

# Estuarine Shoreline Stabilization: Public Perceptions and Greenhouse Gas Implications

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## Abbreviations

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AGB: Aboveground Biomass

ATL: Alterniflora - a genus of perennial deciduous grasses found throughout the Outer Banks

BGB: Belowground Biomass

DP: Durant's Point

FP: Festival Park

JUNC: Juncus - a genus of plants found throughout the Outer Banks

HM: High marsh

IWG: Interagency Working Group

JR: Jockey's Ridge

LJ: Private property in Frisco

LM: Low marsh

NGOs: Non-governmental organizations

REED: Reducing Emissions from Deforestation and Forest Degradation

REF: Reference marsh

T<sub>x</sub>: Transect number

UNREDD: United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation

WRC: Wildlife Resource Commission in Edenton

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## Abstract

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Estuarine shorelines span over 10,000 miles of North Carolina's coast and provide numerous ecosystem services, whose functionality depends on a variety of environmental and anthropogenic variables. The threat of erosion, a natural process that results in the removal of sediments from shorelines and their eventual degradation, catalyzes the installation of different types of shoreline protection measures, which can either enhance or hinder ecosystem services. To contribute to the understanding of shoreline protection on the Outer Banks and the surrounding areas, we combined quantitative and qualitative natural and social science approaches to shed light on the ecological implications of shoreline modifications and the decision-making considerations of property owners choosing shoreline stabilization methods.

Using previous literature as a foundation, our study examined the ability of living shorelines to sequester carbon, an important ecosystem service and possible atmospheric carbon dioxide mitigation measure. To determine the viability of living shorelines as a climate change alleviation tactic, we quantified carbon storage in sediments through soil core sampling and methane flux to determine whether the release of methane negated the carbon sequestered. To better understand the factors behind methane flux, we compared the flux rate at each site to multiple variables to assess correlations between methane release and abiotic factors. Salinity has widely been acknowledged as attributing to methane flux rates, however our findings showed no relationship between the two. There was a stronger correlation with percent organic carbon, except for two sites that diverged from the linear trend. In regards to carbon sequestration, the rate had a strong negative correlation with living shoreline age. After calculating the net carbon sequestration rates, we found living shorelines act as carbon sinks, which corresponds with previous research.

To gather information on factors influencing shoreline decision-making, we conducted 22 semi-structured interviews with sound side property owners and managers. We found nearly all the interviewees had noticed erosion on their property, due to natural processes or exacerbated effects from hardened neighboring shorelines. Further analysis revealed that pre-existing values such as aesthetics, recreation, ecocentrism, security, and place attachment influenced decision-making, but not as strongly as expected. The pursuit and source of information had a much stronger influence on the decided protection method. Also unexpected, the cost of installing the shoreline protection method and the permitting process had little correlation with the method chosen. Uncovering these themes may clarify why certain protection methods are used more often than others and techniques to inform shoreline protection method decisions. Because some property owners focused on the ecological impacts of different shoreline protection methods, further quantifying and distributing information on the carbon storage benefit of living shorelines may be influential for those who prioritize ecocentrism while also contributing to atmospheric carbon dioxide mitigation in the face of climate change.

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## Introduction

### **Estuaries and the Services They Provide**

North Carolina has over 10,000 miles of valuable estuarine shoreline (NCDCM, 2015). Estuarine shorelines exist as a boundary between land and the estuary, a semi-enclosed body of water in which fresh and saltwater meet. Due to the many highly productive habitats found where salt and freshwater meet, estuarine ecosystems can sustain a diverse array of unique plant and animal species (EPA, 2016). With such a large geographic range, estuarine shorelines in North Carolina have a breadth of different elevations, salinity levels, inundation patterns, vegetation types, and many other environmental variations that influence the properties of the shoreline and the services it can provide. Although estuarine shorelines and wetlands provide extensive ecosystem services, rapid population growth is driving development. Between 2004 and 2014, northeast North Carolina saw an 8.2% population growth and southeast North Carolina saw a 17.1% population growth (NCDC, 2016). North Carolina is not alone. According to Gittman et al. (2015), shoreline development threatens wetland areas that make up more than half of the coastline spanning the South Atlantic to the Gulf of Mexico (Gittman et al., 2015). As the population and subsequent development in coastal areas increases, so do rates of erosion threatening estuarine shorelines and the ecosystem services they provide.

Estuarine shorelines provide a myriad of ecosystem services, which are indirect or direct benefits derived from the use or existence of a certain ecosystem. Some ecosystem services estuarine shorelines supply includes “raw materials and food, coastal protection, erosion control, water purification, maintenance of fisheries, carbon sequestration, and tourism, recreation, education, and research” (Barbier et al., 2011). The balance between saline and freshwater characteristics of estuaries supports a vibrant community of organisms, including oysters, that provide a food source and prevent erosion (Meyer et al., 1997). Vegetation and oyster reefs along estuarine shorelines also filter out pollutants (Bilkovic and Mitchell, 2013), like excess nitrogen (O’Meara et al., 2013), and improve water quality. Estuarine shorelines act as significant nursery areas that support a diverse abundance of fish species (Beck et al., 2001). Estuarine shorelines not only support the ecological and economic health of coastal communities, but provide invaluable services to people living far from the coast. In this study, our research hones in on one of the many ecosystem services: carbon sequestration.

### **Carbon Sequestration**

Carbon sequestration occurs when vegetation uses atmospheric carbon dioxide and stores it as organic carbon in the form of biomass including roots, leaves, and stems (USDA Forest Service, 2016; McLeod et al., 2011). When plants remove atmospheric carbon dioxide for photosynthesis at a faster rate than decomposition releases carbon as carbon dioxide and methane gas back into the atmosphere, then carbon is stored in the ecosystem within plants and sediments as organic matter. When plants sequester carbon and store it for long periods, the carbon loses its greenhouse gas potential and no longer contributes to global temperature rise; therefore, there are large implications for the reduction of global atmospheric greenhouse gases.

Some ecosystems, including estuarine and coastal ecosystems, are especially adept at sequestering carbon because they have high rates of primary production and low rates of decomposition (Davis et al. 2015). Coastal ecosystems also have the ability to accrete vertically

when experiencing sea level rise, meaning they can trap and build up sediments delivered by rising waters. Vertical accretion prevents coastal ecosystems from becoming oversaturated with carbon (McLeod et al., 2011) and makes them especially valuable for long-term carbon storage. While coastal ecosystems present a promising opportunity for carbon storage and climate change mitigation, sequestered carbon is not removed from the atmosphere indefinitely. When coastal ecosystems are modified or destroyed and the organic matter that store carbon decomposes, carbon is released back into the atmosphere, negating the benefits of carbon sequestration.

In addition to releasing carbon when they are degraded, coastal ecosystems are the largest natural source of methane, a powerful greenhouse gas. Methane emissions occur at variable rates as decomposition takes place in the absence of oxygen (EPA, 2017). Due to the high variability of coastal ecosystems in terms of elevation, vegetation, salinity, and organic matter content of sediments, factors controlling rates of methane flux remain unclear. High rates of methane release could offset the climate benefits of carbon sequestration, warranting further research into methane release in coastal ecosystems.

## Erosion

There are several imminent threats to coastal ecosystems that could jeopardize many of the ecosystem services these environments provide, including carbon sequestration. The largest of these threats is erosion, which directly destroys estuarine shorelines overtime. Estuaries are subject to significant energy from wind, waves, and storms (Cowart et al., 2010), making them especially susceptible to erosion. As estuarine shorelines physically erode when high energy processes break up and carry away sediments, benefits such as carbon sequestration, protection from wave action, and habitat also erode.

The localized rate of erosion a shoreline experiences depends on a multitude of factors, most of which relate to the shoreline’s physical properties. These physical properties include elevation, slope, orientation, and fetch of its neighboring water body. Table 1 highlights several shoreline variables that influence the degree of erosion a shoreline experiences.

**Table 1.** Physical variables shaping estuarine shorelines (Borrowed from Riggs and Ames, 2003)

SHORELINE VARIABLES	DEFINITION	POTENTIAL FOR EROSION	
		LOW	HIGH
Fetch	Average distance of open water in front of shoreline	Short Fetch (<1000 feet)	Long Fetch (>1000 feet)
Offshore bottom character	Water depth and bottom slope in the nearshore area	Shallow, gradual slope (<3 feet)	Deep, steep slope (>3 feet)
Geometry of shoreline	Shape and regularity of shoreline (sinuosity)	Highly irregular or in a cove	Straight or on a headland
Height of sediment bank	Bank height at shoreline or immediately behind sand beach	High (>6 feet)	Low (<6 feet)
Composition of sediment bank	Composition and degree of cementation of bank sediments	Rock, tight clay	Uncemented sand, peat
Fringing vegetation	Type and abundance of vegetation (aquatic plants, marsh grasses, shrubs, trees, etc.) occurring in front of sediment bank	Very abundant, dense	Absent
Boat wakes	Proximity of property to, frequency and type of boat channel use	Absence of boats	Marinas, intracoastal waterway
Storms	Storms are the single most important factor determining specific erosional events	Depends on type, intensity, duration and frequency of storms	



Climate change induced sea-level rise also increases total rates of erosion. As the Earth's temperatures continue to rise and melt large ice masses, global sea levels will also rise because the additional water takes up more area as it expands with increasing temperature (NOAA, 2017). Rising sea levels shift the land-water interface landward and push high energy waves over a greater area causing increased erosion rates (Leatherman et al., 2000). In addition to rising sea levels, climate change also contributes to increased storm intensity with some models projecting an almost twofold increase in the frequency of category four and five storms by the end of the 21st century (Bender et al., 2010). Increasing storm intensity will subject shorelines to higher wind and wave energy that can lead to massive erosion events, accelerating the need for shoreline stabilization.

### Shoreline Stabilization

There are many different ways to stabilize a shoreline against erosion, including hardened structures, like bulkheads or riprap revetments, and living structures, like sills with planted vegetation. These different shoreline stabilization methods each introduce a barrier to reduce erosive forces; however, each approach comes with its own positive and negative consequences.



**Figure 1.** Examples of estuarine shoreline stabilization options. A living shoreline composed of a seaward rock sill with planted vegetation (top-left), a bulkhead (top-right), a riprap revetment

composed of rocks and cement (bottom-left), and a living shoreline with only planted vegetation (bottom-right). (NCDCM, 2013)

Hardened structures form complete barriers between the land and the water made from material like concrete, wood, or metal. According to a study on the ecological consequences of shoreline stabilization, hardened structures have negative impacts on coastal ecosystems by reducing habitat and thus species abundance and biodiversity (Gittman et al., 2016). Hardened shoreline structures have been linked to declining submerged aquatic vegetation populations (Patrick et al., 2012) which provide integral habitat to many other aquatic species as well. While hardened structures do have some environmental drawbacks, hardened structures stabilize 827.1 miles of the North Carolina estuarine shoreline (NCDCM, 2015). Many people may choose hardened shoreline stabilization structures because of their potential durability, relative ease of general permitting, and preservation of water access for recreation (NCDCM, 2013).

Living shorelines, however, are protection measures that use native vegetation and natural materials, like rock or oyster shell, to protect shorelines and preserve natural hydrology and habitat (Davis et al., 2015). By stabilizing the shoreline against erosion and providing increased habitat, carbon sequestration potential, and other ecosystem services, “living shorelines are part of the natural and hybrid infrastructure approach to coastal resiliency” (Davis et al., 2015). Many of the properties that make marshes successful carbon sinks also make them successful shoreline armory; for example, the ability of coastal ecosystems to accrete vertically allows them to store more carbon in the form of biomass (McLeod et al., 2011) and strengthens their ability to prevent against erosion by attenuating wave action (Currin et al., 2010). Ultimately, living shorelines are doubly valuable as they both protect and enhance the functionality of the ecosystem services provided by estuarine shorelines.

As shoreline protection takes center stage in many coastal communities, it is becoming increasingly clear that not all property owners—whether private citizens or organizational representatives—take the same approach. A 2010 study found that in eastern North Carolina, of the 805 miles of modified shoreline, bulkheaded shoreline constituted 497 of those modified miles, while sills with no allotment made for the backplanting of vegetation represented only 5.0 miles of protection (Coward et al., 2010). Despite the numerous benefits of living shorelines, property owners and land managers are choosing to armor their shorelines, suggesting that they consider additional factors when deciding upon shoreline protection.

### **Valuing Shoreline Stabilization**

In choosing a method of protection for their shoreline—whether hardened, living, or natural—property owners and managers incorporate a pre-existing system of values into their decision-making, which includes some conceptualization of an ideal outcome. The overlap between these two factors significantly influences their overall decision in shoreline protection. The extent to which an individual’s underlying value system impacts their decision-making processes is the subject of ongoing research due to the tentative link between values and behavior, though values are relatively stable and resistant to change (Verplanken, 2002). The literature surrounding behavior and decision-making typically defines values as desirable outcomes, or a desirable mode of behavior. Though abstract, values are generally perceived as motivational. For example, living up to a treasured value can create a sense of satisfaction that

stems from goal fulfillment, which is instrumental in the development of an individual's sense of self (Verplanken, 2002; Voyer et al., 2014). This conceptualization of value can be broadly applied to understand the factors that are important in decisions about protecting shoreline property.

### **Purpose and Approach**

A major goal of this study was to conduct an interdisciplinary investigation into the ways shoreline property is valued and protected, which required a multifaceted approach to data collection. This ultimately resulted in the subdivision of the data into two distinct categories, referred to informally as natural science and the human dimension. Each of these respective categories aligned most closely to either a quantitative or qualitative approach to data analysis. While the goal of the analysis of the natural science was to illustrate the quantifiable characteristics of living shorelines and natural marshes as carbon sinks, the human dimension aspect employed qualitative methods to better understand the complex and often individualized processes behind coastal decision-making in a cultural climate like the Outer Banks.

For the quantitative natural science portion of this study, we hypothesized that younger living shoreline projects would display greater carbon sequestration rates due to an influx of organic matter onto an inorganic sandy shoreline. We expected to observe decreasing sequestration rates as marshes aged and became more saturated with carbon in the form of organic matter. We modeled our carbon sequestration work after Davis et al., 2015. We attempt to contextualize carbon sequestration rates using data on methane flux in comparison with net carbon storage. We hypothesized that methane flux would vary based on environmental conditions, showing a negative, linear correlation with salinity.

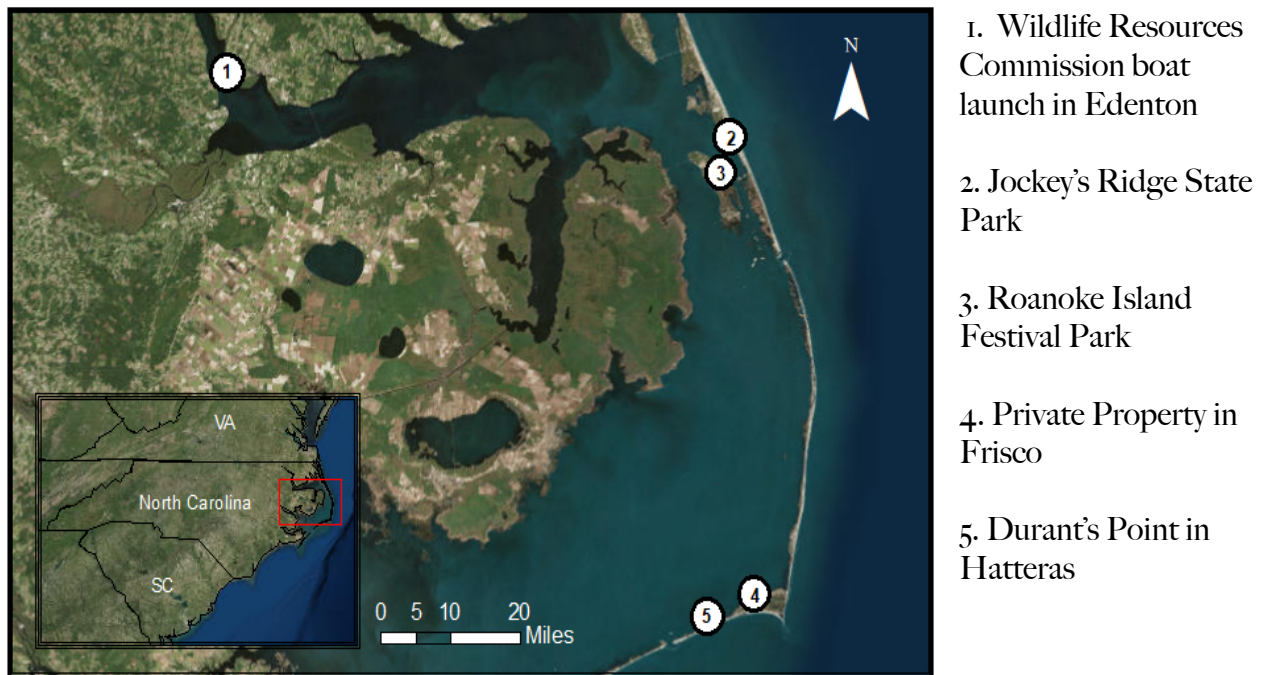
For the qualitative human dimensions portion of this study, we expected to find evidence of concrete factors that influenced our interviewees in their decision to implement shoreline stabilization. To accomplish this goal, we designed our interview guide to elicit the necessary information to evaluate relevant variables to shoreline protection. We predicted that several critical factors would emerge in the decision-making process, factors that could have implications for coastal management. Specifically, we hypothesized that the accessibility of information sources, the permitting process, and costs would be primary drivers in determining estuarine shoreline protection.

## Carbon Storage Capacity of Living Shorelines

### Methods:

#### Study Locations

This study focused on the estuarine shorelines of the Inner and Outer Banks of North Carolina. The natural science component of the study included five sample locations (Figure 2; Table 2): Roanoke Island Festival Park in Manteo (FP), the Wildlife Resources Commission boat launch in Edenton (WRC), Durant's Point in Hatteras (DP), a privately owned soundside property in Frisco (LJ), and Jockey's Ridge State Park (JR). Gas chamber sampling to determine methane flux was conducted at FP, WRC, LJ, and JR. Core and vegetation sampling to determine carbon sequestration, bulk density, and biomass, was conducted at WRC, DP, LJ, FP and JR. All of these locations were suggested by the North Carolina Coastal Federation, who aided in coordinating and planting the living shoreline projects located at each site. Although each location was the site of a living shoreline project, the engineered components of the projects varied (Table 2).



**Figure 2.** Map of sampling locations

Each of the sampling locations, marked by numbers in the map and corresponding to names in the legend, was the location of sediment core and above and belowground biomass sampling and/or methane flux measurements to determine net carbon storage by natural wetland shorelines and living shorelines.

**Table 2.** Key characteristics of sampling locations

This table contains a compilation of the defining features of each sampling location. Note that salinity measurements were taken periodically using water salinity rather than soil salinity. Also note that samples taken from DP were only taken from the low marsh because the location lacked a high marsh region.

Location	Type of Living Shoreline	Age of Shoreline Vegetation	Sampling Employed	Average Salinity (ppt)	Dominant Plant Species		
					High Marsh	Low Marsh	Reference Marsh
WRC	Vegetation with Sill	13 years	Sediment Core, Gas Flux	0.00	<i>Cladium</i> , <i>Centella asiatica</i>	<i>Cladium</i>	N/A
JR	Vegetation	8.5 years	Sediment Core, Gas Flux	10.00-19.00	<i>Spartina patens</i> , <i>Centella asiatica</i>	<i>Juncus</i> , <i>Spartina alterniflora</i>	<i>Juncus</i> , <i>Spartina alterniflora</i> , <i>Greenbrier</i> , <i>Spartina patens</i>
FP	Vegetation with Sill	Unknown	Sediment Core, Gas Flux	14.00	<i>Spartina alterniflora</i>	<i>Juncus</i>	N/A
LJ	Vegetation with Sill	Unknown	Sediment Core, Gas Flux	23.00-25.00	Hummocky <i>Juncus</i> , <i>Spartina alterniflora</i>		N/A
DP	Vegetation with Sill	5.5 years	Sediment Core	23.00-24.00	N/A	<i>Spartina alterniflora</i>	<i>Spartina alterniflora</i>

Each of these natural wetland shorelines is a marsh, an area of low lying land characterized by frequent inundation and the vegetation present. Living shoreline sites used in carbon sequestration calculations were chosen based on the presence of a sandy baseline that represents age zero of the marsh before a living shoreline was implemented. Establishing a baseline at age zero is critical for identifying benefits of living shorelines versus benefits of previously established natural marsh or historic peat layers. Our sampling locations LJ and FP are characterized by sills installed in front of naturally occurring marshes, inhibiting the identification of an age or baseline. For that reason, LJ and FP were considered representative control locations instead of living shoreline sample locations.



Locations for observing methane flux were chosen along a salinity gradient, ranging from freshwater in Edenton to brackish water in Hatteras (Table 2). Sampling along a salinity gradient was important to determine if salinity constitutes a significant variable in controlling the methane flux of coastal ecosystems. Salinity of coastal ecosystems depends on several factors, including storms and wind patterns; therefore, the salinity was taken multiple times at each location to capture some variability.

### Carbon Storage Sampling

Carbon content and above and belowground biomass samples were collected and analyzed to calculate sediment carbon sequestration rates using work by Davis et al. (2015) as a model and in consultation with Davis (unpublished). At three of the sampling locations, including JR, DP, and WRC, sediment cores and aboveground vegetation measurements and biomass were collected. At each of these locations, samples were taken within three replicate transects (T<sub>1</sub>-T<sub>3</sub>) that included high (HM) and low marsh (LM) sites when possible. Low marsh was identified as zero meters from the shoreline. High marsh was identified as a region slightly inland with a distinct plant community indicative of less inundated conditions. Samples were also taken following the same technique from one (DP) or two (JR) transects within a neighboring intact reference marsh when possible. Figure 3 provides a visual example of transects and HM and LM sampling sites at the JR study location. At each sampling location, the date, time, GPS coordinates, and salinity were recorded. Representative data on high and low marsh vegetation at each transect and location was taken by randomly throwing a 26 cm<sup>2</sup> quadrat and recording the total number of stems, heights of ten random stems, and all plant species within the quadrat. Above and belowground biomass samples were taken adjacent to the sampling quadrat at every location.



**Figure 3.** Examples of the delineation of low marsh and high marsh along transects.

### Biomass

To collect aboveground biomass (AGB) samples, the vegetation present in the 30.10 cm<sup>2</sup> area overlaying a belowground biomass 6.2 cm diameter core tube was clipped and bagged. Aboveground biomass clippings were rinsed to remove epiphytes and massed before being dried to a constant weight at 60°C. These samples were homogenized by grinding and subsampled. Subsamples were combusted at 450°C and reweighed to calculate the loss on ignition value, hereon referred to as the organic matter content. The organic matter content for each AGB sample was divided by the sampling area to calculate AGB.

Belowground biomass (BGB) samples were collected in the previously cleared AGB sampling area by inserting a 40 cm long acrylic tube in the ground to a depth of at least 30 cm, or

to a point with a stark decrease in biomass identified by a sandy layer, and extracting a sediment core. Belowground biomass core samples were rinsed over a 2 millimeter mesh sieve, removing sand and shell. The remaining BGB was massed and dried to a constant weight at 60°C. Samples were homogenized by grinding and then subsampled. Subsamples were combusted at 450°C for 4 hours and reweighed. The loss on ignition for each BGB sample was divided by the area of the sampling plot as described above to calculate BGB.

### **Bulk Density and Carbon Content**

An additional sediment core was collected in the manner described above for the BGB samples at each high and low marsh site within each study location adjacent to BGB core sampling sites. Cores were collected to a depth of at least 30 cm to reach sediments deeper than those influenced by surface vegetation. Immediately following collection, each core was plugged in the core tube to keep it intact and refrigerated for no more than 72 hours before processing. Intact belowground sediment cores were extruded from the core tubes in 5 cm increments. Bulk density, the overall density of the soil, was calculated by dividing the mass of the 5 cm depth increments by their volumes. Each increment was placed in a separate tray and then massed, dried, and combusted as described above to determine organic matter content.

When identifiable, a background organic matter level was determined from the 5 cm depth increment at which organic matter stopped decreasing with depth. This depth ranged from 15 to 25 cm. The identified background organic matter level was subtracted from organic matter for overlying 5 cm increments to give a corrected organic matter content for each 5 cm increment. Samples from the following locations were not background corrected as a background organic matter level was not identifiable within the 20 to 30 cm sampled: DP T1 LM, WRC T1 LM, LJ JUNC, LJ ATL. We were unable to calculate average organic matter, bulk density, and sequestration rates without background organic matter content, so these samples were omitted from the calculations that follow.

Total organic carbon stock was calculated from the sum of corrected carbon content values for the top 15 to 20 cm of each core. The total depth of the core summed depended upon the depth increment identified as the background level. Annual carbon sequestration was determined by dividing total organic carbon stock by marsh age. We calculated the mean for LM and HM bulk density, total organic carbon stock, and carbon sequestration rates across the three transects at each study location.

### **Methane Flux**

To determine the atmospheric release of carbon as methane from the vegetated coastal ecosystems in this study, methane flux was measured at four study locations along a salinity gradient. Soil collars consisting of a plastic cylinder with a diameter of 20 cm and depth of 11 cm were placed into the ground at each of the methane flux sampling sites. Soil collars were placed by pushing the cylinder approximately 5 cm into the ground while avoiding heavy vegetation and keeping the cylinder level. Any vegetation within the soil collar was clipped and removed. Up to five collars were placed at each location at sites meant to capture visual estimates of variability in vegetation and elevation. Collars were placed at the study sites at least 48 hr prior to sample collection to allow sediment to settle around and within the chamber, with the exception of one chamber at the WRC location which was placed on the day of sampling.

Each site was sampled at least three times from early October to late November to capture some temporal variability in fluxes and highlight trends that may be related to environmental fluctuations like changing wind patterns. During each sampling occasion, samples were taken from each chamber every 15 minutes for a total of 45 minutes, or 4 incremental samples. To take a sample from the gas flux chambers, the soil collars were capped with dome-like opaque vented PVC caps measuring 10.5 cm in depth for approximately two minutes. Then a 20 ml gas sample was taken from a silicone septa fitted Swagelock gas sampling port on the top of each chamber cap using a 25 ml syringe. Chamber headspace was mixed prior to extraction of each sample by slowly pumping the gas sample through the syringe three times. Gas samples were stored in evacuated 15 milliliter glass vials capped with silicone stoppers for transport to UNC Coastal Studies Institute laboratory for analysis. For each sampling location, a control blank was also taken by collecting ambient air in an evacuated 15 ml vial. Gas samples were collected from each location at least three times over the period of two months. On each sampling occasion, the depth of each chamber and the air temperature were recorded to later calculate the volume of gas in each chamber.

Gas samples were analyzed using a Shimadzu GC-2014 gas chromatograph with a flame ionization detector and Hayesep Q column within 48 hr of collection. A calibration curve was created using measured areas from samples of three known concentrations: 0 ppm, 1 ppm, and 10.3 ppm methane. Area-based rates of methane flux were calculated from the linear changes in methane concentrations in each chamber over time and chamber geometry as previously described (Whalen et al., 1992). Data points in which the rate of change in methane concentration over time had a linear regression with an R squared value of less than .8 were removed from the data set. Any data points collected in which the gas chamber was inundated with water were also removed from the overall data set because the presence of standing water inhibits normal diffusion of methane to the surface.

## Results and Discussion

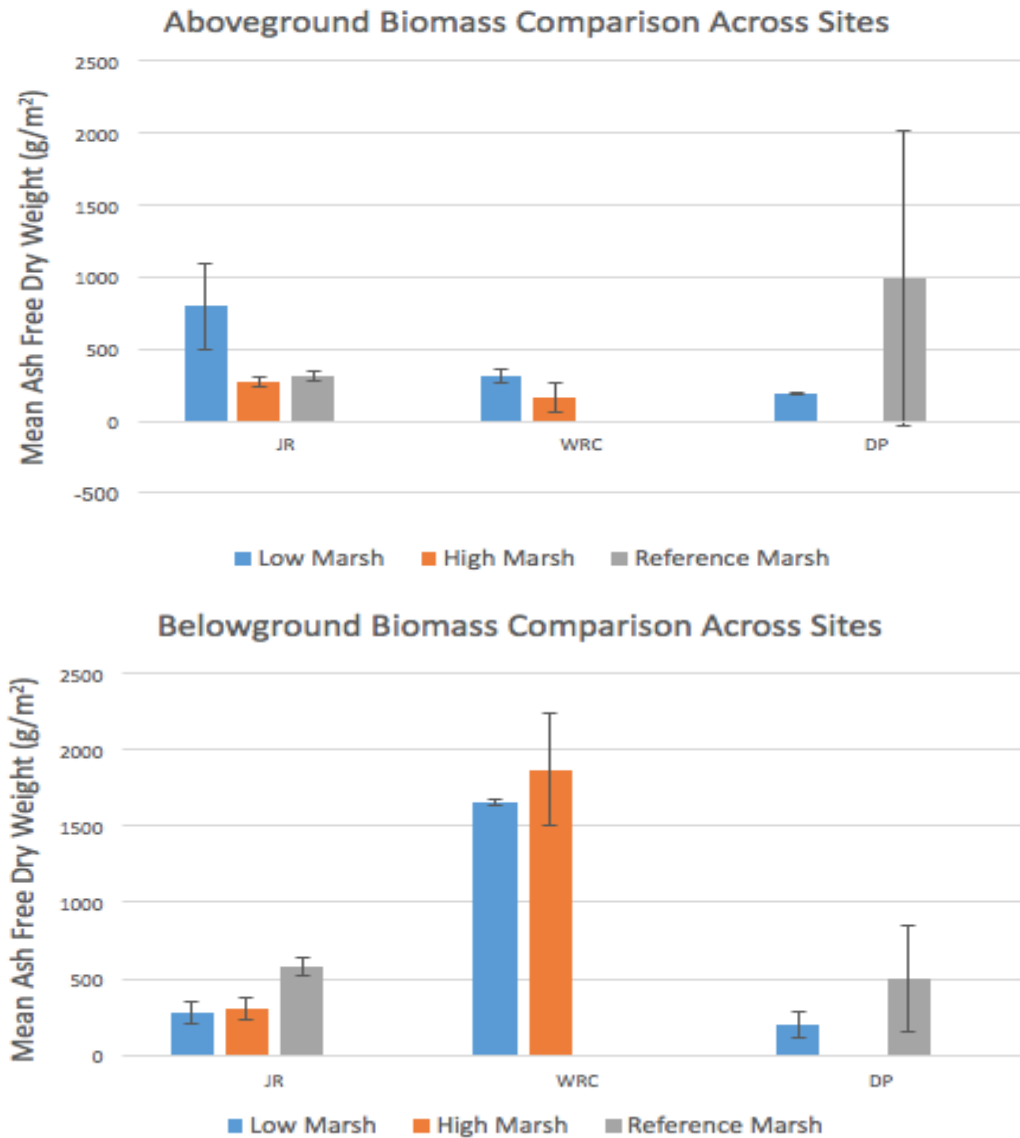
### Biomass

As shown in figure 4, at JR and WRC, LM samples had a higher AGB than HM samples. At DP, a site that lacked a HM, reference marsh samples revealed an AGB value nearly an entire order of magnitude higher than low marsh samples. Additionally, the DP reference marsh standard deviation is significantly larger than others due to the fact that the reference marsh value is an average of both high and low marsh values (Fig. 4). In this case, the organic matter content of the reference HM was significantly greater than that of the LM, thus the error bar is large despite the fact that our overall data appears to have a high level of homogeneity. Overall, JR displayed the highest AGB values for both low and high marsh locations followed by WRC, and DP with the lowest low marsh AGB value. Durant's Point, however, did have a much higher reference marsh AGB value than JR.

Belowground biomass values displayed an opposite trend with regard to low and high marsh distinctions. High marsh samples revealed a higher BGB than low marsh samples at each study location (Fig. 4). Durant's Point once again revealed a higher reference marsh BGB value than LM. In this case, the reference marsh value was a full order of magnitude higher than the



LM value. For BGB, WRC displayed the highest values followed by JR, and DP with the lowest BGB values.



**Figure 4.** Comparison of above (upper graph) and belowground (lower graph) biomass as ash free dry weight between study sites (JR = Jockey’s Ridge; WRC = Wildlife Resources Commission Boat Launch in Edenton; DP = Durant’s Point) and across high, low, and reference marshes. Error bars represent one standard deviation.

Growth and maintenance of vegetation is a primary focus of all living shoreline locations sampled in this study. Vegetation contributes to soil organic matter content and, subsequently, marsh accretion, which allows for a greater carbon sequestration potential. Consequently, biomass values are useful for assessing the vegetation growth occurring at living shoreline sites as well as soil organic matter content. Vegetation was heterogeneous across locations, which may have skewed our data due to difficulty in adequately representing an entire location using a small number of samples. Furthermore, because plants have the ability to spread their root systems far

beyond their aboveground scope, supporting an inverse relationship between AGB and BGB, there may be disconnect between the two values (Davis et al., 2017).

Due to logistical issues involving damage to core tubes by dense vegetation, we had to choose less vegetated sites to take samples. This methodology likely contributed to the low AGB values for WRC. Since the AGB and BGB samples were specifically taken in areas with decreased quantities of vegetation at WRC, the AGB and BGB values are likely an underestimate. This may explain why AGB values for JR were higher than those for WRC despite a greater density of vegetation at the WRC site.

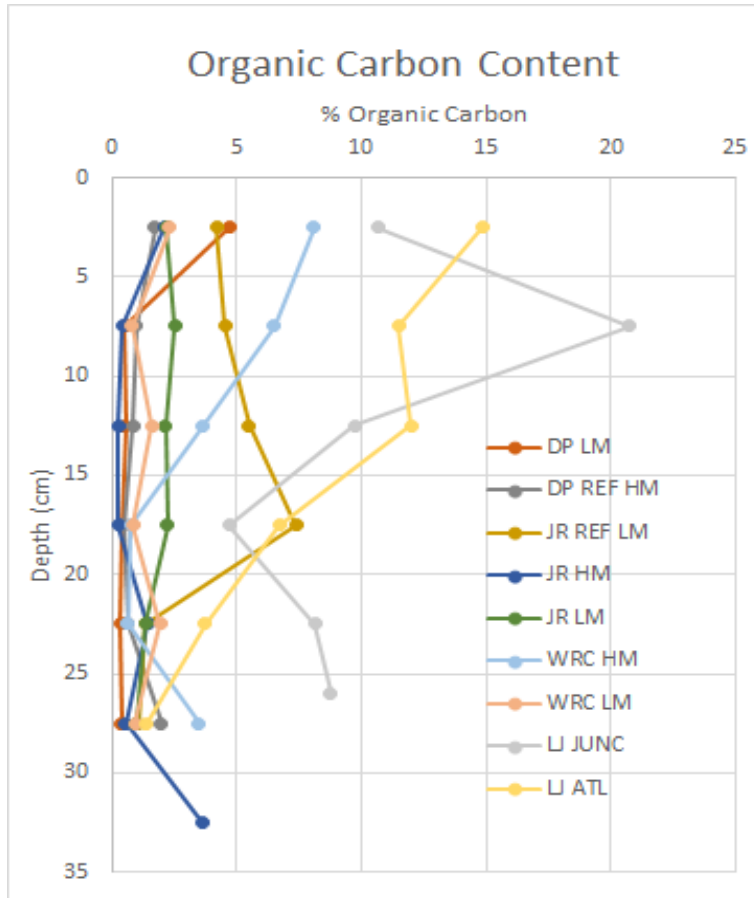
Aboveground biomass values were consistently higher in the LM than the HM across locations. There are multiple factors which may explain this. Marsh plants thrive with inundation and receive nutrients from the water. Consequently, the LM plants, which are more frequently inundated than the HM plants, would be better suited toward growth and provide an increased quantity of AGB. At the WRC location in particular, many of the plants in the HM were trees, thus AGB values for the HM may not fully reflect the true quantity of vegetation because the large plant species could not be sampled.

Despite the fact that samples were intentionally taken in areas with less dense vegetation at the WRC location, BGB values are significantly higher for the WRC location than for either JR or DP. We suspect that this increased BGB value results from the WRC living shoreline being 13 years old while the JR and DP living shorelines are only 8 and 5.5 years old, respectively. Therefore, the WRC plants have had more time to grow expansive root systems and accumulate biomass, resulting in a higher BGB value.

High marsh locations consistently had greater BGB values than LM locations across locations. Higher BGB in HM sites may also be the result of marsh age. These HM sites were older than their LM counterparts and therefore have more expansive root systems. Furthermore, LM sites are destroyed more frequently by hurricanes. In fact, the living shorelines and marshes at our study locations have been affected by eight hurricanes in the past two years and 11 hurricanes in the last five, which could explain the high variability between AGB and BGB within sites (NOAA, 2012-2017). This frequent destruction means that LM plants have less time to accrete sediment and maintain biomass, and as a result have a lower quantity of BGB.

### **Organic Carbon Content**

Carbon content was found to have high levels of heterogeneity both within and among locations. Percent organic matter determined from loss on ignition ranged from 0.015% to 20.74% (Fig. 5) with the highest value at the LJ JUNC site. Organic matter was generally found to decrease with depth, although some profiles showed more variability, such as LJ JUNC, JR REF, and JR HM (Fig. 5).



**Figure 5.** Core depth profiles of organic carbon content calculated via loss on ignition. Cores collected from high and low marsh sites at living shoreline and reference marsh locations along coastal northeastern North Carolina in Fall 2017. (DP=Durant’s Point, JR=Jockey’s Ridge, WRC=Wildlife Resources Commision Boat Launch in Edenton, LJ=Private Property in Frisco)

Organic matter content at JR and WRC high marsh sites decreased with depth to a certain point and then began to increase noticeably. Over time through plant colonization and decomposition, organic matter accumulates in marsh soils. This explains the general trend of organic matter content decreasing with depth. Some samples, including WRC HM and JR HM, displayed an increase in organic matter content near the 30 cm bottom of the core. This depth is not influenced by surface vegetation. We believe that this organic matter is remnant of historic peat layers present before the installation of the living shoreline projects. In addition, we believe sediment disturbances through wave energy and storm events caused the high variability in organic matter content with depth. Variability among sites is influenced by age and vegetation. Our small sample size necessitates review of other similar studies to draw comparisons among and between similar and differing ecosystems.

**Table 3.** Comparison of carbon characteristics including bulk density (g/cm<sup>3</sup>), percent organic carbon, and carbon sequestration (gC myr<sup>-1</sup>) from coastal northeastern North Carolina in Fall 2017 and similar studies conducted on the U.S. east coast.

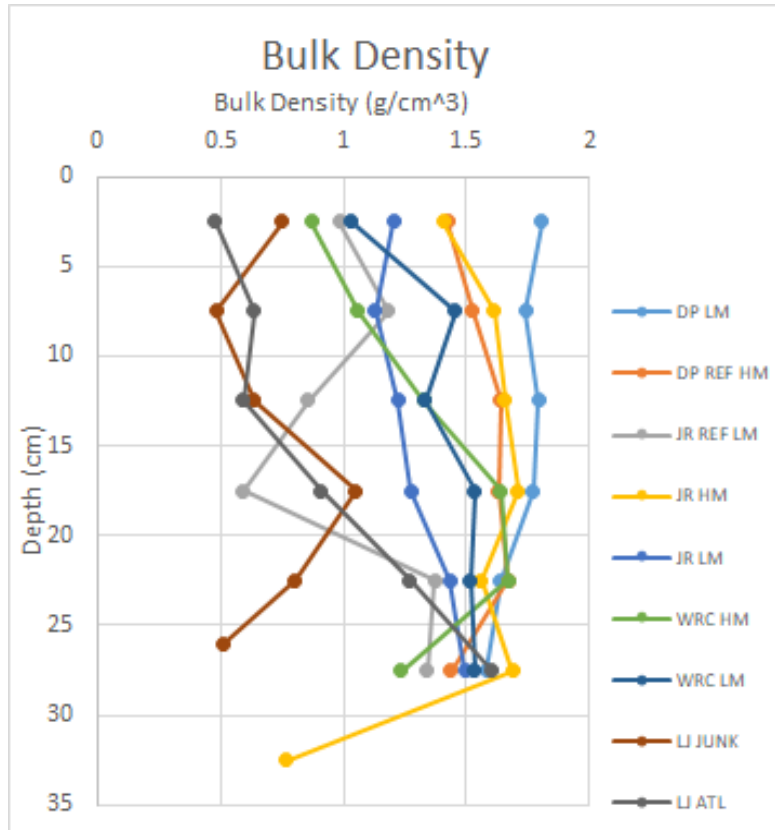
Source Paper	Location	Core Depth (cm)	Bulk Density (g/cm.)	Percent Organic C	Carbon Sequestration (g C myr. )
<u>Roman et al. 1997</u>	<u>MA</u>	<u>10</u>	<u>0.23-0.38</u>	<u>15</u>	<u>89.7-256.5</u>
<u>Anisfeld et al. 1999</u>	<u>CT</u>	<u>30-40</u>	<u>0.84</u>	<u>N/A</u>	<u>155-195</u>
<u>Orson et al. 1998</u>	<u>CT</u>	<u>20</u>	<u>0.362-0.398</u>	<u>N/A</u>	<u>N/A</u>
<u>Kim et al. 2004</u>	<u>DE</u>	<u>18</u>	<u>N/A</u>	<u>10-40</u>	<u>N/A</u>
<u>Artigas et al. 2015</u>	<u>NY</u>	<u>30</u>	<u>N/A</u>	<u>N/A</u>	<u>192.2</u>
<u>Drake et al. 2015</u>	<u>ME-MA</u>	<u>60</u>	<u>0.2-0.22</u>	<u>14.97-16.3</u>	<u>74-126</u>
<u>Armentano and Woodwell 1975</u>	<u>NY</u>	<u>30-85</u>	<u>0.2-0.35</u>	<u>9-13.5</u>	<u>146-196</u>
<u>Davis et al. 2015</u>	<u>NC</u>	<u>30</u>	<u>0.36-1.56</u>	<u>N/A</u>	<u>58-283</u>
<u>This paper</u>	<u>NC</u>	<u>30</u>	<u>0.49-1.8</u>	<u>0-21</u>	<u>27.63-762.7</u>

\*Table adapted from Drake et al. (2015), and formatted for the purposes of this paper.

Our results for percent organic carbon displayed in Figure 5 primarily fall within a range of values from 0% to 7%, with maximum values between 15% and 21%. Previous studies conducted in similar east coast marshes show results slightly above this range with percentages ranging from 9% to 16.3% (Table 3). These results fit our expectations because the majority of marshes observed in the studies referenced in Table 3 were natural marshes, which tend to have both older and more developed rhizospheres, or root systems. In addition, the points in our dataset set that show organic carbon levels above 7% were LJ JUNC and LJ ATL, which are from a location that was an established, naturally vegetated marsh prior to the implementation of a sill structure. The study which aligns most closely with the majority of our data points is Davis et al. (2015), which similarly worked with living shoreline projects that are inherently younger than naturally occurring marsh. Davis' percent organic carbon values ranged from 9% to 13.5%, slightly above ours. These slightly higher values are representative of Davis' more mature marshes with ages between 12 and 38 years old.

### Bulk Density

Bulk Density was generally constant throughout each depth profile, with most profiles showing lower density within the top 0 to 5 cm range and increasing with depth. Bulk density is a measure of soil compaction which is impacted by the presence of roots, other organic matter, and sediment texture.



**Figure 6.** Core depth profiles of soil bulk density. Cores collected from high and low marsh sites at living shoreline and reference marsh locations along coastal northeastern North Carolina in Fall 2017. (DP=Durant's Point, JR=Jockey's Ridge, WRC=Wildlife Resources Commission Launch in Edenton, LJ=Private Property in Frisco)

Plant roots and remnants fill soil space, decreasing bulk density; thus, greater organic matter in the soil should decrease bulk density. Bulk density in our results tended to increase with increasing core depth (Fig. 6), while organic matter generally decreased with increasing core depth (Fig. 5), supporting the proposed relationship between organic matter and bulk density. The three cores from this study that consistently exhibited comparatively low bulk density were LJ JUNC, LJ ATL, and JR REF. These cores constitute all three location where natural marsh is present. Results from Davis et al. (2015) reflect similar results when comparing natural marsh and living shoreline. The two natural marsh sites from Davis et al. (2015; PM-N and AM-N) also exhibited comparably lower bulk density (Davis et al., 2015; Fig. 4a).

Bulk density at LJ, JR, and WRC showed increasing trends with depth to around 20 cm followed by a decrease (Fig. 6). These same locations also showed an increase in organic matter below 20 cm (Fig. 5). This decrease in bulk density along with the increase in organic matter aligns with our assumption of the presence of deep historic peat layers. Our bulk density measurements are quite variable, likely for the same reasons that organic carbon measures were variable.

The bulk density measurements we obtained ranged from 0.49 g/cm to 1.8 g/cm with the majority of results falling above 1.4 g/cm. These results align with those of previous studies. Previous bulk density measurements obtained from naturally occurring east coast marshes

ranged from 0.2 g/cm to 0.38 g/cm (Table 3). Results from Davis et al. (2015) reflect similar results when comparing natural marsh and living shoreline, with bulk density readings from 0.36 g/cm to 1.56 g/cm. These numbers are in the higher range but marginally lower than ours. Again, this can be attributed to the slightly older age of the shorelines sampled in Davis et al. (2015) compared to our study sites.

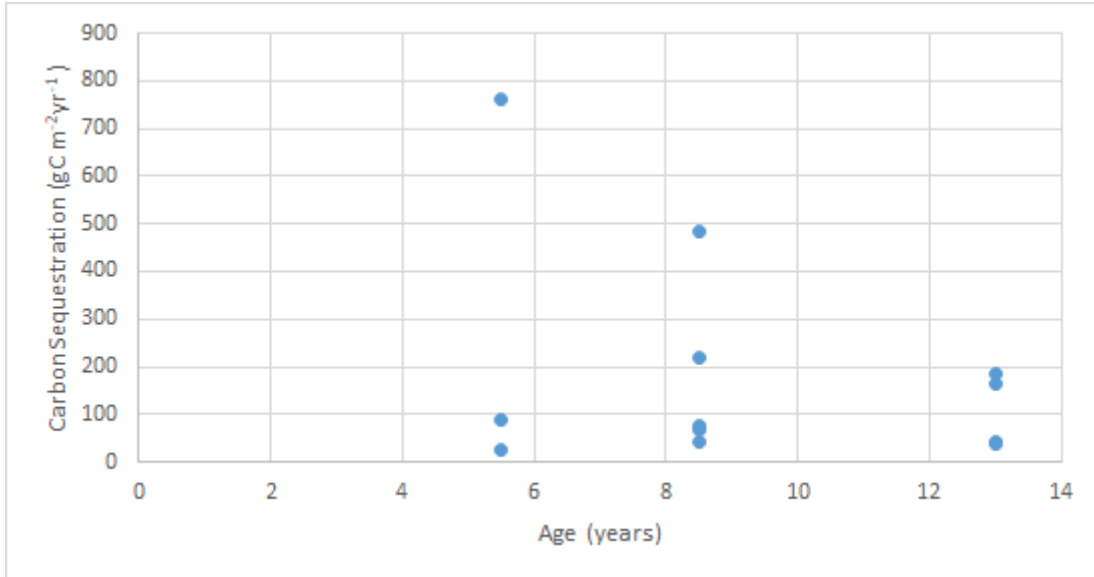
### Carbon Sequestration

All sites where carbon sequestration could be determined showed accumulated carbon storage in natural and created marsh sediments. Annual sequestration rates ranged from 27.63 g C myr at JR HM to 762.7 g C myr at DP LM (Table 4). Table 4 below displays site means for carbon stocks and sequestration rates in high and low marsh sites. Most of the carbon sequestration rates measured here align similarly to sequestration rates in east coast marshes recorded from other sources (Table 3). Other sources showed sequestration rates ranging from 58 gmyr to 283 gmyr, with both minimums and maximums representing living shoreline projects as opposed to naturally occurring marshes. Sequestration rates could not be calculated for reference sites present at JR and DP because of the unknown ages of these naturally occurring marshes. Further research could address this problem by using either Pb-210 or Cs-137 radioisotopes as an alternate method of calculating sequestration (Drake et al. 2015).

**Table 4.** Carbon characteristics including total carbon stocks (g) and average sequestration rates (g C myr) by site. Carbon data from cores collected from high and low marsh locations at living shoreline and reference marsh sites along coastal northeastern North Carolina in Fall 2017. (DP=Durant’s Point, JR=Jockey’s Ridge, WRC=Wildlife Resources Commission Boat Launch in Edenton, LJ=Private Property in Frisco)

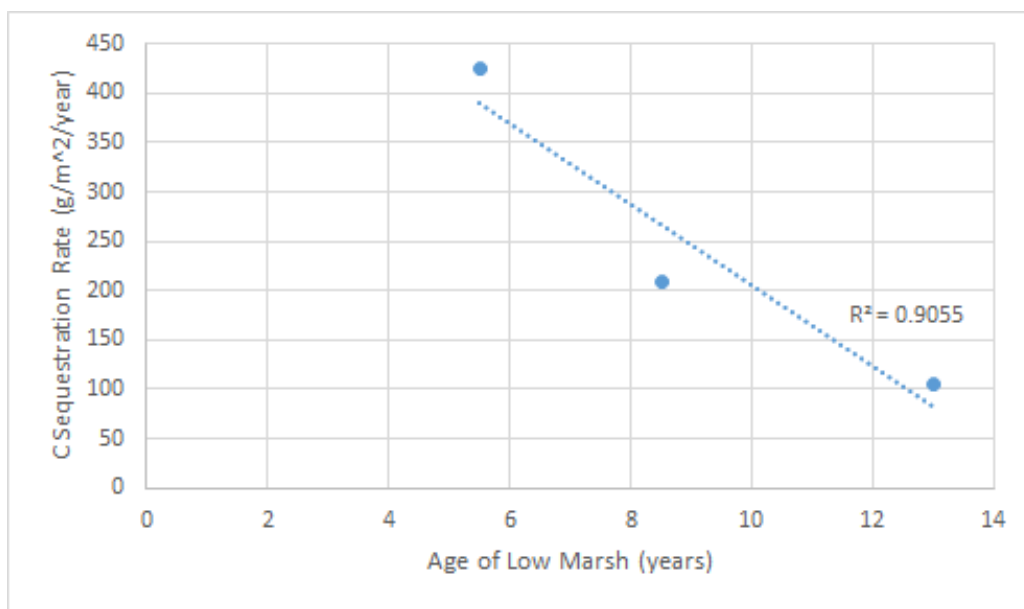
Site	Total C Stock (g)	Sequestration Rate (g C myr.)
DP LM	7.05	424.77
DP REF HM	4.05	*
JR HM	2.46	95.81
JR LM	5.37	209.42
JR REF LM	24.09	*
WRC HM	4.39	111.73
WRC LM	4.12	104.95

\*Reference site of unknown age



**Figure 7.** Relationship between age of living shoreline project (DP = 5.5 years, JR = 8.5 years, WRC = 13 years) and carbon sequestration rates (g C myr<sup>-1</sup>) calculated at each site in coastal northeastern North Carolina during Fall 2017

Carbon sequestration rates (gmyr) varied within each study location, but on average, tended to decrease with shoreline age (Fig. 7). We believe that this trend is due to the rapid early colonization of living shorelines by various vegetation species planted on sandy substrates. The rate of accumulation of organic matter is high in the early stages of marsh development after shoreline stabilization. As the shoreline ages, new plant growth slows as space becomes limited. Decomposition of vegetation and root structures continues, but early sequestration rates are not representative of long-term carbon sequestration potential of living shorelines. One site, DP LM exhibited an uncharacteristically high annual sequestration rate. However, it is possible that this elevated rate is a result of the relatively young age of the DP living shoreline project. Our results are supported by previous work which found a significant correlation between marsh age and carbon sequestration rate, with younger living shoreline projects having a higher capacity for sequestration (Davis et al., 2015; Figure 4a). An analysis of mean low marsh sequestration rates from each sampling location plotted against age reveals a similar finding. Low marsh age was strongly correlated with carbon sequestration ( $R = 0.9055$ ) (Figure 8). Due to the low sample size of high marsh sites, this type of graphical analysis does not accurately represent the relationship between high marsh age and sequestration rates.



**Figure 8.** Age of low marsh sites (DP=5.5 years, JR=8.5 years, WRC=13 years) plotted against mean sequestration rate of all low marsh locations at each living shoreline site (DP=424.77gmyr, JR=209.42gmyr, WRC=104.95gmyr) in a Fall 2017 study in coastal northeastern North Carolina. Correlation is strong with R squared value of 0.9055, indicating a higher potential for sequestration in younger living shoreline projects. (DP= Durant’s Point, JR= Jockey’s Ridge, WRC= Wildlife Resources Commission Launch in Edenton, LJ= Private Property in Frisco)

While this data analysis has promising implications for coastal ecosystem carbon sequestration, it is important to recognize the comparatively small sample size of our study. The results of Figure 8 were calculated based on mean carbon sequestration rates at only 3 living shoreline study locations and 9 total cores. Most studies from Table 3 analyzed upward of 100 cores in total. Across five different locations we extracted 28 cores, losing 2 cores to processing errors and 4 cores to inability to establish a baseline carbon reading. Combined with the inability to calculate a sequestration rate in reference marsh samples (2 cores), this left us with only 20 working cores from which to calculate carbon sequestration rates. Davis et al. (2015) drew conclusions based on only 14 sediment cores; however, this is not necessarily the norm amongst studies of created marsh locations. Mitsch et al. (2014) studied locations similar to living shorelines in an inland riparian environment. 171 cores were taken in total at 5 and 10 year increments. While a lack of a large sample size does not necessarily negate the results of this paper, future studies should sample more living shoreline projects, explore other methods, and take more cores at those locations. Future studies should also look further into other variables impacting carbon sequestration rate, including salinity and vegetation.

### Methane Flux

The net direction of methane flux between the sediment and atmosphere was inconsistent at each chamber on all sampling occasions (Table 5). There were a few instances of methane flux from the atmosphere to the sediment, indicating methane consumption. Net methane production indicates that obligate anaerobic—or requiring the absence of oxygen—microbes, called methanogens, are producing methane at a rate that exceeds methane consumption by



methanotrophs, a microbial group that consumes methane in the presence of oxygen. However, when we calculated the mean result for each location, all means were positive, suggesting net methane production at each location.

Our results, which show large variability across sampling locations and times, support the claim that methane flux depends on a large number of variables (Table 5). There is a substantial amount of heterogeneity in methane flux, organic matter, and salinity levels that we measured across our sampling locations. We expect that there were also variable and changing environmental conditions across sampling occasions and locations that we did not measure or account for, such as pH and elevation. The heterogeneity of wetland methane flux is well-established and likely influenced by spatial and temporal heterogeneity

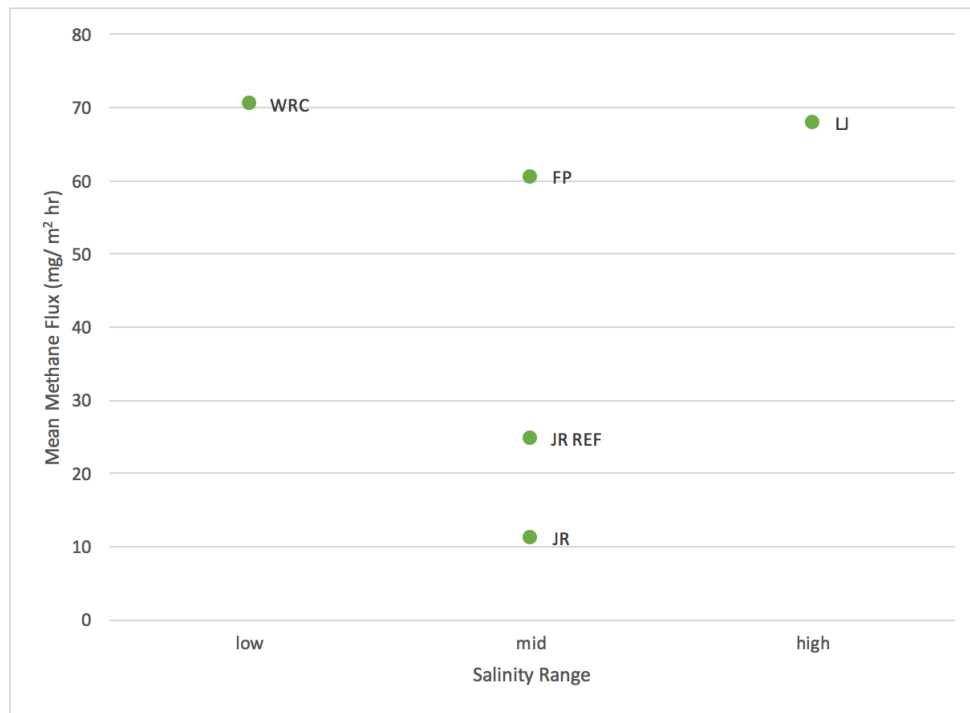
**Table 5:** Methane flux range (mg/m.hr.) for each location within northeastern coastal North Carolina during Fall 2017. (JR = Jockey’s Ridge Living Shoreline, JR REF = Jockey’s Ridge Reference Marsh WRC = Wildlife Resources Commission Boat Launch in Edenton, LJ = Private Property in Frisco)

Locations	Flux Range (mg/m.hr)		Mean Flux (mg/m.hr)
JR	-30.20	25.06	11.06
JR REF	8.30	66.56	24.71
WRC	0	179.76	70.40
FP	-109.74	438.06	60.47
LJ	23.88	141.20	66.51

According to a comprehensive review of methane flux in coastal wetlands by Altor and Mitsch (2006), mean methane fluxes fall between 1.3 and 15 mg/m.hr. Our calculated mean fluxes encompass some of that range, but also extend beyond it (Table 5). The range provided is based on studies of methane flux across many diverse wetlands over a long time span including every season. In contrast, our results only include four wetland locations with relatively similar vegetation that were sampled a small number of times in the fall. To better understand the seasonal and spatial dynamics of methane flux from living shorelines, we would recommend future work expand the scope of our research.

We originally hypothesized that more saline marshes would produce methane at a slower rate than those in freshwater conditions because seawater provides sulfate to the sediment. The presence of sulfate stimulates sulfate-reduction, a more energetically favorable reaction which

precedes methanogenesis, the process in which microbes convert carbon dioxide into methane. This thermodynamic progression results in a decreased emission of methane gas, a characteristic of saltwater areas (Khan et al., 1970), because more energetically favorable terminal electron acceptors such as sulfate are present. In addition, higher concentrations of sulfate help to stimulate methane oxidation, a process in which bacteria turn methane into carbon dioxide, leading to decreased methane emissions in more saline ecosystems (Wang et al., 1996). However, Figure 9 below does not provide strong support of our hypothesis because there is no linear relationship between salinity and methane flux, suggesting that other variables in addition to salinity are likely affecting the rate of methane flux.

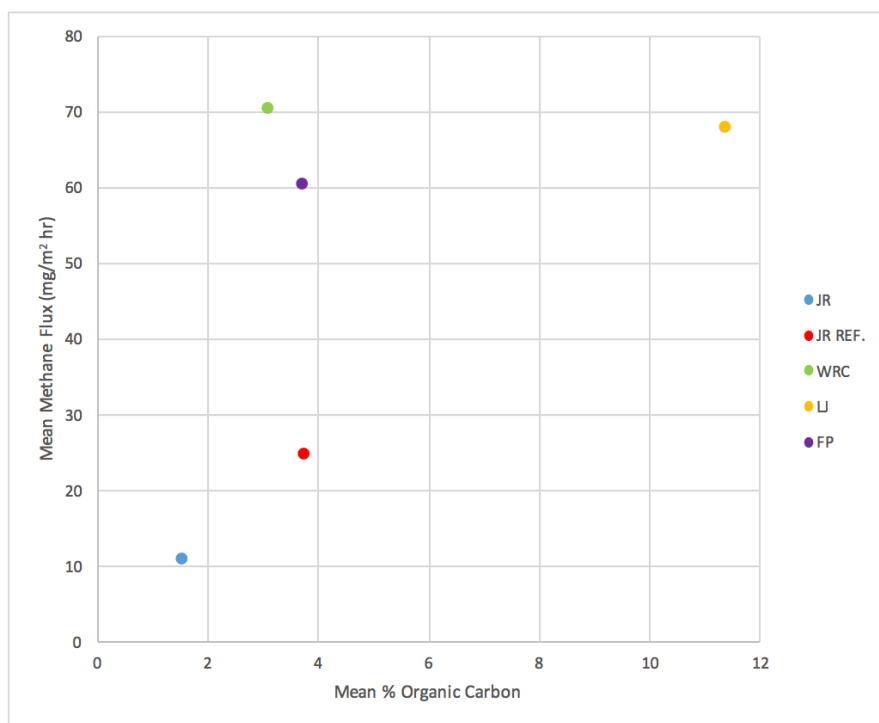


**Figure 9:** Mean hourly methane flux ( $\text{mg}/\text{m}^2 \text{hr}$ ) at each sample site in coastal northeastern North Carolina during Fall 2017 plotted against a relative salinity scale ranging from low salinity freshwater of 0 ppt to mid-level salinity of 10-20 ppt to high salinity brackish water of above 20 ppt. (JR=Jockey’s Ridge Living Shoreline, JR REF= Jockey’s Ridge Reference Marsh WRC= Wildlife Resources Commission Boat Launch in Edenton, LJ= Private Property in Frisco)

In Figure 9, the highly saline location LJ shows methane flux comparable to those at a freshwater site at WRC. Based on the knowledge that the presence of sulfate should inhibit methane production, we would expect LJ to have much lower methane flux. Our results may show much higher fluxes because saline ecosystems can produce relatively high amounts of methane when zones in the sediment become depleted of sulfate (Sansone and Martens, 1981) due to the presence of highly productive sulfate-reducing bacteria (Nissenbaum et al., 1972; Rudd and Taylor, 1980). Additionally, the mechanisms of anaerobic oxidation in saline conditions remain unclear (Wang et al., 1996) and may play some role in the results displayed in Figure 9.

Methane oxidation is an aerobic process in freshwater systems and an anaerobic process in saline conditions, orchestrated as bacteria decompose organic material. The process of oxidation depends on a number of confounding variables including soil hydrology, vegetation, temperature, pH, salinity, and presence of oxygen (Wang et al., 1996).

Upon realizing that methane emissions were not showing strong correlations with salinity, we attempted to explore relationships with other data we collected, including percent organic carbon. We would expect higher percent organic matter to positively correlate with higher methane flux (Crozier et al., 1995) because organic matter content is critical for providing organic substrates used by methanogenic bacteria in the production of methane.



**Figure 10:** Mean hourly methane flux (mg/m<sup>2</sup> hr) at sampling sites in coastal northeastern North Carolina during Fall 2017 plotted against average percent organic carbon at each location. (JR = Jockey’s Ridge Living Shoreline, JR REF = Jockey’s Ridge Reference Marsh, WRC = Wildlife Resources Commission Boat Launch in Edenton, LJ = Private Property in Frisco)

We did not find any clear relationship between mean hourly methane flux rates and average percent organic carbon across all of the locations. It does appear however that if FP and the WRC locations were removed from the data set, a strong, positive correlation would exist for the remaining data points. These sites may defy an otherwise linear trend between organic carbon and methane flux because of the influence of other environmental variables.

For example, WRC is mostly vegetated by *Cladium mariscoides*; whereas most other locations are vegetated by *Spartina alterniflora*, *Spartina patens*, and *Juncus roemerianus*. Wetland vegetation plays an important role in methane flux because it allows for transport of methane gas to the atmosphere and provides compounds for methanogenesis (Chanton and

Dacey, 1991). Vegetation impacts methane emissions in a myriad of different ways that largely depend on vegetation surface area, density, and rhizosphere structure (Sebacher et al., 1985).

In addition to vegetation, hydrology may impact methane flux as well. Sediments within the gas chambers at FP were described on multiple sampling occasions as saturated or soggy. The chambers were also sometimes inundated with water, and while those data points were removed from further analysis, they suggest a higher water content in the sediments at FP, which may affect the process of methane moving from the sediments into the atmosphere, including ebullition and diffusion. In addition, a higher water table at these locations may lead to an even lower overall sulfate concentration in the soils that would be unaccounted for in our salinity measurements, which were taken from water bodies instead of soil samples.

Different vegetation, inundation patterns, and low presence of sulfate at these fresher water sites may lead to changes in soil reduction potential, or the ability of soil to move electrons between oxidizing and reducing agents. In wetland soils, carbon dioxide is reduced, meaning it gains electrons, to become methane during methanogenesis which only occurs at very low soil reduction potentials. While these low soil reduction potentials are rarely reached, every decrease in soil reduction potential beyond that threshold is accompanied by a very large increase in methane production (Wang et al., 1993).

### **Carbon Flux and Storage Implications**

Our finding that living shorelines sequester carbon has larger implications for greenhouse gas concentrations in the atmosphere. As discussed earlier, carbon sequestration in wetland soils reduces the accumulation of carbon dioxide in the atmosphere and decreases the detrimental impact of the greenhouse gas. Therefore, living shorelines have the potential to help mitigate climate change.

Projects focusing on increasing carbon sequestration could help alleviate climate change. These projects, however, have focused on the preservation of terrestrial carbon stocks such as forests and agriculture. For example, the program Reducing Emissions from Deforestation and Forest Degradation (REDD+) recognized the value of forests as a large carbon sink and compensated developing countries for conserving forests (UNREDD, 2017). Although our findings indicate that living shorelines are sequestering carbon, there are no policies such as REDD+ in place that recognize living shorelines as a method to mitigate carbon dioxide emissions.

We designed a hypothetical example to estimate the amount of carbon dioxide that installing living shorelines along North Carolina's coast could remove. Currently, 7% of North Carolina's 10,658 miles of estuarine shoreline is stabilized (NCDCM, 2015). If there was a 50% increase in shoreline stabilization using only living shoreline methods, it would constitute 373 miles or 600,332 meters of shoreline. When determining the total area of added living shoreline, we assumed the average vegetated shoreline width to be 8 meters, based on the average vegetated width of our study locations determined using ArcGIS.

The average net carbon sequestration rate among our locations was 183 g C myr. Applying this average sequestration rate to the total proposed added living shoreline area, we determined an annual sequestration rate of 967 tons of carbon sequestered per year. Using the lowest and highest sequestration rates, as opposed to the overall mean, results in annual sequestered carbon amounting to 574 tons C/yr and 1,548 tons C/yr respectively.

After determining the amount of carbon sequestration, the equivalent amount of carbon dioxide removed from the atmosphere can be calculated. Due to the relative atomic weights, one ton of carbon is equivalent to  $(11/3)$  tons of carbon dioxide (EPA, 2017a). With this ratio, the amount of carbon dioxide removed from the atmosphere would be 3,556 tons of carbon dioxide. In context, 3,556 tons of carbon dioxide is equivalent to the emissions from combusting 362,996 gallons of gasoline (EPA, 2017b).

At a smaller scale, we determined using ArcGIS that a typical sound side property in the Outer Banks area has approximately 25 m of estuarine shoreline. Using the same calculation methods, a living shoreline at a typical sound side property would sequester 36,600 g C myr. Converting to carbon dioxide, this would equate to 134,200 g CO<sub>2</sub> per year or 0.15 tons of CO<sub>2</sub>.

There are limitations to this projected model however, because carbon sequestration has a negative correlation with shoreline age; therefore, newly installed living shoreline projects would have even higher potential rates than those utilized in our calculations. A multitude of environmental variables further impacted by climate change also have the potential to impact these rates. Despite the impact of these variables, a significant increase in carbon storage could be achieved given a relatively small increase in total living shoreline area. Additional research on the variables that influence methane flux could assist in identifying the most favorable sites for net carbon sequestration.

By applying similar financial concepts of the REDD+ program to living shorelines, sound side property owners could receive compensation for installing a living shoreline. To determine an estimate of compensation, we utilized the social cost of carbon dioxide as a grounding figure. The social cost of carbon was determined by the Interagency Working Group (IWG) on the Social Cost of Carbon in 2010, which modeled the effects of increasing carbon dioxide levels on society (IWG, 2016). Projecting the implications of rising carbon dioxide levels on agriculture production, energy system costs, and human health, the IWG determined that the social cost of carbon is \$50 per ton with a 3% discount rate in 2030 (IWG, 2016). In other words, an additional ton of carbon dioxide emitted today would have damages equivalent to \$50 in 2030.

Applying the social cost of carbon dioxide to the hypothetical example, the monetary value of living shorelines sequestering 3,556 tons of carbon dioxide per year would be \$177,000 per year. On a smaller scale, an individual landowner with 25 m of shoreline receive \$8 per year. However, there are limitations in crediting individuals for living shoreline carbon sequestration. Events such as hurricanes, persistent erosion, and shoreline development could release stored carbon back into the atmosphere. Carbon sequestration is also difficult to measure on a case-by-case basis, so providing credits to individuals would be challenging. More research could illustrate the feasibility of crediting living shoreline carbon dioxide mitigation.

### Public Perceptions of Shoreline Stabilization

#### Methods

Employing a qualitative approach allowed us to explore the values and perceptions property owners and public organizations hold for various estuarine shoreline protection measures and the factors that influenced their shoreline protection decision-making. We conducted semi-structured interviews using an interview guide of open-ended questions, enclosed in the Appendix. Interview questions aimed to identify key characteristics of the interviewee's property, how they use it, and the aspects of their shoreline most important to them. Questions changed depending on whether the interviewee had installed a shoreline protection measure on their property, acquired their property with a measure, or own property without an installed protection measure. We asked how the interviewee chose their property, felt about the installation and management of their protection measure, and its effectiveness.

We interviewed private individuals who own sound side shoreline property and representatives of organizations that manage sound front land. The shoreline properties were located between Duck and Hatteras, and as far west as Roanoke Island and Edenton. We received initial referrals for potential interviewees from local contacts connected to the North Carolina Coastal Federation, the Outer Banks Field Site, and the UNC Coastal Studies Institute. Following this, we asked each interviewee for referrals for other local shoreline property owners, generating an expanding pool of possible interviewees via snowball sampling. Interviewees were contacted via email and/or phone to schedule the interviews. Interviewing began in early October and continued to mid-November, 2017.

With the interviewee's consent, we audio-recorded the interviews. Recordings were transcribed verbatim. Using NVivo v.11 we coded and analyzed the transcripts. With this software, codes like "cost," "recreation," and "permitting" were created to categorize the contents of the interview. This procedure identified patterns in the transcripts that described emergent themes related to shoreline protection and the decision-making processes. All interviews and analyses were conducted in accordance with the University of North Carolina's Institutional Review Board (IRB) to maintain the confidentiality of the identities and responses of the interviewees.

In total, we interviewed 26 people in 22 interview sessions. Private landowners comprised 18 of the interviews, and 8 worked with governmental and non-governmental organizations (NGOs). The private landowners possessed various types of shoreline installations including unaltered natural marsh, living shorelines, bulkheads, sills, and riprap revetments. The organization representatives had experience with oyster reefs and other living shoreline methods. We assembled a diverse pool of interviewees with varying priorities, erosion risks to their property, information resources, and experiences with shoreline protection installation. Due to time constraints and receiving repetitious information from additional interviewees, we decided to stop conducting interviews.

## Results and Discussion

Erosion poses an increasingly large threat to the shorelines of estuarine property owners, and decisions determining how these areas are protected will be essential to the survival of managed shorelines throughout eastern North Carolina (Scyphers et al. 2015). Our interviews with local property owners and managers revealed four major themes related to shoreline protection: perceptions of erosion, values and ideals, knowledge and information, and feasibility. Our findings on erosion center around interviewees' personal experiences and losses, both as a result of natural erosive processes and erosion exacerbated by nearby changes to the shoreline. We found that the values and ideals interviewees expressed had varying levels of influence over decision-making regarding shoreline stabilization, while feasibility factors were a part of every decision. Our discussion of knowledge and erosion centers on where and how interviewees discovered their options for shoreline protection.

### Erosion

#### Observations and Perceptions

Nearly every interviewee said that they had observed erosion on their property. They had different feelings about its qualities, causes, and strategies for addressing it on their property, but every property owner acknowledged it as a common reality for property owners on the sound. Observations ranged from sudden and drastic changes to subtle degradation over time. Multiple property owners we interviewed had seen large chunks of their property disappear in a short time period. Storms were one major source of this kind of change. "The shoreline was taken away by Hurricane Irene," explained one private landowner referring to their property, adding, "any land on the water is at risk for erosion." This quote demonstrates the extreme end of rapid shoreline erosion. It also outlines the general feeling of acceptance that was echoed by other interviewees, like this one:

*"It's just something to contend with. On the waterfront you're always having to deal with it, and you have to put some sort of stabilization out there, or it's going to erode."*

There was widespread acknowledgement among both individual and organizational interviewees that waterfront property owners should anticipate at least some erosion.

Some interviewees noticed erosion that was mainly attributable to the installation of a bulkhead on a neighboring property. These adjacent bulkheads tended to change the local dynamics of sand and water, causing erosion where it had not previously been a problem. One private property owner noted, "my neighbor had built a house and a hard wall on my property, and as soon as that happened I lost all this land, and... that's when I got sills immediately." As this interview demonstrates, these sudden changes could be an impetus to installing a living shoreline protection method.

While some interviewees experienced short drastic changes because of storms or neighboring shorelines, more commonly the changes took place slowly. In multiple instances, longtime residents noted the disappearance of either a sand spit, beach, or marsh on their property or between their property and the sound. "When I bought it there was a cove out here.

What they call a sand spit,” described one interviewee, who indicated that the wide, vegetated, and drivable sand spit has since ceased to exist. Other interviews contained similar stories. One resident suggested that this represented a long trend, claiming his “father remembers when the Roanoke marshes used to almost join Wanchese from Mann’s Harbor.” He went on to note that shorelines in the area “no longer have that buffer of the salt marsh absorbing some of the impact anymore like they used to in the old days,” suggesting that the widespread erosion has had large and compounding effects on the shoreline over time.

There was also a common sentiment that erosion rates were accelerating. Two interviewees specified that the increasing rates of erosion occurred mainly in the last ten years. The resident whose father remembered extensive marshes noted that along with their parents’ property, his generation of native kids “inherited the problem of sea level rise and accelerated erosion rates.” Many, though not all, of those interviewed brought up rising water levels in the estuary as a possible explanation for their shoreline erosion.

For some interviewees, erosion was beginning to encroach on their structures. One resident explained the severity of the situation on their property:

*“I’m right at whatever the setback is, the CAMA setback for the building. I’m next to the water. I mean, I’m really close to it. I mean, I can’t go out any further than I’m at right now because of the erosion.”*

A threat to the habitability of the property necessitated the installation of a shoreline protection measure for interviewees like this one. For those who lived on their property, the possibility of losing it to erosion was much more costly than the installation of protection measures.

Not everyone interviewed had experienced erosion on their property. Two properties were situated such that they were sheltered from forces that cause erosion. One was on creek where the owner said, “it’s really pretty sheltered, so it doesn’t get terribly stormy back there, it’s not on the open waters.” An organization that managed shoreline property on the sound was not sure whether they had erosion to the extent that warranted attention, while they acknowledged it is generally a problem in the area. Those were the only three interviewees who did not perceive erosion on the shoreline they owned or managed.

### **Neighbors’ impact on erosion**

Multiple interviewees discussed their experiences in facing increased erosion from neighboring hardened shorelines. Hardened shoreline protection measures deflect wave energy, that hits adjacent shorelines with more force, and increases rates of erosion. This increases the risk to houses and other structures and drives property owners to install a protection method.

In many cases, there appeared to be a lack of knowledge on the impacts that neighbors can have on nearby property. As one bulkheaded property owner elaborated:

*“I did not realize, I realize they had all the permits, but I didn’t understand the effect it might have on us that was not explained to us, but I don’t know that we had a right to that knowledge or even if they knew that.”*



Multiple interviewees demonstrated a lack of awareness, and general feeling of distress, at the unexpected damage shoreline protection measures can produce:

*“I’ve lost like an eighth of an acre of shoreline property which was the result of my neighbor building a hard bulkhead which abutted my property which was a sandy beach. I immediately lost a dune, a tree and about an eighth of an acre.” (Property owner)*

As this quote suggests, losses due to neighboring bulkheads prompted many interviewees to install bulkheads on their own property.

In other instances, damages to property resulted from a lack of shoreline protection on neighbors’ properties. In cases where interviewees lived in high-energy areas and installed bulkheads or other protection methods, some believed that the integrity of their protective structures were undermined by their neighbors. A property owner who lost their original natural shoreline and now had a bulkhead discussed this problem:

*“I can give you an example, to the north, they’ve probably lost almost 150 feet of their property, it’s eroded so bad, now it’s coming on the backside of our property, because they’re not doing anything, and it’s a problem. Matter of fact there’s a house getting ready to go in the water because of the lack of attention they’ve paid.”*

Existing research emphasizes the impact a single individual can have on an entire stretch of shoreline. As one homeowner installs a hardened shoreline, their neighbors react to the increased energy on their shoreline, and this results in a chain reaction of shoreline armoring (Scyphers et al. 2015).

A distinct second group of interviewees were aware of the potential damage their protection measures could cause. This made them hesitant to install any form of shoreline protection. These interviewees knew the different kinds of protection measures, from education or work related to permitting, installation, or other aspects of the protection process. A property owner with a natural, marsh shoreline explained it this way:

*“We’ve talked to an environmental consultant about it and means of maybe expanding the buildable land, or the livable land, but my concern is I don’t want to alter it to the point where it could affect our neighbors’ erosion.”*

A different property owner described it as, “because any erosion that occurs on your neighbor’s property, you are responsible for.” Other sources echoed this sentiment of hesitancy and caution, and provided a valuable counterpoint to the majority of those unaware of the potentially negative impacts of shoreline alteration.

### **Resources addressing erosion**

Although individuals in the area perceived soundside erosion as a major concern, there was acknowledgement the threat of oceanfront erosion overshadowed the efforts and resources

to stabilize the estuarine shoreline. One interviewee from a governmental agency stated that “there’s been a lot of attention to oceanfront shoreline loss.” Moreover, one property owner associated with a homeowner’s association explained:

*“All the energy was going to the oceanside to repair dunes, to repair boardwalks. Nothing was ever going to be done to the sound side.”*

There is evidence that a significant amount of resources are being allocated to address oceanfront erosion, primarily through beach nourishment projects. Beach nourishment projects import sand from offshore sources to widen the beach in order to preserve its public access. Depending on the project size, reported beach nourishment project costs have ranged from \$15 million to \$25 million (Dare County, 2017; Town of Nags Head, 2017).

## **Values, Ideals, and Their Place in Shoreline Protection**

### **Values in Shoreline Protection Decision-making**

In analyzing the interview responses, a handful of frequently-used values emerged: Ecocentrism, Security, Aesthetics, Recreation, and Place Attachment. While intriguing in their own right as indicators of what matters to estuarine property owners in this region, these values provide insight into the intricacies of shoreline protection selection in conjunction with other factors. While the ultimate decision to move forward with shoreline protection is often reactive to specific event—such as beach loss, frequent flooding, or storm damage—choosing in which direction to proceed is up to individual agency (Mcglashan, 2003). It is at this point that values have the largest opportunity to exert an influence.

Not all of the values were created equally in terms of their influence over shoreline protection. Ecocentrism and Security seemed to be particularly important as decision-making factors to those interviewees who embraced them, while Aesthetics, Recreation, and Place Attachment were found to be less important to the overall decision-making process. Interviewees who demonstrated ecocentric tendencies exclusively installed softer shoreline protection methods and more frequently invoked a sense of responsibility for environmental quality as a key aspect of their decision. In contrast, a desire to secure property from estuarine erosion was almost universal across the interviewees, though individual respondents often pursued this goal to different ends. Together, these two values form the core of the cognitive mechanism responsible for the decision-making processes represented in our sample.

### **Ecocentrism: Protection that’s the right thing to do**

Interviewees expressed an appreciation of nature that factored into their decision-making processes. In some cases, they also revealed a deeper connection to the natural world that suggested a moral obligation to nature. The notion of ecocentrism as *the right thing to do* was often explicitly referred to as a factor of decision-making by the interviewees themselves. It is also interesting to note that every single property owner or land manager that experienced warm glow, or the feeling of satisfaction when *doing the right thing*, implemented a softer method of shoreline protection. After being asked to expand upon her reasoning for installing the sills of her living shoreline, one interviewee explained,

*“I guess preserving the environmental quality. Which I think is something to be proud about. You know the water’s cleaner here and, you know, we’re doing the right thing.”*

While installing the living shoreline did protect her property, throughout her interview she repeatedly emphasized the environmental considerations she made in regards to her shoreline protection method and explicitly stated that, in her own opinion, her decision to install the sills had a significant moral component. This conceptualization of *doing the right thing* for nature was echoed in another interview. After being asked about their decision to move away from a bulkhead and into more natural options, a property owner commented,

*“Traditional bulkheading with wood or metal vertical walls seemed sort of unnatural and offensive, so I think we felt a commitment to doing something natural.”*

Bulkheading was not an attractive option for many of the property owners we interviewed, but when the stakeholder possessed a set of values grounded in ecocentrism, they found the decision particularly unappealing.

As these responses illustrate, the interviewees connected a particular course of action with a moral response that existed separately from the logistics (i.e. cost, timing, physical layout of the property) of the decision. This loyalty to a cause then triggered an emotional response—or a warm glow—which ultimately created a positive association between protection method and course of action. This could be a potentially important feedback loop in terms of encouraging those with environmental proclivities to pursue softer shoreline stabilization methods. Generally speaking, ecocentrism had the biggest demonstrable impact as a decision-making factor.

### **Ecocentrism in the Public Sphere**

Ecocentric values were not only expressed by private landowners but also by public organizations, predominantly through their mission statements. Many of our governmental and NGO interviewees elaborated upon their organization’s focus on highlighting the value of the area’s natural resources. For example, one governmental employee elaborated:

*“We have a roundabout mission to get people outdoors, to teach them the value of having places like this and why they need to be protected, and also to educate them about what is here so they can enjoy more.”*

Oftentimes, our interviewees directly referenced their mission statements in terms of how their focus on conservation influenced their decision to install a living shoreline:

*“Well we kind of wanted to do something to restore some habitat ... because anytime we can make more environment for creatures to live, and estuaries being the nursery areas for a lot of our species that we consume*

*it's very important to rebuild a habitat... that's our mission anyway... ”*  
(Governmental)

Whereas the decision to install softer shoreline protection methods based upon ecocentric values often developed as the result of positive emotional associations in private property owners, an organization's mission outlined and guided the types of shoreline stabilization options pursued.

## Security

Perhaps expectedly, the desire to secure a piece of property was a crucial aspect of the decision-making process among our interviewees. Because climate change is exacerbating erosion, property owners and managers are being forced to pursue shoreline protection rather than risk the loss of their property in its entirety (Ludwig, Probst, Kempe, 1996). As a result, interviewees often cited a desire to better secure their properties from the ravages of erosion as a major motivator in the decision to implement shoreline protection. When asked about his motivation for implementing his chosen protection method, one interviewee responded simply, “keeping it,” referring to his property.

Although property protection was a universal goal amongst the interviewees, not all stakeholders approached this goal the same way. Across the interviews, those who had either purchased property with an existing bulkhead or who had chosen to install a bulkhead most ardently voiced the need for protection. After being asked about their installation of a vinyl bulkhead, one interviewee responded, “It is the best. It offers the highest level of protection that we could have at that time.” This sentiment is underscored by the frequency of bulkheaded property owners who often spoke of their shoreline protection in conjunction with the immediacy of the threat posed by erosion. When asked to speculate if she would change her bulkhead if she were given the opportunity, one homeowner responded:

*“We’ve withstood some pretty serious storms. If we didn’t have that we’d probably be pretty wiped out just because the winds kind of generate a lot of the water flow, and when you have storms like that it will bring it right up the canal, and it can wipe you out.”*

The reality of incredibly damaging storms in this area further underscores the need for immediately effective shoreline protection.

There are several emerging differences between how those who hardened their shorelines and those who opted for softer protection methods approached securing their properties. The first is how pressing a concern a particular property owner or manager finds erosion. The immediacy of the threat was often invoked by bulkheaded interviewees, suggesting a perception that bulkheads are the most immediately effective means of protection. The second is how the different property owners conceptualized their shoreline. Those who took a softer approach tended to emphasize how important the shoreline, the physical strip of land between their backyard and the sound, is to them personally. It was not merely a method of protection, but rather a part of their property to be protected in its own right. In contrast, owners with bulkheads seemed more likely to view that shoreline as a means to an end—not necessarily something to be protected, but rather something to be turned into a defense measure. These

differences in perspective may help explain why a group of property owners who share a goal and value—property security—make different decisions.

### **Additional Values Among Shoreline Property Owners**

Although we expected that values would intimately influence the decision-making process of estuarine property owners, we discovered that this is not always the case. Of the five commonly-referenced values that emerged from the interviews, three did not seem to translate readily into decision-making factors and directly influence shoreline decisions. However, the prevalence of these values throughout the responses offers other insights into the cognitive frameworks of our interviewees. In particular, frequent allusion to aesthetics, recreation, and place attachment gives further insight into how our interviewees view their experiences as estuarine property owners and how their values factor into that experience.

#### **Aesthetics**

Many interviewees frequently mentioned the magnificence of the settings in and around the Outer Banks, and how being in close proximity to that natural beauty affected them. As one interviewee commented, “having that [property] on the water, and just that beautiful serenity” was an aspect of her life on the sound that she really valued. While many property owners emphasized similar expressions regarding the physical allure of their properties as well as a desire to be near the water, this value seemed to be the most relevant during the initial property purchase. An interviewee emphasized this point after being asked about the purchase of their home, where she elaborated: “the aesthetic value, being on the water. That was number one.” When describing their family’s relocation to the Outer Banks decades ago, another interviewee added, “we wanted to live on the water and we found a property that we could work with.” As a whole, aesthetics as a value category seemed to be an universally important factor in the location selection process, though not demonstrably influential in regards to specific shoreline protection decisions.

While the possession of aesthetic values did not seem to be a hugely influential factor in choosing shoreline modifications, there was one notable exception to this trend. Stakeholders who either allowed their shoreline to remain natural, or who took on a softer approach to shoreline stabilization mentioned aesthetics more frequently in conjunction with their decision. One interviewee who had installed a living shoreline, describing it as “a hidden paradise,” commented negatively on the attractiveness of bulkheads, claiming, “a bulkhead...it’s not aesthetic. It’s not a good aesthetic.” Another couple expanded upon this sentiment, saying “we considered bulkheading, which just seemed very ugly” and concluding, ultimately, that the “vantage of the sound and the marsh” was a very “beautiful place” to own property. Though the natural beauty of the system was frequently alluded to, there was a shortage of direct references to the aesthetics of the shoreline in particular, which suggests that, as a whole, aesthetics were not critical to property owners and managers in shoreline decision-making.

#### **Recreation**

Living in a tourist and retirement destination, many interviewees valued recreation opportunities that their properties’ provided. However, this manifested differently across the

interviews. A love of boating drove some property owners to install a bulkhead, so they could dock their boats alongside their homes. One interviewee addressed this specifically in regards to their bulkhead, “the reason why we had this was because we had a 29-foot boat in the back and we need substantial room to get onto the boat.” Another property owner who purchased a property with a bulkhead added that they plan to “put in a dock and do boats and jet skis.” The data suggest a perception that bulkheads facilitate boating. However, this does not provide any insight into the decision to modify a shoreline, because only people who purchased property with a bulkhead for boating relayed this.

For other recreational activities, the link between recreation and chosen shoreline protection method is less clear. When asked how they enjoyed their property, one interviewee responded, “I’m a water person. I’m in the water a lot. With paddleboards, fishing, kayaking. Having parties, entertaining on the water.” Though they appreciate their property for recreation it’s not tied directly to the decision to install a living shoreline. In contrast, other property owners that had not installed any type of protection method, rejected the installation of sills because of their recreational interests. When asked about their trepidation in choosing a living shoreline, the property owner responded:

*“I think it would be unsafe. My understanding is you have to have some kind of a sill, right? Behind which you plant plants and the water comes in and deposits the sand and goes back out again. Well, that sill is a water hazard or can become one particularly for water sports and small kids.”*

Although this property owner also enjoyed recreation, the value all but precluded the selection of sills. In addition, the first interviewee goes on to claim that the “clincher” in their decision to install the sill was the “big environmental difference between bulkheads and living shorelines.” This indicates recreation likely played a small role in their decision-making compared ecocentrism.

### **Place Attachment**

Interviewees often invoked place attachment values when outlining their history in the Outer Banks, or what drew them here in the first place.

*“Because I grew up in Washington, D.C. and we used to go to Rehoboth and that area and I fell in love with the Outer Banks, so we started family vacations as early as the early seventies.” (Private landowner)*

Though an abstract concept, interviewees offered a sense of place attachment when they mentioned loved ones or memories. While interviewees demonstrated an emotional connection to the area, the interviews do not suggest this was a conscious factor in decisions to protect shorelines. Although an interviewee’s place attachment to the area may inform their feelings toward their shoreline, the extent to which they actively considered this attachment when making decisions about their shoreline appears limited at best.

While aesthetics, recreation, ecocentrism, security, and place attachment were all values property owners and managers frequently alluded to in their responses, few, if any, actually

explicitly stated that these values were formally incorporated into their own value system. Therefore, it is difficult to claim with certainty that any of the values deemed important in this research formally impacted the decision-making processes of the interviewees, because, in most cases, the interviewees themselves did not explicitly describe a particular value as a concrete decision-making factor. In future research endeavors, it would be interesting to survey interviewees directly about their values, and then conduct additional semi-structured interviews to allow respondents the opportunity to elaborate upon their answers. These results could then be incorporated into the existing body of work that examines important decision-making factors, ultimately facilitating a deeper understanding of the role values play in the decision-making process.

## **Ideals**

During the interviews, we asked property owners to describe their ideal shoreline. All the interviewees described a sandy beach leading to the water. One homeowner stated, “the ideal shoreline would be the way it used to be which was a sandy beach.” However, most interviewees had installed a protection measure that did not align with this ideal. Elaborated upon in other sections, this suggests that other factors preclude achieving the ideal shoreline.

## **Knowledge and Information**

### **Gathering Information**

Interviewees demonstrated differing processes for gathering information about shoreline protection options, and how sources of information influenced their decision-making. Our findings indicate that there are broadly two groups of people considering shoreline protection methods: those who do not look for information and those who do. Interviewees that did not pursue more information on shoreline protection tended to be Outer Banks locals with history in the area. Some interviewees told us that they did not seek more information because they already had enough knowledge from living here. For example, one interviewee stated, “A lot of the knowledge is just historical, it just comes from being here and knowing the wave action and the various different areas of the island.” This suggests that locals assumed their knowledge of the area would allow them to make an informed decision.

Other interviewees who chose not to pursue more information referenced occupational knowledge, such as one interviewee who ended up building a bulkhead: “So, we didn’t seek any information... I worked for a company that built bulkheads so I knew about them.” Others with assumed or actual knowledge claimed their shoreline was not suitable for certain kinds of protection methods like riprap or a living shoreline. Other shoreline property owners emulated their neighbors making statements like, “we really didn’t know of any other...didn’t know anything else to do.” Some interviewees said they did not know where to go for information.

In contrast, interviewees who did seek information did so for different reasons. Some did not believe that they had the required knowledge to make an informed decision, while others were making shoreline decisions for multiple people. Most interviewees who looked for information did find relevant information. Among them were new residents to the area who researched shoreline protection options comprehensively. One of these interviewees was considering a bulkhead or a living shoreline and took it upon themselves to research both options

before deciding to go with a living shoreline. Once the decision was made to go with a living shoreline, that interviewee contacted two different entities: the Coastal Federation and an environmental consultant. His pursuit of information suggests that people not from the area tend to see themselves as lacking the knowledge to make a shoreline protection decision and this in turn drives them to obtain more information.

Another type of person that consulted sources of information was property managers with many people to please. These property managers did not believe that they could make an informed decision all by themselves on extensive properties, so they reached out to experts in different fields. For example, one such interviewee consulted, “engineers, architects, environmental specialists, and other businesses with a similar piece of property.”

Similarly, interviewees from public organizations utilized their networks to access a large pool of information when assessing different shoreline stabilization options. This was achieved through the formation of partnerships with other NGOs, governmental agencies, and contractors. The coordination between multiple public organizations resulted in comprehensive studies of the shoreline, as described by a public lands manager:

*“They came to us with an idea and explained how these shorelines worked, and how it would probably work best for us. We already knew their reputation and had worked with them, and I had actually done a living shoreline before so it fell into place. ... They had done the research, done the homework, and they had actually done the project before in other areas so it was sound backing for whether it was going to work or not.”*

Our findings suggest that public organizations, through their involvement with partnerships, have an extensive network to access information regarding shoreline stabilization options. With expertise on shoreline stabilization provided through their partnerships, our interviewees were able to research the feasibility of implementing a living shoreline.

### **Sources of Information**

Interviewees who sought out external information commonly found themselves going to one or many of the following entities for information: personal networks, organizations, consultants, or university resources. Two themes emerged from their search for information. Firstly, we note that interviewees tended to be impressionable; when they received information for the first time, they tended to trust it as valid, accurate information. Most people who heard from a friend or a neighbor that a certain method was being used were more inclined stop seeking information and choose that same method, whereas if an individual had gotten their information from a website or article, they were more inclined to continue their search.

A second theme that emerged was confusion about who was responsible for the dissemination of information. One interviewee said, “I didn’t even know if I was supposed to ask them questions, or if they were gonna tell me, or what.” People also did not know if they even had a right to some information. One interviewee explicitly said, “I don’t know that we had a right to that knowledge” in discussing his search for information. This led to interviewees’ delayed understanding of the whole process, and much of the time they learned everything they would have liked to know before the installation process, *after* their stabilization measure was installed.



For example, in the ease of acquiring a CAMA General Permit for a bulkhead, one interviewee explained that they got the permit but were never informed about other options.

Interviewees consulted their personal networks, friends, and neighbors who had some relevant knowledge or experience to share with the decision maker. Due to impressionability, this information commonly swayed a decision maker in the direction of their informant. This was particularly the case with bulkheads and neighbors. Logistically, it is more feasible to anchor a new bulkhead to an existing one than to completely change the shoreline one property to the next. In some circumstances, it was simply a matter of convenience, as was stated by a bulkhead-possessing interviewee: “this connects to that neighbor's bulkhead, this connects to that neighbor's bulkhead, so what we have here is a return, sort-of if you think about it that way.” Neighbors and the shoreline protection methods that are common in the surrounding area had a great deal of influence over the decisions interviewees made for their own shorelines.

In other cases, neighboring properties represented a social norm or judgement call of what has worked best for other people in the surrounding area and what was expected to have similar energy conditions to the property owner’s personal shoreline. For one interviewee, seeing the effectiveness of their neighbor’s riprap gave them the desire to improve their own:

*“Mine - I don't have the same amount of rocks as they do, and the waves come further in before they break. That puts saltwater into the yard. Whereas my neighbor's property, their riprap is 10 feet farther out, so the waves break farther out and there are no real issues with their property.”*

Seeing what the majority of people around them are choosing was often the only information property owners considered before choosing a stabilization method of their own.

Organizations like the Coastal Federation or the National Parks Service also serve as a common resource for external information. Many coastal occupants are familiar with these groups, and understand their pertinent role in estuarine shoreline protection measures.

*“The Coastal Federation. It was the best. They helped me, I learned so much. They came out here. I've had them on my property like three or four times, and they know my property well.” (Private landowner)*

Organizations can be helpful and provide on-site, personalized guidance and information. However, interviewees who sought information from organizations did not know if they were supposed to ask specific questions about their options, or if the organization was responsible for clarifying their options. Sometimes however, no response or helpful information from an organization deterred people from going to or listening to that group as is shown in the following instance, “Actually, I reached out to the Coastal Federation to try to put an oyster barrier out there and had no success in their assistance... or cooperation.” This interviewee went on to state that they wanted to install a sort of living shoreline but was unfamiliar with the process.

Individual contractors and consultants were also a common resource for interviewees. They tended to have experience in the field and connections with appropriate organizations and were commonly tasked with learning about the wind and water dynamics at play on a property owner’s coast, and how that plays into an effective stabilization choice. Moreover, they ended up

advising the decision-maker on a protection method, and helping them to move forward with the recommended method.

*“We’ve discussed with this consultant, and he has years and years of experience of wetlands, buildings and all that, and he’s obviously got relationships with the Army Corps and stuff like that, so we’re kind-of going off of some of his recommendations.” (Private landowner)*

However, there are subsets of contractors who specialize in different kinds of construction. If a hired contractor was most familiar with bulkheads, then they tended to recommend and move forward with a bulkhead without informing the decision maker of other alternatives. This process illustrates the impressionability, once again, of some of the interviewees. Regardless of whether a contractor has a sufficient information base or not, the property owner will take what the contractor says and assume its validity. This also played into the confusion of who was responsible for information dissemination as interviewees did not know if their contractor was supposed to tell them about all their options, or if they had to ask.

A final common source of information was university resources. Some interviewees looked into online publications from universities, while others called on professors to help their search for information. This interviewee employed the help of a university professor:

*“We did a little bit of research, and I actually called Professor [redacted] at [redacted] because this was an area of expertise for him. He recommended a nursery in Raleigh where we could find the Spartina grass...”*

The above interviewee drove to the recommended nursery every weekend to pick up grass for planting. Regardless of the specific source, interviewees who mentioned university resources hailed them as sources of unbiased, accurate, real information.

Our findings suggest that information sources drove interviewees to make decisions about their shoreline that they may not have made without the assistance of the information source. These information sources had sway over the final outcomes of people’s shorelines. Individuals also need to recognize their role in the process, and take responsibility for understanding their options.

Particular circumstances that precluded the search for information include homeowners associations and properties acquired with protection measures already installed. Homeowners associations impose requirements on property owners so that they have no say in their shoreline. For example, one interviewee was lamenting how little power they had over their own shoreline:

*“Before we could even do anything we had to have the bulkhead built. Before you can even put your first piling in the ground, the bulkhead has to be built and has to be reviewed.”*

This powerlessness is also evident when interviewees acquired properties with protection measures already installed. In this case, they may have a particular desired shoreline, but because

of the difficulties of removing a stabilization method and installing a new one, they chose to work with what is already there.

### **Organizations' Role in Supplementing Information**

Organizations played critical roles as the suppliers of information. Interviewees from NGOs and governments often perceived their role as an organization was to provide information to the public considering shoreline stabilization options. All of the interviewees from the public organizations installed a living shoreline project and utilized extensive volunteer hours. One interviewee from a governmental agency stated that “the shoreline was possible because of the help of a lot of volunteers.” During the volunteer events, interviewees stated that their organization took the opportunity to educate participants about the processes of an estuary and the components of a living shoreline.

*“We had, as part of the grant we were doing educational work with the eighth grade students of the local middle school. So they would come out and visit us once a year, they would come out and do a field day and kind of learn about the estuary and learn about estuary plants and oysters and reefs and what they do for water quality and all this stuff.” (Governmental)*

This finding suggests that governments and NGOs are interested in educating the public about the processes of estuaries in order to cultivate knowledge of its value to the area. Often stated in their mission statement, these public organizations recognize shoreline stabilization projects as an opportunity to engage the community in educational outreach.

Our interviewees referenced how they intended their living shoreline project to serve as a demonstration for landowners considering various shoreline stabilization options. One interviewee from a governmental agency stated:

*“I think that if we're trying to encourage people to try to do that as an alternative to fixing their own problems on their own private shorelines, having a demonstration project where we can show it's been successful will push people...”*

This statement implies that one of public organizations' goals through the installation of a living shoreline is to illustrate its benefits to landowners. They perceived that their initiative would serve as an example for landowners to reference when they made their decision to stabilize their shoreline. When private landowners considered various options, public organizations anticipated to serve as a resource through its community outreach efforts and demonstration projects.

### **Feasibility**

#### **Cost**

Where interviewees had installed a new shoreline protection method, they were asked to elaborate on whether cost played into their decision of a course of action and whether the costs incurred in the installation was consistent with their expectations. We anticipated comparative

costs of different protection measures and cost feasibility in general would be a factor in decision making. Our findings regarding cost were mixed. Most interviewees acknowledged cost was a consideration, but many downplayed it in comparison to other factors.

Multiple shoreline property owners and managers emphasized that effectiveness of the protection measure was what was most important to them, and they would attempt to fund whatever would effectively protect the shoreline. One private property owner described the priorities in their decision process as “trying to kind of figure out what we thought would work best, looking at the cost, and then looking at what would look [good] aesthetically”. If the protection measure would be effective at achieving the goals they had for the property, the property owners found a way to pay the costs. One resident expressed ambivalence to cost as opposed to other factors because of perceived similarity of expensiveness between measures, saying “it's all costly. It's all time-consuming.”

A few of our interviewees cited costs as a difference between living shoreline and bulkhead that was considered in decision making, but it influenced their decisions differently. One organizational representative said that installing a bulkhead on their property would be more expensive, while a private property owner said living shorelines were not as often used because of prohibitive costs of money, time, and dealing with a more complex permitting process. Properties of interviewees varied widely in size, but numbers thrown out for the costs of installing a bulkhead ranged from \$8,000 to over \$100,000. For one homeowner, the high cost of a bulkhead necessitated refinancing of their home. Those who had installed or considered living shorelines frequently mentioned that the time involved with planning and installing multiple elements as part of that methods was another significant cost. One interviewee exemplified other living shoreline owners when they said:

*“I would say, the cost wasn't cheap. The manpower wasn't easy, as far as learning about the grasses. Just thought about doing something right.”*

On the other hand, the ability to fund shoreline stabilization projects was a determining factor for public organizations. Interviewees from governments and NGOs stated that funding for their projects were secured through partnerships. The partnerships established by our interviewees included other NGOs, governmental agencies, and private businesses. Interviewees frequently stated that partnering with well-funded governmental agencies and NGOs allowed the organization to consider various shoreline stabilization options in a broader scope.

*“I think the process the [governmental agency] is going to go through is gonna be a whole lot more comprehensive. They have greater resources because they're working not so much from a local or regional... they're able to go to the national office and pull from some of those resources that we as a ... small nonprofit wouldn't have.” (NGO)*

Partnerships were influential in the success of local living shoreline projects because they brought in additional resources. Local organizations, limited by budgets constraints, were able to pursue comprehensive shoreline stabilization projects through the arrangement of partnerships.

Pursuing a partnership also allowed a couple of interviewees to seek out funds that were not previously available to the organization. One interviewee from a governmental agency referenced that a non-profit “was able to apply for some grants that [they] ... couldn't get.” This suggests that governments are sometimes limited in their ability to seek out shoreline stabilization projects due to institutional restrictions on applying for state-sponsored grants. However, partnerships with NGOs that operated outside of the public sphere accessed a pool of funds that could be applied to shoreline stabilization projects. Governmental budget constraints could possibly be partially overcome by partnering with non-profits and other organizations who have access to external funding sources.

For interviewees that have not installed a shoreline stabilization project, the possibility of financing a living shoreline through a cost-share program was appealing.

*“If there was grant money available to reduce the cost of the living shoreline which probably wouldn't be available for the hardened alternative, I think that would have a huge impact.” (Governmental)*

This response suggests that living shorelines are a financially viable option for governments and NGOs because of the opportunity for reduced project costs through grants. Moving forward, the expansion of partnership opportunities will be essential for local organizations to implement living shoreline projects. NC Coastal Federation acquired \$500,000 through the NOAA Coastal Ecosystem Resiliency Projects and has funded living shoreline projects throughout North Carolina (NCCF, 2016). Similar cost-share programs with strong incentives to pursue living shorelines would likely influence NGOs, governments, and private landowners in their decision-making process.

## **Permitting**

The topic of permitting was brought up in multiple interviews, but it did not seem to be a major factor in most decision making processes that were reported to us. Many property owners mentioned permitting as one of the steps in the process, but gave no special emphasis to it. A few interviewees who installed living shorelines said that their permitting process was not much different from that of a hardened shoreline installation. In response to whether the project was completed on time, a living shoreline owner said:

*“Easy. Oh, yeah that was easy. I mean it was a little harder to get the CAMA permit. But apparently I've heard that they've eased it up a little bit. It's getting to be almost as easy as having a bulkhead.”*

Our finding that permitting was not a major impact in decision making was consistent with other studies that found shoreline property owners often ranked effectiveness, cost, and durability as more important factors than permitting in their choice of shoreline protection method. (Scyphers et al. 2015 and Smith et al. 2017)

A few other living shoreline owners we interviewed had difficulties with the permitting process. An organizational shoreline manager suggested that the permitting process is more geared toward development than restoration. Several interviewees mentioned that they thought

living shorelines would be more common if the permitting process were easier, but no one said that they abandoned a living shoreline project because of the barrier of permitting.

Permitting did not seem to be as much of a difficulty in living shoreline installations of interviewees as we originally anticipated. We expected to find that implementation of living shorelines was being hampered to a large extent by the permitting process. Gerstel and Brown (2006) and Kochnower et al. (2015) reported that permitting processes are a difficulty for living shoreline owners and much more geared towards shoreline hardening strategies. It could be that this difficulty did not exist among our interviewees' projects, that the issue has been addressed, or that it just did not influence interviewees' decisions. It is also possible that the absence of this trend recognized in other places could have been due to the small sample of the study and the even smaller fraction that had installed a living shoreline.

## Climate

Since we were also researching the carbon sequestration potential of living shorelines, we were interested in whether carbon sequestration and climate change were a part of interviewees decision making processes. Climate change was rarely brought up in the interviews and when it was it was mostly indirectly in terms of sea level rise and accelerating rates of erosion. Climate change was directly mentioned in this context:

*“You know, 10 years ago the water was 25 feet out and now it’s totally different. It’s a changing environment. It seems to be changing rapidly, whatever anyone thinks about, you know, global warming and sea rise.”*  
(Private landowner)

This demonstrates the general sentiment that sea level is rising observably and explains why climate change theory or projections do not need to be brought up in order for its effects to be noticed. There were no suggestions that anyone was aware of the carbon sequestration potential of living shorelines that we studied in our natural science research. It seems that some of our interviewees were aware that their shorelines could be affected by climate related trends, but none of them demonstrated awareness that their shorelines could play any role in affecting factors that influence the climate.

## Implications

Qualitative analysis of interviews with shoreline property owners and organizational land managers yielded multiple findings on how they navigated the decision-making and installation processes of shoreline protection. Nearly all of the interviewees said they had observed erosion on their property, both over time and as the result of storm events. Neighboring shorelines had a large impact on erosion experienced and subsequent shoreline protection measures chosen by the interviewees. Cost and permitting were less important factors than predicted effectiveness of the shoreline protection method in deciding on a shoreline protection strategy. The interviews demonstrated that aesthetics, recreation, and place attachment had minimal impact on an interviewee's shoreline decision compared to ecocentrism and the perception of security

associated with a protection measure. Our findings suggest that information sources drove interviewees to make decisions about their shoreline that they may not have made without the assistance of the information source. Interviewees cited sudden erosion, pressure from neighbors and lack of information in their decisions to install bulkheads despite regarding living shorelines as ideal. For organizational land managers, partnerships offered opportunities for funding and support in installing protection measures. These patterns could be used to more effectively reduce the erosion experienced by private property owners and to promote organizational partnerships for support in the creation of living shorelines. This research contributes to a better understanding of how the public makes decisions and serves to inform those who would like to disseminate shoreline protection information to residents on how to do so effectively.

## Conclusion

In this study, we researched the carbon sequestration and storage potential of living shorelines and how coastal property owners in North Carolina made decisions regarding their shorelines. Our findings indicate that living shorelines sequester carbon, but at a rate that decreases with age. Living shorelines also emit large amounts of carbon in the form of methane, a byproduct of decomposition. Rates of methane flux depend on a number of environmental factors such as salinity, hydrology, organic matter content, and temperature. However, the positive net carbon sequestration at sampling locations indicates that living shorelines uptake and store more carbon than they emit. While we found that living shorelines act as carbon sinks and help mitigate climate change, we also found that the sound front property owners interviewed were unaware of their carbon storage benefit and had limited information about the different protection methods available.

Based on our interview analysis, we recognize a need to educate shoreline property owners about the advantages and disadvantages of various protection methods and the ecosystem services living shorelines provide, as most interviewees conveyed a lack of information. Most interviewees reported that the information sources they consulted failed to provide insight into the alternatives to hardened shoreline protection structures. We found that many interviewees made decisions based primarily on the perceived effectiveness of the method preserving their shoreline. Other property owners focused on the ecological impacts of different shoreline protection methods, revealing that the carbon storage benefit of living shorelines may be influential for those who prioritize ecocentrism, if made aware of it.

Local organizations and other information sources could play an expanded role in educating property owners on shoreline stabilization options. Some organizations, including the North Carolina Coastal Federation and the North Carolina Division of Coastal Management, distribute comprehensive information on shoreline protection options and alternatives to hardened structures; however, our results suggest that the public is not regularly accessing and using this information. More research into effectively disseminating information, to bridge the divide between organizations and the public, would facilitate more informed decision-making. Our findings also underscore how many property owners see their shoreline as an isolated unit, unaware of the positive or negative impacts of their protection decisions on neighboring properties or globally.

We found that living shorelines sequester carbon and thus offset some greenhouse gas emissions. The international community has recognized the benefits from carbon sequestration and developed programs to retain sequestration in terrestrial carbon sinks. However, this concept has not been applied specifically to living shorelines. Replicating and expanding our research in other places and for longer time periods could make shoreline projects a viable option to credit reductions in atmospheric carbon dioxide and thus qualify for ecosystem service payments through greenhouse gas reduction policies. Our findings indicate that additional sources of funding are often sought after by organizations considering a living shoreline; therefore, organizations could view these incentives positively. For private landowners, cost was not a determining factor in their shoreline protection decision, and thus, monetary incentives would be small, likely not influencing their shoreline decisions.



There are challenges to carbon credit-based incentive programs. Carbon sequestration in living shorelines is difficult to measure, credit, and report because sequestration rates depend on dynamic environmental variables. Climate change-induced environmental factors such as sea level rise, and fluctuations in temperature, salinity, and pH all alter the carbon storage capacity of wetland sediments and the rate of methane emissions. As a volatile greenhouse gas, methane emissions from wetlands are temperature-dependent, so a global increase in temperature could increase the amount of methane released, initiating a positive feedback loop where additional atmospheric methane results in additional increases in global temperature. Further research into the net carbon storage at our sampling sites would clarify the capacity of soils and plants in living shorelines to sequester carbon, counteract the release of methane gas, and help mitigate climate change effects.

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## Appendices

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### Appendix A

***OBXFS 2017 Capstone Interview Guide***  
***v. 2017 September 26***  
***Private Landowner***

#### **Materials**

Consent document, iPad (*Remember to check battery life*), charger, pen/pencil, clipboard

#### **Introduction:**

Go over topic of interview and project; give brief summary of what it is we're doing.

- Summary: We are conducting interviews with shoreline property owners in the area to see how people value and make decisions about their shorelines.

Ask the interviewee to review consent document. Make sure s/he doesn't have any questions.

Ask if recording is alright; explain importance of having a recording if they are skeptical.

- Importance: It helps us to better keep track of information and hear what you have to say rather than constantly taking notes.

Ask him/her to mark the recording by stating his/her name, the date and where you are.

(*Reminder: keep the iPad volume low to avoid feedback.*)

#### **Background:**

I'd like to start by asking you to tell me a little about your history here.

How long have you lived in the area?

- *If property was chosen/purchased:* What about this property led you to purchase it?
  - Was being waterfront and having a shoreline a factor?

How long have you owned your current shoreline property?

How would you describe your property to someone who has never seen it before?

- *If shoreline is not discussed:* Could you describe your shoreline for me as well?
- What shoreline protection measures are in place? *If any:* when were they installed?
- How close are buildings on your property to the shoreline?

How do you use or enjoy your shoreline property?

- *If you need to specify:* Do you use your shoreline for anything in particular?
- Ask for specific examples, boating, beach recreation, fishing, general beauty or communion with nature, etc.
- *Prompt:* What's important to you about it?
- What is your ideal shoreline like?



**Assessment of risk to shoreline:**

Now that we've talked about your property, have you noticed any changes to your shoreline since you've lived here?

Have you experienced any challenges or difficulties in regards to your shoreline?

How much of a threat do you perceive erosion is to your shoreline?

- How did you determine this risk?
  - Was there a specific event or experience that alerted you to the issue?
  - *Prompts:* Loss of recreation/accessibility, visually noticing erosion, government outreach
- Do you think your property is (or was) ultimately at risk from erosion?

*Transition to one of three applicable sections below...*

1. *Installed a Shoreline Protection Method*
2. *Acquired With a Shoreline Protection Method*
3. *Acquired Without a Shoreline Protection Method*

**1. Installed a Shoreline Protection Method:**

In terms of protecting your property, what led you to choose to install [*insert protection measure*]?

- What considerations or factors were important to you?
- What other options did you consider?
- How did you narrow your options?
  - *Prompts:* Costs, regulatory burdens, aesthetics, projected time of completion, time commitment of maintenance?
- Was there some critical piece of information or experience that made the difference in making your decision?
- *If they installed something OTHER THAN living shoreline:*
  - Did you consider a living shoreline?
    - *If yes:* What was your thinking about that option?
    - *If no:* Are you familiar with living shorelines?

Where did you go for information about options for your shoreline?

- Do you generally use these sources for decision-making?
- Was there a specific individual or organization that contributed to your decision?

Let's talk about the process of installing and maintaining the [*method used*]. How would you describe this process?

Was the process similar to what you had originally anticipated?

- Were the costs consistent with what you had projected?
- Was it completed in the projected schedule?

How has the [*shoreline protection measure*] worked out?

- What have you noticed in terms of erosion?
  - Is your shoreline still eroding? How much?
- How did it affect your ability to use your shoreline?
- What kinds of benefits or improvements have there been beyond protecting your shoreline?
- What kinds of maintenance have you had to do?
  - Has that been consistent with what you anticipated?

In retrospect, what other information do you wish you had considered when making your decision?

- How would that have affected your choice?

### **2. Acquired with a Protection Measure in Place:**

*For purchased property:* Now that we've talked a little bit about risk, when you purchased your property, how important was the existing [*shoreline protection structure*] in your decision?

- Did you reject prospective properties that didn't have your desired shoreline?
- What was important about having a [*shoreline protection structure*] in place?

How is your [*shoreline protection measure*] working?

- What kinds of benefits have there been to having a [*shoreline protection measure*] beyond protecting your shoreline?

What kinds of maintenance have you had to do?

- Has that required maintenance been consistent with what you anticipated when you acquired the property?

Have you considered making changes to your current shoreline protection measure?

- *If so:* What's made you think about changing to something else?
  - What options have you considered?
  - Have you considered replacing your [*shoreline protection feature*] with a living shoreline?
    - If yes: What's been your thinking about installing a living shoreline?
      - What do you like about this option?
      - What concerns do you have?
    - If not, are you familiar with living shorelines?
- Where do you get your information about shoreline protection?
  - What other sources do you turn to for information about coastal management?

### **3. Acquired Without a Protection Measure in Place:**

Now that we've talked a little bit about risk, when you purchased your property, how important was the existing shoreline in your decision?

- Did you reject prospective properties that didn't have your desired shoreline?
- What was important about having this shoreline?

- How did shoreline protection factor into your purchasing decision?

Have you considered making changes to your shoreline?

- *If yes:* what options have you considered?
- What factors are important to you as you weigh these options?
  - Have you considered installing a living shoreline?
    - *If yes:* What's been your thinking about installing a living shoreline?
      - What do you like about this option?
      - What concerns do you have?
    - *If not,* are you familiar with a living shoreline?
- Where do you get your information about shoreline protection?
  - What other sources do you turn to for information about coastal management?

*If not considering shoreline protection options:* Can you talk about what factors or changes would have to occur for you to consider any kind of shoreline protection methods?

### **Closing Questions:**

- That's everything that I wanted to ask you. Is there anything you'd like to add concerning your property, your shoreline, or shoreline protection in general that we haven't discussed?
- Do you have any questions for me?

### **Conclusion:**

Thank you so much for participating in this interview, [name]. I'd like to reiterate that all of your responses will be kept completely confidential, and that if at any time you have any questions about this interview or our project, you can feel free to contact me or our project coordinator.

*Provide contact info if requested and/or s/he can keep the consent document if s/he wishes.*  
You've been incredibly helpful and giving us some of your time has been extremely valuable.

Do you know of anyone else you think would be a good person for us to interview?

- *Ask for contact information to go along with names.*
- *Clarify that they should not take it upon themselves to ask people to do interviews. If they ask about contacting the person first, explain that they can reach out to the person and ask if they would be willing to hear from a student about the project and then think about participating.*

Thanks again for participating in this study. We will be compiling the findings of our study into a report and giving a public presentation about them at the end of the semester. You are more than welcome to attend. It will be Thursday, December 14 from 2:00-4:00pm at the Coastal Studies Institute.

## Appendix B

### *OBXFS 2017 Capstone Interview Guide v. 2017 September 26 Organization*

#### Materials

Consent document, iPad (*Remember to check battery life*), charger, pen/pencil, clipboard

#### Introduction:

Go over topic of interview and project; give brief summary of what it is we're doing.

- Summary: We are conducting interviews with shoreline property owners in the area to see how people value and make decisions about their shorelines.

Ask the interviewee to review consent document. Make sure s/he doesn't have any questions.

Ask if recording is alright; explain importance of having a recording if they are skeptical.

- Importance: It helps us to better keep track of information and hear what you have to say rather than constantly taking notes.

Ask him/her to mark the recording by stating his/her name, the date and where you are.

(*Reminder: keep the iPad volume low to avoid feedback.*)

#### Background:

I'd like to start by asking you to tell me a little about your history here.

How long have you worked for [*insert facility*]?

What was and is your role in this shoreline project?

How would you describe the property to someone who has never seen it before?

- *If shoreline is not discussed:* Could you describe your shoreline for me as well?
- What shoreline protection measures are in place? *If any:* when were they installed?

How do visitors use or enjoy the shoreline property?

- *If you need to specify:* Do visitors use shoreline for anything in particular?
- Ask for specific examples, boating, beach recreation, fishing, general beauty or communion with nature, etc.

#### Assessment of risk to shoreline:

Now that we've talked about the property, have you noticed any changes to the shoreline since you've worked here?

Have you experienced any challenges or difficulties in regards to the shoreline?

How much of a threat do you perceive erosion is to the shoreline?

- How did you determine this risk?
  - Was there a specific event or experience that alerted you to the issue?

- o *Prompts:* Loss of recreation/accessibility, visually noticing erosion, government outreach
- Do you think the property is (or was) ultimately at risk from erosion?

*Transition to one of three applicable sections below...*

1. *Installed a Living Shoreline*
2. *Have Yet To Install a Protection Measure*

**1. Installed a Living Shoreline:**

In terms of protecting the property, what led you to choose to install a living shoreline?

- What considerations or factors were important to *agency/organization*?
- What other options did you consider?
- How did you narrow your options?
  - o *Prompts:* Costs, regulatory burdens, aesthetics, projected time of completion, time commitment of maintenance?
- Was there some critical piece of information or experience that made the difference in making the decision?

Where did you go for information about options for the shoreline?

- Do you generally use these sources for decision-making?
- Was there a specific individual or organization that contributed to your decision?

Let's talk about the process of installing and maintaining a living shoreline. How would you describe this process?

Did you consult with the public for comments? How?

- What were people's concerns or doubts?
- Were they familiar with a living shoreline?
- Did you incorporate their comments into the planning process?

Was the process similar to what you had originally anticipated?

- Were the costs consistent with what you had projected?
- Was it completed in the projected schedule?

How has the living shoreline worked out?

- What have you noticed in terms of erosion?
  - o Is the shoreline still eroding? How much?
- How did it affect the facility's ability and the user's ability to use the shoreline?
- What kinds of benefits or improvements have there been beyond protecting the shoreline?
- What kinds of maintenance have you had to do?
  - o Has that been consistent with what you anticipated?

In retrospect, what other information do you wish you had considered when making the decision to install a living shoreline?

- How would that have affected your choice?

## **2. Have Yet To Install a Protection Measure**

Now that we've talked a little bit about how the organization/town/etc. assesses risk to the shoreline...

Has the organization/town/etc. considered installing protective measures to the shoreline?

- *If yes:* what options have you considered?
- What factors are important to you as you weigh these options?
  - Have you considered installing a living shoreline?
    - *If yes:* What's been your thinking about installing a living shoreline?
      - What do you like about this option?
      - What concerns do you have?
    - *If no:* Are you familiar with a living shoreline?
- Where do you get your information about shoreline protection?
  - What other sources do you turn to for information about coastal management?

### **Closing Questions:**

- That's everything that I wanted to ask you. Is there anything you'd like to add concerning the property, the shoreline, or shoreline protection in general that we haven't discussed?
- Do you have any questions for me?

### **Conclusion:**

Thank you so much for participating in this interview, [name]. I'd like to reiterate that all of your responses will be kept completely confidential, and that if at any time you have any questions about this interview or our project, you can feel free to contact me or our project coordinator.

*Provide contact info if requested and/or s/he can keep the consent document if s/he wishes.*

You've been incredibly helpful and giving us some of your time has been extremely valuable.

Do you know of anyone else you think would be a good person for us to interview?

- *Ask for contact information to go along with names.*
- *Clarify that they should not take it upon themselves to ask people to do interviews. If they ask about contacting the person first, explain that they can reach out to the person and ask if they would be willing to hear from a student about the project and then think about participating.*

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## Appendix C

### The Social Cost of Carbon Calculations:

$$.035 * 10,658 \text{ miles} = 373.03 \text{ miles}$$

$$373.03 \text{ miles} * \frac{1609.34 \text{ meters}}{1 \text{ mile}} = 600,332.1 \text{ meters}$$

$$600,332.1 \text{ meters} * 8 \text{ meters} = 4,802,656.8 \text{ meters}^2$$

$$4,802,656.8 \text{ meters}^2 * \frac{183.21 \text{ grams C}}{\text{meters}^2 * \text{year}} = 879,894,753 \frac{\text{grams C}}{\text{year}}$$

$$879,894,753 \frac{\text{grams C}}{\text{year}} * \frac{1 \text{ ton C}}{907185 \text{ grams C}} = 969.9 \frac{\text{tons C}}{\text{year}}$$

Sample Calculation to determine tons per year of Carbon storage if there were a 50% increase in current shoreline stabilization using only living shoreline methods

$$969.9 \frac{\text{tons C}}{\text{year}} * \frac{11}{3} \frac{\text{tons CO}^2}{\text{tons C}} = 3,556.3 \frac{\text{tons CO}^2}{\text{year}}$$

Conversion of calculated tons of carbon sequestered per year to tons of carbon dioxide from the atmosphere absorbed per year ([EPA 2017](#)).

$$3,556.3 \frac{\text{tons CO}^2}{\text{year}} * \$50 (\text{social cost of CO}^2) = \$177,815 \text{ avoided social cost per year}$$

Calculation to estimate the avoided social costs of expanding the implementation of living shorelines in NC by 50% (NASEM 2017).