Seasonal, spatial and source variation of *E. coli* counts in False Creek, British Columbia

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Executive Summary

Introduction

The City of Vancouver, British Columbia, has raised concerns regarding the environmental health and safety of water in the False Creek basin. According to both recent and historical water quality reports issued by the B.C. Ministry of Environment (2006), it has been determined that *Escherichia coli (E.coli)* is a clear and major cause for concern regarding the water quality of False Creek. Historical records from the B.C. Ministry of Environment (1990) show that *E. coli* has been surpassing safety levels since the late 1970's. More recently, record high *E. coli* levels were observed this past summer (Vancouver Coastal Health, 2014) - at over 26 times the recommended safety limit for swimmers (Health Canada, 2012). With these events in mind, this study is focused on tackling the question:

What are the spatial and temporal variabilities of *Escherichia coli* in False Creek?

Additionally, this study intends to help fill in notable water quality data gaps related to the various factors that affect the growth and survival of *E. coli,* these include: salinity, temperature, pH, dissolved oxygen, dissolved organic carbon, and nitrate levels (Solic & Krstulovic, 1992).

Objectives

1. Compare *E. coli* levels between summer and winter (2014).
2. Identify the possible sources of contamination of *E. coli* in False Creek.
3. Investigate into potential areas of concern of high *E. coli* levels.
4. Evaluate the spatial variability in *E. coli* concentrations in False Creek with respect to distance from English Bay, and proximity to combined sewer outfalls (CSOs) and marinas.
5. Establish a set of winter baseline data for both an evaluation of *E. coli* and use in future studies.
6. Conduct a False Creek Recreational Survey, regarding public perceptions of water quality in the False Creek waterbody.

Methods

A total of three sampling trips were conducted to gather data over the 8-month study period, these trips occurred on: November 17th, 2014; January 19th, 2015; and March 2nd, 2015. The False Creek survey site was divided into three basins: West basin (from Burrard Street Bridge to Granville Street Bridge), Central basin (from Granville Street Bridge to the Cambie Street Bridge), and East basin (from Cambie Street Bridge to Main Street).
The Recreational Survey of False Creek was conducted anonymously during the period between February 4th, 2015 and March 11th, 2015. The participants consisted of the general public over the age of 19 who visited False Creek on a weekly basis.

Conclusions

1. ***E. coli* sources in False Creek are predominantly human caused.**
    - Human fecal trace confirmed by all three 'bacteriological source tracking' samples taken on January 19th, 2015 in the West, Central and East areas of False Creek, analyzed by Environment Canada: Pacific and Yukon Laboratory for Environmental Testing (PYLET).

2. ***E. coli* levels are significantly higher in the summer vs. winter months.**
    - Supported by the sample data retrieved from Vancouver Coastal Health in summer 2014 (May to September) and our three winter sampling trips (November 2014; January and March 2015).

3. **Both summer and winter exhibit a consistent trend of increasing *E. coli* from the West to East basins of False Creek.**
    - Supported by the samples taken from Vancouver Coastal Health in summer 2014 (May to September) and our three winter sampling trips (November 2014; January and March 2015).

4. **The *E. coli* values taken in the "Fisherman's Wharf" Marina are significantly higher than the average *E. coli* levels in other areas of False Creek**
    - Supported by the comparison of sample points within the marina versus the geometric mean from all of the sample points taken in False Creek (West, Central & East basins).

Recommendations

- Monthly monitoring of *E. coli* levels, boating and recreational activities, and other physical water quality parameters (listed in main report) should be maintained in order to have an in-depth understanding of the state of False Creek.

- Existing and upcoming *E. coli* data sets should be synthesized and available for the public in order to promote interest, awareness, and an educational understanding of their relationship with False Creek.

- Bacterial source tracking should be performed in the summer to improve confidence and understanding of *E. coli* sources in False Creek.

- The False Creek Recreational Survey should be administered either year round every few years, or, seasonally and updated regularly (last survey was conducted roughly 9 years ago) in order to better understand the community's opinions and knowledge of the False Creek basin.

- Steps should be taken to ensure safe bacteriological levels in False Creek. Boat discharge mitigation provides the most straightforward mitigation, thus, the following strategies are recommended:
    - Improved accessibility and ease to boat pumpouts for both live-aboards and visitors
    - Adoption of the Vancouver Park Board 'no-dumping' policy in Burrard Inlet

Author Bios

Aneeta Antony is a fourth year student in Environmental Sciences with an area of concentration in land, air and water. She has a strong passion for public/environmental health, and foundational knowledge about marine ecosystems and the basics of the chemistry behind them through relevant courses taken in UBC. Aneeta is a goal- and detail-oriented person and is capable of thinking analytically and strategically. In this project she was able to gain more knowledge about local issues and had the opportunity to gain hands-on experience with data collection and water sampling.

Daisy Hsu is a fourth year student in Environmental Sciences with an area of concentration in land, air and water. She is capable of compiling and synthesizing environmental information from a variety of sources and has gained technical writing and research skills through classroom and work experience. She has strong interests in hydrology, sustainability and marine pollution. She is also familiar with various domestic jurisdictions such as Chemical Management Plan, Canadian Environmental Protection Act and BC Water Quality Guidelines that will be integrated or used for the project. Daisy is an organized, responsible and proactive individual with strong communication and people skills.

Eric Chen is a fourth year student in Environmental Sciences with an area of concentration in land, air and water. He has a strong performance through teamwork. In four years of study, he has acquired the skill to analyze a data set, and present it in a scientifically manner through experiences from courses taken in UBC (groundwater hydrology, ecology, soil science, oceanography and environmental chemistry.). Eric is a very organized and result oriented person and pay a great attention on details. In this project he was able to improve crisis management, and develop research skills.

Jiayun Chen a fourth year student in Environmental Sciences with an area of concentration in land, air and water. She knows two computer languages: Matlab and R, which will be helpful in data analysis. Jiayun is familiar with Eco-hydrology of watersheds and water system, and she has done water sampling for water quality analysis. This project aided in improving her project planning skills, as well as her communication skills.

Owen Sondergeld is a fourth year student in Environmental Sciences with an area of concentration in land, air and water. This experience has given him the conceptual and technical ability to perform research and conduct field work in a variety of areas within his Land, Air & Water specialization. Additionally, he is pursuing a double major in Philosophy which provides him the ability to critically and logically evaluate project related methods, plans and goals needed to fulfill a specified project. Owen is able to serve as a positive addition to a project team through the use of: effective communication, constructive support, and when necessary, conscientious leadership.

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INTRODUCTION

Background

The City of Vancouver, British Columbia, has expressed an interest for further investigation into the marine, environmental health and safety of the False Creek basin. Referring to both recent and historical water quality reports (outlined in detail below), *Escherichia coli,* otherwise referred to as *E. coli*, has been identified as a clear and major water quality concern for False Creek. This is due to seasonally high levels above the safety threshold with a more recent record breaking summer. Thus, tasked with conducting an 8-month science-based community survey, this study explores the question:

What are the spatial and temporal variabilities of *Escherichia coli* in False Creek?

Several key documents and data sets have been identified as the foundation for developing this survey and research. The BC Ministry of Environment (BCMOE), in 2006, released the "Assessment of Bacteriological Indicators in False Creek," which provides the most recent overview and discussion of *E. coli* and its sources in False Creek. Second, a more detailed water quality assessment was performed in 1990 by the BCMOE in the broader Burrard Inlet area that includes detailed information related to *E. coli* in False Creek, both historically and technically. Foundational data of *E. coli* counts for this study were gathered from Vancouver Coastal Health (2014) and Metro Vancouver (2014).

It is important to note that while several *E. coli* guideline systems exist, this study has followed and referred to the Guidelines for Canadian Recreational Water Quality (2012) when collecting, analyzing and evaluating *E. coli* counts from False Creek. This is due to the fact that it is the guideline system used by both the BC Ministry of Environment and Vancouver Coastal Health. The *E. coli* guideline for Canadian recreational water quality, from Health Canada (2012), goes as follows*:

- Geometric mean concentration (minimum of 5 samples*): ≤ 200 *E. coli*/100 mL

- Single-sample maximum concentration: ≤ 400* *E. coli*/100 mL

*over a 30 day time span

False Creek

False Creek is a small inlet from English Bay, located in the heart of Vancouver, British Columbia, Canada (refer to Map A). Historically, False Creek was a place for heavy industry, but more recently has been a place of 'urban renewal'- with an emphasis on residential development and marinas (Ministry of Environment, 1990). It is the location of Granville Island and Science World, as well as the recently developed Olympic Village.

False Creek is spanned by three bridges: the Burrard Street Bridge, which crosses False Creek furthest west and near the opening to English Bay; the Granville Street Bridge crosses four blocks to the east, near Granville Island; and, the Cambie Street Bridge crosses the creek furthest east, approximately seven blocks from the creek's end by Science World.

The inlet is approximately 3km long, varies between 100m and 400m in width and 3m to 5m in depth (Ministry of Environment, 2006). Referring to more recent bathymetric analysis, and sampling trips, certain areas of the basin appear to more likely extend to approximately 10 to 11 meters in a few areas (refer to Map B).

The geography and natural processes of False Creek have been dramatically altered due to Vancouver's growth and development as a city. Referring to Vancouver's archival records circa 1898, False Creek extended east to Clark Drive, roughly 2km further compared to present day (refer to Map C in Appendix). Furthermore, here is a supplementary history of False Creek quoted from the Ministry of Environment (1990):

> "Historically, industrial development around False Creek in the late 1800's included log storage, a sawmill, shipyards, and slaughterhouses. Granville Island was created during an extensive dredging project in 1913 by forming a navigable channel 6m in depth. Redevelopment since the 1970's has emphasized residential rather than industrial activities along the south shore facilitated by the addition of commercial outlets to Granville Island. Expo '86 developments along the north shore by B.C. Place Corporation continued this trend, with plans for Phase 1 of the post-fair redevelopment project being a mixed commercial-residential-recreational neighborhood."

E. coli Biology

Escherichia Coli (also referred to as *E. coli*) are a large and diverse group of bacteria found in the environment, food products, and intestines of people and animals (CDC, 2014). It is considered an effective indicator for fecal contamination in marine environments (Health Canada, 2014).

Although most strains of *E. coli* are harmless, others can make one ill, with symptoms including: diarrhea, urinary tract infections, respiratory illnesses (such as pneumonia) and other illnesses (CDC, 2014). Symptoms of *E. coli* infection usually occur between 3 to 4 days after exposure, however, some cases can occur as immediate as 1 day, and as long as 10 days after exposure (Health Canada, 2014). In addition to direct exposure, *E. coli* counts also serve as an adequate indicator for risk of swimming-associated gastrointestinal illness due to fecal contamination in marine waters (Health Canada, 2012).

E. coli and other various fecal coliforms through water contamination can pose a risk to public health in local marine environments. Referring to the Ministry of Environment (1990), there are several key area sources of *E. coli* in False Creek: marinas, pleasure craft, combined sewer outflows (CSOs), storm water runoff and area with poor circulation.

E.coli Factors

Various factors affect the growth and survival of *E. coli* with correlation of varying strength. The bacterial count is proportional to the intensity of solar radiation and with that, temperature is the most important factor in the *E. coli* survival rate (Solic & Krstulovic, 1992). Beyond solar radiation, other factors that control the growth and survival of *E. coli* include: salinity, pH and dissolved oxygen, which all affect bacterial survival to a lesser degree (Solic & Krstulovic, 1992). Additional related factors are also discussed: temperature, dissolved organic carbon, nitrate and turbidity (correlated to solar radiation).

Solar Radiation

Solar Radiation was the major factor influencing *E. coli* survival in a study comparing: Solar Radiation, Temperature, Salinity, and pH (Solic and Krstulovic, 1992). Survival of *E. coli* is inversely proportional to the Solar Radiation coefficient, and the *E. coli* die-off rate increases with increasing solar radiation. In another study investigating environmental stresses on *E. coli*, it was shown that:

> "Sunlight mainly affects, directly or indirectly, the capacity for cellular division, as it appears that light exposure leads to a very strong inhibition of cells' ability to form colonies (Troussellier, 1998)."

Turbidity

Turbidity, the measure of clarity in a water body, diminishes the intensity of solar radiation on a water body due to both reflectance and attenuation (Hobson, 2010). While solar radiation was not measured in this study, turbidity is used as a proxy for the potential impact of solar radiation upon *E. coli*. Following the logic as presented, reduced water clarity (or highly turbid water) would correlate to a lower expected (potential) impact from solar radiation; thus, a weakened negative impact upon *E. coli* survival. Less turbid water, then, would correlate to a higher expected (potential) impact on *E. coli* survival. However, there is also conflicting evidence - related to the correlation between turbidity and suspended solids - that supports a positive correlation between turbidity and *E. coli* survival (Mallin et al., 2000). In this study, turbidity has been measured in nephelometric turbidity units (NTU).

Water Temperature

Water temperature is the degree or intensity of heat within a sampled water body. The optimum growth temperature of fecal coliforms is 37^{o}C (Troussellier et al., 1998), and below this temperature, an increasing impact on die-off occurs. Furthermore, an inverse relationship has been observed between the survival of coliform bacteria and temperature (McFeters & Stuart, 1972; Faust et al., 1975; Ayres, 1977). In this study, temperature has been measured in degrees Celsius.

Salinity

Salinity is the dissolved salt content in a body of water, and in this study, is represented through the use of a percentage measurement. With regards to *E. coli*, salinity affects the survival time of bacteria (Ministry of Environment, 2006). Furthermore, there is a negative correlation between salinity and *E. coli* survival, and more specifically, the increase in salinity has been shown to increase the die-off rate of coliform bacteria (Carlucci & Pramer, 1959).

Dissolved Oxygen

Dissolved oxygen, also referred to as DO, represents the amount of oxygen dissolved in a water body. It is an important indicator for a water body's ability to support aquatic life due to the need from oxygen using organisms, such as bacteria (EPA, 2012). While dissolved oxygen has not been observed to have a direct impact on *E. coli* survival (Verstraete and Voets, 1975), the collection of DO values may aid in understanding the relationship between nutrients and bacterial growth as well as a potential indicator of high biochemical oxygen demand (BOD). In this study, DO is measured in milligrams per liter.

Dissolved Organic Carbon

Dissolved organic carbon, also referred to as DOC, is defined as the organic matter that is able to pass through a filter (BC Ministry of Environment, 1998). DOC plays a central role in ecosystems disturbed by human influences, and accelerates eutrophication by pollution (Williamson et al., 1999). With regards to *E. coli*, increasing DOC can:

- Lower the water mixing depth (reduces dispersion, increasing concentration of effluents - i.e. *E. coli*)
- Increase pH (negative impacts on *E. coli* survival occur above a pH of 7)

Particulate Organic Carbon (POC), a counterpart to DOC, is the organic matter that is not able to pass through the relative filter. In this study, DOC is measured in units of milligrams per liter.

pH

pH is a measure of the acidity/basicity of a sample of water, and, represents the amount of free hydrogen or hydroxyl ions in a water body. The optimum pH for *E. coli* has been observed to be between pH 6 and pH 8 and rapid decline is observed above and below these values (Solic & Krstulovic, 1992). In this study, pH is represented in its 0-14 scale, where 7 represent a neutral solution.

Nitrate

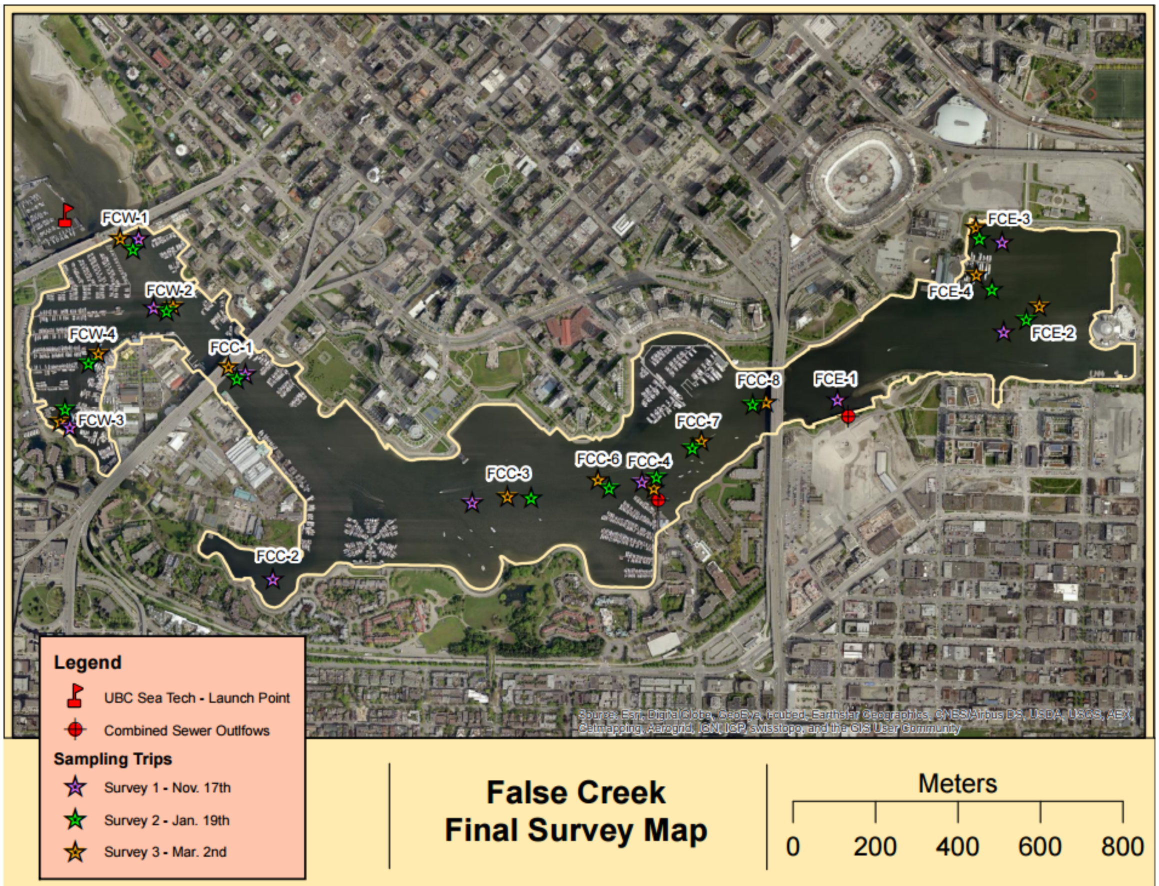
Nitrate has been observed to have a clear, positive correlation with *E. coli* survival (Malline et al., 2000). In addition, another study noted that nitrate can improve survival rates of *E. coli* when above the natural seawater levels (order of 1-100ppm), and additionally, can function as a limiting nutrient for *E. coli* when at unnaturally low levels (below 0.1 ppm) (Carlucci and Pramer, 1959). As a point of reference, natural levels of nitrate in seawater can reach up to 0.7ppm. In this study, nitrate was measured in units of milligrams per liter. To note, mg/L is a ratio in the same order as ppm (1 mg * 1 million = 1 liter).

METHODS

Water Sampling

Sampling Locations

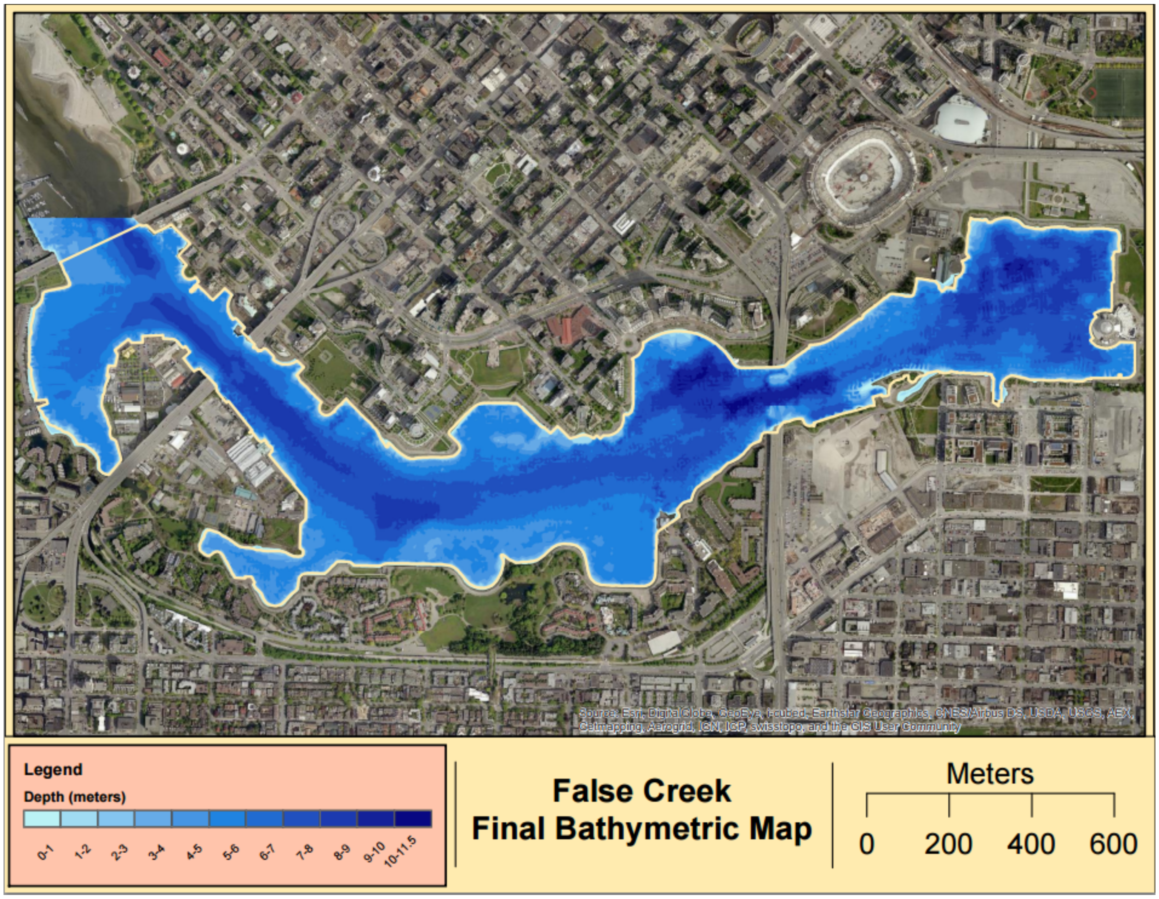
False Creek was divided into three basins (Map A): West basin (from Burrard Street Bridge to the Granville Street Bridge), Central basin (from the Granville Street Bridge to the Cambie Bridge), and East basin (from Cambie bridge to Main Street Science World). Sample locations were selected with emphasis on marinas, and CSOs, also to be comparable with Vancouver Coastal Health's monitoring sites (Ministry of Environment, 2003).



Map A | False Creek water survey map. This map shows all of the sampling locations for the three sampling trips conducted during this study. Purple stars indicate the first sample round in November 17th 2014. Green stars indicate the second sample round in January 19th 2015. Brown stars indicate the third sample round in March 2nd 2015.

Procedure

The boat departed from Vanier Park (Vancouver), and the order of sampling for rounds in November, January, and March were from West to East. After arriving at each sample site, the multiprobe and the Niskin bottle were lowered into the water surface (0.5m) to collect measurements. With the provided bathymetry data of False Creek (Map B), depth profiles were measured in each basin (refer to table 1); depth profiles were performed using the multiprobe and a 1-meter sampling interval (max depth limited by either <1 m from the bottom or at max of 9 m). The Niskin bottle was used to collect water samples for *E.coli*, nitrate, and bacteriological source tracking lab analyses. Detailed sample and calibration procedures are listed under Appendix A.



Map B | False Creek bathymetric map. This map shows the depth of False Creek which ranges from 0 m to 11.5 m.

This research had three different sample rounds in November 2014, January 2015, and March 2015. Table 1 shows the summarized general information of each sample round.

Table 1 | Summary of Water Survey. This table summarizes the general information from the three water surveys done in November/2014, January/2015, and March/2015. N = November/2014. J = January/2015, M = March/2015.

Basin	Sites	Water Depth (m)	Coordinate (Lon, Lat)	Nov. 2014	Jan. 2015	Mar. 2015	Multi-Probe Data	*E. coli*	Nutrient (N/J/M)	Depth Profile (N/J/M)	BST (N/J/M)
West	FCW-1	9.0	-123.136, 49.27520	✓	✓	✓	✓	✓	J/M		
	FCW-2	8.6	-123.135, 49.27406	✓	✓	✓	✓	✓	J/M	J/M	
	FCW-3	6.0	-123.138, 49.27131	✓	✓	✓	✓	✓	J/M		J
	FCW-5	7.3	-123.137, 49.27295		✓	✓	✓	✓	J/M		
Central	FCC-1	8.7	-123.133, 49.27232	✓	✓	✓	✓	✓	J/M		
	FCC-2	5.8	-123.132, 49.268	✓			✓	✓			
	FCC-3	7.9	-123.124, 49.26977	✓	✓	✓	✓	✓	J/M	J/M	
	FCC-4	7.6	-123.118, 49.26986	✓	✓	✓	✓	✓	J/M		J
	FCC-6	7.7	-123.120, 49.27005		✓	✓	✓	✓	J/M		
	FCC-7	7.9	-123.117, 49.27099		✓	✓	✓	✓	J/M		
	FCC-8	9.9	-123.115, 49.27176		✓	✓	✓	✓	J/M		
East	FCE-1	4.8	-123.113, 49.2722	✓			✓	✓			
	FCE-2	8.5	-123.106, 49.27382	✓	✓	✓	✓	✓	J/M	J/M	
	FCE-3	5.3	-123.108, 49.27455	✓	✓	✓	✓	✓	J/M		J
	FCE-4	8.3	-123.108, 49.27572		✓	✓	✓	✓	J/M		

Data Analysis

Measurements and Calculations

A winter baseline data of False Creek was collected in November with respect to Map A, and Table 2 represents the arithmetic mean of each measurement in each basin.

Table 2 | Winter baseline of False Creek. This table contains the winter baseline data. Measurements represent depths of 50 cm and 200 cm.

	Water Temperature (°C)	Salinity (‰)	DO (mg/L)	pH	Turbidity	*E. coli* (MPN/100mL)
Depth:50cm						
West	6.47±0.36	20.80±0.37	10.23±0.22	7.68±0.02	1.63±0.64	16
Central	6.56±0.71	21.11±0.11	10.29±0.42	7.69±0.02	1.13±0.21	22
East	6.22±0.17	21.45±0.27	10.16±0.27	7.65±0.05	0.93±0.25	54
Depth: 200cm						
West	6.93±0.50	22.45±0.60	9.38±0.23	7.63±0.01	1.03±0.29	—
Central	6.90±0.34	22.17±0.33	9.55±0.19	7.66±0.01	0.90±0.26	—
East	6.38±0.07	21.86±0.12	9.64±0.23	7.64±0.03	0.70±0.10	—

All measurements including nitrate and dissolved organic carbon were taken in January and March (Table 3 and Table 4). All measurements were averaged in relation to each basin.

Table 3 | Summary of data in January 2015. This table represents surface water measurements taken in January 2015.

Depth:50cm								
	Water Temperature (°C)	Salinity (‰)	DO (mg/L)	pH	Turbidity	*E. coli* (MPN/100mL)	DOC (mg/L)	*Nitrate (mg/L)
West	6.75±0.05	20.54±0.38	10.27±0.16	7.31±0.04	0.28±0.38	46	1.63±0.08	0.50±0.05
Central	7.06±0.15	21.89±0.74	9.97±0.21	7.36±0.01	-0.07±0.39	38	1.63±0.13	0.53±0.07
East	7.76±0.06	24.29±0.24	9.17±0.03	7.29±0.02	-0.80±0.44	81	1.35±0.02	0.50±0.04

*Some raw data shows "<0.50". Assumed that value is 0.45.

Table 4 | Summary of data in March 2015. This table represents surface water measurements taken in March 2015.

Depth:50cm								
	Water Temperature (°C)	Salinity (‰)	DO (mg/L)	pH	Turbidity	**E. coli* (MPN/100mL)	DOC (mg/L)	**Nitrate (mg/L)
West	7.54±0.21	20.13±0.28	11.94±0.86	7.54±0.12	-0.68±0.76	2	1.92±0.04	0.45±0.00
Central	7.81±0.24	20.58±0.28	12.63±1.08	7.69±0.04	-1.02±0.32	10	1.92±0.06	0.50±0.08
East	8.34±0.02	20.68±0.07	12.42±0.34	7.63±0.01	-1.60±0.00	53	1.89±0.03	0.49±0.07

*Some raw data shows "<1". Assumed that value is 1.

**Some raw data shows "<0.50". Assumed that value is 0.45.

Water temperature, salinity, pH, dissolved oxygen, and turbidity were measured directly onsite from the multiprobe, while dissolved organic carbon, nitrate, and *E. coli* concentrations were measured by ALS Environmental Laboratory.

Data obtained from the November 2014, January 2015, and March 2015 sampling trips were subsequently analyzed using Microsoft Office Excel. Measurements in each basin were represented by their regional average (geometric mean for *E. coli* levels). For example, in Table 2, *E. coli* concentration in the West basin was at 16 MPN/100mL; this was the geometric mean from three sample locations, FCW-1, FCW-2 and FCW-3, which are 12 MPN/100mL, 7 MPN/100mL, 49 MPN/100mL, respectively.

External Data

The 2014 summer *E. coli* data was provided by Vancouver Coastal Health (Figure 1). This set of data was used for comparison with the winter baseline data alongside an additional 2014, summer *E. coli* dataset provided by Metro Vancouver (Figure 2). Both data sets were presented as geometric means and in relation to each basin.

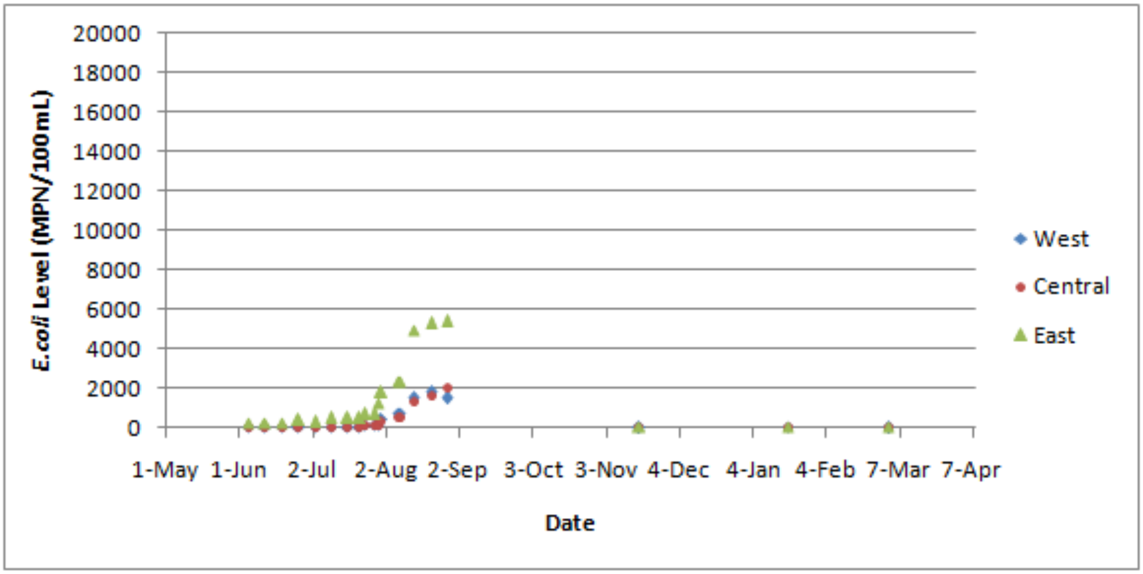


Figure 1 | 2014 Summer *E. coli* data, Vancouver Coastal Health. This figure illustrates the *E. coli* counts (geometric, weekly means) over the summer of 2014. Points in November/2014, January/2015, and March/2015 represent different sampling rounds.

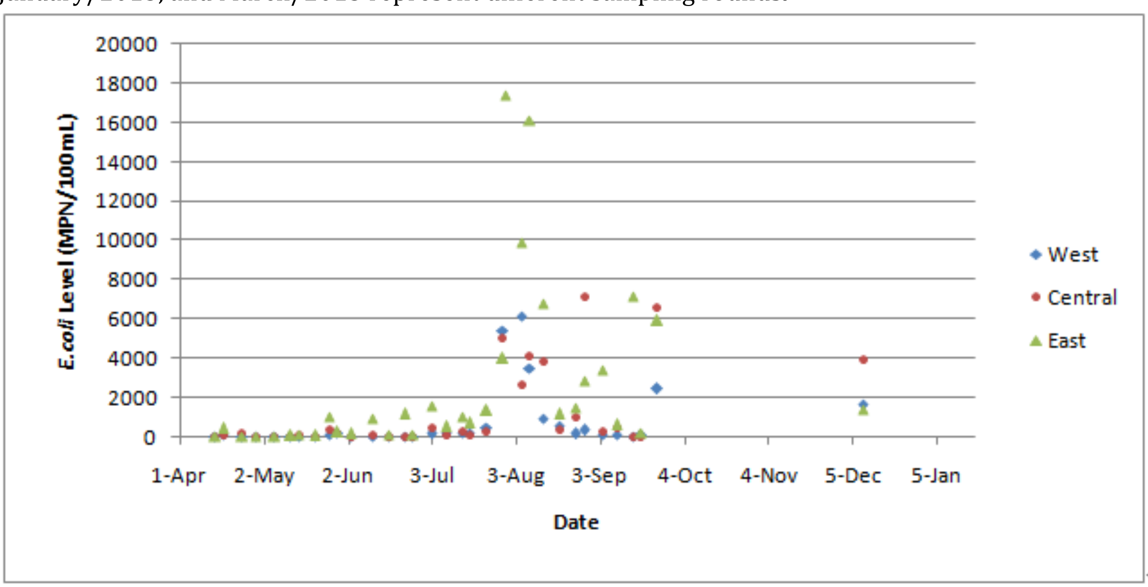


Figure 2 | 2014 near shore *E. coli* data, Metro Vancouver. This figure illustrates near shore *E. coli* counts (geometric, weekly means) over the summer of 2014 collected by Metro Vancouver at shoreline monitoring sites.

Several histograms were then generated to compare the geometric mean of *E. coli* counts in the summer and winter of 2014 (Figure 3). Moreover, to address how *E. coli* levels may vary in marinas, CSOs, and the East basin, regional averages of *E.coli* counts from each sample round were compared relative to its respective sample round average (Figure 4). Raw data of the *E. coli* counts in January 2015 was put together to show how *E.coli* levels changed from site to site (Figure 5).

RESULTS

According to Figure 3, *E. coli* levels were significantly higher in the summer months compared to the winter months. While winter E. coli levels remained low throughout False Creek, the *E. coli* levels in the summer for the East basin had exceeded the *E. coli* safe zone (≤200 MPN/100mL) for Canadian recreational water use (Health Canada, 2012), and the other two basins had neared the maximum *E. coli* safety level. Moreover, both summer and winter data indicated that the East basin had the highest *E. coli* levels relative to the other two basins.

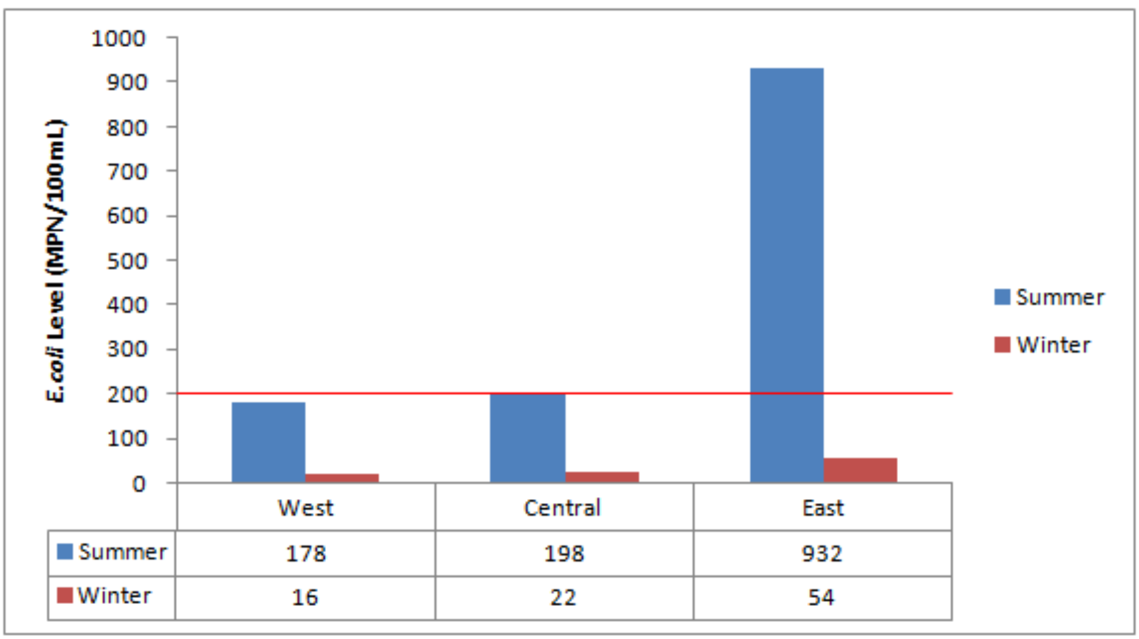


Figure 3 | The average *E. coli* levels in summer and winter of 2014. The graph illustrates the geometric mean of *E. coli* levels in the West, the Central, and the East portions of False Creek in both the summer (June to August 2014) and the winter (November 2014). *E. coli* levels in the summer are much higher than in the winter, and East False Creek shows a relatively high concentration of *E. coli* compared to West and Central False Creek, in both the summer and winter. The red line indicates the

E. coli safe zone (≤ 200 MPN/100 mL) for Canadian recreational water use (Vancouver Coastal Health, 2012).

The *E. coli* data collected from November 2014 indicated that areas in marina, CSO and East basin exceeded the average winter *E. coli* level (26 MPN/100mL) when compared to its respective sample round (Figure 4). In January 2015, the *E. coli* levels in all the locations of concern had once again exceeded the average winter *E. coli* level (40 MPN/100mL) when compared to its respective sample round. In March 2015, the *E. coli* levels were lower, and only CSO and the East basin areas exceeded the average winter *E. coli* level (9 MPN/100).

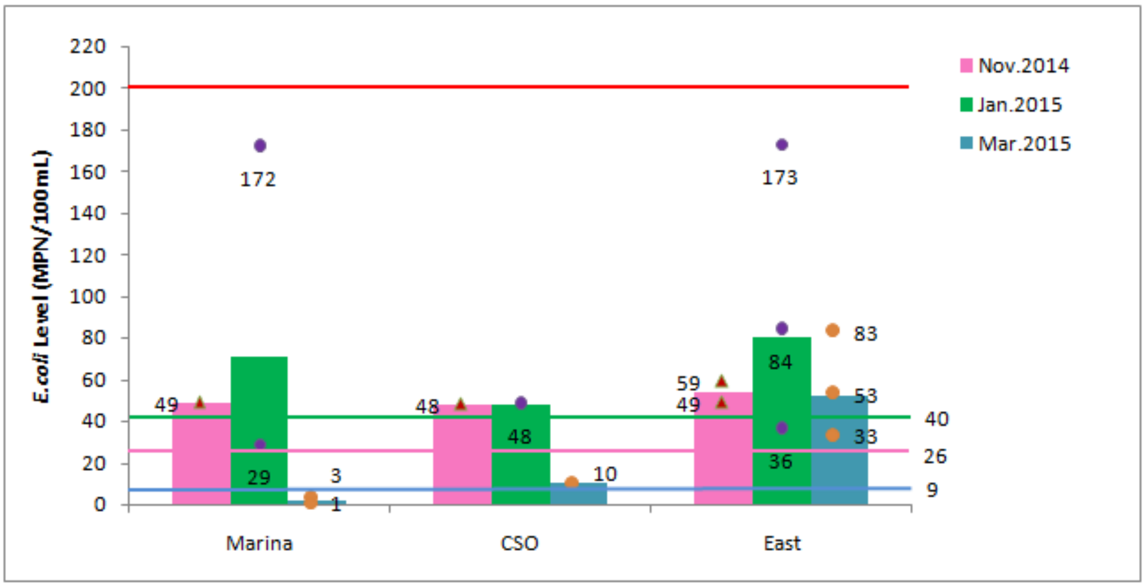


Figure 4 | The differences in *E. coli* levels at the marina, CSO, and the East basin (three locations of concern) relative to the average of November 2014, January 2015, and March 2015. This figure compares the average *E. coli* levels at the marina, CSO, and the East basin relative to the average of its respective sample round. Pink, green, and blue bars/lines represent the data collected from November 2014, January 2015, and March 2015, respectively. The red line indicates the *E. coli* safe zone (≤ 200 MPN/100 mL) for Canadian recreational water use (Vancouver Coastal Health, 2012).

Figure 5 also showed that the East basin had the highest *E. coli* levels compared to the other sites, and that the *E. coli* levels in the "Fisherman's Wharf" Marina (FCW-5) were significantly higher than the other locations except at FCE-4.

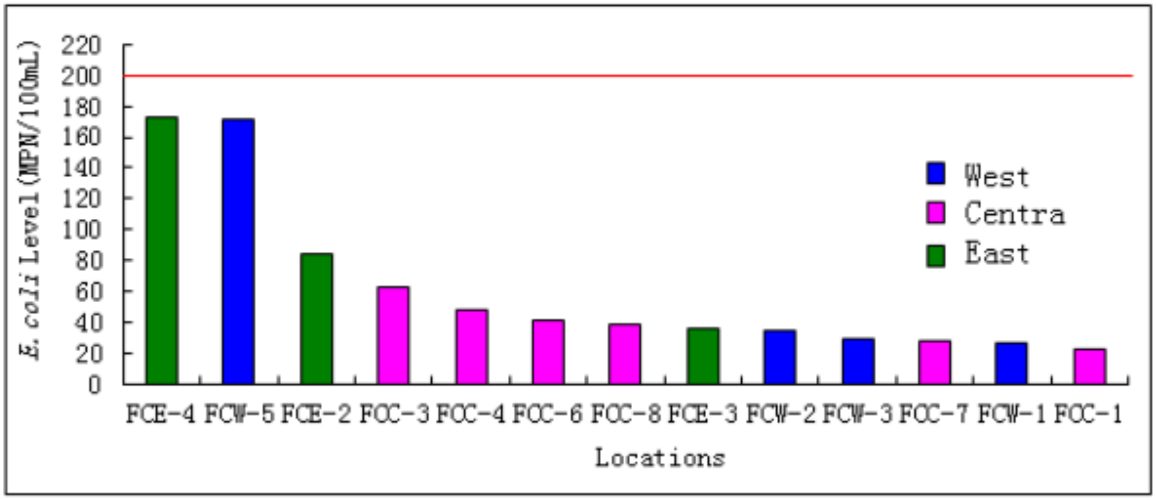


Figure 5 | Summary of *E. coli* levels at each location in January 2015. This figure summarizes the *E. coli* levels at each location (13 locations) in January 2015. The three basins of False Creek are color coded accordingly. The red line indicates the *E. coli* safe zone (≤ 200 MPN/100mL) for Canadian recreational water use (Vancouver Coastal Health, 2012). Refer to Figure Map A for sample sites.

Depth profiles (Figure 6) of water temperature and salinity from FCW-2, FCC-3, and FCE-2 in January followed a close linear relationship, and they both showed a steady increase with depth. On the other hand, both pH and dissolved oxygen decrease with depth. Turbidity profiles from three locations indicated water was clear. Depth profiles of water temperature and salinity (Figure 7) in March indicate a sharp change between 3m to 5m below water surface. Turbidity and pH profiles from January and March are similar with the same pattern; however, dissolved oxygen in January is lower than in March.

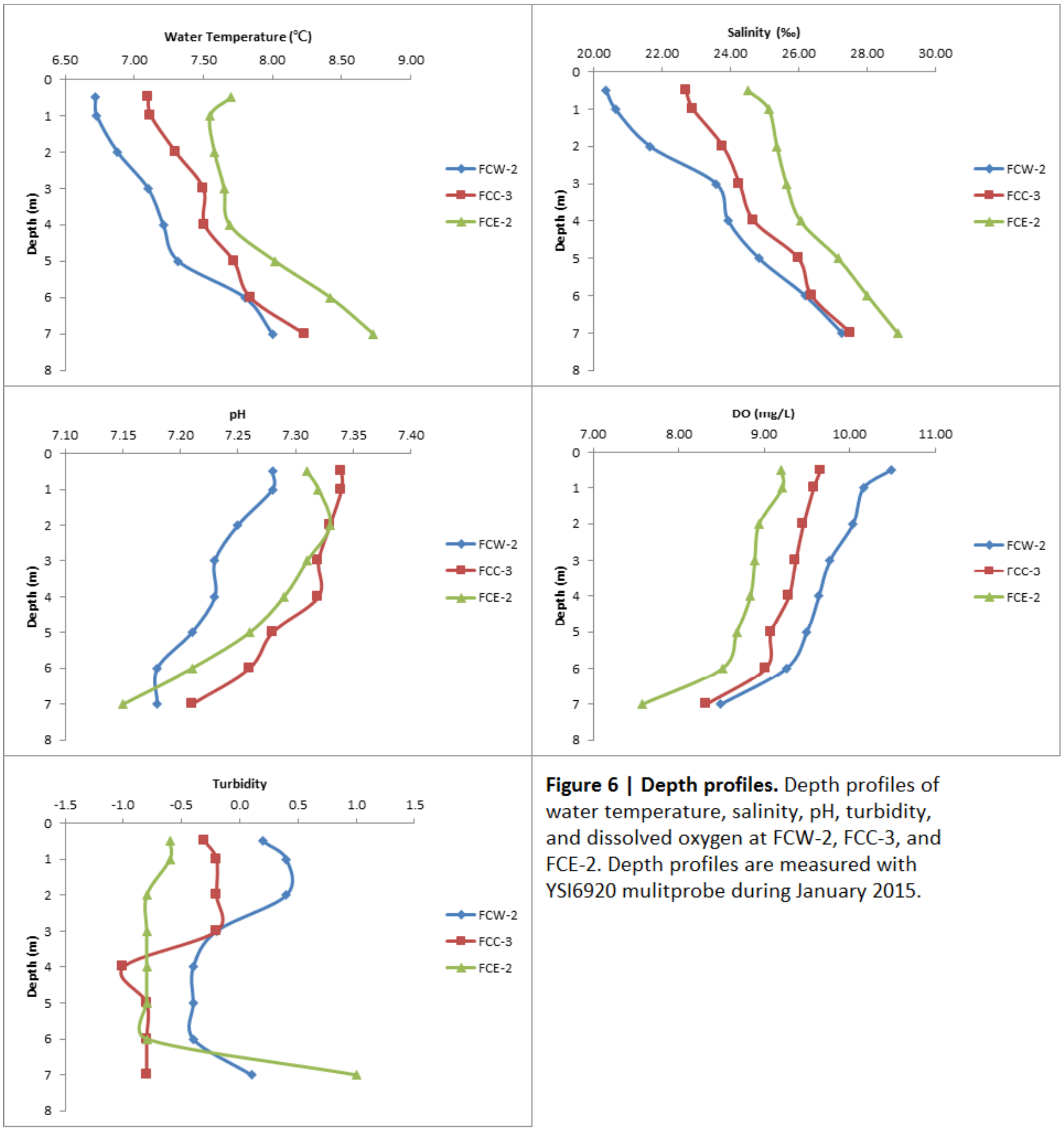


Figure 6 | Depth profiles. Depth profiles of water temperature, salinity, pH, turbidity, and dissolved oxygen at FCW-2, FCC-3, and FCE-2. Depth profiles are measured with YSI6920 mulitprobe during January 2015.

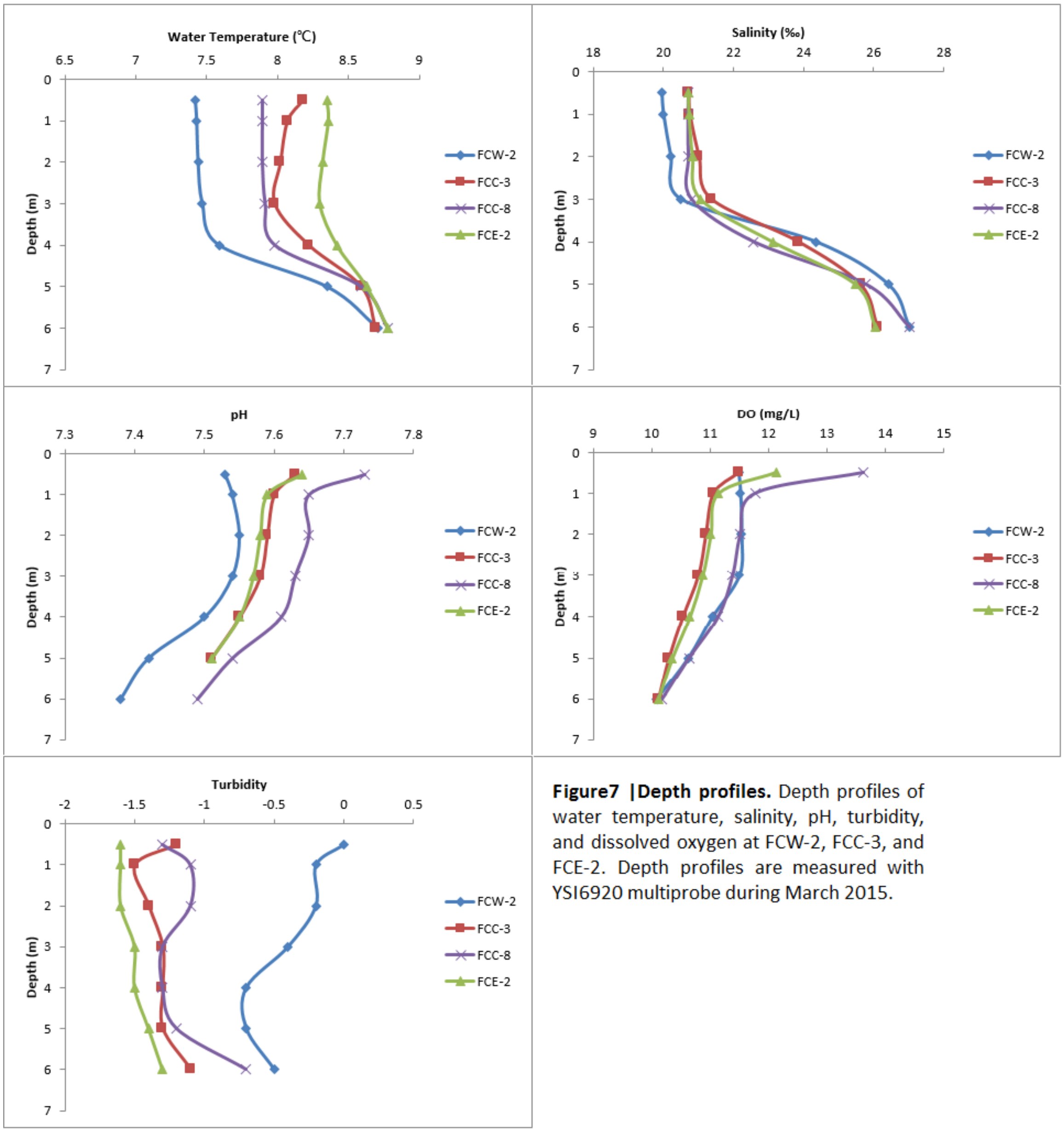


Figure7 |Depth profiles. Depth profiles of water temperature, salinity, pH, turbidity, and dissolved oxygen at FCW-2, FCC-3, and FCE-2. Depth profiles are measured with YSI6920 multiprobe during March 2015.

Based on the result of bacteriological source tracking (Table 5), it was indicated that *E. coli* sources in False Creek are predominantly human caused.

Table 5 | Bacteriological source tracking. This table represents the possible source of *E. coli* in False Creek.

Client's Sample Description	Fecal Count	Human	Ruminant Animal	Pig	Horse	Dog	Elk	Gull	General *Bacteroides*
FCE-3	-	+	*+	-	-	-	-	-	+
FCW-3	-	+	*+	-	-	-	-	-	+
FCC-4	-	+	*+	-	-	-	-	-	+

Bacterial Source Tracking (BST) Analysis Sheet

Environment Canada, Environmental Toxicology Section, Pacific and Yukon Laboratory for Environmental Testing (PYLET)

Environment Canada Environnement Canada

Legend:
- = absent
+ = all possible markers present (1 of 1 for pig, horse, dog, elk; 2 of 2 for human, ruminant animal; result is **bolded**)
*+ = 1 of 2 possible markers present
+f or *+f = faint
? = unsure (potentially present)

RECREATIONAL SURVEY

Discussion of Recreational Use in False Creek

Recreational use in False Creek is growing to accommodate Vancouver's growing population, especially with recent developments in the False Creek area. In order to gain a better understanding of the public's perception of the water quality, and to gain insight on how False Creek is used by the community, we conducted a recreational survey. This survey helped us to better understand what the public's opinions were regarding False Creek's water quality, the activities they participated in, as well as the frequency of their visits to False Creek.

Sampling Location

This survey was conducted along the West, Central, and East edges of False Creek on February 4th, 23rd, and March 2nd.

Procedure

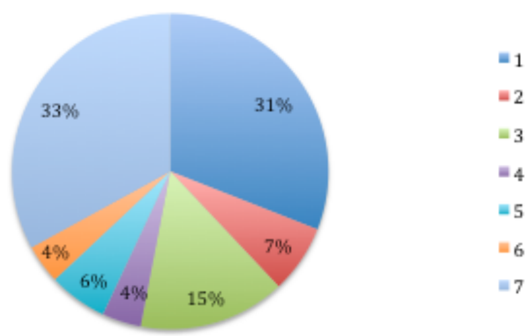
We split the team into five and approached people in our general vicinity. Each member of the group targeted 10-15 people each, along the seawall, and other public spaces within viewing distance of False Creek. When approaching participants we introduced ourselves, informed them of the purpose of our survey, provided them with a consent form which they were to read over, and once consent was provided, we gave them the survey to fill out, which took approximately 10-15 minutes to complete.

Data analysis

Questions with valid quantitative responses were analyzed using Excel to create representative graphs, and those with valid qualitative responses were grouped together and formatted into a table.

Survey Results

There were 54 respondents to the False Creek Recreational Survey. Similar to the 2006 False Creek Recreational Survey by the B.C. Ministry of Environment, there were two major recreational usage groups based on the survey participants. The first group consisted of those who frequented False Creek for walking, jogging, dog-walking, and cycling. The other group consisted of those who participated in activities in the basin itself, such as paddle boarding, and various types of boating activities (i.e., dragon boating, kayaking, sailing, and ferry use). Some other miscellaneous activities that people participated in included: photography, socializing, taking breaks from work, and swimming. A more detailed list of all recorded activities can be found in the Appendix. The summary of weekly visit frequency is summarized in the following pie chart. It can be seen that the majority of our participants were either those who spent only 1 day a week in the False Creek area, or 7 days a week.



The survey participants' responses to the number of days per week they spend in or around False Creek.

We were also interested in knowing which areas of the basin were most frequented by the survey participants. The following table summarizes the results of the 54 participants.

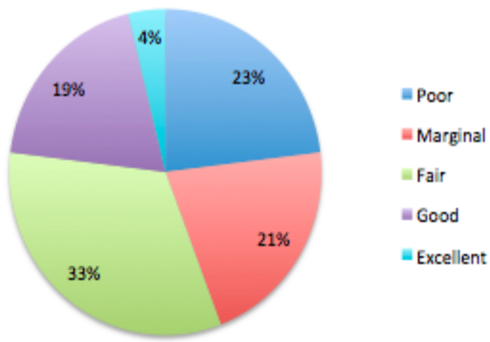
Only West	Only Central	Only East	West and East	West and Central	East and Central	All 3 basins	N/A
17 (31%)	7 (13%)	5 (9%)	0 (0%)	8 (15%)	0 (0%)	14 (26%)	3 (6%)

The response "N/A" was used by participants that were new to the area and unfamiliar with False Creek, or ones that were unsure of which areas they frequented according to our classifications, and had not asked the survey administrators for clarification.

We were also interested in knowing how much water contact was had by participants while participating in recreational activities in False Creek. The following results were concluded: 55% said that they had no contact with the water, while 10% of respondents explicitly stated that they did not have contact with the water anymore because they were aware of the poor water quality. The remaining 35% of respondents said that they had very little contact with the water.

We also asked respondents whether or not they participated in activities in False Creek following rainfall events. We considered the fact that the judgment of aesthetics may differ post-rainfall relative to pre-rainfall, and wanted to see if this had any influence on the responses of the survey. The results were as follows: 43% of participants said that they did participate in activities following rainfall, and 57% did not participate in activities following a rainfall event.

One of our main objectives for the survey was to gain insight on what the public thought of the water quality and the following pie-graph summarizes the results. 77% of the people we surveyed thought the water quality of False Creek was rated as 'Fair' or less, while 23% thought it was either 'Good' or 'Excellent'. Analyses were done to determine whether or not there was a correlation between the amount of time someone spends around False Creek (i.e., frequency of visits), and their rating on the water quality, but there was no significant correlation found.



The survey participants' responses to how they rate the water quality of False Creek.

We also left open ended questions asking if people had noticed changes in the aesthetic quality of the water in False Creek and whether people had experienced positive or negative impacts on their personal health due to the water, along with a question for open comments for participants to voice additional comments.

In response to the aesthetic nature of the water, 21% of the respondents (12 participants) stated that the water is much dirtier now and the quality is digressing, while close to 9% stated that the water is much cleaner now. 60-65% of the participants either stated that they did not notice any changes, or felt like they were unable to answer this question due to the fact that they were new residents who had not been in the area for 5 years.

In response to the question regarding positive or negative health impacts, 71% (40 participants) of respondents stated that they did not experience any impacts. 2 participants responded saying that they experienced a negative impact due to the fact that they were not allowed to swim in False Creek due to high *E.coli* counts in summer 2014 at Sunset Beach. 1 participant stated that they experienced positive emotional benefits from being in a beautiful area.

The majority of respondents left the question for additional comments blank, but 23% of those who did respond said that they were concerned with the quality of False Creek and the fact that this was a problem that more people (the community and the City) needed to take initiative in to solve.

DISCUSSION

Data Interpretation

E.coli concentration, growth and survival rates are directly affected by factors that were investigated in this project: water temperature, salinity, pH, dissolved oxygen and nitrate. In this study, it is further confirmed that the *E. coli* counts have an increasing pattern from the West to East basins of False Creek, which aligned with the pattern of the data obtained from Vancouver Coastal Health and Metro Vancouver. All three data sets exhibited the same spatial pattern of *E. coli* counts. Due to the fact that winter data is not published, this project helped to fill in the winter 2014-2015 data gap. Prior to this research, the following areas were recognized to be of concern by the BC Ministry of Environment: the East basin, CSO discharge locations, and marinas. Even though the average *E. coli* counts in the winter did not exceed the safety threshold of 200 MPN/100 mL, the recognized areas exceeded the average levels measured during the respective sampling. It is highly suspected that with the same pattern demonstrated in the winter time, the summer *E. coli* levels in the concerned areas would also significantly exceed the summer average (as seen with summer 2014 *E.coli* levels which were higher than the safety threshold). The winter baseline data established in this study exhibit a similar pattern as to study conducted by BC Ministry of Environment.

There is a positive correlation between water temperature and the *E. coli* level as seen in Figure 6 and Figure 3. It is supported by Solic & Krstulovic (1992) that the bacteria count number is directly proportional to the intensity of solar radiation, and that temperature is the most important factor regarding *E.coli* survival. This could potentially provide an explanation as to why *E.coli* levels are significantly higher in the summer months as the intensity of solar radiation increases. As there is a strong correlation found between precipitation events and CSO discharges in the 2006 study by BC Ministry of Environment, rain events could therefore be used to predict the elevated bacterial concentrations associated with these discharges.

Temperature has a negative correlation with dissolved oxygen. In other words, warmer temperature holds less dissolved oxygen (EPA, 2012). The water temperature increases from West to East, implying that the dissolved oxygen level should decrease going in the east direction. However, the sampled data did not exhibit a clear trend due to local variations and errors. A reduced dissolved oxygen level is indicative of bacteria and excess amount of biochemical oxygen demand, which uses up DO.

While increased salinity has been observed to cause decreased *E. Coli* survival time (Carlucci & Pramer, 1959), according to the BC Ministry of Environment Report (2006), salinity is not significantly correlated well with *E. coli* concentrations in False Creek. Therefore, with regards to this study, salinity is not a reliable indicator for elevated bacterial levels.

Unlike temperature and dissolved oxygen, normal level of nitrate does not have a direct effect on the marine health. However, a high concentration of nutrients such as nitrate can

increase the growth rate of bacteria (Del Giorgio & Cole, 1998). The source of excess nitrates can possibly be traced through anthropogenic activities such as human wastes, wastewater and industrial pollution. Since the data from this study did not have a clear trend of *E. coli* and nitrate pattern, the nitrate level is not a good indicator for *E. coli* concentration.
It has been found that the inlet has a low inflow of freshwater which results in poor water circulation and mixing with outside waters. As a result, effects of these discharges are exacerbated (BC Ministry of Environment, 2006). This lack of circulation can help to explain the high levels of *E. coli* in the East basin, as pollutants become deposited and trapped in this region from a variety of previously discussed sources.

Challenges (Sampling Procedure and Data Analysis)

Potential for human error and possible water contamination during sampling were kept minimal due to proper handling procedures. During the sampling process, equipment errors were encountered. Due to the water current and nearby boat traffic, the multi-probe was not kept vertically stationary at all times. Learning to use all the sampling equipment (including Niskin bottle, YSI multi-probe, GPS) was one of the initial challenges. The sampling locations may differ slightly from the exact, proposed locations.

Minor challenges were encountered when conducting data analyses. Based on the Guidelines for Canadian Recreational Water Quality, a standard *E.coli* safe zone (<=200 MPN/mL) should be used from a geometric mean of a minimum of five samples (Health Canada, 2012). However, due to time and financial constraints in this study, some sites had less than five samples.

Recreational Survey

For the Recreational Survey analyses, the main challenge faced was due to some participants not responding to every question on the survey. The consequences of this challenge were minimal and we were still able to obtain meaningful results from the completed questions. Refer to the Results section of the paper for further survey results and discussion.

Project Implications

The intention of this project is to help the City of Vancouver to better understand the current state of False Creek in water quality monitoring, as well as the management of False Creek and other water bodies in the future. Due to an increase in boat traffic, it has been recognized that regulations have to be enacted to prevent pleasure craft from discharging sewage into False Creek (BC Ministry of Environment, 1990). With the findings in this project, it highlights the importance of educating the public and regulating boat dumping and trafficking regulations, which need to be strictly monitored. Due to CSOs discharging a mixture of raw sewage, wastewater from homes, businesses and industries, and polluted runoffs (EPA, 1999), CSO regions in False Creek have been recognized as one of our areas of concern.

CONCLUSION

The main fecal pollution source was identified as being from humans; the three bacteriological source tracking samples taken on January 19th, 2015 in the West, Central and East basins of False Creek supported this finding. Ruminant animals and general *bacteroides* were also recognized as possible sources, however, ruminant animals (including dog, pig, elk and horse) returned as a faint or an unknown result; general *bacteroides* could be either human, ruminant animals or from other sources. The *E. coli* levels are significantly higher in the summer months than in the winter months when comparing the historical Vancouver Coastal Health data with the winter *E.coli* samples (refer to figure 3). Both the summer and winter *E. coli* counts exhibit a consistent trend of increasing *E. coli* from the West to East basins of False Creek; referring to BCMOE (2006), this is most likely due to poor circulation and fecal contamination from marinas, CSOs and stormwater runoff (also refer to figure 3). It was also determined that the *E. coli* concentration in "Fisherman's Wharf" marina was significantly higher than the average *E. coli* count in False Creek sampled during this study (or winter).

RECOMMENDATIONS

Monthly monitoring of *E. coli* levels, boating and recreational activities, and other physical water quality parameters should be maintained in order to have an in-depth understanding of the water quality, physical conditions, marine and environmental health of False Creek. Immediately, this will allow for more informed decision-making related to the specific bacteriological concerns that exist at present - recalling the past summer's *E. coli* peak 26 times the Canadian recreational water quality threshold. Furthermore, increased monitoring and data collection can be seen as a broader step towards better understanding our local, natural environment - following alongside the Greenest City: 2020 Action Plan.

Collected *E. coli* data should be organized and made available to the public. This can be used in promoting public interest and awareness of local, natural environments as well as for educational and research purposes. Either weekly or monthly geometric means would be useful for most purposes, however it is worth noting that the raw data should also be saved and made available for (at minimum) research purposes.

Bacterial source tracking analyses should be performed in the summer to gain a more clear understanding of the pollutant sources in False Creek. Results from the winter testing may serve as a sign that dog feces: a speculated (Metro News, 2015) equal contributor to human waste, may not be as significant as initially expected. This would allow for a more definite confirmation for the concern due to human sources , and serve as a justification for recommended mitigation. At minimum, sampling should occur at least once in the West, Central and East areas of the False Creek basin - refer to Map A and Table 5 for sampling points and map. This sampling would seek to further confirm the anthropogenic impact, and dispel speculation of significant, alternative sources of fecal waste (i.e. dog waste). To note, there was no indication of dog waste from the winter bacteriological source tracking samples.

The False Creek Recreational Survey should be administered all year round and updated regularly (last survey was conducted approximately 9 years ago) to avoid bias.

Steps should be taken to ensure safe bacteriological levels in False Creek. Referring to the discussion section as well as the 2006 and 1990 BCMOE reports, boat use has been emphasized as a clear source. Compared with the other two sources (CSO & runoff), boat discharge mitigation may provide the most straightforward mitigation; due to variability of source from stormwater runoff along with eventual removal of CSO's in False Creek. With regards to boat use, the following strategies are recommended:

- Improved accessibility and ease to pumpouts for both live-aboards and visitors
- Adoption of the Vancouver Park Board 'no-dumping' policy in Burrard Inlet
- Investigation into unregistered liveaboards

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