A SPATIO-TEMPORAL ASSESSMENT OF BACK-BARRIER SALT MARSH CHANGE: A COMPARISON OF MULTIDATE AERIAL PHOTOGRAPHY AND SPATIAL LANDSCAPE INDICES

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ABSTRACT:

A study of back-barrier salt marshes was conducted to investigate whether or not urbanization has impacted the distribution and fragmentation characteristics of the marshes. Topsail Island and Masonboro Island, both in southeastern North Carolina, USA, were chosen as comparative study sites since Topsail, a 40km transgressive barrier island, has had increasing urbanization since the 1930s while Masonboro is a protected, undeveloped, island. In addition, they are both located in the same geomorphic setting and quite close to one another which allowed for comparable environments. By gathering, rectifying, interpreting, and digitizing historical aerial photography (from 1938 to 2002) we computed the rate of change in the back-barrier land cover types as well as used GIS to compute the degree of fragmentation through time and place. Results have varied where the marshes behind Masonboro Island were most affected by storm events while Topsail Island marshes have changed mostly due to urbanization and inlet location/migration. In addition, future image processing of IKONOS imagery will be useful as a comparison of spatial resolution and spectral characteristics as well as creation of a full land cover maps of the entire islands. Next, we will incorporate elevation/topographic data from recent LIDAR missions to develop a predictive model of the two islands. It is hypothesized that the IKONOS imagery will provide evidence of island migration and overwash fans, and LIDAR can be used as a factor to predict back barrier marsh stability.

1. INTRODUCTION

1.1 Study Area

Barrier islands and coastal salt marshes are complex ecosystems that move and change through time in response to many factors. For example, hurricanes bring strong winds, rain, and storm surge which can greatly change the distribution of surficial deposits. Through time the islands can migrate and inlets change their positions. The purpose for this study was to measure back-barrier salt marshes has they have changed through time and quantify how these changes have taken place by studying the morphology, or shape, of the marshes.

There are many reasons for investigating how back-barrier marsh systems change through time. For example, they provide protection for the mainland during storms by absorbing the tidal surge and providing a stabilizing environment for storm overwash. These environments are also economically and environmentally important ecosystems because they provide fish nursery habitats, bird nesting and foraging sites, and act as a filter for chemicals entering the ecosystem.

To understand how these habitats change through time, two barrier islands, located in southeastern North Carolina, were investigated (Figure 1). Masonboro and Topsail islands are part of a chain of barrier islands in the geologic system known as the Georgia Bight. As illustrated in Figure 1, these two islands are closely related in location and general size; however Topsail is developed and Masonboro is a National Estuarine Research Reserve and so it has no manmade structures.

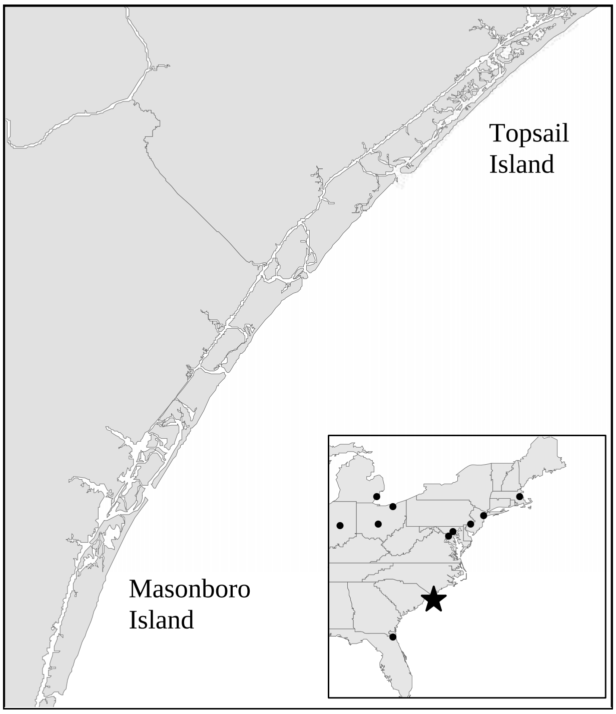

Figure 1. The location of Topsail Island and Masonboro Island, in southeastern North Carolina, USA, are indicated by the star in the inset map.

1.2 Related Literature

In the southeastern United States salt marshes are typically found in tandem with barrier islands. This ecosystem includes the beach, dunes, vegetated zones, maritime forest, swampy terrains, tidal flats, and low-lying salt marshes (Bates and

Jackson, 1984). Researchers have identified several factors related to marsh stability: geomorphology, elevation, vegetation, hydrologic conditions, frequency of tropical storms, tidal range, and sediment supply (Goodbred and Hine, 1995; Davidson-Arnott, et. al., 2002, Croft, 2003; Riggs and Ames, 2003). If estimates are correct and sea level rise is increasing at 1.9 cm/year (Davis, 1994), then the salt marshes in this region require a substantial amount of sediment, either from overwash or other transport mechanisms, to sustain their existing size.

In addition to the geologic and geomorphic processes of marsh formation, there has been a steady increase in coastal development along all coasts of the United States (Titus, 1990) and it is yet to be determined what impact this has on back barrier marshes. Therefore, this study was undertaken to map the back barrier marshes in order to quantify change as well was compute various spatial measures to identify patterns in how these marshes have changed through time.

2. METHODS

2.1 GIS Database Development

It has become quite common to utilize the tools available in a Geographic Information System (GIS) for mapping coastal habitats such as salt marshes (for example, see Delaney and Webb, 1995 and). In this study, the development of this GIS began with a detailed survey of all local, regional, state, and federal agencies that commonly acquire aerial photography. Many dates of photography were identified, however only those dates where photography covered all of the back barrier marshes and were of similar scale (1:12,000 and 1:20,000) were collected and used in the study. For Topsail Island, the most recent photography was from 1998, it was already rectified into orthophotography, and was near-infrared. All other years (1938, 1949, 1956, 1971, and 1986) were in analog format which required scanning and rectifying. After several tests at varying resolutions, it was determined that scanning the aerial photographs at 400 dpi was sufficient for the scale, interpretation and digitization of the marshes.

Two approaches were undertaken to quantify the location and amount of change that has taken place at Topsail and Masonboro Islands from 1938 to 2002. First, at Masonboro, the complexity of the marsh patterns made it very difficult to interpret and digitize all of the small marsh polygons, so after testing various techniques, it was decided that the marshes would be digitized and categorized as high, medium, or low fragmentation. Marsh areas that contained 17 to 53% open water were categorized as highly fragmented, 54 to 6% were medium fragmented, and less than 6% open water were low fragmentation. An example of this classification scheme is illustrated in Figure 2. The years for aerial photograph interpretation were: 1938, 1959, 1962, 1971, 1984, 1998, and 2002.

For Topsail Island, the aerial photography was more precisely mapped where the smallest marsh polygon interpreted and digitized was less than 0.1 hectare. The land cover classification scheme was: marsh, upland, water, and barrier island (Figure 3). The dates of photography for this island were: 1938, 1949, 1956, 1971, 1986, and 1998. The 2002 aerial photography that was used for Masonboro Island was only available for New Hanover County, not Pender County which is where the Topsail Island study area is located. An accuracy assessment was conducted where 140 points were randomly located in the study area and the land cover classes were compared to the aerial photography. An overall accuracy greater than 80 % was confirmed.

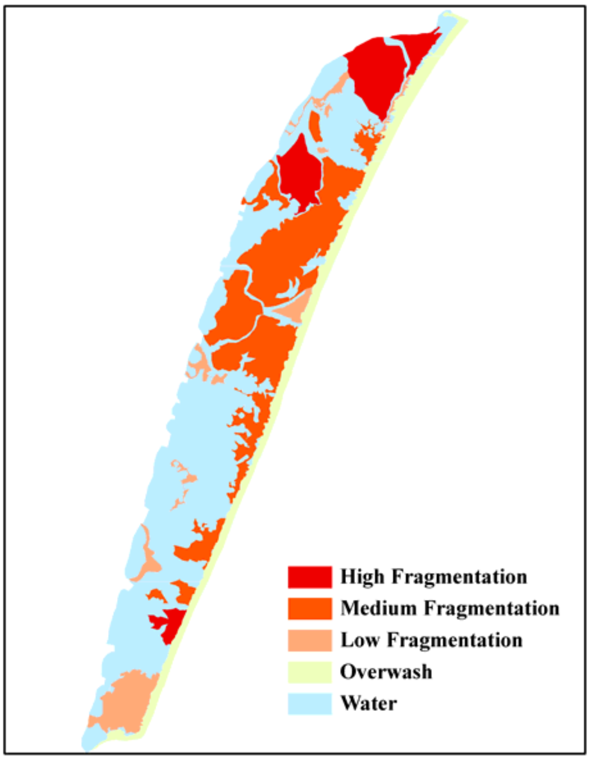

Figure 2. An example of the land cover classification scheme for Masonboro Island. These data were digitized from 1:20,000 2002 aerial photography.

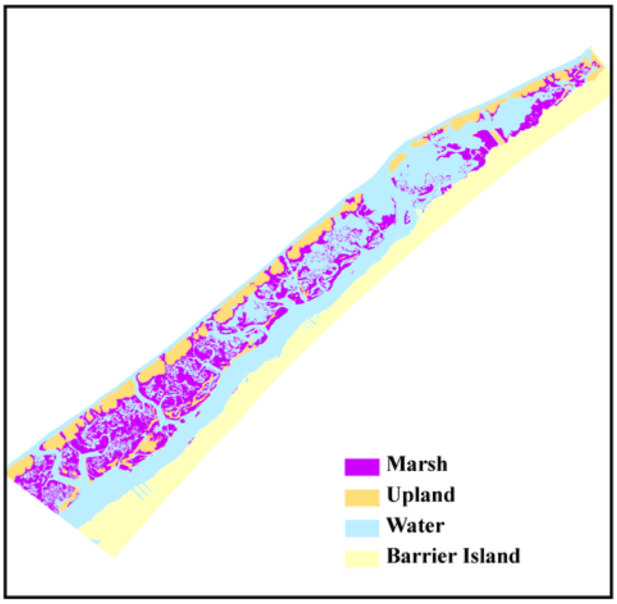

Figure 3. An example of the land cover classification scheme for the Topsail Island study area. These data were digitized from 1:12,000 1998 aerial photography.

2.2 Change Detection Techniques

To compare how much the marsh habitats changed from one time period to the next, a series of change matrices, or were created. The technique used in this study is known as the post-classification comparison where the input data layers have been independently classified/interpreted and then the results are compared, or overlaid (Jensen, 1996). Using this approach, we created matrices documenting how each land cover class changed from one time period to the next. The benefit of this approach is that you can compute how much area (in hectares) has changed and what the land cover has become.

2.3 Fragmentation and Spatial Indices

In the Topsail Island study area, a variety of techniques were tested and implemented for investigating how the marsh landscapes have changed through time. To measure fragmentation, the study area was divided into 28 roughly equally sized areas (0.5 kilometers in width) and within each sample area the number of wetland polygons was divided by the area of wetlands (Kingsford and Thomas, 2002) (Figure 4).

Secondly, a variety of indices were calculated to derive quantitative aspects of the marsh polygon/areas. These indices, or landscape metrics, included: size or area of the polygons, ratio of area to perimeter (Lovejoy, 1982), and fractal dimension or relative amount of edges in a polygon (Mondelbrot, 1982; Olsen et al., 1993; Chen, 2001). The equation for fractal dimension was:

$$S = \frac{2\ln(\mathrm{Pr}/4)}{\ln(A)}$$

Where S = fractal dimension
Pr = perimeter
A = area

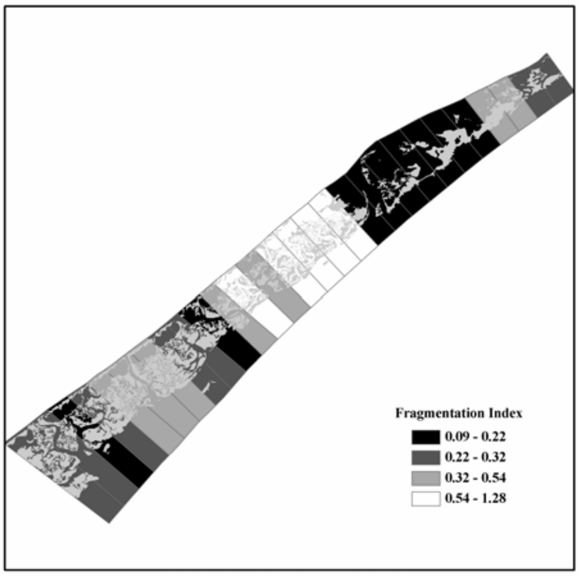

Figure 4. An example of the 1938 fragmentation index for Topsail Island. Each sample area/polygon is attributed with the fragmentation index value which is computed as the number of marsh polygons divided by the total area of marsh.

3. RESULTS AND CONCLUSIONS

3.1 Change Detection Analysis

Masonboro Island

The change in back-barrier marshes behind Masonboro Island illustrated the connection between large storms and marsh growth or decline. The amount and density of marshes was directly related to the impacts that hurricanes had on the area. From 1938 to 1959 there was a 5% loss in total marsh area, a 73% loss in low fragmented marsh, a 250% increase in medium fragmented marsh, and a 40% loss in highly fragmented marsh (Table 1).

During the time frame (1938 to 1959) there were several hurricanes: the 1944 hurricane (August 1, category 1), Hazel (October 15, 1954; category 3), Diane (August 17, 195; category 2), and Helene (September 27, 1958; category 4). Although the total amount of marsh area has remained relatively stable, the change among marsh classes documents the increase in fragmentation immediately after hurricanes when storm surge and overwash sediments cover the marsh, but then as time progresses the marshes become less fragmented as the marshes spread to the recent sediments that filled open water areas.

	Low	Med	High	Total
1938	2,379.32	1,026.41	2,878.70	6,284.43
1959	636.17	3,601.29	1,722.46	5,959.92
1962	2,414.76	2,591.53	1,317.01	6,323.31
1971	141.05	743.85	5,348.81	6,233.72
1998	612.02	1,081.75	5,348.81	7,042.58
2002	1,105.00	3,881.28	1,568.26	6,554.54

Table 1. The amount of marsh (in hectares) for each date in the Masonboro Island study area.

From 1959 to 1962 there was only one hurricane (Donna, September 11, 1960; category 3) which could account for the increase in overall marsh acreage and decrease in medium and highly fragmented marsh (Figure 5). The 1971 and 1998 dates are notable in the much greater percentage of highly fragmented marsh. During this time (1962 to 1998) there were several storms: Ginger, September 30, 1971, category 1; Diana, September 9, 1984, category 2; Bertha, July 12, 1996, category 2; Fran, September 5, 1996, category 3; and Bonnie, August 26, 1998. This increase in fragmentation is due to the decrease in low fragmented marsh because of the impacts from hurricanes. Further research is needed to truly understand the impacts that hurricanes have on marsh habitat; however, from these data we conclude the that overwash sediments have increased the size of adjacent back-barrier marshes.

Topsail Island

In Topsail Island, the change detection analyses revealed that 71% of the marsh in 1938 remained marsh in 1949; this dropped to 65% in 1956, 58% in 1971, 65% in 1986 and increase to 73% in 1998 (Table 2). Interestingly, of the marshes that did not remain as marsh in the next time period, most of this area became water, not upland. In the areas that were upland, some converted to marsh (e.g. 16% in 1938 and 1956) and to a lesser extent, some converted to water. Lastly, water generally stayed the same from one time period to the next at 80 to 90%, but when the water areas changed they became marsh, not upland.

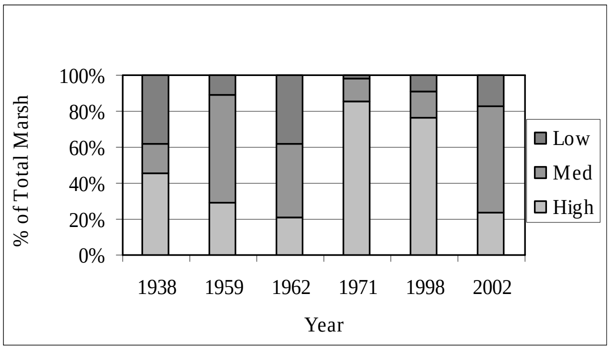

Figure 5. Relative percentages of marsh categories at Masonboro Island.

To visualize this changing land cover, a time series of maps can be created in order to help identify a trend in the spatial configuration of the changing landscape (Figure 6). Through this spatial and temporal analysis we have identified several physiographic regions that correspond to active and historical inlet areas, overwash areas, and human-influenced areas such as urbanization and dredge spoil areas.

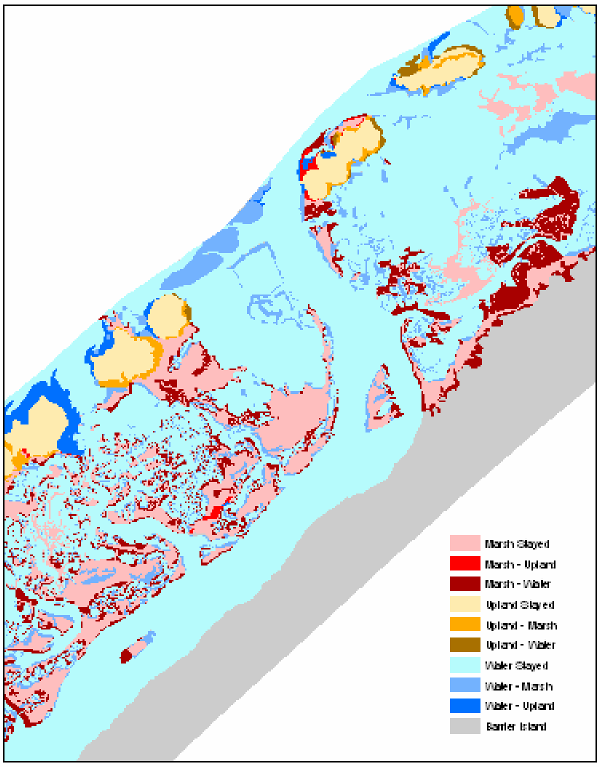

Figure 6. An example map of land cover change on a portion of Topsail Island from 1938 to 1949.

3.2 Spatial Indices

The spatial indices were applied to each year in the Topsail Island study area. Statistical analysis concluded there was no difference in the Area versus Area/Perimeter indices and these indices predicted marsh survival that ranged from 55 to 72%. Interestingly, although the Fractal Dimension index had a lower probability of predicting marshes that remained through time (34 to 50%), this index outperformed the others by predicting which marshes would not remain (Figure 7). Therefore, a combination of these indices would best predict which marshes will last and which will not.

3.3 Conclusions

This research has documented how the marshes at Topsail and Masonboro Islands, North Carolina, have changed from 1938 to 2002. Through GIS analysis several conclusions can be made: 1) There has been an overall loss in marsh area, 2) marshes have changed to water and water and upland areas have become marsh, 3) hurricanes have influenced the unsettled island of Masonboro more than they have at the developed Topsail Island, 4) Inlet migration and urbanization appear to have an impact at Topsail Island, and 5) computing spatial indices has helped to build a spatial model of marsh predictability.

Future research will expand on these results to incorporate new data and build more comprehensive models of the islands. For example, we have gathered IKONOS imagery and are building a larger land cover basemap that extends from the ocean to the Intracoastal waterway. In addition, we have gathered LIDAR topography for both study areas and are building topographic models for both islands. These new data will be used to develop more comprehensive models of the two islands in order to further investigate the processes that are effecting marsh distribution and in turn be helpful in building predictive models.

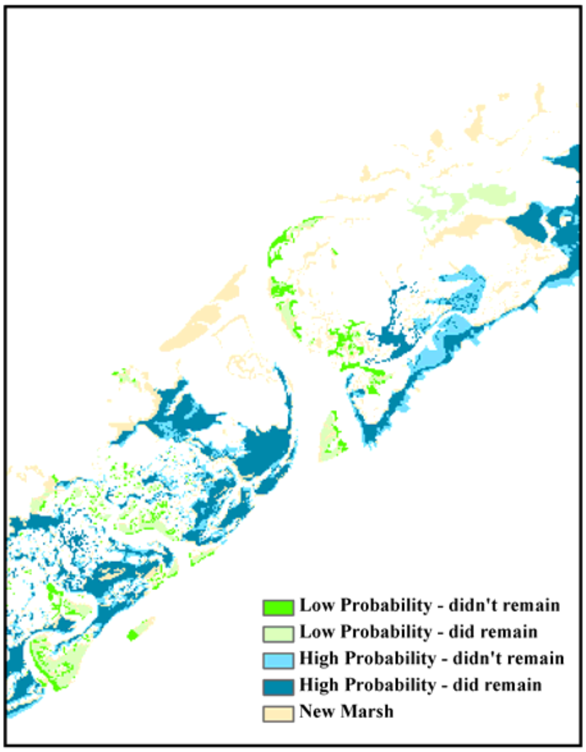

Figure 7. An example map of the Fractal Dimension index for a portion of Topsail Island from 1938 to 1949.

		Area (hectares)			
		1949			
		marsh	upland	water	Total
1938	marsh	449.2	28.6	156.8	634.6
	upland	45.0	215.7	20.7	281.4
	water	118.1	17.6	947.0	1,082.7
		1956			
		marsh	upland	water	total
1949	marsh	402.6	36.5	176.7	615.8
	upland	42.6	202.9	13.5	259.0
	water	143.9	24.3	961.6	1,129.8
		1971			
		marsh	upland	water	total
1956	marsh	338.8	53.9	192.2	584.8
	upland	47.6	180.2	33.5	261.4
	water	192.9	28.7	922.9	1,144.5
		1986			
		marsh	upland	water	total
1971	marsh	378.3	49.7	151.8	579.9
	upland	38.3	205.1	17.3	260.7
	water	134.8	17.1	1,003.7	1,155.6
		1998			
		marsh	upland	water	total
1986	marsh	405.6	34.4	114.1	554.0
	upland	17.4	239.9	14.6	271.9
	water	80.6	10.0	1,087.2	1,177.7

		Percent Change		
		1949		
		marsh	upland	water
1938	marsh	**70.8**	4.5	24.7
	upland	16.0	**76.7**	7.3
	water	10.9	1.6	**87.5**
		1956		
		marsh	upland	water
1949	marsh	**65.4**	5.9	28.7
	upland	16.4	**78.4**	5.2
	water	12.7	2.1	**85.1**
		1971		
		marsh	upland	water
1956	marsh	**57.9**	9.2	32.9
	upland	18.2	**68.9**	12.8
	water	16.9	2.5	**80.6**
		1986		
		marsh	upland	water
1971	marsh	**65.2**	8.6	26.2
	upland	14.7	**78.7**	6.7
	water	11.7	1.5	**86.9**
		1998		
		marsh	upland	water
1986	marsh	**73.2**	6.2	20.6
	upland	6.4	**88.2**	5.4
	water	6.8	0.8	**92.3**

Table 2. Total area (in hectares) and percent change from one time period to the next for marsh, upland, and water in the Topsail Island study area.

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4.1 Acknowledgements

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