Analysis of Pacific Herring (*Clupea pallasii)* Spawn Populations in False Creek

ENVR 400 2019 Capstone Project
by
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CITYSTUDIO

THE UNIVERSITY OF BRITISH COLUMBIA

Executive Summary

Introduction

Prior to the development of False Creek by European settlers, False Creek supported a rich and diverse ecosystem. The creek was five times the area it is presently, surrounded by dense temperate rainforest with a large tidal mudflat in the east end. The shallow areas of the creek were home to large eelgrass beds which supported substantial marine biodiversity and in turn, attracted predators such as migratory birds. However, over the past hundred years industrialization has resulted in False Creek becoming desolate of such biodiversity (Fraser Riverkeeper, 2018). Included in the species lost is *Clupea pallasii*, more commonly known as Pacific herring. As seen in Figure 1, Pacific herring is the main food source for many west coast marine species including whales, dolphins, seals, salmon and more. Thus, this forage fish is what drives our rich marine biodiversity and in turn promotes B.C.'s fishery and tourism industry. Further, Pacific herring is crucial to the culture, economy and diet of Coastal Salish peoples.

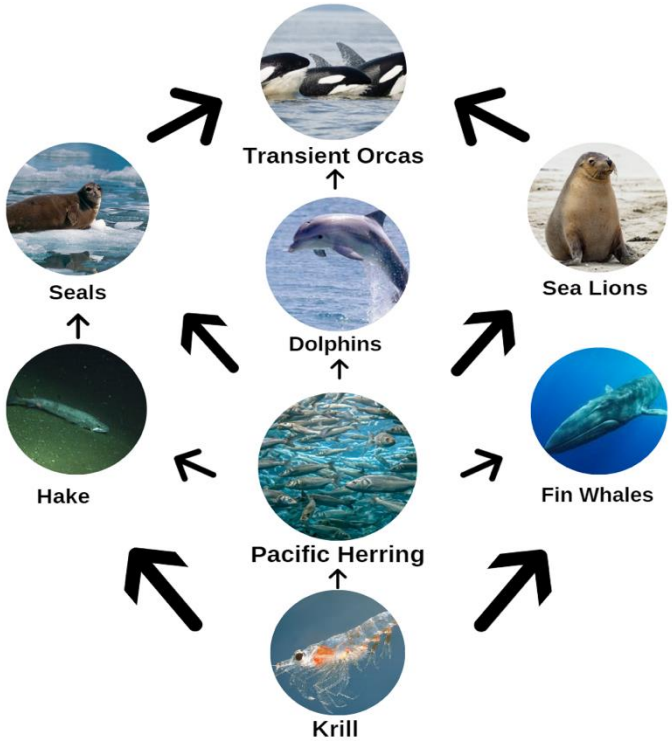

Figure 1. *Importance of Pacific herring in False Creek food web (Surma et al., 2018).*

However, over the past few years, media attention, including Global TV, has brought attention to observed herring spawning in False Creek during the February to April spawning season. These spawning events can be attributed to the work of the Squamish Streamkeepers; a community volunteer group consisting of marine biologists, retired fishermen and others. In False Creek, their methods consist of wrapping wood pilings with Enviro-liner to protect eggs from the toxic creosote coating on pilings and employing nets, creating a safe substrate for egg deposition as pictured in Figure 2 (The Squamish Streamkeepers, personal interview, November 16, 2018).

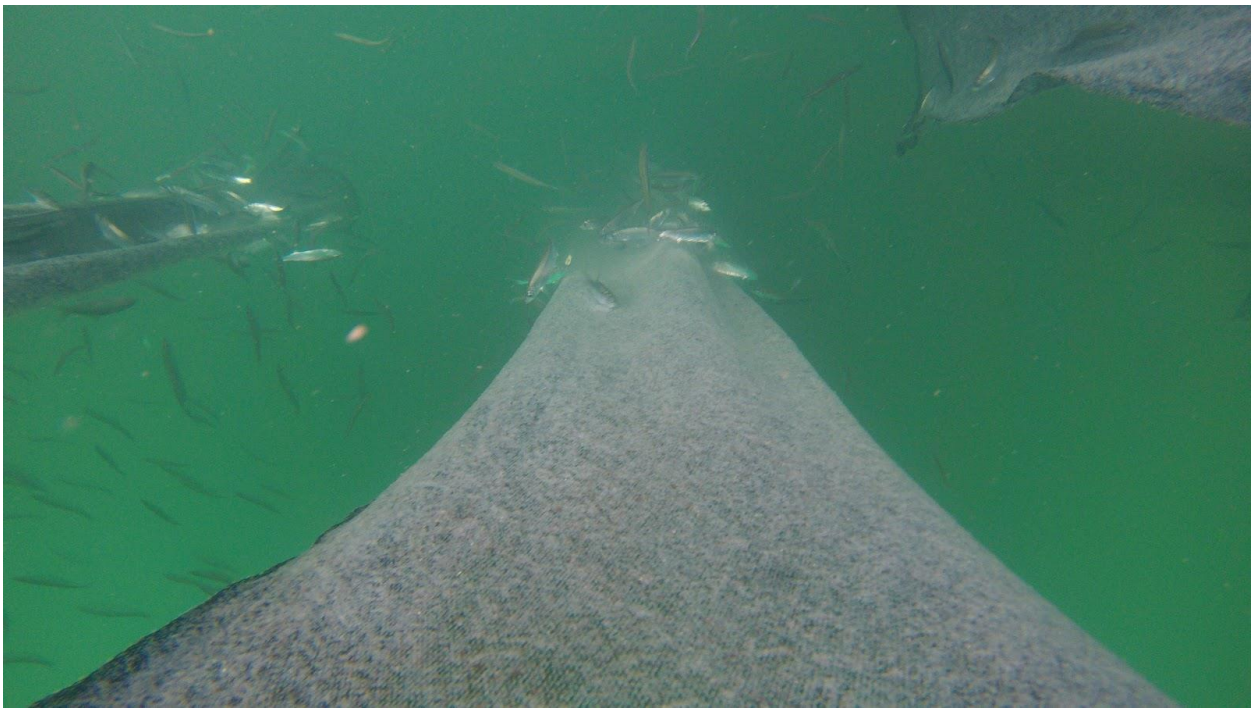

***Figure 2**. Witnessed herring spawning at Fisherman's Wharf dock A on March 3, 2019.*

The work of the Squamish Streamkeepers in promoting herring spawning in False Creek aligns with CityStudio and the City of Vancouver's interest in restoring the ecosystem in False Creek, especially with future development plans in the area. Increasing herring populations to False Creek will be a starting point of future conservation plans such as restoring the intertidal biodiversity and native bird populations around this urban zone – ultimately assisting the City of Vancouver's Greenest City Action plan's goal to increase access to nature in the city.

As ENVR 400 students, we worked with the Squamish Streamkeepers to provide CityStudio with formal data collection that was lacking from the Squamish Streamkeepers methods and best management practices for increasing herring spawning in False Creek; supported by an extensive literature review contained in this report.

The **research questions** that inspired this project are:

1) What is the role of Pacific herring in False Creek, culturally and ecologically?
2) What is the water quality in False Creek? Can these waters support herring spawning?
3) Who are the Squamish Streamkeepers? Do their methods support herring spawning in False Creek?
4) Where and when do herring spawn in False Creek?
5) How can the Vancouver community become involved?

Methodology

Firstly, an extensive literature search concerning herring ecology, False Creek, and the Squamish Streamkeepers was conducted. Following, an experiment was devised to monitor the herring nets of the Squamish Streamkeepers at locations: Fisherman's Wharf, Burrard Civic Marina and Heather Civic Marina. Their nets were first installed on February 2nd, 2019. All three locations were monitored weekly between February 2nd, 2019 to March 3rd, 2019. Underwater pictures of the nets were taken using a GoPro® which were later analyzed using the software ENVI® to determine the temporal percent of egg coverage on individual nets.

Findings

The first occurrence of eggs was observed February 17th, 2019 on dock B at Fisherman's Wharf. In the following weeks, the percent egg coverage continued to increase at this location. Eggs were later observed on dock A at Fisherman's Wharf March 3rd, 2019. No eggs were observed at Heather Civic Marina or Burrard Civic Marina during our monitoring period as seen in **Error! Reference source not found.**.

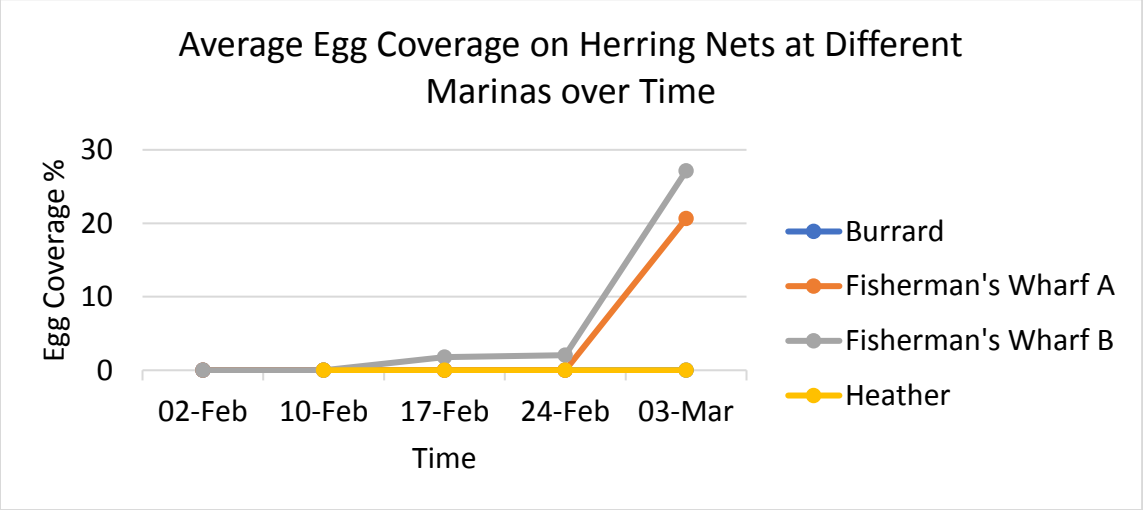

Figure 3. *Change of herring egg coverage with time of all nets for each of the marinas that were studied; Burrard Civic Marina, Fisherman's Wharf Dock A, Fisherman's Wharf Dock B, and Heather Civic Marina.*

Conclusions and Recommendations

Our observations indicate that the herring nets are an important substrate for herring spawning, specifically at Fisherman's Wharf. As this experiment was the first attempt to monitor spawning in False Creek, we acknowledge our experiment has associated limitations and uncertainties which we address by providing recommendations for future improvements.

We also recognize our project has significant opportunities for collaboration through citizen science. We hope these collaborations will evoke curiosity and enthusiasm in locals to become involved in the creation of a healthy False Creek urban ecosystem.

To further this project, we suggest the following recommendations:

- Creating a citizen monitoring program
- Collaborating with nearby schools and engaging early education of local biodiversity and its importance
- Forming partnerships with non-governmental organizations (NGOs) and Vancouver Aquarium to further promote the cause
- Conducting further in-depth research about False Creek ecosystem and its effects on herring spawning

Author Bios

Lal Deniz Basok
Lal is a 4th year student in the Environmental Sciences program, soon to be graduating with a specialization in ecology and conservation. She has experience in field work, data analysis, water quality monitoring, and aquatic/terrestrial ecosystem mapping from the internships and courses she has been involved in.

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Chunchen is a 4th year Environmental Sciences student focusing within the Land, Air and Water specialization at University of British Columbia. The knowledge gained from geology, hydrology, and oceanography courses has assisted her in this project. Her experience in literature research, quantitative data analysis, team-based coursework, and international field course study also further contributed to developing this project.

Meg Lovett
Meg is in her final year of the Environmental Sciences program within the Land, Air & Water specialization. With past and current work experience as a Research Assistant, Meg has been involved in the design and data collection of field experiments, analysis of data and has experience executing large scale literature reviews.

Carey Yan
Carey is completing his Bachelors of Environmental Sciences this year at the University of British Columbia and has experience in field surveying and data analysis.

Figure 4. *Our team at data monitoring site Fisherman's Wharf A (Not pictured: Carey Yan)*

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1. Introduction

1.1. Herring Ecology

1.1.1. Distribution and Habitat in British Columbia

Pacific herring, *Clupea pallasii* (Figure 5) is a pelagic fish species that can be found along Pacific coasts stretching from Baja California to Alaska (DFO, 2018a). In British Columbia, the stocks of herring have been determined by observing spawning and egg deposition from1928 to 2013. Over 5,000 km, 18%, of the coast of B.C. has been allocated as Pacific herring spawning range. However, only 1-2% of this range is used for continuous spawning every year. These locations are significantly important for major fisheries and represent areas that demand the most attention for maintaining sustainable populations (Hay & McCarter, 2015).

Figure 5. *School of adult Pacific herring, Clupea pallasii ("Pacific herring", 2015).*

There are five large stocks and two small stocks, which are mostly used by fisheries for herring roe and bait for other harvests and aquaculture. These five major stock areas are Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG) and West Coast Vancouver Island (WCVI). The two small stocks are located on the west coast of Haida Gwaii (Area 2W) and Quatsino Sound (Area 27) on Vancouver Island (DFO, 2018b).

These stocks migrate south to their overwintering regions during winter, returning in summer to their feeding grounds (Figure 6**Figure 6**). They do not migrate more than 200 km (EOL, 2015). During March and April, they aggregate near the shore for spawning (Hay, 1985). In the Strait of Georgia, major spawning areas include Qualicum, Nanoose Bay, Powell River, Boundary Bay, Swanson Channel, and Baynes Sound, the latter being the largest spawning area recorded throughout all of British Columbia coast. These locations are usually the downwind sides of islands or mainland coastlines and thus protected from strong wind. Narrow fjords or inlets that are much more stagnant with less circulation are not observed to have heavy spawning most of the time. Therefore, spawning regions that are most favorable are sites with intermediate ocean water contact (inlets, fjords and estuaries) and considerable water circulation (Hay & McCarter, 2015).

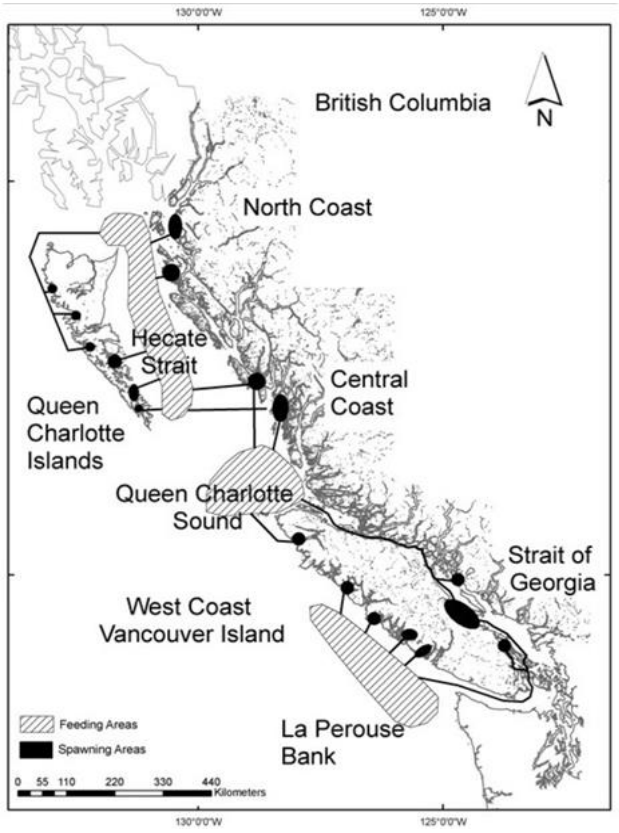


Figure 6. *Map of vital spawning locations (Black) and feeding areas (shaded) of Pacific herring in British Columbia (DFO, 2014).*

Juveniles (Age 0 herring) prefer shallow areas during the night, unlike adults that are found in intermediate depths (Table 1). They also tend to stay close to eelgrass beds in low salinity water areas in aggregate channels and bays until maturation when they migrate to deeper waters (Lewandoski & Bishop, 2018).

Table 1. *Environmental habitat ranges of Pacific herring. Data collected from 1668 specimens (EOL, 2015).*

Environmental range	Value
Depth (m)	0 - 254.5
Temperature (°C)	-0.959 - 8.705
Nitrate (umol/L)	2.534 - 34.597
Salinity (PSU)	28.657 - 33.906
Oxygen (ml/l)	2.565 - 8.596
Phosphate (umol/l)	0.354 - 2.965
Silicate (umol/l)	11.425 - 54.528

Adult Pacific herring have been observed to avoid areas where there is high traffic of vessels, high siltation, and high abundance of predators (Hay & McCarter, 2015). Hence, it is unexpected that herring spawning has been observed in False Creek due to the large amount of traffic from personal boats and False Creek ferries. The spawning adult herring population in False Creek is believed to be from the Strait of Georgia stock. They overwinter and spawn in False Creek and return to their feeding grounds in Ucluelet in the summer (The Squamish Streamkeepers, personal interview, November 16, 2018).

1.1.2. Life history and Ecology

Every spring in shallow coastline habitats the herring spawn event occurs, marked by white milt and the gathering of seabirds and mammals gather around the intertidal zone. Pacific herring spawning mostly occurs between February and April in the Strait of Georgia when the amplitude of tides is at the minimum and lasts for two to four days (Figure 7). Typically, herring of at least three years of age contribute to the spawning and unlike salmonids, do not die and will spawn the upcoming year (Hay, 1985).

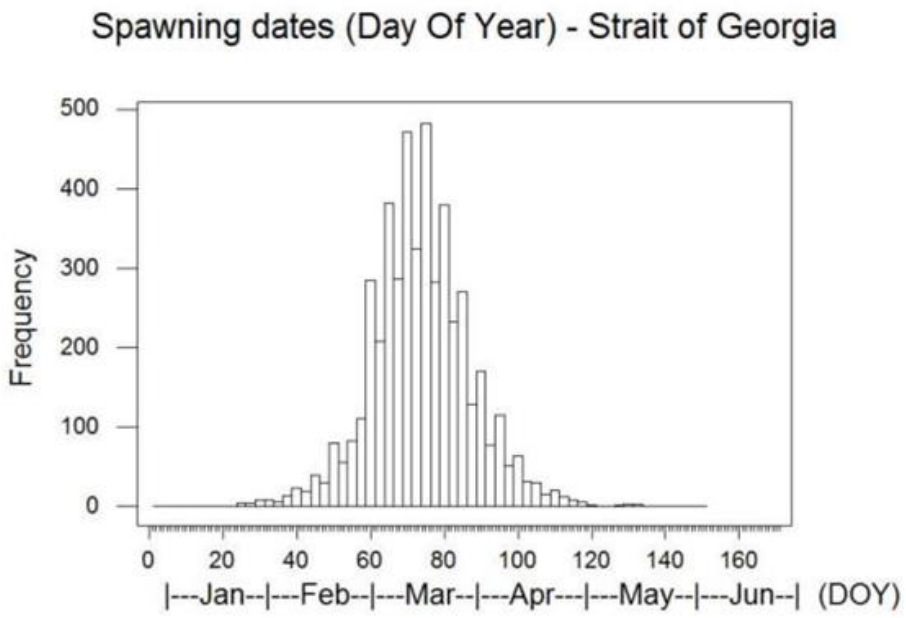


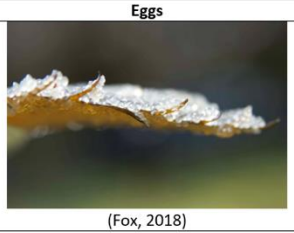
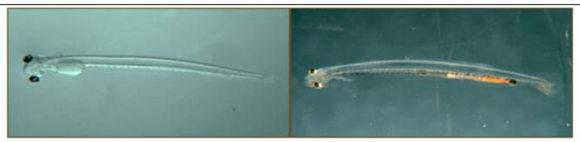
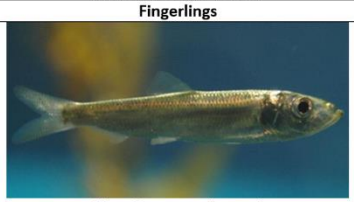
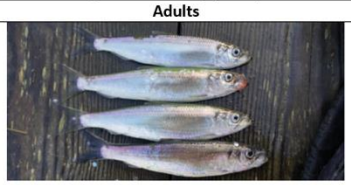
***Figure** 7. Spawning frequency for Pacific herring from January to June in the Strait of Georgia (Hay & McCarterm 2015).*

Herring can deposit over 3 million eggs per meter cube of substrate. One female lays approximately twenty thousand eggs. Preferred substrate for deposition includes: eelgrass, branched or flat red algae, brown algae such as Laminaria (kelp), Sargassum and Desmarestia. Preferred spawning substrate is textured, possibly explaining herring's tendency to spawn on wood pilings in False Creek (Shelton et al., 2014).

Unfortunately, Pacific herring eggs are susceptible to many environmental factors that can affect the number of herring eggs deposited and hatched. Factors affecting growth can also influence population dynamics and productivity of stocks. Salinity (‰S) and temperature (°C) were found to be the most impactful variables for early developmental stages. However, strong waves and predation can also be of great disturbance. Maximum hatching larvae size and viability occurs around ~16‰ S and ~7°C. Optimal conditions for egg survival and spawning is 10 to 23‰ S and 6.5 to 10.5°C. Salinity and temperatures exceeding these values can result in high mortality after hatching, larval inactivity and developmental abnormalities. Conditions of 7.8 to 25‰ S and 7 to 13°C needs to be maintained for the survival of larvae after hatching (Alderdice & Velsen, 1971).

After fertilization of the egg, it takes 10 to 14 days for the healthy larvae to hatch ("Pacific Herring", 2015). Another two weeks are required for the larvae to consume their yolk sac and b begin feeding on crustaceans and small fish larvae, ostracods, diatoms, and krill. Larvae is also prey to ctenophores and chaetognaths (EOL, 2015). At this point, the larvae are about 10 mm long (Table 2) Larvae that take shelter in shallow waters near spawning zones grow to be juveniles in two to three months ("Pacific Herring", 2015).

Table 2. *Figures of developmental stages of Pacific herring showing egg, larvae, juvenile, fingerling and adult stages, respectively.*

Eggs

(Fox, 2018)
Larvae

("Pacific Herring", 2015)
Juveniles
("Pacific Herring", 2015)
Fingerlings

("Pacific Herring", 2015)
Adults

(E-Fauna BC, 2018)

These juveniles will then start to form schools in inlets and bays providing an excellent food source for seals, salmon, cormorants, gulls, and piscivore ducks. During this stage they also begin feeding on copepods and chaetognaths (Foy & Norcross, 1999). After developing scales and functional fins, herring relocate to deeper waters to become sexually mature and join adult herring schools offshore in the next two to three years ("Pacific Herring", 2015). They then generally remain in the same stock for the rest of their lives. Adults can grow up to 15-25 cm and at this stage are a very important food source for lingcod, salmonids, pacific cod, pacific hake, sea lions, and whales (Figure 8). They also now prefer to feed on euphausiids (krill) and calanoids (Foy & Norcross, 1999).

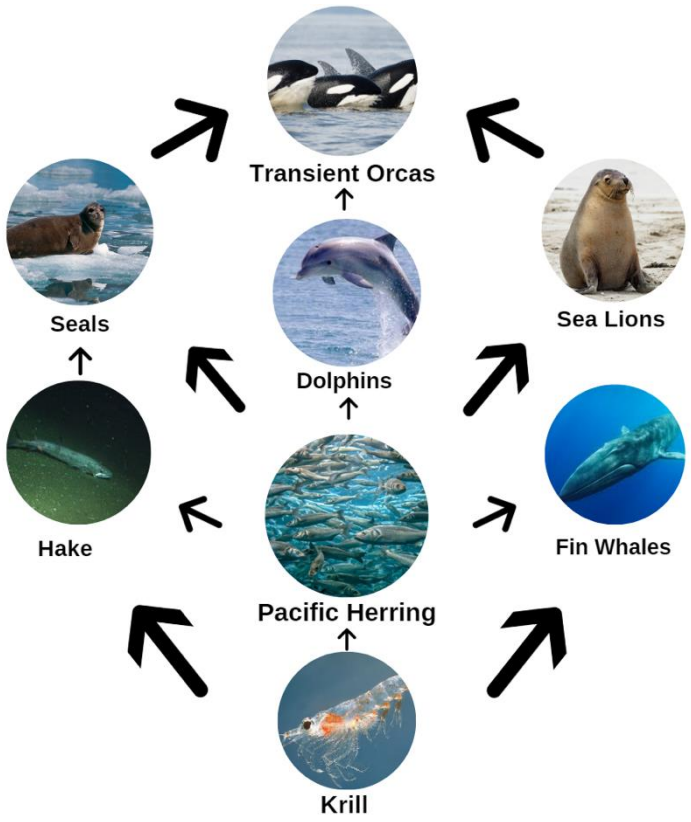


Figure 8. *Simplified diagram of major trophic interactions involving Pacific herring in the modelled food web (thickness of arrows proportional to the biomass flux) (Surma et al., 2018).*

1.2. First Nations Significance

The city of Vancouver is home to three Indigenous nations: Musqueam, Squamish and Tsleil-Waututh. These groups are part of a larger nation known as the Coastal Salish. When the first settlers arrived in the late 1850s, False Creek was an ecologically rich site blanketed with thick eelgrass; ideal conditions for herring spawning. Indigenous peoples occupied the surrounding forest of False Creek. Where Granville Island is situated today was once a popular fishing

ground. With the increase of urbanization and colonization, the Indigenous peoples were displaced from these lands (City of Vancouver, 2017).

Figure 9. *Heiltsuk First Nations harvesting traditional spawn on kelp (McAllister, 2015).*

For millennia, Coastal Salish First Nations have relied on Pacific herring for food, cultural, social, ceremonial and economic purposes (Gauvreau, Lepofsky, Rutherford & Reid, 2017). In particular, herring roe is of significant importance in Indigenous communities. The traditional spawn on kelp industry (SOK) involves the suspension of hemlock, cedar branches or kelp blades underwater in spawning grounds during early spring (

Figure 9). The spawning event produces multiple layers of roe on the substrate which is then harvested. To this day, herring roe is a significant element in the seasonal diet of coastal First Nations as well as potlatch feasts (Protect Pacific Herring, n.d.). Commercially, herring roe plays a significant economic role in First Nations communities. The Heiltsuk nation, located in Bella Bella, alone can earn up to four million dollars during profitable years attributed to the lucrative herring roe market in Japan (Secher, 2014).

1.3. Health of False Creek Ecosystem

1.3.1. Metals

The natural vegetation along with streams and tides, found in the past ecosystem of False Creek, acted as a buffer system for both runoff and tidal waters (Fraser Riverkeeper, 2018). However, due to the coming of the Canadian Pacific Railway (CPR) in the 1890's, False Creek became the primary transportation and distribution center for international trade. As a result, there became development of industrial plants, including wood processing companies, fishing industry, iron works, and metal shops. In order to accommodate the expansion of industry in this area, the mudflats were filled in, thus inhibiting the natural filtration and flushing of the region due to the removal of vegetation (Fraser Riverkeeper, 2018). False Creek (Figure 10) eventually became heavily polluted with oil contaminants, sewage and toxic effluent from sawmills and other industries (Miro, 2011). These past discharges included high concentrations of cadmium, mercury, and lead which mostly remain in the sediment today, particularly in the eastern end of False Creek (Fraser Riverkeeper, 2018).

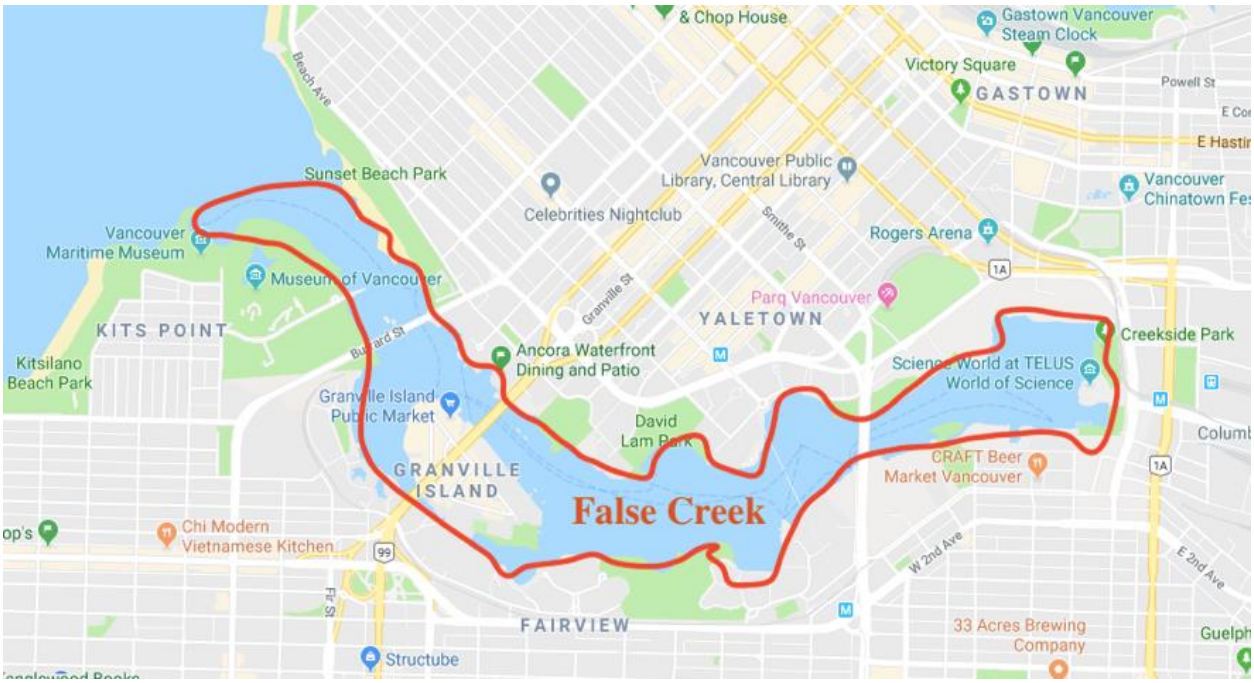


Figure 10. *Map of False Creek, Vancouver, British Columbia (Google Maps, 2018)*

These heavy metals can have severe consequences for fish species. The main concern of heavy metal is the process of bioaccumulation. Fish absorb heavy metals through their intestinal tract from ingested food or the surrounding environment (especially bottom sediments), as well through their gills and skin. Due to bioaccumulation, as the size of herring increases, higher concentrations of heavy metal, in particular mercury, are found in the fish (Polak-Juszczak, 2009). These concentrations are then passed up the food chain as prey are consumed in large quantities by their predators. Therefore, bioaccumulation presents serious negative consequences to top predators such as orcas and dolphins. Elements such as cadmium, mercury, and lead, as found in False Creek, have the potential to cause disturbances in growth and reproduction as well as histopathological alteration in the skin, gills, liver, spleen, and kidneys (Arantes et al., 2016). However, the levels of metals in False Creek are not available to allow us to interpret the impact of metals on herrings in False Creek.

Of specific importance for this project is the consideration of the effect of metals on spawning. In a review by Jezierska B., Lugowska K. and Witeska M. (2008), the authors noted that the presence of heavy metal can hamper embryonic development with effects including reduced hatchability, increased abnormality of newly hatched larvae, reduced body size of larvae and reduced survival of larvae. Their findings suggest the development period following fertilization and the hatching out period are most vulnerable to metal intoxication. In summary, the exposure to heavy metal in sediments has negative impacts on local fish populations and aquatic ecosystems as a whole, however cannot be quantified in False Creek due to a lack of metal concentration data.

1.3.2. Temperature and Salinity

Water temperatures are directly related to air temperatures in False Creek (Cummings, 2016). Solar radiation is the main factor which affects the air temperature and therefore the water temperature. Thus, water temperatures peak in summer and decrease as air temperatures decrease. In addition, as shown in Figure 8, the water temperatures decrease with water depth. According to Taylor (1964), herring hatching occurs within 12 to 20 days, depending on water temperatures; preferably 6 - 13 °C. As seen in Figure 11, herring cannot spawn during summer time in False Creek due to the water temperature exceeding their maximum tolerance level.

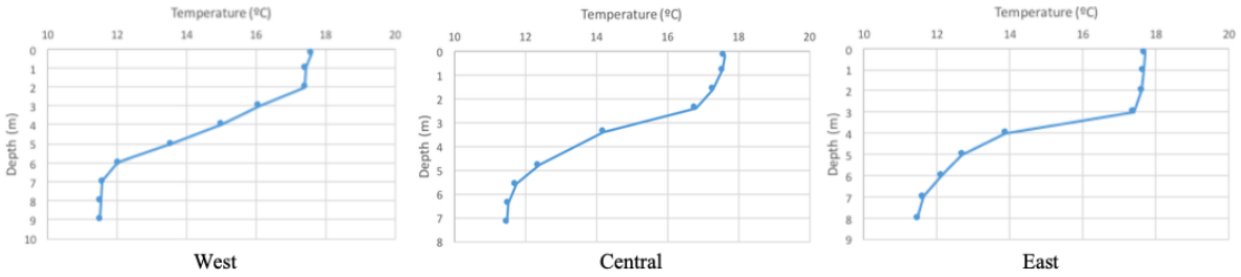


Figure 11. *Water temperature depth profile for west, central, and east False Creek in 2016 (Cummings, 2016).*

Contrary to temperature, salinity increases with depth and then stabilizes below a depth of 6 m as seen in Figure 12 (Cummings, 2016). Different fish species have different levels of salinity tolerance, and herring are considered as a fish species to be fairly tolerant of high salinity. The optimum salinity for the development and survival of herring eggs and larvae is 16.48 ‰ (McMynn & Hoar, 1953). However, by analyzing Figure 12, the conditions for herring eggs and larvae are not optimal below 3m depth in False Creek.

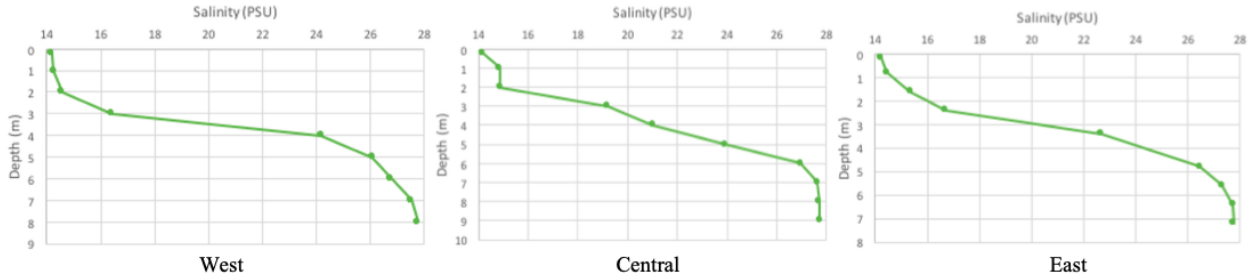


***Figure 12**. Water salinity depth profiles for west, central, and east False Creek in 2016 (Cummings, 2016)*

1.3.3. Escherichia coli (E.coli) Effects on Fish

False Creek is characterized by the presence of *E.Coli* (Cummings, 2016). *Escherichia coli (E.coli),* an enteric bacteria from intestinal tracts of mammals, exists in the water body of False Creek, and has become one of the major constraints in aquaculture. Reported by Vancouver Coastal Health (Figure 13), concentration of *E.coli* bacteria increases from west to east, with the highest concentrations along the eastern shoreline. In addition, the concentration of *E.coli* bacteria increased greatly from 2016 to 2018 (Vancouver Coastal Health, 2016, 2017, 2018). It has been found that *E. coli* penetrates and accumulates in fish tissue, negatively affecting the health of fish (Fattal et al., 1988). Thus, *E. coli* may negatively impact the health of herring in False Creek, however literature regarding the affects to herring specifically are very limited.

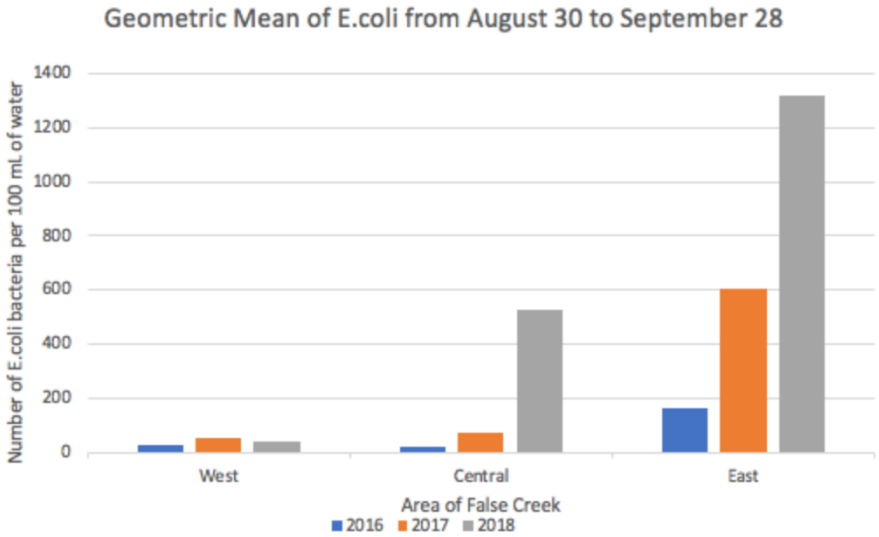


***Figure 13**. Number of E.coli bacteria per 100 mL of water in West, Central, and East of False Creek. The geometric mean of E.coli was collected over the most recent 30 days before September 28th, 2016, September 28th, 2017, and September 28th, 2018.*

1.3.4. Availability of Spawning Substrate

Due to the dredging of eelgrass beds to accompany industrial expansion, available spawning substrate for herring may be limited. The lack of available substrate seems to be more significant than the type of substrate. (Rooper et al., 1999 & Shelton et al., 2014). In an attempt to increase the presence of natural substrate, the Washington Department of Natural Resources investigated the restoration of eelgrass and kelp beds at Puget Sound and found a 13% success rate in transplantation projects, however these projects are accompanied at a high cost. New methods are being investigated including planting seeds and tying whole plants to frames. The implementation of these or similar methods in False Creek should be further explored.

1.3.5. Creosote Effects on Herring

The use of creosote for wood pilings is prevalent across Vancouver's marinas as it is resilient, cost effective and is perfectly legal for use, granted by the Pest Control Products Act in 2011 (Health Canada, 2011). Although there are many other environmental conditions which could influence the rate in which herring eggs spawn in this region (some which have been touched on in this report) creosote pilings are one of the main substrates in False Creek in which herring lay their eggs; resulting in a direct effect on herring spawn rates. As mentioned previously, part of the herring's life cycle is to travel to intertidal zones to lay their eggs on substrates like eelgrass and kelp (Figure 14) ("Pacific Herring", 2015).

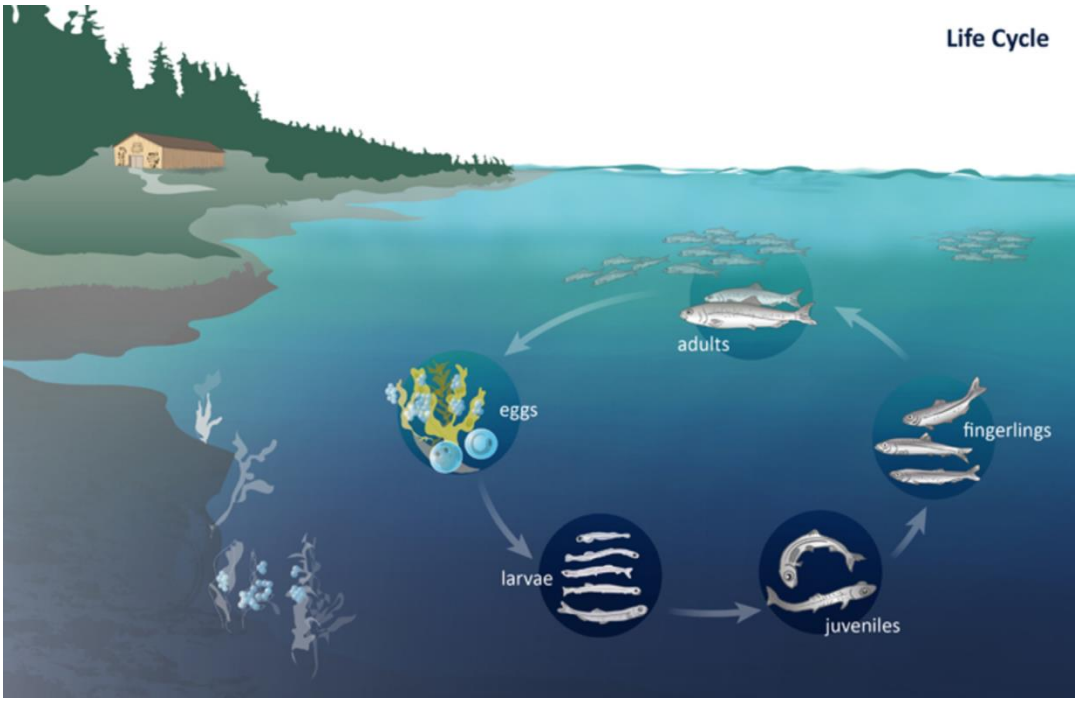


***Figure 14**. Life cycle of Pacific herring ("Pacific Herring", 2015). False Creek does not have eel grass as shown in the diagram and so eggs are laid on creosote pilings instead.*

When these substrates are not present, as in False Creek, herring will lay their eggs on any other available substrates such as pilings. Although pilings provide a stable foundation for the eggs to grow, the creosote used to preserve the material negatively affects herring spawns. Creosote is made of about 80% polycyclic aromatic hydrocarbons (PAHs) and due to its stable structure, it is often used on wood pilings as it has the ability to significantly reduce decay by bacteria (Hutton and Samis, 2000). Although its wood preservative properties are ideal, these preservatives have been linked to several health issues in marine organisms which range from immediate mortality of herring embryos to morphological and cardiovascular defects such as spinal curvature, reduced jaw function and weak heart rhythms (West et al, 2014). One experiment has shown that creosote pilings have been reported to reduce Pacific herring hatching rates by 90% and embryos that do survive suffer from a 93% reduction in heart rate (**Error! Reference source not found.**) (Vines et al., 2000).

PAHs slowly dissolves in water and have the potential to accumulate in intertidal or shallow habitats where some herring lay their eggs (West el al, 2014). Exposure to solar radiation and elevated temperatures could also enhance this process as microliter size particles precipitate out and fall (Hutton and Samis, 2000). Wraps could be used as a physical barrier between herring eggs and pilings, reducing the rate in which PAH particles dissociate in the water through shading pilings from solar radiation. Nets could be used to provide complex substrates for herring to lay their eggs and have been shown to increase the survival of early herring life stages by limiting predation (Von Nordheim et al, 2018). The best management practices used in this project will incorporate the use of nets to mitigate the effects of creosote on herring eggs and as a result, promote higher spawn rates of Pacific herring at False Creek.

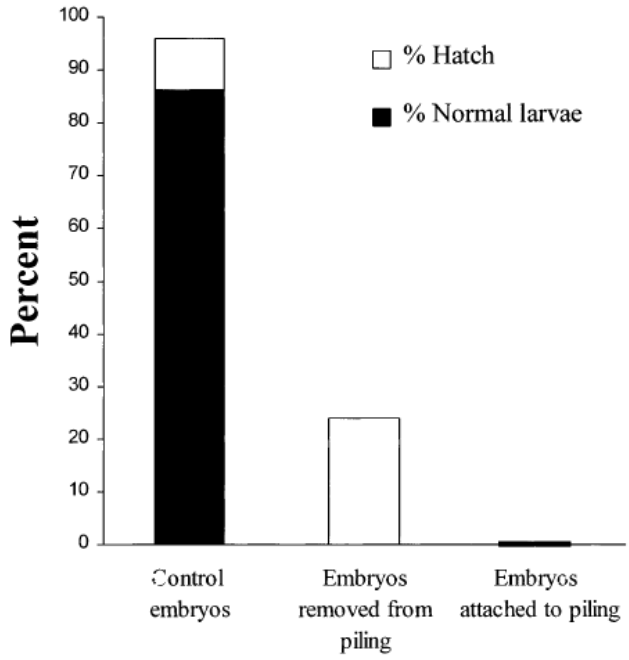


***Figure 15**. Effects of creosote-treated pilings on hatching success and normal larval morphology in herring embryos. Control embryos were embryos on a non-creosote-treated piling, while embryos exposed to creosote pilings were either removed on stayed attached. Empty bars represent the hatch rate and filled bars represent the chance of normal morphology (Vines et al., 2000)*

1.4. Squamish Streamkeepers

1.4.1. Background

Squamish Streamkeepers was founded in 2000 with the initial goal of informing Fisheries and Oceans Canada (DFO) about rebuilding Coho salmon streams around Squamish, British Columbia. They have helped monitor many streams and ponds to rescue Coho populations from dry rivers and blocked streams. They spent ten years improving fresh water conditions in these streams.

In 2006, they began working on increasing herring spawning in Howe Sound where the sawmill industry killed many herring and destroyed the spawning habitat in the area. They observed that herring had attempted to spawn on the Squamish Terminals dock wood pilings but many of the eggs were dead due to the seepage of creosote. The Squamish Streamkeepers then started to wrap these pilings with plastic as well as deploying a gill net attached to float lines in the summer of 2006. They later changed their wrapping material to Enviro Liner® and observed a supposed 100% viable hatching success from all eggs that were deposited. In March 2014, Howe sound saw roughly over a hundred dolphins feeding on herring -- an indication of a rehabilitated herring spawning habitat in this area.

1.4.2. Success in False Creek

In 2010, the Squamish Streamkeepers observed the same situation where they were seeing herring roe on pilings covered with creosote and barnacles at Fisherman's Wharf in False Creek. Dr. Jonn Matsen, of the Squamish Streamkeepers, observed this phenomenon for the following two years and then decided to take action in 2013. In December 2013, the group used Enviro Liner® wraps to cover 60 pilings during low tide. In February of 2014, they estimated the presence of three million eggs per wrap. However, creosote continued to seep into the surrounding water from under the wraps. Along with the surface oil slick, gas, and diesel, approximately 50% of the three million eggs died. To reduce mortality, they suggest that the eggs must be kept under the water and a foot above the ground for crustacean damage. Despite the damage from the creosote, they were able to see millions of larvae by implementing these suggestions. Further, they decided that Enviro Liner® may not be the ideal option as it absorbs oil in the intertidal zone over long periods of time (The Squamish Streamkeepers, personal interview, November 16, 2018).

In January 2016, they deployed sub-tidal knotless nylon nets to avoid surface oil. Several million herring hatched successfully on these nets between February to March. They estimate that the 160 nets they deployed hatch out 3 million eggs each, sometimes up to three to four times a year (Figure 16). In March 2018, they implemented a shorter but longer net at Burrard Civic Marina and again, witnessed a successful spawning season -- an estimated one billion eggs on these nets. Their next goal is to establish spawning in Coal Harbor where there is natural kelp and to restore the populations there that used to exist until early 1900 before the development in False Creek (The Squamish Streamkeepers, personal interview, November 16, 2018).

Figure 16. *An example of knotless nets that were placed under the Burrard Civic Marina*

2. Methods

2.1 Overview

This literature review presented in the prior section of this report was used to strengthen our knowledge of the species and the environment at False Creek, which later allowed us to make informed decisions when devising our experiment and further recommending best management practices.

Following our literature research, we worked with the Squamish Streamkeepers in the field, helping us to understand the reasoning behind the design of the nets and as well as the implementation process. We adopted their design and implemented a net at Heather Civic Marina in False Creek in addition to the Squamish Streamkeepers nets which were placed at Burrard Civic Marina and Fisherman's Wharf in an attempt to capture spatial distribution.This allowed us to understand the extent and pattern herring are depositing their eggs. A map of the net locations if displayed in figure 17.

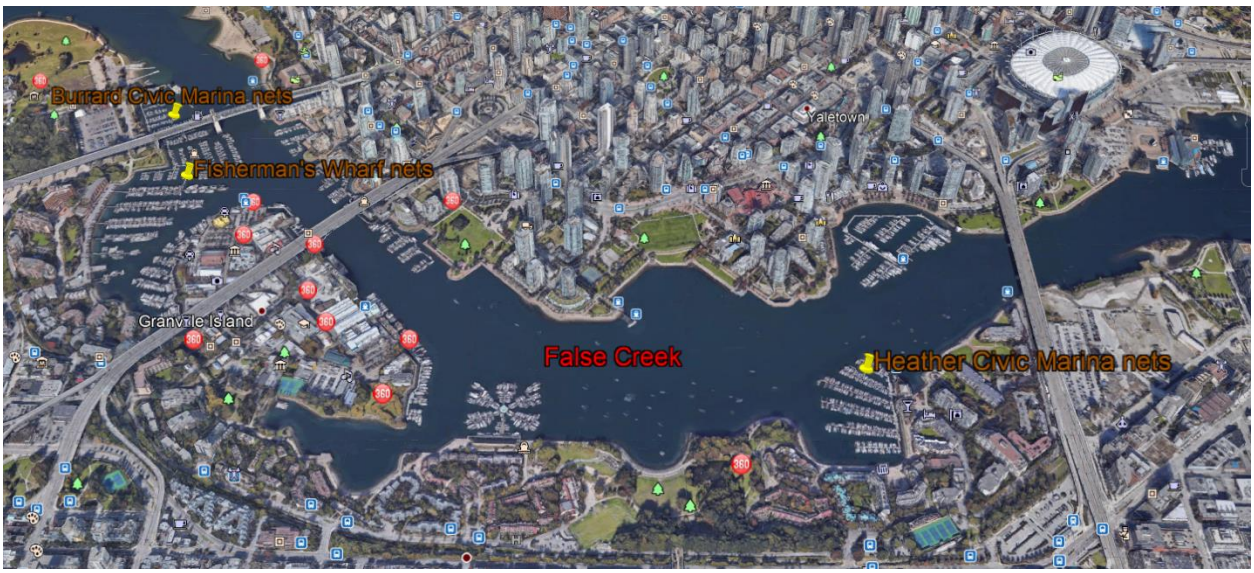


Figure 17. *A map of where nets will be installed throughout herring spawning season in 2019.*

2.2. Experimental Design

The Squamish Streamkeepers had done exciting work over the years along False Creek, but a more quantifiable approach was necessary to understand the fully support their methods. Our

experiment consisted of two components: monitoring the Squamish Streamkeepers nets at Fisherman's Wharf and Burrard Civic Marina, and installing and monitoring a net at Heather Civic Marina, a location that previously hasn't been studied.

2.2.1. Study area & Survey Points

The study area for this project took place at three marinas: the south end of Burrard Civic Marina, docks A and B in Fisherman's Wharf and along the North dock in Heather Civic Marina (Figure 13). These locations were chosen due to their ideal characteristics: extending perpendicularly outward from the shoreline which allows for north facing net placements, were generally well shaded and had circulating water. The docks extending perpendicular from the shoreline is ideal as it attracts herring which may swim through the center of the creek rather than along the shore. The ability to place nets north facing and in well shaded circulating water is ideal as it reduces the occurrence of other marine organisms, such as algae, from occupying the net.

We surveyed each marina differently as the net placement by the Squamish Streamkeepers differed for each marina. For Burrard Civic Marina, we monitored the singular net placed by the Squamish Streamkeepers, located at the south end. This net extends 100 ft horizontally. Along the length, we surveyed five evenly spaced points. At Fisherman's Wharf, we surveyed ten evenly-spaced herring nets on two docks (5 nets in dock A and 5 nets in dock B); dock A being the northern dock, and dock B being just south of dock. Nets are named A1 - A5 (or B1 - B5), with letters representing which dock and numbers 1-5 representing nets placed from east to west. At Fisherman's Wharf A, stations 1, 2, 3, 4, and 5 are A02, A07, A13, A19, and A23 from west to east. At Fisherman's Wharf A, stations 1, 2, 3, 4, and 5 are B02, B07, B14, B19, and B23 from west to east. Only docks A and B will be monitored as they are the only docks in which nets were placed by the Squamish Streamkeepers. Lastly, a single net was installed and monitored by us at the north end of Heather Civic marina. Only one net was implemented as we were only granted access to one location in this marina. Figure 18 displays all the survey locations, with locations at Fisherman's Wharf and Burrard Civic Marina more closely seen in

Figure 19.

***Figure 18**. Survey locations of herring nets across False Creek. Pink indicators represent Burrard civic marina nets, blue indicators represent fisherman's wharf herring nets and the green indicator represents the placement of the Heather Civic marina herring net.*

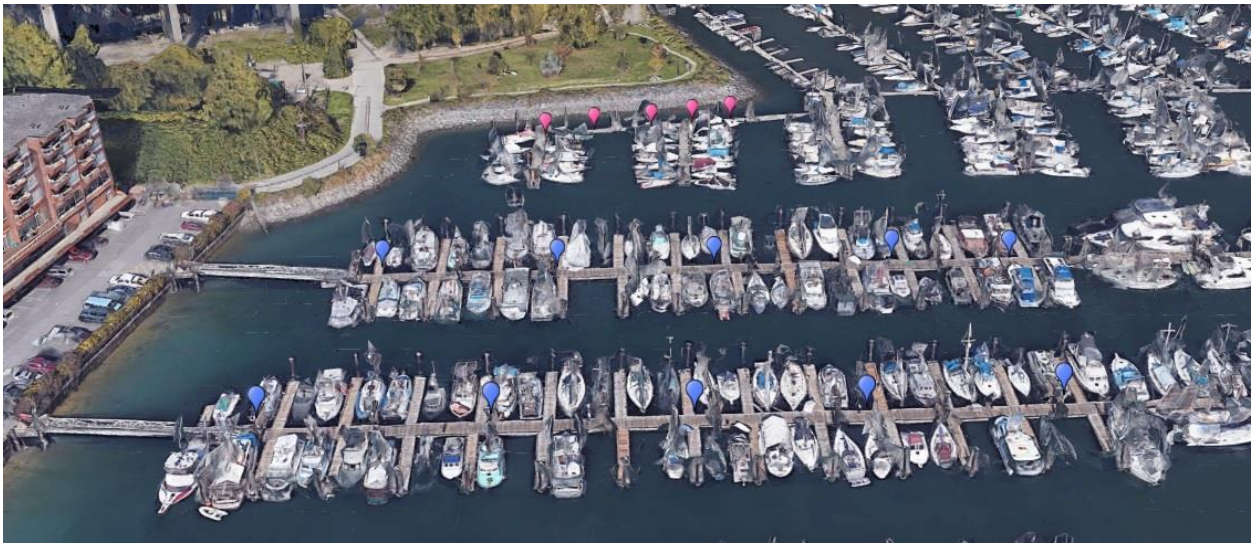


***Figure 19**. A close up image of the exact survey locations within Burrard Civic Marina (pink) and Fisherman's wharf (blue). From left to right (or west to east) monitored dock numbers are, in dock A, A02, A07, A13, A19, and A23 and in dock B B02, B07, B14, B19, and B23.*

2.3.3. Design of Herring nets

Figure 20. *Design of the herring nets installed at Fisherman's Wharf and Heather Civic Marina.*

Each herring net was made using 90 cm of PVC pipe attached with a knotless netting using zap traps. At the bottom of the net, a lead line inside a rope is attached with zap straps (Figure 20). PVC pipes were used due it's high resilience to dissolution and rigidness. The lead line at the bottom increases the weight of the net allowing it to sink and remain submerged. The overall length of material for each net (extending downwards) is dependant on the depth of the water levels. At Fisherman's Wharf, the water is roughly 3.3 m deep and thus nets at this location are approximately 3 m long. The net placed at Heather Marina was also 3 m long due to deep water. The width of both nets at these locations was 90 cm. At Burrard Civic Marina, one long horizontal net was placed vertically extending 90 cm and horizontally 30m due to shallowness. The rationale for keeping the nets off the bottom is to avoid intertidal species which may act as predators to the eggs (see Appendix B for further description).

2.3.3. Implementation

The vertical nets were placed at least 30 cm apart from each other on Fisherman's Wharf dock A and B. Nets were placed on the west side of the dock to avoid direct sunlight to impede algae growth. Nets were attached to the dock using a string attached to the PVC pipe which was then wrapped around the elevated wooden beam on the edge of the dock and knotted with a bowline knot. Nets were submerged so the PVC pipe was approximately 10 cm underwater. Nets were placed along the docks near boats which were stationary to minimize human interference of the nets; fishermen were consulted before implementation. Heather Civic Marina followed the same protocol. At Burrard Civic Marina, a 90cm x 3000 cm net was installed with the width of the net running parallel to the dock. An empty dock at the south end of this marina was located to host the length of this net. All the nets monitored in this study were placed on January 20th, 2019. See Figure 21 for photos of net placement.

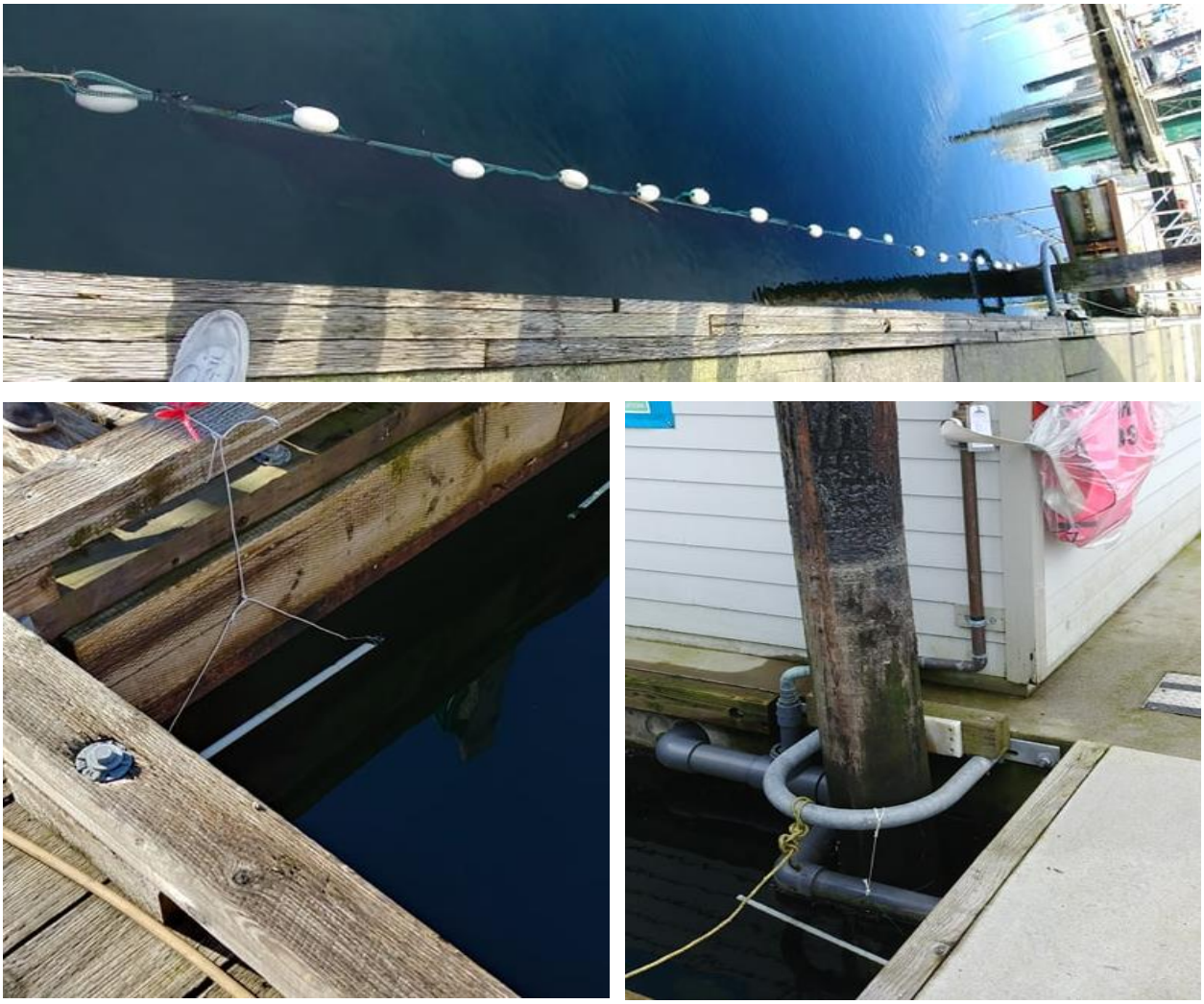


Figure 21. *Photos of net placements across the 3 marinas. Top: Burrard Civic Marina. Bottom left: Fisherman's Wharf. Bottom right: Heather Marina.*

2.3.4. Monitoring Techniques

Our group took turns monitoring the nets weekly for changes in herring egg abundances from February 2nd 2019 to March 3rd 2019. A total of five field surveys were conducted throughout this study period. Surveys were done every week, with the first survey starting on Saturday February 2nd, 2019, and subsequent surveys recorded on Sundays. Surveys started at 10 a.m. in Heather Marina and ended at 12 p.m. in Burrard Civic Marina. We monitored the relative proportion of the herring net covered in herring eggs. This was preferred as counting the number of eggs within a cross-section and then extrapolating for the entire net or counting the number of eggs across the entire net proved to be too difficult with potentially a large amount of human error. Water quality, tide height, and tidal speeds were not recorded during the surveys but general field notes such as time, weather and members present can be found in Appendix C.

To monitor the relative proportion of a herring net covered by herring eggs, we submerged a

GoPro camera attached to a ProGearX GoPro stick approximately 30 cm away from the net center and to specific depths: 45 cm into the water in Heather marina and Fisherman's Wharf, and 30 cm in Burrard civic marina (the GoPro stick had three pegs when extended, each peg representing 15 cm). The difference in depth which we measured at is due to the difference in vertical length of the nets. The GoPro was set on photo and video mode, with photos automatically taken every five seconds. For every survey point, the GoPro was submerged for approximately 25 seconds and allowed at least 10 seconds fully submerged to make sure still photos were taken. Photos and clips were taken for each survey points each week across the study period to assess any differences and changes in herring egg coverage.

2.4 Data Analysis

2.4.1. Quantitative Analysis

In order to determine the relative proportion of a herring net which is covered in herring eggs, we used photos acquired through our survey. The pictures taken at the depths 45 cm and 30 cm of the herring net were analyzed using "supervised classification" within the software ENVI. We selected pixels in the image we knew were herring eggs and used these values to identify the rest of the pixels with similar reflectance values (colour) as herring eggs. The number of pixels recognized as herring eggs were divided by the number of total pixels within the image to give us the relative proportion of herring eggs on a net. This process is done for every survey location every week across the study period which gave us proportion values across geographical distances and time. Figure and

Figure 22 provide an example of the classification result from a photo taken during surveying.

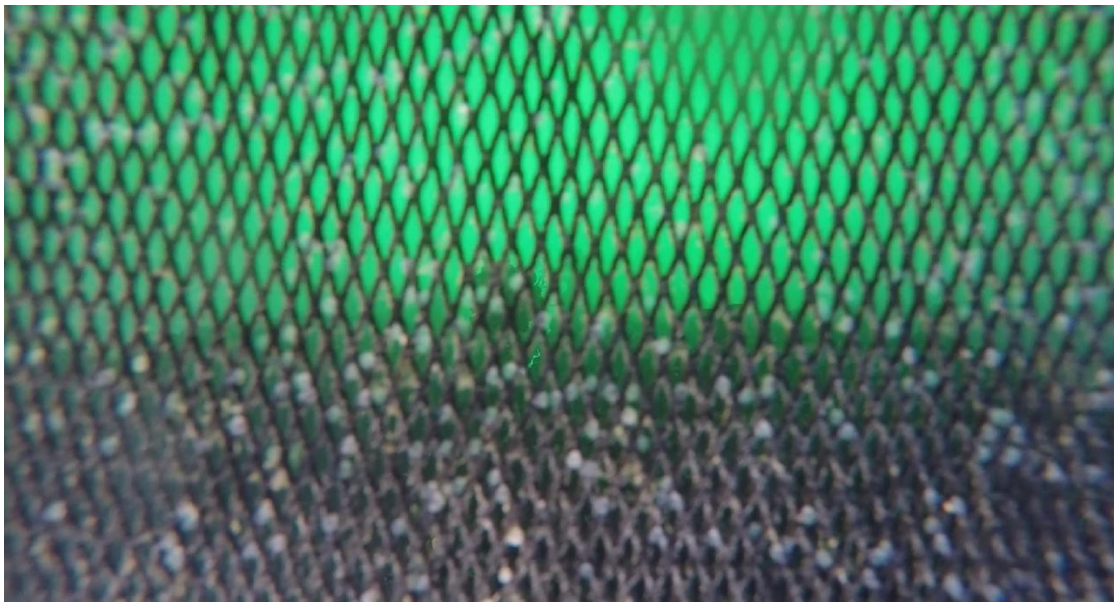


Figure 22. *Photo of Fisherman's Wharf B07 taken at 1 ft below surface on February 17th 2019.*

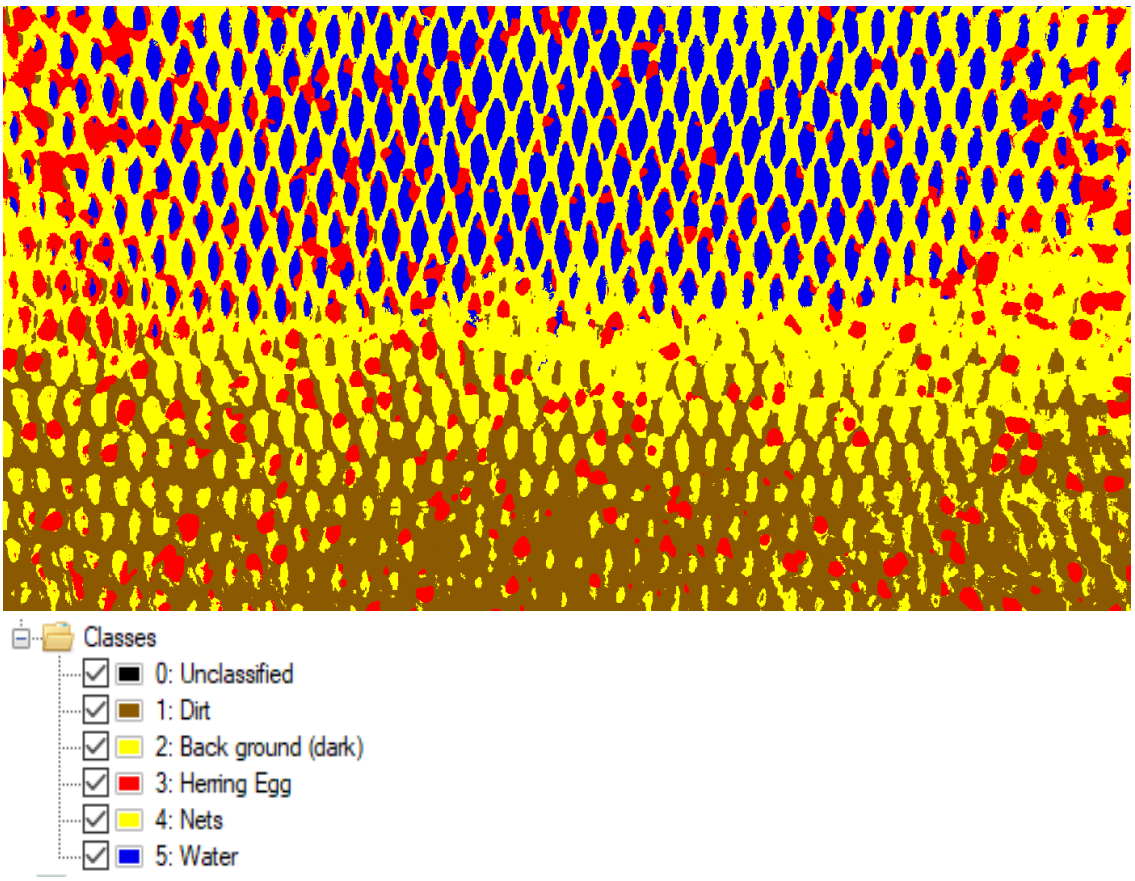


Figure 22. *Classified image of Figure 15 using ENVI.*

2.4.2. Limitations of Data Analysis

Our methodology used carries a lot of limitations and potential errors. Firstly, the photos were taken only at a specific depth into the water and in the center of the net due to equipment limitations. This procedure in itself means the photos captured are not representative of the entire net as herring eggs seemed to be depositing from the bottom and up along the net (The Squamish Streamkeepers, personal interview, November 16, 2018). This also means that although we were capturing a constant depth of water, we may not have been capturing the same distance on the net due to differences in how low the nets were hung in the water. Secondly, the photos were not taken perfectly still due to wave action, resulting in the smoothing of boundaries between different entities such as the herring net and eggs. This made it extremely difficult to determine whether some pixels were herring eggs or herring nets. Lastly, the classification of certain pixels being recognized as herring eggs is limited by the number of electromagnetic bands recorded by our instrument. Our GoPro camera only measures three bands in the visible light spectrum. This can be an issue as objects that are the same color as herring eggs will also reflect the same readings in these bands -- resulting in this method potentially classifying other objects as herring

eggs. This could be avoided if our equipment measured reflectance in other/more electromagnetic bands such as the infrared spectrum.

3. Results

The coverage of eggs on herring nets is considered as an indicator of the activity level of herring spawning at the corresponding location. The data of egg coverage collected from sixteen stations (five from Burrard Civic Marina, five from Fisherman's Wharf Dock A, five from Fisherman's Wharf Dock B, and one from Heather Civic Marina) was analyzed and helped us tentatively answer the following research questions of this project:

1. Does the Squamish Streamkeepers' best management practice support herring spawning in False Creek?
2. Can methods of the Squamish Streamkeepers be replicated elsewhere in False Creek?
3. Where and when do herring spawn in False Creek?

The results will be discussed individually pertaining to the research question:

1) Result: Squamish Streamkeepers' best management practice of installing herring nets support herring spawning in Fisherman's Wharf in False Creek.

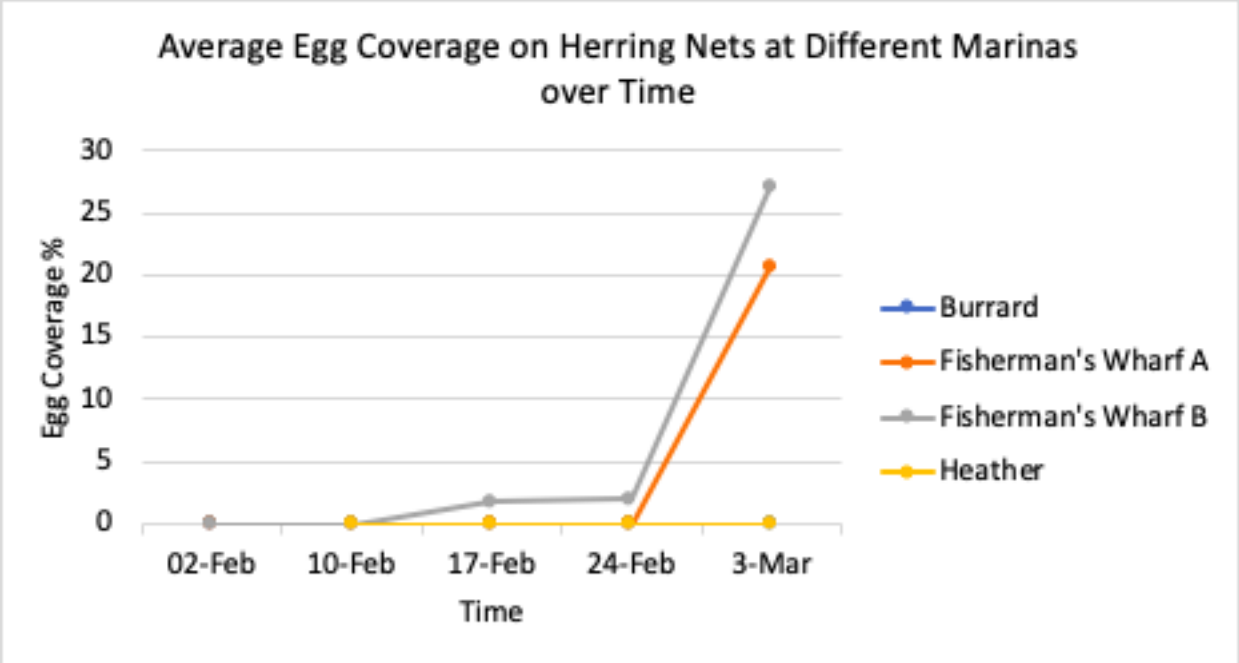


***Figure 23**. Total herring egg coverage (%) of suvery points for each dock studied.*

As seen in Figure 23, on Feb. 17th, 2019, herring eggs were first observed at Fisherman's Wharf Dock B. The average egg coverage at Dock B continued to increase until March 3rd. On March 3rd, 2019, a large increase of herring eggs was observed at both Dock A and Dock B at Fisherman's Wharf, where we witnessed the spawning of herring in action (see Appendix A for image). No eggs were observed at Burrard Civic Marina or Heather Civic Marina during our data collection period.

2) Result: The Squamish Streamkeepers' best management practice does not appear to be replicable elsewhere in False Creek

Figure 23 shows that egg coverages at Burrard Civic Marina and Heather Civic Marina are 0 from Feb.2nd to Mar 3rd, 2019, while the egg coverages at Fisherman's Wharf A are greater than 0 from Feb 24th, and that at Fisherman's Wharf B are greater than 0 from Feb. 17th. This result indicates that herring spawned at Fisherman's Wharf only but not Burrard Civic Marina or Heather Civic Marina. The best management practice is not replicable in Burrard Civic Marina and Heather Marina.

3) Result: Herring's preferred spawning locations and time

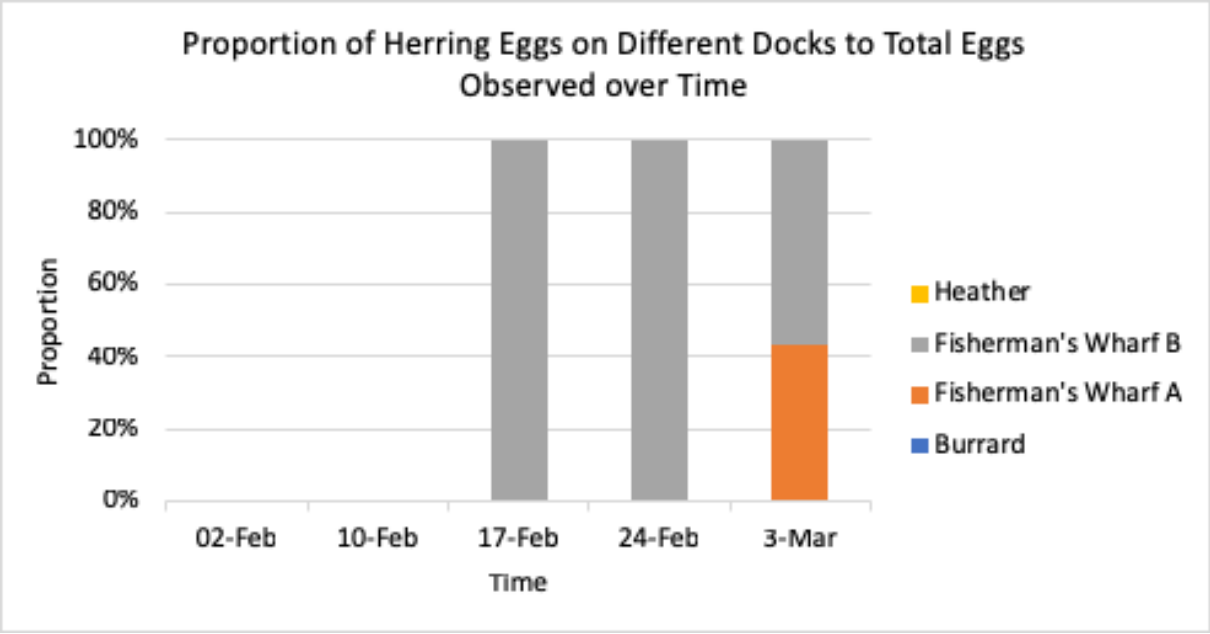


Figure 24. *Herring egg distribution across Burrard Civic Marina, Fisherman's Wharf dock A and dock B and Heather Civic Marina over time.*

Figure 24 shows the proportions of egg coverage at different marina docks in False Creek. From the results, Fisherman's Wharf Dock B is the most preferred dock for herring to spawn as seen with 100% proportion for Feb. 17th and 24th and almost 60% for March 3rd. Fisherman's Wharf

Dock A is the second most preferred dock for herring to spawn with a 40% proportion of eggs on March 3rd. Burrard Civic Marina and Heather Civic Marina do not seem to be preferred as seen by the 0% proportion through the data collection period.

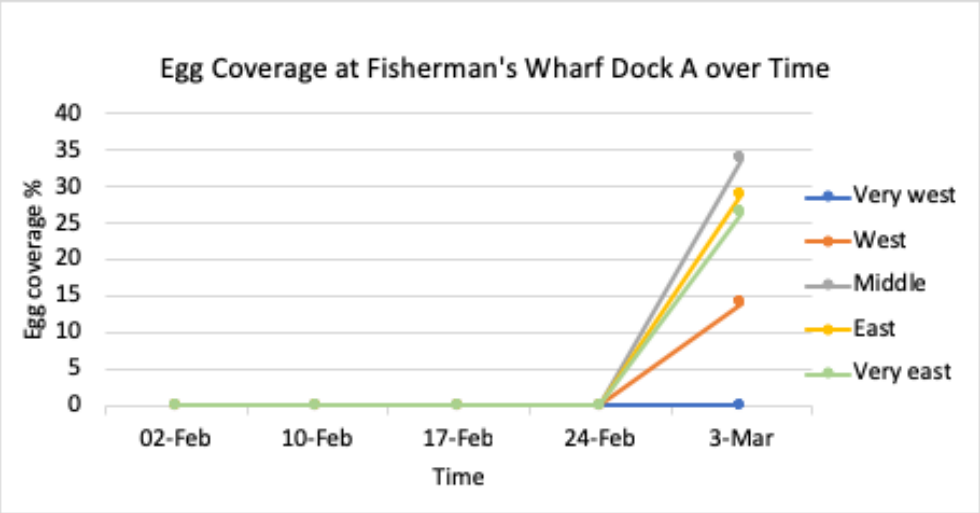


Figure 25*. Egg coverage (%) at different survey points (very west, west, middle, east, and very east) at Fisherman's Wharf dock A over time.*

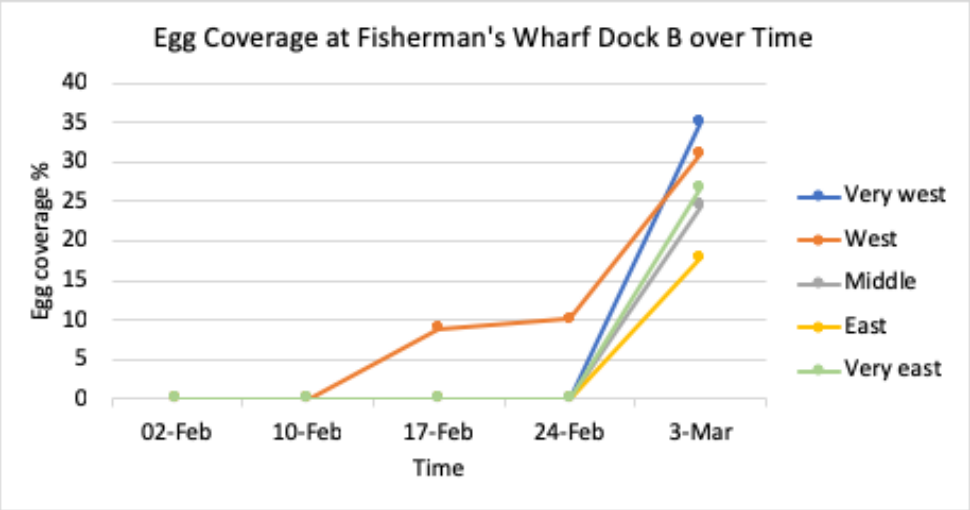


Figure 26. *Egg coverage (%) at different survey points (very west, west, middle, east, and very east) at Fisherman's Wharf dock B over time.*

Within the docks A and B at Fisherman's wharf, a preference of spawning locations was observed. At Fisherman's Wharf Dock A location preference is in the following order: middle, east, very east, west, then very west (Figure 25). Figure 26 shows location preference at Fisherman's Wharf Dock B is in the following order: very west, west, very east, middle, then east. The proportion of herring eggs at each survey point for Fisherman's Wharf is also visually represented in Figure 27

Figure 27.

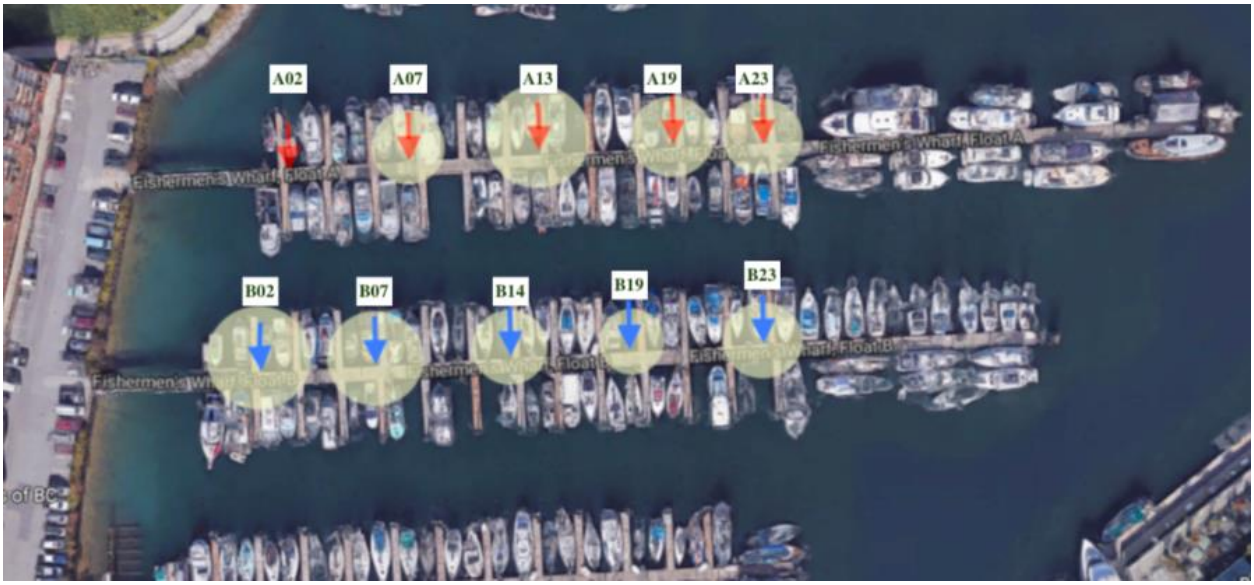


Figure 27*. Spatial distribution map of herring eggs in Fisherman's Wharf. Red arrows indicate the locations where we examine the herring nets at Fisherman's Wharf Dock A, which are A02, A07, A13, A19, and A23 from west to east. Blue arrows indicate the locations where we examine the herring nets at Fisherman's Wharf Dock B, which are B02, B07, B14, B19, and B23 from west to east. The size of the circles is proportional (represented by square metres on the map) to the average egg coverage of nets across five weeks.*

Figure 27 shows that the herring egg population is higher at Fisherman's Wharf B than at Fisherman's Wharf A. A03 and B02 are the most preferred locations for herring spawning, while A02 is the least preferred location for herring spawning.

To see of presence/absence data collected in the field please refer to Appendix C.

4. Discussion

We can conclude that the Squamish Streamkeepers best management practice of herring nets are effective in promoting herring spawning at False Creek, specifically at Fisherman's Wharf. From our results and observations, we are also able to make some inferences about the pattern of herring spawning at False Creek.

Firstly, the highest amount of egg coverage from our results occurred at the west and very west locations of Fisherman's dock B. This was also where we observed herring to be actively spawning. Higher preference for coast locations maybe be attributed to less boat traffic, which as mentioned in the previous literature, serves as a more favourable spawning environment. The late onset of herring spawning that was observed, as seen by the significant increase in egg coverage between the 24th of February and March 3rd could be a result of the cold snap that occurred. Therefore, colder waters may inhibit the onset of spawning. The Squamish Streamkeepers also "cleaned" the nets right before the spawning event occurred. This consisted of taking the nets out of the water, hosing them down and putting them back in. This method

may work to clean off sediment build up and algae on the nets, which may allow eggs to adhere better to the nets. Furthermore, at Fisherman's Wharf, we observed that herring had also spawned on the nearby pilings which had been previously wrapped by the Squamish Streamkeepers, providing more available substrate, especially compared to the other marinas. Pictures taken of eggs on the pilings and the nets were sent to Jeff Marliave who confirmed that solidified the eggs were alive.

The lack of spawning observed at Heather Civic marina could be a result of us not cleaning the net, as the Squamish Streamkeepers did for the others, and therefore the presence of algae could have been a deterrent for spawning. As well, the location of this net was closer to the middle of the False Creek compared to the survey points at Fisherman's Wharf which were closer to the coast. Experiencing more boat traffic leading to added noise and wave action could have impeded spawning at this location as note. Further, more steel pilings were present at this location which may not be a suitable spawning substrate due to it's smooth texture. This observation could also be attributed to the greater depth of water at this location compared to Fisherman's Wharf, as herring prefer shallower water for spawning.

The absence of herring spawning at Burrard Civic Marina could be a result of the length of the nets. While observing the active spawning of herring on March 3rd, we observed that the herring were spawning towards the bottom of the net (~1.5m ft and below) and thus making a 1m net inadequate. As well, Burrard Marina tended to be more exposed to sunlight, promoting algae growth which could have also been a factor. Towards the end of our sampling, the Squamish Streamkeepers installed a plastic tarp over the Burrard net to shade from the sun, and thus may host upcoming spawning events better.

False Creek's legacy of pollution raises concerns for promoting herring spawning. However, E. coli did not seem to have an effect on herring spawning locations. Based on the report of *E.coli* in False Creek, that states the concentration of *E.coli* is highest along the shoreline, (Vancouver Coastal Health, 2018), we would have expected to see spawning inhibited at these coastal survey points. However, the result is not consistent with our results leading us to believe *E.Coli* does not play a factor in herring spawning. Further, differences in egg coverage between Fisherman Wharf's docks maybe be attributed to visible waste pollution. We noticed more waste floating at Fisherman's Wharf Dock A than Dock B which may be seen as a potential threat by herring. As well, we are still uncertain regarding the effects of oil released boats on the viability of the eggs, as oil on the surface of the water was very prominent. Because herring seem to prefer to lay their eggs at depth and oil remains buoyant at the top, this may not be a serious factor.

In summary, although the best management practices of the Squamish Streamkeepers' were successful at Fisherman's Wharf, especially at the end of March, their practice did not appear to be replicable at other locations in False Creek. As our study was the first experiment to monitor

herring spawning in False Creek we recognize our results come with limitations and uncertainties and thus have provided a table with recommendations for improvements below (Table 3).

Table 3. *Table of project recommendations for future use and explanation of how it affected our results.*

Project Limitations	**Description**	**Recommendations**
Time limitation	Our monitoring period was limited by our project timeline and thus we were unable to capture the full herring spawning period.	Since herring spawning runs until the end of April, monitoring during that period of time will result in better observations and results (Hay & McCarter, 2015).
Unusual weather	In February 2019, there was large amounts of snow and temperatures were below average for the month. We think this might have affected the first time herring spawned in False Creek since it might have affected their reproductive phenology and the time of spawning may have occurred later than usual.	Expanding the monitoring time by one or two weeks before and after the spawning season can be a caution taken for weather anomalies.
Algae	We observed a large amount of algae growth and sediment on the nets which affected accurate classification of egg abundance. The algae and sediment may also negatively affect herring spawning. The Squamish Streamkeepers clean the nets by either shaking the nets or hosing them down to avoid this, but	Lowering the nets to avoid heavy solar radiation which supports algae growth will be part of the solution (Xenopoulos et al., 2002). Most reasonable explanation for this is the amount of wastewater that triggers algae growth (Abdel-Raouf et al., 2012). Disinfection and better

	mechanical removal can disturb the eggs and is not an optimal solution since it also requires a lot of labor.	sewage treatment might be required (See Appendix A for images of algae on nets).
Boat disturbance	While boats are docking and leaving the marinas, they can cause turbulence in the water can affect spawning. This was only observed to be a problem in the Fisherman's Wharf.	There are better locations for installing the nets which has zero contact to boats. One of these locations is right under Burrard Street Bridge in Burrard Marina. Many more nets can be installed right next to the piers of the bridge.
Accuracy of pictures	There is not enough consistency when it comes to taking pictures by submerging a camera in the water. Our pictures naturally show some variation in terms of clarity and location (distance from the net and distance from the surface of water).	A camera that also measures distance can be used. Taking pictures with SCUBA can also be an option.
Discrepancies between Marinas	The net that was installed at Heather Civic Marina was not "cleaned" like the nets at Fisherman's and Burrard Marina. Not having clean nets may have deterred herring from spawning and therefore affected accuracy of results.	Improved communication with the Squamish Streamkeepers would allow for the same procedure and timing of cleaning, and therefore would be a controlled factor
Number of nets	Having only one net at Heather Civic Marina most likely did not give an accurate representation of the location.	Ideally, to get an accurate representation of the locations, the same number of nets should be monitored at

		each location in question to decrease the error of the study.
Length of nets	Different lengths of nets were used between Burrard Marina (~ 3ft) and the other two marinas (Heather and Fisherman's, ~10ft). Longer nets may favour spawning. As seen when observing the herring spawning, herring seemed to prefer depth of ~5ft or greater.	The length of the net is dependant on the depth of the water. However, at Burrard, the water is deep enough to install longer nets and should be tried.
Cleaning and rearrange of herring nets during the project	During our monitoring period, Streamkeepers pulled out all the nets and cleaned them on March 1st. After cleaning, they mixed them and put them back randomly.	Since the herring eggs that were spawned on the herring nets would be removed by the cleaning process. It is recommended not to interrupt the nets during the spawning activity. However, before herring spawn, there can be frequent cleaning sessions.
Monitoring of water quality	We were unable to measure in-situ water temperature, salinity and flow speed of the water as it was out of the scope of our project.	Adding water quality monitoring to the weekly data collection methods will better help determine what locations are most suitable for herring spawning by comparing the results to literature.

5. Next Steps

5.1. Citizen Science

According to our observations, one of the most important things going forward is to improve our methods of monitoring the nets during the spawning season. This will require continual communication between the Squamish Streamkeepers and the City of Vancouver to know when and where the nets will be placed every year. This would further allow the city, if chosen to do so, to implement nets in locations that aren't currently utilized by the Squamish Streamkeepers. An increase in the number of nets along with improved weekly monitoring would require a great amount of involvement and thus should be tackled as a big team of enthusiastic people.

5.1.1. "Adopt a Net"

Our first proposal is an "Adopt-A-Net" project where members of the community around False Creek can take responsibility of monitoring the nets between the time of installment and removal of the nets. The first step would be to create awareness to encourage people to sign-up. During our work at the various marinas, we observed just how keen fishermen, boat owners, and marina personnel are on helping the Squamish Streamkeepers. Reaching out to them would be a good start to see if anyone is interested in participating. A promotion on CityStudio website is also a good start for reaching out to other community members. Posters can be displayed around False Creek and brochures can be distributed in shops and restaurants to further promote the cause and get people to sign up (Figure 28).

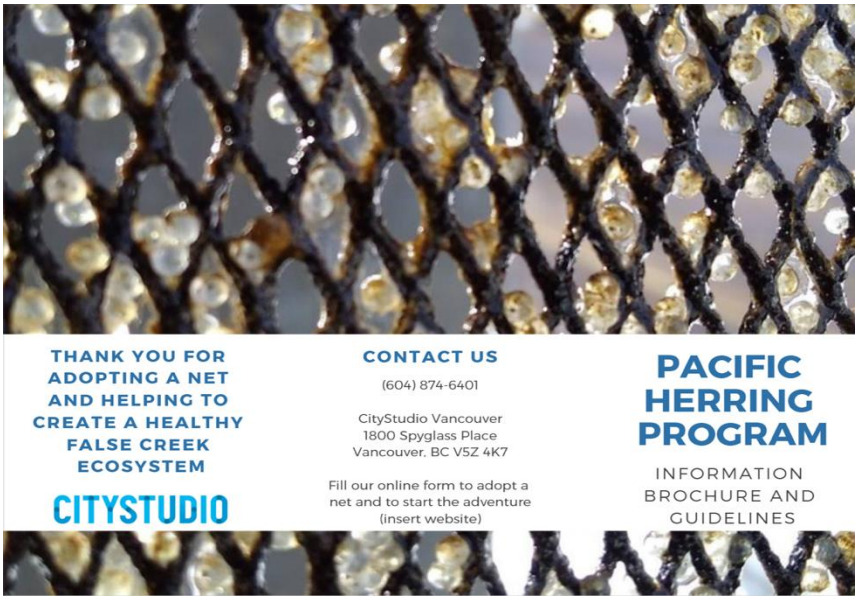


Figure 28. *Template for a possible tri-fold brochure of the "Adopt-a-Net" program.*

A simple website could also be created where people can submit personal information for further communication. Each net can be assigned a number, and each person can be assigned a net by an email with the location and number of the net to be monitored. The next step is to create another survey site where citizens will submit their observations. Not everyone has the tools to quantify eggs like we have done thus the best way to obtain information would be through citizens collecting presence/absence data from visual observations while not disturbing the nets. The number of the net, date, time, and presence/absence should be submitted to create a dataframe. Additional comments such as the intensity of the eggs, weather, and any other observations can be submitted for more information. If the person has access to an underwater camera, or any camera to take pictures, an image submission link can also be added.

5.1.2. Collaboration with classrooms

To reach out to more people, not only to promote the project but also educate people on the natural ecosystems in the city and marine life, CityStudio can share this project with other organizations.

Teaching is a very effective tool to involve people from all ages to work together. CityStudio can collaborate with elementary schools and high schools to make this a project of interest for kids and youth. Some schools close to False Creek that can be contacted are; Henry Hudson Elementary School, Elsie Roy Elementary School, St. Patrick Elementary School, St. John's School, Sir Charles Tupper Secondary School, and Kitsilano Secondary School.
All science classes have the aim to get hands-on experience to improve analysis and data collection skills. These skills can be gained by conducting experiments and observations. The

monitoring program can be continued by students or a field trip can be arranged to False Creek to have a field lecture given by a guest lecturer from CityStudio, the Squamish Streamkeepers or researchers from local universities. Topics of discussion can include: life history/cycle of herring, importance of herring in the British Columbia ecosystem, herring as an important fisheries source and broader concepts such as trophic cascades and keystones species in the Pacific Northwest. All of our team members are willing to assist CityStudio in the future if this kind of project happens. BC's New Curriculum suggests there are some subjects that can be associated with fisheries science and herring reproduction ("BC's New Curriculum", 2019);

- Grade 3 science: "biodiversity in the local environment" and "ecosystems"
- Grade 4 science: "biomes"
- Grade 8 science: "characteristics of life"
- Grade 11 environmental science: "sustainability of ecosystems" and "stewardship and restoration of ecosystems"

5.1.3. Collaboration with the Vancouver Aquarium

The Vancouver Aquarium is a popular tourist/local attraction and therefore a collaboration would be significant in educating the public on the importance of herring on our coasts. The aquarium currently has an exhibit which features herring and other pacific northwest fish, therefore a display linking that exhibit to the local community initiatives of the Squamish Streamkeepers could provide an exciting opportunity. This display could be put on during the herring spawning period and include an example net, maps showing where the public can observe the spawning at False Creek and potentially present an enclosure which could host the hatching of eggs. As well, this collaboration would provide a clear overall picture of the importance of herring in the food web in the Pacific northwest as predators (and fan favourites), including seals and sea lions, are also present at the aquarium. Brochures, as mentioned above, could also be provided at this display.

5.1.4. iNaturalist

"iNaturalist" is a citizen science project and online social network of naturalists, citizen scientists and biologists. As an app, this would allow community members, particularly interested in science, to easily document their observations of herring spawning around False Creek. From this, CityStudio would be able gain reliable data and aid in the monitoring process.

5.1.5. NGO Partnership

Another partnership possibility is reaching out to non-governmental organizations (NGOs). NGOs can adopt projects that will attract volunteers. Urban ecosystems like False Creek are understudied and many people would want to witness an ecological phenomenon like this in

False Creek. The existence of an ecologically important species such as Pacific herring is a rare thing to observe in such dense urban areas and therefore it may attract many people that are willing to contribute voluntarily. This collaboration can be very successful to further reach out to local citizens by increasing publicity and promotion of the project. Here are some NGOs that are close to False Creek and have adopted similar projects before;

- Wilderness Committee
- Pacific Wild: Currently have an initiative "BigFishLittleFish" which aims to protect herring populations from overfishing on our coast.
- Greenpeace Canada
- Environmental Youth Alliance
- Ecojustice
- Nature Trust British Columbia

Many of these NGOs have worked with fisheries and marine ecosystems before. A common conservation project is protecting salmons in rivers and the conservation of Southern Resident Killer Whales (SRKW). Some salmonid species such as the Chinook salmon prefer to eat herring in British Columbia. Chinook salmon is also a huge part of the diet of SRKW (Ford & Ellis, 2006). Hence, most of these NGOs already have a good understanding on how important herring is in the food chain and they will have a motivation to take part in our project.

5.2. Further Research

This study provided a ground base for a more expansive location study that could be done regarding herring spawning. Further research would be to test more locations, including the north side of False Creek as well as more locations on the south side. Our third location, Heather Civic Marina, was a distance of approximately 2.5km, allowing for the opportunities of net placement in between our locations. This would further knowledge of precisely how far the herring swim into False Creek to spawn. As well, as a consequence of our project limitations, further topics that should be explored include:

- How algae/sediment on the nets affects herring spawning,
- How sunlight and placement of the nets in regards to the sun's trajectory affects herring spawning.
- Effects of fast/slow moving water on herring spawning.
- What is the minimum length the nets should be?
- How future development at False Creek, including the shift towards concrete pilings at Burrard Marina, will affect the Squamish Streamkeepers project.

- How can the community members accurately monitor the egg coverage of the nets without lifting the nets out of the water?
- Effects of oil and gases from marinas on viability of eggs.
- Could the transplantation of eelgrass be a viable solution to increase spawning substrate at False Creek?

There are numerous questions that still need to be explored and answered in regards to herring spawning at False Creek and the use of herring nets to support spawning.

6. Conclusion

Pacific herring is a species that has an important value both economically and ecologically in British Columbia waters. Hence, it is important to study herring and research ways to increase herring populations in the of Strait of Georgia. From this study we can conclude that the methods of the Squamish Streamkeepers do promote Pacific herring spawning in False Creek waters and can now be supported through quantifiable data. Although further research and actions are still required, this finding supports the City of Vancouver's goal of increasing access to nature as well as future community involvement.

7. Acknowledgments

We would like to thank our community project partners Angela Danyluk and Ileana Costrut from CityStudio Vancouver for their guidance and inspiration behind this project. As well, we would like to express our appreciation for our course instructors Michael Lipson and Tara Ivanochko for their assistance, motivation and support in our project. Finally, we would like to thank the Squamish Streamkeepers for fully welcoming us into their project and taking the time to teach us about herring spawning at False Creek.

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8. Appendix A

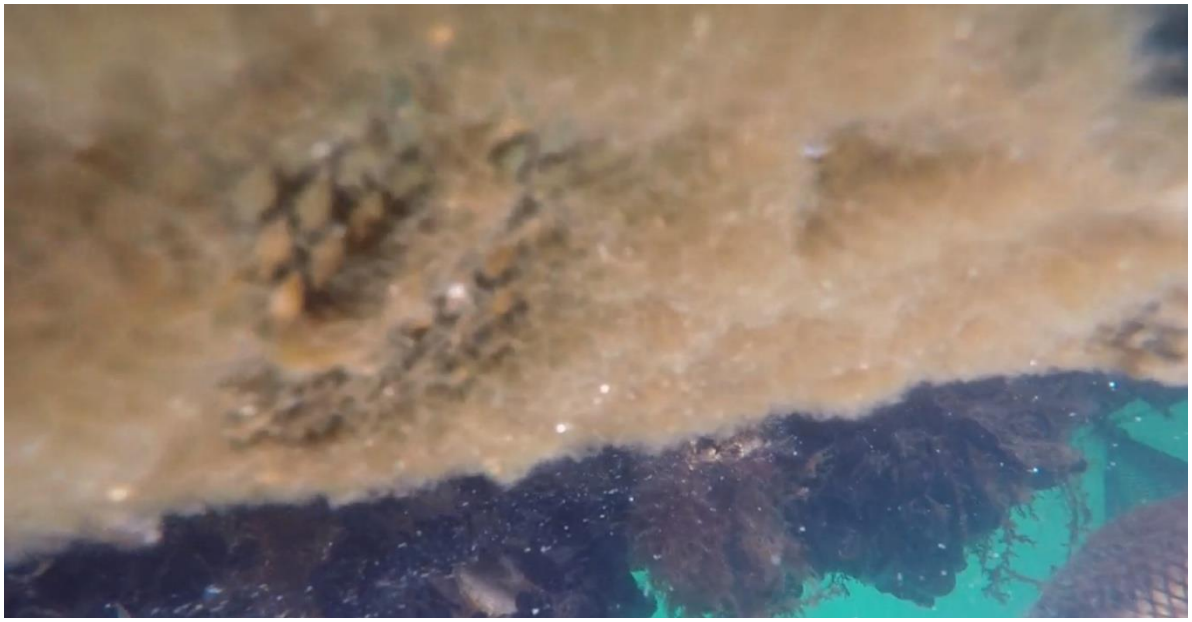

***Figure 29**. Algae were observed on nets in clumps in Burrard Marina. Picture taken by GoPro on February 24th, 2019.*

***Figure 30**. Picture of the net in Burrard Marina, covered in algae and sediment. Picture taken by GoPro on February 24th, 2019.*

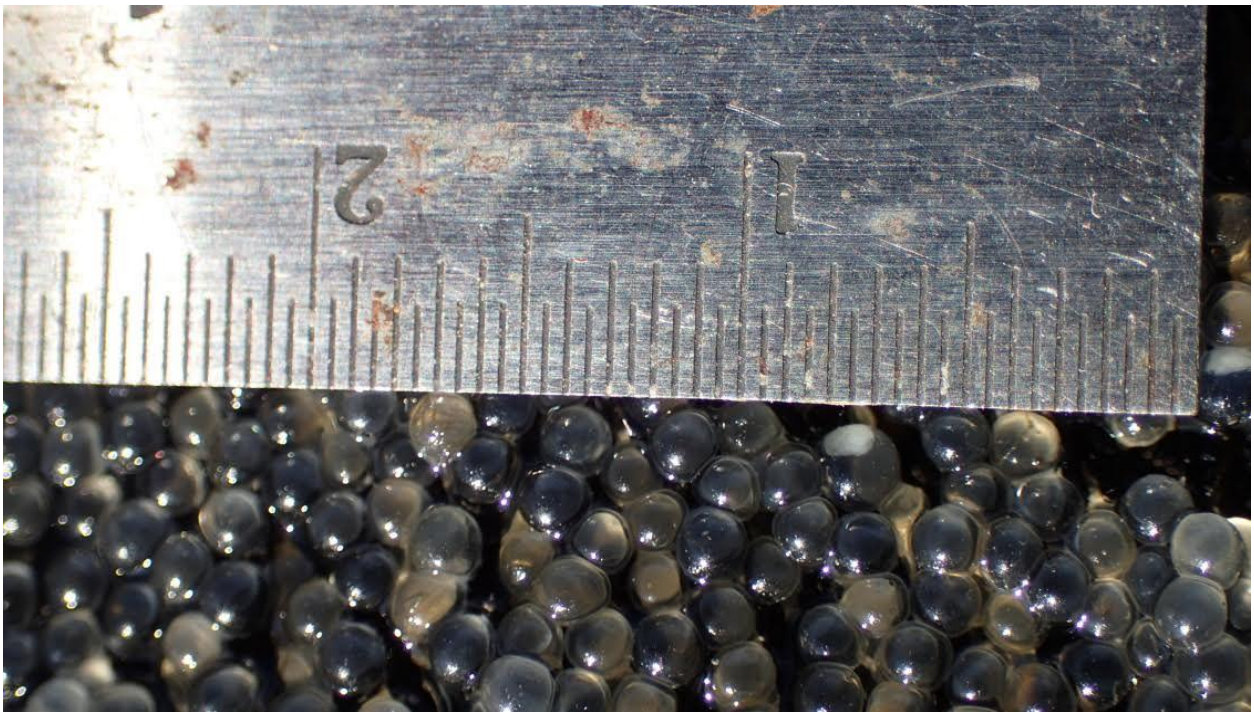

Figure 31*. Photo taken by Jonn Matsen of the Squamish Streamkeepers of net at location 1 on Fisherman's Wharf A on March 9th, 2019.*

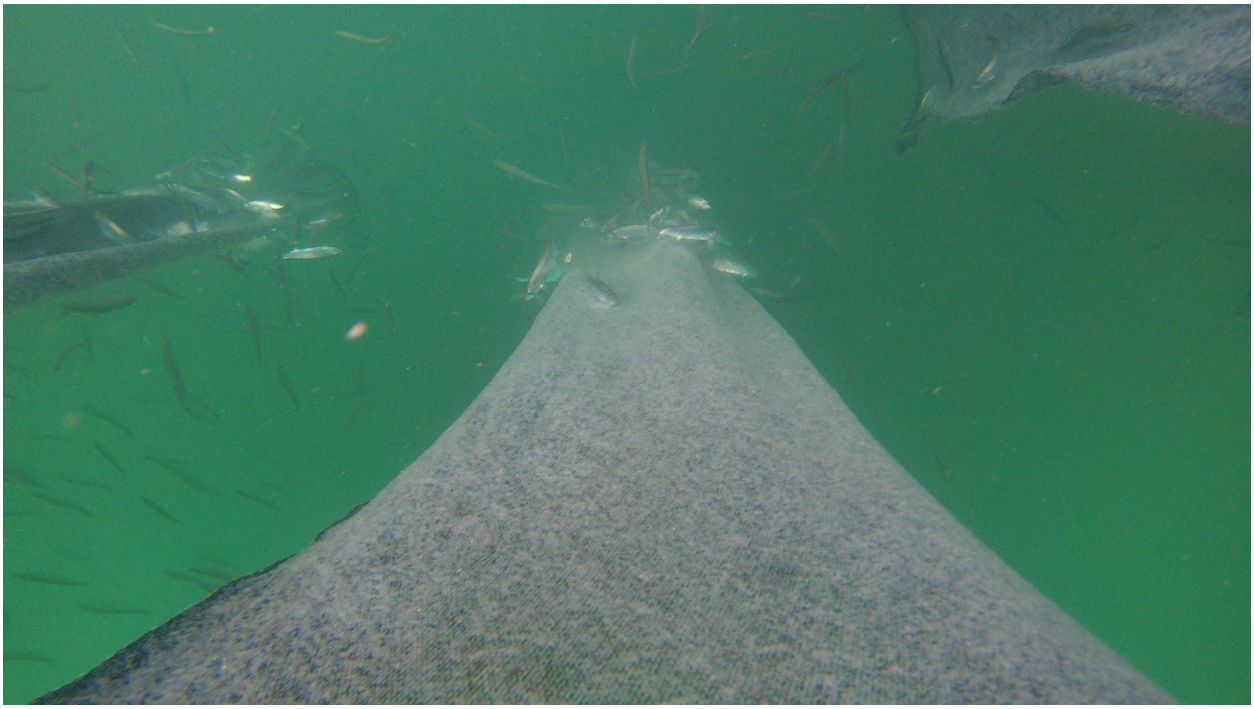

Figure 32. *Witnessed herring spawning at Fisherman's Wharf dock A on March 3, 2019. Picture taken by Meg Lovett.*

Table 4. *Number of eggs per cubic meter that can be laid by Pacific herring and corresponding intensity class (Hay, 1985). This table can be used to scientifically classify the intensity of spawning on the nets.*

Intensity classification	Estimated number of eggs/m^2
Very light	50,000
Very light to light	180,000
Light	420,000
Light to medium	665,000
Medium	1,008,000
Medium to heavy	1,417,000
Heavy	1,889,000
Heavy to very heavy	2,423,000
Very heavy	3,019,000

9. Appendix B

Methodology of herring nets, installation & monitoring

Herring nets have been shown to provide non-toxic substrate for herring nets to lay their eggs on, facilitating an increase in herring spawn rates and amount (Matsen, 2018). This appendix will review the steps used to create, implement, monitor and remove the herring nets used in this study.

Creating the nets

Each herring net was made using 90 cm of PVC pipe attached with a knotless netting (nylon) using zap traps. A thin rope is fit through the PVC pipe and then double knotted near the center of the pipe, making sure there is a long loose end of the rope in the center. This end will be used to tie the net onto the dock. At the bottom of the net, a lead line inside a rope is attached with zap straps. PVC pipes were used due its high resilience to dissolution and rigidness. The lead line at the bottom increases the weight of the net allowing it to sink and remain submerged (Figure 34). The overall length of material for each net (extending downwards) is dependant on the depth of the water levels. At Fisherman's Wharf, the water is roughly 330 cm deep and thus nets at this location are approximately 300 cm long. The net placed at Heather Marina was also 300 cm long due to deep water. The width of both nets at these locations was 90 cm. At Burrard Civic Marina, one long horizontal net was placed vertically extending 90 cm and horizontally 300 cm due to shallowness. The rationale for keeping the nets off the bottom is to avoid intertidal species which may act as predators to the eggs. The materials can be purchased at any general fishery store or equipment store like Deakins equipment or MEC. A picture of the net is shown below:

Figure 34*. Herring net design and parts.*

Location and placement

The study area for this project was at three marinas: the south end of Burrard Civic Marina, docks A and B in Fisherman's Wharf and along the North dock in Heather Civic Marina.

Figure 35. *Survey locations of herring nets across False Creek shown above. Pink indicators represent Burrard civic marina nets, blue indicators represent fisherman's wharf herring nets and the green indicator (right side) represents the placement of the Heather C.*

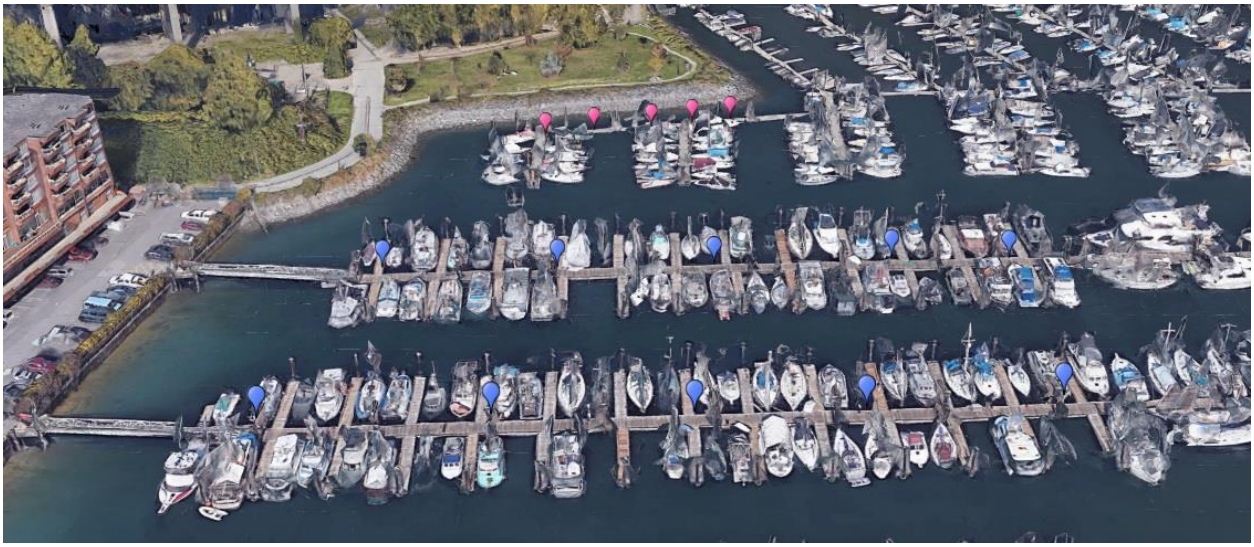

Figure 36. *A close up image of the exact survey locations within Burrard Civic Marina (pink) and Fisherman's wharf (blue).*

These locations were chosen because of their ideal characteristics: extends perpendicularly outward from the shoreline, allowed for north facing net placements, were generally well shaded and had circulating water (Figure 35 & Figure 36). The docks extending perpendicular from the shoreline is ideal as it captures herrings which may swim through the center of the creek rather than along the shore. The ability to place nets north facing and in well shaded circulating water is ideal as it reduces the occurrence of other marine organism which uses light from occupying the space.

We surveyed each marina differently as the net placement by the Squamish streamkeepers differed for each marina. For Burrard Civic Marina, we monitored the singular net placed by the Squamish Streamkeepers which is located at the south end. This net extends 3000 cm horizontally so we will be measuring five points evenly across this distance. For Fisherman's Wharf, we will be surveying ten evenly-spaced herring nets across two docks (5 nets in dock A and 5 nets in dock B), with dock A being the northern dock, and dock B being just south of dock A. Nets will be named A1 - A5 (or B1 - B5), with letters representing which dock and numbers 1-5 representing nets placed from east to west. Only docks A and B will be monitored as the only nets placed by the Squamish Streamkeepers are within these docks. Lastly, a single net was set and monitored by us in the North end of Heather Civic marina. The rationale behind only implementing 1 net was because we were only granted access to one location in this marina. A figure of the placement is shown in figure 37.

The vertical nets were placed at least 30 cm apart from each other on Fisherman's Wharf dock A and B. Nets were placed on the north side of the dock to avoid direct sunlight to impede algae growth. Nets were attached to the dock using a string attached to the PVC pipe which was then wrapped around the elevated wooden beam on the edge of the dock and knotted with a bowline

knot. Nets were submerged so the PVC pipe was approximately 10 cm underwater. Nets were placed along the docks near boats which were stationary to minimize human interference of the nets; fishermen were consulted before implementation. Heather Civic Marina followed the same protocol. At Burrard Civic Marina, a 300x90 cm net was installed with the length of the net running parallel to the dock. An empty dock at the south end of this marina was located to host the length of this net. All the nets monitored in this study were placed on January 20th, 2019.

Figure 37. *Photos of net placements across the 3 marinas. Bottom: Burrard Civic Marina. Top right: Fisherman's Wharf. Top left: Heather Marina.*

Monitoring

Our group took turns monitoring the nets weekly for changes in herring egg abundances from February 2nd 2019 to March 3rd 2019. A total of 5 field surveys were conducted throughout this study period. Surveys were done every week, with the first survey starting on Saturday February 2nd, 2019, and subsequent surveys taken on Sundays. Surveys started at 9 a.m. in Heather Marina and ended at 12 p.m. in Burrard Civic Marina. We monitored the relative proportion of the herring net covered in herring eggs. This was preferred as counting the number of eggs within a cross-section and then extrapolating for the entire net, or counting the number of eggs across the entire net proved to be too difficult with potentially a lot of human error. Water quality, tide height, and tidal speeds were not recorded during the surveys but general field notes such as time, weather and members present can be found in Appendix C.

To monitor the relative proportion of a herring net covered by herring eggs, we lied on our stomachs on the dock and submerged a GoPro camera attached to a ProGearX GoPro stick approximately 30 cm away from the net center and to specific depths: 45 cm into the water in Heather marina and Fisherman's Wharf, and 30 cm in Burrard civic marina (the GoPro stick had three pegs when extended, each peg representing 15 cm). The difference in depth which we measured at is due to the difference in vertical length of the nets. The GoPro was set on photo and video mode, with photos automatically taken every five seconds. For every survey point, the GoPro was submerged for approximately 25 seconds and allowed at least 10 seconds fully submerged to make sure still photos were taken. Photos and clips were taken for each survey points each week across the study period to assess any differences and changes in herring egg coverage.

Cleaning

Cleaning of the herring nets only were done with nets covered in either dust or algae. The decision to clean the nets had no scientific basis however, and simply was done to free up space to allow herrings to lay their eggs. The nets are first lifted out of the water and then sprayed with water using a high power water hose (found in marinas). This process was only done by the Squamish Streamkeepers and was done once on March 1st, 2019 with the Fisherman's wharf and Burrard marina's nets we were monitoring.

Removal

Nets were remove simply by untying the bowline knot and lifting the nets up and out of the water. Make sure to always be holding onto the net while untying to prevent it from falling into the water when the knot becomes loose. After the net is untied and out of the water, the net should be hosed down to remove any material still attached.

Safety

Make sure the goPro camera and stick are securely attached to one another before submerging the device into the water. If not properly secured, it could drop and be dangerous to retrieve. Going on your knees or stomach is ideal when placing/removing the nets, as well as when monitoring with a goPro because the water surface will be roughly 1 m in elevation below the platform on the dock. Remove all hats or glasses when performing the monitoring procedures as your body will be angled downwards and will often lead to objects which aren't perfectly secured to drop. Lastly, depending on the marina's policy and the participants ability to swim, wear a life jacket when working on the marinas.

10. Appendix C

Field notes on February 2nd, 2019:

Members: Cordelia, Carey, Meg, Lal
Weather conditions: sunny

Field notes on February 10th, 2019:

Members: Cordelia, Carey
Weather conditions: sunny and windy for Heather, cloudy and windy with little snow at Fishermen's Wharf and Burrard

Field notes on February 17th, 2019:

Members: Lal, Carey
Weather conditions: Cloudy, sunny.
Start/end time: 9:12 a.m. (Heather Marina) - 10:22 a.m. (Burrard Civic Marina)
Notes: Light snowfall/precipitation at the end of survey (last 5 minutes). Encountered the Squamish Streamkeepers monitoring nets as well. Eggs were observed in net B07, with greater concentration of eggs near the bottom of the net.

Field notes on February 24th, 2019:

Members: Carey
Weather conditions: Cloudy, sunny
Start/end time: 10:06 a.m. (Heather Marina) - 11:20 a.m. (Burrard Civic Marina)
Notes: Algae species were present on several dock B nets in Fisherman's Wharf, and the entire Burrard Civic Marina net was covered in Algae.

Field notes on March 3rd, 2019:

Members: Cordelia, Meg
Weather conditions: March 3rd: sunny, little wind
Notes:

- Before March 3rd, the Squamish Streamkeepers pulled all the nets out and cleaned them including the ones that we were monitoring. After cleaning, all nets were mixed up together and were put back in the water randomly. We started monitoring the new nets at the locations assigned before as usual.
- A herring school was found moving in the shallow water at Dock B at Fisherman's Wharf.

Table 5. *The information contains the herring egg coverage on the herring nets which were chosen to be examined at Burrard Civic Marina, Fisherman's Wharf A, Fisherman's Wharf B, and Heather Civic Marina. Station numbers of 1, 2, 3, 4, and 5 represent the posit*

Date	Burrard Stations	Presence %	Fisherman's Wharf A Stations	Presence %	Fisherman's Wharf B Stations	Presence %		
02-Feb	1	0	1	0	1	0		
02-Feb	2	0	2	0	2	0		
02-Feb	3	0	3	0	3	0		
02-Feb	4	0	4	0	4	0		
02-Feb	5	0	5	0	5	0		
Date	Burrard Stations	Presence %	Fisherman's Wharf A Stations	Presence %	Fisherman's Wharf B Stations	Presence %	Heather Station	Presence %
10-Feb	1	0	1	0	1	0	1	0
10-Feb	2	0	2	0	2	0		
10-Feb	3	0	3	0	3	0		
10-Feb	4	0	4	0	4	0		
10-Feb	5	0	5	0	5	0		
Date	Burrard Stations	Presence %	Fisherman's Wharf A Stations	Presence %	Fisherman's Wharf B Stations	Presence %	Heather Station	Presence %
17-Feb	1	0	1	0	1	0	1	0
17-Feb	2	0	2	0	2	0.0891		
17-Feb	3	0	3	0	3	0		
17-Feb	4	0	4	0	4	0		
17-Feb	5	0	5	0	5	0		
Date	Burrard Stations	Presence %	Fisherman's Wharf A Stations	Presence %	Fisherman's Wharf B Stations	Presence %	Heather Station	Presence %
24-Feb	1	0	1	0	1	0	1	0
24-Feb	2	0	2	0	2	0.1017		
24-Feb	3	0	3	0	3	0		
24-Feb	4	0	4	0	4	0		
24-Feb	5	0	5	0	5	0		
Date	Burrard Stations	Presence %	Fisherman's Wharf A Stations	Presence %	Fisherman's Wharf B Stations	Presence %	Heather Station	Presence %
3-Mar	1	0	1	0	1	0.352	1	0
3-Mar	2	0	2	0.1401	2	0.3114		

3-Mar	3	0	3	0.3387	3	0.2449		
Date	Burrard Stations	Presence %	Fisherman's Wharf A Stations	Presence %	Fisherman's Wharf B Stations	Presence %	Heather Station	Presence %
3-Mar	4	0	4	0.289	4	0.1797		
3-Mar	5	0	5	0.264	5	0.2678		