Evaluation of a Mechanical Grader for the Improvement of the Aquaculture Production of the Eastern Oyster, *Crassostrea virginica*, in the Northern Gulf of Mexico

by

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Abstract

In order to develop culture regiments that increase oyster product quality and profitability, commercially available oyster aquaculture growout gear, a rotary style mechanical grader ("tumbler") and three handling treatments were evaluated for their ability to physically impact oyster morphology, increase the consistency of morphology, reduce exterior biofouling and reduce mortality. The gear and the handling treatments were evaluated in two experiments, the first of which compared four gear types with three handling treatments using a constant monthly frequency. The second experiment compared two similar gear types with the three handling treatments across four frequencies: seasonal, monthly, biweekly and weekly. Oysters were grown on a commercially developed lease in Grand Bay, Alabama. During a growing season of 147 days, oysters were subjected to monthly handling treatments that involved an emersion and handling treatment, a tumbling and handling treatment and a no handling, no tumbling treatment. End harvest oysters were evaluated based on time required to manually remove biofouling, shell metrics, and percent mortality.

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List of Abbreviations

ALS	Adjustable Longline System
ANOVA	Analysis of Variance
AUSL	Auburn University Shellfish Laboratory
FB	Floating Bags
HSD	(Tukey’s HSD) Honestly Significant Difference
LP	LowPro™ Bottom Cages
LSU	Louisiana State University
PVC	(Pipes) Polyvinyl chloride
OG	OysterGro™ Floating Cages
UF	University of Florida

Chapter 1: Introduction and Literature Review

1.1 Commercial Significance of Oysters in the Gulf Region

The oyster industry in the Gulf of Mexico revolves around the population fluctuations of the Eastern oyster, *Crassostrea virginica* (Schlesselman, 1955). The Gulf is a region where, in the states of Texas, Louisiana, Mississippi, Alabama and Florida, oyster harvest can be traced back to the cultures of Native Americans indigenous to the Gulf coastline (Dugas et al., 1997; Supan, 2002). Historically, the largest oyster production came from the Chesapeake Bay rather than the Gulf. In the 1880's the production out of the Chesapeake began to drastically diminish, although public demand for oyster products remained stable (Wirth and Minton, 2004). During this time, the Gulf oyster industry was based primarily on wild harvest of public reefs but also included some areas of extensive bottom-culture. Privatized bottom-leases (hereafter leases) were areas that had been supplemented with empty oyster shell in hopes of accumulating wild "set," or wild juvenile oysters, as they metamorphose from a planktonic larval stage to a sessile oyster juvenile. When the oyster supply became limited in the Chesapeake due to overfishing, disease, habitat degradation, and parasites, the Gulf oyster industry began to expand (Schlesselman, 1997; Wirth and Minton, 2004; EOBRT, 2007).

As reliance on the Gulf States' oyster production increased, oysters harvested from Louisiana, Florida and Texas comprised the bulk of the oyster industry along America's southern coast. In 2001, Louisiana was the production leader of Eastern oysters (by weight) with industry members contributing to average landings in the 4,500-

5,900 metric ton range (10-13 million pounds)(Wirth and Minton, 2004). Louisiana's contribution provided 37% of the total oyster meat production for the United States (Wirth and Minton, 2004). Between 1997 and 2001 Louisiana's 54% majority of oyster landings in the Gulf regions translated to 32% of the nation's total oyster landings (Wirth and Minton, 2004). Even in the late 1990's harvests in Florida fluctuated with environmental conditions, but production ranged from 900 to 2700 metric tons of oyster meat (2 to 6 million pounds), which accounted for about 20% of the Gulf's annual production (Dugas et al., 1997). Harvests from Texas, Mississippi and Alabama vary over the years and primarily rely on oyster collection from public reef areas, although revealed in the late 1990's the addition of new leases was documented (Dugas et al., 1997).

The traditional oyster product originating from the Gulf States was shucked meat. Shucked meat product is a raw oyster that has been harvested, removed from its shell and packaged with little additional value-added services (Wirth and Minton, 2004). Additional value-added services would include meat size grading, breading, stewing, canning, smoking, etc. (Wirth and Minton, 2004). The secondary product to the shucked oyster was counter-stock, or half-shell, oysters. Half-shell oysters are oysters of higher quality than the shucked oyster and are sold live-in-shell to restaurants to be served on the half-shell (Wirth and Minton, 2004).

Although the supply of oysters from the Gulf of Mexico seemed to compensate for the decline in populations in the Chesapeake Bay, Gulf populations experience their own variability and limitations. The shucked meat market has many factors that make it vulnerable to harvest variability. Since productivity within the shucked market is largely based on the harvest of wild oysters, fluctuations in environmental conditions can drastically affect annual yields. In the past, oyster landings have declined in part due to hurricanes, salinity fluctuations and water quality closures (Dugas et al., 1997; EOBRT, 2007). In 1985, Hurricane Elena devastated oyster reefs in Apalachicola Bay, FL. Reefs were impacted so severely that the following year could not support commercial harvest (Berrigan, 1988; Edmiston et al., 2008). Fluctuations in salinities can occur when freshwater inputs from rivers and rain contribute to changes within the many estuaries of the Gulf. Heavy rainfall can lead to increased freshwater inputs that drastically reduce estuary salinities. Adult oysters can survive periods of low salinities (10 parts per thousand (ppt) or less), but planktonic larvae and small juveniles require at least 10ppt salinity to persist and grow (Sellers and Stanley, 1984; EOBRT, 2007) Alternatively, drought conditions can lead to elevated salinities in the estuarine waters which can promote the inshore range expansion of predators like the southern oyster drill, *Thais haemastoma floridana* (Burkenroad, 1931). Oyster drills are especially destructive to oyster spat and smaller oysters, often preventing crops from surviving to a marketable size (>76mm) (Burkenroad, 1931).

Water quality conditions in the Gulf of Mexico can also affect the oyster harvests that supply the shucked meat market. Harmful algal blooms known as red tides have been responsible for some fishery closures. Following the aftermath of Hurricane Katrina, oysters in Louisiana were closed to harvesting for over 3 months, directly related to the red tide being transported into the Bay's oystering areas (Edminston et al., 2008). More recently the Gulf's oyster fishery was closed due to the events surrounding the April 2010 Deepwater Horizon oil spill. Harvests spanning Louisiana, Mississippi, Alabama and Florida were closed due to an explosion of a drilling platform, which resulted in an 87day leak that discharged over 4.9 million barrels of oil into the Gulf of Mexico (OSAT, 2010). Concerns over the combination of oil and oil dispersants in the water led to the closure of 88,500mi^2 of Gulf fishing zones (OSAT, 2010). Although oil contamination did not reach all areas of the Gulf coastline, oyster areas that had oil presence were areas that relied on wild reefs and extensive culture to supply the industry. In those wild reefs and extensively planted beds oysters could not be moved away from the oil's trajectory. Subsequently, many crops in Louisiana were lost due to contamination and mortality, a fate that may have been mitigated by the more mobile culture techniques of oyster aquaculture.

With the replenishment of annual oyster crops dependent on the survival, growth and natural reproduction of wild oyster reefs, the shucked meat market in the Gulf of Mexico can fluctuate dramatically. The traditional ways of oystermen in the South often give way to unpredictable harvests and market values that fluctuate based on supply. In areas of the country where wild oyster populations can no longer naturally support a fishery, oystermen are increasingly turning to more intensive forms of aquaculture to stabilize the industry and meet product demands.

1.2 Oyster Aquaculture

Oyster aquaculture can be any form of oyster cultivation by humans. There are two main forms, which are most commonly referred to in the oyster industry as extensive culture and intensive culture. The previous section briefly described extensive culture. In this form, oysters are grown on the substrate with little attention from oystermen until they reach a harvestable size. Extensive oyster crops are most commonly derived from wild setting larvae and are either collected from the wild and transported to a particular lease site or larvae are attracted to set within the lease on the empty oyster shells (cultch) planted by the farmers. The following section will address intensive culture in the United States.

In areas like the Chesapeake Bay, the shift away from natural seed oysters was a function of both their relative scarcity and disease concerns (Wieland, 2007). Hatcheries provided a reliable source for seed oysters that were spawned from broodstock that was selectively bred to improve disease resistance. The hatcheries provided farmers with juvenile oysters that were set on microcultch. Microcultch consists of fine sand-like particles, which are large enough for the adherence of only a single oyster. This technique produces an oyster that is not clumped together with several other oysters. The fine cultch material eventually wears away, producing a single, cultch-less appearance. The single, cultch-less appearance of the hatchery-produced oyster makes them a desirable product for the half-shell market.

The cost of hatchery-produced seed means that farmers need to eventually harvest and sell as many of the purchased oysters as possible, which is often a challenge with extensive culture. The use of tongs, dredges and divers are not very efficient for harvesting subtidal oyster beds, with only some portion of the planted oysters actually being recovered for harvest (Wieland, 2007). Aside from the losses due to harvest techniques, as the planted oysters grow they are left unprotected from natural predators, generally exhibiting a 50% mortality rate soon after planting (Wieland, 2007).

Intensive culture takes advantage of an improved single seed oyster and has developed methods to protect crops and maximize harvests. Intensive culture utilized cage structures to enclose seed oysters during growout, protecting against natural predators like crabs, snails, and drum (Wieland, 2007; Creswell et al., 2008). Additionally, the design of many intensive culture cages elevates oysters off the bottom, which is a factor in itself that deters many benthic predators (Creswell & McNevin, 2008). Cages can be elevated by feet-like structures or they can be suspended into the water column by floats. Oysters grown in elevated cages also have the benefit of increased growth rate by being raised above the bottom into the water column where the food availability and water flow is available in all directions (Kraeuter, 2007). Increasing growth rate in turn decreases the intervals between harvests. Whereas extensively grown oysters can require as much as four years to reach a marketable size (approx. 75 mm), intensively grown oysters, as demonstrated in Florida, can reach a marketable size in as little as 14 months (Creswell & McNevin, 2008).

1.3 The Half-Shell Market and Product Quality

Unlike the shucked meat market, the half-shell market relies on the quality and appearance of the oyster shell as well as the meat within. Instead of marketing oysters by the pint of shucked meats, the half-shell market products are sold live in shell and valued most commonly by the individual oyster. Half-shell oysters are served freshly prepared as either a raw product or with some degree of culinary accouterments, yet all versions are presented on the bottom-half of the shucked shell. The inclusion of the shell in the presentation means that oysters for the half-shell market are more closely scrutinized than those used for shucked meats.

Oysters that achieve premium half-shell market prices must meet quality guidelines. These guidelines are often vaguely defined and can vary from location to location or even company to company. First, oysters are critiqued on size. Depending on market regulations many products must be above a certain size in order to be legally sold (usually >76 mm shell height). Many processors sell oysters according to size grades, with price increasing with selectivity. Examples of these size selections, in order of increasing value and size, include: “Counts”, “Standard”, “Select”, “Extra Select”, and “Jumbo” (Australian Seafood Cooperative Research Centre, 2009; Bon Secour Fisheries, 2011; Little Shemogue Oyster Company, 2011). Secondly, oysters are inspected for biofouling. Biofouling (e.g., barnacles, algae, worm tubes, etc.) can lead to premature spoiling, foul odors, and overall unpleasant product appearance or taste. In countries such as Canada, food regulations require that oysters for the half-shell market must be live, individual oysters, cleaned free of debris (Canadian Food Inspection Agency, 2009). With potential markets imposing regulations on biofouling, finding ways to reduce biofouling during growout as well as reduce time spent cleaning after harvest are increasingly important topics of interest among farmers (Mallet, 2009; Sala and Lucchetti, 2008)

Third, oysters are scrutinized for conditions of appearance that have been found to have higher approval from consumers. As seen in the Pacific oyster industry, the quality of oysters is becoming more important as production and competition increases (Brake et al., 2003). Where taste is a characteristic that becomes more important as the market-life of an oyster draws to an end, shell shape quality is an important characteristic from the very beginning. Thus, shape has become recognized across the global shellfish industry as a valuable marketing tool (Brake et al., 2003). Currently, Canadian Eastern oysters are sold according to one of four shape criteria: “Fancy”, “Choice”, “Standard”, or “Commercial” (Canadian Food Inspection Agency, 2009). These categories are based on a ratio of shell height to shell length and a consideration to shell width. Poorly shaped oysters are those that have exceedingly long shell heights (the measurement from the hinge to the bill) and or particularly flat cup shape (referring to the width, also known as depth, of the shell (Canadian Food Inspection Agency, 2009). Although consumer shape preferences have been rarely documented, one can estimate some basic guidelines from the literature. In the past, oysters that had a very long and narrow shell were often referred to as “coon” oysters or more recently “bananas” or “snappers”, a negative review of shape (Galtsoff, 1964). Oysters that have a rounded shape, or a more proportional relationship between shell height and shell length, are likely preferred by consumers.

1.4 Potential for Intensive Oyster Aquaculture in the Gulf Region

The maximum market potential in the Gulf region has yet to be realized. The Gulf of Mexico is the source for roughly 90% of the Eastern oysters sold within the United States. However, oyster sales in the Gulf region contribute to only 75% of the total national market value (NOAA, 2009). Despite having a significantly larger harvest by pound than any other area in the US, a large majority of the Gulf product is for the shucked market; therefore harvesters only receive an average wholesale market price of $3.21 US per pound (NOAA, 2009; Supan, 2002). This value is significantly less than those from states that rely primarily on aquacultured product for the premium half-shell market. Eastern oysters harvested in Massachusetts, Maine and Rhode Island can achieve market values of approximately $40 US per pound in the wholesale market (NOAA, 2009).

Adoption of intensive oyster aquaculture has the potential to both increase the value of oysters harvested from the Gulf and triple the size of the oyster industry in the Gulf States. Intensive culture will open a market niche for both hatchery-produced seed and premium half-shell oysters in addition to the established shucked meat market. Along with these new market niches come associated jobs such as hatchery workers, gear builders, farmers processors construction workers, surveyors, farm laborers, processing laborers, shipping workers, etc. As the oyster industry as a whole experiences a generational fade of traditional oystermen, new means of production will be needed to fulfill the market demand for oysters.

Currently, there are two functioning shellfish hatcheries in the region, one established by Louisiana State University (LSU) in Grande Isle, Louisiana and one establish by Auburn University in Dauphin Island, Alabama. Working side-by-side these two facilities have been researching the problems that must be solved before intensive oyster aquaculture in the Gulf can become a sustainable addition to the oyster industry. Research focusing on intensive cultured growout can provide methods and practices to establish new directions for the Gulf oyster industry. There is one commercial oyster aquaculture farm in Alabama (personal observation) and a few off-bottom farming endeavors targeting the half-shell market along the entirety of the Gulf of Mexico (USDA, 2005). In order to further develop intensive oyster culture in the region, it is necessary to conduct investigations that provide baseline data about culture techniques and regiments. These investigations will serve as an impetus for expansion of the half-shell market both within the Gulf region and across the industry as a whole.

1.5 Objectives of the Study

The objectives of the study were to evaluate the potential of gear type and handling treatments to manipulate oyster product quality. The evaluation was conducted with the information gained by two experiments. The first experiment consisted of an evaluation of four gear types in combination with three handling treatments. The objectives and coordinating hypotheses for experiment one were:

Objective #1.1) Determine if gear type selection had significant impacts on the growth and development of oysters cultured under three handling treatments: never handled, never tumbled; monthly handled and monthly emersed; and lastly monthly handled and monthly tumbled.

> **Hypothesis #1)** There will be significant differences in shell morphology based on gear selection.

> **Hypothesis #2)** There will be an increased effect on shell morphology due to increasing input of handling.

Objective #1.2) Determine if gear type selection or handling treatment had significant impacts on the consistency of shell morphology among the oysters grown in the four gear types and cultured under the three handling treatments.

Hypothesis #3) There will be an increased reduction in variation among oysters grown in any of the gear types when handling treatment is increased to the tumbled treatment.

Objective #1.3) Determine if gear type selection or handling treatment had significant impacts on the time required to remove biofouling from a sample of 5 oysters.

Hypothesis #4) As handling increases from never handled to handled and emersed and then to handled and tumbled, the time required to remove biofouling will correspondingly decrease, regardless of gear type.

Objective #1.4) Determine if gear type selection or handling treatment had significant impacts on overall percent mortality.

Hypothesis #5) As handling increases from never handled to handled and emersed and then to handled and tumbled, the percent mortality observed will increase, regardless of gear type.

The second experiment investigated the effects of the frequency of handling. In this section, comparisons of the effects of two handling treatments were investigated at four different and increasing frequencies. The frequencies investigated were seasonally, monthly, biweekly and weekly. These treated frequencies were then compared with a never handled, never tumbled control, as in the first section. The objectives and coordinating hypotheses for experiment two were:

Objective #2.1) Assess four different frequencies of handling for effects on the final shell morphology of oysters grown in floating bag and OysterGro™ gear.

> **Hypothesis #1)** Increasing the frequency which oysters are handled will increase the degree to which the corresponding shell morphology is impacted.
>
> **Hypothesis #2)** Tumbling the oysters on a weekly basis would have the greatest impact on shell morphology when compared to the other treatments and frequencies.

Objective #2.2) Determine if the combination of handling frequency and handling treatment impacted the consistency of shell morphology produced in oysters grown in the two gear types.

> **Hypothesis #3)** As handling frequency increases and handling inputs increase from never handled, never tumbled, to handled and emersed to handled and tumbled, consistency of shell morphology will increase.

Objective #2.3) Determine if the combination of handling frequency and handling treatment impacted the time required to remove the biofouling from a sample of 5 oysters.

Hypothesis #4) As handling frequency and handling inputs increase, the time required to remove the biofouling from a sample of 5 oysters will become reduced.

Objective #2.4) Determine if the combination of handling frequency and handling treatment impacted the percent mortality of oysters grown in the floating bag and OysterGro™ gear.

Hypothesis #5) As handling frequency and handling input increases, the percent mortality of oysters grown in either gear type will increase.

Chapter 2: Evaluation of a Mechanical Grader, A Test of Gear Type and Handling

2.1 Abstract

In order to optimize culture regimes that increase oyster product quality, four types of commercially available oyster aquaculture growout gear and a rotary style mechanical grader ("tumbler") were evaluated for their ability to physically influence oyster morphology, the consistency of morphology, reduce exterior biofouling and reduce mortality. Oysters were grown on a commercial oyster lease in Grand Bay, Alabama. During the final grow-out season in the second year (147 days), oysters were subjected to one of three monthly handling treatments: a tumbled treatment, an emersed treatment (with oysters removed from the water and handled identically to tumbled oysters but not subjected to tumbling), and a never handled control treatment (never tumbled or emersed). At the conclusion of the study, oysters were evaluated based on shell morphology, consistency of shell morphology, time required to manually remove biofouling, and percent mortality.

Gear selection had a greater influence on shell morphology than handling treatment, as singularly exhibited in six out of eight variables of morphology. The application of any of the three handling treatments or the selection of any of the four gear types did not produce any significant effects on the coefficients of variation for the variables of shell length, shell width, whole wet weight, and dry shell weight. However, significant differences in the coefficient of variation were observed for the variables of shell height and dry tissue weight.

There was a significant effect of gear type selection on biofouling removal time, which resulted in the oysters produced in the OysterGro™ gear having the least amount of fouling when compare to the ALS gear type, noting no significant difference between floating bags and LowPro™ with respect to biofouling.

The ALS, floating bags and LowPro™ gear types did not have significantly different mortality rates and there was no cost of mortality due to a monthly emersed or tumbled treatment when compared to the never handled control. The majority of gear types displayed mortality rates below 10%.

2.2 Introduction

As the once abundant harvests of wild oysters from the Chesapeake Bay and other regions have become unsustainable, the resilient consumer demand for oysters has presented an opportunity for the Gulf of Mexico to expand the traditional scope of the region's market to include the intensive aquaculture production of oysters for the half-shell market. However, in the Gulf region, there are few commercial oyster farms. The current industry is primarily reliant on the lower value shucking market, with no hatchery raised seed production, and few instances of intensive cage culture. These three limiting factors combined with recent environmental damage surrounding the 2010 Deepwater Horizon oil spill have yielded a situation where the maximum market potential in the Gulf of Mexico has yet to be realized.

The Gulf of Mexico's naturally productive waters are one of the few remaining areas in the world with sustainable oyster reefs (Beck et al., 2011). In recent years the Gulf of Mexico had been the source for roughly 90% of the Eastern oysters sold within the United States, with oystermen primarily targeting the shucked meat market. However, oyster sales in the Gulf region contribute to only 75% of the total national market value (NOAA, 2009). The majority of Gulf oysters are directly harvested off wild reefs or grown extensively on bottom-leases (Supan, 2002). Gulf oysters harvested for the shucked market on average receive a wholesale market price of $3.21 US per pound (Supan, 2002; NOAA, 2009). However, eastern oysters intensively farmed for the half-shell market in Massachusetts, Maine and Rhode Island can achieve wholesale market values of approximately $40 US per pound (NOAA, 2009). With natural reef production on a global decline since 2000, many once productive oyster bays in other parts of the world have turned to the intensive aquaculture production of shellfish to meet the undiminished demand from consumers (EOBRT, 2007; Beck et al., 2011; FAO, 2010). The adoptation of intensive culture techniques by the Gulf oyster industry to target the half-shell market would present opportunities for the industry to increase yields and profitability.

The April 2010 Deepwater Horizon oil spill increased interest from the region's oyster industry regarding the potential decline of seed sources, the need for additional market niches and alternate culture methods. Precautionary closures and concerns about contamination from the oil spill closed many publically utilized reefs throughout the Gulf region. Public reefs were a source of not only marketed adult oysters but just as importantly, a source of juvenile seed oysters from which many extensive bottom-leases were stocked. With long-term effects of the oil spill under investigation, concerns about the future viability of the public reefs increased interest in the hatchery-produced seed used in aquaculture techniques. Unlike wild seed sources on public reefs, hatchery produced seed is a reliable and controllable source of seed stock. Single-shell seed oysters produced in hatcheries eliminate the need to break clumps of oysters to separate out individuals. Although there is a cost associated with purchasing seed compared to collecting it from the wild, hatchery produced seed primarily caters to the half-shell market where a premium half-shell oyster is considerably more valuable than a manually separated single or a shucked meat product.

The limitations of the traditional Gulf oyster industry may be overcome with the utilization of high capacity off-bottom growout systems stocked with hatchery produced seed to produce a reliable source for premium oysters for the half-shell market. Currently, there are two commercial shellfish aquaculture farms in Alabama (personal observation) and a few off-bottom farming endeavors targeting the half-shell market along the entirety of the Gulf of Mexico (USDA, 2005). High production costs can restrict industry expansion and serve as barriers to new oystermen (Wirth and Minton, 2004). If off-bottom aquaculture is going to be successful in the region, revenue from the high-value, premium half-shell oysters that can be produced using intensive aquaculture techniques must outweigh the cost of production.

With increasing interest in oyster aquaculture and the new types of culture gear becoming commercially available, there is a need for research investigating the commercial viability of new equipment to determine to what extent their use translates into improved production output and oyster quality. An informal survey of current oyster farms across the country resulted in the selection of four gear types for comparison along with a rotary style mechanical grader. Selection was based on commercial availability, range of investment levels as well as range in unit design. The gear types investigated were the adjustable longline system (ALS), floating bag gear, LowPro™ bottom cages, and OysterGro™ floating cages. The mechanical grader selected was the QuickTube™ Sorter. Floating bags, LowPro™ and OysterGro™ as well as the mechanical grader were commercially available through the Chesapeake Bay Oyster Company (VA). The ALS was only commercially available in Australia, however, previous research efforts by Louisiana State University determined that the ALS gear had potential within the industry to serve as not only a growout gear type but also as a interchangeable nursery stock rearing system (Maxwell, 2007).

Floating bags had been previously implemented in culture systems found along the Canadian and New England coastline (Mallet et al., 2009). The price per unit was at the low end of the spectrum as far as initial investment was concerned and its design was not only easy to manipulate but the main structure utilized the same mesh bag component as found in the LowPro™ gear and the OysterGro™ gear. This enabled bulk purchasing for inserts for those three gear types as well as gear designs that were essentially increasing increments of the same base unit. LowPro™ and OysterGro™ gear were successively larger investments than the floating bags, yet provided housing for more oysters per area of lease. The gear selection provided several viable culture options at different levels of investment suitable for multiple budgets.

The mechanical grader was chosen for its design, which reduced the amount of workers needed to complete size variant sorting. The rotary design was also the source of industry claims that prompted this project's investigation, which indicated that "tumbling" improved shell appearance and quality and also reduced biofouling.

Previous evaluations of growout gear included studies to reduce biofouling and predation as well as optimize growout densities, but the bulk of these experiments were dominated by studies describing the effects of oyster culture on sediments and associated infaunal assemblages, with little information on the commercial application and function dynamics of the equipment (Crawford et al., 2003; Mallet et al., 2006; Forrest et al., 2009). There has also been work to develop biofouling management regimes and the subsequent impact of these techniques on shellfish production (Mallet et al., 2009). However, this work has not fully addressed biofouling removal strategies for many of the available commercial gear types, demonstrating a need for additional investigations to determine cost-effective biofouling removal across a variety of culture gear options (Mallet et al., 2009).

The use of certain gear types in combination with maintenance regimes have been reported to directly and immediately reduce labor associated with biofouling over the course of the growing season as well as anecdotally improve shell morphology (Cheney, 2010). Despite potential benefits, there is a lack of published work substantiating the indirect effects of using a mechanical grader on shell size, shell shape, degree of biofouling or oyster mortality. Work aimed at optimizing culture equipment and handling regimes is a critically needed element for shellfish farming (Robert et al., 1993; Handley, 2002; Louro et al., 2007, Mallet et al., 2009). In the case of the eastern oyster, studies are needed to evaluate the potential of integrating optimal gear type and handling regimes to manually improve the quality of single shell oyster production. The information gained would contribute to well-informed business plans for recruiting new oyster farmers and educating current farmers in both the Gulf region and the oyster industry worldwide.

With these goals in mind, the project investigated four different gear types with and without the use of a mechanical grader. A third treatment was also developed to assess the effects of the handling and emersion associated with transporting the oysters to the site that housed the mechanical grader. The optimal culturing methodology would 1) maximize yield (growth and survival), 2) reduce time associated with biofouling removal, 3) improve product consistency, and 4) produce a premium half-shell product with consumer-recognized characteristics. Premium quality half-shell oysters exhibit uniformity in shape and size with shells that are deeply cupped, and have shell width to height ratios of 0.25 or larger and have fan shape ratios of shell length to shell height of 0.63 or larger (Brake et al., 2003; Cheney, 2010). These characteristics increase market value (Brake et al., 2003; Cheney, 2010) by catering to the consumers' visual preferences while providing a product selection that can be retailed with consistent shape and size dimensions.

This experiment tested whether gear type, handling treatment (tumbled, emersed and never handled), or the combination of these two factors significantly affected any of the following four response variables: shell morphology (shell height, shell length, shell width, whole wet weight, dry shell weight, dry tissue weight, fan shape, and cup shape), consistency of shell morphology, time required to remove biofouling, and percent mortality. For shell morphology, it was predicted that both gear type and tumbling (the most extreme handling treatment) would produce significantly differently sized and shaped oysters. For consistency of shell morphology, it was hypothesized that variation among oysters grown in different gear types would be measurably reduced by tumbling. For biofouling (measured as the time required to remove biofouling from a sample of 5 oysters), it was hypothesized that there would be significant differences in biofouling removal time between gear types. It was also expected that the application of a tumbled treatment would reduce biofouling removal time over the results from either an emersed treatment or a never handled control. Finally, it was hypothesized that there would be significant differences in percent mortality among gear, and that percent mortality would increase as handling increased from never handled to emersed and handled, to tumbled and handled.

2.3 Methodology

2.3.1 Overview of Farm Site

The study was conducted in Grand Bay (Sandy Bay) Alabama, extending 549 m from the mean high water mark of the property utilizing the riparian rights granted by the State of Alabama to the waterfront landowner. The farm currently occupies a space of 4.53 acres (Fig 2.1).

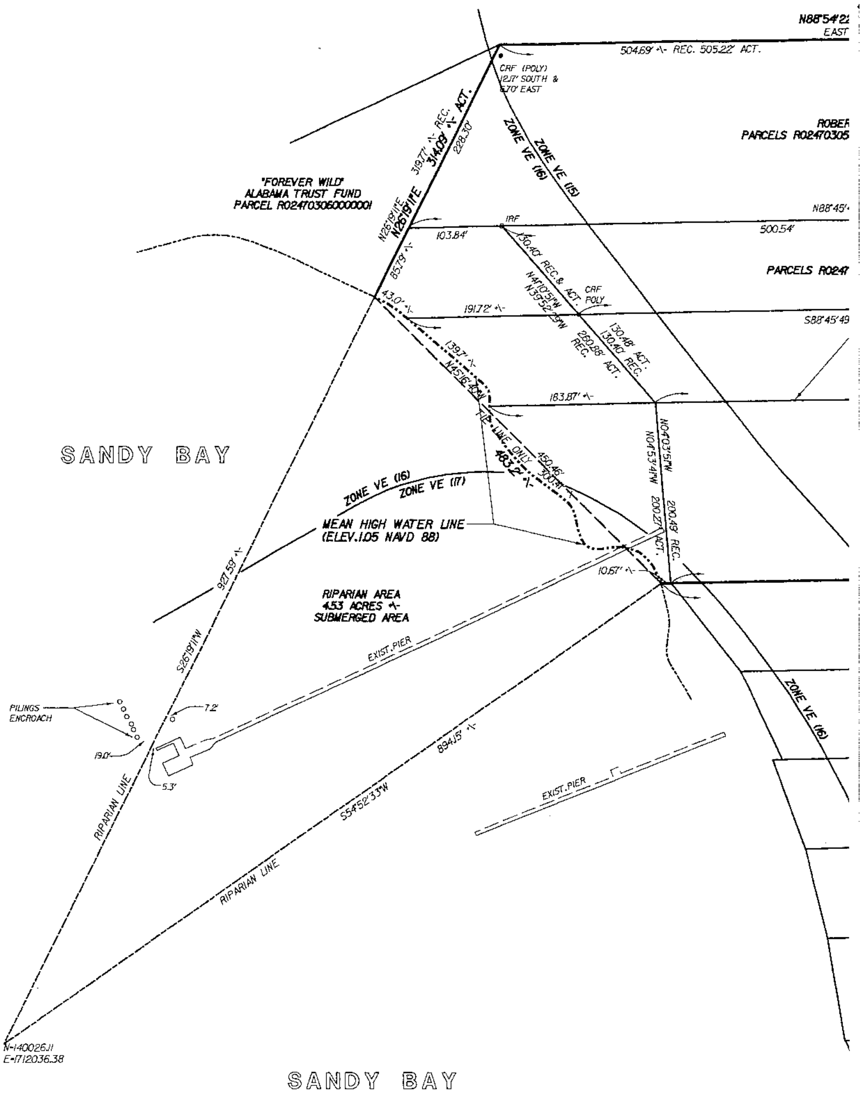

Figure 2.1. Survey map of the study site in Sandy Bay, Alabama. Image credit: Lawyer and Company. Date: 6/10/07. Project No.: 07-061. Drawing No.: 07-061-1

The area is situated adjacent to an Alabama Forever Wild Land Trust area, where with little boat traffic; the area serves as a natural nursery for the juveniles of several species of fish, crab, shrimp, etc. The experimental site is a commercial oyster farm developed in conjunction with Auburn University and the Alabama Cooperative Extension System. Throughout the study, salinities were monitored during weekly visits to the farm site using a YSI® salinity probe. Salinities typically ranged from 12 to 30 parts per thousand (ppt). Four gear runs were situated perpendicular to shore with an average minimum water depth of 0.9 m nearest the shore and an average maximum water depth of 1.5 m at the southernmost point (Fig. 2.2).

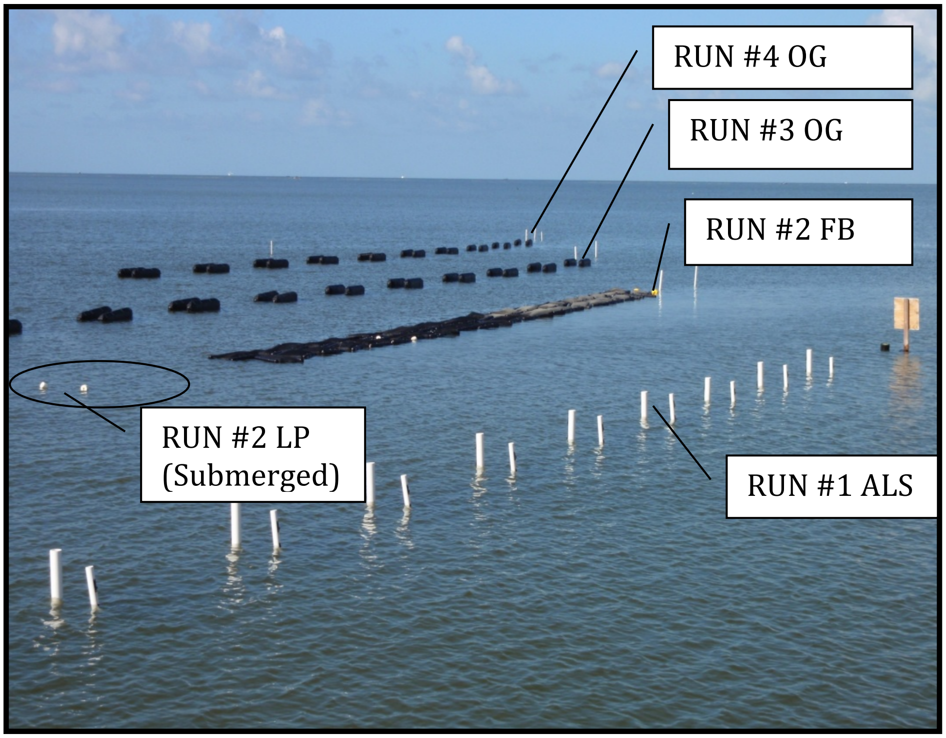

Figure 2.2. A photograph showing the four gear runs installed at the Sandy Bay study site. Run #1 is 100m long for the adjustable long line system (ALS). Run #2 is a combination of the floating bag gear (FB) and the LowPro™ gear (LP). Run #3 and run #4 have OysterGro™ gear (OG). All of the OysterGro™ cages used in the experiment were located in run # 3.

2.3.2 Gear Types and Mechanical Grader

Adjustable Longline System

The Adjustable Longline System (hereafter ALS) gear was manufactured by BST, an oyster equipment supply company located in Australia. They have developed an adjustable longline system that involves installing pylons to support a cable from which tube shaped baskets (14 mm mesh) are suspended. The system's adjustability comes from the multiple PVC poles that have several levels of riser clips attached. The ALS gear is designed to control biofouling by lifting the cable and raising the tube shaped baskets (0.711 m x 0.203 m) out of the water for a period of approximately 24 hrs, letting the sunlight and air desiccate the biofouling organisms on the cage and on the oysters. The entire length of cable can be lifted or lowered according to the height of the riser clips so that the baskets may be fully submerged, partially submerged or entirely exposed. The length of the entire run for this gear was 100 m and within that length of cable the gear setup would accommodate a double line of approximately 200 ALS bags (BST Oyster Supply Company, 2009) (Fig. 2.3A-C).

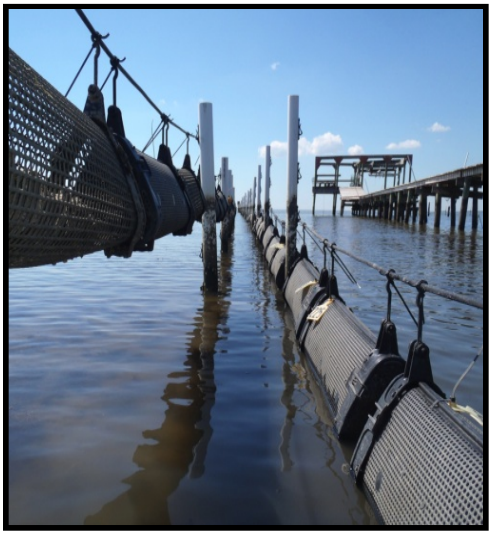

Figure 2.3A. Photograph of ALS gear installation at farm-site; two rows: fully exposed (left) and partially submerged (right).

Figure 2.3B. Photograph of ALS baskets in varying mesh sizes.

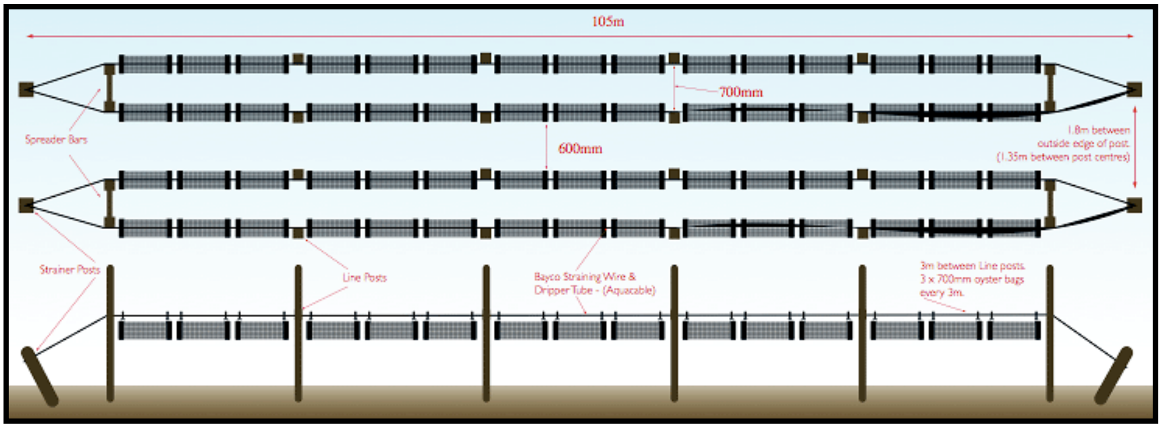

Figure 2.3C. Diagram of ALS construction. Image credit: BST Oyster Supply, www.bstoysters.com.

Floating Bags

Screw-anchors were used to install a 100 m line with a 44.6 m distance from the ALS setup in gear run #1 to allow for boat navigation between gear types (Fig. 2.2). The line held floating bags in a linear formation with two rows inside the designated run. The line floated at the surface of the water, with enough slack to allow for the rise and fall of tides and waves. The floating bags were attached to the line by clips that allow the bags to be flipped 180° (like pages in a book) to control for biofouling. Bags were (0.838 m x 0.483 m x 0.102 m) mesh bags with 12 mm holes that have plastic tube pontoon floats lashed to each side like wings (Mallet et al., 2009). The pontoons floated the bags at the surface of the water with the top portion of the mesh bag exposed to the air while the bottom half sags under the water, holding the oysters completely submerged. The on-farm anti-biofouling regime provided by the manufacturer recommended that gear units were flipped 180° and then allowed to desiccate on one side for a week before returning to the original position, while keeping oysters submerged in the water the entire time (Mallet et al., 2009; Chesapeake Bay Oyster Company, 2009) (Fig. 2.4A-B).

Figure 2.4A. Photograph of floating bags run

Figure 2.4B. Photograph of individual unit.

LowPro™ Bottom Cages

LowPro™ cages are constructed from vinyl-coated wire and elevated 152.4 mm off the bottom by wire feet. The cages are constructed so that there is one bottom level and one top level, each divided into two trays by a built-in wire divider wall (Chesapeake Bay Oyster Company, 2009). For this study, only the two top trays were used to house mesh bags of the experimental oysters, the bottom being stocked with oysters that were not included in the measurements. The rigid cage material provides protection from predators like stingrays, crabs, and predatory snails (i.e. oyster drills, *Thais haemastoma floridana*). The mesh bags provided a secondary layer of predator protection and enabled the oysters to be easily handled and removed from the cage. LowPro's™ were placed subtidally using a boat and davit and remain submerged the duration of the study. No further on-farm anti-biofouling regimes were recommended for subtidal LowPro's™, therefore no additional maintenance was performed during the 147days of growout. During the scheduled monthly collection of the handled treatments, the cages were opened and the bags were lifted out of the cage by hand, leaving the cage submerged (Fig. 2.5A-B).

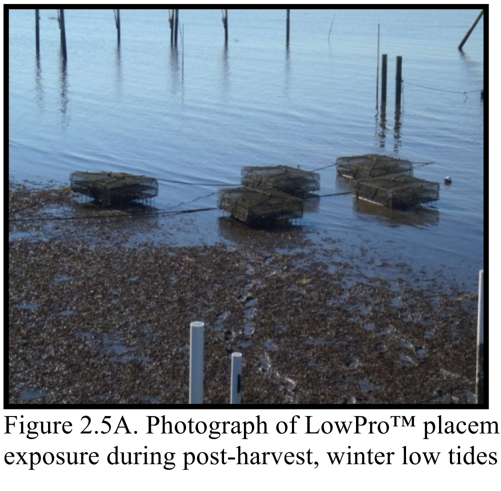

Figure 2.5A. Photograph of LowPro™ placement; exposure during post-harvest, winter low tides

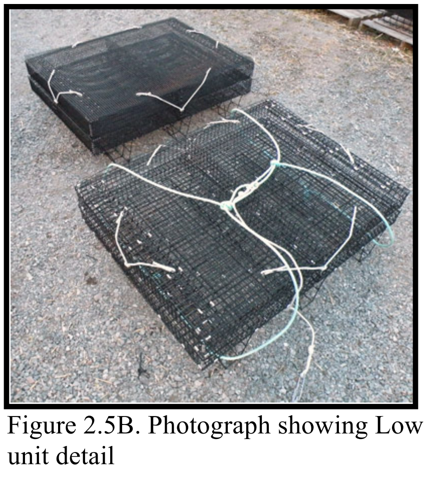

Figure 2.5B. Photograph showing LowPro™ cage cage unit detail

OysterGro™ Floating Cages

OysterGro™ cages are designed by the OysterGro™ Company and distributed by the Chesapeake Bay Oyster Company. The cages are also constructed out of a vinyl-coated wire material and shaped so that the body of the cage has three compartments that can hold two 12 mm mesh bags each. The compartments can be accessed by a hinged door on one side that opens and closes with the attachment of stretch-rope closures. The body of the cage is attached to large pontoons, which can be used to suspend the cage downward into the water column ("growout position") or can be used to flip the cage out of the water for desiccation ("desiccation position"). The cages were flipped up into desiccation position for 24 hrs on a weekly basis throughout the duration of the experiment. The cages were aligned in two gear runs at the site, tethered in place by a line that was attached to pylons (OysterGro™, 2011) (Fig. 2.6A-C).

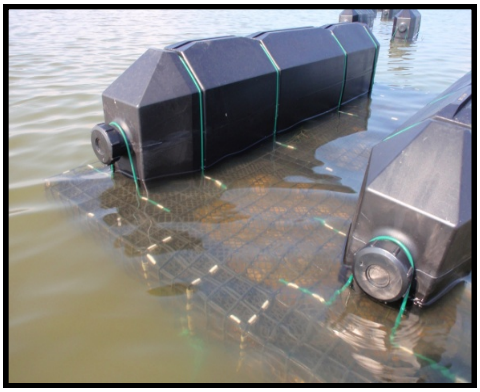

Figure 2.6A. Photograph showing OysterGro™ cage detail while in growout position

Figure 2.6B. Photograph showing cage in growout and desiccation positions. Photo credit: Chesapeake Bay Oyster Company

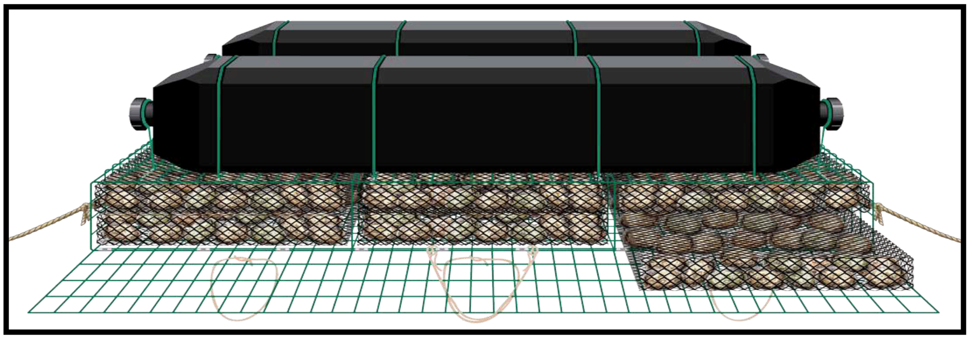

Figure 2.6C. Diagram showing detail for growing compartments of OysterGro™ cage. Each compartment can hold two mesh bags. Image credit: OysterGro™ Company, www.oystergro.com

Mechanical Grader

The mechanical grader evaluated was the QuickTube Sorter™ manufactured by the Chesapeake Bay Oyster Company. This rotary style grader used an interchangeable system of rotating aluminum grading tubes. Each tube was manufactured with holes sized for grading single shell oysters. The grading holes were placed in two sections on the tube, which equated to three size sorts, a smaller hole to separate out the smallest oysters first, then a larger hole at the end half. The largest oysters fall out the end of the tube equaling the third size sort. The holes can be customized but the standard equipment included two tubes which were each divided into two grading sections: the seed tube with the first section of holes 15.88 mm in diameter and the second section of holes 22.23 mm in diameter and a market/sub-market tube with a 31.75 mm diameter section and a 44.45 mm diameter section (Chesapeake Bay Oyster Company, 2009). In addition to rotating grading tubes, the QuickTube Sorter™ was equipped with a spray bar wash down connection. This was attached to a freshwater supply and when in use, sprayed a constant stream of water across the oysters as they were tumbled. The grader's legs were positioned at an angle to increase the slope that facilitated the movement of oysters through the equipment. For this study, the grader was positioned at an approximate 18° angle. This angle provided on average 60 seconds of tumbling time per bag (Fig. 2.7A-B).

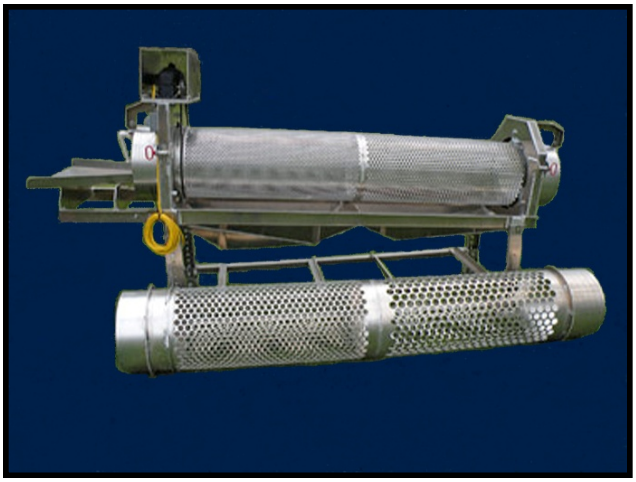

Figure 2.7A. Image of the QuickTube Sorter™ rotary grader and the interchangeable grading tubes. Image credit: Chesapeake Bay Oyster Company.

Figure 2.7B. Photograph of grading tube, spray wash connection and rotating oysters.

2.3.3 Experimental Setup

A two factor complete factorial test of gear type (4 levels) by handling treatment (3 levels) was conducted to address the hypotheses developed for the study. The four types of off-bottom oyster aquaculture gear (ALS, FB, LP & OG, described in the previous section) were deployed on June 15th, 2010. The experiment was conducted until harvest on November 8th, 2010 for a final grow-out season consisting of 147 days. All gear was stocked with oyster seed that had been spawned at the Auburn University Shellfish Laboratory (AUSL) in 2009 and held in a constant nursery environment at the same commercially operated oyster farm in Sandy Bay, Alabama. Gear was situated on the farm site in parallel runs, with the first run being for the ALS gear, the second run contained the floating bags at one end and the LowPro's™ at the other end, and the third run contained the OysterGro™ cages (Fig 2.2). The LowPro's™ were situated at the inshore section of gear run number two because the substrate in that area was more firm than any of the areas cover by the remaining gear runs, thus this area was thought to reduce the chances of the LowPro™ gear sinking into the soft mud sediment.

Each of the four gear types utilized 9 bags/baskets (to be generally referred to as bags) with three identically stocked bags for each of the three treatments. All oysters used for this experiment were initially processed through the grader in order to achieve consistency in starting size. Initial grading was also representative of the normal production cycle that oysters faced when being moved from the nursery setting to the growout setting. Nursery oysters were sorted into three size groups: small (< 31.75 mm), medium (31.75 mm to 44.45 mm) and large (> 44.45 mm). Oysters used in the experiment were selected from the total "medium sorted" oysters after thorough mixing to reduce the chance of any introduction of bias. A sample of oysters was scooped from a bin containing all of the medium sorted oysters. Then, from the collected medium oysters, bag-stocking densities were achieved by counting live oysters until the required sample size was fulfilled. Bags used for the floating bag, LowPro™ and OysterGro™ gear were each stocked with 150 hand-counted oysters. The ALS gear, which used smaller baskets, was only stocked with 75 hand-counted oysters per basket in order to approximate the same density ratio of space within the bag to number of oysters present as in the other gear types. Furthermore, all bags were labeled with sequentially numbered waterproof tags for identification and to designate a position on each gear line. A random number generator was then used to assign one of three possible treatment types within each gear type based on tag number. The three experimental handling treatments were: 1) an on-farm control, 2) an emersed and handled treatment and 3) an emersed, handled and tumbled treatment. These treatments are to be described in detail in the following section.

2.3.4 Handling Procedures

As previously mentioned, there were three possible handling treatments for this experiment: 1) an on-farm control, 2) and emersed and handled treatment and 3) an emersed, handled and tumbled treatment. The on-farm control (referred hereafter as the never handled control) represented the effects of only growing oysters in the four gear types according to the recommended management procedures provided by the manufacturers. This included the application of weekly on-farm anti-biofouling regimes where such maintenance was recommended (in all gear types except LowPro™), but did not include any further handling treatments that would remove the oysters from the gear runs. The never handled control was developed as the “no tumbling” control treatment, to represent the effects of culturing oysters in the four gear types without any influence from the use of a mechanical grader during the growout season.

The main test treatment that was developed was the emersed, handled and tumbled treatment (hereafter the tumbled treatment). The purpose of the tumbled treatment was to measure the effects of processing oysters with the mechanical grader on a monthly basis throughout the growout season (June 15th through November 8th). However, it was apparent that an intermediate treatment needed to be developed. In order to apply a tumbling treatment to a group of oysters from the farm-site, the oysters had to be transported by open-bed truck to AUSL where the mechanical grader was located. This transportation consisted of 60 mi round-trip travel, with half of the distance being over a rough dirt road. Therefore, the emersed and handled treatment (hereafter the emersed treatment) was developed to separate the effects of physically loading and unloading the oyster bags into the truck (handling), the drying effects of the emersion experienced in the open truck bed during transport, the physical agitation caused by the road conditions and also by the emersion effects experienced while being out of the water for a total period of approximately 24 hrs. The tumbled treatment experienced identical treatment to the emersed treatment, except, upon arrival at AUSL, the oysters were processed through the mechanical grader.

The baseline handling regime for the emersed and tumbled treatments within all gear types was once per month throughout the growing season (June 15th –November 8th). Bags assigned to both the emersed and tumbled treatments were collected from the farm site, loaded in a nonspecific fashion into an open truck bed and transported to AUSL. The hatchery workspace at AUSL is located underneath the building, which is elevated on pylons. The hatchery has a cement floor, which is a shaded but open-air workspace.

Upon arrival at AUSL, bags assigned to the emersed treatment were separated out and stacked on the hatchery floor. Bags assigned to the tumbled treatment were opened and oysters were loaded into the mechanical grader one bagful at a time to ascertain that oysters from each numbered bag were returned to their original bag and later original gear type. Each bag was unloaded onto the hopper table and then inserted into the grading tube with approximately three even measures to ensure a layer of oysters only one or two oysters deep. This method reduced clumping and allowed for all oysters to experience approximately the same amount of washing spray and physical contact with the grading tube. The loading process was completed in 2-3 seconds, which allowed for oysters to also experience approximately the same amount of time in the grading tube and the same amount of shell-to-shell contact. Tumbling ended as soon as the last oyster was sorted out of the grading tube.

Both live oysters and dead shells were collected from the sorting bins and returned to original bag before the next bag was processed. Dead oyster shells were purposely returned to the bags in order to maintain a consistent space/growout density when compared to the never handled control treatments; removing the shells would have essentially allowed remaining oysters more growing space, and in the case of air desiccation, less sunlight shade-cover provided by clustered shell masses. Most importantly, dead shells were retained to ensure that tumbling treatments maintained a consistent batch of 150 or 75 oysters, dependent on gear type, when processed through the mechanical grader. Since the treatment bags could not be mixed, the dead shells helped to simulate the shell-to-shell contact during tumbling and consistent time-in-sorting-tube due to the movement of clustered shells that oysters would normally experience in a commercial setting where the oysters would be continuously fed into the grading tubes from a hopper basket. Both the shell-to-shell contact and the time-in-sorting-tube are factors which, if not controlled for, could have had confounding effects on the shell altering effects of the mechanical grader.

Tumbled oysters were also sprayed with freshwater during the tumbling process; this was a function of the mechanical grader aimed at removing sediments and other biofouling debris and organisms. The mesh bags for the tumbled treatment were not washed and the oysters were directly re-loaded to the same bags after being tumbled. This ensured that bag condition (biofouling and moisture levels) was essentially the same for the emersion treatment bags and the tumbled treatment bags, so as not to have confounding effects on the data collected from oyster measurements.

Throughout the duration of the experiment, all gear types were maintained according to the recommendations provided by the manufacturers. For the ALS, floating bag and OysterGro™ gear this meant the application of on-farm anti-biofouling regiments. Each gear had a separate routine, as described in section 2.3.2, in order to control biofouling on the gear material during growout. For these routines, the gear remained on the gear line and was maintained on a weekly basis throughout the experiment. ALS and OysterGro™ gear were exposed once weekly, allowing approximately 24 hrs of desiccation. The ALS cable was lifted to the highest riser clip, exposing the baskets completely and lowered the next day. The OysterGro™ gear was flipped over into the desiccation position to allow the cage section housing the oysters to be exposed for 24 hrs by sitting on top of the gear's large pontoon floats that usually function to suspend the cage just below the surface of the water. The cages would be returned to the growout position the next day. The floating bags would be flipped over 180° (like flipping a page in a book) to expose the previously submerged side of the gear. The floating bag would then remain on that side for an entire week, being flipped weekly to expose the alternate side, noting the oysters remained fully submerged the entire time. No additional anti-biofouling maintenance was performed on the LowPro™ cages after the initial deployment.

Temperature was also measured throughout the experiment with the use of two Onset® "HOBO® Water Temp Pro v2" data loggers. One data logger was deployed into a never handled control bag in the floating bag gear (in order to stay submerged the entire growout period) to record water temperatures every ten minutes; the logger remained in the bag for the duration of the study (June 15th through November 8th, 2010). The second logger was used to measure the air temperatures experienced by the oysters during the monthly handling treatments, when the bags were being removed from the water and exposed to the ambient temperatures for approximately 24 hrs. This air temperature logger was placed in the first bag collected from the water at the farm-site and was programmed to record temperatures every 60 seconds during monthly handling.

2.3.5 Data Collection

At the conclusion of the experiment on November 8th, 2010, bags from all twelve experimental combinations (4 gear types x 3 handling regimes) were brought dockside and emptied into counting trays one bag at a time. Mortality rates from each bag were recorded, with dead oysters removed. Unbiased samples of 5 oysters were collected from the remaining live oysters, with a total of 15 oysters collected from each treatment. Samples were placed in labeled Ziploc® bags and transported by an enclosed, air-conditioned vehicle to AUSL to avoid further air exposure and potential shell damage from the alternate truck-mode of transportation.

Samples were then placed in a Frigidaire® Gallery™ drop freezer at -16°C for 24 hrs. After 24 hrs the samples were processed. A goal of the experiment was to measure the effects of handling on the amount of biofouling present on an oyster at the time of harvest. Often, at the time of harvest, oysters receive little more than a water wash to remove biofouling before market. The appearance of high levels of biofouling can negatively affect the market value of an oyster product. Dry ash weights are commonly used to measure the amount of biofouling, but for this experiment it was felt that ash weight would not be an accurate measure of biofouling levels (and appearance) since the farm-site experienced multiple types of biofouling. It was observed that when measuring ash weights, the occurrence of a single barnacle or large overset (a wild oyster larvae setting onto the farmed oyster's shell) would confound samples of low biofouling when compared to lower ash weights recorded from other oysters with high degrees of mud or algae that report low measurements when the water weight is removed. Therefore, the degree of biofouling was measured in terms of time (measured in seconds) required for a person using a Russell-Dexter™ shucking knife and a wire brush to effectively remove the biofouling from a set of five oysters. To control for individual bias, the same person cleaned every oyster. Oysters were cleaned in groups of 5 oysters per treatment, with each treatment across the four gear types processed indiscriminately.

After biofouling was removed, shell metrics were collected using a Mitutoyo® brand waterproof, “Digimatic” digital caliper (model CD-6”PMX, which was rounded to the nearest 0.0001 mm). Then, whole wet weight was collected using a Mettler-Toledo® brand scale model AL204 (rounded to the nearest 0.0001 g). Oysters were carefully shucked to collect the dry shell weight, with shells being placed on Petri plates and allowed to air dry at room temperature (20-23.3°C) for 48 hrs. When the oysters were shucked, the dry tissue weight was collected after the body tissue was placed on aluminum weighing dishes and placed in a Fischer Scientific® brand ISOTEMP™ drying oven for 48 hrs at 80°C. Dry shell weights and dry tissue weights were measured using the Mettler-Toledo® scale (rounded to the nearest 0.0001 g) with the dish weight subtracted from the total weight.

2.3.6 Data Analysis

Data analysis targeted four main characteristics for potential improvements: shell morphology, consistency of shell morphology, biofouling removal time and percent mortality. Initially, gear type and handling treatments were evaluated for potential improvements to shell morphology. The analysis included a comparison of basic shell metrics and weights (height, length, width, whole wet weight, dry shell weight and dry tissue weight), an index of the cup-shape ratio (shell width to shell height) and an index of the fan-shape ratio of the oyster (shell length to shell height) (Fig. 2.8).

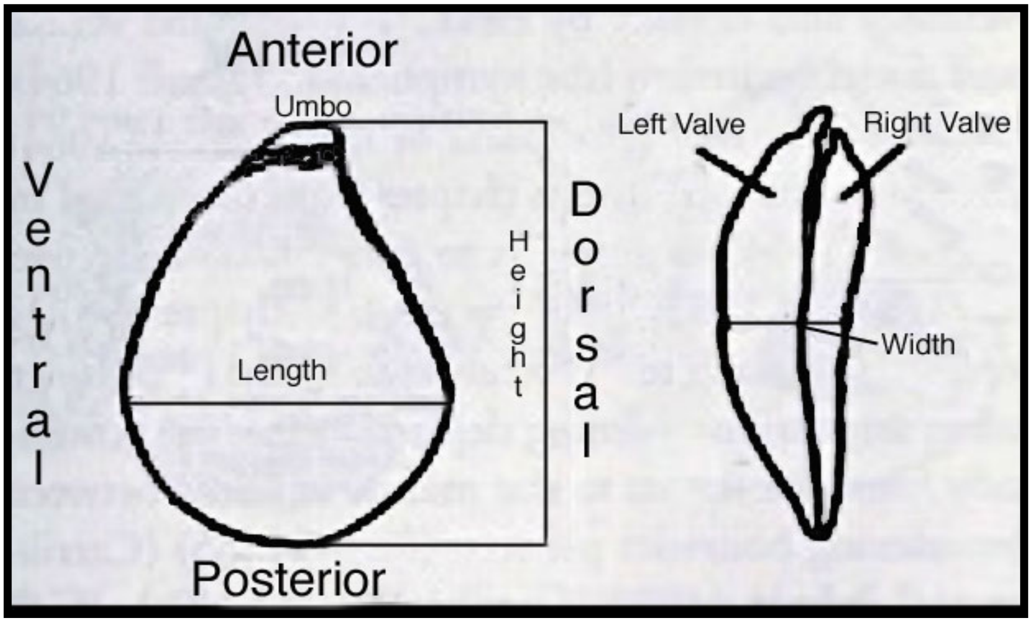

Figure 2.8. Shell dimension terminology. Image Credit: Adapted from Carriker, 1996

Secondly, gear type and handling treatments were evaluated for improvements to consistency of shell morphology. The analysis included a comparison of the coefficient of variation for all shell metric measurements. Thirdly, in order to evaluate improvements in biofouling removal time, the analysis looked at the labor (as a function of time) associated with cleaning five oysters for market. Finally, percent mortality was compared across the four gear types and three treatments.

The statistical package SYSTAT® 13 was used to analyze the biometric data. The Shapiro-Wilk Test of Normality was used to verify the assumptions of normality (Table 2.1). For response variables that did not initially satisfy the Shapiro-Wilk Test of Normality (where normality was achieved with a p-value greater than or equal to 0.05), the data set was rank transformed in order to better approximate normality.

	Shell Height	Shell Length	Shell Width	WWW	DSW	DTW	CUP	FAN	FRT	% Mort	Ranked % Mort
S-W P-value	0.980	0.378	0.067	0.762	0.859	0.234	0.376	0.967	0.204	0.000	0.310

Table 2.1. Shapiro-Wilk Test of Normality P-values. Values equal to or greater than 0.05 approximate a normal distribution.

Once the assumptions of normality were determined to be satisfied, an ANOVA was used to determine the effects of gear type, handling treatment and the interaction of both gear type and handling treatment on each individual variable (height, length, width, etc.). Significant p-values (≤0.05) produced by the ANOVA were further investigated with the use of a post-hoc pairwise comparison using a Tukey’s Honestly Significant Difference (HSD) Test. Significant differences (p≤0.05) revealed by this test were used to assign grouping letters which distinguished significant differences in the graphs produced for comparison. Tukey’s Honestly Significant Difference (HSD) Test tables and supporting data are referenced in Appendix A (and are cited as A-1, etc.).

2.4 Results

2.4.1 Environmental Temperature

During handling, the air temperatures ranged from 17°C to 47°C (Fig. 2.9.) and water temperatures ranged from approximately 20°C to 34°C (Fig. 2.10).

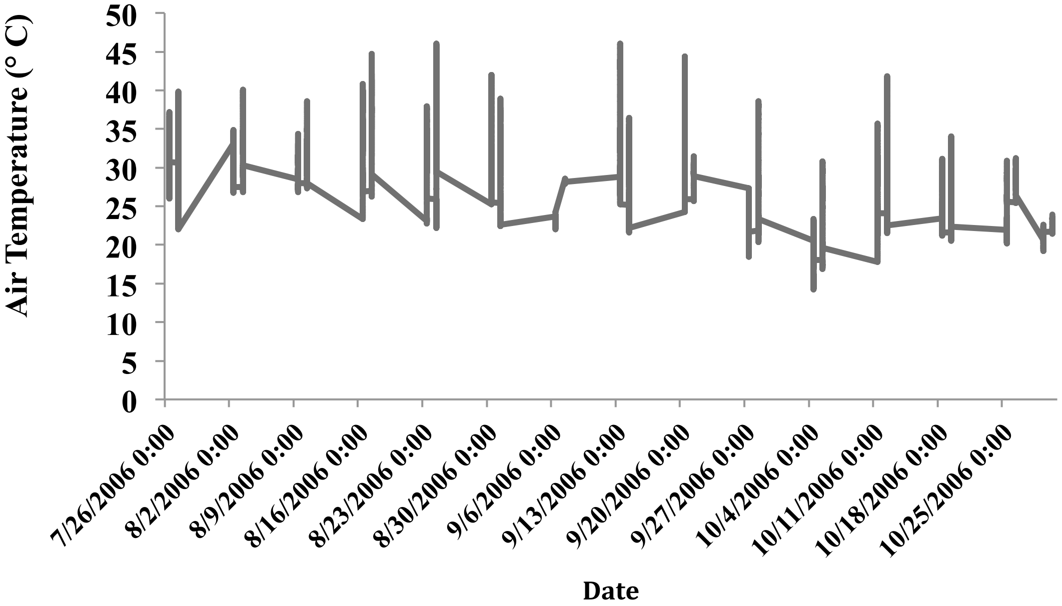

Figure 2.9. Air Temperature in Degrees Celsius as recorded every 60 secs at time of handling.

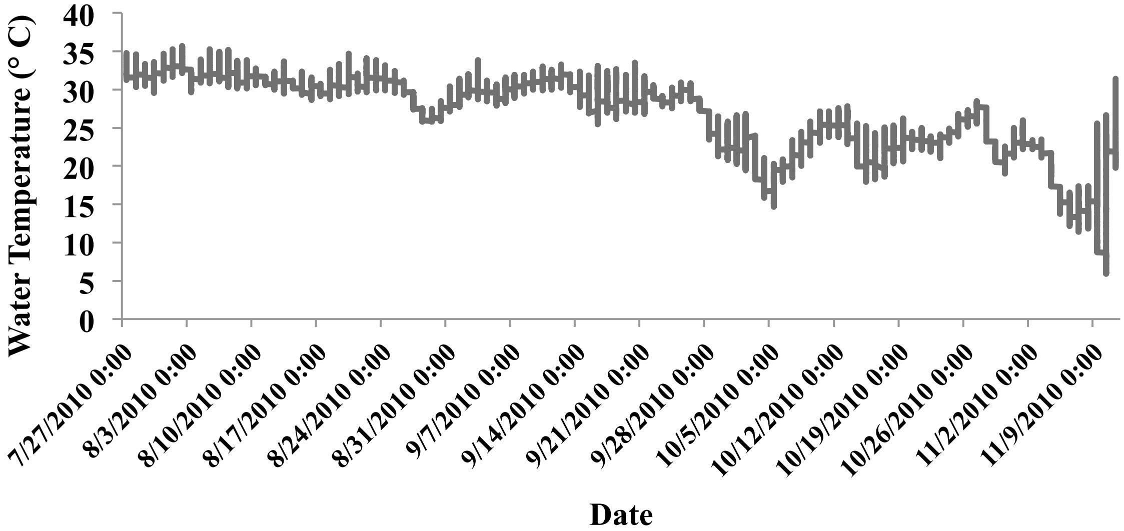

Figure 2.10. Water Temperature in Degrees Celsius as recorded every ten minutes by the data logger.

2.4.2 Shell Morphology

Shell Height

There were significant effects of gear type (p<0.001) and handling treatment (p=0.004) on final shell height (Table 2.2), but no significant interaction (p=0.059). Oysters grown in LowPro™ gear (Fig. 2.11) had significantly shorter shell height than those grown in any of the three other gear types (Tukey HSD, p≤0.042)(Table A-1). Oysters grown in OysterGro™ cages were also significantly shorter in shell height than oysters grown in either ALS or floating bags (p≤0.003), while oysters grown in ALS gear or floating bag gear did not differ (p=0.185).

Analysis of Variance					
Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	1,544.062	3	514.687	32.052	0.000
TREATMENT	228.074	2	114.037	7.102	0.004
GEAR*TREATMENT	230.777	6	38.463	2.395	0.059
Error	385.390	24	16.058		

Table 2.2 Shell Height ANOVA

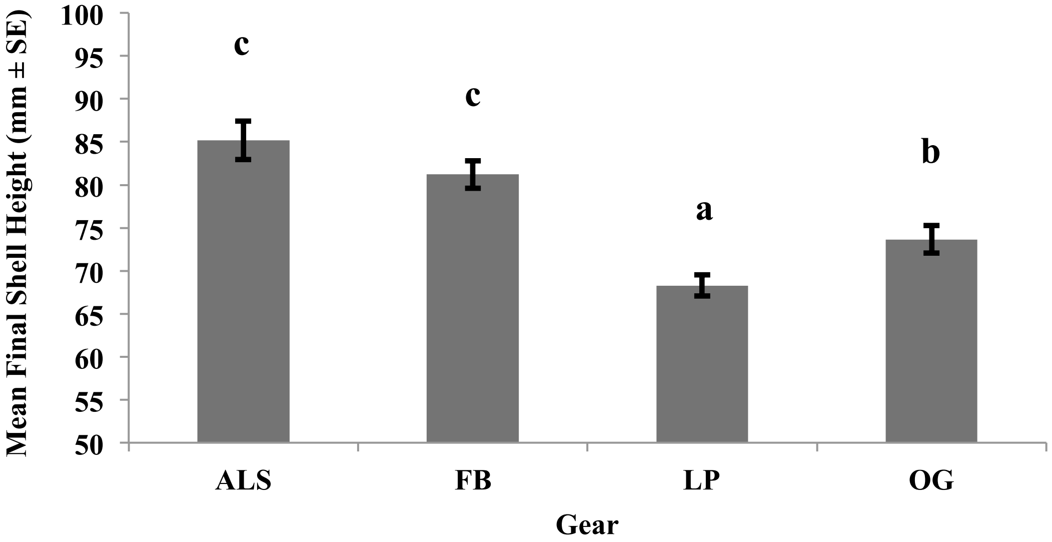

Figure 2.11. Mean final shell height (mm ± SE) of oysters grown in the four gear types: adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). Means with the same grouping letter are not significantly different.

In regards to the effect of handling treatment on shell height, oysters subjected to tumbling were significantly shorter than either the never handled control or the emersion and handling control (p≤0.044) treatments, while the latter two treatments did not differ (p=0.513)(Table A-2, Fig. 2.12).

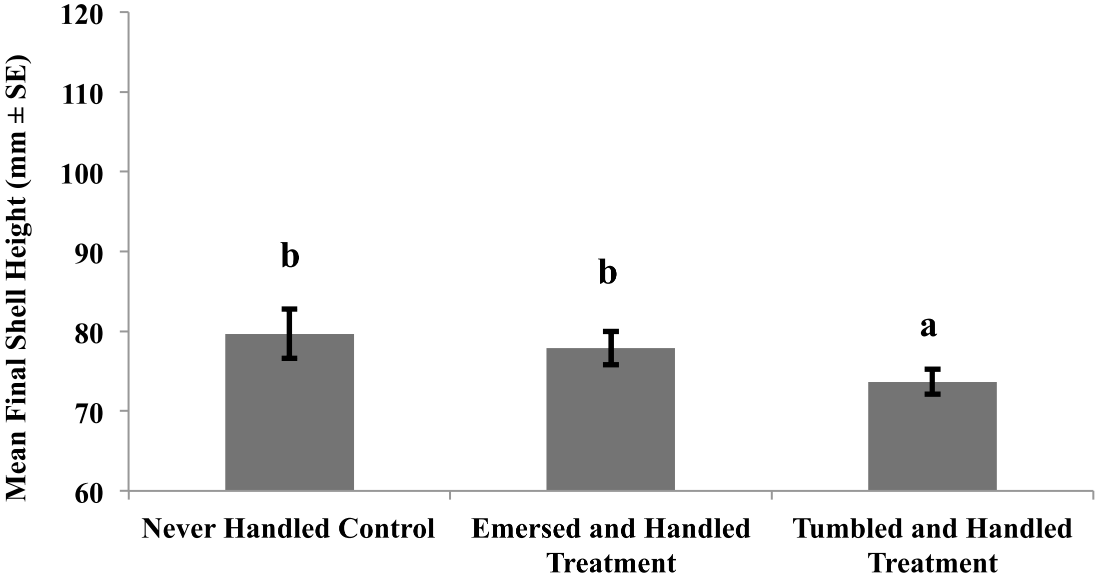

Figure 2.12. Mean shell height (mm ± SE) of oysters grown under three handling treatments. Means with the same grouping letter are not significantly different.

Shell Length

There was a significant interaction between gear type and handling treatment with respect to final shell length (p=0.034)(Table 2.3, Fig. 2.13). In the ALS gear and the floating bags, the never handled control treatment produced oysters with a significantly greater shell length than oysters of any handling treatment grown in the LowPro™ gear (p≤0.014)(Table A-3). Within the floating bags, the tumbled treatment resulted in a significant reduction of shell length when compared to the never handled control (p=0.004)(Table A-3). A closer look at the effects of handling treatment revealed that across all four gear types, there was no significant difference in shell length values from the application of an emersed treatment or a tumbled treatment. Furthermore, there was no significant difference from any of the three handling treatments upon the shell lengths produced in either the LowPro™ (p≤0.997) or OysterGro™ gear types (p=1.000)(Table A-3).

Analysis of Variance Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	221.213	3	73.738	16.265	0.000
TREATMENT	63.758	2	31.879	7.032	0.004
GEAR*TREATMENT	75.613	6	12.602	2.780	0.034
Error	108.806	24	4.534		

Table 2.3. Shell Length ANOVA

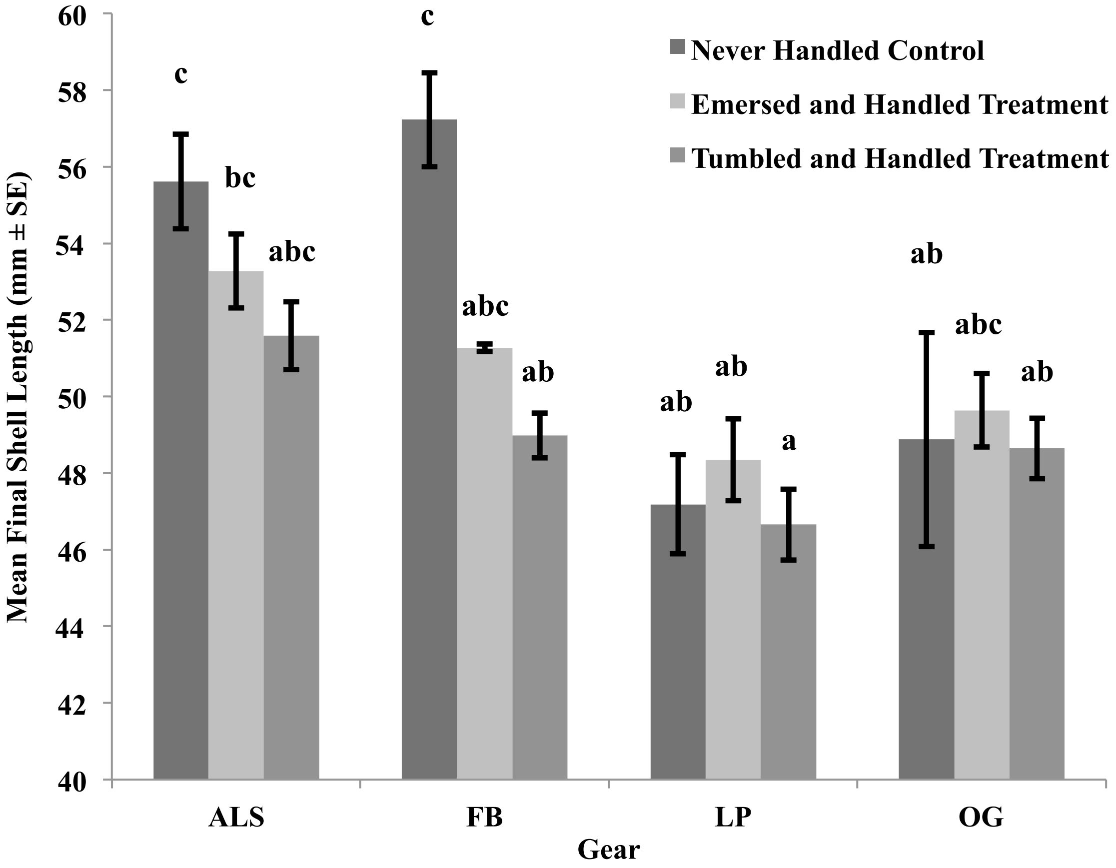

Figure 2.13. Interaction of gear type and handling treatment on mean final shell length (mm ± SE). The four gear types evaluated were the adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). The three handling treatments evaluated were the never handled control, an emersed and handled treatment and a tumbled and handled treatment. Means with the same grouping letter are not significantly different.

Shell Width

For shell width, there was a significant effect of gear ($p<0.001$), but no effect of handling treatment ($p=0.864$) or significant interaction between these factors ($p=0.061$)(Table 2.4, Fig. 2.14). Oysters grown in the ALS and the floating bag gear had significantly greater shell widths than oysters grown in the LowPro™ gear ($p=0.001$), while those grown in OysterGro™ gear did not significantly differ from those grown in any other type of gear ($p\geq0.066$)(Table A-4). Oysters grown in the ALS gear and the floating bag gear did not significantly differ from each other ($p=1.00$)(Fig. 2.14).

Analysis of Variance					
Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	36.076	3	12.025	9.329	0.000
TREATMENT	0.378	2	0.189	0.147	0.864
GEAR*TREATMENT	18.302	6	3.050	2.366	0.061
Error	30.937	24	1.289		

Table 2.4. Shell Width ANOVA

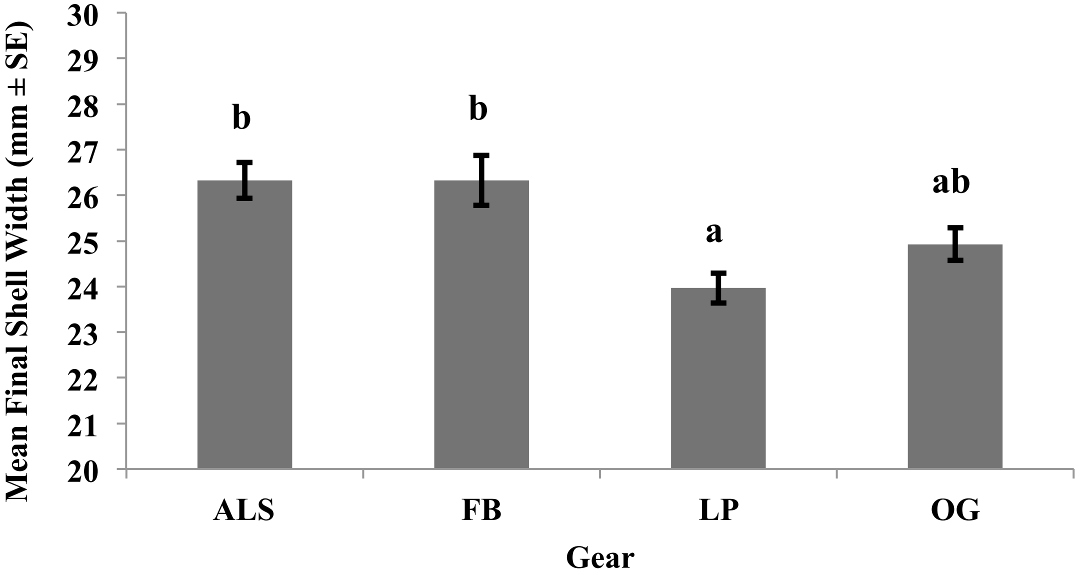

Figure 2.14. Mean shell width (mm ± SE) of oysters grown in the four gear types: adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). Means with the same grouping letter are not significantly different.

Cup Shape Ratio

There was a significant effect of gear type on the measure of cup shape (p=0.005) where cup shape was the ratio of shell width to shell height (Table 2.5, Fig. 2.15). There was no significant effect from handling treatment (p=0.072) or significant interaction between these factors (p=0.658). Oysters grown in LowPro™ gear produced a significantly more cupped shaped oyster than the ALS gear (p=0.004)(Table A-5). There were no further significant differences among gear types (p≥0.064) (Fig. 2.15).

Analysis of Variance Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	0.009	3	0.003	5.551	0.005
TREATMENT	0.003	2	0.002	2.947	0.072
GEAR*TREATMENT	0.002	6	0.000	0.693	0.658
Error	0.013	24	0.001		

Table 2.5. Cup Ratio ANOVA

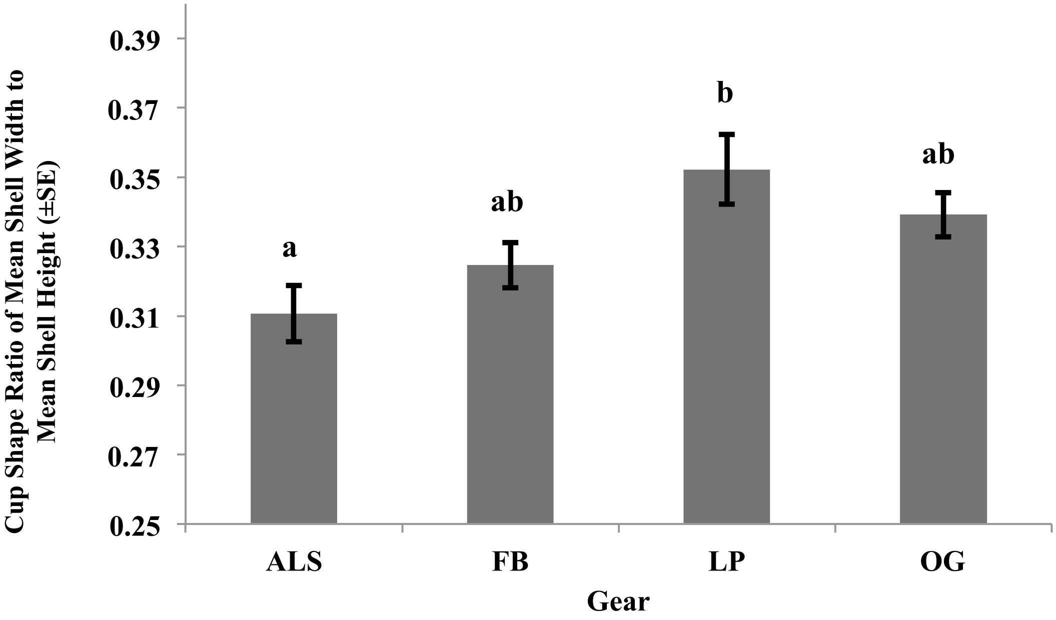

Figure 2.15. Mean cup shape ratio of mean final shell width to mean final shell height (mm ± SE) of oysters grown in the four gear types: adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). Means with the same grouping letter are not significantly different.

Fan Shape Ratio

There was a significant interaction between gear and handling treatment with respect to the fan shape of the shell (p=0.020) with fan shape being the ratio of shell length to shell height (Table 2.6, Fig. 2.16). The never handled control and the emersed treatment within the ALS gear produced oysters that were significantly less fan shaped than oysters from any handling treatment within the LowPro™ gear (p≤0.006)(Table A-6). There was also a significant difference between the floating bag tumbled treatment and the LowPro™ never handled control (p=0.015), where the floating bag tumbled treatment was significantly less fan shaped. Finally, with regard to the effect of handling treatment within each separate gear type, there was no effect from an emersed treatment or a tumbled treatment over the never handled control (Table A-6, Fig. 2.16).

Analysis of Variance Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	0.021	3	0.007	15.577	0.000
TREATMENT	0.001	2	0.001	1.159	0.331
GEAR*TREATMENT	0.009	6	0.001	3.151	0.020
Error	0.011	24	0.000		

Table 2.6. Fan Ratio ANOVA

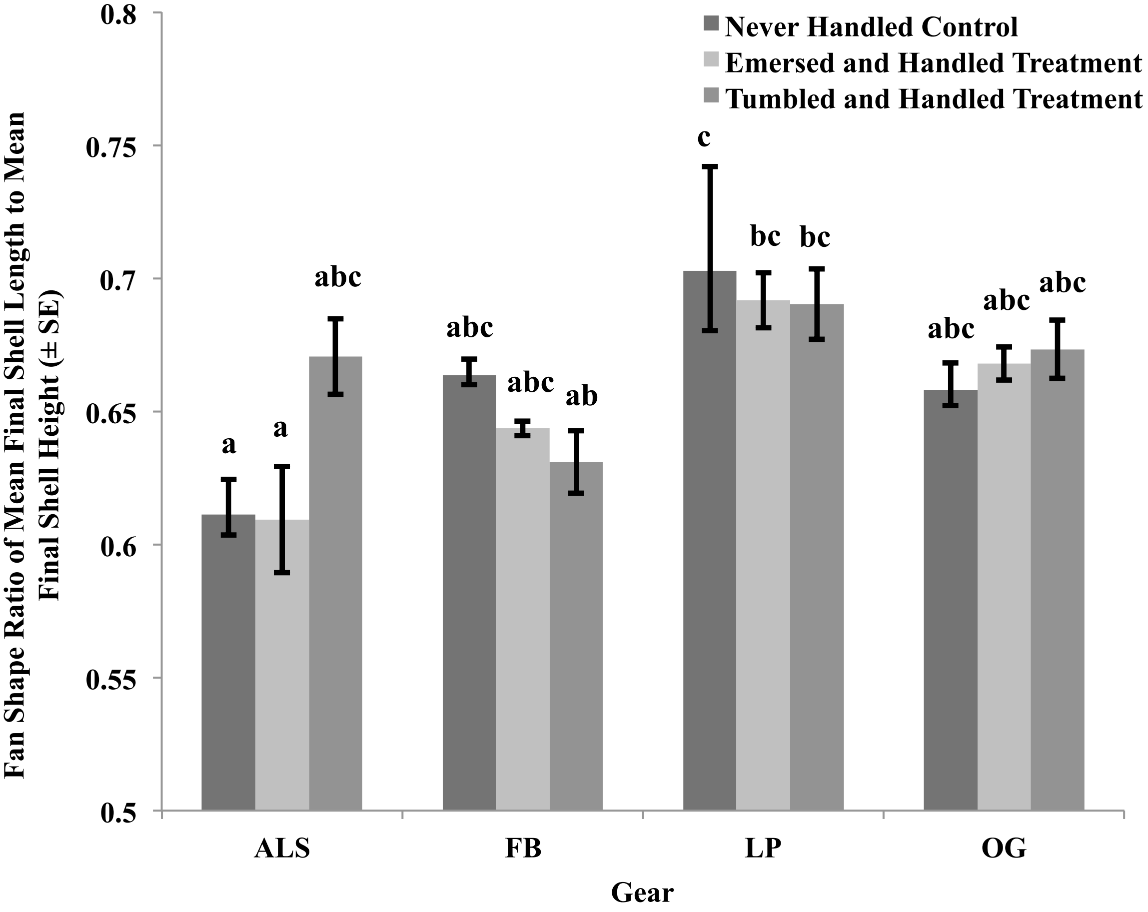

Figure 2.16. Interaction of gear type and handling treatment on fan shape ratio (mean final shell length to mean final shell height ± SE). The four gear types evaluated were the adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). The three handling treatments evaluated were the never handled control, an emersed and handled treatment and a tumbled and handled treatment. Means with the same grouping letter are not significantly different.

Whole Wet Weight

Gear type also produced a significant effect upon whole wet weight of oysters ($p<0.001$), but again the handling treatment had no effect ($p=0.311$) and there was no significant interaction ($p=0.080$)(Table 2.7). Oysters grown in LowPro™ gear had significantly lower whole wet weight than oysters grown in any other gear type ($p<0.001$)(Table A-7, Fig. 2.17). Oysters grown in OysterGro™ gear had greater whole wet weight than LowPro™ raised oysters ($p<0.001$), but had significantly less weight than oysters raised in ALS or floating bag gear ($p<0.001$)(Table A-7). Oysters grown in ALS and floating bag gear were the heaviest and did not significantly differ from each other ($p=1.000$)(Fig. 2.17).

Analysis of Variance					
Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	4,172.621	3	1,390.874	39.063	0.000
TREATMENT	87.303	2	43.651	1.226	0.311
GEAR*TREATMENT	466.848	6	77.808	2.185	0.080
Error	854.549	24	35.606		

Table 2.7. Whole Wet Weight ANOVA

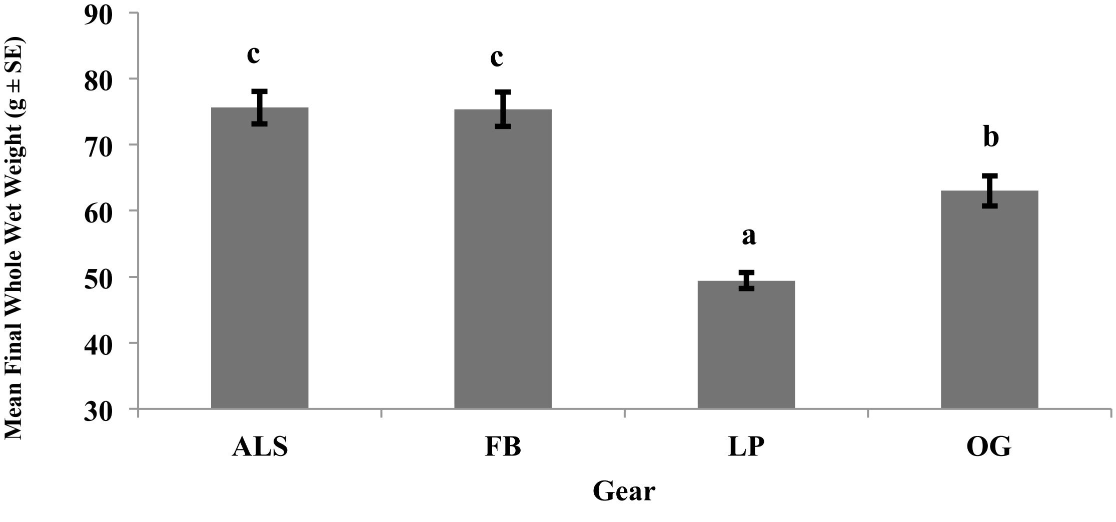

Figure 2.17. Mean whole wet weight (g ± SE) of oysters grown in the four gear types: adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). Means with the same grouping letter are not significantly different.

Dry Shell Weight

There was a significant effect of gear on dry shell weight (p<0.001), but handling treatment had no effect (p=0.578) and there was no significant interaction (p=0.144) (Table 2.8, Fig. 2.18). Oysters grown in LowPro™ gear had significantly lower dry shell weight than oysters grown in any other gear type (p<0.001), while oysters grown in OysterGro™ gear had significantly less weight than oysters grown in either ALS or floating bag gear (p=0.001)(Table A-8). Oysters grown in ALS and floating bag gear did not differ (p=0.996)(Fig. 2.18).

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
GEAR	2,348.921	3	782.974	45.069	0.000
TREATMENT	19.513	2	9.757	0.562	0.578
GEAR*TREATMENT	186.505	6	31.084	1.789	0.144
Error	416.947	24	17.373		

Table 2.8. Dry Shell Weight ANOVA

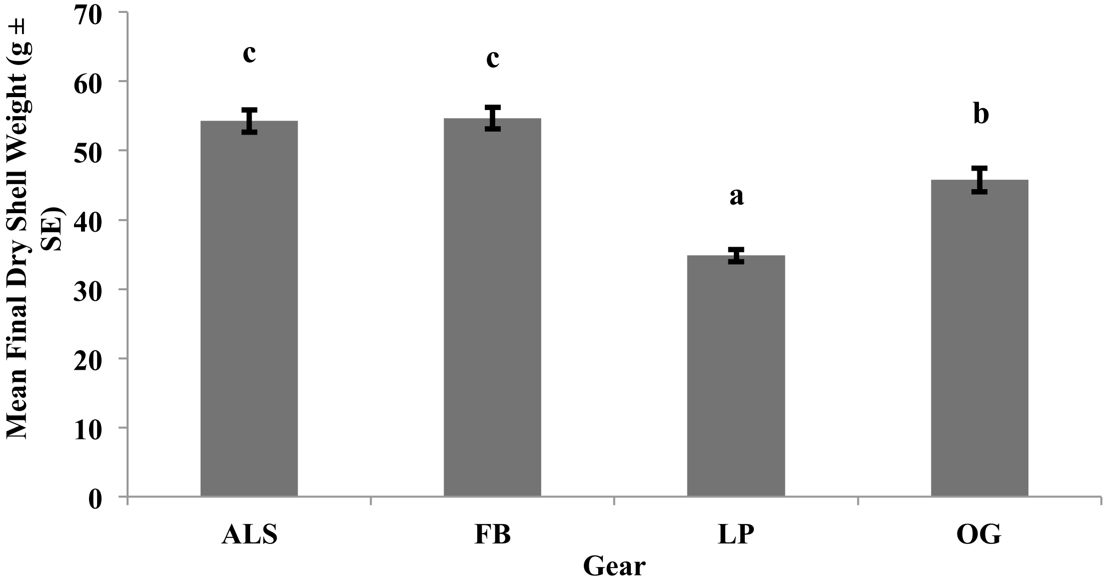

Figure 2.18. Mean dry shell weight (g ± SE) of oysters grown in the four gear types: adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). Means with the same grouping letter are not significantly different.

Dry Tissue Weight

There was a significant effect of gear type on final dry tissue weight (p<0.001) but no effect of handling treatment (p=0.963) and there was no significant interaction (p=0.284)(Table 2.9). Oysters grown in LowPro™ gear had significantly lower dry tissue weight than oysters grown in any other gear type (p<0.001), while there were no significant differences among the oysters grown in the three other gear types (p≥0.160)(Table A-9)(Fig. 2.19).

Analysis of Variance					
Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	3.621	3	1.207	28.401	0.000
TREATMENT	0.003	2	0.002	0.038	0.963
GEAR*TREATMENT	0.338	6	0.056	1.326	0.284
Error	1.020	24	0.042		

Table 2.9. Dry Tissue Weight ANOVA

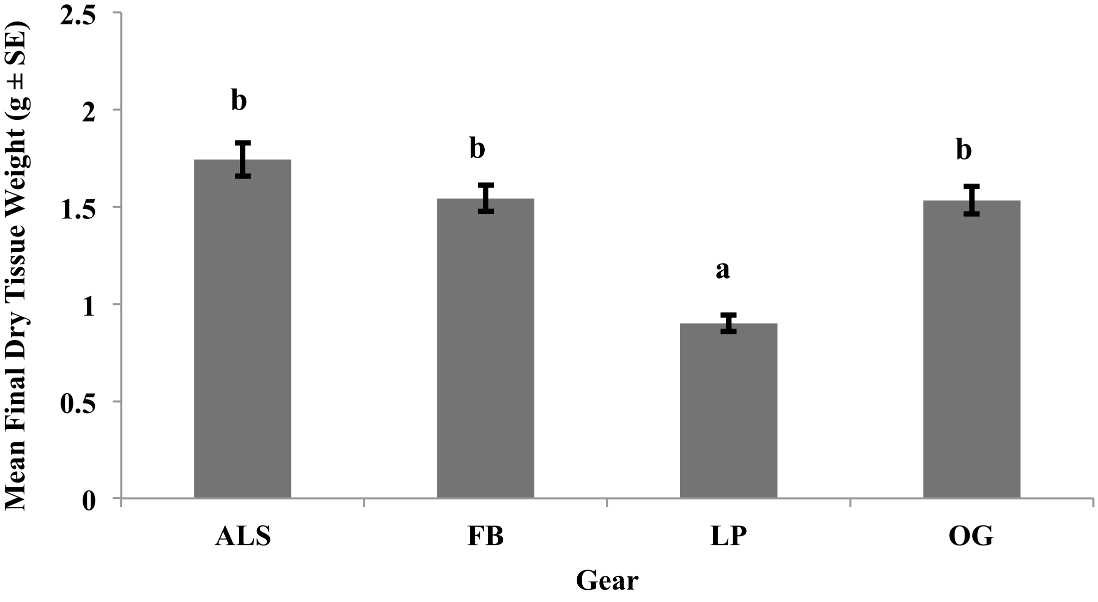

Figure 2.19. Mean dry tissue weight (g ± SE) of oysters grown in the four gear types: adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). Means with the same grouping letter are not significantly different.

2.4.3 Consistency of Shell Morphology

Coefficient of Variation for Shell Height

There was a significant interaction between the effect of gear type and handling treatment on the coefficient of variation for shell height (p=0.028)(Table 2.10). The only pairwise comparison within a gear type that differed significantly was between the ALS emersion treatment and the ALS tumbled treatment; the coefficient of variation for the emersion treatment was significantly larger than that of the tumbled treatment (p=0.046)(Table A-10). All other comparisons were not significantly different (p≥0.077)(Fig. 2.20).

Analysis of Variance					
Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	0.001	3	0.000	0.856	0.477
TREATMENT	0.005	2	0.003	4.315	0.025
GEAR*TREATMENT	0.010	6	0.002	2.908	0.028
Error	0.014	24	0.001		

Table 2.10. Coefficient of Variation for Shell Height ANOVA

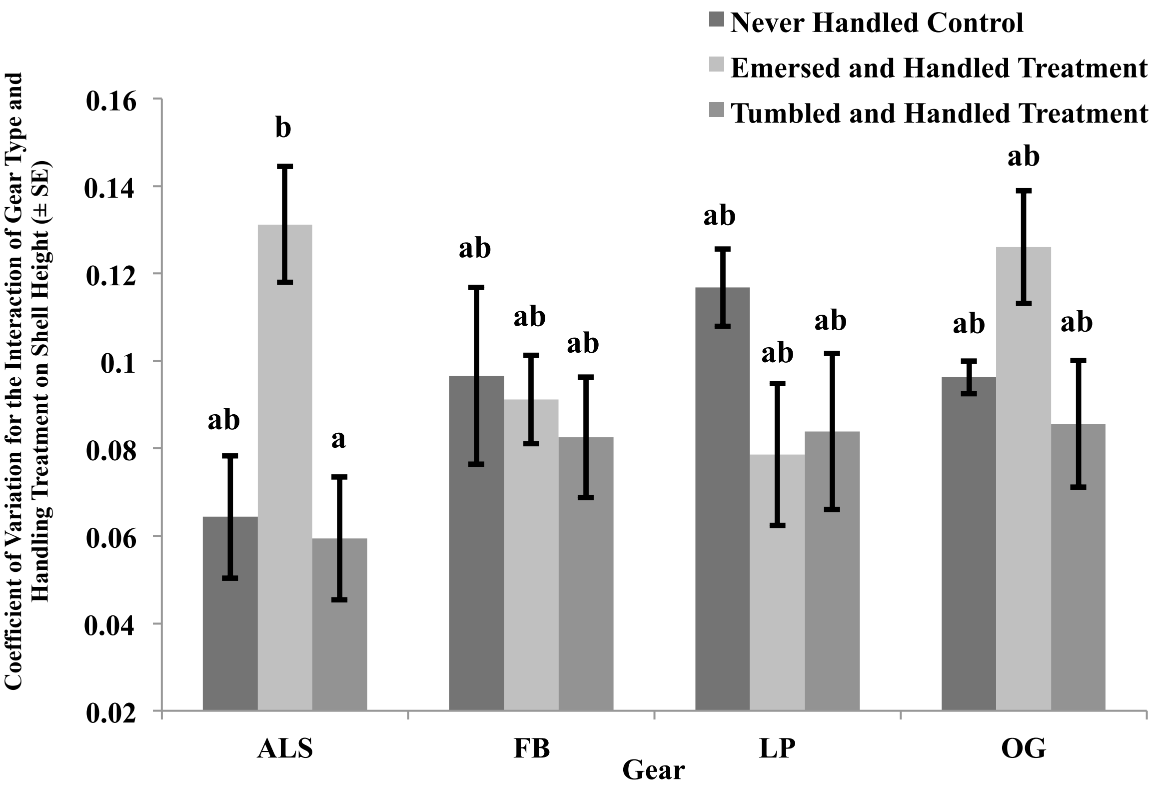

Figure 2.20. Interaction of gear type and handling treatment on mean coefficient of variation for shell height (± SE). The four gear types evaluated were the adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). The three handling treatments evaluated were the never handled control, an emersed and handled treatment and a tumbled and handled treatment. Means with the same grouping letter are not significantly different.

Coefficient of Variation of Shell Length, Shell Width, Whole Wet Weight, Dry Shell Weight and Dry Tissue Weight

There were no significant effects of either gear type, handling treatment or interaction among these factors, in terms of the coefficient of variation for shell length (Table 2.11), shell width (Table 2.12), whole wet weight (Table 2.13), or dry shell weight (Table 2.14). There was no significant effect of gear type on the coefficient of variation for dry tissue weight but handling treatment did have a significant effect ($p=0.029$)(Table 2.15). In this case, across all gear types, the coefficient of variation of dry tissue weight for the never handled control was significantly larger than that of the tumbled treatment ($p=0.030$)(Table A-11), with the emersed treatment not differing significantly from either of these treatments ($p\geq0.107$)(Fig. 2.21).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
GEAR	0.002	3	0.001	0.507	0.681
TREATMENT	0.001	2	0.001	0.544	0.588
GEAR*TREATMENT	0.002	6	0.000	0.253	0.953
Error	0.031	24	0.001		

Table 2.11. Coefficient of Variation for Shell Length ANOVA

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
GEAR	0.003	3	0.001	0.425	0.737
TREATMENT	0.003	2	0.001	0.708	0.503
GEAR*TREATMENT	0.006	6	0.001	0.480	0.816
Error	0.050	24	0.002		

Table 2.12. Coefficient of Variation for Shell Width ANOVA

Analysis of Variance

Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	0.006	3	0.002	0.572	0.639
TREATMENT	0.004	2	0.002	0.551	0.584
GEAR*TREATMENT	0.011	6	0.002	0.490	0.809
Error	0.089	24	0.004		

Table 2.13. Coefficient of Variation for Whole Wet Weight ANOVA

Analysis of Variance

Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	0.005	3	0.002	0.429	0.734
TREATMENT	0.005	2	0.003	0.634	0.539
GEAR*TREATMENT	0.016	6	0.003	0.671	0.674
Error	0.096	24	0.004		

Table 2.14. Coefficient of Variation for Dry Shell Weight ANOVA

Analysis of Variance

Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	0.016	3	0.005	0.789	0.512
TREATMENT	0.055	2	0.027	4.130	0.029
GEAR*TREATMENT	0.018	6	0.003	0.463	0.829
Error	0.160	24	0.007		

Table 2.15. Coefficient of Variation for Dry Tissue Weight ANOVA

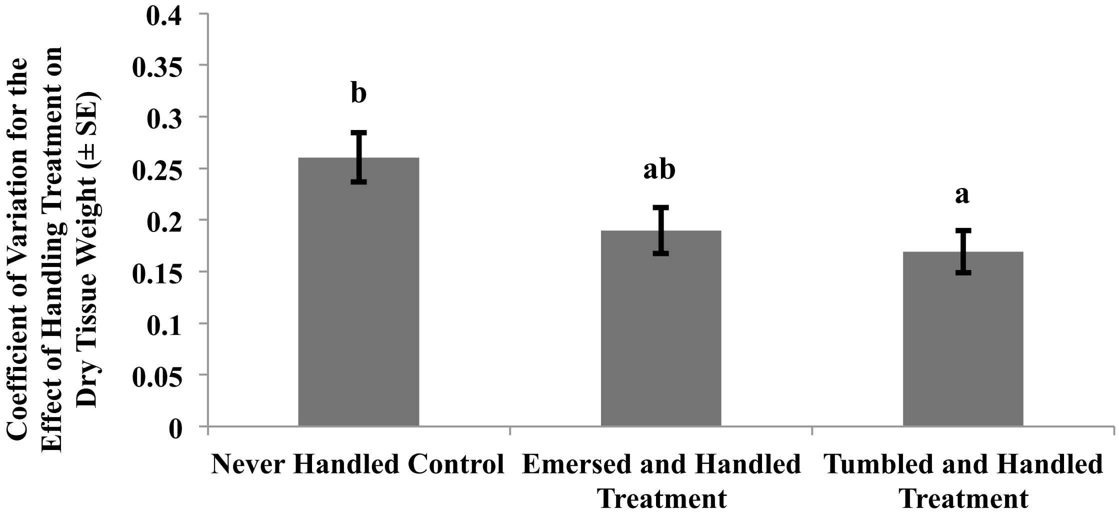

Figure 2.21. Mean coefficient of variation for dry tissue weight (± SE) of oysters grown under three handling treatments: a never handled control, an emersed and handled treatment and a tumbled and handled treatment. Means with the same grouping letter are not significantly different.

2.4.4 Biofouling Removal Time

For the time required to clean the biofouling from 5 oysters (measured in seconds), there were significant effects of both gear type (p=0.045) and handling treatment (p<0.001), but no significant interaction (p=0.086)(Table 2.16). Among the gear types, oysters grown in OysterGro™ gear had significantly shorter biofouling removal times than those grown in the ALS gear (p=0.040)(Table A-12). There were no other significant post-hoc pairwise differences due to effect of gear type (p≥0.116)(Fig. 2.22).

Analysis of Variance Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	3,768.306	3	1,256.102	3.110	0.045
TREATMENT	15,085.167	2	7,542.583	18.674	0.000
GEAR*TREATMENT	5,171.278	6	861.880	2.134	0.086
Error	9,694.000	24	403.917		

Table 2.16. Biofouling Removal Time ANOVA

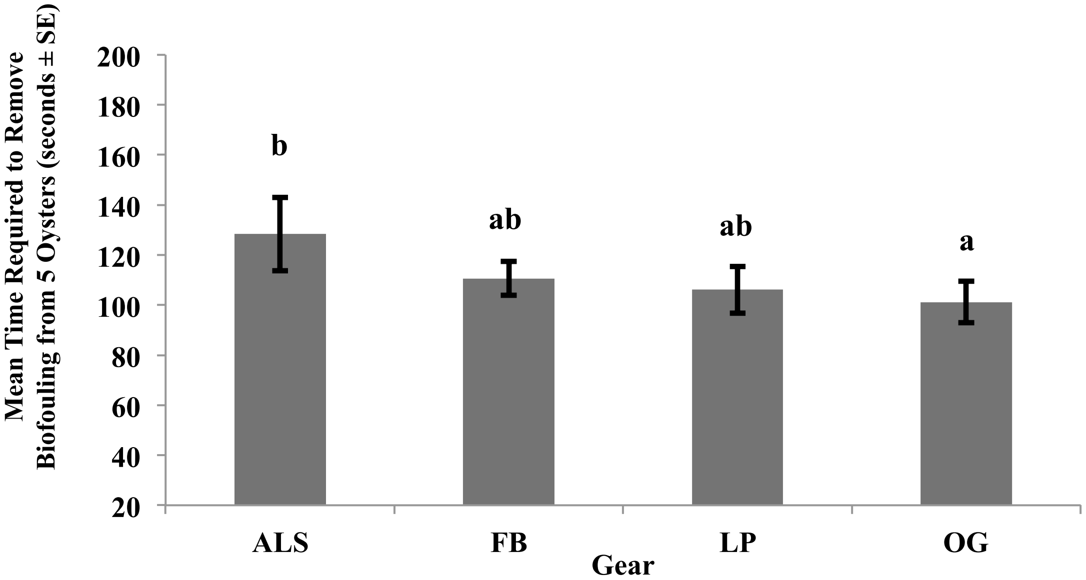

Figure 2.22. Mean time (seconds ± SE) required to remove the biofouling from a set of five oysters grown in the four gear types: adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). Means with the same grouping letter are not significantly different.

Among handling treatments, the never handled oysters required significantly more time to remove biofouling than the oysters subjected to either the tumbling treatment or the emersion and handling control (p≤0.001)(Table A-13). The latter two treatments did not significantly differ (p=0.158)(Fig. 2.23).

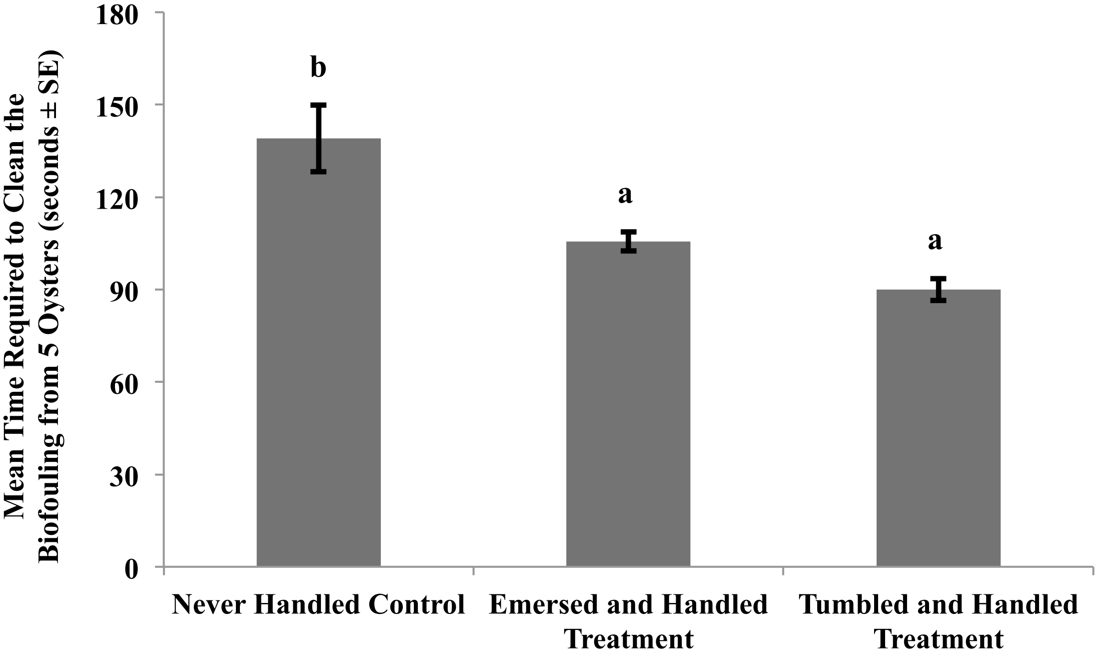

Figure 2.23. Mean time (seconds ± SE) required to remove the biofouling from a set of five oysters grown under three handling treatments: a never handled control, an emersed and handled treatment and a tumbled and handled treatment. Means with the same grouping letter are not significantly different.

2.4.5 Percent Mortality

There was a significant effect of gear type on the rank transformed percent mortality ($p<0.001$), but no differences due to handling treatment ($p=0.597$), or interaction among these factors ($p=0.954$)(Table 2.17). Oysters grown in OysterGro™ gear experienced significantly higher mortality than oysters grown in any other gear type ($p\leq0.001$), while there was no difference among the three remaining gear types ($p\geq0.332$)(Table A-14) graphed as the percent mortality (Fig. 2.24).

Analysis of Variance					
Source	Type III SS	Df	Mean Squares	F-Ratio	p-Value
GEAR	9,571.722	3	3,190.574	14.693	0.000
TREATMENT	229.056	2	114.528	0.527	0.597
GEAR*TREATMENT	327.278	6	54.546	0.251	0.954
Error	5,211.500	24	217.146		

Table 2.17 Rank Transformed Percent Mortality ANOVA

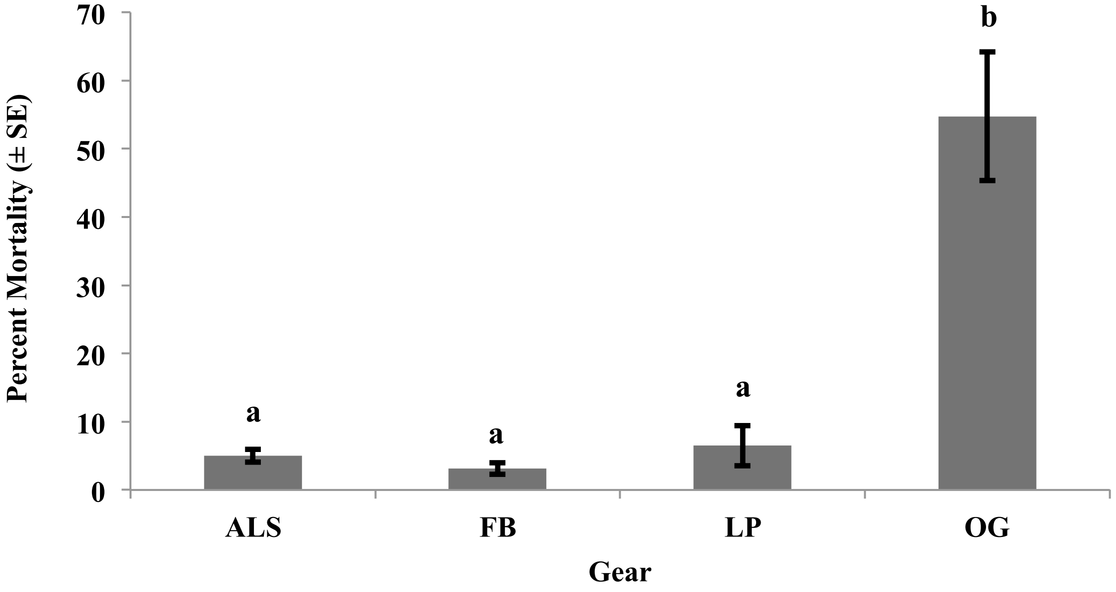

Figure 2.24. Mean percent mortality (± SE) of oysters grown in each of the four gear types: adjustable long line system (ALS), floating bags (FB), LowPro™ (LP), and OysterGro™ (OG). Grouping letters are a reflection of statistical analyses performed on the rank transformed data, with means that have the same grouping letter being not significantly different.

2.5 Discussion

2.5.1 Overview

This study examined the potential for oyster quality to be improved by the combination of gear type selection and handling treatments conducted throughout the growout season. Key considerations during evaluation were final shell morphology (shell size and shape), consistency of shell morphology, reduction of biofouling removal time, and percent mortality. While all of the experimental combinations produced a marketable product for the half shell market based upon the review of comparable metrics, selection of an 'optimum' combination of gear and handling treatment will depend heavily upon which response variables (e.g., shell shape, product consistency, etc.) the consumer market considers most important as well as how environmental factors (growth rate, biofouling, etc.) at individual farm-sites dictate culture priorities.

2.5.2 Shell Morphology

Gear selection had a greater influence on shell morphology than handling treatment, as singularly exhibited in six out of eight variables of morphology (Fig. 2.11, 2.14, 2.17, 2.18 and 2.19) and exhibited in interactions in the two remaining variables (Fig. 2.13 and 2.16). Where handling treatment had an effect, it showed that tumbling significantly reduced shell height measurements across all gear types, likely due to breakage of the fragile growing edge on the outside rim of the bill during the grading (tumbling) process, above and beyond the loss of growth due to emersion and handling (Fig. 2.12). This result can be viewed as a potential factor that may contribute to the lengthening of the growing period required to reach targeted harvest sizes; however the optical appearance for marketability of the shell may have been enhanced by the tumbling process. When compared to the never handled control, additional monthly handling, especially the tumbled treatment, can be reported as having no positive effect on the final shell morphology metrics of oysters grown in the ALS, floating bag, LowPro™ or OysterGro™ gear types.

In the oyster industry, the size of an oyster most often refers to its shell height, the measurement from hinge to bill. The size of an oyster corresponds with several key aspects of oyster culture. Given a common time frame and starting size, as in this study, final shell metrics can be used as a proxy for growth rate and can predict the length of growout. The period of growout can be predicted since oysters are often size graded at the time of harvest to obtain market-sized product in most fisheries and many aquaculture operations. The use of a rotary grader, like the one used in this experiment, would sort oysters based on two points of measurement. In order to be sorted into the market size category (approximately 76 mm in shell height) measurements would require both the shell height and shell length to surpass the diameter of the largest grading hole, a shell height of at least 44.45 mm.

The results from this study suggest that ALS and floating bag gear have a growth rate advantage over the LowPro™ and OysterGro™ gear. Significantly smaller final shell measurements suggest that LowPro™ and OysterGro™ grown oysters would seem to require longer growout periods to reach the standard market size, however, across all gear types, both the respective shell height and shell length measurements surpassed the grading hole requirements and oysters from all treatments would be graded into the marketable category and harvested at the same time.

When compared to Brake's (2003) description of a "good cup shape ratio," all of the gear types used in this study produced cup shapes that exceeded the accepted standards of a 0.25 shell width to shell height ratio (Fig. 2.15). When assessing fan shape, oysters produced in all gear types also met or exceeded the standard for "good fan shape ratio" of 0.63 shell length to shell height ratio (Fig. 2.16). Within each gear type, when compared to the never handled control, the application of an emersion treatment or a tumbling treatment had no effect on either shell cup shape ratio or fan shape ratio (Fig. 2.15 and 2.16). The results showed that the best recorded cup or fan shape could be achieved through gear selection alone, when compared to the effect from the monthly handling regimes. In this study, oysters grown in LowPro™ bottom cages produced the best cup and fan shaped oysters, however, it is unlikely that the measured ratios of cup and fan shape are each singular indicators of the marketability of an oyster sold within the half-shell market. Additionally, it is even more unlikely that the measurable significant differences in cup and fan shape observed between oysters produced in the ALS and LowPro™ gear types would be visually distinguishable to even an informed consumer.

2.5.3 Consistency of Shell Morphology

The application of any of the three handling treatments or the selection of any of the four gear types did not produce any significant effects on the coefficients of variation for the variables of shell length, shell width, whole wet weight, and dry shell weight. The only significant differences in coefficient of variation were observed for the variables of shell height and dry tissue weight.

The only significant difference observed within interaction of gear type and handling treatment for the coefficient of variation for shell height was between the tumbled and emersed treatments within the ALS gear type, where the emersed treatment showed a larger range of shell height measurements than the tumbled treatment. However, neither the emersed treatment nor the tumbled treatment was significantly different from the value of the never handled control (Fig 2.20). Since there was ultimately no difference or clear pattern in the coefficient of variation for shell height over the value achieved from the never handled control, it could be concluded that the two monthly handling regimes were ineffective at influencing product consistency.

Across all gear types, the coefficient of variation for dry tissue weight was significantly reduced over the value for the never handled control by the application of a monthly tumbled treatment (Fig. 2.21). However, there was no effect on the consistency of dry tissue weight from an emersed treatment. Results suggest that although there is potential for a tumbling treatment to improve consistency for the variable of dry tissue weight, the benefit gained from increased consistency would need to justify the amount of labor and resources dedicated to the application of this treatment.

Overall, significant differences in the ranges of variation in oyster metrics were few, regardless of gear type or handling treatment. This may be contributed to the fact that all oysters had been initially graded to be of equal size for gear deployment in June 2010. Initial grading to separate size variants alone might increase product consistency of exterior shell morphology (shell height) and further application of tumbling treatments may result in more consistent dry tissue weight.

2.5.4 Biofouling Removal Time

The biofouling removal time was used as a proxy for the amount of biofouling present on the oysters produced across the four gear types and three handling treatments. Although oysters are usually harvested and sold to market without much additional hand cleaning, the results of this study can also be used to estimate a segment of labor required in preparing oysters for culinary use. Reduction of preparation time may be a valuable marketing angle for farmers when trying to sell harvests.

There was a significant effect of gear type selection on biofouling removal time, which resulted in the oysters produced in the OysterGro™ gear having the least amount of fouling when compare to the ALS gear type, noting no significant difference between floating bags and LowPro™ with respect to biofouling (Fig. 2.22). However, the value of this reduction in fouling may not have significant economical impact since the difference per oyster between ALS and OysterGro™ respectfully, is 25.6 seconds and 20.2 seconds to complete the biofouling removal process.

Any handling treatment that removed the oysters from the water significantly reduced removal time of biofouling organisms: this handling being the emersed and handled treatment and the tumbled and handled treatment (Fig 2.23). Although tumbled oysters required the least amount of time to clean for market when compared to the never handled control, however it should be noted that there was no significant difference between the effects of the tumbled treatment and the emersed treatment. Therefore, for a farm site where biofouling is not significant, the implementation of a mechanical grader for the extra-operational purpose of reducing biofouling would only create additional labor costs and utility expenditures. An emersed treatment would be sufficient to produce the maximum amount of biofouling removal time reduction achieved in this study, however the value of the reduction in fouling over the never handled control must justify the additional labor involved with the application of the emersed treatment.

2.5.5 Mortality

The reduction of the percent mortality within each gear type is a critical factor affecting the profitability of an oyster farm. The reduction of mortality increases harvest quantity and subsequent return on investment made in seed. Natural mortality rates among wild reef and extensively cultivated oysters in the Gulf region can be attributed to factors of predation, siltation, and fluctuations in salinity (Sellers and Stanley, 1984). In the Gulf of Mexico it is common for oyster populations composed of new spat to year-old adults to experience mortality rates as high as 90% (Sellers and Stanley, 1984). All of the combinations of gear type and handling treatment used in this study dramatically reduced mortality rate when compared to the natural rate of 90%. The majority of gear types displayed rates below 10% (Fig. 2.24).

It can be concluded that the ALS, floating bags and LowPro™ gear types did not have significantly different mortality rates and there was no cost of mortality due to a monthly emersed or tumbled treatment when compared to the never handled control (Fig. 2.24).

Chapter 3: Effect of the Frequency of Handling on Oysters Cultivated in Floating Bag Gear and OysterGro™ Floating Cages.

3.1 Abstract

Handling treatments using a mechanical grader were evaluated at four frequencies for potential impacts on oyster morphology, the consistency of morphology, exterior biofouling removal and percent mortality. Oysters were grown in OysterGro™ gear and floating bag gear on a commercially developed oyster lease in Grand Bay, Alabama. During a growing season of 147 days, oysters were subjected to different frequencies (seasonal, monthly, biweekly and weekly) of experimental handling treatments, which involved an emersed and handled treatment and a tumbled and handled treatment. The two test treatments were then compared to a never handled, never tumbled control treatment. At time of harvest, oysters were evaluated based on time required to manually remove biofouling, shell metrics, and percent mortality.

Comparisons of gear revealed that the OysterGro™ gear exhibited elevated mortality, potentially due to the anti-biofouling regimes performed at the farm. For seven of the eight morphology variables, the OysterGro™ gear produced oysters that were not significantly different from the never handled control, regardless of frequency or treatment. Product consistency was unaffected by handling treatment or frequency. Across all six variables, coefficients of variation were not significantly different from those displayed from the never handled control. Tumbling was only beneficial for reducing percent mortality. Thus, the never handled control treatment was the most cost-effective treatment for use with the OysterGro™ gear.

Where handling treatments and or frequencies caused significant differences within oysters grown in the floating bag gear, only the differences with biofouling removal time were beneficial when compared to the never handled controls. When handling increased to a monthly level or more frequent, all metric measurements of shell morphology showed significant reduction over the never handled controls. Regardless of handling treatment or frequency, mortality levels remained unchanged from those exhibited from no handling. Product consistency was increased in terms of the coefficients of variation for shell width and whole wet weight, but only after the application of a weekly tumbled treatment. The tradeoffs between gains in product consistency and biofouling removal time reduction may not be cost effective when addressing increased labor associated with the additional handling.

3.2 Introduction

As interest in oyster aquaculture increases within the Gulf of Mexico region, there is a need for reliable and accessible information regarding the implementation of culture gear in coastal waters. Oysters in the warm coastal waters of the Gulf of Mexico generally exhibit faster growth rates when compared to cohorts of Eastern oysters along the eastern coast of America, presumably partly due to the extended growing seasons associated with mild winter temperatures. In oyster aquaculture, size grading is often practiced in order to maintain adequate growing space in culture gear as oysters become larger and also to separate size variants in order to maintain harvest groups of similar size. In addition to these effects, numerous oyster farmers have claimed additional benefits of size-sorting with a mechanical grader, including improved shell shape, reduced biofouling and a decrease in variation among the oysters produced. Prior work (Chapter 2) indicated a variety of effects of grading dependent upon the gear type used to raise oysters. Here, this study investigated the effects of the frequency of grading (with appropriate controls).

The associated physical disturbances from the use of a mechanical grader have been anecdotally suggested to affect the growth, shape, mortality and associated biofouling of the cultured oysters. Along with the physical disturbances caused by the use of the mechanical grader, referred to as "tumbling", the process of grading oyster also involves removing oyster growout bags from the farm site and transporting them to the grading site. Transportation incurs disturbances from the handling and moving of bags, loading bags into vehicles and also from the emersion exposure oysters experience when they are removed from the water. Generally, these disturbances can be collectively described as "handling". To date, there has been no information collected on the effect of handling frequency on the shape, biofouling or percent mortality of oysters grown in floating bag gear or OysterGro™ floating cages.

The goal of this study was to investigate the effects of frequency of two handling treatments: an emersed and handled treatment and an emersed, handled, and tumbled treatment. Handling occurred at four frequencies: seasonally, monthly, biweekly and weekly. Oysters subjected to a seasonal frequency were handled once (1x) during the growing season, monthly oysters were handled five times (5x), biweekly oysters were handled ten times (10x) and weekly oysters were handled twenty times (20x). Results from the study were compared to a control set that was not handled or emersed throughout the duration of the experiment.

This experiment selected two gear types that were previously used in experiment one (Chapter 2), the floating bag gear and the OysterGro™ gear. The two gear types were selected because they were both commercially available in the United States and they both grew the oysters suspended just below the surface of the water. Additionally, the two gear types were chosen for their differing level of investment as well as differences in unit design and maximum density. Experiment two tested whether the frequency of handling, the handling treatment, or the combination of these two factors significantly affected any of the following four response variables: shell morphology (shell height, shell length, shell width, whole wet weight, dry shell weight, dry tissue weight, fan shape, and cup shape), consistency of shell morphology, time required to remove biofouling, and percent mortality.

Four objectives were developed with coordinating test hypotheses; the first objective was to assess four different frequencies of handling and two types of handing for any effects on the final shell morphology of oysters grown in the two types of gear. Tests hypotheses for the first objective predicted that increasing the frequency which oysters are handled will increase the degree to which the corresponding shell morphology is impacted and that tumbling the oysters on a weekly basis would have the greatest impact on shell morphology when compared to the other treatments and frequencies.

The second objective was to determine if the combination of handling frequency and handling treatment impacted the consistency of shell morphology produced in oysters grown in floating bags or OysterGro™ gear. It was predicted that as handling frequency increased and handling inputs increased from never handled and never tumbled, to handled and emersed to handled and tumbled, consistency of shell morphology would increase.

The third objective was to determine if the combination of handling frequency and handling treatment impacted the time required to remove the biofouling from a sample of 5 oysters. The test hypothesis that was developed for objective three predicted that as handling frequency and handling inputs increase, the time required to remove the biofouling from a sample of 5 oysters would become reduced.

The fourth and final objective was to determine if the combination of handling frequency and handling treatment impacted the percent mortality of oysters grown in the aquaculture gear. The test hypothesis that was developed for objective four predicted that as handling frequency and handling input increases, the percent mortality of oysters grown in floating bags and OysterGro™ gear would increase.

3.3 Methodology

3.3.1 Overview of Farm Site

The study was conducted in Grand Bay (Sandy Bay) Alabama, extending 549m from the mean high water mark of the property utilizing the riparian rights granted by the State of Alabama to the waterfront landowner. The farm currently occupies a space of 4.53 acres (Fig 3.1).

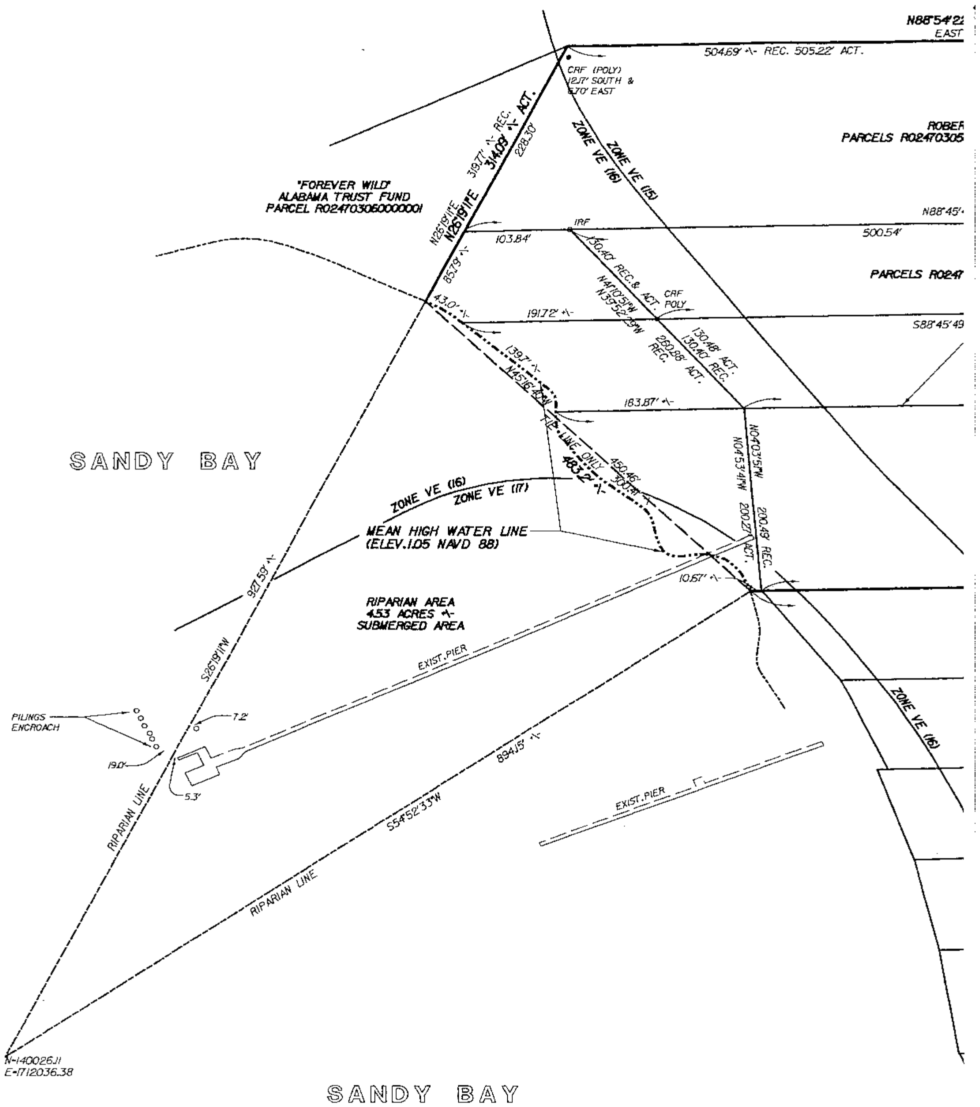

Figure 3.1. Survey map of the study site in Sandy Bay, Alabama. Image credit: Lawyer and Company. Date: 6/10/07. Project No.: 07-061. Drawing No.: 07-061-1.

The area is situated adjacent to an Alabama Forever Wild Land Trust area, where with little boat traffic; the area serves as a natural nursery for the juveniles of several species of fish, crab, shrimp, etc. The experimental site is a commercial oyster farm developed in conjunction with Auburn University and the Alabama Cooperative Extension System. Throughout the study, salinities were monitored during weekly visits to the farm site using a YSI® salinity probe. Salinities typically ranged from 12 to 30 parts per thousand (ppt). Four gear runs were situated perpendicular to shore with an average minimum water depth of 0.9 m nearest the shore and an average maximum water depth of 1.5 m at the southernmost point (Fig. 2.2).

Figure 3.2. A photograph showing four gear runs installed at the Sandy Bay study site. Floating bag gear (FB) and OysterGro™ gear (OG) used in experiment two were located in runs two and three. Run #2 is a combination of the floating bag gear (FB) and the LowPro™ gear (LP). Run #3 and run #4 have OysterGro™ gear (OG). All of the OysterGro™ cages used in the experiment were located in run # 3.

3.3.2 Gear Types and Mechanical Grader

The mechanical grader selected was the QuickTube™ Sorter. The floating bags, OysterGro™ cages as well as the mechanical grader were commercially available through the Chesapeake Bay Oyster Company (VA).

Floating bags had been previously implemented in culture systems found along the Canadian and New England coastline (Mallet, 2009). The price per unit was at the low end of the spectrum as far as initial investment was concerned and its design was not only easy to manipulate but the main structure utilized the same mesh bag component as found in the OysterGro™ gear. This enabled bulk purchasing for mesh bag inserts. OysterGro™ gear was a larger investment than the floating bag gear, yet the OysterGro™ cages provided housing for more oysters per area of lease. The gear selection provided several viable culture options at different levels of investment suitable for multiple budgets.

The mechanical grader selected was also manufactured by the Chesapeake Bay Oyster Company, which facilitated distribution. The grader was chosen for its design, which reduced the amount of workers needed to complete size variant sorting. The rotary design was also the source of industry claims that prompted this project's investigation, which indicated that "tumbling" improved shell quality and reduced biofouling. The mechanical grader and the two gear types were described previously in Chapter 2; for further detail refer back to pages 38-41.

3.3.3 Experimental Setup

The two types of off-bottom oyster aquaculture gear (described in the previous section) were deployed on June 15th, 2010. The experiment was conducted through November 8th, 2010 for a final grow-out season consisting of 147 days. All gear was stocked with oyster seed that had been spawned at the Auburn University Shellfish Laboratory (AUSL) in 2009 and held in a constant nursery environment at the same commercially operated oyster farm in Sandy Bay, Alabama. Four parallel gear runs were installed at the farm site, with two runs containing the gear used in this study. The second run contained the floating bags and the third run contained the OysterGro™ cages (refer back to Fig 3.2).

For each gear type there were two handling treatments at four frequencies and one untreated, never handled control. Each treatment was comprised of three identically stocked bags, randomly distributed throughout each gear run. The handling treatments were: 1) a tumbled, emersed and handled treatment (hereafter the tumbled treatment), 2) a corresponding emersed and handled treatment (hereafter the emersed treatment) and 3) a never handled, never tumbled control (hereafter the never handled control). The tumbled treatment was designed to test the effects of the tumbling action of the mechanical grader on the oysters as well as the subsequent handling involved with the transportation of the oysters to the hatchery for grading. The emersion treatment was designed to test the effects of the air emersion and handling oysters experienced during transport to the hatchery, without the inclusion of a tumbling regiment. The handling and emersion time of both treatments was equal, with the application of a tumbling regiment being the difference between the two treatments. The never handled control was not removed from the water and was not exposed to handling additional to the on-farm anti-biofouling regime.

All oysters used for this experiment were initially processed through the grader in order to achieve consistency in starting size. Initial grading was also representative of the normal production cycle that oysters faced when being moved from the nursery setting to the growout setting. Nursery oysters were sorted into three size groups: small (<31.75 mm), medium (31.75 mm to 44.45 mm) and large (> 44.45 mm). Oysters used in the experiment were selected from the total “medium sorted” oysters after thorough mixing to reduce the chance of any selection bias. Oysters were scooped from the bin containing all of the medium sorted oysters. Then, from the collected medium oysters, bag-stocking densities were achieved by counting live oysters until the required sample size was fulfilled. Mesh bags used for the floating bag gear and OysterGro™ gear were each stocked with 150 hand-counted, randomly selected oysters. Furthermore, all bags were stocked with oysters then labeled with sequentially numbered waterproof tags. The tags were used for identification and to designate a position on each gear line. A random number generator was then used to assign treatment type and to assign position to bags along each gear line based on tag number. Both gear types utilized the same mesh bags to house the oysters for growout. A single bag became a floating bag unit and the slots in the OysterGro™ cage were filled with six mesh bags to complete the unit. A single OysterGro™ cage contained several randomly placed bags, representing each treatment

Both gear types were submitted to manufacturer recommended, on-farm anti-biofouling regiments. Each gear type had a separate routine, which was prescribed in order to control biofouling on the gear material during growout. For this routine, the gear remained on the gear line and was maintained on a weekly basis throughout the experiment. The OysterGro™ gear was exposed once weekly, allowing approximately 24 hrs of desiccation before being flipped back into growout position. OysterGro™ cages were flipped over into desiccation position to allow the cage section that was housing the oysters to be exposed by sitting on top of the gear's large pontoon floats that usually functioned to suspend the cage just below the surface of the water. The floating bags were flipped over 180° (like flipping a page in a book) to expose the previously submerged side of the gear. The floating bag would then remain on that side for an entire week, being flipped weekly to expose the alternate side. Note that the oysters in the floating bag gear are situated in the water so that they remain submerged throughout the anti-biofouling regiment; the oysters in the OysterGro™ gear are fully exposed during the 24 hrs of anti-biofouling maintenance.

3.3.4 Handling Procedures

As in the previous experiment (Chapter 2), there were three possible handling treatments for this experiment: 1) an on-farm control 2) and emersed and handled treatment and 3) an emersed, handled and tumbled treatment. The on-farm control (referred hereafter as the never handled control) represented the effects of only growing oysters in the two gear types according to the recommended management procedures provided by the manufacturers. This included the application of weekly on-farm anti-biofouling regimes where such maintenance was recommended, but did not include any further handling treatments that would remove the oysters from the gear runs. The never handled control was developed as the "no tumbling" control treatment, to represent the effects of culturing oysters in the four gear types without any influence from the use of a mechanical grader during the growout season.

The main test treatment that was developed was the emersed, handled and tumbled treatment (hereafter the tumbled treatment). The purpose of the tumbled treatment was to measure the effects of processing oysters with the mechanical grader on a monthly basis throughout the 2010 growout season (June 15th through November 8th). However, it was apparent that an intermediate treatment needed to be developed. In order to apply a tumbling treatment to a group of oysters from the farm-site, the oysters had to be transported by open-bed truck to AUSL where the mechanical grader was located. This transportation consisted of 60 mi round-trip travel, with a quarter of the distance being over a rough dirt road. Therefore, the emersed and handled treatment (hereafter the emersed treatment) was developed to separate the effects of physically loading and unloading the oyster bags into the truck (handling), the drying effects of the emersion experienced in the open truck bed during transport, the physical agitation caused by the road conditions and also by the emersion effects experienced while being out of the water for a total period of approximately 24 hrs. The tumbled treatment experienced identical treatment to the emersed treatment, except, upon arrival at AUSL, the oysters were processed through the mechanical grader.

Handling frequency was the variable of interest and was tested throughout the growing season of June to November. A random number generator was used to assign identically stocked bags (n=3) into four handling frequencies across the two gear types: seasonal (1x), monthly (5x), biweekly (10x) and weekly (20x). The random number generator was also used to assign the positions of these bags with the gear runs for the two gear types. In each gear type, three bags were also assigned to a zero frequency (0x) to represent the on-farm control. Each frequency (1x, 5x, 10x, and 20x) was randomly assigned as a tumbled treatment or an emersion treatment. Bags were collected from the farm site according to their assigned frequency and brought to AUSL throughout the growing season (June 15th –November 8th). Bags assigned to both the emersed and tumbled treatments were collected from the farm site, loaded in a nonspecific fashion into an open truck bed and transported to AUSL. The hatchery workspace at AUSL is located underneath the building, which is elevated on pylons. The hatchery has a cement floor, which is a shaded but open-air workspace.

Upon arrival at AUSL, bags assigned to the emersed treatment were separated out and stacked on the hatchery floor. Bags assigned to the tumbled treatment were opened and oysters were loaded into the mechanical grader one bagful at a time to ascertain that oysters from each numbered bag were returned to their original bag and later original gear type. Each bag was unloaded onto the hopper table and then inserted into the grading tube with approximately three even measures to ensure a layer of oysters only one or two oysters deep. This method reduced clumping and allowed for all oysters to experience approximately the same amount of washing spray and physical contact with the grading tube. The loading process was completed in 2-3 seconds, which allowed for oysters to also experience approximately the same amount of time in the grading tube and the same amount of shell-to-shell contact. Tumbling ended as soon as the last oyster was sorted out of the grading tube.

Both live oysters and dead shells were collected from the sorting bins and returned to original bag before the next bag was processed. Dead oyster shells were purposely returned to the bags in order to maintain a consistent space/growout density when compared to the never handled control treatments; removing the shells would have essentially allowed remaining oysters more growing space, and in the case of air desiccation, less sunlight shade-cover provided by clustered shell masses. Most importantly, dead shells were retained to ensure that tumbling treatments maintained a consistent batch of 150 or 75 oysters, dependent on gear type, when processed through the mechanical grader. Since the treatment bags could not be mixed, the dead shells helped to simulate the shell-to-shell contact during tumbling and consistent time-in-sorting-tube due to the movement of clustered shells that oysters would normally experience in a commercial setting where the oysters would be continuously fed into the grading tubes from a hopper basket. Both the shell-to-shell contact and the time-in-sorting-tube are factors which, if not controlled for, could have had confounding effects on the shell altering effects of the mechanical grader.

Tumbled oysters were also sprayed with freshwater during the tumbling process; this was a function of the mechanical grader aimed at removing sediments and any biofouling. The mesh bags for the tumbled treatment were not washed and the oysters were directly re-loaded to the same bags after being tumbled. This ensured that bag condition (biofouling and moisture levels) was essentially the same for the emersion treatment bags and the tumbled treatment bags, so as not to have confounding effects on the data collected from oyster measurements.

Temperature was also measured throughout the experiment with the use of two Onset® “HOBO® Water Temp Pro v2” data loggers. One data logger was deployed into a never handled control bag in the floating bag gear (in order to stay submerged the entire growout period) to record water temperatures every ten minutes; the logger remained in the bag for the duration of the study (June 15th through November 8th, 2010). The second logger was used to measure the air temperatures experienced by the oysters during the monthly handling treatments, when the bags were being removed from the water and exposed to the ambient temperatures for approximately 24 hrs. This air temperature logger was placed in the first bag collected from the water at the farm-site and was programmed to record temperatures every 60 seconds during monthly handling.

3.3.5 Data Collection

At the conclusion of the experiment on November 8th, 2010, bags from all seventeen experimental combinations [{2 gear types x 2 experimental handling treatments (tumbled or emersion) x 4 frequencies} + 1 never handled control] were brought dockside and emptied into counting trays. Mortality rates from each bag were recorded, with dead oysters being removed. Unbiased samples of 5 oysters were collected from the remaining live oysters, with a total of 15 live oysters collected from each treatment. Samples were place in labeled Ziploc® bags and transported by an enclosed, air-conditioned vehicle to the hatchery to avoid further air exposure and potential shell damage from the alternate truck mode of transportation.

Samples were then placed in a Frigidaire® Gallery™ drop freezer at -16°C for 24 hrs. After 24 hrs the samples were processed. A goal of the experiment was to measure the effects of handling on the amount of biofouling present on an oyster at the time of harvest. Often, at the time of harvest, oysters receive little more than a water wash to remove biofouling before market. The appearance of high levels of biofouling can negatively affect the market value of an oyster product. Dry ash weights are commonly used to measure the amount of biofouling, but for this experiment it was felt that ash weight would not be an accurate measure of biofouling levels (and appearance) since the farm-site experienced multiple types of biofouling. It was observed that when measuring ash weights, the occurrence of a single barnacle or large overset (a wild oyster larvae setting onto the farmed oyster's shell) would confound samples of low biofouling when compared to lower ash weights recorded from other oysters with high degrees of mud or algae that report low measurements when the water weight is removed. Therefore, the degree of biofouling was measured in terms of time (measured in seconds) required for a person using a Russell-Dexter™ shucking knife and a wire brush to effectively remove the biofouling from a set of five oysters. To control for individual bias, the same person cleaned every oyster. Oysters were cleaned in groups of 5 oysters per treatment, with each treatment across the four gear types processed indiscriminately.

After biofouling was removed, shell metrics were collected using a Mitutoyo® brand waterproof, "Digimatic" digital caliper (model CD-6"PMX, which was rounded to the nearest 0.0001 mm). Then, whole wet weight was collected using a Mettler-Toledo® brand scale model AL204 (rounded to the nearest 0.0001 g). Oysters were carefully shucked to collect the dry shell weight, with shells being placed on Petri plates and allowed to air dry at room temperature (20-23.3°C) for 48 hrs. When the oysters were shucked, the dry tissue weight was collected after the body tissue was placed on aluminum weighing dishes and placed in a Fischer Scientific® brand ISOTEMP™ drying oven for 48 hrs at 80°C. Dry shell weights and dry tissue weights were measured using the Mettler-Toledo® scale (rounded to the nearest 0.0001 g) with the dish weight subtracted from the total weight.

3.3.6 Data Analysis

Data analysis targeted four main characteristics for potential improvements due to handling treatment and handling frequency, for both OysterGro and floating bag gear: shell morphology, consistency of shell morphology, biofouling removal time and percent mortality. Initially, handling treatments and frequencies were evaluated for potential improvements to shell morphology. The analysis included a comparison of basic shell metrics and weights (height, length, width, whole wet weight, dry shell weight and dry tissue weight), an index of the cup-shape ratio (shell width to shell height) and an index of the fan-shape ratio of the oyster (shell length to shell height) (Fig. 3.3).

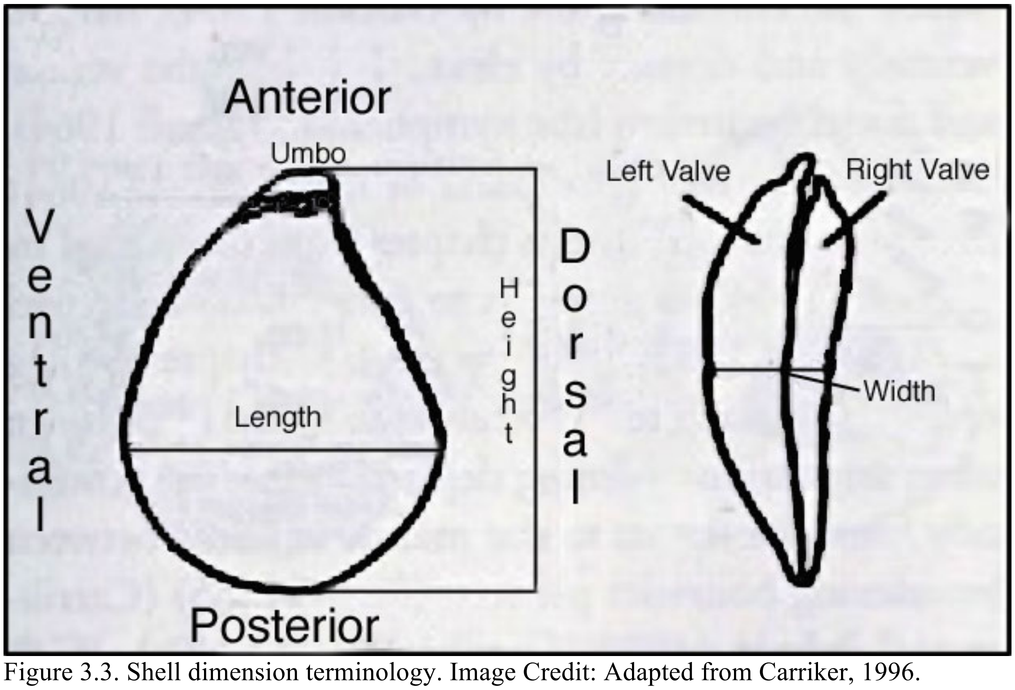

Figure 3.3. Shell dimension terminology. Image Credit: Adapted from Carriker, 1996.

Secondly, handling treatments and frequency were evaluated for improvements to consistency of shell morphology. The analysis included a comparison of the coefficient of variation for all shell metric measurements. Thirdly, in order to evaluate improvements in biofouling removal time, the analysis looked at the labor (as a function of time) associated with cleaning five oysters for market. Finally, percent mortality was compared across the experimental treatments.

The statistical package SYSTAT® 13 was used to analyze the biometric data. The Shapiro-Wilk Test of Normality was used to verify the assumptions of normality (Table 3.1-3.2) for each variable within the two sample populations of oysters, which was based on gear type (OysterGro™ or floating bags). For response variables that did not initially satisfy the Shapiro-Wilk Test of Normality (where normality was achieved with a p-value greater than or equal to 0.05), a Log10 transformation was used on the data. Once a normal distribution was established, an analysis of variance (ANOVA) was used to determine the effects of handling frequency (all frequencies except the never handled control/zero frequency) and handling treatment (emersed and tumbled) on each individual variable. Resulting significant p-values ($p \leq 0.05$) for the ANOVA were evaluated with a post-hoc pairwise comparison using Tukey's Honestly-Significant-Difference Test (HSD) ($p \leq 0.05$). The Tukey's HSD Test was used to assign grouping letters to the treatments to display relationships of significant and non-significant differences within the produced graphs.

	Shell Height	Shell Length	Shell Width	WWW	DSW	DTW	CUP	FAN	FRT	% Mort	Log10 % Mort
S-W P-value	0.980	0.378	0.067	0.762	0.859	0.234	0.376	0.967	0.204	0.000	0.577

Table 3.1. Shapiro-Wilk Test of Normality P-values for OysterGro™ cages. Values equal to or greater than 0.05 approximate a normal distribution.

	Shell Height	Shell Length	Shell Width	WWW	DSW	DTW	CUP	FAN	FRT	% Mort	Log10 % Mort
S-W P-value	0.624	0.127	0.216	0.540	0.276	0.777	0.394	0.957	0.081	0.016	0.399

Table 3.2. Shapiro-Wilk Test of Normality P-values for floating bag gear. Values equal to or greater than 0.05 approximate a normal distribution.

Comparisons to the never handled control were compared separately due to the fact that the never handled control was only at a handling frequency of zero, where the emersed and tumbled treatments both had frequencies of 1x, 5x, 10x and 20x. Therefore, four separate ANOVA's were conducted for each variable for each frequency. Within each frequency, three treatments were compared: the never handled control, the emersed treatment and the tumbled treatment. Resulting significant p-values ($p \leq 0.05$) were then further analyzed using another Tukey's HSD Test to determine where the significant differences occurred at the treatment level., Significant p-values in the ANOVA were 0.05 or less. For purposes of simplicity, the p-values resulting from the ANOVA and Tukey's HSD Test comparisons of the never handled control to the four separate frequencies are provided in a condensed table. P-values are presented in a simplified table with all ANOVA tables for these results referenced in Appendix B (and are cited as B-1, etc.) as are any Tukey's HSD Test tables for the initial comparison of frequency and treatment.

3.4 Results

3.4.1 Overview

Upon the collection of data, it was apparent that there was a very high level of mortality within the OysterGro™ gear when compared to the floating bag gear. This variation may be attributed to the on-farm anti-biofouling regimes that was applied on a weekly basis throughout the growing season. Since the level of mortality experienced in the OysterGro™ gear was potentially created by inappropriate management of the gear, the results from the OysterGro™ and floating bag gear will be presented independently beginning with the OysterGro™ data.

OysterGro™ Results

3.4.2 Shell Morphology

Shell Height

There was a significant interaction between the effects of handling frequency and handling treatment with respect to the mean final shell height of oysters grown in the OysterGro™ gear (p=0.035)(Table 3.3). When comparing the mean final shell height values across the four test frequencies (seasonally, monthly, biweekly, and weekly) and two handling treatments, the weekly tumbled treatment exhibited a significantly smaller shell height than any of the other values (p≤0.023), including the weekly emersion treatment (p=0.009)(Table B-1)(Fig. 3.4). In addition, the handling treatments applied on a weekly frequency were the only test frequency to significantly vary from the mean final shell height observed in the never handled control (p=0.042)(Table 3.4, Tables B-2: B-5). Within the weekly frequency, the shell heights of the oysters subjected to the tumbled treatment were significantly smaller than the shell heights of the oysters in the never handled control (p=0.040), noting that there was no significant difference between the emersed treatment and the never handled control (p=0.659)(Table 3.5, Table B-6).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	238.181	3	79.394	10.083	0.001
TREATMENT	79.119	1	79.119	10.048	0.006
FREQUENCY*TREATMENT	86.808	3	28.936	3.675	0.035
Error	125.987	16	7.874		

Table 3.3. OysterGro™ Shell Height ANOVA

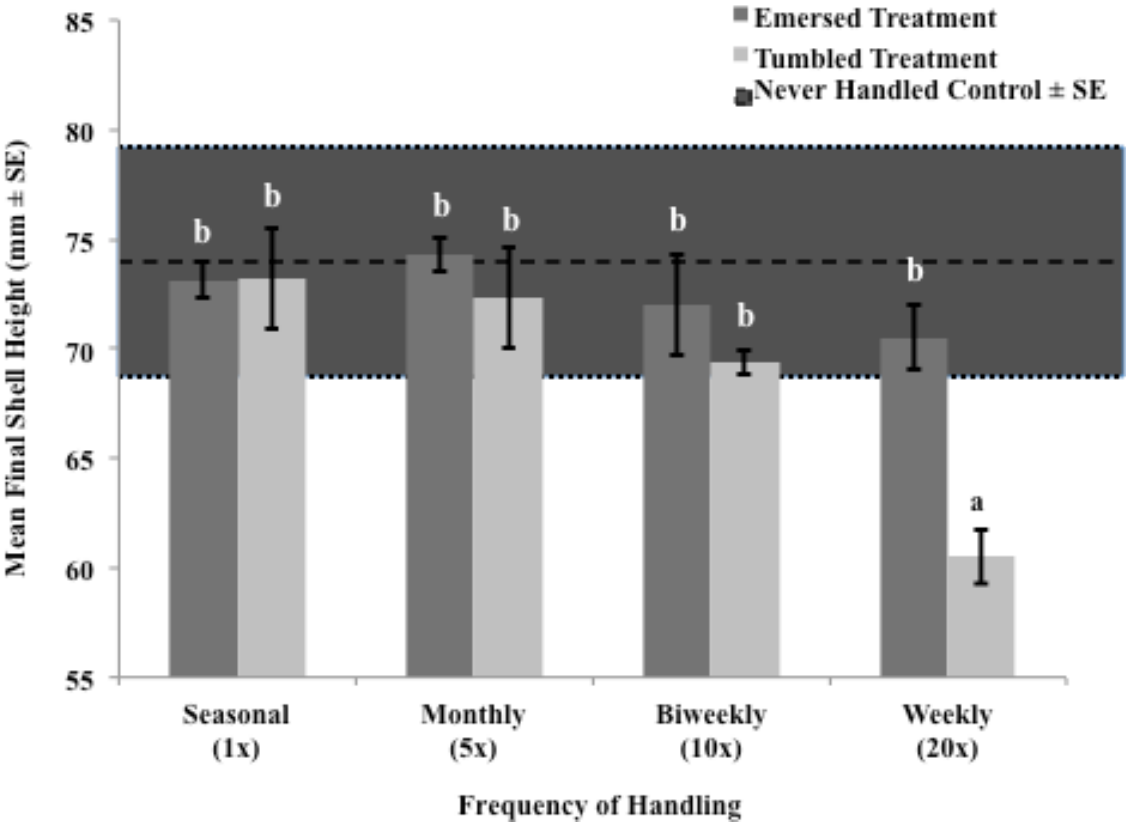

Figure 3.4. Interaction of handling frequency and handling treatment on mean final shell height (mm ± SE) of oysters grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final shell height values of a never handled control, represented by dotted lines (mm ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.954**	**0.873**	**0.559**	**0.042**

Table 3.4. ANOVA comparison of the shell height values for the test frequencies to the shell height values for the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-2:B-5).

		Weekly
Never	**Emersed**	**0.659**
Never	**Tumbled**	**0.040**

Table 3.5. Pairwise comparisons of the shell height values of the never handled control to the emersion and tumbled treatments within the weekly frequency, resultant of the significant p-values obtained from the ANOVA (Table 3.4). P-values less than or equal to 0.05 are significant. (See table B-6).

Shell Length

There was a significant interaction between handling frequency and handling treatment with respect to mean final shell length of oysters grown in the OysterGro™ gear (p=0.022)(Table 3.6). The mean final shell length value for the weekly tumbled treatment was significantly smaller than every other treatment in every other frequency (p≤0.017) with the exception of the biweekly tumbled treatment (p=0.429)(Table B-7)(Fig 3.5). When comparing the shell length values to those of the never handled control, only the weekly frequency showed a significant difference (p=0.047) at the frequency level but not the treatment level (p=0.056)(Table 3.7,Table B-8:B-12). Multiple comparisons or multiple testing problems can occur when one considers a set of statistical inferences simultaneously. This can result from including confidence intervals that fail to include their corresponding population parameters or hypothesis tests that incorrectly reject the null hypothesis. In this case, the ANOVA comparison revealed that the oysters subjected to the weekly frequency were significantly smaller than the oysters in the never handled control. However, the Tukey's HSD comparison of the never handled control to the tumbled treatment level produced a close, but not significant, p-value (p=0.056)(Table 3.8, Table B-12).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	96.826	3	32.275	7.945	0.002
TREATMENT	34.063	1	34.063	8.385	0.011
FREQUENCY*TREATMENT	51.857	3	17.286	4.255	0.022
Error	64.999	16	4.062		

Table 3.6. OysterGro™ Shell Length ANOVA

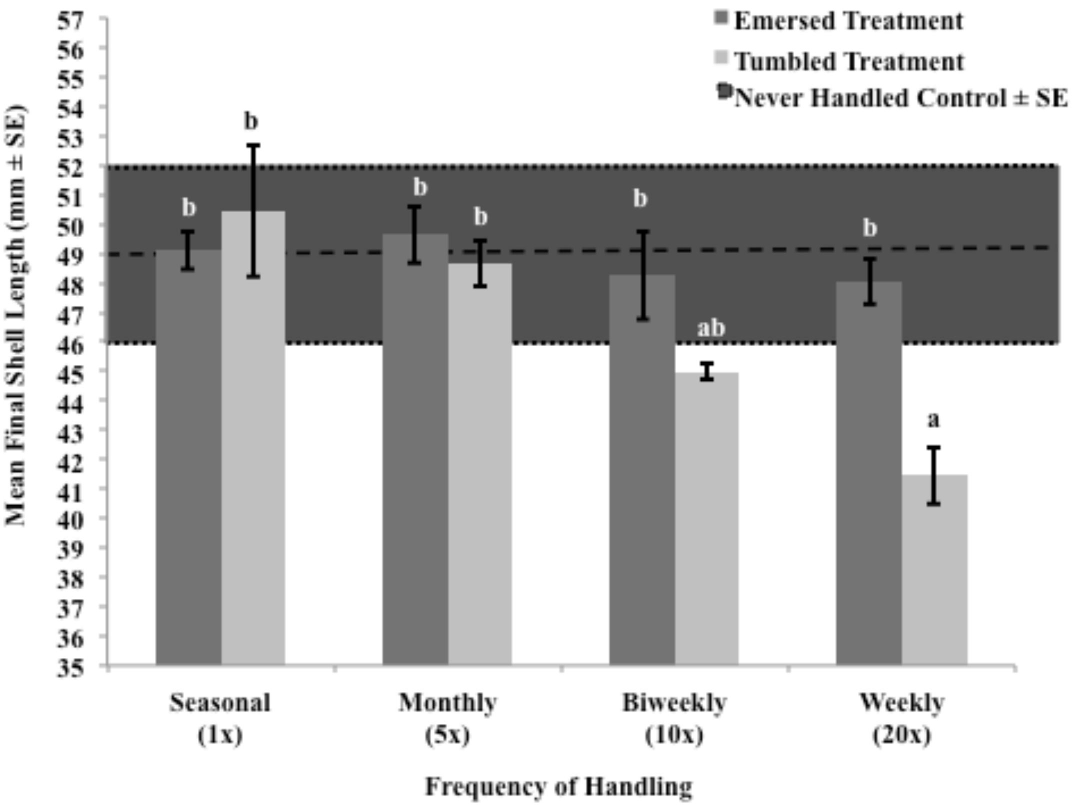

Figure 3.5. Interaction of handling frequency and handling treatment on mean final shell length (mm ± SE) of oysters grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final shell length values of a never handled control, represented by dotted lines (mm ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.852**	**0.918**	**0.340**	**0.047**

Table 3.7. ANOVA comparisons of the shell length values for the test frequencies to the shell length values for the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-8:B-11).

		Weekly
Never	**Emersed**	**0.943**
Never	**Tumbled**	**0.056***

Table 3.8. Pairwise comparison of the shell length values of the never handled control to the emersion and tumbled treatments within the weekly frequency, resultant of the significant p-values obtained from the ANOVA (Table 3.7). P-values less than or equal to 0.05 are significant *unless justified by the p-value found in Table 3.7. (See table B-12).

Shell Width

There was no significant effect from handling frequency, handling treatment or the interaction between these factors on the mean final shell width of oysters grown in the OysterGro™ gear ($p \geq 0.055$)(Table 3.9)(Fig. 3.6). When compared to the never handled control, there was no significant difference between the values of shell width for the four handling frequencies and two handling treatments ($p \geq 0.162$)(Table 3.10, Table B-13:B-16).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	5.489	3	1.830	1.195	0.343
TREATMENT	6.586	1	6.586	4.302	0.055
FREQUENCY*TREATMENT	5.582	3	1.861	1.216	0.336
Error	24.493	16	1.531		

Table 3.9. OysterGro™ Shell Width ANOVA

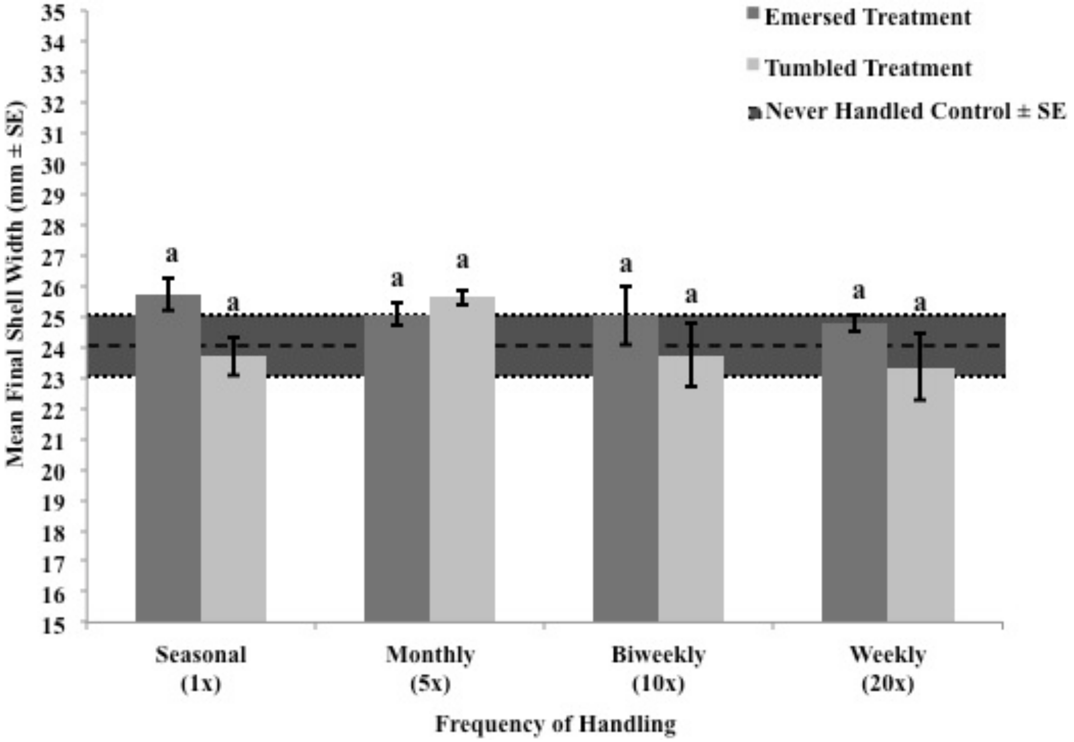

Figure 3.6. Mean final shell widths (mm ± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final shell width values of a never handled control treatment (mm ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.162**	**0.216**	**0.637**	**0.497**

Table 3.10. ANOVA comparison of the shell width values for the test frequencies to the shell width values for the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-13:B-16).

Whole Wet Weight

There was a significant effect from handling frequency on the whole wet weight of oysters grown in the OysterGro™ gear (p=0.022)(Table 3.11). Handling treatment, however, created no significant difference in the values of whole wet weight (p=0.081) and there was no significant interaction (p=0.562). When a post-hoc pairwise comparison was conducted to evaluate the four handling frequencies, the oysters in the monthly handling frequency were found to be significantly larger than the oysters in the weekly frequency (p=0.015)(Table B-17). No other significant differences were revealed (Fig. 3.7). The whole wet weight values of the four handling frequencies were further compared to the whole wet weight values of the never handled control. This comparison revealed no significant differences between the never handled control values and the values of any of the four handling frequencies (p≥0.095)(Table 3.12, Table B-18:B-21).

Analysis of Variance **Source**	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	488.988	3	162.996	4.265	0.022
TREATMENT	132.337	1	132.337	3.463	0.081
FREQUENCY*TREATMENT	80.983	3	26.994	0.706	0.562
Error	611.422	16	38.214		

Table 3.11. OysterGro™ Whole Wet Weight ANOVA

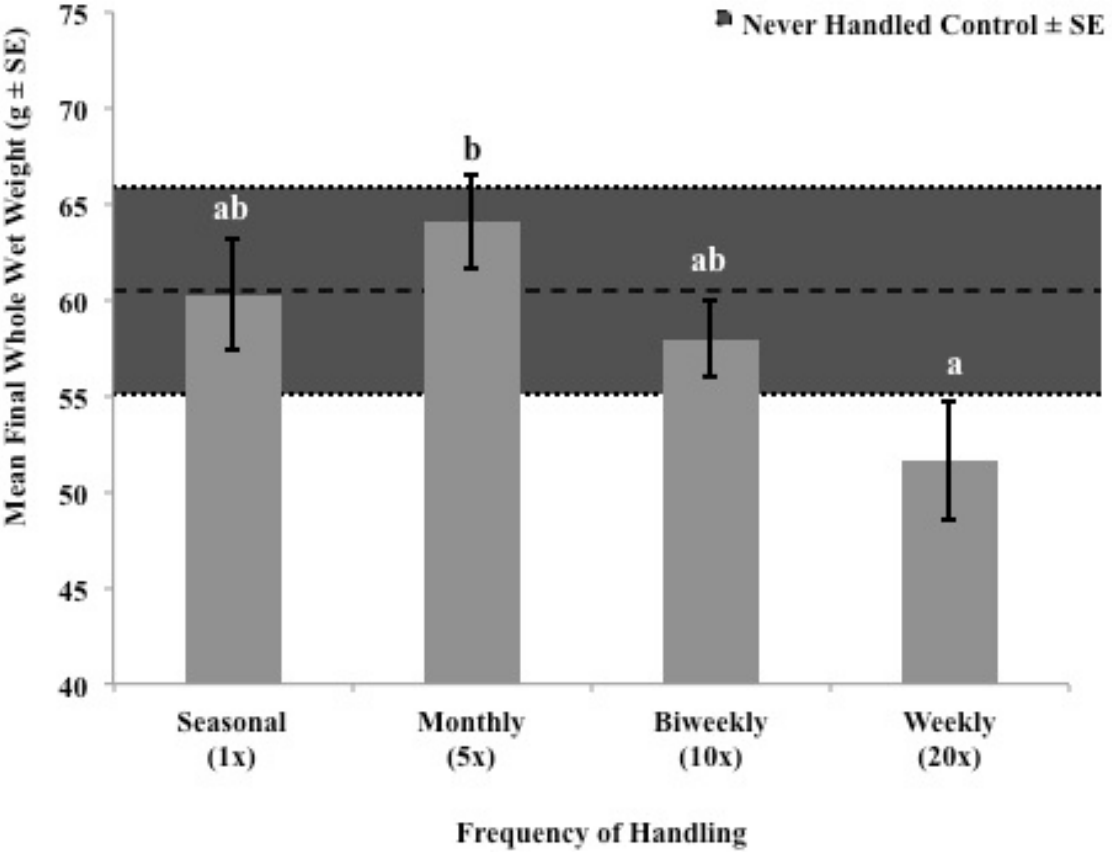

Figure 3.7. Mean final whole wet weight (g ± SE) of oysters grown in the OysterGro™ gear and subjected to four handling frequencies, seasonal, monthly, biweekly and weekly. A secondary comparison is made to the values of whole wet weight from the never handled control, represented by the dotted lines (g ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.955**	**0.816**	**0.635**	**0.095**

Table 3.12. ANOVA comparison of the whole wet weight values for the test frequencies to the whole wet weight values for the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-18:B-21).

Dry Shell Weight

There was a significant effect from handling frequency on the dry shell weight of oysters grown in the OysterGro™ gear (p=0.026)(Table 3.13). Handling treatment created no significant difference in the values of dry shell weight (p=0.105), and there was no significant interaction (p=0.546). When a post-hoc pairwise comparison was conducted to evaluate the four handling frequencies, the monthly handling frequency produced significantly larger oyster dry shell weights than the weekly frequency (p=0.027)(Table B-22). No other significant differences were revealed (Fig. 3.8). The dry shell weight values of the four handling frequencies were further compared to the dry shell weight values of the never handled control. This comparison revealed no significant differences between the never handled control values and the values of any of the four handling frequencies (p≥0.127)(Table 3.14, Table B-23:B-26).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	261.255	3	87.085	4.052	0.026
TREATMENT	63.554	1	63.554	2.957	0.105
FREQUENCY*TREATMENT	47.392	3	15.797	0.735	0.546
Error	343.890	16	21.493		

Table 3.13. OysterGro™ Dry Shell Weight ANOVA

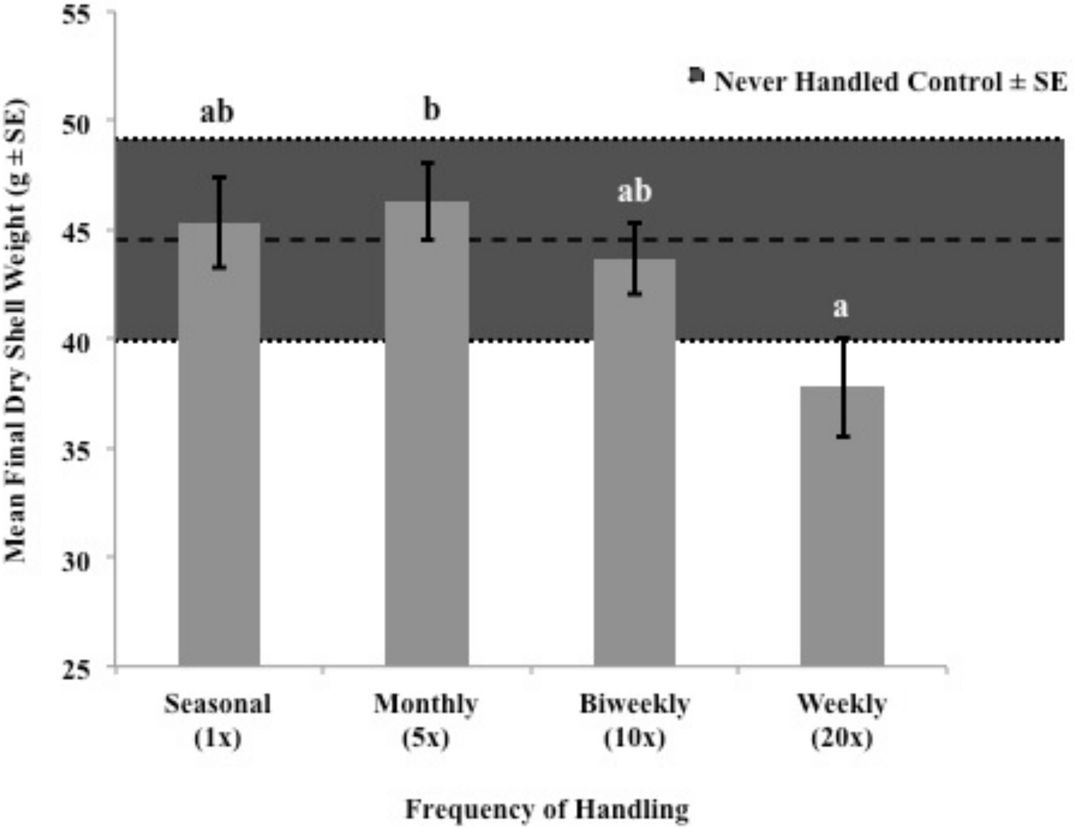

Figure 3.8. Mean final dry shell weight (g ± SE) of oysters grown in the OysterGro™ gear and subjected to four handling frequencies, seasonal, monthly, biweekly and weekly. A secondary comparison is made to the values of dry shell weight from the never handled control, represented by the dotted lines (g ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	Monthly	Biweekly	Weekly
P-value of Comparison to Never Handled Control	**0.955**	**0.928**	**0.678**	**0.127**

Table 3.14. ANOVA comparison of the dry shell weight values for the test frequencies to the dry shell weight values for the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-23:B-26).

Dry Tissue Weight

There was a significant effect from handling frequency on the dry tissue weight of oysters grown in the OysterGro™ gear (p=0.016)(Table 3.15). Handling treatment, however, created no significant difference in the values of dry tissue weight (p=0.134) and there was no significant interaction (p=0.863). When a post-hoc pairwise comparison was conducted to evaluate the four handling frequencies, the oysters in the monthly handling frequency were found to be significantly larger than the oysters in the weekly frequency (p=0.010)(Table B-27). No other significant differences were revealed (Fig. 3.9). The dry tissue weight values of the four handling frequencies were further compared to the dry tissue weight values of the never handled control. This comparison revealed no significant differences between the never handled control values and the values of any of the four handling frequencies (p≥0.110)(Table 3.16, Table B-28:B-31).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.372	3	0.124	4.640	0.016
TREATMENT	0.067	1	0.067	2.494	0.134
FREQUENCY*TREATMENT	0.020	3	0.007	0.245	0.863
Error	0.428	16	0.027		

Table 3.15. OysterGro™ Dry Tissue Weight ANOVA

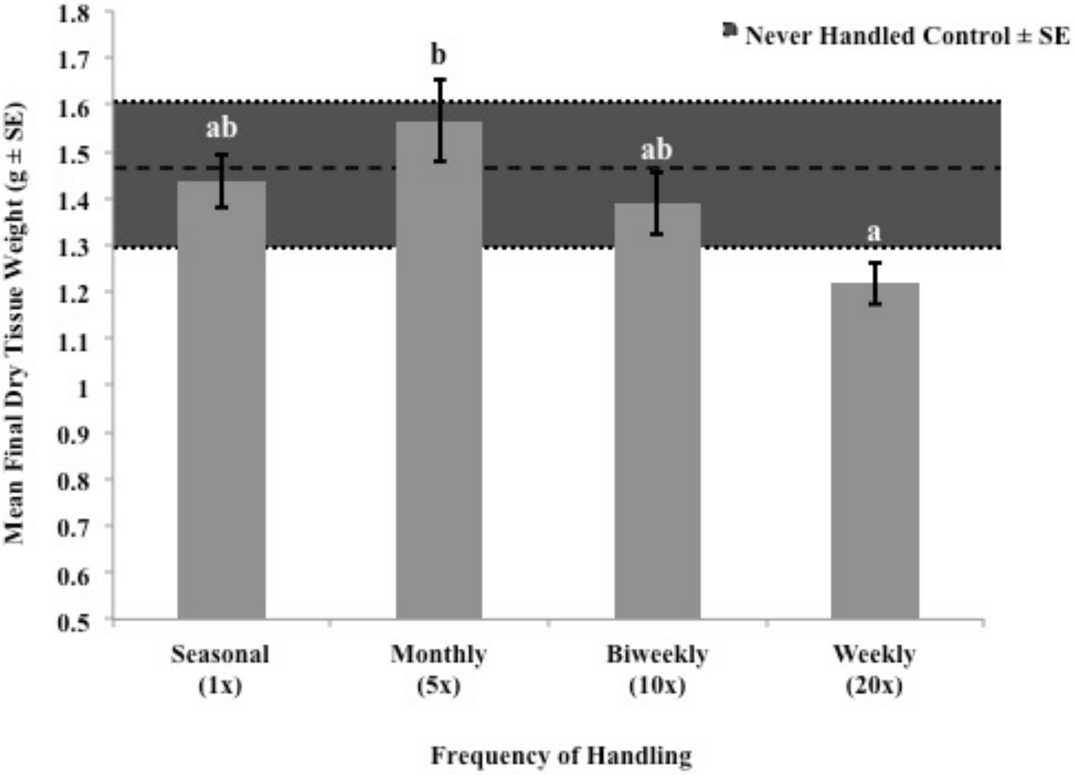

Figure 3.9. Mean final dry tissue weight (g ± SE) of oysters grown in the OysterGro™ gear and subjected to four handling frequencies, seasonal, monthly, biweekly and weekly. A secondary comparison is made to the values of dry tissue weight from the never handled control, represented by the dotted lines (g ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.654**	**0.851**	**0.583**	**0.110**

Table 3.16. ANOVA comparison of the dry tissue weight values for the test frequencies to the dry tissue weight values for the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-28:B-31).

Cup Ratio

There was no significant effect from handling frequency, handling treatment or the interaction between these two factors on the mean final cup ratio of oysters grown in the OysterGro™ gear (p≥0.056)(Table 3.17)(Fig. 3.10). When compared to the never handled control, there was no significant difference between the values of cup ratio for the four handling frequencies and two handling treatments (p≥0.056)(Table 3.18, Table B-32:B-35).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.003	3	0.001	2.978	0.063
TREATMENT	0.000	1	0.000	0.368	0.553
FREQUENCY*TREATMENT	0.003	3	0.001	3.114	0.056
Error	0.006	16	0.000		

Table 3.17. OysterGro™ Cup Ratio ANOVA

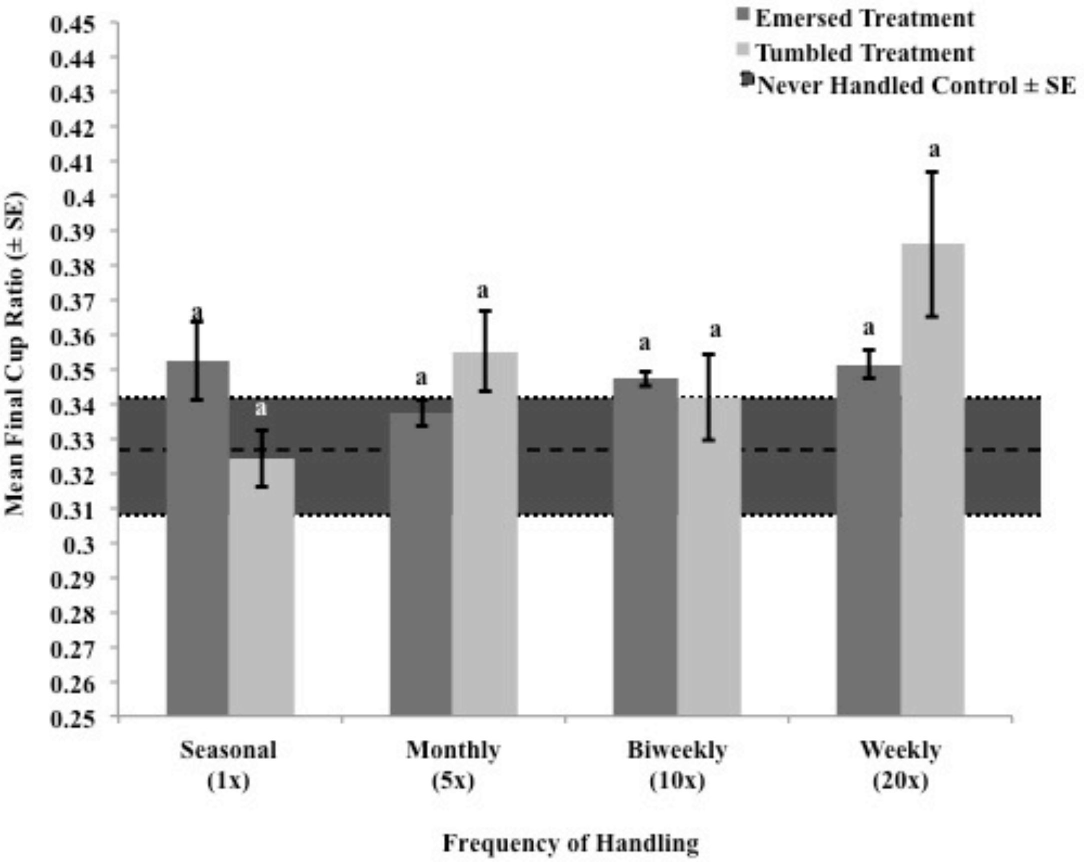

Figure 3.10. Mean final cup ratios (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final cup ratio values of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	Monthly	Biweekly	Weekly
P-value of Comparison to Never Handled Control	**0.168**	**0.161**	**0.309**	**0.056**

Table 3.18. ANOVA comparison of the cup ratio values for the test frequencies to the cup ratio values for the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-32:B-36).

Fan Ratio

There was no significant effect from handling frequency, handling treatment or interaction between these factors on the mean final fan ratio of oysters grown in the OysterGro™ gear (p≥0.152)(Table 3.19)(Fig. 3.11). When compared to the never handled control, there was no significant difference between the values of fan ratio for the four handling frequencies and two handling treatments (p≥0.087)(Table 3.20, Table B-37:B-40).

Analysis of Variance **Source**	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.002	3	0.001	2.020	0.152
TREATMENT	0.000	1	0.000	0.011	0.916
FREQUENCY*TREATMENT	0.001	3	0.000	1.160	0.356
Error	0.006	16	0.000		

Table 3.19. OysterGro™ Fan Ratio ANOVA

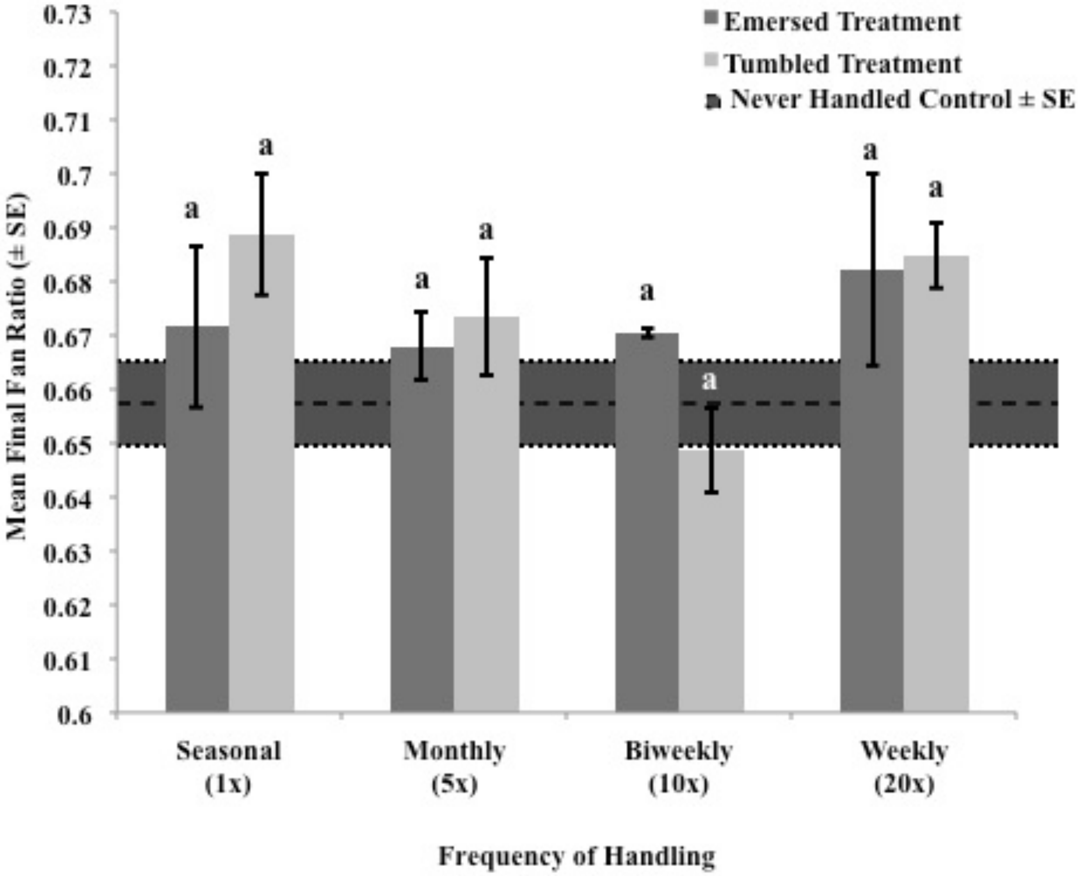

Figure 3.11. Mean final fan ratios (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final fan ratio values of a never handled control represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.239**	**0.441**	**0.087**	**0.261**

Table 3.20. ANOVA comparison of the fan ratio values for the test frequencies to the fan ratio values for the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-37:B-40).

3.4.3 Product Consistency

Coefficients of Variation

There was no significant effect from handling frequency, handling treatment or interaction between these factors on the coefficients of variation for shell height, shell length, shell width, whole wet weight, dry shell weight, or dry tissue weight of oysters grown in the OysterGro™ gear ($p \geq 0.186$)(Table 3.21, 3.23, 3.25, 3.27, 3.29, 3.31)(Fig. 3.12-3.17). When compared to the never handled control, there was no significant difference between the coefficient of variations for the four handling frequencies and two handling treatments ($p \geq 0.069$)(Table 3.22, 3.24, 3.26, 3.28, 3.30, 3.32; Tables B-41:B-64).

Analysis of Variance **Source**	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.004	3	0.001	1.362	0.290
TREATMENT	0.001	1	0.001	0.786	0.388
FREQUENCY*TREATMENT	0.006	3	0.002	1.808	0.186
Error	0.017	16	0.001		

Table 3.21. OysterGro™ Coefficient of Variation for Shell Height ANOVA

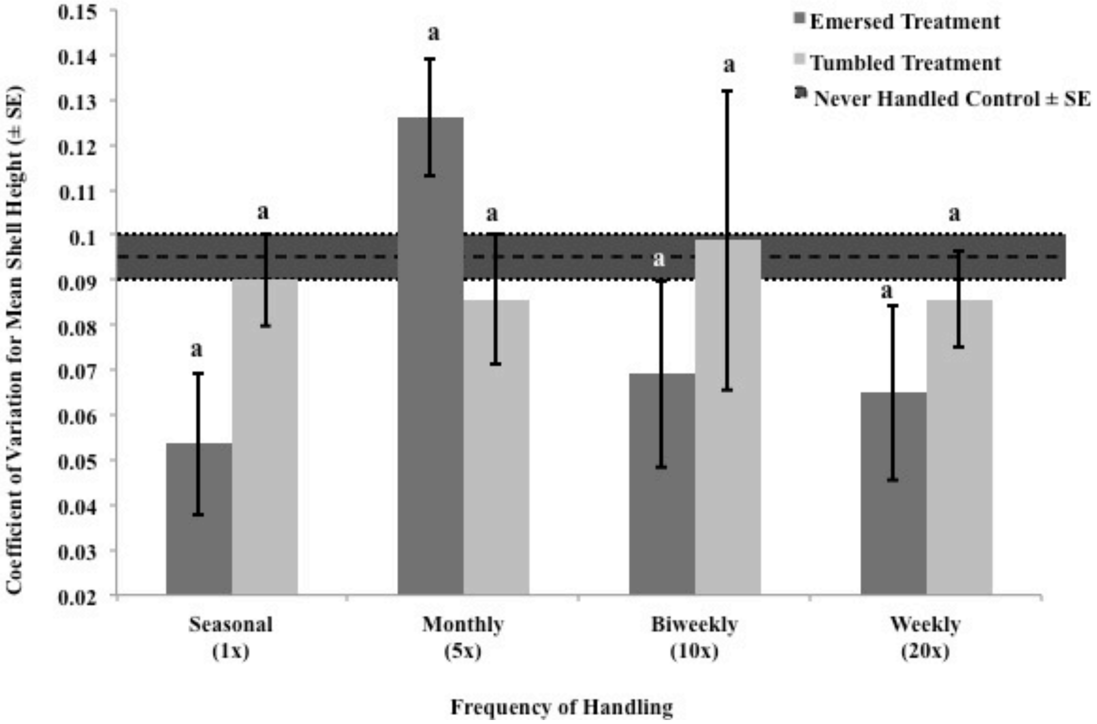

Figure 3.12. Mean coefficient of variation for final shell height (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for shell height of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.069**	**0.105**	**0.618**	**0.290**

Table 3.22. ANOVA comparisons of the coefficient of variation for shell height of the test frequencies to the coefficient of variation for shell height of the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-41:B-44).

Analysis of Variance Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
FREQUENCY	0.003	3	0.001	1.344	0.295
TREATMENT	0.000	1	0.000	0.177	0.680
FREQUENCY*TREATMENT	0.001	3	0.000	0.366	0.779
Error	0.013	16	0.001		

Table 3.23. OysterGro™ Coefficient of Variation for Shell Length ANOVA

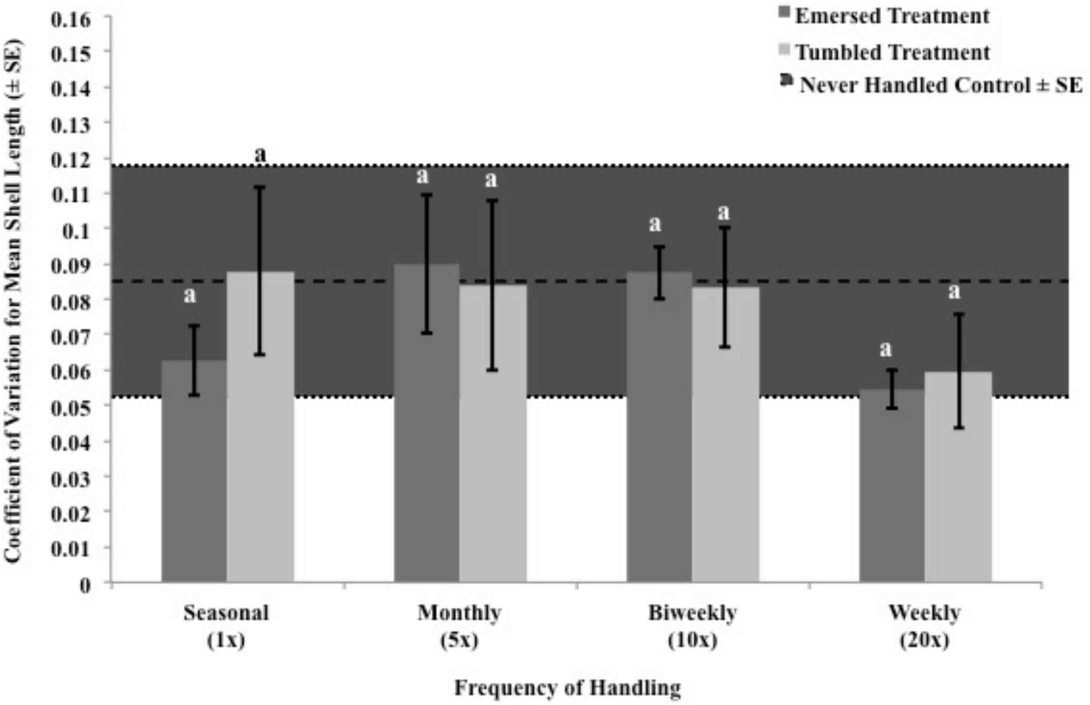

Figure 3.13. Mean coefficient of variation for final shell length (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for shell length of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	Monthly	Biweekly	Weekly
P-value of Comparison to Never Handled Control	**0.734**	**0.982**	**0.989**	**0.594**

Table 3.24. ANOVA comparisons of the coefficient of variation for shell length of the test frequencies to the coefficient of variation for shell length of the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-45:B-48).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.001	3	0.000	0.215	0.885
TREATMENT	0.001	1	0.001	0.461	0.507
FREQUENCY*TREATMENT	0.001	3	0.000	0.190	0.901
Error	0.031	16	0.002		

Table 3.25. OysterGro™ Coefficient of Variation for Shell Width ANOVA

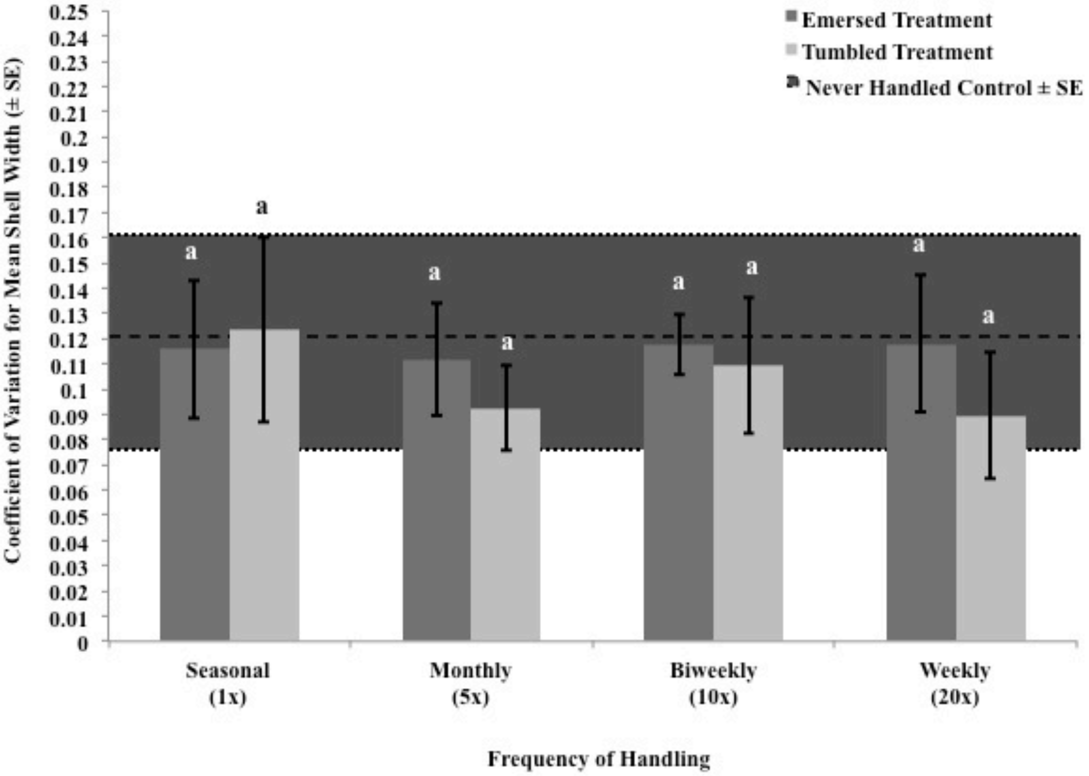

Figure 3.14. Mean coefficient of variation for final shell width (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for shell width of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.989**	**0.827**	**0.974**	**0.791**

Table 3.26. ANOVA comparison of the coefficient of variation for shell width of the test frequencies to the coefficient of variation for shell width of the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-49:B-52).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.007	3	0.002	0.577	0.638
TREATMENT	0.001	1	0.001	0.156	0.698
FREQUENCY*TREATMENT	0.011	3	0.004	0.838	0.492
Error	0.067	16	0.004		

Table 3.27. OysterGro™ Coefficient of Variation for Whole Wet Weight ANOVA

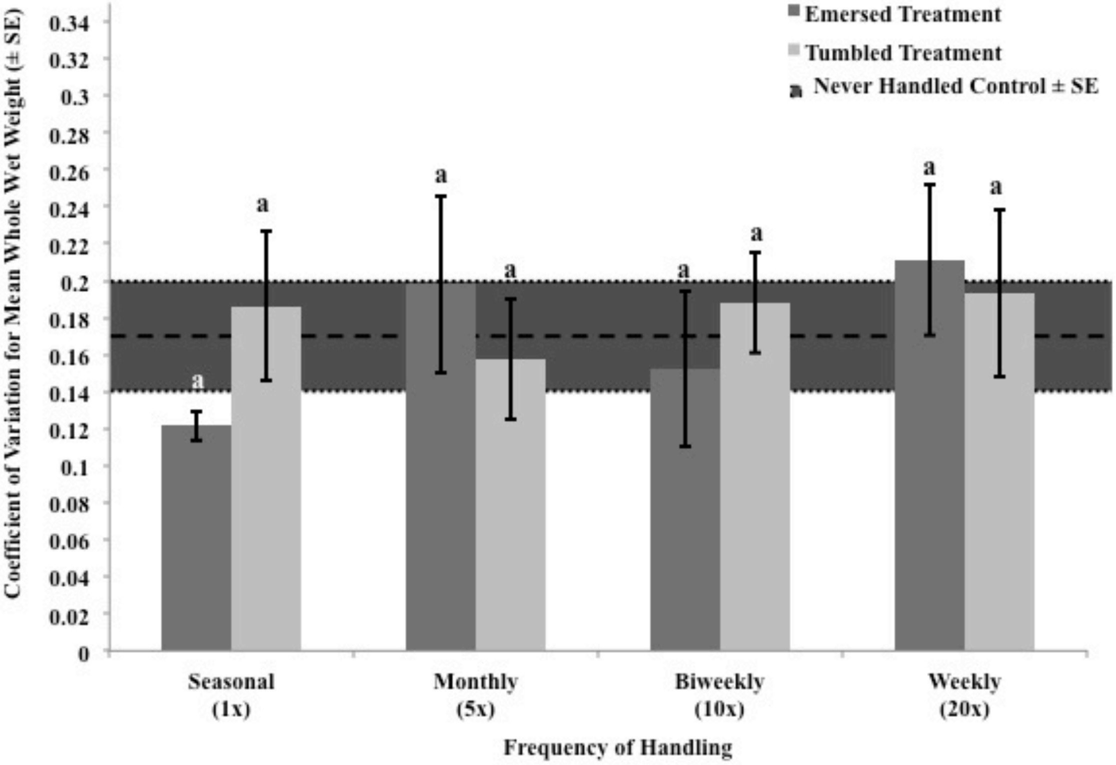

Figure 3.15. Mean coefficient of variation for final whole wet weight (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for whole wet weight of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.341**	**0.754**	**0.764**	**0.778**

Table 3.28. ANOVA comparison of the coefficient of variation for whole wet weight of the test frequencies to the coefficient of variation for whole wet weight of the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-53:B-56).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.011	3	0.004	0.861	0.481
TREATMENT	0.000	1	0.000	0.112	0.742
FREQUENCY*TREATMENT	0.007	3	0.002	0.562	0.648
Error	0.070	16	0.004		

Table 3.29. OysterGro™ Coefficient of Variation for Dry Shell Weight ANOVA

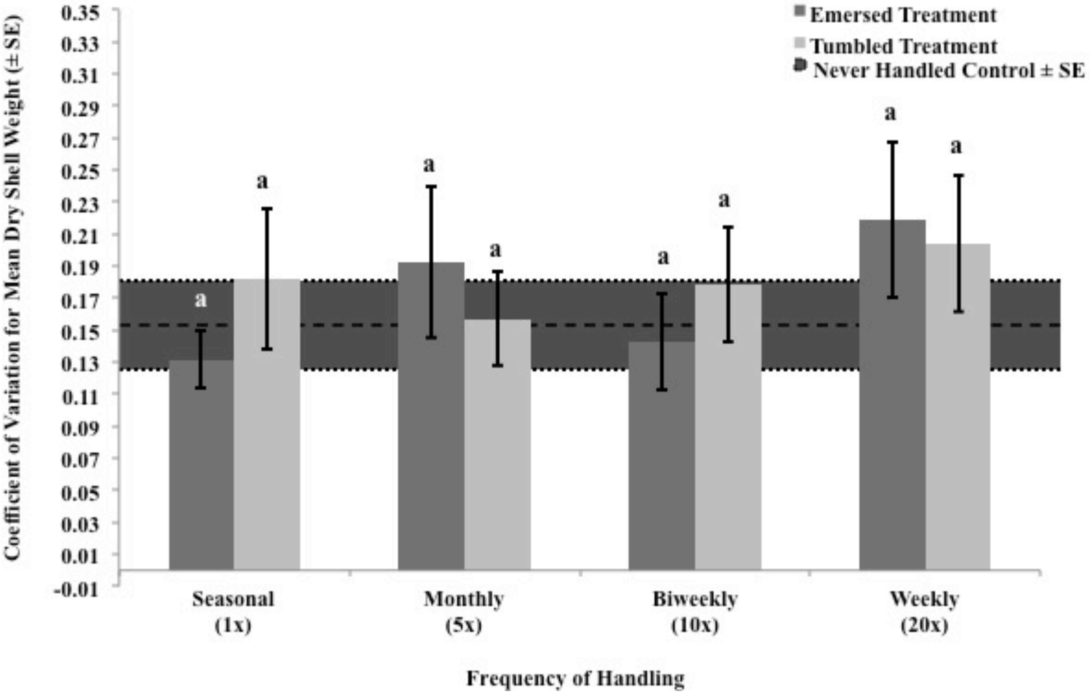

Figure 3.16. Mean coefficient of variation for final dry shell weight (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for dry shell weight of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.562**	**0.716**	**0.722**	**0.536**

Table 3.30. ANOVA comparison of the coefficient of variation for dry shell weight of the test frequencies to the coefficient of variation for dry shell weight of the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-57:B-60).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.001	3	0.000	0.070	0.975
TREATMENT	0.003	1	0.003	0.377	0.548
FREQUENCY*TREATMENT	0.015	3	0.005	0.755	0.536
Error	0.107	16	0.007		

Table 3.31. OysterGro™ Coefficient of Variation for Dry Tissue Weight ANOVA

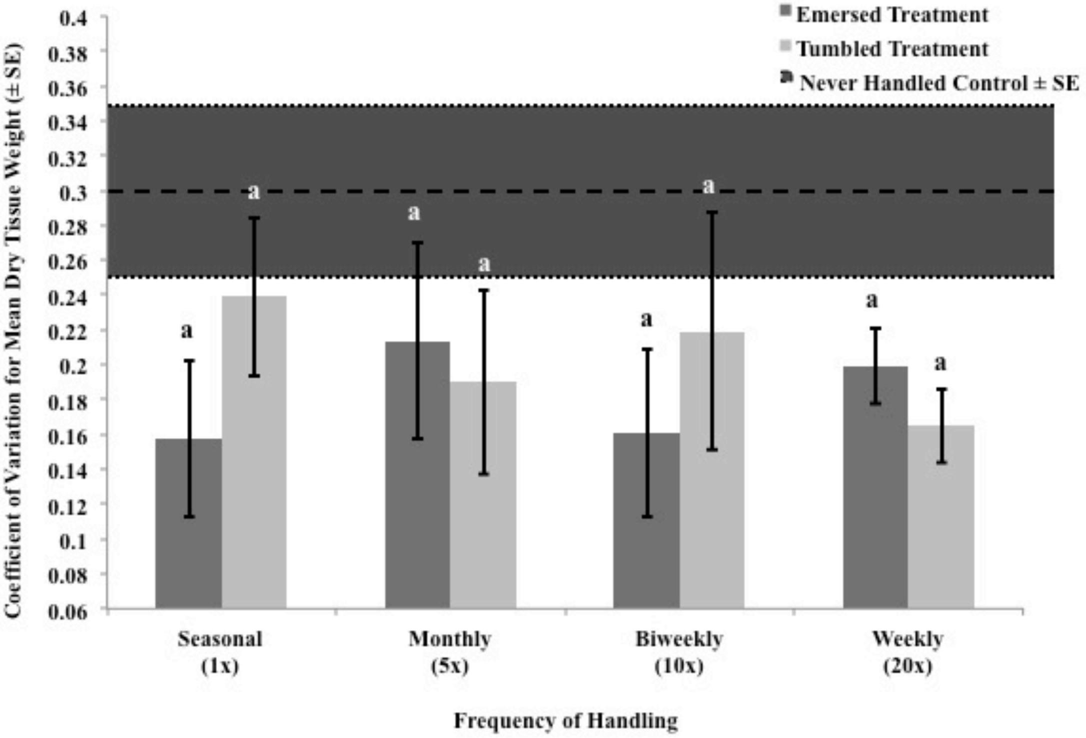

Figure 3.17. Mean coefficient of variation for final dry tissue weight (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the OysterGro™ gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for dry tissue weight of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.183**	**0.382**	**0.296**	**0.072**

Table 3.32. ANOVA comparison of the coefficient of variation for dry tissue weight of the test frequencies to the coefficient of variation for dry tissue weight of the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-61:B-64).

3.4.4 Biofouling Removal Time

There was no significant effect from handling frequency on the biofouling removal time (p=0.130) or interaction (p=0.223); however, handling treatment created significant differences (p=0.003)(Table 3.33). Regardless of frequency, the emersion treatment required significantly more time to clean 5 oysters than the tumbled treatment (Fig. 3.18). When compared to the never handled control, there were no significant differences in biofouling removal time (p≥0.239)(Table 3.34, Table B-65:B-68).

Analysis of Variance **Source**	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	687.000	3	229.000	2.178	0.130
TREATMENT	1,290.667	1	1,290.667	12.277	0.003
FREQUENCY*TREATMENT	512.333	3	170.778	1.625	0.223
Error	1,682.000	16	105.125		

Table 3.33. OysterGro™ Biofouling Removal Time ANOVA

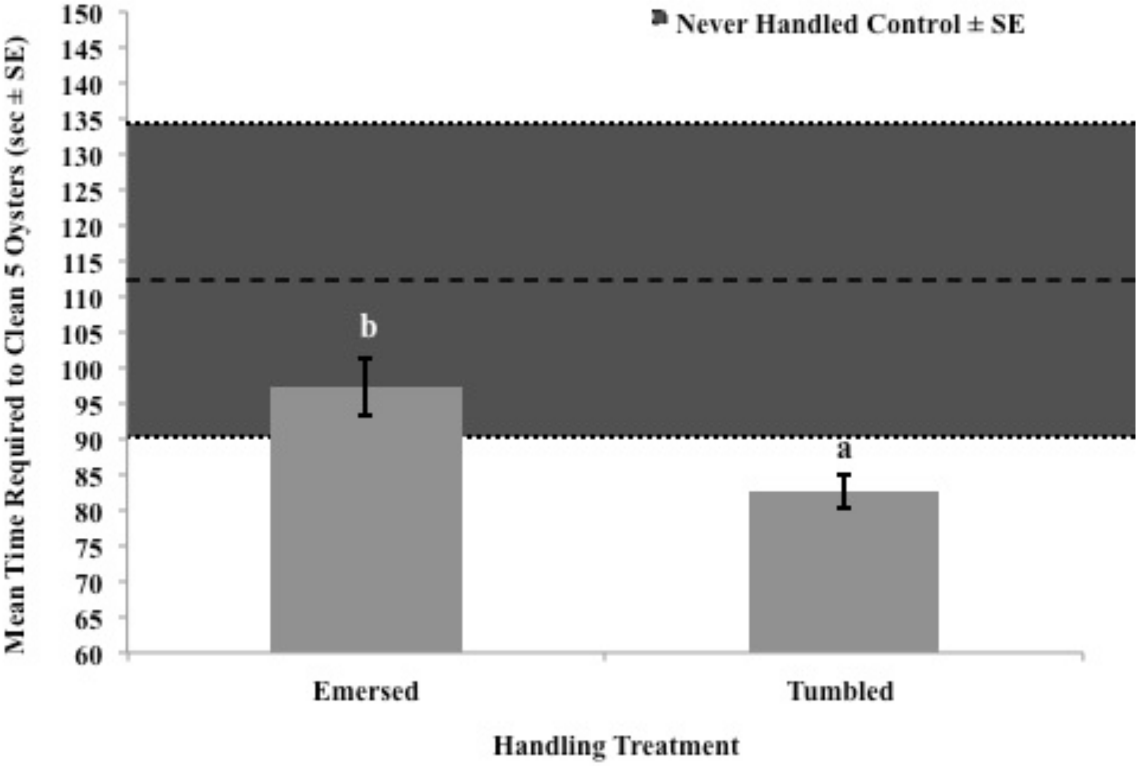

Figure 3.18. Mean biofouling removal time (sec. ± SE) of oysters grown in the OysterGro™ gear and subjected to two handling treatments, emersed and tumbled. Handling treatments were also compared to the biofouling removal time of the never handled control, represented by dotted lines (sec. ± SE). Means with the same grouping letters are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.599**	**0.302**	**0.239**	**0.297**

Table 3.34. ANOVA comparison of the mean time required to clean 5 oysters from the two handling treatments to the mean time required to clean 5 oysters from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-65:B-68).

3.4.5 Percent Mortality

In order to achieve a distribution that approximated normality (Shapiro-Wilk Test of Normality), the data for the percent mortality was log10 transformed. Within the log10 transformed percent mortality, there was a significant effect from the handling frequency (p=0.001) and no effect from the handling treatment (p=0.130) or interaction between the factors (p=0.210)(Table 3.35). When the mortality was compared across the four handling frequencies, the post-hoc pairwise comparison revealed significantly lower mortality in the weekly frequency treatment when compared to the seasonal, monthly and biweekly frequencies (p≤0.049)(Table B-69). There were no other significant differences among the four handling frequencies (p≥0.205)(Fig. 3.19).

Percent mortality was further compared to the percent mortality of the never handled control. The comparisons revealed that were significant differences between the percent mortality of the never handled control and the percent mortality of the biweekly and weekly tested frequencies (p≤0.030)(Table 3.36, Table B-70:B-72. B-74). When a pairwise comparison was conducted, the log10 percent mortality in the never handled control was significantly greater than the biweekly tumbled treatment (p=0.030) and both the emersed and tumbled treatment of the weekly frequency (p≤0.016)(Table 3.37, Table B-73, B-75).

Analysis of Variance **Source**	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	2.577	3	0.859	9.310	0.001
TREATMENT	0.237	1	0.237	2.572	0.130
FREQUENCY*TREATMENT	0.470	3	0.157	1.697	0.210
Error	1.384	15	0.092		

Table 3.35. OysterGro™ Log10 Transformed Percent Mortality ANOVA

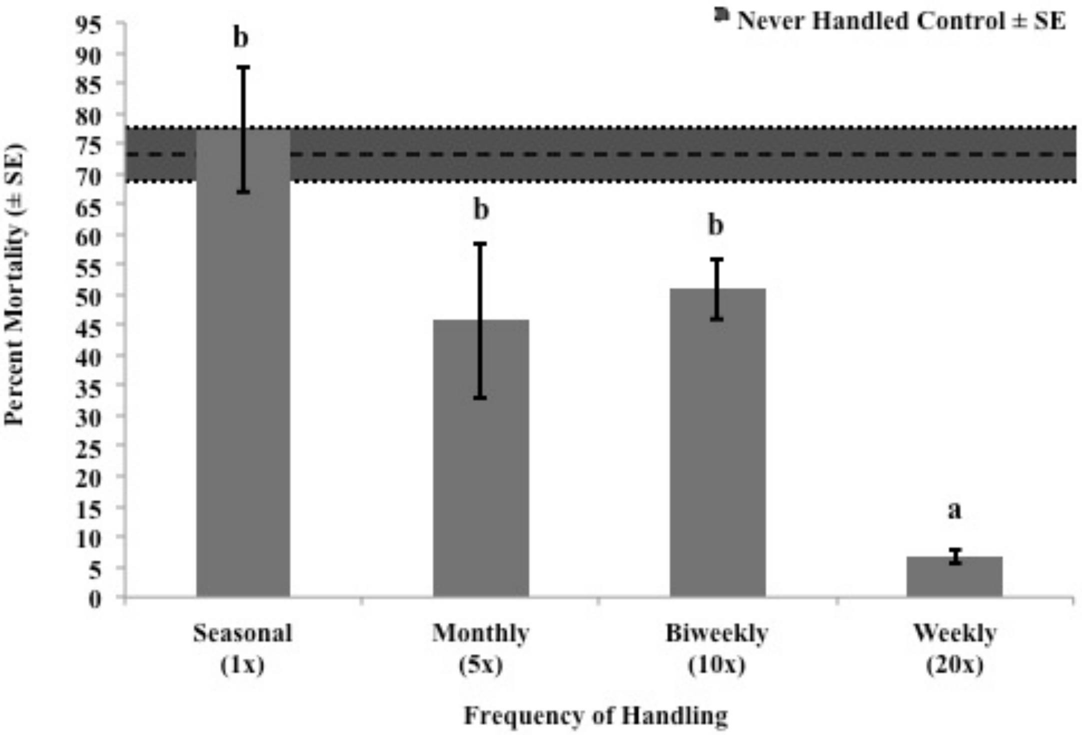

Figure 3.19. Percent mortality (± SE) of oysters grown in the OysterGro™ gear. The percent mortality of the four frequencies was also compared to the percent mortality of the never handled control, represented by the dotted lines (± SE). Grouping letters represent significant differences based on the analysis of the log10 transformed percent mortality. Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.288**	**0.463**	**0.030**	**0.004**

Table 3.36. ANOVA comparison of the mean log10 percent mortality from the two handling treatments to the mean log10 percent mortality from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-70:B-72, B-74).

		Biweekly	**Weekly**
Never	**Emersed**	**0.663**	**0.005**
Never	**Tumbled**	**0.030**	**0.016**

Table 3.37. Pairwise comparisons of the log10 percent mortality of the never handled control to the emersion and tumbled treatments within the biweekly and weekly frequencies, resultant of the significant p-values obtained from the ANOVA (Table 3.36). P-values less than or equal to 0.05 are significant. (See tables B-73:B-75).

Floating Bag Results

3.4.6 Shell Morphology

Shell Height

There was a significant interaction between the effects of handling frequency and handling treatment with respect to the mean final shell height of oysters grown in the floating bag gear (p=0.044)(Table 3.38). When comparing the mean final shell height values across the four test frequencies and two handling treatments, the oysters in weekly tumbled treatment exhibited a significantly smaller shell height than any of the other treatments (p≤0.042) except for the biweekly tumbled treatment (p=0.061)(Table B-76). In addition, oysters in both emersion and tumbled treatments for the seasonal frequency were significantly larger than oysters in both treatments for the biweekly and weekly frequencies (p≤0.042)(Fig. 3.20). The shell height values for the four handling frequencies and two handling treatments were also compared to the mean final shell height values from the never handled control (Table 3.39, Table B-77, B-78, B-80, B-82). In this case the shell heights of the oysters subjected to the monthly tumbled treatment (p=0.046), and shell height values from both treatments in the biweekly and weekly frequencies were significantly smaller than the shell heights of the oysters in the never handled control (p≤0.035)(Table 3.40, Table B-79, B-81, B-83).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	855.086	3	285.029	25.881	0.000
TREATMENT	73.596	1	73.596	6.683	0.021
FREQUENCY*TREATMENT	113.938	3	37.979	3.449	0.044
Error	165.193	15	11.013		

Table 3.38. Floating Bag Shell Height ANOVA

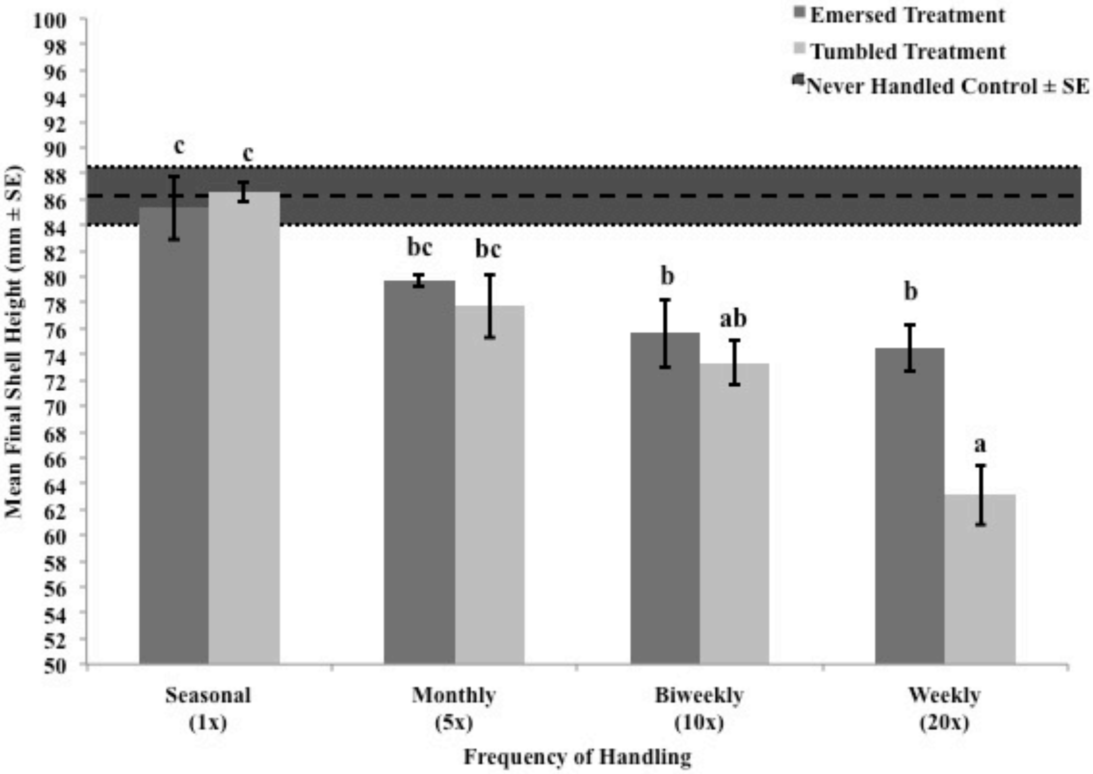

Figure 3.20. Interaction of handling frequency and handling treatment on mean final shell height (mm ± SE) of oysters grown in the floating bag gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final shell height values of a never handled control, represented by dotted lines (mm ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.901**	**0.046**	**0.014**	**0.002**

Table 3.39. ANOVA comparison of the mean shell height from the two handling treatments to the mean shell height from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-77, B-78, B-80 and B-82).

		Monthly	**Biweekly**	**Weekly**
Never	**Emersed**	**0.115**	**0.035**	**0.021**
Never	**Tumbled**	**0.046**	**0.015**	**0.002**

Table 3.40. Pairwise comparison of the shell height values of the never handled control to the emersion and tumbled treatments within the four tested frequencies resultant of the significant p-values obtained from the ANOVA (Table 3.39). P-values less than or equal to 0.05 are significant. (See tables B-79, B-81, and B-83).

Shell Length

There was a significant effect of both frequency and treatment on the mean final shell length of oysters grown in the floating bag gear ($p \leq 0.001$), but no interaction between these factors ($p=0.510$)(Table 3.41). A post-hoc pairwise comparison of the effects of handling frequency revealed that oysters subjected to a seasonal handling frequency had significantly longer shell lengths compared to any other handling frequency (Table B-84)(Fig. 3.21). There was no significant difference between oysters subjected to monthly or biweekly handling frequencies ($p=0.382$). However, both monthly and biweekly frequencies were significantly larger than oysters subjected to the weekly handling frequency, which produced oysters with the smallest mean final shell length values ($p \leq 0.014$). Across all frequencies the tumbled treatment produced oysters with significantly smaller shell lengths when compared to the emersion treatment ($p=0.001$)(Table 3.41).

The four handling frequencies and both handling treatments were further compared to the mean final shell length values from the never handled control. The comparison revealed that the oysters subjected to the monthly, biweekly and weekly frequencies were significantly smaller in shell length than oysters from the never handled control ($p \leq 0.002$)(Table 3.42, Table B-85, B-86, B-88, B-90). Where there was a significant difference between test frequency and never handled control, a pairwise comparison was made using Tukey's Honestly Significant Difference Test. Where the never handled control was different than the monthly, biweekly and the weekly frequencies it was revealed that the never handled control was significantly larger than both the emersion treatment and the tumbled treatment for each frequency (p≤0.014)(Table 3.43, Table B-87, B-89, B-91).

Analysis of Variance **Source**	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	341.708	3	113.903	30.311	0.000
TREATMENT	69.728	1	69.728	18.556	0.001
FREQUENCY*TREATMENT	9.090	3	3.030	0.806	0.510
Error	56.367	15	3.758		

Table 3.41. Floating Bag Shell Length ANOVA

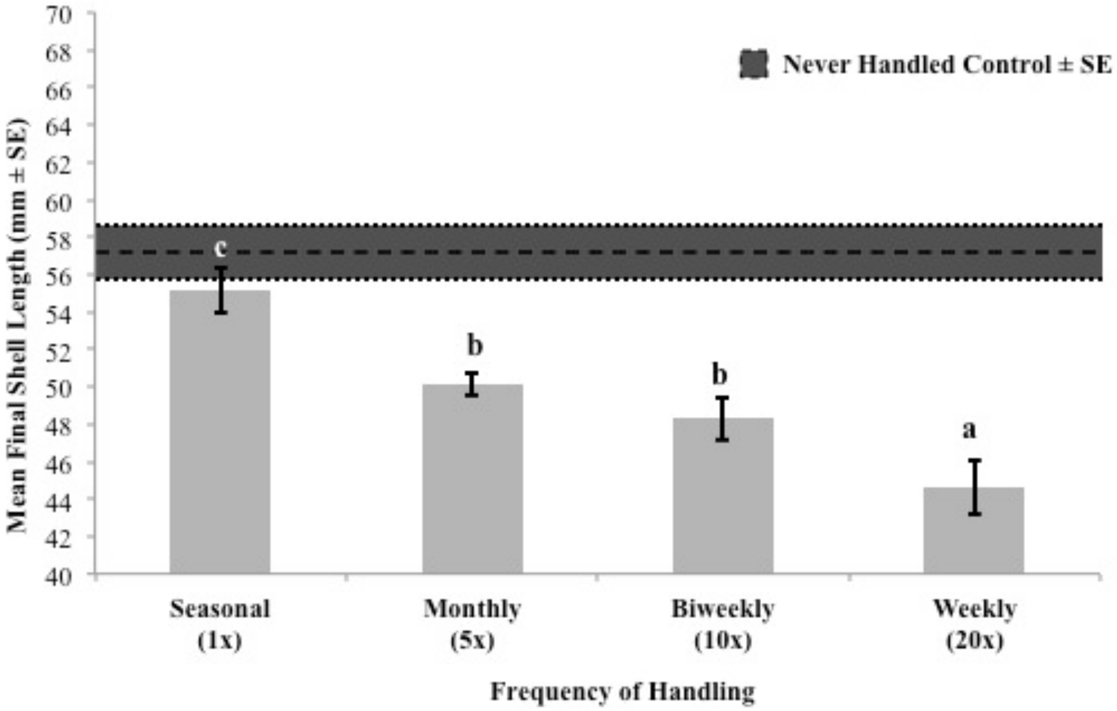

Figure 3.21. Effects of handling frequency on the values of mean final shell length (mm ± SE) of oysters grown in the floating bag gear. An additional comparison was made to the never handled control, represented by dotted lines (mm ± SE). Means with the same grouping letters are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.341**	**0.001**	**0.002**	**0.000**

Table 3.42. ANOVA comparison of the mean final shell length from the two handling treatments to the mean final shell length from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-85, B-86, B-88 and B-90).

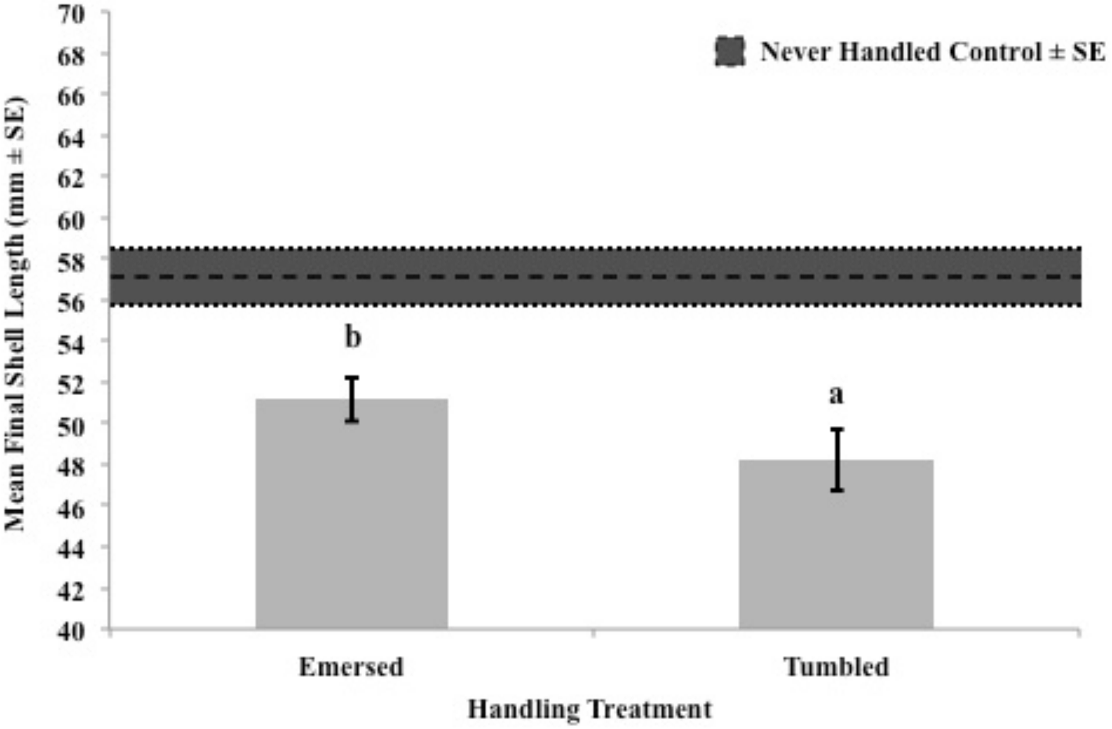

Figure 3.22. Effects of handling treatment on the values of mean final shell length (mm ± SE) of oysters grown in the floating bag gear. An additional comparison was made to the never handled control, represented by dotted lines (mm ± SE). Means with the same grouping letters are not significantly different.

		Monthly	**Biweekly**	**Weekly**
Never	**Emersed**	**0.004**	**0.014**	**0.001**
Never	**Tumbled**	**0.001**	**0.002**	**0.000**

Table 3.43. Pairwise comparison of the shell length values of the never handled control to the emersion and tumbled treatments within the monthly, biweekly and weekly frequencies, resultant of the significant p-values obtained from the ANOVA (Table 3.42). P-values less than or equal to 0.05 are significant. (See tables B-87, B-89, and B-91).

Shell Width

The measurement of shell width was significantly effected by the handling frequency (p=0.001) and the handling treatment (p=0.012), but not by any interaction between these factors (p=0.531)(Table 3.44). When shell width was compared across the four handling frequencies, the seasonal frequency produced oysters with a significantly larger average measurement than the biweekly and weekly frequencies (p≤0.026)(Table B-92)(Fig. 3.23). There were no other significant differences between the four frequencies. When shell width was compared across the two handling treatments (emersed and tumbled) every emersed treatment produced oysters significantly wider than every tumbled treatment (p=0.012)(Table 3.44)(Fig. 3.24).

When compared to the values of shell width from the never handled control, the biweekly and weekly frequencies produced significantly different results (p≤0.015)(Table 3.45, Table B-93:B-95, B-97). The never handled control was significantly wider than both the biweekly tumbled treatment (p=0.009) and the weekly tumbled treatment (p=0.015)(Table 3.46, Table B-96, B-98). However, the never handled control was not significantly different from the emersed treatment of either frequency (p≥0.058).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	32.293	3	10.764	9.470	0.001
TREATMENT	9.217	1	9.217	8.109	0.012
FREQUENCY*TREATMENT	2.608	3	0.869	0.765	0.531
Error	17.050	15	1.137		

Table 3.44. Floating Bag Shell Width ANOVA

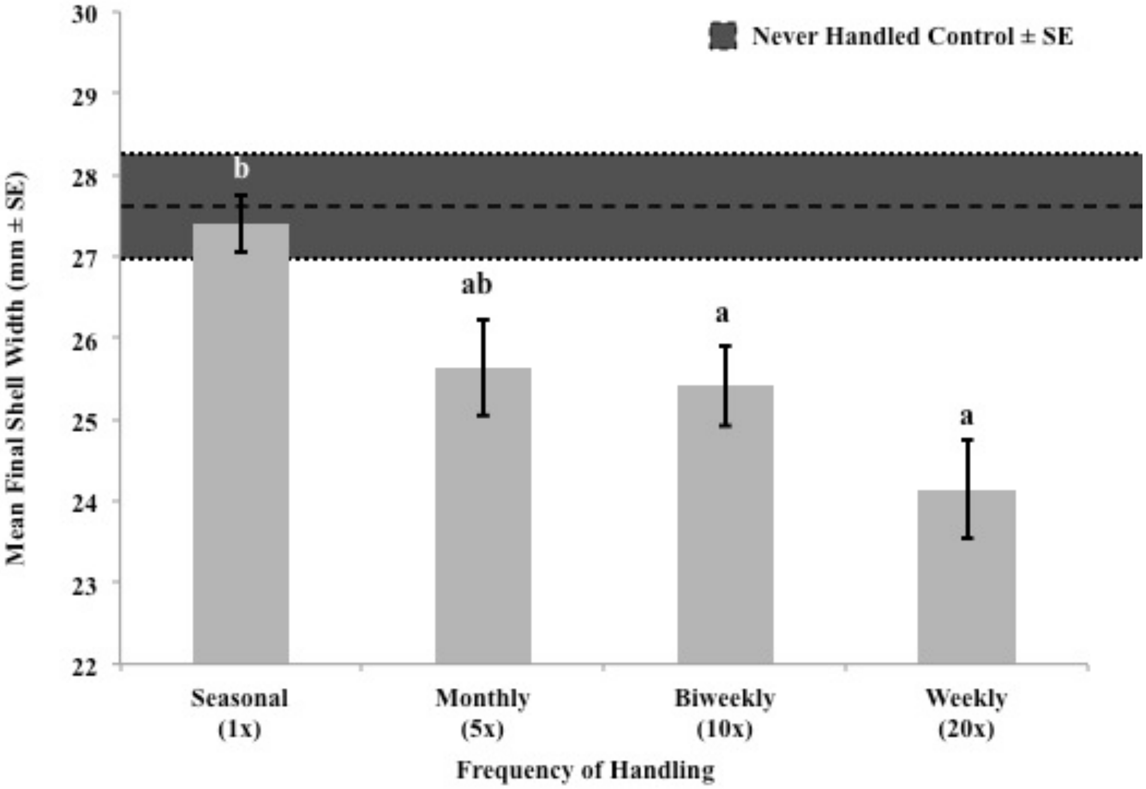

Figure 3.23. Effects of handling frequency on the values of mean final shell width (mm ± SE) of oysters grown in the floating bag gear. An additional comparison was made to the never handled control, represented by dotted lines (mm ± SE). Means with the same grouping letters are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.890**	**0.120**	**0.010**	**0.015**

Table 3.45. ANOVA comparison of the mean final shell width from the two handling treatments to the mean final shell width from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-93, B-95, and B-97).

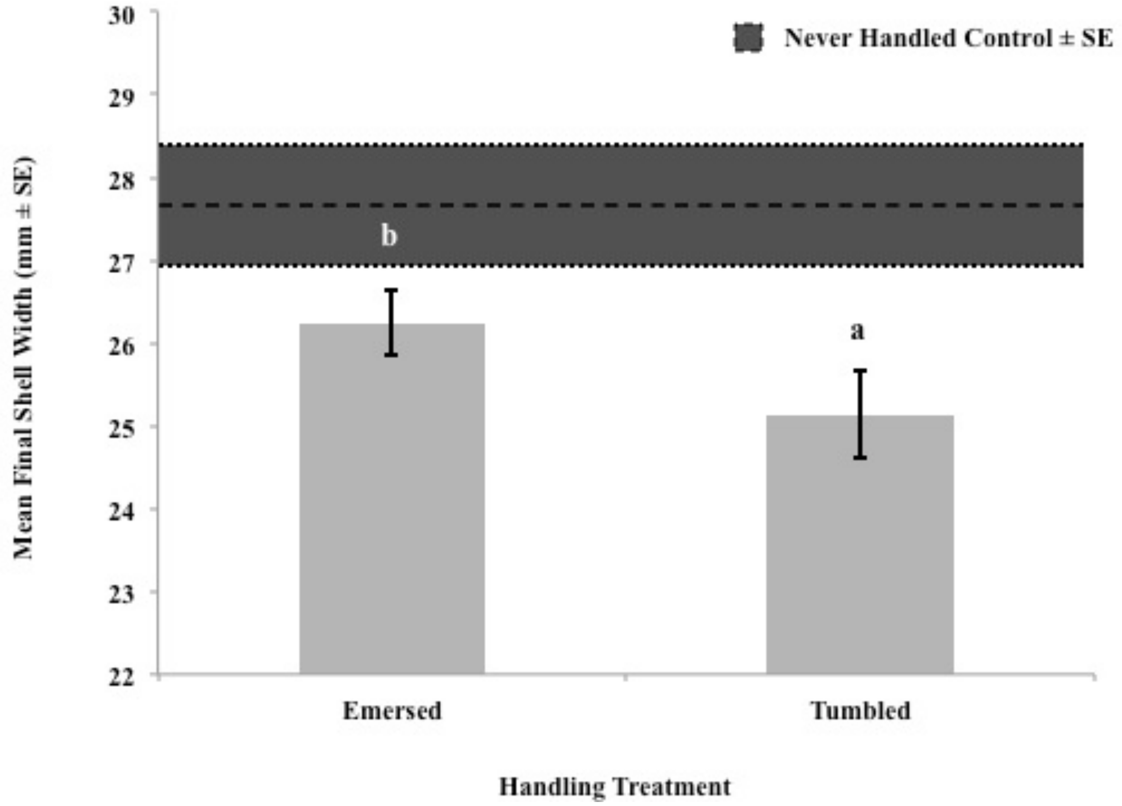

Figure 3.24. Effects of handling treatment on the values of mean final shell width (mm ± SE) of oysters grown in the floating bag gear. An additional comparison was made to the never handled control, represented by dotted lines (mm ± SE). Means with the same grouping letters are not significantly different.

		Biweekly	**Weekly**
Never	**Emersed**	**0.224**	**0.058**
Never	**Tumbled**	**0.009**	**0.015**

Table 3.46. Pairwise comparison of the shell width values of the never handled control to the emersion and tumbled treatments within the biweekly and weekly frequencies, resultant of the significant p-values obtained from the ANOVA (Table 3.45). P-values less than or equal to 0.05 are significant. (See tables B-96 and B-98).

Whole Wet Weight

There was a significant effect from the handling frequency (p=0.000) in terms of the whole wet weight of oysters grown in floating bags, but no significant effect from the handling treatment (p=0.052) or from an interaction between these factors (p=0.391)(Table 3.47). When comparing the four handling frequencies, the seasonal frequency produced oysters significantly larger than the oysters in either the biweekly or the weekly frequencies (p≤0.001)(Table B-99)(Fig. 3.25). There was no significant difference between the seasonal and the monthly frequency whole wet weight values (p=0.055). The monthly frequency, however, was significantly larger than the whole wet weight values from the weekly frequency (p=0.003). The whole wet weight from the biweekly frequency was not significantly different from that of the monthly or the weekly frequency (p≥0.089).

When the test frequencies were compared to the whole wet weight values of the never handled control, the biweekly and weekly frequencies were significantly different (p=0.001)(Table 3.48, Table B-100, B-101, B-103, B-105). Compared to these test frequencies, the never handled control values were significantly larger than both treatments (emersed and tumbled) within the biweekly and weekly frequencies (p≤0.007)(Table 3.49, Table B-102, B-104, B-106).

Analysis of Variance **Source**	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	1,776.929	3	592.310	18.115	0.000
TREATMENT	145.758	1	145.758	4.458	0.052
FREQUENCY*TREATMENT	105.042	3	35.014	1.071	0.391
Error	490.453	15	32.697		

Table 3.47. Floating Bag Whole Wet Weight ANOVA

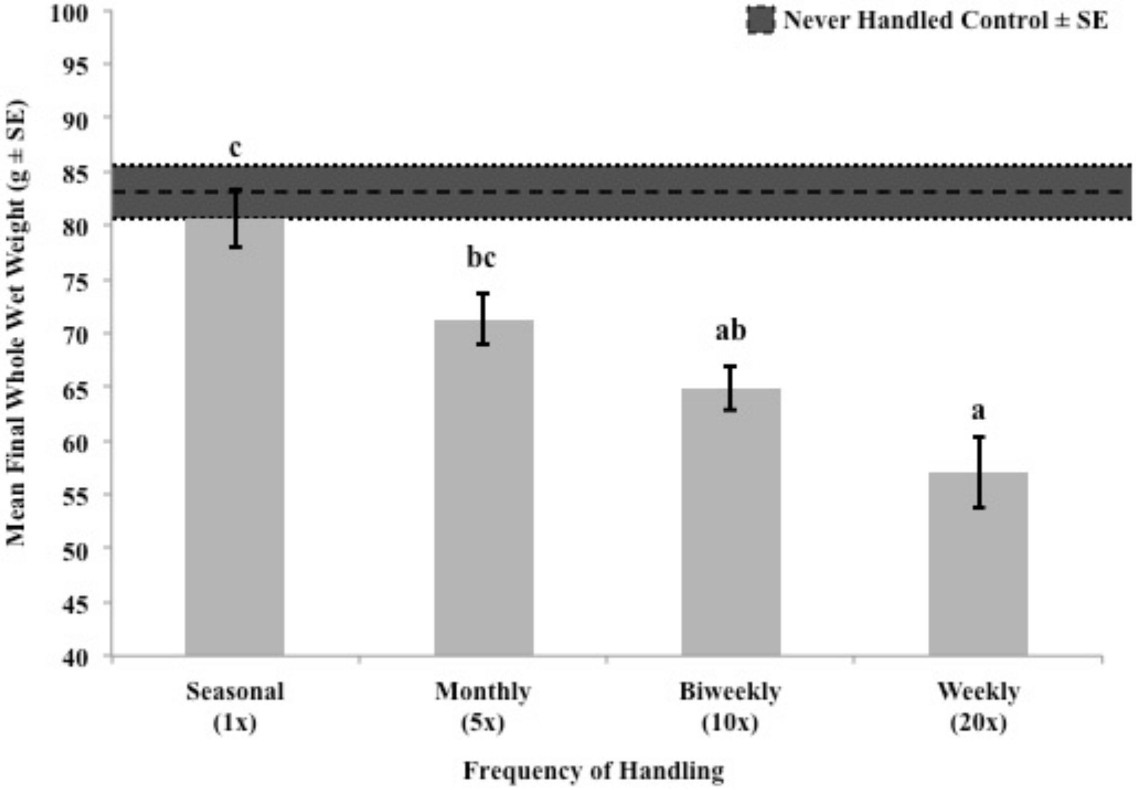

Figure 3.25. Effects of handling frequency on the values of mean final whole wet weight (g ± SE) of oysters grown in the floating bag gear. An additional comparison was made to the never handled control, represented by dotted lines (g ± SE). Means with the same grouping letters are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.828**	**0.054**	**0.001**	**0.001**

Table 3.48. ANOVA comparison of the mean final whole wet weight from the two handling treatments to the mean final whole wet weight from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-100, B-101, B-103, and B-105).

		Biweekly	**Weekly**
Never	**Emersed**	**0.007**	**0.003**
Never	**Tumbled**	**0.001**	**0.001**

Table 3.49. Pairwise comparison of the whole wet weight values of the never handled control to the emersion and tumbled treatments within the biweekly and weekly frequencies, resultant of the significant p-values obtained from the ANOVA (Table 3.48). P-values less than or equal to 0.05 are significant. (See tables B-104 and B-106).

Dry Shell Weight

There was a significant effect from handling frequency (p=0.000) on the mean final dry shell weight of oysters grown in floating bags (Table 3.50). There was no effect from handling treatment (p=0.119) or interaction between these factors (p=0.446). When the four handling frequencies were compared, the dry shell weight values from the seasonal frequency were significantly larger than the biweekly and weekly frequencies (p≤0.004)(Table B-107). The seasonal values were not significantly different from the monthly frequency (p=0.130), however, the oysters in the monthly frequency were significantly larger than those in the weekly frequency (p=0.002)(Fig. 3.26). The weekly frequency was significantly smaller than all other frequencies, seasonal, monthly, and biweekly (p≤0.050).

When the dry shell weight values of the tested handling frequencies were compared to those of the never handled control, it was revealed that only the biweekly and weekly frequencies were significantly different (p≤0.001)(Table 3.51, Table B-108:B-110, B-112). Where there were differences, the dry shell weight values for the never handled control were significantly larger than both the emersed and the tumbled treatment within each compared frequency (p≤0.001)(Table 3.52, Table B-111, B-113).

Analysis of Variance **Source**	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	766.171	3	255.390	16.818	0.000
TREATMENT	41.422	1	41.422	2.728	0.119
FREQUENCY*TREATMENT	42.774	3	14.258	0.939	0.446
Error	227.781	15	15.185		

Table 3.50. Floating Bag Dry Shell Weight ANOVA.

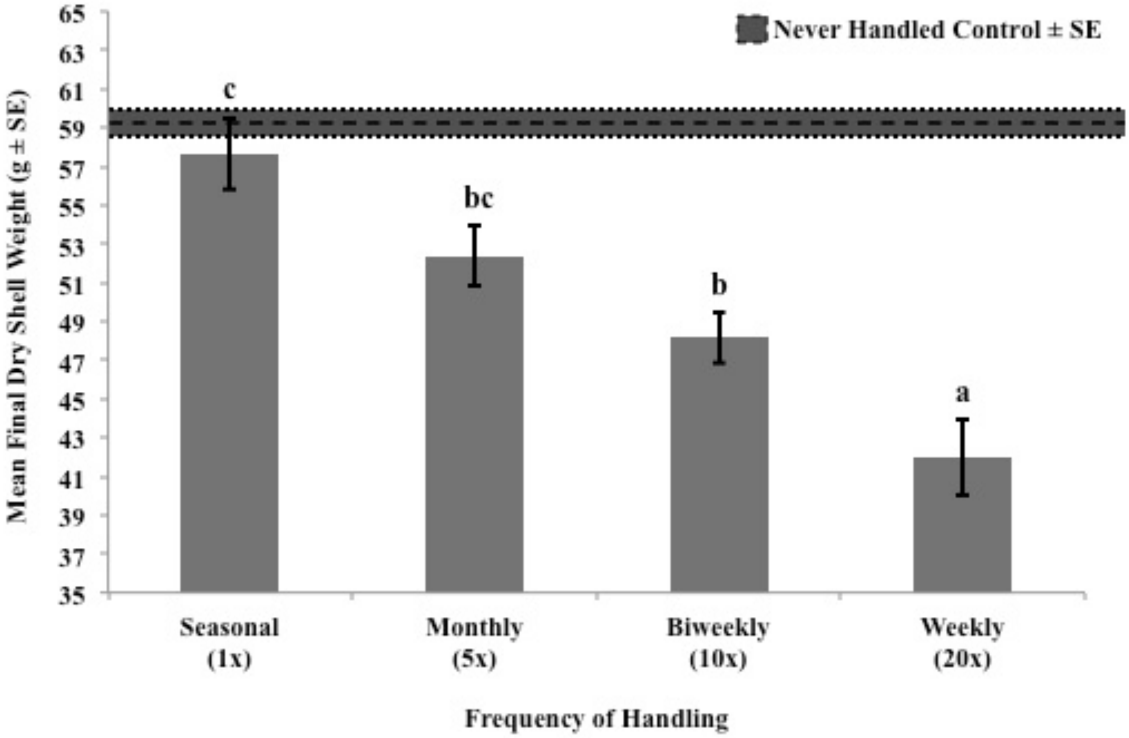

Figure 3.26. Mean final dry shell weight (g ± SE) of oysters grown in the floating bag gear and subjected to four handling frequencies, seasonal, monthly, biweekly and weekly. A secondary comparison is made to the values of dry shell weight from the never handled control, represented by the dotted lines (g ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.861**	**0.086**	**0.001**	**0.000**

Table 3.51. ANOVA comparison of the mean final dry shell weight from the two handling treatments to the mean final dry shell weight from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-108:B-110, and B-112).

		Biweekly	**Weekly**
Never	**Emersed**	**0.007**	**0.001**
Never	**Tumbled**	**0.001**	**0.000**

Table 3.52. Pairwise comparison of the dry shell weight values of the never handled control to the emersion and tumbled treatments within the biweekly and weekly frequencies, resultant of the significant p-values obtained from the ANOVA (Table 3.51). P-values less than or equal to 0.05 are significant. (See tables B-111 and B-113).

Dry Tissue Weight

There was a significant effect from handling frequency (p=0.021) on the mean final dry tissue weight of oysters grown in the floating bag gear (Table 3.53). There was no significant effect from handling treatment (p=0.230) or interaction between these factors (p=0.255). When the dry tissue weight values for the four tested frequencies were compared, the only significant difference was between the seasonal frequency and the weekly frequency (Fig. 3.27). In this case the seasonal frequency produced oysters that had dry tissue weights that were significantly larger than the dry tissue weights of those submitted to a weekly handling frequency (p=0.014)(Table B-114).

When the dry tissue weights of the tested frequencies were compared to those of the never handled control, only the weekly frequency showed a significant difference (p=0.012)(Table 3.54, Table B-115:B-118). In this case the dry tissue weights from the never handled control were only significantly larger than the weekly tumbled treatment (p=0.011), showing no difference from the emersed treatment (p=0.084)(Table 3.55, Table B-119).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.275	3	0.092	4.393	0.021
TREATMENT	0.033	1	0.033	1.565	0.230
FREQUENCY*TREATMENT	0.094	3	0.031	1.502	0.255
Error	0.313	15	0.021		

Table 3.53. Floating Bag Dry Tissue Weight ANOVA.

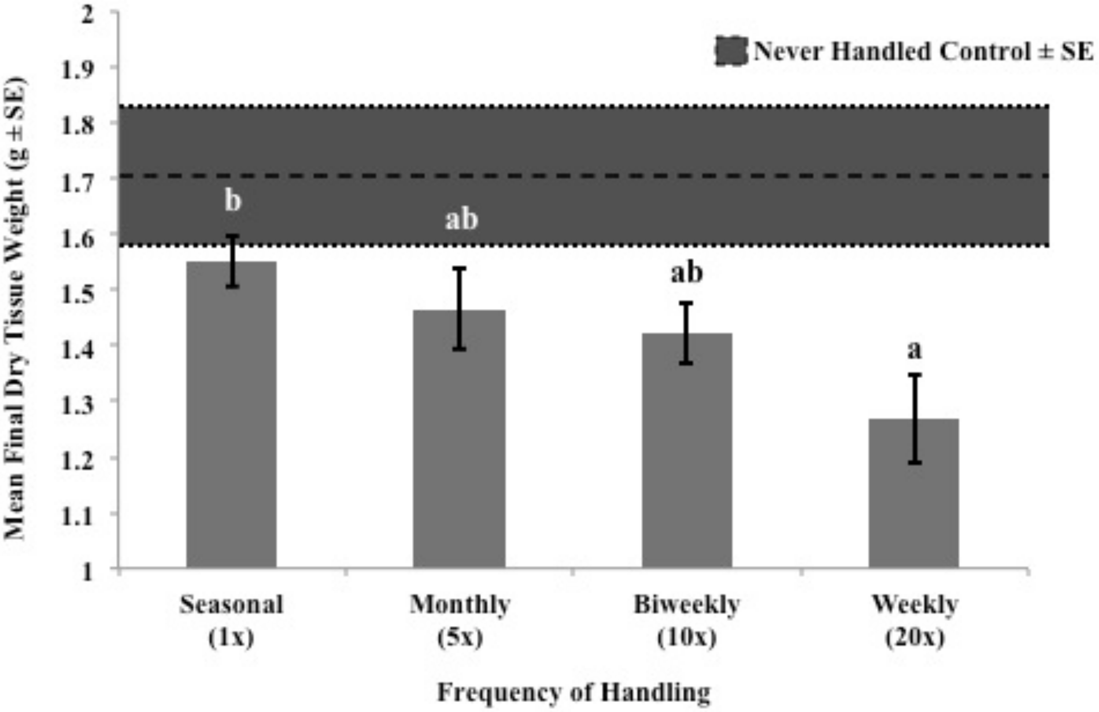

Figure 3.27. Mean final dry tissue weight (g ± SE) of oysters grown in the floating bag gear and subjected to four handling frequencies, seasonal, monthly, biweekly and weekly. A secondary comparison is made to the values of dry tissue weight from the never handled control, represented by the dotted lines (g ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.446**	**0.291**	**0.119**	**0.012**

Table 3.54. ANOVA comparison of the mean final dry tissue weight from the two handling treatments to the mean final dry tissue weight from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-115:B-118).

		Weekly
Never	**Emersed**	**0.084**
Never	**Tumbled**	**0.011**

Table 3.55. Pairwise comparison of the dry tissue weight values of the never handled control to the emersion and tumbled treatments within the weekly frequency resultant of the significant p-values obtained from the ANOVA (Table 3.54). P-values less than or equal to 0.05 are significant. (See table B-119).

Cup

There was a significant effect from handling frequency (p=0.036) on the mean final cup ratio of oysters grown in the floating bag gear, where the cup ratio was the ratio of the shell width to shell height (Table 3.56). There was no significant effect from handling treatment (p=0.947) or interaction between the factors (p=0.171). When the cup ratio values for the four tested frequencies were compared, the only significant difference was between the seasonal frequency and the weekly frequency. In this case the seasonal frequency produced oysters that had cup ratios that were significantly smaller than the cup ratios of those submitted to a weekly handling frequency (p=0.047)(Table B-120)(Fig. 3.28). When the cup ratios of the tested treatments were compared to those of the never handled control, there were no significant differences (p≥0.185)(Table 3.57, B-121:B-124).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.003	3	0.001	3.674	0.036
TREATMENT	0.000	1	0.000	0.004	0.947
FREQUENCY*TREATMENT	0.002	3	0.001	1.914	0.171
Error	0.005	15	0.000		

Table 3.56. Floating Bag Cup Ratio ANOVA.

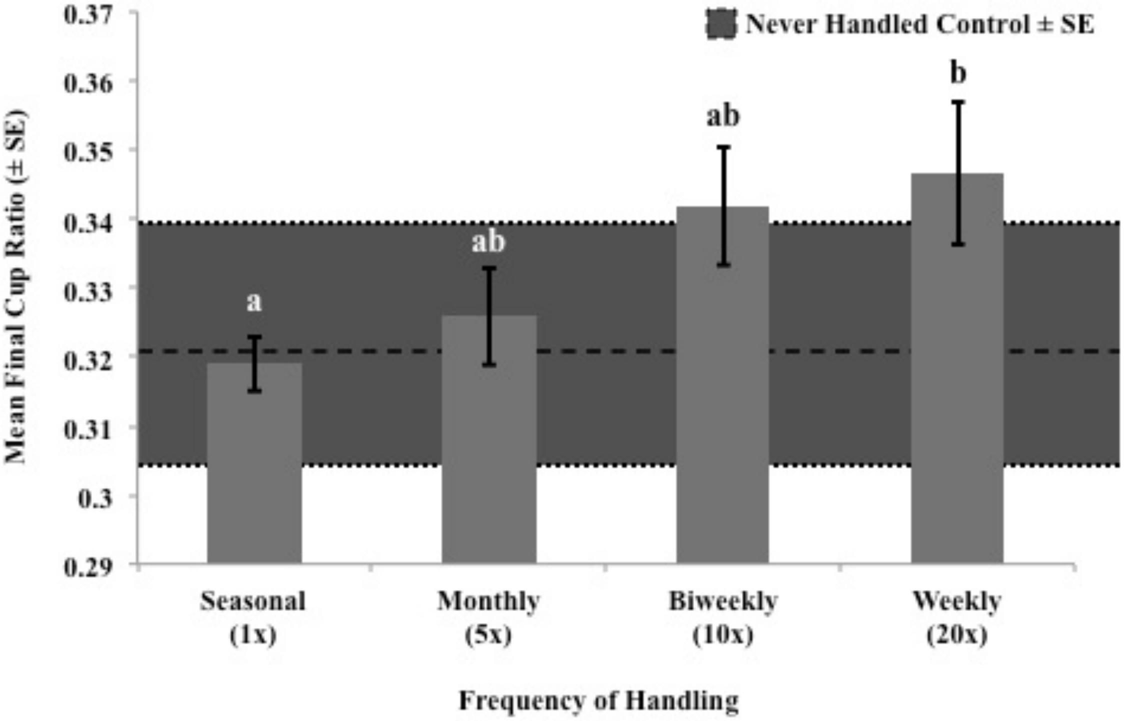

Figure 3.28. Mean final cup ratio (± SE) of oysters grown in the floating bag gear and subjected to four handling frequencies, seasonal, monthly, biweekly and weekly. A secondary comparison is made to the cup ratio from the never handled control, represented by the dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.860**	**0.898**	**0.411**	**0.185**

Table 3.57. ANOVA comparison of the mean final cup ratio from the two handling treatments to the mean final cup ratio from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-121:B-124).

Fan

There were no significant effects from handling frequency (p=0.874), handling treatment (p=0.171) or interaction between these factors (p=0.186) on the fan ratio (shell length to shell height) of oysters grown in floating bags (Table 3.58)(Fig. 3.29). When the fan ratio values of the tested variables were compared to the fan ratio values of the never handled control, there was only a significant difference between the control and the monthly frequency (p=0.050)(Table 3.59, Table B-125, B-126, B-128, B-129). In this case the fan ratios within the never handled control were significantly larger than the fan ratios of the monthly tumbled treatment (p=0.044)(Table 3.60, Table B-127). There were no other significant differences between the never handled controls and any other treatment at any other frequency.

Analysis of Variance **Source**	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.000	3	0.000	0.230	0.874
TREATMENT	0.001	1	0.001	2.063	0.171
FREQUENCY*TREATMENT	0.003	3	0.001	1.825	0.186
Error	0.008	15	0.001		

Table 3.58. Floating Bag Fan Ratio ANOVA.

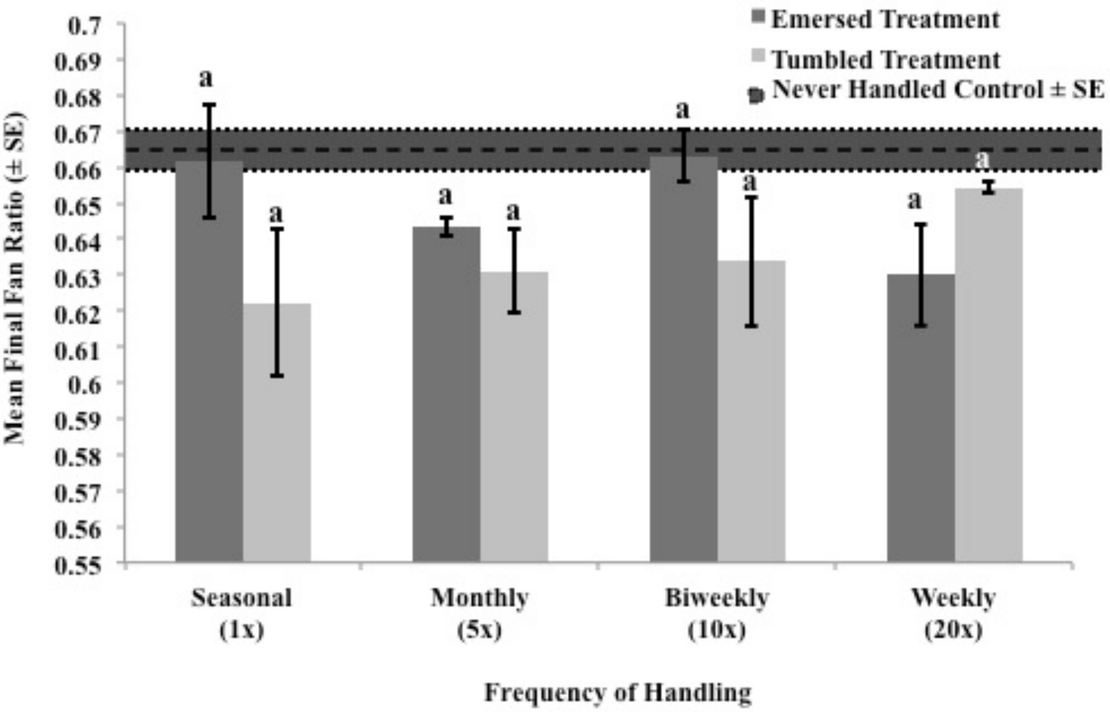

Figure 3.29. Mean final fan ratios (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the floating bag gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final fan ratio values of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.169**	**0.050**	**0.189**	**0.116**

Table 3.59. ANOVA comparison of the mean final fan ratio from the two handling treatments to the mean final fan ratio from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-125, B-126, B-128, and B-129).

		Monthly
Never	**Emersed**	**0.205**
Never	**Tumbled**	**0.044**

Table 3.60. Pairwise comparison of the fan ratio values of the never handled control to the emersion and tumbled treatments within the monthly frequency, resultant of the significant p-values obtained from the ANOVA (Table 3.59). P-values less than or equal to 0.05 are significant. (See table B-127).

3.5.2 Consistency of Shell Morphology

Coefficients of Variation

There was no significant effect from handling frequency, handling treatment or interaction between these factors ($p \geq 0.120$) on the coefficients of variation of shell height, shell length, shell width, whole wet weight, dry shell weight or dry tissue weight for oysters grown in the floating bag gear (Table 3.61, 3.63, 3.65, 3.68, 3.71, 3.73)(Fig. 3.30-3.35). When compared to the never handled control, there was no significant difference between the coefficient of variation for shell height or the coefficient of variation for shell length for the four handling frequencies and two handling treatments ($p \geq 0.120$)(Table 3.62 and 3.64, Table B-130:B-133 and B-134:B-137).

In the coefficients of variation for shell width and whole wet weight only the weekly frequency was significantly different when compared to the never handled control ($p \leq 0.49$)(Table 3.66 and 3.69; Table B-138:B-141 and B-143:B-146). Within the weekly frequency, the coefficient of variation for the never handled control was significantly larger than the tumbled treatments ($p \leq 0.045$)(Table 3.67 and 3.70; Table B-142 and B-147). In the remaining coefficients of variation, dry shell weight and dry tissue weight, there was no significant differences when compared to the values of the never handled control ($p \geq 0.069$)(Table 3.72 and 3.74; Table B-148:151 and B-152:B-155).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.001	3	0.000	0.461	0.713
TREATMENT	0.000	1	0.000	0.035	0.854
FREQUENCY*TREATMENT	0.000	3	0.000	0.111	0.953
Error	0.013	15	0.001		

Table 3.61. Floating Bag Coefficient of Variation for Shell Height ANOVA.

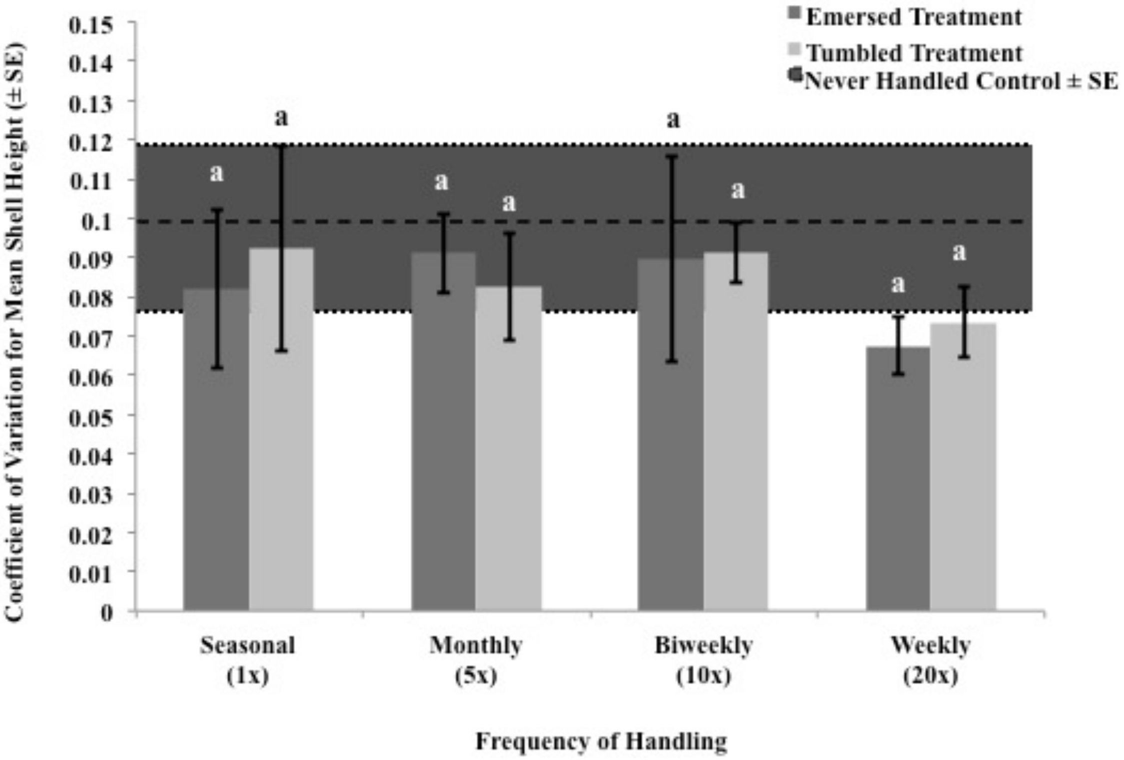

Figure 3.30. Mean coefficient of variation for final shell height (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the floating bag gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for shell height of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.893**	**0.814**	**0.966**	**0.379**

Table 3.62. ANOVA comparison of the coefficient of variation for shell height from the two handling treatments to the coefficient of variation for shell height from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-130:B-133).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.001	3	0.000	0.554	0.653
TREATMENT	0.002	1	0.002	2.718	0.120
FREQUENCY*TREATMENT	0.000	3	0.000	0.054	0.983
Error	0.010	15	0.001		

Table 3.63. Floating Bag Coefficient of Variation for Shell Length ANOVA.

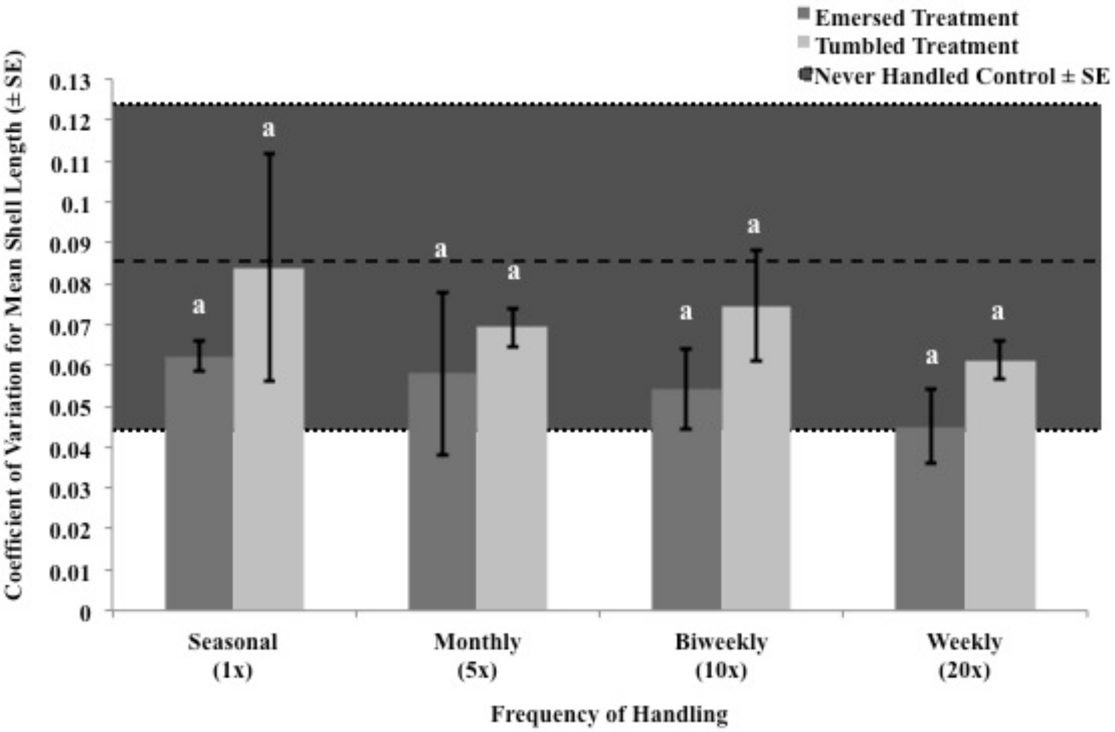

Figure 3.31. Mean coefficient of variation for final shell length (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the floating bag gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for shell length of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	Monthly	Biweekly	Weekly
P-value of Comparison to Never Handled Control	**0.821**	**0.782**	**0.697**	**0.591**

Table 3.64. ANOVA comparison of the coefficient of variation for shell length from the two handling treatments to the coefficient of variation for shell length from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-134:B-137).

Analysis of Variance **Source**	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.004	3	0.001	0.570	0.643
TREATMENT	0.000	1	0.000	0.115	0.739
FREQUENCY*TREATMENT	0.008	3	0.003	1.169	0.354
Error	0.035	15	0.002		

Table 3.65. Floating Bag Coefficient of Variation for Shell Width ANOVA.

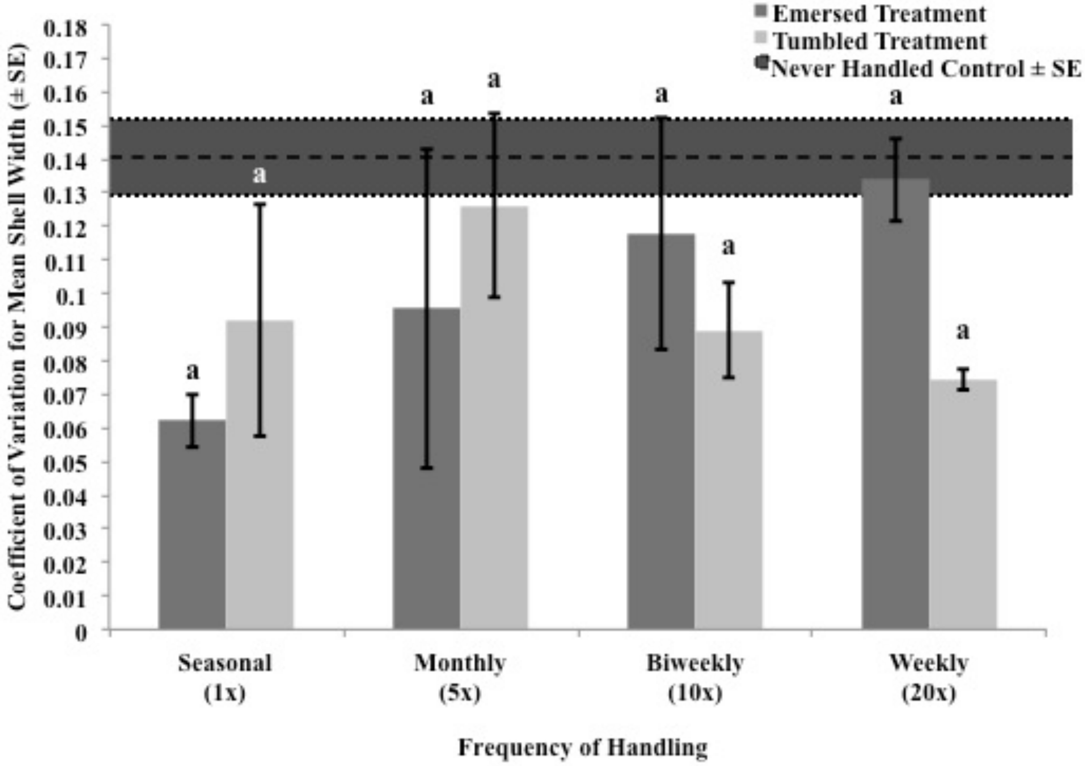

Figure 3.32. Mean coefficient of variation for final shell width (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the floating bag gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for shell width of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.103**	**0.626**	**0.334**	**0.024**

Table 3.66. ANOVA comparison of the coefficient of variation for shell width from the two handling treatments to the coefficient of variation of shell width from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-138:B-141).

		Weekly
Never	**Emersed**	**0.898**
Never	**Tumbled**	**0.026**

Table 3.67. Pairwise comparison of the coefficient of variation of shell width of the never handled control to the emersion and tumbled treatments within the weekly frequency, resultant of the significant p-values obtained from the ANOVA (Table 3.66). P-values less than or equal to 0.05 are significant. (See table B-142).

Analysis of Variance					
Source	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.002	3	0.001	0.137	0.936
TREATMENT	0.002	1	0.002	0.310	0.586
FREQUENCY*TREATMENT	0.005	3	0.002	0.349	0.790
Error	0.078	15	0.005		

Table 3.68. Floating Bag Coefficient of Variation for Whole Wet Weight ANOVA.

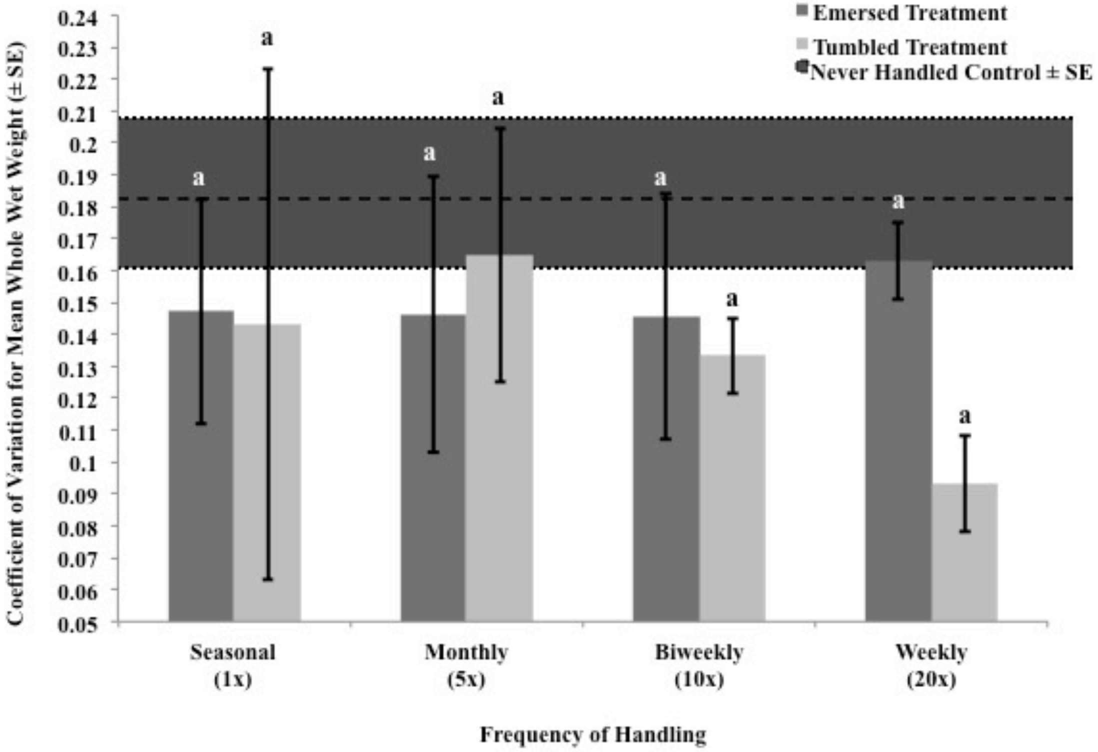

Figure 3.33. Mean coefficient of variation for final whole wet weight (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the floating bag gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for whole wet weight of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.839**	**0.780**	**0.432**	**0.049**

Table 3.69. ANOVA comparison of the coefficient of variation for whole wet weight from the two handling treatments to the coefficient of variation for whole wet weight from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-143:B-146).

		Weekly
Never	**Emersed**	**0.688**
Never	**Tumbled**	**0.045**

Table 3.70 Pairwise comparison of the coefficient of variation for whole wet weight of the never handled control to the emersion and tumbled treatments within weekly tested frequency, resultant of the significant p-values obtained from the ANOVA (Table 3.69). P-values less than or equal to 0.05 are significant. (See table B-147).

Analysis of Variance **Source**	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.005	3	0.002	0.427	0.737
TREATMENT	0.000	1	0.000	0.038	0.849
FREQUENCY*TREATMENT	0.011	3	0.004	0.863	0.482
Error	0.062	15	0.004		

Table 3.71. Floating Bag Coefficient of Variation for Dry Shell Weight ANOVA.

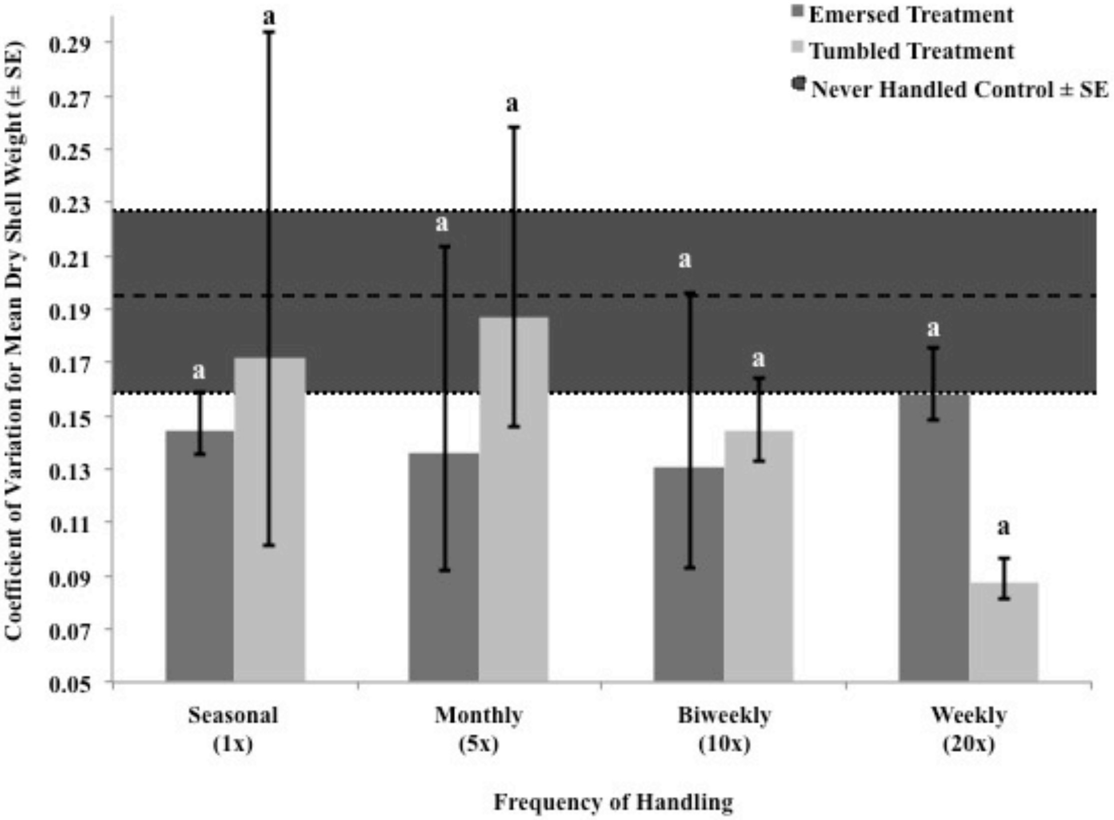

Figure 3.34. Mean coefficient of variation for final dry shell weight (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the floating bag gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for dry shell weight of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.753**	**0.572**	**0.353**	**0.069**

Table 3.72. ANOVA comparison of the coefficient of variation for dry shell weight from the two handling treatments to the coefficient of variation for dry shell weight from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-148:B-151).

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.006	3	0.002	0.259	0.854
TREATMENT	0.004	1	0.004	0.447	0.514
FREQUENCY*TREATMENT	0.008	3	0.003	0.344	0.794
Error	0.123	15	0.008		

Table 3.73. Floating Bag Coefficient of Variation for Dry Tissue Weight ANOVA.

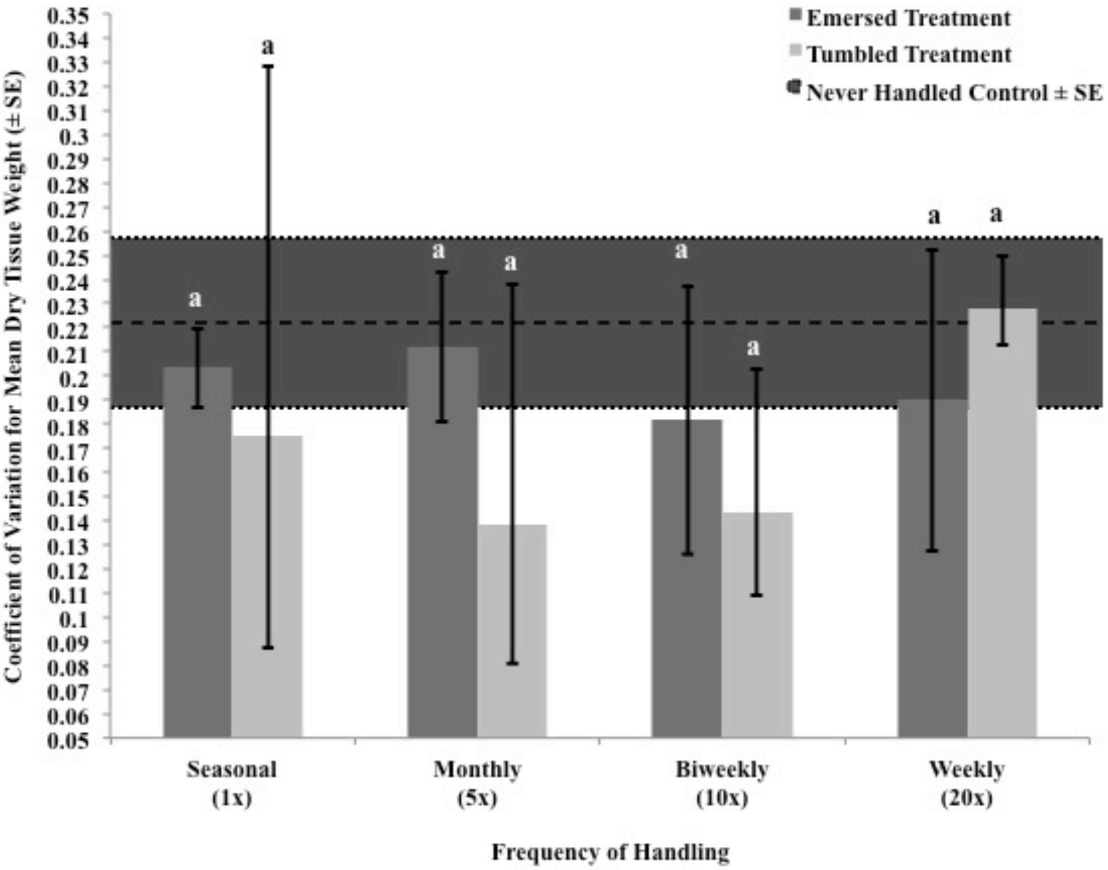

Figure 3.35. Mean coefficient of variation for final dry tissue weight (± SE) of the emersion treatment and the tumbled treatment across four handling frequencies and grown in the floating bag gear. The four test frequencies (seasonal, monthly, biweekly and weekly) were also compared the mean final coefficient of variation for dry tissue weight of a never handled control, represented by dotted lines (± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.839**	**0.373**	**0.470**	**0.837**

Table 3.74. ANOVA comparison of the coefficient of variation for dry tissue weight from the two handling treatments to the coefficient of variation for dry tissue weight from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-152:B-155).

3.5.3 Biofouling Removal Time

There was a significant interaction between handling frequency and handling treatment on the biofouling removal time of oysters grown in floating bag gear (p=0.021)(Table 3.75). The seasonal tumbled treatment required significantly more biofouling removal time than every other tumbled treatment (p≤0.006). The biweekly and weekly emersed treatments required significantly less biofouling removal time than the seasonal tumbled treatment (p≤0.023)(Table B-156)(Fig. 3.36). There was no significant difference between the monthly emersed treatment and any of the other emersed or tumbled treatments (p≥0.105).

When compared to the biofouling removal time of the never handled control, the monthly, biweekly and weekly frequencies showed significant differences (p≤0.003)(Table 3.76, Tables B-158, B-160, B-162). In each case, the oysters in the never handled control required significantly more biofouling removal time than either the emersed or the tumbled treatment in the monthly, biweekly and weekly frequencies (p≤0.033)(Table 3.77, Tables B-159, B-161, B-163).

Analysis of Variance Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
FREQUENCY	5,497.070	3	1,832.357	12.274	0.000
TREATMENT	48.039	1	48.039	0.322	0.579
FREQUENCY*TREATMENT	1,966.754	3	655.585	4.391	0.021
Error	2,239.333	15	149.289		

Table 3.75. Floating Bag Biofouling Removal Time ANOVA

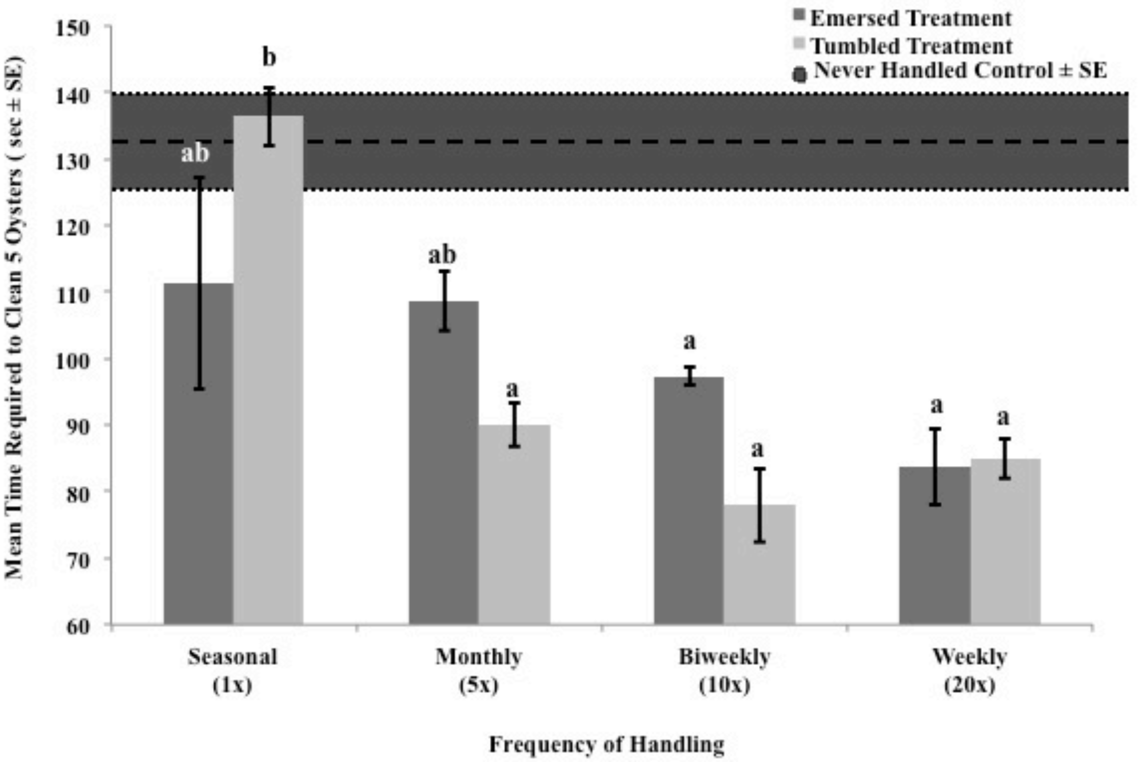

Figure 3.36. Interaction of handling frequency and handling treatment on mean biofouling removal time (sec ± SE) of oysters grown in the floating bag gear. The four test frequencies (seasonal, monthly, biweekly and weekly) and two handling treatments (emersed and tumbled) were also compared the mean biofouling removal time values of a never handled control, represented by dotted lines (sec ± SE). Means with the same grouping letter are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.254**	**0.003**	**0.001**	**0.003**

Table 3.76. ANOVA comparison of the mean time required to clean 5 oysters from the two handling treatments to the mean time required to clean 5 oysters from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-157, B-158, B-160, and B-162).

		Monthly	**Biweekly**	**Weekly**
Never	**Emersed**	**0.033**	**0.006**	**0.004**
Never	**Tumbled**	**0.002**	**0.001**	**0.007**

Table 3.77. Pairwise comparison of the mean biofouling removal time for the never handled control to the emersion and tumbled treatments within the four tested frequencies, resultant of the significant p-values obtained from the ANOVA (Table 3.76). P-values less than or equal to 0.05 are significant. (See tables B-159, B-161 and B-163).

3.5.4 Percent Mortality

In order to achieve a distribution that approximated normality as reported in a Shapiro-Wilk Test of Normality, the data for the percent mortality was log10 transformed. Within the log10 transformed percent mortality, there was a significant effect from both the handling frequency (p=0.039) and the handling treatment (p=0.015), but no interaction between these factors (p=0.658)(Table 3.78). The ANOVA of the log10 percent mortality indicated a significant effect (p=0.039, Table 3.78), however, when a pairwise comparison was conducted using a Tukey's HSD Test, no significant p-values were revealed (p≥0.063)(Table B-164). Multiple comparisons or multiple testing problems can occur when one considers a set of statistical inferences simultaneously. This can result from including confidence intervals that fail to include their corresponding population parameters or hypothesis tests that incorrectly reject the null hypothesis.

When comparing handling treatments, the tumbled treatment had a significantly higher percent mortality than the emersed treatment (p=0.020)(Fig. 3.38). Percent mortality was further compared to the percent mortality of the never handled control. This comparison revealed that there were no significant differences between the log10 percent mortality of the never handled control and the log10 percent mortality of any of the tested handling treatments at any of the tested handling frequencies (p≥0.458)(Table 3.79, Table B-165:B-168).

Analysis of Variance **Source**	**Type III SS**	**Df**	**Mean Squares**	**F-Ratio**	**p-Value**
FREQUENCY	0.442	3	0.147	3.580	0.039
TREATMENT	0.308	1	0.308	7.491	0.015
FREQUENCY*TREATMENT	0.068	3	0.023	0.547	0.658
Error	0.617	15	0.041		

Table 3.78. Floating Bag Log10 Transformed Percent Mortality ANOVA

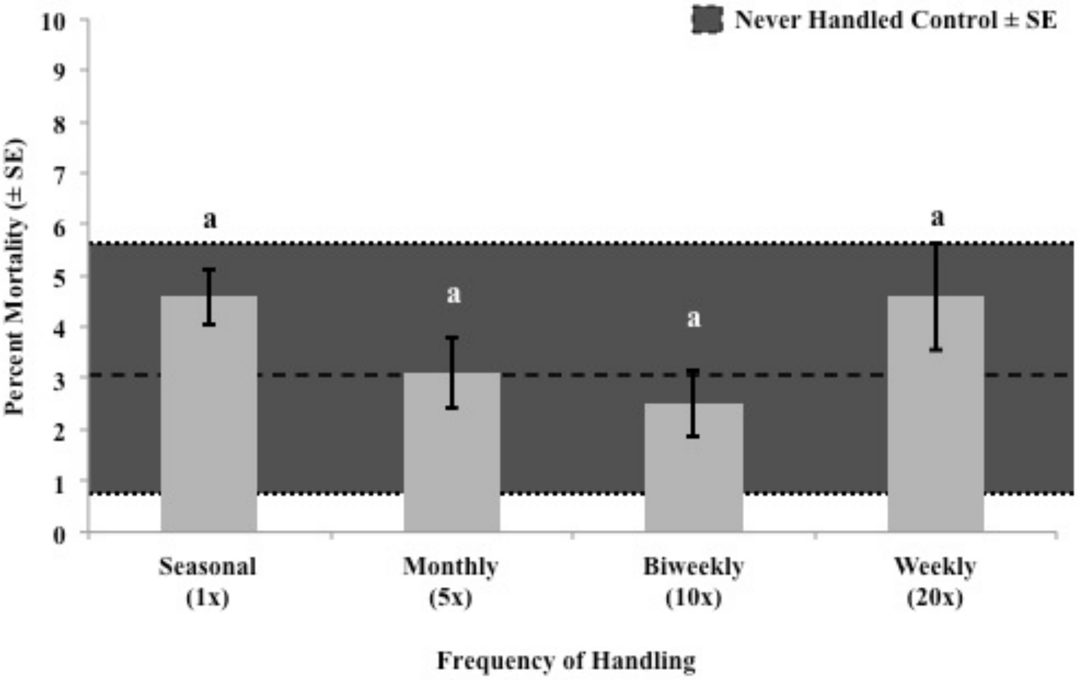

Figure 3.37. Effects of handling frequency on the values of percent mortality (± SE) of oysters grown in the floating bag gear. An additional comparison was made to the never handled control, represented by dotted lines (± SE). Grouping letters represent analysis of log10 transformed values where means of the same grouping letters are not significantly different.

	Seasonal	**Monthly**	**Biweekly**	**Weekly**
P-value of Comparison to Never Handled Control	**0.812**	**0.721**	**0.458**	**0.506**

Table 3.79. ANOVA comparison of the log10 transformed percent mortality from the two handling treatments to the log10 transformed percent mortality from the never handled control. P-values less than or equal to 0.05 are significant. (See tables B-165:B-168).

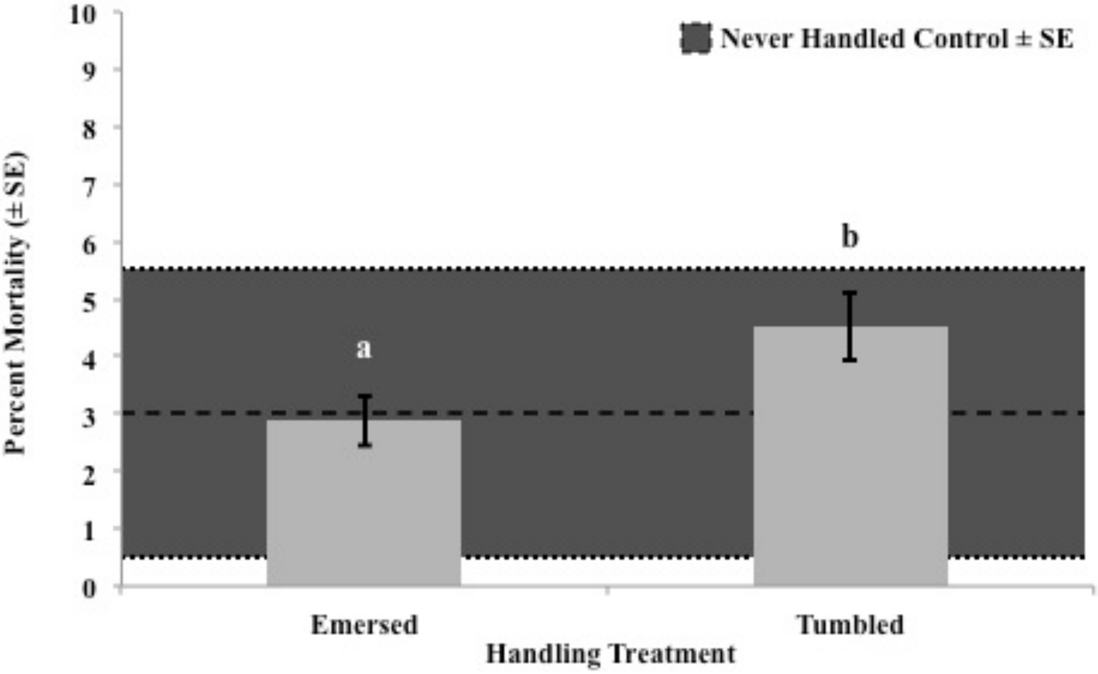

Figure 3.38. Effects of handling treatment on the values of percent mortality (± SE) of oysters grown in the floating bag gear. An additional comparison was made to the never handled control, represented by dotted lines (± SE) but there was no significant differences detected. Grouping letters represent analysis of log10 transformed values where means of the same grouping letters are not significantly different

3.5 Discussion

3.5.1 Overview

This study examined the potential for oyster quality to be improved by the combination of three handling treatments applied throughout the growing season in four different frequencies when compared to a never handled control. Key considerations during evaluation were final shell morphology (shell size and shape), consistency of shell morphology, reduction of biofouling removal time, and percent mortality. Across the two gear types used in the experiment, the oysters grown in the OysterGro™ gear were not significantly improved by the addition of any handling treatment at any handling frequency when compared to the values of the never handled control oysters. The floating bag oysters exhibited a significant reduction in shell metrics and biofouling from handling treatments that occurred at frequencies of monthly, biweekly or weekly. However, in each case, resulting oysters were not improved over oysters in the never handled control and additional handling was observed to incur more costs through increased labor than the potential gains in biofouling removal time and product consistency.

3.5.2 Shell Morphology

The data for the OysterGro™ gear showed that across the four tested frequencies (at both levels of handling) seven out of the eight tested measurements had no significant difference from the measurements of the never handled control. The only frequency level to differ from the control was the weekly tumbled treatment for the shell height measurements (Figs. 3.4). In this case the results produced oysters that were significantly smaller than all of the other treatments as well as smaller than the never handled control measurements. Since the growth and development of the test treatment OysterGro™ oysters was not significantly different from the measurements of the OysterGro™ never handled control, then there would be no morphological benefit from recommending the implementation of either handling treatment at any frequency level.

There was a general trend within the oysters grown in the floating bag gear: as handling frequency increased from seasonal to monthly to biweekly to weekly, the morphological measurements of the oysters became significantly reduced. This trend was also seen for the intensity of handling, as handling increased from "never handled and never tumbled" to "handled and emersed" to "handled and tumbled" the oyster morphological measurements decreased. Across every variable measurement of morphology there was no significant difference between the monthly treatment and the biweekly treatment. If a handling regime was a necessary choice over no handling, and the characteristic of value was based on the morphology of the oyster, the results from this experiment would suggest that the implementation of a seasonal or monthly frequency of handling would be most appropriate. Both the seasonal and monthly frequencies maintained a shell morphology that was not significantly different from the values measured from the never handled controls, while more frequent handling produced smaller oysters.

However, if a combined evaluation were made based on total benefits gained from measurements of morphology, biofouling removal time, and mortality, the monthly emersion treatment would be most highly recommended. The monthly emersion frequency preserved the survival, size and shape of the oysters while significantly reducing biofouling removal time over the never handled controls. At this level a farmer could maintain the best oyster product morphology and biofouling reduction with the least amount of labor investment.

3.5.3 Consistency of Shell Morphology

Both the OysterGro™ gear and the floating bag gear exhibited no significant differences from the effects of frequency or treatment across all coefficients of variation for any of the variables: height, length, width, whole wet weight, dry shell weight, or dry tissue weight. There were only two instances where, when compared to the never handled control, did any test treatment show a difference. In both instances it was within the floating bag gear where the weekly tumbled treatment showed a significantly reduced coefficient of variation when compared to the never handled control. The variables where this was exhibited were the coefficient of variation for shell width and also for whole wet weight (Figs. 3.33 and 3.34). In all other comparisons, the tested values were not significantly different from the never handled control.

Generally, these data can be interpreted as suggesting that in the cases of shell width and whole wet weight of oysters grown in floating bags, the application of a weekly tumbled treatment produced a group of oysters with less variation than floating bag oysters that were never handled. Although these results are statistically significant, the actual implications are such that a farmer would have to tumble their floating bag oysters every week in order to see any benefit towards improving consistency. The actual visually perceived difference this may translate into oyster metrics may be very little, since even at a biweekly tumbling treatment the coefficient of variation of shell width and whole wet weight was no different than the never handled control. The amount of increased labor and associated reductions in shell morphology from the application of a weekly tumbled treatment are not likely to be justified by this reduction in coefficient of variation.

3.5.4 Biofouling Removal Time

Although there was an effect of handling treatment on the results of biofouling removal time within the OysterGro™ gear, there was no benefit from the reduction in removal time gained by the tumbled treatment over the emersed treatment. The resulting times from both test treatments were not significantly different than those observed from the never handled control (Table 3.34, Fig. 3.18). Therefore the level of fouling on oysters grown in the OysterGro™ gear was not improved by the application of any handling treatments additional to the weekly on-farm anti-biofouling regimes applied during the growing season.

In the floating bag gear, increasing handling frequency to a monthly, biweekly or weekly frequency significantly reduced biofouling removal time when compared to the never handled control (Table 3.76-3.77, Fig. 3.37). However, the actual benefit gained in biofouling removal time reduction would be the same regardless of whether handling frequency was increased from a never handled control level to a monthly level, biweekly level or even a weekly level. Among these increased frequencies, there was also no benefit in the application of a tumbled treatment over an emersed treatment. Therefore, a monthly emersion treatment would achieve the maximum reduction in the amount of biofouling on floating bag oysters (and subsequent time spent cleaning oysters), while balancing the costs from the labor necessary to conduct the treatment.

3.5.5 Mortality

Within the OysterGro™ gear the observed mortality correlated with the amount of exposure oysters received during on farm anti-biofouling regiments. As the oysters were increasingly collected and brought to the hatchery the percent mortality decreased. The oysters that were left exposed in the sun during anti-biofouling regiments were the frequencies that exhibited the highest mortality rates. As shown in Figure 3.19, the weekly frequency had a significantly reduced percent mortality. Oysters in this frequency were collected each week and taken to the hatchery. Weekly oysters were never exposed to the on farm anti-biofouling regiments, resulting in the only frequency with a percent mortality under 10%. All other frequencies experienced anti-biofouling exposure at a minimum frequency of every other week. During these times, air temperatures were estimated to be in excess of 115°F (refer to data previously presented in Chapter 2). It can be assumed that 24 hr air exposure under such temperature conditions is fatal to oysters in OysterGro™ cages. Gear management strategies will need to be redesigned in order to reduce percent mortality to an acceptable level of no more than 10% per growing season.

In the floating bag gear it was generally observed that as handling frequency increased from seasonal to monthly to biweekly, the percent mortality decreased. There appeared to be a threshold for mortality at the biweekly level. When the frequency was further increased to a weekly level, the percent mortality increased to a level equivalent to that of the seasonal frequency. In every tested frequency there was a significant increase in mortality from the tumbling treatment when compared to the emersed treatment (Fig. 3.39). Although this alludes to tumbling as a source of mortality, across all treatments and frequencies, the mortality rates of the oysters grown in the floating bags were not significantly different than the never handled control (Fig. 3.38). Therefore, oysters grown within the floating bag gear would not receive any significant benefit from the application of either an emersed or tumbled treatment, however, if other benefits were revealed, there would be no harm from additional handling.

Chapter 4: Conclusions and Implications

4.1 Experiment 1: Importance of Tumbling Among Gear Types

As the Gulf shellfish industry begins to expand via incorporation of intensive aquaculture techniques, there is a need to evaluate the ability of differing intensive culture gears and practices to increase production efficiency and product quality. This study was designed to investigate the effects of incorporating a mechanical grader into the growout process as a method by which farmers might improve the morphology, value and productivity of their harvests. The production of an oyster that efficiently satisfies the demands of consumers and processors would increase the competitiveness of the nascent aquaculture sector in the Gulf of Mexico.

Experiment one investigated the effects of gear type selection and handling treatment (specifically tumbling) on shell morphology, consistency of shell morphology, biofouling removal and reduction of mortality. Oysters in the ALS gear and the floating bags grew larger shells and would ultimately achieve the shortest growout-to-harvest time period. LowPro™ and OysterGro™ gear produced harvested oysters with smaller shell metrics, but the oysters displayed better fan and cup ratios than those grown in either the ALS or the floating bags. While faster product turnover is a benefit resulting from accelerated growth, accelerated growth may also produce "banana" shaped oysters with reduced marketability.

The test hypothesis was validated by the data: as handling increased in intensity (never handled to emersed to tumbled), the shell height measurements across all gear types were affected. The intentions of the trial were to improve the shell morphology of oysters by increasing size and improving shape; however the effects of tumbling significantly reduced the shell height when compared to the never handled control. By reducing the overall appearance of size (often judged by shell height), the implementation of tumbling has the potential to positively influence the marketability of oysters that can be sold in market niches that place higher market values on oysters with smaller overall metrics, or in niches where processors frequently reject products with "banana" shapes. Thus, tumbling may be a means of controlling the accelerated growth exhibited from some gear types like ALS and floating bags in order to prevent malformed shells that are unacceptable to consumers. Alternatively, if handling is a prescribed routine, for instance in areas that receive high levels of biofouling and require frequent cleaning of growout bags, gear selection may compensate for lost growth associated with shell breakage. In this case, farmers can choose gear types that displayed accelerated growth rates (larger shell heights at harvest) in order to balance out the shell reducing effects of handling.

However, it must be noted that unless oysters are graded at some point before harvest, the benefits of shell size provided by the gear types would go unnoticed. It was observed that regardless of the significant differences in the shell heights of the oysters grown in ALS/floating bags versus oysters grown in LowPro™/OysterGro™, at the time of grading for harvest, all of the oysters were sorted into the 'marketable' category. Therefore, the growth advantages displayed within the four gear types did not affect the growth period if the oysters were only measured at harvest. Grading throughout the year would be necessary to capitalize on gear selection advantages identified in experiment one.

4.2 Experiment 2: Importance of the Frequency of Tumbling

The research conducted in experiment two was concentrated on evaluating the effects of handling on oysters grown in OysterGro™ floating cages and floating bag gear. The results obtained from experiment one suggested that commercial aquaculture of oysters had the potential to benefit from implementing handling treatments during the growing season. Where experiment one only tested monthly treatments of emersion or tumbling, the objectives of experiment two were designed to assess the effects of increasing frequencies on the shell morphology, consistency of shell morphology, biofouling removal and reduction of mortality of oysters grown in the OysterGro™ gear and the floating bag gear. By evaluating increasing levels of handling frequency the experiment sought to uncover thresholds of handling that would result in maximum beneficial growth and biofouling reduction or dictate the level at which detrimental effects would increase. Specifically, the trials investigated whether or not oysters could be tumbled too often or if constant handling was beneficial to producing a more marketable product.

Data collected from the OysterGro™ gear showed that regardless of the increase in handling frequency or handling treatment, the measurements across all variables of morphology were not different from the measurements of the never handled control and showed no significant variation between treatments. Significant variation only occurred between the weekly tumbled and the never handled control for the shell height and percent mortality of oysters. For shell height the weekly tumbled oysters were significantly smaller than the never handled control, which may have negative impacts on the marketability of the product if it is shown that consumers prefer larger oysters.

Variation in percent mortality showed that in the weekly tumbled treatment, where oysters never experienced on-farm anti-biofouling regimes, mortality was significantly reduced. However, mortality was reduced because the oysters were completely removed from the farm-site and placed in the shade, suggesting that future anti-biofouling methods may benefit from solar protection.

Within the floating bags, seven out of eight variables of morphology showed that an increase of handling frequency and handling treatment significantly reduced the six main shell morphology measurements when compared to the never handled controls. As seen in the OysterGro™ results, small final product morphology may result in reduced marketability if consumers desire an oyster with larger morphological dimensions. With this in mind, although the weekly tumbled treatment had the most impact to morphology, the never handled, seasonal and monthly treatments would be the best choices to maintain the largest oyster measurements.

In order to determine if handling frequency had effects on the consistency of shell morphology the coefficients of variation of the shell variables were assessed. The analysis of the coefficients of variation from both the OysterGro™ gear and the floating bag gear revealed that, across all six variables, there was no effect from either handling frequency or handling treatment. The only instance of significant variation was within the coefficients of variation for shell width and whole wet weight for the floating bag gear. Here, the results showed that the coefficient of variation for the weekly tumbled treatment in both cases was significantly less than that of the never handled control. These results indicate that weekly tumbling significantly reduced the amount of variation seen within the measurements of shell width and whole wet weight when compared to never handling floating bag oysters. Reducing the variation of whole wet weight may be useful in commercial production if the final product value is assigned by an estimation of weight. If harvested oysters were reliably consistent in whole wet weight, the estimation of harvest numbers could be quickly determined based on dockside weight. This could enable farmers to project sales and shipment sizes more quickly than counting individuals. However, further studies are needed to determine the cost effectiveness of utilizing handling treatments to manipulate oyster morphology over genetic selection trials.

With respect to the impact of handling frequency and handling treatment on biofouling removal, there was no significant effect from increased handling frequency or handling treatment in the OysterGro™ gear. Within the floating bag gear there was a trend that showed that as handling frequency increased, the biofouling removal time significantly decreased. Where the seasonal treatment had no significant variation from the never handled control, when the frequency increased to at least a monthly handling frequency the biofouling removal time was significantly reduced. Since the results showed that there was no further time reducing benefit from increasing the frequency to biweekly or weekly, the best recommended handling frequency for floating bags would be the monthly emersion treatment. The use of a mechanical grader additional to the purpose of sorting size variants was determined to have no significant benefit in terms of improving shell morphology, product consistency, or biofouling reduction.

In terms of identifying potential thresholds for mortality based on frequency and intensity of handling, the results from this experiment refuted the predicted outcome that increased handling frequency would result in increased mortality. The results for the

OysterGro™ gear showed that as handling frequency increased, the percent mortality decreased significantly. However, effects from environmental conditions may have masked potential effects from handling. The results from the floating bags also refuted the hypothesis for objective four, where there were no significant differences from the never handled control when comparing the effects from the increasing frequencies.

In summary, increasing the frequency of handling resulted in oysters that became smaller in final shell height measurements. There was no further benefit to handling oysters more frequently than once per month. Where biofouling removal was important, increasing frequency would generally reduce the time spent cleaning oysters, however, there was no further benefit to time reduction from handling more frequently than once per month. Biofouling removal time would be the only variable that would justify the use of a mechanical grader. Across all variables where handling treatment had a significant effect, tumbling created a significantly reduced result. Tumbling was shown to significantly reduce the coefficient of variation for whole wet weight, which could suggest more consistently weighted oysters. However, the potential benefit from this result is not likely to supersede the cost of labor needed to carry out the handling regiment. In terms of product consistency, the use of any single gear type (experiment two) versus multiple gear types (experiment one) within a farm setting would have greater influence on the product consistency than the effects of handling. At the time of stocking, hatchery produced oysters did not have variations in shell metrics that produced distinguishable differences in product consistency. Growing all oysters in the same gear design would better determine metrics at harvest than a situation where oysters from several gear types are tumbled to reduce variation.

With a high mortality, the OysterGro™ gear will need to have an adjusted on farm anti-biofouling regiment to produce a standard for ambient conditions found in the Gulf region. Investigations are also needed on the cost of labor for handling and biofouling removal when compared to the inclusion and exclusion of a mechanical grader. Lastly, investigations are most importantly needed on consumer preferences of size, shape and price of half-shell oysters. These values would enable a cost-efficiency rating of each handling frequency and treatment in order to determine where production costs meet profitability.

4.3 Gear Comparison and Final Recommendations

Gear Comparison

The results of this study can be used as extension tools to develop oyster aquaculture business plans as well as other oyster aquaculture related proposals. By investigating four different gear types, we now have data to show that certain gear types produce oysters with growth rate advantages and some produce oysters with shape advantages. Each gear type was commercially available at a different price point and required varying inputs of labor for maintenance. Therefore, based on the available investment a farmer chose to expend for gear and labor, appropriate recommendations can be made to suit budget and harvest goals. The following section contains a brief summary of the investments associated with each gear type as well as the mechanical grader. Further cost considerations of equipment are provided in Appendix C.

Adjustable Longline System (ALS)

The length of the entire run for this gear was 100m and within that length of cable the gear setup would accommodate a double line of approximately 200 ALS bags (BST Oyster Supply Company, 2009). Initial estimates of startup overhead (on a per acre basis) average ALS gear to cost approximately $38,545 with a projected annual harvest of 108K oysters. Annual labor estimates for an acre (8 runs) of ALS gear approximate 828 hours, which total, on average, $8,000 in labor wages (Pers. Comm, G. Chaplin, 2011).

Floating Bags (FB)

Initial overhead investments (on a per acre basis) estimate costs at approximately $28,165 with a projected annual harvest of 135K oysters. Annual labor estimates for an acre (5 runs of 200 bags in two rows of 100 bags each) of floating bag gear approximate 684 hours which total, on average, $6,840 in labor wages (Pers. Comm, G. Chaplin, 2011).

LowPro™ (LP)

Initial overhead investments (on a per acre basis) estimate LowPro™ gear to cost approximately $30,948 with a projected annual harvest of 86K oysters. Annual labor estimates for an acre (4 runs of 40 units per run) of LowPro™ gear approximate 608 hours, which total, on average, $6,080 in labor wages (Pers. Comm, G. Chaplin, 2011).

OysterGro™ (OG)

Initial overhead investments (on a per acre basis) estimate OysterGro™ gear to cost approximately $18,101 with a projected annual harvest of 65K oysters. Annual labor estimates for an acre (4 runs with 20 units per run) of OysterGro™ gear approximate 760 hours, which total, on average, $7,600 in labor wages (Pers. Comm, G. Chaplin, 2011).

QuickTube Sorter Mechanical Grader

The cost for the mechanical grader purchased for this study was $9,500 (Pers. Comm, G. Chaplin, 2011; Chesapeake Bay Oyster Co., 2009). This design uses a 1/2hp 120v motor that draws 41.58 amps. Based on the cost of electricity in Dauphin Island, AL. ($0.0752/kwh as of January 4, 2012), the mechanical grader costs $0.38 per hour to operate. On the day which all tumbling treatments from both experiments were processed, a total of 63 bags, the mechanical grader was operated for approximately 1.5 hrs, with an average time to process individual bags of 90 secs. The cost for operating the mechanical grader to process all tumbling samples was approximately $0.57. Using this processing cost as the maximum cost since all other tumbling days included fewer treatments, over the entire growing season the mechanical grader was used on 20 different occasions and the total cost of operation could be estimated at $11.40 (Table 4.1).

For 63 Tumbled Treatment Bags	**Seasonal**	**Monthly**	**Biweekly**	**Weekly**
Number of Times Tumbled	1	5	10	20
Hours of Grading During Project	1.5	7.5	15	30
Electricity Cost of Tumbler Use ($0.38/kWh)	$0.57	$2.85	$5.70	$11.40

Table 4.1. Cost of electricity required to power the mechanical grader during experimental processing.

The cost of electricity used during oyster tumbling/processing can be estimated for the four gear types on a per acre basis using the same methods as previously used for the estimation of costs incurred during the two experiments. Over the duration of the growing season (June 15th – November 8th), the time investment of tumbling can amount to as much as 40 hrs for an acre of gear for a single "session" of tumbling (Table 4.2).

This of course could be completed over several days or might require multiple graders, regardless, the 40 hrs would be required to process an acre of (ALS) gear one time. If processing were to occur as frequent as on a weekly basis this time investment would increase to as much as 800 hrs over the duration of the growing season (Table 4.3). The cost for weekly tumbling over the growing season would be approximately $300 for a one acre area of (ALS) gear. The investment in time alone would require significant considerations in terms of laborers hired or quantities of equipment used.

	Bags/run	**Grading Time(hrs) /run**	**Runs/acre**	**Grading Time(hrs) / acre**
ALS	200	5	8	40
Floating Bags	200	5	5	25
LowPro™	40*4=160	4	4	16
OysterGro™	20*6=120	3	4	12

Table 4.2. Time investment of the mechanical grader to process one acre of selected gear

For an Acre of Runs for Each Gear Type	**Seasonal**	**Monthly**	**Biweekly**	**Weekly**
ALS Hours of Grading	40	200	400	800
ALS Cost of Grading	**$15.20**	**$76.00**	**$152.00**	**$304.00**
Floating Bags Hours of Grading	25	125	250	500
Floating Bags Cost of Grading	**$9.50**	**$47.50**	**$95.00**	**$190.00**
LowPro™ Hours of Grading	16	80	160	320
LowPro™ Cost of Grading	**$6.08**	**$30.40**	**$60.80**	**$121.60**
OysterGro™ Hours of Grading	12	60	120	240
OysterGro™ Cost of Grading	**$4.56**	**$22.80**	**$45.60**	**$91.20**

Table 4.3. Time and monetary investment associated with the use of the mechanical grader over four frequencies throughout the growing season, for one acre of gear for each type. Based on $.38/kWH

Final Recommendations

Based on the results of this study, the floating bag gear type would be most highly recommended when considering the initial construction of an oyster aquaculture farm. Floating bag gear demonstrated the ability to produce oysters that had shell morphologies that were measured among the largest and most desirably shaped. Additionally, when considering a 10% mortality rate from the initial stocking to end harvest, the floating bag gear type can cost-effectively produce the most oysters when comparing a one-acre arrangement of each gear type (Table 4.4). The difference in monetary investment between one acre of any of the other gear types compared to one acre of floating bag gear can compensate for the additional cost in labor and utilities associated with using the mechanical grader throughout the growing season for the added benefit of biofouling reduction.

Gear Type	Stocking rate per unit/units per run/runs per acre	Acres of gear required to meet goal	Annual Hours of Labor	Year One Costs of Gear + Labor + Grader
Floating Bag	150 / 200 / 5	1	684	$44,005
ALS	75 / 200 / 8	1.2	993	$76,747
LowPro™	600 / 40 / 4	1.5	912	$87,753
OysterGro™	900 / 20 / 4	2	1520	$96,604

Table 4.4. Cost comparison of gear types under hypothetical production goal of 130,000 oysters at a labor cost of $10/hour and a mortality rate of 10% from stocking to harvest. Estimates provided by Glen Chaplin, Auburn University Shellfish Lab. Labor included oyster maintenance and gear cleaning.

Appendix A: Chapter Two Supporting Data

Table A-1

Tukey's Honestly-Significant-Difference Test					
GEAR	GEAR	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS	FB	3.950	0.185	-1.261	9.161
ALS	LP	16.881	0.000	11.670	22.092
ALS	OG	11.509	0.000	6.298	16.720
FB	LP	12.931	0.000	7.720	18.142
FB	OG	7.559	0.003	2.348	12.770
LP	OG	-5.373	0.042	-10.584	-0.162

Table A-1. Tukey’s HSD Table for Gear Effect on Shell Height

Table A-2

Tukey's Honestly-Significant-Difference Test					
TREATMENT	TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Emersed	Never Handled	-1.827	0.513	-5.913	2.258
Emersed	Tumbled	4.186	0.044	0.100	8.271
Never Handled	Tumbled	6.013	0.003	1.928	10.099

Table A-2. Tukey’s HSD Table for Effect of Treatment on Shell Height

Table A-3

Tukey's Honestly-Significant-Difference Test					
GEAR*TREATMENT	GEAR*TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS*E	ALS*N	-2.335	0.964	-8.603	3.934
ALS*E	ALS*T	1.688	0.997	-4.580	7.956
ALS*E	FB*E	2.001	0.988	-4.268	8.269
ALS*E	FB*N	-3.951	0.519	-10.220	2.317
ALS*E	FB*T	4.298	0.400	-1.970	10.566
ALS*E	LP*E	4.923	0.228	-1.346	11.191
ALS*E	LP*N	6.088	0.062	-0.180	12.356
ALS*E	LP*T	6.619	0.032	0.351	12.888
ALS*E	OG*E	3.638	0.632	-2.630	9.906
ALS*E	OG*N	4.396	0.369	-1.872	10.664
ALS*E	OG*T	4.631	0.301	-1.638	10.899
ALS*N	ALS*T	4.023	0.494	-2.246	10.291

Tukey's Honestly-Significant-Difference Test

GEAR*TREATMENT	GEAR*TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS*N	FB*E	4.335	0.388	-1.933	10.604
ALS*N	FB*N	-1.617	0.998	-7.885	4.652
ALS*N	FB*T	6.633	0.032	0.364	12.901
ALS*N	LP*E	7.257	0.014	0.989	13.526
ALS*N	LP*N	8.423	0.003	2.154	14.691
ALS*N	LP*T	8.954	0.001	2.686	15.222
ALS*N	OG*E	5.973	0.072	-0.296	12.241
ALS*N	OG*N	6.731	0.028	0.462	12.999
ALS*N	OG*T	6.965	0.021	0.697	13.234
ALS*T	FB*E	0.313	1.000	-5.956	6.581
ALS*T	FB*N	-5.639	0.106	-11.908	0.629
ALS*T	FB*T	2.610	0.926	-3.658	8.878
ALS*T	LP*E	3.235	0.771	-3.034	9.503
ALS*T	LP*N	4.400	0.368	-1.868	10.668
ALS*T	LP*T	4.931	0.226	-1.337	11.200
ALS*T	OG*E	1.950	0.990	-4.318	8.218
ALS*T	OG*N	2.708	0.908	-3.560	8.976
ALS*T	OG*T	2.943	0.855	-3.326	9.211
FB*E	FB*N	-5.952	0.073	-12.220	0.316
FB*E	FB*T	2.297	0.968	-3.971	8.566
FB*E	LP*E	2.922	0.860	-3.346	9.190
FB*E	LP*N	4.087	0.471	-2.181	10.356
FB*E	LP*T	4.619	0.304	-1.650	10.887
FB*E	OG*E	1.637	0.998	-4.631	7.906
FB*E	OG*N	2.395	0.957	-3.873	8.664
FB*E	OG*T	2.630	0.923	-3.638	8.898
FB*N	FB*T	8.249	0.004	1.981	14.518
FB*N	LP*E	8.874	0.002	2.606	15.142
FB*N	LP*N	10.039	0.000	3.771	16.308
FB*N	LP*T	10.571	0.000	4.302	16.839
FB*N	OG*E	7.589	0.009	1.321	13.858
FB*N	OG*N	8.347	0.003	2.079	14.616
FB*N	OG*T	8.582	0.002	2.314	14.850
FB*T	LP*E	0.625	1.000	-5.644	6.893
FB*T	LP*N	1.790	0.995	-4.478	8.058
FB*T	LP*T	2.321	0.965	-3.947	8.590
FB*T	OG*E	-0.660	1.000	-6.928	5.608
FB*T	OG*N	0.098	1.000	-6.170	6.366
FB*T	OG*T	0.333	1.000	-5.936	6.601
LP*E	LP*N	1.165	1.000	-5.103	7.434
LP*E	LP*T	1.697	0.997	-4.572	7.965
LP*E	OG*E	-1.285	1.000	-7.553	4.984
LP*E	OG*N	-0.527	1.000	-6.795	5.742
LP*E	OG*T	-0.292	1.000	-6.560	5.976
LP*N	LP*T	0.531	1.000	-5.737	6.800
LP*N	OG*E	-2.450	0.950	-8.718	3.818

Tukey's Honestly-Significant-Difference Test					
GEAR*TREATMENT	GEAR*TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
LP*N	OG*N	-1.692	0.997	-7.960	4.576
LP*N	OG*T	-1.457	0.999	-7.726	4.811
LP*T	OG*E	-2.981	0.845	-9.250	3.287
LP*T	OG*N	-2.223	0.974	-8.492	4.045
LP*T	OG*T	-1.989	0.989	-8.257	4.280
OG*E	OG*N	0.758	1.000	-5.510	7.026
OG*E	OG*T	0.993	1.000	-5.276	7.261
OG*N	OG*T	0.235	1.000	-6.034	6.503

Table A-3. Interaction of Gear Type and Treatment on Shell Length

Table A-4

Tukey's Honestly-Significant-Difference Test					
GEAR	GEAR	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS	FB	0.004	1.000	-1.472	1.481
ALS	LP	2.366	0.001	0.890	3.842
ALS	OG	1.405	0.066	-0.072	2.881
FB	LP	2.362	0.001	0.885	3.838
FB	OG	1.400	0.067	-0.076	2.877
LP	OG	-0.961	0.300	-2.438	0.515

Table A-4. Tukey’s HSD Table for Effect of Gear on Shell Width

Table A-5

Tukey's Honestly-Significant-Difference Test					
GEAR	GEAR	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS	FB	-0.014	0.576	-0.044	0.016
ALS	LP	-0.042	0.004	-0.071	-0.012
ALS	OG	-0.029	0.064	-0.058	0.001
FB	LP	-0.028	0.076	-0.057	0.002
FB	OG	-0.015	0.541	-0.044	0.015
LP	OG	0.013	0.630	-0.017	0.043

Table A-5. Tukey’s HSD Table for Effect of Gear Type on Cup Ratio

Table A-6

Tukey's Honestly-Significant-Difference Test

GEAR*TREATMENT	GEAR*TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS*E	ALS*N	-0.002	1.000	-0.064	0.061
ALS*E	ALS*T	-0.061	0.058	-0.124	0.001
ALS*E	FB*E	-0.034	0.704	-0.097	0.028
ALS*E	FB*N	-0.054	0.132	-0.117	0.008
ALS*E	FB*T	-0.022	0.978	-0.084	0.041
ALS*E	LP*E	-0.082	0.004	-0.145	-0.020
ALS*E	LP*N	-0.094	0.001	-0.156	-0.031
ALS*E	LP*T	-0.081	0.004	-0.143	-0.018
ALS*E	OG*E	-0.059	0.080	-0.121	0.004
ALS*E	OG*N	-0.049	0.236	-0.111	0.014
ALS*E	OG*T	-0.064	0.041	-0.126	-0.002
ALS*N	ALS*T	-0.059	0.072	-0.122	0.003
ALS*N	FB*E	-0.032	0.764	-0.095	0.030
ALS*N	FB*N	-0.052	0.161	-0.115	0.010
ALS*N	FB*T	-0.020	0.989	-0.082	0.043
ALS*N	LP*E	-0.081	0.005	-0.143	-0.018
ALS*N	LP*N	-0.092	0.001	-0.154	-0.029
ALS*N	LP*T	-0.079	0.006	-0.142	-0.017
ALS*N	OG*E	-0.057	0.099	-0.119	0.006
ALS*N	OG*N	-0.047	0.281	-0.109	0.016
ALS*N	OG*T	-0.062	0.052	-0.125	0.000
ALS*T	FB*E	0.027	0.908	-0.035	0.089
ALS*T	FB*N	0.007	1.000	-0.055	0.069
ALS*T	FB*T	0.040	0.511	-0.023	0.102
ALS*T	LP*E	-0.021	0.982	-0.084	0.041
ALS*T	LP*N	-0.032	0.767	-0.095	0.030
ALS*T	LP*T	-0.020	0.989	-0.082	0.043
ALS*T	OG*E	0.003	1.000	-0.060	0.065
ALS*T	OG*N	0.013	1.000	-0.050	0.075
ALS*T	OG*T	-0.003	1.000	-0.065	0.060
FB*E	FB*N	-0.020	0.988	-0.082	0.042
FB*E	FB*T	0.013	1.000	-0.050	0.075
FB*E	LP*E	-0.048	0.249	-0.111	0.014
FB*E	LP*N	-0.059	0.073	-0.122	0.003
FB*E	LP*T	-0.047	0.285	-0.109	0.016
FB*E	OG*E	-0.024	0.951	-0.087	0.038
FB*E	OG*N	-0.014	0.999	-0.077	0.048
FB*E	OG*T	-0.030	0.843	-0.092	0.033
FB*N	FB*T	0.033	0.759	-0.030	0.095
FB*N	LP*E	-0.028	0.883	-0.091	0.034
FB*N	LP*N	-0.039	0.521	-0.102	0.023
FB*N	LP*T	-0.027	0.913	-0.089	0.036
FB*N	OG*E	-0.004	1.000	-0.067	0.058
FB*N	OG*N	0.006	1.000	-0.057	0.068
FB*N	OG*T	-0.010	1.000	-0.072	0.053

Tukey's Honestly-Significant-Difference Test					
GEAR*TREATMENT	GEAR*TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
FB*T	LP*E	-0.061	0.062	-0.123	0.002
FB*T	LP*N	-0.072	0.015	-0.134	-0.009
FB*T	LP*T	-0.059	0.074	-0.122	0.003
FB*T	OG*E	-0.037	0.606	-0.099	0.025
FB*T	OG*N	-0.027	0.907	-0.090	0.035
FB*T	OG*T	-0.042	0.416	-0.105	0.020
LP*E	LP*N	-0.011	1.000	-0.074	0.051
LP*E	LP*T	0.001	1.000	-0.061	0.064
LP*E	OG*E	0.024	0.958	-0.039	0.086
LP*E	OG*N	0.034	0.722	-0.029	0.096
LP*E	OG*T	0.018	0.994	-0.044	0.081
LP*N	LP*T	0.013	1.000	-0.050	0.075
LP*N	OG*E	0.035	0.679	-0.028	0.097
LP*N	OG*N	0.045	0.337	-0.018	0.107
LP*N	OG*T	0.030	0.849	-0.033	0.092
LP*T	OG*E	0.022	0.973	-0.040	0.085
LP*T	OG*N	0.032	0.770	-0.030	0.095
LP*T	OG*T	0.017	0.997	-0.046	0.079
OG*E	OG*N	0.010	1.000	-0.053	0.072
OG*E	OG*T	-0.005	1.000	-0.068	0.057
OG*N	OG*T	-0.015	0.999	-0.078	0.047

Table A-6. Tukey’s HSD Table for the Interaction of Gear Type and Treatment for Fan Ratio

Table A-7

Tukey's Honestly-Significant-Difference Test					
GEAR	GEAR	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS	FB	0.235	1.000	-7.525	7.995
ALS	LP	26.180	0.000	18.420	33.940
ALS	OG	12.594	0.001	4.834	20.354
FB	LP	25.945	0.000	18.185	33.705
FB	OG	12.359	0.001	4.599	20.119
LP	OG	-13.586	0.000	-21.346	-5.826

Table A-7. Tukey’s HSD Table for Effect of Gear Type on Whole Wet Weight

Table A-8

Tukey's Honestly-Significant-Difference Test					
GEAR	GEAR	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS	FB	-0.419	0.996	-5.840	5.001
ALS	LP	19.438	0.000	14.018	24.859
ALS	OG	8.512	0.001	3.092	13.933

Tukey's Honestly-Significant-Difference Test					
GEAR	GEAR	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
FB	LP	19.858	0.000	14.437	25.278
FB	OG	8.932	0.001	3.512	14.352
LP	OG	-10.926	0.000	-16.346	-5.506

Table A-8. Tukey’s HSD Table for Effect of Gear Type on Dry Shell Weight

Table A-9

Tukey's Honestly-Significant-Difference Test					
GEAR	GEAR	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS	FB	0.200	0.195	-0.068	0.468
ALS	LP	0.843	0.000	0.575	1.111
ALS	OG	0.211	0.160	-0.057	0.479
FB	LP	0.643	0.000	0.375	0.911
FB	OG	0.011	1.000	-0.257	0.279
LP	OG	-0.632	0.000	-0.900	-0.364

Table A-9. Tukey’s HSD Table of Effect of Gear Type on Dry Tissue Weight

Table A-10

Tukey's Honestly-Significant-Difference Test					
GEAR*TREATMENT	GEAR*TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS*E	ALS*N	0.067	0.077	-0.004	0.138
ALS*E	ALS*T	0.072	0.046	0.001	0.143
ALS*E	FB*E	0.040	0.667	-0.031	0.111
ALS*E	FB*N	0.035	0.823	-0.036	0.106
ALS*E	FB*T	0.049	0.401	-0.022	0.120
ALS*E	LP*E	0.053	0.296	-0.018	0.124
ALS*E	LP*N	0.014	1.000	-0.056	0.085
ALS*E	LP*T	0.047	0.439	-0.024	0.118
ALS*E	OG*E	0.005	1.000	-0.066	0.076
ALS*E	OG*N	0.035	0.815	-0.036	0.106
ALS*E	OG*T	0.046	0.493	-0.025	0.116
ALS*N	BST*T	0.005	1.000	-0.066	0.076
ALS*N	FB*E	-0.027	0.960	-0.098	0.044
ALS*N	FB*N	-0.032	0.878	-0.103	0.039
ALS*N	FB*T	-0.018	0.998	-0.089	0.053
ALS*N	LP*E	-0.014	1.000	-0.085	0.057
ALS*N	LP*N	-0.052	0.301	-0.123	0.019
ALS*N	LP*T	-0.020	0.996	-0.090	0.051
ALS*N	OG*E	-0.062	0.131	-0.133	0.009
ALS*N	OG*N	-0.032	0.884	-0.103	0.039
ALS*N	OG*T	-0.021	0.993	-0.092	0.050

Tukey's Honestly-Significant-Difference Test					
GEAR*TREATMENT	GEAR*TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS*T	FB*E	-0.032	0.888	-0.103	0.039
ALS*T	FB*N	-0.037	0.755	-0.108	0.034
ALS*T	FB*T	-0.023	0.986	-0.094	0.048
ALS*T	LP*E	-0.019	0.997	-0.090	0.052
ALS*T	LP*N	-0.057	0.197	-0.128	0.014
ALS*T	LP*T	-0.024	0.979	-0.095	0.046
ALS*T	OG*E	-0.067	0.079	-0.138	0.004
ALS*T	OG*N	-0.037	0.764	-0.108	0.034
ALS*T	OG*T	-0.026	0.966	-0.097	0.045
FB*E	FB*N	-0.005	1.000	-0.076	0.066
FB*E	FB*T	0.009	1.000	-0.062	0.080
FB*E	LP*E	0.013	1.000	-0.058	0.083
FB*E	LP*N	-0.026	0.971	-0.097	0.045
FB*E	LP*T	0.007	1.000	-0.064	0.078
FB*E	OG*E	-0.035	0.816	-0.106	0.036
FB*E	OG*N	-0.005	1.000	-0.076	0.066
FB*E	OG*T	0.005	1.000	-0.065	0.076
FB*N	FB*T	0.014	1.000	-0.057	0.085
FB*N	LP*E	0.018	0.998	-0.053	0.089
FB*N	LP*N	-0.020	0.995	-0.091	0.051
FB*N	LP*T	0.013	1.000	-0.058	0.084
FB*N	OG*E	-0.029	0.927	-0.100	0.041
FB*N	OG*N	0.000	1.000	-0.071	0.071
FB*N	OG*T	0.011	1.000	-0.060	0.082
FB*T	LP*E	0.004	1.000	-0.067	0.075
FB*T	LP*N	-0.034	0.834	-0.105	0.037
FB*T	LP*T	-0.001	1.000	-0.072	0.070
FB*T	OG*E	-0.043	0.558	-0.114	0.027
FB*T	OG*N	-0.014	1.000	-0.085	0.057
FB*T	OG*T	-0.003	1.000	-0.074	0.068
LP*E	LP*N	-0.038	0.726	-0.109	0.033
LP*E	LP*T	-0.005	1.000	-0.076	0.066
LP*E	OG*E	-0.047	0.435	-0.118	0.023
LP*E	OG*N	-0.018	0.999	-0.089	0.053
LP*E	OG*T	-0.007	1.000	-0.078	0.064
LP*N	LP*T	0.033	0.865	-0.038	0.104
LP*N	OG*E	-0.009	1.000	-0.080	0.062
LP*N	OG*N	0.020	0.995	-0.050	0.091
LP*N	OG*T	0.031	0.900	-0.040	0.102
LP*T	OG*E	-0.042	0.601	-0.113	0.029
LP*T	OG*N	-0.012	1.000	-0.083	0.059
LP*T	OG*T	-0.002	1.000	-0.073	0.069
OG*E	OG*N	0.030	0.922	-0.041	0.101
OG*E	OG*T	0.040	0.656	-0.031	0.111
OG*N	OG*T	0.011	1.000	-0.060	0.082

Table A-10. Tukey’s HSD Table for Interaction of Gear Type and Treatment for Coefficient of Variation of Shell Height

Table A-11

Tukey's Honestly-Significant-Difference Test					
TREATMENT	TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Emersed	Never Handled	-0.071	0.107	-0.154	0.013
Emersed	Tumbled	0.021	0.812	-0.063	0.104
Never Handled	Tumbled	0.091	0.030	0.008	0.174

Table A-11. Tukey’s HSD Table for Effect of Treatment on Coefficient of Variation for Dry Tissue Weight

Table A-12

Tukey's Honestly-Significant-Difference Test					
GEAR	GEAR	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS	FB	17.667	0.269	-8.469	43.802
ALS	LP	22.222	0.116	-3.914	48.358
ALS	OG	27.111	0.040	0.975	53.247
FB	LP	4.556	0.963	-21.580	30.691
FB	OG	9.444	0.753	-16.691	35.580
LP	OG	4.889	0.954	-21.247	31.025

Table A-12. Tukey’s HSD Table for Effect of Gear Type on Biofouling Removal Time

Table A-13

Tukey's Honestly-Significant-Difference Test					
TREATMENT	TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Emersion	Never Handled	-33.417	0.001	-53.907	-12.926
Emersion	Tumbled	15.667	0.158	-4.824	36.157
Never Handled	Tumbled	49.083	0.000	28.593	69.574

Table A-13. Tukey’s HSD Table for Effect of Treatment on Biofouling Removal Time

Table A-14

Tukey's Honestly-Significant-Difference Test					
GEAR	GEAR	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
ALS	FB	12.000	0.332	-7.163	31.163
ALS	LP	3.722	0.949	-15.441	22.885
ALS	OG	-31.056	0.001	-50.219	-11.893
FB	LP	-8.278	0.638	-27.441	10.885
FB	OG	-43.056	0.000	-62.219	-23.893
LP	OG	-34.778	0.000	-53.941	-15.615

Table A-14. Tukey’s HSD Table for Effect of Gear Type on Rank Transformed Percent Mortality

Appendix B: Chapter Three Supporting Data

OysterGro™ Data

Table B-1

Tukey's Honestly-Significant-Difference Test					
FREQUENCY*TREATMENT	**FREQUENCY*TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1*Emersed	1*Tumbled	-0.075	1.000	-8.007	7.858
1*Emersed	5*Emersed	-1.163	0.999	-9.095	6.770
1*Emersed	5*Tumbled	0.821	1.000	-7.111	8.754
1*Emersed	10*Emersed	1.134	1.000	-6.798	9.066
1*Emersed	10*Tumbled	3.761	0.721	-4.171	11.694
1*Emersed	20*Emersed	2.617	0.937	-5.315	10.550
1*Emersed	20*Tumbled	12.606	0.001	4.674	20.538
1*Tumbled	5*Emersed	-1.088	1.000	-9.020	6.844
1*Tumbled	5*Tumbled	0.896	1.000	-7.036	8.828
1*Tumbled	10*Emersed	1.209	0.999	-6.724	9.141
1*Tumbled	10*Tumbled	3.836	0.702	-4.096	11.768
1*Tumbled	20*Emersed	2.692	0.928	-5.240	10.624
1*Tumbled	20*Tumbled	12.681	0.001	4.748	20.613
5*Emersed	5*Tumbled	1.984	0.985	-5.948	9.916
5*Emersed	10*Emersed	2.297	0.967	-5.636	10.229
5*Emersed	10*Tumbled	4.924	0.427	-3.008	12.856
5*Emersed	20*Emersed	3.780	0.716	-4.152	11.712
5*Emersed	20*Tumbled	13.769	0.000	5.836	21.701
5*Tumbled	10*Emersed	0.313	1.000	-7.620	8.245
5*Tumbled	10*Tumbled	2.940	0.892	-4.992	10.872
5*Tumbled	20*Emersed	1.796	0.992	-6.136	9.728
5*Tumbled	20*Tumbled	11.785	0.002	3.852	19.717
10*Emersed	10*Tumbled	2.627	0.936	-5.305	10.560
10*Emersed	20*Emersed	1.483	0.997	-6.449	9.416
10*Emersed	20*Tumbled	11.472	0.003	3.540	19.404
10*Tumbled	20*Emersed	-1.144	0.999	-9.076	6.788
10*Tumbled	20*Tumbled	8.845	0.023	0.912	16.777
20*Emersed	20*Tumbled	9.989	0.009	2.056	17.921

Table B-1. Interaction of frequency and treatment on shell height of oysters grown in the OysterGro™ gear.

Table B-2

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	2.809	2	1.404	0.048	0.954
Error	176.697	6	29.450		

Table B-2. Shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-3

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	8.109	2	4.055	0.138	0.873
Error	175.725	6	29.288		

Table B-3. Shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-4

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	37.268	2	18.634	0.642	0.559
Error	174.221	6	29.037		

Table B-4. Shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-5

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	305.680	2	152.840	5.625	0.042
Error	163.022	6	27.170		

Table B-5. Shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-6

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-3.838	0.659	-16.897	9.221
Emersed	Tumbled	9.989	0.124	-3.071	23.048
Never	Tumbled	13.827	0.040	0.767	26.886

Table B-6. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on shell height of oysters grown in OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-7

Tukey's Honestly-Significant-Difference Test					
FREQUENCY*TREATMENT	**FREQUENCY*TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1*Emersed	1*Tumbled	-1.355	0.989	-7.052	4.343
1*Emersed	5*Emersed	-0.538	1.000	-6.236	5.160
1*Emersed	5*Tumbled	0.455	1.000	-5.243	6.152
1*Emersed	10*Emersed	0.831	0.999	-4.866	6.529
1*Emersed	10*Tumbled	4.115	0.262	-1.582	9.813
1*Emersed	20*Emersed	1.037	0.998	-4.660	6.735
1*Emersed	20*Tumbled	7.646	0.005	1.948	13.344
1*Tumbled	5*Emersed	0.817	1.000	-4.881	6.514
1*Tumbled	5*Tumbled	1.809	0.948	-3.888	7.507
1*Tumbled	10*Emersed	2.186	0.875	-3.512	7.884
1*Tumbled	10*Tumbled	5.470	0.065	-0.228	11.168
1*Tumbled	20*Emersed	2.392	0.820	-3.306	8.090
1*Tumbled	20*Tumbled	9.001	0.001	3.303	14.698
5*Emersed	5*Tumbled	0.993	0.998	-4.705	6.690
5*Emersed	10*Emersed	1.369	0.988	-4.328	7.067
5*Emersed	10*Tumbled	4.653	0.155	-1.044	10.351
5*Emersed	20*Emersed	1.575	0.974	-4.122	7.273
5*Emersed	20*Tumbled	8.184	0.003	2.486	13.882
5*Tumbled	10*Emersed	0.377	1.000	-5.321	6.074
5*Tumbled	10*Tumbled	3.661	0.388	-2.037	9.358
5*Tumbled	20*Emersed	0.583	1.000	-5.115	6.280
5*Tumbled	20*Tumbled	7.191	0.009	1.494	12.889
10*Emersed	10*Tumbled	3.284	0.513	-2.414	8.982
10*Emersed	20*Emersed	0.206	1.000	-5.492	5.904
10*Emersed	20*Tumbled	6.815	0.014	1.117	12.512
10*Tumbled	20*Emersed	-3.078	0.587	-8.776	2.620
10*Tumbled	20*Tumbled	3.531	0.429	-2.167	9.228
20*Emersed	20*Tumbled	6.609	0.017	0.911	12.306

Table B-7. Interaction of frequency and treatment on shell length of oysters grown in the OysterGro™ gear.

Table B-8

Nv1

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	4.363	2	2.182	0.165	0.852
Error	79.431	6	13.239		

Table B-8. Shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-9

Nv5

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	1.615	2	0.808	0.086	0.918
Error	56.188	6	9.365		

Table B-9. Shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-10

Nv10

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	26.332	2	13.166	1.297	0.340
Error	60.910	6	10.152		

Table B-10. Shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-11

Nv20

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	99.488	2	49.744	5.314	0.047
Error	56.161	6	9.360		

Table B-11. Shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-12

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-0.817	0.943	-8.482	6.848
Emersed	Tumbled	6.609	0.085	-1.056	14.274
Never	Tumbled	7.426	0.056	-0.239	15.091

Table B-12. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on shell length of oysters grown in OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-13

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	7.016	2	3.508	2.505	0.162
Error	8.402	6	1.400		

Table B-13. Shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-14

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	3.671	2	1.836	2.001	0.216
Error	5.504	6	0.917		

Table B-14. Shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-15

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	2.633	2	1.317	0.487	0.637
Error	16.227	6	2.704		

Table B-15. Shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-16

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	3.063	2	1.531	0.787	0.497
Error	11.681	6	1.947		

Table B-16. Shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-17

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	-3.812	0.713	-14.024	6.399
1	10	2.258	0.920	-7.954	12.469
1	20	8.623	0.114	-1.588	18.834
5	10	6.070	0.355	-4.141	16.281
5	20	12.435	0.015	2.224	22.647
10	20	6.365	0.317	-3.846	16.577

Table B-17. Tukey's HSD table for effect of handling frequency on whole wet weight of oysters grown in OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-18

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	6.608	2	3.304	0.046	0.955
Error	427.918	6	71.320		

Table B-18.WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-19

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	24.712	2	12.356	0.211	0.816
Error	351.520	6	58.587		

Table B-19.WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-20

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	44.404	2	22.202	0.490	0.635
Error	271.690	6	45.282		

Table B-20.WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-21

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	346.011	2	173.005	3.570	0.095
Error	290.800	6	48.467		

Table B-21.WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-22

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	-0.949	0.984	-8.607	6.709
1	10	1.663	0.924	-5.995	9.321
1	20	7.545	0.054	-0.113	15.203
5	10	2.612	0.765	-5.046	10.270
5	20	8.494	0.027	0.836	16.152
10	20	5.883	0.166	-1.775	13.541

Table B-22. Tukey's HSD table for effect of handling frequency on dry shell weight of oysters grown in OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-23

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	3.653	2	1.826	0.046	0.955
Error	236.071	6	39.345		

Table B-23. DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-24

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	5.162	2	2.581	0.076	0.928
Error	203.961	6	33.994		

Table B-24. DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-25

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	23.259	2	11.630	0.414	0.678
Error	168.351	6	28.058		

Table B-25. DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-26

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	182.209	2	91.105	2.968	0.127
Error	184.181	6	30.697		

Table B-26. DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-27

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	-0.127	0.546	-0.397	0.143
1	10	0.050	0.951	-0.220	0.320
1	20	0.220	0.133	-0.050	0.490
5	10	0.177	0.275	-0.093	0.447
5	20	0.347	0.010	0.077	0.617
10	20	0.170	0.309	-0.100	0.440

Table B-27. Tukey’s HSD table for effect of handling frequency on dry tissue weight of oysters grown in OysterGro™ gear.

Table B-28

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.028	2	0.014	0.456	0.654
Error	0.187	6	0.031		

Table B-28. DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-29

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.019	2	0.009	0.166	0.851
Error	0.342	6	0.057		

Table B-29. DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-30

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.043	2	0.021	0.592	0.583
Error	0.216	6	0.036		

Table B-30. DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-31

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.155	2	0.078	3.260	0.110
Error	0.143	6	0.024		

Table B-31. DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-32

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	2.433	0.168
Error	0.002	6	0.000		

Table B-32. Cup ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-33

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.001	2.509	0.161
Error	0.002	6	0.000		

Table B-33. Cup ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-34

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.000	1.439	0.309
Error	0.002	6	0.000		

Table B-34. Cup ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-35

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.006	2	0.003	4.854	0.056
Error	0.003	6	0.001		

Table B-35. Cup ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-36

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	0.026	0.427	-0.034	0.086
Emersed	Tumbled	-0.035	0.258	-0.095	0.026
Never	Tumbled	-0.061	0.048	-0.121	-0.001

Table B-36. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on cup ratio of oysters grown in OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-37

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.001	1.835	0.239
Error	0.002	6	0.000		

Table B-37. Fan ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-38

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.942	0.441
Error	0.001	6	0.000		

Table B-38. Fan ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-39

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.000	3.777	0.087
Error	0.001	6	0.000		

Table B-39. Fan ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-40

Nv20

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.001	2	0.001	1.696	0.261
Error	0.002	6	0.000		

Table B-40. Fan ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-41

Nv1

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.003	2	0.002	4.316	0.069
Error	0.002	6	0.000		

Table B-41. CV of shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-42

Nv5

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.003	2	0.001	3.354	0.105
Error	0.002	6	0.000		

Table B-42. CV of shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-43

Nv10

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.002	2	0.001	0.523	0.618
Error	0.009	6	0.002		

Table B-43. CV of shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-44

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	1.532	0.290
Error	0.003	6	0.000		

Table B-44. CV of shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-45

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.001	0.326	0.734
Error	0.010	6	0.002		

Table B-45. CV of shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-46

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.018	0.982
Error	0.012	6	0.002		

Table B-46. CV of shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-47

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.011	0.989
Error	0.008	6	0.001		

Table B-47. CV of shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-48

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.001	0.568	0.594
Error	0.008	6	0.001		

Table B-48. CV of shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-49

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.012	0.989
Error	0.025	6	0.004		

Table B-49. CV of shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-50

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.001	0.195	0.827
Error	0.017	6	0.003		

Table B-50. CV of shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-51

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.026	0.974
Error	0.017	6	0.003		

Table B-51. CV of shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-52

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	0.243	0.791
Error	0.020	6	0.003		

Table B-52. CV of shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-53

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.007	2	0.003	1.292	0.341
Error	0.016	6	0.003		

Table B-53. CV of WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-54

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.003	2	0.001	0.297	0.754
Error	0.026	6	0.004		

Table B-54. CV of WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-55

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	0.281	0.764
Error	0.021	6	0.003		

Table B-55. CV of WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-56

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	0.261	0.778
Error	0.028	6	0.005		

Table B-56. CV of WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-57

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.004	2	0.002	0.635	0.562
Error	0.018	6	0.003		

Table B-57. CV of DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-58

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.003	2	0.001	0.353	0.716
Error	0.023	6	0.004		

Table B-58. CV of DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-59

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	0.343	0.722
Error	0.018	6	0.003		

Table B-59. CV of DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-60

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.007	2	0.003	0.693	0.536
Error	0.029	6	0.005		

Table B-60. CV of DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-61

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.030	2	0.015	2.284	0.183
Error	0.039	6	0.007		

Table B-61. CV of DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-62

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.019	2	0.010	1.133	0.382
Error	0.050	6	0.008		

Table B-62. CV of DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-63

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.028	2	0.014	1.500	0.296
Error	0.056	6	0.009		

Table B-63. CV of DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-64

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.028	2	0.014	4.227	0.072
Error	0.020	6	0.003		

Table B-64. CV of DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-65

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	729.556	2	364.778	0.559	0.599
Error	3,912.000	6	652.000		

Table B-65. Biofouling removal time ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-66

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	1,622.222	2	811.111	1.472	0.302
Error	3,305.333	6	550.889		

Table B-66. Biofouling removal time ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-67

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	1,976.889	2	988.444	1.833	0.239
Error	3,236.000	6	539.333		

Table B-67. Biofouling removal time ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-68

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	1,693.556	2	846.778	1.495	0.297
Error	3,399.333	6	566.556		

Table B-68. Biofouling removal time ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-69

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	0.086	0.960	-0.420	0.591
1	10	0.365	0.205	-0.141	0.870
1	20	0.902	0.001	0.372	1.432
5	10	0.279	0.413	-0.227	0.784
5	20	0.816	0.003	0.286	1.346
10	20	0.537	0.049	0.007	1.067

Table B-69. Tukey's HSD table for effect of handling frequency on log10 transformed percent mortality of oysters grown in OysterGro™ gear.

Table B-70

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENTS	0.302	2	0.151	1.543	0.288
Error	0.586	6	0.098		

Table B-70. Log10 transformed percent mortality ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-71

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENTS	0.062	2	0.031	0.877	0.463
Error	0.210	6	0.035		

Table B-71. Log10 transformed percent mortality ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-72

Nv10

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENTS	0.837	2	0.418	6.606	0.030
Error	0.380	6	0.063		

Table B-72. Log10 transformed percent mortality ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-73

Nv10

Tukey's Honestly-Significant-Difference Test					
TREATMENTS	TREATMENTS	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Emersed	Never	-0.184	0.663	-0.814	0.447
Emersed	Tumbled	0.535	0.090	-0.096	1.166
Never	Tumbled	0.719	0.030	0.088	1.349

Table B-73. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the biweekly frequency on the log10 transformed percent mortality of oysters grown in OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-74

Nv20

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENTS	1.945	2	0.973	19.476	0.004
Error	0.250	5	0.050		

Table B-74. Log10 transformed percent mortality ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the OysterGro™ gear. P-values of 0.05 or less are significantly different.

Table B-75

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENTS	TREATMENTS	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Emersed	Never	-1.083	0.005	-1.676	-0.489
Emersed	Tumbled	-0.188	0.652	-0.852	0.476
Never	Tumbled	0.895	0.016	0.231	1.559

Table B-75. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the log10 transformed percent mortality of oysters grown in OysterGro™ gear. P-values of 0.05 or less are significantly different.

Floating Bag Data

Table B-76

Tukey's Honestly-Significant-Difference Test					
FREQUENCY* TREATMENT	FREQUENCY* TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
1*Emersed	1*Tumbled	-1.233	1.000	-10.698	8.231
1*Emersed	5*Emersed	5.655	0.463	-3.810	15.119
1*Emersed	5*Tumbled	7.622	0.163	-1.843	17.087
1*Emersed	10*Emersed	9.709	0.042	0.245	19.174
1*Emersed	10*Tumbled	12.003	0.009	2.538	21.467
1*Emersed	20*Emersed	10.829	0.020	1.364	20.293
1*Emersed	20*Tumbled	22.242	0.000	11.660	32.824
1*Tumbled	5*Emersed	6.888	0.250	-2.577	16.353
1*Tumbled	5*Tumbled	8.855	0.075	-0.609	18.320
1*Tumbled	10*Emersed	10.943	0.018	1.478	20.407
1*Tumbled	10*Tumbled	13.236	0.004	3.771	22.701
1*Tumbled	20*Emersed	12.062	0.008	2.597	21.527
1*Tumbled	20*Tumbled	23.475	0.000	12.893	34.057
5*Emersed	5*Tumbled	1.967	0.995	-7.497	11.432
5*Emersed	10*Emersed	4.055	0.798	-5.410	13.519
5*Emersed	10*Tumbled	6.348	0.333	-3.117	15.813
5*Emersed	20*Emersed	5.174	0.565	-4.291	14.639
5*Emersed	20*Tumbled	16.587	0.001	6.005	27.169
5*Tumbled	10*Emersed	2.087	0.992	-7.377	11.552
5*Tumbled	10*Tumbled	4.381	0.735	-5.084	13.845
5*Tumbled	20*Emersed	3.207	0.925	-6.258	12.671
5*Tumbled	20*Tumbled	14.620	0.004	4.038	25.202
10*Emersed	10*Tumbled	2.293	0.987	-7.171	11.758
10*Emersed	20*Emersed	1.119	1.000	-8.345	10.584
10*Emersed	20*Tumbled	12.532	0.015	1.950	23.114
10*Tumbled	20*Emersed	-1.174	1.000	-10.639	8.291
10*Tumbled	20*Tumbled	10.239	0.061	-0.343	20.821
20*Emersed	20*Tumbled	11.413	0.030	0.831	21.995

Table B-76. Tukey’s HSD table for the interaction of frequency and treatment on shell height for oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-77

Nv1

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	2.479	2	1.239	0.106	0.901
Error	70.400	6	11.733		

Table B-77. Shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-78

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	120.385	2	60.193	5.370	0.046
Error	67.260	6	11.210		

Table B-78. Shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-79

Nv5

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-6.585	0.115	-14.974	1.803
Emersed	Tumbled	1.967	0.762	-6.421	10.356
Never	Tumbled	8.553	0.046	0.164	16.941

Table B-79. Tukey’s HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the monthly frequency on the shell height of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-80

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	285.740	2	142.870	9.493	0.014
Error	90.296	6	15.049		

Table B-80. Shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-81

Nv10

Tukey's Honestly-Significant-Difference Test					
TREATMENT$(i)	**TREATMENT$(j)**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-10.640	0.035	-20.359	-0.921
Emersed	Tumbled	2.293	0.759	-7.426	12.013
Never	Tumbled	12.933	0.015	3.214	22.653

Table B-81. Tukey’s HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the biweekly frequency on the shell height of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-82

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	655.977	2	327.989	26.476	0.002
Error	61.940	5	12.388		

Table B-82. Shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-83

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-11.759	0.021	-21.111	-2.408
Emersed	Tumbled	11.413	0.037	0.958	21.868
Never	Tumbled	23.172	0.002	12.717	33.628

Table B-83. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the shell height of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-84

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	5.009	0.002	1.783	8.235
1	10	6.856	0.000	3.630	10.082
1	20	11.049	0.000	7.666	14.432
5	10	1.847	0.382	-1.379	5.073
5	20	6.040	0.001	2.657	9.423
10	20	4.193	0.014	0.810	7.576

Table B-84. Tukey's HSD table for the effect of handling frequency on shell length of oysters grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-85

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	17.971	2	8.985	1.292	0.341
Error	41.718	6	6.953		

Table B-85. Shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-86

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	108.756	2	54.378	29.210	0.001
Error	11.170	6	1.862		

Table B-86. Shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-87

Nv5

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-5.952	0.004	-9.370	-2.534
Emersed	Tumbled	2.297	0.178	-1.121	5.716
Never	Tumbled	8.249	0.001	4.831	11.668

Table B-87. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the monthly frequency on the shell length of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-88

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	180.251	2	90.126	20.416	0.002
Error	26.487	6	4.415		

Table B-88. Shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-89

Nv10

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-7.116	0.014	-12.380	-1.852
Emersed	Tumbled	3.663	0.163	-1.601	8.927
Never	Tumbled	10.779	0.002	5.515	16.043

Table B-89. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the biweekly frequency on the shell length of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-90

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	334.523	2	167.262	63.225	0.000
Error	13.227	5	2.645		

Table B-90. Shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-91

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT)	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-10.333	0.001	-14.654	-6.011
Emersed	Tumbled	5.616	0.029	0.784	10.447
Never	Tumbled	15.948	0.000	11.117	20.780

Table B-91. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the shell length of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-92

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	1.767	0.051	-0.007	3.541
1	10	1.984	0.026	0.210	3.758
1	20	3.435	0.001	1.574	5.296
5	10	0.217	0.984	-1.557	1.991
5	20	1.668	0.091	-0.193	3.529
10	20	1.451	0.162	-0.410	3.312

Table B-92. Tukey's HSD table for the effect of handling frequency on shell width of oysters grown in floating bags. P-values of 0.05 or less are significantly different.

Table B-93

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.246	2	0.123	0.119	0.890
Error	6.207	6	1.034		

Table B-93. Shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-94

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	10.917	2	5.458	3.082	0.120
Error	10.628	6	1.771		

Table B-94. Shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-95

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	15.999	2	8.000	10.706	0.010
Error	4.483	6	0.747		

Table B-95. Shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-96

Nv10

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-1.328	0.224	-3.494	0.838
Emersed	Tumbled	1.920	0.077	-0.246	4.086
Never	Tumbled	3.248	0.009	1.082	5.414

Table B-96. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the biweekly frequency on the shell width of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-97

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	27.464	2	13.732	10.756	0.015
Error	6.383	5	1.277		

Table B-97. Shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-98

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-2.869	0.058	-5.871	0.133
Emersed	Tumbled	1.740	0.297	-1.617	5.096
Never	Tumbled	4.609	0.015	1.253	7.965

Table B-98. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the shell width of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-99

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	9.354	0.055	-0.161	18.869
1	10	15.796	0.001	6.281	25.311
1	20	24.789	0.000	14.809	34.768
5	10	6.442	0.249	-3.073	15.957
5	20	15.435	0.003	5.455	25.414
10	20	8.993	0.089	-0.987	18.972

Table B-99. Tukey's HSD table for the effect of handling frequency on whole wet weight of oysters grown in floating bags.

Table B-100

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	15.915	2	7.957	0.195	0.828

Table B-100. WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-101

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	304.825	2	152.412	4.940	0.054
Error	185.117	6	30.853		

Table B-101. WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-102

Nv5

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-10.993	0.112	-24.909	2.923
Emersed	Tumbled	2.364	0.864	-11.552	16.280
Never	Tumbled	13.357	0.058	-0.560	27.273

Table B-102. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the monthly frequency on the WWW of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-103

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	747.656	2	373.828	23.776	0.001
Error	94.337	6	15.723		

Table B-103. WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-104

Nv10

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-15.603	0.007	-25.537	-5.668
Emersed	Tumbled	6.028	0.229	-3.907	15.962
Never	Tumbled	21.630	0.001	11.696	31.565

Table B-104. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the biweekly frequency on the WWW of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-105

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	1,478.237	2	739.119	45.868	0.001
Error	80.570	5	16.114		

Table B-105. WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-106

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-21.671	0.003	-32.336	-11.005
Emersed	Tumbled	11.878	0.051	-0.047	23.802
Never	Tumbled	33.548	0.001	21.624	45.473

Table B-106. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the WWW of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-107

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	5.294	0.130	-1.191	11.778
1	10	9.483	0.004	2.999	15.967
1	20	16.357	0.000	9.556	23.158
5	10	4.189	0.285	-2.295	10.674
5	20	11.063	0.002	4.262	17.864
10	20	6.874	0.050	0.073	13.675

Table B-107. Tukey's HSD table for the effect of handling frequency on dry shell weight of oysters grown in floating bags. P-values of 0.05 or less are significantly different.

Table B-108

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	5.344	2	2.672	0.153	0.861
Error	104.603	6	17.434		

Table B-108. DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-109

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	95.984	2	47.992	3.787	0.086
Error	76.035	6	12.672		

Table B-109. DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-110

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	269.618	2	134.809	25.033	0.001
Error	32.312	6	5.385		

Table B-110. DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-111

Nv10

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-9.166	0.007	-14.980	-3.352
Emersed	Tumbled	3.890	0.180	-1.924	9.704
Never	Tumbled	13.056	0.001	7.242	18.870

Table B-111. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the biweekly frequency on the DSW of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-112

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	616.868	2	308.434	65.923	0.000
Error	23.393	5	4.679		

Table B-112. DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-113

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-14.590	0.001	-20.337	-8.843
Emersed	Tumbled	6.789	0.041	0.364	13.215
Never	Tumbled	21.380	0.000	14.954	27.805

Table B-113. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the DSW of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-114

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	FREQUENCY	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
1	5	0.087	0.727	-0.153	0.327
1	10	0.131	0.420	-0.109	0.372
1	20	0.314	0.014	0.062	0.566
5	10	0.044	0.950	-0.196	0.285
5	20	0.227	0.089	-0.025	0.479
10	20	0.183	0.208	-0.069	0.435

Table B-114. Tukey’s HSD table for the effect of handling frequency on dry tissue weight of oysters grown in floating bags. P-values of 0.05 or less are significantly different.

Table B-115

Nv1

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.043	2	0.022	0.926	0.446
Error	0.141	6	0.023		

Table B-115. DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-116

Nv5

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.115	2	0.057	1.529	0.291
Error	0.225	6	0.038		

Table B-116. DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-117

Nv10

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.163	2	0.081	3.104	0.119
Error	0.157	6	0.026		

Table B-117. DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-118

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.455	2	0.227	11.956	0.012
Error	0.095	5	0.019		

Table B-118. DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-119

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-0.314	0.084	-0.680	0.053
Emersed	Tumbled	0.296	0.138	-0.114	0.706
Never	Tumbled	0.609	0.011	0.200	1.019

Table B-119. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the DTW of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-120

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	-0.007	0.898	-0.036	0.022
1	10	-0.023	0.146	-0.052	0.006
1	20	-0.031	0.047	-0.061	-0.001
5	10	-0.016	0.414	-0.045	0.013
5	20	-0.024	0.153	-0.054	0.006
10	20	-0.008	0.872	-0.038	0.022

Table B-120. Tukey's HSD table for the effect of handling frequency on cup ratio of oysters grown in floating bags. P-values of 0.05 or less are significantly different.

Table B-121

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.155	0.860
Error	0.002	6	0.000		

Table B-121. Cup ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-122

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.110	0.898
Error	0.003	6	0.000		

Table B-122. Cup ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-123

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.001	1.034	0.411
Error	0.003	6	0.001		

Table B-123. Cup ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-124

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	2.409	0.185
Error	0.002	5	0.000		

Table B-124. Cup ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-125

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.003	2	0.002	2.421	0.169
Error	0.004	6	0.001		

Table B-125. Fan ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-126

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	5.135	0.050
Error	0.001	6	0.000		

Table B-126. Fan ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-127

Nv5

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-0.020	0.205	-0.051	0.011
Emersed	Tumbled	0.013	0.482	-0.019	0.044
Never	Tumbled	0.033	0.044	0.001	0.064

Table B-127. Tukey’s HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the monthly frequency on the fan ratio of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-128

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	2.230	0.189
Error	0.002	6	0.000		

Table B-128. Fan ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-129

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	3.411	0.116
Error	0.001	5	0.000		

Table B-129. Fan ratio ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-130

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.116	0.893
Error	0.009	6	0.001		

Table B-130. CV of shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-131

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.213	0.814
Error	0.004	6	0.001		

Table B-131. CV of shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-132

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.000	2	0.000	0.035	0.966
Error	0.007	6	0.001		

Table B-132. CV of shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-133

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.001	1.184	0.379
Error	0.003	5	0.001		

Table B-133. CV of shell height ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-134

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.000	0.204	0.821
Error	0.014	6	0.002		

Table B-134. CV of shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-135

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.000	0.256	0.782
Error	0.012	6	0.002		

Table B-135. CV of shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-136

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.001	2	0.001	0.383	0.697
Error	0.011	6	0.002		

Table B-136. CV of shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-137

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.002	2	0.001	0.586	0.591
Error	0.010	5	0.002		

Table B-137. CV of shell length ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-138

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.009	2	0.005	3.409	0.103
Error	0.008	6	0.001		

Table B-138. CV of shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-139

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.003	2	0.002	0.508	0.626
Error	0.019	6	0.003		

Table B-139. CV of shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-140

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.004	2	0.002	1.326	0.334
Error	0.009	6	0.002		

Table B-140. CV of shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-141

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.006	2	0.003	8.692	0.024
Error	0.002	5	0.000		

Table B-141. CV of shell width ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-142

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
Emersed	Never	-0.007	0.898	-0.056	0.042
Emersed	Tumbled	0.059	0.038	0.004	0.114
Never	Tumbled	0.066	0.026	0.011	0.121

Table B-142. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the CV of shell width of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-143

Nv1

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.003	2	0.001	0.181	0.839
Error	0.049	6	0.008		

Table B-143. CV of WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-144

Nv5

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.002	2	0.001	0.259	0.780
Error	0.024	6	0.004		

Table B-144. CV of WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-145

Nv10

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.004	2	0.002	0.968	0.432
Error	0.013	6	0.002		

Table B-145. CV of WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-146

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.010	2	0.005	5.871	0.049
Error	0.004	5	0.001		

Table B-146. CV of WWW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-147

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-0.021	0.688	-0.099	0.058
Emersed	Tumbled	0.070	0.105	-0.018	0.157
Never	Tumbled	0.090	0.045	0.003	0.178

Table B-147. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the CV of WWW of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-148

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.004	2	0.002	0.297	0.753
Error	0.037	6	0.006		

Table B-148. CV of DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-149

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.006	2	0.003	0.615	0.572
Error	0.028	6	0.005		

Table B-149. CV of DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-150

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.007	2	0.003	1.244	0.353
Error	0.016	6	0.003		

Table B-150. CV of DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-151

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.014	2	0.007	4.802	0.069
Error	0.007	5	0.001		

Table B-151. CV of DSW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-152

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.003	2	0.002	0.180	0.839
Error	0.055	6	0.009		

Table B-152. CV of DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-153

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.013	2	0.006	1.168	0.373
Error	0.032	6	0.005		

Table B-153. CV of DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-154

Nv10

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.009	2	0.005	0.858	0.470
Error	0.033	6	0.005		

Table B-154. CV of DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-155

Nv20

Analysis of Variance					
Source	Type III SS	df	Mean Squares	F-Ratio	p-Value
TREATMENT	0.002	2	0.001	0.184	0.837
Error	0.031	5	0.006		

Table B-155. CV of DTW ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-156

Tukey's Honestly-Significant-Difference Test					
FREQUENCY*TREATMENT	FREQUENCY*TREATMENT	Difference	p-Value	95% Confidence Interval	
				Lower	Upper
1*Emersed	1*Tumbled	-25.000	0.264	-59.848	9.848
1*Emersed	5*Emersed	2.667	1.000	-32.181	37.514
1*Emersed	5*Tumbled	21.333	0.435	-13.514	56.181
1*Emersed	10*Emersed	14.000	0.843	-20.848	48.848
1*Emersed	10*Tumbled	33.333	0.066	-1.514	68.181
1*Emersed	20*Emersed	27.667	0.174	-7.181	62.514
1*Emersed	20*Tumbled	26.333	0.325	-12.628	65.294
1*Tumbled	5*Emersed	27.667	0.174	-7.181	62.514
1*Tumbled	5*Tumbled	46.333	0.006	11.486	81.181
1*Tumbled	10*Emersed	39.000	0.023	4.152	73.848
1*Tumbled	10*Tumbled	58.333	0.001	23.486	93.181
1*Tumbled	20*Emersed	52.667	0.002	17.819	87.514
1*Tumbled	20*Tumbled	51.333	0.006	12.372	90.294
5*Emersed	5*Tumbled	18.667	0.587	-16.181	53.514
5*Emersed	10*Emersed	11.333	0.938	-23.514	46.181
5*Emersed	10*Tumbled	30.667	0.105	-4.181	65.514
5*Emersed	20*Emersed	25.000	0.264	-9.848	59.848
5*Emersed	20*Tumbled	23.667	0.444	-15.294	62.628
5*Tumbled	10*Emersed	-7.333	0.994	-42.181	27.514
5*Tumbled	10*Tumbled	12.000	0.919	-22.848	46.848
5*Tumbled	20*Emersed	6.333	0.998	-28.514	41.181
5*Tumbled	20*Tumbled	5.000	1.000	-33.961	43.961

Tukey's Honestly-Significant-Difference Test					
FREQUENCY*TREATMENT	**FREQUENCY*TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
10*Emersed	10*Tumbled	19.333	0.548	-15.514	54.181
10*Emersed	20*Emersed	13.667	0.857	-21.181	48.514
10*Emersed	20*Tumbled	12.333	0.946	-26.628	51.294
10*Tumbled	20*Emersed	-5.667	0.999	-40.514	29.181
10*Tumbled	20*Tumbled	-7.000	0.998	-45.961	31.961
20*Emersed	20*Tumbled	-1.333	1.000	-40.294	37.628

Table B-156. Interaction of frequency and treatment on Biofouling removal time of oysters grown in floating bags.

Table B-157

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	1,118.000	2	559.000	1.738	0.254
Error	1,930.000	6	321.667		

Table B-157. Biofouling removal time ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-158

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	2,834.667	2	1,417.333	18.197	0.003
Error	467.333	6	77.889		

Table B-158. Biofouling removal time ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-159

Nv5

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-24.667	0.033	-46.778	-2.556
Emersed	Tumbled	18.667	0.091	-3.444	40.778
Never	Tumbled	43.333	0.002	21.222	65.444

Table B-159. Tukey’s HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the monthly frequency on the Biofouling removal time of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-160

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	4,731.556	2	2,365.778	29.368	0.001
Error	483.333	6	80.556		

Table B-160. Biofouling removal time ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-161

Nv10

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-36.000	0.006	-58.486	-13.514
Emersed	Tumbled	19.333	0.086	-3.153	41.820
Never	Tumbled	55.333	0.001	32.847	77.820

Table B-161. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the biweekly frequency on the Biofouling removal time of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-162

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	4,528.542	2	2,264.271	22.764	0.003
Error	497.333	5	99.467		

Table B-162. Biofouling removal time ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-163

Nv20

Tukey's Honestly-Significant-Difference Test					
TREATMENT	**TREATMENT**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
Emersed	Never	-49.667	0.004	-76.165	-23.168
Emersed	Tumbled	-1.333	0.988	-30.960	28.293
Never	Tumbled	48.333	0.007	18.707	77.960

Table B-163. Tukey's HSD table for the comparison of the never handled control, and the emersed and tumbled treatments at the weekly frequency on the Biofouling removal time of oysters grown in floating bag gear. P-values of 0.05 or less are significantly different.

Table B-164

Tukey's Honestly-Significant-Difference Test					
FREQUENCY	**FREQUENCY**	**Difference**	**p-Value**	**95% Confidence Interval**	
				Lower	**Upper**
1	5	0.204	0.339	-0.134	0.541
1	10	0.323	0.063	-0.015	0.660
1	20	-0.004	1.000	-0.358	0.350
5	10	0.119	0.744	-0.219	0.456
5	20	-0.208	0.370	-0.562	0.146
10	20	-0.327	0.079	-0.681	0.027

Table B-164. Tukey's HSD table for the effect of handling frequency on log10 transformed percent mortality of oysters grown in floating bags.

Table B-165

Nv1

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.033	2	0.017	0.218	0.812
Error	0.382	5	0.076		

Table B-165. Log10 transformed percent mortality ANOVA between the never handled control and the two treatments (emersed and tumbled) from the seasonal frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-166

Nv5

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.070	2	0.035	0.349	0.721
Error	0.503	5	0.101		

Table B-166. Log10 transformed percent mortality ANOVA between the never handled control and the two treatments (emersed and tumbled) from the monthly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-167

Nv10

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.212	2	0.106	0.917	0.458
Error	0.579	5	0.116		

Table B-167. Log10 transformed percent mortality ANOVA between the never handled control and the two treatments (emersed and tumbled) from the biweekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Table B-168

Nv20

Analysis of Variance					
Source	**Type III SS**	**df**	**Mean Squares**	**F-Ratio**	**p-Value**
TREATMENT	0.152	2	0.076	0.813	0.506
Error	0.373	4	0.093		

Table B-168. Log10 transformed percent mortality ANOVA between the never handled control and the two treatments (emersed and tumbled) from the weekly frequency and grown in the floating bag gear. P-values of 0.05 or less are significantly different.

Appendix C: Gear Comparison and Supporting Data

Table C-1

Notable Additional Cost Considerations for Oyster Aquaculture in Alabama	
Harvester's Licence	$26.00/yr
State Lands Easement Fee	$1700.00/yr
Freight Costs of Shipping Gear from Chesapeake Bay Oyster Company (VA) to AL	$1,825.00
Seed Costs per Oyster	$0.04
Seed Costs per Acre (accounting for 10% Mortality before growout density)	
ALS	$5,280.00
Floating Bags	$6,680.00
LowPro™	$4,224.00
OysterGro™	$3,168.00
Cost of Harvesting Identification Tags per Acre ($0.25 per 200ct sack)	
ALS	$150.00
Floating Bags	$187.50
LowPro™	$120.00
OysterGro™	$90.00
Labor	$8-$10/hr
Variable Costs	
Boat/Skiff/Floating Platform	
Pressure Washer	
Transport vehicle (Truck)	
Submerged Aquatic Vegetation (SAV) Survey	
Marine Resources Division Survey	

Table C-1. Notable additional costs for oyster aquaculture in Alabama. Costs are based on 2010-2011 records from initial experimental arm-site construction by AUSL.

Table C-2

Item	**Cost**	**-**	**Per Million Product**
Triploid seed oysters (1.5 million)	11,250	--	11,250
Diploid seed oysters (1.5 million)	9,750	--	9,750
Labor (low: $8/hr * 2,250)	18,000		18,000
Labor (high: $8/hr * 4,500)	36,000		36,000
Labor *(AUSL $10/hr * 912) (LP)	**9,120**	**96,000 – AUSL Product**	**9,120**
		Expected Life	**Annualized Cost**
Bags & barriers (low)	3,400	2 years	1,700
Bags & barriers (high)	6,630	4 years	1,657
Lines, buoys, anchors (low)	2,407	4 years	602
Lines, buoys, etc (high)	4,364	4 years	1,091
Gaff & winch (low)	3,000	5 years	600
Gaff & winch (high)	4,500	5 years	900
Cages (low)	41,625	6 years	6,938
Cages (high)	56,610	6 years	9,435
Floating upweller (low)	3,500	8 years	438
Floating upweller (high)	7,500	8 years	938
Shaker table (low)	4,000	10 years	400
Shaker table (high)	8,500	10 years	850
Sorter/cleaner (low)	0	--	0
Sorter/cleaner	8,00	10 years	800
***(AUSL) -Mechanical Grader**	**9,500**	**10 years**	**950**

Table C-2. Estimated Production Costs for 1 Million Oysters in Off-bottom Cages (LowPro™) and *Auburn University Shellfish Lab Cost (if comparatively different). (Source: Wieland, 2007. Project Data, Chesapeake Bay Oyster Company Farm Planner)

Table C-3

Item	**Cost**		**Per Million Product**
Triploid seed oysters (1.5 million)	11,250	--	11,250
Diploid seed oysters (1.5 million)	9,750	--	9,750
Labor (low: $8/hr * 2,080)	16,640		16,640
Labor (high: $8/hr * 4,160) **Labor *(AUSL $10/hr * 3,197) (FB, ALS, OG)**	33,280 **31,970**	 **340,000 AUSL Product**	33,280 **31,970**
		Expected Life	**Annualized Cost**
Bags & barriers (low)	2,500	4 years	625
Bags & barriers (high)	2,500	2 years	1250
Lines, buoys, anchors (low)	2,407	4 years	602
Lines, buoys, etc (high)	4,364	4 years	1,091
Floats (low)	40,000	4 years	10,000
Floats (high)	65,000	4 years	16,250
Floating upweller (low)	3,500	8 years	438
Floating upweller (high)	7,500	8 years	938
Shaker table (low)	4,000	10 years	400
Shaker table (high)	8,500	10 years	850
Sorter/cleaner (low)	0	--	0
Sorter/cleaner ***(AUSL) -Mechanical Grader**	8,000 **9,500**	10 years **10 years**	800 **950**

Table C-3. Estimated Production Costs for 1 Million Oysters in Floats (ALS, Floating Bag and OysterGro™) and *Auburn University Shellfish Lab Cost (if comparatively different). (Source: Wieland, 2007. Project Data, Chesapeake Bay Oyster Company Farm Planner)

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