Fucus gardneri in North East False Creek

Assessing Urban Intertidal Ecology in Vancouver

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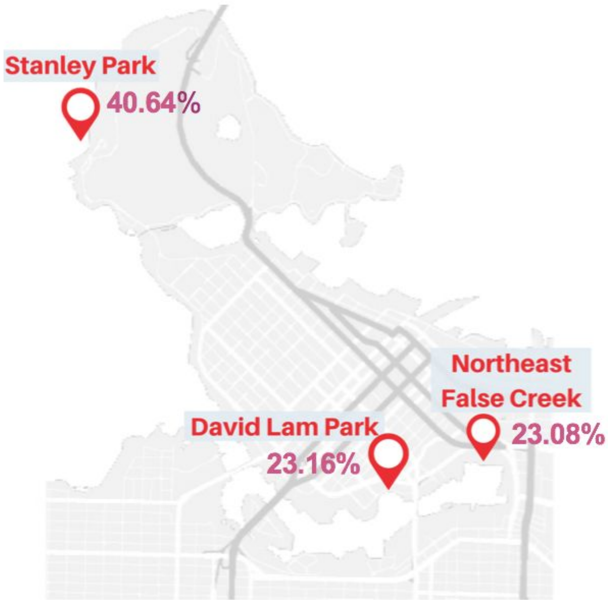
Executive Summary

In 2015, the City of Vancouver proposed a redevelopment plan of Northeast False Creek (NEFC). The new plan consists of more cultural centres, 32 acres of local parks and a redesign of its shoreline (City of Vancouver, 2017). **The shoreline's redesign is currently underway which will lead to a change in the structure and function of the shoreline, improving marine habitat, enhancing biodiversity and connecting oceans with local NEFC Vancouver communities.** Our environmental science research project involved working with a community partner from the City of Vancouver to help restore these natural urban ecosystems.

To learn more about the current condition of NEFC shorelines we studied a type of seaweed called Rockweed for our main focus. Rockweed, scientifically known as *Fucus gardneri* (picture next page), is a common intertidal seaweed that is easy to identify from its vibrant greenish brown colours and abundance along Vancouver's shorelines. It is a major food source for fish, limpets and bird species in the regions of intertidal zones. Additionally, this iconic seaweed is quite tolerant to polluting conditions and freezing temperatures, which is why it was chosen as the focus for our research. **By comparing Rockweed in NEFC to more natural shorelines, we could compare its abundance, reproductive levels, habitat diversity and water conditions for appropriate decisions on the new shoreline reconstruction.**

We chose three different locations to compare the Rockweed and shoreline water conditions: **Stanley Park, David Lam Park,** and **Northeast False Creek** shorelines. Here's a map of downtown Vancouver and the three locations we collected Rockweed samples from. We found a significant amount of percent cover of Rockweed in Stanley Park than compared to the two other locations.



Our main objectives were:

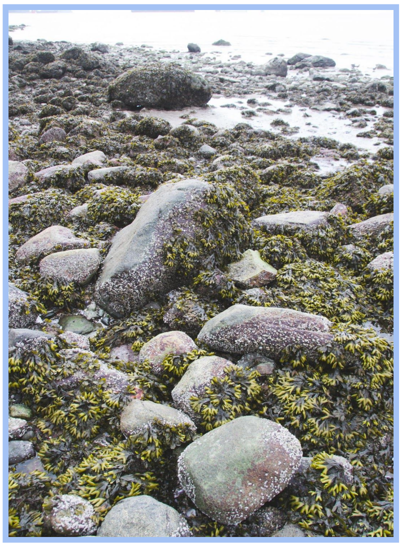
1) To distinguish the differences in characteristics of Rockweed's abundance, percent cover, reproduction, and length at three sampling locations: Stanley Park, David Lam Park and Northeast False Creek.

2) To determine whether or not there is a significant difference in abiotic water conditions (pH, salinity) at the three sites.

3) For each sampling location, determine and classify which of the following variables best correlate to the percent cover of *F. gardneri*: substrate type, substrate length, substrate texture, tidal elevation, percent cover of bare rock presence of other species.

On the right -> is a sample of a **reproductive Rockweed** from one of our field data collection nights. From which of the three locations (pictures on the next page) was this Rockweed found in? (Answer at bottom of last page)

Photo Credit: Carlina Kim

Stanley Park	Northeast False Creek	David Lam
		

Types of rocks in each location:

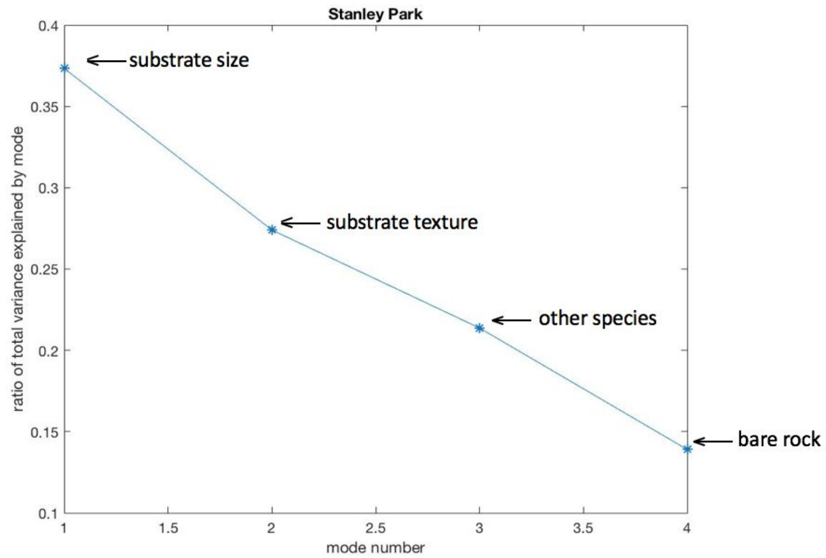
• Variety of sizes • Smooth and rough types • Provides good habitat for Rockweed	• Rip rap • Angular • Uniform • Large in size	• Cobbles • Rounded • Uniform • Small in size

We found that Stanley Park has significantly more reproductive, percent cover and abundance in Rockweed compared to sites of David Lam Park and NEFC. After analyzing and comparing these three sites, these were our main findings from our objectives.

Findings:

1. Stanley Park has by the far the greatest amount in variables of percent cover, abundance, length of the species, and reproductive capabilities. Rockweed loves Stanley Park!
2. There is no significant difference in pH values across all three sites and salinity values fluctuate too much in a day to see any significance.
3. The slope of the shoreline was shallower and more complex at Stanley Park.
4. Variation in size and type of habitable rocks correlated most strongly with high percent cover.

After data collecting over the course of three months, we determined the key relationships between the variables. Here are our results.



The plot illustrates the ratio of total variance of percentage cover explained by each relevant factor. The including factors are substrate size, substrate texture, other species and bare rock. Substrate size was determined as the most crucial factor impacting the percentage cover variation, as it explained most ratio of variance.

We encourage the City of Vancouver to increase the diversity in size and type of habitable rocks to better support attachment by Rockweed and other species. This will result in better support for Rockweed and higher species diversity. Also, gradual shorelines are recommended for re-designing to reduce environmental stress and competition for space. Our team hopes our research will help inform decisions makers and city developers on pursuing the construction of suitable shorelines that can best support Rockweed, increase in marine species diversity, and increase connections between the city and natural communities.

If you guessed Stanley Park you are correct!

Abstract

The City of Vancouver is planning the redevelopment of North East False Creek (NEFC) and the design process is currently underway (City of Vancouver, 2017). False Creek used to be a tidal salt marsh, but now resembles a rocky intertidal shoreline, where *Fucus gardneri* (also known as Rockweed) is commonly found. The primary goal of this study is to understand the distribution and abundance of *F. gardneri* across three locations 1) Stanley Park, near Third Beach, 2) the foot of Drake Street, east of David Lam Park 3) the shoreline Northeast of Science World. Project results will inform the design of the new NEFC shoreline that can best accommodate *F. gardneri*, a major food source for fish and bird species in the regions of intertidal zones (Adams et al 2012). We recorded substrate type & size, abundance (number of *F. gardneri* individuals) present in the transect, percent cover, number of reproductive individuals, presence of other species, bare rock percentage and abiotic conditions as variables for this comparative study. *F. gardneri* in Stanley Park had significantly greater reproductive traits, abundance and percent cover. We used Principal Component Analysis (PCA) and found that of all variables, substrate size and type best correlated with percent cover of *F. gardneri* at each location. No significance was found for abiotic conditions of pH levels and salinity. We did find David Lam and NEFC to have much steeper elevations than Stanley Park. We recommend to the city more diverse substrate sizes and types and gradual shorelines to best support *F.gardneri* in NEFC. This redesign will create more opportunities to enhance biodiversity, increase accessibility to shorelines and connections between city and nature.

Author Biographies

Jodie Nowell is a 4th year Environmental Sciences student with her concentration in land, air water and soil, and has always been passionate about environmental sustainability. Jodie completed multiple field courses from which she has acquired strong field work skills and loves working outside. Additionally, she has completed multiple independent and group research projects and has held leadership positions in various clubs and organizations. This past summer, she worked with Parks Canada, conducted some intertidal field work at the Clam Gardens restoration project in the Gulf Islands National Park Reserve.

Carlina Kim is a 4th year Environmental Sciences student with a concentration in land, air, water, and soil systems. Carlina has completed various group work projects (ENVR 200/300) and other independent research projects that allowed her to understand the fundamentals of successful group and research work while developing leadership qualities. She has taken courses related to this project including statistics, ecology, experimentation process, and aqueous environmental chemistry. Her passion for the environment and climate justice comes from her love for hikes and nature photography

Lisha Ge is a 4th year Environmental Sciences student with a concentration in land, air, water, and soil. Lisha has completed multiple field courses (BIOL 230/306) that helped her to accumulate field work experience on some extent. Her backgrounds include experience in physical oceanography, marine ecology and machine learning. This past summer, she worked as a lab assistant in a marine ecological environmental monitoring station, which provided her an experience in real research setting and being familiar with analyzing chemical and physical properties of seawater and sediments samples according to standard analytical methods. Besides, during the past two years, she has learnt R and Matlab programming and have experience in manipulating large data sets.

Xiaoyu Yan is a fourth year student major in Environmental Science with a concentration area in land, air, water and soil. Christina has taken several courses that have research works (ENVR 200/300) and field work (BIOL 230/306) that enables Christina to work in the rockweed group. She has worked in Natural Museums and Science Museum, which offers Christina a strong background understanding of intertidal zones.


STANELY PARK
NORTH EAST FALSE CREEK
DAVID LAM PARK
'N' SHORELINES
HAPPY SEAWEED
kweed in False Creek to help restore natural urban ecosystems
OUR FINDINGS
OUR RECOMMENDATIONS
OUR TEAM
JODIE

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Background

Motivation & Relevance

In the center of Vancouver's metropolitan area, 50 hectares of land sits undeveloped along the northeastern shore of False Creek (Figure 1). In February 2018, the City of Vancouver council voted to proceed with a plan to replace the Georgia and Dunsmuir viaducts with a more resilient and connected street and cycling network. The new North East False Creek (NEFC) area plan seeks to re-establish inter-urban connections, increase green space, and develop a new waterfront neighbourhood with community amenities and entertainment potential (City of Vancouver 2018). One of the goals in the City of Vancouver's Greenest City Action Plan (2015) is improving access to nature, and the redevelopment of NEFC will help achieve this with the creation of new greenways, bikeways and public parks (Vancouver Board of Parks & Recreation, 2016). In addition, the redevelopment of NEFC will include a reconfiguration of the shoreline, which drove our research to understand how this can be done to encourage a more natural shoreline. (City of Vancouver 2018).

Figure 1. Redevelopment area for NEFC. Blue shaded area is the NEFC lands. Study area shown in yellow. SEFC area can be seen in the bottom section of the photograph (City of Vancouver, 2017).

The recent redevelopment of Southeast False Creek (SEFC) in advance of the 2010 Olympics, just South of the future NEFC area, included the construction of a reconfigured shoreline to promote marine intertidal biodiversity and salmonid utilization (Wernick et al 2012). Along with the creation of islands, this project included a variety of natural substratum types (boulders, cobbles, gravel and sand) laid out in such a way to resemble natural shorelines. The slope of the shoreline was also considered and included steep grades with larger substrates and shallow grades with smaller substrates to sustain a large amount of ecological function for marine life (Figure 2). The redevelopment of the shoreline of SEFC has successfully restored ecosystems around False Creek (Adams et al 2012). Another method for shoreline reconstruction and restoration is the “Habitat Skirt” that is currently used along the shoreline adjacent to the Vancouver Convention Centre (Slogan 2015). This method creates four microhabitat types (inward shaded, outward exposed, tide pools, and outer vertical face) within the intertidal zone and was found to promote different species assemblages thus increasing overall diversity (Slogan 2015, Figure 3.).

Figure 2. Arrows point to island structures along the shores of SEFC. The varying substrate types and slopes can be seen (Adams et al 2012)

Figure 3. Habitat skirt constructed though a joint effort by DFO, Tetra Tech EBA and WorleyParsons Westmar along the shores of the Vancouver Convention Centre (Image Source: https://blogs.ubc.ca/vcchabitatskirt)

The proposed development of the shoreline along NEFC offers great potential in enhancing ecosystem function. Presently, the shoreline adjacent to the future NEFC development is composed almost entirely of steep, engineered riprap, which is loose stone used to mimic hard substrates found in natural rocky intertidal systems (Deysher et al. 2002, Reynolds et al 2007, Elwany et al. 2007) (Figure 4). Although riprap is an effective for mitigating erosion, allowing attachment of *Fucus gardneri*, and can house other species like limpets and sea stars, this technique has likely become overused in coastal urban environments resulting in reduced habitat and species diversity (Slogan 2015, Pister 2009, Martins et al 2010, Quigley & Harper 2004). Our research on the distribution and abundance of *F. gardneri*, a common intertidal seaweed, in NEFC will help inform decisions by developers and city planners to pursue the construction of suitable intertidal zones that can support diverse intertidal communities along shorelines in NEFC

Figure 4. Riprap intertidal zone on shoreline adjacent to NEFC development (source: Nowell, J)

Introduction

History of False Creek:

False Creek is a seven km long inlet that separates the downtown core from the rest of the city of Vancouver (Figure 5). The waterway extends from Science World in the east out to English Bay and the Burrard Inlet to the west. Prior to European settler contact, Sḵwxwú7mesh Úxwumixw (Squamish), səl̓ilwətaʔɬ (Tsleil-Waututh) and xʷməθkʷəy̓əm (Musqueam) indigenous peoples lived with the lands and waters around False Creek since time immemorial (Figure 8). At this time, False Creek extended all the way to Clark Drive and the easternmost part of False Creek was a thriving mudflat ecosystem that supported populations of sturgeon, waterfowl and ungulates (Figure 6). Prior to the development, Sḵwxwú7mesh people lived in a village reserve called Seṅáḵw, near what is now Vanier Park (Barman 2007, Campbell 2015). As False Creek developed, city planners sought to develop lands occupied by Squamish people, and successfully coerced them into selling Seṅáḵw in 1913, marking the beginning of change in the False Creek area (Barman, 2007) (Figure 7).

Figure 5. Former extent of False Creek overlaid on the current City of Vancouver, with the 50 ha NEFC development area shown in yellow (Chen, 2015).

Figure 6. False Creek mudflats in 1904 (City of Vancouver Archives)

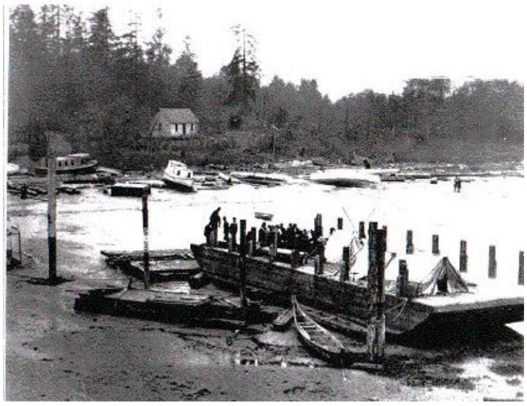


Figure 7. Sḵwxwú7mesh peoples being loaded onto a barge for relocation from Sen̓áḵw in 1913 (City of Vancouver Archives)

Figure 8. First Nations people participate in a canoe race in the Burrard Inlet in 1890 (City of Vancouver Archives)

False Creek has a long history of industrial use and filling. The Canadian Pacific Railway (CPR) acquired and filled the False Creek mudflats in the early 1900s and constructed a railyard (City of Vancouver 2018) (Figure 5). The area around False Creek and NEFC was further developed in 1915 with the construction of the Georgia and Dunsmuir viaducts to carry traffic over the railyard. This urban renewal construction project lead to the expropriation of land and displacement of people living in Hogan’s Alley, the only historic Black community to exist in Vancouver (Compton, 2014). Industrialization throughout the 20th century saw the creation of ship building plants, slaughterhouses, lumber mills and factories along False Creek. In 1980, it was announced that Vancouver would host Expo 86 which prompted the construction of BC Place, Science World, the Expo Line, and the Cambie Street Bridge, further developing the False Creek area. Today, NEFC is once again poised for redevelopment with the removal of the Georgia and Dunsmuir Viaducts and development NEFC lands (City of Vancouver, 2017).

Fucus gardneri

Fucus gardneri is a common rocky intertidal macroalgae found along Pacific coastlines in the Northern Hemisphere from the Arctic Circle down to Central California (O'Clair & Lindstrom, 2000) (Colvard et al 2014). This primary producer is hearty and tolerant to low-salinity environments, freezing temperatures and can thrive under diverse abiotic conditions. It is susceptible to desiccation in the summer months (Haring et al 2002), hence the higher overall length of the plants in the winter (Ang 1991a). *F. gardneri* is one of the few seaweeds that survives emersion better than most other seaweeds. This is because it uses atmospheric carbon dioxide as a component of photosynthesis unlike other seaweed organisms that use only the carbon dioxide available in water (Dr. Robert DeWreede personal communication, October 12, 2017). Conversely, *F. gardneri* is sensitive to oil contamination which may affect its survival in False Creek due to the close proximity to the Burrard Inlet and multiple major shipping ports (Peterson, 2001). Despite this, *F. gardneri* has tolerant characteristics that allow it to survive in the historically polluted and disturbed False Creek waterway (Ang, 1991).

When *F. gardneri* is fertile, it carries reproductive cavities called conceptacles that grow on the tips of their flattened branches (Wright et al., 2004). A single *F. gardneri* plant can be reproductive for various lengths of time and at any time in the year as each branch reaches sexual maturity at different times. *F. gardneri* plants are also perennial and can reproduce several times throughout their lifespan. (Ang 1991). Presence of conceptacles on the seaweed (despite it being winter during the time of our data collection) indicates the plants' ability to reproduce and can be analyzed to assess population growth rate.

F. gardneri in False Creek, Vancouver, BC

Fucus gardneri was chosen for our research for multiple reasons. Firstly, *F. gardneri* is easy to identify by its long, olive-brown coloured branches (Wright et al 2004). Secondly, in False Creek, Vancouver, *F. gardneri* can be found year-round growing on riprap alongside barnacles and mussels forming simple intertidal communities that house various forms of marine life including herring and salmon (Wernick et al 2012). Thirdly, the presence of only *F. gardneri* in an intertidal zone may be an indicator of poor habitat diversity and polluted water (Slogan 2014, Marsden et al 2003, Wernick et al 2012).

Natural shoreline conditions in British Columbia favour *F. gardneri* bands due to naturally sloping intertidal zones and presence of large boulders (Dethier, 1990). Use of riprap and other artificial substrates to mimic these natural conditions allow *F. gardneri* to thrive in False Creek (Slogan 2015). The future shoreline characteristics should reflect those found in natural ecosystems to allow for thriving *F. gardneri* communities, but must also provide a versatile habitat for other communities which include upper intertidal species like *Strongylocentrotus droebachiensis, Mytilus trossulus,* and *Mastocarpus papillatus* (Slogan 2015). The scope of this project restricted our team to the examination of only *F. gardneri,* and not other species or communities that could provide quantitative information about biodiversity and species assemblages in False Creek. However, the above characteristics of *F. gardneri* and current state of urban intertidal ecology in Vancouver allow us to use field observations and *F. gardneri* data to draw conclusions about its appropriate substrate types to help inform decisions regarding shoreline reconstruction at the future NEFC site.

Methods

Site Selection

The researchers selected three sites along the north False Creek strip to conduct our research (Figure 9, 10). The first site is north-west of Creekside Park along the shores adjacent to the future NEFC development. This site is at the end of the easternmost end of the False Creek waterway and the shoreline is comprised mainly of rip rap (Figure 12). The second site is at the foot of Drake St, east of David Lam Park. This site is directly adjacent to a large marina and is exposed to freshwater from a rainwater pipe (Figure 13). The third site is located between Second beach and Third beach in Stanley Park. This site is the most 'natural' of the three sites since it is the furthest from urban influences and has been subjected to limited modification by humans (Figure 14). The distance between the Creekside park site and the David Lam Park site is 1.15 km and the distance between the David Lam Park site and the Stanley Park site is 4.30 km. It should also be noted that all three sites are adjacent to the seawall cycling and walking path, and our team observed many people on the path but never walking directly on the shoreline where the research was conducted.

Figure 9. Stanley Park, Creekside Park and David Lam Park (from left to right) site locations showing the different substrate types and sizes (source: Kim, C & Nowell, J)

The three sites were selected based on their accessibility to the researchers and also the site's aspect, slope and substrate type to facilitate meaningful comparisons between sites and colonization by *F. gardneri* (Murray et al, 2006). The characteristics of the three sites can be found summarized in the table below (Table 1). Additionally, most of the other shorelines along the North side of False Creek, other than the seawall, are sandy beaches that do not support any *F. gardneri*.

Table 1. Sampling site characteristics

	Site 1	**Site 2**	**Site 3**
Location	North East False Creek (NEFC)	David Lam Park (DLP)	Stanley Park (SP)
Aspect	South	South-East	South-West
Slope	Steep	Steep	Flat
Substrate Description	Large, angular rip rap	Small, round cobbles	Mixed

Figure 10. Three sampling sites around False Creek where Site 1 is North East False Creek, site 2 is David Lam Park and Site 3 is Stanley Park

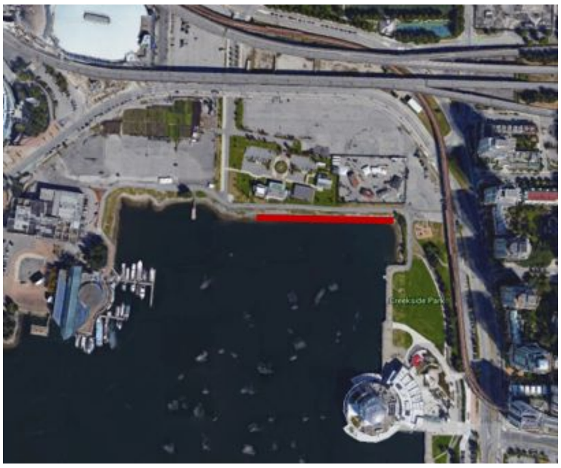


Figure 11. Sample site 1 located Northwest of Creekside Park and adjacent to the NEFC development. Red line shows approximate 100 m transect line

Figure 12. Sample site 2 locates west of Quayside Marina and east of David Lam Park. Red line shows approximate 100 m transect line.

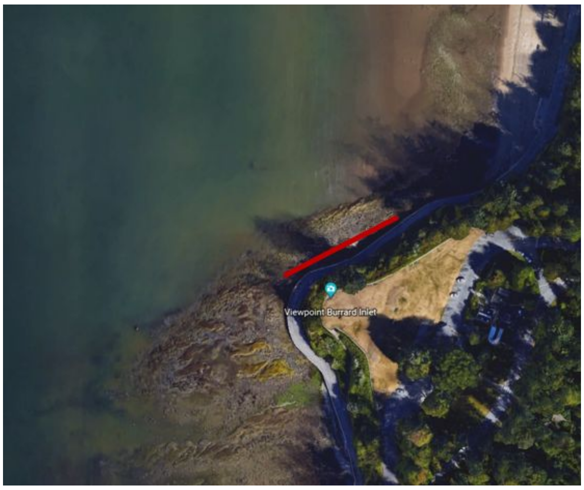


Figure 13. Sample site 3, located southwest of Third Beach. Red line shows approximate 100 m transect line

<u>Sampling Design</u>

I. Fucus gardneri in False Creek

This research was completed using a transect line study design (Murray, Ambrose & Dethier 2006). The position of the transect line placement was determined by visually deciding on the mid zone of the *F gardneri* band where it had the greatest *F. gardneri* concentration. To ensure consistency, the researchers marked the mid zone region in all locations with markers prior to the sampling dates. Along the 100 m transect lines, 12 quadrats were completed for a total of 48 quadrats per site per sampling effort. The quadrats were 25cm by 25cm (Irvine 2013, Miller & Ambrose, 2000). In order to do this, a random sampling methodology was used to minimize bias for our data collection (Gonor, 1978). The transect line was divided into four sections of 25 metres. Each person was assigned to randomly sample a different part of the transect line during every sampling night. A random number generator was used to determine where the quadrat was placed within each section. All four researchers were present for the three data collection efforts that they attempted between December 2017 and January 2018. These collection dates were selected to coincide with maximum low tides.

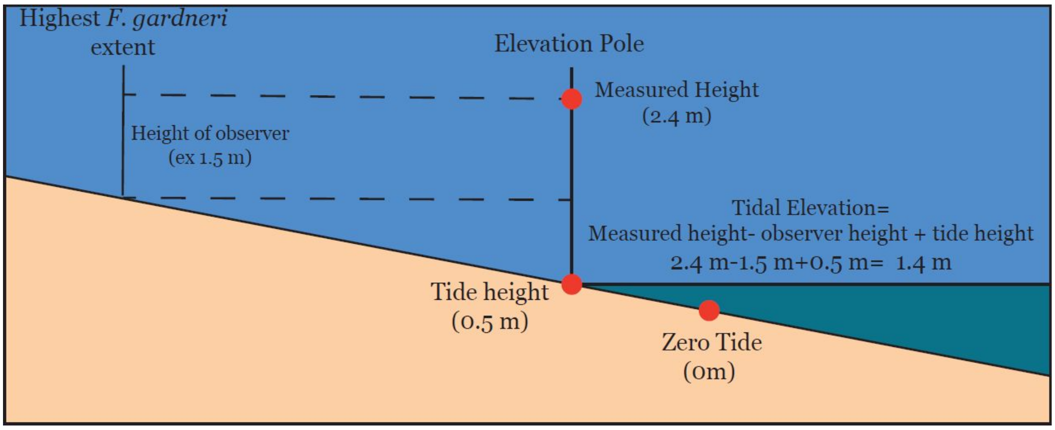


Figure 14. Plot shows the way of measuring the elevation and highest extent of F. gardneri band at sampling sites. (Created by Jodie Nowell using Dr. Robert DeWreede personal communication, October 12, 2017)

Before beginning to sample, the tidal elevation of the section of the *F. gardneri* band was measured at each site (Figure 12). Abiotic conditions, such as water temperature, water pH, and salinity were noted for comparison at each site. For each quadrat, the percent cover, abundance, reproduction of *F. gardneri* as well as the length of *F. gardneri* in the upper right corner of the quadrat was observed (Eberhardt and Thomas 1991). The substrate size, length, and texture were also considered (Dethier, 1990). The presence of other organisms was noted, along with the percent area of bare rock in each quadrat. A photograph was taken of each quadrat for future reference and visual comparative analysis.

After data collection, the following variables were tested in order to fulfill the objectives of this study. Firstly, our research compared the percent cover, abundance, length, and reproduction at the three sites. Researchers expected to find a significant difference in these *F. gardneri* characteristics between the three sites, and also within each site over time. Secondly, a PCA analysis was used to determine which factor had the greatest effect on *F. gardneri* percent cover at each site. Our team hypothesized that the substrate size had the largest effect on the percent cover of *F. gardneri* at all three sites.

II. Testing water quality at sampling sites

After biological data was collected, a separate experimental design was created to determine if there was a significant difference in the abiotic water conditions between the three sampling sites. Using clean containers, three water samples were collected from each site and replicated during two different dates times. To minimize uncertainty between the sites, all samples were collected at the same time by sending separate team members to each site. Researchers then regrouped as quickly as possible to measure the temperature, pH, and salinity from the sites. This procedure was completed a total of three times between February 10th, 2018 and February 11th, 2018. A t-test and correlation analysis was used to determine if there was a significant difference between these water conditions at the three sites.

<u>Data Collection</u>

I. Fucus gardneri in False Creek

Data was collected at the lowest low tide, which occured in the evening in the winter, at all three sites. Data was collected at the NEFC site and the David Lam Park site on the same night, and at Stanley Park either the previous or following night. For each sampling effort, the researchers collected the data at the same time at each site, but each researcher collected data independently based on the methods discussed above. Percent cover was estimated visually by dividing the quadrat up into smaller sections and determining the amount of space taken up by *F. gardneri*. The same thing was done for estimating the percent of bare rock. Photos of each quadrat were taken for reference and were used to check the accuracy of these estimations (Meese & Tomich, 1992). Abundance was determined by counting each individual holdfast of the organism at the surface of the substrate, and individuals that had holdfasts outside of the quadrat but fell within the quadrat were also counted. Length was determined by measuring the upper-right most *F. gardneri* individual with a ruler. Conceptacle presence was used to determine if individuals in the qudrat were reproducing (Ang, 1991). The intensity of reproduction was divided into three sections: "<u>Yes+</u> "for obvious and visual conceptacles, "<u>Yes"</u> for few individuals reproducing, and "<u>No"</u> for no sign of conceptacles (Figure 15).

Figure 15. Sample quadrat from Stanley Park site. Conceptacles, reproductive sign, are highlighted in the red box (source: Kim, C)

This research also looked at other factors that could be affecting *F. gardneri*. Substrate type was determined using marine biology classification (Table 2), and the substrate that *F. gardneri* was attached to was measured lengthwise with a ruler. Substrate texture was classified into smooth, mixed or rough categories based on the bare surface of the substrate. The presence of other microalgae species, such as *Ulva lactuca* (sea lettuce) and other general intertidal invertebrate species such as *Mytilus sp. (*mussels), *Blanus glandula* (barnacles), *Pisaster ochraceus* (seastars), and *Lottia digitalis* (limpets), were noted (Figures 16-20).

Figure 16. Ulva lactua (source: http://knowledge-sastha.blogspot.ca/2014/03/sea-lettuce-facts.html)

Figure 17. Pisaster ochraceus (source: https://www.flickr.com/photos/francoisboucher/6757488237)

Figure 18. Blanus Glandua source (source: https://wanderinweeta.blogspot.ca/2017/03/barnacles- and-barnacle-eaters.html

Figure 20. Lottia digitalis (source: http://www.campsitereports.com/htm/ViewPhoto.php?PiotoID=F00

Figure 19. Mytilus sp. (Source: https://pugetsound.edu/academics/academic-resoc

Table 2. Substrate classification according to size in diameter (Green et al 1999)

Type	Label	Size (in diameter)
Mud	Mu	Silt and clay
Sand	Sa	0.06~2 mm
Granule	Gr	2 ~4 mm
Pebble	Pe	4~64 mm
Cobble	Co	6.4~25.6 cm
Boulder	Bo	25.6~ 63.0 cm
Large Boulder	LBo	>63.0 cm

II. Testing water quality at sampling sites

In order to determine if there was a significant difference in water conditions, a separate experiment was completed. Water samples were collected in clean and dry 125 mL plastic containers. Before the water was collected, the containers were rinsed three times with sea water. Lids were secured tightened in order to prevent evaporation. A pH probe was used to measure the pH and temperature of each water sample, and a refractometer was used to measure the salinity. The pH probe was calibrated and rinsed between each sample with distilled water. During our data analysis, the ambient air temperature needed to be approximately 20℃ in order for the refractometer to work, and therefore had to wait for the samples to warm up close to that temperature for salinity measurements. Therefore, temperature was not used for abiotic comparative analysis.

<u>Data Analysis</u>

In order to determine the trend in *F. gardneri* percent cover, abundance, length and reproduction over time, the average and 95% confidence intervals were calculated at all three sites for each sampling day. A t-test was used to determine the statistical significance of our results. We tested for significant difference in all variables (percent cover, abundance, length, reproduction, salinity and pH) between sites over time. Principal component analysis (PCA) was used to determine the most significant variable affecting *F. gardneri* percent cover at each of the sites. PCA is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called ‘principal components’ (Hotelling, 1933). It is expected that the number of principal components is less than or equal to the smaller number of original variables or the number of observations (Preisendorfer, 1988). The following variables were considered for PCA: substrate type, substrate size, percent bare rock, and presence of other species. Once the most significant mode was determined, we conducted a correlation analysis between the two variables.

Results

Water Quality

In order to determine whether there is a significant difference of pH and salinity levels between the three sites, we used the two sample t-test with 95% confidence interval to compare each pair. The calculated p-values from this test can be seen in Table 3 and Table 4. Table 3 shows that all calculated p-values are greater than 0.05, indicating that there is no significant difference in the pH between the three sampling sites. Salinity at Stanley Park is significantly different from David Lam Park and Creekside Park as the calculated p-values are smaller than 0.05 (Table 4). The value of salinity levels at Stanley Park is smaller than the value at David Lam Park and Creekside Park sampling sites. The salinity at Stanley Park was around 1.011 g/mL and 14.500 psu, while the salinity at David Lam Park and Creekside Park was found to be around 1.014 g/mL and 19.000 psu.

Table 3. The P-value for pH at Stanley Park, David Lam Park and Creekside Park using two tail t-tests with alpha=0.05. P-value < 0.05 shows a significant difference, indicated by *.

P-Value for pH	**Stanley Park**	**David Lam Park**	**Creekside Park**
Stanley Park	-	0.288	0.184
David Lam Park	0.288	-	0.504
Creekside Park	0.184	0.504	-

Table 4. The P-value for salinity at Stanley Park, David Lam Park and Creekside Park using two tail t-tests with alpha=0.05. P-value < 0.05 shows a significant difference, indicated by “*”. Stanley Park is significantly different from Creekside Park and David Lam Park

P-Value for salinity	**Stanley Park**	**David Lam Park**	**Creekside Park**
Stanley Park	-	0.023*	0.019*
David Lam Park	0.023*	-	0.618
Creekside Park	0.019*	0.618	-

Abundance

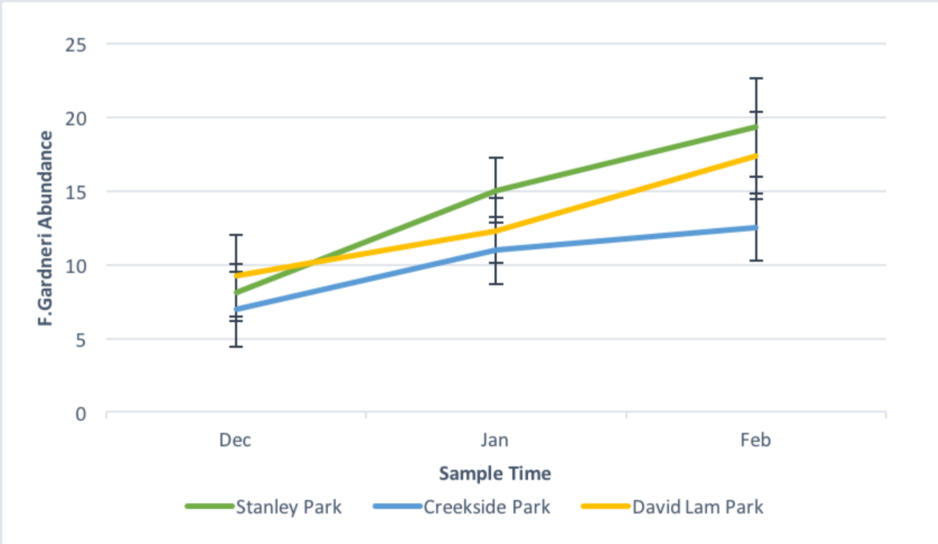


Figure 21. Trend of average abundance (number of individuals) of F. gardneri at the three sampling sites over three sampling days. Error bars represent standard error.

Table 5. The P-value for abundance at Stanley Park, David Lam Park and Creekside Park using two tail t-tests with alpha=0.05. P-value < 0.05 shows a significant difference, indicated by "*". Stanley Park is significantly different from Creekside Park.

P-value for Abundance	**Stanley Park**	**David Lam Park**	**Creekside Park**
Stanley Park	-	0.136	0.00002*
David Lam Park	0.136	-	0.005*
Creekside Park	$2.679* 10^{-5}$ *	0.005*	-

Reproduction

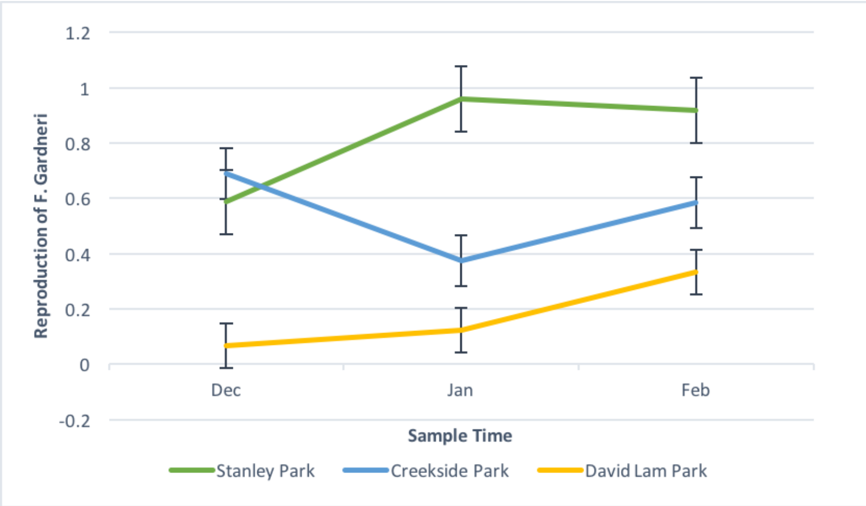


Figure 22. Trend of average percent cover of F. gardneri at the three sampling sites over three sampling days. Error bars represent standard error.

Table 6. The P-value for reproduction at Stanley Park, David Lam Park and Creekside Park using two tail t-tests with alpha=0.05. P-value < 0.05 shows a significant difference, indicated by "*". Stanley Park is significantly different from David Lam Park

P-Value for reproduction	Stanley Park	David Lam Park	Creekside Park
Stanley Park	-	0.011*	0.143
David Lam Park	0.011*	-	0.038*
Creekside Park	0.143	0.038*	-

Percent Cover

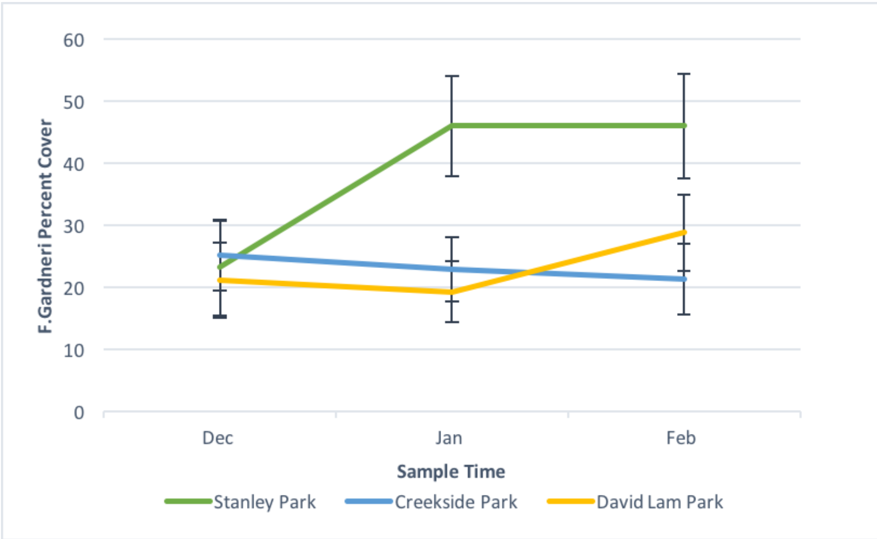


Figure 23. Trend of average percent cover of F. gardneri at the three sampling sites over three sampling days. Error bars represent standard error.

We investigated how *F. gardneri* percent cover changed through time. From the t-test, it was found that there is no significant change in percent cover in both Creekside and David Lam Park over time (Figure 23, Appendix III). In Stanley Park, there is significant difference in percent cover between the December results to January and also from December to February (see appendix III for significance testing results). In order to determine if there was a significant difference between sites, the overall percent cover was averaged for each site, and the significance between all three sites was tested. It was found that Stanley Park is significantly different from David Lam Park and Creekside Park (Table 7, Figure 23).

Table 7. The P-value for *F. gardneri* Percent Cover at Stanley Park, David Lam Park and Creekside Park using two tail t-tests with alpha=0.05. P-value < 0.05 shows a significant difference, indicated by '*'. Stanley Park is significantly different from David Lam Park and Creekside Park.

P-value for Percent Cover	**Stanley Park**	**David Lam Park**	**Creekside Park**
Stanley Park	-	$4.736* 10^{-8}$ *	$2.847* 10^{-8}$ *
David Lam Park	$4.736* 10^{-8}$ *	-	0.973
Creekside Park	$2.847* 10^{-8}$ *	0.973	-

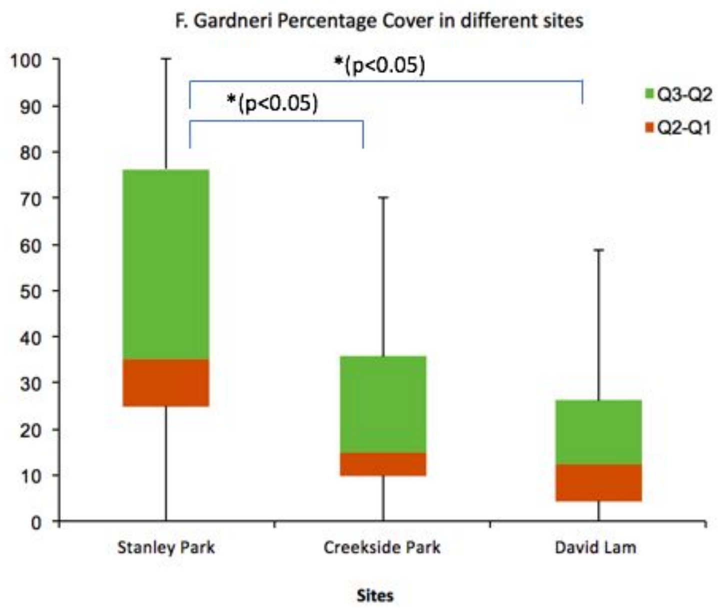
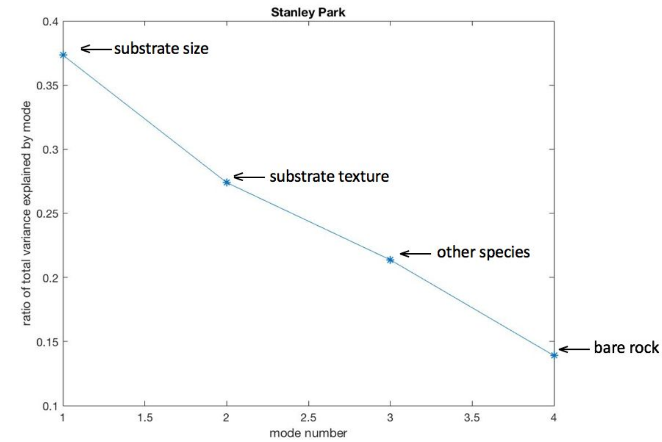


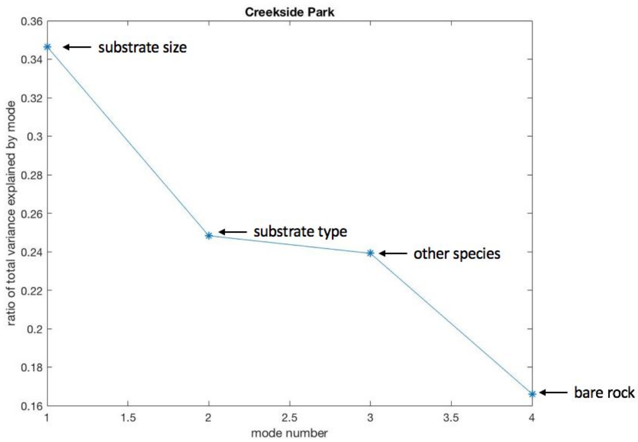
Figure 24. Box plot representation of F. gardneri percent cover at each site, which displays the full range of variation (from min to max), the likely range of variation (the interquartile range), and a typical value (the median) of F. gardneri percent cover. "" indicates a significant difference.*

<u>*Principal Component Analysis*</u>

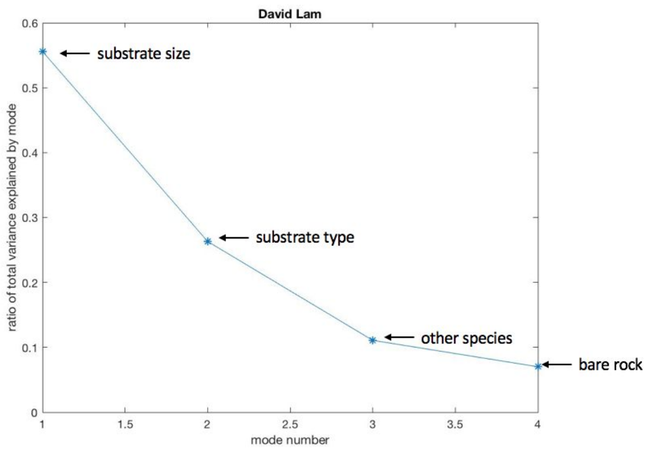
In a Principal Component analysis (PCA), "variance" means *multivariate variability* or *overall variability*. PCA replaces original variables with new variables, called principal components, which are orthogonal and have variances (called eigenvalues) in decreasing order. The fraction of variance explained by a principal component is the ratio between the variance of that principal component and the total variance. Therefore, when we look at David Lam panel in Figure 25, The highest fraction of explained variance among these variables is 57.6%, and the lowest one is 8.1%. We can also compute these fractions for subsets of variables. For instance, variables 1 and 2 together explain 83% of the total variance, and variables 2 and 3 explain 29.8% (Figure 25). We looked at the most significant variable for further analysis because they have the highest variance out of all principal components.



a)

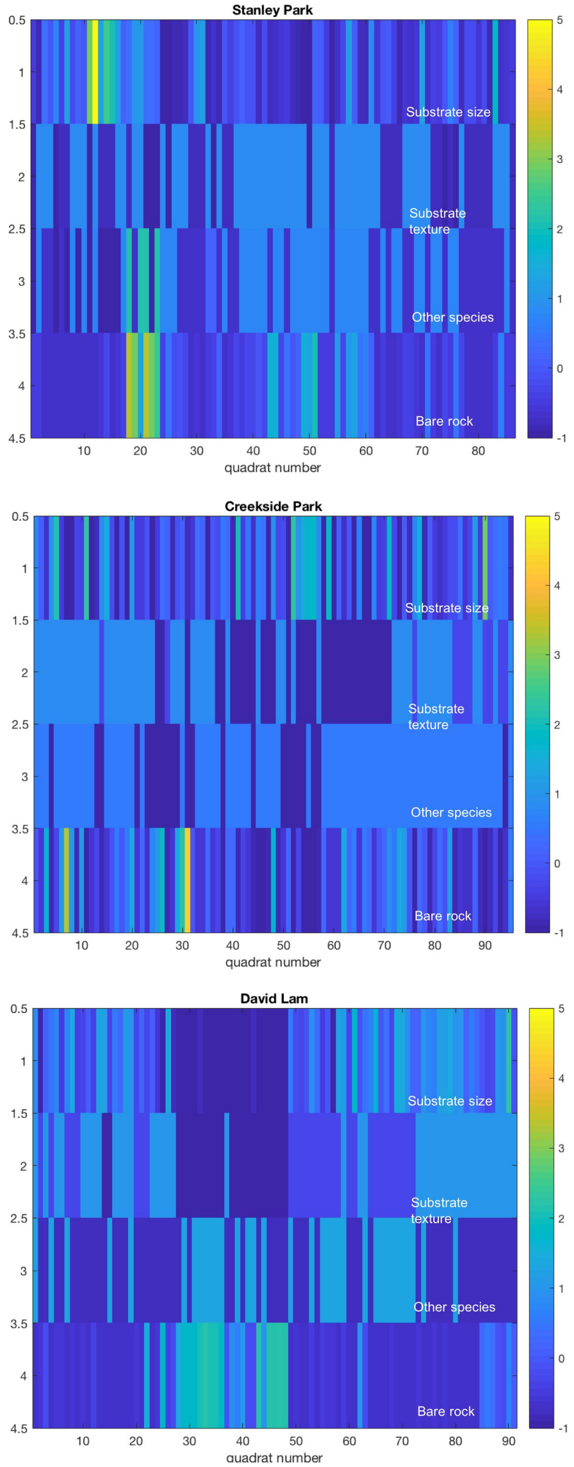


b)



c)

Figure 25. This plot illustrates the ratio of total variance of percentage cover explained by each relevant factor. The factors are substrate size, substrate texture, other species and bare rock. Substrate size was determined as the most crucial factor impacting the percent cover variation, as it represented the highest ratio of variance. (a) is for Stanley Park, (b) is for Creekside Park and (c) is for David Lam Park. The ratio of the variance of percent cover is explained by 37.5% in (a), 34.6 % in (b) and 57.6 % in (c) percent cover.



a)

b)

c)

Figure 26. This plot illustrates the variation of different factors that could probably impact the rockweed percentage cover. In this color pattern, each single color state represents the data point of each quadrat. We also analyzed four factors in each site, including substrate size, substrate texture, other species and bare rock which are all displayed in their own row. The colour bar is the same range for comparison. By looking at how different colour states vary from each other and the approximate range of data point, it can be seen that there is more variation of substrate size in Stanley Park (a) than in the other two sites (b) and (c).

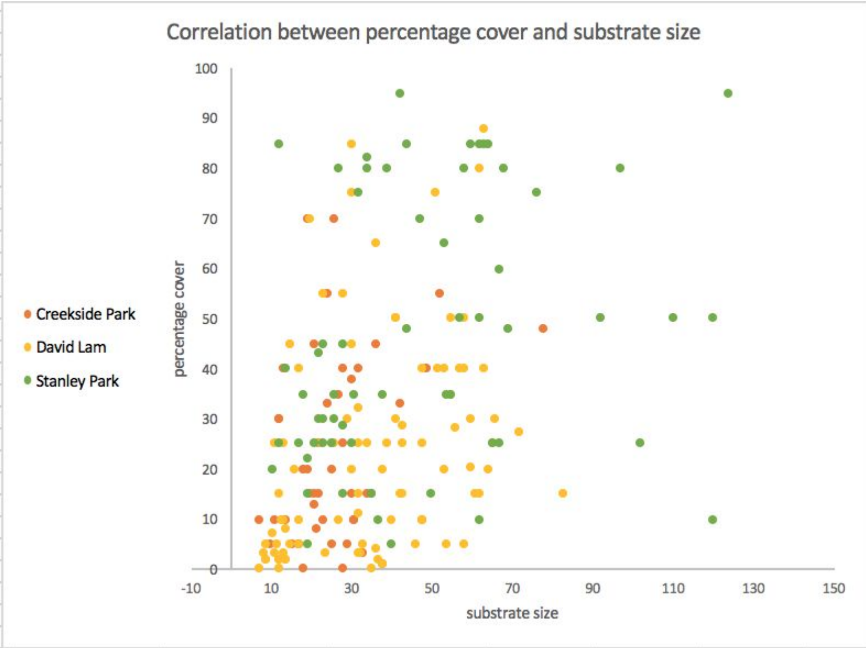


*Figure 27. Scatter plot showing correlation between percent cover and substrate size at each site. Red points represent Creekside Park, yellow points David Lam, and green point represent Stanley Park. The equation of the correlation curve for Creekside Park is 0.4161*substrate size+10.775, 0.1941*substrate size+35.7275 for Stanley Park and 0.4391*substrate size+8.8082 for David Lam Park*

Discussion:

Water Quality

The water quality in False Creek is generally poor, despite efforts from the City of Vancouver to make the waterway swimmable by this summer. Along with heavy-metal pollution from the historic industrial operations (City of Vancouver 1974), there is considerable *E coli* contamination from boat traffic and animal feces (Cummings 2016). The *E. coli* contamination increases from west to east in False Creek, and is associated with the high density of marinas and boat traffic in the area (Anony et al 2015, Cummings 2016). *F. gardneri* is a hearty algae with large tolerance range for temperature, pH, and salinity but is sensitive to contamination from heavy metal and oil, thus rendering the species more vulnerable in False Creek (Marsden et al 2003, Stekoll & Deysher 1996). It was not within the scope of our project to examine the effect of heavy metal and *E. coli* concentrations, as the data is expensive to collect and highly variable over time and space. Instead, we collected data on water pH, temperature, and salinity at the three sites and compared the results.

Our research found a significant difference in the salinity and no significant difference in pH between Stanley Park and the two urban sampling sites (Table 3, Table 4). The Stanley Park location is closer to the Burrard Inlet and mouth of the Capilano River, therefore likely having more estuarine properties. This may explain why the salinity was significantly lower than the urban sites in False Creek (Levings and Samis 2001). Previous studies have shown that low salinities (6-12 psu) have a high relative growth rate and decreases sharply at salinities around 20 psu (Nygard, 2008). *F. gardneri* is low salinity tolerant and have a better growth rate at low-salinity environments so the lower salinity levels in Stanley Park could be one of the explanations to the species success in this particular location (Marsden et al 2003). The sample size we used was small and pH and salinity data is highly variable over time and space due to complex physical, chemical and biological processes that occur in the ocean (Hagens & Middelburg 2016). Further research is required to determine the effect of salinity and pH on the percent cover of *F. gardneri* in False Creek.

Reproduction

The reproduction varied through time at all three sites. At the Stanley Park site, reproduction increased between December and January, and the decreased slightly between January and February. At Creekside Park, the reproduction decreased between December and January and increased between

January and February. Finally, at David Lam Park, reproduction increased slightly between December and January and increase more between January and February (Figure 22)

The reproduction was significantly different at Stanley Park compared to David Lam Park but not Creekside Park, and changed inconsistently over time (Table 6). When a thalli of *F. gardneri* becomes reproductive, it will develop reproductive tissue that can easily be observed. Despite the fact that species that grow in upper intertidal zones experience much more environmental stress, reproduction of *F gardneri* does not vary with intertidal elevation (Wright, Williams & Dethier 2004 & Lamote & Johnson 2008). Furthermore, since the elevation of the transect line was kept relatively constant across all three sites, elevation does not explain this result. We also observed *F gardneri* growing alongside and often on top of barnacles at all three sites. *F gardneri* gremlins that are attached to barnacles have a higher probability of becoming dislodged by waves before reaching sexual maturity, thus reducing their reproductive capacity (van Tamelan & Sketoll 1997). It is possible that the density of barnacles at David Lam Park and Creekside park has an effect on the lower reproduction at these sites, but our team did not study this and requires more research. We did not measure levels of water pollutants and contaminants, but according to prior research this is likely one of the main drivers of significantly lower reproduction at the False Creek sampling sites, and could explain why the reproduction changed over time. (Sketoll & Deysher 1996, 2000 and Driskell et al 2001) More research is necessary to fully understand the effects of water quality on the *F. gardneri* reproduction in False Creek.

Abundance

Figure 28. Photo of quadrat from David Lam Park. The thallus length of F. gardneri is short and the abundance is large (source: Yan, C)

Abundance data was generally inconsistent across the three sites, poorly represented the data and had high variability (Figure 21). For example, the *F. gardneri* individuals at David Lam Park were very small and these quadrats often had high abundance but low percent cover. The abundance of *F. gardneri* increased over time at all three sites (Figure 21). *F. gardneri* generally has a higher growth rate in the winter than the summer due to desiccation (Ang 1991). This partially agrees with our data since days were getting longer as our data was being collected, and desiccation should have increased, thus decreasing the growth of *F. gardneri*. The slope of *F gardneri* abundance decreases from January to February for Stanley Park and Creekside Park meaning that the rate of growth is getting lower compared to the rate of *F. gardneri* growth from December to January. However, the growth rate at David Lam Park remains high. Other potential factors that could explain the increase in overall abundance is an increase in nutrient availability since moderate increase in nutrient can increase the abundance of *F. gardneri*.

Percent Cover

Percent cover changes through time at all three sites (Figure 27). The first sampling effort in December shows that Creekside Park had a slightly higher percent cover than Stanley Park. In

January, the percent cover increases dramatically at Stanley Park and decreased slightly at Creekside Park. Our research team did not observe a noticeable change in the percent cover at Stanley Park between January and February, and suspect that human error may have affected the data collected in December. This was our first time conducting our field sampling methodology, and may have measured percent cover inaccurately at this time at all three sites (Figure 23). Seasonality may also explain the change in percent cover over time at Stanley Park. *F. gardneri* cover generally declines from summer to midwinter then increases again in the Spring (Speidel, 2001) so the trends we see with the increase in percent cover through time from all three sites could be explained by changing seasons from December to February.

Percent cover at Creekside Park decreased in percent cover over time, and David Lam experienced an overall increase over time. The relative performance of *F. gardneri* for different sites is complex and differences in the sites could depend on the stage of the life-cycle of each individual (Wright, 2004). Additionally, environmental conditions, such as water quality and wave action, may have changed over time at Creekside Park and David Lam Park, thus potentially affecting the success of *F. gardneri* at these sites. For this specific analysis, there were limitations in the research. Given the limited timeline of four months to collect field data, sufficient and thorough field research was not possible. If time more time was allowed, more research could be conducted to investigate the change of rockweed percent cover through the whole year at the three sites. This opens up possibilities for future research projects for North East False Creek.

One of our objectives was comparing the percent cover distribution around the North East False Creek locations. In Figure 24, the box plot shows the percent cover distribution across each location combining all the data from different dates and different researchers. It is found that most of the Stanley Park values are greater than 20 whereas most of the David Lam Park values are less than 40. The figure shows significantly greater percent cover at Stanley park than the other two sites. The result here also matched with later t-test analysis as the null hypothesis is rejected by the p-value. This is to be expected as Stanley Park is the most ‘natural’ space out of the three sites and NEFC is trying to replicate this location’s attributes.

Principal Component Analysis

Percent cover was the variable that we chose as our indicator of the amount of *F. gardneri* at the three sites, and used this for comparison with substrate size, substrate texture, other species and percent bare rock in our PCA. As mentioned in the *Abundance* section, we chose to use the percent cover data for this because it provided a more accurate representation the amount of *F. gardneri* at the sites (Meese and Tomich 1992). The PCA showed that substrate size represented the highest ratio of variance, and was therefore the most significant factor in determining the percent cover of *F. gardneri* at all three sites (Figure 25). Additionally, the range of substrate sizes at Stanley Park is larger than that at the other sites, indicating a more complex and natural shoreline (Figure 26) (Slogan, 2015). These findings agree with previous research that suggests more natural sites with more variation in substrate size impacts on the success of *F. gardneri* and other species (Slogan 2015, Adams & Wernick 2011, Chapman et al 2002)

<u>Substrate</u>

The most common substrate type found at each site was different. At Creekside Park, the intertidal zone was composed of rip rap and large steep angular slabs of granite. At David Lam Park, the most common substrate was smooth, rounded cobbles with little variation. The Stanley Park site had the most variable substrate types, ranging from grains of sand to large boulders. Our PCA analysis yielded substrate size as the most important variable contributing to percent cover of *F. gardneri*, which supports the argument for the inclusion of more natural substrate types and shoreline shape at the future North East False Creek Site (Figure 26).

The use of rip rap and other homogeneous substrates is very common in urban centres, as it prevents erosions, protects the shoreline and is a good attachment site for *F. gardneri* and other intertidal invertebrates (Slogan 2015 & Thrush et al 2006). This can be seen in our results as the more natural site Stanley Park has the most substrate diversity compared to the more urban False Creek sites (Figure 26). Replacing homogeneous substrates with more diverse substrates encourages attachment and colonization from more species and has been shown to increase species and community diversity in urban intertidal zones (Slogan 2015, Adams et al 2012,). Previous shoreline restoration work in Vancouver, such as the Habitat Skirt at the Convention Centre and the shoreline in South East False Creek, have successfully mimicked substrates found in natural intertidal zones (Slogan 2015 & Adams et al 2012). Furthermore, the steep shorelines found in False Creek are hazardous and not accessible for enjoyment by people. The use of gentle grades, hard and soft sediments and more complex shoreline shapes improves the quality of the intertidal area for both marine species and humans (Hanson et al 2002, Harris 2009). Our PCA results, along with other research suggests that in order to increase biodiversity, overall ecosystem health and human-nature connections, the construction of more complex and natural shorelines is required. (Slogan 2015).

Site Locations

All three sampling sites were located along the North shore of the False Creek waterway and had similar aspects. The aspect of an intertidal community has an effect on the species that are present, so we selected our sampling sites accordingly to control for this variable (Pinn et al 2005). Communities found at higher elevations, such as *F. gardneri* are more likely to experience higher environmental stress from wave action and sunlight, and elevation is the best explanation of species variation along the intertidal gradient. (Chappuis et al 2014). In order to control for this, the elevation of our transect lines were kept relatively constant across all three sampling sites.

The slope, however, was noticeably different at our three sites. The two urban sites, David Lam Park and Creekside Park, had very steep slopes whereas the natural, control site at Stanley Park had a shallow slope. The amount of environmental stress from waves, sunlight, and other factors affect the species richness and abundance in intertidal communities (Heaven & Scrosati 2008). As the slope of a shoreline increases, the wave force experienced by the intertidal zone also increases, and causes more stress on intertidal species (Carrington 2002, Denny & Wethey 2001). Steep shorelines are common in urban areas, since they are better able to break large waves and prevent flooding and erosion (Thornton & Guza 1983). Furthermore, as the slope of intertidal zones increases, the amount of space and width of bands decreases and competition increases (Connell 1961 and Tomanek & Helmuth 2002). It is possible that the slope, and consequently the higher wave action and more competition for space, at the two urban sites had a negative effect on the percent cover of *F. gardneri*. This concept requires further research to be fully understood in the False Creek waterway.

Summary

Our main objectives were as follows:

1) To distinguish the differences in characteristics of *Fucus gardneri* abundance, percent cover, reproduction, and length at three sampling locations: Stanley Park, David Lam Park and Northeast False Creek.

2) To determine whether or not there is a significant difference in abiotic water conditions (pH, salinity and temperature) at the three sites.

3) For each sampling location, determine and classify which variables best correlate to the percent cover of *F. gardneri* from the following list: substrate type, substrate size, substrate texture, tidal elevation, percent cover of bare rock presence of other species.

For each objective, the corresponding findings are listed below:

1) Percent cover, and abundance are significantly different between Stanley Park and David Lam/ Creekside Park (Table 5 & 7). Data for *F. gardneri* length was insufficient to draw any conclusions. Reproduction was significantly different between Stanley Park and David Lam Park, and between Creekside Park and David Lam Park (Table 6)

2) There is no significant difference in the pH values across all three sites. There is a significant difference in the salinity between Stanley Park and David Lam Park/ Creekside Park, but more data a replicated are required to decrease the uncertainty (Table 3 & 4)

3) Substrate size correlated most strongly with the percent cover of *F. gardneri* at all three sites (Figure 25).

Recommendations

From our research, we found that the most significant factors that best correlate to percent cover of *Fucus gardneri* was the substrate size and type for all locations. From our PCA analysis and previous research findings, the variability in the sizes of substrates (boulders to cobble) and types of substrates (rough, smooth, mixed) increases productivity and diversity of these communities in the intertidal zone. We encourage the city to increase the diversity in substrate sizes and types during the redesign process. Gradual shorelines are also recommended to reduce environmental stress from tidal flow and ocean currents on *F .gardneri* and reduce competition for space for *F. gardneri* and other marine species (Carrington 2002, Denny & Wethey 2001, Connell 1961, and Tomanek & Helmuth 2002).

Furthermore, we would like to encourage further research beyond our project to better understand *F. gardneri* and its abundance and distribution across False Creek. Further examination on the water quality for effects of heavy metal and *E.coli* concentrations on their impacts on *F. gardneri* could help city planners determine the next steps in mitigating water pollution in Northeast False Creek. Additionally, the relationship between *F. gardneri* and other intertidal species could be examined further in order to better understand impact of other species on *F. gardneri.*

We hope our research will help encourage the Northeast False Creek planners to restore urban shorelines in order to encourage urban biodiversity.

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Appendix

Appendix I: Data Collection Sheet

Carlina
Jan11 2018-01-11 Stanley park

Time Started:
Weather:
Temperature:
pH:
Transect Elevation:
Low Tide Time:
Low Tide Level:

Note: 1.in substrate type one, if there are more than one type of substrates,
Please indicate it such as LBo+Bo+Sa
2.make sure take photo for all quadrats.

Type	Label	Size (in diameter)
Mud	Mu	Silt and clay
Sand	Sa	0.06~2 mm
Granule	Gr	2 ~4 mm
Pebble	Pe	4~64 mm
Cobble	Co	6.4~25.6 cm
Boulder	Bo	25.6~ 63.0 cm
Large Boulder	LBo	>63.0 cm

Date	January 11, 2018					(measure in cm)		(upper left leaf)	Choose from Yes+/Yes/No	Choose from mussel/barnacle/M+B/NO(no other species)	Any other observation
Quadrat #	Quadrat Range	% cover	% bare rock	Rockweed Abundance	substrate type	substrate size	substrate texture	Fucus length	reproductive	other species?	notes
1	1.25-1.5										
2	3.75-4										
3	10.5-10.75										
4	11.5-11.75										
5	11.75-12										
6	15.25-15.5										
7	15.5-15.75										
8	16-16.25										
9	17.5-17.75										
10	18.25-18.5										
11	19-19.25										
12	24.25-24.5										

Appendix II: Calculated averages of percent cover abundance length and reproduction at al three sites over time

	Stanley Park				Creekside Park				David Lam Park		
	1	2	3		1	2	3		1	2	3
% cover	23.14	45.94	45.92	% cover	25.10	22.85	21.28	% cover	21.16	19.28	28.78
Abundance	8.14	15.04	19.31	Abundance	7.00	10.96	12.54	Abundance	9.25	12.30	17.39
Length (cm)	9.11	6.53	8.48	Length (cm)	6.56	6.40	4.94	Length (cm)	2.80	4.10	4.22
Reproductive	0.68	0.98	0.94	Reproductive	0.73	0.39	0.62	Reproductive	0.08	0.13	0.34

Appendix III: Significance tests at each site over time

```
> t.test(Dec_Creekside$`% cover`,Jan_Creekside$`% cover`)

	Welch Two Sample t-test

data:  Dec_Creekside$`% cover` and Jan_Creekside$`% cover`
t = 0.57218, df = 93.355, p-value = 0.5686
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -5.506930  9.965263
sample estimates:
mean of x mean of y 
 25.08333  22.85417 

> t.test(Dec_Creekside$`% cover`,Feb_Creekside$`% cover`)

	Welch Two Sample t-test

data:  Dec_Creekside$`% cover` and Feb_Creekside$`% cover`
t = 0.93537, df = 93.996, p-value = 0.352
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -4.270972 11.879306
sample estimates:
mean of x mean of y 
 25.08333  21.27917 

> t.test(Feb_Creekside$`% cover`,Jan_Creekside$`% cover`)

	Welch Two Sample t-test

data:  Feb_Creekside$`% cover` and Jan_Creekside$`% cover`
t = -0.40293, df = 93.258, p-value = 0.6879
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -9.336928  6.186928
sample estimates:
mean of x mean of y 
 21.27917  22.85417 

> t.test(Dec_David$`% cover`,Jan_David$`% cover`)

	Welch Two Sample t-test
```

data: Dec_David$`% cover` and Jan_David$`% cover`
t = 0.40359, df = 84.737, p-value = 0.6875
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -6.468626 9.763342
sample estimates:
mean of x mean of y
 20.43902 18.79167

> t.test(Dec_David$`% cover`,Feb_David$`% cover`)

Welch Two Sample t-test

data: Dec_David$`% cover` and Feb_David$`% cover`
t = -1.9302, df = 94.299, p-value = 0.05659
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -16.9205092   0.2389089
sample estimates:
mean of x mean of y
 20.43902 28.77982

> t.test(Feb_David$`% cover`,Jan_David$`% cover`)

Welch Two Sample t-test

data: Feb_David$`% cover` and Jan_David$`% cover`
t = 2.4014, df = 102.91, p-value = 0.01813
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
  1.738989 18.237326
sample estimates:
mean of x mean of y
 28.77982 18.79167

> t.test(Dec_Stanley$`% cover`,Jan_Stanley$`% cover`)

Welch Two Sample t-test

data: Dec_Stanley$`% cover` and Jan_Stanley$`% cover`
t = -4.0121, df = 72.173, p-value = 0.0001453
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:

```
 -34.12732 -11.47182
sample estimates:
mean of x mean of y
 23.13793  45.93750

> t.test(Dec_Stanley$`% cover`,Feb_Stanley$`% cover`)

	Welch Two Sample t-test

data:  Dec_Stanley$`% cover` and Feb_Stanley$`% cover`
t = -3.9449, df = 72.956, p-value = 0.0001817
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -34.28690 -11.27057
sample estimates:
mean of x mean of y
 23.13793  45.91667

> t.test(Feb_Stanley$`% cover`,Jan_Stanley$`% cover`)

	Welch Two Sample t-test

data:  Feb_Stanley$`% cover` and Jan_Stanley$`% cover`
t = -0.0035045, df = 93.917, p-value = 0.9972
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -11.82448  11.78282
sample estimates:
mean of x mean of y
 45.91667  45.93750
```

Appendix IV: Significance tests between sites over time

```
> t.test(Jan_Stanley$`% cover`,Jan_David$`% cover`)

        Welch Two Sample t-test

data:  Jan_Stanley$`% cover` and Jan_David$`% cover`
t = 5.4522, df = 81.958, p-value = 5.133e-07
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 17.24116 37.05050
sample estimates:
mean of x mean of y
 45.93750  18.79167

> t.test(Feb_Stanley$`% cover`,Feb_David$`% cover`)

        Welch Two Sample t-test

data:  Feb_Stanley$`% cover` and Feb_David$`% cover`
t = 3.2472, df = 89.071, p-value = 0.001644
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
  6.650802 27.622882
sample estimates:
mean of x mean of y
 45.91667  28.77982

> t.test(Dec_Stanley$`% cover`,Dec_David$`% cover`)

        Welch Two Sample t-test

data:  Dec_Stanley$`% cover` and Dec_David$`% cover`
t = 0.54904, df = 57.096, p-value = 0.5851
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -7.144281 12.542094
sample estimates:
mean of x mean of y
 23.13793  20.43902

> t.test(Dec_Stanley$`% cover`,Dec_Creekside$`% cover`)

        Welch Two Sample t-test
```

```
data:  Dec_Stanley$`% cover` and Dec_Creekside$`% cover`
t = -0.40245, df = 56.689, p-value = 0.6889
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -11.626317   7.735513
sample estimates:
mean of x mean of y
 23.13793  25.08333

> t.test(Feb_Stanley$`% cover`,Feb_Creekside$`% cover`)

	Welch Two Sample t-test

data:  Feb_Stanley$`% cover` and Feb_Creekside$`% cover`
t = 4.7846, df = 82.553, p-value = 7.405e-06
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 14.39487 34.88013
sample estimates:
mean of x mean of y
 45.91667  21.27917

> t.test(Jan_Stanley$`% cover`,Jan_Creekside$`% cover`)

	Welch Two Sample t-test

data:  Jan_Stanley$`% cover` and Jan_Creekside$`% cover`
t = 4.7017, df = 79.754, p-value = 1.064e-05
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 13.31247 32.85419
sample estimates:
mean of x mean of y
 45.93750  22.85417

> t.test(Jan_David$`% cover`,Jan_Creekside$`% cover`)

	Welch Two Sample t-test

data:  Jan_David$`% cover` and Jan_Creekside$`% cover`
t = -1.0631, df = 93.793, p-value = 0.2905
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
```

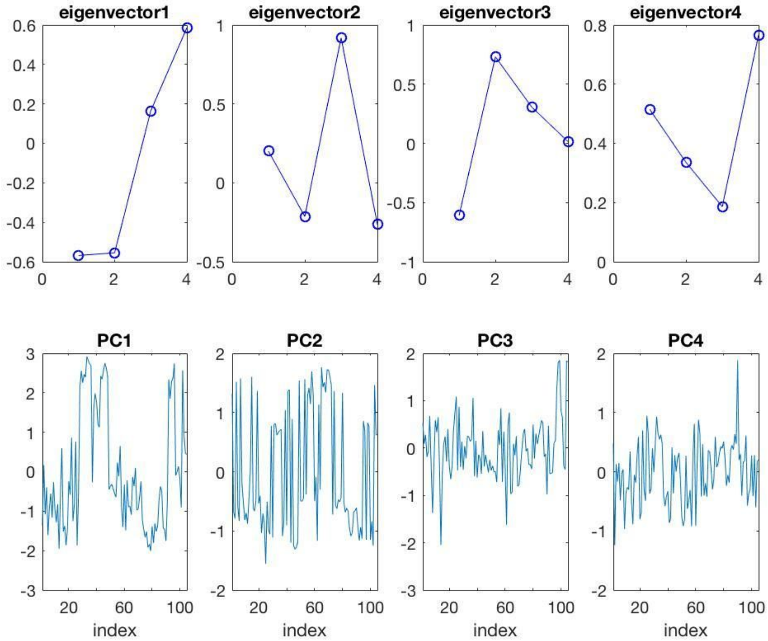
```
 -11.649887   3.524887
sample estimates:
mean of x mean of y 
 18.79167  22.85417 

> t.test(Feb_David$`% cover`,Feb_Creekside$`% cover`)

	Welch Two Sample t-test

data:  Feb_David$`% cover` and Feb_Creekside$`% cover`
t = 1.769, df = 102.98, p-value = 0.07985
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.908357 15.909673
sample estimates:
mean of x mean of y 
 28.77982  21.27917 

> t.test(Dec_David$`% cover`,Dec_Creekside$`% cover`)

	Welch Two Sample t-test

data:  Dec_David$`% cover` and Dec_Creekside$`% cover`
t = -1.1186, df = 85.616, p-value = 0.2664
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -12.898198   3.609581
sample estimates:
mean of x mean of y 
 20.43902  25.08333 
```

p-value		Stanley Park			Creekside park			David Lam Park		
		Dec.	Jan.	Feb.	Dec.	Jan.	Feb.	Dec.	Jan.	Feb.
Stanley Park	Dec.	N/A	0.000 1453	0.000 1817	0.688 9	N/A	N/A	0.585 1	N/A	N/A
	Jan.	0.000 1453	N/A	0.997 2	N/A	1.064 e-05	N/A	N/A	5.133 e-07	N/A
	Feb.	0.000 1817	0.997 2	N/A	N/A	N/A	7.405 e-06	N/A	N/A	0.001 644
Creekside Park	Dec.	0.688 9	N/A	N/A	N/A	0.568 6	0.352	0.266 4	N/A	N/A

	Jan.	N/A	1.064 e-05	N/A	0.568 6	N/A	0.687 9	N/A	0.266 4	N/A
	Feb.	N/A	N/A	7.405 e-06	0.352	0.687 9	N/A	N/A	N/A	0.079 85
David lam Park	Dec.	0.585 1	N/A	N/A	0.266 4	N/A	N/A	N/A	0.687 5	0.056 59
	Jan.	N/A	5.133 e-07	N/A	N/A	0.266 4	N/A	0.687 5	N/A	0.018 13
	Feb.	N/A	N/A	0.001 644	N/A	N/A	0.079 85	0.056 59	0.018 13	N/A

Table 3. P- Value chart of two sample t-tests comparing rockweed percent cover between two sites. <0.05 represents significant difference

Appendix V:



Plot of four modes eigenvectors and principal components. Modes are as follows from left to right: substrate type, substrate size, presence of other species and percent bare rock