Improving the (off)-bottom line: assessing the costs and benefits of different culture techniques on an Alabama commercial oyster farm

by

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Abstract

Off-bottom oyster aquaculture is an expanding industry in the Gulf of Mexico region, however numerous challenges threaten the sustainability of regional farms. To offset the negative effects of these challenges, farmers often ask how they can reduce their production costs without compromising the quality of their oysters or their profitability. This study analyzed how four commonly used management techniques affected profitability through 1) a true accounting of production costs, 2) an analysis of whether buyers recognize differences in oyster quality produced by different methods, and 3) if the resulting differences affect their willingness to pay or purchase decisions. A commercial oyster farm using an adjustable longline system was installed in Grand Bay, AL where combinations of two brands of gear (Hexcyl or SEAPA), two tumbling frequencies (Monthly or Quarterly), two air-drying frequencies (Weekly or Daily), and two oyster seed ploidies (Diploid or Triploid) were tested. The resulting production costs and profits from each treatment combination were tracked and used to conduct investment analyses. In addition, oysters produced by each treatment were assessed quantitatively in the lab and qualitatively through a survey to gauge quality and buyer perception. Treatments including triploid oysters were assessed as having the highest quality, the best perception by buyers, and the most profitable business investments. More labor-intensive treatments did not appear to have an advantage when it came to quality or buyer perception, suggesting farmers can reduce their production costs by using quarterly tumbling and/or daily air-drying without penalty to profitability. Finally, brand of gear had few effects on quality, perception, or investment and therefore should be chosen based on personal circumstance or preference.

Keywords: oysters, aquaculture, profitability, quality, handling, management, willingness to pay

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Table of Contents

Abstract i

Acknowledgements.. ii

List of Tables v

List of Figures vii

Chapter 1: A Brief Overview of Off-Bottom Oyster Farming 1

Commonly used off-bottom farming techniques in Alabama 3

Research aims and objectives...8

Chapter 2: A Comparison of Off-Bottom Oyster Farm Adjustable Longline System Enterprise Budgets for Multiple Management Scenarios...11

Introduction 11

Methodology 13

Results...22

Discussion 38

Chapter 3: Effect of Different Off-Bottom Oyster Farming Management Techniques on Measures of Oyster Quality and Buyer Perception 42

Introduction...42

Methodology 44

Results...54

Quantitative Quality Assessment Results 54

Quality Survey Results 68

Buyer Perception and Purchase Intention Results.. 85

Discussion 88

References 97

Appendix A.. 102

List of Tables

Table 2.1 Organization and Line Numbers of Treatments on the Farm 17

Table 2.2 Assumption Values for all Treatments 27

Table 2.3 Seed Costs 27

Table 2.4 Gear Assumptions 28

Table 2.5 Installation Costs for Hexcyl Brand 29

Table 2.6 Installation Costs for SEAPA Brand 30

Table 2.7 Year 1 Variable Costs 31

Table 2.8 Year 1 Variable Income and Other Values 32

Table 2.9 Year 2 Variable Costs 33

Table 2.10 Year 2 Variable Income and Other Values 34

Table 2.11 Years 3-10 Variables Costs 35

Table 2.12 Years 3-10 Variable Income and Other Values 35

Table 2.13 Breakeven Costs and Income per Oyster for each Treatment Line 38

Table 2.14 MIRR Values 41

Table 2.15 NPV Values 41

Table 3.1 Shipment Dates and Included Treatment Lines 52

Table 3.2 ANOVA of Fan Ratio for Gear x Air-drying x Ploidy Comparison 55

Table 3.3 ANOVA of Fan Ratio for Tumbling x Air-drying x Ploidy Comparison 56

Table 3.4 ANOVA of Cup Ratio for Gear x Air-drying x Ploidy Comparison 58

Table 3.5 ANOVA of Cup Ratio for Tumbling x Air-drying x Ploidy Comparison....................59

Table 3.6 ANOVA of Cleaning Time for Gear x Air-drying x Ploidy Comparison 61

Table 3.7 ANOVA of Cleaning Time for Tumbling x Air-drying x Ploidy Comparison 63

Table 3.8 ANOVA of Condition Index for Gear x Air-drying x Ploidy Comparison 65

Table 3.9 ANOVA of Condition Index for Tumbling x Air-drying x Ploidy Comparison 66

Table 3.10 Predicted Probabilities of Receiving 1st Purchase Rank by Treatment 88

List of Figures

Fig 1.1 Image of OysterGro® Cage....4

Fig 1.2 Image of the Adjustable Longline System....5

Fig 1.3 Image of Mechanical Grader....7

Fig 2.1 Map of Study Site Location....14

Fig 2.2 Image of Adjustable Longline Baskets Raised for Air-Drying....15

Fig 2.3 Image of SEAPA and Hexcyl Brand Baskets....17

Fig 2.4 Average Daily Shell Growth....23

Fig 2.5 Average Daily Shell Growth Re-organized....24

Fig 2.6 Average Daily Tissue Growth....25

Fig 2.7 Average Daily Tissue Growth Re-organized....26

Fig 2.8a Spread of Labor Costs (Percentage)....36

Fig 2.8b Spread of Labor Costs (Absolute Values)....37

Fig 3.1 Map of Study Site Location....45

Fig 3.2 Image of Adjustable Longline Baskets Raised for Air-drying....46

Fig 3.3 Image of SEAPA and Hexcyl Brand Baskets....48

Fig 3.4 Diagram of Shell Measurements....49

Fig 3.5 Comparison of Diploid and Triploid Control Oysters for Fan Ratio....54

Fig 3.6 Interaction of Air-drying and Ploidy on Fan Ratio (Lines 5-8 and 13-16)....55

Fig 3.7 Interaction of Air-drying and Ploidy on Fan Ratio (Lines 9-12 and 13-16)....56

Fig 3.8 Comparison of Diploid and Triploid Control Oysters for Cup Ratio 57

Fig 3.9 Interaction of Gear, Air-drying, and Ploidy on Cup Ratio 58

Fig 3.10 Effect of Air-drying on Cup Ratio (Lines 9-12 and 13-16)..59

Fig 3.11 Effect of Ploidy on Cup Ratio (Lines 9-12 and 13-16) 60

Fig 3.12 Comparison of Diploid and Triploid Control Oysters for Cleaning Time 60

Fig 3.13 Interaction of Air-drying and Ploidy on Cleaning Time (Lines 5-8 and 13-16)............62

Fig 3.14 Interaction of Gear and Ploidy on Cleaning Time 62

Fig 3.15 Interaction of Tumbling, Air-drying, and Ploidy on Cleaning Time 63

Fig 3.16 Comparison of Diploid and Triploid Control Oysters for Cup Ratio 64

Fig 3.17 Interaction of Gear, Air-drying, and Ploidy on Condition Index..................................65

Fig 3.18 Interaction of Tumbling and Air-drying on Condition Index.......................................66

Fig 3.19 Interaction of Tumbling and Ploidy on Condition Index 67

Fig 3.20 Interaction of Air-drying and Ploidy on Condition Index (Lines 9-12 and 13-16).........67

Fig 3.21 Interaction of Gear, Air-drying, and Ploidy on Shell Shape Score 68

Fig 3.22 Interaction of Air-drying and Ploidy on Shell Cleanliness Score (Lines 5-8 and 13-16) 69

Fig 3.23 Interaction of Gear and Ploidy on Shell Cleanliness Score..70

Fig 3.24 Interaction of Tumbling and Air-drying on Shell Cleanliness Score............................71

Fig 3.25 Interaction of Air-drying and Ploidy on Shell Cleanliness Score (Lines 9-12 and 13-16) 72

Fig 3.26 Interaction of Tumbling and Air-drying on Shell Thickness Score 73

Fig 3.27 Interaction of Air-drying and Ploidy on Shuckability Score (Lines 5-8 and 13-16) 74

Fig 3.28 Interaction of Tumbling, Air-drying, and Ploidy on Shuckability Score 75

Fig 3.29 Interaction of Air-drying and Ploidy on Shell Consistency Score (Lines 5-8 and 13-16) 76

Fig 3.30 Effect of Air-drying on Shell Consistency Score (Lines 9-12 and 13-16).....................77

Fig 3.31 Effect of Ploidy on Shell Consistency Score (Lines 9-12 and 13-16) 77

Fig 3.32 Effect of Ploidy on Meat to Shell Ratio Score (Lines 5-8 and 13-16)...........................78

Fig 3.33 Effect of Ploidy on Meat to Shell Ratio Score (Lines 9-12 and 13-16).........................79

Fig 3.34 Interaction of Tumbling and Air-drying on Meat to Shell Ratio Score 79

Fig 3.35 Effect of Ploidy on Meat Condition Score (Lines 5-8 and 13-16).................................80

Fig 3.36 Effect of Air-drying on Meat Condition Score (Lines 9-12 and 13-16) 81

Fig 3.37 Effect of Ploidy on Meat Condition Score (Lines 9-12 and 13-16)...............................81

Fig 3.38 Effect of Air-drying on Meat Consistency Score (Lines 5-8 and 13-16).......................82

Fig 3.39 Effect of Ploidy on Meat Consistency Score (Lines 5-8 and 13-16) 83

Fig 3.40 Effect of Air-drying on Meat Consistency Score (Lines 9-12 and 13-16).....................84

Fig 3.41 Effect of Ploidy on Meat Consistency Score (Lines 9-12 and 13-16) 84

Fig 3.42 Linear Regression for Sum Quality Score and Willingness to Pay 85

Fig 3.43 Interaction of Air-drying and Ploidy on Willingness to Pay (Lines 5-8 and 13-16) 86

Fig 3.44 Effect of Ploidy on Willingness to Pay (Lines 9-12- and 13-16) 87

Chapter 1. A Brief Overview of Off-Bottom Oyster Farming

The Eastern oyster, *Crassostrea virginica (*Gmelin 1791), is a filter-feeding, estuarine bivalve species that has historically grown in reefs along the coasts of the eastern United States and Canada, the Gulf of Mexico, and the West Indies (Sellers and Stanley 1984). The wild harvest of oysters has been going on for centuries, aided by the introduction of dredging and tonging; however, shipping advancements and higher demand by a growing population has led to the overexploitation of many oyster reef populations (MacKenzie and Burrell 1997; Kirby 2004; FAO 2018). In response to continuous growth in demand and shrinking wild stocks, oyster aquaculture has been rapidly expanding worldwide (FAO 2018).

Off-bottom oyster farming, a type of oyster aquaculture, has become increasingly popular due to advances in technology and research (Shaw 1967). In this method hatchery-reared, single set oysters are grown in culture gear suspended within the water column; common gear types include mesh baskets or bags attached to floats, placed in floating cages, placed on racks, or clipped on lines (Walton et al. 2012; Davis et al. 2013). In general, off-bottom methods tend to be used when oysters cannot be grown on bottom due to soft sediment, heavy predation, wave action, and/or tidal level (Garrido-Handog 1990). Specific gear types are chosen based on the conditions of the area in which they are being used (Davis et al. 2013). Many siting tools are now available to farmers that combine environmental, social, and regulatory datasets and allow them to select an area and gear type that will optimize the growth of their crop (Silva et al. 2011; ASMC 2020; UNCW 2020).

Traditionally, oyster aquaculture was supported by the recruitment of wild juvenile oysters, however in past decades disease, catastrophe, and pollution have made natural oyster sets insufficient to meet the demand of the oyster industry. Oyster hatcheries are now an important source of oyster juveniles (seed) for commercial farms as well as stocks that exhibit disease-resistance, fast growth, and desired shell conformation (Dupuy et al. 1977). There are three main steps in hatchery-rearing oysters: spawning, larval care and setting, and growing spat. During the larval setting stage, juvenile oysters undergo metamorphosis in which they permanently attach to a substrate and are afterwards known as spat. Oysters prefer to set on other oyster's shell, a behavior that contributes to the creation of wild oyster reefs. Hatchery managers overcome this behavior by providing microcultch, or finely ground oyster shell, to setting larvae, allowing them to produce the single-set oysters that are used in off-bottom oyster farming. After setting, the oyster seed is grown to various sizes that can be purchased by farmers for final grow-out to harvest. (Wallace et al. 2008).

As Webster (2007) mentions in the University of Maryland's extension report, oyster aquaculture strives to achieve the same objectives as traditional agriculture enterprises: increase survival, maximize growth rate, develop uniformity, protect from predators, manage health, develop product continuity, and grow for market demand. The design of off-bottom culture gear types not only suspend the oysters off the sediment, which reduces predation and increases water flow for feeding, but also provides greater opportunities for farmers to control variables on their farm and achieve these objectives. Farmers can easily access their crop to manage stocking densities, control the position of their gear in the water column for air-drying to reduce biofouling, perform mechanical tumbling and grading, and prepare for storm events, among many other benefits (Comeau et al. 2011; Ring 2012; Davis et al. 2013). Purchasing hatchery-sourced seed also allows farmers to maximize the health and uniformity of their crop.

Due to their labor-intensive nature, off-bottom methods often cost more than alternative methods; however rapid growth and higher oyster quality can offset these costs (Garrido-Handog

1990). Farmed oysters tend to fetch higher market prices than their wild counterparts because they fulfill a niche market for "boutique" oysters on the half shell (Walton et al. 2012). The popularization of oyster raw bar restaurants has driven increased demand for oysters in this market, as many consumers prefer the aesthetics and convenience farmed oysters provide (Loose et al. 2013; Petrolia et al. 2017; Sackton 2013, as cited in Mizuta and Wikfors 2018).

Commonly Used Off-Bottom Farming Techniques in Alabama

While the Gulf of Mexico was not one of the first regions to adapt to off-bottom oyster aquaculture methods, widespread use is now being seen. Historically, the Gulf of Mexico has focused on on-bottom harvest using tongs and dredges and has been the leading producer of wild oysters in the U.S. for many years. The majority of oysters harvested are destined for the shucked meat market, with few reaching the standards of the half shell market. Alabama has been a contributor to wild oyster harvest for decades but damage by Hurricanes Ivan and Katrina, oyster drill predation, and the BP oil spill in 2010 has drastically reduced the number of landings from historical averages. Recently implemented seasonal closures and reduced landing limits set by state agencies aim to conserve oyster resources, but in doing so have also limited the economic opportunities of local oystermen, processors, distributors, and dealers. Off-bottom farms have provided new economic opportunities to a region that is facing unemployment and loss of revenue (May 1971, as cited in VanderKooy 2012; Campbell 2013; NMFS 2020).

In 10 years, the number of off-bottom farms in Alabama has expanded from 0 in 2009 to 22 in 2019. Of these farms, most employ floating cages or longlines, gear types suitable for Alabama's farming conditions. Both gear types can be either flipped or raised out of the water for air-drying, which is imperative for limiting the growth of flow-reducing biofouling that can occur in Alabama’s highly productive waters. In addition, these gear types can be secured for severe weather events, even at shallow sites (Walton et al. 2012; Walton et al. 2013).

Floating cages, e.g. OysterGro®, have a metal frame attached to two air-filled pontoons and are anchored both to the seafloor and each other. The metal frame is divided into compartments to hold a total of either four or six mesh bags of oysters (Fig 1.1). The cages are designed so that they can be flipped with oysters out of the water, the air-drying position, or with the oysters in the water, the growing position. In case of a storm event, the pontoons can be filled with water to sink the cages to the bottom. Each bag in the cage can hold around 150 oysters at harvest size.

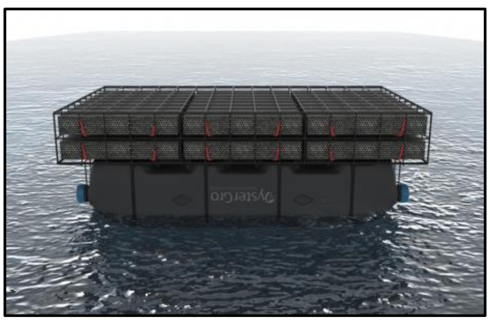

Fig 1.1 OysterGro® floating cage in the air-drying position. (OysterGro® 2020).

The adjustable longline system (ALS) consists of tensioned monofilament in plastic sleeve that is attached to pilings at either end and then strung across riser posts using a clip mechanism (Fig 1.2). The clips allow for the lines to either be raised for air-drying or lowered for storm events. Two lines are usually installed parallel to one another, called a ‘run’. Baskets can either be clipped to a singular line between riser posts or between two lines in a crosswise manner. Depending on the basket volume, baskets can hold anywhere between 75-100 oysters at harvest size (Walton et al. 2012).

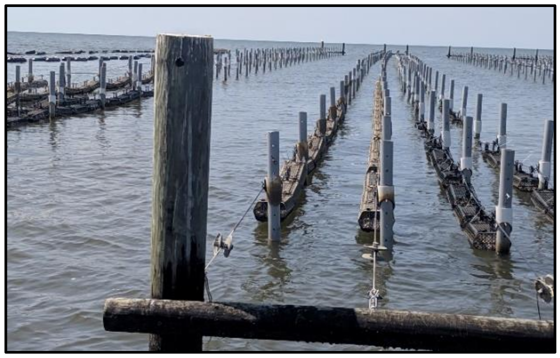

Fig 1.2 Adjustable longline system with Hexcyl brand baskets in the air-drying position.

While consumers enjoy a wide variety of oyster sizes and flavors, they tend to expect a certain caliber of shell and meat quality in the half shell market. Many regions around the world have generally defined standards for oyster marketability that are used by wholesalers when determining purchasing prices, to which farmers typically try to adhere. Oysters with a wide fan, deep cup, and easy to shuck hinge are preferred by both restaurants and consumers and will often fetch a higher price than oysters that are misshapen and shallow. The shell should be free of mud and biofouling, such as barnacles, algae, or spat, that may affect presentation or produce an off-putting odor. Meat should be plump, firm, and fill the shell (Abbe and Albright 2003; Ryan 2008; Mizuta and Wikfors 2018). Therefore, farmers aim to maximize the quality of their oysters, while minimizing their production costs.

When farmers go to purchase oyster seed from a hatchery, they have two choices: diploid or triploid. Diploid oyster seed are natural oysters, genetically as you would find them in the wild with two sets of chromosomes. Triploid oysters are modified to have three sets of chromosomes, done either chemically or by spawning a diploid oyster with a tetraploid oyster (Stanley et al. 1984; Guo et al. 1996). Triploid seed costs more but provides one main advantage to farmers: triploid oysters are sterile. Sterility allows the oysters to allot more energy towards growth rather than reproduction. Also, triploids will not lose meat quality during the summer spawning months and can be marketed at the time when diploids are experiencing poor meat quality. One caveat, however, is the potential for higher triploid mortality due to sensitivity to stressors such as fluctuating environmental conditions, air-drying, tumbling, pollution, and pathogens (Guo et al. 1996; Cheney et al. 2000; Bodenstein 2019; Wadsworth et al. 2019a). Despite seed choice, Alabama's growing conditions can produce marketable oysters year-round as opposed to the northern United States where the growth period may be shorter due to the colder water temperatures (Shumway 1996).

One of the more labor-intensive management techniques a farmer usually implements is air-drying. Air-drying requires farmers to flip their gear up to expose oysters and then back into the water for resubmersion at set intervals. Oysters can survive for prolonged periods out of the water depending on air temperature, whereas fouling such as algae and barnacles will not survive. To reduce labor costs, farmers can choose gear that is easily controlled within their site conditions as well as can be handled by the amount of available labor. The highly productive waters in Alabama can lead to rapid fouling and restricted food supply to the oysters; the slowed growth, mortality, and reduction in aesthetics that results can negatively affect farmers' bottom line. If fouling is not routinely taken care of farmers can incur higher labor costs when both gear and harvested oysters for market must be cleaned (Walton et al. 2012).

A second labor-intensive management technique is tumbling. Tumbling can occur naturally as gear and oysters shift within the water, depending on the gear type used and farm site. Many farmers opt to manually tumble their oysters as well by sending them through a cylindrical, mechanical grader (Fig 1.3). The oysters must be collected from the farm, a very labor-intensive step, and put through one end of the grader. Along the tube of the grader are various sized holes that split the oysters into different size grades. By doing so, farmers can reduce competition among their crop and improve growth rates. In addition, as the oysters fall towards the other end the tube rotates and new shell growth is chipped away, giving the oysters a more uniform "cupped" shape that is desired by the half shell market (Ring 2012). After tumbling, farmers restock their gear and return oysters to the farm or, if large enough, harvest the oysters for sale. Most mechanical graders are also equipped with a water spraying system that cleans the oysters free of mud and debris, reducing manual labor needed to prepare the oysters for the half shell market.

How often a farmer splits or size grades their oysters as they grow can further impact the

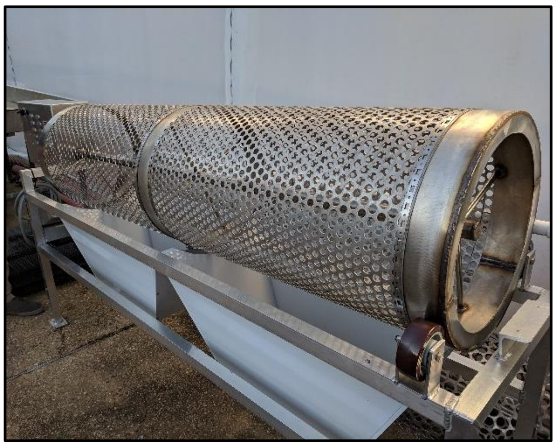

Fig 1.3 Mechanical grader used for tumbling and sorting oysters

resulting quality of their product. If a farmer puts in more labor to keep oysters at optimal stocking densities, they can be rewarded with more desirable shell aesthetics and a better meat to shell ratio. Oysters kept at low stocking densities have more room to tumble around the gear and wave action at the farm will help chip away the outer edge of shell and encourage the formation of a deeper cup (Davis 2013). Optimal densities will vary by oyster size, food availability, season, and exposure of the farm site (Rubio 2009).

For both floating cage systems and ALS there are multiple brands available on the market which can vary by cost, durability, ease of use, and capacity. Depending on the design of the gear installation costs vary, and some may require more, or specialized, labor to install. Floating cage systems are anchored to the sea floor, requiring someone with diving experience to install the anchor. Similarly, ALS requires the installation of pilings to be able to properly tension the lines. The ALS can usually be handled by one laborer, whereas some floating cage systems may require two laborers to flip the cages. New designs and advancements are continuously being developed that help decrease labor costs involved in producing half shell market oysters.

Research Aims and Objectives

Even though Alabama's farm-raised oysters have strong market demand and are receiving an average price of $0.47 per oyster in 2018, farmers are still facing many challenges such as seed shortages, permitting challenges, and water quality issues (ACES 2019). These challenges on top of high startup costs cause many new farmers to struggle in sustaining their businesses**.** While these challenges may be out of farmers' control, our research aims to find a solution to improve farmers' profitability through optimizing the management decisions they make. Standard management techniques have yet to be established as each carries its own pros and cons; in general we have observed that some farmers who opt for labor-intensive management techniques receive higher farm gate prices whereas others who use less labor-intensive management techniques receive lower farm gate prices, but the mechanisms by which management techniques affect profitability are not well understood. Therefore, our project analyzes the effects of different types and frequency of management techniques on profitability through 1) a true accounting of production costs, 2) determining if buyers recognize differences in oyster quality produced by different methods, and 3) determining if the resulting differences in quality affect buyers' willingness to pay or purchasing decisions.

In order to meet all of our research objectives, we installed and operated a model commercial oyster farm. In terms of our first objective, we used this farm to develop realistic enterprise budgets for a suspended intertidal adjustable longline system, based on various management decisions. On the farm, we employed multiple combinations of management techniques, or 'treatments', and tracked all capital and labor costs put into each treatment: we employed combinations of different gear brands, tumbling frequencies, air-drying frequencies, and oyster seed ploidies. Biometric data such as survival and growth were collected to gauge differences in time until harvest and required seed budgets. We created a unique enterprise budget for each scenario to determine how production and labor costs differed, and ultimately, profitability. These enterprise budgets also held value of getting realistic numbers to current and potential regional oyster farmers for business planning purposes.

The second objective of our research was to determine if oyster quality differed among the treatments at harvest and if buyers were able to perceive these differences. We used both quantitative and qualitative methods to determine if farmers affected quality through different management techniques. In the lab we measured dimensions of the shell, cleaning times, and ratios of meat to shell as quantitative metrics of quality, which we compared to subjective quality scores reported by chefs and wholesalers who responded to a survey. Metrics included in the survey were shell shape, shell thickness, shuckability, cleanliness, meat to shell ratio, meat condition, and consistency of the included metrics.

Our third and final objective sought to determine if any differences in quality among the treatments perceived by buyers affected their willingness to pay or purchasing decision. In addition to quality scores, survey participants also responded with the price they would be willing to pay per oyster at wholesale and the order in which they would purchase the oysters presented to them. Resulting prices were included in the enterprise budgets from our first objective to give us an estimate of profitability of each of the different combinations of management decisions.

Chapter 2. A Comparison of Off-Bottom Oyster Farm Adjustable Longline System Enterprise Budgets for Multiple Management Scenarios

Abstract

The adjustable longline system (ALS) is one of the most commonly used methods of off-bottom oyster farming in the Gulf of Mexico region, and allows farmers to implement a wide range of management decisions. Farmers often ask what is the optimal combination of management decisions that will reduce their production costs without compromising their profitability. A commercial oyster farm using the ALS was installed in Grand Bay, AL where we tested combinations of two brands of gear (Hexcyl or SEAPA), two tumbling frequencies (Monthly or Quarterly), two air-drying frequencies (Weekly or Daily), and two oyster seed ploidies (Diploid or Triploid) for their effect on profitability. All production costs and revenue for each treatment were tracked in unique enterprise budgets and investment analyses were conducted based on the net present value and modified internal rate of return. Performance metrics such as growth and survival were also recorded for each treatment. Nine of the twelve resulting management scenarios were deemed profitable. Treatments that included daily air-dried triploids were found to be the most profitable and treatments that had the lowest or no profitability included diploid oysters. Gear brand and tumbling frequency did not appear to significantly affect profitability.

Introduction

Alabama oystermen have historically focused on harvesting oysters for the shucked meat market, however, decline of wild oyster populations and stricter state regulations have limited their annual landings (May 1971, as cited in VanderKooy 2012; NMFS 2020). Off-bottom oyster farming, or raising oysters suspended off the seafloor or floating in the water in baskets or bags, provides new economic opportunities producing premium oysters for the half-shell market. While off-bottom farming is a relatively new industry in Alabama and other Gulf of Mexico states, interest, investment, and production have been booming. In just 10 years Alabama has gone from 0 to 22 oyster farms, created 34 full-time and 30 part-time jobs, and received over $1,000,000 in farm gate value in 2018 (ACES 2019). Despite the potential for high production, this new industry is not without its own challenges. Farmers typically will not see a profit until year 2 or 3 of operating an oyster farm due to high startup costs and labor demands (R. Grice, personal communication, 2020). In addition, poor water quality, permitting hurdles, and seed supply shortages can further threaten sustainability of regional businesses.

One of the most common off-bottom farming methods used in the Gulf of Mexico region is the adjustable longline system (ALS), where mesh baskets are suspended on a tensioned monofilament line inside a rigid plastic sleeve that is attached to pilings at either end. The line is supported by riser posts at regular intervals using a clip mechanism. Clips are positioned at multiple tidal heights along the riser posts, allowing farmers to adjust the position of their baskets in the water column. Farmers routinely raise baskets out of the water, the 'drying position', to control biofouling on gear or oysters, or submerge the baskets, the 'growing position' for feeding and storm preparation (Watson et al. 2009). It is recommended farmers air-dry their oysters for 24 hours once per week during the months of March-November, and biweekly during the winter months of December-February (Davis 2013). Despite the benefits regular air-drying provides, high labor costs are required to air-dry oysters this frequently. To combat costs Leon Stott, an Australian farmer working with SEAPA (one brand of ALS gear), suggests a lower-labor alternative of setting lines at a specific tidal height allowing regular air-drying as the tides go in and out each day (Walton, personal communication, 2020).

In addition to determining which air-drying methods to use, regional oyster farmers have also debated on the costs and benefits of high versus low frequency tumbling (e.g. monthly versus quarterly). Studies have suggested that frequent tumbling improves oyster shape, consistency, and cleanliness, however it comes at the cost of higher labor and growth. Lastly, while more expensive, sterile triploid oyster seed has higher popularity than diploid seed among regional farmers due to faster growth and higher quality meat during summer spawning months, new questions are arising surrounding higher triploid sensitivity to handling and environmental stressors (Ring 2012; Bodenstein 2019).

While the off-bottom oyster farming industry holds a lot of promise in the Gulf region, optimization of management techniques is essential for its success. Research on how to balance oyster quality that meets the standard of the half-shell market with affordable labor costs would benefit regional farmers' creation of well-informed and sustainable business plans (Robert et al. 1993; Handley 2002; Louro et al. 2007). The aim of this study was to determine how different combinations of management techniques for the ALS system affected oyster, *Crassostrea virginica*, performance, production, and profitability.

Methodology

Site Description

In order to create a realistic economic model of an oyster farm, a one-acre commercial farm was installed in collaboration with Julian Stewart, the local aquaculture teacher for Alma Bryant High School in Irvington, AL, located at Grand Bay Oyster Park in Grand Bay, Alabama (Fig 2.1). Students were employed to work on the farm as a part of a student vocational training program. The farm consisted of 16 adjustable longlines that were each 100m long and had the capacity to hold approximately 100 oyster baskets, or ~10,000 oysters at final grow-out stocking density. Oyster seed (diploids 30±1.35mm, triploids 40±00.75mm) to stock the farm was obtained from the Auburn University Shellfish Lab and was deployed on October 23rd, 2018. Each of the 16 longlines was assigned a nested design of farm management techniques.

Fig 2.1 Location of study site in Grand Bay, AL (denoted by star) (Google Maps, 2020).

Experimental Treatments

The management techniques included in the study were common decisions made by off-bottom oyster farmers: two gear brands x two tumbling frequencies x two air-drying frequencies x two oyster ploidies. Each resulting combination of management techniques, or 'treatment', (16 total) was employed on one of the 16 longlines installed (Table 2.1). The adjustable longline style of gear was selected due to its prevalence as an off-bottom oyster farming method in the Gulf region and other parts of the country. Management techniques were selected based on those which are commonly used by regional farmers that utilize this style of gear. We acknowledge that the design is pseudo-replicated at the level of application of a management treatment (16 treatments assigned to 16 lines), but argue that the information gained by the larger scale test outweighs the limitations of pseudo-replication for comparison of profit per oyster and ten-year internal rate of return among treatments.

The two air-drying frequencies tested were daily air-drying during routine tidal exposure or weekly air-drying for a prolonged duration (e.g. 24 hours) (Fig 2.2). In the daily air-drying treatment, ALS baskets were set at a height designed to have the oysters and gear out of the water for approximately 60% of day, following the protocols of a nearby commercial oyster farm, Sandy Bay Oyster Company. The height of lines assigned daily air-drying were adjusted based on extreme tidal changes. In the weekly air-drying treatment, ALS baskets were set sub-tidally and raised weekly for 24-hour desiccation, following the protocols of the Auburn University Shellfish Lab. Weekly air-drying was reduced to biweekly air-drying during the months December-February. In the event of hurricanes or other severe weather all lines were completely submerged and then returned to respective treatment heights.

Fig 2.2 ALS baskets raised for weekly 24-hour air-drying (front) and set for tidal air-drying (back)

The two tumbling frequencies tested were oysters tumbled once a month (monthly) and once every three months (quarterly). Oysters were tumbled using the mechanical grader owned by Point Aux Pins oyster farm, which had 32mm and 45mm holes in its grading tube. After tumbling, oysters were restocked at ~25% full per bag. Baskets were tagged based on treatment so that they could be returned to their respective treatment line if separated. In addition, baskets were also tagged based on what size hole they sorted through in the tube (32mm, 45mm, and anything that retained through the tube) to aid in recording stocking densities and growth over time. Oysters were first tumbled November of 2018 and last tumbled December of 2019, the conclusion of the study, for a total of 14 monthly tumblings and 4 quarterly tumblings.

In addition, both diploid and triploid oyster seed were tested as these are the two commercial oyster seed types currently available to farmers. Diploid seed was deployed at 30±1.35mm and triploid seed was deployed at 40±0.75mm. Initial stocking densities were 1,000 oysters per bag across 10 bags per treatment line, or 10,000 oysters total stocked per treatment line.

Lastly the two gear brands tested were the 15L capacity SEAPA and 25L capacity Hexcyl brand ALS baskets and lines. Seed started in 6mm mesh SEAPA baskets and 3mm mesh Hexcyl baskets and moved up to either 12mm SEAPA or 15mm Hexcyl baskets respectively (Fig 2.3). The SEAPA Stormbreaker system, a system that uses a flexible basket clip for energy absorption and line clamp bearing to reduce basket sliding, was used in conjunction with the SEAPA baskets and lines.

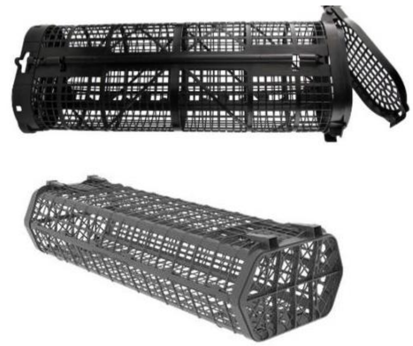

Fig 2.3 15L 12mm mesh SEAPA basket (Top) (SEAPA, 2020)
and 25L 15mm mesh Hexcyl basket (Bottom) (Hexcyl, 2020)

Six BST brand baskets were placed on a non-treatment line and used as a control for growth and survival rates. Three baskets contained 50 diploids each and 3 baskets contained 50 triploids each. A random sample of 100 diploid and 100 triploid oysters was taken from the initial seed order at deployment to stock the control bags. Bags were placed at a sub-tidal level and were not handled during the duration of the study. These oysters were used as a general reference for growth rates and survival of oysters at the site, without any imposed farm management treatments.

Table 2.1 Organization of treatments and respective line numbers on farm

Line	Gear	Tumbling	Air-Drying	Ploidy	Abbreviation
1	Hexcyl	Monthly	Weekly	Diploid	HMW2
2	Hexcyl	Monthly	Weekly	Triploid	HMW3
3	Hexcyl	Monthly	Daily	Diploid	HMD2
4	Hexcyl	Monthly	Daily	Triploid	HMD3
5	Hexcyl	Quarterly	Weekly	Diploid	HQW2
6	Hexcyl	Quarterly	Weekly	Triploid	HQW3
7	Hexcyl	Quarterly	Daily	Diploid	HQD2
8	Hexcyl	Quarterly	Daily	Triploid	HQD3
9	SEAPA	Monthly	Weekly	Diploid	SMW2
10	SEAPA	Monthly	Weekly	Triploid	SMW3
11	SEAPA	Monthly	Daily	Diploid	SMD2
12	SEAPA	Monthly	Daily	Triploid	SMD3
13	SEAPA	Quarterly	Weekly	Diploid	SQW2
14	SEAPA	Quarterly	Weekly	Triploid	SQW3
15	SEAPA	Quarterly	Daily	Diploid	SQD2
16	SEAPA	Quarterly	Daily	Triploid	SQD3

Data Collection

Data were collected with the goal of creating a unique enterprise budget for each treatment. The enterprise budget template used was developed by Matt Parker of the University of Maryland (Parker et al. 2016) and modified for the region (Grice et al. 2020); here we modified the enterprise budgets for each treatment. Within the enterprise budgets each treatment line was scaled up to a 1-acre farm (16 lines) and an assumed annual production of 160,000 oysters (10,000 per line), equivalent to the experimental farm installed. Oysters reached harvest in one year for all treatment lines. Any values not included in data collection were based on regional estimates. All labor costs were based on a $12/hr rate; our farm did not have any supervisory labor and therefore it was not included in the budget. Overhead costs were set at 5% of total variable costs and repairs were set at 4% of installation costs. An additional ten years of enterprise budgets were extrapolated for each treatment based on the data collected to account for slow revenue in the first years of farm operation and growth rate of oysters to market size (Parker 2019; Grice, personal communication, 2020).

The price and quantity of all installation items were recorded specific to each treatment. The adjustable longline gear was installed using sliding PVC sleeves with clips to attach to the line. The sleeves were able to be adjusted in the water column along each post via nails put into holes that locked the sleeves into place. All Hexcyl brand treatment lines were installed using respective branded riser clips, Kevlar lines with plastic sleeves, and line attachment hardware. All SEAPA brand lines were installed using respective branded riser clips, cable with plastic sleeves, line attachment hardware, and ‘Stormbreaker’ clamp bearings. Labor to make and install all lines, riser posts, PVC sleeves, and baskets was recorded in man hours and included in installation costs. All production costs were recorded on a per line basis, but later scaled up to a 1-acre farm consisting of 16 lines.

Variable costs recorded included labor for tumbling and air-drying management techniques, labor for maintenance activities, labor for harvest, fuel, retail containers, and seed. Management techniques included raising and lowering lines for air-drying, collecting baskets for tumbling, putting oysters through the mechanical tumbler, re-bagging oysters, and putting oysters back on their respective lines. Maintenance activities included storm preparation, broken gear repair, and gear recovery. Oysters were harvested and sold, and the number of oysters harvested per line was recorded and used to track labor and number of retail containers. Fuel was recorded for each boat trip as well as the amount used to in the generator to run the mechanical tumbler.

Survival was included as an assumption for each line's enterprise budget and used to estimate seed purchased in subsequent years. Survival rate was calculated based on a comparison of final count data, including harvested oysters, in December 2019 to initial deployment stocking densities in October of 2018. In December of 2019, up to three baskets of each tagged size grade (fell through tumbler holes 32mm, 45mm, 45mm+) were counted fully and averaged. The average for each size grade was multiplied by the total number of baskets in that size grade and added together to get a total count (e.g. 300 oysters/32mm basket in 1 basket + 100 oysters/45mm basket in 5 baskets + 70 oysters/45mm+ basket in 10 baskets = 1,500 total oysters on farm) . The estimated count per line was added to the number of oysters already harvested and divided by the initial stocking density of 10,000 per line to get a total estimate of survival (e.g. (1,500 oysters on farm + 5,800 oysters harvested) / 10,000 oysters initially stocked * 100 = 73% survival).

Average shell growth per day (mm/day) was calculated by subtracting the average oyster height at deployment from the average shell height when a treatment line first reached harvest size and dividing by the number of days deployed. Average tissue growth per day (g/day) was calculated by subtracting the average dry tissue weight at deployment from the average dry tissue weight when a treatment line first reached harvest size and dividing by the number of days deployed. Control lines were harvested in conjunction with our treatment lines and were used as comparison for both growth metrics.

Price per oyster for each treatment line was based on anonymous survey responses from wholesalers and chefs. Survey participants were provided with a sample of oysters from each treatment line and asked the wholesale price they would be willing to offer for each group (explained further in Chapter 3). The resulting average willingness to pay per oyster recorded for each treatment line was input as the selling price in each respective enterprise budget.

Data Analysis

Due to storm debris damage and basket loss in March of 2019, treatment lines 1-4 (HMW2, HMW3, HMD2, HMD3) were not included in final analysis. We chose to remove these lines from our analysis due to the possibility of baskets being reassigned to the wrong treatment lines. Therefore, only results for treatment lines 5-16 are represented. Lines 5-8 (Hexcyl gear, quarterly tumbling) and lines 13-16 (SEAPA gear, quarterly tumbling) were used for comparing performance of gear type, air-drying, and ploidy treatments within a single tumbling regime (quarterly). Lines 9-12 (SEAPA gear, monthly tumbling) and lines 13-16 (SEAPA gear, quarterly tumbling) were used for comparing performance of tumbling, air-dying, and ploidy treatments within a single gear type (SEAPA).

All data was analyzed using RStudio ©, a program for statistical computing. Analysis of Variance (ANOVA) tests were used to analyze the significance between shell and tissue growth data and two different three way interactions: 1) Gear type x Air-drying x Ploidy interactions (Lines 5-8 and Lines 13-16), and 2) Tumbling x Air-drying x Ploidy interactions (Lines 9-12 and Lines 13-16). An $\alpha = 0.05$ was used to determine significant differences among groups. A full model including all interactions was run first and then any insignificant interactions were removed before running the model again. Tukey's honest significant difference test (Tukey's HSD) was used to conduct post-hoc analyses of significant effects ($p<0.05$) found in the ANOVA. The Shapiro-Wilk Test of Normality and Levene's Test were used to verify assumptions of normally distributed residuals and homogeneity of variance for each dataset. A p-value >0.05 for either test of assumptions indicated that the null hypothesis that the data is normally distributed or homogenous cannot be rejected; growth datasets that failed the tests for assumptions ($p<0.05$) were log transformed to satisfy test assumptions.

Willingness to pay per oyster for each treatment line was determined by averaging all participant responses by line and was multiplied by the total number of harvestable oysters to determine an estimate of gross income. For year one, the number of harvestable oysters was determined on a per line basis by adding the number of oysters already harvested to the count estimate of oysters that fell through the 45mm+ hole during grading. For years 2-10, the number of harvestable oysters was determined by Equation 1, in which years 3-10 remained constant.

(Equation 1)

$$\left(\frac{\text{160,000 Seed}}{\text{Survival Rate Year 1}} * \text{Proportion of Oysters Harvested Year 1}\right) +$$

$$(\text{Oysters Not Harvested Year 1})$$

All fixed and variable costs were divided by the number of oysters produced to determine the breakeven cost per oyster. Costs were also subtracted from gross income, to give an estimate of Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA, Zelmanovich et. al 2017). Each fixed and variable cost was assigned as a percentage of total production costs. Changes in production costs and gross income for years 2 and 3-10 were extrapolated based on any increases in the number of oysters harvested due to a higher amount of seed purchased to meet desired annual production of 160,000 oysters or undersized oysters that were left over from the previous growing season. Labor and fuel costs were increased by the same proportion increase of oysters harvested.

All treatment lines' enterprise budgets reached stabilized income and expenses in three years of extrapolation. Annual cash flow statements, net present value (NPV), and a ten-year modified internal rate of return (MIRR) were calculated based on a total of ten years of operation for each treatment scenario. A ten-year period included multiple crops and provided a better estimation of profitability (Parker, 2019). To calculate NPV, an 8.07% interest rate was used based on the rate for mollusk aquaculture in developed countries determined by Campo & Zuniga-Jara (2017). To calculate MIRR 8.07% was also used for the interest rate and 1.74% was used for the reinvestment rate, based on the ten-year U.S. treasury bond rate from 1/23/2020.

Results

There are many risks and variables in operating an off-bottom oyster farm, and therefore it is important to note that these results will not apply to all farming operations, and are intended primarily to allow a comparison of the relative importance of various farm management decisions on a farm's profitability. Site conditions, markets, and required equipment may vary, all of which can affect production costs and profits. In addition, financial resources vary person to person, which is why we decided not to include interest, taxes, depreciation, and amortization in our results. These results are not meant to serve as strict guidelines for operation, but rather general comparisons of how different management methods could be applied and their economic effect.

Shell Growth

When we assessed daily growth rates in terms of daily shell height increase (mm) per day, we found that diploids had higher average daily shell growth rates than triploids in both the control groups (Diploid average 0.13 mm/day, Triploid average 0.11 mm/day, p≤0.05) and the treatment groups (Diploid average 0.10 mm/day, Triploid average 0.07 mm/day, p<0.01). Growth rate varied within ploidy based on total treatment combination: treatments with daily air-drying had lower average daily shell growth rate than their weekly air-drying counterparts (p<0.01, Fig 2.4).

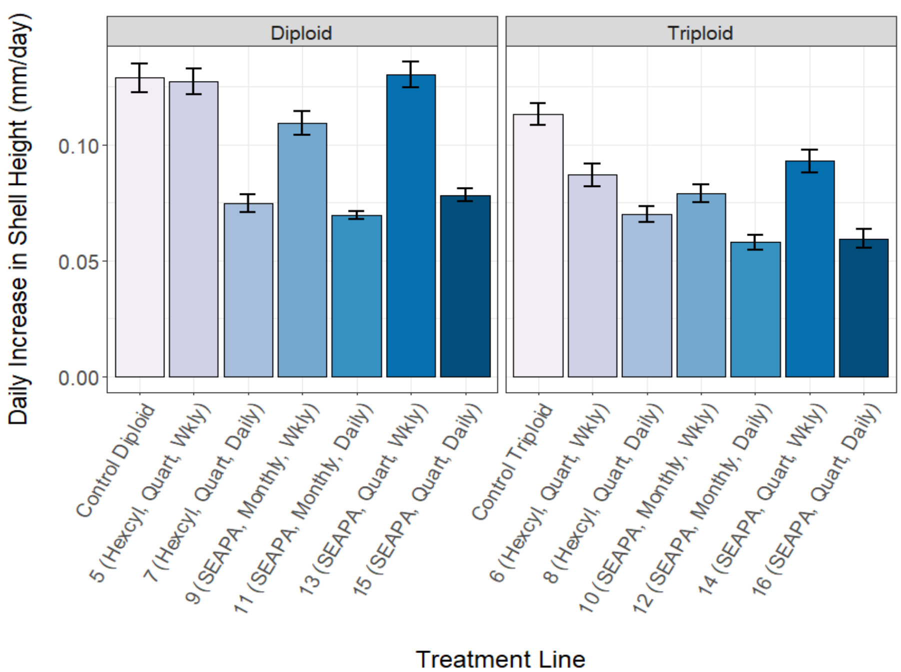

Figure 2.4 Average daily shell height growth (mm) per day for all experimental treatment lines (5-16) and control lines that remained submerged for the duration of the study

When we looked at average daily shell height growth based on their assigned gear and tumbling treatments a pattern emerged: Weekly/Diploid treatments produced the highest average daily shell growth (0.12 mm/day) followed by descending average daily shell growth rates of Weekly/Triploid (0.09 mm/day), Daily/Diploid (0.08 mm/day), and Daily/Triploid treatments (0.07 mm/day, Fig 2.5).

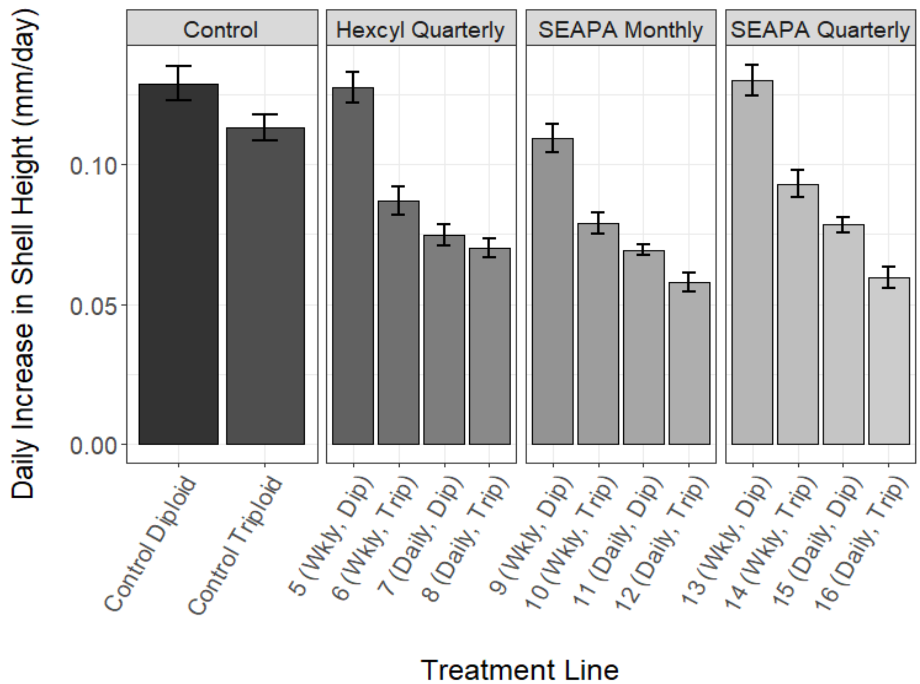

Figure 2.5 Average daily shell height growth (mm) per day for all experimental treatment lines (5-16), reordered based on Gear x Tumbling treatment

Tissue Growth

When we assessed daily growth rates in terms of daily tissue weight increase (g) per day, we found that triploids had higher average daily tissue growth rates than diploids in the control groups (Diploid average 0.0067 g/day, Triploid average 0.0093 g/day, $p<0.01$) and weekly air-drying treatments (Weekly/Diploid average 0.0033 g/day, Weekly/Triploid 0.0059 g/day, p≤0.01). Surprisingly, diploids with quarterly tumbling and daily air-drying had higher daily tissue growth rates than triploids with daily air-drying treatments ($p<0.01$, Fig 2.6)

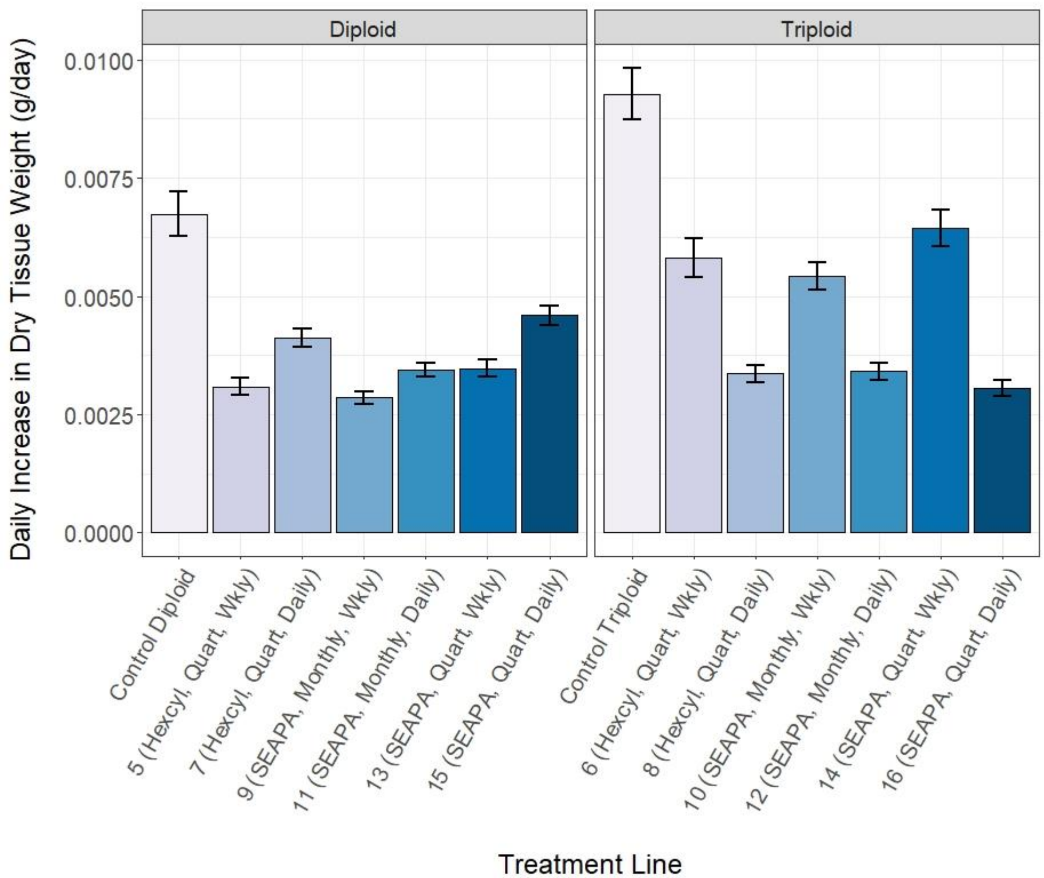

Figure 2.6 Average daily tissue growth (g) per day for all experimental treatment lines (5-16) and control lines that remained submerged for the duration of the study

When we looked at average daily tissue growth based on their assigned gear and tumbling treatments another pattern emerged: Weekly/Triploid treatments produced the highest average daily tissue growth and Quarterly/Daily/Diploid treatments produced the second highest average daily tissue growth (Fig 2.7).

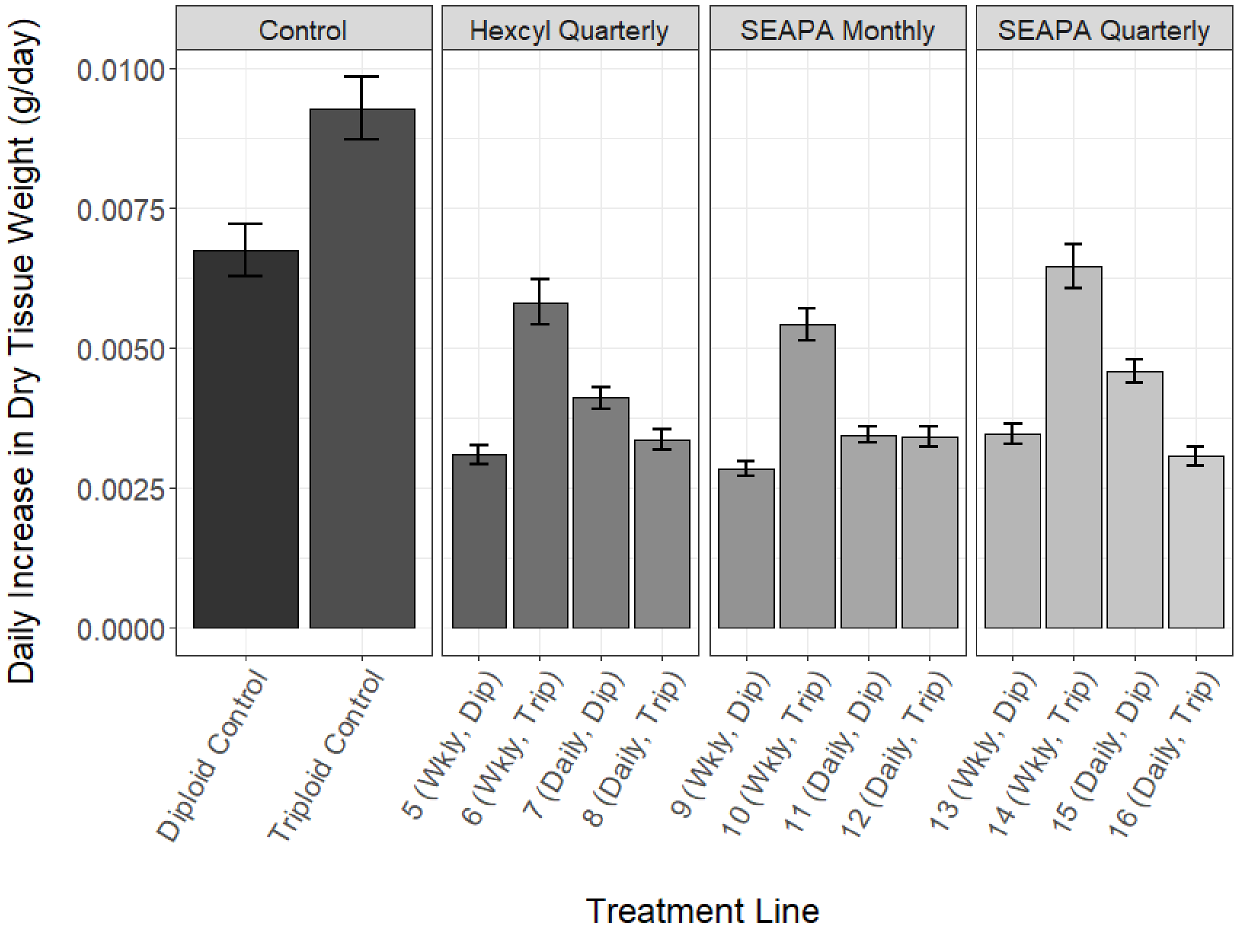

Figure 2.7 Average daily tissue growth (g) per day for all experimental treatment lines (5-16), reordered based on Gear x Tumbling treatment

Assumptions

Assumptions remained constant across all years of operation. Some assumptions varied by treatment i.e. ploidy or gear type. All values shown have been scaled up to meet the assumption of a 1-acre farm, in which one run is equivalent to two lines. Aquaculture insurance is not offered in many locations, therefore only an estimate of required insurances (general liability, auto, protection and indemnity) were included. Lease rent was specific to the study site and is higher than the average rent costs in the region (Table 2.2).

Table 2.2 Assumption values for items constant across all treatments

Assumption	**Value**
Desired Annual Production	160,000 oysters
Lease Size	1 acre
Runs per Acre	8
Number of Years Until Harvest Size	1 year
Retail Containers	1,600 (at 100 oysters per mesh bag)
Marketing Expenses	$1,200.00 annually
Lease Rent	$418.66/acre
General Labor Rate	$12.00/hr
Insurance	$1,000.00 required

For seed costs, it was assumed 160,000 seed was purchased during the first year of operation for all treatment lines assuming a 100% survival rate to start. Diploid seed is on average ~$5 cheaper per 1,000 6mm spat than triploid seed in the Gulf of Mexico region (Table 2.3).While the cost of seed remained constant across all operation years, the amount of seed purchased changed in subsequent years based on the recorded survival rates (Table 2.8).

Table 2.3 Assumption values for diploid versus triploid seed costs

Ploidy	**Seed Cost**
Diploid	$21.67/1,000 6mm spat
Triploid	$26.30/1,000 6mm spat

A comparison of Hexcyl brand and SEAPA brand gear was chosen to be included in the study as they are both commonly used longline brands in the Gulf of Mexico region (Table 2.4). Previous enterprise budgets have been made for BST brand longline gear, therefore we hoped to create additional resources for regional farmers by creating two alternative gear brand enterprise budgets.

Table 2.4 Assumption values for treatment lines including Hexcyl brand gear versus SEAPA brand gear

Assumption	Value for Hexcyl Gear Treatment Lines	Value for SEAPA Gear Treatment Lines
Market size oysters per container	105	75
Baskets per Acre	1,524	2,133

Fixed Costs

Overall, choice of gear had a minimal effect on installation costs with a difference of only ~$1,000 (Table 2.5, Table 2.6). The cost of small and large mesh sized baskets made up around half of the installation costs, with a truck, vessel, and tumbler being the next biggest investments to start. Despite having to purchase more SEAPA baskets due to their smaller capacity and including the "Stormbreaker system" in conjunction with the gear, SEAPA brand installation costs were not significantly different from Hexcyl brand installation costs. It took slightly more labor hours to install SEAPA baskets than Hexcyl baskets. Also included in the fixed costs was repair costs; repair costs for each gear brand were 4% of the total installation costs. Hexcyl brand repair costs came out to be $5,051 annually and SEAPA brand repair costs came out to be $5,003 annually.

Table 2.5 Installation costs, including labor, for a one-acre farm with Hexcyl brand gear

Required Items	Quantity	Unit	Cost Per Unit	Total Cost
Vessel	1	Each	$ 10,000.00	$ 10,000
Harvest Baskets	45	Each	$ 20.00	$ 900
Truck	1	Each	$ 15,000.00	$ 15,000
Pilings (16 feet)-for runs	16	Each	$ 318.00	$ 5,328
3" PVC pipe (10' length)	496	Each	$ 9.95	$ 4,935
Rivets to attach clips to sleeve	992	Each	$ 0.22	$ 218
Hexcyl riser clips for sleeves	496	Each	$ 1.90	$ 942
Riser Clip Sleeves (4" PVC 10' / 20)	496	Each	$ 1.08	$ 536
Kevlar Core Rope + Plastic Sleeve	6000	Feet	$ 1.50	$ 9,000
Hexcyl line attachment hardware	16	Each	$ 35.90	$ 574
Line wear reduction sleeves	480	Each	$ 0.15	$ 72
Hexcyl Baskets (3mm)	1600	Each	$ 17.00	$ 27,200
Hexcyl Baskets (15mm)	1600	Each	$ 20.00	$ 32,000
Power washer	1	Each	$ 300.00	$ 300
Installation Labor	653.25	Man Hours	$ 12.00	$ 7,839
Required Item Total				**$ 114,845**

Optional Items	Quantity	Unit	Cost Per Unit	Total Cost
Tumbler	1	Each	$ 10,760.00	$ 10,760
Sorting Tables	1	Each	$ 100.00	$ 100
Gasoline Generator	1	Each	$ 559.00	$ 559
Optional Item Total				**$ 11,419**
Grand Total				**$ 126,264**

Table 2.6 Installation costs, including labor, for a one-acre farm with SEAPA brand gear

Required Items	Quantity	Unit	Cost Per Unit	Total Cost
Vessel	1	Each	$ 10,000.00	$ 10,000
Harvest Baskets	45	Each	$ 20.00	$ 900
Truck	1	Each	$ 15,000.00	$ 15,000
Pilings (16 feet)-for runs	16	Each	$ 318.00	$ 5,328
3" PVC pipe (10' length)	496	Each	$ 9.95	$ 4,935
Rivets to attach clips to sleeve	992	Each	$ 0.22	$ 218
SEAPA riser clips for sleeves	496	Each	$ 0.75	$ 372
Riser Clip Sleeves (4" PVC 10' / 20)	496	Each	$ 1.08	$ 536
SEAPA Cable + Plastic Sleeve	6000	Feet	$ 0.70	$ 4176
SEAPA line attachment hardware	16	Each	$ 48.98	$ 784
SEAPA "Stormbreaker System" Clamp Bearings	1920	Each	$ 1.71	$ 3,283
SEAPA Baskets (6mm)	1920	Each	$ 16.50	$ 31,680
SEAPA Baskets (12mm)	1920	Each	$ 14.49	$ 27,821
Power washer	1	Each	$ 300.00	$ 300
Installation Labor	693.25	Man Hours	$ 12.00	$ 8,319
Required Item Total				**$ 113,652**

Optional Items	Quantity	Unit	Cost Per Unit	Total Cost
Tumbler	1	Each	$ 10,760.00	$ 10,760
Sorting Tables	1	Each	$ 100.00	$ 100
Gasoline Generator	1	Each	$ 559.00	$ 559
Optional Item Total				**$ 11,419**
Grand Total				**$ 125,071**

Variable Costs per Treatment Line

Variable costs include values we measured and calculated throughout the course of the study. Labor costs differed among tumbling treatment methods, with monthly tumbling costing more than equivalent treatment combinations assigned quarterly tumbling. The labor cost increase ranged between 12% to 98% between tumbling methods. Weekly air-drying treatment methods cost significantly more in terms of labor costs than daily air-drying. The labor cost increase ranged between 45% and 166% between air-drying methods. Labor costs differed slightly between gear types, likely due to the difference in basket volume and number per longline. SEAPA gear types required between 11-18% increased labor costs compared to Hexcyl gear types. Triploid oyster seed had higher labor costs than diploid seed, but there was high variation; the labor cost increase ranged between 1% and 32% for triploid oyster seed. Fuel costs differed the most among air-drying treatments: weekly air-drying treatments had on average a 78% cost increase for fuel when compared to equivalent treatments with air-drying instead (Table 2.7).

Table 2.7 Year 1 variable costs and values per treatment line, ranked from lowest (1) to highest total costs (12)

Treatment Line	Labor ($12/hr)	Average Yearly Fuel Cost	Overhead (5% of Var. Costs)	Total Costs	Rank
5 (HQW2)	$18,520	$1,111	$1,216	$32,990	6
6 (HQW3)	$22,405	$1,115	$1,447	$37,854	9
7 (HQD2)	$8,331	$542	$677	$21,648	1
8 (HQD3)	$8,418	$638	$724	$22,654	2
9 (SMW2)	$27,986	$1,398	$1,703	$43,193	11
10 (SMW3)	$28,627	$1,672	$1,786	$44,936	12
11 (SMD2)	$14,974	$639	$1,015	$28,728	5
12 (SMD3)	$19,735	$1,105	$1,313	$35,003	7
13 (SQW2)	$20,563	$1,029	$1,314	$35,007	8
14 (SQW3)	$25,672	$1,018	$1,606	$41,145	10
15 (SQD2)	$9,391	$639	$735	$22,865	3
16 (SQD3)	$9,960	$647	$801	$24,248	4

While survival of oysters stocked on a farm often vary year to year, for the sake of comparison survival was assumed to be constant for all 10 years of operation and was based on our measured value per treatment line (Table 2.8). Price can also vary between years but was also assumed to be constant for all 10 years of operation and was based on the average value recorded from our survey results per treatment line. Both price and the number of oysters harvested in the first year varied among the treatment lines, resulting in a wide range of EBITDAs anywhere from $1,580 to $49,968 (Table 2.8).

Table 2.8 Year 1 variable income and other values per treatment line, where survival and price remain constant for all years of operation, ranked from highest (1) to lowest EBITDA (12)

Treatment Line	Survival	Total Oysters Harvested per Year	Price per Oyster	Gross Income	Total Costs	EBITDA*	Rank
5 (HQW2)	65%	99,296	$0.57	$56,599	$32,990	$23,609	5
6 (HQW3)	79%	122,976	$0.61	$75,015	$37,854	$37,161	4
7 (HQD2)	53%	46,528	$0.50	$23,264	$21,648	$1,580	12
8 (HQD3)	47%	43,888	$0.70	$30,722	$22,654	$8,067	11
9 (SMW2)	73%	109,712	$0.55	$60,342	$43,193	$17,148	7
10 (SMW3)	82%	131,600	$0.64	$84,224	$44,936	$39,288	3
11 (SMD2)	99%	66,112	$0.61	$40,328	$28,728	$11,601	9
12 (SMD3)	83%	132,768	$0.64	$84,972	$35,003	$49,968	1
13 (SQW2)	57%	87,552	$0.54	$47,278	$35,007	$12,271	8
14 (SQW3)	79%	126,112	$0.65	$81,973	$41,145	$40,827	2
15 (SQD2)	97%	66,112	$0.52	$34,378	$22,865	$11,513	10
16 (SQD3)	79%	67,296	$0.65	$43,742	$24,248	$19,494	6

* Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA)

Because the growth rate varied among oysters treated with different management techniques, some oysters took longer to reach harvest size. Therefore, rather than only looking at the first year of operation we felt it was important to look at operation costs and profits over a 10-year period. For the second year of operation, seed costs increased in order to account for survival rates and the desired annual production rate of 160,000 oysters per acre. Treatment lines 5, 7, and 8 (HQW2, HQD2, and HQD3) had the highest cost increases for seed: 54%, 90%, and 114% cost increase respectively. The rest of the treatment lines had seed cost increases between 0-38%. Labor costs for each treatment line increased between 19-111% for the second year of operation due to the additional labor required. Lines with lower survival rates had higher overall costs in the second year of operation because more seed was purchased to reach the production goal, and hence had to be handled (Table 2.9).

Table 2.9 Year 2 variable costs and values extrapolated per treatment line, ranked from lowest (1) to highest total costs (12)

Treatment Line	Cost of Seed	Labor ($12/hr)	Average Yearly Fuel Cost	Overhead (5% of Var. Costs)	Total Costs	Rank
5 (HQW2)	$5,331	$27,795	$1,648	$1,800	$45,258	7
6 (HQW3)	$5,339	$28,078	$1,410	$1,803	$45,315	8
7 (HQD2)	$6,588	$16,427	$1,115	$1,267	$34,077	3
8 (HQD3)	$8,995	$17,759	$1,284	$1,463	$38,180	5
9 (SMW2)	$4,789	$38,309	$1,988	$2,316	$56,048	12
10 (SMW3)	$5,129	$34,409	$2,009	$2,139	$52,332	11
11 (SMD2)	$3,502	$20,645	$1,019	$1,320	$35,133	4
12 (SMD3)	$5,076	$23,540	$1,368	$1,560	$40,192	6
13 (SQW2)	$3,467	$34,530	$1,752	$2,049	$50,444	10
14 (SQW3)	$5,313	$31,987	$1,304	$1,991	$49,242	9
15 (SQD2)	$3,589	$14,967	$1,013	$1,040	$29,255	1
16 (SQD3)	$5,313	$15,640	$1,033	$1,160	$31,789	2

At the end of the first year of operation, oysters sorted in 45mm+ baskets were considered harvested in addition to oysters already harvested and sold. Oysters remaining in 32mm or 45mm baskets were considered to not be ready for harvest at the end of the first year. Any oysters not harvested within the first year of operation were assumed to be harvested during the second year of operation along with any new seed grown during that period. We did not apply annual mortality rates to the oysters that were not harvested within the first year, because they were assumed to be harvested within the initial months of the second year of operation. Therefore, our harvest estimates may be higher than real world operations. In our extrapolation we were almost able to achieve our desired production rates in the second year of operation among all treatment lines. EBITDA ranged from $28,963-$62,204 for all treatment lines. There was high variation in EBITDAs for the treatment lines between the first and second years of operation; lines had EBITDA increases anywhere between 24-1,733%, which is why we felt extrapolation was important to fairly judge the economic performance of all treatment lines (Table 2.10).

Table 2.10 Year 2 variable income and values extrapolated per treatment line, ranked from highest (1) to lowest EBITDA (12)

Treatment Line	Total Oysters Harvested per Year	Price per Oyster	Gross Income	Total Costs	EBITDA	Rank
5 (HQW2)	157,467	$0.57	$89,756	$45,258	$44,498	9
6 (HQW3)	159,090	$0.61	$97,045	$45,315	$51,730	6
7 (HQD2)	126,080	$0.50	$63,040	$34,077	$28,963	12
8 (HQD3)	124,770	$0.70	$87,339	$38,180	$49,159	8
9 (SMW2)	157,615	$0.55	$86,688	$56,048	$30,640	11
10 (SMW3)	159,983	$0.64	$102,389	$52,332	$50,058	7
11 (SMD2)	159,068	$0.61	$97,031	$35,133	$61,899	3
12 (SMD3)	159,993	$0.64	$102,396	$40,192	$62,204	1
13 (SQW2)	157,248	$0.54	$84,914	$50,444	$34,470	10
14 (SQW3)	159,840	$0.65	$103,896	$49,242	$54,654	4
15 (SQD2)	156,887	$0.52	$81,581	$29,255	$52,326	5
16 (SQD3)	144,394	$0.65	$93,856	$31,789	$62,067	2

By the third year of extrapolation, costs appeared to stabilize. Labor costs for the treatment lines increased between 0-12% between the second and third years of operation. Overall costs for all treatment lines increased between 0-7% between the second and third years of operation (Table 2.11).

Table 2.11 Years 3-10 variable costs and values extrapolated per treatment line, where the cost of seed remained constant from year 2, ranked from lowest (1) to highest total costs (12)

Treatment Line	Labor ($12/hr)	Average Yearly Fuel Cost	Overhead (5% of Var. Costs)	Total Costs	Rank
5 (HQW2)	$27,946	$1,658	$1,808	$45,428	8
6 (HQW3)	$28,133	$1,414	$1,806	$45,376	7
7 (HQD2)	$18,462	$1,251	$1,376	$36,362	4
8 (HQD3)	$19,873	$1,426	$1,576	$40,554	6
9 (SMW2)	$38,452	$1,998	$2,257	$54,821	12
10 (SMW3)	$34,410	$2,009	$2,139	$52,333	11
11 (SMD2)	$20,701	$1,023	$1,323	$35,195	3
12 (SMD3)	$23,541	$1,368	$1,561	$40,192	5
13 (SQW2)	$34,695	$1,752	$2,057	$50,618	10
14 (SQW3)	$31,997	$1,305	$1,992	$49,253	9
15 (SQD2)	$15,153	$1,026	$1,050	$29,465	1
16 (SQD3)	$16,576	$1,095	$1,210	$32,841	2

By the third year of operation, we extrapolated that all treatment lines reached the desired annual production of 160,000 oysters. EBITDA ranged from $33,179-$71,446. EBITDA increase between the second and third years of operation ranged from 0-51%. Treatment lines 7 and 8 (HQD2 and HQD3) had the highest EBITDA increase between the second and third years of operation at 51% and 45% respectively (Table 2.12).

Table 2.12 Years 3-10 variable income and values extrapolated per treatment line, ranked from highest (1) to lowest EBITDA (12)

Treatment Line	Total Oysters Harvested per Year	Price per Oyster	Gross Income	Total Costs	EBITDA	Rank
5 (HQW2)	160,000	$0.57	$91,200	$45,428	$45,772	9
6 (HQW3)	160,000	$0.61	$97,600	$45,376	$52,224	7
7 (HQD2)	160,000	$0.50	$80,000	$36,362	$43,638	10
8 (HQD3)	160,000	$0.70	$112,000	$40,554	$71,446	1
9 (SMW2)	160,000	$0.55	$88,000	$54,821	$33,179	12
10 (SMW3)	160,000	$0.64	$102,400	$52,333	$50,067	8
11 (SMD2)	160,000	$0.61	$97,600	$35,195	$62,405	3
12 (SMD3)	160,000	$0.64	$102,400	$40,192	$62,208	4
13 (SQW2)	160,000	$0.54	$86,400	$50,618	$35,782	11
14 (SQW3)	160,000	$0.65	$104,000	$49,253	$54,747	5
15 (SQD2)	160,000	$0.52	$83,200	$29,465	$53,735	6
16 (SQD3)	160,000	$0.65	$104,000	$32,841	$71,159	2

Cost Summary and Breakeven Analysis

Labor made up the majority of all production costs, anywhere between 37-65% for each treatment line. For all treatment lines the remaining costs were split approximately evenly among other variable costs and fixed costs (Fig 2.8a and 2.8b).

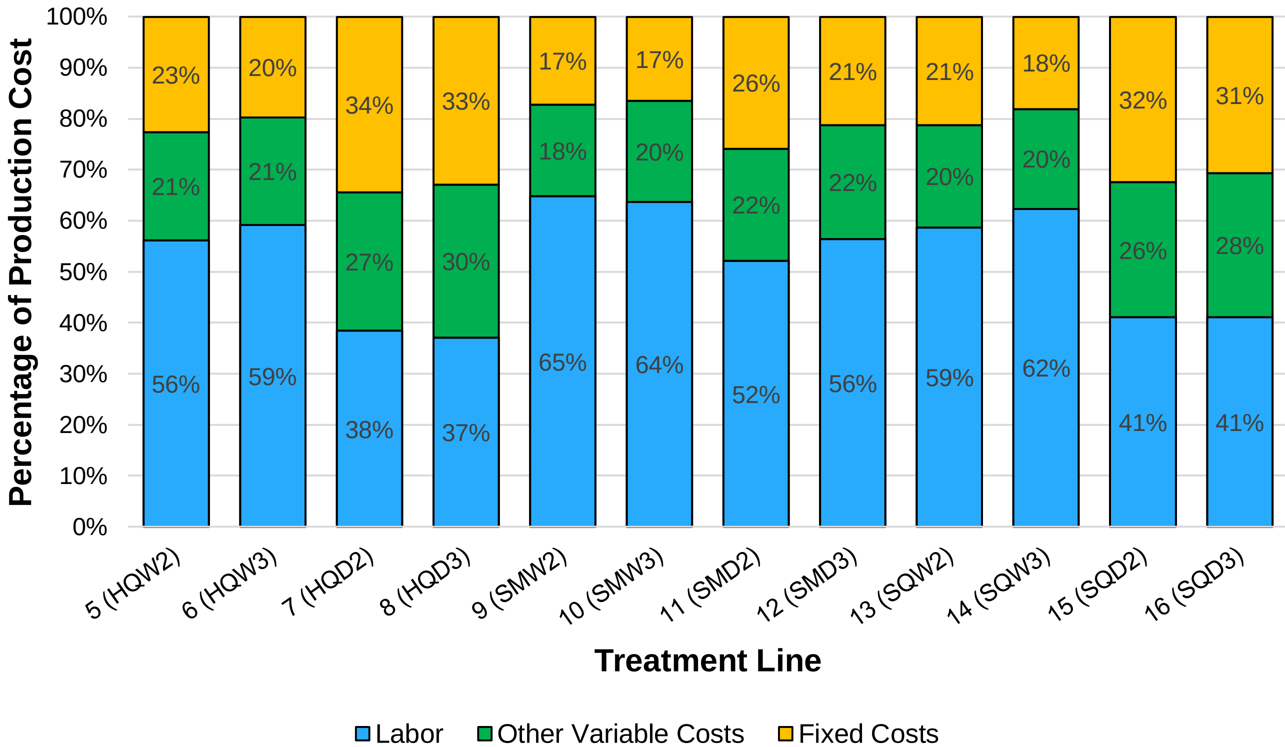

Figure 2.8a Total production costs split into respective labor, other variable cost, and fixed cost percentages for all treatment lines

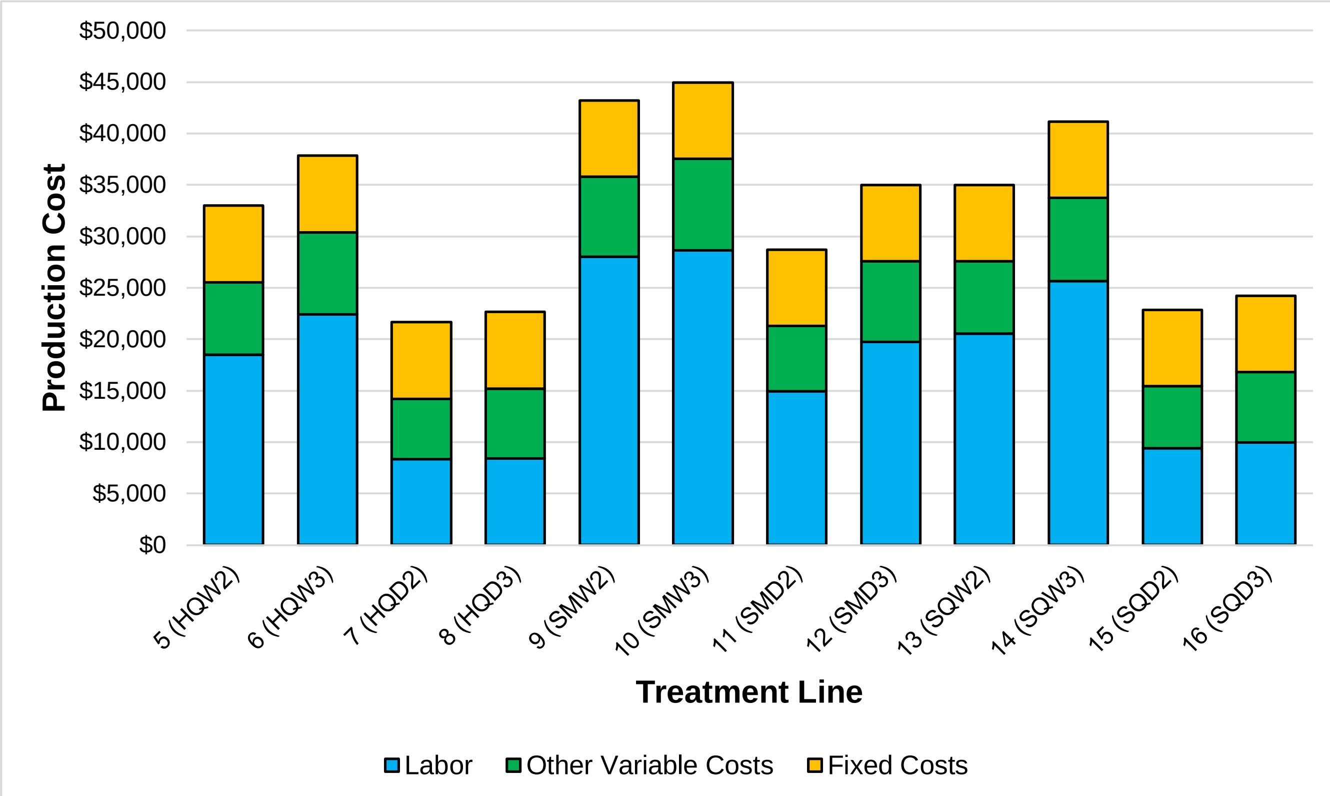

Figure 2.8b Total production costs split into respective labor, other variable cost, and fixed cost absolute values for all treatment lines

Breakeven costs and income per oyster varied between operation years, with breakeven costs decreasing and income increasing from year 1 to year 3. In year 1 treatment line 7 (HQD2) had the lowest income per oyster at $0.03 and line 12 (SQD3) had the highest income per oyster at $0.38. By year 3 and beyond treatment line 9 (SMW2) had the lowest income per oyster at $0.21 and lines 8 and 16 (HQD3 and SQD3) had the highest income per oyster at $0.45 (Table 2.13)

Table 2.13 Breakeven costs and income per oyster for ten years of operation for all treatment lines

Treatment Line	Year 1: Break Even Cost per Oyster	Year 1: Income per Oyster	Year 2: Break Even Cost per Oyster	Year 2: Income per Oyster	Year 3-10: Break Even Cost per Oyster	Year 3-10: Income per Oyster
5 (HQD2)	$0.33	$0.24	$0.29	$0.28	$0.28	$0.29
6 (HQW3)	$0.31	$0.30	$0.29	$0.33	$0.28	$0.33
7 (HQD2)	$0.47	$0.03	$0.27	$0.23	$0.23	$0.27
8 (HQD3)	$0.52	$0.18	$0.31	$0.39	$0.25	$0.45
9 (SMW2)	$0.39	$0.16	$0.36	$0.19	$0.34	$0.21
10 (SMW3)	$0.34	$0.30	$0.33	$0.31	$0.33	$0.31
11 (SMD2)	$0.44	$0.18	$0.22	$0.39	$0.22	$0.39
12 (SMD3)	$0.26	$0.38	$0.25	$0.39	$0.25	$0.39
13 (SQW2)	$0.40	$0.14	$0.32	$0.22	$0.32	$0.22
14 (SQW3)	$0.33	$0.32	$0.31	$0.34	$0.31	$0.34
15 (SQD2)	$0.35	$0.17	$0.19	$0.33	$0.18	$0.34
16 (SQD3)	$0.36	$0.29	$0.22	$0.43	$0.21	$0.45

Discussion

Growth

More frequent air-drying exposure through daily air-drying management techniques resulted in lower average daily shell growth in both diploid and triploid oysters, even among different tumbling frequencies (Figs 2.4 and 2.5). A study by La Peyre et al. (2017) found similar results in which oysters exposed to daily air-drying produced lower shell growth than oysters with weekly air-drying or held subtidally; they suggested that oysters grown with daily air-drying put less energy towards shell production than oysters grown with weekly air-drying or full submersion. Crenshaw (1980) and Wilbur and Saleuddin (1983) explain that periodic air-drying causes oysters to experience oxygen deprivation in which acidic byproducts of anaerobic glycolysis must be neutralized by alkali shell reserves; hence, more frequent air-drying may contribute to slower shell growth (as cited in O'Meley 1995). Contradictory to previous studies, we found in our study that diploids with less frequent air-drying exposure (weekly air-drying) produced oysters with the highest rates of shell growth, not triploids (Wadsworth et al. 2019b). Diploid control oysters also had higher shell growth on average than triploid controls. We are uncertain as to why our diploids expressed higher shell growth rates than triploid as the literature appears to agree that triploids demonstrate higher growth than diploids even with drying and/or tumbling stressors applied (Bodenstein 2019). We suggest possible explanations may include stress from a prolonged low salinity event experienced in Grand Bay, AL during the summer of 2019 or genetic differences due to source of seed stock, although the exact mechanisms are unknown and more research needs to be done to determine a scientific basis for the observed data (Callam et al. 2016). We also found that oysters subject to quarterly tumbling had slightly higher shell growth rates than monthly tumbling, most likely due to less frequent shell abrasion. We did not observe any differences in gear brand for average daily shell growth rate.

Our controls exhibited the highest average daily tissue growth rate, likely due to their ability for continuous filtration and lack of handling stressors (Figs 2.6-2.7). O'Meley (1995) found that machine-grading can cause whole weight losses; all the treatment lines included in our study were subject to machine-grading (tumbling) which may explain why they exhibited lower average daily tissue growth than our controls. Among our treatments we found the largest differences among oyster ploidy and air-drying management techniques. Triploids exposed to weekly air-drying had the highest average daily tissue growth, which was expected: most literature supports triploid tissue growth advantage over diploids (Wadsworth 2019b). Triploids exposed to daily air-drying may have exhibited lower average daily tissue growth due to higher triploid sensitivity to stressors; daily air-drying subjected oysters to high air-temperatures more frequently than weekly air-drying (Bodenstein 2019; Wadsworth et al. 2019a). In addition, the combined handling stress of frequent air-drying and tumbling may explain why the average daily tissue growth rate for triploids with daily air-drying was significantly lower than those with weekly air-drying. Daily air-dried diploids had significantly higher average daily tissue growth than daily air-dried triploids in quarterly tumbled treatments, but not in monthly tumbled treatments. Diploids may be less susceptible to air-drying stressors than triploids, especially during the summer months, and can exceed triploid tissue growth rates with less frequent tumbling stress. Gillmor suggests that there is an optimal amount of periodic exposure for growth, therefore the combination of frequent tumbling (monthly) and air-drying (daily) may be beyond this optimum for both diploid and triploid oysters (1982, as cited in O'Meley 1995). Again, we did not observe any differences in gear brand for average daily tissue growth rate.

Investment Analysis

When the data for each treatment line were extrapolated for 10 years (with operation years 3-10 remaining constant), 9 of the 12 treatment enterprise budget scenarios were deemed profitable. A profitable scenario was defined as a treatment line that had both a positive MIRR and NPV. MIRR was used instead of IRR because it is considered to be a more accurate measurement of costs and profitability for investment scenarios due to its recognition of reinvestment cash flows (Kierulff 2008). The three treatment lines that were not deemed as profitable were 7 (HQD2), 13 (SQW2), and 9 (SMW2). Of the treatments that were profitable, management techniques including triploid seed tended to be a more profitable investment than those including diploid seed despite higher production costs. Treatment lines including diploid seed made up the five lowest performing treatment lines in terms of both MIRR and NPV. In addition, lines assigned daily air-drying tended to be the most profitable investments, which suggests that farmers can reduce their labor costs and increase their profits by setting their longline baskets at a tidal height rather than manually air-drying each week. Our results aligned with a study done by Maxwell and Supan (2010), in which the optimal management scenario involved both daily air-dying and triploid oysters. Tumbling frequency management techniques did not appear to have a large effect on profitability, suggesting farmers can also reduce their labor costs without penalty to their profits by cutting back on their tumbling frequency. Gear type also did not appear to affect profitability, suggesting farmers can choose a brand of gear that suits their needs best also without penalty to their profits (Table 2.14, Table 2.15).

Table 2.14 MIRRs for all treatment lines based on 10-years of operation

Treatment Line	MIRR
12 (SMD3)	10.82%
16 (SQD3)	10.77%
8 (HQD3)	10.07%
11 (SMD2)	9.16%
14 (SQW3)	8.98%
6 (HQW3)	8.26%
10 (SMW3)	7.95%
15 (SQD2)	7.51%
5 (HQW2)	5.95%
7 (HQD2)	4.49%
13 (SQW2)	3.23%
9 (SMW2)	2.59%

Table 2.15 NPVs for all treatment lines based on 10-years of operation

Treatment Line	NPV
16 (SQD3)	$ 147,133.33
12 (SMD3)	$ 132,685.75
8 (HQD3)	$ 127,826.84
11 (SMD2)	$ 100,485.24
14 (SQW3)	$ 85,000.12
6 (HQW3)	$ 67,490.59
10 (SMW3)	$ 58,789.43
15 (SQD2)	$ 53,460.69
5 (HQW2)	$ 14,297.35
7 (HQD2)	$ (20,006.85)
13 (SQW2)	$ (41,560.90)
9 (SMW2)	$ (52,237.89)

Chapter 3. Effect of Different Off-Bottom Oyster Farming Management Techniques on Measures of Oyster Quality and Buyer Perception

Abstract

Off-bottom oyster aquaculture, an expanding industry in the Gulf of Mexico region, faces numerous challenges that threaten the sustainability of regional farms. To offset the negative effects of these challenges, farmers often ask how they can reduce their production costs without compromising the quality of their oysters or their profitability. This study aimed to determine how four commonly used management techniques can affect profitability through an analysis of whether buyers recognize differences in oyster quality produced by different methods and if the resulting differences affect their willingness to pay or purchase decisions. A commercial oyster farm using the adjustable longline system was installed in Grand Bay, AL where combinations of two brands of gear (Hexcyl or SEAPA), two tumbling frequencies (Monthly or Quarterly), two air-drying frequencies (Weekly or Daily), and two oyster seed ploidies (Diploid or Triploid) were tested. Oysters produced by each treatment were assessed quantitatively in the lab and qualitatively through a survey to gauge quality and buyer perception. Both assessments found triploid oysters as having high quality and a positive effect on buyer purchasing decision. More labor-intensive treatments did not appear to have an advantage when it came to quality or buyer purchasing decisions, suggesting farmers can reduce their production costs by using quarterly tumbling and daily air-drying without penalty to profitability. Finally, brand of gear had few effects on quality or buyer purchasing decisions and should be chosen based on personal circumstance or preference.

Introduction

The rise in off-bottom oyster farming, or oyster aquaculture in gear suspended off the ocean floor, has both been fueled by and generated increasing demand for high-end, “boutique” oysters served on the half-shell. While consumer preference varies for oyster taste and size, many prefer the ease of shucking and aesthetics farmed oysters provide (Loose et al. 2013; Petrolia et al. 2017; Sackton 2013, as cited in Mizuta and Wikfors 2018). Farmers tend to have greater control over their oysters in this production method, resulting in higher quality and market value than what is typically observed for wild oysters (Walton et al. 2013; Petrolia et al. 2017). High quality oysters are generally defined as having hinges that are not misshapen, a wide fan, a deep cup (Brake et al. 2003), a shell free of mud or biofouling that could produce off-putting odors or affect presentation (Watson et al. 2009), and plump meat that fills the shell (Ruello 2002; Ryan 2008).

Because farmers have greater control over their oysters, they are constantly in search of the optimal combination of management techniques that can be implemented to improve oyster quality while limiting production costs to ultimately increase profitability. Previous studies have suggested that common management decisions farmers make such as the ploidy of their seed, the type of gear they use, how often they air-dry their oysters, and how often they mechanically grade (“tumble”) their oysters can affect the resulting quality of the oysters they produce (O’Meley 1995; Handley 2002; Rubio 2009; Ring 2012; Davis 2013; LaPeyre et al. 2017; Mizuta and Wikfors 2018; Bodenstein 2019; Capelle et al. 2019; Chapman et al. 2019; Wadsworth et al. 2019b). It is less clear, however, if these differences in quality are perceived by potential buyers and if a price premium is obtained.

We tested the effect of multiple combinations of several common management techniques on oyster quality: combinations of two brands of adjustable longline gear (Hexcyl and SEAPA), two tumbling frequencies (Monthly and Quarterly), two air-drying frequencies (Weekly or Daily), and two oyster ploidies (Diploid and Triploid). Differences were expected in production costs due to the varying labor requirements of each management technique (Chapter 2). We also wanted to see if these different management techniques produce oysters of different quality and if buyers perceive and are willing to pay for higher quality oysters. Here we quantitatively compared the quality of the oysters produced by each of the different management combinations through indices of growth, shell shape, shell cleanliness, and meat condition (Abbe and Sanders 1988).

While studies on consumer perception and preferences have been done before, most focus on alternative qualities of oysters such as branding, safety, taste, and so forth; few studies have actually focused on how consumers perceive aesthetic qualities of oysters (Kow et al. 2008; Petrolia et al. 2017; van Houcke et al. 2018; Mizuta and Wikfors 2019). Brake et al. (2003) suggests that the first impression a consumer has of an oyster is based on its aesthetics, making shell and meat morphology a very important marketing tool. Therefore, we engaged chefs and wholesalers across the country in an anonymous survey to determine if buyers perceive the same quality differences as those observed in our quantitative measurements. We also tested if these buyers were willing to pay more for oysters they perceived as being high quality, and which variables played the biggest role in determining willingness to pay. Buyers facilitate demand, therefore understanding consumer preferences and how farmers can meet those expectations is critical to maximizing profits.

Methodology

Site Description

A one-acre commercial farm was installed in collaboration with Julian Stewart, the local aquaculture teacher for Alma Bryant High School in Irvington, AL, located at Grand Bay Oyster

Park in Grand Bay, Alabama (Fig 3.1). Students were employed to work on the farm as a part of a student vocational training program. The farm consisted of 16 adjustable longlines that were each 100m long and had the capacity to hold approximately 100 oyster baskets, or ~10,000 oysters at final grow-out stocking density. Oyster seed (diploids 30±1.35mm, triploids 40±00.75mm) to stock the farm was obtained from the Auburn University Shellfish Lab and was deployed on October 23rd, 2018. Each of the 16 longlines were assigned a nested design of farm management techniques.

Fig 3.1 Location of study site in Grand Bay, AL (denoted by star) (Google Maps, 2020).

Experimental Treatments

The management techniques included in the study were common decisions made by off-bottom oyster farmers: two gear brands x two tumbling frequencies x two air-drying frequencies x two oyster ploidies. Each resulting combination of management techniques, or 'treatment', (16 total) was employed on one of the 16 longlines installed. The adjustable longline style of gear was selected due to its prevalence as an off-bottom oyster farming method in the Gulf region and other parts of the country. Management techniques were selected based on which are commonly used by regional farmers that utilize this style of gear.

The two air-drying frequencies tested were daily air-drying during routine tidal exposure or weekly air-drying for a prolonged duration (e.g. 24 hours) (Fig 3.2). In the daily air-drying treatment, ALS baskets were set at a height designed to have the oysters and gear out of the water for approximately 60% of day, following the protocols of a nearby commercial oyster farm, Sandy Bay Oyster Company. The height of lines assigned daily air-drying were adjusted based on extreme tidal changes. In the weekly air-drying treatment, ALS baskets were set sub-tidally and raised weekly for 24-hour desiccation, following the protocols of the Auburn University Shellfish Lab. Weekly air-drying was reduced to biweekly air-drying during the months December-February. In the event of hurricanes or other severe weather all lines were completely submerged and then returned to respective treatment heights.

Fig 3.2 ALS baskets raised for weekly 24-hour air-drying (front) and set for tidal air-drying (back)

The two tumbling frequencies tested were oysters tumbled once a month (monthly) and once every three months (quarterly). Oysters were tumbled using the mechanical tumbler owned by Point Aux Pins oyster farm, which had 32mm and 45mm holes in its grading tube. After tumbling, oysters were restocked at ~25% full per bag. Baskets were tagged based on treatment so that they could be returned to their respective treatment line if separated. In addition, baskets were also tagged based on what size hole they sorted through in the tube (32mm, 45mm, and anything that retained through the tube) to aid in recording stocking densities and growth over time. Oysters were first tumbled November of 2018 and last tumbled December of 2019, the conclusion of the study, for a total of 14 monthly tumblings and 4 quarterly tumblings.

In addition, both diploid and triploid oyster seed were tested as these are the two commercial oyster seed types currently available to farmers. Diploid seed was deployed at 30±1.35mm and triploid seed was deployed at 40±0.75mm. Initial stocking densities were 1,000 oysters per bag across 10 bags per treatment line, or 10,000 oysters total stocked per treatment line.

Lastly the two gear brands we tested were the 15L capacity SEAPA and 25L capacity Hexcyl brand ALS baskets and lines. Seed started in 6mm mesh SEAPA baskets and 3mm mesh Hexcyl baskets and moved up to either 12mm SEAPA or 15mm Hexcyl baskets respectively (Fig 3.3). The SEAPA Stormbreaker system, a system that uses a flexible basket clip for energy absorption and line clamp bearing to reduce basket sliding, was used in conjunction with the SEAPA baskets and lines.

Fig 3.3 15L 12mm mesh SEAPA basket (Top) (SEAPA, 2020) and 25L 15mm mesh Hexcyl basket (Bottom) (Hexcyl, 2020)

Six control BST brand baskets were placed on a non-treatment line. Three baskets contained 50 diploids each and 3 baskets contained 50 triploids each. A random sample of 100 diploid and 100 triploid oysters was taken from the initial seed order at deployment to stock the control bags. Bags were placed at a sub-tidal level and were not handled during the duration of the study. These oysters were used as a general reference and had no imposed farm management treatments.

Quantitative Assessment of Quality

A treatment line was sampled only after at least 100 oysters reached harvest size on that treatment line, based on the number of oysters that graded out to the end of the tumbler. From these oysters, 100 oysters, excluding any that had grown connected as “doubles”, were selected at random and brought into the lab. Of the 100 oysters, 72 oysters were shipped along with surveys and 20 of the remaining oysters were used to conduct quantitative measurements of quality: cup and fan ratios (calculated from shell height, shell length, and shell width), condition index (calculated from whole weight, dry shell weight, and dry tissue weight) and cleanliness (with standardized cleaning time used as a proxy) were recorded for each of the 20 oysters that were sampled (Fig 3.4).

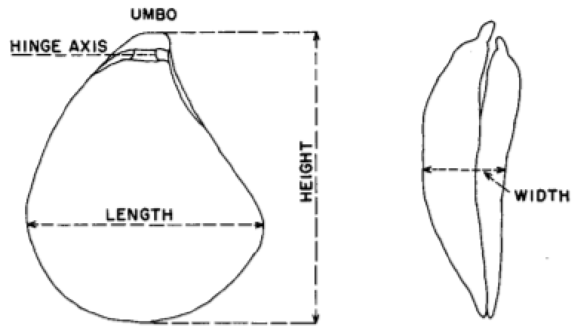

Figure 3.4 Diagram representing how shell measurements were recorded (from Galtsoff, 1964).

Each oyster in the sample was assigned a unique number ID and placed in a petri dish with the corresponding number. Shell height, width, and length was measured with calipers to the nearest 0.1 mm. The ratio of shell height to length was recorded as fan ratio and the ratio of shell width to height was recorded as cup ratio. Each oyster was manually cleaned of fouling organisms using a shucking knife and wire brush and the cleaning time was recorded as a measurement of oyster cleanliness. Each oyster was patted dry and measured to the nearest ±0.001g for whole wet weight. Oysters were then shucked, and the meat was separated fully from the shell and placed into an aluminum tin with the oyster's corresponding ID number. The meat was dried at 80°C for 48 hours in a drying oven. After 48 hours the dry meat weight was measured to the nearest +-0.001g. The oyster shells were left to dry at room temperature for 48 hours and then weighed to the nearest +-0.001g for dry shell weight. Condition index was recorded as the ratio of dry tissue to the difference between whole wet weight and dry shell weight (Abbe and Sanders 1988).

Damage from storm debris caused basket loss from treatment lines 1-4 (HMW2, HMW3, HMD2, HMD3); we decided to omit these lines from our final analysis because diploid and triploid oysters may have been mixed during basket recovery. All data was analyzed using RStudio ©, a program for statistical computing. A Student's t-test ($\alpha = 0.05$) was used to compare diploid and triploid control oysters for Fan Ratio, Cup Ratio, Cleaning Time, and Condition Index. Analysis of Variance (ANOVA) tests were used to analyze the significance between oyster quality metrics (Fan Ratio, Cup Ratio, Cleaning Time, and Condition Index) and two different three way interactions: 1) Gear type x Air-drying x Ploidy interactions (Lines 5-8 and Lines 13-16), and 2) Tumbling x Air-drying x Ploidy interactions (Lines 9-12 and Lines 13-16). A p-value of 0.05 was used to determine significant differences among groups. A full model including all interactions was assessed first and then any insignificant interactions were removed before running the model again. Tukey's honest significant difference test (Tukey's HSD) was used to conduct post-hoc analyses of significant effects ($p<0.05$) found in the ANOVA. The Shapiro-Wilk Test of Normality and Levene's Test were used to verify assumptions of normally distributed residuals and homogeneity of variance for each dataset. A p-value >0.05 for either test of assumptions indicated that the null hypothesis that the data were normally distributed or homogenous cannot be rejected. If assumptions were not met, quality datasets were either transformed by rank, log10, or reciprocal. If after rank transforming assumptions were still not met, then we relied on robustness of the statistical tests to uphold interpretation of results.

Buyer Perception of Quality

In addition to the quantitative assessment in the lab, we conducted a qualitative assessment of quality as perceived by commercial buyers. A blind survey was used to determine participants' perception of shell shape, shell cleanliness, shell thickness, ease of shucking, meat to shell ratio, meat condition, consistency of both shell and meat among the provided samples, their willingness to pay for each variety, and their preference of purchase order. All quality metrics were scored on a Likert 5-point scale by participants, with 1 being very poor up to 5 being very good.

Twelve participating buyers (six chefs and six wholesalers) across the United States agreed to participate in our study. Each participant was provided with up to four copies of the questionnaire with each shipment of oysters so that colleagues within the same business could evaluate the oysters and complete the questionnaires independently, yielding multiple responses per participant in some cases. The questionnaire (approved by Auburn University IRB in March 2019) asked participants to rate a sample of oysters on shell and meat quality metrics, rank the order in which they would purchase each of the included lines (varieties), and what they would be willing to pay per oyster (Appendix A). Each sample contained oysters from a subset of the total set of lines; that is, in a given shipment, each participant received oysters from 4-6 lines. As this study focused on the effects of culture practices on quality, participants were asked not to taste the oysters and assume taste was the same and acceptable for all treatment lines. Five shipments were sent out over the course of the study, with each treatment line being sent out at least once but not more than twice (Table 3.1). If during tumbling at least 100 oysters met the requirements for sampling, oysters were re-submerged for a minimum of 7 days and then harvested for the study as described above. During harvest, oysters were given a standard rinse and then chilled with damp burlap in a walk-in cooler (35-41°F) overnight. For a given shipment to a given respondent, 6 oysters were included per treatment line. Each set of oysters from each line were differentiated via different colored mesh bags and tags with letter indications that corresponded to survey IDs. Remaining oysters from each sample were labelled and preserved in a freezer for quantitative assessment, as mentioned in the previous section.

Table 3.1 Date and treatment lines included in each of the five survey shipments

Shipment Number	Date	Treatment Lines Included
1	June 26, 2019	6: Hexcyl, Quarterly, Weekly, Triploid 10: SEAPA, Monthly, Weekly, Triploid 13: SEAPA, Quarterly, Weekly, Diploid 14: SEAPA Quarterly, Weekly, Triploid
2	August 20, 2019	1: Hexcyl, Monthly, Weekly, Diploid 2: Hexcyl, Monthly, Weekly Triploid 8: Hexcyl, Quarterly, Daily, Triploid 9: SEAPA, Monthly, Weekly, Diploid 10: SEAPA, Monthly, Weekly, Triploid
3	September 18, 2019	2: Hexcyl, Monthly, Weekly, Triploid 5: Hexcyl, Quarterly, Weekly, Diploid 12: SEAPA, Monthly, Daily, Triploid 16: SEAPA, Quarterly, Daily, Triploid
4	November 20, 2019	1: Hexcyl, Monthly, Weekly, Diploid 3: Hexcyl, Monthly, Daily, Diploid 4: Hexcyl, Monthly, Daily, Triploid 5: Hexcyl, Quarterly, Weekly, Diploid 11: SEAPA, Monthly, Daily, Diploid 12: SEAPA, Monthly, Daily, Triploid
5	January 13, 2020	4: Hexcyl, Monthly, Daily, Triploid 6: Hexcyl, Quarterly, Weekly, Triploid 7: Hexcyl, Quarterly, Weekly, Triploid 11: SEAPA, Monthly, Daily, Diploid 13: SEAPA, Quarterly, Weekly, Diploid 15: SEAPA, Quarterly, Daily, Diploid

All survey quality metrics were analyzed by an ordinal logistic regression using R Software. Two separate models were run: a model with Gear type x Air-drying x Ploidy interactions (Lines 5-8 and Lines 13-16) and a model with Tumbling x Air-drying x Ploidy interactions (Lines 9-12 and Lines 13-16). The proportional odds assumption was checked using the Brant Test; all models met the assumptions of the ordinal logistic regression. Models were adjusted to include only significant interactions and pairwise comparisons were assessed using the 'emmeans' package, both with a significant p-value of 0.05.

Buyer Purchase Intention

Two of the survey questions explored consumers' purchase intentions: a price ($) they would offer per oyster at wholesale and the ranked order (1st-6th) they would be willing to purchase the included oyster varieties. Before running any purchase intention models, we conducted descriptive statistics for each dataset and represented the results graphically (Appendix A). The replicates of treatment lines that were included in multiple shipments for the survey were compared with an ANOVA to determine if results differed substantially between shipment dates.

We tested two different hedonic linear regression models for willingness to pay (WTP) with a p-value of 0.05: the relationship between WTP and the overall sum of the quality scores, and the relationship between WTP and the individual quality metric scores. Summed quality scores and individual quality metric scores were treated as continuous variables within the models. The assumption of normally distributed residuals was tested using the Shapiro-Wilk Test of Normality, where $p>0.05$ indicated a normal distribution, and homogeneity of variance was tested using Levene's test ($p>0.05$); both models met the assumptions of the linear regression.

We also ran an ANOVA to analyze significant interactions between WTP and each treatment combination. Again, because lines 1-4 were not able to be assessed in the study, treatment combinations were analyzed by Gear x Air-drying x Ploidy interactions (Lines 5-8 and Lines 13-16) and Tumbling x Air-drying x Ploidy interactions (Lines 9-12 and Lines 13-16). Any insignificant interactions were removed from the model. Tukey's honest significant difference test (Tukey's HSD) was used to conduct post-hoc analyses of significant effects ($p<0.05$) found in the ANOVA.

Purchase rank data were analyzed in Stata© software using three ranked logistic regression models: the relationship between purchase rank and the overall sum of the quality scores, purchase rank and the individual quality metrics, and purchase rank and each individual treatment. Purchase ranks were grouped within shipment and by participant for comparison. The sum of the quality scores and individual quality metric scores were treated as continuous variables. Treatments were assessed for significant main effects ($p<0.05$) and results were cross-checked by an assessment of individual treatment line (5-16) for robustness. Predicted probabilities of receiving a rank of “1” were generated for each treatment.

Results

Quantitative Quality Assessment Results

Fan Ratio

Fan ratios (the ratio of shell height to length) were not significantly different between diploid and triploid control oysters ($p=0.69$). Both, however, exceeded the idealized 0.67 ratio (Fig 3.5).

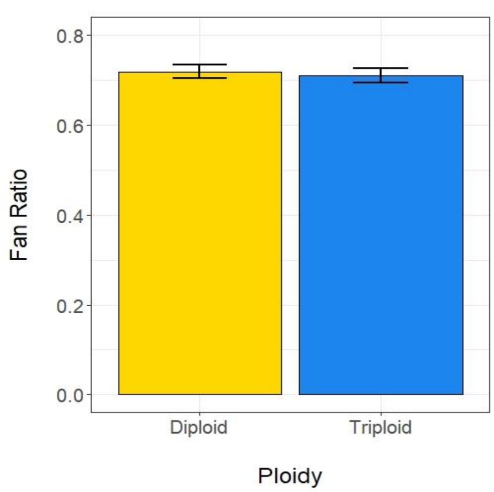

Figure 3.5 Average fan ratios (±SE) for diploid and triploid control lines

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16), we found a significant interaction effect of Air-drying x Ploidy ($p<0.01$) on fan ratio (Table 3.2). Weekly/Diploid treatments produced oysters with a significantly lower fan ratio than other treatment combinations ($p<0.01$) with no differences among the other treatments ($p\geq0.96$). All treatments, however, exceeded the idealized 0.67 ratio (Fig 3.6).

Table 3.2 ANOVA analysis of fan ratio for full model of Gear x Air-drying x Ploidy comparison (lines 5-8 and 13-16). Type III sum of squares (Type III SS), degrees of freedom (DF), and p-value are reported. Significant p-values are indicated by '*'.

ANALYSIS OF VARIANCE SOURCE	TYPE III SS	DF	F-VALUE	P-VALUE
GEAR	0.01	1	2.45	0.12
AIR-DRYING	0.06	1	14.01	<0.01*
PLOIDY	0.00	1	<0.01	0.95
GEAR:AIR-DRYING	<0.01	1	0.32	0.57
GEAR:PLOIDY	<0.01	1	0.01	0.91
AIR-DRYING:PLOIDY	0.03	1	7.33	0.01*
GEAR:AIR-DRYING:PLOIDY	<0.01	1	0.20	0.66
ERROR	0.97	212		

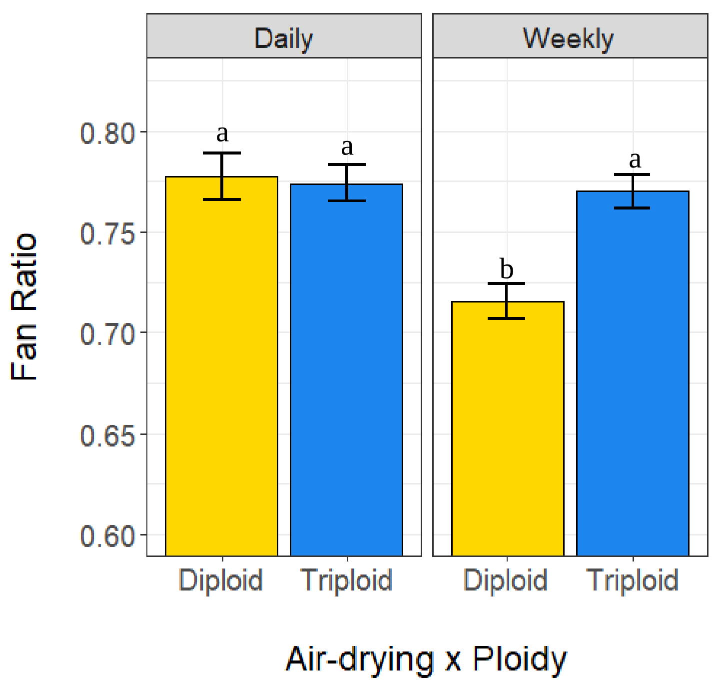

Figure 3.6 Average fan ratios (±SE) for lines comparing Air-drying x Ploidy treatments (lines 5-8 and 13-16)

Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16), we again found a significant interaction effect of Air-drying x Ploidy on fan ratio (p=0.01, Table 3.3). Again, Weekly/Diploid treatments produced oysters with a significantly lower fan ratio than other treatment combinations (p<0.01) with no differences among the other treatments (p≥0.79). All treatments, however, exceeded the idealized 0.67 ratio (Fig 3.7).

Table 3.3 ANOVA analysis of fan ratio for adjusted model of Tumbling x Air-drying x Ploidy comparison (lines 9-12 and 13-16)

ANALYSIS OF VARIANCE SOURCE	TYPE III SS	DF	F-VALUE	P-VALUE
TUMBLING	<0.01	1	0.46	0.50
AIR-DRYING	0.08	1	19.24	<0.01*
PLOIDY	<0.01	1	0.42	0.52
AIR-DRYING:PLOIDY	0.03	1	6.26	0.01*
ERROR	1.03	235		

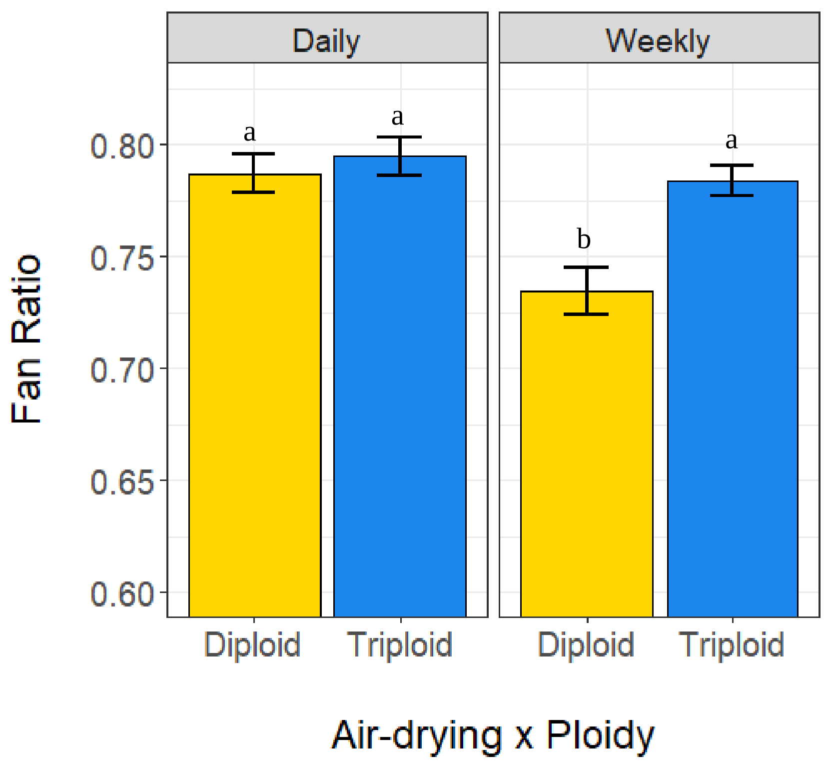

Figure 3.7 Average fan ratios (±SE) for lines comparing Air-drying x Ploidy treatments (lines 9-12 and 13-16)

Cup Ratio

Cup ratios (the ratio of shell length to width) were not significantly different between diploid and triploid control oysters (p=0.08) Both, however, exceeded the idealized 0.33 ratio (Fig 3.8).

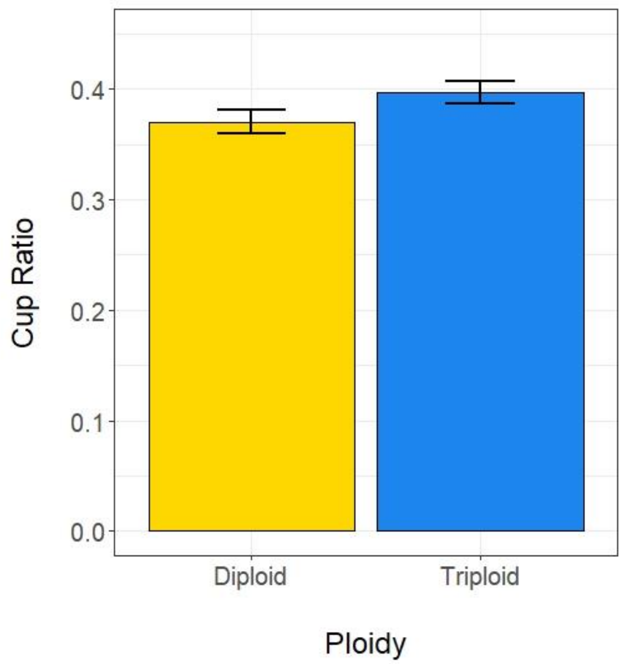

Figure 3.8 Average cup ratios (±SE) for diploid and triploid control lines

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16) we found a significant interaction effect of Gear x Air-drying x Ploidy ($p<0.01$) on cup ratio (Table 3.4). The treatments with the deepest cups were the Hexcyl/Daily/Diploid and the SEAPA/Daily/Triploid, which, curiously, were significantly greater than the cups from the oysters in the Hexcyl/Daily/Triploid treatment ($p\leq0.05$). None of the other treatments significantly differed from each other. The average cup ratios for all treatments exceeded the idealized 0.33 ratio (Fig 3.9).

Table 3.4 ANOVA analysis of cup ratio for full model of Gear x Air-drying x Ploidy comparison (lines 5-8 and 13-16)

ANALYSIS OF VARIANCE SOURCE	TYPE III SS	DF	F-VALUE	P-VALUE
GEAR	0.00	1	0.01	0.92
AIR-DRYING	0.01	1	1.91	0.17
PLOIDY	0.02	1	9.03	<0.01*
GEAR:AIR-DRYING	<0.01	1	0.36	0.55
GEAR:PLOIDY	0.01	1	5.60	0.02*
AIR-DRYING:PLOIDY	0.02	1	8.71	<0.01*
GEAR:AIR-DRYING:PLOIDY	0.03	1	9.84	<0.01*
ERROR	0.56	212		

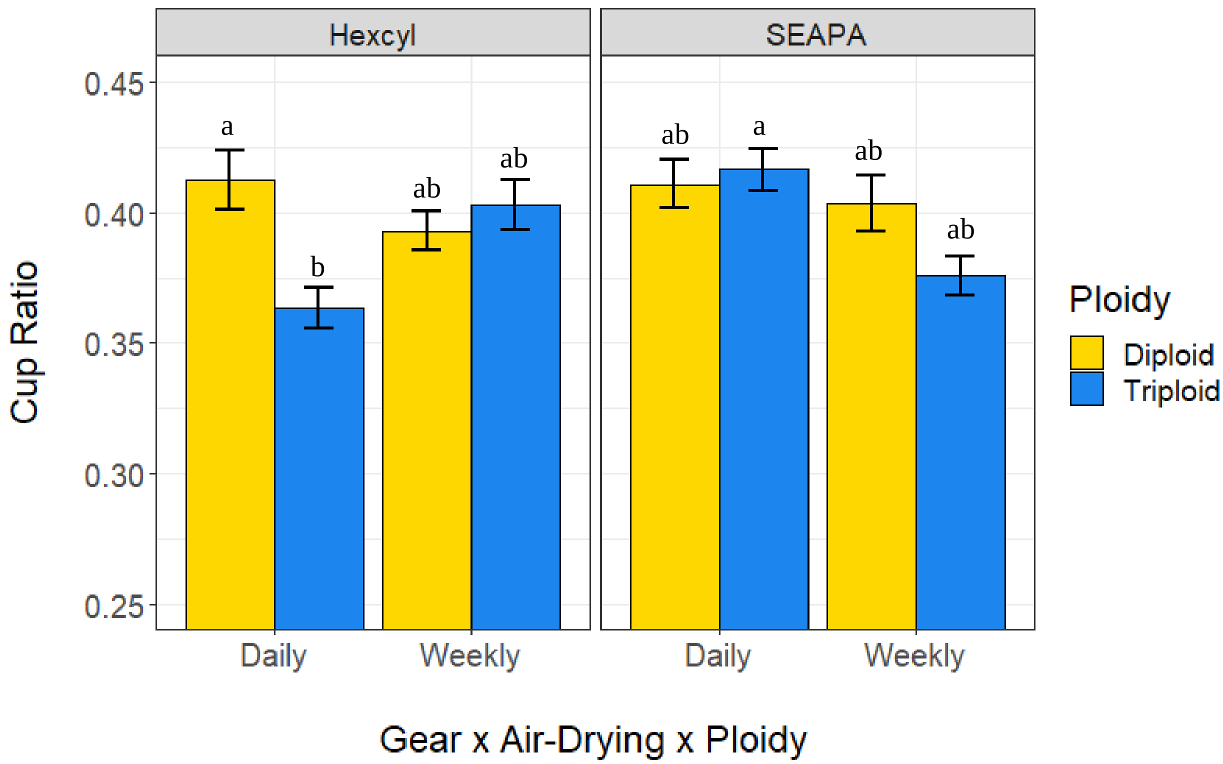

Figure 3.9 Average cup ratios (±SE) for lines comparing Gear x Air-drying x Ploidy treatments (lines 5-8 and 13-16)

Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16) we found a significant effect of Air-drying (p<0.01) and Ploidy (p=0.03) on cup ratio (Table 3.5), where oysters grown with daily air-drying had significantly higher cup ratios than oysters grown with weekly air-drying and diploid oysters had significantly higher cup ratios than triploid oysters. The average cup ratios for all treatments exceeded the idealized 0.33 ratio (Fig 3.10, 3.11).

Table 3.5 ANOVA analysis of cup ratio for main effects model of Tumbling x Air-drying x Ploidy comparison (lines 9-12 and 13-16)

ANALYSIS OF VARIANCE SOURCE	TYPE III SS	DF	F-VALUE	P-VALUE
TUMBLING	<0.01	1	0.07	0.79
AIR-DRYING	0.03	1	17.97	<0.01*
PLOIDY	0.01	1	4.85	0.03*
ERROR	0.43	236		

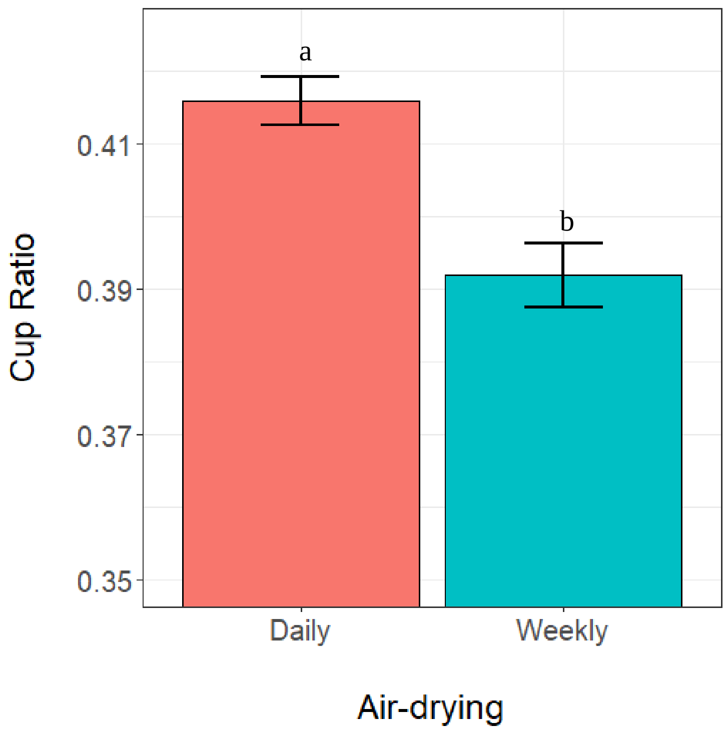

Figure 3.10 Average cup ratios (±SE) for lines comparing Air-drying treatments (lines 9-12 and 13-16)

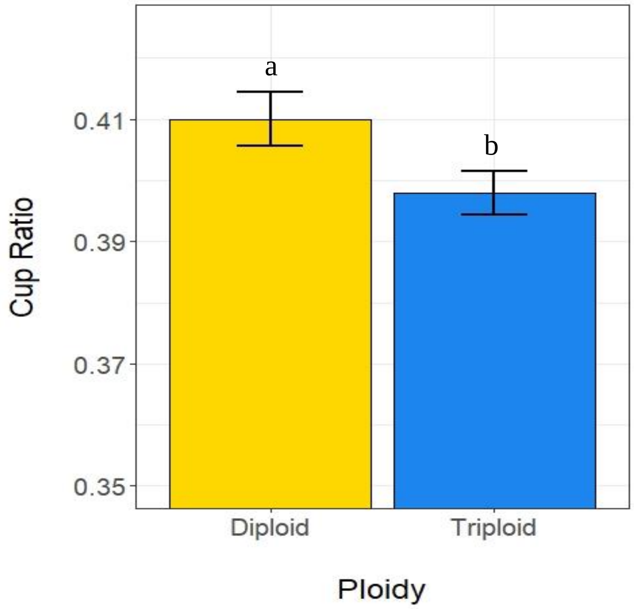

Figure 3.11 Average cup ratios (±SE) for lines comparing Ploidy treatments (lines 9-12 and 13-16)

Cleaning Time

Cleaning times were not significantly different for diploid and triploid control oysters (p=0.79, Fig 3.12)

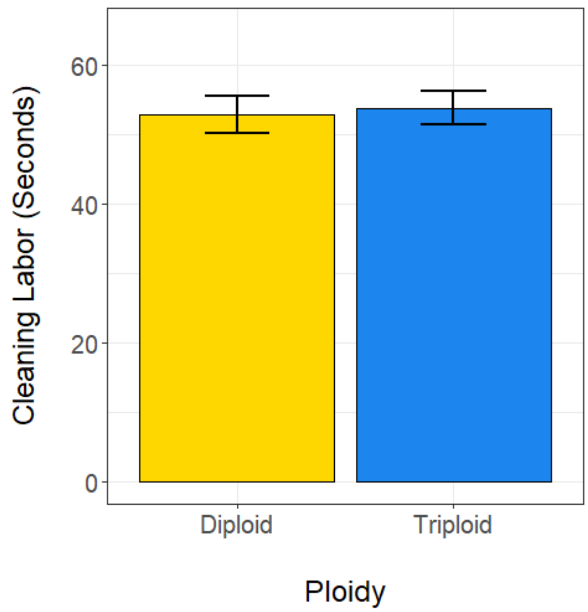

Figure 3.12 Average cleaning times (±SE) for diploid and triploid control lines

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16) we found a significant interaction effect of Air-drying x Ploidy ($p<0.01$) and Gear x Ploidy ($p<0.01$) on cleaning time (Table 3.6). Daily/Diploid treatments (Fig 3.13) produced oysters with significantly higher cleaning times than all other treatment combinations ($p<0.01$), while both Weekly treatments (Weekly/ Diploid and Weekly/Triploid) had greater cleaning times than the Daily/Triploid treatments ($p<0.01$), but did not differ from each other ($p=0.28$). The average cleaning time ranged among treatments from around 20 up to 70 seconds. In terms of the Gear x Ploidy interaction, SEAPA/Diploid treatments (Fig 3.14) produced oysters with significantly higher cleaning times than all other treatment combinations ($p<0.01$), while both Hexcyl treatments (Hexcyl/Diploid and Hexcyl/Triploid) had greater cleaning times than the SEAPA/Triploid treatments ($p\leq0.02$), but did not significantly differ from each other ($p=0.09$). The average cleaning time ranged between 50 and 150 seconds.

Table 3.6 ANOVA analysis of rank transformed cleaning time for full model of Gear x Air-drying x Ploidy comparison (lines 5-8 and 13-16)

ANALYSIS OF VARIANCE SOURCE	TYPE III SS	DF	F-VALUE	P-VALUE
GEAR	8806	1	3.85	0.05
AIR-DRYING	54166	1	196.50	<0.01*
PLOIDY	70099	1	30.68	<0.01*
GEAR:AIR-DRYING	846	1	0.37	0.54
GEAR:PLOIDY	33191	1	14.53	<0.01*
AIR-DRYING:PLOIDY	109846	1	48.08	<0.01*
GEAR:AIR-DRYING:PLOIDY	2397	1	1.05	0.31
ERROR	484366	212		

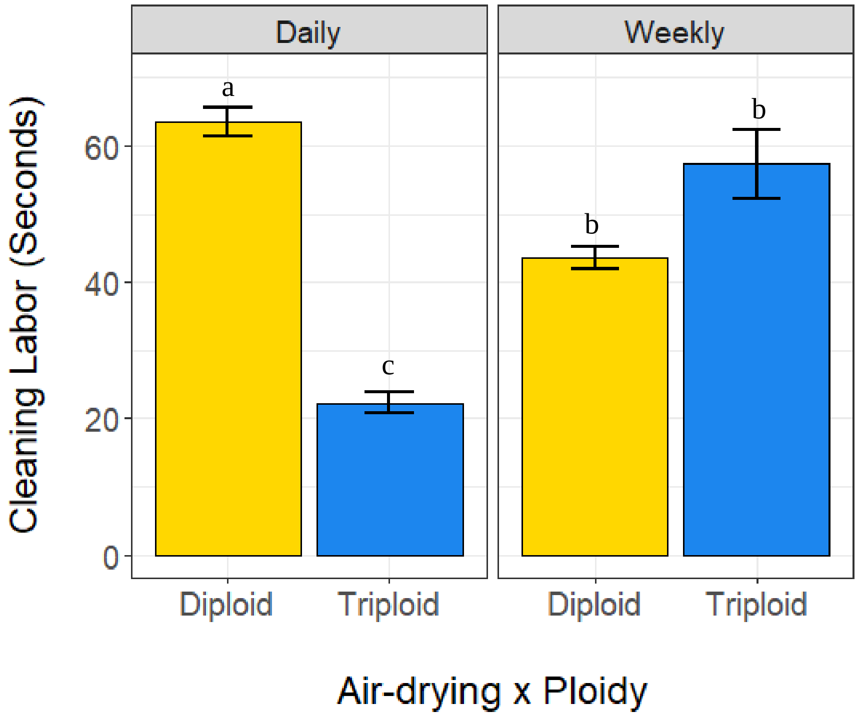

Figure 3.13 Average cleaning times (±SE) for lines comparing Air-drying x Ploidy treatments (lines 5-8 and 13-16)

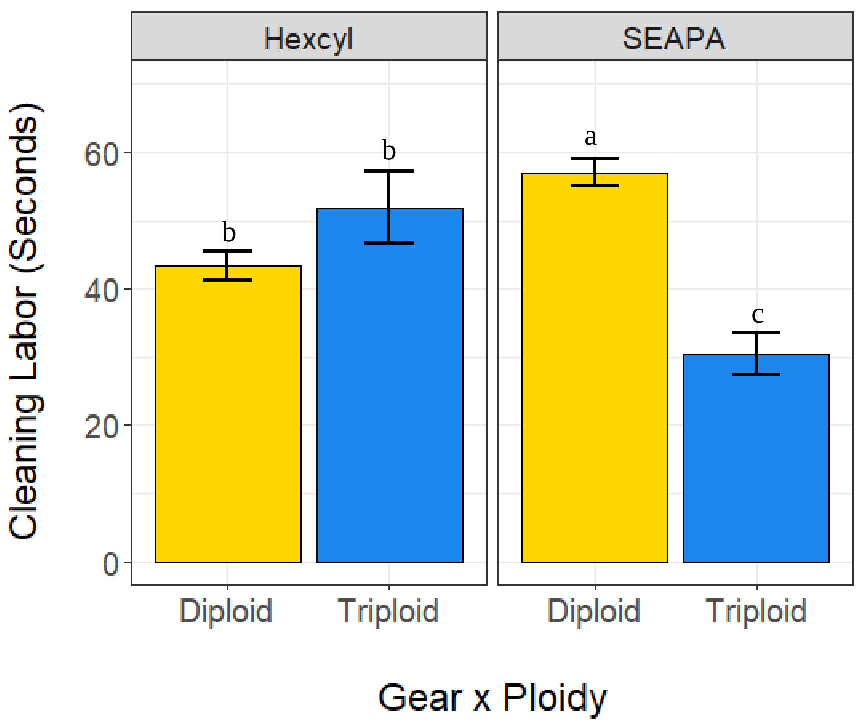

Figure 3.14 Average cleaning times (±SE) for lines comparing Gear x Ploidy treatments (lines 5-8 and 13-16)

Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16) we found a significant interaction effect of Tumbling x Air-drying x Ploidy ($p<0.01$) on cleaning time (Table 3.7). Cleaning times were variable among the included treatments: the Quarterly/Daily/Diploid treatment had significantly higher cleaning times than other treatments ($p\leq0.02$), the Quarterly/Daily/Triploid treatment had significantly lower cleaning times than other treatments ($p<0.01$), and the Monthly/Weekly/Triploid treatment had significantly higher cleaning times than the other Monthly treatments ($p\leq0.03$). The average cleaning time ranged from 10 to 80 seconds (Fig 3.15).

Table 3.7 ANOVA analysis of rank transformed cleaning time for full model of Tumbling x Air-drying x Ploidy comparison (lines 9-12 and 13-16)

ANALYSIS OF VARIANCE SOURCE	TYPE III SS	DF	F-VALUE	P-VALUE
TUMBLING	148967	1	47.94	<0.01*
AIR-DRYING	337	1	0.11	0.74
PLOIDY	444	1	0.14	0.71
TUMBLING:AIR-DRYING	32260	1	10.38	<0.01*
TUMBLING:PLOIDY	234531	1	75.48	<0.01*
AIR-DRYING:PLOIDY	15851	1	5.10	0.02*
TUMBLING:AIR-DRYING:PLOIDY	53046	1	17.07	<0.01*
ERROR	720900	232		

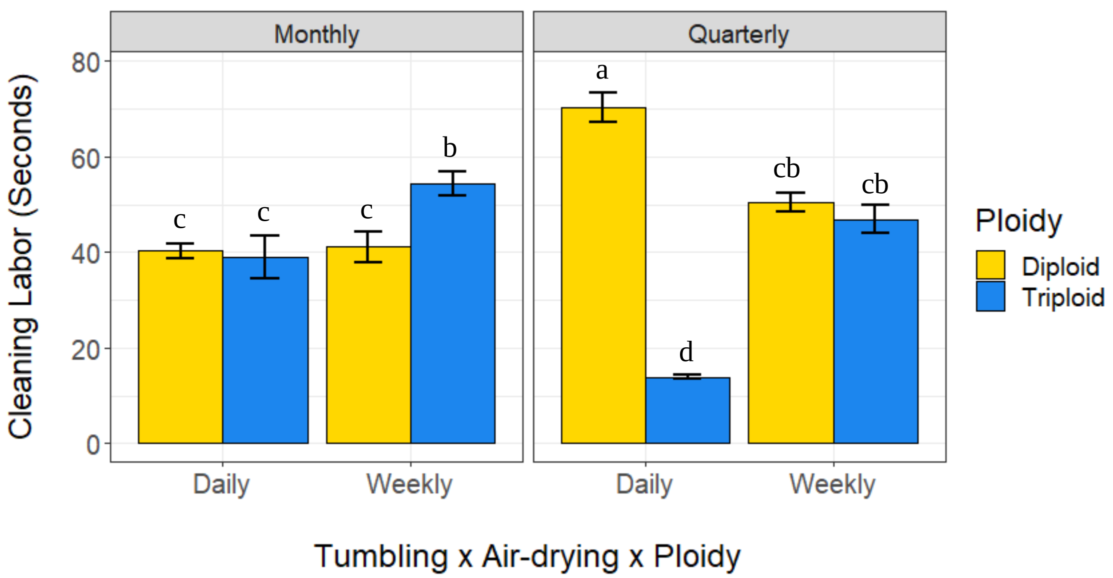

Figure 3.15 Average cleaning times (±SE) for lines comparing Tumbling x Air-drying x Ploidy treatments (lines 9-12 and 13-16)

Condition Index

Condition Index was significantly different for diploid and triploid control oysters ($p<0.01$, Fig 3.16).

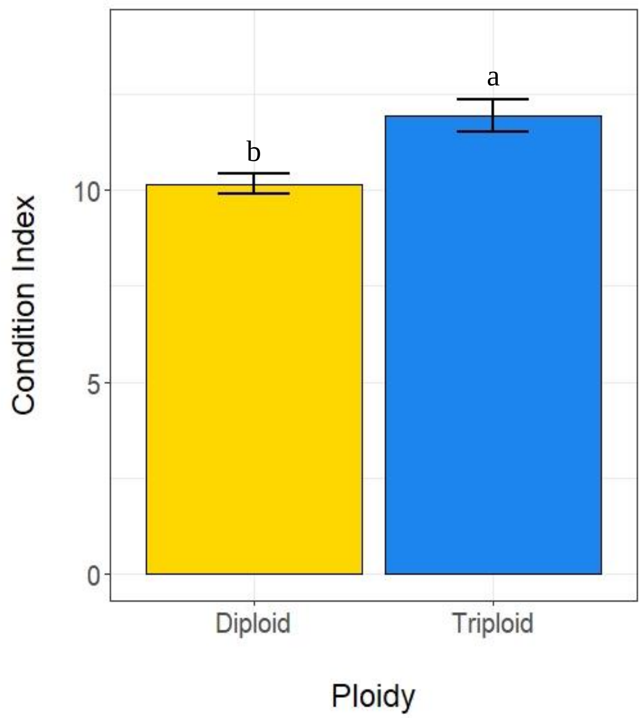

Figure 3.16 Average condition index (±SE) for diploid and triploid control lines

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16) we found a significant interaction effect of Gear x Air-drying x Ploidy on condition index ($p<0.01$, Table 3.8). Daily/Diploid and Weekly/Triploid treatments for both gear types had significantly higher condition indices than all other treatments ($p<0.01$), except for SEAPA/Weekly/Diploid, which was not significantly different from SEAPA/Weekly/Triploid ($p=0.13$). The Hexcyl/Weekly/Diploid treatment was significantly lower than all other treatments ($p\leq0.02$). Condition index values ranged between 7 and 14 (Fig 3.17).

Table 3.8 ANOVA analysis of condition index for full model of Gear x Air-drying x Ploidy comparison (lines 5-8 and 13-16)

ANALYSIS OF VARIANCE SOURCE	TYPE III SS	DF	F-VALUE	P-VALUE
GEAR	0.04	1	116.88	<0.01*
AIR-DRYING	0.02	1	42.18	<0.01*
PLOIDY	<0.01	1	0.31	0.58
GEAR:AIR-DRYING	0.05	1	145.76	<0.01*
GEAR:PLOIDY	0.01	1	17.68	<0.01*
AIR-DRYING:PLOIDY	<0.01	1	0.03	0.87
GEAR:AIR-DRYING:PLOIDY	<0.01	1	10.08	<0.01*
ERROR	0.08	212		

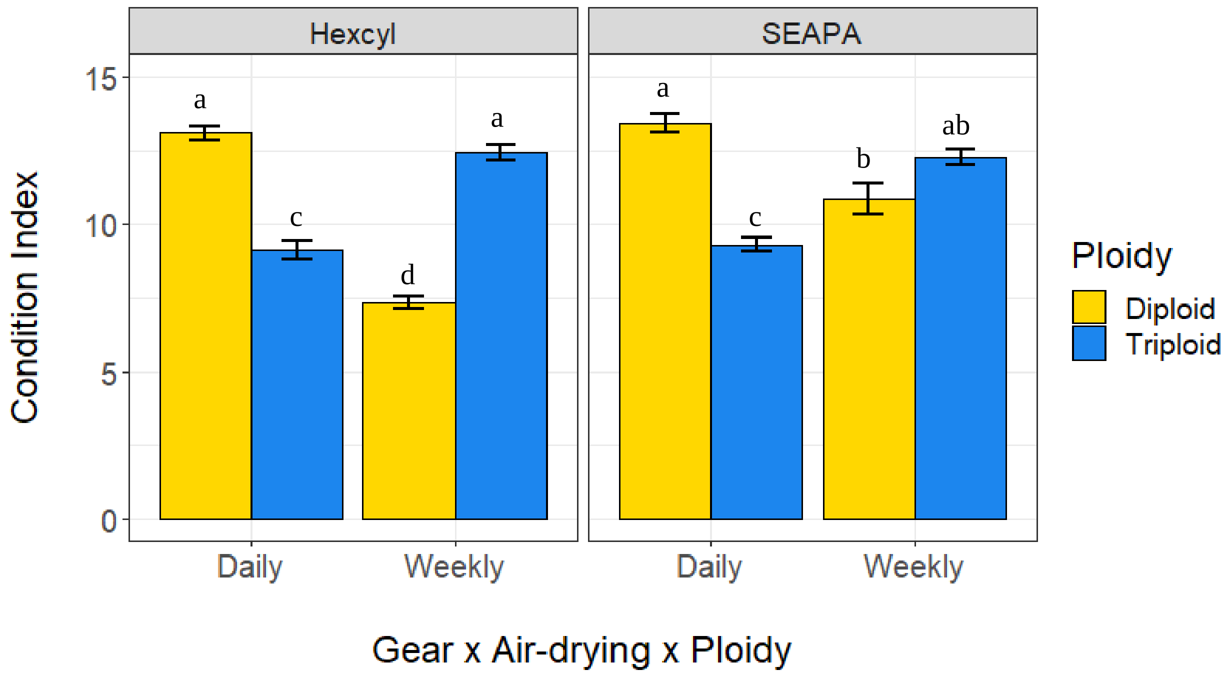

Figure 3.17 Average condition index value (±SE) for lines comparing Gear x Air-drying x Ploidy treatments (lines 5-8 and 13-16)

Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16) we found a significant interaction effect of Tumbling x Air-drying (p<0.01), Tumbling x Ploidy (p<0.01), and Air-drying x Ploidy (p<0.01) on condition index (Table 3.9). Monthly/Weekly treatments produced oysters with significantly lower condition index values than other treatment combinations (p<0.01, Fig 3.18). Quarterly/Diploid treatments produced oysters with significantly higher condition index values than Monthly/Diploid and Quarterly/Triploid treatments ($p<0.01$) but were not significantly different from Monthly/Triploid treatments ($p=0.27$, Fig 3.19). Daily/Diploid treatments produced oysters with significantly higher condition index that all other treatments ($p\leq0.02$), and Weekly/Triploid treatments produced oysters with significantly higher than Daily/Triploid and Weekly/Diploid treatments ($p<0.01$). Condition index values ranged between 9 and 14 (Fig 3.20).

Table 3.9 ANOVA analysis of condition index for full model of Tumbling x Air-drying x Ploidy comparison (lines 9-12 and 13-16)

ANALYSIS OF VARIANCE SOURCE	TYPE III SS	DF	F-VALUE	P-VALUE
TUMBLING	<0.01	1	1.20	0.27
AIR-DRYING	0.04	1	99.91	<0.01*
PLOIDY	0.01	1	18.52	<0.01*
TUMBLING:AIR-DRYING	<0.01	1	12.55	<0.01*
TUMBLING:PLOIDY	<0.01	1	9.94	<0.01*
AIR-DRYING:PLOIDY	0.03	1	80.15	<0.01*
TUMBLING:AIR-DRYING:PLOIDY	<0.01	1	0.17	0.68
ERROR	0.08	232		

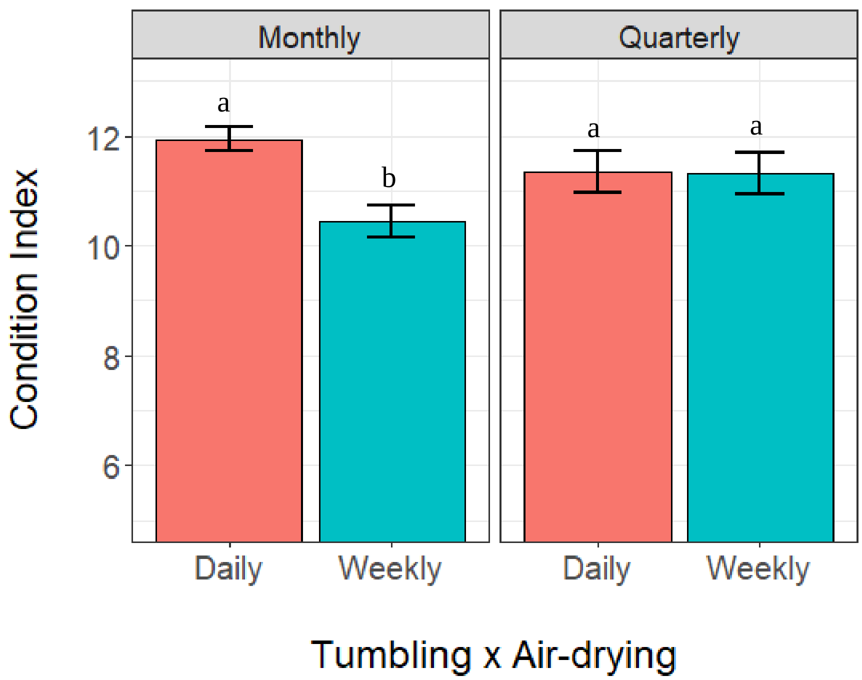

Figure 3.18 Average condition index value (±SE) for lines Tumbling x Air-drying (lines 9-12 and 13-16)

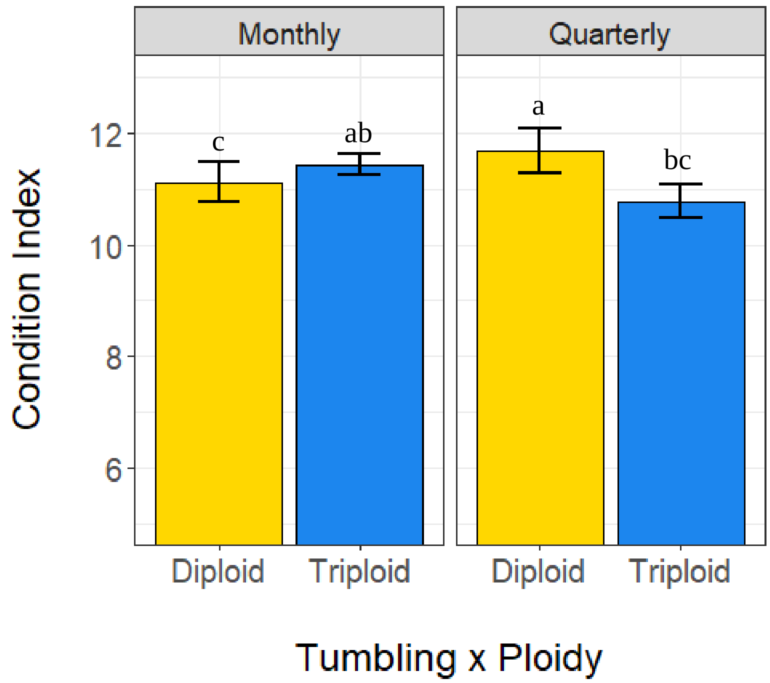

Figure 3.19 Average condition index value (±SE) for lines comparing Tumbling x Ploidy (lines 9-12 and 13-16)

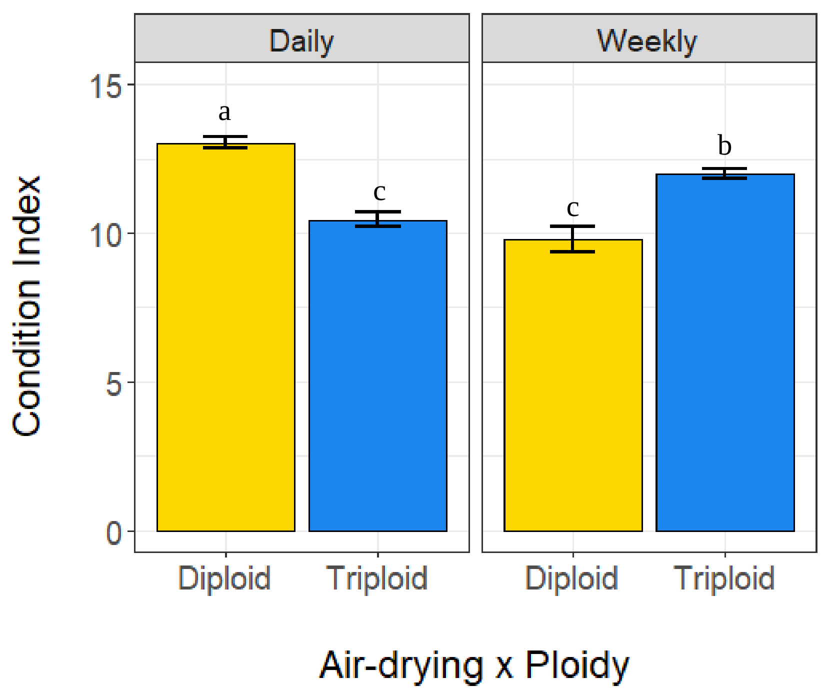

Figure 3.20 Average condition index value (±SE) for lines comparing Air-drying x Ploidy (lines 9-12 and 13-16)

Quality Survey Results

Shell Shape

Assessing an ordinal linear regression of gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16), we found a significant Gear x Air-drying x Ploidy effect on the shell shape score ($p=0.01$). Treatment combinations of Hexcyl/Daily/Triploid had an estimated average shell shape score higher than all other Hexcyl treatments and SEAPA/Weekly/Diploid treatments ($p\leq0.02$). The estimated averages of SEAPA/Daily and SEAPA/Weekly/Triploid treatments were not significantly different from other treatments ($p\geq0.07$, Fig 3.21). There were no significant effects when assessing the tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16).

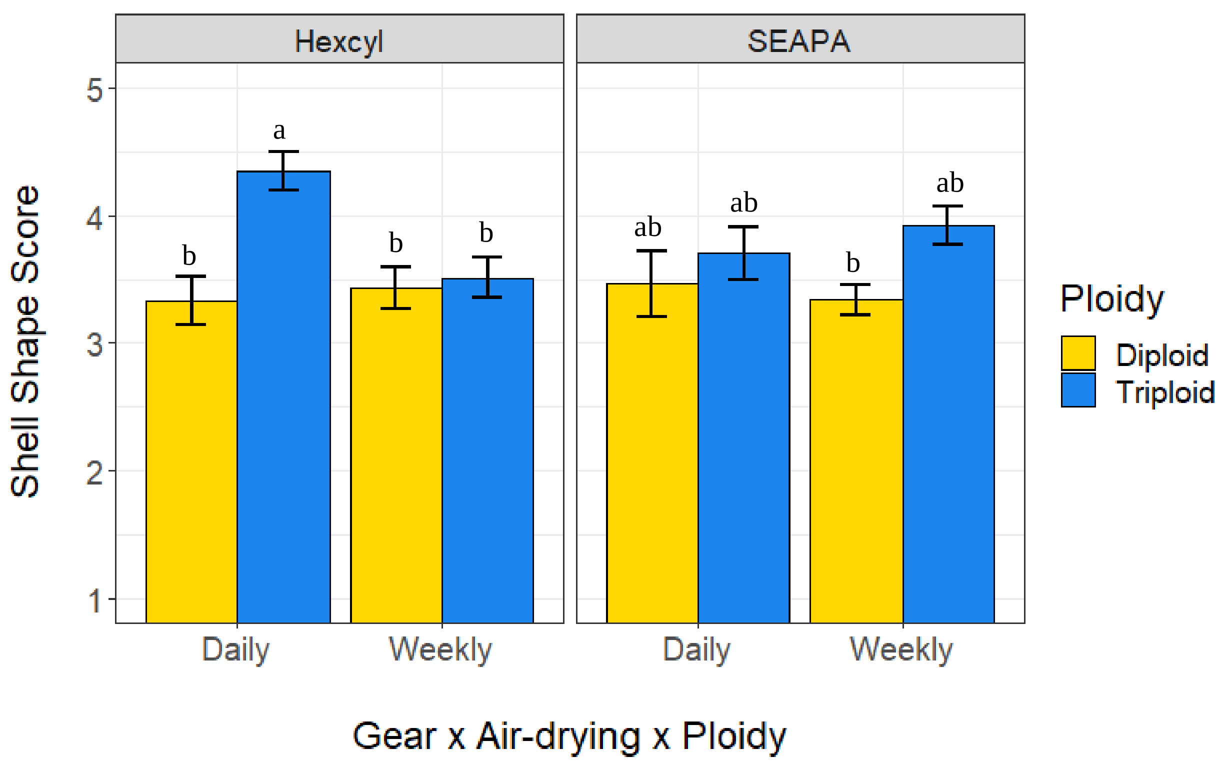

Figure 3.21 Estimated average shell shape score (±SE) for each Gear x Air-drying x Ploidy interaction (lines 5-8 and 13-16)

Shell Cleanliness

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16), we found two significant interactions for shell cleanliness: Air-drying x Ploidy ($p<0.01$) and Gear x Ploidy ($p<0.01$). When we assessed the Air-drying x Ploidy interaction, we found that treatments of Weekly/Diploid had a significantly lower estimated average cleanliness score than Daily/Diploid and Weekly/Triploid treatments ($p\leq0.02$), but not Daily/Triploid treatments ($p=0.20$, Fig 3.22).

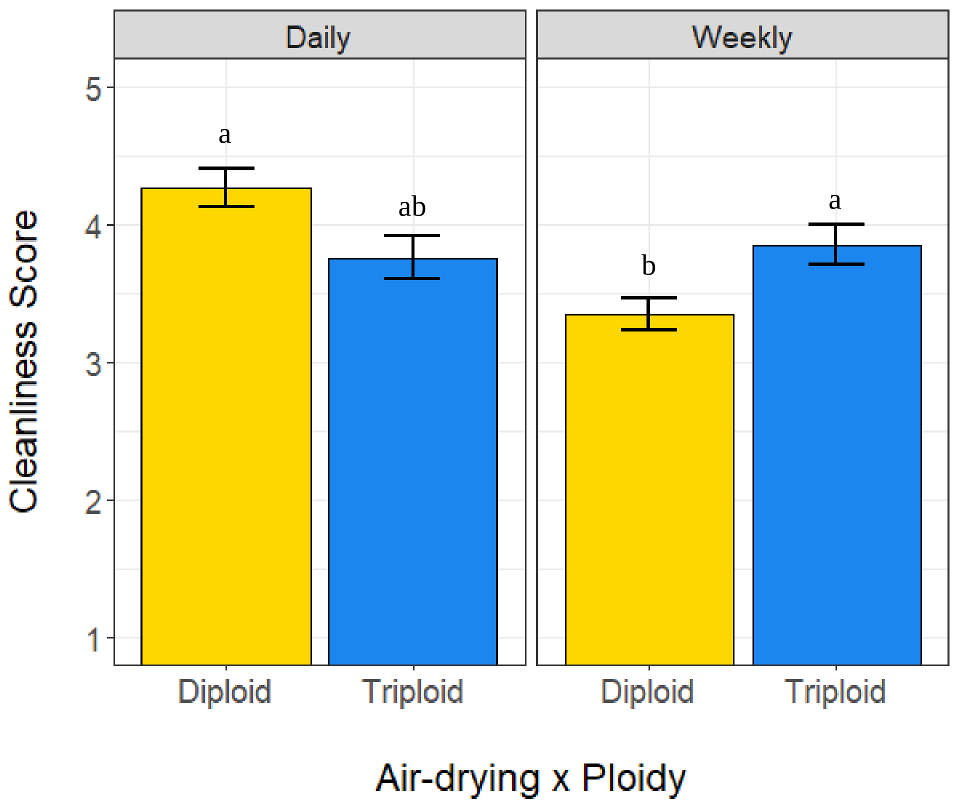

Figure 3.22 Estimated average shell cleanliness score (±SE) for each Air-drying x Ploidy effect (lines 5-8 and 13-16)

Assessing the Gear x Ploidy interaction, we found that Hexcyl/Triploid treatments and SEAPA/Diploid treatments, which did not have significantly different estimated average cleanliness scores from each other (p=0.99), had a significantly higher estimated average cleanliness scores than Hexcyl/Diploid treatments (p=0.03). In addition, the estimated average cleanliness score for SEAPA/Triploid treatments was not significantly different from either Hexcyl/Diploid treatments or SEAPA/Diploid treatments ($p \geq 0.06$) but was significantly lower than Hexcyl/Triploid treatments (p=0.03, Fig 3.23).

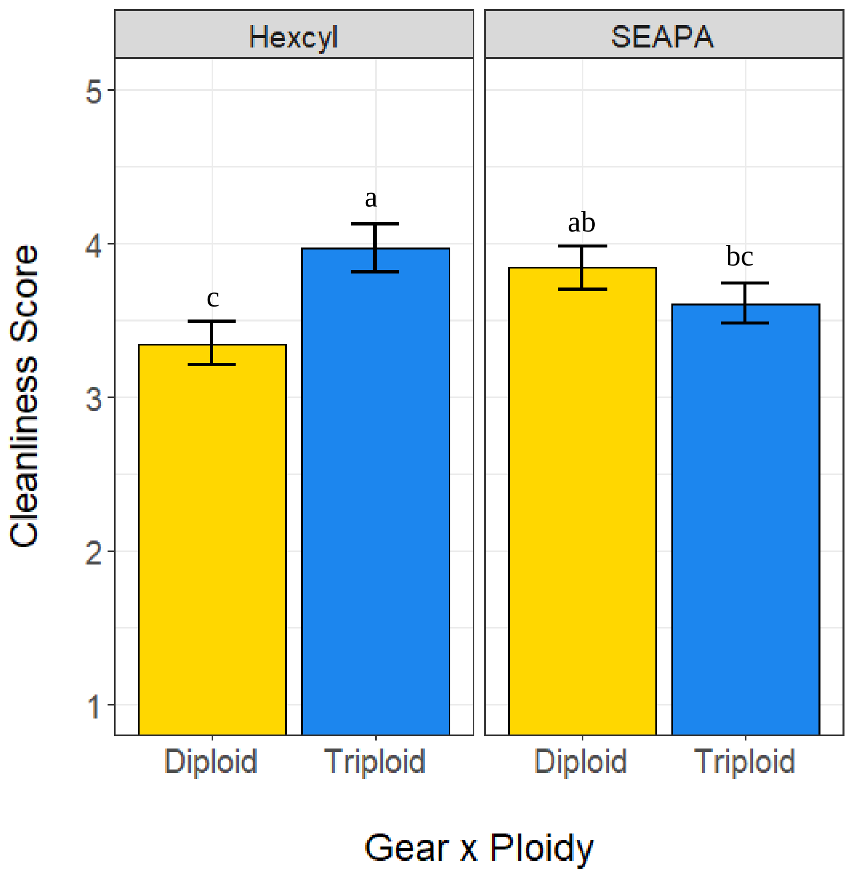

Figure 3.23 Estimated average shell cleanliness score (±SE) for each Gear x Ploidy effect (lines 5-8 and 13-16)

Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16), we found two significant interactions for shell cleanliness: Tumbling x Air-drying ($p<0.01$) and Air-drying x Ploidy ($p<0.01$). In the Tumbling x Air-drying interaction, we found that daily air-drying produced a higher estimated average cleanliness score than weekly air-drying within monthly tumbling treatments ($p<0.01$), but not within quarterly tumbling treatments ($p=0.32$). In addition, daily air-drying treatments did not significantly differ between tumbling treatments ($p=0.23$), but weekly air-drying produced a significantly higher estimated average cleanliness score in quarterly tumbling treatments than in monthly tumbling treatments ($p<0.01$, Fig 3.24).

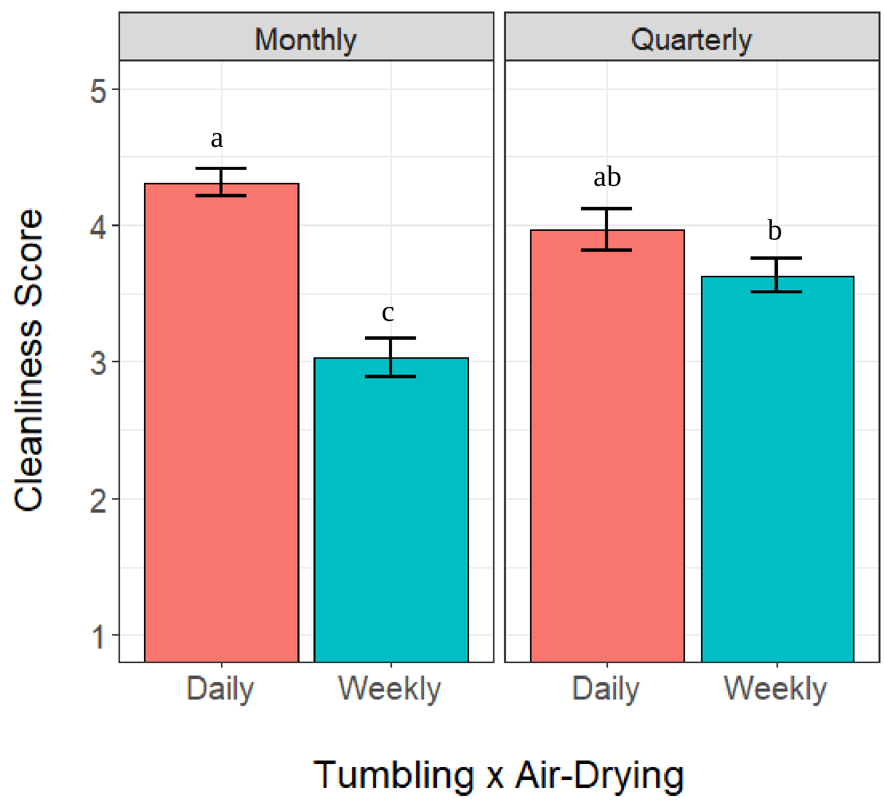

Figure 3.24 Estimated average shell cleanliness score (±SE) for each Tumbling x Air-drying effect (lines 9-12 and 13-16)

Assessing the Air-drying x Ploidy interaction, we found that the estimated average cleanliness score for diploid and triploid oysters was significantly different within daily air-drying ($p=0.03$), but not weekly air-drying treatments ($p=0.69$). However, both daily air-drying combinations produced significantly higher estimated average cleanliness scores than both weekly air-drying combinations ($p\leq0.03$, Fig 3.25).

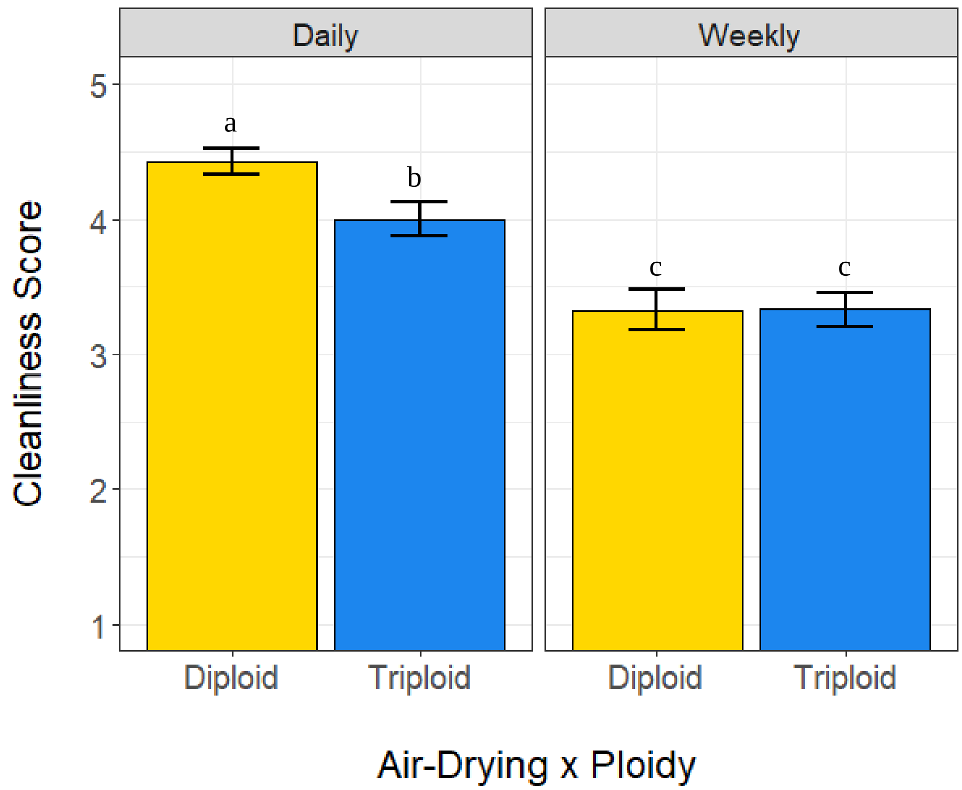

Figure 3.25 Estimated average shell cleanliness score (±SE) for each Air-drying x Ploidy effect (lines 9-12 and 13-16)

Shell Thickness

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16), we found no significant treatment effects for shell thickness. Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16), we found one significant interaction effect for shell thickness: Tumbling x Air-drying ($p<0.01$). When we assessed this interaction, we found that Monthly/Daily treatments had a significantly higher estimated average shell thickness score than all other treatment combinations ($p \leq 0.02$, Fig 3.26).

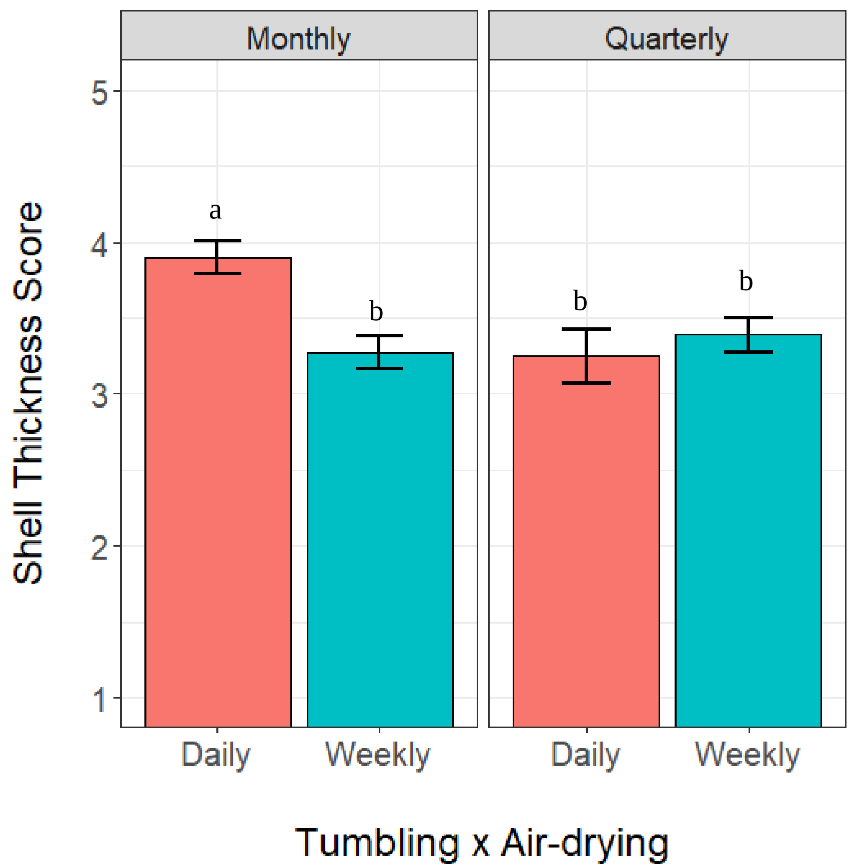

Figure 3.26 Estimated average shell thickness score (±SE) for each Tumbling x Air-drying effect (lines 9-12 and 13-16)

Shuckability

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16), we found one significant treatment effect for shuckability: Air-drying x Ploidy ($p<0.01$). When we assessed the Air-drying x Ploidy interaction, we found that treatments of Daily/Triploid had a significantly higher estimated average shuckability scores than all other treatment combinations ($p \leq 0.01$). The average shuckability score for Weekly/Triploid treatments was significantly higher than Daily/Diploid treatments ($p=0.01$), however Weekly/Diploid treatments were not significantly different from either ($p \geq 0.18$, Fig 3.27).

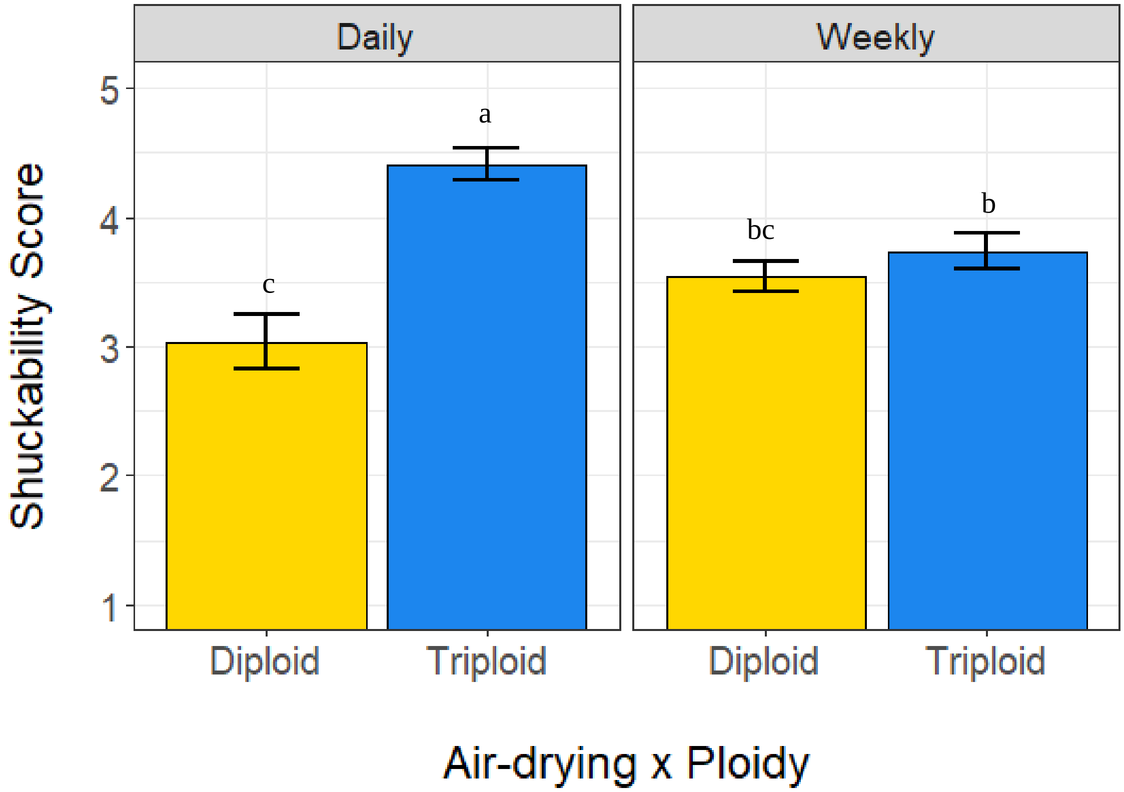

Figure 3.27 Estimated average shuckability score (±SE) for each Air-drying x Ploidy effect (lines 5-8 and 13-16)

Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16), we found a significant interaction effect of Tumbling x Air-drying x Ploidy for shuckability ($p<0.01$). We found that the Monthly/Daily/Diploid treatment and all treatments with triploid oysters were not significantly different from each other ($p \geq 0.30$) and all had significantly higher estimated average shuckability scores than the Quarterly/Daily/Diploid treatment ($p \leq 0.04$). Both the Monthly/Weekly/Diploid and Quarterly/Weekly/Diploid treatments were not significantly different than the Quarterly/Daily/Diploid or Monthly/Weekly/Triploid treatments (p≥0.15, Fig 3.28).

Shell Consistency

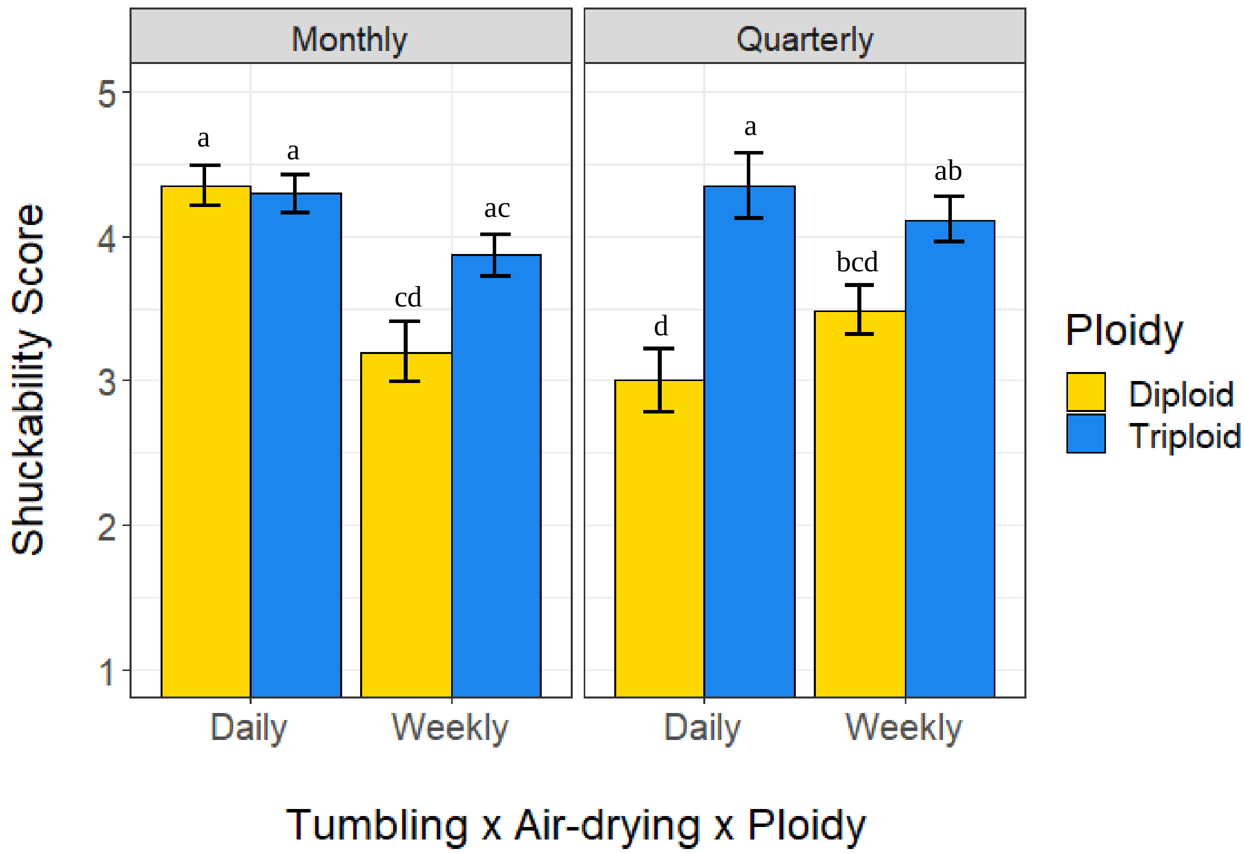

Figure 3.28 Estimated average shuckability score (±SE) for each Tumbling x Air-drying x Ploidy effect (lines 9-12 and 13-16)

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16), there was one significant interaction: Air-drying x Ploidy (p=0.03) on shell consistency. Daily/Triploid treatments had a significantly higher estimated average shell consistency score than all other treatments (p≤0.02). Weekly/Triploid treatments had a significantly higher estimated average shell consistency score than Weekly/Diploid treatments (p<0.01), but neither was significantly different from Daily/Diploid treatments (p≥0.06, Fig 3.29).

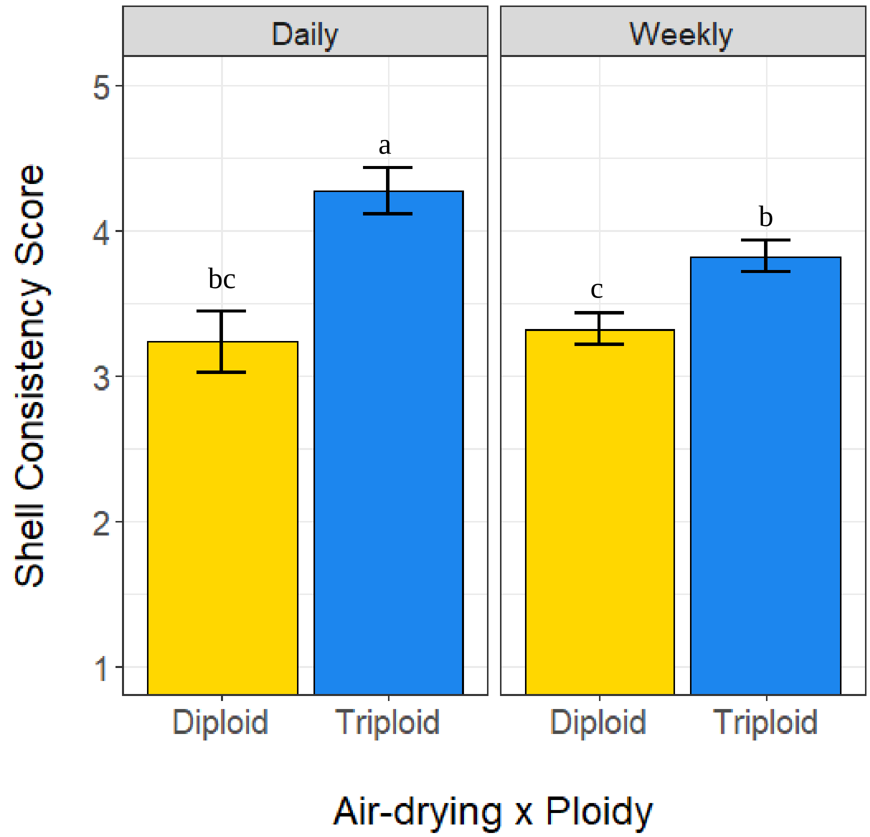

Figure 3.29 Estimated average shell consistency score (±SE) for each Ploidy effect (lines 5-8 and 13-16)

Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16), we found no significant interaction effects but Air-drying ($p<0.01$) and Ploidy ($p<0.01$) had significant main effects on shell consistency. Daily air-drying produced oysters with significantly higher estimated average shell consistency scores than weekly air-drying and triploid oysters had a significantly higher estimated average shell consistency score than diploid oysters (Fig 3.30 and 3.31).

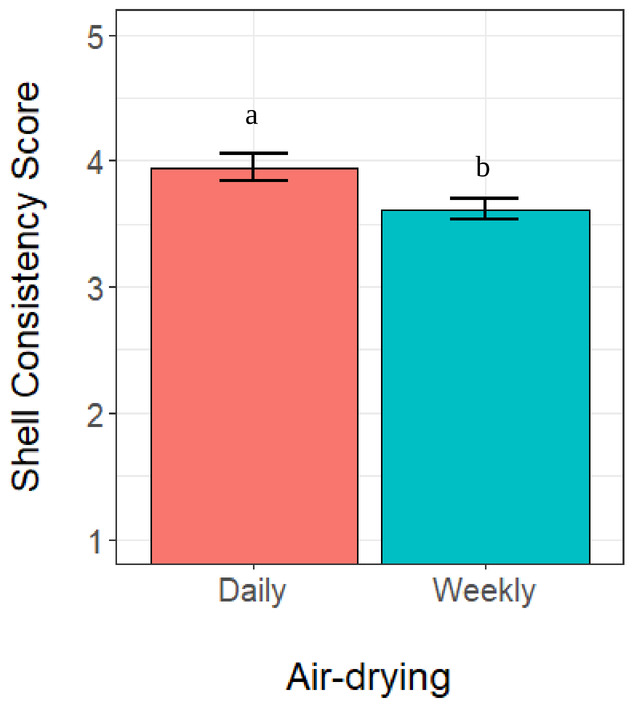

Figure 3.30 Estimated average shell consistency score (±SE) for each Air-drying effect (lines 9-12 and 13-16)

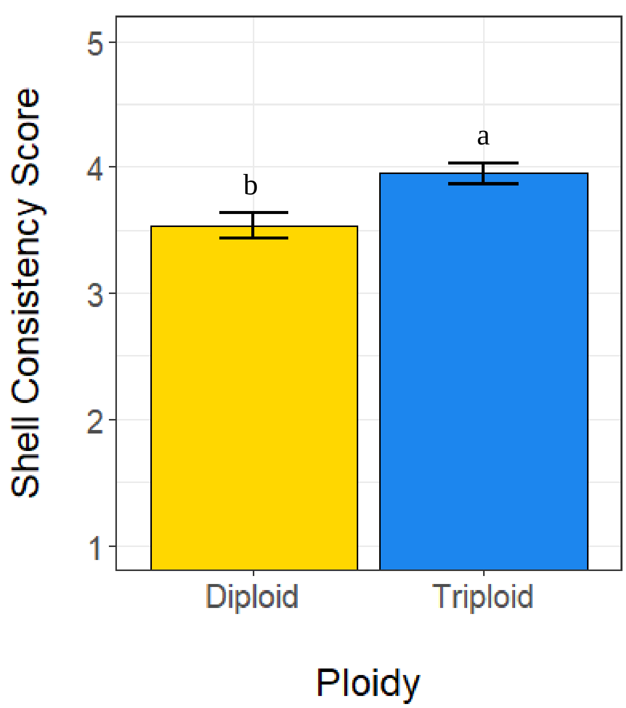

Figure 3.31 Estimated average shell consistency score (±SE) for each Ploidy effect (lines 9-12 and 13-16)

Meat to Shell Ratio

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16), we found a significant effect of Ploidy on meat to shell ratio ($p<0.01$). Triploid oysters had a significantly higher estimated average meat to shell ratio score than diploid oysters (Fig 3.32).

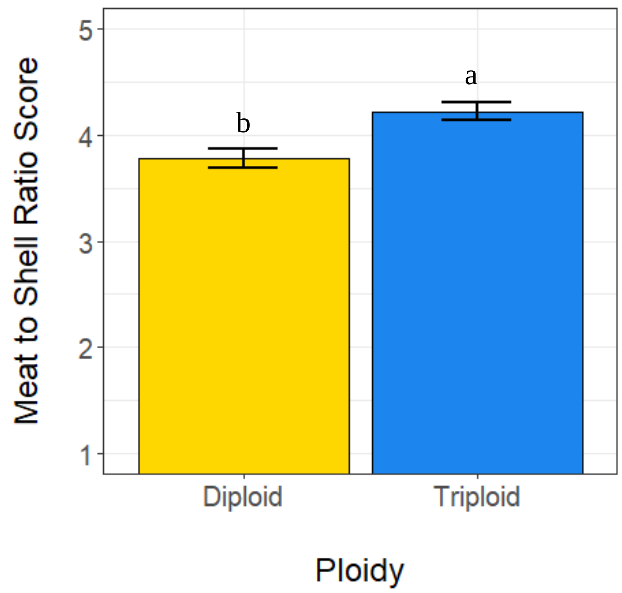

Figure 3.32 Estimated average meat to shell ratio score (±SE) for each Ploidy effect (lines 5-8 and 13-16)

For lines that we assessed tumbling, air-drying, and ploidy treatments (lines 9-12 and 13-16) we found a significant main effect of Ploidy ($p<0.01$) and a significant interaction effect of Tumbling x Air-drying on meat to shell ratio ($p=0.02$). Again, triploid oysters had a significantly higher estimated average meat to shell ratio score than diploid oysters (Fig 3.33).

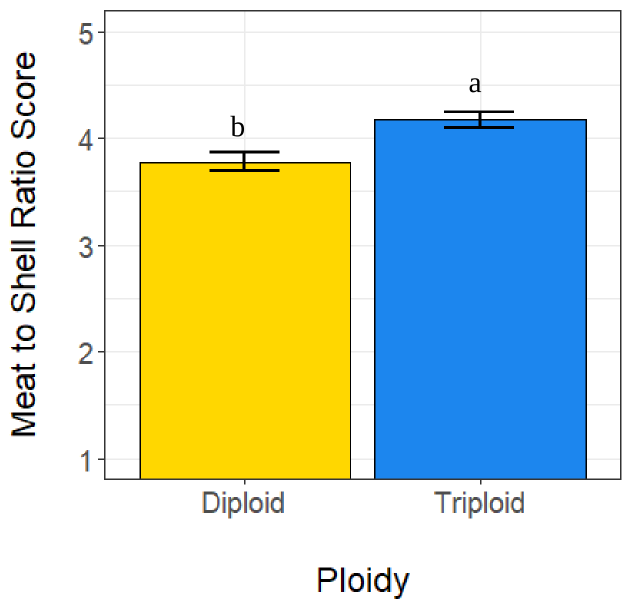

Figure 3.33 Estimated average meat to shell ratio score (±SE) for each Ploidy effect (lines 9-12 and 13-16)

In the Tumbling x Air-drying effect, Monthly/Daily treatments had a significantly higher estimated average meat to shell ratio score than Monthly/Weekly treatments (p=0.02), but neither were significantly different from either Quarterly treatment (p≥0.07, Fig 3.34).

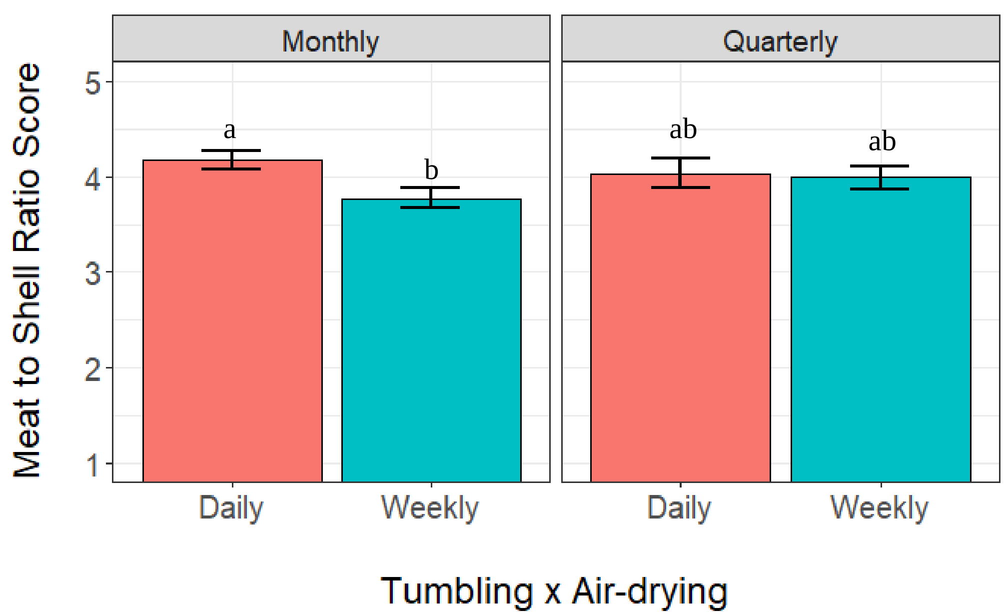

Figure 3.34 Estimated average meat to shell ratio score for (±SE) each Tumbling x Air-drying effect (lines 9-12 and 13-16)

Meat Condition

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16), we found a significant Ploidy effect on meat condition ($p<0.01$). There were no significant interactions. Triploid oysters had a significantly higher estimated average meat condition score than diploid oysters (Fig 3.35).

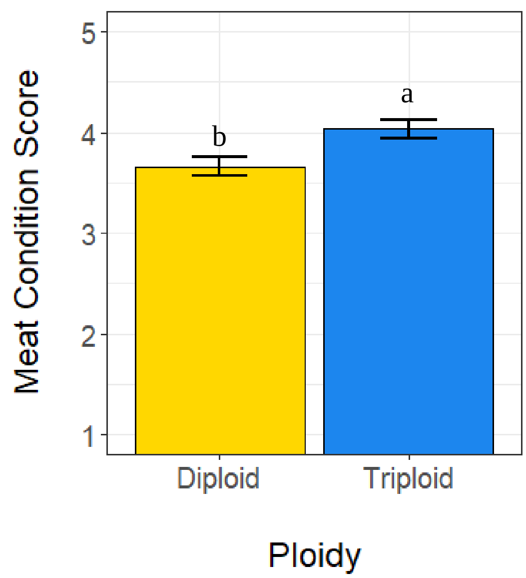

Figure 3.35 Average meat condition score (±SE) for each Ploidy effect (lines 5-8 and 13-16)

Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16), we found significant main effects of both Air-drying ($p<0.01$) and Ploidy ($p=0.02$) on meat condition score, but no significant interactions. Daily air-drying had a significantly higher estimated average meat condition score than weekly air-drying treatments and triploid oysters had a significantly higher average meat condition score than diploid oysters (Figs 3.36 and 3.37).

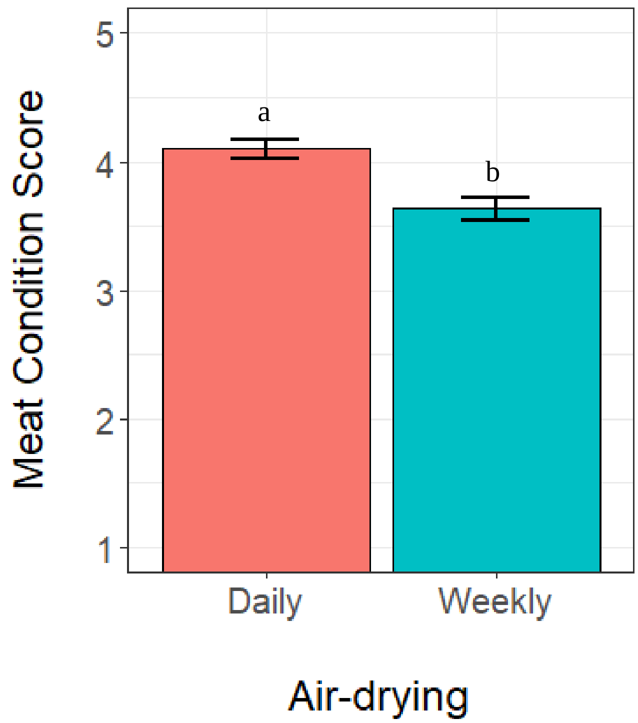

Figure 3.36 Estimated average meat condition score (±SE) for each Air-drying effect (lines 9-12 and 13-16)

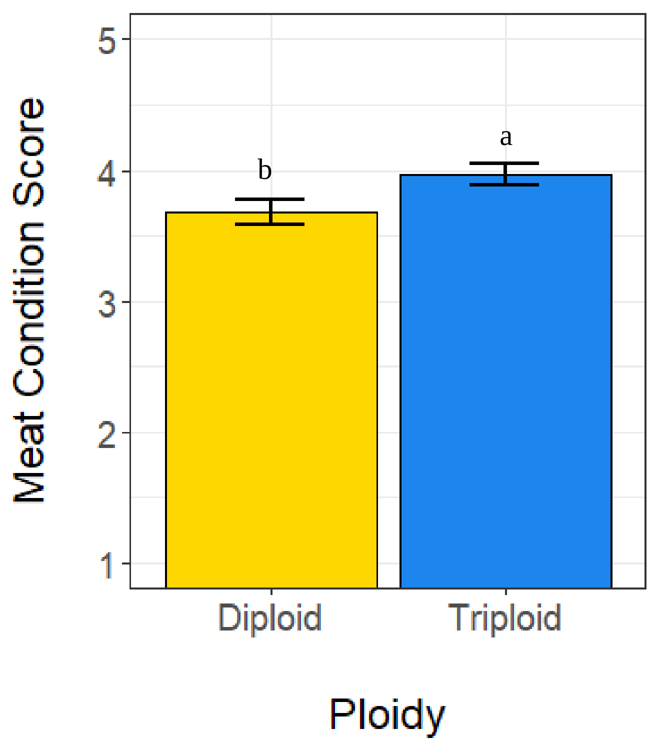

Figure 3.37 Estimated average meat condition score (±SE) for each Ploidy effect (lines 9-12 and 13-16)

Meat Consistency

Assessing gear, air-drying, and ploidy treatments and their interactions (lines 5-8 and 13-16) we found significant Air-drying (p=0.04) and Ploidy (p<0.01) main effects on meat consistency scores, but no significant interactions. Oysters grown with daily air-drying had a significantly higher estimated average meat consistency score than oysters grown with weekly air-drying (Fig 3.38). Triploid oysters had a significantly higher estimated average meat consistency score than diploid oysters (Fig 3.39).

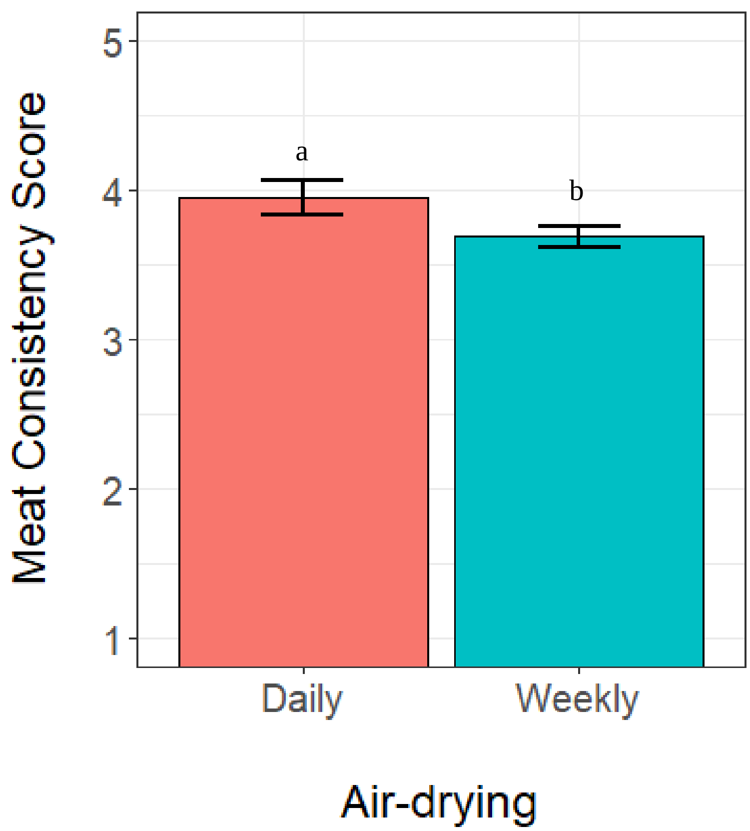

Figure 3.38 Estimated average meat consistency score (±SE) for each Air-drying effect (lines 5-8 and 13-16)

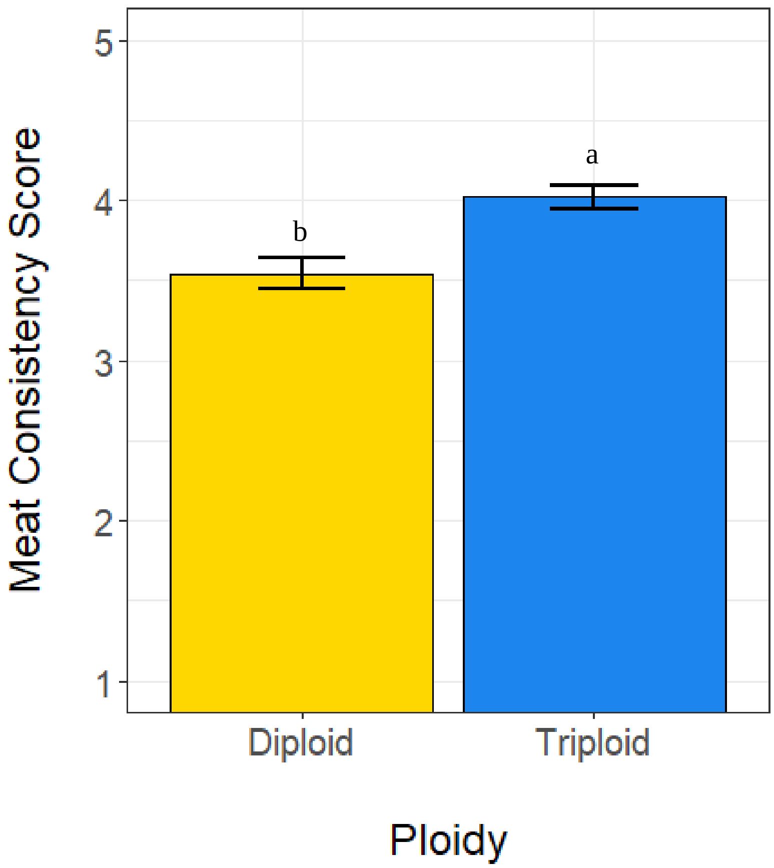

Figure 3.39 Estimated average meat consistency score (±SE) for each Ploidy effect (lines 5-8 and 13-16)

Assessing tumbling, air-drying, and ploidy treatments and their interactions (lines 9-12 and 13-16), we found also found significant Air-drying ($p<0.01$) and Ploidy ($p<0.01$) main effects on meat consistency scores, but no significant interactions. Again, daily air-drying treatments had a significantly higher estimated average meat consistency score than weekly air-drying treatments and triploid oysters had a significantly higher estimated average meat consistency score than diploid oysters (Figs 3.40 and 3.41).

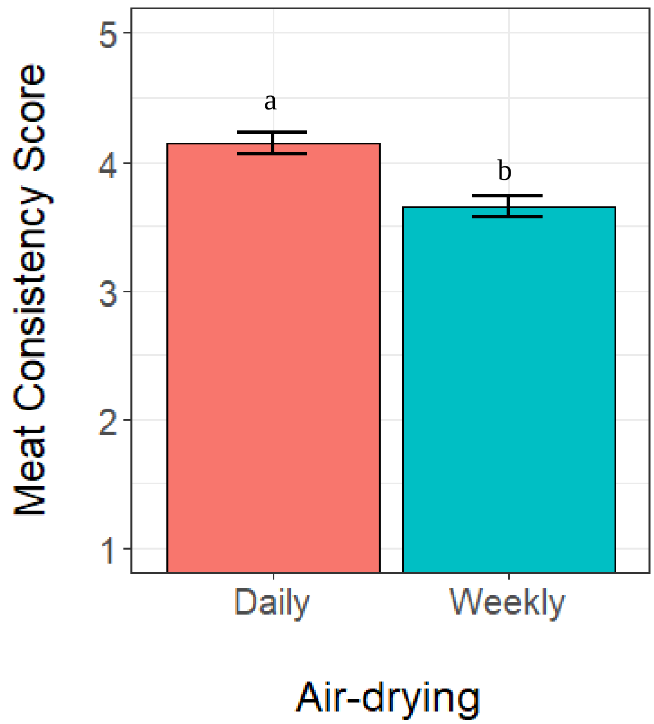

Figure 3.40 Estimated average meat consistency score (±SE) for each Air-drying effect (lines 9-12 and 13-16)

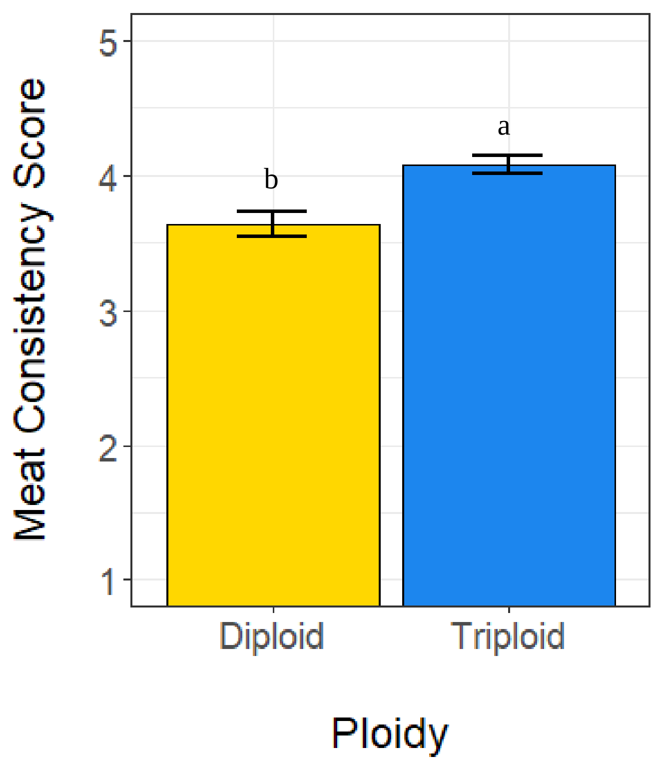

Figure 3.41 Estimated average meat consistency score (±SE) for each Ploidy effect (lines 9-12 and 13-16)

Buyer Perception and Purchase Intention Results

Overall, participants offered a minimum of \$0.20, a maximum of \$1.00, and an average of \$0.60 per oyster (±\$0.14) at wholesale for the included treatment lines. On average, every survey quality metric (Shell Shape, Cleanliness, Shell Thickness, Shuckability, Shell Consistency, Meat to Shell Ratio, Meat Condition and Meat Consistency) received a score of 3 ('fair') or higher. There were few 1 ('very poor') or 2 ('poor') scores reported (Appendix A). An ANOVA test of treatment lines sent in replicate shipments (Lines 5, 6, 10, 12, and 13), demonstrated that there were no significant differences in willingness to pay between any of the treatment line replicates ($p \geq 0.1$) except for one treatment line: line 6 ($p<0.01$). This suggests that, in general, our survey participants answered the surveys consistently for each treatment line.

A linear regression between willingness to pay and the overall sum of the quality scores demonstrated a significant relationship, in which for each 1 point score increase in quality we observed a \$0.01 (±.0003) increase in willingness to pay per oyster ($p<0.01$). However, the sum of the quality scores did not explain a high proportion of the variation in willingness to pay ($r^2=0.19$, Fig 3.42).

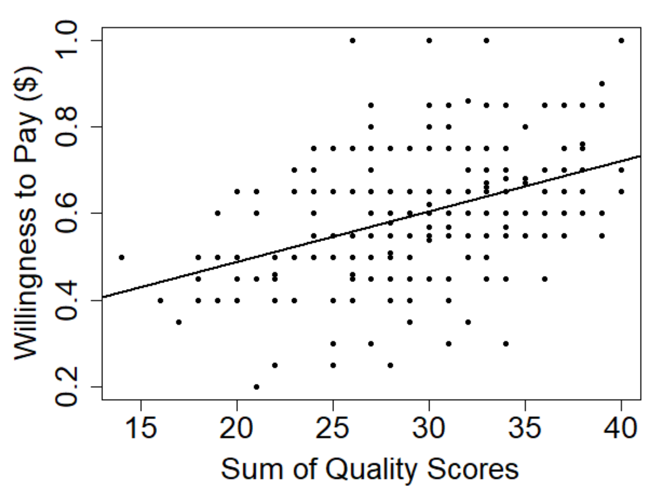

Figure 3.42 Linear regression model of the effect of sum of all quality scores on buyer willingness to pay

For linear regressions between willingness to pay and each survey quality metric, only shuckability and meat consistency quality metrics had significant effects on what participants were willing to pay. For each 1 point score increase in shuckability, participants were willing to pay \$0.05 (±0.02) more per oyster ($p<0.01$) and for each 1 point score increase in meat consistency, participants were willing to pay \$0.03 (±0.02) more per oyster ($p=0.03$). However, both variables did not explain a high proportion of the variation in willingness to pay ($r^2=0.26$).

In the case of the effect of treatment on willingness to pay, the ANOVA analysis for the Gear x Air-drying x Ploidy treatment (lines 5-8 and 13-16) had one significant interaction: Air-drying x Ploidy ($p=0.02$). On average, triploid oysters received a higher price per oyster, regardless of air-drying frequency ($p\leq0.04$, Fig 3.43). When we analyzed the Tumbling x Air-drying x Ploidy treatment (lines 9-12 and 13-16) there were no significant interactions, but ploidy had a significant main effect on willingness to pay ($p<0.01$). Again, triploids received a higher price per oyster on average ($p<0.01$, Fig 3.44).

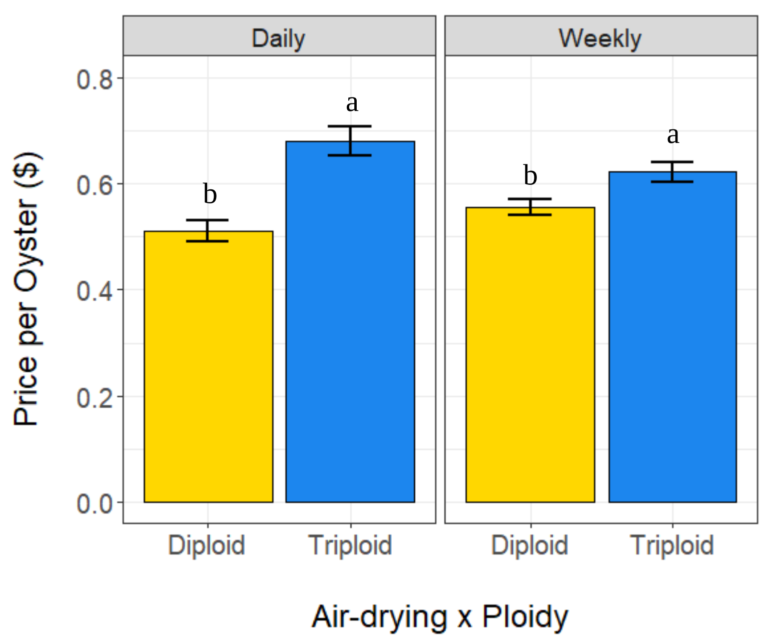

Figure 3.43 Average willingness to pay per oyster (±SE) for lines comparing Air-drying x Ploidy treatments (lines 5-8 and 13-16)

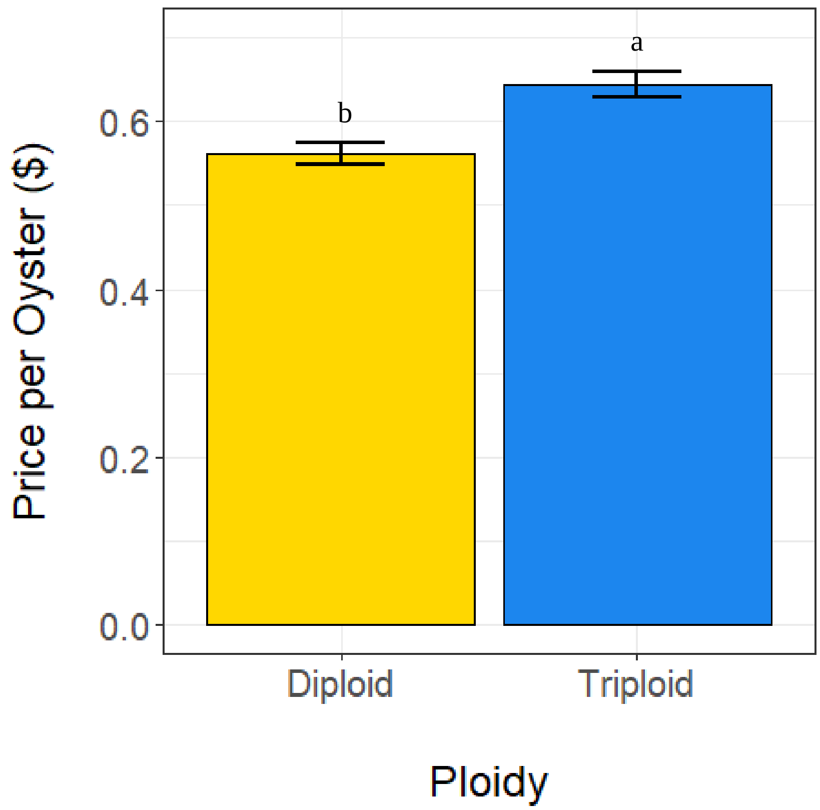

Figure 3.44 Average willingness to pay per oyster (±SE) for lines comparing Ploidy treatments (lines 9-12 and 13-16)

When assessing a ranked logistic regression between the sum of all quality metric scores and the order in which participants were willing to purchase the oysters (1^{st}-6^{th}), we found a positive significant relationship ($p<0.01$). Therefore, on average a treatment line received a higher purchase rank as the overall sum of the quality scores increased.

A ranked logistic regression for the effect of each quality metric on purchase rank demonstrated shell shape ($p<0.01$) as a significant quality metric in addition to the same significant quality metrics found in in the willingness to pay regression, shuckability ($p<0.01$) and meat consistency ($p<0.01$). As shell shape, shuckability, and meat consistency scores increase we expect the purchase rank to improve.

In the case of the effect of treatment on purchase rank, we found significant main effects of Drying and Ploidy across all lines ($p<0.01$). Daily air-dried oysters received higher purchase ranks than weekly air-dried oysters and triploid oysters received higher purchase ranks than diploid oysters. Generated probabilities demonstrated that combinations of daily air-drying and triploid oysters were among the most probable to receive a rank of "1st" (Table 3.10). Weekly air-dried triploids had the next highest probabilities, except for Line 14 (SQW3) which had a slightly lower probability of receiving a rank of "1st" than other triploid lines. All combinations including diploid oysters had the lowest probabilities. These results were further confirmed by individual line comparisons ($p<0.05$).

Table 3.10 Predicted probabilities of each treatment line being ranked first.

Line	**Gear**	**Tumbling**	**Air-drying**	**Ploidy**	**Probability of Top Ranking**
8	Hexcyl	Quarterly	Daily	Triploid	0.59
12	SEAPA	Monthly	Daily	Triploid	0.57
16	SEAPA	Quarterly	Daily	Triploid	0.35
10	SEAPA	Monthly	Weekly	Triploid	0.32
6	Hexcyl	Quarterly	Weekly	Triploid	0.29
11	SEAPA	Monthly	Daily	Diploid	0.28
7	Hexcyl	Quarterly	Daily	Diploid	0.25
14	SEAPA	Quarterly	Weekly	Triploid	0.22
15	SEAPA	Quarterly	Daily	Diploid	0.17
9	SEAPA	Monthly	Weekly	Diploid	0.14
5	Hexcyl	Quarterly	Weekly	Diploid	0.12
13	SEAPA	Quarterly	Weekly	Diploid	0.099

Discussion

Shell Metrics

Weekly diploids were observed to have the lowest fan ratio in the quantitative assessment (Figs 3.6 and 3.7). Since weekly diploids had the highest average daily shell growth rate, they may have grown more in terms of height rather than length leading to a lower fan ratio. Seed's study (2009) found that fast growth can also lead to physical compression that encourages an elongate shape over more triangular shaped shells. When compared to control oysters, weekly diploids performed about the same in terms of fan ratio, whereas other treatment lines exceeded the quality of the control oysters. In contrast, participants did not see many differences in shell shape among the treatments. Participants did perceive SEAPA/Weekly/Diploid treatments as having lower quality, but only when compared to one other treatment (Hexcyl/Daily/Triploid, Fig 3.21). Despite any differences among treatment lines, fan ratios were all above 0.67 (SL/SH=2/3), which is considered a favorable score in the quantitative analysis (Mizuta and Wikfors 2019). Survey participants also scored all treatment lines as having average or above average shell shapes.

Differences in Hexcyl and SEAPA basket designs may have affected movement within the water column and led to higher variability of cup ratios in Hexcyl brand gear (Fig 3.9). Daily air-dried oysters were likely subjected to more frequent wave action than weekly air-dried oysters, resulting in greater oyster depth and hence higher cup ratios (Orton 1936; O'Meley 1995). Most daily air-drying treatments had cup ratios that exceeded control oysters', whereas other treatments either performed about the same or worse than the control oysters. Again, despite any observed differences all treatment lines exhibited cup ratios above 0.33 (SW/SH=1/3), which is considered a favorable score in the quantitative analysis (Mizuta and Wikfors 2019).

There was disagreement of shell cleanliness between our quantitative analysis and survey results (Figs 3.13, 3.14, and 3.22- 3.25). Cleaning times calculated during the quantitative analysis were variable among treatments, with some exceeding the quality of control oysters and some having lower quality than the control oysters. We do not have a clear explanation as to why the variation we observed occurred. Despite variable quantitative results, survey participants scored all treatment lines as having above average cleanliness.

Shell thickness was scored the highest in the survey among treatments with the presumably most shell abrasion and handling (monthly tumbling and daily air-drying, Fig 3.26). A study by Scherer (2012) found that oysters will rapidly increase calcium carbonate production in response to risk such as predators. Management techniques with high shell abrasion may induce this physiological response where more calcium carbonate is deposited within the shell when new growth is restricted.

Shuckability was scored the highest among triploids (Figs 3.27 and 3.28). The shape of the shell, the strength of the shell, the style of shucking used, among many other variables all contribute to how easily an oyster is shucked. We did, however, observe that triploids had lower average daily shell growth when compared to diploids, but participants scored both ploidies as having similar shell thickness. Scherer (2012) found an inverse relationship between shell thickness and density when oysters were exposed to risk, as oysters tend to rebuild shell with less dense calcium carbonate instead of stronger organic materials. Therefore, the abrasion experienced by triploids may explain why they were easier to shuck without being too brittle, which would render them unusable at a high-end raw bar.

Lastly, shell consistency was scored the highest among daily air-drying and triploid oysters (Figs 3.29-3.31). Daily air-drying subjected the oysters to, presumably, higher shell abrasion than weekly air-drying, which may have prevented inconsistent shell growth. Anecdotally, many farmers have noticed this effect in which greater handling tends to produce more consistent oysters. Triploids overall had slower shell growth possibly promoting a more uniform appearance among oysters within the same treatment line. In contrast, faster shell growth in diploids could have led to quicker crowding in between grading and re-stocking events, which is known to cause variation in shell shape (Seed 2009). In addition, triploids are sterile and do not use their energy reserves for gametogenesis; variation in shell growth and shape may be a consequence of diploid energy expenditure towards spawning and gonadal maturation (Capelle et al. 2019).

Meat Metrics

The condition index metric combined dry tissue, dry shell, and whole wet weight assessments to determine how much the oysters' meats filled their shell cavities. The treatment lines that we observed to have the highest dry tissue weights, combinations of Daily/Diploid and Weekly/Triploid, in turn also had the highest condition indices (Fig 3.17, Fig 3.20). These two treatment combinations exceeded the quality of control oysters, while other treatment combinations performed noticeably lower. Daily air-drying may have proved to be beyond the threshold for triploid stress tolerance, as oysters with this treatment had both lower shell and meat growth, resulting in lower condition indices as well. In contrast, while diploids with daily air-drying had lower shell growth, more frequent air-drying may have been a promoting factor for tissue growth and higher condition indices. La Peyre et al. (2017) found that oysters exposed to daily air-drying spent more energy reserves on tissue growth rather than shell growth, which is what we may be observing in our daily air-dried diploids for dry tissue weight. Tumbling frequency had separate interactions with ploidy and air-drying frequency, in which monthly tumbling combined with weekly air-drying proves to be disadvantageous for condition index and quarterly tumbling combined with diploid oysters proves to be advantageous (Figs 3.18 and 3.19). Survey results agreed that overall triploids possessed higher scoring meat condition than diploids and daily air-drying produced better meat condition than weekly air-drying (Figs 3.35-3.37). Survey participants also agreed that triploids had better meat to shell ratios than diploid oysters, and that oysters with a combination of monthly tumbling and weekly air-drying produced lower meat to shell ratios than other treatment combinations (Figs 3.32-3.34).

Survey participants scored triploid oysters and oysters that were air-dried daily as having higher consistency among meat quality metrics (Figs 3.38-3.41). As with shell consistency, differences in energy expenditure between sterile triploids and fertile diploids could have also affected meat consistency (Capelle et al. 2019). In addition, diploids spawn throughout the summer months and as gametes are released there can be visual changes in the meat; oyster meats can be considerably inconsistent if a chef or wholesaler is presented with both diploids that have spawned and have not spawned (Stanley et al. 1981; Maguire et al. 1994; Wadsworth 2019b). As daily air-drying limits shell growth but promotes tissue growth, meat may look visually more consistent because it can easily fill the smaller space within the oyster.

Conclusions Regarding Quality

While it is known that environmental factors such as food availability, water temperature, salinity, high energy environments, turbidity, population density, substratum, and depth of the photic zone can affect shell and meat growth, culture methods and handling techniques can have further effects on oyster quality (Agius et al. 1978; Seed 1980, as cited in O'Meley 1995; Wilson 1987; Brown and Hartwick 1988; Ring 2012; Davis 2013; Bodenstein 2019). Our results support the conclusion that farmers can affect the quality of oysters they are producing, for better or worse, through their choice of management techniques. Our results also suggest that quality metrics obtained through quantitative analysis can be accurate predictors for qualitative scores oysters may receive when sent off to wholesalers or chefs.

Despite our observed differences in quality among treatment lines, our oysters had acceptable fan and cup ratios and received average or above average for all survey metrics. A common denominator among all of our treatment lines was the presence of oyster handling; when farmers handle their oysters it can not only improve the quality and marketability of oysters for the half-shell market, but it also allows farmers to have eyes on their gear and assess any environmental conditions (tidal heights, wave action, air temperatures, etc.) that could impact how they employ certain management techniques. More specifically, our results suggest that the frequency of tumbling did not have large effects on perceived quality, however daily air-drying produced oysters perceived as being high quality more often than weekly air-drying.

Beyond handling, our results also suggest that the use of triploid oysters improve perceived quality to a greater degree than diploid oysters. Even so, farmers should consider the physiology of their oysters, especially differences among diploid and triploid oysters, and the effects of changing environmental conditions when determining which handling stressors to apply or how frequently; many of the differences we observed between diploid and triploid oysters were supported by the literature, suggesting responses to certain stressors can be predicted and should be acted on accordingly. In addition, some combinations of management techniques produced high quality oysters when measured quantitatively, but the quality was still lower than control oysters, suggesting the labor put towards certain management techniques, such as weekly air-dried diploids, may not be worth the cost.

Buyer Perception and Purchase Intention

Historically, oysters produced in the Gulf region with traditional on-bottom methods have received lower prices than oysters grown elsewhere in the United States as they were often intended for the shucked market or sold as generic oysters in the half-shell market. However, the expansion of off-bottom oyster farms has changed the market for Gulf-coast oysters: farmers are able to highlight the unique qualities of their oysters through innovation, branding, and rising demand for half-shell oysters (Walton et al. 2012; Petrolia et al. 2017; ASMC 2020; NMFS 2020). The 2018 Situation and Outlook Report for Oyster Aquaculture in Alabama reported an average price of $0.46 per oyster received by farmers (ACES 2019); all the varieties of oysters produced by the treatments we implemented in this study were offered average prices above the current Alabama average, ranging from $0.50 up to $0.70 per oyster. In addition, these prices were offered by chefs and wholesalers located across the United States, not only within the Gulf region, suggesting Gulf-coast oysters are proving to be a competitive product in the half-shell market. While this is a positive outlook for farmers producing oysters in the Gulf region, they should still be aware that the oysters received variable prices.

As we discussed previously, all our treatment lines received above average quality scores in the survey. However, when we assessed willingness to pay against the overall sum of the quality scores we found that, while it does not explain a lot of the variation in price or purchase preference, even small increases in quality can improve a farmer’s chances of receiving a higher price per oyster and their oysters being first pick at purchase (Fig 3.42). Therefore, in terms of our third objective we found that buyers are willing to pay more for differences in quality. Farmers should be perceptive of how their management techniques are affecting oyster quality if they want to optimize their profits.

Buyers have different perceptions of what traits make an oyster valuable (Krenn 2013), but we found a few traits in our study that most buyers answered consistent prices for. Shuckability and meat consistency were the only traits that had significant effects on willingness to pay, meaning buyers agreed high quality of these metrics deserve higher prices and vice versa.

There was disagreement among buyers as to how the other traits affected the price they offered per oyster, suggesting preference for these are more buyer specific. These same traits had significant effects on the order buyers were willing to purchase each oyster variety, in addition to shell shape. Previously farmers and markets have focused on meat quality as the primary determinant of oyster value, however more recent studies suggest high quality shell metrics have become more desirable (Ruello 2002; Kow et al. 2008; Krenn 2013; van Houcke et al. 2018; Mizuta and Wikfor, 2019) . Ruello (2002) suggests that "an attractive oyster will gain attention even if it has a high price point whereas an unattractive oyster is not seen as good value regardless of a cheap price point," which could explain why shell morphology traits did not have significant effects on willingness to pay but did on purchase order. Ruello also suggests that "perceived value is the key to increasing demand," to which we suggest farmers develop good relationships with their buyers/market to observe trends in their consumers' needs and understand how to meet those needs.

When we assessed how management techniques affected both willingness to pay and purchase order, triploids proved to have higher values for both (Figs 3.43 and 3.44). Shipments of diploids and triploids were sent in both the spawning months and non-spawning months (Table 3.1), and we observed that triploid values still exceeded diploids in non-spawning seasons. In chapter 2 we found that all operations using triploid seed were profitable no matter the handling techniques or gear brand. Therefore, we suggest that the use of triploid oyster seed can improve both the perception of the oysters a farmer produces as well as their profitability. Handling is still important to achieve a minimum standard of quality, but there is leeway for farmers to reduce labor costs (i.e. using daily air-drying and/or quarterly tumbling) while still meeting the needs of consumers.

A limitation of this study included the small sample size of survey participants (N= between 12 and 48 for each shipment). There is a limited demographic of wholesalers and chefs that deal in oysters on the half-shell to begin with, and we did not get 100% of responses from those who agreed to participate. Our survey required heavy involvement in which participants needed to shuck and assess oysters in addition to filling in responses, which was not always possible for them to complete due to other priorities. Shipping live oysters to our participants was also costly which limited the number of varieties and number of oysters per variety we could send with each shipment. This limited the amount of data we could collect with each shipment. Of those that completed the survey, many noted that it was difficult to assess the price they would be willing to pay per oyster without being able to taste each variety. A study done by van Houcke et al. (2018) found that sensory qualities ranked among the most important oyster quality characteristics for general consumers, therefore it may be advantageous to include sensory qualities such as taste and odor in any future studies. Finally, larger differences in quality metrics and survey responses may have been observed if the absence of the tumbling and air-drying techniques was included as a treatment in addition to both frequencies; the absence of each handling technique could be used as a baseline that could put in context the magnitude of each frequency treatment effect.

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APPENDIX A

SURVEY

Background

This survey is being conducted as part of an Auburn University Shellfish Lab research project, which aims to determine how the quality of different oyster varieties are perceived by those in the oyster industry and consumers.

If you have any questions regarding this study, you may contact us by email:

smh0106@auburn.edu

Instructions

This survey is also available to be taken online via the following link (case sensitive):

auburn.qualtrics.com/jfe/form/SV_82oOBYjMu0mcuEt

ANONYMOUS SURVEY ID:
If you are using the online survey, please enter this ID.

You have been provided with 4-6 different varieties of oysters (A, B, C, …) grown using varying culture methods, with a sample of 6 randomly selected oysters per variety.

Look over the sample oysters provided and rate the attributes of each variety as a group from 1-5, with 5 being very good and 1 being very poor, based on the given criteria (no decimals please!). You will need to shuck the oysters to observe internal characteristics. Do not taste the oysters and do not base your evaluation on this attribute; for the purpose of this comparison assume these oysters all taste the same.

Once you have rated the oysters, determine a price ($) you would be willing to pay per oyster for that particular variety (not what you would sell them for) and the order of your purchase preference (1st, 2nd, 3rd, …).

Your responses to this survey will be anonymous.

(Please check one) I am a:

☐ chef

☐ wholesaler

1	2	3	4	5
Very Poor	Poor	Fair	Good	Very Good

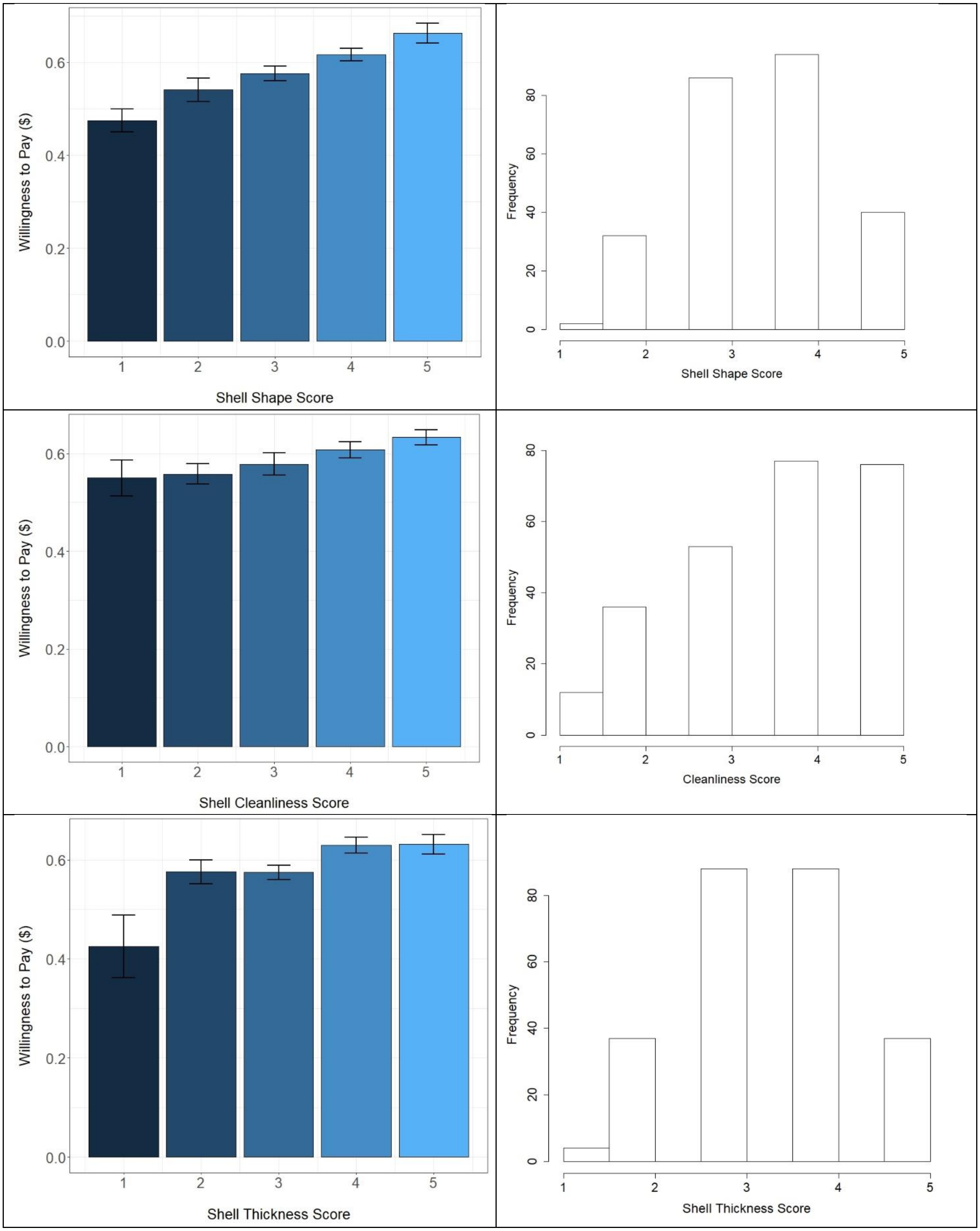
Please fill out the table:

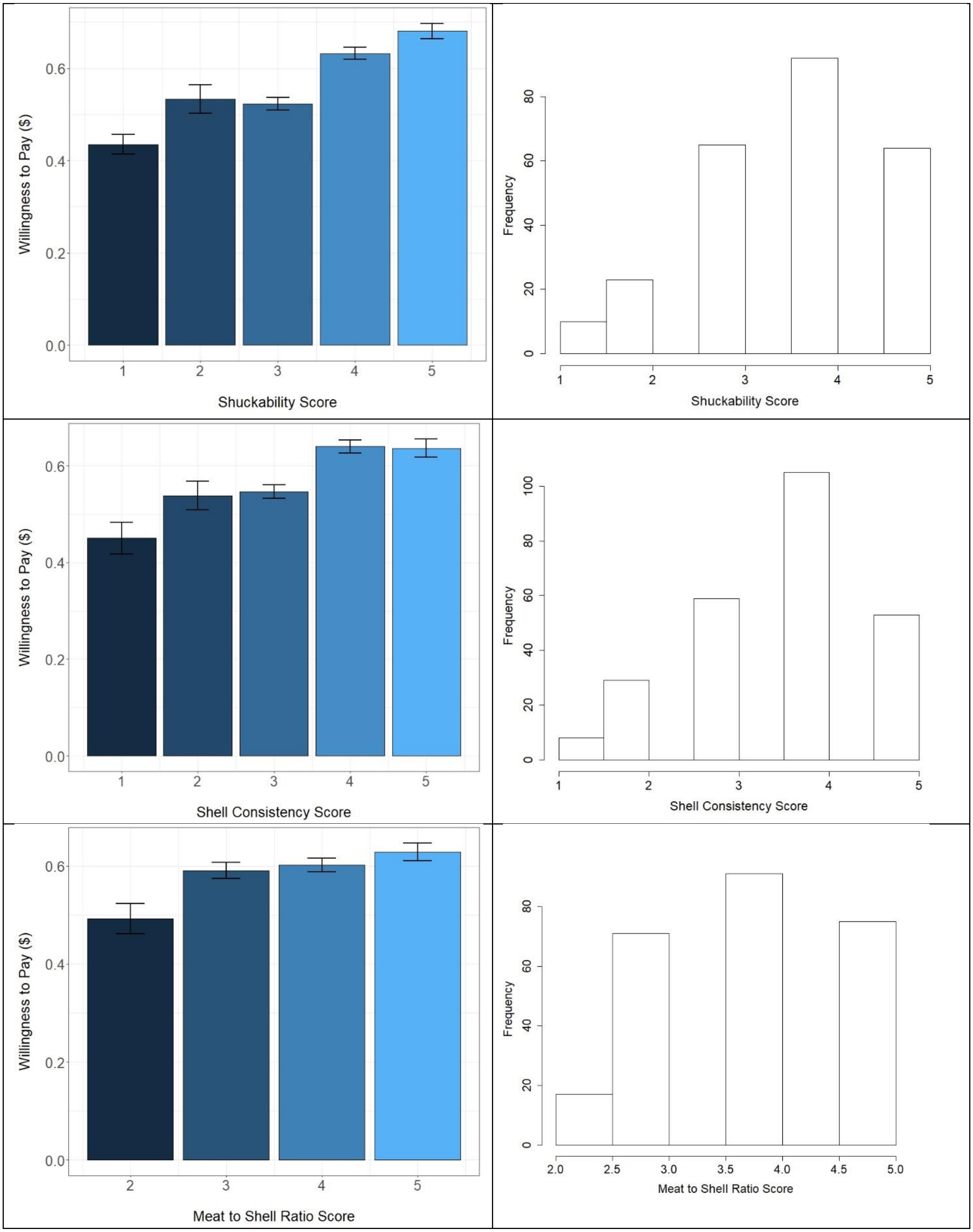
	Shell (1-5)					Meat (1-5)			Price Offered ($ Per Oyster)	Purchase Preference (1^{st}-6^{th})
Variety	Shape	Cleanliness	Thickness	Shuckability	Consistency	Meat to Shell Ratio	Meat Condition	Consistency		
A										
B										
C										
D										
E										
F										

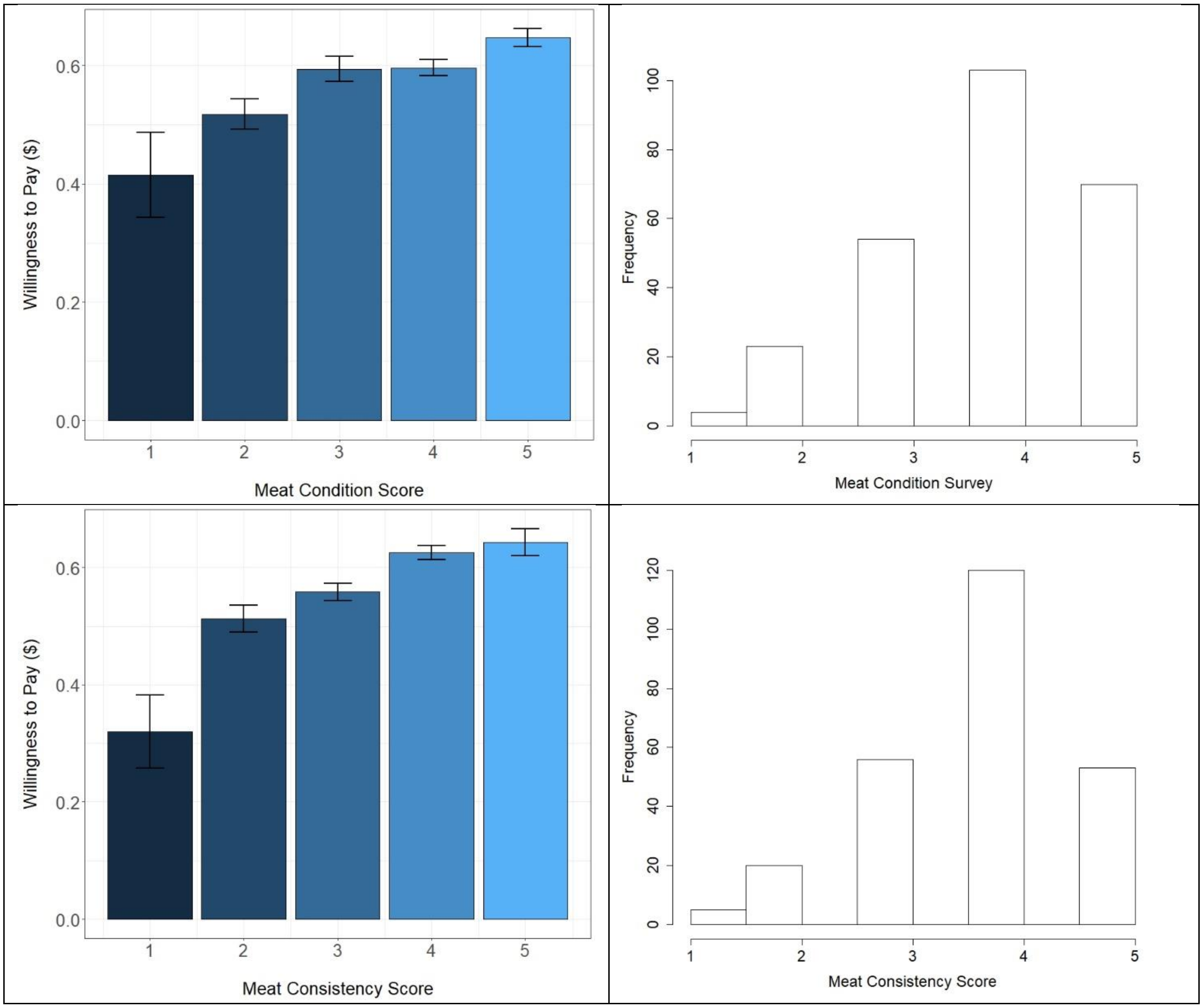
Please make any notes about factors that affected your answers below:

The Auburn University Institutional Review Board has approved this Document for use from 08/16/2019 to --------------
Protocol # 19-040 EX1901

CONSUMING RAW OR UNDERCOOKED MEATS, POULTRY, SEAFOOD, SHELLFISH, OR EGGS MAY INCREASE RISK OF FOODBORNE ILLNESS ESPECIALLY IF YOU HAVE CERTAIN MEDICAL CONDITIONS


Willingness to Pay ($)
0.0
0.2
0.4
0.6
1
2
3
4
5
Shell Shape Score
Frequency
0
20
40
60
80
Shell Shape Score
Willingness to Pay ($)
Shell Cleanliness Score
Frequency
Cleanliness Score
Willingness to Pay ($)
Shell Thickness Score
Frequency
Shell Thickness Score


Willingness to Pay ($)
Shuckability Score
Frequency
Shuckability Score
Willingness to Pay ($)
Shell Consistency Score
Frequency
Shell Consistency Score
Willingness to Pay ($)
Meat to Shell Ratio Score
Frequency
Meat to Shell Ratio Score


Willingness to Pay ($)
0.0
0.2
0.4
0.6
1
2
3
4
5
Meat Condition Score
Frequency
0
20
40
60
80
100
Meat Condition Survey
Willingness to Pay ($)
Meat Consistency Score
Frequency
120
Meat Consistency Score