Assessing Shifts in the Intertidal Fish Communities of Port Moody Arm

by

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Abstract

The intertidal fish communities of Port Moody Arm have been exposed to a range of stressors stemming from a long history of industrialisation in the Burrard Inlet. In the last decade, the Arm has seen important changes in industry such as the closure of the Burrard Thermal Power Plant and the Flavelle sawmill. I hypothesize that these changes will in turn affect the intertidal fish communities. Using the same methods as the ones used in a 2010 survey, we conducted bi-weekly beach seines at five sites around the Arm throughout the summer of 2022. Overall, I found that species diversity and richness had significantly increased between 2010 and 2022. I also observed that most species were captured more frequently in 2022 than in 2010. I did not find a significant difference in abundance. This report outlines the importance of continued monitoring in the Arm to examine population trends of intertidal fish.

Keywords: Intertidal fish; temporal shifts; Port Moody Arm; changes in industry; diversity; richness.

Dedication

I dedicate this research project to my parents, Jane Horton and Joël Cormier, and my sister, Elisabeth Cormier, who have supported and encouraged me every step of the way.

I also want to dedicate this report to my cohort. One of the best things to come out of this program is the connections that I have made with each and every one of you.

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I am extremely grateful for the Tsleil-Waututh Nation for letting me conduct my research on their land. Special thanks to Graham Nicholas for being our contact within the Nation and for being so responsive throughout the process.

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Table of Contents

List of Figures

Chapter 1. Introduction

Industrialisation along shorelines has been linked to the degradation of the surrounding intertidal zones through contaminant runoff, physical modifications (such as shoreline hardening and dredging), noise disturbances, etc. Fish are often used as an indicator of environmental health as they are sensitive to stressors and respond through shifts in their community (Fausch et al. 1990). The Port Moody Arm of Burrard Inlet has a long history of industrialisation. However, throughout the last decade, there has been a shift in direction of the management of the ecosystem moving toward passive restoration through closures and relocations of industry. An extensive intertidal fish survey was conducted in 2010, prior to the passive restoration of the Arm. In 2022, I was interested in evaluating how the intertidal fish communities have responded to the restoration of the Arm. Therefore, twelve years later, I repeated the methods of the 2010 intertidal fish survey to contrast any shifts in the community structure. The passive restoration when combined with reduced industry in the Arm was expected to result in improved intertidal conditions, which should be reflected in changes in fish species abundance, composition, diversity, and richness.

1.1. Burrard Inlet and Port Moody Arm

The Burrard Inlet is located in southwestern British Columbia, Canada. Its mouth discharges into the Strait of Georgia from Point Atkinson on the north shore and Point Grey on the south shore. The Burrard Inlet is 30 kilometers long from its mouth to the city of Port Moody in the east. Five hydrological regions form the Burrard Inlet: Outer Harbour, Central Harbour, Inner Harbour, Port Moody Arm, with the Indian Arm extending in a northerly direction between Central Harbour and Port Moody Arm. Port Moody Arm, the easternmost region of the inlet, is surrounded by the city of Port Moody. The Arm is 7 kilometers long and has an average depth of 9 meters (Levings et al. 2004). There are approximately 12 km of shoreline in Port Moody Arm. The Inlet exhibits a mixed diurnal tidal pattern (Levings et al. 2004).

The sorting of sediment performed by wave action has led to a noticeable east-to-west gradient in sediment type and size throughout Port Moody Arm (Levings et al. 2004). Sites closer to the Arm’s western limit tend to have coarser sediment with greater sand, gravel and cobble content. The Arm accumulates sediment at an estimated rate of between 0.3 cm $year^{-1}$ (Yunker et al. 1999) to 1 cm $year^{-1}$ (Pedersen & Waters 1989). Given its shallow depth and high rate of sedimentation, a portion of the Arm has to be periodically dredged to allow large commercial vessels ships to pass through (Levings et al. 2004), potentially disrupting the physical and biological processes that may in turn affect local fish communities that depend on these shorelines.

1.2. Industry and Water Quality in Port Moody Arm

Port Moody Arm, not unlike Burrard Inlet, has a long history of shoreline industry. Examples of industries operating around the Arm include a chemical treatment plant, hydroelectric thermal plant, oil refineries, and sawmills. In the last decade, several large industries, including Flavelle Sawmill and Burrard Thermal, have moved out of the Arm or have closed.

Water quality in Port Moody Arm has historically been quite poor which in turn has affected its fish communities. Goyette and Boyd (1989) examined the distribution of polynuclear hydrocarbons (PAHs), a type of petroleum waste, and hepatic lesions in English sole in the Burrard Inlet. Port Moody Arm had the highest rates of both PAHs and hepatic lesions when compared to other regions of the Inlet. Burd and Brinkhurst (1990) surveyed the benthic invertebrate communities which represent an important food source for fish in the Burrard Inlet. The Burd and Brinkhurst (1990) study observed that species were less abundant and diverse in the Arm compared to other regions of Burrard Inlet probably due to high concentrations of metals and organics in the sediment. Boyd et al. (1998) added to these findings by analyzing the sediment for contaminants. They found that the sediment in Port Moody Arm had the highest toxicity of any site in the Inlet (Boyd et al. 1998). With the closure of several polluting industries around the Arm, it is expected that water quality will have improved, and therefore, fish communities will have responded by increasing metrics of community health. I was interested to see if this translated to a greater fish diversity and abundance in Port Moody Arm.

1.3. Previous Fish Surveys

Several trawls were conducted in 1985 and 1986 in the Burrard Inlet (Goyette and Thomas 1987). They found 29 species of demersal fish in Port Moody Arm, including many species of flatfish such as English sole (*Pleuronectes vetulus*) and flathead sole (*Hippoglossoides elassodon*) (Goyette and Thomas 1987). Flatfish (and other species) have been known to use the intertidal zone as nursery grounds (Goyette and Thomas 1987). This study serves as a reminder of the importance of intertidal zones for fish communities.

In a report published in 1994, the Burke Mountain Naturalists compiled data acquired from various projects conducted by the Department of Fisheries and Oceans (DFO) in Port Moody Arm (Hanrahan 1994). These projects used a variety of sampling techniques including beach seining, hook and line fishing, and electroshocking (Hanrahan 1994). Overall, they found that at least 48 species of fish inhabit the Arm at some point in their life cycle (Hanrahan 1994). They recommended that part of the Arm, known as Shoreline Park, be given the designation of a “nature park” to reflect its ecological significance for plants and wildlife including bird, mammals, and fish (Hanrahan 1994).

In 1992, Naito and Hwang (2000) looked at the timing and distribution of salmonid species in the Burrard Inlet, including sites in Port Moody Arm. They found that the intertidal zone of the Arm plays an important role in the rearing of juvenile salmonids including cutthroat trout (*Oncorhynchus clarkii*), chinook (*Oncorhynchus tshawytscha*), chum (*Oncorhynchus keta*), coho (*Oncorhynchus kisutch*), and pink salmon (*Oncorhynchus gorbuscha*; Naito and Hwang 2000).

In 2010, a study called *What Swims Beneath* was conducted in Port Moody Arm with the main goal of building from disconnected studies to establish a baseline inventory of the fish species that occupy the intertidal zone in the Arm (Graham 2011). This 2010 study followed a salmonid survey conducted in 1992 by Naito and Hwang (2000). The 2010 survey of Graham (2011) expanded that of Naito and Hwang (2000) by conducting one of the first surveys in the area that included all species of intertidal fish, not just the salmonids. The findings of the *What Swims Beneath* study served as the baseline data for this research project.

1.4. Changes in Industry

Since the release of the *What Swims Beneath* study, several industries around the Arm have shut down. Firstly, Burrard Thermal, a power-generating plant, closed in 2016.

The thermal plant had the largest permitted water discharge in the Inlet, with approximately 1.7 million m^3 day^{-1} of cooling water (~27ºC) into the Arm (Levings *et al.* 2004). On the other hand, the average surface temperature of the Arm is approximately 16-18ºC (Levings *et al.* 2004).

The second major change in industry around the Arm occurred in 2020 with the closure of the Flavelle Sawmill. Sawmill discharge, such as saw dust and other wood waste, has been known to adversely affect fish abundance and diversity. For example, Faremi *et al.* (2021) found that fish communities downstream of a sawmill were significantly less abundant and diverse when compared to the upstream communities. Another unintended consequence of the closure of the Flavelle Sawmill was the removal of log booms in the Arm. These large floating structures were used by seals as a haul out, and in early summer as a pupping ground. When present, seals represent an important predator for fish, which could place top-down pressure on the fish community causing reductions in abundance.

With all these changes happening in Port Moody Arm, it is expected that fish communities found in 2022 will be different than those found in 2010.

1.5. Goals and Objectives

1. Examine the differences in intertidal fish abundance, composition, diversity, and richness between 2010 and 2022 to provide recommendations.
    a. Conduct biweekly beach seines at five sites in the Arm from June to August 2022.
2. Examine the within-year dynamics of fish abundance, diversity, and richness.

Chapter 2. Methods

2.1. Study Sites

The five shoreline sites sampled in the 2022 study were the same five sites surveyed in 2010. These were Barnett Marine Park, Dockrill, Old Orchard Park, Reed Point, and Slaughterhouse Creek (Graham 2011; Figure 1). These sites were selected based on ease of access and representative diversity of substrate found in the Arm (Graham 2011). Two of these sites had also been sampled in 1992 (Naito and Hwang 2000). Their methods were replicated at the same five sites they sampled.

Barnett Marine Park is the westernmost site near the intersection between the Inner Inlet, Indian Arm, and Port Moody Arm. It is the only study site located in the city of Burnaby. This park is a popular beach used for a variety of recreational uses including kayaking, paddleboarding, fishing, etc. The eastern section of this site, which was the one sampled in this project, is located near a tidal channel. The shoreline is mostly green space (grass, forested areas) with some facilities (washrooms, kayak rental storage, picnic tables, etc.)

Dockrill is located at the mouth of Mossom Creek, one of only two creeks that flow into the Arm that can support salmonids. The Mossom Creek Hatchery, which is located upstream of the site, releases approximately 100,000 Chum fry and 5-10,000 Coho smolts annually as well as pink salmon. The shoreline at this site is mostly residential, with houses and large backyards.

Old Orchard is Port Moody's only swimming beach. The upper part of this site is a small, forested area above which is a residential street with houses that overlook the Inlet.

Reed Point is the only site sampled in this project that is artificial. It was constructed as part of the compensation requirements for the expansion of the railway located on the south side of the Arm. Boulders were piled on top of each other to form a large mound.

Slaughterhouse Creek is the easternmost site of the Arm. Silt and other fine sediment accumulate at this site making it a large mudflat. Mudflats, such as this one, are highly productive sites. They are used by invertebrates which burrow into the mud forming tunnels. These tunnels are used by other small fish for shelter. Fish also prey on the invertebrates found in the muddy substrate.

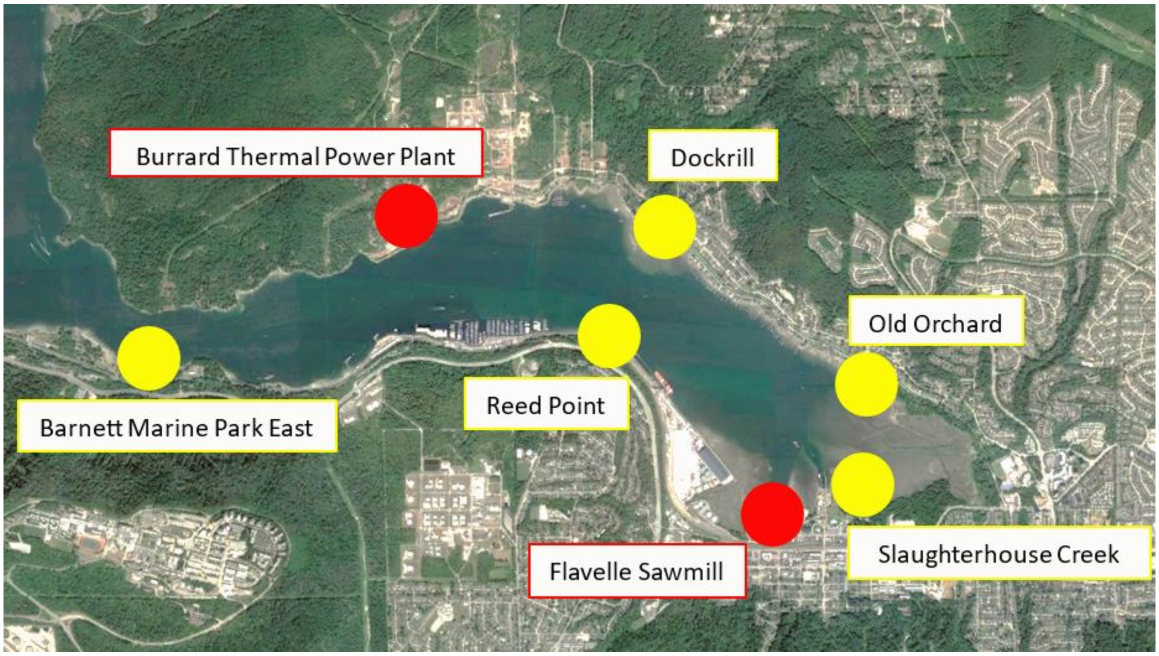

Figure 1. The five sites sampled (in yellow) and the two industries that closed in the last decade (in red) in Port Moody Arm.

2.2. Beach Seines

Intertidal fish communities were assessed at each site in six bi-weekly beach seines between June and August 2022. The net and the boat used in the procedure described below were the same ones used in 2010 to avoid introducing unnecessary differences between the two years. The team consisted of at least six volunteers to ensure that the fish were returned to the water as quickly as possible. Additionally, two of the researchers that were involved in the 2010 survey were present in 2022, including the boat captain, to ensure that the method used were consistent between the years.

Two sets were collected at each site, unless sampling conditions were judged to be potentially harmful to fish (e.g., high temperature and turbidity). Sets were conducted using a 30.48 meter long and 1.83 meter deep seine (outer mesh size of 1.3 cm, inner mesh size of 0.6 cm). On one side of the sampling area, volunteers held ropes that were attached to the net. A shallow drafted skiff (Medusa 2 skiff, 7.38 meters long) then carried the net to another pair of volunteers located on the other side of the sampling area, forming a semicircle with the net. In the event when the boat could not reach the shore (i.e., the tide was too low or the site was too flat), the net was dropped into the water and volunteers carried it to shore forming a semicircle. In either case, both pairs of volunteers then pulled the net to shore, trapping fish for processing. Volunteers made sure that the lead line was constantly touching the substrate to avoid fish escapement. In the event that a large boulder blocked the net, a volunteer would either remove it (when possible) or rapidly lift the net over the obstacle. Once the net was mostly out of the water, all fish were transferred into buckets of fresh marine water. Each individual was identified to species. Those that could not be identified in the field were photographed. The images were later uploaded onto iNaturalist where local fish enthusiasts could suggest possible species identifications. Species were considered to be positively identified after at least two non-conflicting identifications. In the event of conflicting answers, the images were sent to local fish experts. Any species that were not positively identified, were left as “unknown" and were excluded from the analysis. This occurred twice and did not make significant differences to our community analysis.

Most individuals were measured (nose-to-fork length) unless they were highly abundant (i.e., more than 20 caught in one set). In this case, a random subset was measured to be representative of the captured population. The size of the subset measured depended on the overall variability in length within the sample (i.e., fewer individuals were measured if they were all of similar in sizes). Before the fish were released, the second set was put in place to avoid catching the same individuals twice. The second set was placed approximately 10 meters away from one end of the first set. After both sets were processed, water temperature (ºC), pH, dissolved oxygen (mg L^{-1}, %), and specific conductance (µS m^{-1}) were measured using a YSI Multimeter Pro at a depth of 50 cm.

2.3. Beach Profiles

Beach profiles at each site were conducted to assess slope and sediment type relative to tidal height. They were used to estimate the sediment composition where each seine net survey was conducted. At each site, a flag was placed at the current tidal line and the time was noted. The current tidal height was obtained using tidal data which was updated every minute[1].

The eye level height of the volunteer holding the Rangefinder (observer) was added to the current tidal height, and a piece of flagging tape was placed at that height on the survey rod. One volunteer holding the rod walked into the water perpendicularly to the tidal line until the Rangefinder indicated an angle of 0° with the tape. The survey rod was now located at bottom of the intertidal zone (i.e., tidal height of 0 m). Due to safety concerns, it was not always possible to reach this point, in which case, the remainder of the profile was extrapolated using the last available slope.

Another piece of tape was placed at the observer's eye level. At each interval, the observer pointed the Rangefinder to the eye line marker on the survey rod, noting distance and slope. Substrate was assessed by estimating the percentage of mud, sand, pebble, gravel, cobble, and boulders at each interval. The person holding the rod then walked to where the observer was standing. Then, the observers walked the predetermined distances away from the survey rod and repeated these methods until they reached the top of the beach. The length of the intervals depended on the length of the profile and the variability in slope at each site. In other words, a longer intertidal area with a constant slope was measured at larger intervals than a short, highly variable slope.

Comparing the profiles of the two years was not possible as each site is topologically heterogenous and, therefore, even within a site, two transects would look very different from one another. Future studies would need to establish a starting point (or landmark) as well as a direction (using a compass) to be able to compare between years. Profiles of each site for 2010 and 2022 are included in the appendix of this report.

2.4. Statistical Analysis

Abundance, Diversity, and Richness Models

Abundance was measured by summing the area-adjusted fish counts for each set at each site. I used a generalized linear mixed-effect model (GLMM) to compare

[1] https://tides.gc.ca/en/stations/07755/2022-08-22?tz=PDT&unit=m

differences in abundance between species between 2010 and 2022 and throughout the summer, I assumed the data followed a quasi-Poisson distribution. This permitted more flexibility in the within sample variance, allowing for an extra parameter to capture the sample over-dispersion.

Richness was measured for each set by simply counting the number of species caught. To model species richness, I fit a generalized linear mixed model but set the overdispersion parameter to 1. The data followed a Poisson distribution.

The Shannon-Weiner Diversity Index was measured for each set using the following equation:

$$H = -\Sigma p_i * \ln(p_i)$$

where H is the diversity index of a set and p_i is the proportion of the set that is made up of species i. To assess differences in diversity between years and throughout the sampling season, I used a linear mixed model (LMM) since the diversity index was normally distributed.

For all three models, I considered two fixed effects and one random effect. The time of year (i.e., number of days since January, DSJ) was a continuous fixed variable that describes the change in the response across the season. The seasonal biology and life cycles of the different fish species meant that abundance, diversity, and richness did not change linearly with time. This nonlinearity was accommodated through b-splines. The b-spline had three degrees of freedom as this model had the lowest overall AIC score. Differences between years (2010 or 2022) was included as a second fixed effect in the models with one degree of freedom. The sites at which the individuals were sampled were considered to be random site replicates and included in the model as random effects.

Below are the linear models used in the analysis of abundance, diversity, and richness respectively.

Model 1: GLMM(Abundance ~ Year + bs(DSJ) + (1|Site), family = Quasi-poisson)

Model 2: LMM(Diversity ~ Year + bs(DSJ) + (1|Site), family = Gaussian)

Model 3: GLMM(Richness ~ Year + bs(DSJ) + (1|Site), family = Poisson)

Differences in Community Composition Between 2010 and 2022

To examine the difference in species composition between 2010 and 2022, I conducted a Permutational Multivariate Analysis of Variance (PERMANOVA) using the *adonis* function the R's vegan package. Non-metric Multidimensional Scaling (NMDS) was also used to analyze the directionality of species composition among sites in 2010 and 2022. NMDS helps to interpret information from multiple dimensions (multiple community measures) using rank orders (Kruskal 1964). A statistical shift in the intertidal fish species would indicate a community shift in species composition.

Differences Between Sets 1 and 2

In 2022, two sets of beach seines were conducted at each site on each sampling day (when possible). To keep it consistent with the 2010 sampling, I only included the data from the first set in my analysis. However, I wanted to check if this would significantly change the 2022 data. To do so, I compared the intertidal fish communities of sets 1 and 2 at each of the five sites across the 6 seine surveys. To compare species composition, I conducted a PERMANOVA test. For abundance, diversity, and richness, I used a Wilcoxon test.

Chapter 3. Results

The dataset that I used to compare fish communities in 2010 and 2022 included the first sets conducted between June and August. For this analysis, seven (7) sampling days and 35 sets were considered for 2010 compared to six (6) days and 29 sets in 2022. No fish were caught in the first set conducted at Slaughterhouse on August 8th, 2022, and therefore, this set was not included in the analysis.

Across all surveys conducted between June and August 2010, 14 species were found belonging to 9 orders, 10 families, and 11 genera. The most abundant and most commonly found species (i.e., seen in the highest number of sets) were arrow goby (*Clevelandia ios*), shiner perch (*Cymatogaster aggregate*), staghorn sculpin (*Leptocottus armatus*), and three-spined stickleback (*Gasterosteus aculeatus*). In 2022, 22 species were included in this dataset belonging to 11 orders, 12 families, and 18 genera. The most abundant species were arrow goby, shiner perch, staghorn sculpin, northern anchovy (*Engraulis mordax*), and three-spined stickleback. With the exception of the northern anchovy, these species were also the most commonly seen throughout the sampling period. Some species that were caught in 2022 were excluded from the dataset as they were only captured in the second sets: rainbow trout (*Oncorhynchus mykiss*), buffalo sculpin (*Enophrys bison*), and striped sculpin (*Embiotoca lateralis*). However, these species were caught infrequently and in low numbers, and therefore removing them did not significantly affect the results.

Some species were found more frequently (i.e., in a higher percentage of sets) in 2022 compared to 2010. Three-spined stickleback were found in 38% of sets conducted in 2010 and 60% of the ones in 2022. Shiner perch were found in 41% (2010) and 70% (2022) of sets. Gunnels were caught more frequently in 2022: saddleback gunnel (from 9% to 33%; *Pholis ornata*), penpoint gunnel (0% to 10%; *Apodichthys flavidus*), crescent gunnel (3% to 10%; *Pholis laeta*). Sculpin were also found more often: sharpnose sculpin (0% to 37%; *Clinocottus acuticeps*), staghorn sculpin (59% to 73%), and tidepool sculpin (3% to 17%; *Oligocottus maculosus*). Other species include arrow goby (47% to 60%), bay pipefish (29% to 40%; *Syngnathus leptorhynchus*), and starry flounder (29% to 40%; *Platichthys stellatus*). Plainfin midshipman (0% to 17%; *Porichthys notatus*) and northern anchovy (0% to 10%) were not detected in 2010 but were fairly abundant in 2022. Finally, padded sculpin (*Artedius fenestralis*), C-O sole (*Pleuronichthys coenosus*), eulachon (*Thaleichthys pacificus*), speckled sanddab (*Citharichthys stigmaeus*), and pile perch (*Phanerodon vacca*) were only detected in 2022, but in small numbers and in a small percentage of sets (around 3%).

Some species were found less frequently. Surf smelt (*Hypomesus pretiosus*), which were caught in 18% of the sets conducted in 2010, were not detected in 2022. Similarly, sand lance (*Ammodytes dubius*) were found in 6% of sets in 2010 but not detected in 2022. Finally, two salmonid species were less frequent in 2022: chinook salmon (15% to 3%; *Oncorhynchus tshawytscha*) and cutthroat trout (18% to 7%; *Oncorhynchus clarkii*). I found no significant difference in pink salmon (*Oncorhynchus gorbuscha*) frequency between years.

I found no significant difference in fish abundance between 2010 and 2022 (GLMM p-value = 0.822) and throughout the sampling periods (i.e., days since January; p-value > 0.05). On the other hand, I found a significant shift to higher diversity in 2022 compared to 2010 (LMM p-value = 0.009) with no statistical trends within the sampling period (p-value > 0.05). Additionally, I found a significant difference in species richness between 2010 and 2022 (p-value = 6.74e-05) as well as throughout the time of year (p-value = 0.0382). On average, 3.3 species (95% CI [2.5, 4.1]) were caught in each set in 2010 compared to 5.5 species (95% CI [4.3, 6.7]) in 2022 (Figure 2).

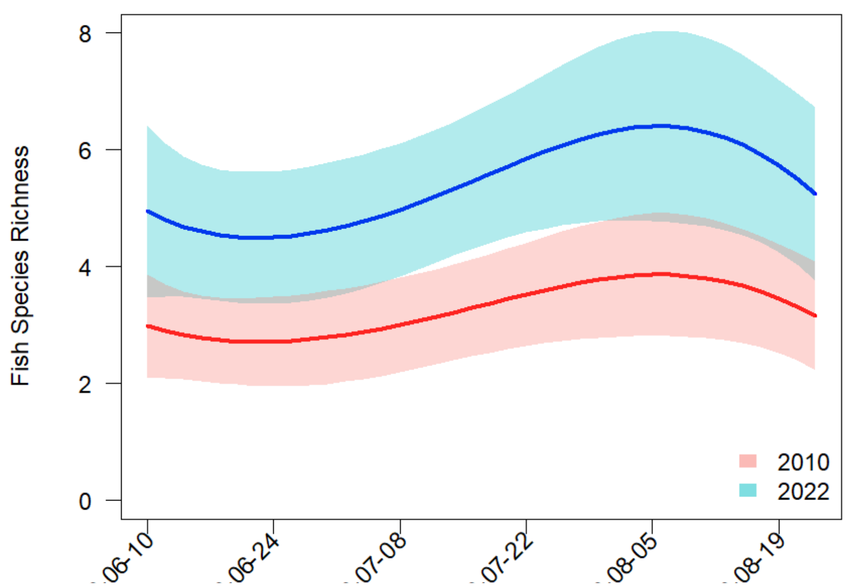

Figure 2. Species richness in 2010 (in red with 95% confidence interval) and 2022 (in blue with 95% confidence interval) in Port Moody Arm.

The intertidal community structure of Port Moody Arm stayed relatively stable between 2010 and 2022 (PERMANOVA p-value = 0.181; Figure 3). When considering each individual site, I found no statistically significant difference in species composition between 2010 and 2022 for either of the five sites (Figure 4): Barnett (p-value = 0.591), Dockrill (p-value = 0.056), Old Orchard (p-value = 0.778), Reed Point (p-value = 0.688), and Slaughterhouse (p-value = 0.508). The two polygons for Slaughterhouse do not overlap, however, this is likely due to the small sample size. It is also worth mentioning that, again, due to the study's small sample size, it is possible that trends were not detected. A more long-term study would allow us to get a better sense of if and how the communities are shifting over time.

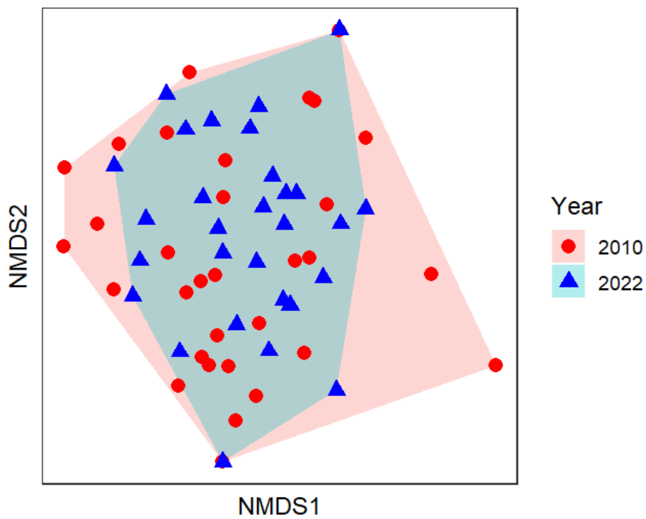

Figure 3. Non-Metric Multidimensional Scaling (NDMS) graph comparing fish species composition of 2010 (in red) and 2022 (in blue) in Port Moody Arm.

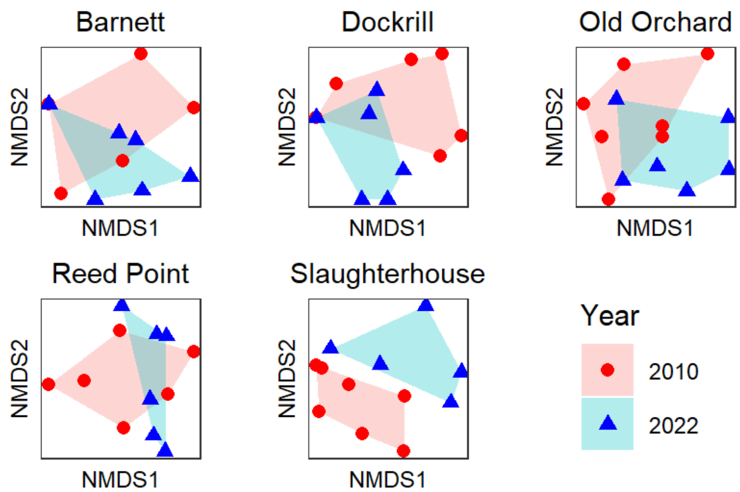

Figure 4. NDMS graph comparing species composition of 2010 (in red) and 2022 (in blue) at each sample site in Port Moody Arm.

A closer examination of the intertidal fish data revealed some differences at each site between 2010 and 2022 in terms of richness, diversity, and in individual species catch frequency. In 2010, shiner perch were the most frequently found and abundant species in Barnett Marine Park. In 2022, shiner perch were still the most common species, with staghorn sculpin being found more frequently as well. The average number of species caught in a beach seine in 2022 (4.2 species) was greater than of 2010 (3.4 species; Figure 5). The diversity index did not change significantly (0.73 compared to 0.71; Figure 6). In Dockrill, in 2010, arrow goby was the only commonly found species. In 2022, on the other hand, arrow goby, shiner perch, sculpins (staghorn and sharpnose), gunnels (crescent, saddleback, and penpoint), and bay pipefish were relatively frequent and abundant. Dockrill had a large increase the average number of species caught (1.7 to 5.5; Figure 5) and in diversity (0.12 to 0.60; Figure 6). In Old Orchard, arrow goby, shiner perch, staghorn sculpin, starry flounder, bay pipefish, three-spined stickleback were fairly common in both 2010 and 2022. Additionally, sculpins and gunnels were more common in 2022. The average number species caught per set increased from 4.0 species in 2010 to 6.8 in 2022 (Figure 5). The diversity index also increased from 0.48 to 0.92 (Figure 6). In Reed Point, shiner perch was the most common species found in 2010, which was still the case in 2022. However, in 2022, three-spined stickleback, sharpnose sculpin, bay pipefish, staghorn sculpin also became fairly common. There was a large increase in the average number of species caught in 2010 (2.6 species) compared to 2022 (6.2 species; Figure 5) as well as the diversity index between the years (0.37 vs. 1.0; Figure 6). Finally, in Slaughterhouse, arrow goby, staghorn sculpin, three-spined stickleback, and starry flounder were the most common species in 2010. In 2022, the species found were similar to 2010 except starry flounder, which were less frequent. Northern anchovy was also quite abundant that year but was only found in one set at the end of August. Slaughterhouse was the only site that saw a decrease in the average number of species caught per set (4.4 in 2010 compared to 3.4 in 2022; Figure 5). However, the diversity index did not change significantly (0.58 compared to 0.57; Figure 6).

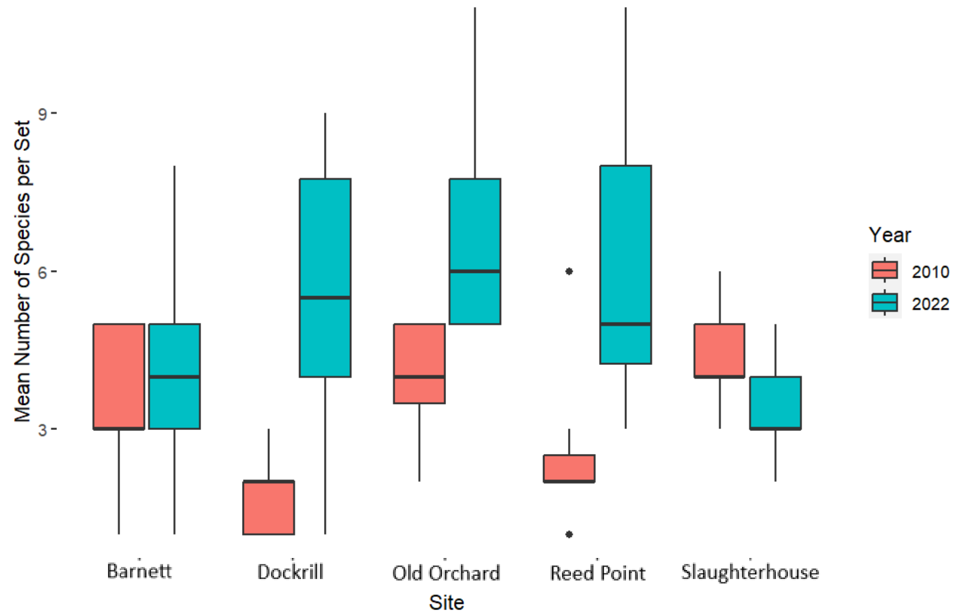

Figure 5. Distribution of species richness (number of species caught per set; y axis) at each site (x axis) taken between June and August 2010 (in orange) and 2022 (in blue) for each site sampled in Port Moody Arm.

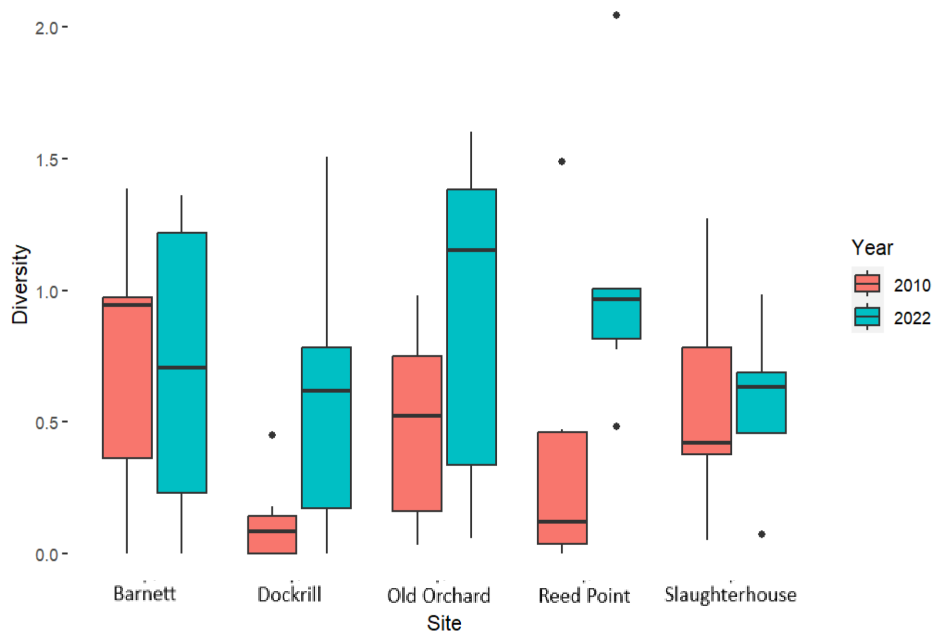

Figure 6. Shannon Weiner Diversity Index (y axis) at each site (x axis) averaged across samples taken between June and August 2010 (in orange) and 2022 (in blue) for each site sampled in Port Moody Arm. Outlier values in diversity are indicated as dots beyond the extent of the boxplot whiskers. An outlier is defined here as any data points that are more than 1.5 times the interquartile range away from the upper or lower quartile.

The dataset that I used to compare two seine sets conducted on the same day at the same location only included the data that were replicated (i.e., two sets at one site) between June to August. As a result, only 2022 data were considered in this analysis as no replicates were done in 2010. A total of 48 sets were considered (24 for each set) and a total of 24 species were included in this dataset.

Overall, I found no significant difference between sets in abundance (p-value = 0.934), composition (p-value = 0.950; Figure 7), diversity (p-value = 0.381), and richness (p-value = 0.096). This suggests that the effects of the beach seine surveys didn't upset the local community in any significant way. Some species-specific differences were observed. Sharpnose sculpin, crescent gunnel, saddleback gunnel, bay pipefish, starry flounder, and plainfin midshipman were found more abundantly in the first set than in the second one. All of these species, except crescent gunnel, were also found more frequently in the first set. All other species were not abundant or frequent enough to draw any meaningful conclusions.

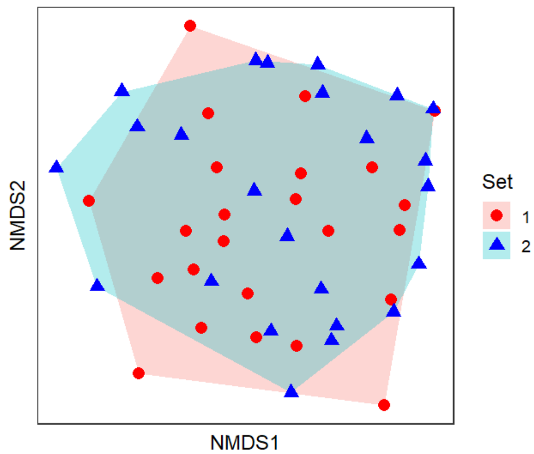

Figure 7. NMDS graph showing the variation in two-dimensional space of fish communities for sets 1 (in red) and 2 (in blue) conducted in Port Moody Arm. The more overlap there is between the two polygons, the more similar the two sets are.

Finally, I looked at the nose-to-fork measurements collected in 2022 (not 2010 as the measurements were unavailable) for the four most dominant species in Port Moody Arm: arrow goby, shiner perch, staghorn sculpin, three-spined stickleback (Figure 8). All four species showed changes in the size classes found in the Arm throughout the 2022 sampling period. Arrow goby, shiner perch, and three-spined stickleback size distributions shifted from larger fish in June to mostly smaller fish in July and August 2022. On the other hand, the average size of staghorn sculpin increased from June to mid-July and a smaller size class appeared in August. These size classes correspond to different life stages of each species that occupied the Arm throughout the 2022 sampling period. For example, different age classes of arrow goby were found including mature individuals (> 34 mm; Hart 1973 as cited in Graham 2011) and what are likely young-of-the-year (Figure 8). These observations reinforce the notion that several fish species rely on the intertidal zone of Port Moody Arm for some or most of their life cycle.

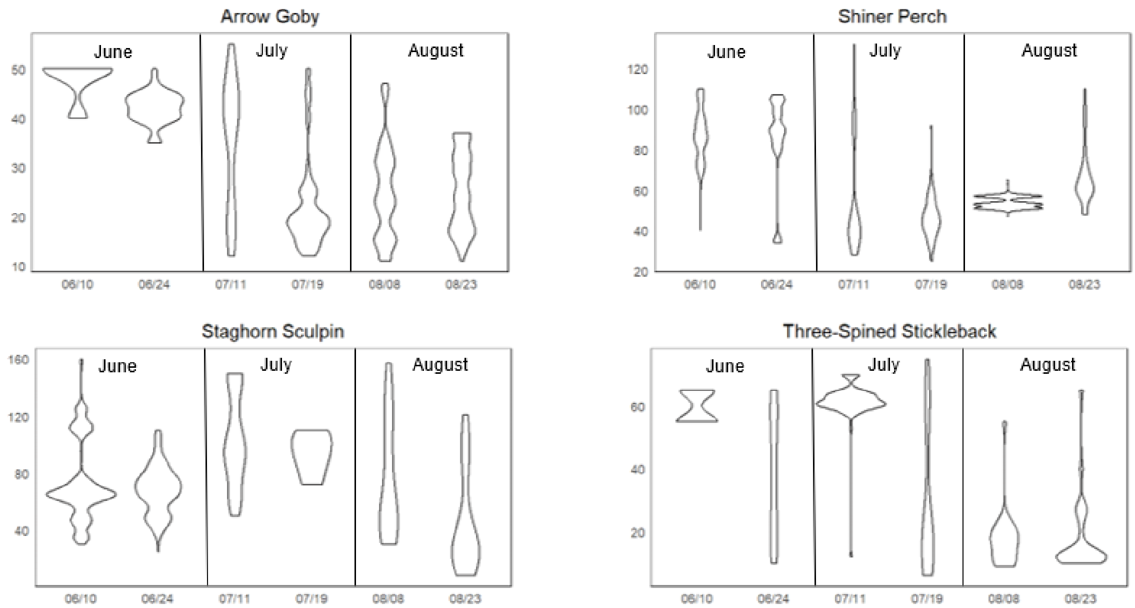

Figure 8. The fork-nose length distribution (in mm) throughout the 2022 sampling period for the four dominant species in Port Moody Arm: arrow goby, shiner perch, staghorn sculpin, and three-spined stickleback. Measurements for the 2010 sampling data were unavailable.

Chapter 4. Discussion

The goal of this project was to assess if and how the intertidal fish communities of Port Moody Arm have changed since the last survey conducted in 2010 as a result of passive restoration in the wake of closures of several industries. For this project, I examined intertidal fish communities in 2022 and compared them to the 2010 survey. Below, I discuss the main results of this project regarding species abundance, catch frequency, composition, diversity, and richness.

4.1. Species Catch Frequency, Diversity, and Richness

The intertidal fish communities of Port Moody Arm were more diverse in 2022 than in 2010. Specifically, Dockrill, Old Orchard, and Reed Point saw a large increase in diversity, whereas Slaughterhouse and Barnett Marine Park saw no significant change. Indeed, on average, the diversity score for 2010 was 0.63 whereas in 2022 it was 0.96. The index used to measure diversity is known as the Shannon-Wiener Diversity Index, which takes into account species richness and evenness. For example, an area with few species (i.e., low richness) that is dominated by one species (i.e., low evenness) will have a lower diversity rating compared to one that has many evenly distributed species.

Species richness was much greater in 2022 than in 2010. On average, two more species were caught in each set that we conducted in 2022 (5 species per set) compared to 2010 (3 species per set). All sites, except Slaughterhouse, saw a large increase in the average number of species caught in each set. Additionally, in Port Moody Arm, more species were found in 2022 (22 species) than in 2010 (14 species). The increase in richness throughout the sampling period is likely linked to the fact that many species spent longer periods of time in the Arm in 2022 compared to 2010 as one can see by their higher catch frequency.

Many species were found more frequently throughout 2022. For example, three-spined stickleback, shiner perch, gunnels, sculpins, arrow goby, bay pipefish, and starry flounder were found more often in 2022 than in 2010. Although the 2022 percentages might be slightly enhanced due to the sampling season’s smaller sample size, not all the increase in frequency can be explained by the difference in sampling effort. This finding indicates that some species are possibly spending more time in the intertidal zone of Port

Moody Arm. Additionally, sharpnose sculpin, plainfin midshipman and northern anchovy were not detected between June and August 2010 but were fairly common in 2022, which strongly suggests that their populations have either increased in size or moved into the Arm since 2010. Overall, the majority of intertidal fish that were found during the sampling periods are now more frequent, which could imply that Port Moody Arm is a more suitable environment for them.

4.2. Dominant Species

The dominant species found in the intertidal zone of Port Moody Arm have not changed significantly in the last decade. Indeed, arrow goby, shiner perch, staghorn sculpin, and three-spined stickleback were the most common and abundant species in both 2010 and 2022. Additionally, I found no significant difference in the species composition between both years. These findings are consistent with a study conducted by Benazza *et al.* (2015) that looked at intertidal fish communities in the north of France between 2000 and 2013. Overall, they found that the species assemblages had been resistant to change and were fairly predictable throughout the years. The stability of the dominant species in Port Moody Arm is critical as these species often play an important role in the marine food web for other larger fish and marine mammals. For instance, the arrow goby is an important food source for the staghorn sculpin (Tasto 1974 as cited in Graham 2011), which in turn is predated upon by larger fish, such as salmonids (Hart 1973 as cited in Graham 2011). The stability of the dominant species coupled with the fact that the overall abundance has not changed between the two years suggests that the base of the Arm's food web is a consistent and reliable source through the years.

The only significant difference in terms of the dominant species assemblage is the northern anchovy. Indeed, this species is the only one that was not detected in 2010 but was very abundant in 2022. However, this species is not new to British Columbia. In fact, in the late 1800s, the northern anchovy was a commercially important species in the province (DFO 2002). Its harvest peaked in the early 1940s but has since greatly declined (DFO 2002). Only a few studies have been conducted in British Columbia to assess the northern anchovy population size. Emmett *et al.* (1997) found that the northern stock had declined considerably. In 2010, no northern anchovy was found in the Arm. In contrast, in 2022, the sampling team and I caught thousands of them, and we would often see them swimming around the boat. According to a report by the Department of Fisheries and

Oceans Canada, it is unclear what factors affect anchovy population size and distribution (DFO 2002). Regardless, the northern anchovy population appears to be recovering or returning to the Arm.

4.3. Changes in Industry and Fish Communities

Some of the changes in species catch frequency, diversity, and richness could be related to the changes in industry around the Arm. For instance, the Burrard Thermal power-generating plant, which closed in 2016 (between the two sampling periods) was permitted to discharge millions of cubic meters of cooling water per day into Port Moody Arm. The average temperature of the discharged water was approximately 27^{o}C which was much warmer than that of the Arm which was around 16-18^{o}C (Levings *et al.* 2004). Changes in temperature can lead to physiological stress which in turn can affect the short-term and long-term survival of fish by blocking the distribution of energy for processes including growth, immunity, and reproduction (Alfonso *et al.* 2020). The consequences of this can be felt at a population level and can lead to shifts in fish communities (Adams, 1990; Barton, 2002). Furthermore, chronic environmental stress can negatively affect how their offspring handle stress (Colson et al., 2015, 2019; Redfern et al., 2017), thereby amplifying the impact of the stressor in future generations.

In the case of Port Moody Arm, fish generally had the option to respond through behavioral changes, specifically by moving to other parts of the inlet that were unaffected by the change in temperature. Indeed, studies have found that fish are able to detect small differences in temperature and consequently will seek out new depths (vertical movement) or areas (horizontal movement) that are more suitable to them (Brett 1952, Sullivan and Fisher 1953). However, not all species would react in the same way. I hypothesize that the four dominant species found in 2010 have a higher tolerance to stress than other species which allowed them to stay in the Arm. This would explain why the other species were a lot less common and why diversity was much lower in 2010. This would also be consistent with other studies which have found that environmental stressors reduce species diversity (Gorham and Gordon 1960; Woodwell 1970; Freedman and Hutchinson 1980). Based on lower catch frequency, it seems as though individuals were also spending less time in the Arm in 2010 compared to 2022, reinforcing the idea that some fish species were potentially avoiding an environmental stressor. The passive restoration of the Arm has potentially led to making it a more suitable environment for intertidal fish.

4.4. Study Limitations and Recommendations

This study came with a few limitations which are important to acknowledge. For instance, randomness played an important role in what species were caught, especially when dealing with uncommon or rare species. For example, although they were not detected in 2010, padded sculpin, C-O sole, eulachon, speckled sanddab, pile perch were found in low abundance and frequency throughout the 2022 sampling period. However, it is possible that these species were present in 2010 but were simply not found due to how uncommon they are. Conversely, some relatively uncommon species were found less frequently in 2022 (e.g., chinook salmon, cutthroat trout, sand lance, and surf smelt). When dealing with rare or uncommon species, one must be careful not to jump to conclusions regarding population trends seeing as luck and small sample size could have affected what species were detected.

Species distribution can also affect the likelihood of catching certain species, even fairly common species. The individuals of many fish species will often group together to form schools leading to a non-homogenous distribution throughout the sites. Additionally, fish are dynamic and can move great distances so the species found at a specific site might vary between different days or even between different sections within a site. Therefore, due to random chance, a certain species might not be captured and would remain undetected even though it is present in the Arm. For example, sand lances were not detected during the six sampling days of 2022. This could lead to the wrong conclusion that there are no more sand lances in the Arm. However, a separate survey conducted by the department of Fisheries and Oceans Canada at Barnett Marine Park on June 5th, 2022, found 31 sand lances in one set. It is important to understand the limitations of this kind of survey. Although beach seines do provide a general idea of the species that are found at our sample site, they are not able to capture everything, and some species might simply go undetected.

Determining trends using only two years of data might lead to erroneous or misleading statements. It is important to be cautious with the observations made in this report. A more intensive and long-term sampling program would allow us to confirm or reassess some of the trends outlined above. For example, conducting beach seines in Port Moody Arm more frequently would allow us to see if the population of northern anchovy is truly recovering or if 2022 was simply an exception. It would also allow us to compile a more representative list of species present in Port Moody Arm. However, it should be noted though that these kinds of studies require a lot of planning and resources (funding, volunteers, equipment, etc.) and thus could prove challenging to do more frequently.

Certain modifications can be done to this project to allow for a smaller research team, for example, by reducing the number of sets conducted at each site. Indeed, I found no significant difference between sets 1 and 2 in terms of their species abundance, composition, diversity, and richness. The amount of information gained by the second set is quite small relative to that gained by the first set. In fact, just three additional species (six individuals) were found only in the second set compared to the 22 caught in the first set. This finding has potential implications for future surveys of this nature in Port Moody Arm. Indeed, similar projects could limit themselves to one set at each site especially if the crew is too small to handle two sets at once. Based on my results, this would likely not significantly affect the data. However, when possible, multiple sets should be conducted at each site in order to get a more complete idea of the fish species that are found in the intertidal zone of Port Moody.

4.5. La Niña and Pacific Decadal Oscillation

Both sampling periods (June to August 2010 and 2022) overlapped with La Niña events and negative Pacific Decadal Oscillation (PDO) phases which are characterized by lower sea surface temperatures on the west coast of North America. These atmospheric and oceanic processes have been shown to cause variations in fish communities on the Pacific coast of North America (Zhou 2015) by affecting fish migration. However, both sampling periods were affected by similar large scale oceanic processes, and therefore, it is unlikely that the differences between 2010 and 2022 can be explained by these events. Since there is a variation in fish community as a result of these processes, it is important to also survey over a long period of time. A long-term sampling program would help capture this variation and provide a better sense of the different species that use the Arm.

Chapter 5. Conclusion

The intertidal zone of Port Moody Arm is home to a rich and diverse fish community. Protecting and restoring this ecologically important area is vital for the conservation of the fish that rely on the Arm throughout various life stages. One example of restoration efforts that have taken place in the Arm is the closure of some industries along the shoreline. It is hypothesized that that these changes have allowed fish communities to recover. Comparing data from 2010 and 2022 provided several insights: (1) the fish community was more diverse in 2022 than in 2010, (2) there was a higher species richness in 2022, (3) the abundance was similar between the years, (4) most of the fish species were caught more frequently in 2022, (5) the fish community composition was fairly stable between the two years, and (6) the dominant species have not changed in the last decade (with the exception of Northern Anchovies). Due to how complex this system is, it is important to be cautious with these findings as two years of data is likely not enough to establish definitive trends. Long term monitoring will allow us to better understand the natural variations of the system as well as the general population trends. These surveys can also serve as baseline data for any future restoration projects that take place in Port Moody Arm. The more we know about this system, the better equipped we will be at protecting and restoring it.

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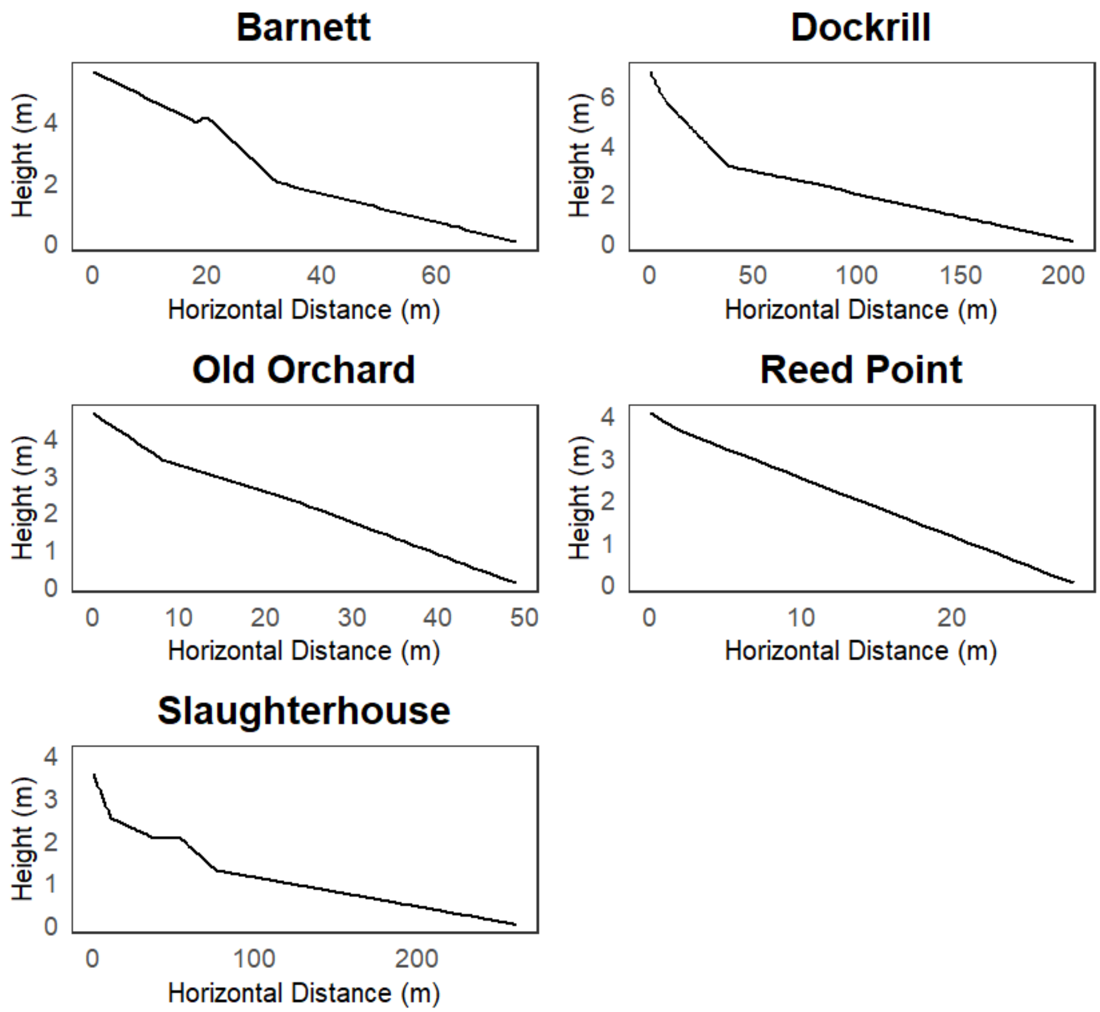
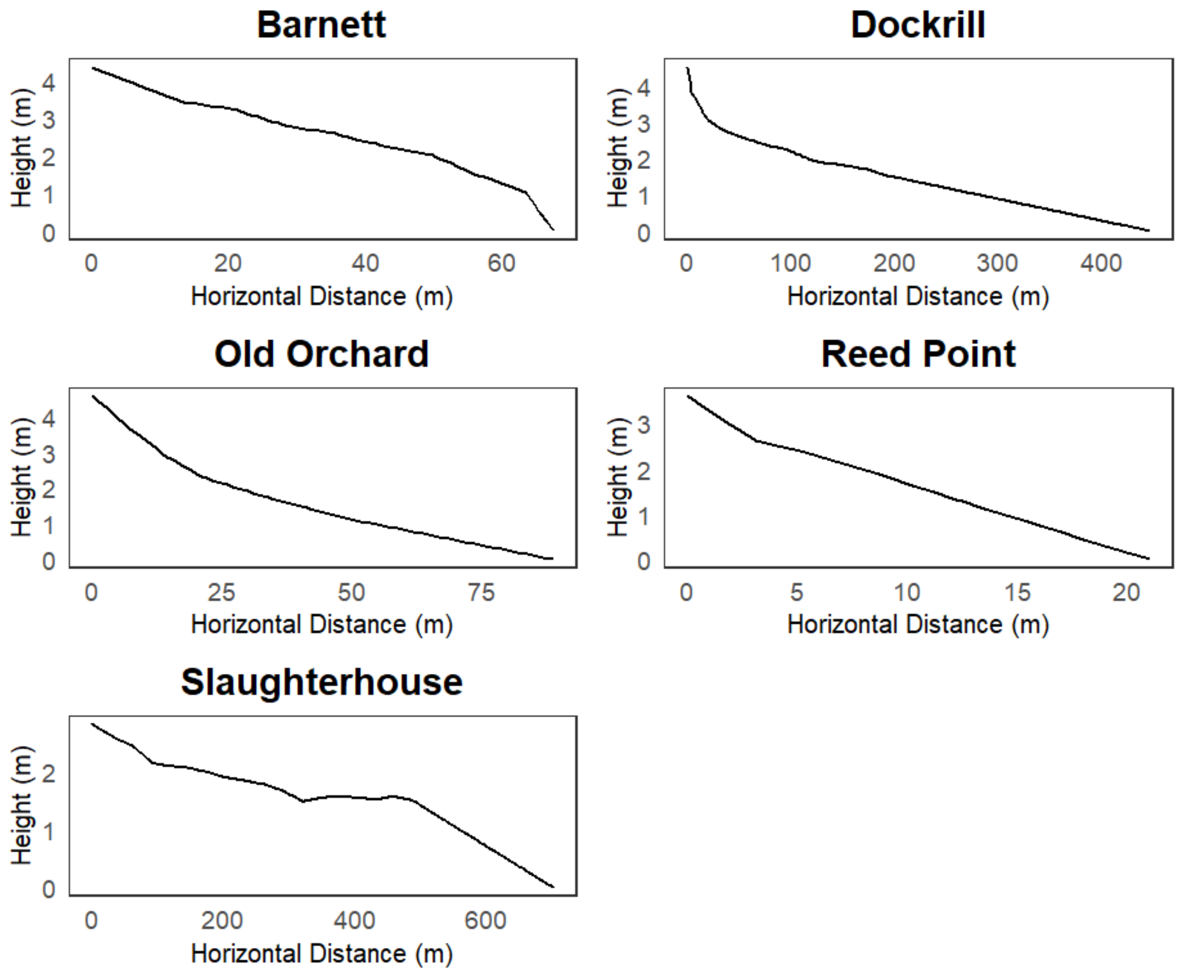
Appendix A.



Appendix 1. Beach profiles of the five sampling sites conducted in 2010.



Appendix 2. Beach profiles of the five sampling sites conducted in 2022.