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Investigating the use of bioengineered oyster reefs as a method of shoreline protection and carbon storage

Daniel D. Dehon

Louisiana State University and Agricultural and Mechanical College

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INVESTIGATING THE USE OF BIOENGINEERED OYSTER REEFS AS A METHOD OF SHORELINE PROTECTION AND CARBON STORAGE

A Thesis
Submitted to the Graduate Faculty of the

Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science in
Biological and Agricultural Engineering

in

The Department of Biological and Agricultural Engineering

by

Daniel D. Dehon
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Abstract

The Louisiana Gulf Coast is losing land at an alarming rate for a combination of reasons. At the same time carbon dioxide is accumulating in the atmosphere and the oceans by the increased burning of fossil fuels. Therefore, bioengineered oyster dominated artificial reefs have been developed in an effort to mitigate erosion while storing carbon in the oyster shells. These reefs support the growth of a native oyster species, *Crassostrea virginica*, which are considered ecological engineers and serve to improve water quality, protect coastal wetlands, capture and store carbon, and enhance the economy. Evaluation of test pieces showed the addition of biological material to encourage significantly higher oyster recruitment ($p=0.002$). Locations lower in the water column and further from shore also had higher recruitment rates ($p=0.0004$, $p=0.05$ respectively). The test on carbon storage potential showed a carbon payback period of $\sim 6$-8 months and a 500% payback after thirty months. A map of potential emplacement sites (“oyster zone”) was also created to aid in selecting future project locations. Preliminary engineering design was done in order to optimize the geometry of these structures and the emplacement techniques. Future work in this area should include monitoring and documentation of full-scale project emplacements and oyster growth patterns. This project has revealed the potential for the use of a sustainable, ecologically beneficial, and cost effective method of shoreline protection with the added benefit of long-term carbon storage.
Chapter 1: Introduction and Literature Review

Louisiana Coast

The coastal marsh areas along the Louisiana Gulf Coast are being lost at an alarming rate. Erosion is occurring in most coastal areas, but it is Louisiana that is receiving the majority of wetland loss, which accounts for 90 percent of the coastal marsh loss in the nation (USACE, 2004). The current rate of land loss in Louisiana is a little over 10 square miles per year (Day et al 2007 and Costello 2007). Land subsidence and sea level rise are also contributing factors to land loss. The subsidence rates in Louisiana are accelerated due to the fact that most of Southern Louisiana was part of the Mississippi River Delta Plain at some point in the past. Thus, riverine sediments formed the land, which over time slowly compacted and sank. This results in subsidence rates as high as 6–8 mm yr\(^{-1}\) according to the long tide-gauge located in Grand Isle, Louisiana (Blum and Roberts 2009). These subsidence rates are decreased at areas further inland and are approximately 1-3 mm yr\(^{-1}\) at the latitude of Baton Rouge (Blum and Roberts 2009). At the same time, the Intergovernmental Panel on Climate Change (IPCC) concludes that rates of global sea-level rise are accelerating (Vemeer and Rahmstort 2009). Tide-gauge records from tectonically stable sites show a mean of 1.7 mm yr\(^{-1}\) in the twentieth century. However, tide-gauges and satellite imagery have indicated higher rates of about 3 mm yr\(^{-1}\) (Fitzgerald et al 2008 and Blum and Roberts 2009). The combination of sea level rise and land subsidence currently results in a net subsidence rate of about 1 cm yr\(^{-1}\). By 2100 it could be as high as 2 cm yr\(^{-1}\) (Fitzgerald et al 2008). The Louisiana coast is an important ecosystem that provides a habitat for a wide variety of plant and
animal species, both on the land and in the water. These coastal estuaries are also important in the protection of major metropolitan areas from hurricanes and other gulf storms. As these wetlands shrink in size, the amount of protection that they provide is also reduced. The loss of land mass can be contributed to the lack of riverine sediment input, land subsidence, sea level rise, altered hydrology from canal construction and other anthropological action, and erosion (Day et al 2007).

**Breakwater Introduction**

There are various options that exist to reduce the effects of coastal erosion. These include both soft structure approaches (e.g., beach nourishment) and hard structures (e.g., revetments, groins, jetties, seawalls, offshore breakwaters, etc.). Both of these approaches fall under the broader term of “shoreline engineering” (CCEZM 1990). Many developed coast with a city infrastructure near the water are already using both types of shoreline engineering to protect against erosion. Each method serves different needs in preventing coastal erosion, but this paper will focus primarily on offshore and nearshore breakwaters.

Offshore breakwaters provide a physical barrier that dissipates wave energy through wave diffraction, dissipation, and reflection (Benassai 2006, Campbell 2004, CCEZM 1990). Breakwaters are typically constructed from rock, cement armor stones, sunken barges or ships, or any heavy objects that break up wave action (CCEZM 1990). Breakwaters are typically segmented and detached; thus, they provide substantial protection while allowing water as well as sediment and organism in the water to pass through, which allows beach fruition. These barriers also provide a sheltered area, which serves as a reservoir for sediments carried by the diffracted waves (Benassai 2006). These
provide a similar effect as a sediment fence, which is used to promote sedimentation 
(Scarton et al 2000 and Boumans et al 1997) As the sediment builds up over time, the 
breakwaters create salients and sometimes tombolos (shore connects to breakwater) 
(Chen 2008). These shoreline responses can be seen in Figure 1.1, essentially reversing 
coastal erosion, at least locally.

Figure 1.1. Shoreline response to breakwaters (USACE 2002).

Breakwaters are a proven method of shoreline protection. They can be 
permanently submerged, intertidal, or exposed (emerged). Submerged and intertidal 
breakwaters are also referred to reef breakwaters, as they can mimic natural reefs. 
Submerged breakwaters reduce wave action on the beach by forcing wave breaking over 
the reef (USACE 2002). The use of offshore breakwaters as a means of beach protection 
and passive nourishment has increased more quickly than groin-type structures in the last
decades (Benassai 2006). This shows a strong trend toward the use of breakwaters over groins as a means of beach protection and stabilization (Benassai 2006). This is in part due to the limited ecosystem impact, as they are intended to simulate naturally occurring reefs.

There are new technologies that take reef breakwaters from simple physical barriers to engineered ecosystems, providing a hard substrate to allow different organism to attach and grow (Campbell 2004, Ortego 2006). The goal of these projects is to create a biologically dominated artificial reef that mimics those that occur naturally. These reefs would serve as shoreline protection while also enhancing the natural ecosystem. A biologically dominated breakwater allows the use of less initial material, which reduces the overall cost of the project. However, the full potential of the project may not be realized until years after its emplacement. Therefore, this technology is an investment that improves through time as the oysters grow, while more conventional shoreline protection techniques require the addition of material through time. Therefore, the long-term cost of this technology is reduced in that respect.

A group of biological engineers at Louisiana State University have developed a new technology termed “oysterbreaks” to artificially mimic natural reefs (Campbell 2004, Ortego 2006). Past studies at Louisiana State University have shown that oysterbreaks have shown real potential as a practical solution to the coastal erosion problem that Louisiana is facing (Campbell 2004, Ortego 2006). These oysterbreaks are constructed by casting concrete in such a way that the rings may be stacked and interlock with one another (Figure 1.2). The forms are filled with a combination of concrete, biologically derived materials, and other additions that enhance the growth of oysters.
Figure 1.2. Stack of interlocking rings forming oysterbreak

The composition of the concrete is such that it creates a rough outer surface, which makes it easier for oysters and other organisms to attach to the structure; it may provide protection from wave energy and predators, especially for juveniles. This technology is still in the early stages of development, but testing up to this point has revealed that concrete with biological additives, showed superior growth to those without any additives in Ortego’s study (Ortego 2006). Concrete samples were deployed in Caminada Bay near Grand Isle, Louisiana in June of 2005. By March of 2006, concrete with oyster shell experienced the most growth (16.2% increase in perimeter of the bar), followed by samples with cottonseed (11.2% increase in perimeter). Samples with no additive had the least oyster growth (7.9% increase in perimeter). (Figure 1.4) (Ortego 2006) Other ring
emplacements have shown up to a 175% increase in mass due to oyster growth after two and a half years (Figure 1.3).

Figure 1.3. Oysterbreak placed in 2007 at Rockefeller Refuge after two years of growth

Also, wave tests were conducted in the lab, which show that as a structure such as this grows in size, its ability to dissipate wave energy also increases (Campbell 2004). These studies have helped to show that oysterbreaks are a possibility in coastal protection that naturally sustain and build themselves. Further testing and studies are on going to prove these structures as a practical solution to coastal erosion in the Louisiana estuaries.
Oyster Introduction

The eastern oyster (referred to as oysters in this paper), *Crassostrea virginica*, is a sessile invertebrate bivalve commonly found in estuarine waters (Kennedy 1996). Of all the factors that can affect the biology of an estuarine organism such as *C. virginica*, the fluctuation of both temperature and salinity has the most profound effect. Temperature and salinity affect most aspects of oyster biology including feeding, growth, time of spawning, parasite-disease interaction, distribution, utilization of food reserves, and respiration (Shumway 1996). The eastern oyster is fairly temperature tolerant and can be found along the east coast of the United States from Canada around to the Western Gulf of Mexico and down into the tropical zone (Shumway 1996). Oysters can tolerate
salinities between 0 and 42 parts per thousand (ppt), but the optimal range is 14 to 28 ppt (Shumway 1996; EOBRT 2007) Along with temperature and salinity, oysters are also affected by the variations in pH, light, seston concentrations, food availability, and predators pressure. Thus, these bivalves are site specific and the proper conditions must exist for them to grow and proliferate. A map that outlines areas where these conditions exist would be a useful tool, when deciding if artificial reefs could be used for coastal protection.

Once fertilization and initial growth occurs, oysters begins enters a free swimming, planktotrophic larva veliger stage with an ability to swim vertically at a speed up to 2 mm/s (Kennedy 1996), while water currents provide horizontal motion. Oysters at this stage are at a high risk of death, due to exposure to predators and disease (EOBRT 2007). The oysters that survive this stage eventually enter the benthic settling stage, in which they are called pediveligers. It is in this stage that they crawl along hard surfaces using a ciliated foot. These pediveligers crawl along the substrate sensing cues associated with appropriate settlement materials, termed “cultch”. If the appropriate stimuli occur, the oyster cements itself to the substrate and undergoes further metamorphoses, becoming “spat”, the smallest stage of settled oysters (Kennedy 1996). Many oysters do not make it through this stage of life due to competition, predation, disease and environment. Average daily mortality rates range from 20% to 76% depending on these factors (Drinnan and Stallworthy 1979). After becoming spat, most oysters can reach market size
Figure 1.5. A depiction of the lifecycle of the eastern oyster (after Berrigan et. al 1991)

(>90mm) in 2-5 years depending on temperature (Shumway 1996). However, research has shown that oysters in warm water conditions near the Gulf of Mexico can reach this size in only 9 months (Menzel 1951). This is possible since oyster growth is faster in warmer waters and may occur year round. In colder areas, growth is limited to 7 or 8
months of the year (Shumway 1996).

The eastern oyster is a gonochoric or dioecious protandric hermaphrodite (Thompson et al. 1996) with a reproductive cycle that occurs yearly and external fertilization that occurs in the water column. Gonochorism, dioecious, or unisexualism describes sexually reproducing species in which individuals have just one of at least two distinct sexes. Each individual oyster is usually male in its first year with the ability to change between sexes, thus protandric as male is usually first. The adaptive significance of sex reversal and the factors influencing them are not yet clear. Studies suggest a variety of factors including male to female ratio, temperature, nutritive stress, and other environmental stresses may influence changes in sex (Eble et al. 1996). Spawning times vary for the eastern oyster depending on location, but this can be attributed to temperature differences. In the Chesapeake Bay area, spawning occurs from June until October, and further north the spawning season is usually confined to June through August. In the Gulf of Mexico area, spawning typically occurs from May until late October (EOBRT 2007). Therefore, artificial oyster reefs should be emplaced in spring or summer months in order to get optimal growth over the first year. Temperature plays such a significant role in spawning that it can be triggered in oyster hatcheries by increasing the water temperature (Castagna et al. 1996).

A variety of chemical and physical factors have been found to affect oyster setting. Research has shown that higher temperatures promote setting, but settlement response does not seem to vary with salinity (EOBRT 2007). The larvae also exhibit rugotropism, settling in small pits and irregular surfaces. Larvae have also been shown to respond to light effects negatively (negatively phototrophic), settling in shaded areas and on undersurfaces (Kennedy 1996). Thus, darker surfaces could act as an attractant for oyster
attachment. Oysters are also gregarious, settling in areas where other oysters are present. This is probably due to a waterborne pheromone that the oysters release (Kennedy 1996). It has been known for decades that surface films promote oyster growth, but it was not until the past twenty years that scientists understood the relationship. The bacteria in these films produce melanin and melanin precursors enhance the settlement of the eastern oyster. It has also been discovered that ammonia induces settlement behavior (Kennedy 1996).

Oyster growth rate is strongly affected by temperature and latitude. Length is most commonly used when measuring the size of an oyster. Figure 1.6 depicts the method to measure height of oysters, from bill to hinge. Generally, in warmer waters oysters tend to grow faster, while oysters in colder waters have a slower growth rate. In the Gulf of Mexico, oysters can reach market size (75 mm) in 2 years, and in Long Island Sound this same growth can take 4 to 5 years to attain (Shumway 1996). Growth in warmer waters is essentially year round, but in areas like Long Island Sound growth may be restricted to 8 months or less (Shumway 1996). Growth studies on oysters in Louisiana have shown some of the fastest rates. The different studies of these growth rates can be seen in Table 1.1. Oyster spat growth rates range from 8 to 15 mm per month (Kennedy 1996). These growth rates are based on shell growth, which is primarily the result of calcium carbonate deposits.

Oysters have been regarded by many as “ecological keystone species” or “ecosystem engineers” for the roles they serve in their environment (EOBRT 2007; Piazza et al. 2005). Oyster populations contribute to the integrity and functionality of
Figure 1.6. Oyster height depicted with a white line.

Table 1.1. Summary of growth rates studies on *Crassotrea virginica* in Louisiana. From Shumway (1996)

<table>
<thead>
<tr>
<th>Study</th>
<th>Linear Growth (length of shell)</th>
<th>Elapsed Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Setting to 1 in</td>
<td>6 wk*</td>
</tr>
<tr>
<td>2</td>
<td>Setting to 3.5 in</td>
<td>18 mo</td>
</tr>
<tr>
<td>3</td>
<td>Setting to 4 or 6 in</td>
<td>23 mo</td>
</tr>
<tr>
<td>4</td>
<td>Setting to 3.1 in</td>
<td>10.3 mo</td>
</tr>
<tr>
<td>5</td>
<td>Setting to 3.7 in</td>
<td>39 wk*</td>
</tr>
</tbody>
</table>
estuarine ecosystems. Some of the functions include water filtering, shoreline stabilization, recycling of biological material, boosting benthic productivity, and providing feeding and nesting habitat for numerous other species. Oysters serve to improve water quality by consuming phytoplankton and suspended detritus, and storing the nutrients as biomass, depositing the nutrients to the benthos, or creating high quality protein (gametes and eggs) for other filter feeders (Ortego 2006). Clearance rates (volume of water totally cleared of suspended particles per unit time) for adult oysters have been reported as high as 10 L h⁻¹ g⁻¹ dry tissue weight (EOBRT 2007). This high clearance rate have led some to speculate the use of oysters as a bioremediation tool to reduce toxin loads in estuaries (EOBRT 2007). Oyster reef are hypothesized to contribute to shoreline stabilization by providing a hard structure that affect hydraulic movement. This reef structure is able to protect the shoreline by dissipating a portion of the energy from incoming waves. These reefs can also serve in reducing long shore currents, which normally carry loose sediment away from the shore. This interaction can result in an increase in sedimentation on the shore side of a reef, ultimately building land in some cases (Piazza et al. 2005). Oyster reefs serve as a refuge for a variety of juvenile and adult finfish; oysters also serve as a food source for some crustaceans in this estuarine environment (Newell et al. 2004). Over 300 different species have been identified inhabiting oyster reefs, including motile arthropods such as crabs, snapping shrimps, isopods and amphipods, polychaetes, gastropods such as the oyster drill, as well as sessile invertebrates such as mussels, chitons, limpets, barnacles, anemones, bryozoans, hydroids, and sponges. “Suspension and deposit feeding activities provide trophic support for higher consumer levels by converting detritus to animal biomass and to primary producers through mineralization of carbon and release of nutrients such as nitrogen and
phosphorous” (EOBRT 2007). In this current study birds, juvenile fish, crabs, mussels, and barnacles were observed on or near the reefs.

Oysters, especially in Louisiana, support an important and economically beneficial fishing industry. The U.S. National Marine Fisheries Service (NMFS 2004) estimates that the dollar value for oyster landings nationally was $103 million in 2003, $111 million in 2004 (NMFS 2004). As a production leader Louisiana contributes significantly to the Gulf and United States supply. The Gulf Region is a leading supplier accounting for 65% of the nations production (NMFS 2004). From 1997-2001 Louisiana contributed 54% in the Gulf Region and 32% of the total U. S. landings (Wirth 2004). Through 1997-2007, Louisiana oyster production has averaged 12.8 million pounds of meat per year, which is 34% of the total annual US production. Louisiana oyster production has an annual value well in excess of $30 million of dockside sales (Oyster Stock Assessment Report 2009).

Oysters can carry out a variety of functions in an estuary ecosystem. Oyster reefs provide a barrier against erosion and refuge for juvenile fish. Oysters also improve water quality and are a food source for some species. Commercial production is also a great source of revenue for Louisiana. The shells also contain carbon, which may provide additional benefits in the carbon cycle.

Potential Biosequestration of Carbon

Carbon is one of the most abundant elements on Earth, and the carbon cycle describes how this element is recycled and reused throughout the biosphere and all its organisms (Figure 1.7). Anthropologic activities such as deforestation and burning of fossil fuels have interrupted the cycle’s natural flow. Human activities add about 5.5
billion tons per year of carbon dioxide to the atmosphere (NASA Earth Science
Enterprise). This has caused a build up of carbon dioxide in the atmosphere, which has
gained the attention of many people. Louisiana emits a total of approximately 61.5
million metric tons of carbon per year based on a study under the Vulcan Project (Gurney
et. al. 2009).

Figure 1.7. Earth’s Carbon Cycle. (after NASA Earth Science Enterprise)

In 1997, the Kyoto Protocol was adopted by the United Nations Framework
Convention on Climate Change (UNFCCC). The major feature of the Kyoto Protocol is
that it sets binding targets for 37 industrialized countries and the European community
for reducing greenhouse gas (GHG) emissions. The overall goal of UNFCCC is
achieving “stabilization of greenhouse gas concentrations in the atmosphere at a level
that would prevent dangerous anthropogenic interference with the climate system” (unfccc.int 2009). This has led to the development of more efficient energy production that will generate less carbon, more efficient usage of energy, and the emergence of technologies and practices that capture and store carbon. The capture and storage of carbon has been termed carbon sequestration.

A number of physical, chemical, and biological processes can carry out carbon sequestration; but this paper will be focusing on the biological processes. Biosequestration is the term used to describe such methods of carbon capture and storage. Afforestation, reforestation and (avoided) deforestation come under the broad heading of biosequestration. Sequestration is carried out by plants through the process of photosynthesis, in which carbon dioxide is converted into oxygen and plant material. The amount of carbon sequestered can vary greatly depending on the species, site, and other external factors. The net amount of carbon sequestered by these projects is evaluated based on the balance between the changes in aboveground vegetation, roots, the litter layer, and the soil (Hicky 2009). The units used for this type of sequestration are tons of carbon per hectare per year. These terrestrial sequestration methods work well, but it is the ocean that stores the vast majority of carbon on the planet as seen in Figure 1.7. Implementing techniques that use the ocean as a sink for carbon could prove to be effective as well.

Oysters have the potential of sequestering carbon in their shells, which are made of calcium carbonate. However, through the process of shell generation the oyster also produces some carbon dioxide. Investigating the possibility of biosequestration by oysters is an important element in evaluating the use of artificial oyster reefs. If this
becomes a viable method of sequestration, carbon credits may be able offset the costs of future projects.

The potential for oysters to sequester carbon is dependent on the process through which the shell is formed. The chemical process that forms the shell is called calcification, which is the formation of calcium carbonate. Carbon makes up 12% of calcium carbonate by mass. The chemical process for calcification is:

\[ \text{Ca}^{2+} + 2\text{HCO}_3^- \rightarrow \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \]  
(Equation 1.1)

This shows how the oyster converts a calcium ion and two bicarbonate molecules into one calcium carbonate, one carbon dioxide molecule, and water. It may seem that since there is a release of carbon dioxide from this one equation that these bivalves are actually producing carbon instead of reducing the amount in the water column. However, this is not the complete chemical process. The source of the reactant carbon and fate of the carbon products must be investigated in order to fully understand the overall effect on the cycle.

The calcium carbonate deposited is accounted for in the shell mass, and the carbon in the shell may be locked up for millennia. Oysters offer a medium to capture and store carbon for a much longer time than agricultural products or even forest. Thus, the main question in the process is the source of bicarbonate and the fate of the carbon dioxide. The simple answer to this question is the water, but this does not resolve the question of the oyster’s role in carbon sequestration. Thus, the carbon cycle within the ocean must be investigated.
The main source for oceanic carbon input is from the atmosphere though absorption of carbon dioxide; this process currently absorbs about 2 Gt of carbon per year (Stewart 2005). As atmospheric carbon dioxide production and concentration increase, the amount of carbon dioxide absorbed by the ocean will also increase, thus elevating the ocean’s carbon dioxide content. However, all the carbon dioxide does not remain in this form in water. As the concentration of carbon dioxide in water increases, a series of reactions occur in order to allow for more carbon dioxide absorption and to balance the different forms of carbon in the water. One of these equilibrium reactions proceeds as follows:

\[
\text{CO}_2 + \text{CO}_3^{2-} + \text{H}_2\text{O} \rightarrow 2\text{HCO}_3^- \quad \text{(Equation 1.2)}
\]

This shows how carbon dioxide combines with carbonate and water to form two bicarbonate after entering the water. Therefore, increased amounts of carbon dioxide entering the ocean due to increases in atmospheric carbon dioxide would also cause an increase in bicarbonate concentrations (Gattuso 2009).

Using Equations 1.1 and 1.2, it is possible to evaluate the role oyster shell formation plays in the carbon cycle. Based on these equations Figure 1.8 has been rendered to visually depict this process. The figure illustrates how the oyster uses calcium (Ca) and carbonate (CO₃) to form its shell (white text), and the rest of the reactants and products are recycled (black text). The boxes not outlined (oyster) and outlined boxes (water) depict the locations of reactions and source of reactants. This illustration enables the equation to be simplified and written as:

\[
\text{Ca}^{2+} + \text{CO}_3^{2-} \rightarrow \text{CaCO}_3 \quad \text{(Equation 1.3)}
\]
Figure 1.8. Oyster’s role in oceanic carbon cycle.

Equation 3 depicts the simplified reaction that ignores the cycled materials and shows how calcium and carbonate enter the cycle and are converted into calcium carbonate to form the shell. Therefore the carbon that is being locked up in the shell is carbonate. The calcium in this equation has a less significant role as the calcium concentration is two orders of magnitude higher than carbonate concentration in seawater (Gattuso et. al 1998). Understanding how carbonate concentrations affect the oceanic carbon cycle will clarify how the oysters affect the cycle as well.

As previously stated, increases in carbon dioxide in the atmosphere have led to increases in oceanic carbon dioxide absorption. This has had profound effects on the
seawater carbonate system. It lowers pH (ocean acidification), and more importantly for this paper it decreases the availability of carbonate ions. Increases in carbon dioxide push this equation to the right and use up carbonate in the process, which reduces the amount that will be available for calcification. Therefore, the process of calcification actually promotes ocean acidification, and reduces the oceans potential for carbon uptake by locking up carbonate. However, studies (Gazeau et. al 2007) have shown that oysters are quite resilient in spite of the changes in pH.

Summary

Southern Louisiana is losing land for a number of reasons. The use of hard structures to mitigate coastal erosion has been much explored. Enhancing these structures by incorporating the local biology, like oysters, has proven to have additional benefits. However, oysters do have limitations as to where they can grow and thrive; a map defining areas where oysters could grow, “an oyster zone”, would provide an outline of where artificial oyster reefs could possibly be used. Oysters also store a form of carbon in their shell; this form of carbon storage has only been preliminarily explored and may provide additional benefits for using this method of coastal protection.
Chapter 2: Evaluation of Oyster Growth and Settlement

Introduction

This project is focused on growing oysters on a target structures made of designed substrates; this growth will enhance the overall functions of these engineered structures in reducing erosion as well as the ecological benefits oysters provide. In order for an artificial oyster reef to be successful, it must attract and grow oysters. Based on these criteria, two primary goals were selected. The first goal was to determine how different materials and locations in the water column would affect growth. The second goal was to determine at what rates oysters settle and grow on these reefs.

The first objective was to determine whether there was an increase in bar size, measured as a change in bar perimeter, over time (H₀: \( \mu_{1 \text{ months}} = \mu_{2 \text{ months}} = \mu_{3 \text{ months}} = \mu_{4 \text{ months}} = \mu_{5 \text{ months}} \)).

The second objective was to determine if there was a difference in oyster settlement, measured by oyster counts between different groups of samples with or without additives, colorant, surface texture (H₀: \( \mu_{\text{no additive}} = \mu_{\text{std}} \); H₀₂: \( \mu_{\text{regular}} = \mu_{\text{std}} \); H₀₃: \( \mu_{\text{dark}} = \mu_{\text{std}} \); H₀₄: \( \mu_{\text{ASTM}} = \mu_{\text{std}} \)).

The third objective was to determine if there was a difference in oyster settlement, measured by oyster counts between different locations in the water column (H₀: \( \mu_{\text{high}} = \mu_{\text{middle}} = \mu_{\text{low}} \)).
The fourth objective was to determine if there was a difference in oyster settlement, measured by oyster counts between different distances from the shore (H₀: \( \mu_{\text{near}} = \mu_{\text{far}} \)).

The fifth objective was to determine rates at which oysters grew on the substrate based on oyster height measurements (Rate = change in oyster height (mm)/time (months)).

**Materials and Methods**

A series of concrete bars of various proportions were made as test pieces. The bars were made by mixing Holcim Type I Portland cement, Quickrete all purpose sand, and #7/#8 size limestone gravel in a 1 HP electric cement mixer. The forms were made by cutting equal 76 cm sections of plastic trapezoidal cross-section gutter and capping each end (Figure 2.1). The cement mixture was hand poured and packed (approximately 2 atm) into the forms; the samples were covered with a tarp and allowed to set overnight before being removed from the molds. Bases used to support the samples were poured in a similar manner using specialized molds made of rolled aluminum and wood. These forms produce ring shaped structures designed to stack and interlock with one another (Figure 1.2). These ring structures simply serve as a support and will not be sampled. Some of the bars had no additives, some had cottonseed, some had dark coloring, and some were made using ASTM concrete mixing ratios (Table 2.1).
Table 2.1. Weight of each material used for each treatment type.

<table>
<thead>
<tr>
<th>Treatment Type:</th>
<th>Standard</th>
<th>Dark</th>
<th>No Additive</th>
<th>ASTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement (lb)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Sand (lb)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Limestone Gravel (lb)</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Water (lb)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Iron Oxide liquid (colorant) (lb)</td>
<td>0</td>
<td>0.125</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cotton Seed (lb)</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Figure 2.1. Drawing of 76 cm long test piece.

On June 23, 2009 the sample were transported by truck to Rockefeller Refuge, where they were loaded onto boats to be brought to the test site (Map 2.1). All of the pieces were placed by hand without the use of machinery. The rings, each approximately 45 kg (100 lbs), were lowered from the boat to a person in the water (similar to others emplaced at the same site in 2007). Once in the water, the rings could be rolled along the bottom and set into position. This was found to be the easiest method of deployment.
during a preliminary test at Louisiana State University’s Aquaculture Station at Ben Hur Farm. A total of 12

rings and 72 bars were placed at the site. The rings were placed in two rows parallel to the shore in order to allow sampling for varying tidal exposure. At the time of the placement, the tide was at the mean low tide, 0.0 ft when using a tidal chart. At this tidal level the tops of the bars near the shore (~1 m from shore) were partially exposed, and the outer bars (~2 m from shore) were just below the surface. Six bars surrounded each ring; the bars were placed so that one end rested in the mud and then leaned against the ring.

Map 2.1. Project location in Rockefeller Refuge
The area was also marked with PVC poles to mark each ring. A diagram of the location of each treatment type was made in order to locate a specific type of bar during future sampling. Only one or two treatment types surrounded each ring. This again was done to aid in keeping track of the different sample types, especially during high tides.

For each site assessment, each bar was removed from the water, measured (lengthwise), and divided into three equal segments (approximate length of 25cm). These segments were referenced as low, middle, and high based on the location in the water column. Perimeters were measured at the middle of each segment. Oysters were counted by placing a 3” diameter open circle (½ “ section of 3” PVC) onto the samples and counting the oysters with at least half the shell within the circle. The open circle was placed randomly using a random number chart. Calipers were used to measure the shell height (bill to hinge) of the oyster nearest the center of the circle. This process was repeated for each segment of the bar. Two bars of each treatment type, of which one was from each tidal treatment, were tested at every site visit and returned to the water in the same position. This sampling was done monthly for five months.

The following parameters were tested:

1. total increase in perimeter,
2. oyster counts, and
3. oyster shell height measurements.
A Microsoft Excel spreadsheet was created to evaluate the different sample groups with one-tailed students’ T test. The following groups were taken into consideration:

1. all samples,
2. samples with no additive,
3. samples with cottonseed,
4. samples with dark coloring,
5. samples with ASTM (standard) concrete,
6. samples near shore,
7. samples far shore,
8. samples at high section of bar,
9. samples at middle section of bar,
10. and samples at low section of bar.

Spat plates were also deployed in order to monitor the amount of viable oyster larvae in the water. These plates were placed according to Supan (1983). Two 10 x 10 x 0.6cm pieces of Hardie board (James Hardie mfg.) suspended through the center with polypropylene rope (0.6 cm diameter) and held apart by a 0.6 cm piece of PVC (1.25 cm diameter) were used. A plastic zip-tie was used in one corner to prevent plate-to-plate rubbing. The plates were anchored to a PVC pole above the water and to a shell bag, resting on the bottom. Oyster spat were counted and recorded as the number of spat per m² per day, using the formula:
Total no. spat ÷ total no. of plate sides × 100 cm²/side

/Total no. of days exposed

During each site visit, theses plates were replaced with fresh plates and taken back to the lab for analysis.

Figure 2.2. Spat plates with spat circled

**Results**

After the test pieces had been in the water for five months, oysters had begun to grow on all bars. The oyster counts did not reveal any one type of concrete to outperform all others, but they did show the samples with no additive to recruit the least amount of oysters.
Table 2.2-2.6. Average oyster counts per 3 in. circle with 95% confidence interval for each treatment type during the each month of testing.

<table>
<thead>
<tr>
<th>Month 1</th>
<th>Month 2</th>
<th>Month 3</th>
<th>Month 4</th>
<th>Month 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>ASTM</td>
<td>Dark</td>
<td>No Add</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>20</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>20</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>20</td>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the first month of testing the concrete with no additive showed a significantly lower oyster count compared to the other test pieces (p= 0.002). The rest of the test pieces showed no significant difference (p >0. 19).

In the second month of testing the no additive treatment once again showed a significantly lower oyster count (p= 0.11). The ASTM treatment had a slightly significant
higher recruitment and the regular treatment also had a slightly significant lower recruitment ($p=0.15$ and $p=0.13$ respectively).

In the third month of testing, the no additive treatment showed a lower recruitment, but it was only slightly significant ($p=0.15$). The rest of the test pieces showed no significant difference ($p > 0.29$).

In both the fourth and fifth months the no additive pieces showed significantly lower oyster counts ($p=0.06$ for both months). In the fourth month the regular pieces had significantly higher oyster counts ($p=0.10$). In the fifth month the ASTM showed a slightly higher counts for the second time ($p=0.10$).

The oyster counts for different water heights show the high level to have the least growth then the middle and the low level the most (Table 2.7). The results from the statistical analysis for each data set were significant in all cases ($p<0.0004$).

The oyster counts for the near and far shore test pieces were significantly different ($p=0.05$). The test pieces further from shore showed higher counts (Table 2.8).

Percent increases in the mass were calculated for three, five, and thirty months of growth. After three months the average percent increase in mass was 8.6%. After five months of growth, the average percent increase in mass was 10.2%. After thirty months of growth, the calculated percent increase in mass was 175%.

Average oyster sizes were calculated for each month of growth. The average oyster sizes were 7.4mm, 16.0mm, 27.1mm, 30.6mm, and 39.5mm in each month for the
A five-month study. The average size of oysters taken from pieces in the water for 30 months was 104.3mm.

Spat plates were not deployed until the second month of testing. The spat fall during the third month was 7.5 spat per m² per day. During the fourth month, spat fall dropped to approximately 4.8 spat per m² per day. In the fifth month, spat levels dropped once again to approximately 3.7 spat per m² per day.

Figure 2.3. Oyster height growth in a five-month study with a linear trend line.
Figure 2.4. Oyster height growth with five-month monthly data and thirty-month data included with a logarithmic trend line.

Table 2.7. Oyster counts for different heights in the water column with 95% confidence intervals.
Table 2.8. Oyster counts for different distances from the shore with 95% confidence intervals.

<table>
<thead>
<tr>
<th>Distance from Shore</th>
<th>Oyster Counts per 3in circle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Far</td>
<td>10</td>
</tr>
<tr>
<td>Near</td>
<td>6</td>
</tr>
</tbody>
</table>

**Discussion**

In the oyster count test, the data analysis did not result in a statistically significant superior substrate. This may be in part due to the large existing oyster population, which would allow any reasonable substrate to attract and grow oysters. However, the ASTM test pieces did have significantly higher counts compared to the rest of the samples over the entire test period, but the ASTM pieces were not the highest in each month. The ASTM concrete had a smoother surface compared to the other test pieces; this may have been the factor that contributed its success. The oysters could have been trapped within the pits and crevasses of the other pieces, which did not allow the oysters to grow and survive. The test samples with no additive had significantly less success in each month and were found to be the least successful in attracting oyster settlement. All other test pieces contained cottonseed; these results agree with those of Campbell (2004), Hall et al
(2009), and Ortego (2006) that stated that the addition of biological materials enhance oyster recruitment and settling.

The results from height in water and distance from shore oyster counts showed how important proper placement is to successful oyster recruitment. Samples lower in the water column and further from the shore were able to attract significantly more oysters. Since these tests were set up in the intertidal zone, portions of the test pieces were exposed to the air during low tides. These pieces correspond to the high and near shore data. Exposure to air as well as terrestrial predators put additional strain on these oysters, which resulted in less growth and less survival. Zonation is a term to describe these settlement patterns. The zonation of oysters has been well documented by Roegner and Mann (1995). The results from this study agree with the zonation of oysters they outlined.

Oyster growth rates based on oyster height data for the five-month test period resulted in a nearly linear representation of growth (Figure 2.3). In these first five months of growth, the oysters growing on our test pieces were within the growth range for spat from Kennedy (1996), which was between 8 and 15 millimeters a month (except for the fourth month with 3.5mm). This was most likely caused by the higher values for oyster growth in the third month, which deviates from the linear trend line. With additional data from test pieces in the water for thirty months, a longer representation of oyster growth was possible (Figure 2.4). A graphical representation of growth over a longer time scale reveals a logarithmic growth curve; this represents speedy earlier growth that slows with time. These growth rates would provide the reef with enough growth to combat the effects of sea level rise outlined by Fitzgerald et al (2008) and Blum and Roberts (2009).
The first null hypothesis was rejected which determined that there was a measureable difference in perimeter for each moth of testing. The second, third, and fourth null hypothesis were also rejected, as there were many significant differences in oyster counts for different sample groups. The fifth objective was completed through the production of Figures 2.3 and 2.5.

Conclusion and Future Work

The purpose of this study was to determine what effects location and materials have in oyster settlement and growth and at what rates oysters grow on this material. These different concrete mixtures used were all able to attract and grow oyster with similar success, except those without any additives. The overall success in oyster recruitment is most likely due to the abundance of oysters present in this area. There was a large oyster population in the area that grew on almost any hard substrate, even a fiberglass fishing pole. In areas with an existing oyster population, location of the structure in the water has the largest effect on oyster growth. Placing the substrate far enough from the shore so that the tops of the structures are near the water surface during a zero tide will allow the structure to grow oysters while still providing shoreline protection from wave energy. Initial oyster growth in this study was between 3.5mm and 11.1mm per month for the first five months. These growth rates may slow with time as the oyster reaches its full growth potential. The combination of initial rapid growth and a later slowing of growth suggests a logarithmic growth curve for oyster through their life. However, this does not result in a logarithmic curve of reefs that would limit their potential, since new oysters will grow on top of the old after each spawning season.
In order to maximize the growth and success of future projects, other criteria should be taken into account. The materials should be deployed to coincide with the spring oyster spawning. Factors related to the location of the project need to be well thought-out in order to maximize the accumulation of oysters. These include salinity (most important), temperature, predation pressure, natural spat levels, oyster disease, and other species. Areas with low natural spat levels may require seeding of the material.

There have been no large-scale projects to date using this technology, but there are some planned for the near future. A $1.98 M CWPPRA project has been approved to use this technology on the coast of Rockefeller Refuge in an effort to protect ~1000 ft of shoreline (LCWCRTF 2010). Another project funded by The Nature Conservancy has also been discussed and has been set to be placed in 2010. Large-scale success would validate this as a viable method of shoreline protection and possibly encourage more investment in this new technology.
Chapter 3: Carbon Storage Potential of Oyster Reefs

Introduction

The basis of this project was to investigate the potential carbon capture and storage benefits of the oysters growing on artificial reefs. In order for this project to be successful the structures most attract and grow oysters, which use carbon to form their shells. Thus, the overall goal for this project was to determine whether or not these structures could be viable means of long-term carbon storage.

The first objective was to determine whether the mass of the bars increase with time (H₀: μ_initial < μ_3 months < μ_5 months).

The second objective was to determine the percent increase in mass for each growth period as a percent of the original structures mass measured in kilograms.

The third objective was to determine percentage of the oyster that is water, organic matter, and inorganic matter.

The fourth objective was to determine the percent increase in mass due to carbon only.

The fifth objective was to determine whether the percent increase in mass due to carbon is in excess of the percent of carbon released in making the concrete (%C). (H₀: %C < μ_3 months, %C < μ_5 months, %C < μ_30 months).
**Materials and Methods**

A series of concrete bars were made as test pieces. The bars were made by mixing Holcim Type I Portland cement, Quickrete all purpose sand, and #7/#8 size limestone gravel in a 1 HP electric cement mixer. The forms were made by cutting equal 76 cm sections of plastic trapezoidal cross-section gutter and capping each end. The cement mixtures were hand-poured and packed into the forms; the samples were covered with a tarp and allowed to set over night before being removed from the molds. Bases used to support the samples were poured in a similar manner using specialized molds made of rolled aluminum and wood. These forms produce ring shaped structures designed to stack and interlock with one another. These ring structures simply serve as a support and will not be sampled.

On June 23, 2009 the samples were transported by truck to Rockefeller Refuge, where they were loaded onto boats to be brought to the test site (Map 3.1). All of the pieces were placed by hand without the use of machinery. The rings, some in excess of 100 lbs., were lowered from the boat to a person in the water. Once in the water, the rings could be rolled along the bottom and set into position. This was found to be the easiest method of deployment during a preliminary test at Louisiana State University’s Aquaculture Station at Ben Hur Farm. A total of 12 rings and 72 bars were placed at the site. Six bars surrounded each ring; the bars were placed so that one end rest in the mud and then leaned against the ring.
Along with on sight sampling done for another project, a limited number of whole bars were brought back to the lab at designated times for analysis for this project. Bars were taken for testing after three and five months of growth. The following parameters were tested:

1. Initial bar mass with oysters (kg),
2. Bar mass without oysters (kg),
3. Height of oysters (mm),
4. Initial mass of oysters (g),
5. Dry mass of oysters (g), and
6. Ashed mass of oysters (g).
These bars were photographed from various angles, then cut into three equal sections with a hydraulic saw. An initial mass of each section was recorded, and then all oysters were removed before a final mass was taken. From this data the amount of added mass as well as percent increase in mass was calculated. Along with the bar test pieces, a portion (approximately one sixth) of a ring (Figure 3.1) that had been in the same location for two and a half years was brought back to the lab to be tested.

Figure 3.1 Portion of a ring that was brought back to the lab for testing

in the similar manner. In order to preserve the integrity of this piece, only a few oysters were removed and an estimate of the original mass was calculated. Oysters removed from the bars were also tested for percent composition. Initial masses and oyster height

39
were measured. The samples were then placed in a drying oven at 100 °C over night and weighed again. They were then placed in an ashing oven at 550 °C for 30 minutes and weighed a final time. From this data set the mass and percent of water, organic material, and noncombustible material was calculated.

From these lab results and information on the carbon content of shell (inorganic material) and carbon cost of producing concrete, it is possible to evaluate the long-term carbon storage potential of this technology. The amount of carbon dioxide released during the making of a 1 kg concrete block is approximately 0.1 kg of carbon dioxide or 10% of the mass of the concrete (EPA 2006). By using atomic masses it is possible to calculate the percentage of carbon in carbon dioxide, 27.3% carbon. Thus the amount of carbon used to create a one-pound concrete block is 0.0273 kg of carbon or 2.73% of the mass of concrete (Formula 3.1). The oyster shell stores carbon in the form of calcium carbonate, which is ~12% carbon by mass.

\[
10\% \text{ Carbon Dioxide} \times 0.0273 = 2.73\% \quad \text{(Formula 3.1)}
\]

In calculating the amount of carbon added to the structures, the percentage of noncombustible material was used as the percentage of the oyster that is shell. Thus multiplying the added mass by the percent of noncombustible material and the percent of carbon contained in the shell (12%) will result in the percentage of added mass that is carbon. If this value exceeds 2.73%, then the amount of carbon deposited on the structure has surpassed the amount released in creating it. It is also possible to calculate the percent of added mass required to breakeven on carbon usage by using the average percentage of shell mass (69.3%). Multiplying this percentage by the carbon content of the shell reveals the amount of the added mass that is carbon, 8.32% (Formula 3.2). Therefore,
when the percent of added mass times .0832 equals 2.73, the amount of carbon released equals the amount of carbon stored. Performing this calculation reveals that a 32.8% increase in mass would reach a breakeven point. From this value the amount of excess carbon can be calculated with Formula 3.3.

\[ 69.3\% \text{ Added Shell Mass} \times 0.12 = 8.32\% \text{ Added Carbon Mass} \] 
(Formula 3.2)

\[ \left(\% \text{ Added Mass} - 32.8\right) \times 0.0832 \times \text{Added Mass} = \text{Mass of Excess Carbon} \] 
(Formula 3.3)

**Results**

After having been in the water for three months, there was visible growth on all the bars. The samples returned to the lab revealed an increase in mass for each section of the bars with an average of 8.6% mass increase. The oysters from this test piece ranged in size from 20-35mm. The average mass of these oysters was 1.44 g. The percent composition by mass of these oysters was 33.1% water, 5.1% combustible (organic matter), and 61.8% noncombustible (inorganic matter).

After five months of growth, the size of the oysters tested ranged from 30 to 45 mm in height. The samples returned to the lab revealed an increase in mass for each section of the bars with an average of 10.2% mass increase. The oysters from this test piece ranged in size from 30-45mm. The average mass of these oysters was 13.6g. The percent composition by mass of these oysters was 25.9% water, 3.9% combustible (organic matter), and 70.2% noncombustible (inorganic matter).

The portion of a ring that was brought back to the lab had a mass of 42 pounds. The initial mass of the entire ring was 100 pounds; the portion that was returned to the lab
was approximately one-sixth of the entire ring. Thus the mass of the original mass of the ring was 16.7 pounds. From these calculations and measurements, the percent of added mass due to growth was 175%. The oysters from this test piece ranged in size from 85-130mm, and were further divided into two classes (85-100mm and >100mm). The average mass of the large and small oysters was 102.5g and 57.1g respectively. The percent composition by mass of the smaller oysters was 29.4% water, 2.9% combustible (organic matter), and 70.6% noncombustible (inorganic matter). The percent composition by mass of the larger oysters was 25.6% water, 3.3% combustible (organic matter), and 74.4% noncombustible (inorganic matter).

Table 3.1 Summary of the percent composition of oysters from each sample set

<table>
<thead>
<tr>
<th>Time (months)</th>
<th>% Water</th>
<th>% Organic</th>
<th>% Noncombustible</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>33.1</td>
<td>5.1</td>
<td>61.8</td>
</tr>
<tr>
<td>5</td>
<td>25.9</td>
<td>3.9</td>
<td>70.2</td>
</tr>
<tr>
<td>30 (small)</td>
<td>29.4</td>
<td>2.9</td>
<td>70.6</td>
</tr>
<tr>
<td>30 (large)</td>
<td>25.6</td>
<td>3.3</td>
<td>74.4</td>
</tr>
</tbody>
</table>

\[ \text{(%Added Carbon} - 2.72) \times \text{Mass of Structure} = \text{Mass of Excess Carbon} \]

(Formula 3.4)

\[ \text{%Added Mass} \times \%\text{Shell} \times .12 = \%\text{Added Carbon} \] (Formula 3.5)

Formula 3.5 enables the calculation a percentage of added mass due to carbon. In the third month, the percentage of added mass that is carbon was 0.64%. After five months of growth, the percentage of added mass that is carbon was 0.86%. In these first
two tests, the structures have yet to reach 32.8% increase in mass or 2.73% of carbon addition. After thirty months of growth, the percentage of added mass that is carbon was 14.83% (using values for small oysters) or 15.62% (using values for large oysters). Both of these values are far in excess of the 2.73% required to breakeven. Thus, there is a positive amount of total carbon storage in both cases. With Formula 3.4 the amount of excess carbon can be calculated for a 100 pound ring. Using the values for the small oysters, 12.1 pounds of excess carbon is locked up in the shells and 12.9 pounds of excess carbon for the values for large oysters for this geometry and location.

Table 3.2 Summary of Carbon Balance for each sample set

<table>
<thead>
<tr>
<th>Time (months)</th>
<th>% Mass Increase</th>
<th>% Mass of Carbon Increase</th>
<th>%Carbon-2.73</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>8.6</td>
<td>0.064</td>
<td>-2.09</td>
</tr>
<tr>
<td>5</td>
<td>10.2</td>
<td>0.86</td>
<td>-1.87</td>
</tr>
<tr>
<td>30 (small)</td>
<td>175</td>
<td>14.83</td>
<td>12.1</td>
</tr>
<tr>
<td>30 (large)</td>
<td>175</td>
<td>15.62</td>
<td>12.89</td>
</tr>
</tbody>
</table>

Discussion

In the first two data sets (three and five months), the structures were able to attract enough oysters to have a significant increase in mass. These oysters are only in the early stages of development and still have much growth potential. Also as seen in the test piece that had been in the water for thirty months, the oysters become the new growth substrate and new oysters attach to the reef each spat season. The thirty-month test piece’s success was the result of three spat seasons, thus three layers of oysters. Similar
results would be expected for the new test pieces after subsequent spat seasons and addition layers of oyster.

The overall goal of this project was to investigate the long-term storage potential of artificial oyster reefs. Carbon was stored in the shells of these organisms, but carbon was also released in the process of making the concrete structure for the oysters to attach to. Therefore, the structures must first capture enough carbon to offset this value. This point was not reached in a relatively short period of time (five months), but by thirty months the oysters were able to capture and store approximately 12% of the structure’s initial mass in excess carbon. One simple way to either increase this value or to reach it in a shorter period of time would be to decrease the mass of the structure while maintaining approximately the same surface area. A reduction in thickness would be one way this goal could be reached.

The approved large-scale CWPPRA project using this technology will use 1850 metric tons of this substrate. The goal of this project is to protect 1000 ft of shoreline that is retreating at a rate of 30.9 ft yr⁻¹ (LCWCRTF 2009). If this project has the similar success to the small-scale project in the same area, it could potentially capture between 274 and 288 metric tons of carbon in thirty months. This is only considered by CWPPRA as a demonstration project to test this technology. Its success could lead to the use of this technology on even larger projects with a greater potential for carbon storage.
Chapter 4: Conclusion and Future Work

Project Summary

The scope of this project was to evaluate the growth of the target species (the eastern oyster, *Crassostrea virginica*) on our substrate and to investigate the carbon storage potential of the oysters growing on this substrate. The test site location in Rockefeller Refuge proved to be a favorable environment for oysters with an already thriving oyster population. The habitat in this area was found to be so conducive to oyster growth that there was little difference seen in oyster recruitment and growth regardless of substrate variation. However, there were substantial variations in oyster settlement and growth at different locations in the water column as well as at different distances from the shore. These findings revealed how important it is to properly emplace these structures to ensure oyster settlement and growth. The structures should be situated so that the tops are at or near the water’s surface during a zero tide event.

The second part of this project was to evaluate the carbon storage potential of the oysters on the structures. Data collected from lab analysis of the test pieces was used to evaluate the carbon content of the oysters at different growth stages. Oysters store carbon in their shells, which are made of calcium carbonate. The carbon content of oysters at different growth stages was calculated through a series of drying and ashing techniques. The carbon content and measured additional mass due to oyster growth were used to calculate how much carbon was added to the structure. These values could then be compared to the amount of carbon released through making the structure. Test results from three and five months of growth revealed the potential of eventually storing more
carbon than the amount used through creating the structure. A sample taken from a test piece that had been in the water for thirty months revealed a carbon content of more than five times the amount of carbon used in the production of the test piece. Future large-scale projects using these designed structures could have the ability to store considerable amounts of carbon through oyster growth, but the project has to be in an area where oysters can grow.

**Mapping the “Oyster Zone”**

This technology has seen various degrees of success at different test sites in southern Louisiana. Success is limited by the attachment and growth of oysters to these structures. Therefore the reefs must be placed in an area that is conducive to oyster growth. One of the key water quality parameters that would limit the growth potential of oysters is salinity. With this in consideration a map of potential emplacement sites was created based on salinity data. Since the map is based on salinity data and not existing oyster populations, seeding of oysters may be required in some areas found on the map. Larger versions of this map can be viewed in the appendix.

The map was created using ArcMap software, which is the main component of ESRI’s ArcGIS suite of geospatial processing programs. This program is used to view, edit, create, and analyze geospatial data. Multiple layers can be edited and placed on top of one another to form a composite map.
Future Considerations

With the first large-scale projects in the near future, monitoring the placement and oyster growth would provide vital details about this technology. From these finding it would then be possible to create the best management practices for the use of this technology. These could then be used to improve a method of properly placing these structures and make the emplacement process more efficient and cost effective. This is still a new technology that has yet to be tested full-scale; if successful it would serve as a viable method of shoreline protection that is both cost effective and ecologically beneficial.

Future projects could also benefit though community involvement. In fact it benefits the community to become more involved with such projects because in many
cases it is their land that is at stake. The involvement of the oyster community would also prove to be mutuality beneficial. These reefs would provide the oyster farmers with a larger breeding population, which would increase the oyster population in this area. The oyster farmer’s knowledge of the potential sites and access to shallow draft vessel would provide a means of deployment for future projects. Developing a community-based project could provide another means to employ this technology.
Bibliography


EPA (2006), *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks* "Raw materials Acquisition and Manufacturing" column g, chapter 2: p.24,


Type Breakwater. Biological and Agricultural Engineering. Baton Rouge, LA, Louisiana State University. Master of Science in Biological and Agricultural Engineering.


unfccc.int (2009). Kyoto Protocol


Appendix: Data

Temperature and salinity data from test site done by employees of Rockefeller Refuge using a YSI 600-LS temperature and conductivity probe.

<table>
<thead>
<tr>
<th>Date</th>
<th>Salinity (ppt)</th>
<th>Temperature (Celcius)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/7/09</td>
<td>20.2</td>
<td>16.1</td>
</tr>
<tr>
<td>2/4/09</td>
<td>12</td>
<td>9.8</td>
</tr>
<tr>
<td>3/4/09</td>
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</tr>
<tr>
<td>5/6/09</td>
<td>7.1</td>
<td>26.9</td>
</tr>
<tr>
<td>6/1/09</td>
<td>19.3</td>
<td>28.3</td>
</tr>
<tr>
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<td>32.5</td>
<td>30.2</td>
</tr>
<tr>
<td>8/5/09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/1/09</td>
<td>28.2</td>
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</tr>
<tr>
<td>10/5/09</td>
<td>17.3</td>
<td>29.1</td>
</tr>
<tr>
<td>11/4/09</td>
<td>5.6</td>
<td>18.3</td>
</tr>
</tbody>
</table>

Average 17.35 22.02
Diagram of oyster (Martin 2004)

“Oyster Zone” map of southwestern Louisiana. Hatched area represents possible oyster growth.
“Oyster Zone” map of southwestern Louisiana. Hatched area represents possible oyster growth.
Vita

Daniel Dehon was born in New Orleans, Louisiana, in October 1984 to Patrick and Maureen Dehon. He was raised in Lakeview, a New Orleans neighborhood. After graduating high school from the Jesuit High School in New Orleans, Louisiana, in 2003, he enrolled at Louisiana State University as a first-generation Tiger. In May 2008, Daniel graduated with a Bachelor of Science degree in biological engineering and continued with graduate studies in the same department in August 2008. He is a candidate for the degree of Master of Science in Biological and Agricultural Engineering to be awarded in May 2010.