12-2022

Growth and Mortality of American Oysters (Crassostrea virginica) for Several Years in the Mississippi Sound – Effects of Freshwater Influence

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Growth and Mortality of American Oysters (*Crassostrea virginica*) for Several Years in the Mississippi Sound – Effects of Freshwater Influence

by

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A Thesis
Submitted to the Honors College of
The University of Southern Mississippi
in Partial Fulfillment
of Honors Requirements

December 2022

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ABSTRACT

The American oyster, *Crassostrea virginica*, is a filter feeding bivalve native to the Gulf of Mexico, and an essential part of the Mississippi Sound estuarine ecosystem. In recent years, influx of freshwater into the Mississippi Sound as a result of frequent rainfall events has altered the water chemistry in several ways that are detrimental to the oyster populations. In this thesis, I examine the growth rate of *C. virginica* over the last five years in association with salinity fluctuations in the Mississippi Sound. Given diminishing populations and limited recruitment, researchers have facilitated citizen-scientist managed oyster gardens along the coast of the state to help restore reefs in the sound. The St. Stanislaus Marine Science Program has managed oyster gardens over the last five years, from which it has been observed that periods of low salinity, often during times of extreme freshwater discharge following severe storms, correlate with limited growth and increased mortality of gardened oysters.

Keywords: Recruitment, Hypercapnia, Spat, Oyster Gardening, Ocean Acidification

DEDICATION

To Mrs. Letha Boudreaux, who introduced me to marine biology and has supported me since day one.

ACKNOWLEDGMENTS

I would like to acknowledge Dr. Chet Rakocinski for his guidance and patience, without whom this thesis would not be complete. I would also like to acknowledge the St. Stanislaus Marine Science Program as well as the interns and marine science students from St. Stanislaus College for their participation in sampling and data collection. This thesis would not have been made possible without the support and partnership of Mississippi Department of Marine Resources, the Mississippi Alabama Sea Grant Consortium, and the Auburn University Shellfish Laboratory.

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LIST OF ABBREVIATIONS

AUSL	Auburn University Shellfish Laboratory
DO	Dissolved Oxygen
MASGC	Mississippi Alabama Sea Grant Consortium
MDMR	Mississippi Department of Marine Resources
NOAA	National Oceanic and Atmospheric Administration
SMR	Standard Metabolic Rate
SSC	Saint Stanislaus College
SSCMSP	Saint Stanislaus College Marine Science Program
USGS	United States Geological Survey

CHAPTER I: INTRODUCTION

Oyster Biology

The reproductive cycle of the oyster begins in the early spring and is triggered by a change in temperature, salinity, and/or phytoplankton abundance (*Oyster life cycle*, 2020). Peak spawning typically occurs from July to August (Hayes & Menzel, 1981) or when temperatures of 20° C to 30° C at around 10 ppt consistently occur (*Oyster life cycle*, 2020). If there is no significant change in temperature to trigger spawning, the season may begin later in September (Hayes & Menzel, 1981). Within the first two months of spawning, adult oysters release egg and sperm into the water column, where the gametes are joined and larvae are formed (*Oyster life cycle*, 2020). For the first two weeks of life, oyster larvae feed upon phytoplankton throughout the water column storing energy (*Oyster life cycle*, 2020). Around two weeks of age, larvae enter the pediveliger stage and develop a foot to attach to a hard substrate (*Oyster life cycle*, 2020). A chemical cue released from adult oysters draws larvae closer when settling to concentrate the population structure within the broader metapopulation, although some have been observed to drift for miles before settling (Morgan & Rakocinski, 2022). Upon settlement, the larva undergoes an internal metamorphosis becoming what scientists call spat (*Oyster life cycle*, 2020). The spat consume phytoplankton and form their calcium carbonate shell (*Oyster life cycle*, 2020). Oysters will be designated as juveniles after one year of life and considered an adult at three years of age (*Oyster life cycle*, 2020). Although still juveniles, young oysters can release gametes and contribute to the spawning season if salinity and temperature conditions allow for early settlement and maturity, however, juveniles will produce gametes at a lower rate than adult oysters (Hayes & Menzel, 1981).

Among the many mollusks, bivalves, and other invertebrates that play significant roles within the ecosystem; the American Oyster, *Crassostrea virginica*, acts as an "ecosystem engineer" of many reef communities (Beniash et al., 2010). These engineers offer a variety of ecosystem services, including filtering the water, facilitating nutrient removal and improving nutrient cycling (Morgan & Rakocinski, 2022). Oysters rely on their strong calcium carbonate ($CaCO_3$) shells for protection and life functions (Beniash et al., 2010). Aragonite and calcite are two minerals important to the structural integrity of molluscan shells, including that of *C. virginica* (Beniash et al., 2010). These minerals, along with $CaCO_3$ act as a buffer for stabilizing the pH (Beniash et al., 2010). The study of Beniash et al. (2010) focuses on the effects of elevated CO_2 and the formation of environmental hypercapnia, which can be caused by increases in atmospheric CO_2 and upwelling, biological activity, acidic run-off, and freshwater input. These effects include but are not limited to increased vulnerability to predation in invertebrates, reduced nutrient availability, salinity fluctuations, and ultimately decreased population sizes and survivability. For sufficient growth and development, oysters require water chemistry within specific ranges of pH, temperature, dissolved oxygen (DO), and salinity (Beniash et al., 2010).

A key biotic factor that limits recruitment of oyster populations is predation. The distribution and abundance of the American oyster is controlled by predators of various sizes and species (Newell et al., 2007). In a 2007 study in Chesapeake Bay, *C. virginica* was observed to dedicate more energy to strengthening their shell when exposed to a certain predator crab species (Newell et al., 2007). Common predators for *C. virginica* include the oyster drill in the Gulf of Mexico, as well as various mud crab species, the blue crab (*Callinectes sapidus*), and flatworm species (Newell et al., 2007). Blue crabs and mud crab species utilize claws to fracture oyster shells for feeding (Newell et al., 2007), made easier when shell composition is weakened by compromised water chemistry (Beniash et al., 2010). Flatworm species such as *Stylochus ellipticus* feed on the oyster's soft body by entering the shell through openings in the valves of the shell (Newell et al., 2007).

Salinity affects both the American oyster and its predators (Garton & Stickle, 1980). A common predator of *C. virginica* in the Gulf of Mexico is the oyster drill, *Thais haemastoma* (Garton & Stickle, 1980). *T. haemastoma* are sensitive to fluctuations in salinity and are most abundant and active at high temperatures and salinities (Garton & Stickle, 1980). Garton and Stickle (1980) determined that predation by the oyster drill does not pose a threat to oyster populations in salinities lower than 15 ppt; in estuaries at lower salinities, the oyster drills are not abundant enough to have a detrimental effect on oyster recruitment.

Freshwater Influences

Populations of *C. virginica* are native to the southeastern United States and are commonly associated with estuarine environments (Beniash et al., 2010). Oyster communities possess high productivity and biodiversity (Beniash et al., 2010). Estuarine organisms are often exposed to pollution and fluctuations in water chemistry, given their location and proximity to human development and run-off from rivers and streams. However, physiological adaptations have allowed estuarine organisms, such as the

American oyster, to survive and reproduce (Beniash et al., 2010). The increase of CO_2 in an estuarine ecosystem can result in hypercapnia which yields high mortality and a significant reduction in the viability of mollusk larvae (Beniash et al., 2010).

The mixing of freshwater with saltwater lowers the salinity, which in turn decreases $CaCO_3$ saturation (Beniash et al., 2010). Influx of freshwater also alters CO_2 levels and thus $CaCO_3$ saturation of the water chemistry (Beniash et al., 2010). The increase of CO_2 causes a shift in equilibrium that, in turn, leads to degradation of calcium carbonate with increased dissolution of living and dead oyster shells (Beniash et al., 2010). Without sufficient availability of $CaCO_3$, oyster shells are thinner, weaker, and more susceptible to fracture (Beniash et al., 2010). The analysis performed by Beniash et al. (2010) found that, in response to a weakened shell of juvenile American oysters, there is also an increase in standard metabolic rate (SMR), increasing metabolic costs. Juveniles are more vulnerable to changes in water chemistry and are not fully equipped with sufficient shell strength or learned behaviors for protection and flexibility to buffer against such changes. Beniash et al. (2010) found that the SMR doubled in juveniles, while only increasing by 15 percent in adults which were better equipped to respond.

Salinity exerts a powerful influence on oyster populations and estuarine ecosystems and can be readily influenced by rainfall patterns and consequent freshwater discharge. The average annual salinity of the Mississippi Sound ranges from 9 to 21 ppt, and the annual temperature averages from 14.5°C to 19.4°C (Morgan & Rakocinski, 2022). A decline in salinity significantly decreases growth rate, whereas high salinity historically correlates with high predation (Rakocinski et al., 2022). It is important to acknowledge trending increases in rainfall in the southeastern United States region.

Precipitation maps from NOAA show an abnormal increase in inland rainfall in 2019, a continuously increasing amount of inland rainfall in 2020, and record regional rainfall in 2021 (Rakocinski et al., 2022). Excessive rainfall combined with more severe storms in recent years have given rise to consistent threats to oyster recruitment (Rakocinski et al., 2022).

The influx of freshwater into brackish or saltwater environments lowers salinity and is often accompanied by harmful algal blooms and low bottom dissolved oxygen, as seen with the opening of the Bonnet Carre Spillway in 2018 and 2019 (Rakocinski et al., 2022). In 2019, the Bonnet Carre Spillway was opened for 43 days beginning in late February and again for 80 days in the middle of May (Morgan & Rakocinski, 2022). During this time, more than 90 percent of the oyster population in the Mississippi Sound was destroyed (Morgan & Rakocinski, 2022).

Oyster Gardening

Historically, the western Mississippi Sound held some of the most productive oyster populations in the southeastern United States, until the metapopulation was decimated by the consequences of multiple openings of the Bonnet Carre Spillway, especially in 2019 (Morgan & Rakocinski, 2022). Since the construction of the Bonnet Carre Spillway in 1931, run-off and excess freshwater have been entering the Mississippi Sound from the Mississippi River (Morgan & Rakocinski, 2022). Within the last eleven years, the spillway has been opened six times, each time diminishing *C. virginica* populations in its wake (Morgan & Rakocinski, 2022). With the substantial decrease in adult oyster populations, there is reduced output of larvae, and thus limited recruitment (Morgan & Rakocinski, 2022). To overcome this limitation, researchers need to consider the metapopulation of the American oyster as a means to recover the declining stocks (Morgan & Rakocinski, 2022).

Cultivating an oyster garden is one way that researchers and eco-minded citizens can help to restore oyster populations and reef ecosystems. Procedurally, oyster spat are set onto clean oyster shells by citizen scientists and transported to designated gardening sites (Thriffley et al., 2020). Upon being delivered to volunteer gardeners, the spat-covered shells are distributed into baskets and suspended from shoreline structures in the water column approximately one foot above the seafloor. The baskets are kept off the bottom to reduce predation by benthic organisms and fouling by sedimentation or vegetation (Thriffley et al., 2020). A weekly maintenance regime is performed to remove sediment, predators, and algal growth, and to measure spat to monitor their growth (Thriffley et al., 2020). At each visit, salinity and temperature are also recorded (Thriffley et al., 2020).

St. Stanislaus College Marine Science Program

One key oyster garden site has been established for multiple years at the St. Stanislaus College (SSC) in Bay Saint Louis Mississippi. St. Stanislaus College is a boarding school located on the coast of Bay St. Louis, Mississippi with its own pier extending out into the Mississippi Sound and the Gulf of Mexico. The oyster gardening program at SSC began in 2017 in partnership with the Mississippi Alabama Sea Grant Consortium (MASGC) and the Mississippi Department of Marine Resources (MDMR) (Greer et al., 2018).

The SSC Marine Science Program is one of nine collaborating oyster gardening entities in the state of Mississippi (Greer et al., 2018). The purpose of this collaboration is to provide a protective environment for juvenile oysters to reach maturity in a natural setting under watchful care. In doing so, the goal is to develop an approach for enhancing oyster populations in the Gulf of Mexico (Greer et al., 2018). Upon receiving spat from the MASGC, shells and spat are distributed into baskets and suspended off the SSC pier (Fig. 1). The baskets are checked periodically for predation, damage, and fouling. The length of each growing season varies; however, at the end of the season grown oysters are returned to the MASGC and MDMR and later distributed to local reefs (Weber et al., 2018).

Figure 1. SSC Students conducting oyster gardening activities.

An oyster gardening season typically begins in June and ends in November. However, in some years with inclement weather and environmental conditions, seasons were extended to give the growth and survival of gardened oysters a chance to stabilize as conditions fluctuated.

During the 2017-2018 school year, I was a junior in high school enrolled in the SSC marine science class. This was the first year that the SSC MSP began the oyster gardening program. In the class, part of our curriculum included field work and participation in oyster garden maintenance. In designated class periods, I participated in data collections and observations as further described in the Methods section. Becoming more comfortable with the equipment and being able to perform the sampling procedures independently, I wanted to stay involved in the oyster gardening program even after the course ended. The following school year, 2018-2019, I was able to serve as an intern for the SSC MSP and work closely with fellow interns, students, and representatives from MDMR. In this internship, the other interns and I served as lead monitors for the oyster gardening program and instructed students on garden maintenance and data collection. Throughout the gardening season, we organized data sheets and created a poster presentation that was presented at the 2018 Alabama Mississippi Bays and Bayous Symposium. In this poster presentation, we described our program and analyses of the season's growth data. Upon my graduation from high school, I kept in touch with the program director, Mrs. Letha Boudreaux, and have been able to work with her interns and students over the years in further developing the oyster gardening program. In maintaining my involvement with the program, I have been employed by SSC to teach marine science electives at their summer camp, educating elementary and junior high students on oyster gardens while monitoring their status between growing seasons.

Oyster Gardening Baskets

The oyster shells with live spat on them are distributed into several baskets. The exact number of shells per basket depends on the size of the shells and the number of shells available. The baskets measure 18x14x8 inches and are made of coated wire. A hook is attached to the opening end of the basket to ensure the basket stays closed when submerged. In recent years as the baskets have become more worn, zip ties have been used to provide a more secure closure. Each basket is attached to a rope that is securely fastened to the pier several feet above the water level. The baskets are suspended within the water column deep enough to be submerged but not touching the bottom.

Ecosystem Baskets

In December of 2017, the interns of the SSC Marine Science program under Mrs. Letha Boudreaux's instruction and supervision suspended six ecosystem baskets in addition to the oyster gardening baskets under the SSC pier. The ecosystem baskets were the same material, size, and build of the oyster garden baskets, but only contained clean oyster shells (Weber et al., 2018). The purpose of these baskets was to document natural settlement of spat and to simulate reef ecosystem development on a small scale. These baskets were not checked as regularly as the oyster garden baskets, typically monthly. Observations of oyster growth and other marine organisms present as well as any fouling or sedimentation were recorded, however this data was not included in the study. The implementation of ecosystem baskets to the oyster gardening program will lead to a better understanding of the natural settlement process by observing spat recruitment naturally as opposed to receiving shells with spat already settled upon them. Observing a reflection of the natural settlement process gives students insights for further experimentation and understanding of the early recruitment of *C. virginica* in the reef ecosystem.

Objectives

The objective of this study is to examine growth and consequent mortality of the transplanted American oysters at the SSC pier in the Mississippi Sound over several years. The study focuses on (1) the growth of transplanted oysters from oyster garden baskets at the SSC garden site; (2) the observation of presence, development, and in situ settlement of spat in ecosystem baskets; and (3) the effects of freshwater influx on water chemistry in the Mississippi Sound and on oyster survivorship.

CHAPTER II: METHODS

Gardening Seasons

Each oyster gardening season begins in the summer, typically in June or July. The 2017 season began with the impact of Tropical Storm Cindy in the week of June 20th and finished with the impact of Hurricane Nate in mid-October. On June 20, 2017, the first batch of oyster spat was received from MASGC by SSC marine science interns and SSC Marine Science Program director, Mrs. Letha Boudreaux. Upon arrival, initial oyster lengths averaged 0.5 cm. Sixteen baskets were suspended off the edge of the pier with approximately 600 spat attached to oyster shells within each basket. The 2018 oyster season began on June 1 with 400 shells of spat; the number of initial spat per shell was not specified in the records.

In 2019, the delivery of spat to SSC was delayed due to excessively low water salinity. Thus, the third year of the Oyster Gardening Program at SSC began August 13, 2019. On the day of arrival, 400 spat averaged 1.99 cm in size. The batch of spat was held at the AUSL for a longer period of time to allow for growth before relocation.

There was little documentation of the 2020 gardening season, as this season occurred during the COVID-19 pandemic. Like the previous year, this season was extended into the following year, and the same batch of spat were monitored into June 2021 until the arrival of new spat on June 25, 2021. On June 25, 2021, the water salinity was 0.7 ppt. At this time, the oyster shells delivered to SSC MSP from the Mississippi hatchery harbored notably fewer live spat. Low salinity persisted until mid-August, when oyster measurements began.

The SSC MSP is currently in their sixth year of oyster gardening, which began August 16, 2022. So far this year, salinity has remained within a viable range, although many baskets are housing some dead spat. However, those oysters that are growing have reached an average size of 2 cm.

Sampling Regime

Measurements are performed by SSC marine science students and interns weekly. Using gloves, each basket is raised out of the water by the attached rope and dunked several times at the surface to shake off any loose sediment before being placed on the pier. The baskets are then opened, and the clusters of oyster shells are removed. The clusters are set on the pier next to their home basket. Both basket and clusters are rinsed of algae and sediment using a freshwater hose. Calipers are used to measure the oysters' height from umbo to the furthest point in centimeters, although some measurements in millimeters were later converted. Performing measurements in groups of two to three students, one student records measurements and makes observations of predators while the other calls out reported measurements of oyster heights. Predators are removed, identified, recorded, and released. Students are instructed to record 5-10 measurements, not only measuring the largest oysters, but rather selecting individuals randomly. Other notable observations include the presence of dead spat, signs of predation, level of fouling, and any significant damages to the oysters or the basket. Observations of dead spat were not consistently quantified to be utilized in the study. Once cleaning, measuring, and documenting is completed, the oyster clusters are returned to their baskets which are then closed, secured, and lowered back into the water.

CHAPTER III: RESULTS

In the first year of oyster gardening, the SSC MSP was able to grow 7,614 viable oysters by their release date of November 17, 2017 (79 % survival). When returned to MASGC and MDMR, the oysters averaged 5 cm in size (growth rate = 0.83% d^{-1}; where specific growth rate = (log(length T2/length T1)/ number days)*100) . Of the nine gardening programs in the state of Mississippi for the 2017 season, the SSC program was responsible for growing over half of the total gardened oyster count, which totaled 14,354 oysters. The 2018 growing season was good, with 9,669 oysters grown at SSC, or 25.8% of 37,500 oysters grown in the Mississippi gardening program. On October 18, the oysters averaged 5.7 cm in size, compared to 1.96 cm initially on June 1 (growth rate = 0.33% d^{-1}). This season had minimal rainfall and maintained moderate salinity ranging from 6 to 19 ppt for most of the season.

In 2019, only 3,600 living oysters were returned at the end of the season, averaging 4.14 cm in size, or 7.4% of the 48,558 oysters grown statewide (growth rate = 0.164% d^{-1}). The growing season was extended for a longer time period than in previous years, with records of measurements extending to March 23, 2020. It is estimated that the SSC MSP grew approximately 300 oysters during the 2020 season. Salinity was higher than in 2019 for the bulk of the 2020 season, despite Hurricane Laura making landfall in southwest Louisiana, causing strong winds and high tides and resulting in the loss of two oyster gardening baskets.

Salinity remained high until a series of severe storms occurred in April of 2021 which lowered the salinity to almost zero ppt. Prior to Hurricane Ida hitting the Gulf Coast on August 26th, the salinity was recorded as 16.3 ppt on August 18th. Effects from

Hurricane Ida persisted, lowering the salinity to 2.4 ppt on the surface and 4.6 ppt on the bottom on September 2, 2021. The season was extended, and only 39 viable oysters were available for relocation when recovered on May 5, 2022.

Year 1 in 2017 lacked the detailed documentation, hence there is no graph to show growth over several months. However, stable salinity levels promoted oyster growth from an initial average of 2 cm in the first two months to 5 cm at the time of collection three months later (i.e., ~ 0.442% d^{-1}). Figure 2 depicts the growth of the oysters in SSC's care for the second year of the program. In Figures 2-6, the average measurement for each month is shown along the y-axis and above each colored bar. Over six months, the average oyster size more than doubled in 2018 (Figure 2). Year 3 was a productive year, showing steady growth throughout both 2019 and 2020 (Figure 3) (i.e., ~ 0.25% d^{-1}). Year 4 consisted of only two months of measurement in 2021 with no additional measurements taken in 2020, as depicted in Figure 4. Measurements during Year 5 spanned several months in 2021 and 2022 (Figure 5).

The documentation of spat settlement within ecosystem baskets was not included in the routine checks, and thus was not consistently recorded. However, the presence of spat settlement was a common occurrence in each of the ecosystem baskets consistently throughout the years of the study as inferred based on early observations of the baskets and prior knowledge of oyster settlement and recruitment.

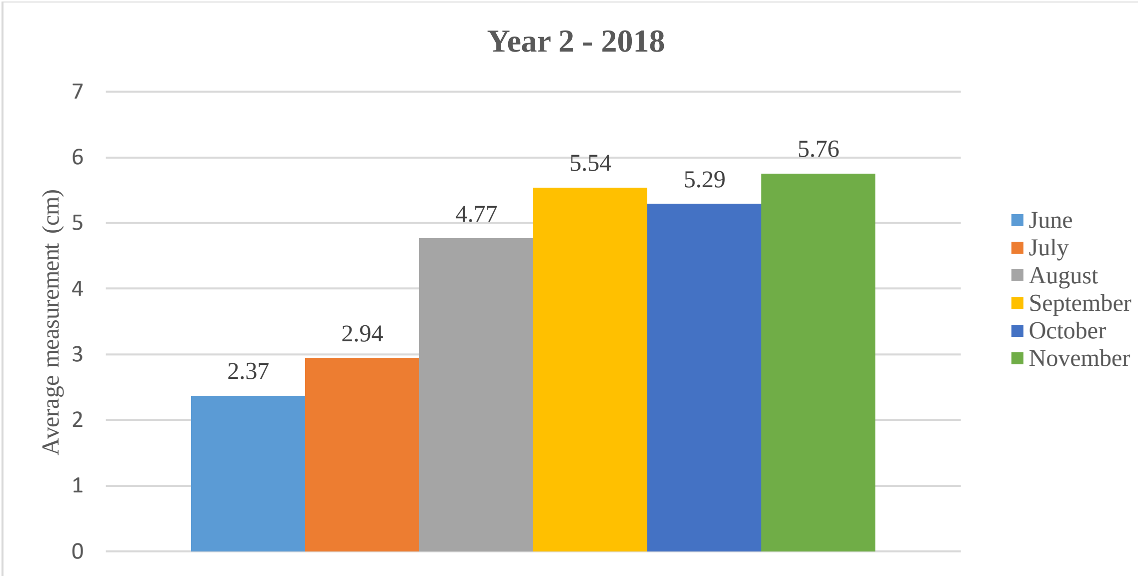

Figure 2. Year 2 average monthly measurements [cm].

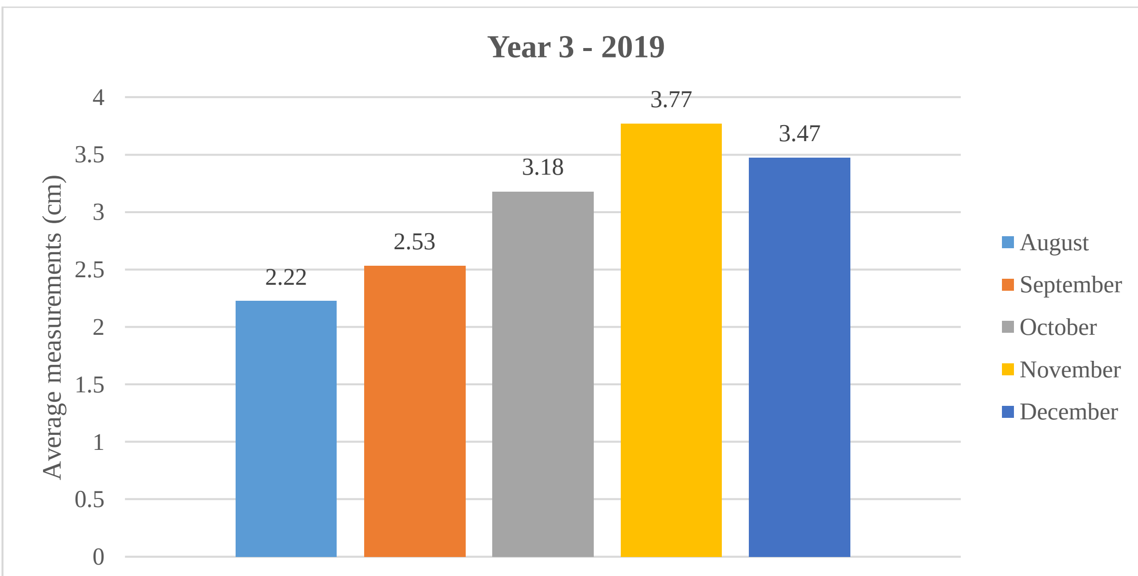

Figure 3a. Year 3 – 2019 average monthly measurements [cm].

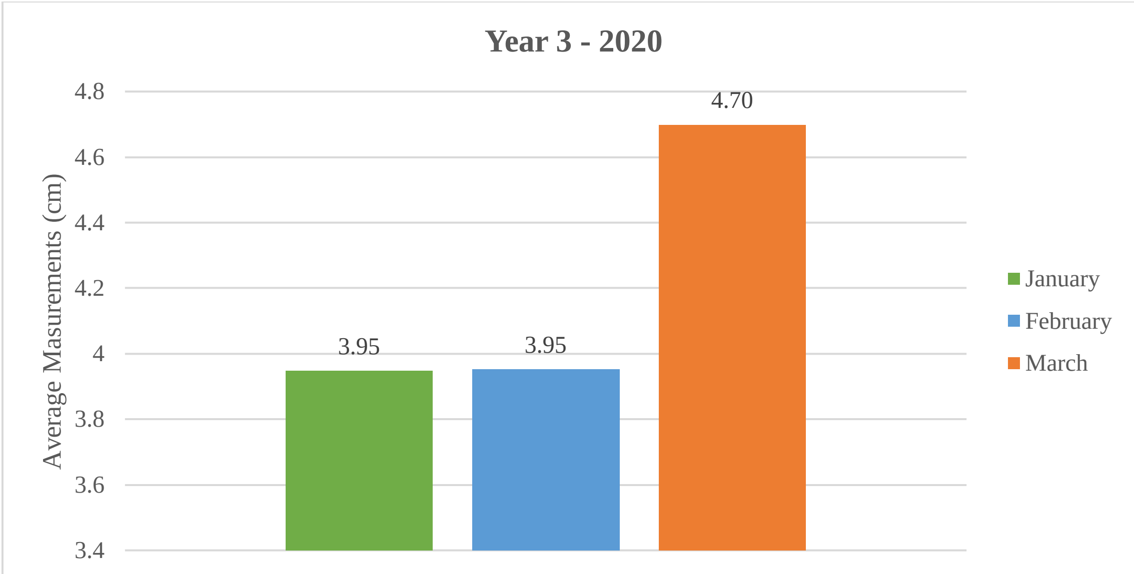

Figure 3b. Year 3 – 2020 average monthly measurements [cm].

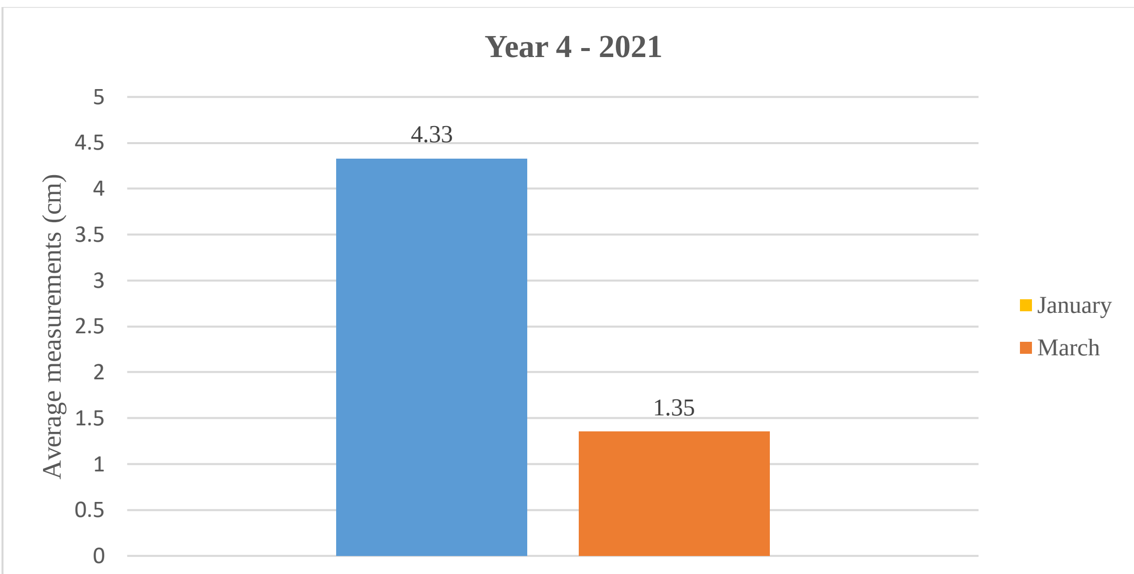

Figure 4. Year 4 average monthly measurements. The 2020 portion of Year 4 yielded no measurements [cm].

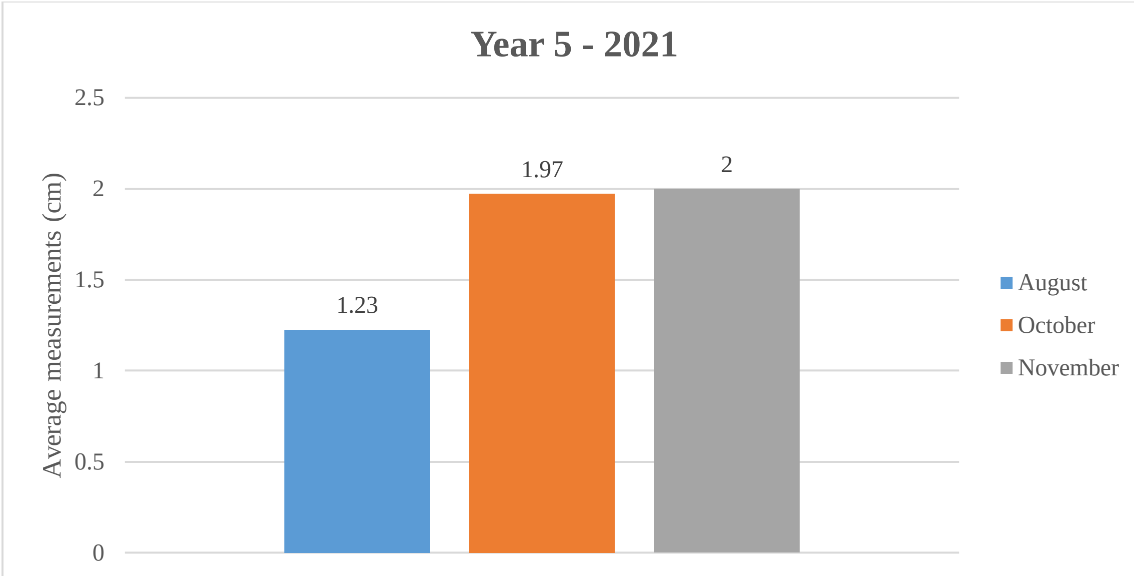

Figure 5a. Year 5- 2021 average monthly measurements [cm].

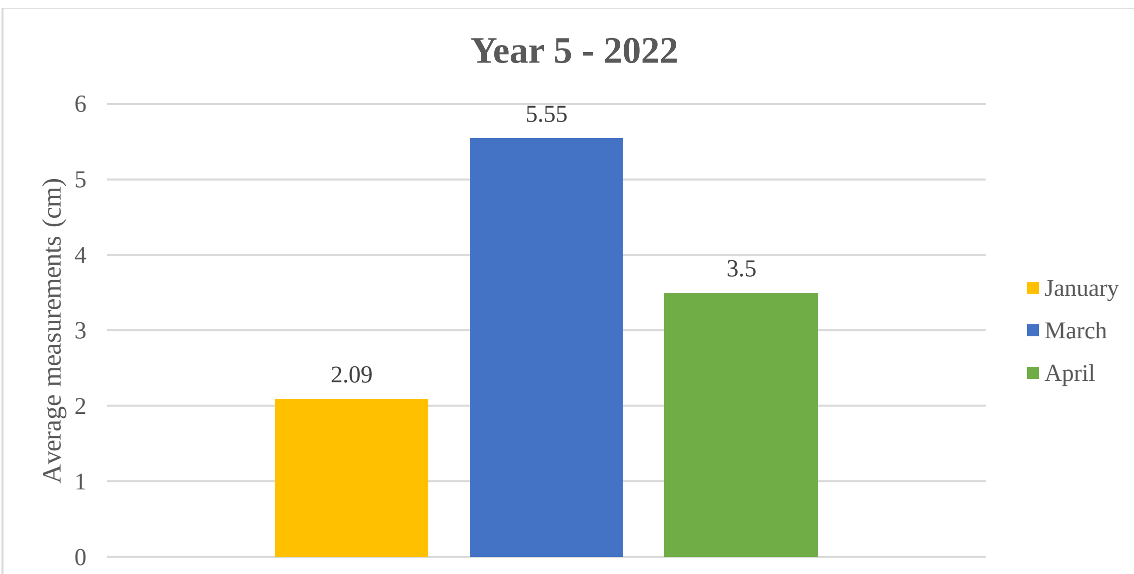

Figure 5b. Year 5 – 2022 average monthly measurements [cm].

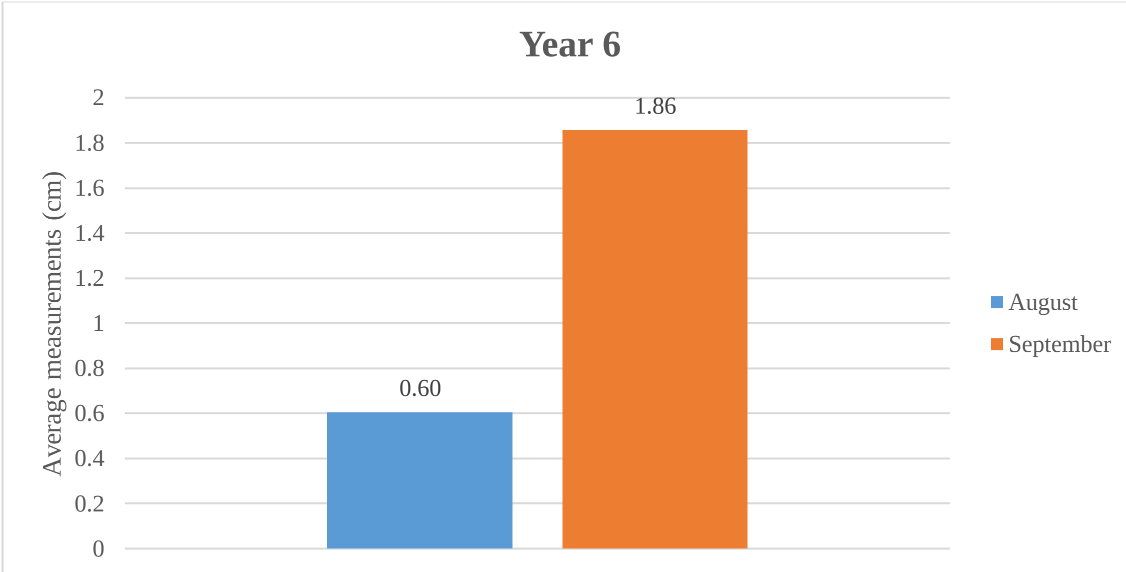

Figure 6. Year 6 average monthly measurements [cm]. Year 6 is currently active.

Predators and other organisms present in baskets at the time of sampling were documented (Appendix A) and can be used to analyze how salinity affects the presence or absence of predators. It was observed that more organisms are found in the baskets during times of higher salinities; however, the most consistently observed predators in all salinities included undetermined worm species, *Callinectes sapidus*, mussel species, barnacle species, undetermined goby species, and undetermined blenny species. Other common organisms found include the predator *Menippe mercenaria*, *Gobiesox strumosus*, *Palaemonetes paludosus*, and various juvenile fish species. An estimate of organism abundance can be viewed in Appendix A. Mortality was reported in most data sheets of Year 5 but not for previous years.

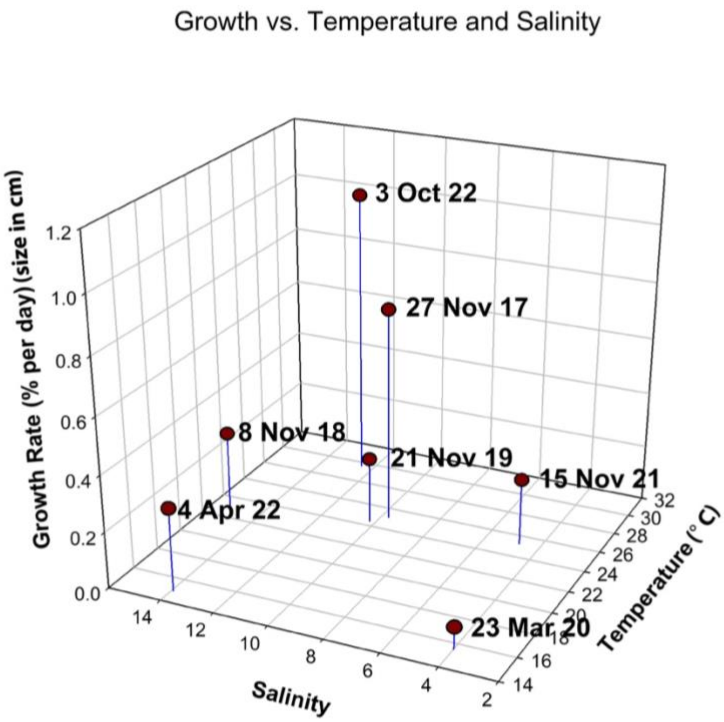

Figure 7. Cumulative percent growth rate per day vs. salinity and temperature with the data points labelled by the end dates of the growth series.

The cumulative growth rate data are too sparse and nonlinear to be very amenable to a multiple regression, but there are clear trends of lower growth corresponding with lower salinity and temperature values. The salinity and temperature values were obtained from the USGS Coastal Salinity Index time series data for the Mississippi Sound at USGS St. Joseph Island Light House. The salinity and temperature values represent rolling averages of between 3- and 5-month periods preceding the end dates of the growth series. Period durations for salinity roughly matched those for growth, however, durations for temperature were all for three months prior to end dates for growth data due to limitations of the USGS output function.

CHAPTER IV: DISCUSSION

Freshwater Implications

As freshwater enters the brackish and saline environment of the Mississippi Sound, salinity is lowered and water chemistry is altered, thereby affecting *C. virginica* development and survival. Monthly averages of oyster measurements (Figures 2-6) show the progressive growth of oysters in the SSC MSP oyster gardening baskets over time. Analyzing the salinity and temperature fluctuations and correlating those with the rate of growth (Figure 7), it is concluded that a severe decrease in salinity disrupts oyster growth and diminishes the population overall. A recent study of early oyster recruitment by Morgan and Rakocinski in the Mississippi Sound encompassed a sample site near the location of the SSC oyster gardening site. *Crassostrea virginica* serve the estuarine ecosystem in many ways, including by filtering water and improving nutrient cycling (Morgan & Rakocinski, 2022). The absence of these and other aquatic invertebrates can lead to a cascade of negative effects within the marine ecosystem. When water chemistry is altered by acidification, the concentration of CO_2 and hydrogen ions weakens the calcium carbonate shells of oysters and other mollusks (Beniash et al., 2010). Salinity and temperature not only affect growth rates of the American oyster, but also abundant associated organisms of oyster reef communities.

As previously noted, some growing seasons were extended to give growth and survival of gardened oysters a chance to stabilize as conditions fluctuated. The 2019 season was extended into March 2020, Thus, some of the slower growth was attributable to colder water during grow-out. However, a low growth rate also occurred in the year during which the Bonnet Carre Spillway was opened in Louisiana, bringing copious amounts of freshwater into the Gulf of Mexico, and causing a harmful algal bloom to form in the bulk of the season.

A broader analysis of the freshwater influences on metapopulations of *Crassostrea virginica* throughout the Gulf of Mexico could be performed using data from other locations to create a larger scope, however, the main objective of this study was to specifically examine changes in growth over several years at the St. Stanislaus location. The SSC location was selected due to longer term data available and accessibility to the site, equipment, and personnel. The magnitude of the project would be bigger with data from other locations, venturing outside of the capacity of individual study possible within the time frame of the Honors Thesis.

Moving Forward

As the SSC MSP has grown over the years, data collection has become more detailed. Thus, earlier years of data may not be as insightful as the data collected during more recent years. An inconsistent factor that introduces potential error is the documentation by students. Although provided instruction and assistance by interns, there is no way to guarantee consistency and accuracy when using student data. Student measurements may not always be exact or specimen choice randomized. With more years of gardening in the future, more rigorous procedures can be added to the sampling regime of the program to improve the applicability of the results. With more consistent documentation of salinity, dissolved oxygen, temperature, and mortality to survivorship ratio, the program can provide researchers like myself with more data for further study. The ecosystem basket portion of the program also has room to grow, as more can be measured and documented there as well. The SSC MSP has utilized the oyster gardening program and ecosystem baskets to educate students of SSC and Our Lady Academy who partake in marine science courses at SSC, as well as students from local elementary schools and those that attend the SSC summer camp, Camp Stanislaus. An important aspect of conservation and STEM research is outreach and education. The SSC MSP values this outreach benefit strongly. Outreach occurs formally through Explore Science Day with elementary school students and through the Marine Science Specialty camp, as well as through a marine science elective at Camp Stanislaus. At this event and during these camp sessions, students are exposed to marine science concepts and are able to interact with the ecosystem baskets firsthand, catching a glimpse into the natural ecosystem that harbors the American oyster, *Crassostrea virginica*.

APPENDIX A: SUPPLEMENTAL MATERIAL

Below is a collection of species observed in the oyster gardening baskets for each year of collection. There is no data available for Year 4. Common names and abundances of species observed in the oyster gardening baskets are based on student notes on data sheets. The abundance of each organism is based on the scale below.

Single = 1
Few = 2-4
Multiple = 5-10
Many = 10+
TNTC = too numerous to count
ND = not determined

Table 1. Year 1.

Common Name	Scientific name	Abundance
Algae	unknown	
Barnacles	unknown	TNTC
Blue crab	*Callinectes sapidus*	single
Comb jellies	*Ctenophora*	TNTC
Goby spp	unknown	Many
Grass shrimp	*Palaemonetes paludosus*	Few
Juvenile blue crabs	*Callinectes sapidus*	few
Juvenile mussels	unknown	TNTC
Pinfish	*Lagodon rhomboides*	single
Skilletfish	*Gobiesox strumosus*	few
Stone crab	*Menippe mercenaria*	Few

Table 2. Year 2

Common Name	Scientific name	Abundance
Algae	unknown	
Amphipods	unknown	Few
Barnacles	unknown	TNTC
Blenny spp	unknown	Few
Blue crab	*Callinectes sapidus*	ND
Bryozoans	unknown	ND
Crab spp	unknown	Multiple
Goby spp	unknown	Multiple
Grass shrimp	*Palaemonetes paludosus*	Few
Mangrove snapper	*Lutjanus griseus*	single
Mussel spp	unknown	TNTC
Polychaete worms	*Polychaeta*	Few
Skilletfish	*Gobiesox strumosus*	Few
Stone crabs	*Menippe mercenaria*	Multiple
Worm spp	unknown	Few

Table 3. Year 3.

Common Name	Scientific name	Abundance
Amphipod	unknown	single
Barnacles	unknown	TNTC
Blenny spp	unknown	few
Blue crab	*Callinectes sapidus*	few
Bryozoans	unknown	ND
Clam spp	unknown	ND
Comb jelly	*Ctenophora*	multiple
Crab spp	unknown	many
Fish spp	unknown	multiple
Goby spp	unknown	few
Mussel spp	unknown	TNTC
Polychaete worm	*Polychaeta*	Few
Shrimp spp	unknown	few
Stone crabs	*Menippe mercenaria*	Few
Unknown parasite	unknown	ND
Worm spp	unknown	many

Table 4. Year 5.

Common Name	Scientific name	Abundance
Blenny spp	unknown	Multiple
Blue crab	*Callinectes sapidus*	ND
Comb jellyfish	*Ctenophora*	ND
Crab spp	unknown	Few
Goby spp	unknown	ND
Pinfish	*Lagodon rhomboides*	Few
Skilletfish	*Gobiesox strumosus*	ND
Snail spp	unknown	ND

Table 5. Year 6.

Common Name	Scientific name	Abundance
Arthropod	unknown	ND
Barnacles	unknown	TNTC
Flat worms	*Platyhelminthes*	few
Goby spp	unknown	ND
Juvenile crab spp	unknown	few
Mussel spp	unknown	TNTC
Polychaete worms	*Polychaeta*	Few
Spadefish	*Chaetodipterus faber*	Single
Worm spp	unknown	many

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