North Carolina Bird Islands and Sanctuaries for the Future

by

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Masters project proposal submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of Duke University

I certify the following:

1. Does this proposed MP involve human subjects research? ___ Yes __X__No

    a. If yes, has an approved IRB protocol been obtained? ___ Yes __X__No

2. Does this proposed MP involve the use of animals in research? ___ Yes __X__No

    a. If yes, has an approved IACUC protocol been obtained? ___ Yes __X__No

3. Does this proposed MP involve signing a non-disclosure agreement? __Yes _X_No

    a. If yes, does the advisor have a signed copy? ___ Yes _X_No

Executive Summary

The Pine Island Sanctuary freshwater marsh has been eroding by 0.23 meters per year and from 2003-2016 has lost approximately 8 acres of marsh. The marsh, currently totaling 2,600 acres, is losing on average 0.8 acres/year, which translates into $1,815.54/yr of marsh property value loss, or $1,892.38/year including lost ecosystem services in 2018 dollars. I quantified lost ecosystem services including carbon sequestration, nitrogen mitigation, and the recreational value of duck hunting, calculating lost ecosystem service values using a transferred benefit model. The values used were derived from studies based on similar marsh conditions. For the area calculations, I used orthophotos and two geographic information system software extensions. Digital Shoreline Analysis System, DSAS, uses digitized shorelines over a period of time to calculate shoreline change statistics. The DSAS calculations served as a benchmark to compare to unsupervised iso-clustering calculations, which allowed me to determine an average rate of shoreline change throughout the marsh. The average difference between the two methods was 3cm/year and the max difference was 7cm/year. Looking ahead, marsh sills, living shorelines, and rip raps are some examples of erosion control that could be used to mitigate Pine Island's erosion. If the cost of the erosion control measure is less than the current rate of erosion costs on a yearly basis, the Audubon Society should undergo the project.

Introduction

The National Audubon Society is nationally known as a non-profit environmental conservation organization for birds. The society was named after John James Audubon and founded in 1886 by George Bird Grinnell (Zimmer 2017). T. Gilbert Pearson founded the North

Carolina Audubon Society in 1902 and currently has ten chapters that range from the Scaly Mountain in the west all the way to Cape Fear (Pine Island Audubon Center 2017). Today, Audubon Society of NC manages 20 plus sanctuaries on the coast of North Carolina (Pine Island Audubon Center 2017). These sanctuaries support over a third of the state's coastal bird population. With rapid human development, agriculture variation, sea level rise, upstream alterations, and climate variation, these sanctuaries are in danger of being degraded past the state of repair.

Pine Island Sanctuary is located on the outer banks of North Carolina, north of Duck and south of Corolla. Pine Island Sanctuary has a multitude of marsh islands ranging in size and contains maritime evergreen forests, maritime shrub, and tidal freshwater marsh. For a satellite image of Pine Island Sanctuary, consult Appendix B. Common facultative anaerobic and aerobic vegetation species in Pine Island include Live oak, Loblolly pine, Red Bay, Red Maple, and Swamp Black Gum. There are also facultative and obligate anaerobes including needle rush and Spartina alternaflora all throughout the marsh. A site survey report conducted by Mike Schalafe indicated that the site is "outstanding" and further mentions rare species including: Limosella australis, Papilio Cresphontes (swallow tail butterfly), and beach heather.

When individuals recognized the recreational value associated with Pine Island, many private hunting clubs were established, but over the years, downsizing has occurred as an apparent result of lower bird numbers. The exact reason why bird numbers are lower is still of considerable debate, but variables such as sea level rise, loss of marsh, hunting regulations, and land management practices are always in the discussion. The Audubon Society must prepare to decide whether to invest in their coastal sanctuaries or allocate resources elsewhere. The results of this project will provide clarity on the current and near future status of their freshwater marsh.

Objective

The Audubon Society writes grants to obtain funding to maintain, protect and mitigate high priority areas to strive for their organization's mission. Convincing investors to contribute to their mission is difficult and providing quantified change in the marsh will be useful for the Audubon Society. Pine Island Sanctuary is home to many migratory birds, rare species and healthy marsh, but what exactly do these species contribute in terms of economic value? This is the purpose of this project, to research literature, perform geospatial analysis, and quantify the ecosystem valuation of the marsh for the Audubon Society. The Audubon Society can then use this information to make a decision on how best to preserve their marsh.

Shoreline Mapping Method Decision

To determine the economic value of marsh in the Pine Island Sanctuary, I will approximate the current land, how it has changed, and ascribe a dollar value to it. Methods such as basic digitization and complicated photogrammetric algorithms are helpful in quantifying land change. By following a series of steps illustrated in Laura J. Moore's paper "Shoreline Mapping Techniques," I narrowed down my project methodology.

Digital Shoreline Analysis System (DSAS)

The Digital Shoreline Analysis System is a geospatial analysis technique that computes statistical rates of change from user-digitized shorelines. The major factors for choosing this method were the current resources at my disposal, time, and cost. Other methods of calculating shoreline change such as point measurements, stereo zoom transfer scope, softcopy photogrammetry, and orthogonal grid mapping were not considered because of cost. I will also use an unsupervised iso-cluster classification method to quantify the marsh area. These two methods provide a range of estimates on the true rate of change in the marsh.

Data

To determine marsh change, I collected Currituck county images in 1993, 2003, 2008, 2010, 2012, and 2016 via nconemap.com. Nconemap is a North Carolina public service website that provides geospatial data for free. All the criteria for current and future orthophotos include the resolution, flight altitude, photo overlap, projection, cameras, and age (Business Plan for Orthoimagery, 2010). Every parameter for recognized state orthoimagery can be found in the *North Carolina Technical Specifications for Digital Orthophoto Base Mapping* as issued by the Land Records Management Division under the North Carolina Department of the Secretary of State. The major benefit of this data is the standardized geometric corrections.
I discarded the 1993 orthophoto due to its lack of resolution and number of raster bands. This reduced the time frame that shoreline comparisons were made from 1993-2016 to 2003-2016.

Potential Problems

Orthophotos are beneficial in shoreline change analysis because they are accessible, well documented, and cost effective; they are also commonly used in the GIS field as a common data input. This being the case, shoreline and area change estimates will have inherit error as the data is not 100% accurate. Other potential errors imbedded in the data include the photo timing, water levels, and wind.

The metadata for the orthophotos revealed that the pictures were taken in January of each year except for the 2008 orthophoto that was taken May 30th. Even though the vegetation presented different characteristics than the other photos, I used 2008 photo because of its reliable ortho-rectification.

Methodology

The selected shorelines were chosen for their location and low sinuosity. Six sample shorelines were chosen in three different locations ranging east to west across the sound (Appendix A). The shores were also analyzed on the north, east, south, and west sides of the marsh islands to assess the different ranges of shoreline change throughout the marsh. To determine the accuracy of an unsupervised iso-clustering quantification of Pine Island, I compared the results with six samples using DSAS as a reference on the true rate of change.

DSAS requires a series of steps that includes digitizing the shorelines, creating a reference baseline, and casting the transects to derive the intersection points for time analysis. I created a baseline to cast transects to calculate rates of change from the shorelines by defining an onshore parallel baseline. Figure 1 shows a baseline, transects, and the composite shoreline feature layer for a sample shoreline. The baseline is purple, transects navy blue, and the shorelines are colored red - dark green from oldest to most recent.

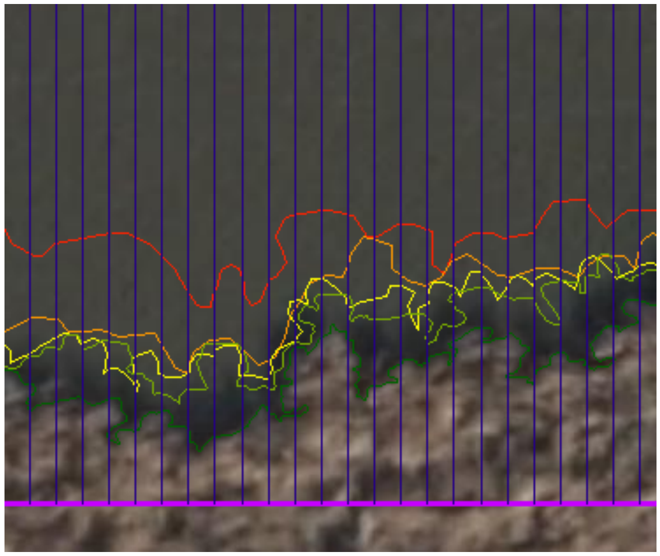

Figure 1. Composite DSAS file illustration to show geospatial statistically derived results.

After specifying that the shoreline uncertainty as .457 meters, which is the horizontal accuracy in the orthophoto metadata, and identifying which statistics to calculate, DSAS returned an output. An example output of DSAS is shown below in table 1.

Table 1. DSAS calculated the end point rate (EPR), shoreline change envelope (SCE), net shoreline movement (NSM), linear regression rate (LRR), and LCI95 which is the lower end of the 95% confidence interval.

TransectId	EPR	SCE	NSM	LRR	LCI95
1	-0.27	3.47	-3.47	-0.26	0.207
2	-0.22	2.83	-2.83	-0.21	0.18
3	-0.23	2.99	-2.99	-0.22	0.134
4	-0.23	3.04	-3.04	-0.22	0.17
5	-0.09	1.33	-1.19	-0.1	0.126

The linear rate of regression, LRR, is determined by fitting a line between all shoreline points for each transect. The end point rate, EPR, represents the rate between the oldest and most recent shoreline by dividing the distance over time. The linear regression 95, LCI95, is the distance that the confidence interval spans from the LRR number. Shoreline change envelope, SCE, is the distance between the closest and furthest shorelines intersecting a particular transect, not necessarily the oldest and most recent shoreline data points. The net shoreline movement, NSM, represents the movement of a shoreline back and forth from a baseline.

After gathering the six samples, I ran the unsupervised technique on the same sites with the property extent of the DSAS transects. I specified 10 output classes to create new relative means to be reclassified between water and marsh. Running the unsupervised tool generated a random color scheme with multiple classes (Figure 2).

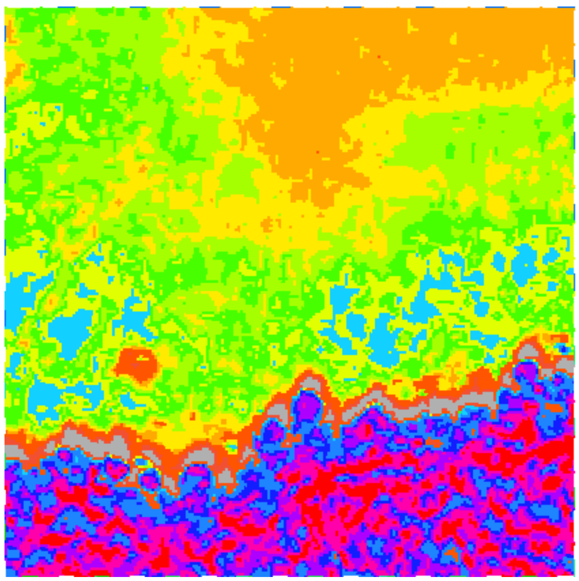

Figure 2. Unsupervised iso-clustering of a 2008 raster sample shoreline.

The output of the unsupervised iso-clustering was then reclassified to distinguish between marsh and water. Raster data, such as the orthophotos in use, have thousands of cells layered by rows and columns. Each cell has a defined length and width. With the known cell sizes, the difference in cells identified as marsh between any time period, and the appropriate geometry of each sample, I determined the respective shoreline change. Figure 3 is a simple example of a raster dataset and a zoomed in layer illustrating the fine scale extent of the cells. Appendix B contains a comprehensive list of statistics generated from both DSAS and unsupervised iso-clustering.

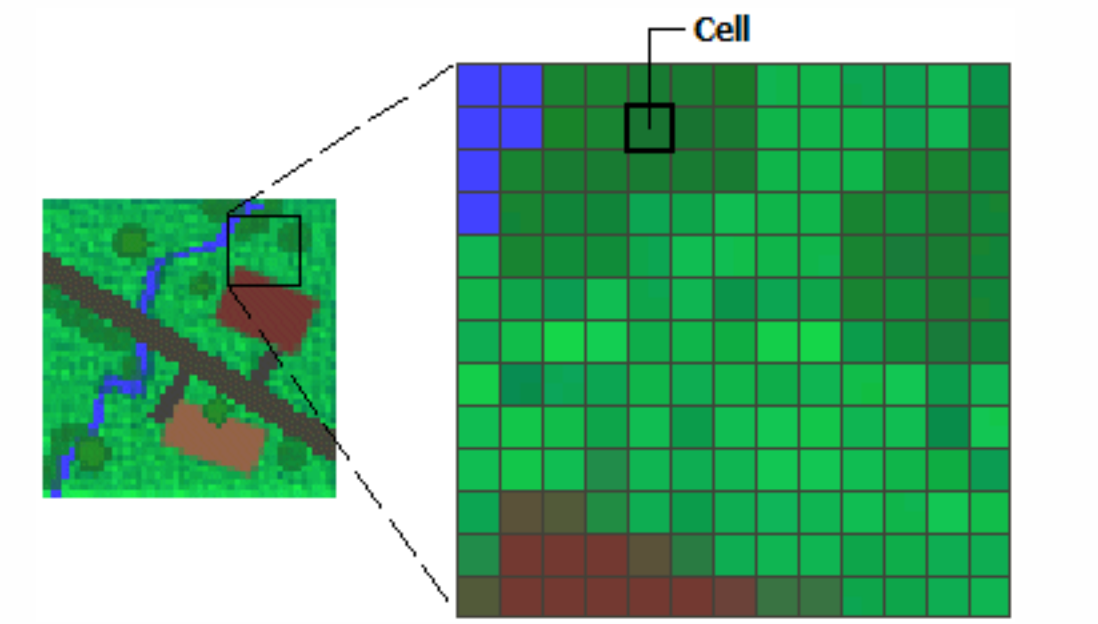

Figure 3. A simple raster dataset illustration demonstrating that cells make up the photo. Knowing the cell size is important for calculating area change in a given sample area.

Economic Valuation of Marsh

Pine Island's marsh provides benefits to society and the environment in the form of flood protection, erosion control, wildlife habitat, fisheries, water purification, recreation, carbon sequestration, and nitrogen mitigation. The value of the land itself is hedonic, meaning we can determine the market value of the land with market prices. The largest issue though in determining ecosystem services is the lack of site-specific data and a consistent methodology. These challenges were addressed by the use of a transferred benefit model were I ascribed shadow prices to the ecosystem services to appraise the land. Given the scope of this project, I analyzed three marsh services: duck hunting recreational value, carbon sequestration, and nitrogen mitigation. Also, given the lack of data, assumptions had to be made to help quantify the ecosystem services, as explained throughout the following sections.

Carbon Sequestration

Mature marshes, such as Pine Island, accumulate significant amounts of carbon and act as carbon sinks. The extent that a marsh can process carbon and other nutrients is a factor of marsh age, salinity, hydrologic drivers, soil drainage, and redox potential. Given Pine Island marsh conditions, I researched carbon sequestration estimates from similar marshes around the world (Chmura et al. 2003, Narron et al. 2018, Radabaugh et al. 2017, Macreadie et al. 2017). The approximate carbon accumulation used for my samples site is 210 g CO_2 m^{-2} yr^{-1}.

The Chicago Climate Exchange priced carbon by the ton at $7.40; over the years though, the market priced CO_2 to a nickel and the Chicago Climate Exchange eventually crashed. Though there is no current stock trading for CO_2, it costs utilities and other manufactures to mitigate its emission. Synapse, Energy Economics Inc, released a report on March 3, 2015 and revealed a range of prices that CO_2 could cost per ton. The low end was $15/ton and the high end was $25/ton (Luckow et al. 2015).

Making the assumption that the sequestration rate is constant over the span of a year, Pine Island would theoretically sequester 2,435 tons of carbon/year or .93 tons/acre/year. Since 2003, roughly 20 acres has been lost which equates to 18.6 tons of carbon, or $269 dollars' worth of carbon storage if we multiply by the average carbon price of $14.50.

Nitrogen

Marshes play a significant role in denitrification and Pine Island is no exception. Agrigcultural practices dominate the Currituck sound and the marshes help mitigate the nitrogen loading from these non point source pollution sources. The hydrology, soil type, nutrient loading rate, and landscape geology affect the removal of nitrogen (Faulkner and Richardson 1989; Reddy et al. 1999; Novak et al. 2004; Lowrance et al. 2006). Depending on the marsh age, salinity, hydrologic drivers, soil characteristics, water residence time, and redox potential nitrogen removal can be approximated to be between 10% and 30% (Belton 2013).

On average, natural fresh water contains approximately 1mg/l of nitrate (USACE 2011). The Currituck sound is approximately 153 square miles and has an average depth of 5ft. These assumptions correspond to 488,980.72 acre-feet of water (USACE 2013). Knowing Pine Island is 3% of the total Currituck sound marsh, Pine Island is responsible for 3% of the total nitrogen in the water1,755.54 kg of nitrogen if the nitrogen is evenly distributed throughout the sound. The shadow price for nitrogen mitigated is $25.27/kg N (2008), now $29.22 in 2018 (Ribaudo et al. 2005, Bureau of Labor Statistics 2018). 2600 acres of tidal marsh mitigates roughly 1,755.54 Kg N which comes out to be somewhere between $1.95-5.85/acre depending on the range of nitrogen mitigation [10-30%] (Appendix C).

Recreation – Duck Hunting

Pine Island was originally founded as a duck hunting club in the early 1900's and continues today be in limited capacity. The establishment holds permits to operate multiple hunting blinds throughout the marsh. They hold these blinds but mainly do not hunt to preserve space for migrating and native birds. With the marsh eroding, the capacity of this property to hold birds is diminishing.

The U.S. Forest Service carried out an analysis to monetize outdoor recreation values and found one day of duck hunting to be worth $55.99 (Rosenberger and Loomis 1996, Bureau of Labor Statistics 2018). Making the assumption that the amount of duck hunting days lies within the range of 100,000 – 400,000 given the amount of food supply the marsh provides, and a shadow price of $55.99, the overall change in cost of the land depends on the change in land and its corresponding effect on the amount on duck hunting days. After using Murray's methodology to calculate the service flow the ecosystem provides via duck hunting, the economic worth of duck hunting averaged out to be $39.96/acre (Tables 2 & 3).

Tables 2,3 Calculations to derive the average service flow Pine Island marsh contributes via duck hunting recreation using Murray et al. 2008 methodology.

Original Land Area	Change in Area	New Total Area	% Change Due to Erosion
2600	12	2588	-0.004615385

% Change Due to Erosion	Duck Hunter Days	Decrease in Duck Hunter Days	Total Change in Consumer Surplus	Consumer Surplus	Producer Surplus	Total $/Acre
-0.005	400,000.00	(1,846.15)	$(103,366.15)	$(39.94)	$15.00	$54.94
	300,000.00	(1,384.62)	$(77,524.62)	$(29.96)	$15.00	$44.96
	200,000.00	(923.08)	$(51,683.08)	$(19.97)	$15.00	$34.97
	100,000.00	(461.54)	$(25,841.54)	$(9.99)	$15.00	$24.99
				Average Waterfowl Service Flow		
				$		39.96

Results

The largest difference between the DSAS LRR calculation and unsupervised iso-clustering for any given sample was approximately 7cm/year at shore 5 (Table 4).

Table 4. Demonstrates the average change in the marsh shoreline/year for our 6 sample sites. The SCE statistic is represented as a positive number as it cannot be a negative distance.

Location	Mean NSM (2003-2016)	Mean SCE (2003-2016)	Mean LRR/year	ISO Change/year	Baseline Distance
Shore 1	-5.28	5.28	-0.40	-0.45	30.06
Shore 2	-3.11	3.23	-0.23	-0.29	99.18
Shore 3	-4.18	4.26	-0.31	-0.26	14.00
Shore 4	-1.93	2.10	-0.15	-0.17	27.00
Shore 5	-1.74	2.04	-0.14	-0.21	10.00
Shore 6	-2.11	2.23	-0.15	-0.19	28.00

The average LRR over the six sites is .23 meters/year. Assuming that the total land area of the Pine Island Sanctuary to be 2600 acres as of 2003, and the average shoreline change amongst our samples, approximately .7-.9 acres are lost a year (Appendix B). To gather a better understanding on the overall trend of the marsh, I ran confidence interval tests to determine whether the marsh is eroding or aggrading. For each transect, I ran a 95% confidence interval test to calculate the where range that the true rate of regression is.

Figure 4 below demonstrates that there is a 95% probability that for any given transect on shore 1 is eroding rather than aggrading. It is worth noting that the rate of change for a marsh shoreline is non-uniform and that different transects will typically experience differing rates of change. For this reason, the best bet at a well-rounded rate of change is the average of all the transects for a shoreline.

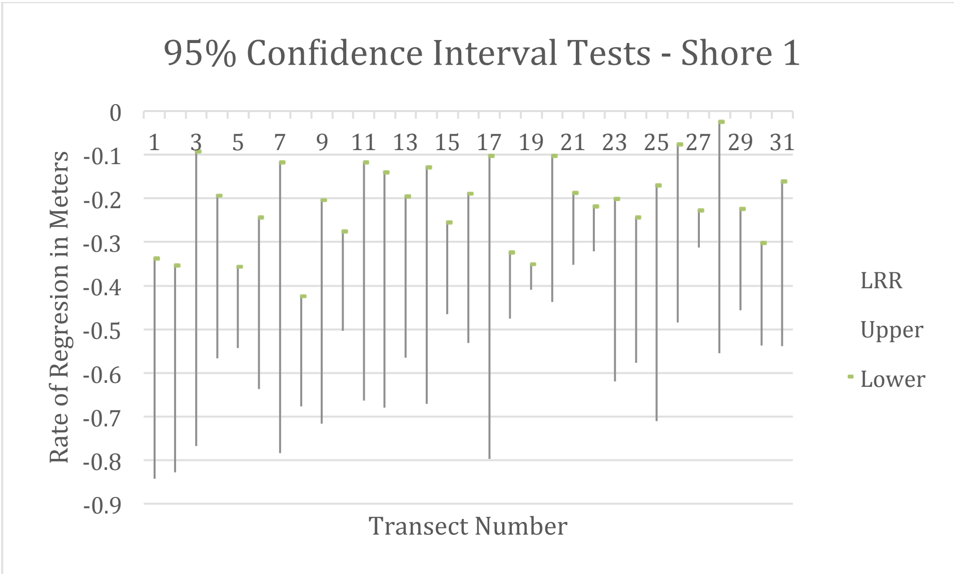

Figure 4. The upper and lower bounds where the true shoreline rate loss is given a 95% confidence interval for shore 1.

I also projected the change of Pine Island marsh area over 30 years from 2003 to 2033 using the current trends with the marsh. Using the sample averages, standard deviation and assuming a normal distribution, I derived random rates of change using Microsoft Excel's random number generator. With this new random shoreline change statistic and utilizing Monte Carlo analysis with 1000 iterations, I calculated the total area change over the year and the next 30 years. Table 4 shows these random shoreline change iterations over 30 years and projects that by 2033, the approximate Pine Island marsh will total 2,580 acres; a net change of approximately 20 acres from the 2003 total.

Table 4. This table shows the scenario of shoreline erosion spanning from 2003-2016 and how much land Pine Island has/will have given the current trends.

Year	Shoreline Change	New Total Area (sq meters)	Total Land Change
1	0.245	10,518,827.19	3,172.81
2	0.216	10,516,028.50	2,798.70
3	0.340	10,511,621.46	4,407.03
4	0.266	10,508,178.24	3,443.22
5	0.282	10,504,527.78	3,650.46
6	0.241	10,501,402.56	3,125.22
7	0.398	10,496,250.09	5,152.47
8	0.088	10,495,107.58	1,142.51
9	0.121	10,493,533.92	1,573.66
10	0.131	10,491,831.61	1,702.31
11	0.129	10,490,162.00	1,669.61
12	0.277	10,486,570.01	3,591.99
13	0.212	10,483,828.29	2,741.72
14	0.177	10,481,535.74	2,292.55
15	0.194	10,479,028.45	2,507.29
16	0.117	10,477,517.97	1,510.48
17	0.277	10,473,925.57	3,592.40
18	0.204	10,471,289.76	2,635.81
19	0.199	10,468,719.12	2,570.64
20	0.260	10,465,354.14	3,364.98
21	0.288	10,461,624.26	3,729.88
22	0.391	10,456,560.85	5,063.40
23	0.381	10,451,632.76	4,928.10
24	0.268	10,448,162.36	3,470.39
25	0.276	10,444,592.18	3,570.19
26	0.100	10,443,295.21	1,296.96
27	0.133	10,441,576.30	1,718.91
28	0.191	10,439,105.99	2,470.31
29	0.087	10,437,987.90	1,118.09
30	0.187	10,435,566.66	2,421.24
31	0.051	10,434,907.30	659.36
		New Total Area	10,434,907.30
		Overall Change (sq meters)	87,092.70
		Change in Acres	21.52

Economic Implications

The going market price for the Pine Island marsh is $5,900,500 (Currituck County, 2017). Using this current market price appraised by Currituck County, an acre of freshwater tidal marsh in the Currituck Sound is $2,269.42. If an average of .8 acres are being lost annually, Pine Island is losing $1,815.54 a year in land. When we add in the ecosystem services and calculate the net present value over 30 years, with a discount rate of 4%, 1% inflation in revenues and expenses, and a range of land appreciation between 5-10%, land lost would cost the Audubon Society $72,177.41 - $230,141.07.

Discussion

Pine Island marsh is losing roughly $1,872.73 worth of marsh a year after incorporating the ecosystem services. Potential solutions for back-bay marsh loss include both bulkheads and living shorelines. If the total cost of the restoration project does not exceed the net present value of the land loss on a yearly basis, then the restoration should be pursued. The only problem with this cost recognition is that there is no tangible revenue associated with the environmental solution, but rather ecosystem service maintenance. Until markets appear that foster the development of carbon and nitrogen mitigation, landowners cannot get paid for their ecosystems. Another option that the Audubon Society could pursue is leasing the land for hunting privileges.

To address this erosion issue, the Audubon Society should identify certain areas within their marsh that they deem necessary to repair. After doing this, they should calculate the rate of erosion associated with the area, the bank height, water depth within the area, and fetch length to help determine which method of erosion control is necessary. After determining the appropriate erosion mitigation measure, the costs should be analyzed and if there is a net benefit, the restoration should be done.

The assumed transferred benefit prices and averaged rates of erosion are the largest uncertainties in this study. The lack of time and resources also made it difficult to capture exact carbon sequestration and nitrogen fixation capabilities in the Pine Island marsh. In addition, using historical rates of change rather than modeled forecasting can be misleading for making decisions in the future as marshes are dynamically changing. However, this study provides insight on the current trend in the marsh and is useful for the short term.

Conclusion

The Audubon Society should continue monitoring the status of their assets and determine whether the marsh is worth preserving. Whether they choose to act on some restoration or prevention plan is up to management, but more valuations such as the one done here can help property managers make more informed decisions.

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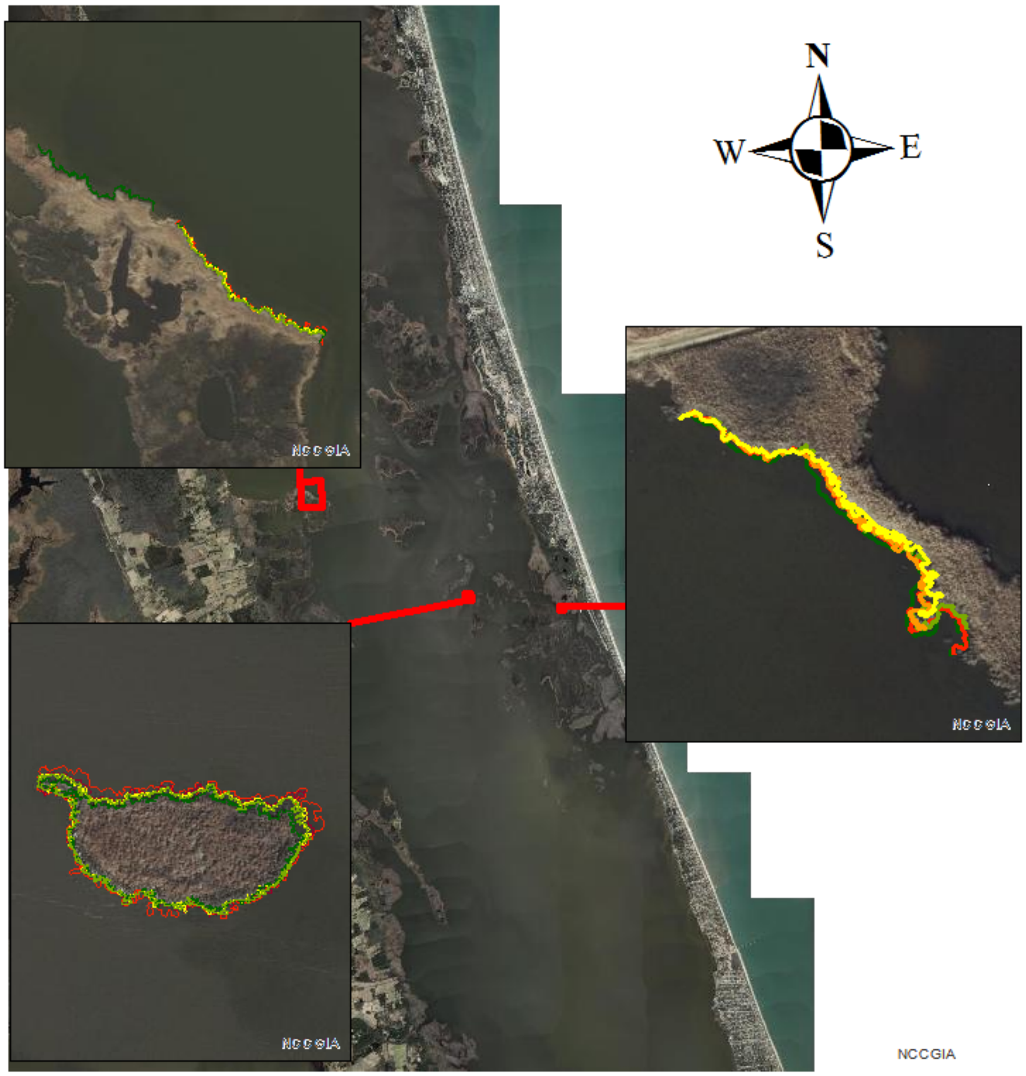
Appendix A

Pine Island Sanctuary - Corrola, NC

Created by Adrian McInnis
3/1/2018

Shore Locations in Pine Island Sanctuary



Created by Adrian McInnis
3/1/2018

Appendix B

The following tables are the calculations derived from using DSAS.

Shore 1											
OBJECTID	TransectId	TCD	EPR	ECI	SCE	NSM	LMS	LRR	LR2	LSE	LCI95
1	1	0	-0.62	0.001	8.1	-8.1	-0.56	-0.59	0.95	0.76	0.253
2	2	1	-0.59	0.001	7.75	-7.75	-0.45	-0.59	0.95	0.72	0.237
3	3	2	-0.42	0.001	5.52	-5.52	-0.19	-0.43	0.84	1.02	0.338
4	4	3	-0.38	0.001	4.91	-4.91	-0.38	-0.38	0.93	0.56	0.186
5	5	4	-0.46	0.001	5.97	-5.97	-0.4	-0.45	0.99	0.28	0.093
6	6	5	-0.46	0.001	6.03	-6.03	-0.33	-0.44	0.94	0.6	0.197
7	7	6	-0.48	0.001	6.24	-6.24	-0.45	-0.45	0.86	1.01	0.333
8	8	7	-0.56	0.001	7.32	-7.32	-0.47	-0.55	0.98	0.38	0.126
9	9	8	-0.45	0.001	5.82	-5.82	-0.58	-0.46	0.92	0.77	0.256
10	10	9	-0.4	0.001	5.22	-5.22	-0.4	-0.39	0.98	0.34	0.114
11	11	10	-0.42	0.001	5.52	-5.52	-0.23	-0.39	0.87	0.83	0.273
12	12	11	-0.44	0.001	5.78	-5.78	-0.44	-0.41	0.89	0.81	0.269
13	13	12	-0.38	0.001	4.91	-4.91	-0.25	-0.38	0.93	0.56	0.185
14	14	13	-0.39	0.001	5.07	-5.07	-0.3	-0.4	0.88	0.82	0.271
15	15	14	-0.37	0.001	4.82	-4.82	-0.36	-0.36	0.97	0.32	0.105
16	16	15	-0.36	0.001	4.7	-4.7	-0.36	-0.36	0.94	0.52	0.171
17	17	16	-0.43	0.001	5.63	-5.63	-0.43	-0.45	0.85	1.05	0.347
18	18	17	-0.4	0.001	5.22	-5.22	-0.45	-0.4	0.99	0.23	0.075
19	19	18	-0.38	0.001	5.01	-5.01	-0.38	-0.38	1	0.09	0.03
20	20	19	-0.27	0.001	3.53	-3.53	-0.34	-0.27	0.9	0.5	0.167
21	21	20	-0.27	0.001	3.57	-3.57	-0.23	-0.27	0.97	0.25	0.082
22	22	21	-0.28	0.001	3.67	-3.67	-0.25	-0.27	0.99	0.16	0.051
23	23	22	-0.43	0.001	5.57	-5.57	-0.29	-0.41	0.93	0.63	0.209
24	24	23	-0.44	0.001	5.75	-5.75	-0.45	-0.41	0.95	0.5	0.166
25	25	24	-0.47	0.001	6.17	-6.17	-0.3	-0.44	0.9	0.82	0.27
26	26	25	-0.3	0.001	3.93	-3.93	-0.31	-0.28	0.86	0.62	0.204
27	27	26	-0.26	0.001	3.44	-3.44	-0.27	-0.27	0.99	0.13	0.043
28	28	27	-0.3	0.001	3.94	-3.94	-0.35	-0.29	0.81	0.8	0.265
29	29	28	-0.32	0.001	4.22	-4.22	-0.32	-0.34	0.97	0.35	0.116
30	30	29	-0.42	0.001	5.52	-5.52	-0.42	-0.42	0.98	0.35	0.117
31	31	30	-0.38	0.001	4.92	-4.92	-0.34	-0.35	0.92	0.57	0.188

Shore 2											
OBJECTID	TransectId	TCD	EPR	ECI	SCE	NSM	LMS	LRR	LR2	LSE	LCI95
1	10	9	-0.23	0.05	2.96	-2.96	-0.18	-0.22	0.95	0.28	0.093
2	11	10	-0.15	0.05	1.94	-1.94	-0.07	-0.14	0.8	0.39	0.13
3	12	11	-0.15	0.05	1.97	-1.97	-0.16	-0.15	0.99	0.06	0.022
4	13	12	-0.14	0.05	1.77	-1.77	-0.14	-0.14	0.98	0.11	0.038
5	14	13	-0.2	0.05	2.61	-2.61	-0.16	-0.19	0.96	0.22	0.073
6	15	14	-0.16	0.05	2.07	-2.07	-0.16	-0.15	0.98	0.11	0.038
7	16	15	-0.13	0.05	1.64	-1.64	-0.09	-0.12	0.93	0.18	0.059
8	17	16	-0.17	0.05	2.23	-2.23	-0.16	-0.16	0.97	0.15	0.05
9	18	17	-0.28	0.05	3.71	-3.71	-0.16	-0.27	0.89	0.53	0.177
10	19	18	-0.24	0.05	3.19	-3.19	-0.19	-0.24	0.97	0.23	0.075
11	20	19	-0.32	0.05	4.18	-4.18	-0.11	-0.31	0.82	0.81	0.268
12	21	20	-0.43	0.05	5.64	-5.64	-0.47	-0.42	0.94	0.6	0.2
13	22	21	-0.26	0.05	3.42	-3.42	-0.25	-0.25	0.93	0.39	0.129
14	23	22	-0.19	0.05	2.53	-2.53	-0.18	-0.19	0.95	0.24	0.08
15	24	23	-0.16	0.05	2.13	-2.13	-0.16	-0.16	0.99	0.11	0.036
16	25	24	-0.1	0.05	1.36	-1.36	-0.11	-0.1	0.95	0.13	0.042
17	26	25	-0.14	0.05	1.84	-1.84	-0.14	-0.13	0.97	0.14	0.046
18	27	26	-0.05	0.05	0.75	-0.63	-0.09	-0.05	0.7	0.19	0.061
19	28	27	-0.26	0.05	3.36	-3.36	-0.05	-0.25	0.75	0.8	0.265
20	29	28	-0.22	0.05	2.9	-2.87	-0.23	-0.24	0.82	0.64	0.211
21	30	29	-0.28	0.05	3.72	-3.72	-0.07	-0.26	0.67	1.01	0.335
22	31	30	-0.31	0.05	4.09	-4.09	-0.02	-0.28	0.6	1.26	0.418
23	32	31	-0.49	0.05	6.38	-6.38	-0.21	-0.45	0.8	1.26	0.418
24	33	32	-0.07	0.05	1.37	-0.97	-0.07	-0.05	0.18	0.63	0.208
25	34	33	-0.09	0.05	1.22	-1.22	-0.09	-0.09	0.82	0.22	0.074
26	35	34	-0.14	0.05	1.85	-1.85	-0.05	-0.14	0.75	0.45	0.148
27	36	35	-0.3	0.05	3.98	-3.98	-0.16	-0.29	0.88	0.59	0.196
28	37	36	-0.37	0.05	4.8	-4.8	-0.14	-0.35	0.84	0.87	0.287
29	38	37	-0.23	0.05	3.2	-2.98	-0.05	-0.23	0.67	0.89	0.294
30	39	38	-0.1	0.05	1.27	-1.27	-0.11	-0.1	0.92	0.15	0.051
31	40	39	-0.27	0.05	3.57	-3.57	-0.03	-0.25	0.71	0.89	0.295
32	41	40	-0.3	0.05	3.86	-3.86	-0.05	-0.29	0.72	1	0.331

33	42	41	-0.24	0.05	3.2	-3.2	-0.25	-0.25	0.97	0.24	0.081
34	43	42	-0.25	0.05	3.3	-3.3	-0.25	-0.21	0.59	0.96	0.319
35	44	43	-0.17	0.05	2.26	-2.26	-0.16	-0.18	0.96	0.19	0.063
36	45	44	-0.15	0.05	1.97	-1.97	-0.16	-0.15	0.82	0.38	0.127
37	46	45	-0.18	0.05	2.34	-2.34	-0.18	-0.17	0.73	0.58	0.193
38	47	46	-0.11	0.05	1.46	-1.46	-0.11	-0.11	0.93	0.16	0.053
39	48	47	-0.15	0.05	1.94	-1.94	-0.16	-0.14	0.9	0.26	0.087
40	49	48	-0.11	0.05	1.43	-1.43	-0.03	-0.1	0.67	0.41	0.135
41	50	49	-0.09	0.05	1.57	-1.13	0.03	-0.07	0.3	0.63	0.21
42	51	50	-0.19	0.05	2.48	-2.48	-0.16	-0.19	0.99	0.11	0.036
43	52	51	-0.15	0.05	2	-2	-0.07	-0.14	0.82	0.37	0.123
44	53	52	-0.08	0.05	1.06	-1.06	0	-0.07	0.54	0.35	0.115
45	54	53	-0.09	0.05	1.23	-1.23	-0.09	-0.09	0.87	0.18	0.059
46	55	54	-0.25	0.05	3.26	-3.26	-0.25	-0.26	0.84	0.61	0.203
47	56	55	-0.25	0.05	3.27	-3.27	-0.25	-0.26	0.88	0.54	0.18
48	57	56	-0.23	0.05	3	-3	-0.23	-0.22	0.95	0.28	0.094
49	58	57	-0.39	0.05	5.08	-5.08	-0.35	-0.38	0.96	0.45	0.15
50	59	58	-0.29	0.05	3.74	-3.74	-0.38	-0.29	0.89	0.57	0.187
51	60	59	-0.35	0.05	4.61	-4.61	-0.14	-0.35	0.82	0.9	0.299
52	61	60	-0.08	0.05	1.11	-1.11	-0.09	-0.09	0.97	0.09	0.031
53	62	61	-0.08	0.05	1.12	-0.99	-0.07	-0.08	0.7	0.28	0.092
54	63	62	-0.09	0.05	1.2	-1.2	-0.09	-0.09	0.97	0.09	0.03
55	64	63	-0.11	0.05	1.49	-1.49	-0.09	-0.12	0.96	0.13	0.044
56	65	64	-0.16	0.05	2.04	-2.04	-0.11	-0.15	0.95	0.2	0.065
57	66	65	-0.16	0.05	2.09	-2.09	-0.09	-0.15	0.86	0.33	0.108
58	67	66	-0.14	0.05	1.85	-1.85	-0.14	-0.15	0.97	0.14	0.045
59	68	67	-0.17	0.05	2.24	-2.24	-0.18	-0.16	0.91	0.28	0.091
60	69	68	-0.21	0.05	2.73	-2.73	-0.02	-0.18	0.6	0.84	0.277
61	70	69	-0.02	0.05	0.69	-0.24	-0.05	-0.02	0.09	0.3	0.098
62	71	70	-0.34	0.05	4.45	-4.45	-0.07	-0.34	0.72	1.16	0.385
63	72	71	-0.4	0.05	5.19	-5.19	-0.4	-0.37	0.74	1.23	0.407
64	73	72	-0.38	0.05	4.95	-4.95	-0.38	-0.38	0.97	0.34	0.114
65	74	73	-0.33	0.05	4.38	-4.38	-0.27	-0.33	0.96	0.37	0.124
66	75	74	-0.57	0.05	7.39	-7.39	-0.55	-0.6	0.86	1.32	0.438
67	76	75	-0.59	0.05	7.73	-7.73	-0.14	-0.54	0.66	2.15	0.713
68	77	76	-0.38	0.05	4.98	-4.98	-0.16	-0.35	0.79	1.01	0.333
69	78	77	-0.21	0.05	2.73	-2.73	-0.09	-0.19	0.77	0.57	0.19
70	79	78	-0.13	0.05	1.65	-1.65	-0.18	-0.13	0.92	0.22	0.073
71	80	79	-0.06	0.05	1.01	-0.81	-0.12	-0.07	0.67	0.25	0.084
72	81	80	-0.09	0.05	1.18	-1.18	-0.09	-0.09	0.97	0.08	0.027
73	82	81	-0.11	0.05	7.85	-1.41	-0.11	-0.22	0.1	3.55	1.175
74	83	82	-0.53	0.05	7.81	-6.94	-0.53	-0.63	0.62	2.74	0.907

75	84	83	-0.52	0.05	6.8	-6.8	-0.53	-0.58	0.76	1.81	0.599
76	85	84	-0.44	0.05	5.7	-5.7	-0.14	-0.39	0.72	1.36	0.452
77	86	85	-0.31	0.05	4.08	-4.08	-0.11	-0.28	0.75	0.91	0.301
78	87	86	-0.29	0.05	3.83	-3.83	-0.45	-0.29	0.82	0.73	0.242
79	88	87	-0.15	0.05	2.02	-2.02	-0.03	-0.14	0.69	0.52	0.172
80	89	88	-0.14	0.05	1.82	-1.82	-0.14	-0.14	0.99	0.06	0.018
81	90	89	-0.21	0.05	2.8	-2.8	-0.21	-0.21	0.96	0.24	0.079
82	91	90	-0.09	0.05	1.78	-1.14	-0.21	-0.08	0.36	0.61	0.201
83	92	91	-0.16	0.05	2.14	-2.14	-0.05	-0.15	0.73	0.51	0.17
84	93	92	-0.65	0.05	8.55	-8.55	-0.65	-0.64	0.93	0.96	0.319
85	94	93	-0.38	0.05	5.01	-5.01	-0.23	-0.37	0.88	0.77	0.254
86	95	94	-0.37	0.05	4.79	-4.79	-0.16	-0.34	0.79	0.95	0.314
87	96	95	-0.33	0.05	4.29	-4.29	-0.33	-0.35	0.84	0.85	0.281
88	97	96	-0.38	0.05	4.98	-4.98	-0.38	-0.42	0.79	1.2	0.397
89	98	97	-0.43	0.05	5.68	-5.68	-0.44	-0.43	0.8	1.19	0.393
90	99	98	-0.44	0.05	5.87	-5.79	-0.05	-0.4	0.57	1.91	0.633
91	100	99	-0.36	0.05	4.81	-4.67	0.02	-0.31	0.58	1.48	0.49

Shore 3											
OBJECTID	TransectId	TCD	EPR	ECI	SCE	NSM	LMS	LRR	LR2	LSE	LCI95
1	1	0	-0.35	0.05	4.56	-4.56	-0.14	-0.33	0.84	0.79	0.263
2	2	1	-0.35	0.05	4.52	-4.52	-0.34	-0.34	0.99	0.2	0.065
3	3	2	-0.33	0.05	4.35	-4.35	-0.32	-0.32	0.96	0.36	0.119
4	4	3	-0.18	0.05	2.72	-2.4	0.04	-0.14	0.38	1.01	0.334
5	5	4	-0.52	0.05	6.82	-6.82	-0.53	-0.54	0.95	0.69	0.229
6	6	5	-0.51	0.05	6.68	-6.68	-0.51	-0.54	0.94	0.77	0.254
7	7	6	-0.44	0.05	5.76	-5.76	-0.44	-0.47	0.93	0.74	0.244
8	8	7	-0.29	0.05	3.81	-3.81	-0.27	-0.27	0.95	0.34	0.112
9	9	8	-0.22	0.05	2.84	-2.84	-0.21	-0.21	0.98	0.19	0.062
10	10	9	-0.13	0.05	1.86	-1.69	0.02	-0.11	0.47	0.65	0.215
11	11	10	-0.14	0.05	2.44	-1.77	-0.07	-0.11	0.33	0.9	0.298
12	12	11	-0.25	0.05	3.28	-3.26	0	-0.24	0.7	0.85	0.282
13	13	12	-0.4	0.05	5.26	-5.26	-0.4	-0.41	0.94	0.59	0.195
14	14	13	-0.37	0.05	4.78	-4.78	-0.29	-0.35	0.96	0.41	0.135

Shore 4											
OBJECTID	TransectId	TCD	EPR	ECI	SCE	NSM	LMS	LRR	LR2	LSE	LCI95
1	1	0	-0.27	0.05	3.47	-3.47	-0.27	-0.26	0.84	0.63	0.207
2	2	1	-0.22	0.05	2.83	-2.83	-0.21	-0.21	0.82	0.54	0.18
3	3	2	-0.23	0.05	2.99	-2.99	-0.16	-0.22	0.9	0.41	0.134
4	4	3	-0.23	0.05	3.04	-3.04	-0.23	-0.22	0.85	0.51	0.17
5	5	4	-0.09	0.05	1.33	-1.19	-0.09	-0.1	0.69	0.38	0.126
6	6	5	-0.18	0.05	2.32	-2.32	-0.18	-0.19	0.96	0.2	0.066
7	7	6	-0.17	0.05	2.19	-2.19	-0.16	-0.16	0.9	0.29	0.097
8	8	7	-0.13	0.05	1.71	-1.71	-0.12	-0.13	0.97	0.11	0.038
9	9	8	-0.18	0.05	2.32	-2.32	-0.25	-0.19	0.91	0.33	0.109
10	10	9	-0.07	0.05	0.91	-0.91	-0.09	-0.07	0.88	0.16	0.051
11	11	10	-0.1	0.05	1.35	-1.35	-0.11	-0.1	0.96	0.12	0.04
12	12	11	-0.16	0.05	2.04	-2.04	-0.16	-0.16	0.95	0.2	0.068
13	13	12	-0.15	0.05	2.02	-2.02	-0.21	-0.16	0.91	0.28	0.092
14	14	13	-0.09	0.05	1.12	-1.12	-0.09	-0.09	0.83	0.22	0.071
15	15	14	-0.12	0.05	1.65	-1.52	-0.18	-0.12	0.78	0.35	0.117
16	16	15	-0.24	0.05	3.12	-3.12	-0.16	-0.23	0.95	0.31	0.104
17	17	16	-0.24	0.05	3.92	-3.14	-0.25	-0.25	0.63	1.07	0.354
18	18	17	-0.16	0.05	2.05	-2.05	-0.16	-0.16	0.92	0.25	0.084
19	19	18	-0.14	0.05	1.8	-1.8	-0.21	-0.14	0.88	0.3	0.099
20	20	19	-0.13	0.05	1.66	-1.66	-0.12	-0.13	0.99	0.07	0.023
21	21	20	-0.22	0.05	2.85	-2.85	-0.21	-0.23	0.85	0.54	0.179
22	22	21	-0.24	0.05	3.41	-3.19	-0.39	-0.28	0.8	0.78	0.259
23	23	22	-0.1	0.05	1.44	-1.35	-0.11	-0.12	0.73	0.42	0.139
24	24	23	-0.11	0.05	1.58	-1.49	-0.12	-0.12	0.74	0.4	0.133
25	25	24	-0.18	0.05	2.3	-2.3	-0.18	-0.18	0.97	0.19	0.062
26	26	25	-0.08	0.05	1.1	-1.1	-0.09	-0.08	0.64	0.35	0.115
27	27	26	-0.01	0.05	0.58	-0.13	-0.07	-0.02	0.11	0.25	0.081
28	28	27	0.09	0.05	1.66	1.19	-0.07	0.08	0.35	0.63	0.209

Shore 5											
OBJECTID	TransectId	TCD	EPR	ECI	SCE	NSM	LMS	LRR	LR2	LSE	LCI95
1	1	0	-0.03	0.05	0.68	-0.45	-0.03	-0.05	0.46	0.27	0.09
2	2	1	-0.09	0.05	2.47	-1.12	-0.27	-0.08	0.2	0.94	0.31
3	3	2	-0.27	0.05	3.79	-3.52	-0.42	-0.28	0.77	0.86	0.284
4	4	3	-0.21	0.05	3.36	-2.74	-0.37	-0.24	0.77	0.73	0.243
5	5	4	-0.12	0.05	1.81	-1.56	-0.19	-0.13	0.73	0.43	0.141
6	6	5	-0.1	0.05	1.56	-1.36	-0.18	-0.12	0.82	0.31	0.102
7	7	6	-0.11	0.05	1.58	-1.48	-0.11	-0.13	0.87	0.27	0.088
8	8	7	-0.14	0.05	1.83	-1.83	-0.18	-0.14	0.93	0.21	0.07
9	9	8	-0.16	0.05	2.1	-2.1	-0.21	-0.17	0.92	0.29	0.095
10	10	9	-0.09	0.05	1.24	-1.24	-0.09	-0.09	0.97	0.1	0.032

Shore 6											
OBJECTID	TransectId	TCD	EPR	ECI	SCE	NSM	LMS	LRR	LR2	LSE	LCI95
1	1	0	-0.32	0.05	4.2	-4.2	-0.21	-0.31	0.92	0.49	0.163
2	2	1	-0.24	0.05	3.14	-3.14	-0.12	-0.24	0.9	0.46	0.15
3	3	2	-0.27	0.05	3.55	-3.55	-0.27	-0.25	0.93	0.39	0.129
4	4	3	-0.22	0.05	2.9	-2.9	-0.18	-0.21	0.97	0.2	0.066
5	5	4	-0.24	0.05	3.17	-3.17	-0.25	-0.23	0.96	0.26	0.086
6	6	5	-0.17	0.05	2.17	-2.17	-0.16	-0.16	0.95	0.19	0.064
7	7	6	-0.13	0.05	1.67	-1.67	-0.12	-0.12	0.66	0.46	0.153
8	8	7	-0.22	0.05	2.82	-2.82	-0.21	-0.2	0.95	0.27	0.089
9	9	8	-0.13	0.05	1.67	-1.67	-0.09	-0.12	0.92	0.2	0.065
10	10	9	-0.09	0.05	1.24	-1.24	-0.07	-0.09	0.95	0.12	0.039
11	11	10	-0.22	0.05	2.85	-2.85	-0.03	-0.19	0.64	0.79	0.26
12	12	11	-0.19	0.05	2.53	-2.53	-0.21	-0.19	0.92	0.3	0.098
13	13	12	-0.05	0.05	0.75	-0.61	0	-0.04	0.45	0.26	0.084
14	14	13	-0.06	0.05	1.99	-0.82	-0.1	-0.08	0.21	0.82	0.269
15	15	14	-0.21	0.05	2.77	-2.77	-0.21	-0.2	0.93	0.3	0.1
16	16	15	-0.12	0.05	1.68	-1.56	-0.19	-0.13	0.72	0.43	0.143
17	17	16	-0.23	0.05	2.98	-2.98	-0.21	-0.21	0.9	0.39	0.129
18	18	17	-0.14	0.05	1.81	-1.81	-0.11	-0.14	0.96	0.16	0.054
19	19	18	-0.25	0.05	3.26	-3.26	-0.25	-0.23	0.9	0.42	0.139
20	20	19	-0.18	0.05	2.32	-2.32	-0.09	-0.17	0.91	0.3	0.1
21	21	20	-0.23	0.05	3.03	-3.03	-0.23	-0.18	0.46	1.08	0.357
22	22	21	-0.08	0.05	1.11	-1.11	-0.09	-0.09	0.8	0.24	0.08
23	23	22	-0.03	0.05	0.68	-0.35	-0.02	-0.02	0.14	0.28	0.092
24	24	23	-0.13	0.05	2.84	-1.75	0.11	-0.11	0.2	1.23	0.406
25	25	24	-0.16	0.05	2.37	-2.05	0.03	-0.13	0.42	0.86	0.283
26	26	25	-0.16	0.05	2.32	-2.14	-0.18	-0.13	0.4	0.85	0.28
27	27	26	-0.06	0.05	0.8	-0.8	-0.07	-0.05	0.56	0.26	0.084
28	28	27	-0.06	0.05	0.82	-0.82	-0.07	-0.05	0.55	0.26	0.085
29	29	28	-0.08	0.05	1.24	-1.02	-0.07	-0.09	0.52	0.45	0.15

The following tables are the calculations derived from the iso clustering method.

Shore 1					
Category	**2003**	**2016**	**change**	**.25 square feet to meters squared**	**approximate shoreline change (iso method)**
Water	10331	17910	7579	176.028035	5.856532322
Marsh	12536	4955	7581	176.0744866	5.858077785

Shore 2					
Category	**2003**	**2016**	**change**	**square feet to square meter**	**approximate shoreline change (iso method)**
Water	76249	92549	16300	378.579888	3.817276062
Marsh	51730	35422	16308	378.7656941	3.819149572

Shore 3					
Category	**2003**	**2016**	**change**	**square feet to square meter**	**approximate shoreline change (iso method)**
Water	4926	6993	2067	48.00764592	3.429118056
Land	4473	2406	2067	48.00764592	3.429118056

Shore 4					
Category	**2003**	**2016**	**change**	**square feet to square meter**	**approximate shoreline change (iso method)**
Water	8609	11194	2585	60.04	2.22
Marsh	11064	8474	2590	60.15	2.23

Shore 5					
Category	**2003**	**2016**	**change**	**.25 sq feet to meters sq**	**Shoreline Change**
Water	868	2054	1186	27.54575136	2.754575136
Marsh	1853	667	1186	27.54575136	2.754575136

Shore 6					
Category	**2003**	**2016**	**change**	**.25 sq feet to meters sq**	**Shoreline Change**
Water	21405	24430	3025	70.257924	2.509211571
Marsh	9486	6462	3024	70.23469824	2.50838208

Appendix C

These tables are the calculations to determine the approximate amount of nitrogen that is fixated based on the marsh to water ratio.

% Area of PI marsh	0.029106321	
Total Amount of Nitrogen in Currituck Sound	60,314.79	
Amount of nitrogen pine island is responsible for	1,755.54	
per acre responsibility	0.67	kg/acre
Efficieny Removal PI		
10%	175.55	kg
15%	263.33	kg
20%	351.11	kg
25%	438.89	kg
30%	526.66	kg
Per Acre Efficiency Removal		
10%	0.066809626	kg
15%	0.10021444	kg
20%	0.133619253	kg
25%	0.167024066	kg
30%	0.200428879	kg
Efficiency Removal/$	Kg/N	Price/Acre of N removal
10%	0.066809626	1.952177285
15%	0.10021444	2.928265927
20%	0.133619253	3.904354569
25%	0.167024066	4.880443211
30%	0.200428879	5.856531854