Investigation on the Half Shell:
The Social-Ecological Role of Oyster Aquaculture in North Carolina

UNC Institute for the Environment Outer Banks Field Site 2015
Capstone Report

December 8, 2015
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Acknowledgements

Special Thanks to Corey Adams, Joey Daniels, Linda D’Anna, Lindsay Dubbs, Lee Leidy, and Andy Keeler

We would like to acknowledge the following people and organizations for their help and contributions to our work:

Beth Storie, Feather Phillips, Pat Raves, Peggy Birkemeier, Tom White, George Wood, Ladd Bayliss, Albert and Carolyn Gard, Kathy McMahan, John McCord, Randy Swilling, Robert Perry, Bill Smyth, Michael Piehler, Nathan Richards, Nancy White, Robert McClendon, Reide Corbett, Mike Muglia, Sara Mirabilio, Kim Armstrong, Marie Magee, Jonathan Jones, Jeff Gottermeyer, Mike Hosey, Maggie Fuentes, Stephanie O’Daly, Bill and Ellen Kealy, Bill and Peggy Birkemeier, Beth Storie and Michael McOwen, Jaye Massecar

Thank you to all of the interviewees who volunteered their time and thoughts to our project.
Abbreviations

APES: Albemarle-Pamlico Estuarine System
BRACO: Blue Ribbon Advisory Council
CAB: Community Advisory Board
CAM: Coastal Area Management Act
Chl a: Chlorophyll a
NCDENR/DENR: North Carolina Department of Environment and Natural Resources
GMO: Genetically-Modified Organism
K: Light Extinction
NC: North Carolina
N.C.G.S: North Carolina General Statute
NGO: Non-Governmental Organization
NIMBY: Not in my Backyard
NOAA: National Oceanic and Atmospheric Administration
NWP: Nationwide Permit
OBXFS: Outer Banks Field Site
PAR: Photosynthetically Active Radiation
ppt: Parts per thousand
SAV: Submerged Aquatic Vegetation
UNC CSI: University of North Carolina Coastal Studies Institute
UNCW: University of North Carolina at Wilmington
Abstract

The interest in oyster aquaculture in North Carolina has increased as the natural oyster stock has been decimated and no longer yields enough to sustain livelihoods or societal demand. Here, we investigate the effects oyster aquaculture may have on different elements of the environment and coastal communities of the Albemarle Pamlico Estuarine System (APES). Using laboratory experiments and field data, we assess how the presence of oysters influences water quality factors and submerged aquatic vegetation (SAV) growth. Observations between days and collection sites fluctuated significantly, though they did not follow an identifiable pattern. The SAV density measured inside and immediately outside the aquaculture facility was comparable to and exceeded that of a control site without oysters, suggesting that farming oysters does not inhibit the growth of SAV and possibly promotes it. We compared filtration rates of farmed triploid oysters, farmed triploid oysters in cages, and wild diploid oysters, and ultimately found that farmed oysters filtered faster than wild oysters. Interviews with local stakeholders provided insight into their current knowledge and perceptions regarding oyster aquaculture. Interviewees suggested that oyster aquaculture provides a potential economic boost for coastal communities, but there is concern that facilities would interrupt commercial and recreational uses of the water. Interviewees also mentioned that the current permitting process is restrictive to people interested in entering the industry, and the physicality of the work further discourages potential farmers. Oyster aquaculture has become a contested issue for NC, and further research is necessary to guide regulations that balance the marine and public interests.
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Introduction

Oysters are an important component of the North Carolina coastal ecosystem. As a keystone species, oysters play a major role in maintaining the well being of the Albemarle-Pamlico Estuarine System (Sanjeeva, 2008). They are also responsible for providing numerous ecosystem services. Ecosystem services are “the benefits of nature to households, communities, and economies” (Boyd, 2007). These services are important because they highlight just how much humans rely on the environment in which we live, and they allow us to quantify the benefits we receive from the natural environment.

Oyster reefs have been in decline over the past 130 years, and are significantly less abundant than they once were, particularly in North America, Australia, and Europe (Beck, 2011). In NC, there are two main sources of oysters: wild and restored reefs, and oyster aquaculture farms. Currently, less than 2,500 acres are leased for oyster aquaculture (Turano, 2011). This is a small portion of the ecologically available space in the Sound.

The NC oyster aquaculture industry brought in less than $600,000 in sales in 2012 (Comparative, 2013). Our study examines the state of oyster aquaculture in NC and how different ecological and economic factors affect the industry. For our Capstone research, we asked ourselves, what could increased oyster aquaculture development in NC mean for the surrounding social-ecological system? A social-
ecological system is one that combines the human and environmental aspects of an ecosystem, pairing natural processes and human processes through their interactions with one another. The term “social-ecological” emphasizes the “integrated concept of humans-in-nature” (Fikrit, 2003).

The 2014 Outer Banks Field Site Capstone, “The Oyster Banks: A Dive into the Political, Scientific, and Social Realms of Oysters and Oyster Aquaculture in North Carolina,” focused on the effects oyster aquaculture has on vegetation and fish as well as the preferences and views of coastal citizens. The 2014 Capstone found that oyster aquaculture can improve water quality, but their data on SAV in areas surrounding aquaculture facilities were inconclusive. They determined that more information was needed regarding aquaculture’s effects on SAV. They also found that consumers of oysters were more likely to prefer wild-caught oysters to aquaculture oysters, and that there was a positive relationship between oyster consumption and knowledge of oysters.

Building off of these results, we divided our project into two sections: natural science and social science. The natural science research component focused on the impact of aquaculture sites on submerged aquatic vegetation, water clarity, and oyster filtration rates. Vegetation and water clarity data were collected from four sites in the Roanoke Sound: inside and outside an oyster aquaculture facility, a wild reef, and a control site without oysters. Our social science research focused on perceptions and knowledge of oyster aquaculture in NC. Research was conducted through interviews
with people who have a stake in the Sound and fit into one of four categories: commercial fishing, recreational business, oyster aquaculture, and government/nonprofit.

Background

North Carolina’s native oyster is the eastern oyster (*Crassostrea virginica*), a species found along the eastern seaboard of the US and the Gulf of Mexico. The eastern oyster can survive in water temperatures ranging from -1°C to around 36°C, but only for short periods of time at temperatures below 8°C or above 32°C (Kennedy, 1996). These bivalves can also survive short periods of time out of the water during low tides (Kennedy, 1996). Optimum salinity conditions for oysters range from 10 to 28 ppt, but they can survive in conditions as low as 6 ppt and as high as 35 ppt (Puglisi, 2008). Salinity and temperature toleration varies among different oyster populations with atmospheric and water conditions. Most oyster habitat exists in shallow waters, but oysters can occasionally be found in deeper waters as well (Kennedy, 1996).

Adult oysters reproduce when water temperatures exceed 20°C (SCORE, 2015). Oysters are broadcast spawners, meaning they release eggs and sperm into the water column for fertilization (SCORE, 2015). Fertilized eggs develop into larvae in around 24 hours, and remain in the water column for two to three weeks until they settle. At the settlement stage, oyster larvae develop a “foot,” a small appendage that allows them to move around as they search for a suitable hard substrate—usually another oyster shell—that will become their habitat for the rest of their lives (SCORE, 2015).
Once the oyster larvae find their substrate, they release a substance that cements them to the surface. Once cemented, they remain attached permanently. When the juvenile oysters have settled, they are known as “spat” or “seed.” The spat continue to grow, reaching maturity in one to three years (SCORE, 2015).

The primary food source for the eastern oyster is phytoplankton – small, photosynthetic organisms that live in the water column (Kennedy, 1996). A reliable supply of phytoplankton is necessary for oysters, as they cannot move to seek out a food source.

Within our social-ecological scope, we looked at the exchange between human processes and ecological processes. Humans affect oyster populations in the Albemarle-Pamlico Estuarine System (APES) in many ways. Pollution from many sources feeds into the Sound through rivers and can lead to algal blooms, causing hypoxia or anoxia (low oxygen or no oxygen conditions, respectively). These hypoxic and anoxic conditions can cause fish, shellfish, and vegetation kills in the sound. Humans also have historically overharvested the oysters in the APES. Oyster populations today are a fraction of what they used to be (Grabowski et al, 2012).

Humans also benefit from oysters in various ways. Oysters are filter feeders, cycling up to 50 gallons of water each day as they consume phytoplankton and clear suspended sediments from the water column (CBF, 2015). Their filtering decreases the water’s turbidity—a measure of the suspended particulates in the water column that make the water less clear. By removing nitrogen and phytoplankton from the water,
Oysters prevent harmful algal blooms. This filtration results in water quality improvements, which are an important ecosystem services.

Oysters provide many other ecosystems services. They sequester, or remove, carbon from the water in order to make their calcium carbonate shells (Committee, 2010). Oysters’ biodeposits, in the form of pseudofeces, contain carbon and nitrogen, nutrients for benthic algae and vegetation, which in turn provide food and habitat for other aquatic life. Oyster reefs provide erosion control along the shorelines. When waves pass through a reef, the flow slows down, causing the water to carry away less sediment from the shorelines (Committee, 2010).

Oyster reefs themselves act as habitat for many species of fish. With increased habitat, these fish populations grow, and more can be caught and sold commercially (Grabowski et al, 2012). There is also a large culinary demand for oysters across the United States. The supply of oysters is declining due to overharvesting, habitat destruction, and increased harvest regulation (Grabowski et al, 2012). It is harder for fishermen to find wild oysters to sell, and when they do find a bed, there are strict limits on the oyster season and allowed haul (how many bushels each harvester can collect in a day). Still, oysters provide a vital ecosystem service in food provision, and they create jobs in harvesting, processing, deliveries, and sales.

All of these ecosystem services combine to make oysters valuable organisms both to the natural environment and to humans. It remains unclear, however, how service provisioning may differ between wild oysters and farmed oysters. Eastern
oysters cultivated in aquaculture facilities have the same habitat requirements as wild oysters. The main difference is that farmed oysters do not attach to a substrate. Oyster seed is raised in hatcheries and then introduced to a farm using different variations of either bottom or off-bottom aquaculture (Pangea, 2015). Bottom aquaculture consists of spreading oyster spat along the waterbed where they grow to maturity (Pangea, 2015). These oysters have already passed the stage in their life cycle where they would have cemented themselves to a substrate, so they simply rest on the bottom instead. Off-bottom aquaculture has many different variations: cage aquaculture, rack-and-bag aquaculture, tray aquaculture, surface aquaculture, and suspended aquaculture. In each of these methods, oysters are confined in different types of cages, racks, or bags and are placed either on the surface, raised slightly off of the bottom, or suspended in the water column (Pangea, 2015).

Reproduction is another major difference between aquaculture and wild oysters. Wild oysters are diploid organisms that produce gonads. Farmed oysters are triploid organisms—they have three sets of chromosomes instead of two, rendering them sterile (Coast Seafoods, 2011). This allows them to focus all of their energy on growth, rather than reproduction. Farmed triploid oysters reach a sellable size more quickly than wild oysters and they retain their meat and flavor year round. Wild diploid oysters lose mass when they release their gametes in the early summer, affecting their taste and consistency (Coast Seafoods, 2011).
North Carolina has been slow to expand in the oyster aquaculture industry, which may be linked to legislation and regulation. One influential policy in the earlier days of oyster aquaculture was the Session Law 1993-44. This law created a moratorium on shellfish leases in Core Sound, preventing growth in part of the industry and making it more difficult for potential farmers to obtain leases for certain areas in the Sound.

In contrast, NC had its first NC Oyster Summit in 1994, which focused on ways the state could expand its oyster programs, not only in aquaculture, but also with wild oyster restoration. A key outcome of the 1994 NC Oyster Summit was the creation of the Blue Ribbon Advisory Council (BRACO). BRACO produced a report expressing interest in expanding oyster aquaculture, but the legislature chose to not implement any of their recommendations.

In 2002, despite the previous scientific research and recommendations provided by the BRACO report, the legislature imposed more regulations on the shellfish aquaculture industry through Session Law 2002-15. This law renewed the moratorium on shellfish leases in Core Sound until October 2003. Then, in 2003, Session Law 2003-64 declared permanent intentions to limit shellfish lease area in Western Core Sound. This created a disparity between research and legislation. The moratorium on Core Sound leases has continued through 2015.

In 2009 the State changed the renewal period of shellfish leases from ten years to five years. To renew a lease, a farm must meet a production requirement. The ten-
year renewal period accounts for potential difficulties and unexpected issues, allowing farmers to see visible returns. The five-year period heightens the risk of not meeting production requirements and increases the difficulty of obtaining loans for new oyster farms. This discouraged industry growth because farmers were unable to make long term plans and could not count on their lease being renewed.

Another regulatory barrier to the oyster aquaculture industry arose in March of 2012 when the Army Corps of Engineers released Nationwide Permit (NWP) 48, which states that “Adverse impacts to Submerged Aquatic Vegetation (SAV) are not authorized by any NWP within any of the twenty coastal counties defined by North Carolina’s Coastal Area Management Act of 1974 (CAMA).” This intolerance of any negative effects on SAV prevented leasing of a significant portion of the Sound for oyster aquaculture use. This NWP will expire in March of 2017.
Natural Science:
Ecological effects of an oyster aquaculture facility in Roanoke Sound, North Carolina

Introduction

An estuary is a partially enclosed body of water that exists along a coastline where a freshwater source meets a salt-water body, creating vital habitat for organisms that require these unique conditions (Pritchard, 1967). Situated between landmasses and oceans, estuaries intercept the outflow from land-based water sources and play an important role in filtering water before it reaches the ocean. As a result, estuaries can become sinks for pollutants and nutrients, leading to poor water quality, algal blooms, and other environmental issues (Pritchard, 1967).

Oysters can play a critical role in cleaning these water bodies. As suspension feeders, oysters filter particles out of the water such as algae, bacteria, and detritus. They either ingest these particles for energy or reject them, turning the material into pseudofeces that will be deposited onto the estuary bottom (Ray, 2015, Grabowski, 2012). Cleaner water is a more habitable environment for other organisms and promotes submerged aquatic vegetation (SAV) growth. SAV provides critical nursery grounds for fish and other aquatic species as well as permanent habitat for many other organisms (Jackson, 2001; Boström, 1999). Additionally, SAV is an important blue carbon sink for the surrounding area (Mcleod and others, 2011). North Carolina protects
SAV under Army Corps of Engineers NWP 48, which limits potentially negative human disturbances.

Current studies conflict over whether oyster aquaculture has a net positive or negative effect on SAV. Some studies argue that through increased sediment deposition, erosion, and shading, rack and bag aquaculture decreases the relative abundance of SAV in surrounding areas (Everett, 1995, Skinner et al, 2013). However, Dumbauld (2015) argued that there was no large change in the abundance of SAV adjacent to oyster aquaculture facilities overall, and Dealteris (2004) showed shellfish aquaculture gear to provide better habitat than areas consisting solely of SAV. With conflicting studies and an overall lack of information on the effects of oyster aquaculture on the surrounding environment, we set out to further add to this body of knowledge by collecting data on water quality and SAV growth surrounding an aquaculture facility in Roanoke Sound, NC.

We chose three study sites in Roanoke Sound (Figure 1) to assess water quality and SAV growth at locations with and without oyster aquaculture. By comparing water clarity parameters including light extinction, turbidity concentrations, Secchi depth, and chlorophyll a (chl a) concentrations, we attempted to determine if the aquaculture facility had a measurable effect on the surrounding water column. We hypothesized that the oyster aquaculture facility would have positive effects on water clarity compared to the control site and wild reef because of the local impacts of oyster filtration.
We also measured SAV density and distribution around areas with and without aquaculture to evaluate if the facility promotes or inhibits SAV growth. The presence of aquaculture gear—racks or bags—could negatively affect SAV growth by blocking sunlight, disrupting bottom sediments, and reducing available surface area for SAV. However, a facility could also positively affect SAV growth by improving water clarity, reducing erosion, and enriching sediment nutrient concentrations. We hypothesized that the oyster aquaculture facility would positively affect SAV density 1) within the facility when unobstructed by gear, and 2) in areas immediately adjacent to the facility.

Finally, we designed a laboratory filtration study to assess the impacts of oyster type and gear on oyster filtration. We specifically measured chl $a$ because it is often used as an indicator of water quality, and more importantly because phytoplankton have chl $a$ in their cells. Phytoplankton are the primary source of food for oysters, and in a closed system, such as that created for our experiments, their concentrations in the water column are reduced as oysters feed (Kennedy, 1996). Algae blooms—excessive quantities of phytoplankton in the water column—can limit light availability and growth of other primary producers, including rooted SAV, which also affects the consumers that rely on these producers (Landsberg, 2002). Chl $a$ concentrations indicate the presence and quantity of phytoplankton in the water column (Boyer et al, 2009). Assessing how the presence of oysters directly influences chl $a$ concentrations indicates their filtering ability.
Our filtration experiment consisted of four tanks, three containing oysters and one control. The tanks with oysters consisted of: aquaculture triploid oysters in a rack similar to those in an aquaculture facility, aquaculture triploid oysters in a random configuration similar the conditions of a wild reef, and wild diploid oysters in a similar random configuration. With these three treatments, we were able to compare the effect of the rack versus no rack and compare the effect of triploid oysters versus diploid oysters. We hypothesized that there would be a difference in filtration rates between diploid and triploid oysters as well as between rack-confined and non rack-confined oysters.

**Methods**

**Study Sites**

*a. Inside and Outside of the Oyster Aquaculture Facility*

Our field research took place at an oyster aquaculture facility in Roanoke Sound, NC (Figure 1) that is owned by Wanchese Seafood and operated by Joey Daniels. The facility is located approximately 6 km from Oregon Inlet and approximately 80 m east of a dredge spoil island (35°48’33.93” N, 75°34′59.01” W) that is between Off Island (east) and Duck Island (west). We recorded an average water depth of 0.79 m inside the facility and 0.81 m outside the facility. The facility is about 47,422 m² and organized into quadrants (Figure 2) containing racks and bags of oysters and an open boat lane. Use of the site for oyster (*Crassostria virginica*, triploid) aquaculture began in April of 2012.
Figure 1: Map of the locations of the aquaculture facility, the control site, and the wild oyster reef (Google Earth).

b. Control

Our control site (Figure 1), which has no oysters, is located 1.25 km north of the oyster aquaculture facility (35°49’08.88” N, 75°35’22.78 W) and shares many of the same characteristics as the facility. It is located along a dredge spoil island, has a similar tidal range, has an average depth of 0.83 m, and is affected by the same seasonal winds.
c. Wild Oyster Reef

We chose the wild oyster reef (35°49’24.50” N, 75°37’01.70” W) (Figure 1) to compare the effects of wild oysters (*Crassostria virginica*, diploid) to the those in the aquaculture facility. Water depths here (average of 1.22 m) are too great for SAV to grow, thus we were unable to collect SAV data.

*Figure 2: Map of the oyster aquaculture facility operated by Joey Daniels in Roanoke Sound, North Carolina (Allen et al, 2014).*

d. Sampling locations

We took water quality measurements at the aquaculture facility and the control site on August 24, 2015, and at the aquaculture facility, control site, and wild reef on September 4, 2015, September 18, 2015, and September 30, 2015. Three water quality-sampling locations were chosen at random at each sampling site (inside and outside the aquaculture facility, the control site, and the wild oyster reef). Boat accessibility (usually
dependent on water depth) was important in choosing sampling locations at each site. We typically took samples from outside the facility within 10 m of the facility’s boundary. We took measurements outside the north and south sides of the facility on all sampling days because of the predominant flow of water associated with tides and because of their relatively shallow depths, which allowed the corer to reach the bottom to collect a benthic water sample. In order to understand the differences in proximity to the dredge island (shallow water; west side) and boating canal (deep water; east side), we also took measurements along the west and east sides on two sampling dates. At the control site, we chose sampling locations at similar distances from the adjacent island as those taken inside the aquaculture facility. The wild oyster reef sampling locations were chosen at random. We verified the presence of live oysters at the wild oyster reef by using nets to pull up any oysters.

**Water Clarity**

*a. Environmental Parameters*

We used a YSI 6600 V2-4 water quality-sampling sonde to measure water temperature (Celsius), salinity (ppt), pH, turbidity (NTU), dissolved oxygen (%), and chl a (μg/L) inside and outside the aquaculture site, the wild oyster reef, and the control site. On each sampling day, we measured three random locations in boat accessible areas at every sampling site. We recorded the date and time as well as any other factors
that may have affected the measurements, including observations of current and previous weather occurrences (Table 1).

On the first sampling day, we only took measurements at the surface and bottom depths, but analysis showed that it did not provide meaningful results. To address this issue, for the rest of the sampling dates, we changed our approach and took measurements at 0.1 m increments from the surface to the bottom of the water column at each sample location. Instead of using the depth measurement on the YSI, we secured a tape measure to the device to determine every 0.1 m. The tape measure was a more precise method for getting measurements at every depth increment.

\textit{b. Turbidity}

We compared the turbidity by determining the means and standard deviations of our data from each sampling site for each sampling day and all the sampling days collectively. We had 56 data points from the aquaculture facility (27 inside and 29 outside), 32 data points from the control site, and 35 data points from the wild reef.
Table 1: Sampling conditions on each sampling date at the sampling sites. Meteorological conditions, including the most relevant times of high and low tides, wind directions, wind speeds, and air temperatures, for each site on each day were recorded by the nearby Oregon Inlet NOAA National Data Buoy, Station ORIN7, within the hour of the recorded sampling times (NOAA, 2015). There was little variation in meteorological data on sampling dates across sampling times. Weather conditions, including the relative degree of sunniness and cloud cover, were recorded as we observed them each day.

<table>
<thead>
<tr>
<th>Day 1: 8/24/15</th>
<th></th>
<th></th>
<th>Reef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Tide: 9:17 AM</td>
<td>High Tide: 3:51 PM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inside</td>
<td>Outside</td>
<td>Control</td>
</tr>
<tr>
<td>Sampling Time</td>
<td>9:15AM</td>
<td>11:15AM</td>
<td>No Data</td>
</tr>
<tr>
<td>Wind Direction (deg)</td>
<td>324</td>
<td>326</td>
<td>No Data</td>
</tr>
<tr>
<td>Wind Speed (m/s)</td>
<td>1.2</td>
<td>1.2</td>
<td>No Data</td>
</tr>
<tr>
<td>Air Temperature (deg. C)</td>
<td>22.2</td>
<td>22.6</td>
<td>No Data</td>
</tr>
<tr>
<td>Weather Conditions</td>
<td>Clear skies with a few clouds</td>
<td>No Data</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 2: 9/4/15</th>
<th></th>
<th></th>
<th>Reef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Tide: 7:20 AM</td>
<td>High Tide: 1:16 PM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inside</td>
<td>Outside</td>
<td>Control</td>
</tr>
<tr>
<td>Sampling Time</td>
<td>8:00AM</td>
<td>7:30AM</td>
<td>12:45PM</td>
</tr>
<tr>
<td>Wind Direction (deg)</td>
<td>272</td>
<td>270</td>
<td>306</td>
</tr>
<tr>
<td>Wind Speed (m/s)</td>
<td>2.3</td>
<td>1.8</td>
<td>3</td>
</tr>
<tr>
<td>Air Temperature (deg. C)</td>
<td>26.2</td>
<td>26.1</td>
<td>27.1</td>
</tr>
<tr>
<td>Weather Conditions</td>
<td>Partly Cloudy</td>
<td></td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Day 3: 9/18/15</th>
<th></th>
<th></th>
<th>Reef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Tide: 5:17 AM</td>
<td>High Tide: 11:31 AM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inside</td>
<td>Outside</td>
<td>Control</td>
</tr>
<tr>
<td>Sampling Time</td>
<td>9:30AM</td>
<td>10:45AM</td>
<td>1:00PM</td>
</tr>
<tr>
<td>Wind Direction (deg)</td>
<td>29</td>
<td>36</td>
<td>45</td>
</tr>
<tr>
<td>Wind Speed (m/s)</td>
<td>4</td>
<td>3.9</td>
<td>4.2</td>
</tr>
<tr>
<td>Air Temperature (deg. C)</td>
<td>24.2</td>
<td>24.1</td>
<td>25.2</td>
</tr>
<tr>
<td>Weather Conditions</td>
<td>Sunny, partly cloudy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Day 4: 9/30/15**

Low Tide: 4:47 PM  
High Tide: 10:04 AM

<table>
<thead>
<tr>
<th>Sampling Time</th>
<th>Inside</th>
<th>Outside</th>
<th>Control</th>
<th>Reef</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9:30AM</td>
<td>11:00AM</td>
<td>1:30PM</td>
<td></td>
</tr>
<tr>
<td>Wind Direction (deg)</td>
<td>168</td>
<td>194</td>
<td>201</td>
<td></td>
</tr>
<tr>
<td>Wind Speed (m/s)</td>
<td>3.4</td>
<td>4.1</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Air Temperature (deg. C)</td>
<td>24.8</td>
<td>24.7</td>
<td>24.6</td>
<td></td>
</tr>
<tr>
<td>Weather Conditions</td>
<td>High altitude wispy cloud cover</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**c. Chl a**

On each sampling date, we collected both surface and benthic water samples for chl a analysis in 250 mL brown water bottles. Surface water samples were collected from the top 7 cm of the water column by grab sampling. We collected benthic water samples by decanting surface water from ~5 cm sediment cores collected in a 7 cm diameter, ~2.5 m tall core tube at each sampling location on each sampling date. Core samples were not collected until all other water quality measurements were taken so that the suspension of sediment associated with coring would not affect them. We placed all the water samples in a cooler for transport to the laboratory at the UNC Coastal Studies Institute (UNC CSI) where they were filtered and prepared for chl a analysis within 48 hours of sample collection.

We used two methods to collect chl a data: using a YSI 6600 V2-4 water quality-sampling sonde and extracting chl a from surface and benthic water samples. After initial analysis, we determined that the extracted chl a measurements (water samples) from near the sediment surface (bottom of the water column) were less prone to
anomalies associated with sediment suspension (when the YSI came into contact with the bottom sediments) than those taken with the YSI monitor. Because of this, we only used the extracted chl a measurements in our data analysis.

We returned to the UNC CSI laboratory less than six hours after collection and filtered water samples through glass fiber filters (Whatman GF/F; 25 mm) for chl a analysis. After filtration, we folded each filter and wrapped them in aluminum foil to be stored at 4°C for 24 hours.

We used the Wisconsin State Lab of Hygiene chl a method as the basis for extracting chl a from the filtered water samples (EES method, 1991). Briefly, we placed the filters in centrifuge tubes and added 14 mL of 90% acetone solution. After, we used a Branson Digital Sonifier model 102C to sonify each sample for 20 seconds. The sonifier was out of order for our first two sets of samples (August 24 and September 4), so we completed the cell disruption step on those dates by hand with a tissue grinder. All disrupted chl a samples sat overnight (12-16 hours) at 4°C to allow complete extraction. The following day, we ran the extracted samples through a centrifuge for 30 minutes to separate the chl a from the filter. In each test tube, there was a clear substance separated on top of a murky, more solid substance. The clear substance contained the chl a in acetone solution and was decanted for analysis using an Evolution 201/200 UV-Visible Spectrophotometer. We measured each sample at 750nm, 665nm, 663nm, 645nm, and 630nm wavelengths.
For calculation of uncorrected chl a concentrations, we first subtracted the 750 nm absorbency (Abs) from the 663nm, 645nm, and 630nm values to correct for turbidity. We then inserted the turbidity-corrected absorbency data from the spectrophotometer measurements into the following equation to calculate the uncorrected chl a concentration.

\[
\text{Uncorrected Chlorophyll a (µg/L) = } \frac{[11.64 (\text{Abs663}) - 2.16 (\text{Abs645}) + 0.10 (\text{Abs630})]}{E(F)} \]

Where \( F \) = Dilution Factor (i.e., if the 663 Abs is >0.99 with the 1 cm cell, dilute, re-analyze and insert the dilution factor in the equation)

\( E = \) The volume of acetone used for the extraction (mL)

\( V = \) The volume of water filtered (L)

\( L = \) The cell path length (cm)

(EES method, 1991)

We corrected final chl a measurements with a 90% acetone blank to obtain results not affected by any inaccuracies from the spectrophotometer. To analyze chl a, we compiled all of the data from each collection date and sorted it by study site to create three large data sets (an aquaculture facility set, a wild reef set, and a control site set). The aquaculture facility had 47 data points (23 inside and 24 outside), the control site had 21 data points, and the wild reef had 16 data points. When categorized by dates, we had 16 data points on August 24, 18 data points on September 4, 23 data points on September 18, and 23 data points on September 30.

We individually corrected each data set for outliers by calculating upper and lower fences from the first and third quartiles. We conducted two-sample T-tests to
determine whether differences in the data sets were statistically significant. We also sorted our original data by date to test how homogenous our data was across the sample period. We individually corrected each set for outliers the same way and then conducted two-sample T-tests.

**d. Bottom and Secchi Depths**

We compared the Secchi depths among each of the sampling sites and sampling dates. However, in a large portion of our measurements, the Secchi disk could still be seen at the bottom, so many observations were qualitative rather than quantitative. For quantitative data analysis, we used the mean Secchi depth at each treatment site to compare water clarity among locations. We also compared qualitative observations from Secchi depth results to quantitative data from the LiCor analysis because both methods assessed water clarity.

At each sampling site, we lowered the Secchi disk into the water column from the side of the boat fully exposed to the sun. We measured the Secchi depth (m; depth where disk is no longer visible) and the bottom depth at each sampling site and date. If the disk was visible throughout the water column, we recorded Secchi depth as “bottom.”

**e. Light Extinction**

On each sampling date, we used a LiCor LI-400 with PAR and reference sensors to measure photosynthetically active radiation (PAR) at solar radiation wavelengths of 400-700 nm at three random locations within each sampling site. The spherical PAR
bulb senses light from 360° degrees and the small reference sensor only detects the light from above. The reference measurement was important because it indicated any change in ambient light or cloud cover as the depth profile was measured. We used PAR measurements to calculate light extinction (K) through the water column. We took the PAR measurements by noting the reference first and then lowering the LiCor into the water, taking measurements at the surface and every 0.25 or 0.5 m increment until the bottom was reached. We began our research by measuring at every 0.5m on August 24 and September 4, but changed the increment to 0.25m on September 18 and September 30 for a more precise average k value. We attached a measuring tape to the LiCor for a more precise depth measurement. Locations with aquaculture gear could not be accessed so we did not take light extinction measurements in these areas.

We used the Lambert-Beer Equation to calculate the light extinction from the LiCor PAR measurements for each location and date.

\[ k = \frac{-\ln(l_0) - \ln(l_z)}{z} \]

where

- \( z \) = depth, in meters
- \( l_0 \) = PAR at the surface
- \( l_z \) = PAR at depth, \( z \)
- \( k \) = Light Extinction Coefficient

We calculated the \( k \) for each depth and then took the average of all of the depths from each sampling location on each date. We then combined all the data for each individual site and calculated the standard deviation. When averaging the data from each site, the aquaculture facility had 24 data points (12 inside and 12 outside),
the control site had 12 data points, and the wild reef had 9 data points. When categorized by dates, we had 9 data points on August 24, 12 on September 4, 12 on September 18, and 12 on September 30. For the purpose of our data analysis we took the absolute value of the light extinction value, $k$, to make our graphs.

**Submerged Aquatic Vegetation (SAV)**

We assessed SAV distribution at the aquaculture facility and the control site on September 4, September 28, and September 30, 2015. The water at the wild oyster reef was too deep for SAV growth.

On September 4, we chose three random sampling locations inside the aquaculture facility based on accessibility. Outside of the aquaculture facility, we sampled along transects starting from two designated posts on the north (labeled NE and NW) and south (labeled SE and SW) borders of the facility. We measured and recorded the distance from the shore of the dredge spoil island to each of the four posts. Transects started at one of the four designated posts on the facility’s perimeter and extended to 25 m away from the post. We collected SAV from six locations along each transect: at the post (0 m), and 1 m, 2 m, 5 m, 10 m, and 25 m from the post. At the control site, we collected a total of three SAV samples at distances from the dredge spoil island corresponding to the distances of three of the four posts to the dredge spoil island adjacent to the aquaculture facility.
We used a different method to collect SAV on the September 18 and September 30 because the initial method was not uniform between sites. We also wanted to add more samples per site and a more randomly distributed selection so that we could better compare average SAV density among sites. For the new method, we collected ten random SAV samples at each site for a total of thirty samples. On September 4, collection teams randomly chose sampling locations at each sampling site. On September 18 and 30, we chose sampling locations at each site using Excel’s random number generator to ensure randomized and unbiased distribution. We utilized the numbers to randomly sample within a 50 m perimeter of the facility.

At each sampling location, we dropped a weighted 0.25m² PVC pipe quadrat at arm’s length. All rooted SAV within the quadrat was collected manually by uprooting and placed in gallon-sized zip-lock bags. We washed all collected SAV and separated the living, aboveground biomass from the roots and dead organic matter. After drying the living aboveground biomass in a low-heat dehydration oven at 60°C for at least 48 hours, we recorded the dry mass for each sample.

We compared SAV density among different sampling locations by calculating the mean and standard error of the SAV dry mass across all dates and for the specific locations within and outside of the aquaculture facility and control site. We calculated these summary statistics in order to compare SAV density in different directions outside of the aquaculture facility (North, West, and South), at different distances from the perimeter of the facility (0, 1, 2, 5, 10, and 25 m), and near different features inside
of the facility (boat channel, close to submerged oyster racks, close to floating oyster bags, and clear areas).

Filtration

a. Experimental Set-Up

The day before the experiment, we collected 40 gallons of water from the edge of the Oregon Inlet Boat Ramp. We filled four tanks of equal size with 35 L of water. We collected plankton using a 153-micron mesh plankton net from the Bonner Bridge at Oregon Inlet when the tide was going out. We pulled the net 6 times (approximately 2 minutes for each pull) and emptied the contents into a bucket. We then placed an air stone into the bucket to provide oxygen and stored it in the lab for approximately 24 hours. The plankton source chl a concentration was 240.1 µg/L (determined from a 100 mL filtered sample through spectrophotometry) immediately before the experiment.

On the morning of the study, we collected wild (diploid) oysters from a reef near Oregon Inlet and acquired aquaculture (triploid) oysters from a local aquaculture facility in the Pamlico Sound near Wanchese, NC (Joey Daniels - Wanchese Seafood). Joey Daniels harvested the farmed oysters the morning of the study and kept them out of water for approximately 30 minutes for transportation. All oysters were kept in buckets of Sound water before beginning the experiment.

In order to measure filtration rate differences between wild (diploid) oysters, aquaculture (triploid) oysters, and aquaculture (triploid) oysters in a rack structure, we set up four closed-system aquarium tanks with water and plankton from the Sound. We
used a closed-tank system with a water pump and air stones to circulate the water (Hoellein 2014). We set up one pump (Sicce Voyager 3,000 L/hr Stream Pump) at the end of each tank and one standard small air stone at the center of the bottom of each tank (Figure 3).

**Figure 3:** Photo and overhead diagram of filtration tank set up. Pumps and air stones were aligned similarly for each tank and all tanks were oriented in the same direction at the same distance from windows.

We placed the four aquarium tanks equidistant from windows, turned off the lights, and closed all blinds in the lab room so that light interference was minimized. Additionally, we constructed a scaled-down version of a rack used at Joey Daniels’ aquaculture facility using the same rack materials. The rack was 19 cm long x 11.5 cm wide x 5.5 cm tall, and it was lifted an additional 4 cm off of the ground.

We randomly chose five aquaculture oysters for the non-rack triploid group, five more for the rack triploid group, and five wild oysters for the non-rack diploid group. We then measured the approximate length and width of each oyster (to the nearest 0.1 cm) as well as the mass. One tank was designated as the control tank with no oysters and the three remaining tanks were each assigned one of the oyster groups.
We took initial measurements of salinity, turbidity, chl \(a\), pH, temperature, and dissolved oxygen in each tank with a YSI 660 V2-4 before oysters or phytoplankton were added. We then placed the oysters in their assigned tanks with pumps and air stones running for 30 minutes before the experiment started to allow for acclimation, and took YSI measurements a second time.

b. Experiment

After the acclimation period, we added 1.0 L of mixed water containing our phytoplankton to each tank. Simultaneously, we started a timer to make note of when measurements were made throughout the experiment. We took YSI measurements every 10 minutes starting at minute 0. We took a 100 mL water sample for both CHN (although we ended up not analyzing this because of technical difficulties with the CHN instrument) and chl \(a\) analysis from each tank every hour, starting at minute 0. The experiment lasted 3 hours. At hour 3, we removed and re-weighed all oysters. We then shucked the oysters from each treatment group and dried them in aluminum foil for 48 hours at 60°C to measure dry mass of the oysters in each treatment group.

c. Analysis

We calculated linear rates of change and r-squared values for the chl \(a\) concentrations from each tank. We used the rate of change from the control tank as a chl \(a\) settling rate. We subtracted this value from each other tank’s rate to calculate a filtration rate corrected for settling. From there, we divided each rate by the dry mass of the oysters within their tank, which gave us the filtration rates per gram dry mass.
Results and Discussion

Water temperature remained within a moderate range of 24.30°C to 28.49°C throughout our sampling period of late summer to early autumn (Appendix B). This is well within the eastern oyster’s normal growing temperature range of 10°C to 30°C (Division of Marine Fisheries, 2005). Salinity across all days and sites fell between 14.41ppt to 29.02ppt (Appendix B), which almost duplicates the eastern oyster’s range of suitable salinity of 14-30ppt (Division of Marine Fisheries, 2005). Depending on the species of SAV, high-salinity seagrasses can grow in salinity ranges from 0-36ppt, with the majority of SAV patches occurring within a moderate range of 15-26ppt (Division of Marine Fisheries, 2005). The pH range was slightly basic at all sites on all days, falling in a consistent range of 8.51-8.71 (Appendix B). Eastern oysters may have trouble with shell formation at higher levels of acidity, but this moderate level should not present significant trouble to them. Levels of dissolved oxygen ranged from 6.3ppm to 10.7ppm (Appendix B), falling well above the eastern oyster’s lower tolerance limit of 1-2ppm (Division of Marine Fisheries, 2005). Hypoxia and anoxia can be a frequent problem within the estuary for depths greater than 5m and sometimes in more shallow depths. Additionally, lower levels of light penetration deeper in the water column mean that SAV in North Carolina estuarine bottoms generally cannot grow at depths below 2.5m (Division of Marine Fisheries, 2005). Our sample sites ranged in depth from 0.6-1.35m, and hypoxic/anoxic conditions were not observed on any days at any of our sample sites.
(Appendix B). On all four days, all four sampling sites had water quality parameters that fell within the eastern oyster’s suitable ranges for each.

**Water Clarity**

We compared water clarity measurements, including turbidity, chl \( a \), \( k \), and Secchi depth among study sites and sampling days. Apart from a significant difference in chl \( a \) concentrations between two sites, we found no statistically significant differences in turbidity or light extinction among the four study sites over the course of the study.

Because our turbidity data did not show a difference among study sites, we rejected our water clarity hypothesis. We believe this discrepancy is due to tidal mixing during sampling; time of day and tidal influence were not consistent among all sampling days. Mixing during ebb and flood tides could have stirred and suspended sediment particles, masking local impacts of oyster filtration. Therefore, data results could be skewed if we took samples during tidal ebb or flood. Additionally, a large storm came through days before taking measurements on September 30, which, as Palanques (2006) found, can affect water clarity. Not allowing enough time for suspended sediment to settle after being disrupted by the boat’s motor could have also affected the measurements.
The turbidity values varied more by date than by location (Figure 4). Turbidity values from September 4 and 18 show the largest difference—turbidity values on September 4 were the lowest at the control site, and the values on September 18 were the lowest at locations with oysters present. Turbidity values on September 30 were the lowest across all sampling days. No other patterns were derived from the data.

![Figure 4: Average turbidity for each sampling date (x-axis) by study site (legend of study sites). Turbidity values varied significantly among sampling dates rather than among study sites.](image)

We found no significant difference in chl α concentrations between the aquaculture facility and control site (Table 2). However, we found significantly higher chl α concentrations at the wild reef than at the aquaculture facility (Figure 5). While this finding supports our general hypothesis that the chl α concentrations are lower at the aquaculture facility, analysis in context of environmental parameters led us to
conclude that the relationship might be due to similar water flow at the aquaculture and control sites. When we grouped data by location (i.e. aquaculture and control sites versus the wild reef site), we found that there was a significant difference in chl $a$ concentrations ($p = 0.04$, two-tailed T-test) between both the aquaculture and control sites compared to the more protected wild oyster reef site, suggesting that location within the sound matters water flow and dilution.

Table 2: Two sample T-test of chl $a$ concentration by site. There are significantly higher chl $a$ concentrations at the aquaculture facility than at the wild reef. Analysis did not show statistical differences between the aquaculture facility and the control site or between the wild reef and the control site.

<table>
<thead>
<tr>
<th>Site</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquaculture facility vs. Control</td>
<td>0.73</td>
</tr>
<tr>
<td>Aquaculture facility vs. Wild Reef</td>
<td>0.04</td>
</tr>
<tr>
<td>Wild Reef vs. Control</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Figure 5: Average chl a (µg/L) concentrations by study site (n=47 for aquaculture facility, n=21 for control site, and n=16 for wild reef). Chl a concentrations were significantly lower on average at the aquaculture site than at the wild reef. Error bars represent standard error.

Furthermore, there were no significant differences in k between sites (Figure 6). This could indicate that the aquaculture facility may not affect k as we hypothesized. Similar to turbidity measurements, the tidal cycle was not taken into account when sampling. We did, however, find a trend in light extinction across all sampling sites between the sampling dates (Figure 5). This could be due to outside factors independent of oyster presence such as varying water levels associated with lunar and
wind tides or mixing rates within the Sound.

Figure 6: Average Light Extinction ($k$) on each sampling date (x-axis) by study site (legend of study sites). Light Extinction values varied significantly among sampling dates rather than among study sites.

Secchi depths were not comparable between sites because of high variation in bottom depths across the study sites. Additionally, Secchi depth could not be measured at some sampling locations because the Secchi disk reached the bottom before disappearing. We did, however, still use bottom depth measurements from the Secchi disk for our environmental parameters that helped in data analysis.

While there are many variables that affect water clarity parameters. We suspect that dilution of any effect from oyster filtration due to water flow differences between
the sites had the greatest impact. Water flow on the Sound is mainly influenced by wind-driven tides that mix the water column due to its shallow nature. Additionally, the aquaculture facility is adjacent to a boat channel and approximately 6 km from the inlet, so there is likely a high rate of tidal water flow (Figure 1). The wild reef is in a very different location in terms of water flow. It is in a protected cove surrounded by marshland and is farther from the inlet (Figure 1). Wang et al. (2010) found that water flow was the most significant factor in determining water clarity in St. George Sound (Apalachicola Bay, Florida), which is also a shallow estuarine system with significant “wind driven mixing of the water column.” A potential future study could compare water clarity measurements between aquaculture and wild reefs in locations with similar water flows to hold dilution constant.

**Filtration**

Chl $a$ concentrations decreased linearly over time in all treatments containing oysters. The only tank with minimal change over time was the control tank. After correcting treatments with oysters for settling of chl $a$, we found that the tank with non-rack triploid oysters had the highest filtration rate per gram dry mass, 0.112 $\mu g/L/hr/g_{(dry\ mass)}$ ($R^2 = 0.969$) (Figure 7), and was almost double the lowest filtration rate observed in the tank with non-rack wild diploid oysters, 0.072 $\mu g/L/hr/g_{(dry\ mass)}$ ($R^2 = 0.891$). The filtration rate for the wild diploid oysters in a similar study assessing oyster filtration rates (0.094 $\mu g/L/hr/g_{(dry\ mass)}$) lies between the rates observed for diploid and
triploid oysters in our study (when scaled to the average dry mass per oyster for diploid oysters in our study; Jones et al, 2000).

**Figure 7:** Filtration rate of three different treatments: triploid oysters, non-racked triploid oysters, and non-racked diploid oysters. Filtration rate is rate of reduction of chl a concentration (µg/L) per hour per gram of oyster dry mass. No error or significance can be calculated because we only performed one trial (n=1).

Because the experiment only included one replicate, we cannot make strong inferences about the effectiveness of different treatments on the oysters’ filtering ability. Future studies investigating oyster filtration should include more replicates. In addition, previous studies investigating the effects of oysters on water quality have collected pseudofeces from the filter feeders in order to measure the rate of oyster deposition (Newell 2005). This measurement could be used in conjunction with chl a concentrations in future studies.
Submerged aquatic vegetation (SAV)

We originally hypothesized that there would be a difference in SAV dry mass between the aquaculture facility and the control site. We hypothesized that gear at the facility might promote SAV growth near the perimeter because the ropes and bags catch SAV seed pods and allow them to settle as well as reduce scour of SAV associated with strong water flow. Finally, we hypothesized that presence of oysters at the aquaculture site would promote overall SAV growth because of enhanced water clarity due to oyster filtration. We assumed that these different factors interact with one another and with other environmental factors that control SAV density. Therefore, we attempted to test each of the hypotheses separately in order to determine each factor's influence as well as the combined impact of all factors on SAV growth at the aquaculture facility as compared to the control site.

SAV densities were temporally (averages and standard errors in Figure 8) and spatially (averages and standard errors in Figure 9) heterogeneous. Over the three sampling dates, average SAV density ranged from approximately 0.8 g/m² on September 18 to 2.5 g/m² on September 30 (Figure 8). Additionally, average SAV density across all sampling dates was higher at the aquaculture facility (inside and outside combined) than at the control site (Figure 9), though the difference was not significant. The highest average SAV density occurred within 50 m of the facility (1.60 g/m²), followed by inside the facility (1.21 g/m²), and then the control site (0.99 g/m²).
Variance in SAV density was higher at the facility (inside and outside) than at the control site.

**Figure 8 (left):** SAV dry mass (g) per meter squared area of estuary bottom by date sampled. The samples showed high temporal heterogeneity. Error bars represent standard error of the data. (n=30 for each sampling date)

**Figure 9 (right):** SAV dry mass (g) per meter squared area of estuary bottom at the control sites and the facility, which includes inside of the facility as well as within 50 m from the perimeter of the facility. Error bars represent standard error and demonstrate the spatial heterogeneity of SAV among sampling locations. (n=23 at control site and n=66 for aquaculture facility). This difference is not significant, but the average SAV density at the facility was qualitatively higher than at the control site.

We found no significant difference in average SAV density between the aquaculture facility and the control site. By sampling SAV mass directly outside of the facility and in different areas within the facility, our data suggest that the facility promotes or at least does not severely impact the density of SAV. We attribute this finding to the scale of our study—we extended the study site to include inside and
within 50 meters of the facility. Other studies have concluded that aquaculture gear inhibits growth directly below the gear (Everett, 1995), which we did not directly measure. However, we believe that our study better represents the influence of an aquaculture facility (at least of this size) on a more representative spatial scale because it includes the area surrounding and within the facility.

![Figure 10](image_url)

**Figure 10:** SAV dry mass (g) per meter squared area of estuary bottom compared among different areas within the site and compared to the control (n= 2 for clear, n= 2 for racks, n=9 for boat channel, n= 4 for bags, and n=23 for control). Error bars represent standard error for each use area SAV was collected near. Error is very large for several categories because of limited sampling in these areas (sampling was random within the facility).
Within the facility, we found differences in the average density of SAV between areas used for different purposes (Figure 10). We found the highest average SAV densities near bottom racks (2.7 g/m²), in clear areas (1.7 g/m²), and in the boat channel (2.4 g/m²). Lowest average SAV density was recorded near floating bags (0.079 g/m²; compared to control site average SAV density of 0.99 g/m²).

We observed higher average SAV mass to the north and south of the facility as compared to the west side (p-value 0.060, two-tailed T-test). This supports our hypothesis and suggests that the facility may reduce erosion and scour that could negatively affect SAV. However, a direct measure of suspended sediments and/or erosion rates would be necessary to confirm this assertion.

While we observed higher SAV density at the aquaculture facility than at the control site (which was not a significant difference), our water clarity data does not indicate that this difference can be attributed to water clarity improvements at the facility. This suggests that the facility promotes SAV growth through other mechanisms. Many environmental and biological factors influence SAV distribution (Fonseca, 1998; Townsend and Fonseca, 1998; Fourqurean et al, 2001). Local heterogeneity contributed to high error associated with our results. Variance in SAV dry mass at the facility compared to other sites suggests that factors related to aquaculture gear or activity increase local SAV heterogeneity.

The tidal- and lunar-driven currents predominantly flow north/south, so we hypothesized that the facility was slowing down the flow of the water and reducing
scour of SAV in the north/south directions. We collected higher SAV dry mass in the northern and southern directions of the facility compared to the western direction, which supports this hypothesis.

We found highest SAV dry mass near bottom racks, though this is not a robust comparison because we only collected two SAV samples near bottom racks (versus 5-10 samples in other areas). Regardless, the average SAV dry mass near bottom racks was higher than in any other location within the facility or control. Other studies observed no growth of SAV directly beneath bottom racks (Everett, 1995). Our data did not cover the area directly beneath bottom racks, and therefore cannot be used to address impact of direct obstruction on SAV growth by bottom gear.

Our data supports the hypothesis that shading from aquaculture gear inhibits SAV growth because of the low SAV dry mass near floating bags and higher SAV dry mass in the boat channel (p-value 0.0081, two-tailed T-test) and in clear areas. Our samples most likely captured shading impacts. We were able to sample almost directly underneath the floating bags because they shift position on the top of the water column.

Finally, average SAV density tended to increase from 0 to 25 meters out from the facility’s edge (Figure 11). This did not support our hypothesis that SAV density would be highest near the perimeter (around 0 meters from the facility’s edge). However, a 2014 study of SAV at the same aquaculture facility and control site (The oyster banks: a dive into the political, scientific, and social realms of oysters and oyster
aquaculture in NC) found a zone of high density of SAV around 50 meters from the perimeter of facility. It is possible that our samples only captured part of the trend of SAV growth outside of the facility, and that it could have a positive impact on growth at a distance further away.

![Graph showing SAV density vs meters from edge of facility]

**Figure 11:** SAV dry mass (g) per meter squared area of estuary bottom.

**Conclusion**

Overall, our data show that the aquaculture facility does not negatively impact SAV growth or water clarity. This suggests that the aquaculture facility that we studied in the Roanoke Sound has a neutral ecological impact and does not influence local water clarity at such a dynamic and well-mixed location within the estuary.
We found no significant differences in chl α concentration, turbidity, light extinction, or SAV density between the aquaculture facility and the control site. Water clarity measures seem to be influenced more by differences in water flow and location than by the presence of oysters, whether wild or farmed, which is exemplified by the significant difference in chl α concentration between the aquaculture facility and the wild oyster reef. Therefore, the impacts of the facility on water clarity, whether negative or positive, were most likely undetected because they were masked by water flow. Even though the data trends were not statistically significant, we found higher SAV density inside and outside of the aquaculture facility than at the control site, which supports our hypothesis that the facility may promote SAV growth.

If our limited filtration study is representative, triploid and racked triploid oysters used for aquaculture have the capacity to filter at a rate similar to, if not higher than wild diploid oysters. Therefore, the aquaculture facility should provide the same water quality benefits of oyster filtration as a wild reef. In order to more rigorously test these results, additional filtration study trials should be conducted.

A more comprehensive study of the effects of aquaculture facilities in diverse areas of the Sound over a longer time period would yield more robust information about the influence of oyster aquaculture on its surrounding environment. A similar study of water clarity and SAV should be performed in a region with lower water flow to conclusively determine local water clarity impacts of an oyster aquaculture facility. Additionally, future field studies should control for environmental factors such as tidal
flow, weather conditions, and recent storms as well as interference of the boat's motor on water clarity measurements. Since water clarity parameters are highly variable and SAV growth is seasonal, we recommend more collection dates over a full year for a more robust comparison among sites.

Our findings are significant because they demonstrate that oyster aquaculture has the potential to provide similar ecosystem services as wild oyster reefs without causing negative ecological impacts. First, we found that oyster filtration among wild, aquaculture, and racked aquaculture oysters is comparable. Second, we found no significant differences among the study sites that we can attribute to impacts caused by the aquaculture gear. Finally, previous studies have demonstrated that aquaculture gear can serve as better habitat for juvenile fish than SAV beds alone (Delteris, 2004). These findings challenge the assumption that oyster aquaculture facilities have a negative impact on SAV density. This has the potential to influence regulation concerning siting of oyster aquaculture facilities.
Social Science:
Local perceptions of oyster farming in North Carolina’s Albemarle-Pamlico estuarine region

Introduction

Coastal resources and stocks of economically valuable aquatic species continue to be stressed by human use and development along the Atlantic coast. One such commercially valuable estuarine species is the eastern oyster, *Crassostrea virginica*. North Carolina’s stock of wild oysters declined throughout the twentieth century (Division of Marine Fisheries, 2005). Commercial overharvesting took a toll on natural eastern oyster stocks. Human population increases and improvements in oyster harvesting technologies degraded oyster reef structure and accelerated harvest faster than wild stocks could replenish themselves (Newell, 1988). The damaged reef structure and smaller oyster population was vulnerable to degraded water quality and increased incidence of disease, leading to further mortality and limited recovery (ECSGA, 2015). By 2005, overharvesting along with a plethora of secondary factors diminished commercial harvests of wild oysters in NC to a meager 10% of their record catch in 1889, the year dredging began in NC (Division of Marine Fisheries, 2005). This resulted not only in decreased water quality, but also in the loss of a viable commercial fishing sector and cultural tradition within coastal communities along the Albemarle and Pamlico Sounds.
With the diminished size of the wild oyster population, aquaculture has emerged as a viable alternative to supplement supply for the growing half-shell market (Hudson and Murray, 2014). Aquaculture is increasingly used to meet the seafood demand previously supplied by now-stressed wild stocks (FAO, 2014). It can also be seen as an economic supplement to communities that depend on seasonal fishing income, because aquaculture shellfish are sold year-round (Turano et al, 2012).

Unlike finfish aquaculture operations that utilize hormones, require the addition of fish food, and concentrate fish waste, shellfish aquaculture is seen by many to be much more environmentally benign (Monterey Bay Aquarium Foundation). This is because shellfish like the eastern oyster are filter feeders, which consume phytoplankton and other small particles from the water column, cleaning the water in the process (Dumbauld et al, 2009). The cages and bags used in oyster aquaculture facilities can also act as habitat for the many fish species (Tallman and Forrester, 2007).

In the past few decades, other states like Louisiana, Maryland, and Virginia have established policies, regulatory frameworks, and industry infrastructure to support thriving shellfish aquaculture industries (NC Rural Economic Development Center, 2013). However, shellfish aquaculture remains a comparatively small industry in North Carolina. Last year, oyster farmers in Virginia sold almost 40 million oysters, whereas oyster farmers in North Carolina sold only three to four million oysters (NC Rural Economic Development Center, 2013). In 2014, the NC oyster aquaculture industry
netted $343,000, much less than the $17.1 million brought in by Virginia that same year (Lee, 2015).

Even with growing interest in oyster aquaculture in North Carolina, the potential socio-economic impacts of an expanding and robust oyster aquaculture industry on coastal communities remain largely unknown and understudied. In their 2012 survey of the North Carolina aquaculture industry, N.C. Sea Grant suggests that such impacts could include increased diversification in the local seafood market, lessened competition from seafood imports, addition of new primary and secondary income sources for watermen, and increased stimulation and stability in post-recession rural coastal economies (Turano et al., 2012). Through semi-structured interviews with key stakeholders who depend on the APES and reviews of the existing literature, we seek to understand local perceptions about how a larger aquaculture industry could impact the coastal environment and communities. We examined the regulatory, environmental, and economic challenges facing the industry in an attempt to clarify the reasons behind the lack of growth in North Carolina’s oyster aquaculture industry and why other states have been more successful in fostering expansion.

Methods

Approach

We took a qualitative research approach to assess perceptions of oyster aquaculture held by users of the Albemarle-Pamlico Estuarine system. A qualitative study allowed us to integrate multiple perspectives and to develop deeper descriptions
of perceptions of oyster aquaculture than a qualitative study would permit (Dey, 1993; Weiss, 1994). Instead of presenting our interviewees with yes/no questions or a survey, we asked questions that would allow interviewees to tell us their thoughts instead of us leading them to the answers.

Data collection and analysis was guided by grounded theory. Grounded theory is a process that generates concepts by identifying themes in the data to link information from various sources together (Strauss and Corbin, 1990). This approach requires coding, which looks for emergent concepts in the data. These codes break the data into pieces and assign them to different categories that allow for the data to be organized into reoccurring themes. Grounded theory does not seek to formulate a research question or hypotheses before collecting the data; instead, these are determined from the data during analysis (Glaser and Strauss, 1967). Therefore, collecting information, coding, analysis, and creating questions were all completed simultaneously, while remaining grounded in the data.

Sampling

We utilized purposive sampling to select interviewees from the pool of stakeholders in the Sound. A stakeholder is person who has an inherently vested interest in the matter being studied. This interest may be institutional, recreational, economic, or cultural. After careful consideration, we agreed upon four key stakeholder groups to the Sound that we believed would be able to provide the best information to address our questions. These four groups were: commercial fishing, recreational
business, oyster aquaculture, and government/nonprofit. Members of these groups frequently use the Sound, typically have broad knowledge or understanding of the Sound, and/or are involved in oyster aquaculture.

We used referrals to identify interviewees, with initial contacts coming from members of the Community Advisory Board (CAB) for the Outer Banks Field Site. The CAB is a group of local residents who generally advise our academic program and more specifically assist us with our project. We obtained subsequent interview referrals by using snowball sampling, whereby each interview participant suggested other potential interviewees. We had difficulty contacting commercial fishermen, so we went to a local fishing port in Wanchese to recruit commercial fishing interviewees in person. In total, we interviewed 27 people: 8 commercial fishing, 4 recreational business, 7 oyster aquaculture, and 8 government/nonprofit. The interviewees were located as far north as Nags Head, as far south as Wilmington, and as far inland as Columbia, North Carolina.

Interviews

We conducted interviews at a mutually agreeable date, time, and location, typically at the participant’s workplace, home, or the University of North Carolina Coastal Studies Institute (UNC CSI). We recorded interviews on an iPad and they lasted, on average, forty-five minutes to one hour. The Institutional Review Board of the University of North Carolina at Chapel Hill approved the interview process.
Interviews were semi-structured based on an interview guide where question order and follow-up questions could vary depending on individual responses. We asked participants open-ended questions focusing on their connection to the Sound, changes they have observed in the Sound, expected changes in the future, concerns about the state of the area, perspectives of oyster aquaculture (including perceived positive or negative effects), and how it may have affected them in their line of work (see Appendix A for full Interview Guide). To limit interviewer influence, if interviewees asked questions on the topic, interviewers avoided providing opinions or more information until the end of the interview. A map of the area was brought along for referring to and marking important areas mentioned.

Time kept us from achieving what we would consider to be saturation of interviews. However, by the end, many topics were reoccurring, so we believe we were close to achieving saturation. We would have preferred to talk to more recreational business owners, particularly those employed in businesses besides charter boats. We also were unable to talk to every government agency associated with the use of the Sound. Additionally, a wider geographic range of commercial fishing interviewees would have benefited our study.

Analysis

We transcribed each interview and then analyzed them using NVivo, a qualitative analysis software package. We utilized a coding process to organize sections of the transcripts into labeled groups. These labels are called nodes or codes. We
constructed and defined a master code list so that the coding process was as consistent as possible. We then coded the transcripts with the same list of codes so that we could identify major themes that occurred throughout the interviews.

**Results and Discussion**

By completely immersing ourselves in the data, themes naturally began to emerge. We categorized the themes into six sections: coastal economy, industry barriers, natural environment, water quality and development, spatial and user conflict, and awareness and education. Coastal economy describes the current state of the economy, sources of revenue, and how oyster aquaculture may fit in, and industry barriers illustrate the obstacles oyster farmers directly face. The natural environment details the benefits oysters provide as a keystone species, and water quality and development discusses how development will affect the ecosystem services oysters provide. Spatial and user conflict describes how oyster aquaculture may impact stakeholder interactions with the Sound. Awareness and education characterizes the gaps in knowledge about oyster aquaculture. While each of these themes presents different ideas, they are interrelated and impact one another.

**Coastal economy**

Outer Banks, NC is known for its booming tourist season, but the year-round residents are concerned that the coastal economy cannot depend solely on this single industry. Many interviewees mentioned increased coastal development, but this was
typically in light of its negative consequences—no one spoke about it benefitting the locals.

Everyone preaches about how wonderful the tourism is but, you know, try living here in January. You still have those stupid high grocery bills and everything else but you don’t have any of that work that you can go over and do in the summertime. All those restaurants close, and all those cottages are empty, and they don’t need people cleaning the cottages, waiting tables in the wintertime and all that. The economy dies, there’s nothing here but boat building and fishing. (Oyster Aquaculture)

Starting in October, jobs offered by the tourism industry disappear and many people struggle to get a paycheck in the winter months. Cultivating oysters occurs daily year-round, so those employed in tourism could potentially use this as a source of revenue after the tourist season ends.

Many interviewees spoke about declining fish and oyster populations. Because fishing is so integrated into coastal communities, changes in the commercial industry have ripple effects throughout the rest of the economy.

Everything affects you out here, the weather affects you out here, you know the fish populations affect you out here, everything affects you because the community is so tightly tied to [fishing] because it always has been. And there’s nothing else here. (Oyster Aquaculture)

With declining fish populations and increased regulations, there are fewer fishermen on the water. Fewer fishermen result in lower demand for people who build and fix boats, sell fishing gear, transport seafood, etc. Some interviewees felt that oyster aquaculture has the potential to bring jobs to the coastal community.
It would create jobs because there's employment opportunities not just for farming, but for processing. ...and there could be some other industries, like value-added products, that could also increase jobs, stabilize the economy too. (Oyster Aquaculture)

Examples of the potential employment opportunities mentioned by the interviewee include owners of facilities, workers who maintain various parts at the facilities, workers at oyster hatcheries, workers who transport and ship the oysters, and workers at fish markets. Interviewees asserted that those suffering due to the decline of the commercial fish harvest could change industries to have a steady income.

In order to make a living as a commercial fisherman you have to—you have to deal across multiple species. And I think an oyster has the potential to be another species that the commercial fishermen can put into their livelihood and that...has the potential to resonate throughout a lot of these rural, coastal communities in terms of keeping them resilient and keeping the people working. (Oyster Aquaculture)

They indicated that the creation of any jobs at all would be beneficial to coastal communities. Other interviewees, however, stated that they did not foresee fisherman entering the oyster aquaculture industry.

...less than probably 25% would consider doing that [working in oyster aquaculture]. They’d have to be really down and out to try and take that job. Even though it still involves being on the water, but you’re having to turn cages or maintenance of the lines or whatever technique you’re trying to do in aquaculture... by and large, you know, the independence, being your own man, is what it’s all about. And so, going to work and wearing a hard hat and being the whole safety regime of production and its just not appealing to a lot of these fishermen. (Commercial Fishermen)
If other fishermen hold this same belief, the employment opportunities created by an expansion of the oyster aquaculture industry may not be as beneficial to the commercial industry as many of the interviewees believed.

**Barriers to the Industry**

While oyster aquaculture may be beneficial to the coastal economy, many interviewees mentioned potential obstacles to entering the industry.

*a. Regulation*

Like any other industry, oyster aquaculture must have regulations; however, interviewees suggested that North Carolina’s aquaculture regulations are challenging for oyster farmers and expressed concerns about the fragmented and unsupportive regulatory system.

...some of the impediments that have been brought to my attention are that it is very difficult to go through the aquaculture permitting process, and there’s a lot of paperwork involved, and upfront expense. [Oyster farmers] also felt for a while that they weren’t getting support from the state to do aquaculture. There was no policy saying that aquaculture wasn’t allowed in the state of North Carolina, but I think there was a feeling that they weren’t being given permission to do it. (Government/NGO)

As discussed in the Background, the changes in legislation throughout the past decade discourage entry into the industry. Oyster aquaculture requires a consensus between agencies on how to streamline complicated processes, such as permitting, for farmers.
b. Submerged aquatic vegetation

Army Corps of Engineers NWP 48 is a crucial oyster aquaculture permit to obtain in regard to SAV. The interpretation of NWP 48 emerged as one of the greatest perceived barriers to the industry in NC.

It was hard to get our lease. Some other people could be doing this, but they could’ve been less determined than us and given up. That would not have needed to happen if it was a little easier to get started. We go and we pull an acre spot or a five acre spot and there’s, uh, 50 square feet of grass or less, and that whole area gets denied. (Oyster Aquaculture)

This is a common sentiment shared by other aquaculture interviewees. Regulatory agencies understand that obtaining leases can be a difficult barrier for oyster farmers, but one of their major concerns is to ensure stable populations of SAV for wetlands.

Well the marine life is one of the main concerns that [our agency has], and of course trying to balance the development that [this agency is] permitting and being certain that the activities and structures we’re permitting are structures that won’t impede marine life... One of the things we look at is SAV. We don’t permit structures in areas that have SAV because we see that as a marine nursery area. We do protect coastal wetlands because of the quality of that area for marine life and nursery areas so those are really what our main concerns are. (Government/NGO)

While aquaculture interviewees demonstrated that they understand the ecosystem services that SAV provides, they argued that oyster aquaculture might encourage SAV growth rather than impede it.

There seems to be some discrepancy in what use to prioritize: aquaculture or SAV conservation. Regulators are still finding a balance between the two, and much is still unclear about how both uses might interact with one another.
Contrary to previous regulations, the Session Law 2015-241, House Bill 97 encourages growth of oyster aquaculture. While this is hopeful for the industry, interviewees discussed the need for more consistent, clear, and concise regulation concerning oyster aquaculture.

I've heard many, many stories from farmers... about how cumbersome [regulations] can be, but I've also talked to the regulatory people that talk about how challenging regulating something that's not really part of their central mandate is. I don't think there is a bad guy in this situation, I just think it's something that hasn't been well thought out or well worked out because there's never been a need before. I guess now there is a need [for regulation], so hopefully they will be able to follow through with some of the legislation that suggested that they simplify or make this work better. (Oyster Aquaculture)

Oyster farmers appeared to disagree with industry regulations, particularly the strict SAV NWP 48 mandates. If regulation surrounding this issue is not resolved in 2017 (when the permit terms are slated to be revisited), it could prevent or hinder industry growth.

In addition to policy concerns, interviewees discussed other barriers to oyster aquaculture in North Carolina. The major themes that we saw in our interviews were seed, site selection, cost, lack of network, physicality of the work, and oyster mortality.

\textit{c. Seed}

Barriers to growth in the oyster aquaculture industry come in all shapes and sizes, and oyster seeds, as small as they are, cause a large problem for farmers.

Essentially, oyster seeds are baby oysters that remain unattached to any substrate. Before the larvae are large enough to put in racks or bags in an aquaculture facility, they must mature in a nursery. Some growers have these on site, while others must rely on
hatcheries dedicated to the production of seed, which is then sold in large quantities to oyster farmers to grow for harvest. NC farmers have limited options to obtain seed.

In North Carolina, there are two hatcheries: Millpoint commercial hatchery in Sea Level and a research facility at University of North Carolina at Wilmington (UNCW). While Millpoint does distribute seed to oyster farmers in NC, it is extremely small and cannot supply seed in the quantities farmers need. This forces farmers to go to other states and takes money out of NC. The UNCW research hatchery opened in 2011, and was the only one of three planned hatcheries built by the state. This hatchery is used for research only, and not for commercial supply. Additional production and education hatcheries were not funded, but they may still be constructed in the future. UNCW research includes two areas of focus: selective genetic breeding and identifying potential shellfish species that could diversify crops. Unlike other states, such as Virginia, North Carolina does not have its own genetic line of oysters.

And the truth of the matter is that our industry has historically depended heavily on Virginia and those lines from Virginia to support their farms. But what they find is one, as the industry has grown in Virginia, it is increasingly difficult to actually get any oysters out of Virginia. Two, it’s expensive to get them in because they have to be disease tested, which is expensive. Third, when they get them down here sometimes they don’t do so well. Yes, they are selectively bred to do fabulously in Virginia but our systems are different than Virginia. Our waters are different, phytoplankton communities might be different, and so the idea that we can just borrow from Virginia might not be, or doesn’t seem to be true. (Oyster Aquaculture)

This illustrates the importance of a genetic line specific to North Carolina that is bred to do well in NC waters. There is a genetic transition zone through the Pamlico Sound,
however, that may cause difficulties. The UNCW research hatchery is experimenting to create the best NC oyster lines tailored for their environment. Moreover, this stakeholder articulates difficulties farmers face from seed imported from other states. North Carolina may require a commercial production hatchery to become competitive with other states, such as Virginia and Louisiana.

d. Site selection

Picking a site to host an oyster aquaculture facility turned out to be a difficulty encountered by many of the interviewees that work with oyster aquaculture. There were many considerations mentioned that affected final location decisions. Among these, SAV was a large consideration and constraint. Other considerations included movement of the water, potential interference with current uses, distance from a workstation on land, and pollution problems.

Water conditions have to meet certain requirements to be appropriate for facilities.

...you got to look at each water body individually. You got to look at the flushing of the water body; you've got to look at the water depths. There are many things that can come into play when you talk about actually having a successful area for oyster farming. (Oyster Aquaculture)

Certain locations don't offer the protection or water flow needed to adequately sustain oyster aquaculture. Some of the aquaculture interviewees who mentioned location
discussed the importance of knowing the area being considered. Not understanding the Sound and its movements could potentially have very expensive consequences.

Another reason to understand each potential aquaculture site is to avoid conflicts with any current uses. According to interviewees, oyster farmers take measures to minimize interferences with these users.

I mean, if you’re part of a community and you’ve been part of a community, typically you know who fishes where, you know who surfs where, who kite boards where. And so if you can find a spot that has little or no impact on the balance of the community, I think that’s your ideal situation. (Oyster Aquaculture)

This stakeholder mentioned being a part of the community. This is not always the case for people looking into oyster aquaculture, but many interviewees mentioned that it is frequently considered. People who have lived or worked in an area typically become intertwined in the community, and frequently try to make decisions that benefit collective whole. Many interviewees took specific pains to avoid creating a conflict.

Distance from land operations is another major concern when choosing a site. Many aquaculture facilities are not conveniently located near the harbors. Many have to travel to their sites by boat, and then either set up a barge at the site, or bring the oysters back to land to sort. This is very physical work and can take extensive equipment, fuel, and time.

Another consideration is potential pollution that may affect the site. While filtering, oysters take in pollutants and absorb them into their tissues. In areas with
higher levels of pollution, this makes them dangerous for consumption. This restricts areas where oysters can be harvested. Areas that may be polluted, such as locations near docks with lots of boats, would not be optimal for an oyster aquaculture facility.

e. Cost

Cost, specifically upfront cost, was one of the largest concerns mentioned by interviewees for entering into oyster aquaculture. The amount of capitol required to obtain permits and equipment, seed, and upkeep, can be significant. One oyster aquaculture farmer said it succinctly, “you have to have money to make this stuff happen.”

Once a farmer chooses a site, there are fees associated with the approval process and the permit for the lease. Along with initial payments, there is also a filing fee of $100 for renewal of leases and a rental fee of $10.00 per acre per year (N.C.G.S §113-202(j)). Equipment costs depend on what type is used and add to the upfront cost of starting a facility.

Along with the upfront costs, if a site requires travel, farmers have to pay for boat usage and fuel costs. Another cost that occurs on a yearly basis is the cost of seed, unless the oyster farmer produces it on site. Other charges can pop up as well, such as upkeep, hiring workers, and storm damage. Oysters can take anywhere from 18 months to 3 years to develop to market size, so new farmers don’t see profits for over a year.
f. Physicality

Oyster aquaculture is a physically intensive job.

The uh, from the production side, like I said, it’s very physical. You’re farming on the water and it’s a moving surface… if you don’t love physical work, it might not be for you. You get cut; oysters are like razors certain times of the years. You get cuts, you can easily get, you get bumped around and dinged around… quite frankly it’s hard on you. (Oyster Aquaculture)

Oyster farmers have to handle the oysters every day from the time they are seed to the day they are sold. This entails putting them in floating bags and flipping them on a regular basis to help speed up the filtering process.

g. Mortality

Interviewees mentioned oyster mortality less than most of the other issues, but it was still an area of concern. The two main concerns about oyster mortality were boring sponge and natural storm events like hurricanes. Since oysters are a product that takes several years to cultivate, if one of these events occurs, it can be economically devastating to farmers.

It’s not like you can very quickly retool or recover. I mean, if something comes along and wipes out every oyster we have, it’s going to take 3 or 4 years to get back on our feet. So that’s one of the big drawbacks of our business. Hopefully that will never happen, but you never know. There’s lots of things. There’s risk on that front. And there’s insurance to protect against that kind of thing. It covers catastrophe, but it doesn’t compensate you for several years you put into it. So from the business perspectives, that’s one of the negatives. (Oyster Aquaculture)
While beneficial in many aspects, oyster aquaculture is at the mercy of Mother Nature, making it a potentially risky venture.

**h. Industry comparison**

We asked interviewees specifically about their ideas regarding the differences between the aquaculture industry in North Carolina and in other states. In particular, we looked at the discrepancy in the size of the industry between North Carolina and Virginia. We found that many people are aware of the differences between the two industries, but there was general confusion as to why the two industries were so dissimilar. In 2005, the industries were comparable in revenue, but by 2012 Virginia’s industry grew to about $9 million while North Carolina’s remained relatively stagnant (Table 3). (NC Sea Grant, 2013)

**Table 3: Oyster Aquaculture Sales in Virginia and North Carolina (NC Sea Grant, 2013)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Virginia</th>
<th>North Carolina</th>
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</thead>
<tbody>
<tr>
<td>2005</td>
<td>$240,000</td>
<td>$257,143</td>
</tr>
<tr>
<td>2006</td>
<td>$930,000</td>
<td>$306,698</td>
</tr>
<tr>
<td>2007</td>
<td>$1,440,000</td>
<td>$272,154</td>
</tr>
<tr>
<td>2008</td>
<td>$2,842,000</td>
<td>$221,946</td>
</tr>
<tr>
<td>2009</td>
<td>$3,276,000</td>
<td>$154,054</td>
</tr>
<tr>
<td>2010</td>
<td>$5,239,000</td>
<td>$247,074</td>
</tr>
<tr>
<td>2011</td>
<td>$6,990,000</td>
<td>$332,565</td>
</tr>
<tr>
<td>2012</td>
<td>$9,554,000</td>
<td>$595,446</td>
</tr>
</tbody>
</table>

Interviewees mentioned that North Carolina’s industry might have lagged behind Virginia’s either because we have no commercial hatchery or because of how difficult it is to obtain a lease for a facility.
Another reason that was mentioned by many different interviewees was simply that enough people did not show interest.

As far as why it hasn’t taken off, I mean it takes money to make money. So, I don’t think the right people that have the money have decided that it would be a good business venture. (Recreational Business)

Whether NC needs more interest to garner better legislation and reduce costs or if the better legislation and reduced costs will spark interest is unsure. There was not a general consensus among interviewees about how to cultivate more aquaculture in North Carolina.

**Natural Environment**

When assessing how oyster aquaculture would affect the natural environment, the majority of interviewees noted both the various benefits oysters would provide as well as a few concerns. “Keystone species” was a common term used by many interviewees in the study to describe oysters.

Well oysters are, as you now, are keystone species. They help, not only the environment as a whole by filtering the water, getting it clearer, so then our precious SAV can grow better because more sunlight gets to the bottom, but just them growing reefs provides structure for juvenile finfish, other crustaceans- just about everything at the lower levels once they grow up and are fishable. So, they just are the keystone for basically the whole environment out there. (Oyster Aquaculture)

While many voiced concerns about space and user conflict, generally those interviewed believed that oysters would be beneficial to the surrounding environment. A focal point regarding their perceived benefits was how they could improve water quality in the
estuary. A majority of those in every interviewee category noted this as a positive aspect that could come from introducing more oyster aquaculture. Whether a farmer, a fisherman, a recreational user, or a government/nonprofit agent, many understood that the combined filtering potential of an entire oyster farm would be a great asset to the estuary. Some interviewees mentioned that the estuary in general would be healthier and better able to support other species living in the area.

Clearer water would also help increase SAV growth in the area by allowing more sunlight to penetrate the water column, increasing plant growth.

Everything sorta relies on the filtration power of oysters... And throwing that out of balance is really bad and the estuary has to be vibrant and alive and make sure there's no giant algae blooms and fish kills. (Oyster Aquaculture)

However, those already in the aquaculture industry noted that while oysters have a positive affect on the water quality in a system, the existing quality of the water is a determinant to the location of potential farms.

It’s really hard to find something that’s open long enough throughout the year without closures for rain events and runoff. (Oyster Aquaculture)

Areas with poor water quality will not be approved in the leasing process because of the chance of diseases caused by pollutants in the area. Oysters are filter feeders so they can become contaminated as pollutants in the water build up inside their tissues. If an aquaculture facility exists in an area that is contaminated by pollution, the oysters would not be able to be sold for consumption. Therefore, the effect of oyster aquaculture, while beneficial to the surrounding environment, would not help the areas
that need it most. As one oyster aquaculture farmer said, “To me, that oyster is much more valuable where it was in the polluted water, since it’s a cleaning filter feeder.”

A large number of interviewees also mentioned oyster aquaculture’s ability to provide habitat for organisms in the sound.

Many of the same ecosystem services that natural oyster reefs provide are also characteristics of aquaculture; the oysters in the cage filter water just the same way that a reef oyster does. They also provide habitat. When we haul up the gear with oysters in them, there are all other types of other organisms in there. There's always a blue crab- a big fat blue crab. There's often times shrimp, snails, finfish...the gear itself provides habitat in the same way that a reef does. Maybe not exactly equivalent, but I think that those two major ecosystem services are provided by aquaculture as well as reefs. (Oyster Aquaculture)

The majority of those who mentioned this were in the aquaculture industry already, but at least one individual from the other three interviewee groups also discussed potential habitat as a benefit of oyster farms. Whether for fish or other crustaceans, oyster farms provide healthier environments, making the areas around them hotspots for activity.

As estuaries are huge nurseries for a variety of organisms, increasing aquaculture facilities could provide more structured habitats, which would be beneficial not only for more biodiversity, but also for the commercial fishing industry; supporting more juvenile fish allows for a larger commercial fish stock in the future. Additionally, another farmer mentioned that pseudofeces deposited onto the estuary floor by oysters acts as a nitrogen rich fertilizer that could enhance SAV growth. As SAV is a critical habitat for other organisms in the estuary, this could add to an oyster aquaculture facility’s ability to create healthy habitats.
Along with the environmental benefits of farmed oysters, interviewees in the aquaculture stakeholder group mentioned that, for the most part, their oysters may provide more reliable, sustained benefits than wild oysters.

...we know our oysters survive and make it to market size and are filtering the water from day 1 through day 600 or whatever it takes to get it to market. We just keep putting more and more behind it. Even though we might be taking oysters out of the water that could have continued filtering the water, I might be putting 3 to 1 back in because we’re growing our business. (Oyster Aquaculture)

Aquaculture oysters are protected by gear and are, more or less, guaranteed to filter the local water until they are harvested and sold. These benefits are strengthened since the majority of the oysters raised in aquaculture facilities are bred to survive extreme conditions like salinity or temperature spikes and drops. Additionally, aquaculture interviewees also discussed how aquaculture oysters allow for the harvest of a local seafood product without the environmental implications of wild harvest. Dredging the sound, one way of harvesting wild oysters, disrupts the hardened structures that oysters and other plant and animal life depend on for habitat (Conner, 1979).

When asked about their concerns regarding increased oyster aquaculture in the sound, very few interviewees mentioned any. Of the 27 people interviewed, only six mentioned any potential negative impacts on the environment, all of which can be grouped into four categories: potential diseases, introducing nonnative species, response to genetically modified organisms, and gear impact.

The first and most frequently discussed was the spread of disease, particularly the boring sponge: “…the only thing I can think of now that is becoming more of an
issue as we study it is that of the boring sponge. They [aquacultured oysters] may
become sinks for boring sponge at some point.” This issue was only brought up by three
of the seven aquaculture interviewees.

Another point of concern was introducing nonnative oyster species to the Sound
that may propagate and displace the wild stocks. Two interviewees were worried that
most farmed oysters are triploid, as opposed to the wild diploids, and customers would
be dissuaded from purchasing them because they are genetically modified.

Overwhelmingly, the majority of interviewees from each stakeholder group
believed more oysters would have a positive effect on the surrounding environment.
From improving water quality and habitats to being less invasive than wild oyster
harvesting, many interviewees indicated that aquaculture facilities would be a good
addition to North Carolina’s estuarine environment. While some mentioned concerns
associated with bringing more aquaculture to the area, the general consensus was that
more positive aspects can come from the industry increasing than bad effects. As one
individual said, “So do the ecosystem services outweigh any sort of potential negative
effects? I would say yes at this point.”

Water Quality and Development

Interviewees had different perceptions about the relationship between oyster
aquaculture and water quality. Some mentioned that areas with higher development
and bad water quality would be good sites for oyster aquaculture because the oysters
would provide the needed ecosystem service of water filtration. However, interviewees
in the aquaculture stakeholder group mentioned that these same areas are usually off-limits to aquaculture or wild harvest due to high contamination (fecal coliform, chemical runoff, etc.):

One of the big limiting factors is gonna be population density in the area. Unfortunately, people and oysters don’t mix. Either people make the habitat unsuitable for the oysters, or they make the environment so that any oysters that grow you can’t eat them because they’re polluted...So as far as a business and growing oysters, you’re probably better off to find the lower density areas on the coast. (Oyster Aquaculture)

As population increases drive development in coastal counties of North Carolina, the growing proportion of impervious land cover creates storm water runoff problems that can close shellfish waters temporarily or permanently (Angione, 2006).

But I think over the past 20, 30 years with more development, more people living in the area, more closures because people have moved in and now all the sudden you’ve got so many people and so much runoff in the area you can’t oyster there half the time anymore. They see water quality as being a bigger and bigger issue. (Oyster Aquaculture)

As little as 1.5 inches of rainfall can add enough contaminants such as “oil, sand, chemicals and fertilizers” to close shellfish waters (Angione, 2006). Increases in population density, when coupled with large storm water runoff problems, are strongly correlated with rises in levels of fecal coliform bacteria that make shellfish dangerous to eat (Angione, 2006). This is particularly salient for growing municipalities along the Outer Banks, most of which treat sewage on a house-by-house basis with septic tanks.

Nags Head does not have a septic system. They should. Anything like that close to the water, you know it has to hurt water quality. I don’t know any township in
Dare County other than in Manteo and Pirate’s Cove that has a sewer system.... Why don’t we have a sewer system?... It wouldn’t do anything but increase the water quality. You’d have more crabs, you’d have more fish, more oysters, you’d have better water quality.... A [sewer] system around here would be a big, big asset to the whole Dare County system. (Recreational Business)

Contamination issues are particularly significant to oyster farmers because most of their consumers are eating their product raw on the half-shell (Angione, 2006).

Interviewees also expressed the sentiment that oyster aquaculture could act as a check on future coastal development.

I think we need to keep a real good check on coastal development; I know it’s coming...And I think this is where shellfish farming could come in and play a big role because if we get shellfish farms in these areas where it’s low density right now and not many people and water quality is really good because not many people are living there and then somebody puts in a subdivision, and then all of a sudden they start testing the water, and all of a sudden your shellfish farm can’t harvest half the time because of the runoff coming from this subdivision. Well now you’ve got something quantitative... you can say, 'I’ve been here, I had a successful business,’ and unfortunately it comes down to dollars and cents... “You’re costing me money.” So now you’ve got something to go to the state with and say this is not just an environmental issue, this is a business issue. (Oyster Aquaculture)

As discussed above, this interviewee believed that oyster aquaculture has the potential to improve current water quality and can help control for future changes caused by development.

Spatial and User Conflict

A recurring theme throughout the interviews was the potential for conflict between oyster aquaculture and other Sound users. Many interviewees mentioned at
least some concern about the varying degrees of stakeholder use conflicts that the oyster aquaculture industry could present. Interviewees perceived different types of possible spatial, visual, and economic conflicts.

Interviewees brought up issues with facility locations, how this might affect them or their communities, and how it might affect other users. User conflicts were typically mentioned as the main concern for the growth of oyster aquaculture. However, many interviewees thought that environmental factors as well as the siting and leasing process prevented many direct user conflicts. In general, interviewees cited hypothetical user conflicts among Sound users rather than any personal or actual conflicts from experience.

The only thing that I can really think of, and it's one of those things you don't know until it starts happening and developing, is just any issues it could present to the commercial fisherman and any navigation areas. If it would maybe create some areas that would become off limits to commercial vessels. You know, different recreational users and boaters. That would be the only negative thing I can think of. And that may not be one. (Governmental/NGO)

This interviewee brings up user conflict as a potential problem, and as the only negative aspect of oyster aquaculture. We found a similar response across all of our interviewee groups. Interviewees generally thought that aquaculture would only be an issue if it monopolized the area, impeding navigation and other uses of the Sound.

There was a consensus among aquaculture and governmental/NGO interviewees that there is plenty of space in the Sound where oyster aquaculture facilities could be sited.

I won't say all the goods for taking, but there's plenty of room for an industry to grow. There really is. (Oyster Aquaculture)
However, many aquaculture interviewees frequently expressed that the siting process is often very difficult. This suggests that most interviewees who are familiar with siting oyster aquaculture facilities and obtaining leases (aquaculture and governmental/NGO groups) think that there is a lot of available area for siting facilities, but that on a case-by-case basis, obtaining a lease is often difficult.

The recreational interviewee group brought up more specific user conflicts. Interviewees discussed specific hypothetical conflicts, such as construction of an aquaculture facility in someone’s favorite fishing spot or duck blind. The recreational interviewees only mentioned hypothetical situations rather than any direct spatial conflicts that they personally experienced or knew about. Additionally, interviewees mentioned that some people will always have a problem with proposed aquaculture site locations, but the siting process generally resolves these conflicts. Many mentioned that the natural characteristics of ideal oyster aquaculture sites, such as their relatively shallow depth, are not ideal for commercial activities like those that require navigation with deeper-drafted boats, which inherently mitigates user conflicts. Overall, the recreational interviewees had positive opinions regarding oyster aquaculture and would like to see the industry grow as long as spatial user conflicts continue to be handled through the siting process.

We observed a discrepancy among interviewee perceptions about how the public could use aquaculture facilities. Oyster aquaculture facilities typically involve leasing the bottom of the Sound (unless the lessee also has a water column lease), so
the waters above remain in the public trust for free and unobstructed use by the public
(N.C.G.S. § 1-45.1).

Another part of the perception problem is why do people care if there’s a farm there? What is it stopping them from doing? It’s still public trust waters. If I have a farm, if you want to come fishing on, I can’t stop you...But, I think that the public perception, or some people think that, ‘Well if there’s a bunch of oyster farms then we’re not going to be able to go fishing or do this or do that.’ And that’s really not the case. Yeah, you’re not going to be able to ride your jet ski through there anymore because you’ll run into one of those poles and be hurt or something, but if someone wants to go kayaking or swimming or whatever they want to do, they’re welcome to do it... We are just renting the right to put our gear on that public trust bottom, and it doesn’t close it off to anybody. They’re not allowed to disturb our gear or they’re not allowed to pull up our cages and try to steal oysters out of them. But other than that, they can do whatever they want to do, it’s not taking it out of the public trust, it’s still there for them. (Oyster Aquaculture)

This aquaculture interviewee acknowledged that there is a degree of physical limitation to how public trust waters within aquaculture facilities can be used, such as pilings and cages impeding boat traffic or things like jet skiing. However, he pointed out that the area is still under public trust and everything short of damaging their gear is appropriate and allowable within oyster farms. However, other interviewees did not seem to be aware of the rights of the public to use the waters within aquaculture facilities.

Again, you’re going to have conflicts between the folks growing the oysters and other commercial fisherman and you’re going to have conflicts between folks growing the oysters and recreational fisherman who might use that area for fishing. That is on the assumption that once you lease some of the bottom, that then no one can really use it for anything else. (Governmental/NGO)
This different perspective highlights a limited public awareness of what users are legally able to do within aquaculture facilities. It also displays the perception of facilities as an obstruction of use for other Sound users.

One interviewee mentioned that only cultivating oysters in racks on the bottom of the Sound could reduce user conflict because they are out of sight and not an obvious obstruction to some navigation. However, this underscores the idea that the visual impact of a facility may change how most users perceive what they are allowed to do around or within facilities. A perception among the aquaculture stakeholder group was that other Sound users would prefer not to see aquaculture facilities near their homes or communities.

Prohibited waters... a lot of that comes from NIMBY-Not in my back yard- that’s a big thing. In other places, you’ll hear of people that buy a piece of waterfront property and don’t want to look at an oyster farm, that’ll mess up their view. (Oyster Aquaculture)

When potential property buyers consider purchasing sound-side real estate, physical access to the waters and pristine views are amenities for which they will pay a high premium. Many are hesitant to have these features potentially compromised by a use of the Sound that takes up a defined space adjacent to their property.

Just because somebody says 'I don’t want you to have your lease here because I don’t wanna see it,’ is that a valid reason?...We are gonna have the NIMBY people that will tell you to your face that they ‘love oysters, and think what you’re doing is great, but I don’t wanna see it’...if it’s in their eyesight because they just spent a whole lot of money to have a spot on the water they think they own everything they see and their view shouldn’t change ever because they paid for that. (Oyster Aquaculture)
These interviewees perceive NIMBY-ism (not in my backyard) as a common motivation for nearby homeowners and landowners to prevent aquaculture development in areas they interact with regularly and in areas that they value or have invested in financially.

This NIMBY sentiment is viewed as what led to a shellfish moratorium in Core Sound in Carteret County in the 1990s, which put a ban on shellfish leases (Ross, 2015).

Down in Core Sound there’s a moratorium and has been for a long time. Those people got together and decided they didn’t like people leasing the bottom. They didn’t want it, and they still don’t want it. They’re riled up... It’s been a long time, and they’re still passionate about it. (Oyster Aquaculture)

According to one aquaculture interviewee, the moratorium on shellfish leases in Core Sound closed some of the state’s estuarine areas with the best potential to commercially grow shellfish such as oysters. The North Carolina General Assembly passed a proposal to lift the Core Sound moratorium on October 1st, 2015 in Section 14.7(b), with plans for DENR to consult with stakeholders and submit a report on the matter by April 1, 2016 (ncleg.net). Interviewees thought that even if some Sound users favor oyster aquaculture, they still might not want a facility that is visible from their backyard.

Several of our interviewees have harvested oysters recreationally or know others who do. The majority of these interviewees did not see any conflict with oyster aquaculture. However, some interviewees who fish commercially for oysters did have concerns with oyster aquaculture expanding in NC. They worried about the state’s political and economic resources being spent on expanding oyster aquaculture, as they would rather have these resources spent to foster and create new wild oyster reefs.
opened periodically for wild harvesting. Many oystermen who valued oyster restoration and sanctuary projects worried that the fast-growing, sterile triploid oysters predominately used in oyster farms would not contribute to larval production and spat propagation in other areas.

I know [an oyster farmer] has that whole thing on that and he’s doing good...The only thing is that his oysters are triploid and the wild oysters are diploid and they do not reproduce...If he is using oysters that would actually mate with our oysters that would positively help the environment then it would drift on from there where it would start new beds and then you would have new beds. (Commercial Fishermen)

Sterile triploids would offer filtration benefits, but not an oyster seed source.

There seemed to be a limited awareness of oyster aquaculture among the commercial fishermen interviewees who dredge for oysters.

I’m a little bit opposed to that because he can harvest oysters that are too small and it actually hurts my part of the industry because he is doing it illegal from us. If he had 3 inch oysters okay I’d be fine with it. He can sell a one-inch oyster and I don’t like that. I know ____ is head of the committee and whatever I love him to death they’re family that’s family you know what I mean I am family to the __________s. I see it causing conflict (Commercial Fishermen)

This fisherman saw aquaculture as competition because he thought that, since the three-inch harvest limit on oysters does not apply to oyster aquaculture, oyster farmers were able to sell more than wild harvesters like him. However, most oyster aquaculture operations do not sell oysters smaller than three inches because there is no market for them. In addition, oyster fishermen are often selling to an entirely different market altogether than oyster farmers.
We sell our oysters at 3 inches and up anyways because people complain if they are too small. It is important, however, that we are able to sell them smaller because that allows us the ability to sell seed oysters to one another. Our oysters nearly always leave the local area, and most leave the state. They are sold in one hundred count boxes for about $40 dollars. It would probably take five or more boxes to make a bushel... We are clearly not selling to the same markets.... To be clear, I have no problem with the wild harvest of oysters. This time of year you can usually find a sack sitting on my back porch that I bought from someone in Wanchese. I think it is a healthy activity that produces a fine product that I've enjoyed all my life. I hope it will always be allowed in our state. The suggestion that we compete for the same markets, is not accurate. (Oyster Aquaculture)

Crabber interviewees also provided insight into potential commercial use conflicts that oyster aquaculture facilities may cause. Many noted that the shallow estuarine bottoms where the facilities are most often sited are similar to areas where they put crab pots. However, many of the major crabbing areas are near river mouths, the northern Albemarle Sound, and other areas where salinity is too low to support oyster aquaculture. In areas fished for crabs that fell within the oyster’s salinity range, some crabbers noted that the expansion of oyster aquaculture would not conflict with their activities, provided that the industry did not become too expansive and monopolize shallow areas in the estuary.

Awareness & Education

Across interviewee groups, we observed heterogeneity in knowledge of oyster aquaculture, regarding both sources of information and perceptions of certain aspects. Many interviewees discussed the public’s awareness of oyster farming. They suggested
more education on the subject in order for the oyster farming industry to grow in North Carolina.

Interviewees obtained their knowledge of the oyster aquaculture industry from already established businesses, word of mouth, and print sources. Those in the industry themselves got started in a variety of ways. A few oyster aquaculture interviewees mentioned learning about the industry through already established companies.

...we’d never heard of people having a perpetual franchise to cultivate oysters and shellfish, it’s very rare...in this state, you know, there’re a couple dozen of them, but not many, and, uh, in researching it we had heard of Island Creek up in Massachusetts and we read Shucked and we visited some farms up and down the East Coast, Sea Grant took us up to Maryland, Virginia, a big trip there, but I had lived in Connecticut before and, uh, there was an oyster, it’s now aquaculture, but it was a traditional oyster farm right there, um, and so I was familiar with some of the traditional operations, but not aquaculture. (Oyster Aquaculture)

Those in the other interviewee groups had wide ranging levels of awareness, with many interviewees having only heard a little about oyster farming. Various media were cited as information sources.

I read an article recently that said that there is a demand of over a hundred million dollars spent on oysters and so North Carolina's take of that is only one million [dollars]. What’s wrong with that picture? (Government/NGO)

News sources currently play an important role in putting faces to a small but growing industry and educating those unaware of efforts to grow oysters in the Sound. The government and non-profit interviewees also typically knew about oyster farming due to their experience with oyster restoration projects.
Interviewees in the commercial fishing industry drew opinions from their experiences with wild oyster harvest and from their relationships with those in the aquaculture industry. Many of the fishermen we interviewed harvested wild oysters at some point in their lives, and they discussed issues in the decline of wild oysters in the area. Their knowledge of oyster farming came from those they knew in the industry and from perceptions of farmed oysters in the marketplace. Some commercial fishing interviewees discussed whether they had considered farming oysters in the future.

No, I hadn’t thought about it. But, I’ve talked to some people, some guys that used to come down from Virginia fishing. That’s what they do now, is farm oysters. They’re doing really well at it. So, it definitely has been something that has crossed my mind lately because being a fisherman is something I kind of know about. It seems like there is some good money in it. So, I have been kind of considering the option here lately. (Commercial Fishermen)

This interviewee also said that if commercial fishing becomes more difficult due to regulation and declining fish stocks in the future, he could see himself turning to oyster aquaculture.

Recreational interviewees also mentioned their connections to people in the industry and their experiences with wild oyster harvesting and restoration. Overall they seemed to know more about the oyster farming industry than the commercial fishing group and had ideas on important aspects oyster farmers must consider.

...you know and the guys that are doing these oyster beds down here, you know I used to live beside [aquaculture farmer] when he got started and I think it’s great, I think it’s gonna take some ingenuity. You can read a book all day long that says you do A, B, and C. But A, B, and C that’s working in Columbia is not A, B, and C that’s gonna work at the inlet. You gotta be able to adapt it. (Recreational Business)
There is a consensus among interviewees about the importance of education related to the Sound, Sound processes, and aquaculture specifically. Interviewees discussed topics including the idea that people don’t always know how their actions affect the environment, how much the natural environment along the coast impacts the coastal economy, and how hard it is to change behaviors that have been engrained for generations.

In some cases, you know, we kind of step on our own feet by not allowing some of the natural processes to occur that could be—that could be important in keeping the sound functioning in a healthier manner. (Government/NGO)

This interviewee and many others across all interviewee groups also suggested that we need to understand how intertwined a healthy Sound and the livelihoods of those working it are. They said that the Sound is the main driver of the coastal economy, and we need to know how to use it and not abuse it.

Interviewees highlighted how difficult change can be and the relatively slow acceptance of new practices. There is a strong sense of tradition, and many interviewees’ families have been working on the Sound for generations and have very strong ties to their roots.

Daddy didn’t do it that way, and granddaddy didn’t do it that way, and I’m not going to do it that way.” He said, “Well, that’s the mentality of the watermen. And if they see somebody do it and make some money, they’ll think, ‘we’ll do it too.’ (Oyster Aquaculture)

Many in the community may want to hold on to the ways of previous generations while aquaculture represents a new and uncharted territory. Commercial fishing interviewees mentioned that they simply don’t know enough about aquaculture to get involved.
I just need to study on it and see what I need to do and what I need to get to do it and just...I’d like to have more knowledge of it before I try to...You know what I mean. It’s hard to succeed at something you don’t have much knowledge about. (Commercial Fishermen)

There are some existing efforts to provide education for those interested in entering the aquaculture industry. One aquaculture interviewee mentioned two new demonstration facilities that will be established in North Carolina for aquaculture education.

We got money from NOAA to set up a demonstration center, one here and one at UNCW. So this is research sanctioned water out here, so by this time next year-or less probably- by February or March we’ll have oyster gear our there for demonstration purposes and to do experiments with. (Oyster Aquaculture)

The project will allow employees to demonstrate the technology and techniques involved with aquaculture, as well as to conduct field tests on new types of gear that will improve the efficiency of the industry (NC Sea Grant, 2015).

Other interviewees also mentioned informing the public at the grade school level. A few cited efforts by NC Sea Grant to include aquaculture education in some school curriculums, and many want to see a push for greater knowledge of the Sound in general in the younger generations.

**Conclusion**

Stakeholder interviewees generally expressed concern with the current state of North Carolina’s coastal economy, especially with regards to the effects of tourism and development. On the whole, interviewees highly valued local job creation. Furthermore, our interviews revealed that many stakeholders believe oyster
aquaculture has the potential to create direct and indirect avenues of employment in the coastal economy. However, oyster farmers noted several barriers to starting up their aquaculture operations. The confusing and meticulous permitting process needed to lease public bottom was mentioned by most as a considerable obstacle to starting an oyster farm, as were agency interpretations of NWP 48. Another impediment mentioned in selecting suitable sites for oyster farms was finding locations that could be easily accessed and are not polluted. Interviewees said that large upfront costs, delayed profit realization, and risk costs associated with storms and other damage made capital investment in startup intimidating and risky. They pointed out that a local system of hatcheries to develop and supply locally adapted seed varieties is crucial for industry growth.

We can reasonably conceive that oyster aquaculture could become a source of seasonal employment for those in the community who experience employment gaps. The implications of oyster aquaculture as a source of stable employment suggest that coastal communities in NC would benefit overall from an expanded aquaculture industry. It is therefore necessary to evaluate and respond to the various impediments to growth that the industry faces.

Some aquaculture interviewees suggested future changes going beyond the on-the-water component of aquaculture. Many interviewees discussed the necessity of the on-land component of the aquaculture industry. They mentioned the need for a reliable means of transporting their product inland to sustain their businesses. There is
a large demand for oysters throughout NC and in other states, so if the delivery framework is more extensive, farmers will be better equipped to meet the demand.

Interviewees generally voiced positive opinions regarding the potential effect of a larger oyster aquaculture industry on North Carolina’s estuarine environment. Potential negative effects of increased oyster aquaculture on the estuarine environment were discussed by around a fifth of stakeholder interviewees. However, most interviewees mentioned that oyster aquaculture’s benefits to the estuarine environment would far outweigh these potential negative effects. The eastern oyster’s status as a keystone species as well as their habitat and water filtration benefits were the most commonly expressed upsides to having more oysters in the Sound.

However, we found reasonable cause to infer that estuarine areas with development-degraded water quality will likely not be affected by the water filtration benefits of the oyster aquaculture industry. Oyster farms must be sited in cleaner and less environmentally degraded waters to protect the stock from pollutants. While more oyster farms would improve estuarine water quality as a whole, they would not be able to improve locally polluted waters because these areas are environmentally and economically unsuitable for oyster farming.

Our research revealed that there was a general lack of awareness of oyster aquaculture among interviewees. A broad misunderstanding of how Sound users could utilize the public trust within aquaculture facilities was prevalent in many interviews. We found that many interviewees mentioned some degree of concern regarding the
potential for spatial conflicts between the various activities of the users of the estuary and oyster aquaculture. However, these concerns were often framed under hypothetical scenarios where oyster farming had come to monopolize every suitable area in the Sound.

To stimulate public support in coastal communities, more efforts towards educating the public and other stakeholder groups is necessary. Education extension efforts within the commercial fishing sector of coastal communities could address concerns with oyster farming and potentially recruit oyster farmers within this group. Increased extension efforts to recruit and train new oyster farmers and more networking and communication activity between oyster farmers could be key factors in increasing the oyster aquaculture enterprise and fostering greater success within the industry in NC.

Considering the fact that most interviewees outside the aquaculture stakeholder group had never had direct contact or exposure to oyster farms, their perceptions and attitudes toward expansion of oyster aquaculture tended to be hypothetical. An increase in public education about oyster aquaculture and broader understanding of how the site permitting process balances and evaluates various spatial uses would likely alleviate many concerns about oyster aquaculture’s potential to interfere with current uses. As the industry continues to expand in NC, it will be crucial to reassess public opinion and replace hypothetical with experiential perceptions in order to accurately gauge how oyster farming fits into the Sound.
Final Conclusion

Oyster aquaculture has been gaining public and government attention over the last decade, but there is still much ambiguity regarding oysters and how to regulate their farming. This study contributes to the body of knowledge surrounding oyster aquaculture and the perceptions coastal citizens of North Carolina have about the industry.

We found that the aquaculture facility did not negatively impact SAV growth and water quality compared to our other study sites. SAV density in and around the aquaculture facility shows that the facility potentially might promote vegetative growth. In our laboratory filtration experiment, we found farmed oysters filtered phytoplankton at a rate almost 50% higher than wild oysters, though the study was limited in that we only tested each treatment once. Our findings allow us to conclude that wild reefs and aquaculture facilities may provide comparable filtration ecosystem services.

Given our limited time on the coast, we could not control for certain temporal or spatial variables such as the influence tide has on mixing in the water column. Additionally, estuarine systems are dynamic and are subject to numerous seasonal and yearly fluctuations. A study at larger spatial and temporal scales should be conducted to account for the dynamics of an estuarine system as large as the APES. Comprehensive studies of wild and farmed oysters in changing conditions will be
necessary to fully understand how each interacts with the complex systems in which they exist.

Stakeholder interviews exhibited conflicting opinions on how farming is expected to affect the coastal economy and environment, as well as the lack of comprehensive understanding of the process itself. There was extensive discussion about oyster aquaculture facilities potentially restricting current uses of the Sound, but the permitting process has kept this from happening thus far. With strict permitting regulations and risks associated with entering the aquaculture industry, oyster farming efforts have remained relatively small in North Carolina. If the scale and abundance of facilities are both considered, some interviewees foresee oyster aquaculture as a supplementary industry to coastal economies.

Our sampling of the coastal community was not intended to be a comprehensive representation of individual stakeholder groups or the public as a whole. Still, we suggest that future research specific to North Carolina’s oyster industry expand upon our findings regarding the political and educational aspects of farmed oysters and wild reef restoration, which could help shape the future of a valuable oyster industry in NC. In addition, our interviews revealed that the scale at which oyster aquaculture is carried out has implications for the prosperity of both commercial and recreational activities as well as the natural habitats in the Sound. Collaboration from government, public and private sectors is necessary to ensure aquaculture policy is
effective and includes consideration of the costs and benefits of oyster aquaculture to both niche systems and the entire coastal community.

Human pressures on coastal waters are continuing to increase, and are impacting valuable ecosystems and coastal economies that rely on them. NC and other coastal states need to address these pressures and take steps to protect the ecosystems and local populations at risk. With water quality rapidly declining in many areas, the combination of wild and farmed oysters may mitigate damages while stimulating a lucrative local industry.
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Appendices

Appendix A

OBXFS 2015 Interview Guide
Version date: 2015 September 14

Where:
Gov/NP = government, resource management & nonprofit
Rec = recreational business
Fish = commercial fishing
Aqua = oyster aquaculture

Materials
Consent document, ipad/recorder, map, sticky tabs(marker for map), pencil/pen

Introduction
Ask the interviewee to read the consent document while you set up the guide and map. Make sure s/he doesn't have any questions and ask if they agree to participate and be recorded. While you set up the recorder (Reminder: keep the ipad volume low to avoid any feedback.), brief them about the study. Ask her/him mark the recording by stating her/his name, the date, where you are.

1. Connection to the Water
   • Tell me about your work. What kind of work do you do?
     – How did you get into this work?
       • [Follow-up: How long have you been doing this?
       • [Gov/NP Follow-up: How long have you been working for (insert name of org.)? What other roles have you had here?]
       • [Gov/NP Follow-up: Could you talk a bit about (Org. name)’s mission/goals and how your work fits into that?]
       • [Rec or Aqua Owner Follow-up: Can you tell me how you started your business?]
• [Fish Follow-up: Who else in your family fishes?]

— Have you done other kinds of work on the sound? What was that?

— You may not have a truly “typical” day, but what are the things that you do on a nearly daily basis?
  • OR What does a work day often look like for you?

— Is _____ your only job right now? (Aqua & Fish, especially)

— I brought along this map, (could you talk about) what are some places on the water that you go to for your work or that are important for your work?
  • [Follow-up: What do you do there? OR What happens there? OR What do you use that for?]
  • [Follow-up: Why is (place X) important?]
  • [Follow-up: How did you choose this place (for doing X)?]

• Continuing to think about the coastal environment, what do you think are some of the most important features or resources in (Pamlico Sound) (this area)?
  — [Follow-up: What is so critical about ______?]
    • [Follow-up: How is ______ important to you?]
    • Follow-up: And to your business?
    • [Follow-up: What about to your community?]
    • (Prompts: income, local economy, recreation, culture/heritage, peace/spiritual, beauty/aesthetics, biodiversity, identity)

• What kinds of concerns about the state of the Sound do you have?
  — (Prompts: water quality, species loss, environmental quality, pollution, climate change)
  — [Follow-up: What concerns you about _____?]
  — [Follow-up: What about any concerns over how people use the sound?]
    • (Prompts: crowding, conflicts, changing attitudes, lack of knowledge, development pressure)
  — [Follow-up: (if NO concerns): How come?]
2. *Past & Future Change*

- Thinking back over the last 10 years, what kinds of changes have you seen in the Sound?
  - (Prompts: catch, species increase or decrease, different users, economics)
  - (Note: If they mention only negative changes, ask about positive changes and vice versa)
  - (Note: if they mention only ecological changes ask about social/economic changes and vice versa)
  - [Follow-up: How do you feel about these changes?]

- What do you see the sound like in the future? Say in 20 years?
  - [Follow-up: What would you like the sound to be like in 20 years?]
  - [Fish Follow-up: Do you think future generations will be able to continue a fishing way of life?]
  - [Gov/NP Follow-up: What are your organization’s objectives for how the sound ought to be used and managed into the future?]

3A. *Oyster and Perceptions of Aquaculture – Fish, Rec, Gov/NP Groups*

*Transition needed here, especially if oysters have not factored much into the conversation to this point.*

- In addition to talking to people about the Sound, about how it’s changed, concerns about it, and what it might be like in the future, we are interested in talking about oysters and hearing what perceptions people may have about oyster farming or aquaculture in the Sound.

- What comes to mind when you hear the word “oysters”?

- I’d like to know what you think about increasing the number of oysters in the sound and estuary. Is “more oysters” a good idea?
  - [Follow-up: What makes you think so? Or What makes you say that?]
  - (Prompts: water quality, habitat, shoreline stabilization, fishery, food, natural, historical)
  - [Follow-up: What kinds efforts to improve oyster populations in the Sound have you heard of?]
    - [Follow-up: To your knowledge, how have these successful?]
If you are not sure the person is familiar with aquaculture:

• Are you aware of any oyster farming or aquaculture going on in the Sound (this area)?
  – [Follow-up: What can you tell me about it?]
  – [Follow-up: What do you think about the idea of oyster farming in the Sound?]

Not Aware/Knowledgeable:

• Given what you know about the current state of the sound and current ways it is used, how do you think something like oyster farming would fit in the Sound?

Aware/Knowledgeable:

• How do you think oyster farming can benefit the Sound environment?
  – [Follow-up: What about other Sound users?]
  – [Follow-up: What about the communities around the Sound?]

• How do you think oyster farming can negatively impact the Sound environment?
  – [Follow-up: What about other Sound users?]
  – [Follow-up: What about the communities around the Sound?]

• Compared to other states, oyster farming is a pretty small industry in North Carolina. For example, last year, oyster farmers in Virginia sold almost 40 million oysters. North Carolina oyster farmers sold 3-4 million oysters. What do you make of that difference?
  – [Follow-up: What do you think is different about North Carolina or the situation here that might be contributing to keeping those production numbers relatively low?]
    • (Prompts: regs/laws, lack of interest/awareness)
    • [Follow-up: What of those things do you think might change in the future?]
  – [Fish Follow-up: What do you think of farming oysters, either in addition to or instead of fishing? Is that something you would consider doing?]
  – [Follow-up: What do you think of the idea of a bigger oyster aquaculture industry in North Carolina?]
    • (Prompts: Positive/beneficial aspects: water filtration, jobs, habitat)
3B. Oyster and Perceptions of Aquaculture – Aqua Group

- How do you think oyster farming can benefit the Sound environment?
  - [Follow-up: What about other Sound users?]
  - [Follow-up: What about the communities around the Sound?]

- How do you think oyster farming can negatively impact the Sound environment?
  - [Follow-up: What about other Sound users?]
  - [Follow-up: What about the communities around the Sound?]

- What were people’s reactions when you got into oyster aquaculture?
  - [Follow-up: Have opinions about it changed over time?]
  - [Follow-up: How do people that you meet now react to learning what you do?]
  - [Follow-up: People like to make parallels between aquaculture and commercial fishing, and I’m wondering what kinds of reactions your oyster farm has gotten from commercial fishermen?]

- As you know well I’m sure, compared to other states, oyster aquaculture production here in North Carolina is relatively small. How do you account for that?
  - [Follow-up: What do you think have been the impediments to expansion of the industry here compared to other places?]
  - [Follow-up: Are you in favor of it expanding?]
    - [Follow-up: What kinds of places do you think would be appropriate for expansion?]
    - [Follow-up: What kinds of places do you think oyster farming should not be considered?]
  - [Follow-up: How do you think oyster farming fits in with other uses of the Sound?]
  - [Follow-up: What kinds of possible usage or space conflicts do you think might occur if the industry expanded?]
    - [Follow-up: How do you think different uses of the Sound should be prioritized?]
• [Follow-up: How should decisions about leases and oyster farming be made?]
  ▪ [Follow-up: Who should be involved? Not involved?]

4. Conclusion

• Is there anything else about the Sound, how people use it, (oysters and oyster farming if you covered it) that you think is important that I haven’t asked you about?

• That’s all the questions I have for you, do you have any questions for me?

• THANK YOU and invite to the presentation.
  – We will be compiling the findings of our study, along with the results of our natural science research, in a report and giving a public presentation about them at the end of the semester. If you’d like to attend, the presentation will be on December 10th at 2 pm, that’s a Thursday, at the Coastal Studies Institute in Wanchese.

• Now that you’ve seen what the interview is all about, can you recommend any other people that you think it would be good for us to talk to?
  – (You can mention specific “types” of people we’re interested in interviewing if you think that would help prompt their thinking.)

• When I go back and listen to the recording, if I have any questions or would like to clarify anything you’ve said, would it be OK if I contact you again?

• Thank you for your time.

Addenda

The goal is to keep the focus on what the interviewee has to say about oyster aquaculture, so if you are asked your opinion, find a way to deflect having to answer, perhaps by saying that part of doing the research is to figure where you stand. If the interviewee is not very knowledgeable and wants to know more about it, at the end of the interview, some points you might share are:

• Oyster aquaculture is the practice of growing oysters from tiny seed oysters to harvestable size.
• The oysters are protected from loss or predation inside of “cages” mounted on the estuary bottom or in hard mesh “bags” floating on the water surface.
• The oysters grow by filtering food particles out of the water flowing around them.
• Oyster farmers tend the oysters by keeping the cages and bags free of debris and algal growth that would block the flow of water, and sorting the oysters by size as they grow.
• Pros: no added food, water filtration, habitat, nitrogen control
• Cons: space appropriated, shading, waste production
## Appendix B

### Table 1: Water Variables at All Sites for Each Sample Date

<table>
<thead>
<tr>
<th>Variable</th>
<th>Inside Mean</th>
<th>Inside St. Dev.</th>
<th>Outside Mean</th>
<th>Outside St. Dev.</th>
<th>Control Mean</th>
<th>Control St. Dev.</th>
<th>Reef Mean</th>
<th>Reef St. Dev.</th>
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<td>Outside</td>
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