Retrospective analysis of the embayment in the Rachel Carson Estuarine Research Reserve from 1998 to current

by

Scott Delgado

Dr. Dan Rittschof, Adviser

August 16, 2019

Masters project submitted in partial fulfillment of the

requirements for the Master of Environmental Management degree in

the Nicholas School of the Environment of

Duke University

Executive Summary

The Rachel Carson Estuarine Research Reserve in Beaufort, NC has been a highly monitored and researched area due to its proximity to the Duke Marine Lab, National Oceanic and Atmospheric Administration Beaufort Lab, and preserved status within the reserve. Utilizing data from these resources, the changes to the high-salinity embayment in Bird Shoal were recorded and mapped. The baseline data were acquired from Dr. William Kirby-Smith, Jonathan Kool, Sean Ramach, and the North Carolina Department of Environmental Quality. The primary focus of the study was to compare the shoreline change and the distribution of *Crassostrea virginica* within the embayment in the past 30 years.

The first section of this report outlines the history of the study site in Bird Shoal, along with the previous researchers that have used the Rachel Carson Estuarine reserve as their location of choice. The proximity to multiple government buildings and higher education laboratories has prompted research with in the reserve for decades. The next section deals with extracting the data from multiple sources and utilizing datasets created from Unmanned Aircraft Systems (UAS) to quantitatively and qualitatively compare the changes to the embayment. The final section discusses the details of the changes and the potential causes to the shift in the environment with the embayment. With a decrease in 40% of the water area, the embayment has had a great deal of accretion especially in the southern facing beach. The embayment is now decreasing in size as the northern portions have remained static. The oyster population has bloomed throughout the embayment. They are heavily located in the initial estimates from Kool but have also expanded to both sides of the Bird Shoal inlet and completely covered crab island. As of 2017, the area of oyster distribution is over 6,000 m^2 which has grown substantially from 1999.

Table of Contents:

Introduction

Rachel Carson Estuarine Research Reserve (RCERR) is the site of observation for this project. The Rachel Carson Reserve is located south of Beaufort, North Carolina. It is situated between Beaufort Inlet Channel, North River, and Newport River. The reserve is comprised of dredge spoil islands, salt marshes, and surrounding water that covers a total area of 2,315 acres (NOAA 2009). The focus of the project will be the embayment in the western portion of Bird Shoal. This site was chosen due to its proximity to the Duke Marine Lab and other research facilities that have been recording data from the site for decades. Initial base line data were collected in 1986 prior to the area becoming the RCERR by Dr. William Kirby-Smith at Duke University Marine Laboratory. As part of a master project, Jonathan Kool mapped the bathymetry of the bird shoal embayment at the west end of the reserve on a 10 meter grid (Kool 1999). In addition to physical data, he collected biological data at each grid point. Over a 3 month interval in 2000 as part of his master's project, Sean Ramach laser surveyed the embayment with 3 mm resolution with respect to depth on a 10 meter grid and ground-truthed his data to a USGS marker on Pivers island (Ramach 2001). Now in 2017, the same area has been surveyed by the Johnston lab utilizing Unoccupied Aircraft Systems (UAS).

I chose the embayment for my study because of anecdotal reports that the embayment is a dynamic component of the system that sand has displayed vast physical and biological changes. Unlike stationary landforms, barrier islands erode, migrate, and rebuild over time in response to waves, tides, currents, storms, human activity, and other physical processes in the ocean environment (Stutz, Pilkey 2011). The islands and estuarine waters of the Rachel Carson Estuarine Research Reserve, across from the town of Beaufort is just south of the Beaufort inlet, the mouth of the Newport River estuary and Onslow Bay. Twice-daily tides result in a continuous mix of fresh and salt water creating an observable estuarine environment. Habitats in and around the embayment include from soft mud, sandy bottoms, shell bottoms, dredge spoil beaches, tidal flats, oyster reefs, salt marsh, maritime forest, and submerged vegetation. Most of the area is affected by an erosive trend due to the vulnerability of barrier islands,

storms reshaping the area, and sea level rise (Kopp et al 2015). I will document changes over 30 years of mapping and how oyster populations have changed over time in the reserve.

Bird shoal and the embayment was not a natural barrier island. The formation was artificially created due to large-scale dredge spoils from Beaufort's coast by the Army Corp of Engineers in the 1930's (NOAA 2009). The dredging efforts were to enable and increase ship traffic into the port. All these spoils were placed on the west side of RCER creating a sandy island that overtook marshland. (Egitto 2017) The increase in sand has elevated the island and allowed for shrub thickets and other vegetation to establish a base (Bland 2012). Despite being man-made, the island has been acting comparable to barrier islands and migrating towards Beaufort (Starkey 2016). The maps provided by Kool, Kirby-Smith, and Ramach can be compared to the drone data from 2017 to visualize the shoreline change and variation in oyster population.

The oyster reefs around North Carolina are an important part of the coastal ecosystem. The predominant species on this coast is the eastern oyster (*Crassostrea virginica*) which is abundant in shallow bays and estuaries. They can live in waters from mid intertidal to 25 feet (Lorio and Malone 1994) The eastern oysters typically build their own habitat, creating reefs for additional oysters to grow. These reefs are defined as having a vertical relief that is at least 0.2 meters above the substrate (Beck et al 2009). The formation of oyster habitats accretes due to supplementary sand and discarded shell material if conditions continue to be prosperous for the oysters. The largest restriction is tidal exposure, while other variables include water temperature, salinity, and dissolved oxygen.

Methods

Kool collection

Kool (1999) chose an approximately 300 by 600 rectangular area within the Rachel Carson Estuarine Research Reserve as his study site. The approximate boundaries were 34°42'41" N, 76°40'50" W and 34°42'00" N, 76°39'86" W. The area was gridded into 100 m^2 areas using PVC stakes at the center of each grid point. Coordinates were recorded using a Garmin 12XL GPS unit. At each grid point Kool recorded four sets of data: depth, sediment, and species presence. Depth was collected using a PVC pole with 1.0 centimeter intervals. Depth were standardized using observed water levels and meteorological data collected from the NOAA long term tidal station on Pivers Island (https://tidesandcurrents.noaa.gov/datums.html?id=8656483). Sediments were collected into a plastic bag with teaspoon. Organic content of the samples was calculated using loss of weight of dried samples after combustion at 500 C for 4 hours. Sediment size of combusted material was determined using a cascade of geological sieves. Species presence or absence was observed in a 1m circle around each grid point. Species recorded were mud snails (*Ilyanessa obsoleta*), oysters (*Crassostrea virginica*), and grasses (*Spartina alterniflora and Spartina patens*). All collection took place between October 1998 and April 1999.

Ramach Map and Data Analysis

Similar to Kool's study site, the research site was a 400 m by 600 m rectangle (coordinates: 1. 34°42.740' N, 76°40.485' W, 2. 34°42.529' N, 76°40.485' W, 3. 34°42.529' N, 76°40.092' W, 4. 34°42.740'N, 76°40.092' W.) The rectangle was divided into sections by mean tide level. The area was then subdivided into a 10 m grid using a string line and measuring tape. Each point in the grid was positionally established using a Garmin 12 XL GPS receiver. The points were continually measured until the same pair of coordinates were obtained three times, to eliminate error. The embayment was surveyed using a 24X bull-eye self-leveling survey level and a rod in 1/8 inch increments. All measurements were related to the tidal datum of 1927 from a NOS tidal benchmark located near the RCR. All data were input into ARC-INFO, a command-line based GIS system, to create a point file. Ramach used kriging on the point file to

establish a continuous depth profile for the entire area. The post-kriging data were displayed on a map using ARC-View. This data were collected over the summer of 2000

Ramach collected all the data into spreadsheets to facilitate manipulation of the data. The parameters collected were date/time, sex of crab, width, egg state, tag number, and GPS coordinate. The sex ratio and male/female size were graphed and used for statistical analysis. All the data were input into ARC-INFO and overlaid on the depth profile. The combination of the depth profile and the crab data were used to formulate a 3D position for crab.

Georeferencing

In order to properly compare the data across multiple years, they must all have the same geographic coordinate system. The most current data collected using drones from the Johnson Lab has the coordinate system of World Geodetic System (WGS) 1984, which will be the coordinate system that will be used with the rest of the data. Data provided by the North Carolina Department of Environmental Quality (NCDEQ) for Shellfish Growing Areas (SGA) is already in WGS 1984 so does not need to be transformed. Ramach's data has a coordinate system in North American datum (NAD) 1983. A geographic transformation from NAD 1983 to WGS 1984 was used to properly align the data. Kool's map did not have any geographic coordinate system attached to his data and the projection system was custom and undiscussed in his paper. So Ramach's data from 2000 was used to compare Kool's data from 1998 and 1999. Kool provides the boundaries for his research as 34°42'41" N, 76°40'50" W and 34°42'00" N, 76°39'86" W which gives a general idea of where his data will be located. Due to the custom projection, Kool's maps were georeferenced using visual datapoints from Ramach's maps. The datapoints were the inlet to the embayment, crab island, and beach areas on the perimeter.

Shoreline analysis

The analysis of the shoreline change within the embayment can only be compared to the original study site used by Ramach in the summer of 2000. Ramach used a preliminary 10 meter grid that followed Kool's work. The grid was surveyed and then compared to tidal data from National Ocean Service tidal benchmark. Ramach used a multiple step statistical analysis, called Kriging, to acquire depth across the embayment. The final depth embayment map had a relative depth range of −107 cm to 102 cm which were related to the tidal benchmark. The ambient water level within Ramach's data was 50.75 cm. This value was used as the shoreline marker in order to compare between water and land in the data. The kriged data were normalized by reclassifying land and water to a binary value. After filtering and sharpening the data, they were converted into a vector dataset. The area of the embayment and the surrounding beaches were calculated to give a base data in which to compare the current data.

The Johnston lab provided a digital surface model (DSM) of the RCER during the fall of 2017. A DSM provides elevation at regularly spaced intervals that represent the first surface that is detected. The DSM raster was rendered using the discrete color renderer for easier visibility. The data were also stretched using histogram equalization to view difficult areas near the shoreline. Histogram equalization is useful for increasing the contrast on localized areas without changing the entire contrast of data. This increased the detectability between water, oyster reefs, and sandy beaches. This technique can cause issues for data that has a bit size of 8 or less; however, the bit depth of the DSM raster was 32 bit which allowed a large range of values. After the data were stretched from the original range of −44.3057 - −25.5992 to a broader range of 1 - 255, that raster was visually compared to imagery of the embayment to discover the stretched value of the shoreline. A value of 40 was discovered to be the most accurate point in which beach or marsh transitioned into water.

Before transitioning the raster data into a vector, the data were cleaned and smoothed using a Majority Filter with eight neighbors. A Majority Filter compares neighboring cells in a raster

dataset and confirms that a majority (at least five out of eight) of the cells are contiguous. Utilizing eight neighbors will compare the eight nearest pixels, which is a three by three perimeter, as opposed to only four direct neighbors. The newly stretched DSM is clipped to fit the study area provided by Ramach. The data is reclassified by applying the value of 40 to acquire the shoreline and separate the data into binary values. This is then converted into a polygon vector to mirror the dataset from Ramach. Due to distortions in the data near the center of the embayment, the pixels were removed manually and dissolved into the polygon for water. This was not an issue since the final dataset only required a shoreline and not the depth within the embayment. The area of the embayment and the nearby beaches were calculated within the study site. The percent change in shoreline was calculated using area across the entire site and specifics zones.

Oyster Distribution

The maps provided by Kool's research on oysters in the embayment are kriged datasets. Kool acquired spatially explicit samples of oysters and combined that with all the physical variables that were collected from the study site. The geostatistical technique to obtain the results is called kriging. The interpolation uses the location of the oysters and compares them with surrounding abiotic factors. Kool used salinity, soil types, and sediment particles. The kriging created a predicted data for unobserved locations across the entire embayment. For this dataset to be comparable, the raster had to be reclassified. The PNG files from Kool's research were converted from a 3 band RGB raster to 1 band colormap to separate all the values. The data was then reclassified into predicted values which ranged from 0.0 which was highly unlikely to contain oyster to the opposite of oyster likely occurring at 1.0. With the raster in place, area was calculated for each zone and compared to the total area of the study site. This provided the baseline data

The drone data imagery was high quality, 32 bit raster datasets which allowed fine levels of detail. Similar to the DSM dataset, adjusting the stretch values with image analysis helped

create a contrast between the oyster reefs, beach, and stingray holes. The dataset were run through an unsupervised isocluster with 7 classes. To smooth the raster, a Majority filter was run along with a Resample function. This initially did a solid job of differentiating between sand and oyster, but there were a few issues with the stingray holes sharing classes with the oysters. Three different boundaries were created to resolve this problem. This was completed manually to remove vegetation and other obstructions in the data. The dark water in the imagery was also problematic, so areas in the middle of the embayment had to be carefully classified. Crab island was one such area where the data was finely clipped and then buffered 0.2 meters to integrate the entire reef. All the individual rasters were combined into a single raster in order to convert to a vector for more processing.

Results:

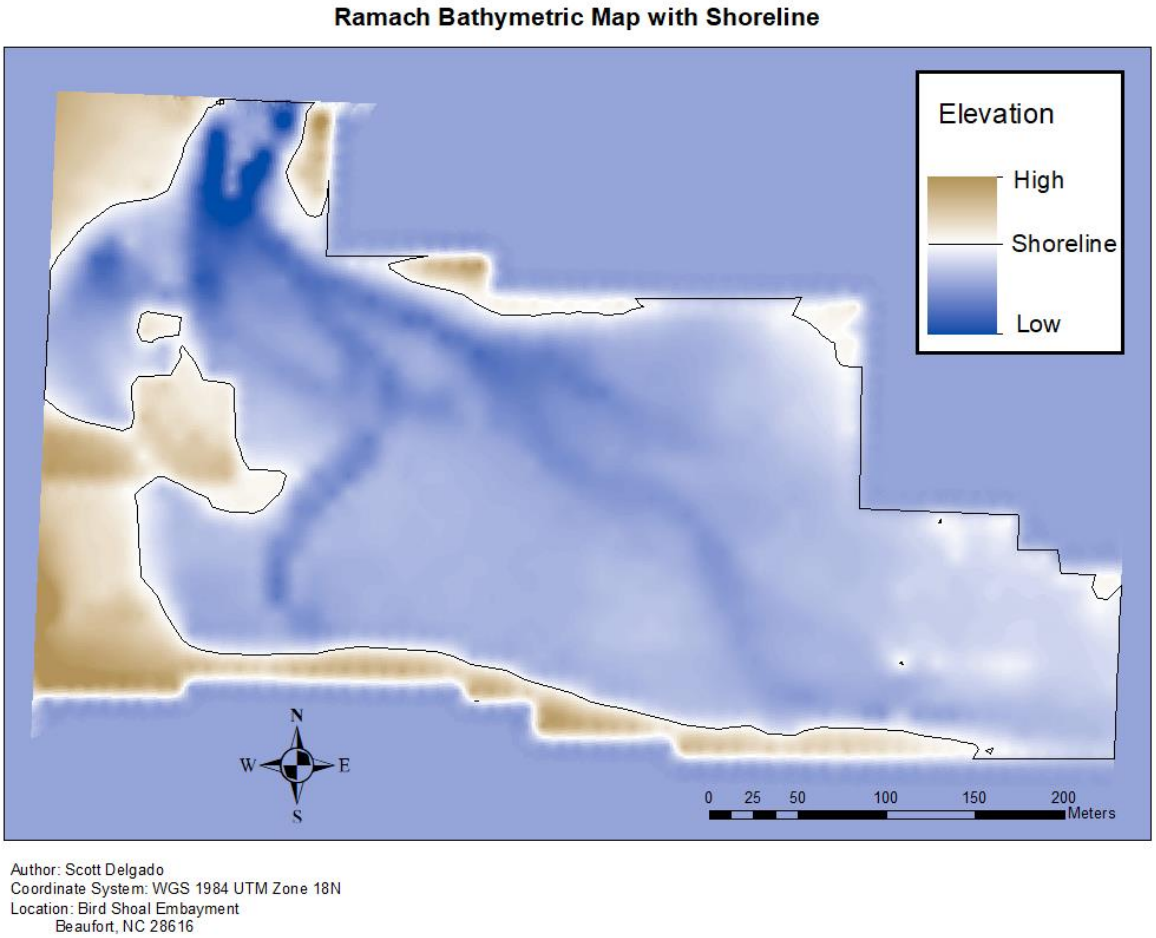

Figure 1. Ramach's bathymetric map with shoreline calculated

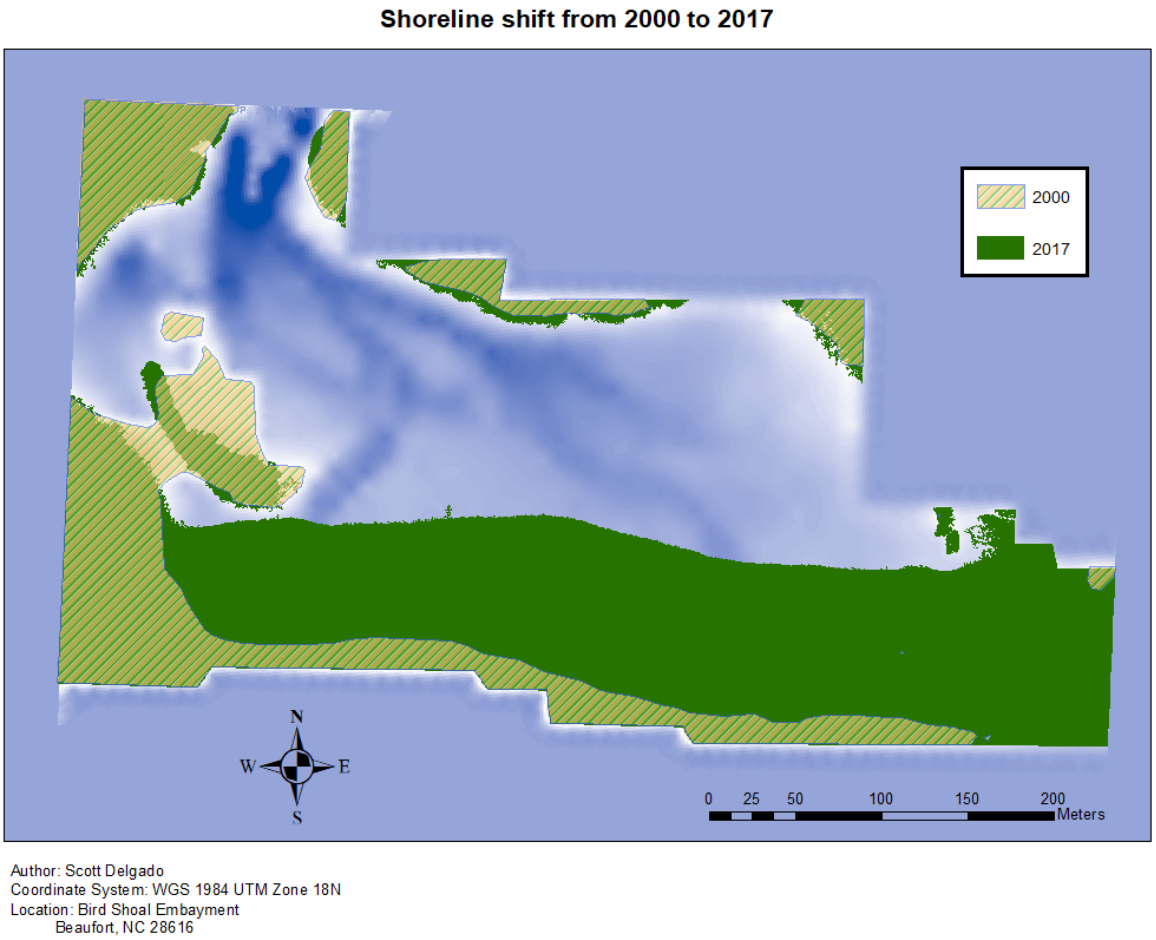

Figure 2. Comparison in the shoreline between 2000 and 2017.

	2000		2017	
Shoreline change	Area	% of site	Area	% of site
Land	30825 m^2	21.15	76,529 m^2	52.51
Water	114,890 m^2	78.85	69,186 m^2	47.84

Table 1. The area of shore and ocean in the study area.

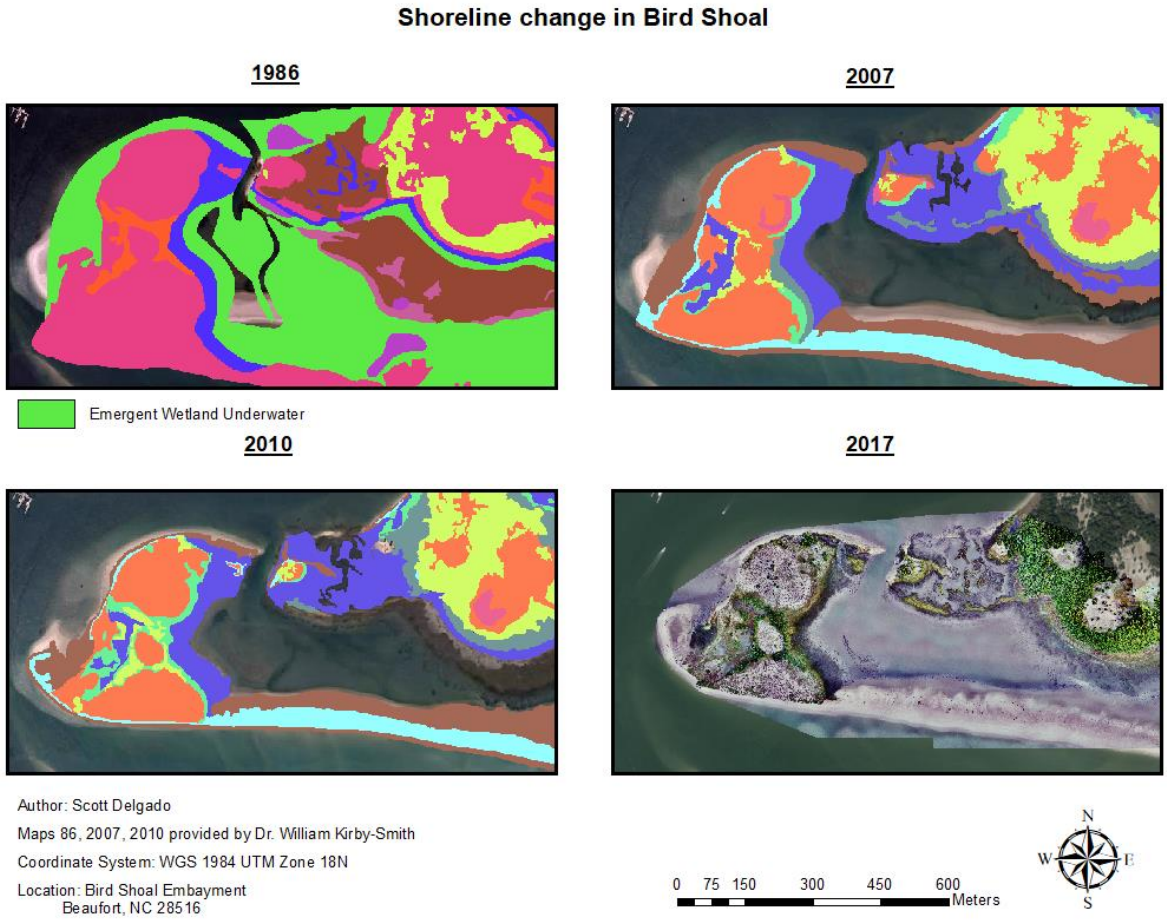

Figure 3. The change in shoreline across 30 years.

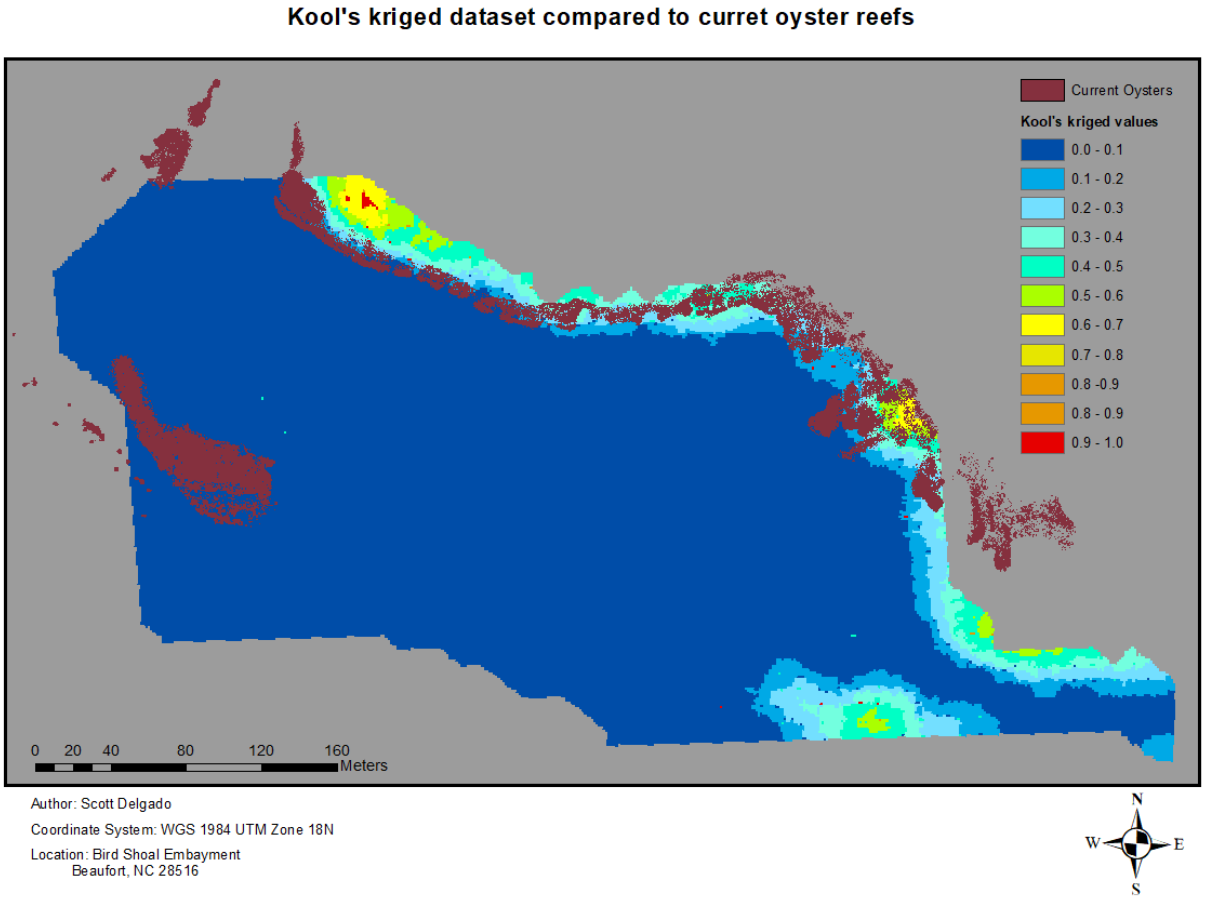

Figure 4. Kool kriged oyster map overlaid by 2017 oyster distribution.

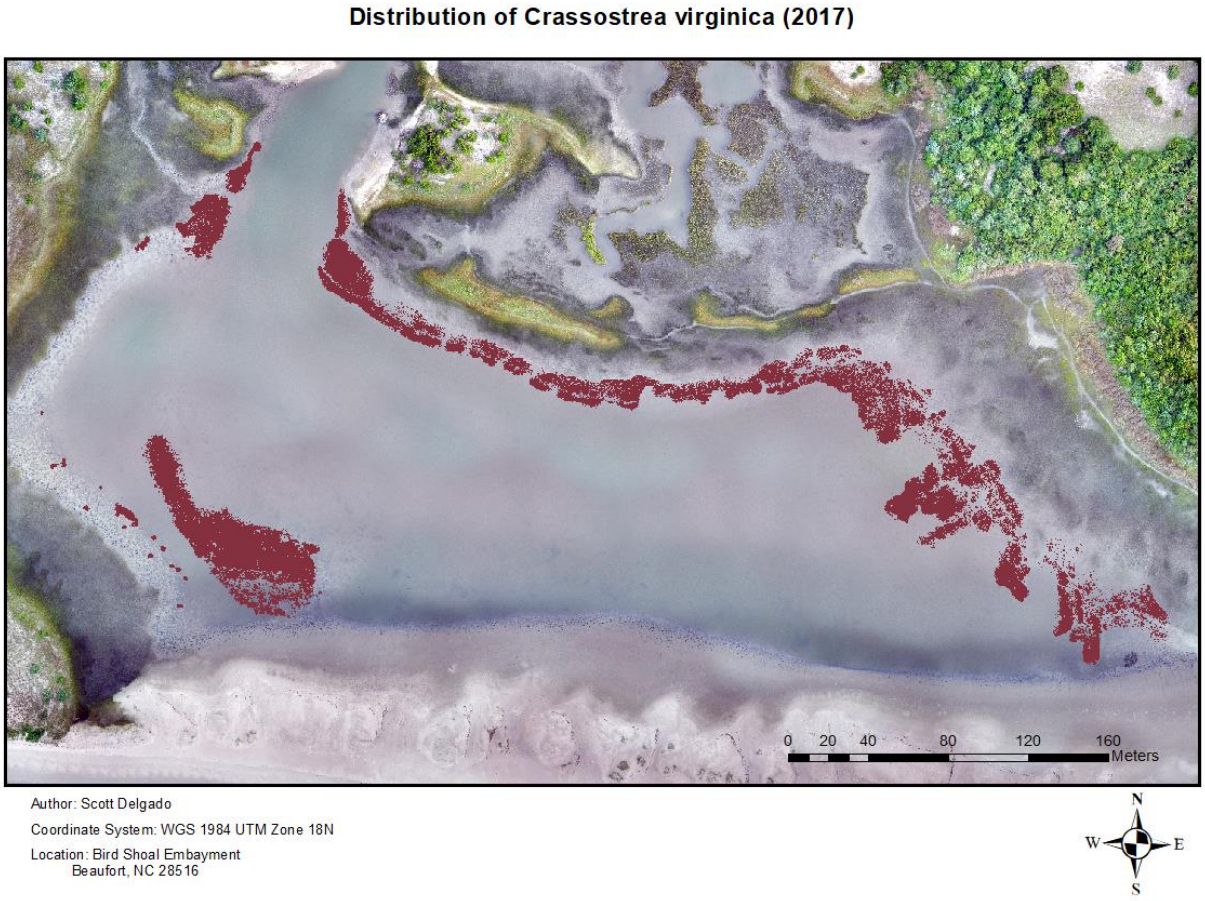

Figure 5. Distribution of *Crassostrea virginica* in 2017.

Discussion:

The results of the shoreline change analysis displayed a major shift in land area within the study site. There was a swing from only 21.15% of the area containing land above sea level to 52.21% in 17 years. This has caused a 39.78% decrease in the area of water in the embayment from 2000 to 2017, making the embayment considerably smaller. The majority of this change was caused by the southern beach accreting by 80 meters into the embayment. The areas in the north of the study area, especially the inlet, stayed the most consistent. These areas were the least likely to be affected by any changes from weather events or erosion from ocean currents. The datasets from Kirby-Smith did not provide quantitative results on the change in shoreline, but they were able to confirm the shift that has taken place between the years of 1986, 2007, 2010, and 2017. The width of the barrier beach between the ocean and the embayment has had slight erosion but has moved deeper into the embayment. It has moved so far that ocean facing beach south of the embayment has now almost shifted to the southern portion of the study area. Outside the study area, there has been accretion to the east of the embayment on the ocean facing beach. This sand is likely accreting from the west portion of the RCERR where dredge spoils were originally dumped. Currents from the Beaufort inlet, which is 2 km south of the reserve, is likely causing the sand to shift alongshore of RCERR (Cleary and Marden 1999).

Kool's original kriged data displayed a probability of oyster populations in the north and eastern portions, in areas closest to the beach, due to the depth at mean sea level being the shallowest. Within the study site, 1,138 m^2 were predicted to have oysters while in 2017 the eastern oyster population has increased to 6,048.8 m^2 in similar areas. These areas are perfect growing conditions since eastern oysters prefer subtidal and mid intertidal zones (Roeger and Mann 1995). Their location in the embayment allows minor flow to increase food concentration, but the velocity isn't too high to minimize their growth because they are in the protection of the embayment (Bartol 1998). The oysters have spread past Kool's initial results to inhabit the mouth of the inlet, small portions of the western side of the embayment, and completely covering crab island. An additional reason that the oyster population has bloomed is due to

Bird Shoal having a protected status for harvesting. The entire area has been closed to harvest for at least 30 continuous years due to water-quality concerns from municipal discharge (Powers 2009). There are no oyster reefs on the southern beach of the embayment. This is likely due to the amount of change that has taken place over the years on the southern side. The dynamic nature of the southern beach would make it difficult for oysters to colonize. The accretion of sand would also position the oysters to be saturated in water for shorter periods of time and desiccate.

The largest limitation of the study was the limited datasets from previous years in which to compare. Kool set the boundaries for his dataset within the embayment specifically looking at snail, oyster, and spartina populations. Ramach then used a similar boundary to keep consistent with Kool. Even after a hurricane in the fall of 1999 which disrupted the bathymetry, the shoreline of the embayment was relatively similar, so no major changes were required for the boundary. With increased accretion in the middle of the 2000s, this shifted the comparative study area northward, especially in the south portion of the embayment. The data provided from Kirby-Smith was useful for visualizing the change in the embayment, but the data was only landcover designations and difficult to acquire specific shorelines for past years. Further research in the area utilize could continue utilizing UAS on a yearly basis. With multiple high quality datapoints, greater findings could be acquired across Bird Shoal or even then entire RCER. I'd recommend consistently acquiring data at both mean high water line and mean low water line. Finally, this future data could be shared routinely shared with the town of Beaufort, NC in order to manage for the future of Beaufort's waterfront and Taylor Creek's development. It will be interesting to see the future affects of the shrinking embayment.

Conclusion:

This study provides an example of high quality data sampled by UAS merged with historic data to discover the change in the environment. Previous datasets within Bird Shoal provided baseline figures for shoreline, land cover, the area of the embayment, and populations of oysters. The results concluded that the embayment has been shifting inward and decreasing in size over the past 30 years. The area is not being repopulated with dredge spoils, so the sand is drifting alongshore to other parts of the reserve. Population and density of oyster reefs has increased across the embayment with likely causes due to stability in the northern section of the embayment and the more than 30 year ban on shellfish harvesting in the area. The embayment should be continually studied to track the changes to Bird Shoal and how it will affect Beaufort and Pivers Island.

Acknowledgements:

I would like to thank Jonathan Kool, Sean Ramach, and Dr. William Kirby-Smith for all the work they accomplished in previous studies in the Bird Shoal Embayment. I appreciate the Johnston Lab for providing high quality drone data and Paula Gillikin from the North Carolina Department of Environmental Quality for providing maps that were decades old. Finally, none of this would have been possible without the patience and guidance from Dr. Dan Rittschof. I would not have finished this program without his support.

References:

1) National Oceanic and Atmospheric Administration (2009) North Carolina National Estuarine Research Reserve Management Plan 2009-2014. Retrieved July 2019 from https://coast.noaa.gov/data/docs/nerrs/Reserves_NOC_MgmtPlan.pdf
2) Kool, Jonathan (1999) A Baseline Assessment of Selected Biological Species and Physical Environmental Factors in the Rachel Carson Estuarine Research Reserve. Duke University Nicholas School of the Environment
3) Ramach, Sean (2001) A 3D Spatial Ecology Study of Blue Crabs, *Callinectes sapidus*, in a High Salinity Embayment. Duke University Nicholas School of the Environment
4) Stutz, Mathew and Pilkey, Orrin (2011) Open-Ocean Barrier Islands: Global Influence of Climatic, Oceanographic, and Depositional Settings. Journal of Coastal Research: Volume 27, Issue 2: pp. 207-222.
5) Kopp RE, Horton BP, Kemp AC, Tebaldi C (2015) Past and future sea-level rise along the coast of North Carolina, USA. Clim Chang 132(4):693–707. https://doi.org/10.1007/s10584-015-1451-x
6) Egitto, Daniel (2017) Marine Lab researchers use drones to study nearby at-risk island. Retrieved June 2019 from https://www.dukechronicle.com/article/2017/09/marine-lab-researchers-use-drones-to-study-nearby-at-risk-island
7) Bland, Sam (2012) The Rachel Carson Reserve. Retrieved May 2019 from https://www.dukechronicle.com/article/2017/09/marine-lab-researchers-use-drones-to-study-nearby-at-risk-island
8) Starkey, Jackie (2016) Beaufort remains concerned about erosion. Retrieved May 2019 from http://www.carolinacoastonline.com/news_times/article_0d5d7cfe-359d-11e6-a745-a72957833584.html
9) Lorio, Wendell and Malone, Sandra (1994) The Cultivation of American Oysters (*Crassostrea virginica*). Southern Regional Aquaculture Center No. 432. October 1994
10) Beck, M.W., R.D. Brumbaugh, L. Airoldi, A. Carranza, L.D. Coen, C. Crawford, O. Defeo, G.J. Edgar, B. Hancock, M.C. Kay, H.S. Lenihan, M.W. Luckenback, C.L. Toropova, and G.

Zhang. (2009) Shellfish Reefs at Risk: a global analysis of problems and solutions. The Nature Conservancy, Arlington VA.

11) Powers, Sean, C. Peterson, J. Grabowski, H. Lenihan. (2009) Success of contrusctructed oyster reefs in no-harvest sanctuaries: implications for restroration. Marine Ecology Progress Series Vol 389: 159-179, 2009. doi: 10.3354/meps08164
12) Cleary, William and Marden, Tara (1999) Shifting Shorelines: A Pictorial Atlas of North Carolina Inlets. North Carolina Sea Grant. NC State University.
13) Roegner, Curtis and Mann, Roger (1995) Early recruitment and growth of the American oyster *Crassostrea virginica* (Bivalvia: Ostreidae) with respect to tidal zonation and season. Marine Ecology Progress Series Vol. 117: 91-101, February 9, 1995.
14) Bartol, Ian, R. Mann, M. Luckenbach (1998) Growth and mortality of oysters (*Crassostrea virginica*) on constructed intertidal reefs: effects of tidal height and substrate level. Journal of Experimental Marine Biology and Ecology Vol 237: 157-184
15)