Measuring Differences in Clam Populations between Two Stream Outflow Areas in False Bay, San Juan Island, Washington

Ryan Pittsinger

Biodiversity and Monitoring for Estuarine Ecosystems (BMEE)

Fall Quarter 2021

Abstract

False Bay, an estuary mudflat located on San Juan Island, Washington has not been studied extensively in the past but is a home to many infaunal species, such as clams. In this study, I focused on the sedimentary effects that two different streams, False Bay Creek and Forest Creek, may have on the clam populations found in both stream outflow areas. I went to False Bay in the month of November and walked along five transects per stream outflow area, sampling for clams and sediment. Clam species were later identified and measured for height and length, and each sediment sample was sieved to determine volumetric proportions of sediment size. The results showed that the clam species *Macoma nasuta* was the most abundant species in the majority of the Forest Creek area and at the farthest region from the False Bay Creek stream. False Bay Creek had the highest abundance of diverse clam species when compared to Forest Creek. In addition, sediment size was smaller overall in the Forest Creek stream area and shows that there are other natural factors besides man made obstructions affecting sediment transport of both streams. This study is setting a baseline for future studies looking into how developmental changes to both streams could affect clam populations in False Bay.

Keywords: False Bay, False Bay Creek, sediment, clam species, *Macoma nasuta,*

Acknowledgments: Thank you to the whole BMEE class for all the feedback and support given throughout the process, specifically James Fitzpatrick for helping with the sampling process and Rob Hoekendorf for helping create the ArcGIS map. Thank you to the staff at FHL for providing the vans to drive out to False Bay. Thank you to the professors of BMEE with helping me with R Studio, clam identification, and suggestions for overall study design.

Introduction

Sediment has been shown to play a large role in the distribution of clam species in estuary ecosystems (Arnold, 1984; Schoeman and Richardson, 2002). Different studies have delved into the exact role sediment plays, such as the study done by Mercaldo-Allen et al. (2017) which found that harvest frequency and sediment size played a larger role in the distribution of the clam species *Mercenaria mercenaria* in two Connecticut clam beds than whether the clam beds were dredged or not. In addition, Joo et al. (2021) focused a study on the optimal sediment grain size for Manila clam growth and survival. The reasoning for this study was the fact that sediment grain size and sorting is a major factor in determining the make-up of the pore water on which clams depend (Joo et al., 2021). Specifically, sediment grain size and sorting affect the amount of dissolved oxygen and organic material found in the pore water (Joo et al., 2021). There have also been studies in the past that have shown a relationship between sediment size and defense against predation. For example, the study done by Arnold (1984), found through a lab experiment that the blue crab species *Callinectes sapidus,* of various size classes, preferred to position themselves in areas of smaller sediment size (sand, mud and sand/mud). When located in these areas, the crabs could better reach the clam species *Mercenaria mercenaria* who were more vulnerable in the smaller sediment than when they were found under granite, gravel or crushed oyster shells (Arnold, 1984).

On San Juan Island, Washington, one area that has not been thoroughly studied is False Bay. False Bay is located on the southwest side of San Juan Island and is characterized as having expansive mud flats and two major stream inputs that meet the salt water, making False Bay an estuary ecosystem. False Bay is also characterized by large amounts of Ulva algae that comes from the ocean and builds up on the shores.

One of the two streams, termed the “False Bay Creek” stream, comes from the upper water collection of the False Bay watershed. The False Bay watershed encompasses water running from Trout Lake to Zylstra Lake to False Bay Creek which then combines with water from the San Juan Valley Creek, eventually flowing out into False Bay itself. The False Bay Creek stream is characterized by a dam on Zylstra Lake, and other man-made obstructions that pump water for human use. It has been shown in previous studies that dams impact the material transport of rivers and streams (Palinkas et al., 2019). For example, the Chesapeake Bay estuary has an inflow of freshwater from the Susquehanna River which flows through the Conowingo Dam (Palinkas et al., 2019). Conowingo Dam was found to have trapped a large portion of the sediment and nutrients of the Susquehanna River with only high-flow events able to get loads of particulate matter into the bay (Palinkas et al., 2019). Therefore, it is theorized that the man-made obstructions in the False Bay Creek stream could be impacting the flow of sediment, most likely blocking the pathway of larger sediment from reaching False Bay. The other stream, termed the “Forest Creek” stream, is known for being a naturally forested area running from the Woods Reservoir and one other stream branch. In terms of possible obstructions to the Forest Creek stream, there is the Woods Reservoir dam and the Heidenreich Dam. There also many pools that branch off or directly block both the Forest Creek stream and the False Bay Creek stream. However, the False Bay Creek stream appears to be used and obstructed for human use more often than the Forest Creek stream.

One of the main reasons for the importance of this study is to establish a baseline pattern of clam distribution in the Forest Creek and False Bay Creek stream output areas. By establishing this baseline, future studies can be done to see how this pattern changes with the changing environment. In particular, steps, such as the approved funding of $1,000,000, have been taken to remove the dam at Zylstra Lake in order to allow for the possibility of fish passing into the Lake for their life cycle. This would presumably allow for larger sediments to pass into False Bay and potentially provide more protection for clam species, changing the established pattern around the outlet of the False Bay Creek stream. This change in pattern could create an environment that is advantageous for the potential future and unintentional introduction of additional clam species. For example, Pacific oysters were intentionally introduced to Vancouver Island in 1927 to be farmed. However, with them came the unintentional introduction of Manila clams (Ferguson et al., 2017; Quayle, 1964). Since this introduction, Manila clams have continued to spread all over North America including False Bay (Ferguson et al., 2017; Quayle, 1964). In addition, bivalve mollusks such as clams are an important part of the estuarine ecosystem, playing a role in the flow of nutrients directly and indirectly by either being prey or kicking up nutrients from the sediment (Vaughn and Hoellein 2018).

In order to observe the future potential impacts of the dam's removal on the clam community, baseline data should be established before the dam is removed. In addition, there have been talks about the possible introduction of beavers in the upper watershed of False Bay. Beavers are natural dam makers and would help restore the upper watershed. However, with their introduction comes the introduction of more dams that would block even more large sediments and potentially leave the clam species at the mouth of the False Bay Creek stream, and possibly the Forest Creek stream as well, more vulnerable to predation. In addition, if further development were to happen with the Forest Creek stream, there would be baseline information on the clam community in order to determine the possible future impacts. These future developments, removing dams and beaver introductions, take time and leave the opportunity for this study to take place repeatedly in order to have the most accurate baseline information.

For this study, I will attempt to answer the research question of how does sediment size and distance from stream mouth impact the clam populations in two stream outflow areas in False Bay, and how do these populations compare? My hypothesis is that due to the False Bay Creek stream being more developed for human needs, the volume ratios of the large sized surface sediment will be significantly larger in the Forest Creek stream as compared to the False Bay Creek stream sediment bed, which will mean that clam biodiversity and abundance will be higher in the Forest Creek stream sediment bed compared to the False Bay Creek stream sediment bed. In addition, I took height and length measurements of each clam I collected with the hypothesis that each clam species would be largest with a higher proportion of larger sediment. Through this analysis, it will be determined whether the differences in stream development results in smaller sediment flowing out into the bay and if there is a corresponding reduction in clam size, biodiversity and abundance at that location, potentially due to the clams becoming more vulnerable to predation.

Methods

Field Work

As can be seen in Figure 1, my general study design consisted of sampling each stream outflow area using transect lines and consistent digging and sieving procedures. Specifically, for each stream area I created five transects all stemming from one point near the mouth of the stream and branching out at specific degree headings which I found using Google Earth Pro. For the False Bay Creek stream area, the headings were as follows: transect 1: 234º; transect 2: 207º; transect 3: 180º; transect 4: 154º; and transect 5: 130º. For the Forest Creek stream area, the headings were as follows: transect 1: 172º; transect 2: 152º; transect 3: 132º; transect 4: 115º; and transect 5: 98º. Each transect was 160 meters long, and I sampled at sampling sites spaced every 40 meters along that transect using my approximately 1-meter pace to find the sampling spot.

On November 2, 2021 I went to False Bay at 7:30 am to catch the low tide. The materials I brought with me were a compass with degree headings, a wooden 1 cm sieve tray, 1 trowel, 1 shovel, 1 ruler, plastic bags, my data sheet, pencil and 1-2 buckets to hold things in. Prior to going, I used Google Earth Pro to find the headings of all 10 transects.

Once at False Bay, I made my way to the "False Bay Creek" stream area. I then used the Google Earth app on my phone to navigate to the mark labelled "False Bay Creek Point" in my Google Earth app, roughly found at the coordinates 48.4906937, 123.0685351. Once at False Bay Creek Point, I used a combination of the Google Earth app, the compass, and the fact that I have a pace of approximately 1 meter per step to navigate myself 40 meters down False Bay Creek Transect 1 where I started sampling.

The sampling process started with the search for clam species. At each sampling site, using a shovel, I dug a hole that was approximately 30 cm x 30 cm x 30 cm, and placed the contents into the wooden 1 cm sieve. Once in the 1 cm sieve, I rubbed the sediment through the sieve using my gloved hands until only possible clam species were remaining. Once the sediment was rubbed through, I collected all the clam species from the sieve and placed them in a labeled bag to be measured and identified back at the lab. Once the clam species had been collected, I refilled the hole with sediment. For the sediment sampling, I dug a hole that was approximately 10 cm deep and 7-10 cm wide near where the clam hole was dug. For this study, 10 cm holes were chosen due to two studies, Arnold (1984) and McGreer (1982), that both studied the relationship between sediment and clams and used 10 cm depths. Once I had finished digging out the sediment, I placed the contents into a labelled plastic to be processed back at the lab. Once I had finished collecting the sediment, I filled the 10 cm hole similar to that of the clam hole.

After I had completed sampling at 40 meters down False Bay Creek Transect 1, I used the Google Earth app and compass to walk 40 more meters down False Bay Creek Transect 1 until I was 80 meters away from False Bay Creek Point, and, repeated the sampling process. I continued moving down False Bay Creek Transect 1 in 40-meter increments, sampling at every new location, until I had reached the end of the transect, which was around 160 meters away from False Bay Creek Point, for a total of four clam samples and four sediment samples for Transect 1.

After False Bay Creek Transect 1 was completely sampled, I walked back to False Bay Creek Point and used my navigational tools to conduct the same sampling process for the rest of the False Bay Creek transects. I came back to False Bay on various dates and at varying times to finish sampling both the False Bay Creek transects, and the Forest Creek transects. I conducted the same process for the Forest Creek Stream, starting at “Forest Creek Point”, roughly located at the coordinates 48.4873657, 123.0771886. I concluded field sampling on November 15th 2021.

Since all of the transects in this study were approximately 160 meters, each transect had 4 sample sites approximately 40 meters apart from each other. I used 160 meter transects because the eluvial fan for the False Bay Creek area stretches about 140 meters away from the mouth of the stream. For this study, I wanted to get a sample outside of the eluvial fan to compare with samples within it, so I added another 40-meter increment outside of the fan making all the transects 160 meters. It was harder to see where the eluvial fan was in the Forest Creek stream area, so I used transects of 160 meters to make the samples from each stream area comparable.

I also planned on taking elevation measurements at each sampling site, as it has been shown in previous studies, such as Dethier et al. (2019), that elevation plays a role in clam distribution. This role is variable though, given that in Dethier et al. (2019), only one site in the estuarine waters of Washington State showed the expected pattern of lower tidal elevations being associated with predators and decreased clam abundance. I planned on taking the elevation measurements after I finished sampling for sediment and clams. However, near the end of the clam and sediment sampling, there was an extensive rainstorm that caused a flooding event that increased the flow of both streams. This event visibly changed the tidal elevations of both stream outflow areas, making any future elevation measurements uncorrelated to previous clam and sediment measurements. In addition, there was far more Ulva in the Forest Creek stream area making digging for clams in the Forest Creek stream area more labor intensive.

Even though I was not able to collect elevation measurements due to the flooding event, future studies could take elevation measurements in order to consider the role of elevation in clam distribution. My plan for elevation sampling consisted of setting up a laser mark elevation device at both False Bay Creek Point and Forest Creek Point. Once I had made sure the "laser broadcaster" was balanced and stable, I would go out to the nearest large rock in order to get baseline data for my elevations. The process for taking elevation data at the rock site and at my different sampling spots would all be the same; I would use an extendable pole with a "laser receiver" attached at the top with a transect line taped at the top as well. I would extend the pole until the laser receiver made a long unbroken beep noise, which would mean the pole was at the same level as the laser broadcaster. Once the sound was made, I would look at the transect tape in order to find out how high the laser receiver was relative to the ground in meters. I would then find my way to the other sampling spots using coordinates, compass, and pace.

Lab Work

Back at the lab, for each sampling point, I conducted the following process. First, I emptied the bag of clams into a tray. I then washed the clams with water and pulled at the seam of intact clams in order to make sure that they were not empty shells. I also counted specimens that had smashed shells and clam meat as relevant data and included them into the analysis. Once the clams were cleaned, I identified each one by species using a key and then measured the width and height of each clam in centimeters. For the sediment analysis, I poured the whole sediment sample into a 1 Liter measuring cup and recorded the volume. I then poured the sample into a two-sieve tower, the top one being 12.7mm and the bottom one being 2mm. Using a bucket of water, I sieved the sample and poured the contents of the 12.7mm sieve into the measuring cup and recorded the volume. I then poured the contents of the measuring cup into the bucket and then filled the cup up with the contents of the 2mm sieve and recorded the volume. With the volumes of the two sieve samples recorded, I found the volume of the sediment smaller than 2mm by subtracting the two volumes from the larger volume sample.

Data Analysis

The data was analyzed through the program R Studio where the dredge package was used to find the best fit model for mean overall clam abundance, clam diversity, and mean length and height of *Macoma nasutas* in relation to distance from stream mouth, mean proportion of three sediment categories (≥12.7mm,2mm – <12.7mm, <2mm), and site. Mean clam abundance was found by averaging the number of clams for each species across the five transects for each distance group in each stream area. For example, total clams found across all five of the transects 160 meters away from the mouth of the False Bay Creek stream were averaged by dividing that total by five. Clam diversity was found by using the R package vegan to conduct a

Shannon-Wiener index assessment for the total number of clams of each species per distance from stream mouth group for each stream area. Mean sediment proportion was first calculated by taking every volume measurement and dividing it by its respective total sediment volume value. These proportions were then averaged across site and distance from stream mouth. Once the dredge package revealed the best fit model for the already mentioned relationships, the models were summarized and put into graphical scatter plot form for visualization. Bar graphs with standard error bars were made for relationships between mean clam abundance for each species and distance from stream mouth, along with mean sediment proportion and distance from stream mouth.

Results

In Figure 2, I observed that overall, there was a significantly higher mean abundance of different clam species in the False Bay Creek area as compared to the Forest Creek stream area. In the False Bay Creek area, the distance where clam abundance, between the four species observed, was the most even was 120-meters away from the False Bay Creek stream mouth. Overall, the clam species that was the most abundant between the two different streams was *Macoma nasuta* the bent nose clam, increasing in abundance as distance from stream mouth increased, although they were not found in the 40- or 80-meter region of the False Bay Creek area. The error bars give probable significance to this pattern, by the False Bay Creek 120- and 160-meter *nasuta* error not overlapping, as well as the Forest Creek 40-, 80- and 160-meter *nasuta* error bars not overlapping as well. *Nuttallia obscurata,* the purple varnish clam, was the second most prevalent clam species in the False Bay Creek stream area, appearing in all distance regions, and showing a pattern of distribution that increased slightly, reaching its peak 120 meters away from the stream mouth. Possible significance to this pattern come from the *obscurata* error bars in the 80- and 120-meter groups not overlapping with the *obscurata* error bars in the 40- and 160- meter groups. *Mya arenaria,* soft shell clams, had a similar peak distribution pattern, peaking in the 120-meter group, but were absent in the 40-meter group. This pattern is also supported by probable significance due to the error bar in the 120-meter group not overlapping with the error bars in the 80- and 160- meter groups. *Venerupis philippinarum,* manila clams, in the False Bay Creek area, exhibited a pattern similar to the *nasutas,* by never reaching a peak mean abundance at a certain distance, but continuing to increase as distance increased as well. This pattern is observable in Figure 1, but with the error bars barely overlapping each other, it is hard to definitively state that this pattern is significant.

For the other clam species besides the *Macoma nasutas* found in the Forest Creek stream area, there were no clear patterns as there were in the False Bay Creek stream area. The second most prevalent species was *Mya arenaria* which was significantly more abundant than the *nasutas* in the 40-meter region of the Forest Creek stream area. However, the 40-meter region was the only place in the Forest Creek stream area where *Mya arenaria* were found. The only other two clam species found in the Forest Creek stream area where *Venerupis philippinarum* and *Leukoma staminea*. These species appeared in very low numbers and only showed up in two separate distance regions, *philippinarum* being in the 80-meter region, and *staminea* in the 120-meter region. These two clam species error bars overlapped with each other, and did not overlap with any other clam species save the *nasutas* in the 40-meter group.

In Figure 3, the Forest Creek stream area for all distances had a significantly higher proportion of sediment that was less than 2mm than sediment that was greater than 2mm or 12.7mm. There is an observable pattern in the Forest Creek graph that with increasing distance from the stream mouth, sediment over 2mm and up to and beyond 12.7mm sediment is decreasing while sediment <2mm is increasing. The error bar of the 2mm sediment in the 40-meter group does not overlap with any other 2mm sediment bar, and the error bar of the <2mm sediment in the 40-meter group does not overlap with any other <2mm sediment bar.

In the False Bay Creek section of the graph, the sediment proportions were more even, particularly in the 80- and 120- meter groups where all three sediment proportion error bars overlapped. The two instances of significant differences came from the 40- and 160-meter groups with the 12.7mm and 2mm sediment proportions being significantly greater than the <2mm sediment proportion in the 40-meter group and vice versa for the 160-meter group. While it is not too clear visually, this significant switch up of sediment proportion between the 40-meter and 160-meter region of the False Bay Creek stream area, shows that sediment became smaller in the distance between the 40-meter region and the 160-meter region. I can also generally confirm this from my experience of sample collecting, as the further I walked out, the softer the sediment usually became.

When comparing the sediment between the two sites, t the proportion of 12.7mm sediment was significantly larger in the False Bay Creek stream area with the close exception of the False Bay Creek 12.7mm sediment error bar barely not overlapping with any of the Forest Creek 12.7mm sediment error bars. There is a similar pattern with the 2mm proportion bars between the two sites. False Bay Creek has significantly higher proportions of 2mm sediment across all distances save for the Forest Creek's 40-meter 2mm error bar. <2mm sediment was significantly higher across all distances in the Forest Creek stream area, except for the error bar overlap between the 40-meter Forest Creek and 160-meter False Bay Creek.

When it came to the linear models, the dredge package found that the best fit model for mean clam abundance was only when distance from stream mouth was taken into consideration with an AIC value of 43.3. This model was then summarized and shown to have a P-value of 0.0396, which is not too far below 0.05, meaning that the relationship is technically significant, but not the most confident. The relationship between mean clam abundance and distance from stream mouth can be seen in Figure 4, as a positive correlation with an R^2 value of 0.53. In terms of clam diversity, the dredge package found that the best fit model was only when mean proportion of 12.7mm sediment was taken into consideration with an AIC value of 18.8. When this model was summarized, it showed a P-value of approximately 0.2, which is above 0.05 and technically not significant. However, as can be seen in Figure 4, there is a positively correlated trend as shown by the linear regression with an R^2 value of approximately 0.26.

Since the *Macoma nasutas* were the most abundant clam species across both stream sites and had the clearest trends, I decided to analyze their measurements alone. The dredge package found that the model that best fit mean *nasuta* height was when only mean proportion of 12.7mm sediment was taken into account, with an AIC value of 30.6. When this model was summarized, it produced a P-value of 0.026, which is below 0.05 and is technically significant, but is not entirely confident. In Figure 4 this relationship is shown as a negative correlated trend with an R^2 value of 0.5899. With *nasuta* length, dredge found again that the best fit model was only when mean 12.7mm sediment proportion was taken into account with an AIC value of 34.5. When this model was summarized, the P-value came out to be 0.021, which is below 0.05 and technically significant, but again not the most confident. In Figure 4, this pattern is represented as a negative correlated trend, with an R^2 value of 0.61.

Discussion

Looking at Figures 2 and 3, my hypothesis was proven to be partially correct, in that clam diversity and abundance were highest at the site with larger sediment, although this site turned out to be the False Bay Creek area and not the Forest Creek Area. I was therefore wrong in my hypothesis that the Forest Creek stream area would have higher clam abundance, clam diversity and larger proportions of sediment. False Bay Creek was shown to have significantly higher amounts of sediment over 12.7mm and even over 2mm, along with higher amounts of clam abundance for each clam species. It appears that there are other major factors at play in terms of sediment transport for these two streams besides development and human use. One possible explanation could be that due to the slow and unpredictable flow of both streams, the majority of the sediment found in False Bay comes from the sea with wave action. It has been shown in previous studies that wave direction, energy, and overall mechanics play a large role in the sedimentation of estuaries (Malvarez et al., 2001). It could be possible, looking at Figure 1, that due to the Forest Creek stream area being in a more relatively "closed-off" area, sediment is not being transported there as effectively as it is for the False Bay Creek stream area which is more "open" and possibly directly in the path of incoming tidal waves.

One of the most striking things I observed when comparing Figure 2 and Figure 3, was that the *Macoma nasutas* were more prevalent at distances where <2mm sediment was highest in terms of proportions. There are exceptions to this pattern, in that the highest mean of *nasuta* abundance was found 160 meters away from the mouth of the False Bay Creek stream, which did not have the highest proportion of <2mm sediment. However, the pattern is still observable, and fits with what *Macoma nasuta* habitat is expected to be like. Specifically, studies such as Alexander et al. (1993) have found that in areas where *Macoma nasutas* are established, like San Francisco Bay, they are more abundant in areas where sediment ranges from silt to muddy sand, which all fall under the category of <2mm. Studies such as Self and Jumars (1988) have also found that the reason *Macoma nasutas* prefer this class of sediment is that it is richer in organic nutrients which *nasutas* can consume as deposit feeders. This also fits with the strongest linear models and regressions, *Macoma nasuta* height and length, having a negatively corelated relationship with mean proportion of 12.7mm sediment. 12.7mm sediment would be in the category of sediment that is associated with smaller abundances of organic matter, leaving little food for the *nasutas* to grow (Self and Jumars, 1988). This in a way disproves my hypothesis that higher proportions of larger sediment would mean larger clam size values. However, as stated above, the *nasutas* are deposit feeders and therefore do not do as well in large sediment environments.

In addition to the mean proportion of 12.7mm sediment impacting *Macoma nasuta* length and height, it was also shown to have a positively correlated relationship to overall mean clam diversity. Although this relationship was not significant, this trend is still supported by previous research that larger sediment grain size provides cover and safety to clams against predation (Arnold 1993). Higher clam diversity in higher proportions of 12.7mm sediment also does not conflict with the fact that 12.7mm contains less organic matter since, besides the *nasutas,* all of the other clam species are filter feeders and most are generalists when it comes to sediment burrowing (Alexander et al., 1993).

Mean overall clam abundance was associated with distance from stream mouth in a significant positively correlated relationship. Even with this relationship not being the most confident, it fits with previous studies that found clam species more abundant further away from the mouths of streams for multiple reasons. For example, Muttray et al. (2012) found that fertilizers and pesticides used in potato farms further up the Dunk and Wilmot watersheds in Prince Edward Island were running off in their respective estuaries and causing clam species to be located further away from the inflowing stream in order to avoid the pollutants. In San Pablo

Bay, a semiarid estuary, Poulton et al. (2004) found a far lower density of the clam *Potamocorbula amurensis* than in years before with the leading theory being that high freshwater current inflow scoured the clam species. In addition, Everett (1991), determined that *Macoma nasuta* show up in low abundance when large amounts of Ulva are removed from an area due to macroalgal blooms being a significant cause of infaunal mortality. All of these factors could in some way be impacting the clam distribution pattern of False Bay, such as possible run-off from the farm lands that the False Bay Creek stream runs through, or the high Ulva build up near the shore and mouth of the Forest Creek stream. In addition, the flooding event, that caused elevation data to not be recorded, eroded away large amounts of sediments in both stream areas and possibly scoured clams as well. If these kinds of events are a common phenomenon, it could have significantly impacted the clam distribution I found in this study.

In terms of this study being repeated in the future, I believe the number of transects should be increased, from 5 to 6 or 7, which would increase the number of samples and give more accuracy to the analysis. In addition, for each sampling site, percent Ulva cover and possible pollutants should be evaluated to give the analysis more context. Also, elevation data should be collected as the clam and sediment samples are taken, to include elevation in the analysis. Elevation and clam sampling should also be conducted in a shorter window of time, in order for the possible correlation between elevation and clam distribution to be the most accurate. Also, pilot studies should be done to scout both streams and observe what factors could possibly be affecting sediment transport. Other studies could be conducted to determine wave direction and energy for False Bay as well. In addition, if future studies were to continue this one, it would be interesting to see how seasonality impacts clam distribution as well.

Figures

Map of Sample Sites

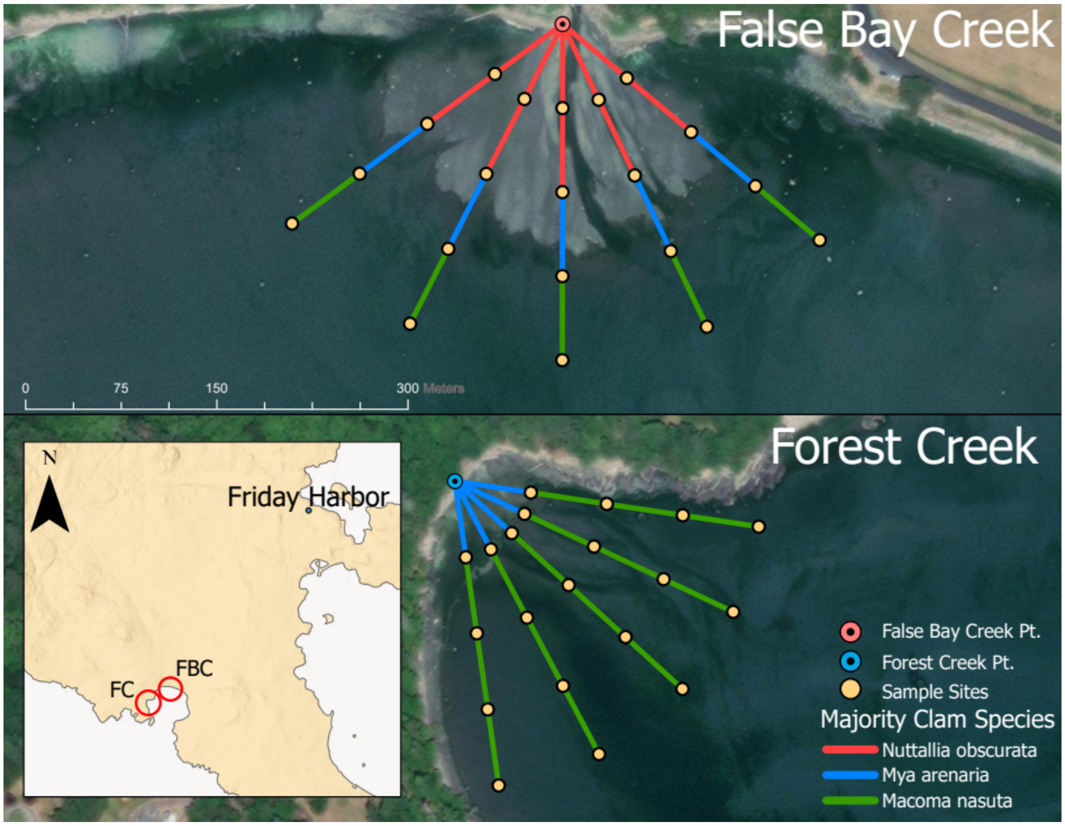
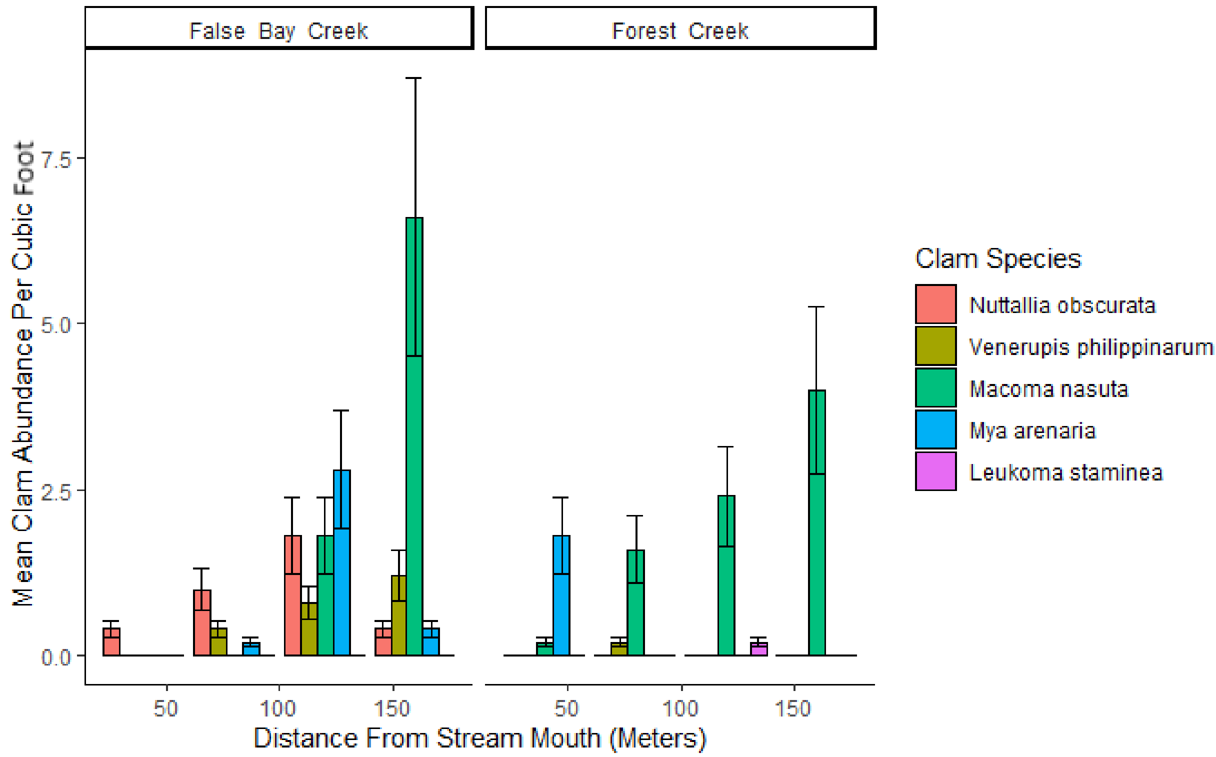


Figure 1: Map made in ArcGIS Pro for both sample sites, False Bay Creek and Forest Creek. Each site has a set of transect numbering 1-5 from left to right. Each transect has four sampling spots separated by 40 meters along the transect and indicated with an orange circle. Each 40-meter segmented area is color coded to what clam species was on average the most abundant, colors made to match that of Figure 2. The reference map in the bottom left shows the general area of the two streams, False Bay Creek (FBC) and Forest Creek (FC) with red circles.



Mean Clam Abundance vs. Distance from Stream Mouth for Forest and False Bay Creek
Figure 2: Bar chart made in R Studio showing mean clam abundance for each clam species across all five transects for each distance increment at each site. Each clam is colored according to the key on the right and includes error bars detailing the standard error of each mean value.

Mean Proportion of Sediment vs. Distance from Stream Mouth for Forest and False Bay Creek

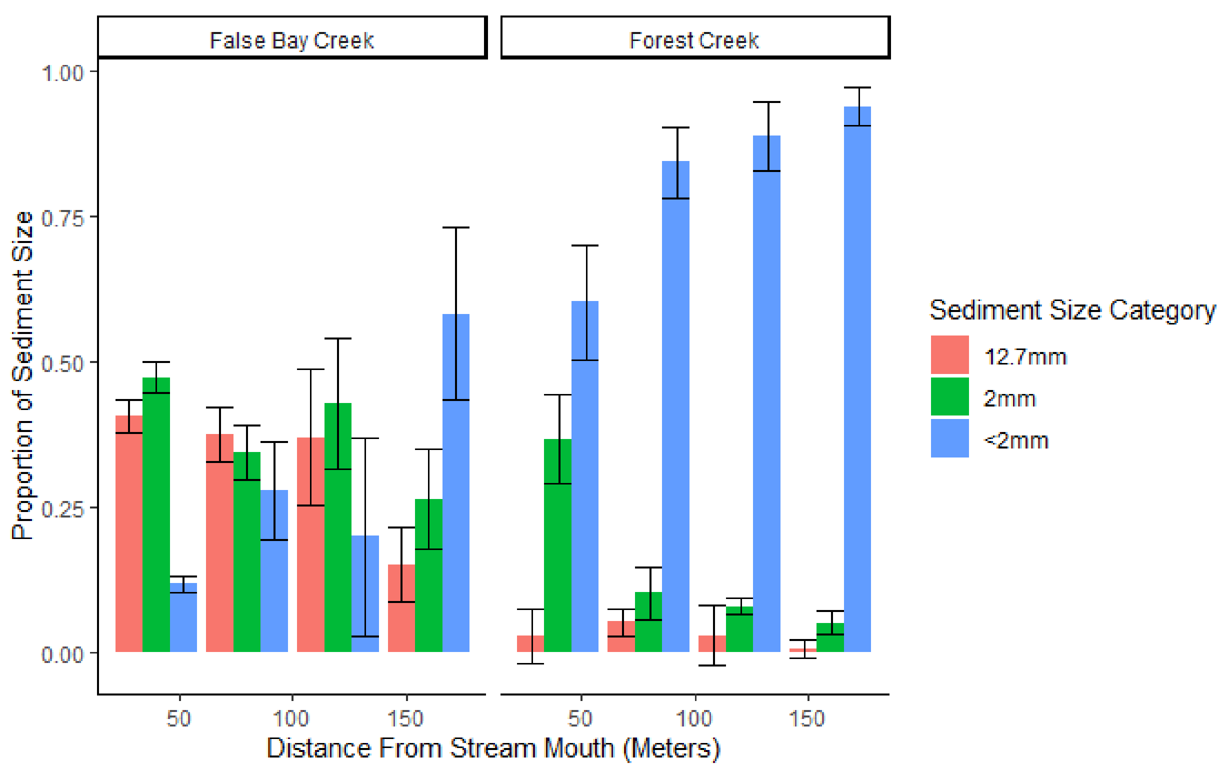


Figure 3: Bar chart made in R Studio showing mean proportion of the three sediment size categories across all five transects for each site. Each sediment category is color coded according to the legend on the right. The sediment size categories represent the categories as follows: 12.7mm: ≥12.7mm sediment; 2mm: ≥2mm - <12.7mm; <2mm: <2mm. Error bars are included to show the standard error of each mean value.

Graphs of Best Fit Linear Models for Mean Clam Abundance, Diversity and *Macoma nasuta* Height and Length

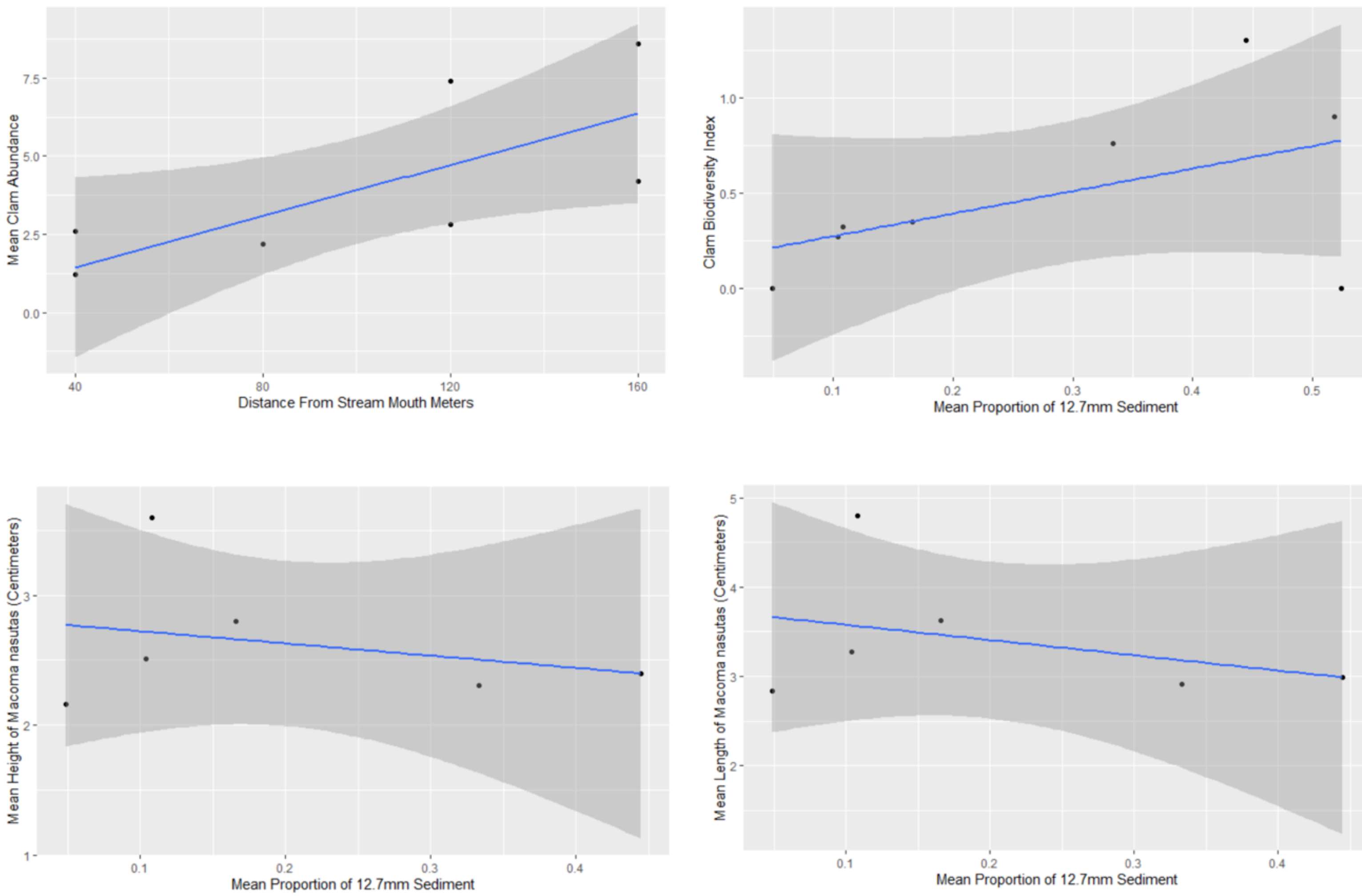


Figure 4: Scatter plots made in R Studio and combined using Adobe Spark. Each graph has a line of best fit from the linear regression that was run. Top left graph is mean clam abundance vs. distance from stream mouth with an R^2 value of 0.53. There are two values for mean clam abundance at the 40-meter mark, but they were equal to each other and cover the same spot. The top right graph shows clam biodiversity index vs. mean proportion of 12.7mm sediment, with an R^2 value of 0.26. The bottom left graph is mean height of *Macoma nasutas* in centimeters vs. mean proportion of 12.7mm sediment, with an R^2 value of approximately 0.59. The bottom right graph is mean length of *Macoma nasutas* in centimeters vs. mean proportion of 12.7mm sediment, with an R^2 value of 0.61.

References

Alexander, R. R., R. J. Stanton, and J. R. Dodd. 1993. Influence of Sediment Grain Size on the Burrowing of Bivalves: Correlation with Distribution and Stratigraphic Persistence of Selected Neogene Clams. *PALAIOS*, 8(3):289, https://doi.org/10.2307/3515151.

Arnold, W. S. 1984. The effects of prey size, predator size, and sediment composition on the rate of predation of the blue crab, Callinectes Sapidus Rathbun, on the hard clam, MercenariaMercenaria (Linné). *Journal of Experimental Marine Biology and Ecology*, 80(3):207–219, https://doi.org/10.1016/0022-0981(84)90150-3.

Dethier, M. N., J. Kobelt, D. Yiu, L. Wentzel, and J. L. Ruesink. 2019. Context-dependence of abiotic and biotic factors influencing performance of juvenile clams. *Estuarine, Coastal and Shelf Science*, 219:201–209, https://doi.org/10.1016/j.ecss.2019.02.013.

Everett, R. A. 1991. Intertidal distribution of infauna in a central California lagoon: the role of seasonal blooms of macroalgae. *Journal of Experimental Marine Biology and Ecology*, 150(2):223–247, https://doi.org/10.1016/0022-0981(91)90069-9.

Ferguson, L., J. Davidson, T. Landry, J. Clements, and T. Therriault. 2017. Didemnum vexillum: invasion potential via harvesting and processing of the Pacific oyster (Crassostrea gigas) in British Columbia, Canada. *Management of Biological Invasions*, 8(4):553–558, https://doi.org/10.3391/mbi.2017.8.4.10.

Joo, S., K. Jo, H. Bae, H. Seo, and T. Kim. 2021. Optimal sediment grain size and sorting for survival and growth of juvenile Manila clams, Venerupis philippinarum. *Aquaculture*, 543:737010, https://doi.org/10.1016/j.aquaculture.2021.737010.

Malvarez, G. C., J. A. G. Cooper, and D. W. T. Jackson. 2001. Relationships Between Wave-Induced Currents and Sediment Grain Size on a Sandy Tidal-Flat. *Journal of Sedimentary Research*, 71(5):705–712, https://doi.org/10.1306/2DC40961-0E47-11D7-8643000102C1865D.

McGreer, E. R. 1982. Factors affecting the distribution of the bivalve, Macoma balthica (L.) on a mudflat receiving sewage effluent, Fraser river estuary, British Columbia. *Marine Environmental Research*, 7(2):131–149, https://doi.org/10.1016/0141-1136(82)90038-1.

Mercaldo-Allen, R., S. Meseck, R. Goldberg, P. Clark, C. Kuropat, and J. M. Rose. 2017. Effects of clam dredging on benthic ecology of two cultivated northern quahog beds with different harvest histories and sediment grain sizes. *Aquaculture International*, 25(5):1971–1985, https://doi.org/10.1007/s10499-017-0167-5.

Muttray, A., C. Reinisch, J. Miller, W. Ernst, P. Gillis, M. Losier, and J. Sherry. 2012. Haemocytic leukemia in Prince Edward Island (PEI) soft shell clam (Mya arenaria): Spatial distribution in agriculturally impacted estuaries. *Science of The Total Environment*, 424:130–142, https://doi.org/10.1016/j.scitotenv.2012.02.029.

Palinkas, C. M., J. M. Testa, J. C. Cornwell, M. Li, and L. P. Sanford. 2019. Influences of a River Dam on Delivery and Fate of Sediments and Particulate Nutrients to the Adjacent Estuary: Case Study of Conowingo Dam and Chesapeake Bay. *Estuaries and Coasts*, 42(8):2072–2095, https://doi.org/10.1007/s12237-019-00634-x.

Poulton, V. K., J. R. Lovvorn, and J. Y. Takekawa. 2004. Spatial and overwinter changes in clam populations of San Pablo Bay, a semiarid estuary with highly variable freshwater inflow. *Estuarine, Coastal and Shelf Science*, 59(3):459–473, https://doi.org/10.1016/j.ecss.2003.10.005.

Quayle, D. B. 1964. Distribution of Introduced Marine Mollusca in British Columbia Waters. *Journal of the Fisheries Research Board of Canada*, 21(5):1155–1181, https://doi.org/10.1139/f64-102.

Schoeman, D. S., and A. J. Richardson. 2002. Investigating biotic and abiotic factors affecting the recruitment of an intertidal clam on an exposed sandy beach using a generalized additive model. *Journal of Experimental Marine Biology and Ecology*, 276(1–2):67–81, https://doi.org/10.1016/S0022-0981(02)00239-3.

Self, R. F. L., and P. A. Jumars. 1988. Cross-phyletic patterns of particle selection by deposit feeders. *Journal of Marine Research*, 46(1):119–143, https://doi.org/10.1357/002224088785113685.

Vaughn, C. C., and T. J. Hoellein. 2018. Bivalve Impacts in Freshwater and Marine Ecosystems. *Annual Review of Ecology, Evolution, and Systematics*, 49(1):183–208, https://doi.org/10.1146/annurev-ecolsys-110617-062703.