released. This was done to reduce animal stress due to handling and time out of their environment. If a large school of one species was caught (i.e., greater than 100 individuals), the group was sub-sampled with a small dip-net to estimate the number of individuals. This was to ensure proper animal care and reduce time out of the water for the animals.

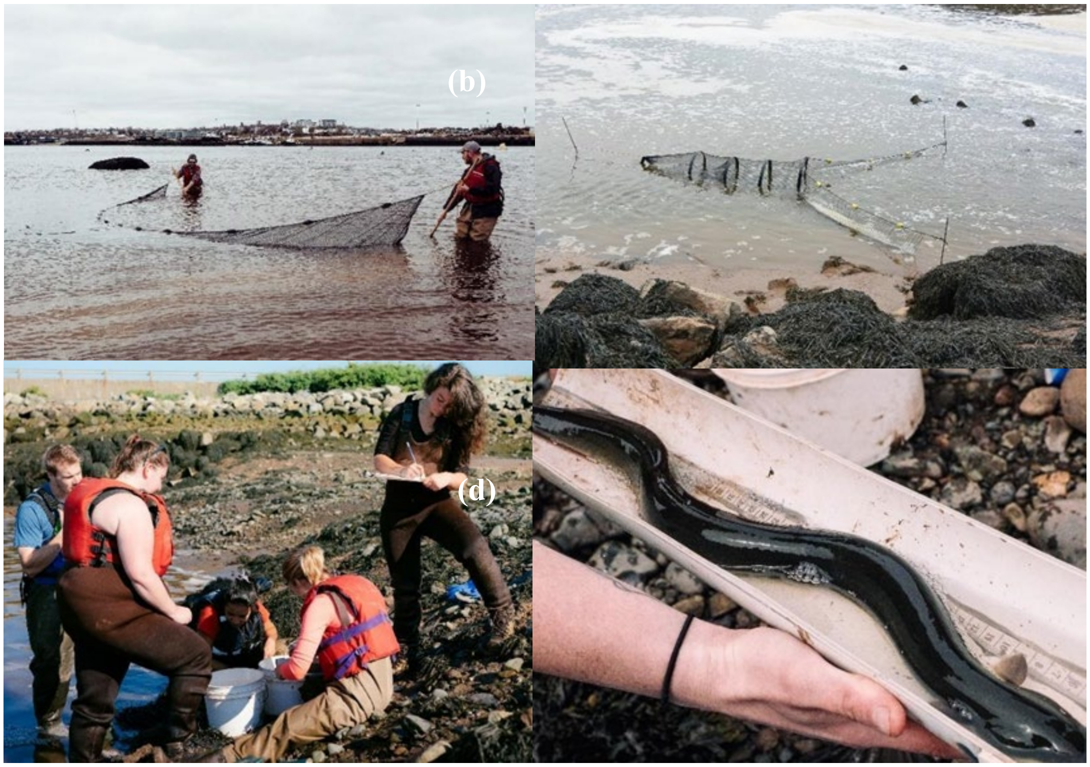

Figure 4. *Fish community collection methods: (a) ACAP staff seining at Tin Can Beach, (b) fyke net, (c) sampling team measuring fish and recording data, (d) an American Eel collected from a fyke net in Courtenay Bay in 2019.*

The fyke nets used were 3.7 m long with four hoops and two 3 m long wings, with 38.1 mm mesh in the wings and body, and 22.2 mm mesh in the cod end. A fyke net was installed at low tide and retrieved after approximately 24 hours. The fyke net was returned to the shoreline, and all fish and invertebrates were identified and counted, and lengths were measured for the first 30 individuals of a species. Animals were returned to the water immediately after processing. Salinity and temperature loggers (Star Oddi) were installed with each fyke net as well, recording every 30 minutes for approximately 24 hours. Logged data before net deployment and after net retrieval were removed from the data set. Salinity data is missing from Little River for 2019 because the appropriate logger broke; a new logger was purchased in 2020. Data is also missing in October 2022, for Inner Harbour and Little River due to logger malfunctions.

4. Results & Discussion

4. 1 Water Quality

4.1.1 In-situ Measurements

The mean values and standard errors for all water quality measurements are presented in Supplementary Table 1. The sites examined in this program range from marine and estuarine, to fully freshwater. The highest mean salinity concentrations were measured at Black Beach (BB) and Mispec Beach (MB), both of which are far outside the Saint John Harbour, while the lowest mean salinity concentrations were mainly at the upstream locations in Marsh Creek and Hazen Creek (Figure 5). There was considerable variation in salinity values across most sites, except for those that were purely marine or freshwater. This demonstrates the strong influence of tidal inflows in the Saint John Harbour and surrounding tributaries. Sites located within rivers (Wolastoq, Kennebecasis River) – such as Spar Cove (SC), Kennebecasis Drive (KD), and Mill Creek (Mill)—experienced a range of salinities due to tidal effects despite their upstream locations. The same was true of sites within smaller creeks that were close to the outflow (Marsh Creek 2 [MC2], Hazen Creek Mouth [HCM]). At many coastal sites and other sites with tidal influence (Spar Cove and Kennebecasis Drive), salinities increased between May and October (Supplementary Figure 1). Conductivity is closely related to salinity and followed similar patterns to those seen in salinity measurements.

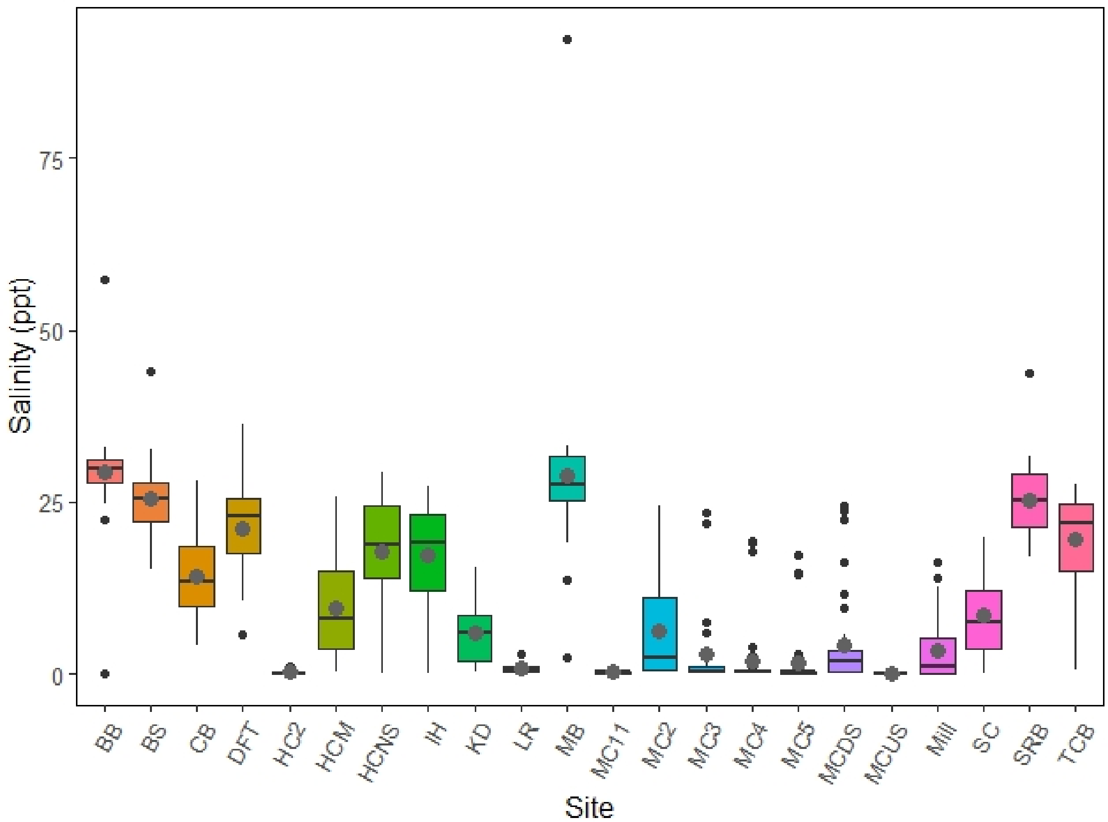

Figure 5. *Salinity concentrations (ppt) across 22 sites between 2018 and 2022. The mean concentration at each site is indicated by grey circles. Outliers are represented by black circles.*

Mean dissolved oxygen concentrations at all sites were suitable for aquatic life (Figure 6). Guidelines to ensure the health of aquatic life have been developed for some water quality parameters by the Canadian Council of Ministers of the Environment (CCME). The recommended dissolved oxygen threshold value for the protection of aquatic life is 6.5 mg/L (Canadian Council of Ministers of the Environment 1999a); all sites had mean concentrations above this threshold. However, some sites had single measurements below this value during the study period. Nearly all sites within the Marsh Creek Watershed saw drops in dissolved oxygen at some points, as did Kennebecasis Drive and Little River (LR). Algal growth was frequently observed at these locations, which may contribute to lower dissolved oxygen concentrations if sampled in early morning. The highest dissolved oxygen concentrations across all sites were generally measured in May (11.37 ± 7.54 mg/L) and October (9.17 ± 1.18 mg/L), when temperatures were lowest, while the lowest dissolved oxygen concentrations were typically in August (7.77 ± 1.69 mg/L) at the height of summer (Supplementary Figure 2). While occasional low oxygen levels do not impair the ability of these habitats to sustain life (fish were consistently observed in Marsh Creek and Little River), these low oxygens level events may increase in frequency with pollution and climate change.

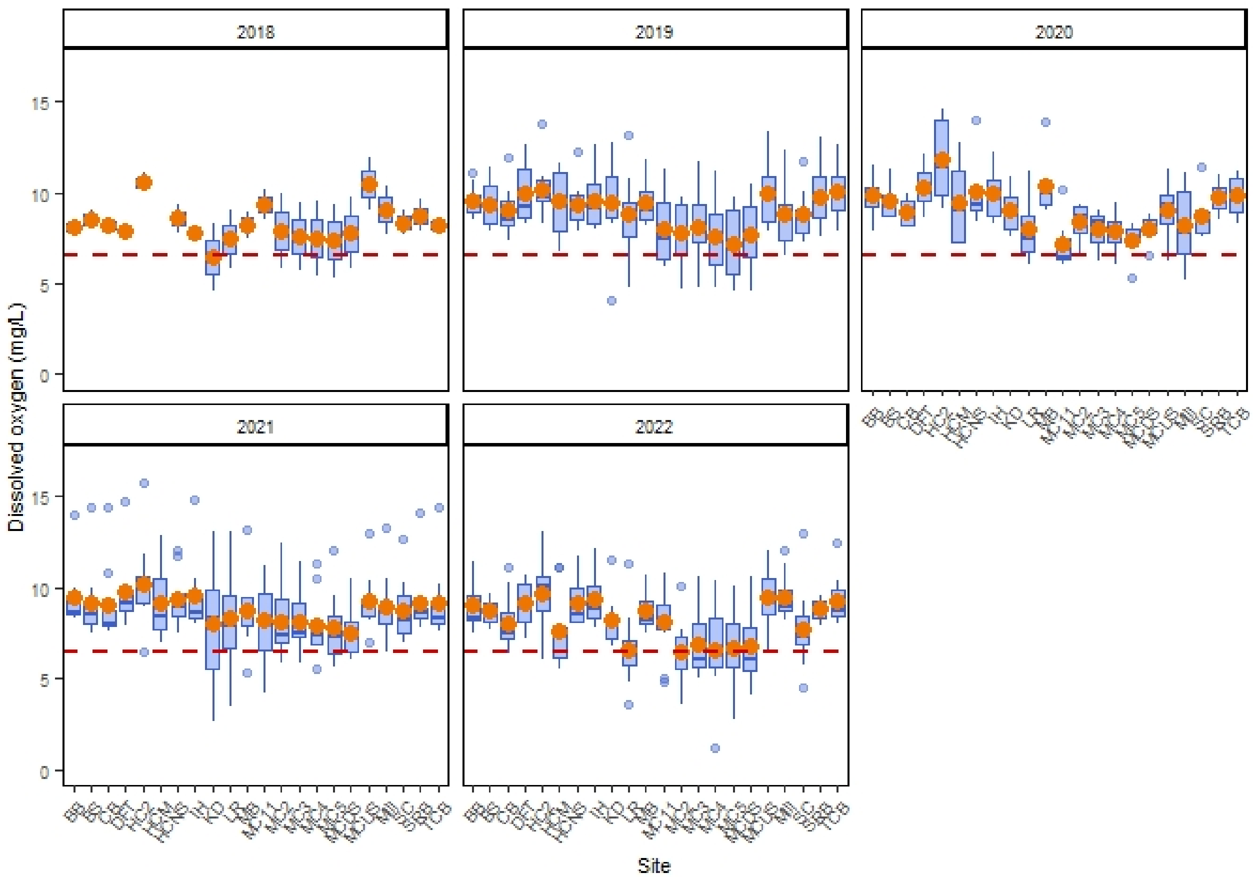

Figure 6. *Dissolved oxygen concentrations (mg/L) across 22 sites between 2018 and 2022. The red dotted line indicates the maximum recommended concentration for the protection of aquatic life (6.5 mg/L), and the mean concentration at each site is indicated by orange circles. Outliers are represented by blue circles.*

Temperatures below 23°C are considered optimal for juvenile salmonids (Breau et al. 2007). Mean water temperatures at all sites (May – October) remained below 23°C, with none of the sites frequently reaching temperatures that would impair salmonid development during sampling events (Figure 7). However, high water temperatures were measured multiple times at Little River and Kennebecasis Drive, with maxima of 26.4°C and 25.2°C, respectively (Supplementary Figure 4). High temperature events can create stressful conditions for aquatic life and have negative impacts on aquatic communities.

These two sites appear to be at increased risk of negative impacts from elevated temperatures.

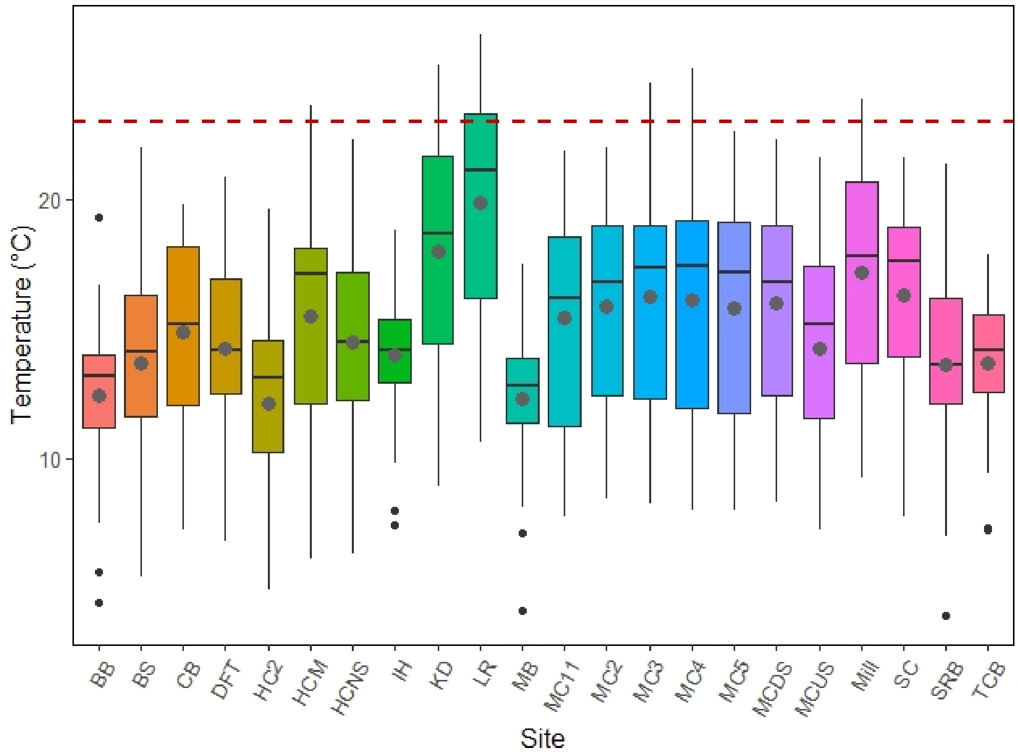

Figure 7. *Water temperatures (°C) across 22 sites between 2018 and 2022. The red dotted line indicates the maximum recommended temperature for salmonids (23°C), and the mean temperature at each site is indicated by grey circles. Outliers are represented by black circles.*

4.1.2 Harbour fishing data loggers

Data loggers attached to fyke nets saw slight variation between sites and from month to month. Little River saw the most variation in month-to-month temperature. This may be due to regular significant industrial inputs upstream, as well as this site being the least brackish of all the sites (Figure 8 and Figure 9). Inner Harbour received the largest salinity variation per month. This is likely due to its location near the Wolastoq's confluence point at the Saint John Harbour, where at low tide there is an increase of fresh water draining from the river. The highest salinity variations were seen earlier in the year (May-June) when there is an increase in rain fall events contributing augmented freshwater input into the harbour. Conductivity varied between sites slightly (Figure 10), with the exception of Little River which had the lowest conductivity due to it being the most freshwater site. Spar Cove also had low conductivity in May, this coincides with spring freshets and flooding causing an increase in freshwater at the site (Figure 10). Mean annual (May-Oct) temperature slightly increased each year for the study area, while mean salinity decreased (Table 2). An increase in temperature may be due to random chance, while the decrease in salinity could be a result of missing data due to logger malfunctions in 2019 and 2022.

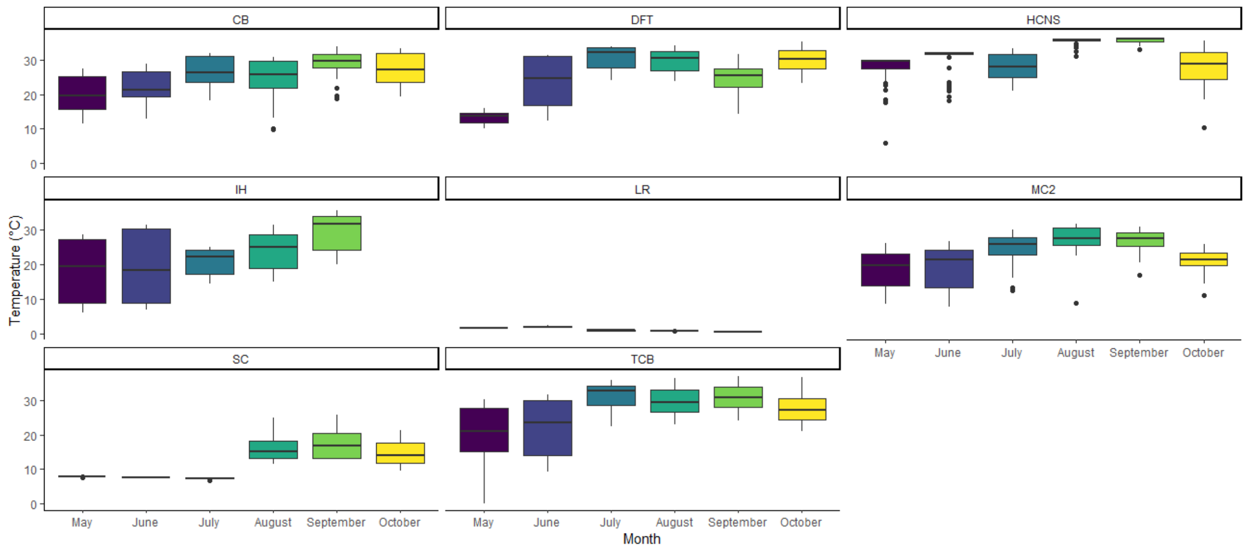

Figure 8. *Temperature readings for 2019-2022 gathered by data loggers attached to fyke nets. Data missing for October for IH is due to a data logger malfunction. Outliers are represented by black circles.*

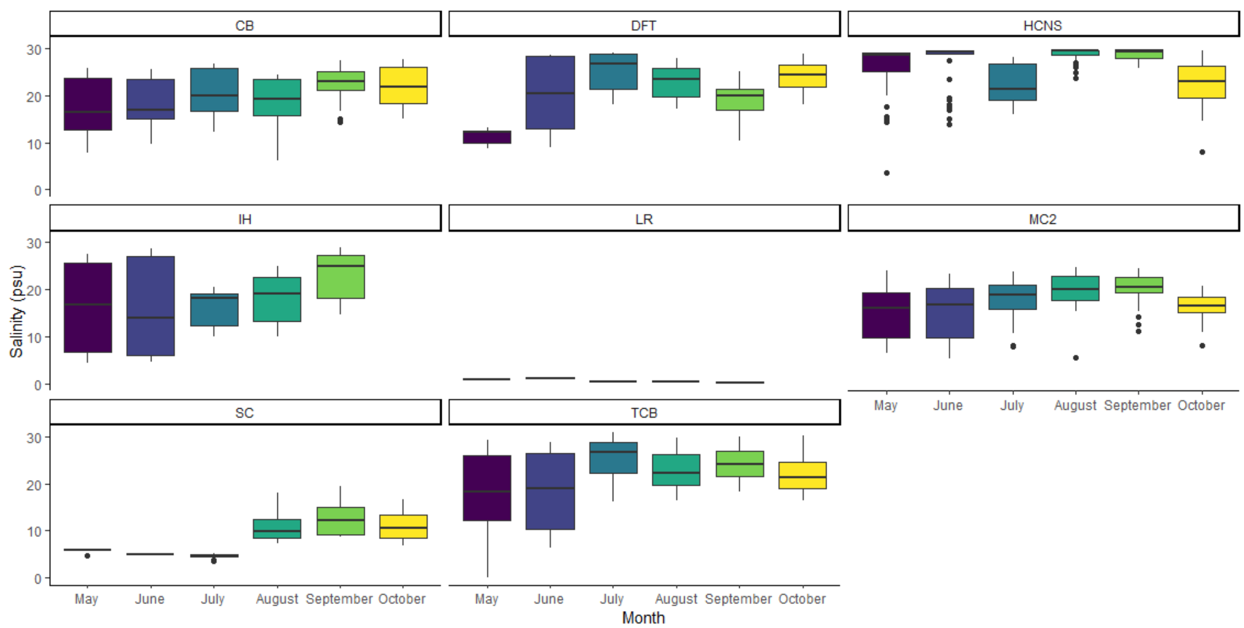

Figure 9. *Salinity readings for 2019- 2022 gathered by data loggers attached to fyke nets. Some data is missing for October for IH and LR from 2022 due to data logger malfunctions Salinity data is also missing from Little River for 2019 because the appropriate logger broke; a new logger was purchased in 2020. Outliers are represented by black circles.*

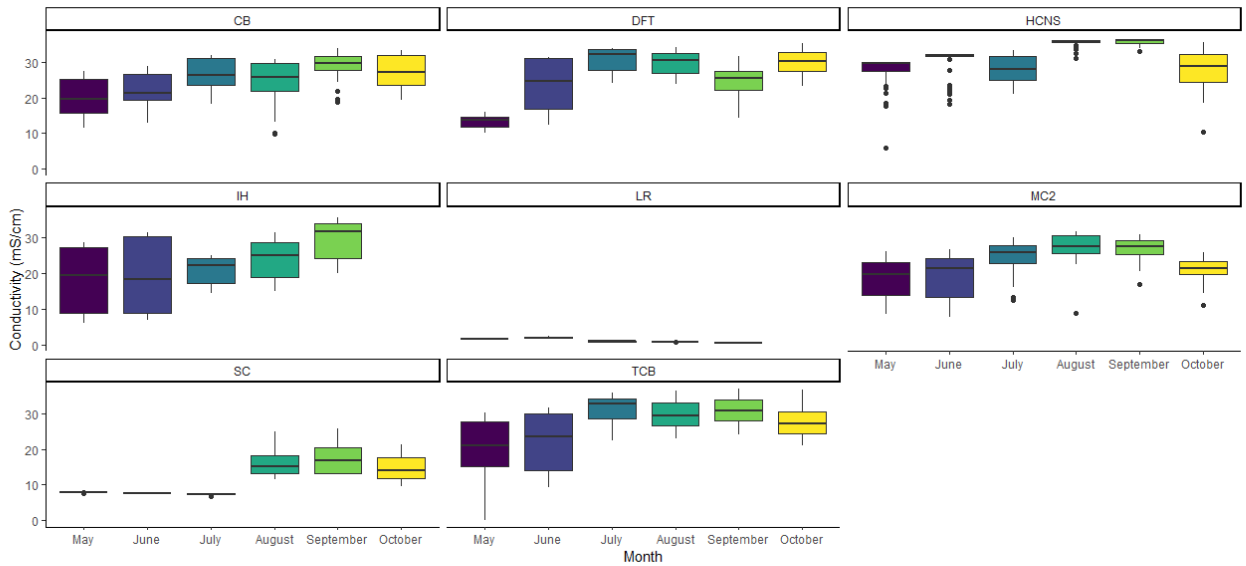

Figure 10. *Conductivity readings for 2019- 2022 gathered by data loggers attached to fyke nets. Some data is missing for October for IH and LR from 2022 due to data logger malfunctions Salinity data is also missing from Little River for 2019 because the appropriate logger broke; a new logger was purchased in 2020. Outliers are represented by black circles.*

Table 2. *Mean temperature and salinity readings from data loggers with corresponding standard deviation (SD) for each year.*

Year	Temperature (°C)		Salinity (psu)		Conductivity (mS/cm)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
2019	12.4	3.92	18.0	8.62	21.7	9.61
2020	14.6	3.92	15.9	9.92	19.6	11.6
2021	14.8	3.79	16.7	8.74	20.9	10.2
2022	15.0	3.71	16.8	9.10	21.1	10.6

4.1.3 Nutrients

Ammonia concentrations varied across sites within the Saint John Harbour. The CCME have reported that most natural waters have total ammonia concentrations below 0.1 mg/L (Canadian Council of Ministers of the Environment 2010); we have taken this as a threshold value above which aquatic life may suffer negative impacts. Mean ammonia concentrations throughout this study period were at or above 0.1 mg/L at six out of seven sites in the Marsh Creek watershed as well as Little River (Figure 11). At most sites there were occasional measurements of high concentrations with median levels generally remaining quite low. Little River had exceptionally high concentrations compared to all other sites, with a mean concentration of 0.74 ± 0.26 mg/L. This is over five times higher than the next highest mean concentrations at Marsh Creek 2 (0.13 ± 0.056 mg/L).

Ammonia concentrations were elevated throughout the Marsh Creek watershed in 2021 and 2022, with a general increase across most Marsh Creek sites. The highest ammonia levels were measured at the middle and downstream sites (MCDS, MC4, MC5), and the lowest levels are at the most upstream site (Marsh Creek Upstream, MCUS; 0.088 ± 0.073 mg/L). This pattern suggests that contamination sources may increase at mid and downstream locations and contamination accumulates as water moves downstream. There are several potential contamination sources along Marsh Creek, with multiple commercial and residential developments along the watercourse.

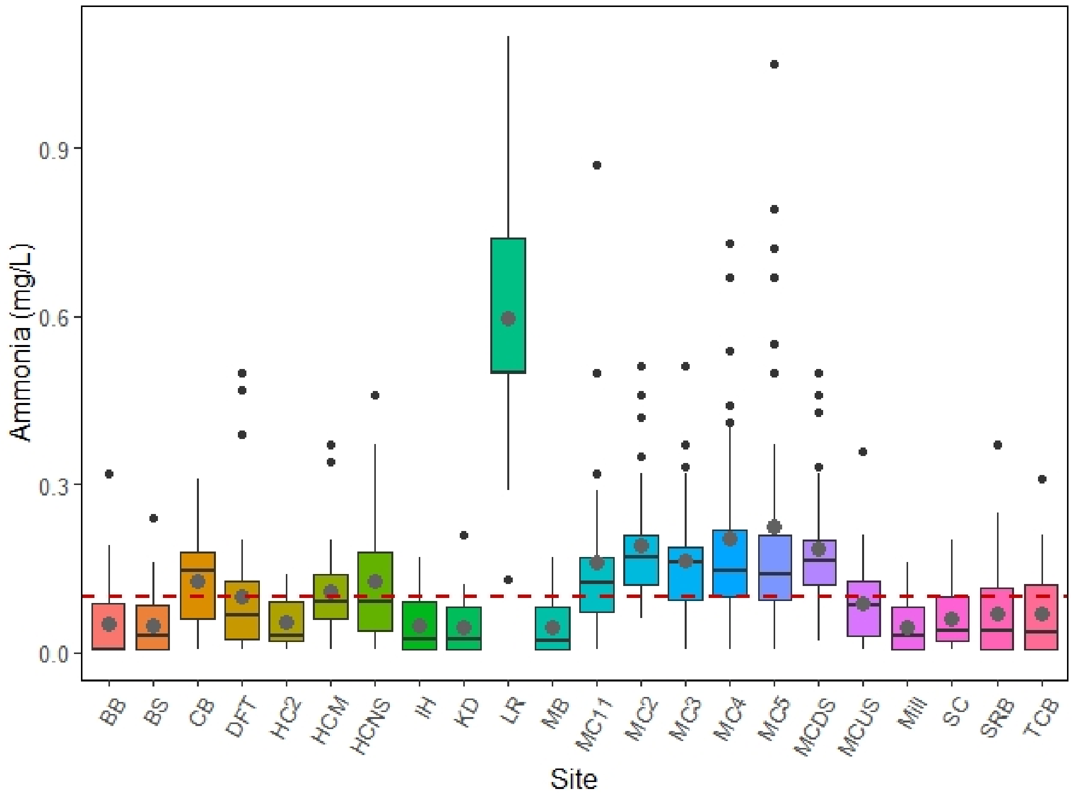

Figure 11. *Ammonia concentrations (mg/L) across 22 sites between 2019 and 2022. The dotted red line indicates the recommended upper limit for healthy aquatic life (0.1 mg/L), and the mean concentration at each site is indicated by the grey circles. Outliers are represented by black circles.*

Ammonia concentrations differed across years between 2019 and 2022 (Figure 12). Ammonia levels exceeded the threshold (0.1 mg/L) most frequently in 2021 and least frequently in 2020. The elevated levels observed in 2021 and 2022 may be due in part to sampling errors, as identified in the Methods section above. However, ammonia concentrations regularly exceeded 0.1 mg/L at numerous sites in previous years as well, particularly in Marsh Creek and Little River. There was also variation among ammonia concentrations by site; the most contaminated sites were Little River and all Marsh Creek sites except for Marsh Creek Upstream.

Due to high ammonia concentrations measured in 2021 and 2022, no ammonia guidelines were developed to identify generally acceptable limits in the Saint John Harbour specifically. Future monitoring to supplement the dataset could allow for a guideline to be developed that will identify when ammonia limits surpass a reasonable threshold.

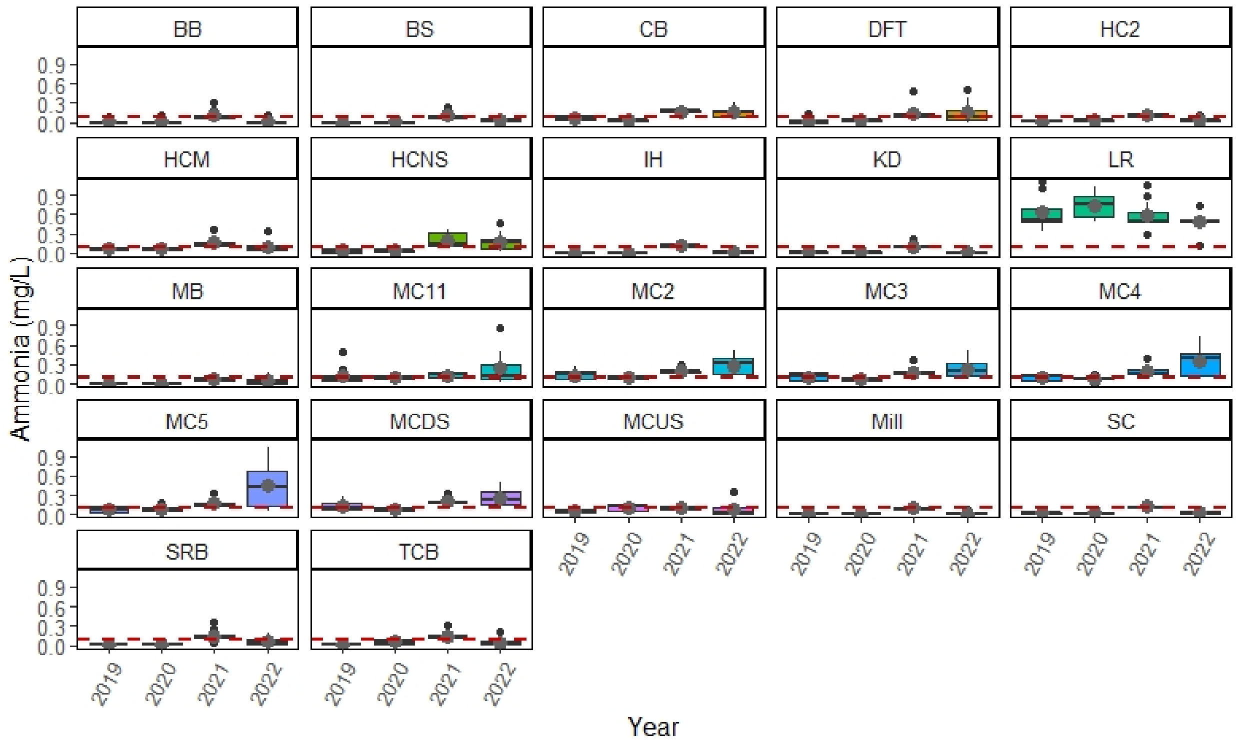

__Figure 12.__ Yearly ammonia concentrations (mg/L) across 22 sites in 2019-2022. The red dotted line indicates the recommended upper limit for healthy aquatic life (0.1 mg/L), and the mean concentration at each site is indicated by the grey circles. Outliers are represented by black circles.

Phosphate concentrations also varied across sites, with elevated levels observed at most sites in 2022 (Figure 13). Orthophosphate (PO_4^{3-}) and phosphorus (P) were both measured in this study. There is currently no CCME guideline for phosphate levels in aquatic environments, but the United States Environmental Protection Agency (EPA) recommends that maximum total phosphate concentrations are kept below 0.05 mg/L or 0.1 mg/L in freshwater streams (US Environmental Protection Agency 1986).

We adopted a phosphate guideline for the Saint John Harbour of 0.04 mg/L based the EPA recommendation. Orthophosphate concentrations were extremely high at Little River; this site had concentrations 7 times higher (0.77 ± 0.66 mg/L) than the next highest site (Courtenay Bay, 0.11 ± 0.042 mg/L; Figure 13).

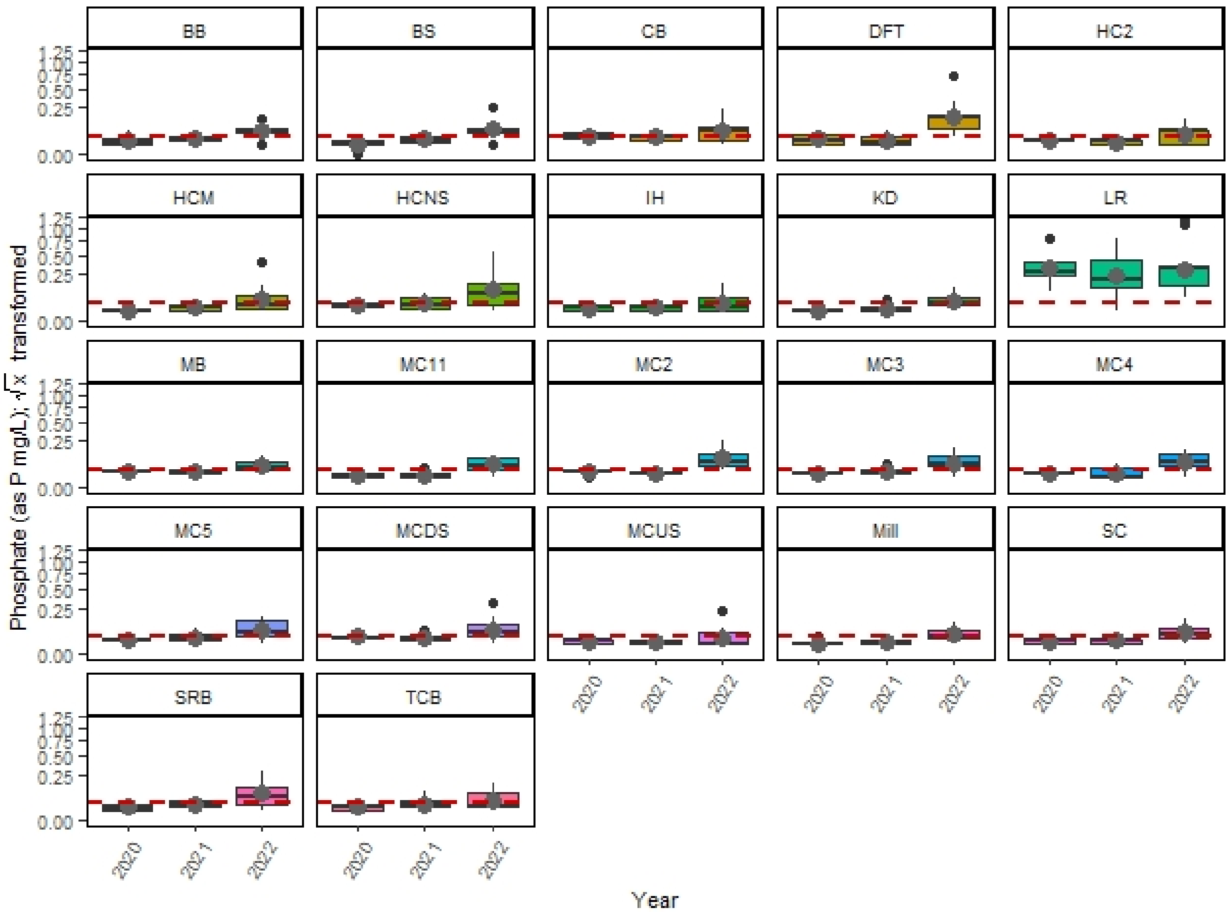

Figure 13. Square root transformed orthophosphate concentrations (mg/L) across 22 sites between 2019 and 2022. The red dotted line indicates the selected threshold value of 0.04 mg/L, and the mean concentration at each site is indicated by the grey circles. Outliers are represented by black circles.

4.1.4 Fecal Coliforms (Escherichia coli)

Many sites in and around the Saint John Harbour had elevated *E. coli* concentrations during the study period. Mean concentrations exceeded the recommended guideline for recreational use (200 MPN/100mL; Canadian Council of Ministers of the Environment 1999c) at 14 sites, with the highest concentrations mainly within the Marsh Creek watershed and Courtenay Bay (Figure 14). Within Marsh Creek, the greatest *E. coli* levels were detected at the most downstream sites, Marsh Creek 2 (1591 ± 1569 MPN/100 mL) and Marsh Creek Downstream (1848 ± 2329 MPN/100mL). Other sites with elevated *E. coli* counts include Kennebecasis Drive (very shallow, plenty of waterfowl), Spar Cove (receives stormwater/sewer overflow inputs), Hazen Creek Mouth, and Hazen Creek Nearshore (both Hazen Creek sites are near a sewage treatment facility).

The lowest *E. coli* levels were generally measured at coastal sites outside of the industrial core of the Saint John Harbour, namely Black Beach (BB), Mispec Beach (MB), Saint's Rest (SRB), Bayshore (BS), and Digby Ferry Terminal (DFT). These sites are located away from industrial and municipal influences, and also benefit from being coastal sites with more water movement. With few exceptions, sites within the Saint John Harbour itself and nearby watercourses had very high *E. coli* concentrations, indicating persistent contamination issues. The highest contamination levels were measured in the summer months (Supplementary Figures 6, 7), perhaps due to increases in rainfall events or sewage overflows. Similarly, many sites that normally have very low *E. coli* levels (i.e., Black Beach, Hazen Creek Nearshore) experienced elevated levels in July 2021. It remains unclear whether some or all of these measurements are the result of errors in sampling/analysis, or if conditions were particularly poor at that point in time due to rainfall, overflows, or some other contamination source. Because of this event, median *E. coli* concentrations are also presented in Supplementary Table 1 to better illustrate the typical *E. coli* levels measured at each site.

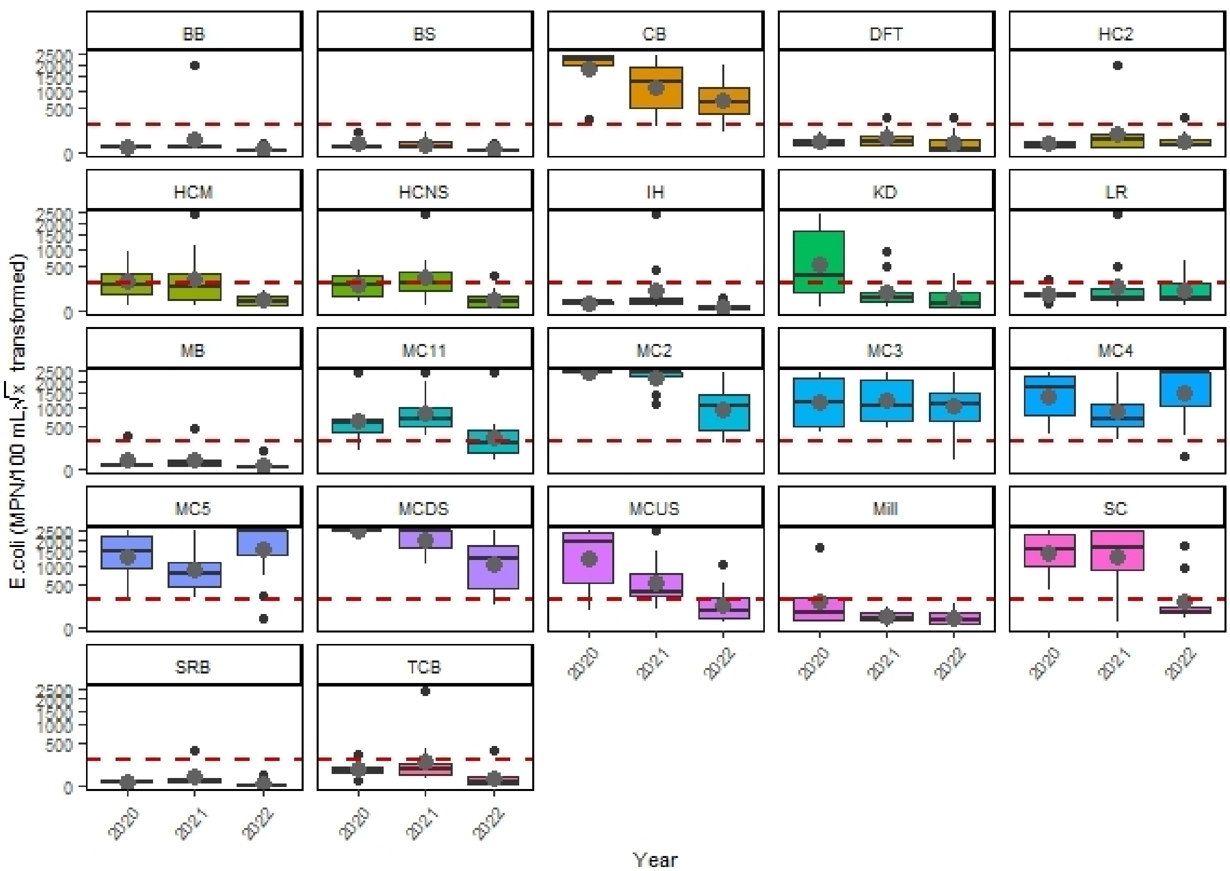

Figure 14. *E. coli concentrations (MPN/100 mL) across 22 sites between 2020 and 2022. The red dotted line indicates the recreational limit (200 MPN/100mL), and the mean concentration at each site is indicated by the grey circles. Outliers are represented by black circles.*

4.2 Sediment PAHs

Total PAH concentrations varied across Harbour sites from 2018 to 2022, with a number of sites exceeding the disposal at sea limit (2.5 mg/kg) (Figure 15). Mean concentrations exceeded this limit at Digby Ferry Terminal, Courtenay Bay, Little River, Spar Cove, Tin

Can Beach, and Marsh Creek. Mean concentrations at other sites remained below the limit; the sites furthest from the Saint John Harbour (Black Beach, Mispec, Saint's Rest) consistently had PAH concentrations below the detection limit of 0.01 mg/kg.

The overall mean of total PAH concentration measured from 2018 to 2022 was 6.12 ± 7.35 mg/kg. This level is high compared to other Saint John Harbour PAH studies, though the extremely high PAH concentrations in Marsh Creek are a major contributor to this high average. A study by Zitko (1999) sampled sediments from industrial areas around the Saint John Harbour from 1996-1999 and found an average total PAH concentration of 1.30 mg/kg. The average total PAH concentration found in our study is more than 4 times higher than that found by Zitko, despite that study having sites centered around industrial areas. Van Geest et al. (2015) found average concentrations of 0.18 and 0.14 mg/kg at reference sites in the inner and outer Harbour, respectively, which are 31 – 40 times lower than the average of sediments from the present study.

The average value from the present study is also higher than the recommended total PAH threshold in sediments from the protection of aquatic life (1.7 mg/kg; Buchman 2008), and the disposal at sea limit (2.5 mg/kg; Canadian Council of Ministers of the Environment 1999d). Van Geest et al. (2015) also identified a range of expected values for total PAH concentrations at references sites in the Harbour (0 – 1.9 mg/kg). The range in total PAH concentrations across sites from the present study far exceeds that range at 0.085 – 167.32 mg/kg, though it is worth noting that we could not reliably measure very low PAH concentrations, and the true lower limit at our sites is likely below 0.085 mg/kg. When considering the extreme PAH values in the heavily contaminated Marsh Creek, using the median value of 0.46 mg/kg might be more representative of the total PAH concentrations generally measured in the Harbour. Almost half the sites had mean total PAH concentrations higher than the reference range identified for the Harbour (Van Geest et al., 2015), with the highest concentrations, in decreasing order, having been found in Marsh Creek > Spar Cove > Tin Can Beach > Little River > Digby Ferry Terminal > Courtenay Bay (Supplementary Table 2).

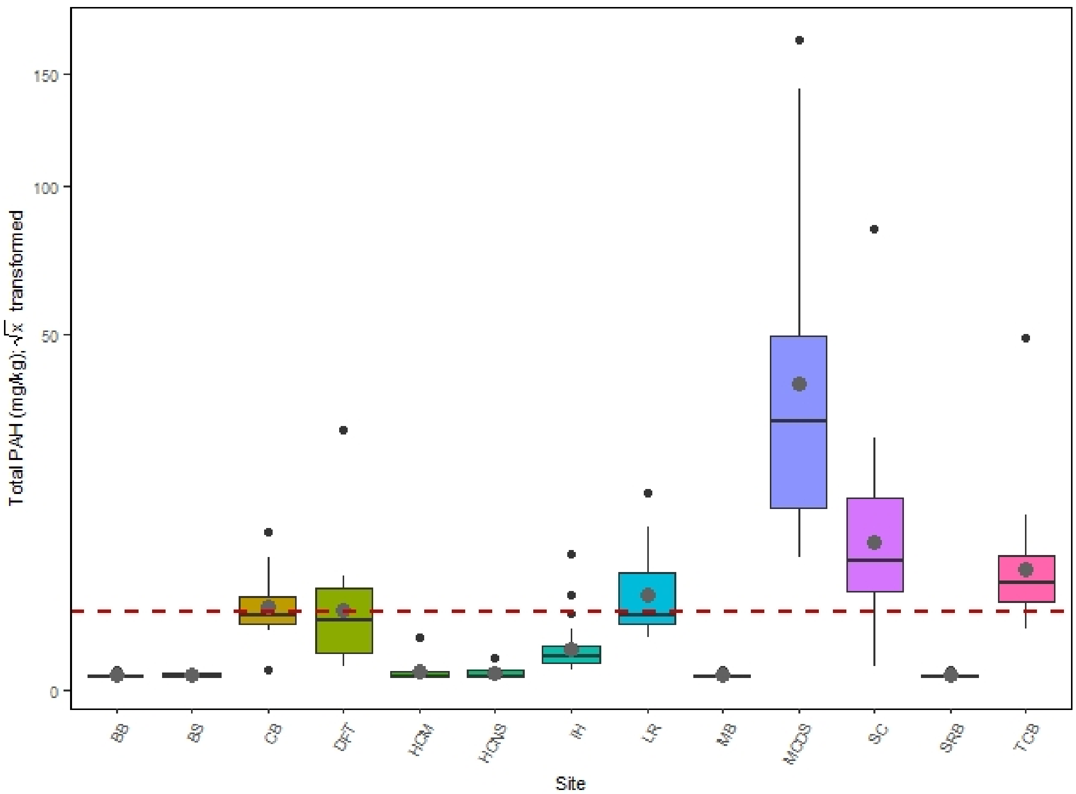

__Figure 15.__ Square root transformed total PAH concentrations (mg/kg) across 13 sites between 2018 and 2022. The disposal-at-sea limit (2.5 mg/kg) is indicated by the red dotted line, mean totals for each site are indicated by grey circles, while black circles represent outliers.

The total PAH concentrations at Marsh Creek ranged from 2.64 – 167.32 mg/kg, indicating that this site consistently has PAH concentrations above the disposal-at-sea limit, and concentrations were generally much higher than this threshold. These extreme values are concerning considering the toxicity thresholds for aquatic life (1.7 mg/kg total PAHs). It should be noted that only a small portion of the full concentration of PAHs found in sediments is available for uptake by biota (Conrnellissen 1999). This means that the heavy contamination seen at some sites within the Harbour may not significantly affect organisms in the water column such as fish. This does not preclude species from being affected by other sources of contamination, however, and extremely high PAH levels such as those in Marsh Creek may still impact organisms, particularly those in the benthos.

The contamination observed in Marsh Creek is partially the result of a historic lumber yard that was situated on the banks of the stream where logs were treated with creosote (a preservative made from a mixture of PAHs) and allowed to drip into the water. Canada Post is currently occupying the contaminated land, and a retaining wall has been constructed that acts as a barrier theoretically preventing more creosote from entering the stream. However, it is estimated that 10,000 m^3 of creosote-soaked sediment remains in the watercourse to this day. This creosote contamination is situated in the tidal portion of the stream and has the potential to migrate further into the Harbour with the moving tides and water flow. Other Harbour sites that have total PAH concentrations above the disposal-at-sea limit may have influences from point sources (i.e., refueling boats and stormwater outflows) or from nonpoint sources (i.e., road-runoff, atmospheric deposition, inputs from marine traffic).

The most prominent PAH analytes were fluoranthene, pyrene, and phenanthrene, which together made up 47.8% of the total (Table 3). Van Geest et al. (2015) also found that phenanthrene, fluoranthene, and pyrene made up most of the Harbour reference site total PAH concentration. Fluoranthene, pyrene, and phenanthrene are all present at levels greater than the CCME interim sediment quality guidelines (ISQGs; Canadian Council of Ministers of the Environment 1999d). The guidelines are 0.11, 0.15, and 0.087 mg/kg for fluoranthene, pyrene, and phenanthrene, respectively, and the mean ± SD for each PAH in this study was 1.21 ± 2.08 mg/kg (fluoranthene), 0.95 ± 1.45 mg/kg (pyrene), and 0.77 ± 1.07 mg/kg (phenanthrene). Bioavailability of PAHs is related to molecular weight, with low-weight PAHs more easily taken up by organisms because they do not sink out of the water column as readily (Vagi et al. 2021). The most abundant PAH analyte in the Saint John Harbour, fluoranthene, has a high molecular weight (Canadian Council of Ministers of the Environment 1999d); this may prevent organisms from being negatively affected by PAHs to some extent.

Table 3. *The percent composition of total PAHs (sum of all PAH analytes) measured across 13 coastal Saint John Harbour sites from 2018 to 2022.*

PAH Analyte	%
Napthalene	1.01
Acenaphthylene	0.57
Acenapthene	1.06
Fluorene	2.19
Phenanthrene	12.60
Anthracene	5.59
Fluoranthene	19.63
Pyrene	15.57
Benz(a)anthracene	7.79
Chrysene/Triphenylene	6.67
Benzo(b+j)fluoranthene	7.51
Benzo(k)fluoranthene	3.01
BIo(e)pyrene	3.82
Benzo(a)pyrene	5.89
Indeno(1,2,3,-c,d)pyrene	3.33
BenIo(g,h,i,)perylene	2.86
Dibenz(a,h)anthracene	0.90

4.3 Biotic Communities

Beach seining and fyke netting was conducted monthly from May to October at eight fishing sites beginning in October of 2018 to October of 2022. A total of 41,715 fish and invertebrates were caught across sites between 2018 and 2022, representing 38 species. Spar Cove had the greatest total catch (13,423 individuals), with the majority of these individuals being Atlantic silverside (*Menidia menidia*), while Little River had the lowest total catch of 451 individuals (Figure 16). Sand shrimp (*Crangon septemspinosa)* was the most frequently caught species (17,204 individuals), followed by the Atlantic silverside (16,686 individuals), Threespine stickleback (*Gasterosteus aculeatus*; 3045 individuals), and the Atlantic tomcod (*Microgadus tomcod*; 2403 individuals). The most consistently sampled species were Atlantic silverside and sand shrimp, which were the only species caught at all eight sites (Figure 17). Although green crabs are frequently caught through these fishing activities, they are not accounted for in this report.

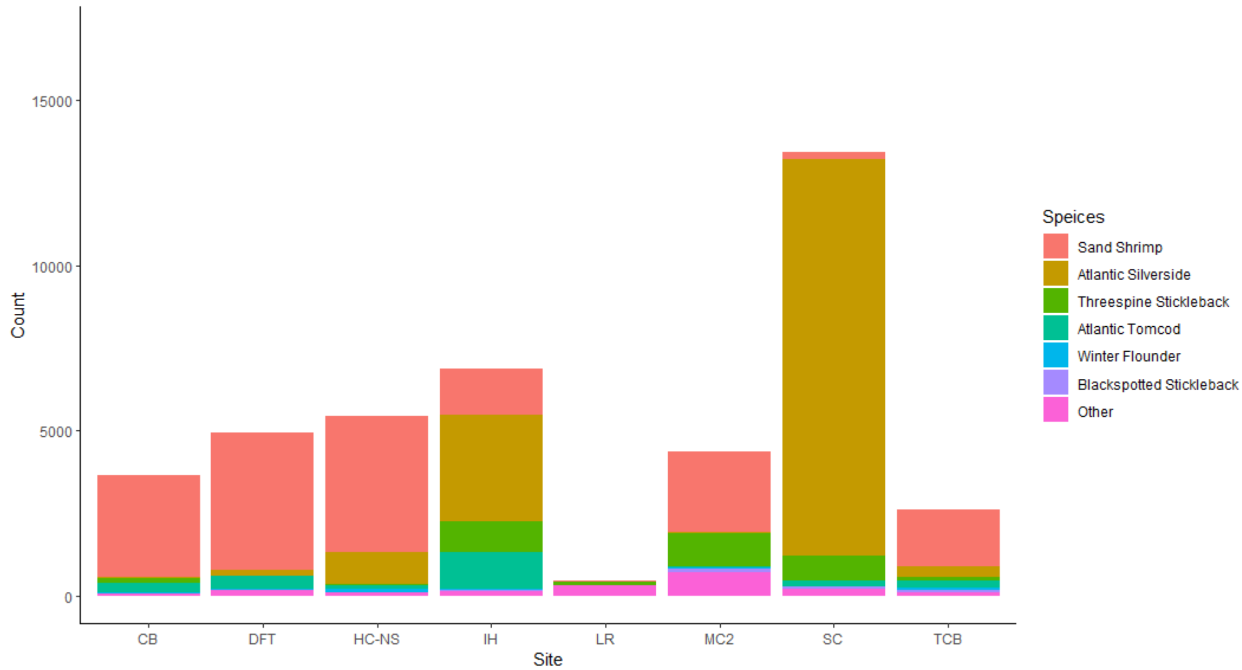

Figure 8. *Total catch across eight fishing sites between 2018 and 2022. Less abundant species (35 species) are grouped into an "Other" category.*

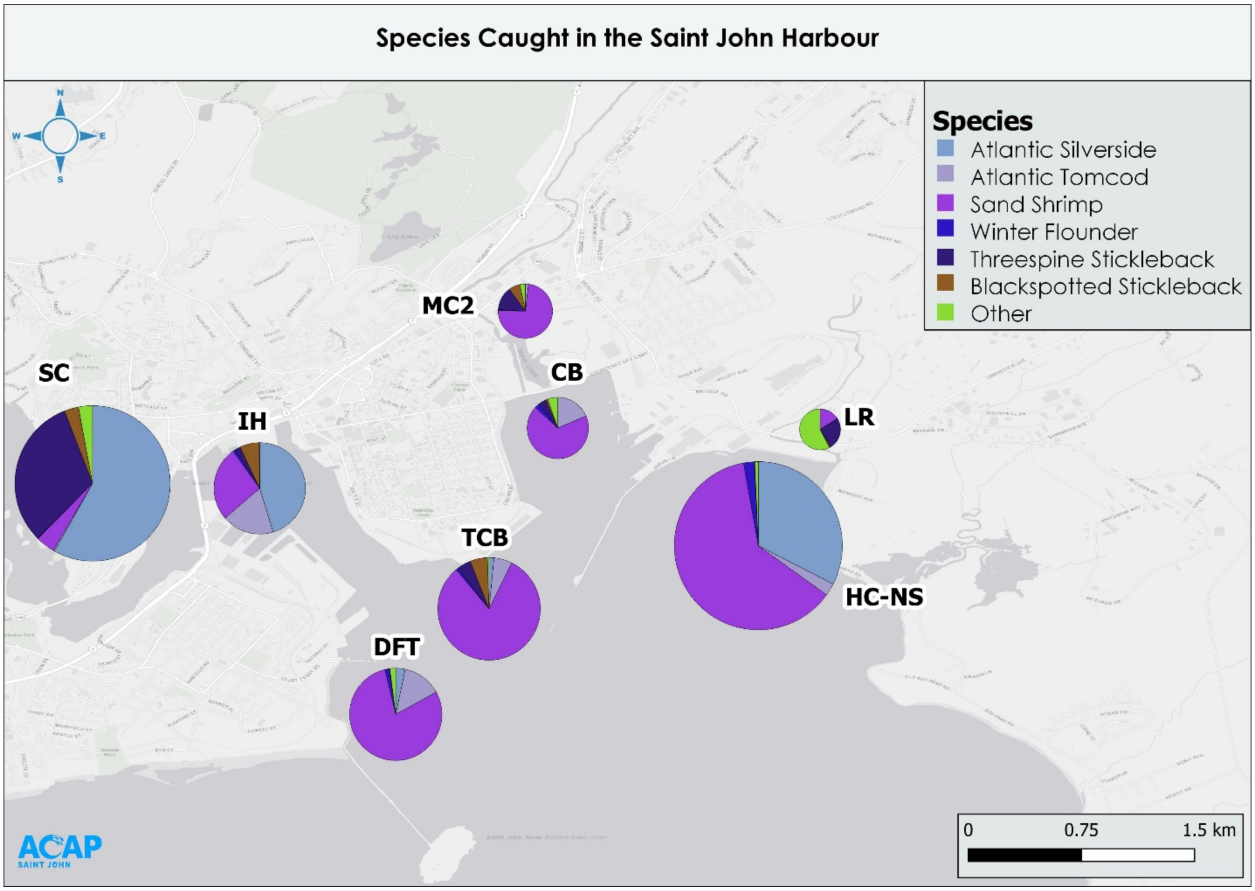

Figure 9. *Map with pie charts of relative species abundances at eight fishing sites (2018 – 2022). "Other" includes 35 additional species. The size of each pie chart is relative to the total number of species caught. The greatest number of individuals were caught at Spar Cove, and the fewest at Little River. Little River also has the highest relative percent of the "Other" Category as the river is predominantly fresh water and thus gets fewer brackish and marine species.*

Total catch from year to year (2019-2022) shows a continuous downward trend of nekton community abundance (Figure 18); however, it was determined that this decrease was insignificant overall and from year to year. Additionally, 2022 saw an increase in the total catch of blackspotted stickleback compared to all other years, exceeding the total catch of threespine stickleback for 2022. The majority of blackspotted stickleback were captured from two brackish sites in the spring, which coincides with the spawning period for that species (Gautreau. M, Curry. R. 2020). Increased identification proficiencies may have also generated the increase. Overall catch abundances at Spar Cove in 2019 were higher than any other year, this may be due to favourable conditions that year, or random chance during sampling.

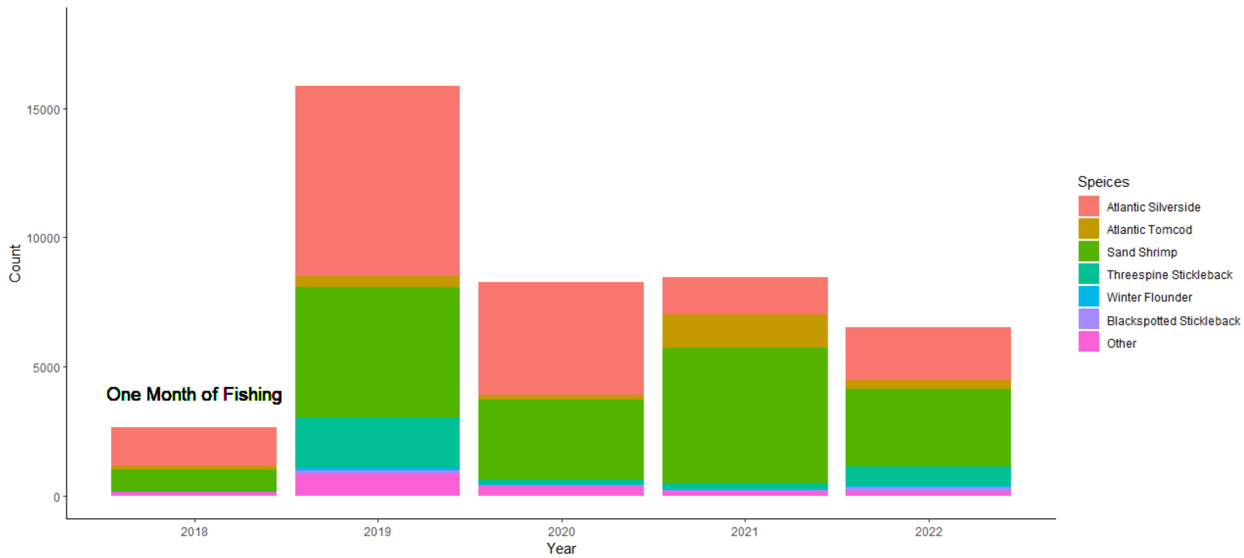

Figure 10. *Total catch from 2018-2022 across all fishing sites. Less abundant species (35 species) are grouped into an "Other" category. Note, 2018 was only fished for one month (October) and is thus not representative of an entire year or comparable with total catches in subsequent years.*

Hazen Creek Nearshore had the highest species richness (20), while Spar Cove had the lowest (15), across years. Spar Cove also had the greatest abundance while having the lowest Pilou Evenness due to its high abundance of a singular species (Atlantic silverside) (Table 4). Little River had the highest diversity index score for both Shannon (1.996) and Simpson's (0.78). This likely due to its relatively high evenness score amongst species caught, as well as it having the lowest salinity of all sites, allowing unique freshwater species to be captured compared to the other brackish and saline sites. Widespread distribution of species at over half of the sites was observed when compared to each other, with highly abundant species remaining similar between most sites (Figure 19).

Table 2. *Diversity, richness, and evenness measures for each fishing site across the period between 2018 and 2022. Richness is the number of species observed at each site and abundance is the number*

of individuals caught. The Shannon-Weiner Index (H') is a measure of species diversity within a community based on the number of species and evenness of abundance. Simpson's Index (λ) is another diversity index that measures dominance, taking into account number of species present as well as relative abundances. Pilou Evenness (J) compares true diversity to the maximum possible diversity measure.

Site	**Richness**	**Abundance**	**Shannon-Weiner Index (H')**	**Simpson's Index (λ)**	**Pilou Evenness (J)**
Courtenay Bay	19	3633	0.65	0.273	0.092
Digby Ferry Terminal	17	4924	0.653	0.276	0.097
Hazen Creek Nearshore	20	5435	0.781	0.387	0.129
Inner Harbour	17	6877	1.411	0.694	0.245
Little River	17	453	1.996	0.78	0.245
Marsh Creek 2	16	4347	1.296	0.615	0.221
Spar Cove	15	103335	0.088	0.025	0.009
Tin Can Beach	17	2582	1.213	0.526	0.185

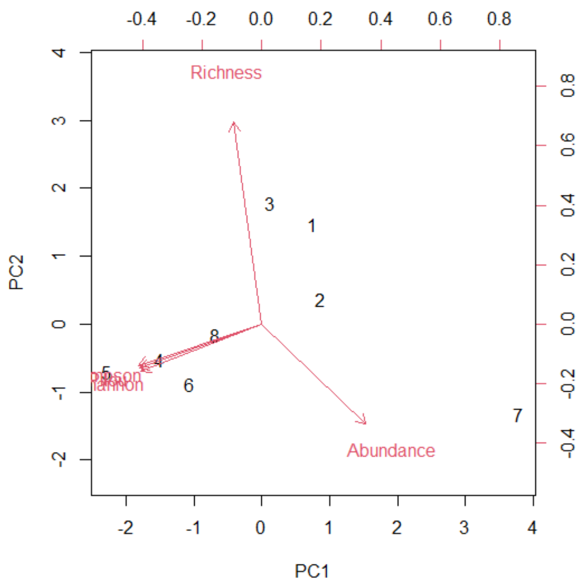

Figure 11. *PCA plot showing site similarity groupings based on diversity. Arrows on the far-left point to the Shannon-Wiener and Simpson Indexes as well as the evenness score. Group 1 (Courtenay Bay [1], Digby Ferry Terminal [2], Hazen Creek-Near shore [3]), Group 2 (Spar Cove [7]), Group 3 (Inner Harbour [4], Littler River [5], Marsh Creek 2 [6], Tin Can Beach [8]).*

A total of 1,710 individuals were caught in fyke nets, while 40,005 individuals were caught in seine nets (Figure 20). Fyke nets target larger animals than seine nets, so there are fewer but larger individuals collected with this method. Supplementary Table 3 summarizes the fyke net collection data across all sites and years of collection. There were 27 species collected in the fyke nets throughout this program. Seine nets target smaller and slower moving animals compared to the fyke nets so there are typically many but smaller individuals collected with this method. Supplementary Table 4 summarizes the seine net collection data across all sites and years of collection. There were 30 species collected in the seine nets from 2018 - 2022.

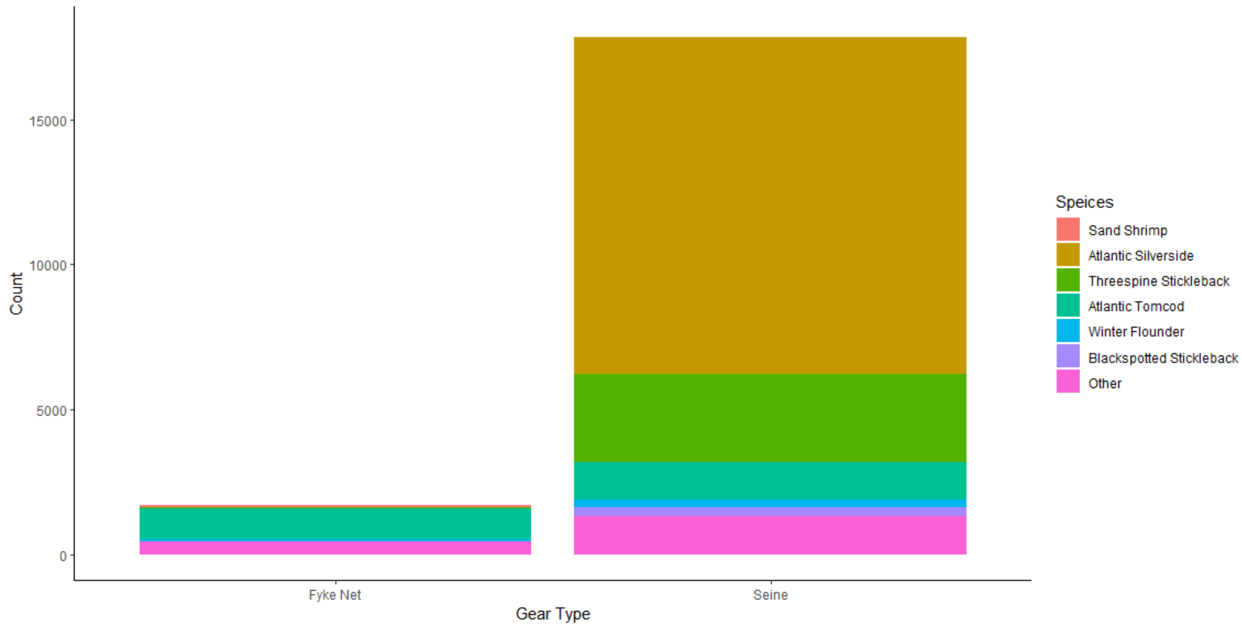

Figure 12. *Total catch by gear type. Less abundant species (32 species) are grouped into an "Other" category.*

4.3.1 Sand Shrimp (Crangon septemspinosa)

Sand shrimp length frequency remained relatively stable between years. Differences in the lengths evident in 2018, 2019, and 2020 are due to a change in measurement taking (Figure 21). Throughout 2018, 2019, and the first half of 2020, data is based on total lengths, while all subsequent data is based on carapace length. This is seen as a more accurate form of measurement for sand shrimp. Using a TukeyHSD test it was found that there was no significant difference between the years of 2021-2022 (F value =67.57, p= 0.95) when measurements switched to carapace length.

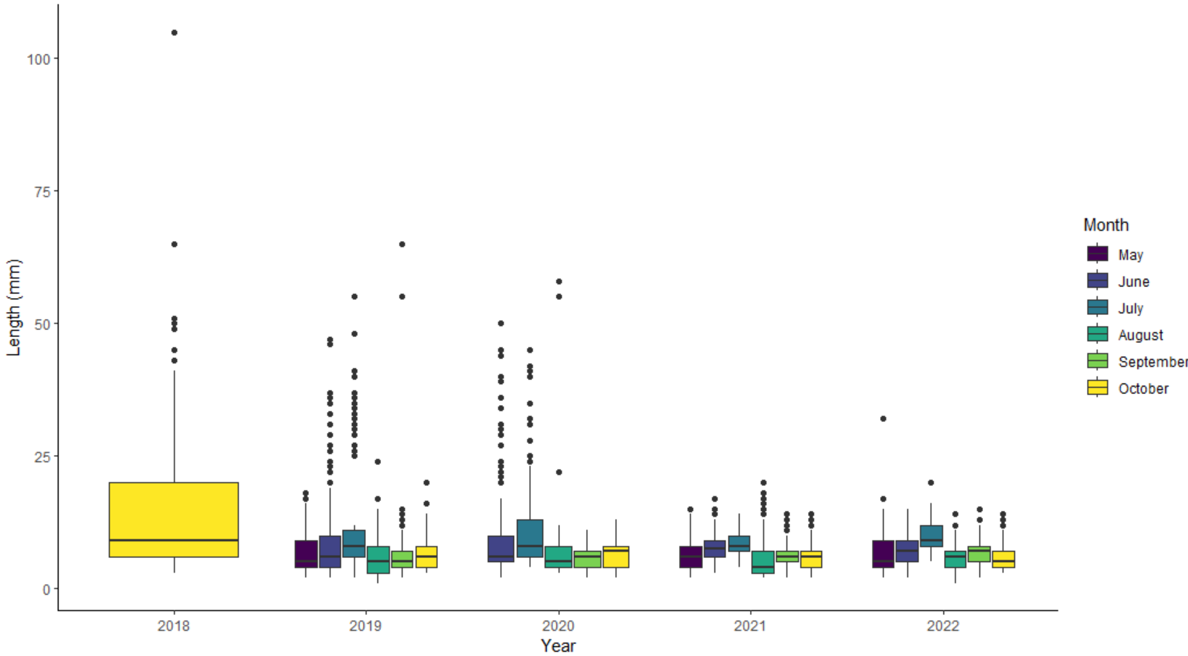

Figure 13. Lengths frequency for sand shrimp across sampling years per month. 2018 was only fished in for the month of October. Outliers are represented by black circles. Note fewer extremes and outliers are present once measurements were switched to carapace length.

4.3.2 Atlantic Silverside (Menidia menidia)

Using an Anova and TukeyHSD tests it was found that there were significant differences in the mean lengths of silversides when comparing the years of 2019 and 2020 (F value = 2.87, p = 0.035), at a 95% confidence interval. Comparisons between all other years showed no significant difference (F value = 7.614, p > 6,000,000). Silverside total catch did not significantly decrease year over year or as a whole (Figure 22).

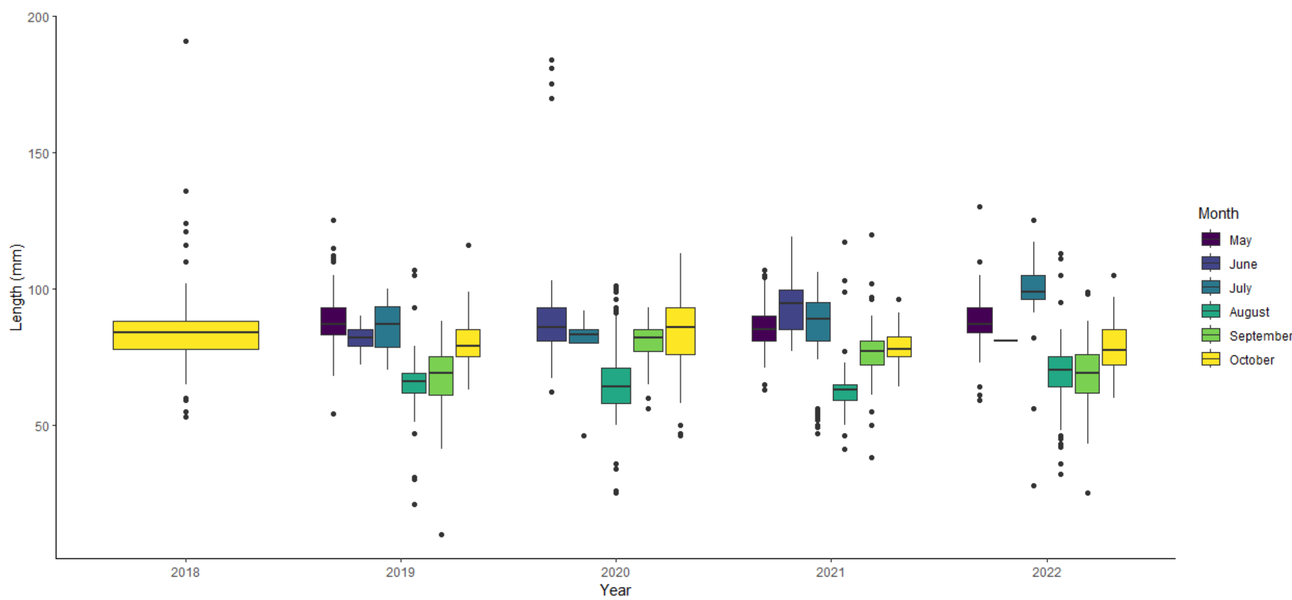

Figure 14. Lengths frequency for Atlantic silverside across sampling years per month. 2018 was only fished in for the month of October. Outliers are represented by black circles.

4.3.3 Atlantic Tomcod (Microgadus tomcod)

An increase in smaller (juvenile) Atlantic tomcod was observed for the months of June and July indicating the post spawning period of the species within the Saint John Harbour (Figure 23). Using and Anova and TukeyHSD tests it was found that there were significant differences in the mean lengths of tomcods when comparing all years to each other with the exception of 2019-2020, at a 95% confidence interval.

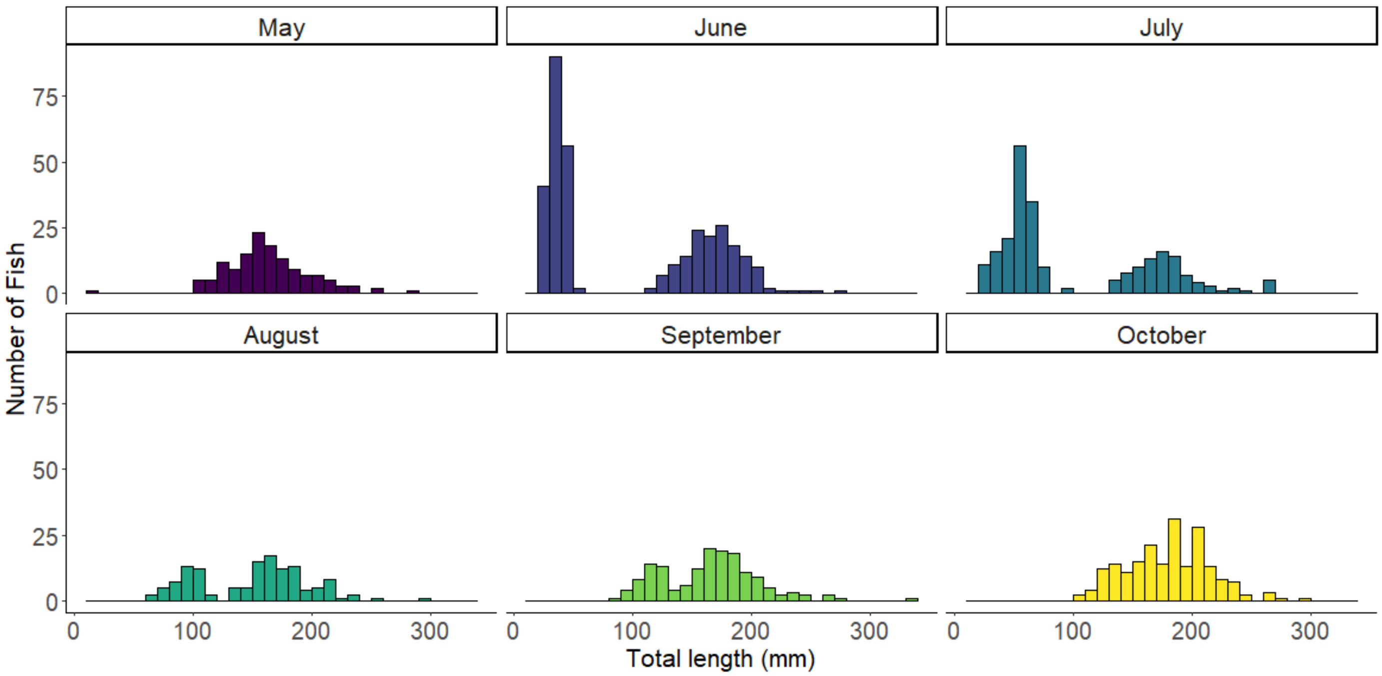

Figure 15. *Lengths frequencies for Atlantic Tomcod by month for 2019-2022.*

5. Conclusions and Recommendations

5.1 Water Quality

During this program, 22 sites in and around the Saint John Harbour were sample for a range of water quality parameters. Our of these sites, 13 were also sampled for sediment PAHs and eight were sampled for fish communities. Overall, most sites outside of Marsh Creek and Little River had acceptable water quality. Marsh Creek/Courtenay Bay and Little River are sites with known historic contamination from industrial and/or municipal effluents. Conditions within these sites may become more detrimental to aquatic life in the future as a result of climate change and further pollution. Temperatures in Little River reach higher maxima than other sites in this study, and the extremely high nutrient concentrations may contribute to algal growth and other processes that can cause declines in dissolved oxygen. Other sites with moderate amounts of pollution, like Kennebecasis Drive, may also deteriorate without action to reduce contamination and/or temperature increases.

Mean phosphate concentrations at most sites are generally below or close to acceptable levels, with the notable exception of Little River and 2022 findings. Little River concentrations were 7 times higher than the next most polluted site; a similar pattern was observed with ammonia, though ammonia concentrations were also elevated in the Marsh Creek watershed. Ammonia measurements tended to be higher in 2021 and 2022 compared to previous years, perhaps due in part to issues with the blank samples used for analysis. Further monitoring is recommended to elucidate whether ammonia is actually increasing throughout the region, and to generate more data that can be used to develop threshold values such as those developed for phosphate.

Mean *E. coli* levels exceeded the recreational guideline (200 MPN/100 mL) at 11 out of 22 sites, which is a concerning trend. The highest concentrations were measured in the Marsh Creek watershed (including the Courtenay Bay outflow) and Spar Cove. Marsh Creek had even higher fecal bacterial counts as the result of raw sewage entering the watercourse. Restoration efforts have improved conditions somewhat since the cessation of raw sewage dumping in 2014, but further remediation or control measures appear to be necessary to reduce fecal bacteria levels within the stream and limit further contamination. For example, there are stormwater/sewar overflow issues that need to be addressed by the City of Saint John; efforts to mitigate these issues have been outlined in the City's *Flood Risk and Mitigation Strategy for Lower Cove Loop* report, and upgrades to infrastructure began to take place in 2022.

Water quality throughout the Harbour can be monitored using methods previously used by ACAP Saint John for other water quality monitoring projects (ACAP Saint John 2021); a water quality index is a useful tool for comparing aquatic health across spatial and temporal scales. Water quality issues such as those observed in Marsh Creek and Little River can be detrimental to aquatic life and human health. The water quality monitoring conducted for this project has highlighted persistent issues in a number of Saint John area watersheds which would benefit from restoration or remediation activities.

5.2 Sediment PAHs

Most sites (seven of 13) in the Saint John Harbour had sediment PAH concentrations within an acceptable range comparable to local literature (Van Geest et al. 2015, Zitko 1999). The six sites with mean concentrations above the disposal-at-sea limit (2.5 mg/kg) were Digby Ferry Terminal, Courtenay Bay, Little River, Spar Cove, Tin Can Beach, and Marsh Creek. All these sites are in close proximity to industry or other commercial activities, and/or have historically been used for industrial purposes. The persistence of these contaminants in the sediments around Saint John is concerning for aquatic health, though the PAHs present in the greatest abundances may be unlikely to readily enter food webs and compromise the health of some aquatic organisms due to the size of the PAHs particles.

Sediment PAHs were extremely high in Marsh Creek, likely due to historical creosote contamination. Creosote in the downstream section of Marsh Creek may enter the Saint John Harbour through the Courtenay Bay Causeway; this can introduce PAHs and a number of other contaminants into the Harbour. Managers may explore the possibility of a Marsh Creek restoration project targeting the creosote contamination, which would improve conditions for aquatic life within the watercourse as well as humans.

5.3 Biotic Communities

It was found that not all sites were similar to each other in regards to both biological and water quality data. Average total catch abundances and mean lengths varied across sites; however, only mean tomcod lengths varied through the years. Little River and Spar Cove were the most dissimilar sites when compared to all eight sites; this is primarily due to their freshwater influence, resulting in a change in species composition and abundance. Total species richness for each site grew over time as long-term fishing efforts increased the probability of capturing new species; this was observed as some species were only caught at certain sites on a few occasions but not consistently each year. Long term baseline monitoring programs are essential in understanding species distribution and communities for this reason.

With the addition of two new container cranes and the expansion of the Port of Saint John, an increase in ship traffic is expected in and around the Saint John Harbour. This intensified harbour activity has the possibility of altering the current environmental baseline. Additional vessel traffic has the potential to increase underwater noise pollution which can affect biological communities and alter/influence species movements and abundances throughout the year. This could also introduce new invasive species to the harbour which can have devastating effects on local native fish stocks, as observed with the European green crab. Water quality may also be affected with the increase in activity.

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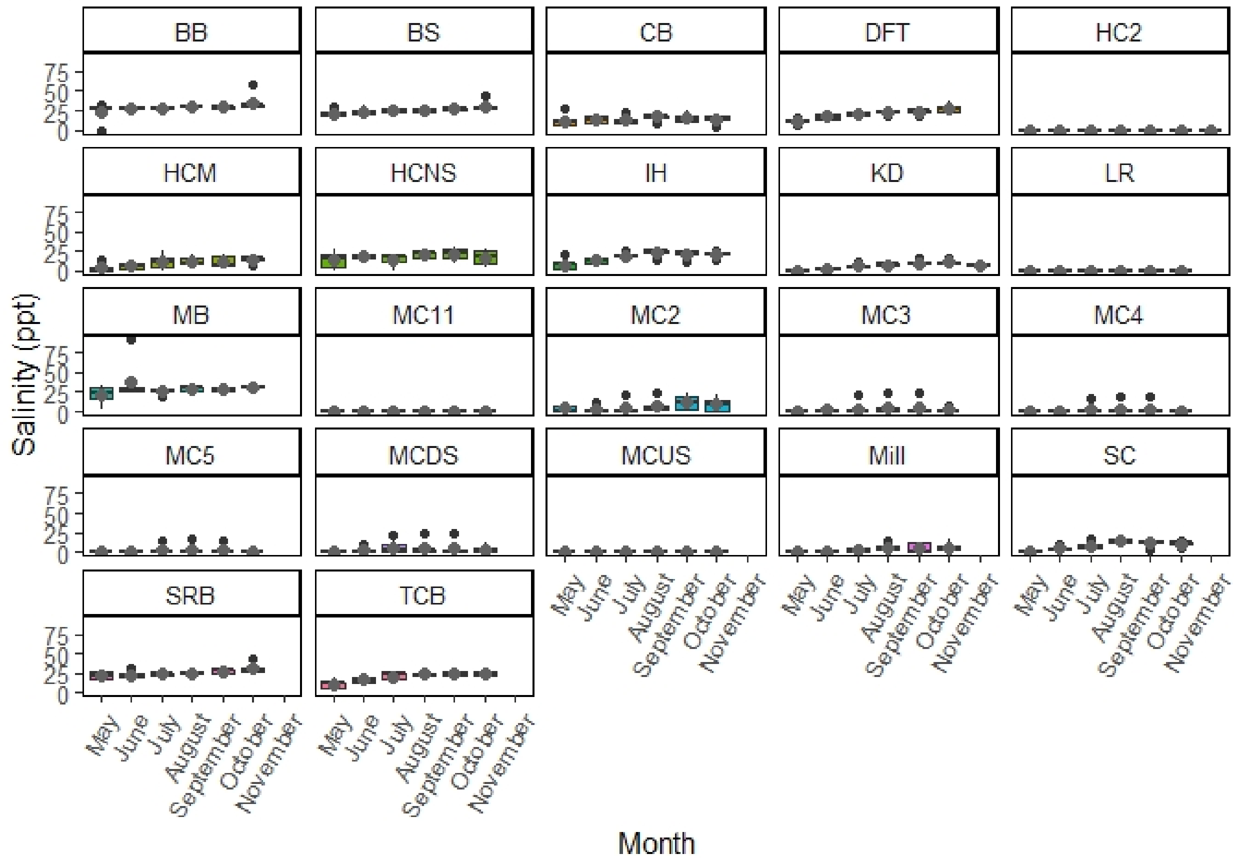
7. Appendix – Supplementary Materials

Supplementary Table 1. Temperature (°C), dissolved oxygen (mg/L), pH, conductivity (µS/cm), salinity (ppt), turbidity (NTU), ammonia, orthophosphate, phosphorus (mg/L), and *E. coli* concentration (MPN/100 mL) of 22 sites in and around the Saint John Harbour. Values are reported as the mean and standard deviation (SD) of in-situ measures from YSI and turbidity meter readings and laboratory analyses (2018-2022).

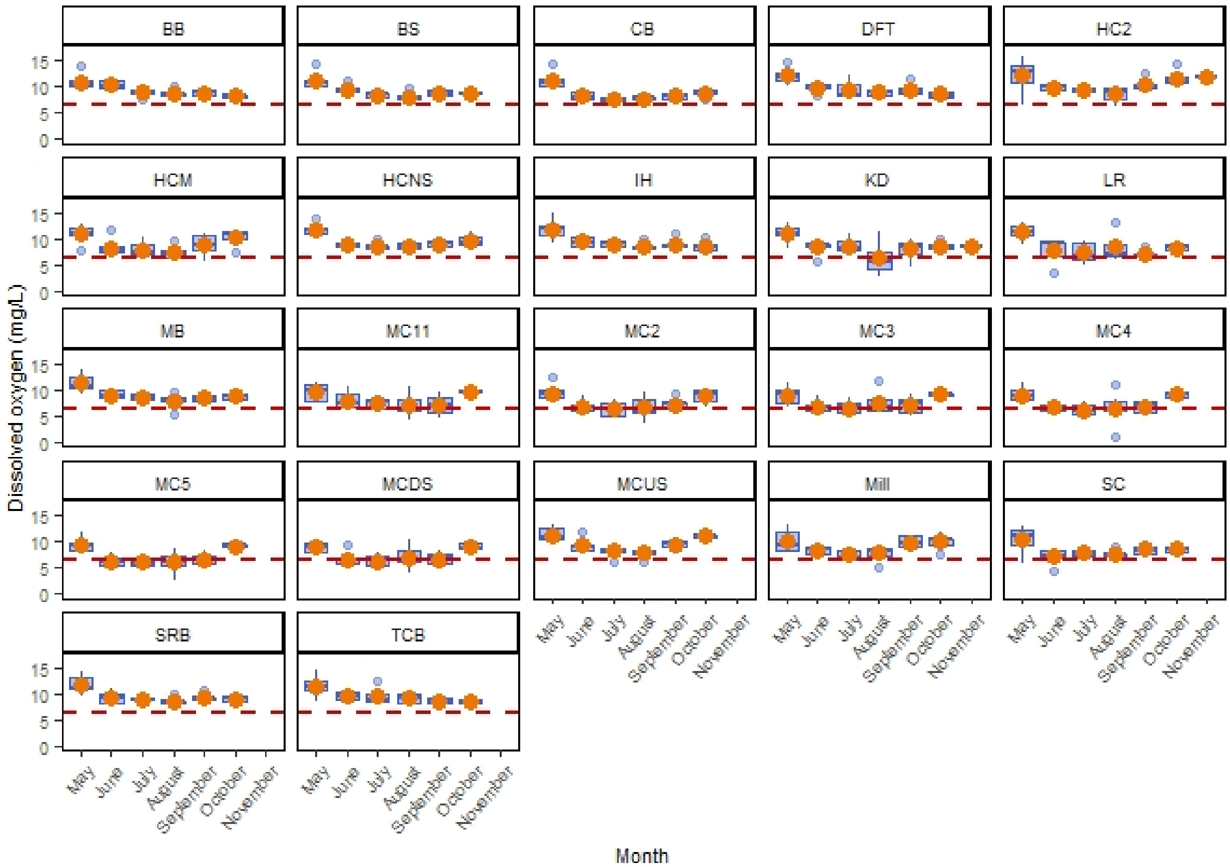
Site	Temperature (°C)		Dissolved Oxygen (mg/L)		pH	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Bayshore	13.53	3.72	12.01	14.94	8.00	0.25
Black Beach	12.30	3.11	11.93	15.13	7.94	0.36
Courtenay Bay	14.71	3.82	10.90	13.77	7.68	0.42
Digby Ferry Terminal	14.06	3.59	12.37	15.14	7.97	0.34
Hazen Creek 2/Expansion	11.94	3.34	10.45	2.19	7.92	0.52
Hazen Creek Mouth	15.35	4.40	8.93	2.14	7.90	0.40
Hazen Creek Nearshore	14.37	3.70	9.44	1.48	8.00	0.43
Inner Harbour	13.81	2.60	9.59	1.82	7.89	0.26
Kennebecasis Drive	17.81	4.72	10.55	12.02	8.06	0.47
Little River	19.70	4.63	7.97	2.48	8.09	0.44
Marsh Creek 11	15.34	4.18	10.29	13.67	7.77	0.47
Marsh Creek 2	15.77	3.93	9.83	13.86	7.75	0.37
Marsh Creek 3	16.14	4.38	9.98	14.13	7.76	0.39
Marsh Creek 4	16.01	4.33	9.76	14.56	7.72	0.46
Marsh Creek 5	15.71	4.17	9.48	14.10	7.77	0.44
Marsh Creek Downstream	15.87	4.01	9.73	14.34	7.73	0.41
Marsh Creek Upstream	14.18	3.96	11.94	15.05	7.85	0.53
Mill Creek	17.01	4.36	11.02	12.38	8.01	0.38
Mispec Beach	12.19	2.74	9.22	1.65	7.90	0.45
Saints Rest Beach	13.46	3.85	14.17	20.42	8.03	0.28
Spar Cove	16.09	3.83	10.81	14.12	7.88	0.30
Tin Can Beach	13.49	2.78	11.92	14.37	7.89	0.33

Site	Conductivity (µS/cm)		Salinity (ppt)		Turbidity (NTU)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Bayshore	50297	48829	25	5	30	31
Black Beach	113920	432624	29	7	27	32
Courtenay Bay	29127	42029	14	6	15	11
Digby Ferry Terminal	31559	9752	47	158	69	112
Hazen Creek 2/Expansion	329	365	0	0	4	10
Hazen Creek Mouth	14758	10520	9	7	14	23
Hazen Creek Nearshore	27124	13006	18	8	86	116
Inner Harbour	28070	10325	17	8	13	15
Kennebecasis Drive	10111	6837	6	4	9	14
Little River	1368	1014	1	1	13	22
Marsh Creek 11	373	108	0	0	11	17
Marsh Creek 2	10219	12062	6	7	10	8
Marsh Creek 3	4587	9552	3	6	9	6
Marsh Creek 4	3133	7826	2	5	11	7
Marsh Creek 5	2707	6682	2	4	9	7
Marsh Creek Downstream	7063	10393	4	6	10	7
Marsh Creek Upstream	189	141	0	0	6	11
Mill Creek	5794	7498	3	4	3	5
Mispec Beach	39222	10836	29	12	26	26
Saints Rest Beach	47413	36025	25	5	46	58
Spar Cove	15057	10656	8	6	9	17
Tin Can Beach	30608	10480	20	7	40	50

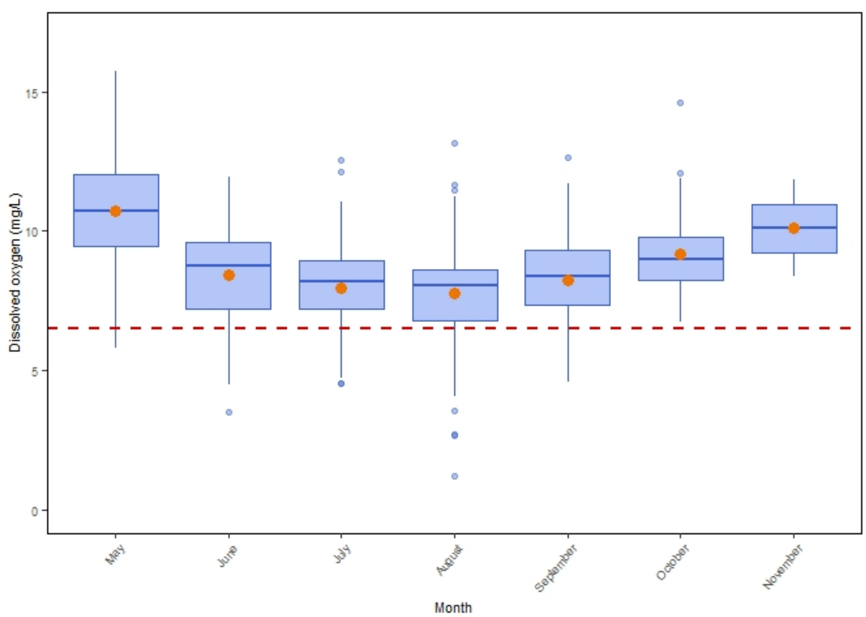
Site	Ammonia (mg/L)		Orthophosphate (mg/L)		P (mg/L)		*E. coli* (MPN/100 mL)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Bayshore	0.0492	0.0558	0.0684	0.0701	0.0523	0.0490	5	9
Black Beach	0.0537	0.0704	0.0770	0.0601	0.0550	0.0384	79	389
Courtenay Bay	0.1270	0.0768	0.0963	0.0731	0.0700	0.0526	854	851
Digby Ferry Terminal	0.0994	0.1239	0.1859	0.4064	0.1004	0.1485	35	76
Hazen Creek 2/Expansion	0.0545	0.0438	0.0568	0.0632	0.0452	0.0430	113	372
Hazen Creek Mouth	0.1091	0.0772	0.0668	0.0863	0.0541	0.0783	181	478
Hazen Creek Nearshore	0.1280	0.1164	0.1516	0.2790	0.1030	0.1259	162	458
Inner Harbour	0.0465	0.0475	0.0636	0.0610	0.0411	0.0405	99	464
Kennebecasis Drive	0.0458	0.0485	0.0598	0.0822	0.0356	0.0329	277	638
Little River	0.6026	0.2252	0.6119	0.5581	0.4852	0.4759	234	577
Marsh Creek 11	0.1612	0.1622	0.1100	0.1560	0.0468	0.0330	645	740
Marsh Creek 2	0.1932	0.1118	0.1127	0.1309	0.0733	0.0564	1591	1569
Marsh Creek 3	0.1630	0.1049	0.0855	0.0884	0.0643	0.0464	1169	823
Marsh Creek 4	0.2024	0.1733	0.1179	0.1384	0.0664	0.0541	1350	954
Marsh Creek 5	0.2246	0.2376	0.1013	0.1265	0.0636	0.0515	1483	952
Marsh Creek Downstream	0.1845	0.1116	0.0924	0.0803	0.0664	0.0591	1848	2329
Marsh Creek Upstream	0.0876	0.0727	0.0587	0.0601	0.0400	0.0443	544	768
Mill Creek	0.0462	0.0444	0.0563	0.0758	0.0335	0.0259	107	325
Mispec Beach	0.0455	0.0514	0.0859	0.0698	0.0596	0.0340	16	55
Saints Rest Beach	0.0684	0.0810	0.1126	0.1628	0.0731	0.0669	5	10
Spar Cove	0.0610	0.0506	0.0783	0.0917	0.0522	0.0448	734	985
Tin Can Beach	0.0696	0.0752	0.0700	0.0558	0.0663	0.0490	51	95



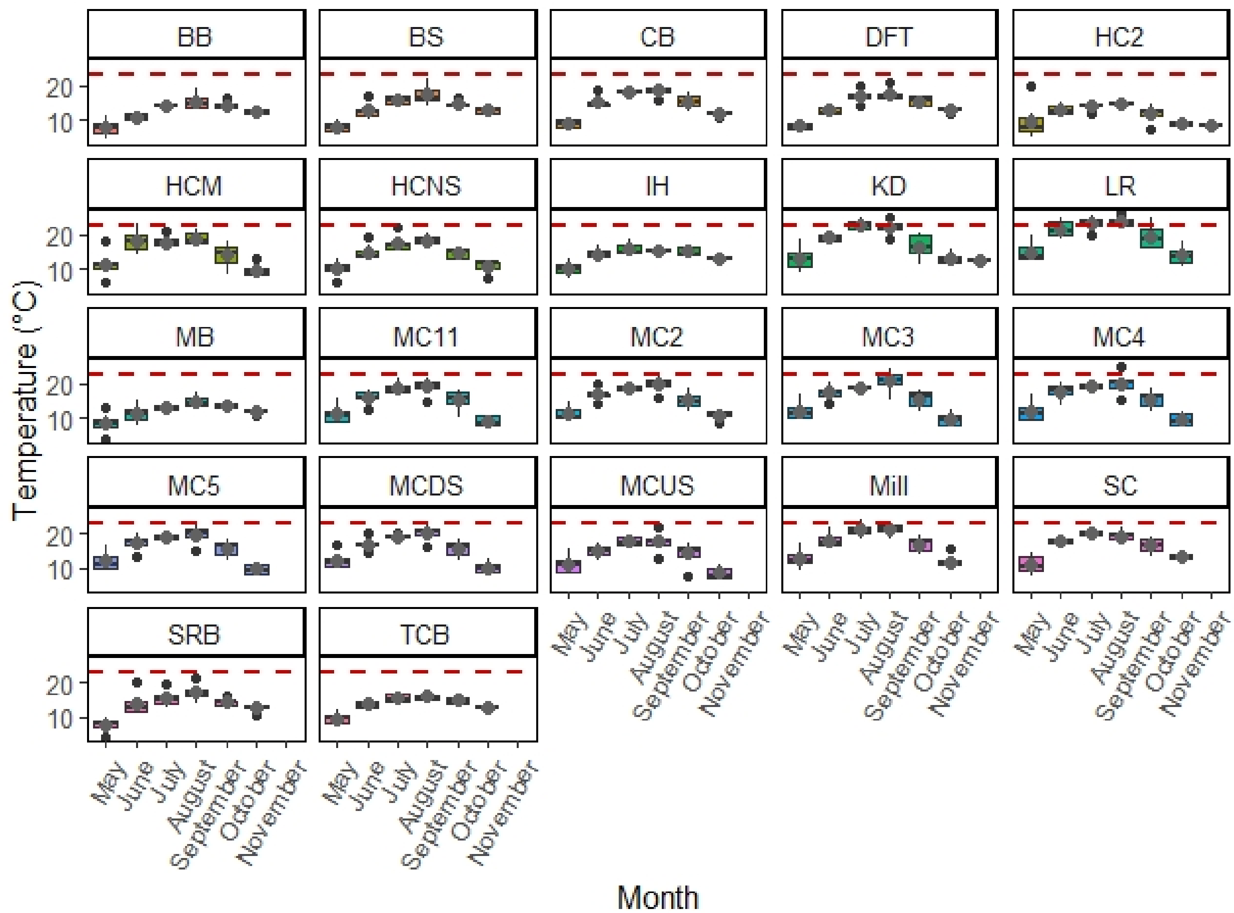
Supplementary Figure 1. Salinity (ppt) of each site across months (May – October) for all years (2018 – 2022).



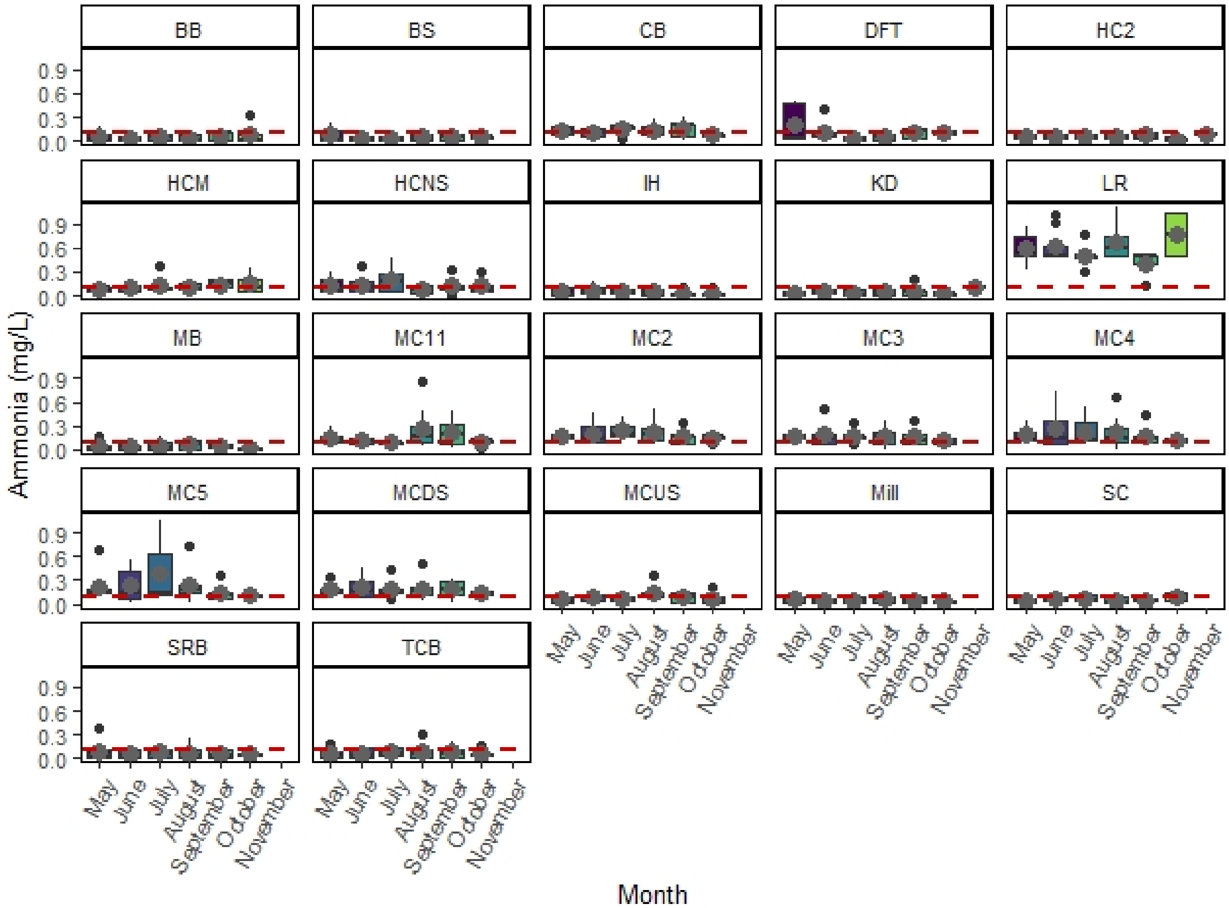
Supplementary Figure 2. Dissolved oxygen (mg/L) of each site across months (May – October) for all years (2018 – 2022).



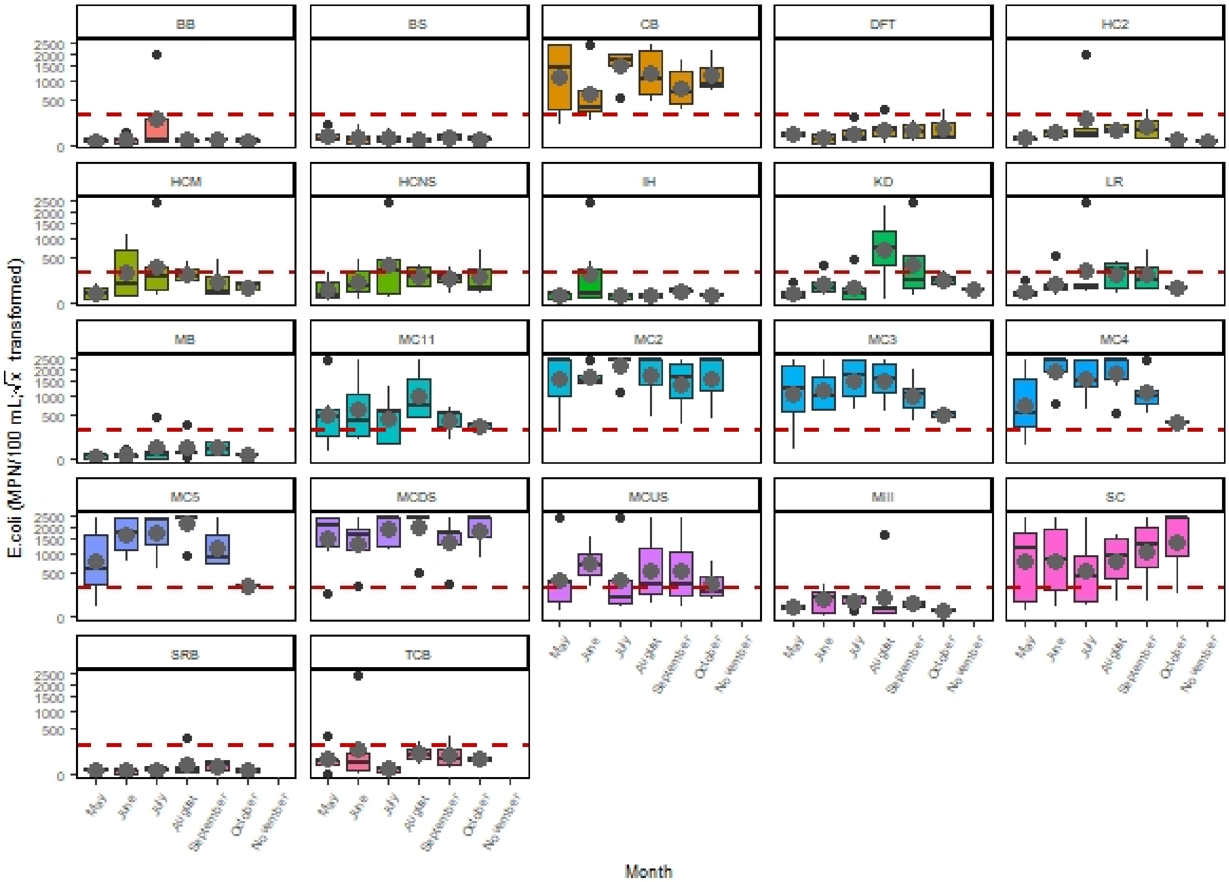
Supplementary Figure 3. Dissolved oxygen (mg/L) across all sites and months (May – October).



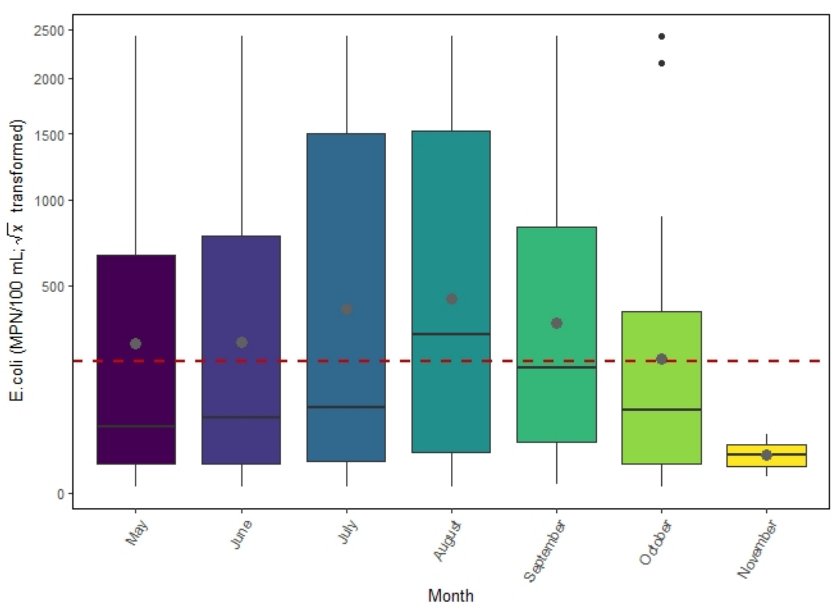
Supplementary Figure 4. Water temperature (°C) of each site across months (May – October) for all years.



Supplementary Figure 5. Ammonia concentrations (mg/L) of each site across months (May – October) for all years (2018 – 2022).



Supplementary Figure 6. *E. coli* (MPN/100 mL) of each site across all months (May – October) for all years (2018 – 2022).



Supplementary Figure 7. *E. coli* (MPN/100 mL) across all sites and months (May – October) from 2018-2022.

Supplementary Table 2. Mean ± SD for all sediments PAHs at 13 sites (2018 – 2022). All PAH concentration units are in mg/kg.

PAH Analyte		Bayshore	Black Beach	Courtenay Bay	Digby Ferry Terminal	Hazen Creek Mouth	Hazen Creek Nearshore	Inner Harbour	Little River	Marsh Creek WS DS	Mispec	Saints Rest Beach	Spar Cove	Tin Can Beach
Naphthalene	*Mean*	0.006	0.006	0.023	0.107	0.006	0.007	0.009	0.025	0.472	0.006	0.006	0.031	0.106
	SD	0.002	0.002	0.020	0.258	0.002	0.005	0.010	0.022	0.959	0.002	0.002	0.023	0.131
Acenaphthylene	*Mean*	0.006	0.006	0.008	0.021	0.006	0.005	0.009	0.045	0.184	0.006	0.006	0.067	0.069
	SD	0.002	0.002	0.004	0.030	0.002	0.001	0.009	0.072	0.140	0.002	0.002	0.065	0.052
Acenaphthene	*Mean*	0.006	0.006	0.036	0.071	0.007	0.006	0.011	0.051	0.471	0.006	0.006	0.061	0.104
	SD	0.002	0.002	0.030	0.142	0.004	0.002	0.011	0.105	0.641	0.002	0.002	0.062	0.250
Fluorene	*Mean*	0.006	0.006	0.099	0.108	0.008	0.006	0.015	0.049	1.208	0.006	0.006	0.145	0.133
	SD	0.002	0.002	0.117	0.211	0.007	0.003	0.019	0.077	1.466	0.002	0.002	0.227	0.252
Phenanthrene	*Mean*	0.006	0.006	0.398	0.654	0.019	0.014	0.106	0.500	6.021	0.006	0.006	1.402	0.925
	SD	0.002	0.002	0.366	1.284	0.049	0.019	0.167	0.658	7.366	0.002	0.002	2.288	1.648
Anthracene	*Mean*	0.006	0.006	0.234	0.189	0.010	0.006	0.031	0.181	3.138	0.006	0.006	0.501	0.274
	SD	0.002	0.002	0.292	0.334	0.017	0.003	0.052	0.186	3.533	0.002	0.002	0.840	0.478
Fluoranthene	*Mean*	0.009	0.006	0.579	0.662	0.022	0.016	0.156	0.641	9.599	0.006	0.006	2.841	1.137
	SD	0.006	0.002	0.516	1.227	0.047	0.019	0.268	0.842	15.324	0.002	0.002	7.081	1.648
Pyrene	*Mean*	0.008	0.006	0.404	0.540	0.020	0.014	0.135	0.696	7.012	0.006	0.006	2.444	1.014
	SD	0.005	0.002	0.351	0.996	0.036	0.014	0.230	0.682	9.854	0.002	0.002	5.248	1.465
Benz(a)anthracene	*Mean*	0.007	0.006	0.247	0.294	0.013	0.008	0.083	0.295	3.694	0.006	0.006	1.001	0.537
	SD	0.002	0.002	0.213	0.508	0.020	0.005	0.143	0.340	4.443	0.002	0.002	1.326	0.670
Chrysene/ Triphenylene	*Mean*	0.006	0.006	0.227	0.254	0.013	0.008	0.070	0.279	3.254	0.006	0.006	0.753	0.454
	SD	0.002	0.002	0.181	0.457	0.018	0.005	0.127	0.264	3.629	0.002	0.002	1.057	0.553
Benzo(b+j) fluoranthene	*Mean*	0.007	0.006	0.272	0.286	0.015	0.010	0.098	0.353	3.369	0.006	0.006	0.846	0.645
	SD	0.002	0.002	0.207	0.430	0.024	0.009	0.163	0.378	3.065	0.002	0.002	0.675	0.696
Benzo(k)fluoranthene	*Mean*	0.006	0.006	0.095	0.108	0.008	0.006	0.035	0.116	1.347	0.006	0.006	0.396	0.233
	SD	0.002	0.002	0.069	0.170	0.009	0.002	0.064	0.139	1.265	0.002	0.002	0.477	0.271
Benzo(e)pyrene	*Mean*	0.006	0.006	0.139	0.136	0.009	0.006	0.048	0.306	1.655	0.006	0.006	0.401	0.308

	SD	0.002	0.002	0.100	0.204	0.010	0.002	0.081	0.207	1.598	0.002	0.002	0.313	0.325
Benzo(a)pyrene	*Mean*	0.006	0.006	0.184	0.219	0.012	0.008	0.076	0.301	2.597	0.006	0.006	0.647	0.555
	SD	0.002	0.002	0.138	0.306	0.020	0.005	0.130	0.304	2.601	0.002	0.002	0.477	0.604
Indeno(1,2,3,-c,d)pyrene	*Mean*	0.006	0.005	0.096	0.106	0.008	0.006	0.040	0.168	1.413	0.006	0.006	0.409	0.322
	SD	0.002	0.002	0.064	0.125	0.009	0.002	0.059	0.173	1.278	0.002	0.002	0.380	0.389
Benzo(g,h,i)perylene	*Mean*	0.006	0.006	0.093	0.091	0.008	0.006	0.039	0.210	1.154	0.006	0.006	0.319	0.288
	SD	0.002	0.002	0.061	0.102	0.009	0.002	0.051	0.150	0.963	0.002	0.002	0.220	0.350
Dibenz(a,h)anthracene	*Mean*	0.006	0.006	0.025	0.028	0.006	0.005	0.010	0.062	0.372	0.006	0.006	0.102	0.074
	SD	0.002	0.002	0.018	0.033	0.002	0.001	0.014	0.051	0.330	0.002	0.002	0.129	0.096
Total PAHs	*Mean*	0.106	0.098	3.161	3.873	0.190	0.137	0.970	4.279	46.960	0.097	0.097	12.367	7.178
	SD	0.032	0.031	2.581	6.791	0.276	0.085	1.579	4.209	50.986	0.031	0.031	19.142	9.821

Supplementary Table 3. Total lengths (mean, SD, n) and total abundances (2018 – 2021) of all fish and invertebrates caught in fyke nets throughout the study period.

Species	Scientific Name	Total Length		Total Abundance Across all Sites					
		Mean	SD	2018	2019	2020	2021	2022	Total
Alosa sp.	*Alosa sp.*	90.0	25.2	2	5	5	3	12	27
American Eel	*Anguilla rostrata*	451.4	173.9	14	12	6	7	3	42
Atlantic Herring	*Clupea harengus*	189					1		1
Atlantic Rock Crab		73.5	2.1	2	1	2	5	1	11
Atlantic Tomcod	*Microgadus tomcod*	170.5		141	387	175	220	163	1086
Blackspotted Stickleback	*Gasterosteus wheatlandi*	41	35.8				1		1
Blueback Herring	*Alosa aestivalis*	80					1		1
Cancer sp.	*Cancer sp.*				1				1
Central Mudminnow	*Umbra limi*	83					1		1
Common Shiner	*Luxilus cornutus*	49				1			1
Fourspine Stickleback	*Apeltes quadracus*	65.6						6	6
Golden Shiner	*Notemigonus crysoleucas*	98.5	3.8		2	18		17	37
Hake	*Merluccius merluccius*	133.8	14		8		1		9
Jonah Crab	*Cancer borealis*		31.2		1				1
Lake Chub	*Couesius plumbeus*	110				1			1
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	335				1			1
Mummichog	*Fundulus heteroclitus*	90.5		1	6	1	7		15
Northern Crayfish	*Orconectes virilis*	40	11.3		1				1
Pollock	*Pollachius virens*	155		1	7	3		1	12
Rainbow Smelt	*Osmerus mordax*	152.8	26.8		31	20	15	9	75
Sand Shrimp	*Crangon septemspinosa*	13.3	28.2		33	25	16	24	98
Striped Bass	*Morone saxatilis*	590	6.7					1	1
Threespine Stickleback	*Gasterosteus aculeatus*	48.7			8	9	1	4	22

White Hake	*Urophycis tenuis*	164	15.9					2	2
White perch	*Morone americana*	163	5.6	1	2			3	6
White Sucker	*Catostomus commersonii*	117.4	44.1		8	86	67	17	178
Winter Flounder	*Pseudopleuronectes americanus*	156.5	37.5		17	7	35	14	73
Total				162	530	360	381	277	1710

Supplementary Table 4. Total lengths (mean, SD, n) and total abundances (2018 – 2021) of all fish and invertebrates caught in seine nets throughout the study period.

Species	Scientific Name	Total Length		Total Length Across all Sites					
		Mean	SD	2018	2019	2020	2021	2022	Total
Alosa sp.	*Alosa sp.*	56.4	6.5		14			24	38
American Eel	*Anguilla rostrata*	156.6	23				3		3
Atlantic Herring	*Clupea harengus*	52	5					3	3
Atlantic Silverside	*Menidia menidia*	79	14.6	1460	7366	4354	1460	2046	16686
Atlantic Tomcod	*Microgadus tomcod*	49.3	23.5	4	34	22	1061	196	1317
Banded Killifish	*Fundulus diaphanus*	41.5	13.4	1	591	4	1		597
Blackspotted Stickleback	*Gasterosteus wheatlandi*	31.8	6.5	2	110	41	17	158	328
Blueback Herring	*Alosa aestivalis*	50.5	7.7				2		2
Common Shiner	*Luxilus cornutus*	47.8	4.7					13	13
Fourspine Stickleback	*Apeltes quadracus*	32.5	9.9	9	7	3	4	33	56
Gasterosteus sp.	*Gasterosteus sp.*	24.8	6.7				11		11
Grubby	*Myoxocephalus aenaeus*	38	32.5		1		1	1	3
Haddock	*Melanogrammus aeglefinus*				1				1
Hake	*Merluccius merluccius*	70.3	20.5	1	2	10	2		15
Lake Chub	*Couesius plumbeus*				2				2
Mummichog	*Myoxocephalus octodecemspinosus*	47.8	11	4	24	69		11	108
Mysid	*Fundulus heteroclitus*	6	1.7	1	32	90	2		125
Ninespine Stickleback	*Mysid sp.*	46.8	6.8	65	3		5	2	75
Northern Pipefish	*Pungitius pungitius*	114.5	42.6	1	2	1	4	2	10
Peprilus sp.	*Peprilus sp.*	37					1		1
Pollock	*Pollachius virens*				6				6
Rainbow Smelt	*Osmerus mordax*	57.7	9.7	39	106	29	32	4	210
Rock Gunnel	*Pholis gunnellus*	89				1	1		2
Sand Shrimp	*Crangon septemspinosa*	7.5	5.9	842	5010	3059	5239	2956	17106
Shorthorn Sculpin	*Myoxocephalus scorpius*	74.9	11.7		1				1
Smooth Flounder	*Pleuronectes putnami*	74.9	11.7			1		11	12

Threespine Stickleback	*Gasterosteus aculeatus*	34.8	10.1	30	1928	148	203	714	3023
White Sucker	*Catostomus commersonii*	92	1.7			1	3		4
Winter Flounder	*Pseudopleuronectes americanus*	76.4	31.8	12	81	58	33	63	247
Total				2471	15321	7891	8085	6237	40005