

Southern Regional Aquaculture Center: Techniques to Improve Production of Off-bottom Cultured Oysters

Final Report

Reporting Period: May 1, 2017 – October 31, 2019

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OBJECTIVES

The objectives of this project were to:

- 1) Determine the impacts of cage manipulation to decrease biofouling, and evaluate the effects on time to harvest, survival, and morphometric factors, such as meat weight and shell shape (height, length, depth).
- 2) Determine the impacts of antifouling agents to decrease biofouling, and evaluate the effects on time to harvest, survival, and morphometric factors, such as meat weight and shell shape (height, length, depth).
- 3) Determine the economic impact of each methodology on production costs.

SUMMARY

This project addressed controlling biofouling on floating oyster cages (OysterGro™) throughout seven southern U.S. states (NC, SC, GA, FL, AL, MS, LA) by employing two strategies: aerial drying ('flipping') and biocide-free, antifouling coating. Triploid oyster seed and twelve OysterGro™ Pro cages with bags per state were provided by the LSU Oyster Research Laboratory (Gulf Coast), Lady's Island Oyster Inc. (Atlantic Coast), and BBI Group; respectively. The project was conducted with industry partners including Carolina Mariculture, Lady's Island Oyster Inc., Southern Cross Sea Farms, and Navy Cove Oyster Company who were responsible for following the prescribed flipping routine. The project was monitored and documented by two dedicated graduate students (Shannon Kirk assigned to the Atlantic states and Ellis Chapman to the Gulf states) each of whom earned their Master of Science degree. The experiment began late summer 2017 and was monitored quarterly for twelve months, with harvest taking place in June 2018. Aerial drying frequencies tested included weekly, every other week, and every three weeks; duration of exposure varied by season but remained constant among grow-out locations. This was a grow-out experiment only with seed planted in 14mm Intermas bags at 30mm shell height. Netminder™ fouling release coating was tested by coating three bags per cage and half of the pontoons per treatment. The coating was applied by the OysterGro™ dealers per the manufacturer's recommendations.

Quarterly sampling included measurement of shell metrics and photo documentation of fouling on the bags; at harvest, meat yield, condition index, survival, and quantitative analysis of fouling on the oysters was also determined. On the Atlantic Coast (NC, SC, GA), generally, drying frequencies and coating had little effect on oyster condition and fouling. However, oysters dried every two or three weeks without coatings showed greater growth compared to oysters dried weekly in coated bags. On the Gulf Coast (FL, AL, MS, LA), generally, the results suggest that weekly aerial exposure contributed to differences in size, shape, biofouling accumulation, quality and survival. The use of antifouling coatings on pontoons and bags reduced wet bag weights in Florida, but otherwise did not impact production in this project. On both coasts, site location was an important factor in determining the quality of oysters produced, specifically the degree of fouling.

Economic feasibility of treatments was assessed using return on investment tools developed for the OysterGro™ system. The coating, however, did not perform early on in the experiment across all states. The majority of the coating had sloughed off of the bags and pontoons in the first month. The economic analysis, therefore examines only the impact of each air drying routine on net profit. A separate model was developed for each state based on the biological results of the study. Based on the results of this study, the most economical approach to managing OysterGro™ cages while maintaining a high quality product is increase the frequency of flipping in the warmer months of the year when fouling organisms are more prevalent. Air drying represents the most cost-effective, proactive way to improve oyster quality.

The results of this project represent an experiment conducted at one site in each state. Each state and, indeed, each waterbody can have its own characteristics and differences in fouling. Site location dictates several factors affecting the quality of the oyster produced there including temperature, salinity, meat quality, wave and current exposure, etc. All of these factors can influence the type and degree of biofouling a grower will need to manage. The information presented here is a reflection of our experience with this experiment and it should not be

assumed the experience will be the same at every site. It does, however, aid the thought process on factors to consider when employing an air drying routine to control biofouling in the Southern United States.

Extension specialists were responsible for disseminating project results to industry members within their state and producing outreach materials. This included production of two videos which are posted on the OysterSouth YouTube channel. Both videos were captioned as well. Project results were presented at regional, national and international meetings and disseminated to local growers via meetings, workshops and newsletters.

INTRODUCTION

Over the past several decades, many southern US states have made efforts to restore their eastern oyster (*Crassostrea virginica*) industries. For example, notable recoveries in the south are occurring in North Carolina and South Carolina; in 2017 North Carolina reported a harvest value of \$5.6 million, which is more than double that of 2012 (NCDMF 2018).

South Carolina has also embraced growth in oyster mariculture, with the South Carolina Sea Grant Consortium extension efforts contributing to 14 oyster farming businesses in 2018, making an estimated \$2.3 million economic impact (Sea Grant, 2018). Georgia, which holds the record for highest US wild landings in the early 1900s, opened its first shellfish hatchery in 2015, allowing the state to access similar technological advances used in other areas of the Southeastern US (Harris 1980). On the Gulf of Mexico (GOM) coast there over 100 oyster farms using off-bottom methods today compared to zero in 2009. The reported harvest value from those GOM farms is estimated to be at least \$3.5 million. The Gulf also boasts research and private hatcheries to support the industry. In addition to farms, both the GOM coast and the Atlantic coast have become home to at least four gear distributors in the past five years. Of note is that Mississippi, Texas, and Georgia are all working on developing an off-bottom oyster farming industry through training programs and/or legislative action. These efforts could significantly increase production in the region.

Advancement of the oyster farming industry in the Southern US can be largely attributed to a reemerging demand for high quality single oysters served on the half-shell. While wild reef oysters or oysters grown using extensive bottom culture methods tend to grow in a variety of shapes and vary in quality, ideal single oysters grown using off-bottom methods have a deeper and wider shape and more consistent quality (Brake et al. 2003). This more marketable shape can occur with controlled reproduction and early management. By spawning high volumes of oyster larvae and allowing them to settle on microcultch (ground oyster shell) in a controlled environment, spat develop individually rather than clumped (Callam and Supan 2018). This culture method reduces the amount of labor needed later to produce a single oyster and creates optimal conditions for desirable shell shape growth. These advancements and increased consumer demand have led to the development of oyster hatcheries specializing in single set oysters. Controlled reproduction of oysters in hatcheries also allows for the manipulation of ploidy, most commonly through the spawning of triploid oysters, which has been used to improve growth in cultured oysters (Stanley et al. 1981; Allen and Downing 1986; Guo et al. 1996; Harding 2007). Triploid oysters have three sets of chromosomes and are effectively sterile, meaning energy used for spawning and gametic development is redirected for somatic tissue growth as evident in higher glycogen content in triploids during spawning season (Allen and Downing 1986; Barber and Mann 1991; Matthiessen and Davis 1992; Dégremont et al. 2012). Manipulation of ploidy hosts a wide range of advantages in the proper environment

regardless of gear type (Walton et al. 2013). One advantage is an increased growth rate, which means these oysters tend to reach market size faster than diploids, reducing the amount of time needed for farmers to profit from their efforts and the time culture operations are at risk from dangerous storms or other environmental stressors (Harding 2007; Stone et al. 2013; Walton et al. 2013; Callam et al. 2016). Increased growth is most often reflected in increased wet tissue weight, implying higher meat yields and an overall higher body condition (Stone et al. 2013; Callam et al. 2016). However, growth rate can vary depending on multiple environmental and management practices. Use of rigorous husbandry techniques, such as using a shellfish tumbler, can increase growth performance of diploids to match that of triploids (Stone et al. 2013). Furthermore, triploid growth rate advantages are minimal in low salinity areas and survival rates of triploids can be reduced to that of diploid strains when oysters become buried in sediment, restricting their ability to filter feed and respire (Colden and Lipcius 2015; Callam et al. 2016).

Proper grow-out gear and culture techniques are crucial for growing the highest quality oysters. Bottom-cages, despite common use, have disadvantages related to both mortality and growth rate. Use of this method increases the likelihood that oysters will experience issues like parasitism and predation (Moroney and Walker 1999). Furthermore, in areas with high sediment deposition rates, oysters in bottom cages are exposed to the problem of sediment burial as described above (Moroney and Walker 1999; Colden and Lipcius 2015; Comeau et al. 2017). These effects are especially apparent in instances where the larger left valve is buried and during quiescent stages experienced by oysters in lower-temperature areas, when oysters narrowly open their valves to flush out waste (Comeau et al. 2017). Use of bottom cages or table structures can also drastically increase sediment deposition, increasing the impact on surrounding benthic habitat and overall environmental footprint (Mallet et al. 2006). Oyster farmers are gravitating towards suspended cage culture methods as more research emerges supporting claims of rapid growth and reduced mortality attributed to the benefits of suspension in plankton-rich surface waters (Adams et al. 1991; Moroney and Walker 1999; Manley et al. 2009; Walton et al. 2013; Thomas et al. 2019). These cages also make oysters more accessible to growers, decreasing the amount of time and energy spent on maintenance such as biofouling mitigation (Williamson et al. 2015). However, suspended oysters may be more prone to biofouling, an issue that can negatively affect growth, condition, and survival.

Suitable shellfish aquaculture conditions are congruent with many other invertebrate species and the benefits bivalves gain from being suspended in plankton-rich surface waters are mirrored by many other invertebrates, increasing the potential for biofouling (Carman et al. 2010). Biofouling is the settlement of unwanted organisms on culture gear or the oysters themselves and is caused by an initial settlement of dissolved organic material that allows for colonization of bacteria and algae (Callow and Callow 2002). In terms of shellfish culture specifically, fouling results in unwanted invertebrate communities forming on gear and the cultured oysters themselves, and can cost oyster industries up to \$300 million in damages or approximately 5-10% of production costs (Willemsen 2005; Fitridge et al. 2012). Fouling organisms can cause physical damage to gear, interfere with the mechanical function of bivalve shells, and compete with cultured bivalves for resources such as food and oxygen (Fitridge et al. 2012). Higher incidences of fouling can be associated with decreased shell height and dry tissue mass that may negate growth advantages of longer feeding times (Bishop and Peterson 2006). Biofouling can also weigh down suspended culture gear, putting it at risk for sinking or loss, particularly during storms (Sala and Lucchetti 2008; Fitridge et al. 2012). Biofouling mitigation is an important part of culturing high-quality oysters, as it may reduce both the negative biological and economical effects of high fouling occurrences. Biofouling accumulation

may be mitigated by use of proper drying regimes and fouling-release agents (Callow and Callow 2002; Mallet et al. 2009). However, mitigation is used to control invertebrates including other oysters, meaning certain methods may affect cultured oyster growth, shape and quality.

A variety of culture techniques have been used to reduce the attachment of fouling organisms while maximizing caged oyster growth and each technique has advantages and disadvantages. A commonly used practice to reduce biofouling is aerial drying for 24 hours. Aerial drying is used with suspended oyster gear and creates an artificial extended low tide. Cultured oyster seed can survive drying mitigation methods while other organisms get stressed and die off, reducing fouling accumulation when this is performed even once during a drying season (Mallet et al., 2009). However, this method is not effective for reducing fouling by wild oysters and barnacles unless done during initial wild settlement (Adams et al., 1991). Aerial drying may also have negative effects on cultured oysters in terms of growth, shell shape, and mortality if not performed properly. For example, drying too frequently decreases the amount of time oysters can feed and could thereby reducing growth rates, especially in colder months when biofouling isn't as prevalent (Bishop and Peterson, 2006).

Chemical options for biofouling control have also been assessed. Copper oxide based biocidal coatings are widely used in aquaculture, but this has resulted in elevated levels of copper in water and sediment surrounding the culture site (Willemsen, 2005). For this reason, the use of fouling-release coatings is increasing in popularity because they are available in peroxide-based, biodegradable formulas. Netminder®, a water-based silicone barrier coating, has been applied and assessed on lantern nets in scallop culture. The fouling-release coating has been suggested to reduce fouling on culture gear, but may increase fouling on bivalves themselves as a result of organisms bypassing hard cage substrates (Tettelbach et al., 2014).

The objective of this project was to gain a better understanding of the efficacy of aerial drying and fouling-release coating treatment methods on oyster growth and quality in seven southern US states (Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, North Carolina). We aimed to determine what combination of factors affected oyster growth, shell shape, weight, and condition throughout seasonal growth periods. These findings can allow us to evaluate the economic effect of each methodology on production cost. In combination with subsequent extension work, the findings can also be used to enhance oyster grower knowledge and improve methodologies for producing high quality oysters in multiple regions of the southern United States.

EXPERIMENTAL DESIGN

OysterGro® Pro floating cages and Intermas™ Bags were acquired from BBI Group (Bouctouche, New Brunswick, Canada) via their authorized dealers in South Carolina (Lady's Island Oyster Inc.) and Alabama (Double D Oyster Company) (Fig. 1). Twelve cages were managed at each site (one site per state). The cages were 1.52 m long, 0.91 m wide, and 0.15 m deep and each held 6 grow-out bags. A total of 72 Intermas™ (14 mm) grow-out bags were used per site (Table 1). Half of the bags for each cage were treated with the fouling-release coating Netminder® (Gladwyne, Pennsylvania, U.S). The coating was applied using paint rollers with the assistance of a company representative in August 2017. Bag coating treatments were considered coated (with Netminder®) or uncoated (no Netminder®). All 12 cages per site were anchored on a single line (Fig. 2), with the exception of Louisiana where they were deployed in two tandem lines, and secured using anchors and rigging appropriate to the location. Cages were approximately 1.8 meters apart and the total length of the line was approximately 38

meters. Bags were stocked with 150, 25mm triploid oyster seed produced at the LSU Oyster Research Laboratory (Gulf Coast states) and Lady's Island Oyster Inc. (Atlantic Coast states) with a total of 10,800 seed deployed at each site (Table 1). Oysters for both coasts were spawned within one week of each other and achieved the start size by September 2017.

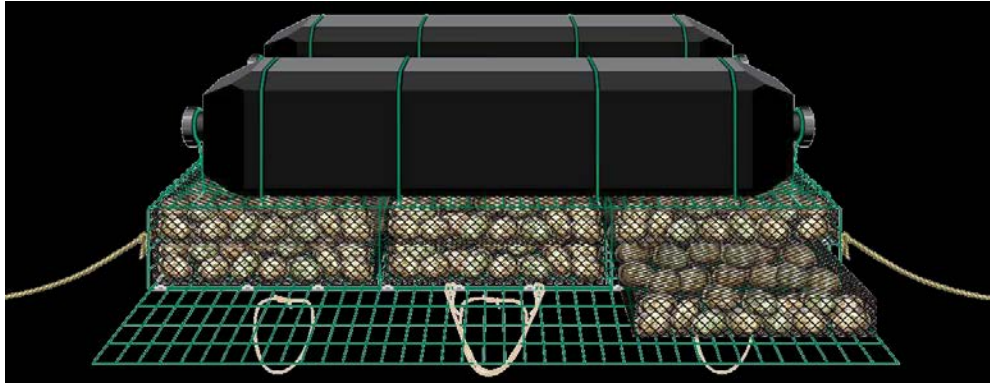


Figure 1. The OysterGro™ floating cage. Each cage consists of an outer housing made of 12-gauge vinyl-coated wire mesh which houses six Intermas™ bags. Each cage measures 60" long, 36" wide, and 6" deep. Source: www.oystergro.com

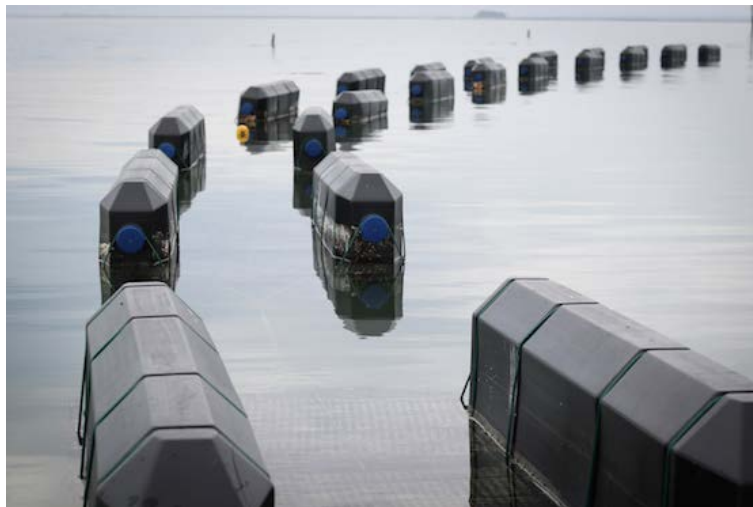


Figure 2. Cages deployed in Georgia

Cages were deployed at seven sites total; three on the Atlantic Coast in mid-October 2017 and four on the Gulf Coast in late September 2017 (Fig. 4 & 5, respectively). Deployment was delayed slightly on the Atlantic Coast to allow a tropical weather system to pass. The three drying treatments were weekly (once every week), biweekly (once every two weeks), or triweekly (once every three weeks). Aerial drying was accomplished by flipping the cage over onto its pontoons (Fig. 6). Biweekly drying was considered the control treatment, as most of the growers we collaborated with implemented this regime. Drying treatments were assigned to the first six cages on the anchor line with the pattern two cages weekly, two cages biweekly, and two cages triweekly and this pattern was repeated for the remaining six cages. This non-random pattern was required to make cage management easier for growers, who were managing multiple commercial cages as well as our research cages for the full growth period. Following a Latin Squares Design, three randomly selected bags of each coating treatment were placed

within each cage to account for error associated with bag placement. Bag orientations within the cages were not changed throughout the experiment.

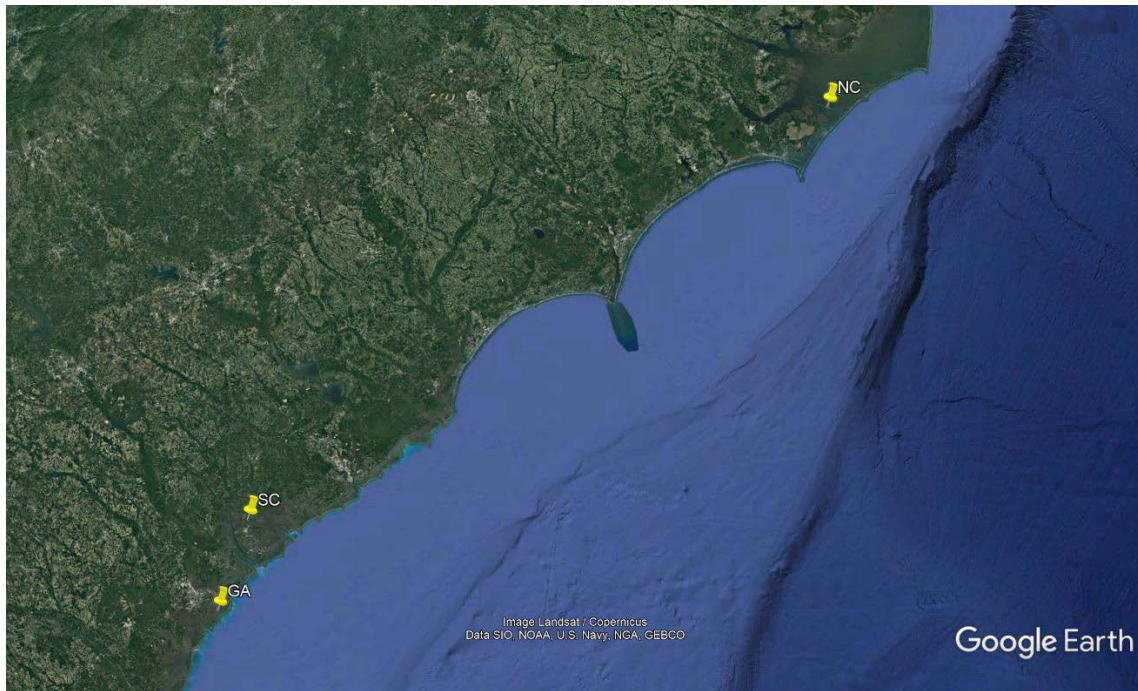


Figure 3. Atlantic Coast study sites including Halfmoon River, GA; Coosaw River, SC; and Cedar Island, NC.



Figure 4. Gulf Coast study sites including Cedar Key, FL; Navy Cove, AL; Biloxi, MS; and Grand Isle, LA.

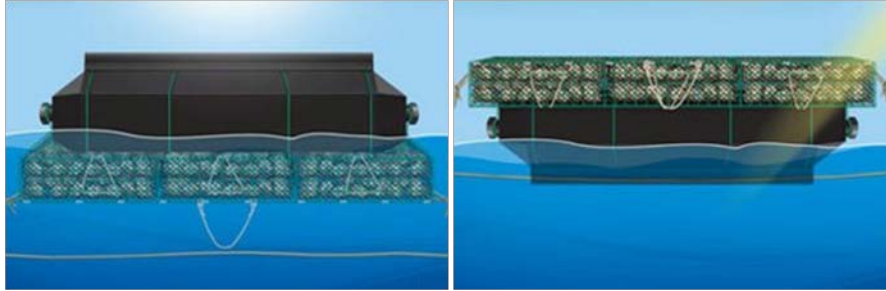


Figure 6. Growing position (left) and drying position (right) of the cage. Source: oystergro.com

Table 1. Experimental design to determine effective biofouling control methods for floating cages in the southern United States.

Treatment	Aerial Drying Frequency	# of Cages	# Cages with Pontoons Coated	# of Bags	Bags Coated	Bags Not Coated	# Oysters /Bag	Total # of Oysters
1	Weekly	4	2	12	6	6	150	1,800
2			2	12	6	6	150	1,800
3	Bi-Weekly	4	2	12	6	6	150	1,800
4			2	12	6	6	150	1,800
5	Tri-Weekly	4	2	12	6	6	150	1,800
6			2	12	6	6	150	1,800
TOTALS		12		72	36	36		10,800

Quarterly shell metrics

Oyster growth was monitored at each site during quarterly sampling trips, which occurred in December of 2017, and March, June, and October of 2018. All three sites were sampled within a two-week period for each quarter. During December and March sampling, a subsample of 10 oysters per bag were haphazardly selected and shell metrics (SH, SL, SW) were measured with the methods described in Galtsoff (1964). These measurements allowed for calculation of cup (SW:SH) and fan (SL:SH) ratios, which are indicators of oyster quality. Oysters were returned to their bags and cages after measurement. During June sampling, 25 oysters were randomly selected from each bag and 10 randomly selected oysters from those 25 were frozen and retained for determination of condition. Shell metrics were measured later during condition procedures and before shucking. Mortalities were counted and retained for later measurement.

All GA oyster bags remained stocked in their cages until October sampling while SC oysters were reduced to one bag of original oysters per cage, removing the bag coating treatment. Oyster measurements and condition analyses were available from all bags at each site in December, March, and June (n = 72). Like June, October sampling consisted of harvesting and freezing oysters. Four GA bags were lost during Hurricane Michael prior to sampling, reducing the number of bags to 68. In GA, 5 oysters per bag were processed (n = 68 bags) and in SC we processed 10 per bag (n = 12 bags). Again, shell metrics were measured later during condition determination and before shucking. NC oysters were lost during Hurricane Florence and were not sampled for October. All oysters were kept frozen for a minimum of 1 week before condition analysis began.

Condition

All June oyster weights were measured to the nearest 0.01 g. Frozen oysters were cleaned with running cold water and a wire brush, dried with a paper towel, and weighed to obtain wet weight (WW). Oysters that gaped before or after cleaning were noted and removed from wet weight, wet tissue weight, and condition analyses. Oysters were measured for shell metrics after cleaning and before being shucked. Each oyster was assigned a plastic weigh boat and a standardized 0.9 g aluminum tin. Soft tissue was removed from shells with a shucking knife and placed in its assigned aluminum tin. The inside of both valves was scraped with a stainless-steel razor to remove any remaining soft tissues, which was added to its respective tin. Soft tissues and tins were weighed, and the tin weight subtracted to determine wet tissue weight (WT). Both valves were patted dry with a paper towel to remove excess liquid before being placed exterior side down in its assigned plastic weight boat. Valves were weighed to determine wet shell weight (WS). Scales were tared with plastic weigh boats prior to placement of the shells and no subtraction of plastic boat weights was needed. Tins with wet tissues were placed on aluminum trays and dried for 48 ± 1 hours at 80°C . Shells were air-dried for 48 hours in accordance to condition index procedures (Abbe and Albright 2003). When removed from the oven, tins and dried soft tissues were left to cool at room temperature for ~5 minutes. Soft tissues were weighed with their tins and the tin weight subtracted from the total weight to determine dry tissue weight (DT). Shells were transferred to an already tared plastic weigh boat, ensuring all pieces of broken valves were transferred as well, and weighed to determine dry shell weight (DS). Scales were tared between each measurement for quality control. Condition index (CI) was calculated according to Abbe and Albright's (2003) formula below:

$$[(\text{DT}) / (\text{WW} - \text{DS})] * 100$$

Growth and mortality

Oyster growth was monitored using the shell height (SH) data recorded during each quarterly sampling trip by subtracting mean SH values for each bag from the previous value for the same bag. Mortality was monitored during June and October sampling. Oysters found gaped or with separated valves were considered dead and were bagged to bring back for further investigation. Only left valves of collected mortalities were counted and SH measured to avoid double counts. These counts allowed us to estimate occurrences of mortality events. Mortalities with SH < 40 mm were used to determine survival rates that exclude initial die offs that occurred before deployment. June mortalities were summed and subtracted from the mean stocking number to determine survival, divided by the mean stocking number, and multiplied by 100 to determine survival percentage per bag. Small (<40 mm) mortalities were also summed, subtracted from total mortalities, divided by the mean stocking number, and multiplied by 100 to determine total grow-out survival percentages per bag. Both survival percentages per bag were used to determine survival rates with and without initial die-offs. Mean survival rates for each drying treatment and bag x drying treatment were calculated by taking the mean survival rates per bag for each treatment. October mortalities were added to mortalities of their corresponding bags and the previously described methods repeated to calculate October survival rates.

Bag fouling

Sampling periods occurred in December of 2017, and March, June, and October of 2018. Fouling accumulation was monitored at each site through photographic documentation of bags during each sampling period. Bags within and across all locations were photographed within a two-week period. During each sampling period, the side of each Intermas bag was

photographed and a 16 cm ruler was included for scale. Each photograph was visually analyzed to quantify fouling as follows: three consecutive rows of five Intermas mesh holes, or a surface area of ~40 cm², were assigned percent coverage values for a total of 15 observations per picture. If there was no fouling obstruction of the hole, it was assigned a value of zero (0%) and if it was completely obstructed, it was assigned a value of one (100%). Intermediate values were estimated to the nearest 0.1 (10%). If the mesh was entirely obstructed by fouling and mesh holes could not be identified, the bag was automatically assigned a value of one (100%). Percent fouling coverage for each bag was determined by taking the mean obstruction value of all 15 observations. At the end of the experimental growth period, all remaining bags were emptied and weighed immediately using a fish scale to determine the overall wet weight of bag fouling and bag sides were photographed again. All bags were constructed using the same specifications, were randomly distributed between coating treatments, and no coating remained on the bags by October, allowing us to compare fouling without subtracting original bag weights.

Oyster fouling

During June sampling, 10 randomly selected oysters from each bag in each state were harvested and frozen for later determination of fouling intensity. For the Atlantic states where fouling monitoring continued until October, oysters were harvested and frozen, but in GA, 5 oysters per bag (n = 68) were processed and 10 oysters per bag (n = 12) were processed in SC and weighed to the nearest 0.01 g. Frozen oysters were rinsed gently with cold running water to remove excess sediment without removing loosely attached fouling, and then patted dry with a paper towel. Oysters were weighed to determine fouled wet weight (FWW). Hard fouling was scraped off and weighed to determine hard fouling weight (HFW). Soft fouling was then removed using running cold water and a wire brush over a sieve to catch any remaining hard fouling or new growth that broke off. Oysters were dried with a paper towel and weighed to obtain clean wet weight (CWW). Additional hard fouling that came off during the cleaning process was weighed and added to HFW and new growth was added to CWW. Oysters that gaped before or after cleaning were noted and removed from all analysis that required CWW. HFW and CWW were subtracted from FWW to determine soft fouling weight (SFW). All fouling weights were divided by CFW to determine total, hard, and soft fouling ratios. Common fouling organisms were also identified. Spat, barnacle, ascidian (*Mogula* sp.), mussel, and bryozoan (*Membranipora* sp.) presence was recorded as present (1) and absent (0).

DATA ANALYSIS

Data were organized using Excel®2016. Bags within cages represented our experimental units as these bags were the lowest level of randomly assigned treatment and each oyster sampled was considered a subsample. Therefore, mean oyster measurements, growth rates, weights, and CI were calculated per bag. Comparisons were made within states with data analyzed quarterly to determine seasonal effects of treatments. No comparisons were made among states because of site variation. Each region in the study (GOM and Atlantic) used different statistical analysis methodology. Please reference Kirk (2019) and Chapman (2019) Master of Science theses for a complete description (Appendix A and B; respectively).

RESULTS AND DISCUSSION

Atlantic Coast

Efficacy of aerial drying and fouling-release coating treatment methods on oyster growth metrics varied by state; however, some consistent trends were evident. Higher drying frequencies seemed to have a negative relationship with SH during earlier growth periods. For example, December, March, and June had lower SH in weekly drying treatments in GA. Weekly drying oysters also grew at slower rates in December. In SC, triweekly drying oysters had higher SH and faster growth rates in March. Weekly drying SH was also lower than biweekly and triweekly drying in NC in March. With all state's data combined, SH was consistently lower in weekly drying treatments across all sampling periods. This may be attributed to oysters having short feeding times due to more frequent drying, as oysters with longer feeding times may show faster growth in colder months when fouling isn't as prevalent (Bishop and Peterson 2006). However, it appears that growth in weekly drying treatments were redirected towards other metrics. GA, SC, and NC weekly drying oysters had higher cup ratios in June with SC weekly drying also having higher fan ratios. Higher cup and fan ratios may mean that the differences could be caused by additional handling, which can break off new growth and encourage shell thickening (Stone et al. 2013). These higher cup ratios may not be a negative result as some growers find that high cup ratios imply high oyster quality (Brake et al. 2003). It is likely that the collisions among oysters within the bags and the additional tumbling from weekly bag flipping may have chipped oysters more frequently, ultimately influencing shell shape to be more desirable, which is congruent with other work evaluating suspended oysters (Manley et al. 2009; Mallet et al. 2013; Thomas et al. 2019).

Shell metric trends appeared to change as oysters continued to grow beyond the desirable harvest size of 76 mm. While GA biweekly and triweekly drying oysters trended to have higher SH in October, the differences among drying treatments were not evident after October. GA oysters also showed no difference among drying treatments when looking at cup and fan ratio. This may be because intense fouling caused cages to flip back over, altering drying frequencies and increasing fouling. The GA site was also adjacent to the sound, so wave action was likely greater due to direct energy input from the ocean. SC oyster shell metric trends also changed in October and SH no longer varied by drying treatment. However, October SC cup and fan ratios in biweekly and triweekly drying treatments were significantly higher than weekly drying ratios, which was a more drastic change than in GA. SC ratio trends may have been more noticeable because cage weight was reduced when many bags were restocked, meaning cages did not flip back over during drying treatments. Changes in cup and fan ratio trends may be a result of increased fouling presence or simply a change in morphological growth of oysters at a certain size.

Bag coating treatment had little effect on shell metrics, especially towards the end of the growth period. However, coated bags had a negative relationship with SH early in the first quarterly period. In GA, oysters grown in uncoated bags had higher SH in December and greater growth in December and March. Uncoated bag SH and growth was higher in SC in March as well. Coating treatments also seemed to affect cup and fan ratios, albeit in different ways depending on the location. SC fan ratios in uncoated bags were higher in December, but NC fan ratios in uncoated bags were lower. These effects may be influenced by sloughing of the coating, which occurred within the first 6 months and may have made the coating available for consumption by the cultured oysters. However, this result contrasts observations of coating effects on SH of other bivalves (Tettelbach et al. 2014). Without histological evidence and more extensive

research, we cannot conclude that the coating had a direct negative effect on shell metrics. Uncoated bags also had higher SH in GA in October, long after the coating disappeared.

Also, differences between bag coatings were not evident when all states' data were combined, as differences were minor or non-existent for shell metrics among all sampling periods. This leads us to believe that there may be another factor influencing differences among bags. Treatment effects on oyster quality varied among states, but there were identifiable similarities. Bag coating had no effect on any condition parameter among any state. There were no differences among treatments for condition index (CI) in any state. However, when all states' data were combined, weekly drying oysters had higher CI. While CI is important, most growers tend to prefer oysters with higher wet weight (WW) and wet tissue weight (WT) as this is what consumers can observe. All states and combined data demonstrated a negative relationship between high drying frequency and WW in June, with biweekly and triweekly drying providing greater weights than weekly drying. However, this effect disappeared by October, with no difference among treatments in GA and SC. WT was also affected by drying treatments, with SC, NC, and combined data demonstrating higher weights for biweekly and triweekly drying treatments in June. While GA had no differences among drying treatments or bag coatings for WT in June or October, biweekly and triweekly drying oysters had higher WW in June. SC oysters had higher WT and WW for biweekly and triweekly drying oysters in June, but those differences disappeared by October. High WW and WT may increase the marketability of an oyster. These observations suggest that reducing drying regimes may provide benefits early on, but not later in summer months when fouling is more prevalent. For a more complete assessment of drying treatments, effects of fouling should be considered as well. In summary, initial differences in growth parameters among treatments were apparent early but subsided by the time oysters reached harvest size across all states. There were no interactions between drying and bag coating treatments, indicating one does not influence the effects of the other. Bag coating treatments had minimal effect on oyster growth and condition towards the end of the grow-out period while drying treatment effects were more substantial.

Overall, biweekly and triweekly drying treatment oysters grown in uncoated bags had slightly better performance than weekly drying or coated bag oysters. By limiting handling of oysters, decreasing numbers of trips for management, and avoiding additional costs of a fouling-release coating, growers may be able to see higher economic returns upon harvest by employing biweekly or triweekly. In contrast, increased handling may result in shell thickening and higher cup ratios, increasing oyster aesthetics and marketability (Brake et al. 2003; Manley et al. 2009; Mallet et al. 2013; Stone et al. 2013; Thomas et al. 2019). As all treatments and sites produced high survival, the tradeoff between fast growth and oyster shell metrics is ultimately up to the grower. Each state showed varying performance that can be attributed to a site effect, which can significantly alter culture success, demonstrating the importance of determination of management techniques based on location and other environmental parameters (Mallet et al. 2009). To determine whether the methods tested in the present study would make an economic difference for growers, effects of the treatments on fouling must be evaluated as well. However, this study provides critical preliminary information for floating oyster cage management options that could improve oyster culture in the southeastern (US) Atlantic states.

Fouling on oysters appeared to be unaffected by both drying regimes and bag coatings. This was unexpected, as tidal aerial exposure has been shown to decrease fouling coverage on oysters (Bishop and Peterson, 2006). Increased fouling on cultured shellfish within bags coated with fouling-release agents has also been observed, as organisms settle on the next hard uncoated substrate they encounter (Sievers et al., 2017; Tettelbach et al., 2014). While there were small but significant differences among drying treatments in hard fouling ratios for SC and

NC oysters in June, there were no differences among any treatments for total or soft fouling ratios among any states in June or October.

Biofouling accumulation trends varied among sampling seasons. Overall, there seemed to be a negative relationship between drying frequency and fouling accumulation in December. Triweekly drying treatments had the highest fouling percent coverage in SC and weekly drying bags had significantly lower percent fouling coverage for GA, NC, and combined data. In contrast, biweekly drying in GA had higher fouling coverage compared to weekly and triweekly bags. However, fouling coverage in all drying treatments in December was low (<20%) and oysters were not yet at harvest size. The negative trend between drying frequency was not as evident in March. While SC and combined data showed that triweekly bags had higher percent coverage, GA and NC showed no difference.

Although trends differed over time and across states, bag coating treatments seemed to have little to no effect throughout. All evidence suggests that there may be a benefit to drying oysters more frequently as it may decrease fouling. However, the lack of significant differences among all treatments for bag weight shows that both drying frequency and coating have little effect on fouling accumulation after a summer season. Most oysters reached harvest size in June before peak summer fouling, when growers would have the opportunity to clean gear before restocking. While GA still showed a clear negative trend between drying frequency and fouling accumulation (weekly drying oysters had lower fouling coverage than biweekly and triweekly drying had the highest coverage) it was the only state that was not at harvest size by June. In direct contrast to December trends, NC had higher coverage in weekly drying treatments, although fouling was still below 20% coverage in June. There was no distinction among drying treatments in SC in June, although assessments may not be accurate because most bags had mud clogging the mesh, making it hard to distinguish between fouling accumulation and sediment caking. There were also no significant differences among treatments with all states' data combined, although triweekly coverage was slightly higher. In October, GA and SC bags showed different results. While GA bags showed no differences among drying treatments, SC bags showed that the negative relationship between drying frequency and fouling accumulation may still be evident, as weekly drying showed lower fouling coverage than triweekly drying.

Presence of fouling organisms followed different trends compared to the other fouling quantifying metrics. GA had the highest fouling occurrence in June, and wild oyster spat was the most frequently present. This is not unexpected, as oysters grown off-bottom in GA are known to have higher occurrence of spat fouling (Adams et al., 1991; Moroney and Walker, 1999; O'Beirn et al., 1996). However, some October trends went against our previous observations of a negative correlation between drying frequency and fouling occurrence. While bryozoans occurred more frequently in triweekly treatments in October, both wild spat and barnacles occurred more frequently in biweekly treatments compared to weekly and triweekly treatments. Also, ascidians showed higher occurrences in weekly treatments in October while mussel occurrence did not seem to be influenced by any treatment. SC fouling occurrence was more dominated by ascidians than other organisms in June, which is likely explained by the ascidians' nature towards settling on available substrate and a lack of hard fouling (Carman et al., 2010). However, there were no differences among any treatments in ascidian occurrence. Barnacles were the only organism that appeared to be affected by treatment in SC, with biweekly and weekly drying oysters showing lower occurrences than triweekly drying oysters. October fouling occurrences in SC shifted towards higher barnacle and spat presence, but there were no differences among any treatment for any fouling type. NC oysters, which had the highest barnacle occurrence compared to any other fouling type, showed no difference among

treatments for spat, barnacles, grapes, or mussels. However, bryozoan occurrence was lower in the weekly drying treatment compared to biweekly and triweekly drying, implying it may have been influenced by drying frequency. With all states data combined, there were no differences among any treatments for presence except for bryozoans, which occurred less frequently in the weekly drying treatment. While this difference is notable, bryozoans aren't typically considered a problem fouling organism and focus should remain on the results of little to no differences among any treatment for spat, barnacle, ascidian, and mussel occurrences.

While our findings suggest that aerial drying frequency and bag coating treatments provide little difference among fouling coverage, ratios, and occurrences, there are many factors that could have altered our findings. Differences in October bag coverage trends and the lack of difference among bag weights in GA and SC may be explained by the overall success of the flipping regimes. With SC having reduced stocks, drying regimes continued without any issue while GA oysters grew heavier than the cages could handle, causing them to flip back over before the full 24-hour drying time was complete, thus decreasing the efficacy of the drying regimes. While fouling ratios may have showed little to no treatment effects, the length of time between sampling season may have resulted in us overlooking differences. By the October sampling period, GA oysters were so significantly fouled that stocked bags were full, and oysters needed to be broken apart in the bags prior to harvest. Freezing oysters prior to fouling analysis may have also affected our results. Ascidians either fell off the oysters as they were removed or lost water while traveling back to the freezers, decreasing both their mass and occurrence. If fouling was assessed biweekly or monthly and with live organisms, differing trends may have been easier to identify.

Gulf Coast States

Size

Increasing flipping frequency restricted oyster growth rates. Weekly aerial exposure resulted in lower shell length, whole wet weight and volume at all four sites. At final harvest, oysters at every site were of a harvestable size, on average, except for weekly flipped oysters in Alabama and Mississippi. Biweekly and triweekly flipped oysters at these sites were harvestable size. There are multiple mechanisms that could possibly result in reduced growth. First, weekly flipping will limit the exposure time that the livestock were suspended in the water, feeding. Triweekly flipped oysters had two more days out of every twenty-one where they continued to feed and grow while weekly and biweekly flipped oysters were subjected to aerial exposure. The second mechanism that could possibly result in restricted growth is an increase in stressor events. Bodenstein (2019) demonstrated that aerial exposure can increase the likelihood of mortality. Only at one site (Florida) did antifouling coatings appear to impact the size of oysters at final harvest. Shell lengths of oysters grown in bags with antifouling coatings at the Florida site were one mm less than those of oysters grown in bags without antifouling coatings. Additionally, the whole wet weight of oysters grown in pontoons with antifouling coatings was, on average, five grams less than the whole wet weight of oysters grown in pontoons without antifouling coatings. These differences were statistically significant but to the grower, it would be very difficult to make statements regarding the size of the oysters at final harvest based upon the presence of a coating, especially when results from the other sites in the project strongly suggest that these coatings did not impact size.

Shape

Larger fan and cup ratios can relate to improved shell and growing conditions. Also, these larger ratios are known to relate to an increase in meat tissue, especially increased cup ratios. Deeper cups are known for yielding “meatier” oysters. Increasing aerial exposure (weekly flipping) consistently increased the fan and cup ratios at every site. Fan ratios were significantly different among treatments only at the AL site where there were no differences in cup ratio. Cup ratios were significantly different at the LA, FL and MS sites in regards to flipping regimes. Increasing the fan and cup ratios could increase the overall value of the oyster livestock themselves. Along with stress, another effect of aerial exposure is the consistent tumbling action caused by localized wave action. Tumbling is another form of stress (Bodenstein, 2019) that is designed to “clean” and “defoul” oysters. As oysters are left exposed in drying position, mud, sediment, and organic material will be prone to desiccation from solar exposure. Once the inside of the bags have been effectively dried and re-submerged, the dried debris will be washed away under the cage. This in turn opened pore channels that may have been clogged, allowed better hydrodynamic ventilation inside the bag, and increased the growing room of the oyster. Maintaining this regular “self-cleaning” resulted in increased space inside the bag and exposed oysters to increased “tumbling” from wave action. Increased wave-related stress resulted in the oysters increasing their overall fan and cup ratios. If “deeper cupped” or “wider shelled” oysters are considered to be a higher value crop, then weekly aerial exposure is strongly suggested as a management technique. Antifouling coatings were occasionally associated with significant influences on certain traits, but there was no set trend for fan and cup ratios. At the MS site, oysters grown in pontoons and bags with antifouling coatings had significantly smaller cup ratios than oysters grown without antifouling coatings, while, results at the AL site suggested that antifouling coatings on pontoons can slightly increase the fan ratio. These differences (statistically significant or not) are marginal and would be insufficient for a grower to deem the oysters “better” or “worse” at final harvest.

Biofouling Accumulation

Before considering the effects of flip regime and antifouling coatings, a well-considered biofouling management strategy would assess the location and environmental conditions of any site. This study had four sites in the northern Gulf of Mexico. The Grand Isle, LA site, on the northern side of Grand Isle, is closely protected by an artificial riprap structure that mitigates the majority of wave-action. The AL site in Fort Morgan, AL is exposed (particularly during the fall and winter months) to a large fetch from the north. This causes substantial tumbling and wave-related stress to livestock during these rough winds. During the spring, this site is typically exposed to freshet events as well. The MS site is located on the southern side of Deer Island, MS and is directly exposed to open fetch of the Gulf of Mexico, particularly during the spring and summer months. At final harvest, based on bag weights and percent fouling, this site had the highest levels of gear biofouling. The FL site is similarly, to the MS site, exposed to the Gulf of Mexico from the south and west. As measured by defouled weight and defouled volume, this site had the greatest biofouling accumulation on the oysters themselves. Overall results suggest that the most protected sites actually had the least amount of biofouling (AL and LA) and the most exposed sites had the greatest amount of biofouling (MS and FL). Flip regime, within this experiment, significantly affected the biofouling accumulation on both gear and livestock. The percent fouling at the AL site was so low that it was deemed “Nonestimable” by the SAS procedure because 0.00 was input repeatedly in the data. When looking at the influence of flipping regime on defouled weight and defouled volume, AL and LA exhibited no differences; however, observed differences at the FL and MS sites were considered statistically significant. Particularly in FL but also in MS, weekly flipped oysters had significantly less (>50%) defouled weight and defouled volume than biweekly or triweekly flipped oysters. Tumbling action inside of bags at these sites presumably improved fan and cup ratios, while reducing the biofouling

accumulation. By increasing spatial allocation, increasing tumbling action, and improving growing conditions, oysters at these more exposed sites seemed to “tumble-off” more biofouling with weekly flipping regimes. If flipping did not occur weekly, then biofouling accumulation was inevitable. The last measurement of biofouling accumulation was based on wet bag weights. Weekly aerial exposure resulted in lighter wet bag weights at three of the four sites (AL, FL, & MS). The LA site was exceptional in the amount of mud present. The three sites had sandy-based bottoms so sediment was less of an issue. Mud in growing bags at the LA site contributed to higher wet bag weights at final harvest. Wet bag weights at this site were not significantly different due to the high quantity of mud stuck on bags at final harvest.

Antifouling coatings only appeared to reduce biofouling accumulation at the FL site. At this site, the presence of antifouling coatings on bags significantly decreased oyster defouled weight and defouled volume. This suggests that the presence of the coating inside the bags yielded a direct effect on the surfaces of the oyster’s shells, thus resulting an overall reduction in the accumulation of biofouling. Wet bag weight at this site was significantly less with antifouling coating; almost half a kg difference. At the FL site, and only the FL site, the use of the antifouling coatings reduced the accumulation of biofouling. It is also worth noting that shell length was also significantly smaller in bags treated with coating. Pontoon coating did not impact biofouling accumulation during this study at these sites in the Gulf of Mexico.

Quality

Quality index data demonstrated, at three of the four sites, that weekly flipping resulted in lower index scores correlating to higher quality oyster meat. Weekly flipping increased meat quality. In AL, there was a linear progression of the index as flipping regime increased. In FL, weekly flipping resulted in lower scores and biweekly and triweekly flipping resulted in similar higher scores. In LA, though statistically insignificant, the meat quality was still greater in weekly oysters. Only in MS were the results less clear but the MS site had the highest quality oysters and all were comparable. Condition index results were similar to those of the quality Index. Weekly flipping resulted in significantly greater condition indices than biweekly and triweekly flipping at three of four sites (AL, FL & MS, but not LA). MS oysters, had the greatest condition index along with Auburn Index, which made them the highest quality oysters in the project. The condition index in LA was poorer and this was suspected to be because of the increase of mud and silt at this site that restricted optimal growing conditions. Aerial exposure, at the other three sites, improved growing conditions inside of bags and reduced biofouling on the oysters themselves, making growth, feeding and living conditions more optimal. Understanding that regular aerial exposure increased the quality index and condition index, it can probably be stated that weekly flipping can condition oysters into higher quality categories. Aerial exposure, as a stressor, mimics a low tide event and forces the oyster to close its shell for an extended period of time. This weekly practice increased the oyster’s durability during times of stress and actually increased the quality and quantity of the livestock. Looking at the effects of pontoon coating site-by-site, there are vast disparities. In AL, there were no significant differences based on pontoon coating but there are significant differences related to bag coating. The condition index of oysters in bags with coating was slightly lower than for oysters grown without bag coatings. In LA, the only significant difference was associated to pontoon coating which suggested that pontoon coating improved meat quality, but meat quality was relatively poor at this site compared to others. In FL, results suggest that oysters grown in pontoons with coating yielded lower quality indices. In MS, the results suggest that quality is better without pontoon coating but condition index is better with bag coating. Differences associated with antifouling coatings on bags and pontoons suggest that the antifouling coatings did not exhibit a specific trend regarding resultant oyster meat quantity and quality. Therefore, it appears, that antifouling coatings did not affect quality or quantity of oysters in this project.

Survival

Site and flip regime influenced survival over the project more than any other factor. The AL site had the lowest survival, which was attributed to a freshet event in February – March 2018, while, the LA site had the greatest survival. Flip regime also impacted survival of oysters. Triweekly flipped oysters consistently had the highest survival at all four sites. Because aerial exposure is a stressor event for oysters, it is theorized that increase in flipping frequency also increase stressor events. An increase in stress-related events can increase mortality. Antifouling coatings on bags and pontoons resulted in no significant differences in the survival of the oysters in this study. Survival was deemed unaffected by the antifouling coatings used here.

ECONOMIC ANALYSIS OF FOULING CONTROL TECHNIQUES

From October 2017-June 2018, 12 OysterGro Pro cages were deployed in each of seven states in Southern US including North Carolina (NC), South Carolina (SC), Georgia (GA), Florida (FL), Alabama (AL), Mississippi (MS) and Louisiana (LA). The cages each house 6 bags which in turn each house 150 oysters. The experiment examined three levels of air drying to control biofouling which included flipping the cage for a 24 hour period on a weekly, every other week, or every three weeks basis. There were four replicates (cages) of each air drying treatment. Netminder fouling release coating was also tested as part of the experiment. Netminder coating was applied to the bags and to the lower half of the pontoons of the cages. The coating, however, did not perform early on in the experiment across all states. The majority of the coating had sloughed off of the bags and pontoons in the first month. This analysis, therefore examines only the impact of each air drying routine on net profit.

ECONOMIC MODEL

This report is accompanied by a Microsoft Excel spreadsheet model which will assist a grower in determining the effect of employing either a weekly, every other week, or every three weeks air drying routine (Appendix C). A separate model has been developed for each state based on the biological results of the study. The following sections of this report will describe the justification behind the assumptions and explain the resultant output which is generated in the table on the right hand side of the spreadsheet once the input section on the left hand side is filled out. Once you have opened the spreadsheet choose the tab that corresponds to the state where your farm is located.

Understanding the Model's Assumptions – The input side of the sheet

Air Drying Labor and Supplies Assumptions

The flip up and flip back rate are based on one, in the water person and one person assisting by shuttling that person from one line/location to the next. Labor arrangements and how flipping is accomplished will differ based on the physical capabilities of the grower, location, water depth, etc. The rows for flipping rate and labor cost allow for two people and should accommodate any arrangement because, generally, flipping can be accomplished by a two person team. Cells B3, B4, B5, and B6 can be manipulated based on the grower's preference. Cells B7-B12 calculate automatically and should not be modified.

Farm Size and Husbandry Assumptions

All of the cells in this section can be modified based on the grower's specific farm set up or preferences. The mortality rates are expressed in a proportion, simply multiply by 100 to envision percentage. Mortality is based on what was experienced during the experiment in each state. The proportion of oysters not market ready size represents the number of oysters in the bag that will not be 76 mm (3 inches) in shell height. The 'Grow Out Time Needed' in the table on the right hand side of the sheet has been set to be able to achieve this 10% target.

Seed, Supplies, and Equipment Assumptions

All of the cells in this section can be modified based on the grower's specific farm set up or preferences. Fuel needs are based on the distance travelled to the farm site used during the experiment. We have not included the cost of a boat or other major equipment that would be part of the farm as that differs from one operation to another. In some cases, a boat may not even be necessary depending on the site.

Sale Price

Here a grower can set the minimum and maximum price he/she believe their oysters can be sold for. For the purposes of generating the model we selected two values which are current prices being achieved for the quality of oyster produced during the experiment.

Understanding the Model Output

The model output is the table located on the right hand side of the spreadsheet. The numbers contained in the output will calculate automatically based on the assumptions you enter on the left hand side of the spreadsheet. The top row of the output, labelled 'Grow Out Time Needed' reflects the time it took for the oysters in our experiment to reach 76 mm (3 inches). Also taken into consideration here is the time required for 90% of the oysters in the bag to be market ready when that bag is harvested. This is an important consideration for a grower as it reduces labor costs associated with sorting and returning sub-market sized oysters back to sea. The 'Grow Out Time Needed' reflects the time needed for the oyster to grow from 35 mm to 76 mm. It considers ONLY the final grow out stage. As a grower, you will need to add in expenses associated with the nursery stages of your farm. Some of the states involved in the experiment experienced a high degree of fouling which would require cleaning the oysters prior to sending them to market. As the authors, we made the assumption that these oysters would enter into the premium half shell market and thereby be required to be relatively devoid of biofouling. The assumption was made that this cleaning would happen by hand, a gentler process, since mechanical manipulation of the oyster immediately prior to harvest can impact shelf life. We recognize a grower may have other venues for fouled product that would not require it to be cleaned. Certainly, this row can be manipulated by the grower to reflect his/her farm/processing/marketing arrangements.

Results and Discussion

In the South Atlantic States (GA, SC, NC) the experiment started in early October with oysters in SC and NC reaching harvest size by June. Oysters in Georgia reached harvest size by August. Our endpoint for the experiment was set at when the majority of oysters in the 'every other week' flipping treatment reached 76 mm (3 inches). Across all states, the oysters flipped less than that (every three weeks) were larger and those flipped more frequently (weekly) were smaller. Reasonably, the oysters not flipped as often have more time to feed and are not jostled around by the flipping action thereby maintaining their fragile growing edge longer. The oysters contained in cages that were flipped on a weekly basis needed a bit longer to reach market size

(4 weeks) but they were slightly 'cuppier' than the other treatments, which is a desirable market characteristic.

The most profitable scenario in SC and NC was to flip every three weeks, however, the oysters reached market size in June prior to the peak of heavy fouling season. In SC, a sample of oysters was maintained in each cage and flipping treatments applied until September. By September, the oysters in cages flipped every other week and every three weeks were more fouled than those flipped every week. In Georgia, the degree of fouling was higher likely due to site selection in a high energy area prone to barnacle settlement. The degree of fouling in GA was such that the oysters would have required some cleaning prior to being sent to market. In SC, had the oysters been held through the summer, those flipped on a non-weekly basis would have required cleaning prior to harvest as well. Based on the results of the study, we recommend employing a more frequent flipping routine when larval settlement (and therefore fouling) is at its peak in your area, which is usually during the warmer months of the year.

We recommend an approach that increases the frequency of flipping in the warmer months because even though fouling can be cleaned off of the oyster it is: 1) more difficult and time consuming to clean the cage and bags and can impact life span of the gear; 2) the appearance of the oyster is marred by cleaning fouling and you may not achieve the price point you desire, and; 3) when fouling becomes heavy it will impact meat quality.

Oysters in Louisiana and Florida reached market size quicker than those in Mississippi and Alabama. In FL and LA, oysters were ready for harvest after 24-30 weeks while in MS and AL they required 32-38 weeks of grow out time. Florida experienced the highest degree of fouling which impacted profit. Although flipping every three weeks is most profitable it is important to consider product quality, impact of fouling on the longevity of the cage and associated rigging, and the fact that meat quality was poorer in those oysters which were in cages flipped only every three weeks. In Alabama, mortality was higher than in other states and did not correlate with air drying frequency but was the biggest factor impacting profit. The shortened grow-out time in FL and LA could lead to higher profits overall and help off-set the cost of a more frequent flipping routine because the crop can be turned over more frequently.

It is important to keep in mind that these models represent an experiment conducted at one site in each state. Each state and indeed each waterbody can have its own characteristics and differences in fouling. The information presented here is a reflection of our experience with this experiment and it should not be assumed the experience will be the same at every site. It does, however, aid the thought process on factors to consider when employing an air drying routine to control biofouling in the Southern United States.

OUTREACH AND ACCOMPLISHMENTS

Popoff Enterprises worked with growers and extension agents in South Carolina, Florida and Alabama to produce two videos. Growers and prospective growers are the target audience for the video entitled "Oyster Farming in the Southern United States Using the OysterGro System" (10 minute duration) which is hosted on the OysterSouth YouTube channel and to date has 1000 views since posting in February 2020. Hosted on the same channel is 'Oyster farming in the South' which is a five minute long video aimed at a consumer audience. This video has been viewed 956 times in the past five months since posting in February 2020. Additionally, the South Carolina Sea Grant Consortium had both videos captioned and can provide that option.

Results of the experiment were presented by each graduate student at the following venues:

Aquaculture America, March 7-11, 2019, New Orleans, LA

Louisiana American Fisheries Society Meeting, 2018

Oyster South Symposium (OSS), February 22-23, 2019, Orange Beach AL (170 attendees).

Economic model results also presented at OSS19. All presentations were recoded and are available on the OysterSouth You Tube channel. To date, Kirk and Chapman's have been viewed 29 and 23 times, respectively.

Georgia Chapter of the American Fisheries Society 2018 Annual Meeting, January 23-25, 2018 (120 attendees)

Georgia Chapter of the American Fisheries Society 2019 Annual Meeting, February 5-7, 2019 (120 attendees)

Two Master of Science level theses were produced and degrees awarded as a result of the project:

Shannon Kirk, University of Georgia. "Efficacy of Biofouling Mitigation Methods for Floating Cage Production of Southeastern Triploid Eastern Oysters (*Crassostrea virginica*)". Degree awarded December 2019

Ellis Chapman, Louisiana State University. "Assessment of Off-Bottom Oyster (*Crassostrea virginica*) aquaculture techniques on biofouling in the Northern Gulf of Mexico". Degree awarded December 2019.

Workshops and Publications

Publications related to SRAC project: title, type of publication and distribution

Chapman, E., Davis, J., Rider, J., Sturmer, L., Walton, W., & Supan, J. 2019. Comparing Off-Bottom Techniques of Oyster Aquaculture *Crassostrea virginica* on Biofouling in the Northern Gulf of Mexico. Program and Abstracts of the 2019 Triennial Aquaculture Meeting of the World Aquaculture Society, National Shellfisheries Association, Fish Culture Section of the American Fisheries Society, and the National Aquaculture Association: 217. ABSTRACT

Simon, N., Sturmer, L., & Markham, R. 2019. Gear Type Comparison for Off-Bottom Oyster Aquaculture in Florida, USA. Program and Abstracts of the 2019 Triennial Aquaculture Meeting of the World Aquaculture Society, National Shellfisheries Association, Fish Culture Section of the American Fisheries Society, and the National Aquaculture Association: 1013. ABSTRACT

Management Strategies for Culturing Oysters in Floating Cages. UF/IFAS Extension, *Online Resource Guide for Shellfish Aquaculture*. <http://shellfish.ifas.ufl.edu/oyster-culture-other-projects/floating-gear-comparison-for-off-bottom-oyster-culture/>. WEBSITE PAGE, 3,488,915 valid hits in 2019

Floating Gear Comparison for Off-bottom Oyster Culture. UF/IFAS Extension, *Online Resource Guide for Shellfish Aquaculture*. [http://shellfish.ifas.ufl.edu/oyster-culture-other-](http://shellfish.ifas.ufl.edu/oyster-culture-other-projects/floating-gear-comparison-for-off-bottom-oyster-culture/)

[projects/comparison-of-stocking-densities-for-floating-bag-oyster-culture/](#). WEBSITE PAGE
3,488,915 valid hits in 2019

Florida results were summarized in the following article:

<https://shellfish.ifas.ufl.edu/oyster-culture-other-projects/biofouling-control/>

Alabama and Mississippi results were distributed via the 'On the Lid' newsletter to 169 readers in May 2020.

Workshops

Workshop for Oyster Growers in Dixie County, 13 November 2018, 18 attendees

Workshops for Oyster Culture Lease Applicants in Franklin County, 5 March 2020, 60 attendees

Presentation of NC and SC results as well as a gear demonstration was done at the NC Aquaculture Development Conference in Morehead City, NC in March 2019. Estimated 100 attendees.

Presentations at professional meetings

Chapman, E., Davis, J., Rider, J., Sturmer, L., Walton, W., & Supan, J. 2019. Comparing Off-Bottom Techniques of Oyster Aquaculture *Crassostrea virginica* on Biofouling in the Northern Gulf of Mexico. Presented at Aquaculture 2019, New Orleans, Louisiana, 7-11 March.

Simon, NA., Sturmer, L., & Markham, R. 2019. Gear Type Comparison for Off-Bottom Oyster Aquaculture in Florida, USA. 24 slides. Presented at Aquaculture 2019, New Orleans, Louisiana, 7-11 March.

Aquaculture 2019 Conference, est. attendance 2000 people

Inputs	Outputs		Outcomes -- Impact		
	Activities	Participation	Short	Medium	Long
<p>Coordinated, collaborative regional research project.</p> <p>Seven research and Extension faculty/specialists.</p> <p>Two university shellfish aquaculture research facilities.</p> <p>Two off-bottom oyster farming graduate students</p> <p>Six private oyster growers.</p> <p>84 floating cages provided by OysterGro™ (12/state)</p> <p>Antifouling coatings provided by collaborator Netminder™</p> <p>Oyster seed provided by LSU and LIO, imported in accordance with each state's requirements</p> <p>Travel funds</p>	<p>Compared effects of frequency of aerial drying on biofouling on oyster cage floats, bags and oysters.</p> <p>Determined effectiveness of antifouling coatings at reducing biofouling on oyster bags and oysters.</p> <p>Evaluated oyster quality and consistency based on fouling treatments tested.</p> <p>Evaluated cost/benefits of each fouling control regime when using floating cages for off-bottom culture of oysters throughout the southern US.</p> <p>Developed recommendations on best biofouling control practices for each state when using floating cages for off-bottom culture of oysters.</p>	<p>Seven research and extension faculty at five universities and one state agency.</p> <p>Two graduate students based at two universities</p> <p>Seven commercial oyster growers.</p> <p>One gear manufacturer, two gear dealers</p> <p>One public hatchery, one private hatchery.</p>	<p>Improved knowledge of optimum frequency of aerial drying for biofouling control</p> <p>New knowledge of the effectiveness of antifouling coatings when using floating cages for oyster culture in the southern US</p> <p>Improved quality and consistency of farmed southern oysters</p> <p>Recommendations for best biofouling control practices in seven southern US states and two southern regions.</p> <p>At least two extension publications</p> <p>Two educational videos aimed at growers and consumers.</p> <p>Reduced production costs.</p>	<p>Adoption of proactive and cost effective fouling control routines by growers using floating gear throughout the southern US. At least two growers have increased their use of floating cages by 20%.</p> <p>Increased revenue for off-bottom oyster farmers.</p> <p>Foster camaraderie and collaboration among new and beginning farmers in the region via OysterSouth. (oystersouth.com). Participation in OS Symposium up over 50% from 2018-2020.</p> <p>Four permits for Oyster Gro cage farms issued in SC during project period.</p> <p>Governments in GA and TX adopted legislation to allow off-bottom oyster farming during the project period. GA demonstration site instrumental in education effort.</p>	<p>Adoption of off-bottom oyster farming throughout the region is a tool for job creation and coastal habitat improvement.</p> <p>Optimizing production increased revenues of farmers allowing for greater stability and/or business expansion.</p> <p>Number of farms growing from 0 to over 100 in ten year period in GOM. Similar trend on the Atlantic Coast.</p> <p>Gear donation allows for its continued use in improving production methods throughout the region.</p>

ACKNOWLEDGEMENTS

This study would not have been possible without the assistance, funding and support of the following: Southeast Regional Aquaculture Center (SRAC), Navy Cove Oyster Company, Southern Cross Oyster Company, Lady's Island Oyster Inc., Louisiana SeaGrant College Research Program, Mississippi-Alabama SeaGrant College Research Program, Florida SeaGrant College Research Program, BBI Group, Louisiana Oyster Research Hatchery Team, Auburn University Shellfish Laboratory at the Dauphin Island Sea Laboratory, George C. Kirkpatrick Shellfish Research Laboratory, Louisiana Department of Wildlife and Fisheries, Mississippi Department of Marine Resources, Florida Wildlife Department The UGA Marine Extension and Georgia Sea Grant provided both funding and field assistance. Special thanks to Brian Cabral, Rob Hein, Joe Harned, Jay Styron, Frank Roberts, Justin Manley, John Pelli, Bob Ratajczak, Morgan Manning, Emily Kenworthy, Victoria Cassidy, Alex Pelletier, and the 2018 MAREX summer interns.

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