EVALUATING TUMBLE CULTURE AS A METHOD TO IMPROVE PACIFIC OYSTER *(CRASSOSTREA [MAGALLANA] GIGAS)* GROWTH ON SOUTHEAST ALASKA SHELLFISH FARMS

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Degree in Marine Science with Distinction

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ABSTRACT

High water turbulence, tidal flux, and biofouling at Alaska's high latitude oyster farms create various challenges for growing marketable Pacific oysters (*Crassostrea [Magallana] gigas*). As oyster mariculture expands in the upper Pacific northwest, developing efficient oyster grow-out methods is critical to ensuring industry success. Surface culture practices, also referred to as tumble culture, are configured to move with surface wave action and be exposed during low tide, thus naturally tumbling oysters, deterring growth of fouling organisms, and potentially reducing husbandry demands. To evaluate the efficiency of tumble culture in creating marketable oysters in Alaska where this method is not currently used, we stocked 48 SEAPA baskets with 500 individual seed oysters with an average total length of 26.2 mm ± 5.44 mm (mean ± standard deviation) and monitored growth over a four-month period. The baskets were deployed in two configurations and tidal zones (intertidal pivot line baskets and subtidal basket stacks) at a commercial oyster farm in Juneau, Alaska in early June 2024, and compared to the farm's existing floating mesh bag method. Subsets of 20 oysters were collected in late June, July, and September 2024, to monitor shell morphology (length, width, depth), as well as whole and wet meat weights to determine differences in growth among the gear configurations and depth strata. The results indicate that there was a significant effect of gear configuration on oyster growth. Subtidal basket oysters had the highest shell growth, though growth was thin and uneven. In contrast, intertidal basket oysters had slightly lower shell growth but had high wet meat content, producing more market desirable shell shapes compared to the other gear configurations. Oysters from the floating mesh bag method had high percent wet meat weight relative to their whole weight, however, these oysters had the slowest overall growth. These results suggest that gear configuration and depth affect oyster growth, with the intertidal basket configuration producing oysters with desirable shell shape and wet meat weight. Ultimately these results can inform Southeast Alaska farmers about additional methods of growing oysters that use currently under-developed intertidal lease areas and result in well-shaped oysters.

Chapter 1

INTRODUCTION

The seaweed and shellfish aquaculture industry, hereafter referred to as mariculture, has continued to grow in Alaska since the early 1990s. In recent years this expansion has been widely driven by the Alaska Mariculture Task Force, who set a goal in 2016 to develop a $100 million per year aquaculture industry in a 20-year timespan through increasing funding and support for the sustainable growth of the sector. Along with the Task Force, the National Oceanic and Atmospheric Administration (NOAA) in collaboration with the state of Alaska, created a multi-year initiative to assess Aquaculture Opportunity Areas. This program offers guidance to farmers and managers on the most effective sites for expanding new aquaculture operations across the state (Alaska Mariculture Task Force, 2021; Alaska Department of Fish and Game; NOAA Fisheries, 2024). With support from both the state and federal agencies, new mariculture operations focused on shellfish, invertebrate, and algae culturing have flourished with oysters being one of the most prominent sectors in the southeast portion of the state. Since 2020, there has been a 145% increase in the number of Pacific oysters produced with a total of 1,337,774 million oysters sold to market in 2023. With over 350 acres of permitted farm sites, oyster farming is gaining popularity in Southeast Alaska and is expected to continue to grow (Alaska Department of Fish and Game; NOAA Fisheries, 2024). As oyster mariculture expands, evaluating the best methods to farm oysters while maintaining profits for farmers has become crucial to secure the long-term success of the industry.

Current methods of oyster farming in Southeast Alaska include the use of subtidal culture techniques such as floating mesh bags and hanging stacks. Floating mesh bags filled with oyster seed and laid out into line formations at the surface of the water are used for much of the oyster grow-out process. In addition, stacks of mesh crates attached to bridles and hung in subtidal zones on the farm are used for various stages of growth and for finishing oysters before sorting them for market (pers. comms. Mesdag). Suspended culture methods like these have been shown to improve oyster growth rates compared to more on-bottom methods used in other regions of the U.S (Walton et al., 2013; Thomas et al., 2019; Hood et al., 2020). The increased flux of water flow and food particles when located farther up in the water column, in addition to a reduction in benthic predators, tends to enhance oyster performance (Mallet et al., 2009; Comeau, 2013; Mizuta et al., 2019). In Southeast Alaska, farmers have found that hanging stacks allows oysters to feed continuously, while the use of both stacks and floating mesh bags maximizes their lease space. This approach is especially effective for Alaskan farms that are typically located in fjord regions, where nearshore depths can increase rapidly (per. comms Hollarsmith).

Although there are numerous benefits to suspended culture, these methods tend to require a large amount of farmer husbandry and maintenance. Growing oysters in floating mesh bags require farmers to flip the bags at weekly intervals to dry them out and remove fouling species (Mizuta et al., 2019; Bodenstein et al., 2021; Mercer et al., 2024). Additionally, at intervals during the grow-out process farmers mechanically tumble the oysters with a machine tumbler to sort them by size and to round out the shell shape before transporting them to market (Mizuta et al., 2019; Hood et al., 2020, Bodenstein et al., 2021, Mercer et al., 2024). Though suspended culture grows desirable market sized oysters in Alaska, additional growing methods that naturally tumble oysters using surface-oriented cages or baskets could enhance overall oyster quality while helping to efficiently expand farm capacity.

Rounded shell shapes, deep cups, and heavy wet meat content in farmed, Pacific oysters are preferred by retail markets (Galtsoff, 1964; Brake et al., 2003; Mizuta et al., 2019). Oysters that are repetitively tumbled as they grow achieve these characteristics. As oysters tumble, parts of the outer shell break off allowing for new shell to subsequently grow back stronger and more rounded. This removal and regrowth of the outer shell also promotes larger net growth in shell depth and cup size in comparison to shell length (Brake et al., 2003; Mizuta et al., 2019). Recent studies have evaluated the efficiency of *in situ* natural tumbling through surface water currents to produce oysters with these desirable physical traits while reducing the need for manual tumbling by the farmer. For Eastern oysters (*Crassostrea gigas*), fixed and suspended methods- where gear hangs on lines close to the surface- in intertidal zones have proven to grow oysters with deep cups, rounded shells, and high internal tissue due to the tidal exchange effectively tumbling the oysters as they grow (Walton et al. 2013, Mizuta et al., 2019; Thomas et al., 2019; Hood et al., 2020). However, excessive tumbling in highly turbulent environments—like those observed with surface culture in other parts of Alaska—has been associated with reduced growth rates and increased mortality (pers. comm. Hollarsmith; Bodenstein et al., 2021). Determining the optimal amount of tumbling for oysters continues to be increasingly important for identifying suitable intertidal zones that can produce quality marketable oysters.

In addition to natural tumbling, another potential benefit of intertidal culture is that air exposure between tides allows oysters to strengthen their adductor muscle, promoting the fattening of internal tissues while also helping them keep their shells closed when transported from farm to market (Toba, 2002; Thomas et al. 2019; Mercer et al., 2024). Periods of air exposure also helps to reduce full settlement of biofouling species, reducing the amount of energy farmers spend on removal during grow-out (Mallet et al., 2009; Mercer et al., 2024; Chuku et al., 2025). However, extended periods of air exposure can stress oysters too much leading to reduced growth and mortality (La Peyre et al., 2018; Gu et al. 2020; Bodenstein et al., 2021; Chuku et al. 2025). For Alaska, low air temperatures in the winter months could be lethal to oysters and prohibit growth, requiring the oysters to be moved from intertidal culture to alternative growing methods between seasons. Optimal air exposure for Pacific oyster growth is continuing to be studied (see Chucku et al., 2025) and will require investigations across different regions with varying temperatures (Gu et al., 2020). As research on air exposure and *in situ* tumbling advances, oyster farmers in Southeast Alaska with intertidal leases that have abundant tidal fluxes could benefit from these methods during the growing season. However, the scale of intertidal tumble culture farming will depend on available substrate, as much of the region's intertidal zones are shaped by recently receded glaciers.

Though previous research has been conducted to analyze seasonal differences in fouling communities and overall quality of oysters in Alaska’s high latitude climate, studies that evaluate comparisons of gear configurations are limited (Oliveira et al., 2006; Ulaski et al., 2024). The purpose of this study was to test whether oyster baskets designed to naturally tumble with water movement could produce marketable oysters at Southeast, Alaka fjord -based farm sites. This study aimed to compare the effectiveness of cylindrical plastic baskets (SEAPA baskets) configured into subtidal hanging stacks and intertidal pivot lines to the floating mesh bag method currently used in Southeast Alaska, to evaluate the impact of gear on oyster growth and marketability. We assessed shell morphometrics (length, width, depth), whole and wet weight, and cup ratios among each gear configuration, to quantify which methods provide high quality oysters. The results of this work can help determine whether different gear configurations that naturally tumble oysters can produce market-desirable traits, offering a sustainable method to expand oyster farming capacity into intertidal waters in Southeast, Alaska.

Chapter 2

MATERIALS AND METHODS

Site Description

This study was conducted at Salty Lady Seafood Company's oyster farm in Bridget Cove Juneau, Alaska. This site is located off Favorite Channel between Mab Island and the coast of Juneau. The fjord region is characterized by a relatively shallow subtidal zone and an intertidal zone composed of a small glacially sloped beach adjacent to the farm location. Oysters for the experiment were grown at both the subtidal and intertidal areas of the farm which both experience similar seasonal variations in temperature and salinity, with extreme tidal cycles ranging from -1.2m-5.7m.

Figure 1 Satellite view of Juneau, AK and the commercial farm site. The blue icons in the inset represent the locations of the farm and Mab Island to the west, while the orange icons represent the deployment zones of each gear configuration in the study.

Source of oysters

Pacific oyster seed from Hawaiian Shellfish LLC in Hilo, Hawaii was shipped to and maintained at Hump Island Oyster Company in Ketchikan, Alaska in a Floating Upweller System (FLUPSY). All seeds were screened using a 12.7 mm screen at this farm before being shipped to Juneau, AK for the experiment. A sample of 50 oysters from this seed stock was collected for our initial "Time-0" measurements in June 2024. Notably, because an upper screen was not used doing the screening process, the sizes of these "Time-0" oysters were not entirely uniform with some oysters being noticeably larger than 12.7mm.

Gear deployment

Forty-eight SEAPA baskets were deployed in June 2024 in both the intertidal and subtidal zones of the farm in two different configurations. All SEAPA baskets were 15L with 6 mm mesh. Baskets deployed at the intertidal plot of the farm were constructed into an array of pivot lines. The array consisted of three separate lines that were each 10.4 m in length and deployed at different angles to the incoming swell (South, Southwest, and West). Each line had four 2.6 m distinct sections with 3 baskets per section. The lines were attached to 2 m steel t-posts driven 1m into the ground anchored by an additional two lines attached to each end. SEAPA tensioners were installed on each line and were tightened using a custom-built tensioning wheel. The lines were deployed midway down the beach where the baskets were fully exposed to air during low tides and fully submerged in water during high tides. Twelve total SEAPA baskets, were attached to each line (n=36 intertidal baskets) hanging approximately 1 m from the sandy bottom (Figure 2A). Each basket was stocked with 500 hand counted individual oyster seed with an average total length of 26.2 mm ± 5.44 mm. Baskets deployed in the subtidal were constructed in 1.5 m long stack formations with 4 baskets attached each. Poly rope was thread through 4 metal bars that were 1 m long 2 cm galvanized conduit and were separated about 1ft apart. One SEAPA basket was clipped to each of the four metal bars with 15 cm pieces of 4 cm PVC attached to the ends of each metal bar to keep baskets in place (Figure 2B). Three stacks were deployed off the floating dock of the farm (n=12 subtidal baskets.). Each basket was stocked with 500 hand counted individual oyster seed with an average total length of 26.2 mm ± 5.44 mm. These stacks were consistently submerged in water throughout the duration of the experiment. Oysters were also deployed into four floating mesh bags at the farm site, each roughly 1.2 m x 0.6 m x 0.1 m with a mesh size of 6.4 mm. This acted as the control group throughout the experiment (Figure 2C). Each mesh bag was stocked with 3000 hand counted individual oyster seed with an average total length of 26.2 mm ± 5.44 mm and deployed following the normal operations of the farm (Figure 2D). Notably, by the end of the experiment, one basket from the intertidal array was not measured and a full subtidal stack of four baskets of oysters was lost.

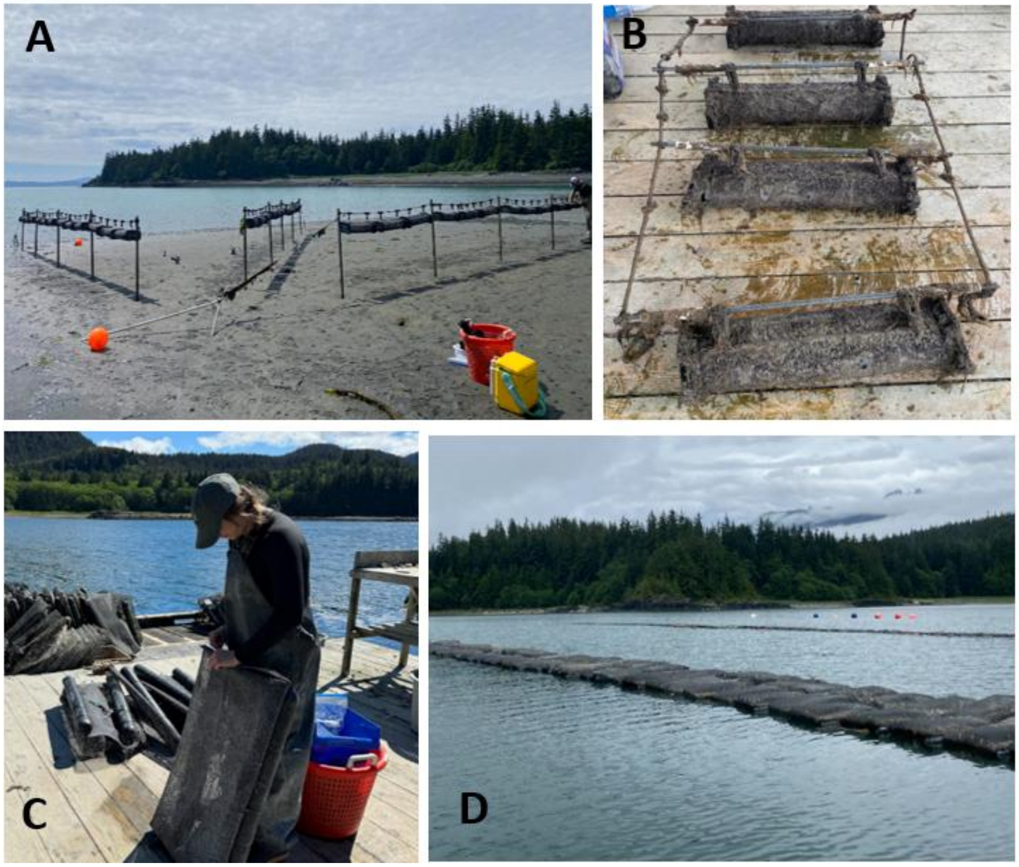

Figure 2 Images of each gear configuration deployed at the farm site. A.) Intertidal pivot line array with SEPA baskets B.) Subtidal stack with SEPA baskets C.) Floating mesh bag D.) Normal deployment of floating mesh bags in the subtidal region at the farm.

Sampling and measurements

At the beginning of the study, a sample of 50 oysters were collected and measured for initial, “Time-0” data. For the remainder of the experiment, subsets of 20 oysters were gathered from each SEAPA basket and floating mesh bag at the end of June, July, and September 2024. Oyster growth was evaluated using shell morphometrics and weights of each individual oyster. The length (distance from the umbo to the bill), width (widest distance across the oyster), and depth (distance from top to bottom-most point of oyster cup) were measured in millimeters (mm) using a hand caliper (Figure 3). Both the whole weight (weight of the entire oyster) and wet meat weight (weight of just inner edible contents) were measured in grams (g) using a balanced scale. For whole weights, all 20 oysters gathered from each basket were measured, while for wet weight measurements, a smaller subset of five oysters from the 20 per basket subset were shucked and evaluated. From these measurements, additional metrics including the percent of wet meat weight relative to the whole weight of the oysters and cup ratio (depth/width) were calculated to evaluate the oyster's market characteristics.

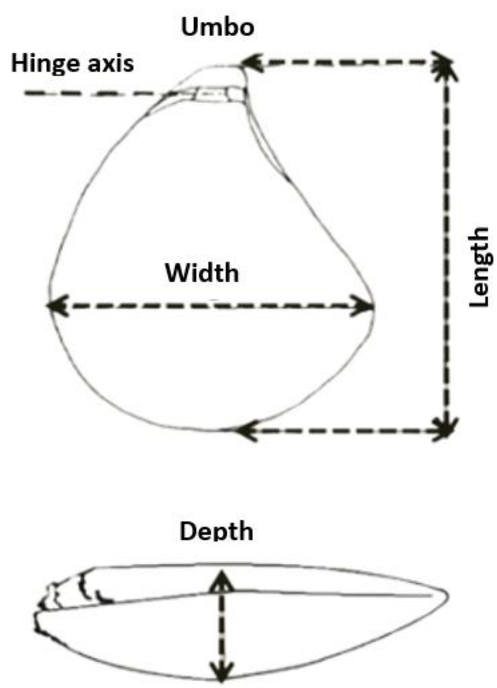

Figure 3 Schematic of an oyster shell labeled with the standard length, width, and depth measurements used to quantify shell growth (Galstoff 1964).

Statistical analyses

The Shapiro Wilks and Levene's Test were used to evaluate normality and equal variance in the data, respectively. All shell morphometric and weight data in this experiment were found to be non-normally distributed. Accordingly, the non-parametric Kruskal Wallis and post-hoc Dunn's Test were utilized for further analyses. The Kruskal Wallis test was used to determine whether there was a significant difference between oyster growth and gear deployments per tidal region. Upon computing significant differences for each metric, the Dunn Test with a Holm-Bonferroni correction was used to further evaluate among which gear deployments oyster growth significantly differed.

Chapter 3

RESULTS

Shell Length

There were significant differences in shell length among gear configurations (Kruskal Wallis chi-squared = 208.66, df = 3, $p < 0.001$). The average shell length of the oyster seed at the beginning of the experiment measured 26.2 mm ± 5.44 mm (mean ± standard deviation). All average shell length measurements among gear configurations significantly differed from the average initial seed measurement (Dunn $p < 0.001$) indicating all oysters grew in length over the four-month period. After 17 weeks of growth, the oysters grown in the intertidal baskets had an average shell length of 43.7 mm ± 7.04 mm, the oysters grown in the subtidal baskets had an average shell length of 48.3 mm ± 10.80 mm, and the oysters grown in the floating mesh bags had an average shell length of 34.5 ± 9.58 mm. Among gear configurations, the average shell length of the oysters all significantly differed from each other (Dunn $p < 0.001$). The subtidal basket oysters had the highest growth in average shell length, followed by the intertidal basket oysters, and the floating mesh bag oysters (Figure 4).

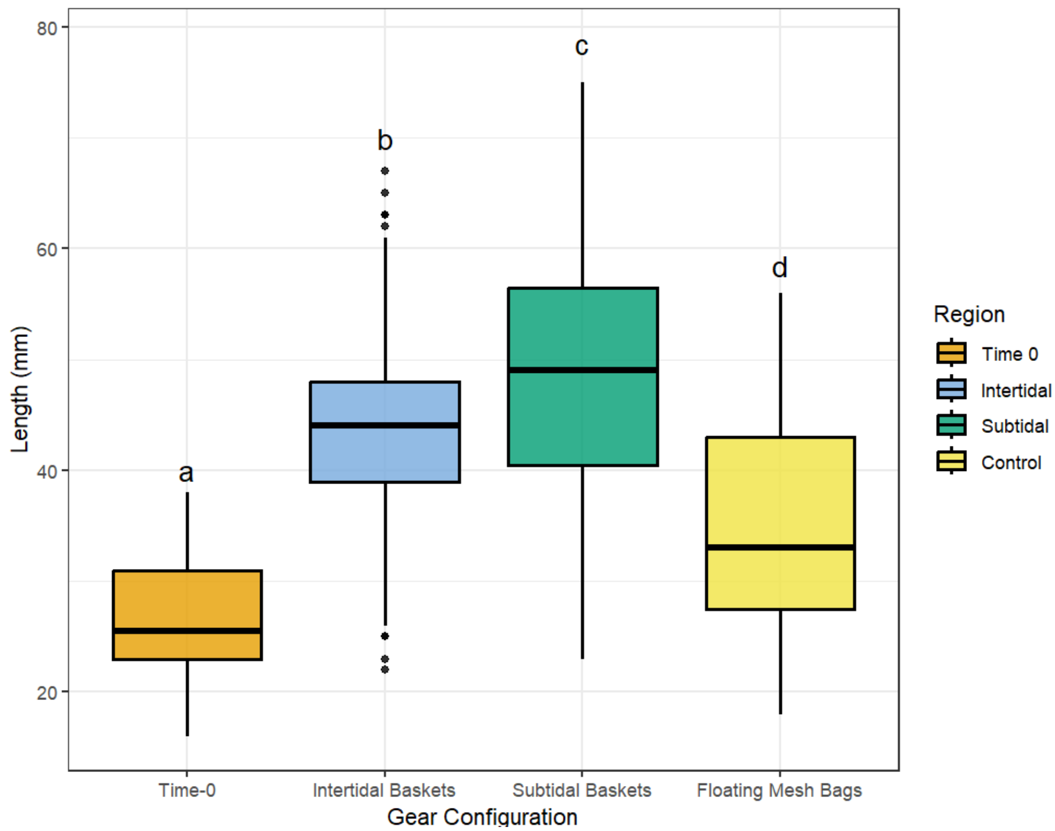

Figure 4 Comparison of the shell length of Pacific oysters (*Crassostrea [Magallana] gigas*) grown in each gear configuration tested in Juneau, AK after 4 months. The letters above the boxes represent the results of pairwise comparisons by the Dunn test. Boxes with different letters are significantly different from each other ($p \leq 0.05$).

Shell Width

Significant differences existed in shell width among gear configurations (Kruskal Wallis chi-squared = 189.49, df = 3, $p < 0.001$). The average shell width of the oyster seed at the start of the experiment measured 17.5 mm ± 2.68 mm (mean ± standard deviation). The average shell width of the oysters from each gear configuration significantly differed from the average initial seed measurement (Dunn $p < 0.001$) indicating all oysters grew in width over the four months. After the final data collection, the oysters grown in the intertidal baskets had an average shell width of 26.2 mm ± 4.01 mm, the oysters grown in the subtidal baskets had an average shell width of 28.5 mm ± 5.01 mm, and the oysters grown in the floating mesh bags had an average shell width of 22.4 mm ± 5.44 mm. Similar to shell length, all average shell width measurements among each gear configuration significantly differed from each other (Dunn $p < 0.001$). The subtidal basket oysters had the highest growth in average shell width, followed by the intertidal basket oysters, and the floating mesh bag oysters (Figure 5).

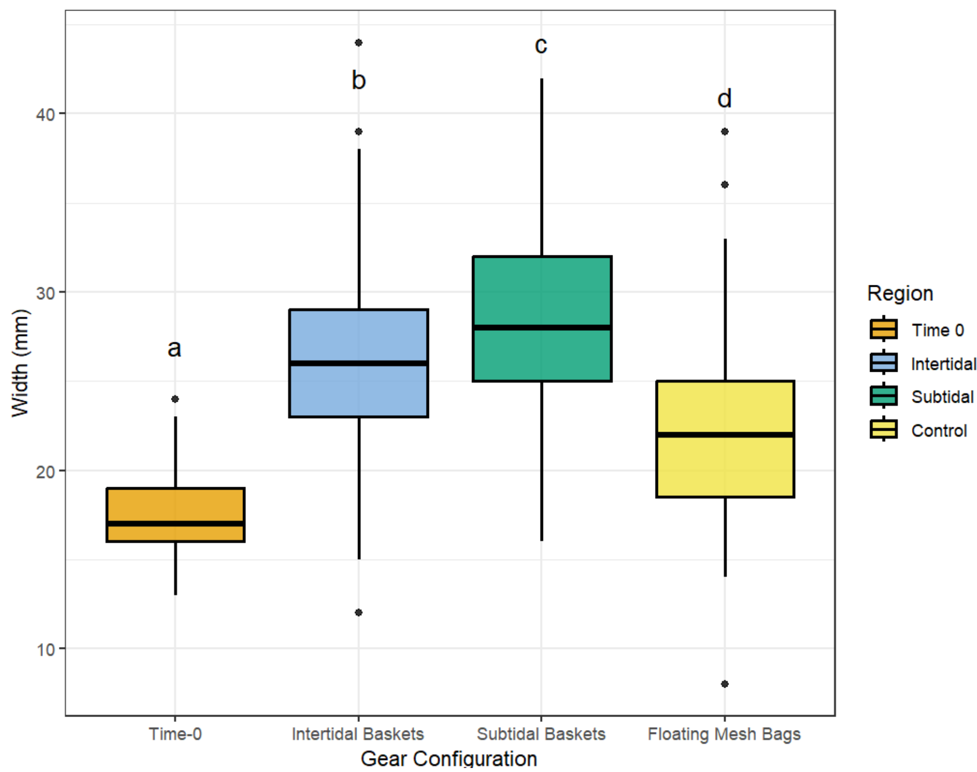

Figure 5 Comparison of the shell width of Pacific oysters (*Crassostrea [Magallana] gigas*) grown in each gear configuration tested in Juneau, AK after 4 months. The letters above the boxes represent the results of pairwise comparisons by the Dunn test. Boxes with different letters are significantly different from each other ($p \leq 0.05$).

Shell Depth

There were some significant differences in shell depth among the gear configurations (Kruskal Wallis chi-squared = 193.12, df = 3, $p < 0.001$). For shell depth, the average value of the oyster seed from the beginning of the experiment measured 6.5 mm ± 1.53 mm (mean ± standard deviation). Like the previous shell metrics, the shell depth of the oysters from each gear configuration significantly differed from the average initial seed measurement (Dunn $p < 0.001$) indicating all oysters grew in depth. After the final data collection, the oysters grown in the intertidal baskets had an average shell depth of 12.5 mm ± 1.96 mm, the oysters grown in the subtidal baskets had an average shell depth of 12.6 mm ± 2.47 mm, and the oysters grown in the floating mesh bags had an average shell depth of 9.9 mm ± 2.98 mm. The average shell depth of the intertidal basket oysters and the subtidal basket oysters both significantly differed from the floating mesh bag oysters (Dunn $p < 0.001$). However, there was no significant difference between the average shell depth of the intertidal and subtidal basket oysters. As with both the shell length and width measurements, the subtidal basket oysters had the highest average growth in shell depth (though not significant from the intertidal oysters), followed closely by the intertidal basket oysters, and the floating mesh bag oysters (Figure 6).

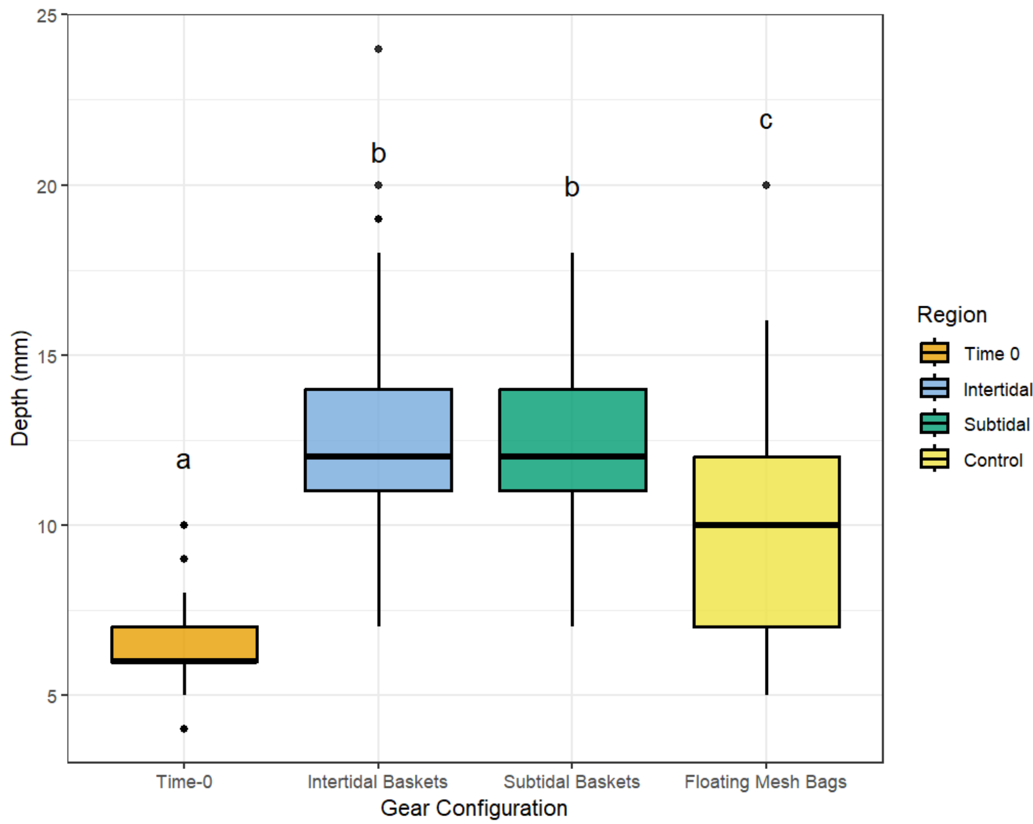

Figure 6 Comparison of the shell depth of Pacific oysters (*Crassostrea [Magallana] gigas*) grown in each gear configuration tested in Juneau, AK after 4 months. The letters above the boxes represent the results of pairwise comparisons by the Dunn test. Boxes with different letters are significantly different from each other ($p \leq 0.05$) while boxes with the same letters are not ($p > 0.05$).

Whole Weight

Significant differences existed in whole weight among gear configurations (Kruskal Wallis chi-squared = 139.39, df =3, $p < 0.001$). The average whole weight from the initial oyster seed measured 1.6g ± 0.81g (mean ± standard deviation). All average whole weight measurements of oysters from each gear configuration significantly differed from the initial seed measurement (Dunn $p < 0.001$) indicating all experimental oysters grew in size. After the final data collection, the oysters grown in the intertidal baskets had an average whole weight of 7.9g ± 3.03g, the oysters grown in the subtidal baskets had an average whole weight of 10.0g ± 4.32g, and the oysters grown in the floating mesh bags had an average whole weight of 5.9g ± 3.36g. The average whole weights among each gear configuration significantly differed from each other (Dunn $p < 0.001$), with the subtidal basket oysters having the highest growth in average whole weight, followed by the intertidal basket oysters, and the floating mesh bag oysters (Figure 7).

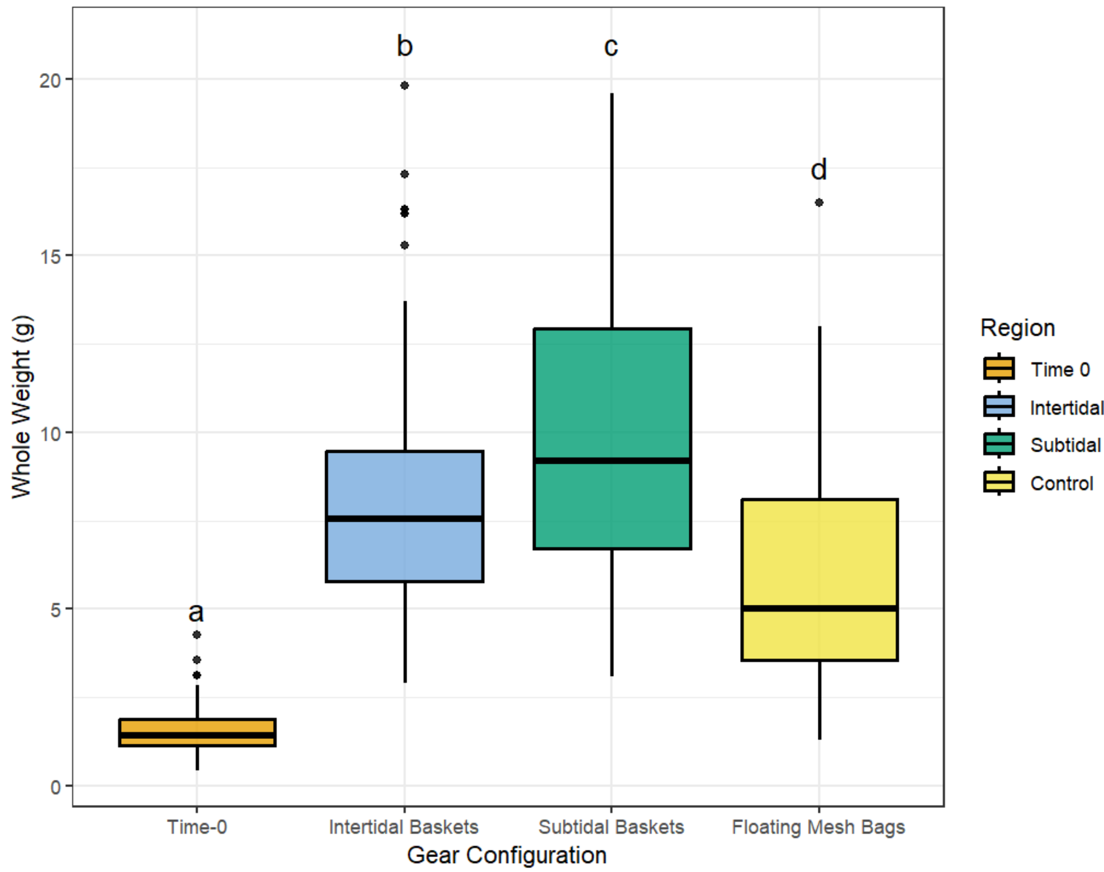

Figure 7 Comparison of the whole weight of Pacific oysters (*Crassostrea [Magallana] gigas*) grown in each gear configuration tested in Juneau, AK after 4 months. The letters above the boxes represent the results of pairwise comparisons by the Dunn test. Boxes with different letters are significantly different from each other (p≤ 0.05).

Wet Meat Weight

There were some significant differences in wet meat weight among gear configurations (Kruskal Wallis chi-squared =129.26, df =3, $p < 0.001$). The average wet meat weight of the oyster seed from the start of the experiment measured 0.23 g ± 0.81g (mean ± standard deviation). Like all the other metrics, the wet meat weight of the oysters grown in each gear configuration significantly differed from the average initial seed measurement (Dunn $p < 0.001$) indicating the oysters had internal muscle and tissue growth. After the final data collection, the oysters grown in the intertidal baskets had an average wet meat weight of 1.36 g ± 0.54 g, the oysters grown in the subtidal baskets had an average wet meat weight of 1.23 g ± 0.57 g, and the oysters grown in the floating mesh bags had an average wet meat weight of 0.99 g ± 0.63 g. The average wet meat weight of the intertidal basket oysters and floating mesh bag oysters significantly differed from each other (Dunn $p < 0.001$). However, the average wet meat weights between the intertidal and the subtidal basket oysters and between the subtidal basket oysters and floating mesh bag oysters were not significantly different from each other. For this metric, the intertidal basket oysters showed the highest growth in terms of average wet meat weight (though not significant from the subtidal oysters), followed by the subtidal basket oysters, and the floating mesh bag oysters (though not significantly different than the subtidal oysters) (Figure 8).

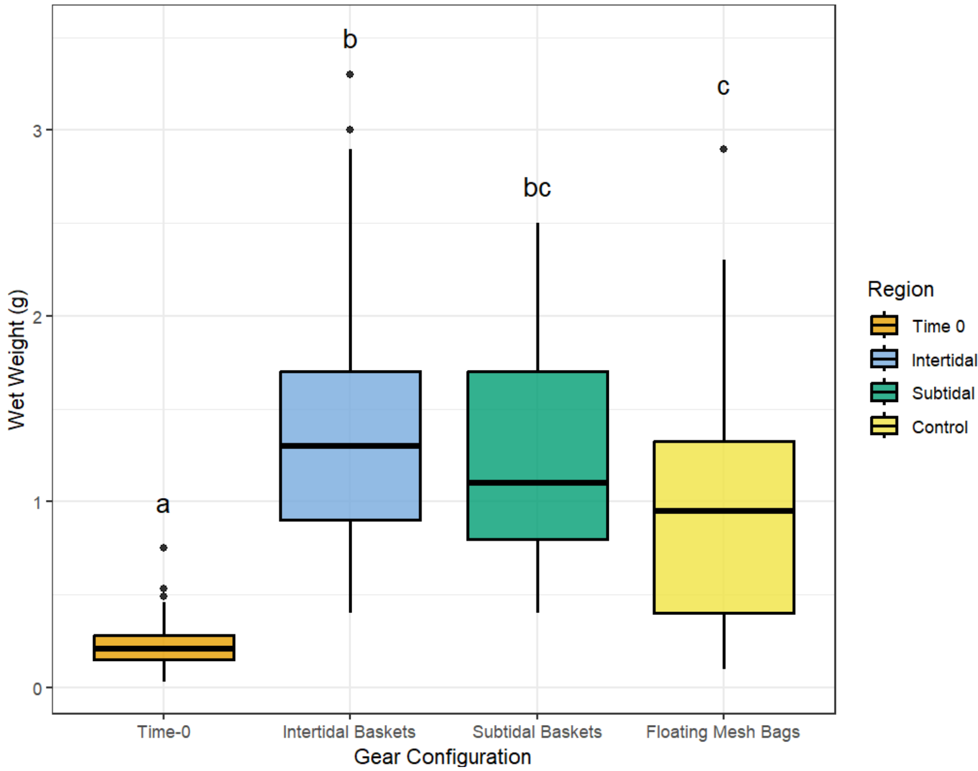

Figure 8 Comparison of the wet meat weight of Pacific oysters (*Crassostrea [Magallana] gigas*) grown in each gear configuration tested in Juneau, AK after 4 months. The letters above the boxes represent the results of pairwise comparisons by the Dunn test. Boxes with different letters are significantly different from each other ($p \leq 0.05$). while boxes with the same letters are not ($p > 0.05$).

Percent meat weight

In terms of meat content relative to whole weight, there were some significant differences in the percentage of wet meat weight among gear configurations. The initial oyster seed at the beginning of the experiment had an average percent wet meat weight of 14.2% ± 2.9%. All but the subtidal basket oysters significantly differed from the average initial seed percentage. The intertidal basket oysters had an average percent wet meat weight of 17.4%+ 3.2%, the subtidal basket oysters had an average percent wet meat weight of 12.4% ± 2.3%, and the floating mesh bag oysters had an average percent wet meat weight of 16.2% ± 3.9%. Among gear configurations, the intertidal basket oysters and floating mesh bag oysters had significantly higher average wet meat weights than the subtidal basket oysters, although did not significantly differ from each other (Figure 9).

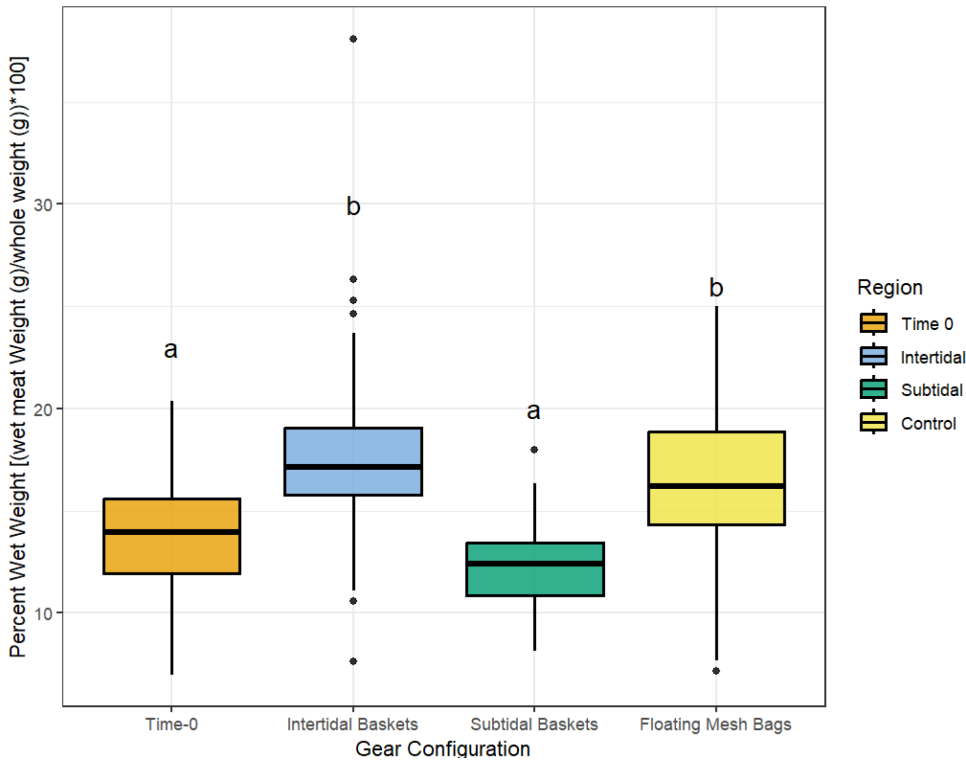

Figure 9 Comparison of the percent wet meat weight of Pacific oysters (*Crassostrea [Magallana] gigas*) grown in each gear configuration tested in Juneau, AK after 4 months. The letters above the boxes represent the results of pairwise comparisons by the Dunn test. Boxes with different letters are significantly different from each other ($p \leq 0.05$). while boxes with the same letters are not ($p > 0.05$)

Cup ratio

For shell shape, significant differences in cup ratio(depth/width) existed among gear configurations. The oyster seed at the start of the experiment had an average cup ratio of 0.37mm ± 0.07mm. All calculated average cup ratios from oysters in each gear configuration significantly differed from the average initial seed ratio indicating the oysters grew in cup size. The intertidal basket oysters had an average cup ratio of 0.48 ± 0.08, the subtidal basket oysters had an average cup ratio of 0.45 ± 0.08, and the floating mesh bag oysters had an average cup ratio of 0.45 ± 0.14. Among gear configurations, the average cup ratios from the subtidal basket and floating mesh bag oysters did not significantly differ from each other, however the intertidal basket oysters significantly differed from both gear configurations. The intertidal basket oysters had higher average cup ratios than both the subtidal basket and floating mesh bag oysters (Figure 10). Additionally, based on qualitative visual observations on shell growth, both the intertidal basket and floating mesh bag oysters developed robust, rounded shell growth throughout the experiment, while the subtidal basket oysters had relatively brittle, uneven growth (Figure 11).

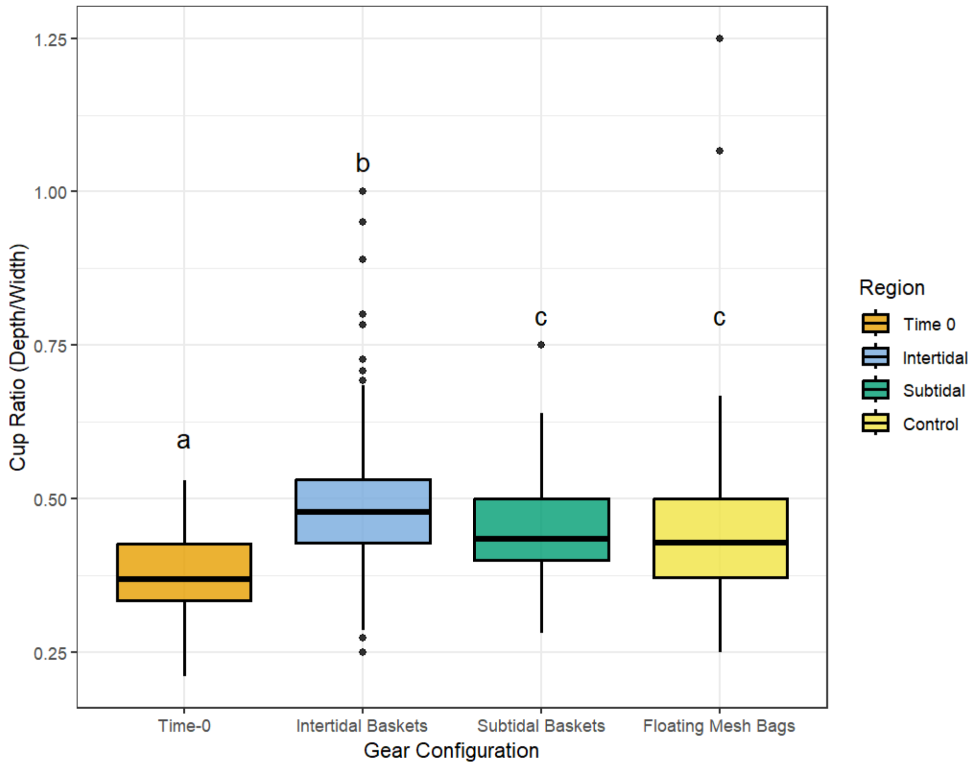

Figure 10 Comparison of the cup ratio (depth/width) of Pacific oysters (Crassostrea [Magallana] gigas) grown in each gear configuration tested in Juneau, AK after 4 months. The letters above the boxes represent the results of pairwise comparisons by the Dunn test. Boxes with different letters are significantly different from each other ($p \leq 0.05$). while boxes with the same letters are not ($p > 0.05$)

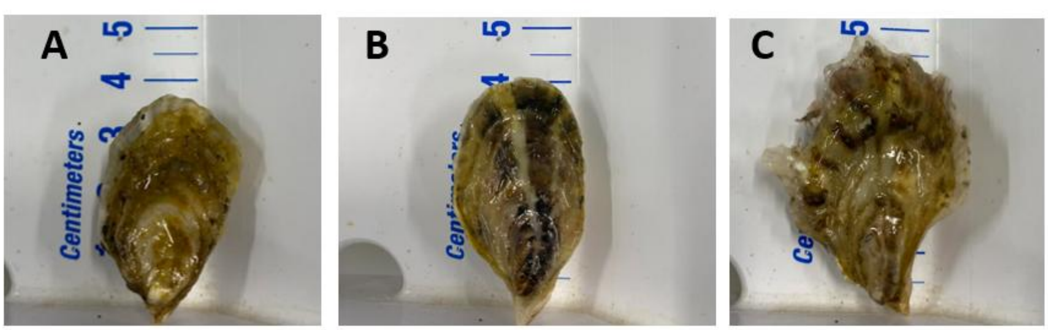

Figure 11 Oysters collected in July 2024 from each gear configuration. A.) Sample oyster from the floating mesh bags, B.) Sample oyster from the intertidal baskets, C.) Sample oyster from the subtidal basket.

*All pictures above are of oysters collected after 2 months of growth, not after final data collection.

Chapter 4

DISCUSSION

Oyster growth varied significantly among each gear configuration tested. In terms of shell length, shell width, shell depth, and whole weight, the oysters in both the subtidal and intertidal baskets had higher growth than the oysters in the floating mesh bags (Figure 4-7). Additionally, subtidal and intertidal basket oysters also had larger growth in wet meat weight compared to the floating mesh bag oysters, though the subtidal and floating mesh bag comparison did not significantly differ (Figure 8). My results highlight that both configurations of baskets produced oysters with higher overall growth in shell morphology and size than the oysters grown in the floating mesh bag method currently being used by the farmers. When evaluating the gear configurations individually, the subtidal basket oysters had the highest growth across all shell metrics and whole weight though lacked equivalent high growth in their wet meat content and cup size. In contrast, the intertidal basket oysters showed slightly lower growth in shell morphology and whole weight than the subtidal basket oysters but had higher average growth in wet meat content and cup size compared to the other two configurations (Figure 8 & 10). The floating mesh bag oysters had the lowest growth across all morphological and weight metrics; however, they had a high wet meat weight to whole weight percentage and high cup ratio, meaning they had more comparable growth of their shell and internal tissue (Figure 9 & 10). Overall, the subtidal and intertidal basket oysters outperformed the mesh bag oysters, however there were caveats with the level of wet meat and shell growth among each gear configuration, producing more market desired characteristics in particular configurations when compared to other treatments.

The variations in wet meat weight and shell morphometrics can likely be attributed to the level of wave movement and tumbling the oysters received. Previous studies have shown that wave action dependent on gear depth can significantly impact oyster performance (Walton et al., 2013; Thomas et al., 2019; Hood et al., 2020; Campbell et al. 2024). Floating gear and intertidal gear that are subjected to higher rates of wave and tidal motion tend to have oysters with higher condition indexes (dry meat weight to shell weight comparisons) compared to oysters grown in bottom culture with minimal wave disturbance (Walton et al., 2013; Thomas et al., 2019; Hood et al., 2020; Campbell et al. 2024). Additionally, in terms of shell morphometrics, oysters tumbled often in turbulent environments tend to have more rounded robust shells due gear movement effectively "pruning" the oysters-though, notably, excessive tumbling can reduce growth (Brake et al., 2003; Mizuta et al., 2019; Bodenstein et al., 2021). In a more recent study, Campbell et al. (2024) evaluated the effects of motion on Eastern oyster (*Crassostrea virginica*) growth among bottom, floating, and suspended gear, finding similar results to these previous studies. Bottom cages with low tidal disturbance deeper in the water column saw oysters with high shell growth at the expense of lower internal tissue growth, while long line baskets that swung with tidal fluxes in the intertidal zone had higher condition indexes and high shell growth. Floating cage oysters resistant to low-frequency motion at the surface showed slower shell growth but high condition indexes.

While the amount of motion among gear configurations in our study has not been fully quantified to date, our results are consistent with previous findings (Walton et al., 2013, Hood et al., 2020; Campbell et al., 2024). Though there was not a significant difference in wet meat weight between the subtidal and intertidal basket oysters, the subtidal basket oysters had a lower average wet meat weight with higher overall shell growth, likely due to experiencing minimal effects of water motion while being consistently submerged in the water (Figure 8). With limited tumbling inside the baskets, the oyster's outer shells were not repeatedly broken or chipped off as they grew, producing large brittle shells and higher shell growth compared to meat content. In contrast, the intertidal basket oysters had a higher average wet meat weight with relatively high shell growth, likely because of the tidal flux providing more consistent motion of the basket (Figure 8). This repetitive natural tumbling of the oysters may have helped to produce oysters with strong rounded shell shapes and comparable growth of the shell and internal tissue. Lastly, the floating mesh bag oysters had slower shell growth but relatively high average percent wet meat to whole weight values and rounded shells that were comparable to the intertidal basket oysters, likely due to slight tumbling from wave motion at the surface and from farmers completely weekly bag flips (Figure 9 & 11). These results suggest that the level of gear motion and tumbling oysters received during grow-out likely influenced the higher shell growth low meat content of the subtidal oysters, but the more rounded shells and high wet meat growth to shell growth seen in both the intertidal basket and floating mesh bag oysters.

In addition to the level of water motion, air exposure could also influence differences seen specifically in oyster wet meat weight among gear configurations. Although excessive air exposure can stress oysters to the point of reduced growth and mortality (see La Peyre et al., 2018 and Bodenstein et al., 2021), shorter periods of exposure are known to strengthen oyster's adductor muscles and promote additional tissue growth as they repeatedly open and close their shells between low and high tides (Toba, 2002; Brake et al., 2003; Chuku et al., 2025). In some cases, farmers move their oysters from floating or suspended culture to intertidal zones in their last few months of growth for what is called a “finishing period” because of the effect of air exposure promoting larger meat growth in addition to wave movement strengthening the shell (Toba, 2002; Brake et. al 2003; Thomas et al., 2019). Though there was not a significant difference between the wet meat weight of the intertidal and subtidal basket oysters, the intertidal basket oysters having extended periods of air exposure throughout their grow-out process, likely promoted the higher average wet meat weights found in these oysters compared to the other gear configurations. Since the subtidal baskets were constantly submerged in water, the oysters had no air exposure and therefore lacked this effect. Similarly, the floating mesh bag oysters had limited air exposure at the water's surface, explaining the lack of significant difference in wet meat weight between this method and the subtidal basket oysters (Figure 8). The combination of extended periods of air exposure with the level of motion the tidal flux provided are likely mechanism that allowed the intertidal basket oysters to grow the most in terms of average wet meat content compared to the other gear configurations.

From a marketability standpoint, these differences in wet meat weights and shell growth metrics are important in determining oyster’s profitability. Farmers, sellers, and consumers, a part of Alaska’s half-shell market, desire oysters that have high meat content, rounded shell shapes, and deep cups (Galtsoff, 1964; Brake et al., 2003; Mizuta et al.,2019). Specifically for oyster cups, a ratio of depth to length, known as the cup ratio, determines the marketability of oysters with higher ratios corresponding to deeper cups and well-shaped shells (Brake et al., 2003; Mizuta et al., 2019). Oysters that tend to have larger rugged shells, with lower meat content and lower cup ratios, are often characterized as less desirable for a high-end half shell market and can fail to be profitable for farmers (Brake et al., 2003; Mizuta et al., 2019, Mercer et al., 2024).

From our visual observations, the oyster shells from the subtidal baskets had brittle uneven growth in addition to the lowest percent wet meat weight, likely due to the lack of tumbling they received as previously discussed (Figure 9 & 11). Although there were small differences in cup ratio among methods, the subtidal basket oysters had a lower average cup ratio than the intertidal tumble basket oysters, though were not significantly different from the ratio of the floating mesh bag oysters (Figure 10). Due to uneven growth of the outer shell, lower meat content compared to overall shell growth, and low average cup ratio, the subtidal basket oysters seemed to develop less market desired characteristics compared to the other gear configurations. Floating mesh bag oysters had lower cup ratios than intertidal basket oysters but had rounder shells and higher average percent wet meat weights-greater than subtidal basket oysters and comparable to intertidal basket oysters- likely due to surface exposure and manual tumbling by farmers (Figure 9-11). These oysters grew the slowest but had more desirable shell shapes and meat content relative to their shell size. For the intertidal basket oysters, they grew similarly to the floating mesh bag oysters but at a greater rate. They produced some of the most market desirable characteristics having smooth rounded shells, high average percent wet meat weight values, and highest cup ratios, which were likely due to the repetitive tumbling and air exposure from the tidal exchange (Figure 9-11). These results suggest that gear configuration plays a significant role in determining the rate of growth and the morphological characteristics of the oyster, namely cup ratio and wet meat weight, which have consequences for the time to market and potential sale price of the oyster.

Though the intertidal baskets produced oysters with market desirable characteristics after four months of growth, there are challenges with adapting this gear configuration in Southeast Alaska. Attaining access to gently sloped intertidal areas that are available for lease can be difficult for farmers to find and attain. Additionally, cold rough winters in the southeast make the intertidal basket array not suitable for remaining intact during the winter months. If this intertidal tumble culture method was to be adopted, it would be important to consider the labor costs of building and dissembling the array system and moving oysters to subtidal methods between seasons. Further studies could aim to develop mechanisms that would make this process of shifting gear between seasons more manageable. It is also important to note that the short fourth month summer duration for this study may not be sufficient in evaluating the long-term growth of oysters using this intertidal method. As Alaska's climate is highly variable in terms of temperature and rainfall between seasons and years, it would be beneficial to track growth over multiple summers and over the 2–3-year period it takes for oysters to become market sized. This would allow for a more comprehensive evaluation of the differences in growth and morphological characteristics seen among gear configurations.

In addition to assessing these limitations, further research should analyze biofouling among gear configurations as well as the time spent addressing biofouling removal to determine if one configuration limits fouling species compared to others. This would provide additional data for evaluating the growth of oysters and the amount of labor needed among gear configurations, since biofouling can inhibit water flow and food particles for oysters and requires farmers to manually remove species. Finally, studies that collect data on the optimal amount of air exposure and motion oysters need to grow marketable shell shapes and sizes would help in developing additional intertidal and suspended gear configurations that maximize the use of natural tumbling for oyster growth.

Chapter 5

CONCLUSION

Overall, gear configuration had a significant effect on oyster growth. The intertidal pivot line baskets produced oysters with more desirable shell shapes and meat content than oysters in the subtidal basket stacks and the floating mesh bags that are currently used by farmers. We note that the amount of tumbling and air exposure the oysters received among gear configuration are plausible explanations for the differences in growth rate and shell morphology among each gear configuration. The intertidal basket oysters had rounded shell shapes, high wet meat content relative to their shell, and high cup ratios, likely due to natural tumbling by the change in tides. For the subtidal basket oysters, the limited basket motion while being submerged in the water column produced oysters with high shell growth that was brittle and uneven, along with lower percent wet meat content, and low average cup ratios. For the floating mesh bag oysters, although growth was slower than both tumble culture methods, they had some marketable characteristics with rounded shells and higher percentage of wet meat weight relative to their whole weight, similar to the intertidal basket oysters, due to both the surface and manual tumbling conducted by the farmer. These results highlight the ability of intertidal culture to produce oysters with market desired characteristics, offering an additional method of farming that could help increase industry expansion and potentially reduce labor costs in Southeast Alaska. Although the benefits of this method will depend on site-by-site conditions, implementing intertidal basket culture would allow farmers to expand farming capacity to seasonally accessible sites and offer a method of natural tumbling that produces quality oysters while reducing the need for manual and machine-based tumbling.

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