Lunenburg Harbour 2018 Water Quality Report

Prepared for

Town of Lunenburg

By

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1. Introduction

1.1. Background

In 2018, Coastal Action was contracted by the Town of Lunenburg to design and carry out a water quality monitoring program in Lunenburg Harbour with a focus on fecal bacteria testing. Preliminary bacteria testing, conducted by the Town of Lunenburg in 2017, identified high bacteria concentrations at several shoreline locations in the inner harbour. These results highlighted the need for a more extensive monitoring program to better understand the bacterial conditions throughout the harbour, how bacterial concentrations are influenced by various environmental factors, and the associated public health risks.

Fecal bacteria pollution in recreational waters presents a serious risk to human health due to the possible presence of pathogenic/infectious microorganisms. There are hundreds of types of disease-causing bacteria, viruses, and protozoa making it impractical to test for all of them. For this reason, non-pathogenic fecal indicator bacteria (FIB) species are used as a proxy. Elevated concentrations of FIBs indicate the possible presence of pathogenic microorganisms; however, the absence of FIBs should not be interpreted to mean that all pathogenic organisms are also absent (Health Canada, 2012).

Enterococci are widely considered the most appropriate FIB species for monitoring marine recreational waters by authoritative bodies including the US EPA, World Health Organization, and Health Canada (Griffin et al., 2003; WHO, 2003; Health Canada, 2012). Health Canada has established guidelines for recreational water contact depending on the level of exposure and the type of water-based recreation:

Primary Contact: Recreational activity in which the whole body or the face and trunk are frequently immersed, or the face is frequently wetted by spray, and where it is likely that some water will be swallowed. Inadvertent immersion, through being swept into the water by a wave or slipping, would also result in whole body contact. Examples include swimming, surfing, waterskiing, whitewater canoeing/rafting/kayaking, windsurfing or subsurface diving.

Secondary Contact: Recreational activity in which only the limbs are regularly wetted and in which greater contact (including swallowing water) is unusual. Examples include rowing, sailing, canoe touring, or fishing.

Table 1: Health Canada recreational fecal enterococci thresholds for primary and secondary contact in marine environments.

Level of water contact	Guideline considerations	Health Canada guideline
Primary Contact	Geometric mean concentration (minimum of 5 samples)	≤ 35 CFU/100 mL
	Single sample maximum concentration	≤ 70 CFU/100 mL
Secondary Contact	Apply a factor of 5 to the geometric mean guideline (5 x 35 CFU/100 mL)	175 CFU/100 mL

1.2. Program Design

Coastal Action designed this monitoring program based on consultations with the Town of Lunenburg to ensure that their main concern of public health and safety was being addressed. Three shoreline locations, which are frequently used for water-based recreational activities, were chosen as weekly monitoring sites. By sampling these sites at a high frequency and collecting water samples from the exact locations where water contact is likely to occur, this component of the monitoring program provides critical information on the risk to human health during various forms of recreation (wading, kayaking, tying boat lines, etc.). At the Boat Launch site, water samples were collected from near the shoreline where individuals are likely to contact water during the process of launching a small watercraft. At Fisherman's Wharf, water samples were collected off the front edge of the wharf, immediately in front of the discharge pipe that releases effluent from the town's sewage treatment plant. This specific location was selected at the request of the Town of Lunenburg, as this is the same spot that town staff sampled in 2017 and it provides valuable information regarding the safety of the water near the effluent pipe. Water contact at Fisherman's Wharf would occur mainly through the handling of wet boat lines. At the Zwicker's Wharf site, water samples were collected from the floating docks located on the western side of the wharf, where direct water contact is most likely to occur during the use of small watercraft.

Additional program components were included to investigate bacterial conditions throughout the harbour and in the bottom sediments. Five harbour sample sites were monitored on a seasonal basis, as well as immediately following two rainfall events. These sites provide a greater understanding of how widespread the bacterial contamination is and how this contamination is influenced by environmental factors such as tidal cycles, seasons, rainfall, and wind. A control site, located near the outer limits of the harbour, is presumed to be outside of the bacteria pollution area as it is in an open-water marine environment with sufficient dilution and flushing, and as such, is predicted to display low bacteria concentrations. The remaining harbour sites were chosen in areas near potential bacteria sources: the shallow water sedimentation zone near the golf course; near the waterfront wharves where stormwater runoff and combined sewer overflow pipes may contribute bacteria; near the community of Garden Lots where straight pipes are still used by many homes; and near High Liner Foods which discharges effluent from an onsite treatment plant.

Four sites were chosen in the harbour for the collection of benthic sediment. Bottom sediment is a known reservoir for bacteria and other pathogens. Bacterial concentrations in sediment can be 100-1000 times higher than those measured in the overlying water column (Van Dansel & Geldreich, 1971; Byappanahalli et al., 2012), with clay substrate providing the best environment for bacteria survival (Craig et al., 2004). Analysis of these sediment samples will provide important information regarding the bacterial load in harbour sediments and the potential for resuspension into the water column.

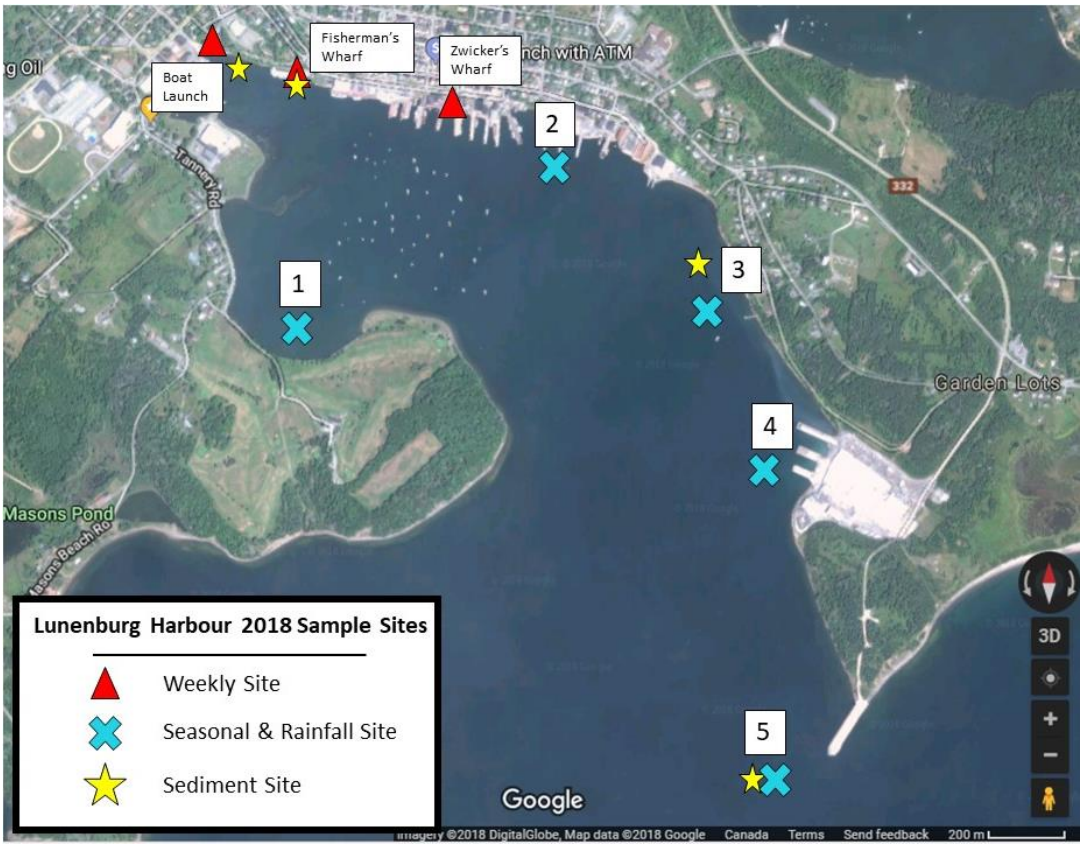

Figure 1: Waterfront and in-harbour sites, for water and sediment samples, for the Lunenburg Harbour Water Quality Program, conducted from June to October 2018.

1.3. Objectives and Scope of Work

The objectives of the program were to obtain a general understanding of bacteria fluctuations within Lunenburg Harbour, and to assess whether public access sites exceeded Health Canada's secondary contact guidelines for fecal enterococci. This program provides a microbial water quality assessment of Lunenburg Harbour; however, it is not a sanitary inspection program nor is it a microbial source tracking program, both of which would identify and provide data on specific sources of bacterial pollution.

To achieve these objectives, the program aimed to answer the following questions:

1) What is the concentration of fecal enterococci within the water of Lunenburg Harbour?
2) Are the three waterfront sites exceeding Health Canada's secondary contact recreational guideline for enterococci?
3) Are the five harbour sites exceeding Health Canada's secondary contact recreational guideline for enterococci?
4) What is the concentration of fecal enterococci within the sediment of Lunenburg Harbour?

To answer these questions, the scope of work included:

- Weekly monitoring of various biological and physical water quality parameters from Zwicker's Wharf, Fisherman's Wharf, and the Boat Launch (waterfront sites) during a variety of tidal stages and weather events.
- Comparing weekly fecal bacteria results to Health Canada's recreational guidelines for secondary contact.
- Providing a weekly summary of the results, field observations, graphs, and comparison to Health Canada's guidelines to the Town of Lunenburg.
- Seasonal monitoring of various biological, chemical, and physical water quality parameters from five harbour sites, with two sampling events occurring after 20-25 mm, and >30 mm rainfall within 24 hours, respectively.
- Comparing seasonal fecal bacteria results to Health Canada's recreational guidelines.
- Providing a summary of the seasonal results, field observations, graphs, and comparison to Health Canada's guidelines to the Town of Lunenburg.
- One-time collection of four benthic sediment samples from Lunenburg Harbour, to be tested for fecal enterococci.
- Preparing this report to summarize results and recommendations for water quality related to Lunenburg Harbour.

2. Methodology

2.1. Site Locations

Table 2: Site names and locations for the Lunenburg Harbour water quality monitoring program, 2018.

Site Name	Sampling Location	Water Sampling Co-ordinates	Sediment Sampling Co-ordinates
Zwicker's Wharf	Waterfront	44.375508, -64.308922	
Fisherman's Wharf	Waterfront	44.376194, -64.313984	44.376111, -64.314000
Boat Launch	Waterfront	44.376950, -64.317271	44.376722, -64.316917
Site 1	Harbour	44.371831, -64.313928	
Site 2	Harbour	44.374206, -64.304056	
Site 3	Harbour	44.371600, -64.300067	44.371889, -64.300306
Site 4	Harbour	44.367106, -64.297939	
Site 5	Harbour	44.360989, -64.301730	44.361130, -64.301275

2.2. Sampling Events

2.2.1. Weekly Sampling

Lunenburg waterfront water quality monitoring was conducted weekly, from June 12 to September 25, 2018. Water quality monitoring included *in-situ* (at site) monitoring of physical parameters, in addition to the collection of water samples for laboratory analysis.

2.2.2. Rainfall Sampling

Lunenburg Harbour water quality monitoring was conducted on July 19 and October 16, 2018, after a heavy (>30 mm rain in 24 hours) and moderate (20-25 mm rain in 24 hours) rainfall, respectively. Samples were collected within 24 hours from when these rainfall events ended. Water quality monitoring included *in-situ* monitoring of physical parameters, in addition to the collection of water samples.

2.2.3. Seasonal Sampling

Lunenburg Harbour water quality monitoring was conducted seasonally, on July 3, August 21, and September 18, 2018. Water quality monitoring included *in-situ* monitoring of physical parameters, in addition to the collection of water samples. Sediment samples were also obtained during one seasonal event.

2.3. Sampling

2.3.1. *In-Situ* Samples

Water quality monitoring of the physical parameters was conducted using a multi-parameter YSI probe. The probe tests for water temperature, barometric pressure, dissolved oxygen, specific conductivity, total dissolved solids, salinity, and pH. The probe is calibrated monthly for pH and conductivity, with dissolved oxygen calibrated in the field prior to sampling. The YSI is removed from its protective cover and placed in the water at the sampling location. The probe is left for approximately five minutes to adjust to the water chemistry. After the probe has adjusted, the physical parameter values are recorded, and the probe is removed and stored.

At the harbour sites, a Secchi disk was used as a measure of water clarity. The Secchi disk is a weighted circular disk with black and white colouring – the disk is lowered into the water until it is no longer visible, and the depth is recorded. The disk is lowered one meter deeper into the water column and then raised until it becomes visible once again and that depth is recorded. Water clarity is reported as the average of these two depth measurements.

2.3.2. Water Samples

Coastal Action collected water samples during the weekly, seasonal, and rainfall sampling events. Weekly samples were tested for fecal enterococci, a strain of bacteria recommended by Health Canada (2012) for saltwater environments. Seasonal and rainfall sampling events collected samples to be tested for total nitrogen, total phosphorus, and fecal enterococci. Each water sample was collected using the same technique.

Using an extendable sampling arm with a bottle on the end, the bottle was filled and rinsed three times with sample water, ensuring the rinse was dumped away from the sample collection site. The three rinses were done to remove any contaminants from the bottle. The bottle was then filled, at approximately 1 ft depth, to collect sample water for analysis. Extra caution was taken at the shoreline sites to avoid disturbing bottom sediments in the shallow conditions.

Sterile bottles were obtained from Maxxam Analytics Laboratory (Maxxam) for sample collection. The bottles contained preservative to ensure the water chemistry integrity was maintained until analysis. The bottles were filled with sample water up to the pre-determined 'fill line' (to ensure a proper ratio of water to preservative) and sealed. The bottles were placed in a cooler on ice to maintain a water temperature below 10°C – the maximum temperature accepted by the laboratory before temperature affects results. Chain of custody forms were filled out, including time and date of sample collection, and signed.

2.3.3. Sediment Samples

Lunenburg Harbour sediment samples were collected using an Ekman dredge, which obtains a sample from the top 15 cm of benthic sediment. The jaws of the dredge were kept open while the dredge was lowered to the harbour bottom. A weighted messenger was sent down the line to a spring-loaded system which closed the jaws. The dredge was then pulled onto the boat, and the sediment was transferred into sterile containers from Maxxam, to be packaged on ice and shipped to Maxxam in Quebec for fecal enterococci analysis.

Additional sediment was collected from each sample site for a parallel pilot study on the use of foraminifera as bio-indicators of marine pollution. These samples were provided to Dr. Brent Wilson FGS, a professor in the Department of Chemical Engineering at the University of the West Indies. Dr. Wilson analyzed the abundance and diversity of foraminifera within the four sediment samples collected from the harbour (see Appendix A for methodology).

2.3.4. Quality Assurance and Quality Control

Quality assurance and quality control (QAQC) measures were used throughout the sampling program, to ensure all data were accurate and without contamination from outside sources (Table 3).

Table 3: QAQC sampling methods applied to the three sampling event types for Lunenburg Harbour water quality monitoring, 2018.

QAQC Sample Type	# during Weekly Sampling	# during Seasonal Sampling	# during Rainfall Sampling
Field Replicate	3	1	1
Field Blank	1	1	

To ensure no contamination occurred during the water sample collection process, two field blanks were used: one during a weekly sampling event and one during a seasonal sampling event. Using deionized water sent by the lab, one site was chosen arbitrarily, and all bottles were filled using the deionized water and analyzed at the lab for regular parameters – fecal enterococci for weekly and total phosphorus and fecal enterococci for seasonal. No total nitrogen blanks were performed as the lab is unable to send deionized water compatible with total nitrogen blanks. A detectable amount of any parameter would indicate contamination during the sampling process.

To determine the variability in water conditions at each site, and confirm the values reported, field replicates were conducted: one at each of the weekly sampling sites, one during a rainfall event, and one during a seasonal event. After arbitrarily choosing which site would have the field replicates conducted,

and after the first set of water samples were collected, a second set of samples were collected (minutes apart) and sent to the lab for testing – fecal enterococci for weekly and total nitrogen, total phosphorus, and fecal enterococci for seasonal and rainfall.

2.4. Laboratory Analyses

The analysis for fecal enterococci in water was performed at Maxxam Analytics in Bedford. Maxxam analyzes fecal enterococci via the accredited membrane filtration method, providing results as colony forming units per 100 mL (CFU/100 mL).

The analysis for fecal enterococci in sediment was done at Maxxam Analytics in Quebec. Maxxam analyzes fecal enterococci via the accredited membrane filtration method, providing results as colony forming units per gram (CFU/g).

The analysis for total nitrogen in water was done at Maxxam Analytics in Burnaby, BC. Maxxam analyzes total nitrogen via the accredited persulfate method, providing results as milligrams per litre (mg/L).

The analysis for total phosphorus in water was done at Maxxam Analytics in Mississauga, ON. Maxxam analyzes total phosphorus via the accredited colourimetric method, providing results as milligrams per litre (mg/L).

2.5. Statistical Analyses

All data were entered into an excel database, and analyzed using the R statistical software, version 3.5.0 (R Core Team, 2018). Non-detectable values were set as their detection limits to allow for statistical analysis. Correlations between parameters were obtained from the best fit line applied to scatterplots (R^2 value) and the 'cor' command (correlation coefficient value). The data were tested for normality using the Shapiro test, and weekly data were tested for autocorrelation, to ensure samples did not have a time-delayed correlation. Data were tested for significant differences using the Mann-Whitney-Wilcoxon (for dependent samples) and Kruskal-Wallis tests (for independent samples). Bacteria concentrations were tested for a significant difference between high tide and low tide, with tidal cycles determined as: High tide if within 2 hours of high tide, low tide if between 4-8 hours from high tide (Figure 2). Data collected during mid tide (2-4 hours from high tide) were not used during the tidal comparison to increase the statistical differences between tides.

Figure 2: Characteristics and timing for each tidal cycle phase used for statistical analysis of the Lunenburg Harbour water quality data.

3. Results

3.1. Water Samples

3.1.1. Waterfront Sites

During weekly sampling at the three waterfront sites, there were minimal differences between the three sites' physical water chemistries (Tables 4-6). Temperatures remained consistent between sites, ranging from 9.2 to 21.1°C over the sampling period (Figure 3). Dissolved oxygen (DO) never fell below 77% at any site during the sampling period, with Fisherman's Wharf having the highest recorded DO – 125.7% (Figure 4). Specific conductivity (SPC), Total Dissolved Solids (TDS), and salinity were all within 5% of each site's mean value. The lowest pH was recorded at Zwicker's Wharf (7.57 pH units); however, all sites had overlapping pH ranges (7.57 to 8.05 pH units).

Table 4: Water quality summary for samples at Zwicker's Wharf collected from June to September 2018.

	Temperature (°C)	DO (%)	SPC (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH	Enterococci (CFU/100 mL)
Min	9.9	77.3	46.16	30008	30.01	7.57	10
Mean	16.99	103.8	47.06	30601	30.63	7.85	298.1
Max	20.9	116.3	47.54	30902	31.01	8.05	1600

Table 5: Water quality summary for samples at Fisherman's Wharf collected from June to September 2018.

	Temperature (°C)	DO (%)	SPC (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH	Enterococci (CFU/100 mL)
Min	9.5	90.1	46.48	30210	30.22	7.8	170
Mean	17.05	110.6	47.16	30654	30.7	7.94	1555.7
Max	21.0	125.7	47.72	31020	31.0	8.05	2500

Table 6: Water quality summary for samples at the Boat Launch collected from June to September 2018.

	Temperature (°C)	DO (%)	SPC (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH	Enterococci (CFU/100 mL)
Min	9.2	78.1	44.83	29040	29.03	7.63	10
Mean	17.15	102.9	46.61	30289	30.3	7.87	1153
Max	21.1	119.3	47.71	31010	30.88	8.01	2500

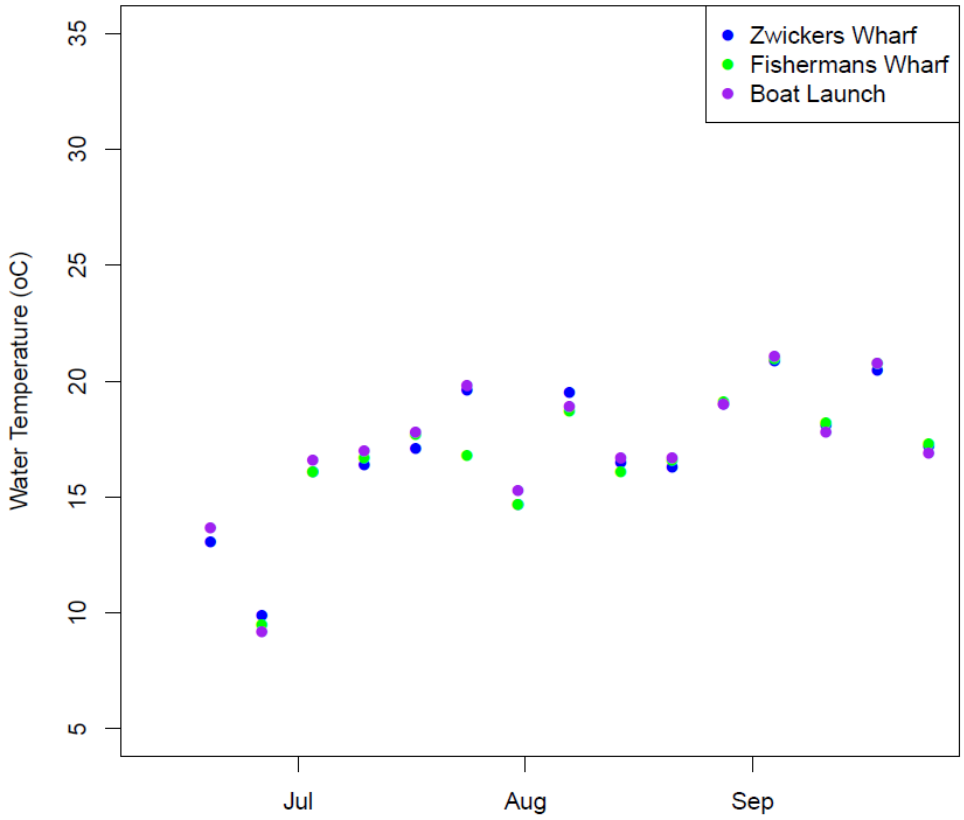

Figure 3: Water temperatures for the three waterfront sites monitored weekly from June to September 2018.

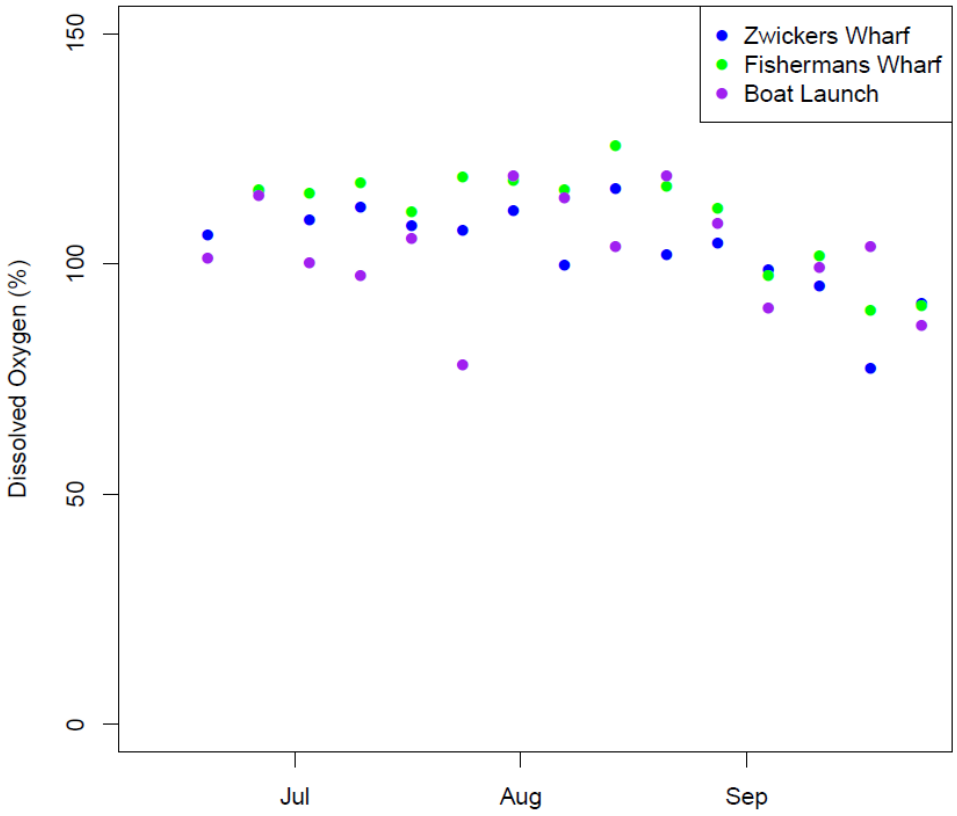

Figure 4: Dissolved oxygen for the three waterfront sites monitored weekly from June to September 2018.

All three waterfront sites exceeded Health Canada's secondary contact recreational guideline (175 CFU/100 mL) during the sampling period (Figure 5). Fecal enterococci concentrations were consistently highest at Fisherman's Wharf (mean of 1555.7 CFU/100 mL), and consistently lowest at Zwicker's Wharf (mean of 298.1 CFU/100 mL). Of the weekly samples collected at the waterfront sites, 50% were greater than the Health Canada secondary contact guideline at Zwicker's Wharf, 93% were greater than the guideline at Fisherman's Wharf, and 75% were greater than the guideline at Boat Launch.

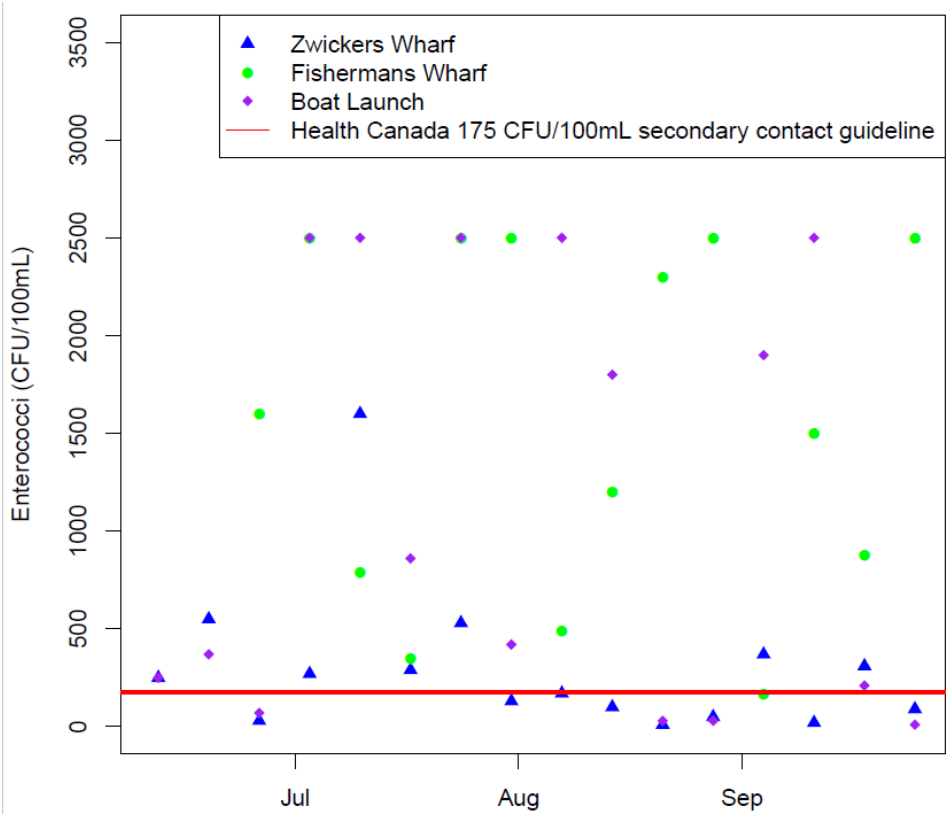

Figure 5: Comparison of fecal enterococci concentrations for the three waterfront sites monitored weekly from June to September 2018 to the Health Canada secondary contact recreational guideline (175 CFU/100 mL).

Fisherman's Wharf does not appear to be correlated to the same parameters as Boat Launch and Zwicker's Wharf. Enterococci at Zwicker's Wharf and Boat Launch both have strong (>0.5 correlation) negative correlations with TDS, SPC, and salinity (Table 7). Enterococci at Fisherman's Wharf only shows a strong [positive] correlation with barometric pressure, and is least correlated with TDS, SPC, and salinity.

Table 7: Correlation (R^2 and correlation coefficient) of various water quality parameters with fecal enterococci concentrations, at three waterfront sites, during weekly sampling of Lunenburg Harbour from June to September 2018.

	Zwicker's Wharf		**Fisherman's Wharf**		**Boat Launch**	
	Scatterplot R^2	Correlation Coefficient	Scatterplot R^2	Correlation Coefficient	Scatterplot R^2	Correlation Coefficient
Temperature (°C)	0.00142	0.11	-0.128	-0.36	0.126	0.31
Pressure (mmHg)	-0.0803	-0.23	0.318	0.56	0.0193	0.015
DO (%)	0.0118	0.18	0.0659	0.17	-0.2	-0.43
TDS (mg/L)	-0.387	-0.62	-0.00309	-0.056	-0.46	-0.68
SPC (mS/cm)	-0.415	-0.63	-0.00322	-0.057	-0.448	-0.69
Salinity (ppt)	-0.394	-0.61	-0.00795	-0.089	-0.426	-0.67
pH	0.00141	-0.01	0.0444	0.21	-0.0851	-0.29

None of the site's weekly bacteria concentrations were normally distributed or autocorrelated. Zwicker's Wharf was independent of the two other waterfront sites; however, due to proximity, Fisherman's Wharf and Boat Launch are dependent on each other. At each site, high tide enterococci concentrations were not found to be significantly different (at 95% confidence) from low tide concentrations (Table 8). In addition, neither high tide, nor low tide enterococci concentrations were significantly different between sites (Table 9). These statistics are based off a small sample size (≤16 samples per site); more data is needed to ensure statistical strength.

Table 8: P-values from the Kruskal-Wallis test indicating significant difference (p-value < 0.05 indicates significant difference at 95% confidence) between enterococci concentrations in high tide versus low tide, from samples collected at the three waterfront sites during weekly sampling of Lunenburg Harbour between June to September 2018.

Site	P-value
Zwicker's Wharf	0.406
Fisherman's Wharf	0.3916
Boat Launch	0.406

Table 9: P-values from the Kruskal-Wallis test (and Wilcoxon test for Fisherman's Wharf versus Boat Launch) indicating significant difference (p-value < 0.05 indicates significant difference at 95% confidence) between enterococci concentrations between sites, for both high tide and low tide, from samples collected at the three waterfront sites during weekly sampling of Lunenburg Harbour between June to September 2018.

	High Tide				Low Tide		
	Zwicker	Fisherman	Boat Launch		Zwicker	Fisherman	Boat Launch
Zwicker		0.2592	0.8495			0.3916	0.406
Fisherman	0.2592		0.4227		0.3916		0.7893
Boat Launch	0.8495	0.4227			0.406	0.7893	

3.1.2. Harbour Sites

The five harbour sites had similar physical water quality characteristics (Tables 10-14). Temperatures within the five harbour sites ranged from 10 to 20°C, with DO never falling below 95%. The water was basic at all sites, with pH ranging from 7.7 to 8.1. Salinity, TDS, and SPC concentrations at each site were within 5% of the mean value for the other four sites. Site 5 had the highest clarity, with a maximum Secchi depth of 10.16 m, while Site 1 had the lowest clarity, with a maximum depth of 3.74 m; as clarity is inferred from the Secchi disk depth, it is limited by the depth of the site and therefore does not lend well to comparison between sites of different depths.

Table 10: Water quality summary for samples at Site 1 collected from July to October 2018.

	Temperature (°C)	DO (%)	SPC (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH	Enterococci (CFU/100 mL)	Secchi Depth (m)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Min	13.6	96.0	45.83	29795	29.72	7.76	10	1.20	0.155	0.04*
Mean	16.1	102.0	46.96	30582	30.63	7.85	130	2.32	0.187	0.044
Max	20.3	113.2	47.56	30925	30.96	7.93	410	3.74	0.228	0.06

**Below detection limit.*

Table 11: Water quality summary for samples at Site 2 collected from July to October 2018.

	Temperature (°C)	DO (%)	SPC (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH	Enterococci (CFU/100 mL)	Secchi Depth (m)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Min	11.1	98.2	45.79	29757	29.65	7.78	10*	5.23	0.02*	0.004*
Mean	15.0	105.0	47.06	30583	30.58	7.89	54.3	6.50	0.149	0.035
Max	20.7	117.9	47.58	30927	30.93	8.03	210	7.45	0.238	0.05

**Below detection limit.*

Table 12: Water quality summary for samples at Site 3 collected from July to October 2018.

	Temperature (°C)	DO (%)	SPC (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH	Enterococci (CFU/100 mL)	Secchi Depth (m)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Min	10.8	95.0	45.49	29624	29.58	7.73	10*	3.82	0.117	0.037
Mean	15.28	106.2	46.95	30533	30.55	7.92	84	4.75	0.209	0.041
Max	20.8	118.3	47.63	30961	30.95	8.06	320	5.29	0.304	0.05

**Below detection limit.*

Table 13: Water quality summary for samples at Site 4 collected from July to October 2018.

	Temperature (°C)	DO (%)	SPC (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH	Enterococci (CFU/100 mL)	Secchi Depth (m)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Min	10.9	95.2	45.71	29689	29.58	7.73	10*	4.98	0.121	0.02*
Mean	15.16	104.0	46.98	30532	30.52	7.91	45	7.25	0.177	0.039
Max	20.7	116.7	47.59	30935	30.92	8.02	120	8.60	0.242	0.06

**Below detection limit.*

Table 14: Water quality summary for samples at Site 5 collected from July to October 2018.

	Temperature (°C)	DO (%)	SPC (mS/cm)	TDS (mg/L)	Salinity (ppt)	pH	Enterococci (CFU/100 mL)	Secchi Depth (m)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Min	11.7	100.8	46.35	30133	30.64	7.71	10*	5.84	0.124	0.022
Mean	15.28	105.8	46.90	30615	30.82	7.92	16	7.81	0.144	0.034
Max	20.4	115.6	47.31	30869	30.99	8.03	30	10.16	0.189	0.04

**Below detection limit.*

Three of the five harbour sites exceeded Health Canada's secondary contact recreational guideline (175 CFU/100 mL) during the sampling period (Figure 6). Fecal enterococci concentrations ranged from below the 10 CFU/100 mL detection limit, to above 400 CFU/100 mL (Tables 10-14). The highest bacteria concentrations were recorded at Site 1, while bacteria concentrations were consistently lowest at Site 5. The Health Canada secondary contact guideline was exceeded for 40% of samples at Site 1, 16.6% of samples at Site 2, 20% of samples at Site 3, and 0% of samples at sites 4 and 5.

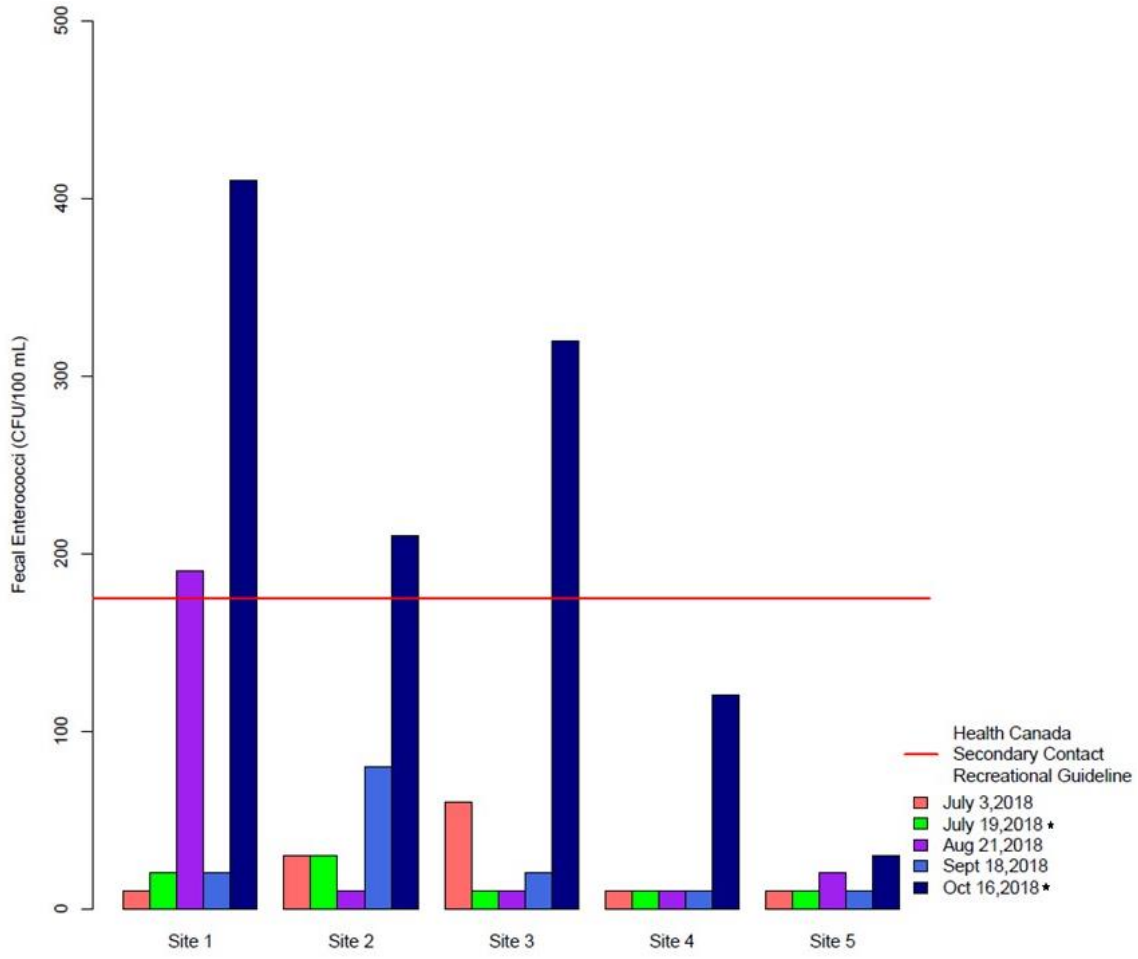

Figure 6: Comparison of fecal enterococci concentrations at the five harbour sites obtained during the seasonal and rainfall sampling of Lunenburg Harbour from July to October 2018 to the Health Canada secondary contact recreational guideline. Stars indicate samples obtained during rainfall sampling.

Although there was minimal difference between phosphorus concentrations between the five sites (Figure 7), nitrogen concentrations differed (Figure 8). The highest nitrogen concentration of 0.304 mg/L was recorded at Site 3. Although nitrogen concentration ranges overlapped at all sites, and aside from the August 21 measurement, nitrogen concentrations were lowest at Site 5.

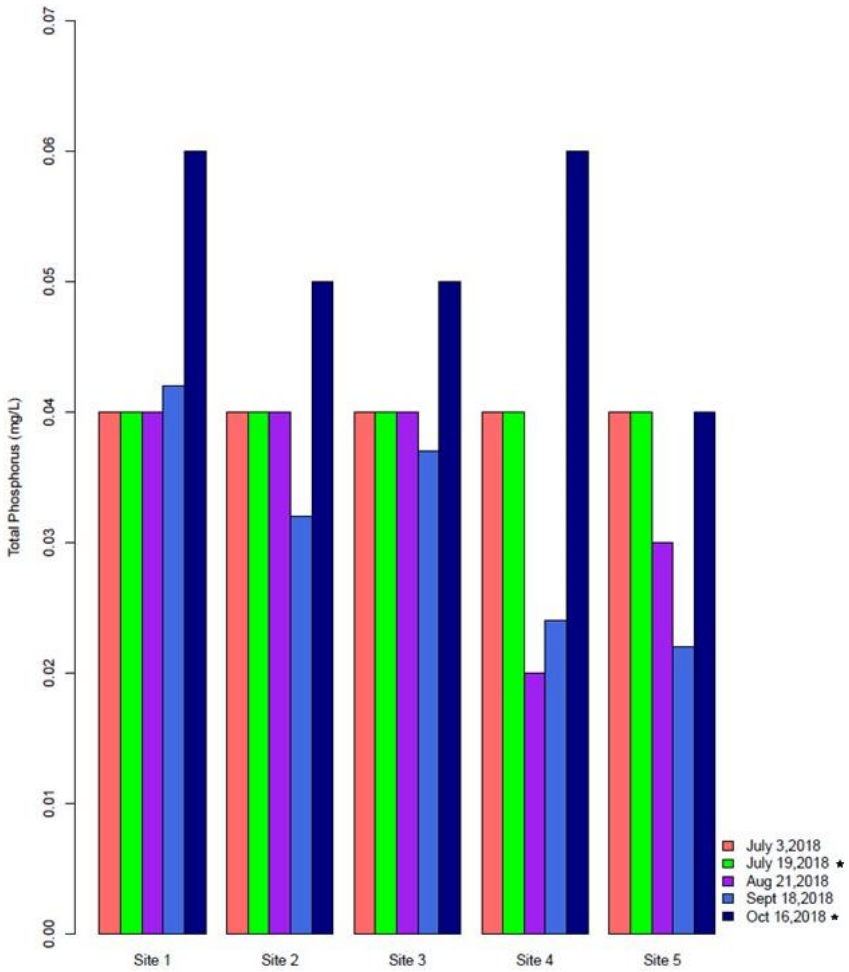

Figure 7: Total phosphorus concentrations at the five harbour sites obtained during the seasonal and rainfall sampling of Lunenburg Harbour from July to October 2018. Stars indicate samples obtained during rainfall sampling.

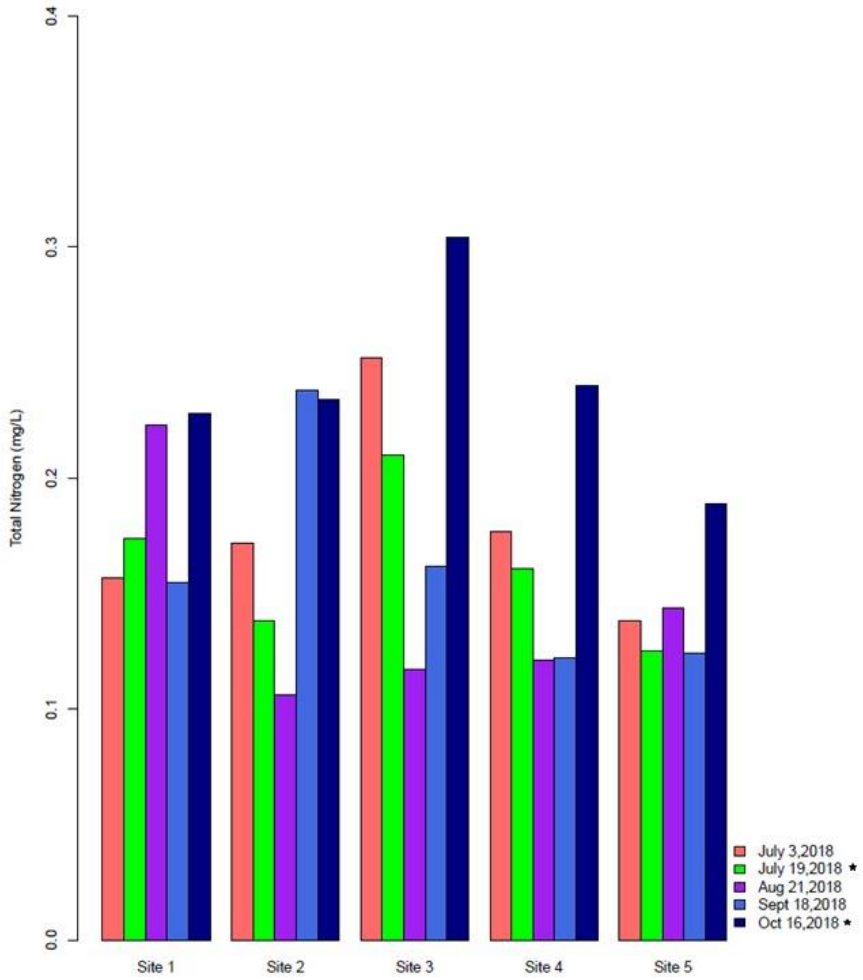

Figure 8: Total nitrogen concentrations at the five harbour sites obtained during the seasonal and rainfall sampling of Lunenburg Harbour from July to October 2018. Stars indicate samples obtained during rainfall sampling.

3.2. Sediment Samples

Fecal enterococci concentrations within sediment from four harbour sites range from <30 to 2400 CFU/g (Figure 9). Site 5 was below the laboratory's 300 CFU/g detection limit for that sample; the sample from Site 3 was also below the laboratory's detection limit (<30 CFU/g for that sample). The detection limit between samples varies, as the laboratory's dilution procedures were sample-dependent.

Sediment from Site 5 was primarily mud with minimal fine sediments, while Site 3 had a range of fine to coarse sediments within a mud matrix. In contrast, the Boat Launch site's sediment was vegetation rich with a range of sediment sizes within a mud matrix, and Fisherman's Wharf's sample was composed of clay.

Figure 9: Fecal enterococci concentrations in sediment samples collected from four sites along the waterfront and harbour during Lunenburg Harbour sampling, on September 18th, 2018.

4. Discussion

Weekly bacteria monitoring at the three waterfront sites has revealed significant, chronic bacterial pollution in parts of Lunenburg Harbour. The frequency of Health Canada's secondary contact guideline exceedances, and the amount by which this guideline was surpassed, pose a great risk to human health during certain types of water recreation. Out of all weekly samples collected, Zwicker's Wharf exceeded the secondary contact guideline 50% of the time, while Fisherman's Wharf exceeded 93% of the time, and the Boat Launch exceeded 75% of the time. Zwicker's Wharf displayed a maximum bacteria concentration of 1600 CFU/100 mL, while both Fisherman's Wharf and the Boat Launch reached concentrations of >2500 CFU/100 mL on multiple occasions.

Recreation in Lunenburg Harbour is, for the most part, restricted to activities which fall under the Health Canada secondary contact category; however, the unlikely event of individuals engaging in primary contact activities is still a possibility. Individuals may be sprayed in the face with water during boating activities, fall overboard or capsize a small watercraft, or wade/swim in the water if they are not aware of the bacteria pollution. As such, it is worth noting the frequency of Health Canada's primary contact guideline exceedances at these three waterfront sample sites. Of the samples collected, Zwicker's Wharf exceeded the primary contact guideline 75% of the time, while Fisherman's Wharf exceeded 100% of the time, and the Boat Launch exceeded 81% of the time.

Many environmental and anthropogenic factors play a role in the bacteria conditions at each site. Bacteria concentrations at both Zwicker's Wharf and the Boat Launch are correlated to parameters which are tidally influenced (TDS, SPC, salinity), meaning that bacteria concentrations are lower at high tide. This correlation is stronger at Zwicker's Wharf compared to the Boat Launch and is not present at Fisherman's Wharf. This suggests that, of the three sites, Zwicker's Wharf experiences the strongest tidal flushing action, with bacteria being dispersed, diluted, and carried to the open ocean due to its location being in closer proximity to the harbour mouth. Despite this tidal influence at Zwicker's Wharf, there is no statistical difference in bacteria concentrations between the three waterfront sites or between low and high tide.

The limited tidal influence on bacteria concentrations at Fisherman's Wharf and the Boat Launch is likely the result of several factors including the restricted shape of that part of the harbour, the wave break structure near Fisherman's Wharf, and the constant source of bacteria discharging from the effluent pipe. The geographical configuration of this back 'pocket' of the harbour and, to a lesser extent, the wave break structure may be limiting water circulation and preventing a full tidal flush of this area. This suggests that not all the bacteria are being flushed from this part of the harbour by tidal processes and may be settling into bottom sediments or other reservoir habitats. In addition, the effluent pipe supplies a constant source of bacteria to this environment, which may be overshadowing any effects of tidal influence. Ideally, sewage effluent pipes are designed to discharge into receiving waters which will facilitate the dispersion and dilution of effluent in a low-nutrient, open water environment where UV radiation and other deactivation processes will ensure a certain degree of public safety (WHO, 2003; Davies-Colley et al., 1994). When sewage effluent is warmer, and of a lower salinity than its receiving water, poor mixing can lead to the development of floating slicks. These slicks are highly susceptible to wind and can be transported to distant locations including recreational areas (WHO, 2003). The bacteria contamination measured at Fisherman's Wharf is likely acting as a significant source for the contamination observed at the Boat Launch due to proximity, through both the movement of floating slicks, limited tidal flushing, and the resuspension of microorganisms from reservoir habitats including benthic sediment, aquatic vegetation, and shoreline soils (Byappanahalli et al., 2012). Additional contributing sources may include stormwater runoff, combined sewer overflow (CSO) discharges, or illegal dumping of boat waste.

Monitoring of the five harbour sites occurred a total of five times. Three seasonal sampling events were conducted on July 3, August 21, and September 18. Two rainfall-dependent events occurred on July 19 and October 16, following 122 mm and 22 mm of rainfall within 48 hours, respectively. Sites 1, 2, and 3 exceeded the Health Canada secondary contact guideline. Site 1 exceeded this guideline on two occasions, on August 21 and October 16. The cause of the exceedance on August 21 is unknown. This part of the harbour is extremely shallow with slow water movement facilitating sedimentation. Sediment was not analyzed at this location; however, potential bacteria sources which may contaminate both the sediment and the overlying water column include the illegal release of boat waste from the nearby mooring field, runoff from surrounding urban areas and the golf course (course fertilization practices are unknown), or the transport of contaminated water or sediment from the Fisherman's Wharf area. The exceedance at Site 1 on October 16 is a result of the moderate rainfall event which occurred less than 24 hours prior to sampling. Sites 2 and 3 also exceeded the secondary contact guideline following this moderate rainfall event.

Bacteria concentrations in aquatic environments can be strongly influenced by precipitation events and the associated increase in runoff volumes, leading to short-term spikes in FIB concentrations. This

predictable response to precipitation is often incorporated into risk management frameworks for recreational areas, where recreational use may be automatically restricted following rainfall events (Health Canada, 2012; WHO 2003; Mallin et al., 2001). The bacteria concentrations in Lunenburg Harbour displayed opposing responses to the two rainfall events which were monitored in this program. Bacteria spikes were not observed following the heavy (122 mm) rainfall event on July 19; however, elevated concentrations and secondary contact exceedances were observed following the moderate (22 mm) rainfall event on October 16. It is hypothesized that dilution, resulting from significant runoff volumes, may have contributed to the lack of FIB response to the heavy rainfall event, while the moderate rainfall event displayed the typical FIB spikes caused by contaminated stormwater runoff and other bacteria sources which are influenced by precipitation. A larger sample size of rainfall events, of varying volumes, would be required to test this theory of rainfall impacts in Lunenburg Harbour.

Nutrient enrichment is one of the greatest threats to the health of coastal ecosystems (NRC, 1994) and can lead to eutrophication and algal blooms (NRC, 1993; CCME, 2007). The most significant anthropogenic sources of nutrients in coastal environments are wastewater discharges, fertilizers, and atmospheric deposition (Valiela, 1995), while discharges from seafood processing plants can act as another important source of nutrients where they exist in coastal waters (DFO, 2003). The Canadian Council of Ministers of the Environment (CCME) has not established nutrient guidelines for the protection of aquatic life as nutrients are not considered toxic substances, but rather substances which can have secondary effects such as eutrophication and oxygen depletion. Nutrient assimilation in a coastal ecosystem depends on a vast number of variables, therefore, a Reference Condition Approach (RCA) is considered the most applicable method for evaluating nutrient conditions. This involves a comparison of similar coastal systems or historical data from the system in question (CCME, 2007).

Nitrogen and phosphorus concentrations were analyzed at the five harbour sites during each of the five sampling events. Phosphorus concentrations were fairly consistent across all sites and all sampling events except for a spike at Sites 1, 2, 3, and 4 following the moderate rainfall event on October 16. Nitrogen, which is the limiting nutrient in temperate marine systems, displayed more variability in concentrations at each site throughout the monitoring period. Nitrogen concentrations were highest at Site 3 and displayed a spike at all sites following the moderate rainfall event on October 16. Nutrients were sampled during the summer months when coastal environments are more susceptible to eutrophication due to flushing rates and freshwater inputs being at their lowest (Vallino & Hopkinson, 1998). During this time, dissolved oxygen concentrations remained above CCME guidelines at all sites for all but one sampling date, no algal blooms were observed, and no other signs of eutrophication were witnessed in the harbour. An in-depth analysis of trophic state and RCA assessment would be needed to develop a better understanding of nutrient assimilation processes in Lunenburg Harbour; however, based on the results of this program, nutrients do not appear to be causing eutrophication or other associated impacts at this time.

Enterococci bacteria concentrations within sediment samples are spatially different within Lunenburg Harbour. The highest concentrations of bacteria were found within the inner harbour, in front of the Boat Launch and Fisherman's Wharf. The inner harbour sites are in a more pollution-heavy region, as the overflow pipe from the combined sewage system is located underneath Fisherman's Wharf. Increased bacteria inputs at these two locations may be influencing the elevated bacteria concentrations within the

sites' sediment samples. As these sites are located within the protected area of the harbour, sediment – and bacteria – settles to the habour bottom, allowing a build-up of bacteria on the harbour floor.

At Fisherman's Wharf, the clay substrate may be a factor in the elevated concentrations of bacteria found within the sediment samples, as clay provides an ideal environment for bacteria (Hartel et al., 2005; Jeng, England, and Bradford, 2005; Jeng et al., 2005). In contrast, sediment from Sites 3 and 5 were mud matrices, with both fine and coarse sediments. Although the Boat Launch substrate was also a mud matrix, the high concentration of vegetation present may explain the elevated bacteria concentrations at the location, as vegetation provides protection from environmental disturbances and acts as a source for nutrients (Quilliam, Jamieson, and Oliver, 2014; Byappanahalli et al., 2012).

High concentrations of bacteria within the sediment can result in increased bacteria concentrations within the overlying water column (Ferguson et al., 2005). When sediment is disturbed, due to wave action, wind, or even human recreation (boats and anchors, swimming, walking), sediment and bacteria are resuspended (Suter, Juhl, and O'Mullan, 2011; Jin et al., 2004). Locations with increased substrate turbulence may therefore have increased water and sediment bacteria concentrations. Within Lunenburg Harbour, the Boat Launch and Fisherman's Wharf are subject to high boat traffic, while Site 3 is in a low-traffic area and Site 5 is too-deep for boats to disturb the harbour sediment. The high potential for sediment resuspension at the Boat Launch and Fisherman's Wharf may explain the high bacteria concentrations recorded in both water column and sediment samples.

An opportunistic pilot study was conducted by Dr. Brent Wilson using sediment collected from Lunenburg Harbour during Coastal Action's sediment sampling activities. Dr. Wilson identified the foraminifera (foram) assemblages within these samples as part of a preliminary assessment of environmental impacts in the harbour using a bio-indicator species. Forams are unicellular protists which are highly diverse, abundant, and easy to collect (Murray, 2006). As one of the most varied groups of shelled microorganisms in the ocean, forams can be used as biological indicators to evaluate long-term environmental conditions (Sen Gupta, 1999; Frontalini & Coccioni, 2011). These benthic invertebrates can tolerate highly stressed environments and are among the last remaining organisms to persist in heavily polluted environments (Scott et al., 2011).

Results of this study revealed a foram community which is dominated by agglutinated (non-calcareous) species of low diversity and abundance. Agglutinated species are found in environments with a high influx of organic matter which causes calcareous tests (shells) to dissolve and can be used to identify reducing conditions caused by pollution (Scott et al., 2001). The co-dominant species found in these samples were *Miliammina fusca* and *Eggerella advena*, which are stress-tolerant forams that can withstand high inputs of organic carbon from sewage and are indicative of poor water quality (Alve et al., 2009). The overall assemblage found in this study is comparable to the assemblages found in the inner Halifax Harbour and the Northwest Arm prior to wastewater treatment improvements (Wilson, unpublished; Dabbous & Scott, 2012).

Results from the Fisherman's Wharf sediment sample indicate that the high influx of organic carbon is causing a localized almost dead zone. Similar dead zones have been widely reported near municipal wastewater pipes (Bandy et al., 1965; McGann et al., 2003). The foram assemblage at the mouth of the

harbour (Site 5, aka Station 2) was also dominated by agglutinated species. This suggests that the impacts of pollution may be widespread across the harbour; however, a comprehensive study of forams throughout Lunenburg Harbour, as well as an investigation into the influence of trace metals, would be needed to confirm these preliminary findings (Wilson, unpublished).

Forams have been widely used as bio-indicators to monitor the success of pollution remediation efforts. If a pollution mitigation program were to take place in Lunenburg Harbour, this study would provide a valuable benchmark that could contribute to the development of a long-term monitoring study. Refer to Appendix A for the full unpublished report from Dr. Wilson.

5. Recommendations

Following the data and discussions presented in this report concerning bacteria concentrations in Lunenburg Harbour, Coastal Action recommends the following:

- A water quality sampling program should be implemented for a greater length of time, to capture the seasonal effects of bacteria due to temperature changes.
    - The sampling program should consider including monitoring foram assemblages as a cost-effective way of monitoring long-term pollution within the harbour sediments.
    - The sampling program should also include DNA tracking of bacteria, to confirm sources and amounts of pollution, to better focus mitigation efforts to improve water quality within the harbour.
- A weekly waterfront sampling program should continue to monitor bacteria at the Boat Launch and Zwicker's Wharf sites, as these are two areas where recreation within the harbour is encouraged.
    - These sites should be closed to the public when the Health Canada secondary contact guideline is exceeded. Warning signs should clearly identify the hazard (bacteria pollution).
    - A floating dock should be made available when these sites are open, to limit contact with the water.
    - The sites should be closed after moderate rainfalls, as bacteria concentrations are known to increase due to urban runoff and sediment resuspension. Water samples should be tested for bacteria after rainstorms to confirm public safety before the sites are reopened and recreational activities resume.
    - Increased samples will aid in ensuring the strength of statistical analyses when comparing between tides and sites.
- A survey should be conducted to determine flushing times for subsections of the harbour, as these may differ across the harbour and will affect water quality.
- Boaters entering the inner harbour should be recommended to turn off motors when able, and not to drag instruments (including cages and anchors) along the harbour floor to avoid the resuspension of sediment and bacteria into the water column.

- The outflow pipe under Fisherman's Wharf should be moved or extended to a section of the harbour with better flushing action. The continued inputs from the pipe allow for optimal conditions for bacteria growth; moving the pipe would stop the supply of both nutrients and bacteria into the minimal-flushing inner harbour.
- Due to the possible interruption of tidal flushing within the inner harbour associated with the wave break, the implementation of a 'living wave break via an artificial reef' should be investigated. The wave break's position in front of Fisherman's Wharf is used to protect infrastructure against storm surge; however, if this barrier was to be converted into a living wave break – an artificial mound which acts as home for oysters and other filter feeders – the wave break could act as both storm surge protection and natural water filtration system. In New York Harbour, the Billion Oyster Project has been creating artificial reefs throughout the harbour to address harbour health (Billion Oyster Project, 2013), and the use of oysters is known to significantly reduce concentrations of bacteria, nutrients, and other particles within waterbodies (Jones, Dennison, & Preston, 2001).
- The inner harbour mooring field should be managed, with increased enforcement to ensure no illegal dumping is occurring within the harbour. The pump-out station within Lunenburg Harbour should be better advertised to provide boats a proper solution for emptying onboard sewage systems.
- An investigation should be done on the straight pipes in the community of Garden Lots. Bacteria monitoring of both water and sediment did not reveal bacteria contamination at Site 3, which suggests that most, if not all, straight pipes in this community may actually be discharging into the Garden Lots Salt Marsh rather than Lunenburg Harbour.

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Appendix A

A PILOT STUDY OF FORAMINIFERA AND POLLUTION IN LUNENBURG HARBOUR,

NOVA SCOTIA, CANADA

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October 20th, 2018

Introduction

This report is being written against a background of known pollution from somewhat treated domestic waste water being released into Lunenburg Harbour. However, the precise details of the extent of treatment being unknown to the author, and sampling being undertaken on one occasion only, no attempt is made to assess the impact of changing treatment levels on the foraminiferal fauna.

Foraminifera (hereafter called "forams" for short – see Lipps et al., 2011) are unicellular protists that are usually abundant in marine environments (Murray, 2006). Their shelled nature makes them ideal proxies for studies of environmental impacts in modern environments (Alve, 1995; Frontalini and Coccioni, 2011; Sreenivasulu et al., 2017; Suokhrie et al., 2017). Typically, large numbers of specimens across a range of species can be recovered from small sediment samples, especially where the sediment is fine grained. This is true even in some anthropogenically impacted areas (Magno et al., 2012). However, foram abundance is reduced at sites subject to especially high inputs of organic matter from sewage outlets (Bandy et al., 1965; Murray, 2006), such that mapping the distributions of benthic (seafloor-dwelling) forams can delimit the extent of impacted areas.

Previous work

There have been a few studies of forams and pollution in Nova Scotia that demonstrate their usefulness:

1. Clark (1971) examined forams associated with marine aquaculture in Clam Bay, east of Halifax. He concluded that the non-calcareous (agglutinated) species *Eggerella advena* is a high nutrient-demand species that can withstand high inputs of total organic carbon. He wrote that this substantiated previous studies that found this species in great numbers around the Orange County sewer outfall in California. In Clam Bay, the area immediately adjacent to the aquaculture outfall was found to be unique, with foram populations varying rapidly over time with no discernible connection to measured oceanographic parameters, but being correlated with the quality of the outfall waters.

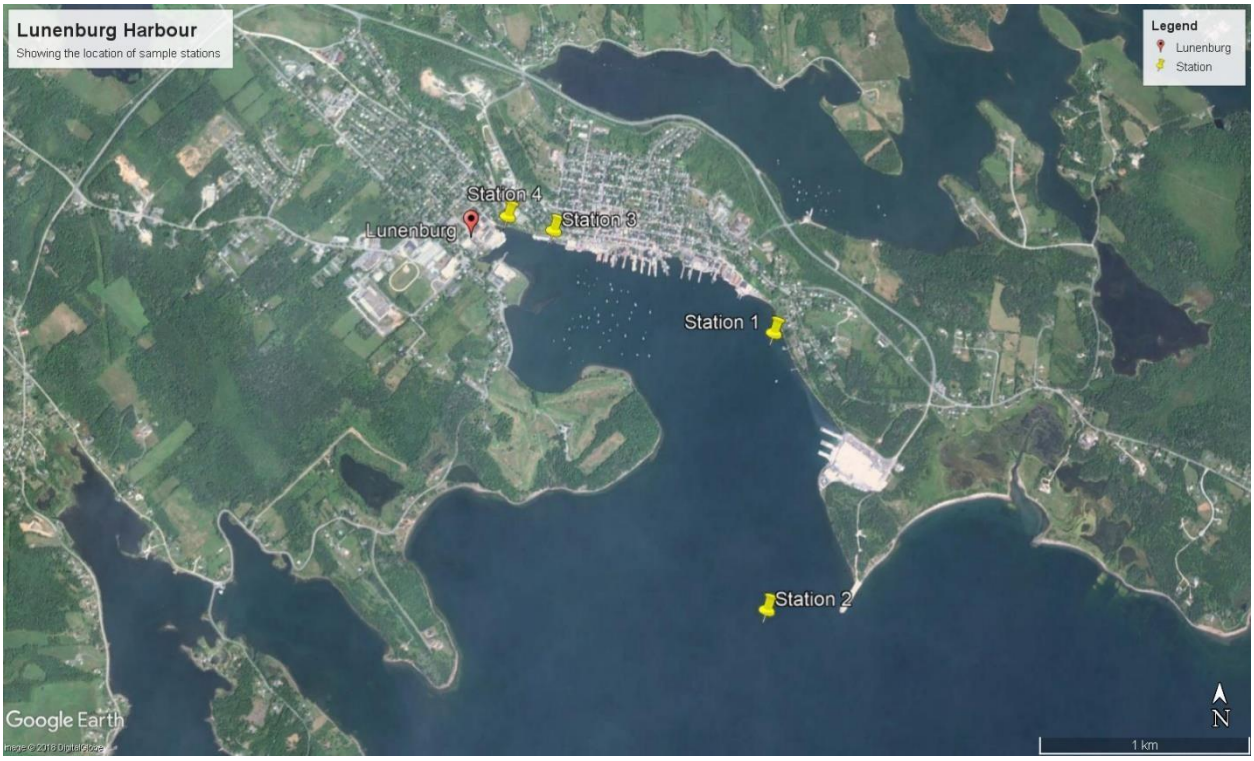
2. Dabbous and Scott (2012) briefly monitored the benthic forams in Halifax Harbour before, during, and after implementation of an enhanced, municipal pollution abatement programme. They found that foram distributions were correlated strongly with the amount of pollution flowing into the harbour. Before enhanced treatment, the confined and extremely polluted inner harbour and North West Arm contained a low abundance fauna of low diversity dominated by agglutinated species. In contrast, the foram assemblage in the outer harbour, where currents carry away waste material to the ocean, was of high diversity and abundance with common calcareous species. During discharge treatment, the composition of the inner harbour foram assemblage changed dramatically, so that it resembled the outer harbour fauna. However, this inner harbour assemblage reverted to its former state once water treatment was stopped.

3. Wilson and Hayek (2018) studied the foram assemblages in a tidal wetland at Lower LaHave, Nova Scotia. This wetland is situated next to LaHave Estuary, which is polluted with domestic waste from straight pipes. These authors found that subaqueous assemblages here yielded the calcareous foram *Elphidium umbilicatulum*, but they found the agglutinated species *Miliammina fusca* was widely distributed and able to withstand a number of different, stressed environments within the wetland (see also Armynot du Châtelet et al., 2018). Wilson and Hayek (2018) concluded that their data provided a useful baseline for assessing the impact of pollution remediation efforts in the LaHave Estuary – a theme that was taken up by Wilson et al. (2018), who assessed the nature of the intertidal foram assemblage at sites along the LaHave Estuary.

In this pilot study, the foram assemblages were examined in four samples taken from different sites around Lunenburg Harbour. It is shown that the fauna is dominantly agglutinated and of low abundance and diversity, but with co-dominant *M. fusca* and *E. advena*, both of which can withstand high stressed environments with a high input of sewage-rich water with much organic carbon.

Materials and Methods

Four samples were taken on September 18th, 2018, typically by dredging, from permanently submerged sites in Lunenburg harbour.



Site	Description	Coordinates	Water Depth (m)
1	Garden Lots - near wharf	44.371661, -64.300489	3.65
2	Past mouth of harbour - by lighthouse	44.359723, -64.301065	12.71
3	In front of Fisherman's Wharf	44.376178, -64.313985	6.87
4	In front of Boat Launch	44.376802, -64.316818	4.43

As shown in the above table, water depths ranged from 3.65 – 12.71 m (Stations 1 [Garden Lots - near wharf] and 2 [Past mouth of harbour - by lighthouse] respectively). It is to be expected that there will be some difference in assemblages, Station 2 possibly occurring in a deeper water biofacies than the remaining stations. Stations 3 (in front of Fisherman's Wharf) and 4 (in front of the boat launch) were located at the head of the harbour.

Four replicates of 10 ml each were extracted from each sample (this typically used almost all the material provided). The replicates were each placed in fresh water and disaggregated, and then washed over a 106-micron sieve to remove silt, clay and fine sand. The resulting residue was dried at ~90°C to kill any possibly toxic bacteria that might make the wet samples dangerous for skin contact. All the forams found were removed and stored on card micropalaeontological slides.

The total number of specimens per replicate was counted to give an indication of the foraminiferal number (FN, number per 10 ml). These data for mean FN per station were compared between Stations using analysis of variance (ANOVA) following transformation to ln(FN + 1). ANOVA was conducted after positive assessments for normality and statistical equality of variances (using Hartley's Fmax test).

The diversity of the assemblage at each station (replicates summed) was assessed using the Shannon Function H (= $-\sum p_i \cdot \ln p_i$, in which p_i is the proportional abundance of the ith species). This was calculated only for those stations yielding >100 forams. Alve et al. (2009), upon examining the foraminiferal assemblages in Norwegian fjords and coastal waters in relation to the Norwegian Pollution Control Authority's classification of environmental quality, showed that H of 2 – 3 is indicative of moderate quality water, H of 1–2 reflects poor quality water, and H <1 occurs in water rated very poor. Martin and Nesbitt (2015) applied this scheme to the polluted Puget Sound, Washington State, USA.

Results

Although 160 ml of sediment was analysed, only 479 benthic foraminifera were recovered (see the accompanying Excel spreadsheet). Two planktonic specimens were recovered from Station 2, which reflects its position nearer the open ocean. The benthic forams were placed in 20 species, of which *Miliammina fusca* (37.8% of total recovery) and *Eggerella advena* (21.3% of total recovery) were most abundant. The total recovery was dominantly of agglutinated specimens, calcareous species forming only 12.5% of the total assemblage. Although a few of the calcareous species were live at the time of sampling (as indicated by their green cytoplasm -- see Correia and Lee, 2000), most were dead, opaque and more-or-less corroded.

The foram number (FN) ranged between 1 specimen per 10 ml (Stn. 3, Rep. C) and 133 specimens per 10 ml (Stn. 1, Rep. C). ANOVA showed that the mean FN differed between Stations ($F_{3,12} = 8.43$, $p = 0.003$), while the *post hoc* Tukey's Q test indicated that there was no difference in mean FN between Stations 1 (mean FN = 63.2), 2 (mean FN = 34) and 4 (mean FN = 20), but that the mean FN at Station 3 (2.5) was significantly lower than that at Stations 1 and 2.

Only two Stations (1 and 2) yielded >100 forams. For these two stations, H was 1.49 (Station 1) and 1.88 (Station 2). The diversity at Station 4 (80 foraminifera) was assessed with caution. At this Station, H = 1.73. It is concluded that all stations had a Shannon Index between 1.0 – 2.0.

Discussion and Conclusions

The majority of the foram assemblage recovered from Lunenburg Harbour comprised agglutinated specimens, despite the marine nature of the area, its connexion to the open ocean and the paucity of freshwater input into the fairhaven. Such an assemblage reflects a high input of total organic carbon, such as from sewerage (cf. Dabbous and Scott, 2012; Martin and Nesbitt, 2015). This is supported by the co-dominance by two species that are capable of withstanding high organic carbon levels: *Miliammina fusca* (see Wilson et al., 2018; Wilson and Hayek, 2018) and *Eggerella advena* (see Clark, 1971). The overall assemblage is comparable to that recorded in the polluted inner harbour and North West Arm of Halifax Harbour prior to the improvement of waste water treatment facilities.

The few calcareous specimens present were mostly dead and opaque and showed signs of dissolution. This is indicative of an acidic environment (Murray, 1967) such as can arise from oxidation of a high organic flux.

The diversity of the foraminiferal assemblages, measured using the Shannon function, was low (1.49 – 1.88). Such low diversities elsewhere have been shown to be indicative of poor water quality (Alve et al., 2009).

The very low recovery of foraminifera from Station 3 (in front of Fisherman's Wharf) indicates that the flux of organic carbon, presumably from a localised source such as a submerged waste-water disposal pipe, is

so high as to be locally causing an almost dead zone. Such zones have been recorded around other municipal waste-water pipes (Bandy et al., 1965; McGann et al., 2003).

Suggested future work

The extent of the area affected by pollution from waste water around Lunenburg Harbour is as yet unknown, although the recovery of a predominantly agglutinated assemblage from Station 2 (beyond the harbour mouth - by the lighthouse) suggests that it may be considerable. It is suggested that a denser and more widespread sampling programme be undertaken to assess the extent of that affected area.

It is to be noted that foraminiferal assemblages have been used positively to assess the impact of pollution abatement programmes around waste disposal pipes (McGann et al., 2003; Stott et al., 1996). In the event that there is a serious pollution mitigation effort in the Lunenburg region, annual monitoring of foraminifera assemblages at selected sites over a period of years might be used to assess the impact of that pollution abatement.

It is known that foraminiferal assemblages are affected not only by organic waste, but also by other pollutants such as trace metals (Debenay et al., 2001; Orabi et al., 2017; Samir, 2000; Vilela et al., 2004). It is suggested that a sediment sampling and analysis programme be developed to assess the levels of trace metals in the Lunenburg area. The results from this could be compared with foraminiferal assemblages in the same samples to assess if, in addition to domestic waste water, trace metals released by activities such as ship building are impacting the foram fauna.

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