INTRODUCTION

Barrier islands are complex systems that are constantly responding to the dynamic forcing of storms and changes in sea level. Included in barrier island systems are the low-lying backbarrier marshes that extend back towards the mainland. The survival of backbarrier marshes is necessary for many physical and biological reasons. Marshes protect the mainland from damaging erosion caused by storms and help absorb flood waters that can be harmful to the mainland. Not only do marshes buffer the mainland from storm impacts and high-energy events, marshes continually protect the mainland from everyday interactions between land and sea (LEONARD *et al*., 1995; STUMPF, 1983; LEONARD *et al*., 1995). Backbarrier marshes also provide habitat for many species of birds, fish, shellfish, and plants that are vital for species population survival (HANSEN, 1993). At some point, most marine organisms spend a portion of their lives in marshes (MITSCH and GOSSELINK, 1993). Marsh survival depends on a complex interaction between geomorphology, sediment supply, tidal range, and sea level rise.

Marsh Sedimentation

Inorganic sediment inputs are a vital component in the maintenance of backbarrier marsh elevation. Vertical accretion of coastal marshes involves a complex interaction between vegetation, sedimentation, and hydrologic conditions (REED, 1995). Figure 1 shows the relationships among the processes that affect marsh stability. Rising sea level and regional subsidence alter hydrologic conditions in the marsh, which, in turn,

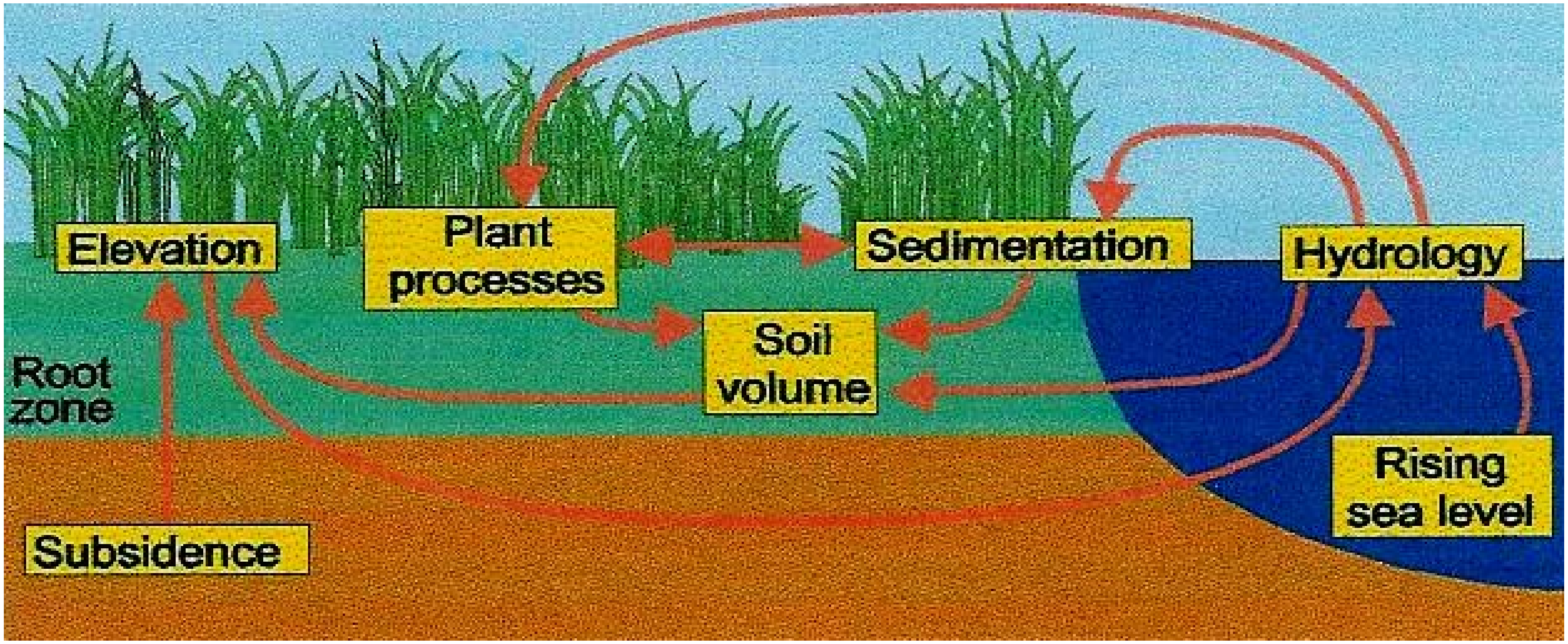


Figure 1: Processes influencing marsh sedimentation (USGS FS-091-97)

affects sedimentation processes and vegetation growth. Below ground production adds to soil volume and, thereby affecting marsh elevation and, indirectly hydrologic conditions (USGS, 1997).

Inorganic materials, mostly in the form of sediments from the nearshore coastal environment, are necessary for the survival of backbarrier marshes during a rise in sea level (BAUMANN *et al*., 1984; ORSON *et al*., 1985; GOODBRED and HINE, 1995). During storm-free periods, the majority of inorganic sediments imported to the marsh surface are derived from tidal creek transport (STUMPF, 1983). These materials, however, are generally delivered only a short distance from the tidal creek and do not reach the marsh interior. However, some level of tidal reworking and transport through open water channels does allow inorganic sediments to reach interior marsh areas (LEONARD, 1997; REED, 1989). Therefore, sedimentation needed to maintain marsh health requires another source of sediment transportation for the marsh interior to be affected.

The most efficient method of wide-spread sediment delivery occurs during storms when storm surge, wind, and waves pummel the island. Inorganic sediments are brought from the beach and shore face to the marshes in the form of washover fans and terraces. Washover fans are sediment deposits that occur when dunes are breached and sediment is deposited in a delta-like shape. Washover terraces form when entire dune lines are destroyed and the sediment is deposited as a whole sheet. In extreme overwash events, washover fans can coalesce to form washover terraces behind a semi-stable dune line. These washover deposits are accumulations of sediments that are transported across the barrier island during storm events. High flood waters and wind waves generated on the flood water surface increase turbulence and total suspended solid concentrations thereby allowing sediments to reach the backbarrier marsh and areas not usually influenced by tidal creek sedimentation (STUMPF, 1983; LEONARD, 1995; LEONARD, 1997).

Inorganic material deficits in the backbarrier marsh are detrimental to the quality of the habitat in that they could lead to a decrease in bulk density of the marsh sediments (REED, 1995). A lowering of the sediment bulk density can initiate water-logging, which can intensify the loss of vegetation (DELAUNE *et al*., 1990). With a decrease in vegetation serving to stabilize the system, erosion will then occur, and open water areas will develop (REED, 1989). In addition, sediments delivered to the backbarrier marshes by storms are generally inorganic, thus introducing important nutrients that mineralize quickly and are absorbed into the system or are buried and may still be available for uptake by marsh vegetation for some time following the event (REED, 1995). Even infrequent storm events can deliver sediments that are buried and remain within the root zone of marsh vegetation, providing beneficial long-term nutrient effects to the system (NYMAN *et al*., 1995; REED, 1995).

Overwash

Barrier islands are composed of several geomorphic provinces: beach, dunes, uplands, backbarrier marshes, backbarrier sound, and in the case of some islands, dredge spoil islands. Dune fields and dune lines play an important role in the overwashing process (HOSIER and CLEARY, 1977). In addition, barrier island/sound areas in close proximity to inlets experience modification and are especially susceptible to frequent overwashing (CLEARY *et al.*, 1979). The island's morphology controls how storm surge affects the island and overwash processes. Higher topography and more stable dunes allow surge energy to be dissipated before causing too much damage; however, topographically low islands with unstable, or less-developed, dunes are more susceptible to overwashing processes (CLEARY *et al*., 1979; HOSIER and CLEARY, 1977).

In a study by HOSIER and CLEARY (1977), the importance and magnitude of overwash on Masonboro Island, North Carolina was determined using analysis of aerial photographs. Physiographic types of oceanic overwash were delineated; type A was a recovery dune ridge that developed during quiescent periods, type B was an intact dune ridge that was often scarped, indicating possible instability in the event of oceanic overwash, type C were isolated washover fans, and type D were washover terraces, which may have formed from the coalescence of washover fans.

The island was divided into five sections based on the dominant physiographic type present in each area in 1977 (Figure 2). Section V was the northern 12,000 meters of the island, followed by Section IV at approximately 4,200 meters. Sections II and III were approximately 4,000 meters and 10,000 meters in respective length. Section I was the southern most end of the island with a length of approximately 8,700 meters. Sections I and V were considered to be the most vulnerable to even minor storms due to the low, breached dune lines near the unstable inlets that bound the north and south ends of the island (HOSIER and CLEARY, 1977). Sections II and IV, have, historically, received the least amount of overwashing, but as beach erosion has continued and the dune lines get narrower, overwashing in these two sections has increased (HOSIER and CLEARY, 1977). Section III was identified as the most stable section of the island due to the abandoned inlet shoulders from Old Cabbage Inlet, but has received overwash on

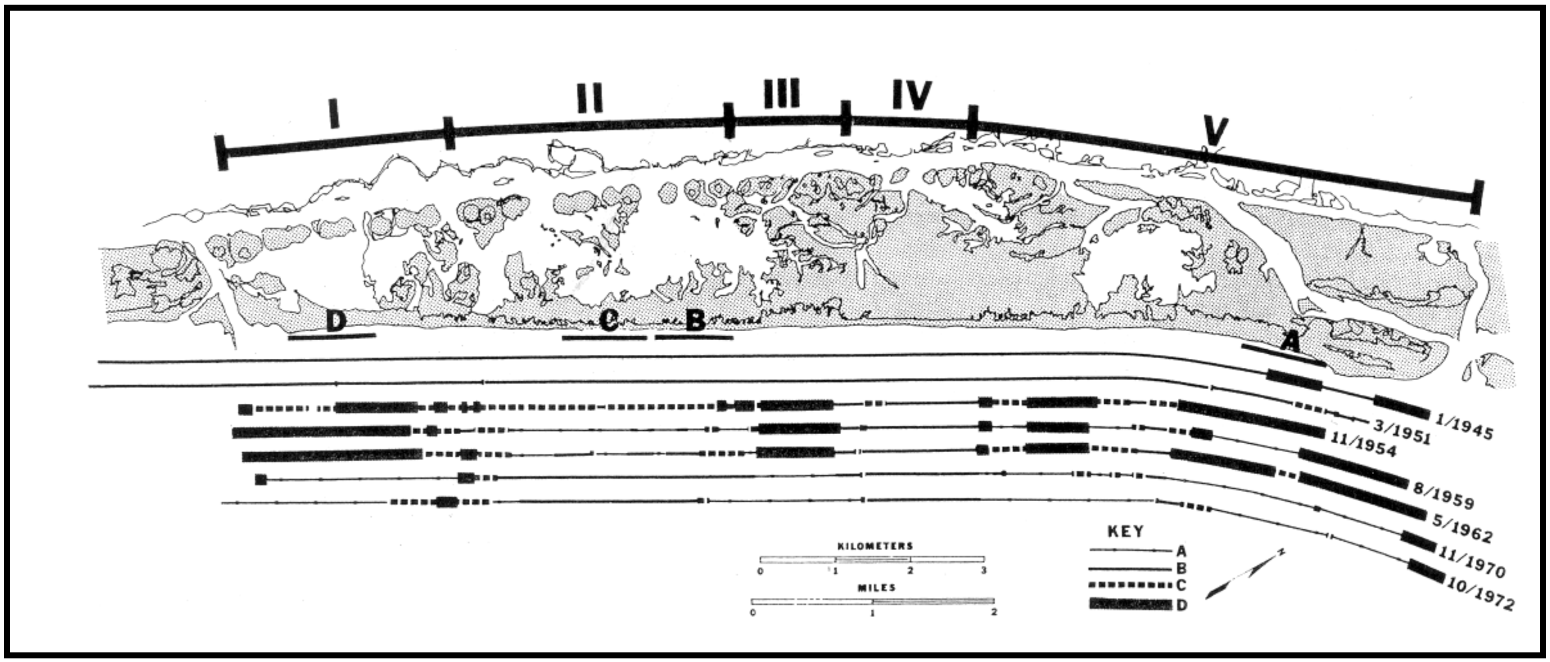


Figure 2: Five sections of Masonboro Island divided based on dominant physiographic type (A-recovery dune ridge, B-intact dune ridge, C-isolated washover fans, D-washover terraces) of overwash deposit according to HOSIER and CLEARY (1977) (used by permission)

occasion and following overwashing, the dunes redeveloped and remained stable (HOSIER and CLEARY, 1977; CLEARY *et al*., 1979). Because this section of the island is the widest and most stable in terms of dunes and marsh, any overwashing that occurs will result in deposition rather than erosion (HOSIER and CLEARY, 1977).

The sections and physiographic types were examined and compared spatially and temporally. In addition, history and frequency of overwash on the island was examined. A cyclic pattern of physiographic types was recognized using aerial photography analysis and vegetation patterns on the overwash fan deposits. Overwash had occurred in two of the five sections, mostly because of the low profile and unstable conditions of the sections in close proximity to inlets. However, all the areas that experienced overwash showed some level of recovery, and revegetation of dunes and washover deposits between storm events. Overwash processes, affecting Masonboro Island, occur at different rates and intensities due to the varying dune structures and the frequency of storms (HOSIER and CLEARY, 1977).

Remote Sensing and GIS

An innovative method for analyzing marsh area change is done using Geographic Information Systems, or GIS, and remote sensing techniques. GIS databases are being used for this study because of its cost effectiveness as a tool, as well as, its ability to provide spatial quantification and quality control (DELANEY and WEBB, 1995). Many studies utilize aerial photographs to examine spatial and temporal changes in marshes that have resulted from natural or anthropogenic processes (DELANEY and WEBB, 1995; HARDISKY and KLEMAS, 1983; WILLIAMS and LYON, 1995; KOWALSKI and

WILCOX, 1999; MCCLENNAN, *et al*., 2000). Several of these studies used aerial photographs and image processing techniques to delineate physiographic areas of the marsh, such as, unconsolidated bottom, emergent vegetation, and high and low marsh (DELANEY and WEBB, 1995; WILLIAMS and LYON, 1995; KOWALSKI and WILCOX, 1999; MCCLENNAN, *et al*., 2000). Usually, these data are put into a GIS database for calculations of dimensions and easy comparison of spatial and temporal changes between land cover types.

A study of Masonboro Island, NC was completed in 1999 by Moundalexis, specifically examining two major storm events, Hurricanes Bertha and Fran, and their effects on backbarrier sedimentation. Using aerial photographs, eighteen transects was chosen for sampling sites throughout different regions on the island. Core samples were collected from washover fans to determine deposit volumes and sedimentological characteristics. Also, vegetation measurements were taken and topographic profiles were constructed across each transect of the island. Vegetation height, plant density and presence of seeds were recorded at each of the thirty-one stations along the three transects. Aerial photographs were analyzed and land cover boundaries were digitized so total marsh area pre- and post-storm could be found. Statistical analyses were completed to support the results that the oceanic overwash deposits created by Hurricanes Bertha and Fran affected the geologic and ecologic conditions within the marsh. Different regions of the island experienced varying amounts of overwash impact due to existing morphology. The inorganic storm sediments to the backbarrier marsh provided valuable inputs to stabilizing the marsh substrate by increasing bulk density and topography, allowing for vegetation succession to occur to higher marsh plants (MOUNDALEXIS, 1999). The study concluded that the sedimentation generated from two major storm events in the same year produced enough sediment deposition to account for 126% of the yearly littoral drift (MOUNDALEXIS, 1999).

OBJECTIVES AND HYPOTHESES

Using knowledge obtained from previous research, this study examined spatial changes in marsh acreage and degree of fragmentation in the backbarrier marshes of Masonboro Island in Southeastern North Carolina. Aerial photographs were used to map marsh fragmentation and perform a change detection in marsh area using GIS. The results of the change detection were then compared to frequency of major storm events to determine the impacts that storms had on this backbarrier marsh. Changes in spatial extent of the marshes were examined over an extended time period, as well as in relation to individual storm events. The specific objectives were to:

1. Identify spatial extent of marsh and total island/sound complex for the years 1938, 1959, 1962, 1971, 1984, 1998, and 2002.
2. Quantify changes in total aerial marsh extent and marsh fragmentation between 1938 and 2002.
3. Determine how the marsh changes. For example, did the observed change go from vegetated marsh to open water or from highly-fragmented marsh to low-fragmented marsh?
4. Relate change in marsh coverages to specific periods of high storm intensity and periods of no storm activity.

These objectives address the following hypotheses:

- In the short-term, marsh loss will occur from the burial of marsh vegetation by washover deposits. This marsh loss is evident following major storm events, like the events examined in this study.

- Existing areas of marsh will become less fragmented over time with the passage of storm events, and areas of open water will become more fragmented as the sound infills and new marsh develops.
- In the long-term, washover deposits will renourish backbarrier marshes with inorganic sediments, which can then be recolonized by marsh grasses, converting back to areas of stable marsh. It is expected that areas of the sound that are infilling with marsh will correlate to the areas undergoing frequent overwashing as suggested by HOSIER and CLEARY in their study of Masonboro Island in 1977.

After loss of marsh has been determined, it must be considered that there are two types of marsh loss: 1) direct loss caused by erosion or abrupt conversion to a different type of backbarrier environment such as washover deposit; 2) and gradual loss, which occurs over a long period of time, where influences of subsidence and sea level rise cause gradual changes in vegetation and hydrology. For the time period being examined in this study, direct losses of marsh will be more evident, especially with increased storm activity. On the other hand, gradual or long-term losses will be more difficult to detect in the aerial photographs given the time frame of 1938 to 2002 and especially when the short-term comparisons of storm events are examined.

STUDY AREA

Onslow Bay is located on the southeastern coast of North Carolina and is bounded by two capes: Cape Lookout and Cape Fear (MOUNDALEXIS, 1999). Within Onslow Bay is the study area of Masonboro Island, North Carolina; an 11.2 km long transgressive barrier island on the coast of New Hanover County, five miles east of Wilmington, North Carolina (Figure 3). The island/sound complex varies in width from 300 to 1,600 meters, but averages about 1,500 meters. The island/sound complex is separated from the mainland by the Intracoastal Waterway and dredge spoil islands and is bounded on the north by Masonboro Inlet and on the south by Carolina Beach Inlet. Masonboro Island was connected to Carolina Beach before Carolina Beach Inlet was artificially created in 1952 for fishing boat navigation (HOSIER and CLEARY, 1977). Masonboro Island has never had any permanent settlements and remains undeveloped today as a North Carolina National Estuarine Research Reserve. However, humans have impacted the island by stabilizing Masonboro Inlet on the north end of the island. The jetty was constructed on the north side of the inlet in 1966 and on the south side in 1980 (MOUNDALEXIS, 1999).

This natural barrier island/sound complex possesses the typical environments of islands on the Mid-Atlantic Coast. Masonboro Island is a low-profile island with broken dune lines that, at most, reach only six meters in height, while the majority is less than five meters above sea level (HOSIER and CLEARY, 1977). Marsh vegetation is dominated by *Spartina alterniflora* Loisel, *Limonium sp., Salicornia sp., Borrichia arborescens (L.)* DC, *Iva frutescens (L.), Distichlis spicata (I.)* Greene, *Spartina patens*

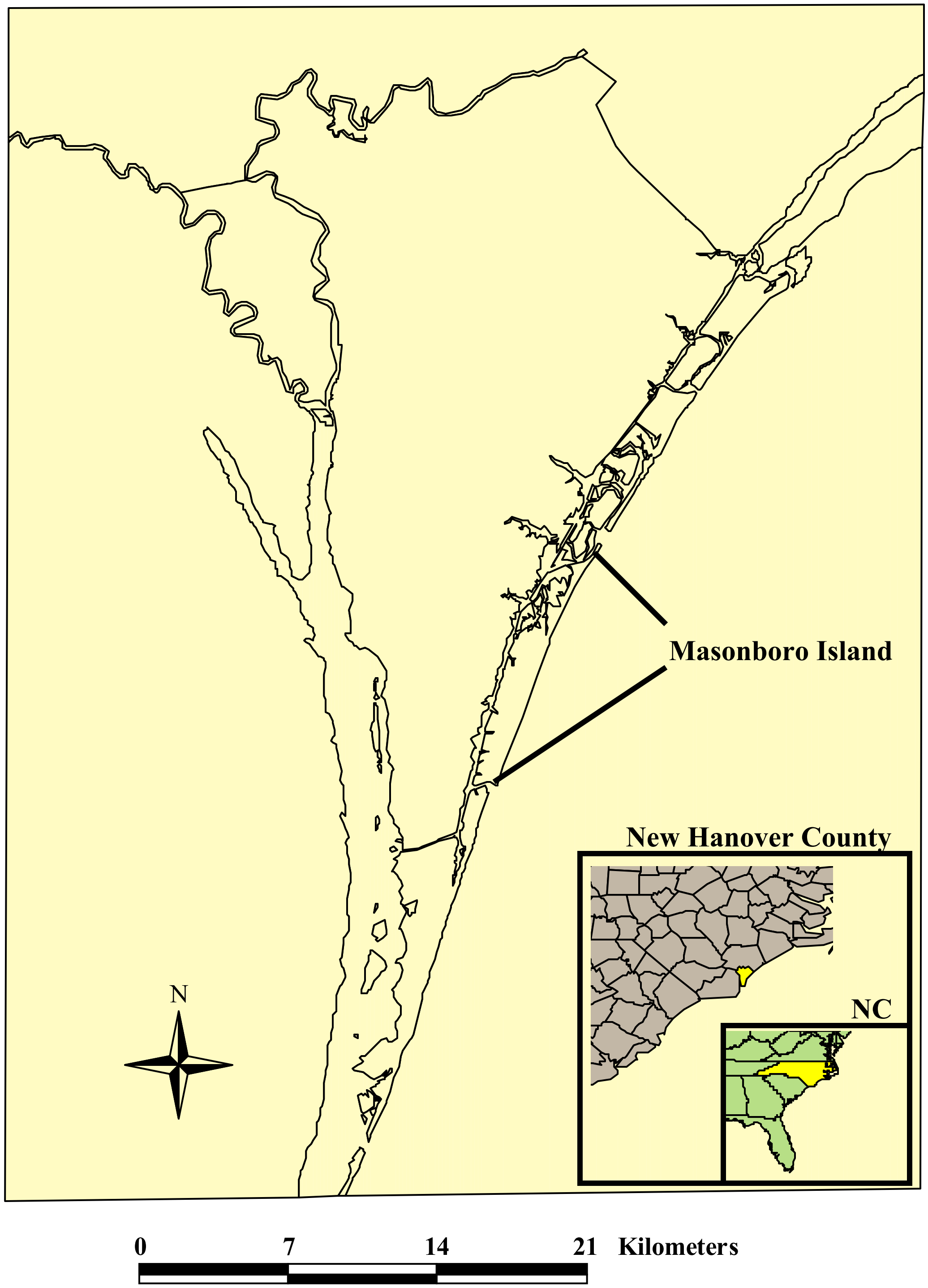


Figure 3: Study site of Masonboro Island located in New Hanover County, North Carolina

(Ait.) Muhl, and *Juncus roemerianus* Scheele (MOUNDALEXIS, 1999). The most developed and mature area of marsh is found on the old flood tidal delta where Cabbage Inlet existed in the center of the island (HOSIER and CLEARY, 1977).

The jetties at the north end of the island have led to a decrease in sediment supply usually delivered to Masonboro Island by longshore currents (MOUNDALEXIS, 1999). Despite this sediment deficiency, Masonboro Island has continued the natural process to keep pace with rising sea level. Masonboro Island was chosen for this study because of the large vegetated marshes located behind the island and the uncharacteristically undeveloped, natural environment. Surrounding islands in the area have undergone significant growth since the early 1900's. Masonboro Island is bounded to the north by Wrightsville Beach and the south by Carolina Beach, both of which are highly developed barrier islands. The barrier island and marshes of Masonboro Island have qualities desired for this study, such as low-topographic profile and the high susceptibility and frequency of tropical storm events. The time period studied was from 1938 to 2002 with specific attention directed to before and after several major storm events during the time period.

Storm Events

Thirty-six storms events have impacted Masonboro Island, North Carolina, by passing within 50 nautical miles of the island, within the 64-year study period (NHC, 2004) (Appendix A). The events ranged from category 4 hurricanes on the Saffir-Simpson Scale to tropical disturbances and affected the study site either through beach erosion, or heavy wind or rainfall. However, not all weather events produced sufficient overwash to impact the backbarrier marshes, but most of the storms impacted the island and/or marshes in some way. Included in these 36 storms events were 11 major hurricanes and 1 major northeastern storm (Figure 4). This study concentrates on these 12 major storm events and their impact to the study site (Appendix B).

METHODS

Photo Selection

Aerial photography from the 1930's to 2002 was gathered from a variety of sources including North Carolina Department of Transportation, New Hanover County, United States Corps of Engineers (Wilmington District), and the Cape Fear Museum. From this collection of photography, photographs of pre- and post-storm events, as well as quiescent periods with no storm activity, were examined and photographs from the years 1938, 1959, 1962, 1971, 1984, 1998, 2002 were chosen for analysis. These years were chosen based on photograph quality, availability, and timing of major storm events (Figure 5).

The 1938 photos from the Cape Fear Museum were the earliest set of photographs that were readily available with full island coverage and of sufficient quality to delineate land cover. Following this set of 1938 photographs, the 1944 Hurricane, Hurricane Hazel (1954), and Hurricane Diane (1955) struck southeastern North Carolina. The next set of photographs was taken in 1959 which preceded the 1960 Hurricane Donna event. These photographs were obtained from the U.S. Army Corps of Engineers in Wilmington, North Carolina. A set of photographs from May of 1962 captures the effects of the

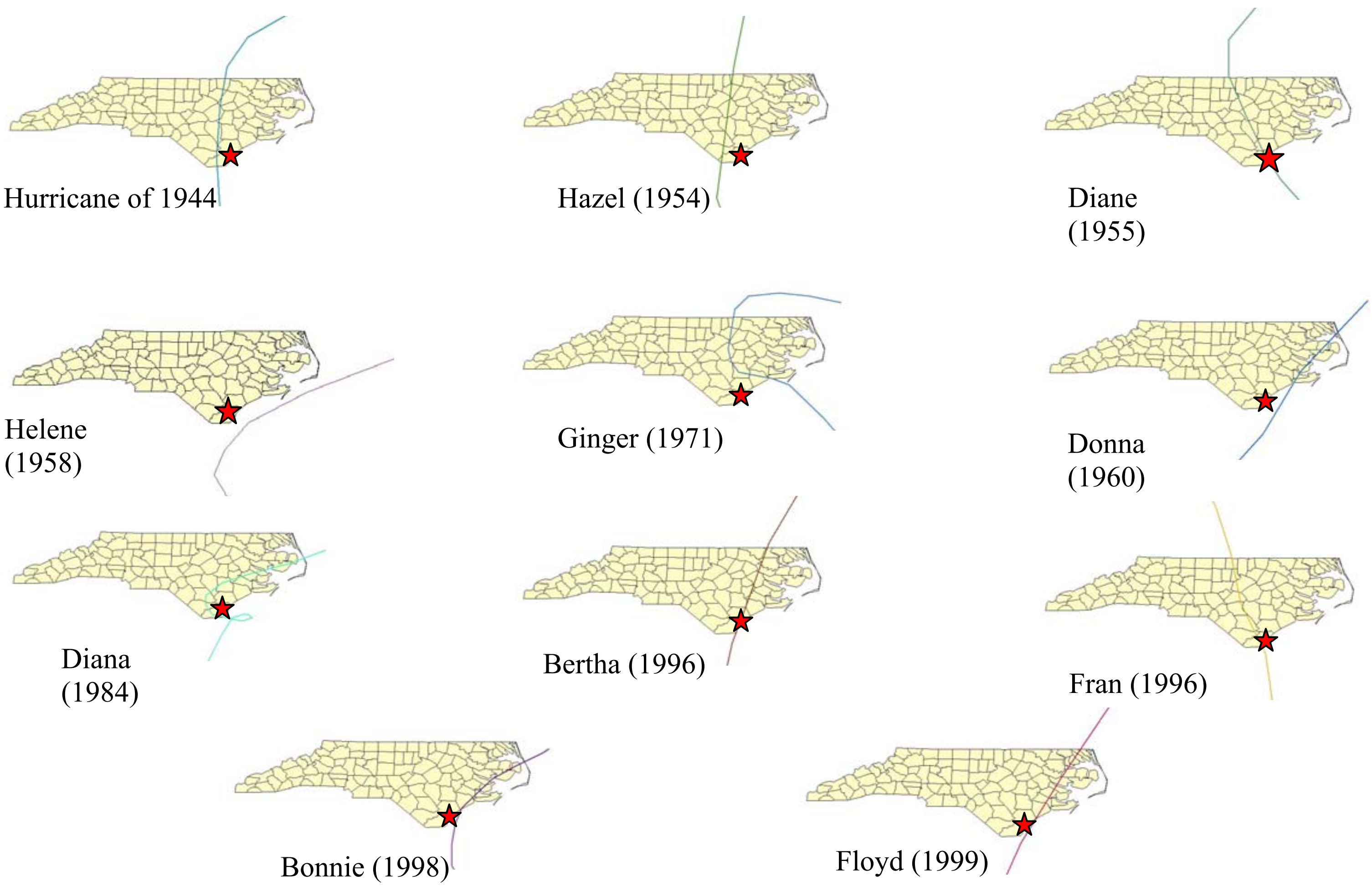
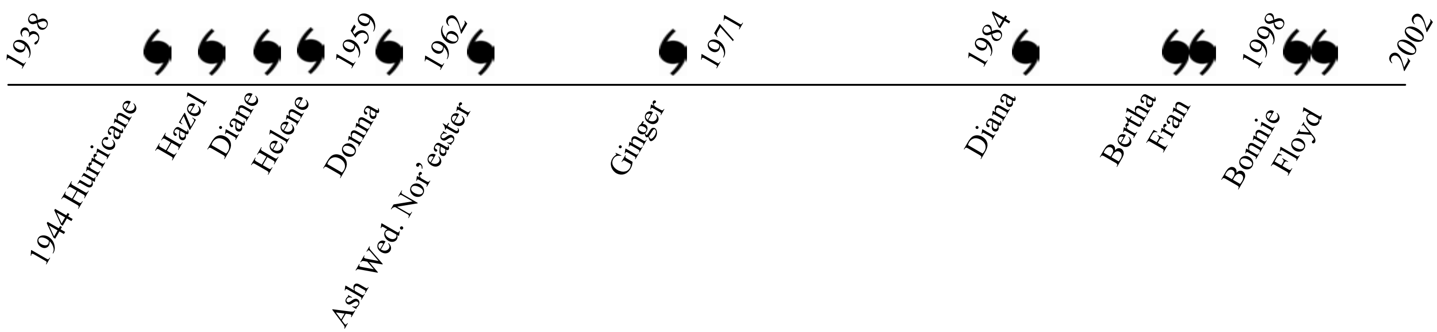


Figure 4: Storm tracks of major hurricanes impacting Masonboro Island, NC between 1938 and 2002



Note: Major storm events shown were of greatest impact to the study site.

Figure 5: Timeline of years of aerial photograph sets and storm events

March 7, Ash Wednesday Storm of 1962. These photographs were also obtained from the U.S. Army Corps of Engineers, Wilmington, North Carolina. The 1971 set of photographs were used in this study to capture the pre-storm conditions of Masonboro Island before Hurricane Ginger struck the Outer Banks, North Carolina, having slight impact on the study site, in September of 1971. Prior to 1971 and after the Ash Wednesday Storm in 1962, no major storm events impacted the North Carolina coast. The 1971 photographs were purchased from the North Carolina Department of Transportation. The 1984 photograph set was obtained from the North Carolina Department of Transportation and capture the study site conditions prior to Hurricane Diana. A set of orthophotographs from 1998 was obtained in digital format from the New Hanover County North Carolina archives. These photographs capture the storm effects of Hurricanes Bertha and Fran, both of which occurred in 1996. The 1998 photographs also capture the pre-storm conditions before Hurricanes Bonnie and Floyd pummeled southeastern North Carolina. Finally, the 2002 set of orthophotographs, also obtained from the New Hanover County archives, are the latest aerial photographs used in this study of Masonboro Island.

Remote Sensing and GIS Analyses

Photographs that were obtained as hard copies were scanned into digital format, at 300 dpi, for easy manipulation in GIS programs. Once in digital form, each image was rectified in the GIS program ArcMap using the align tool (Figure 6). The photographs were rectified to the North Carolina standard projection in the state plane coordinate

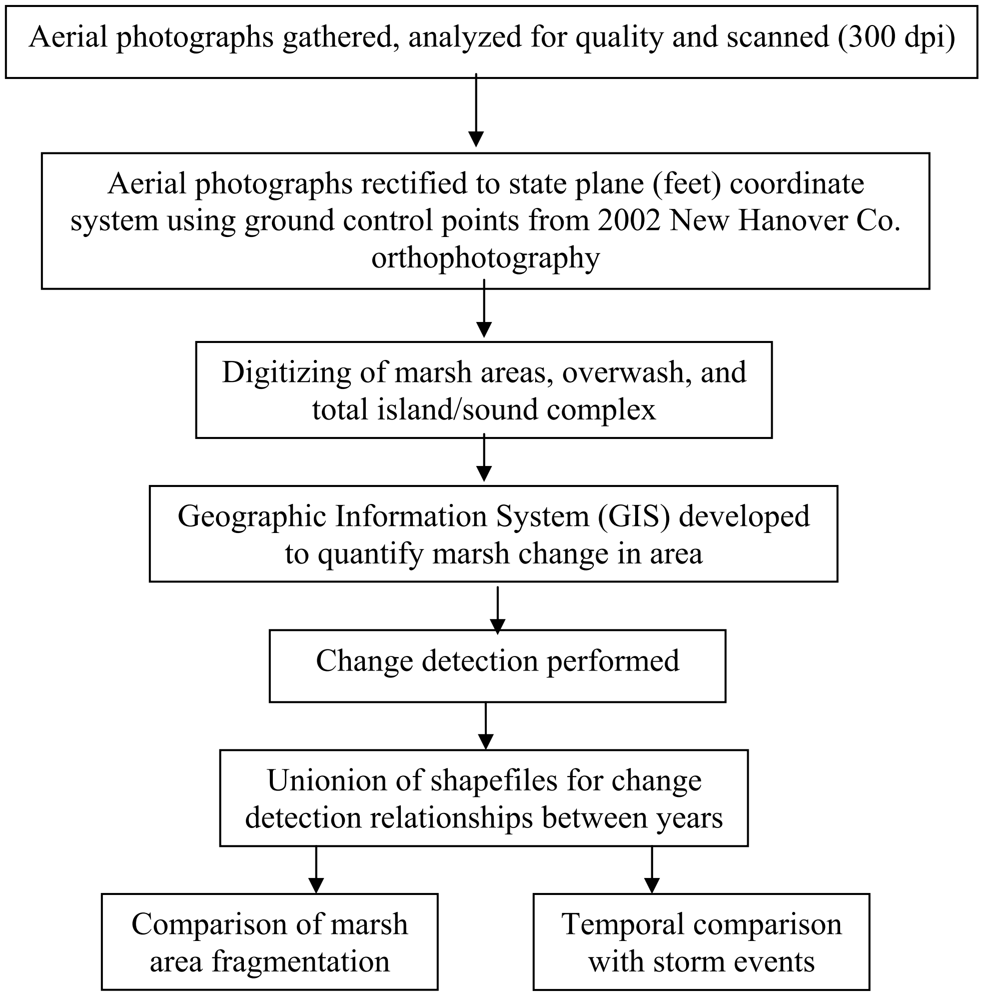


Figure 6: Flow chart of methodology

system, in feet, using the orthophotography from 2002. Grid values were assigned from the orthophotography to the unrectified photograph. A minimum of eight ground control points with less than 1.0 root mean square error was used for rectifying each set of photographs. Ground control points were chosen by visually inspecting the photographs. Also, field ground-truthing was done to insure accuracy of coverage types and boundaries. Ground-truthing involved examination of the land cover at several sites on the aerial photographs, which were confirmed by field, visits to those sites. Several procedures were initially explored to identify the most suitable approach for delineating and quantifying marsh change. Among those methods were supervised classification, unsupervised classification, modified unsupervised classification with extensions, and digitization. Below, the specifics of each method are discussed as well as the reasoning for why each method ultimately was not used.

Unsupervised Classification

The initial method attempted in this study used ERDAS Imagine to perform an unsupervised classification of the rectified aerial photographs using 50 classes with 8 iterations at 95%. After the classification was performed, the 50 classes were designated as either unvegetated supratidal, vegetated supratidal, unvegetated intertidal, vegetated intertidal, and subtidal. However, while assigning classes a designation, it was discovered that some of the classes fell into two or more of these categories. For this reason, several classes were assigned an obscure category that fell between two classes (i.e. a “gray-area” class between supratidal and intertidal, and a “gray-area” class between vegetated intertidal and subtidal).

Several areas of the photographs were assigned an inappropriate and inaccurate designation producing an unclear or mis-leading appearance of landcover classes. An example of this was noticed while comparing subtidal and vegetated intertidal areas. Because the photographs are black and white and classification depends on brightness of the photograph, some very dense, mature areas of marsh (vegetated intertidal) fell into the same class as subtidal (deep water). Both of these areas had a very dark reflective signature. This method of unsupervised classification assigned these two areas in the same category when they are obviously two distinct types of land cover. There was also some error in assigning the category of subtidal. Because the tidal stage was not recorded when the photographs were taken, it is uncertain if any of the "subtidal" areas are exposed during low tide thus making them unvegetated intertidal. After classes were assigned a designation and the final product of classified photo was examined, it was determined that this method was an inappropriate technique for use in this study.

Unsupervised Classification With Extensions

Another method that was explored was an unsupervised classification performed, using ERDAS Imagine, with the extensions clump and eliminate. The clump tool grouped classes together and when utilized with the eliminate tool produced a "cleaner" more accurate classified image. The eliminate tool was set to remove all pixels in a clumped class that were not in a group of 25 or more other pixels of the same class. So, in effect, the "strays" were removed, cleaning up the photograph classes and removing a small amount of the fuzziness around the boundaries between classes. However, there was still enough overlap and error between land cover classes that this method was decidedly inaccurate and inappropriate for this study.

Supervised Classification

A supervised classification was also performed on the photographs but was found to be unusable. The ERDAS IMAGINE 8.6 program would not allow a signature editor file to be created because only multi-layer files could be used. The black and white photographs used for this study are only single-layer files. Field ground-truthing in the study area confirmed that some areas and/or pixels in two obviously different classes would return the same feature signatures like brightness. For example, a less-dense, less-mature area of marsh (vegetated intertidal) can possibly have the same signature return as an area of unvegetated intertidal that is shallower than surrounding water.

Chosen Method

Ultimately, manual digitization of polygons was selected as the method to complete this study. While this method proved to be the most accurate and reliable, inaccuracies were still included. Due to the high amount of human interaction with the GIS program, there was a large amount of qualitative and subjective analyses involved.

While digitizing polygons around marsh features, marsh edge and boundaries between upland vegetation and marsh vegetation was subjective and dependent on the analyst. In addition, because the factor of tidal water levels with time of photography was unknown, areas that are vegetated and tidally influenced were indistinguishable. This was also dependent on the analyst. It was also unknown whether overwash fans and terraces that were being revegetated were vegetated by upland vegetation or marsh vegetation. These factors could not be determined by examining the photographs. Thus, while there may be error in the size of the marsh area, significantly less error was associated with land cover types and delineation. Most of the error associated with this method is related to analyst consistency, photograph quality, and assignment of fragmentation categories. To minimize error, only one analyst was used for this study. Although some amount of error was involved in using this method, it proved to be the most advantageous method for the study.

A GIS was created, using Arcview, to acquire marsh dimensions and qualitatively analyze change between years. To do this, polygons of marsh were manually digitized on each rectified photograph. These marsh polygons were then merged into one shapefile for the entire island to determine total marsh area. This same procedure was done to find the total island/sound area using the wet-dry line on the beach and the landward side of the dredge spoil islands as boundaries. The individual marsh polygons were analyzed for amount of fragmentation and assigned a category of high, medium or low fragmentation. High fragmentation was defined as a high percentage of open water to marsh area for digitized marsh polygons, and low fragmentation is defined as a low percentage. High fragmentation marsh ranged in general from 47% to 83% open water to marsh. Medium fragmentation marsh ranged from about 84% to 93% and low fragmentation marsh ranged from 94% to 99%. These percentages were found by digitizing open water areas within a given marsh polygon to determine area of open water and comparing these values to the total area of that marsh polygon to find a percentage. In addition, visible overwash deposits were digitized on each set of photographs. Total overwash area, measured from the wet-dry line to the visible landward edge of the deposits, was calculated. Fan size or lateral extent of overwash was compared to marsh area and fragmentation in relation to the closest occurring storm events. Overwash areas were also compared to the physiographic island sections and marsh responses.

Within the GIS, coverages were overlain and compared spatially and temporally for changes. A change detection was then performed in Arcview to determine what land cover types changed to and the areas of those changed land cover types. A shapefile from each year containing overwash, high, medium, and low fragmentation marsh, and other was unioned the shapefile of the next year to produce a map showing changed and unchanged areas. For each change detection performed the land cover types were high, medium, and low fragmentation marsh, and overwash. A category called "other" was also included which consisted of open water and uplands, because these two land cover types were not individually digitized. Following this, the changed areas were summarized and an output table was produced showing the pre-changed and resultant land cover type and their corresponding area of change in acres, which were then converted to square kilometers. Change matrices were created for each year comparison and long-term comparison showing the area of changed land cover in both square kilometers and as a percentage of the total island/sound area from 1938, which was the largest extent of the island complex during the study.

Changes in marsh area were finally qualitatively and quantitatively correlated with storm frequency to determine how major storm events affected marsh stability and fragmentation due to overwash processes and sediment supply. Changes in marsh extent and land cover type were examined for each of the five sections of Masonboro Island, identified by HOSIER and CLEARY (1977), based on dominant physiographic type and frequency of overwash. Shapefiles of each length of island section were displayed with the island and marsh shapefiles for easy comparison (Figures 7-13). The total area of each fragmentation category was calculated for each section for each year. These total areas were examined and the fragmentation category that occupied the most area in that section was designated as the dominant fragmentation type for that section for that year.

Due to quality of aerial photographs, areas of open water were not digitized, but rather accounted for by assigning the marsh area polygons, which included some areas of open water, with fragmentation categories. Visual analysis of year-to-year comparisons was done to insure no error existed from an increase in open water area that was not digitized and thus not accounted for. This was done by selecting random open water and marsh area polygons of high, medium, and low fragmentation from different years and overlaying the polygons onto the 2002 aerial photographs. The polygons were inspected to determine if any negative change occurred, a loss of marsh or gain in open water, equaling a degradation of marsh.

Of the six areas compared in this manner, three areas had no identifiable change in open water from one year to the next. The remaining three areas did not have an increase in open water area, but rather an increase in marsh area, indicating the procession of infilling open water areas in marsh to higher-fragmented marsh. This is an example of how marsh areas were overestimated during analysis. The conclusions from the examination of the six areas was that any changes that occurred, but were not accounted for due to not digitizing open water areas are equal to, or offset, by the amount of human error already expected from the methods of this study.

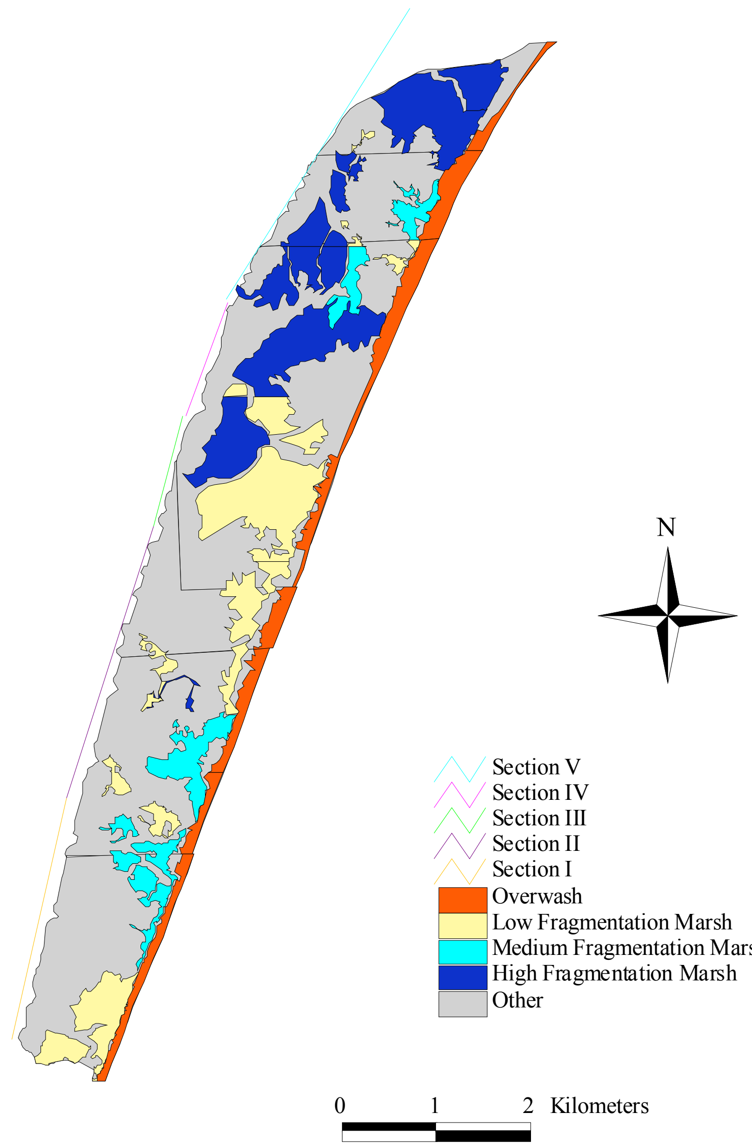


Figure 7: Fragmented marsh and overwash in relation to total island/sound and physiographic sections in 1938

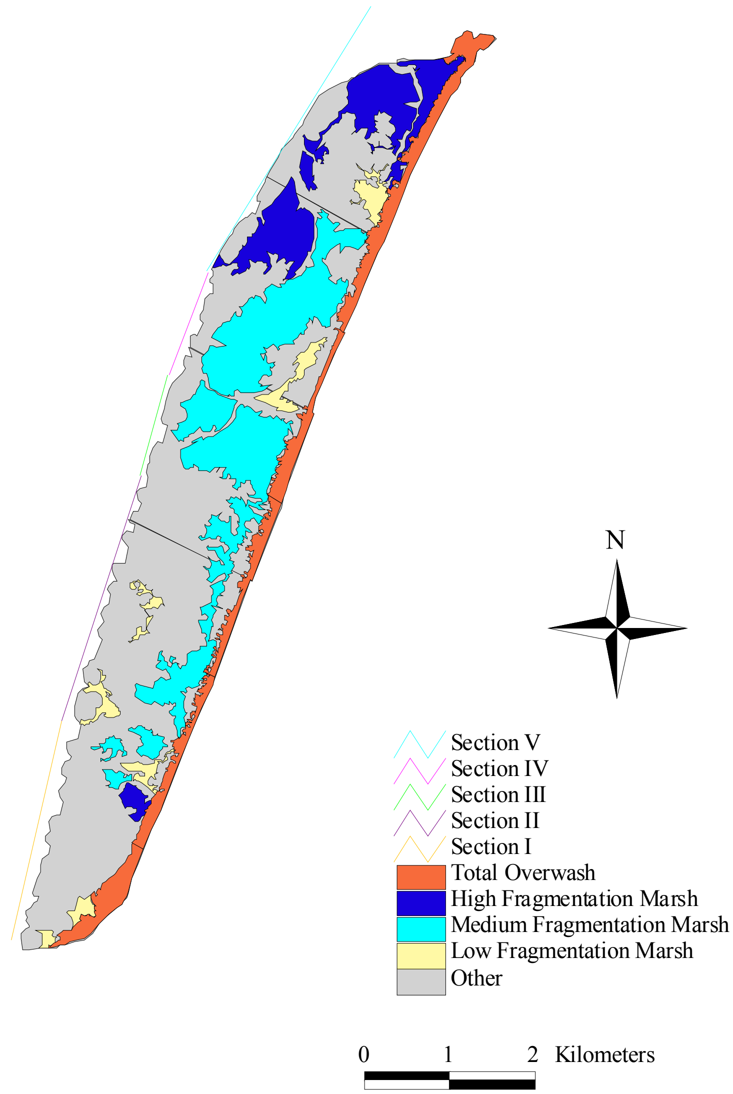


Figure 8: Fragmented marsh and overwash in relation to total island/sound and physiographic sections in 1959

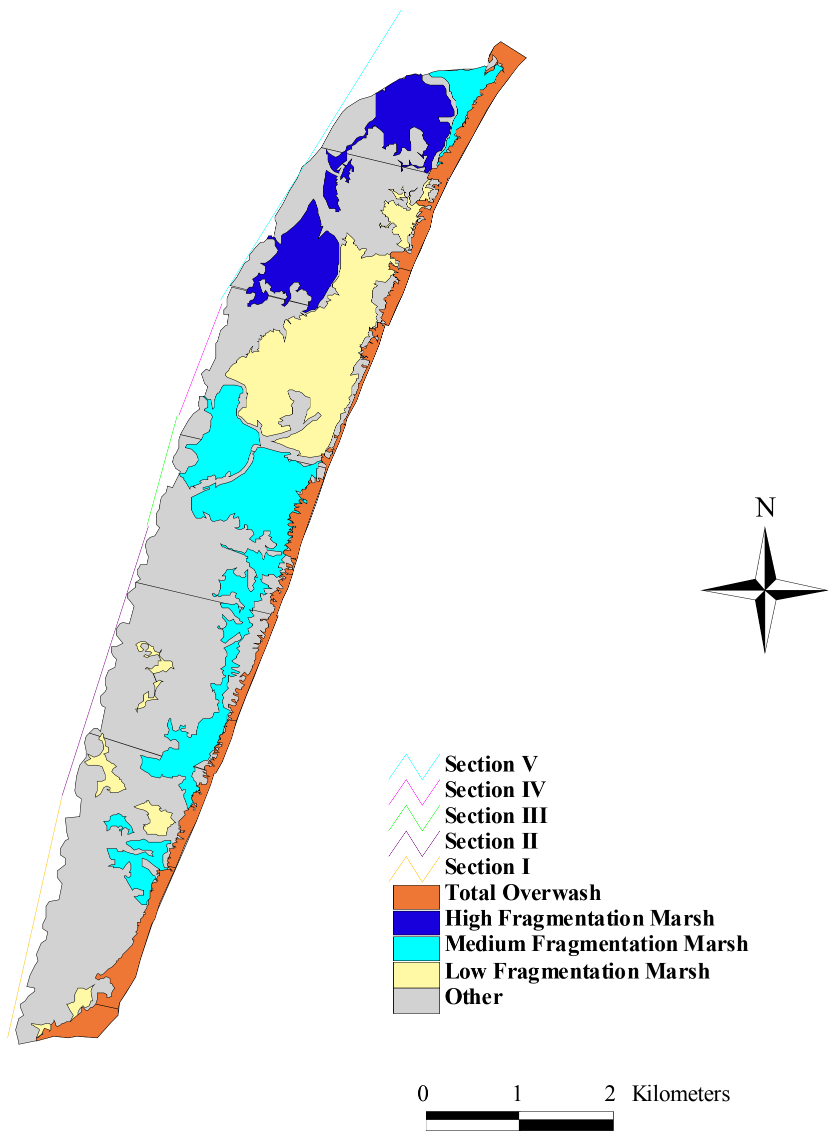


Figure 9: Fragmented marsh and overwash in relation to total island/sound and physiographic section in 1962

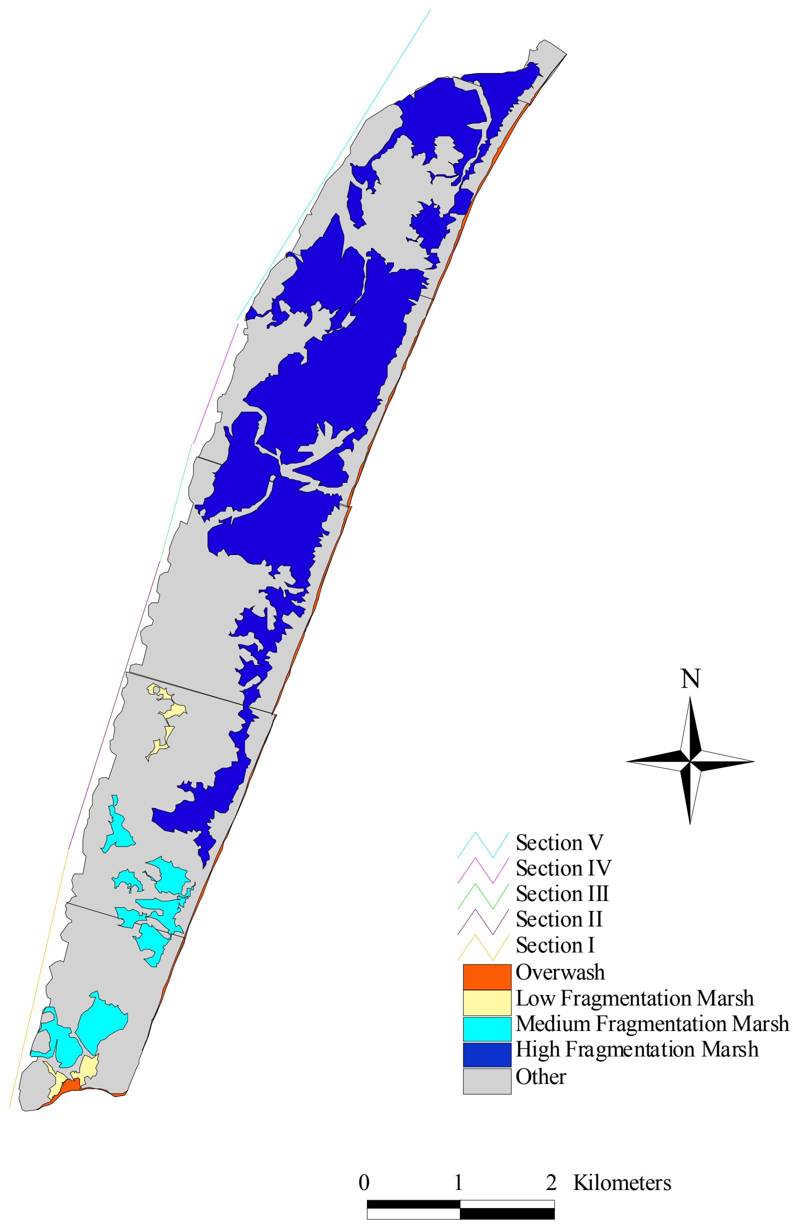


Figure 10: Fragmented marsh and overwash in relation to total island/sound and physiographic sections in 1971

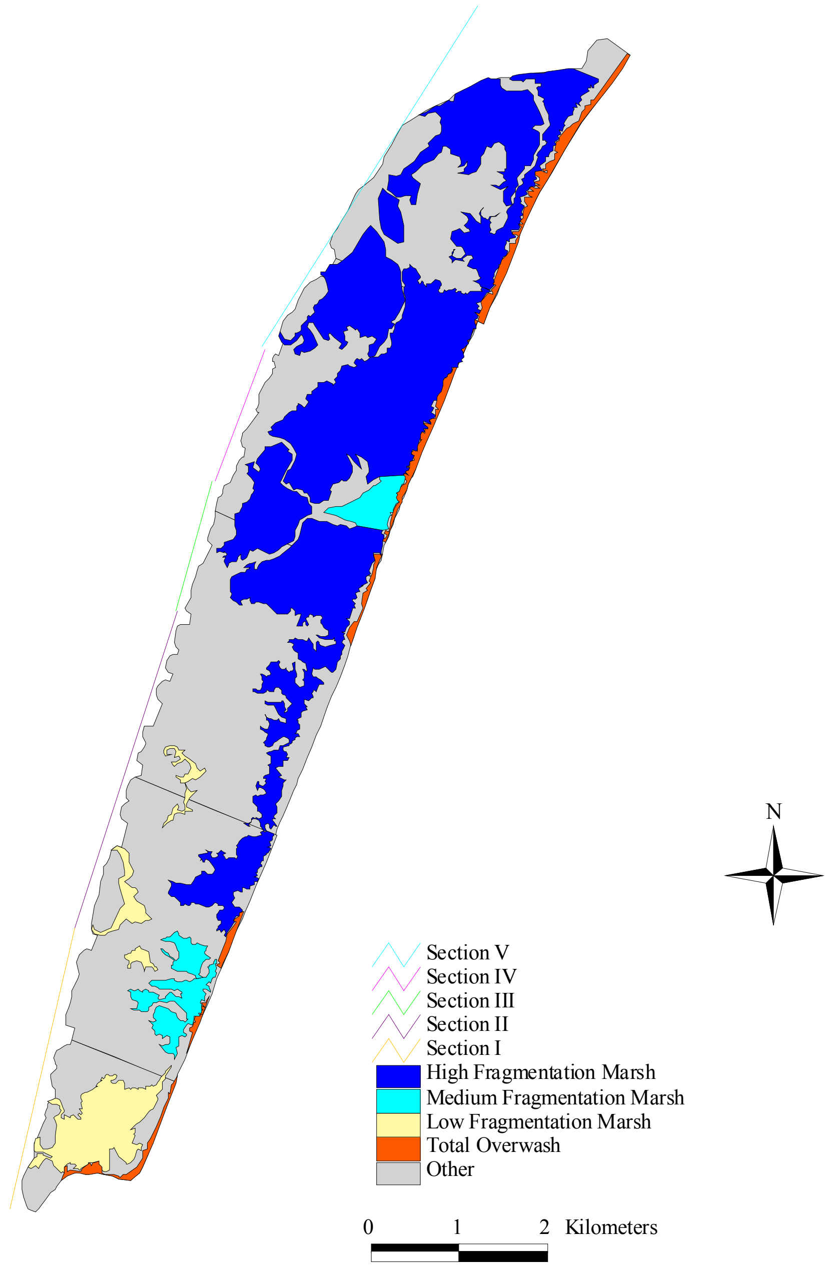


Figure 11: Fragmented marsh and overwash in relation to total island/sound and physiographic sections in 1984

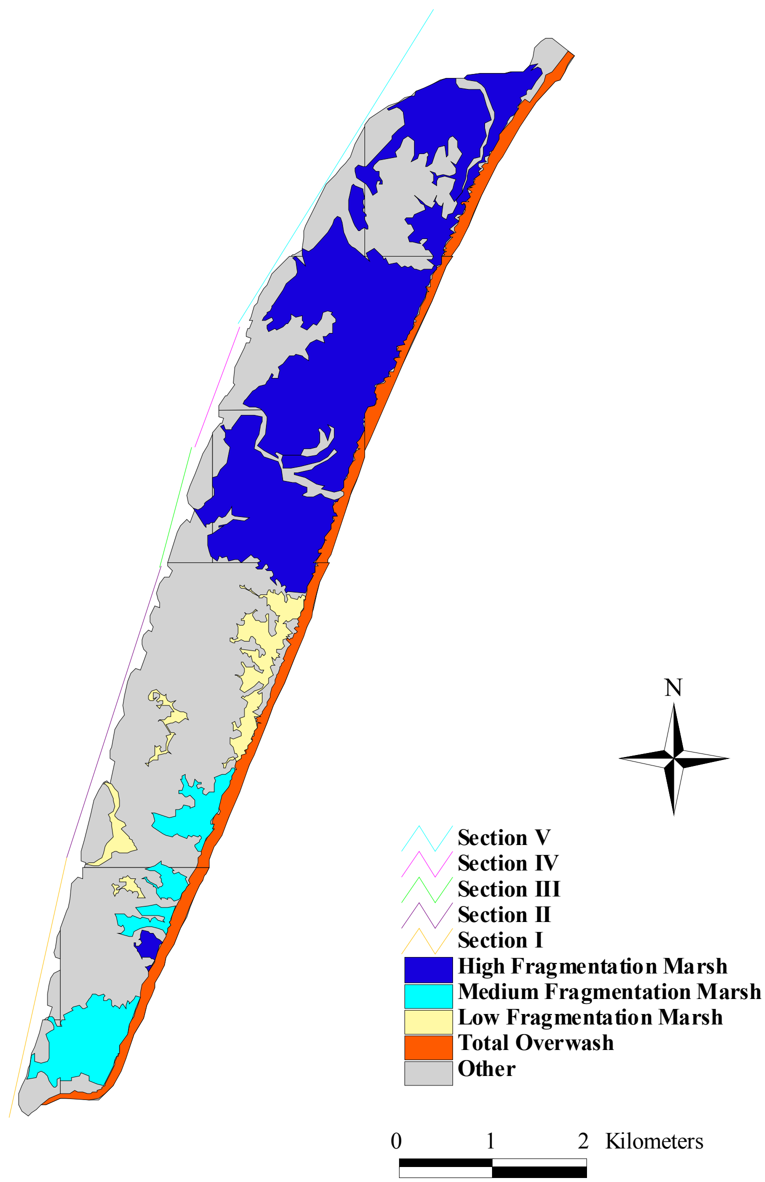


Figure 12: Fragmented marsh and overwash in relation to total island/sound and physiographic sections in 1998

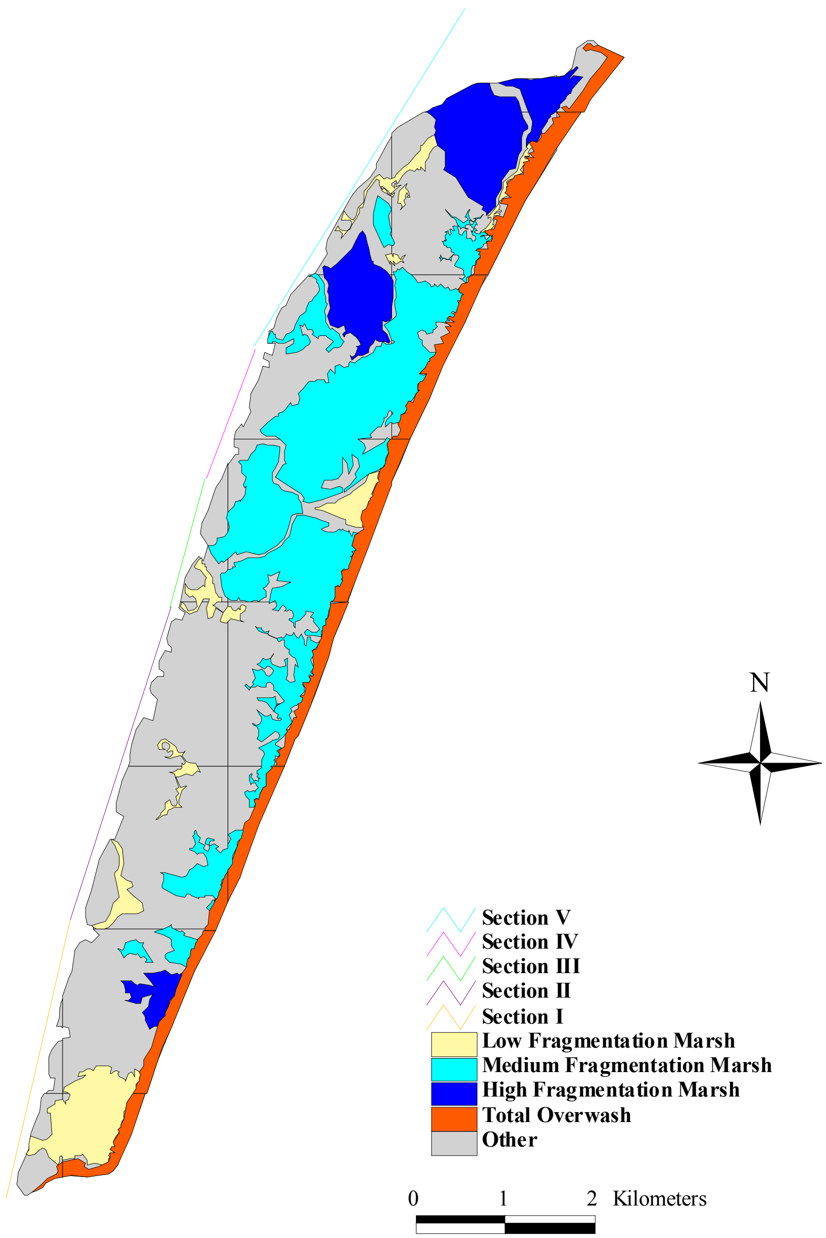


Figure 13: Fragmented marsh and overwash in relation to total island/sound and physiographic sections in 2002

Statistical Analyses

Statistical analyses were performed using the JMP program. One-way ANOVA was used to determine if any significant changes in marsh area occurred between each photograph year or between the long-term time period from 1938 to 2002. For each test, the two factors, year and physiographic section, with percent island that is marsh in each section as the dependent factor, were compared. An alpha level of 0.05 was used to determine significant differences between factors in each test. Any significant differences found between factors were examined using a Tukey-Kramer correlation test to determine where the significant relationships existed.

RESULTS

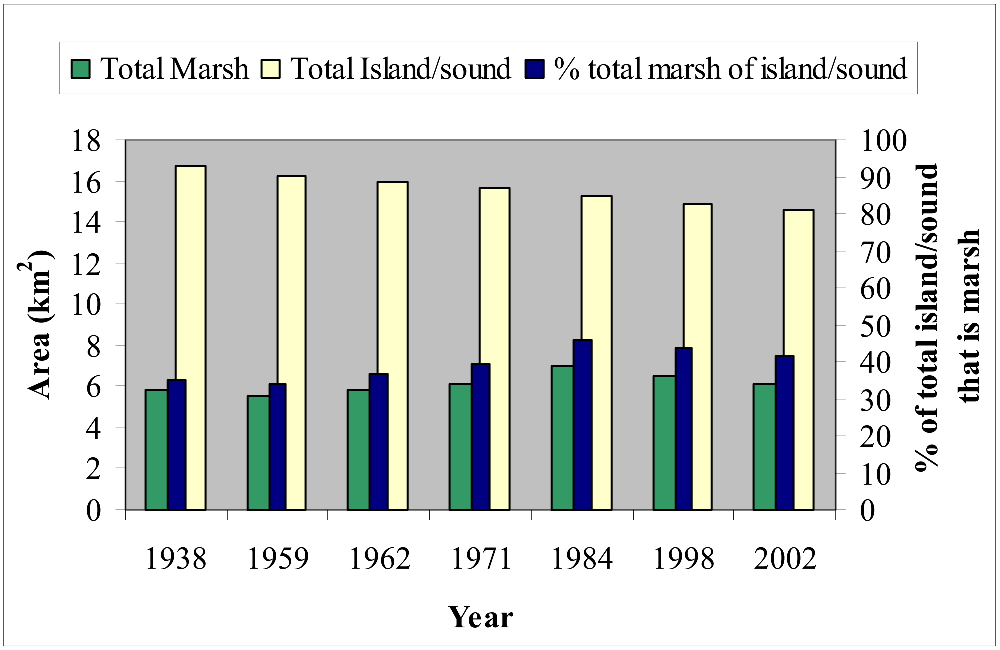
Aerial Marsh Extent

1938 Marsh Distribution

Approximately 5.85 km^2 of marsh existed behind Masonboro Island in 1938 (Figure 14). Vegetated marsh occupied about 34.9% of the 16.73 km^2 island/sound system. Of that 35%, approximately 2.68 km^2 (or 46%) consisted of high fragmentation marsh. Approximately 0.95 km^2 (or 16%) was medium fragmentation marsh, and 2.21 km^2 (or 38%) was low fragmentation marsh.

The total area of marsh located in Physiographic Section V was 2.16 km^2, occupying approximately 44% of the island/sound area. Section IV contained 0.81 km^2 of marsh, 38% of the island/sound in the section. About 1.13 km^2 of marsh, 58% of the island/sound in the section, was found in Section III. There was approximately 0.89 km^2 of marsh in Section II, or 20% of the island/sound area in the section. Approximately 0.85 km^2 of marsh area was located in Section I, and comprised about 26% of the island/sound in that section.

Physiographic Section V contained approximately 70% of the high fragmentation marsh, with Sections IV, III, and II containing the remaining 19%, 10%, and 1% respectively. There was no high fragmentation marsh in the southern-most area of the island/sound complex, Section I. The medium fragmentation marsh was almost equally divided between Sections V, II, and I. Sections IV and III did not contain any medium fragmentation marsh. Most of the low fragmentation marsh, as well as the least amount

A)


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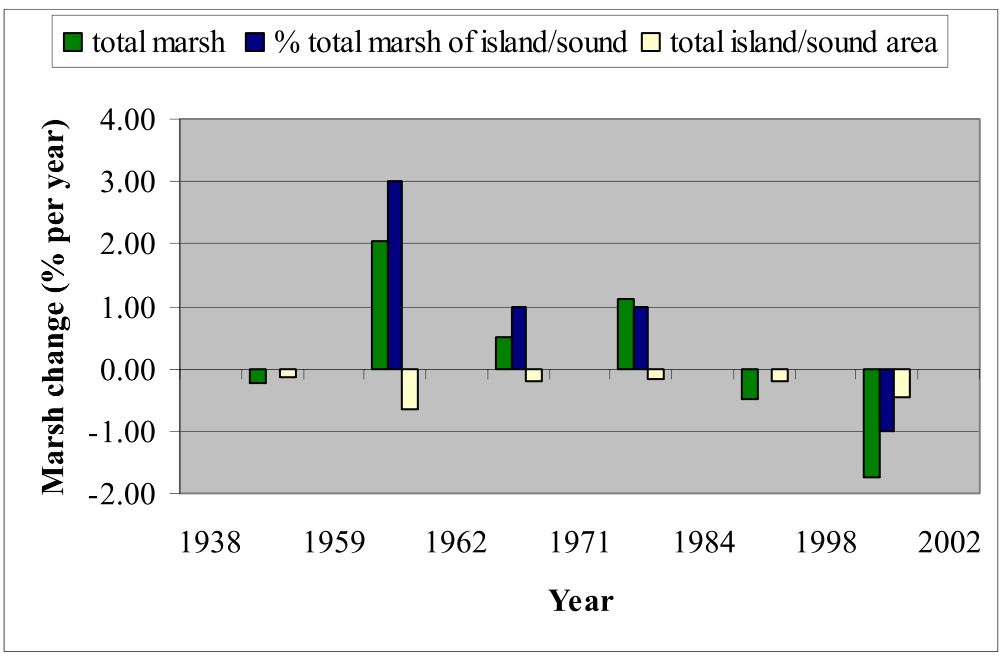


Figure 14: A) Total marsh area, total island/sound area, and percentage of island/sound that is marsh per year B) Percent change in total marsh area, total island/sound area, and % of island/sound that is marsh per year

of total marsh area, existed in the southern half of the island/sound complex (Appendix C). The remaining portions of medium fragmentation marsh were in Sections V and IV, each having 3% and 12 % respectively. Based on overall marsh area in the section, Sections V and IV contained mostly, high fragmentation marsh and were, therefore, dominated by this fragmentation type. Low fragmentation marsh was the dominant fragmentation type in Sections III, II, and I.

1959 Marsh Distribution

The total island/sound area in 1959 was approximately 16.24 km^2, a decrease in area from 1938 of about 3% (Figure 14). Washover deposits comprised 1.65 km^2 of the island/sound area. Marsh occupied approximately 5.54 km^2 of the island's area, or 5% less marsh than in 1938. Total marsh area consisted of 29% high fragmentation marsh, 60% medium fragmentation marsh, and 11% low fragmentation marsh.

A significant difference ($p<0.05$) between the marsh area of each section in 1938 and the marsh area of each section in 1959 occurred in Sections III, IV, and V. In Section V, approximately 2.14 km^2 of the island area in the section consisted of vegetated marsh. Section IV contained approximately half as much marsh or 1.07 km^2, which accounted for 52% of the island in that section. In Section IV, marsh area increased, on average, by 0.6% per year between 1938 and 1959. About 1.04 km^2 of marsh occurred in Section III, while Section II contained 0.88 km^2 of marsh. Section I contained the lowest marsh acreage of any of the sections. The rate of change of marsh area in Section I between 1938 and 1959 was a loss of 0.5% per year.

Almost all of the high fragmentation marsh occurred in Section V, although a small amount existed in Section I. Sections IV, III, and II contained no high fragmentation marsh. The medium fragmentation marsh was, for the most part, equally divided among Sections V, IV, III, and II. The remaining medium fragmentation marsh was located in Section I. Sections V, IV, II, and I contained equal amounts of the low fragmentation marsh. Section III contained no low fragmentation marsh. Section V was dominated by high fragmentation marsh and Section I was dominated by low fragmentation marsh. Medium fragmentation marsh was the dominant type in Sections IV, III, and II.

1962 Marsh Distribution

During the three years since 1959, Masonboro Island lost approximately 2% of the total island/sound area, decreasing in size to 15.93 km^2 (Figure 14). Washover deposits comprised of 1.52 km^2, or about 8% less than the area in 1959. Total marsh areas, however, increased by 6%; a net gain of approximately 5.54 m^2. About 1.22 km^2 of high fragmentation marsh existed in 1962, and accounted for 21% of the total marsh area behind the island. Medium fragmentation marsh contributed to 41% of total marsh area and the remaining 38% of marsh area was occupied by of low fragmentation marsh.

There was about 2.19 km^2 of marsh located in Section V. Sections III, IV, and V experienced a significant ($p<0.0008$) change in marsh area between 1959 and 1962. A relatively rapid increase in marsh area, 0.7% per year, occurred in Section V since 1959. Approximately 1.37 km^2 of marsh existed in Section IV, which experienced a very rapid rate of change (5.1% per year) in marsh area since 1959. Section III also experienced an increase in marsh since 1959 reaching approximately 1.08 km^2. Section II contained about 0.88 km^2 of marsh, about 20% of the island/sound area of the section, and Section I contained approximately 0.35 km^2 of marsh. A rate of loss of marsh area in Section I of 0.6% occurred since 1959.

All of the high fragmentation marsh in 1962 was located in the northern-most Section V. The majority of the medium fragmentation marsh was located in Sections III and II. The remaining medium fragmentation marsh was equally divided among Section V, Section IV, and Section I. Approximately 47% of the low fragmentation marsh occurred in Section V and 40% occurred in Section IV. The remaining 13% was located in Sections II and Section I. Section III did not contain any low fragmentation marsh. High fragmentation marsh was the most dominant type of Section V's marsh area and low fragmentation marsh dominated Section IV's marsh area. Sections III, II, and I were all dominated by medium fragmentation marsh.

1971 Marsh Distribution

In 1971, the total island/sound area of Masonboro Island was 15.66 km^2, a relatively small decrease in area since the 1962 photographs (Figure 14). Marsh comprised approximately 6.14 km^2 of that area, an increase of 4% since 1962. High fragmentation type marsh accounted for about 87% of the total marsh. Medium fragmentation marsh comprised 11% of the total marsh and low fragmentation marsh was a very low 2%.

A significant ($p<0.0004$) amount of change in marsh area per section occurred in Sections III, IV, and V between 1962 and 1971. Physiographic Section V contained about 2.29 km^2 of marsh, and approximately 1.27 km^2 and 1.07 km^2 occurred in Sections IV and III, respectively. The extent of marsh in Section II (0.84 km^2) and Section I (0.67 km^2) were similar, due to a rapid rate of increase (1.4% per year) of marsh area in Section I since 1962.

Section V contained almost half, 48%, of the high fragmentation marsh. The remainder was divided among Sections IV, III, and II. There was no high fragmentation marsh in Section I. Most of the medium fragmentation marsh, 76%, was located in Section I in 1971. The remaining 24% was found in Section II while Sections V, IV, and III did not contain any medium fragmentation marsh. The low fragmentation marsh was distributed almost equally between Sections II and I. There was no low fragmentation marsh in Sections V, IV, and III. High fragmentation marsh was the dominant fragmentation type for Sections V, IV, and III with 100%, and II with 69% of the total marsh area in each section. Medium fragmentation marsh dominated 88% of Section I's area. Low fragmentation marsh did not dominate in any of the physiographic sections.

1984 Marsh Distribution

The total area of Masonboro Island and Sound in 1984 was approximately 15.55 km^2, a decrease in area of about 2% since 1971 (Figure 14). Marsh occupied about 7.04 km^2 of the total area, an increase of 15% from 1971. High fragmentation marsh comprised about 82% of the total marsh, and approximately 7% of the total marsh area consisted of medium fragmentation marsh. The remaining 11% of the marsh area was comprised of low fragmentation marsh. Significant ($p<0.0008$) changes in marsh area per section occurred in Sections III, IV, and V from 1971 to 1984. Physiographic Section

V contained 2.67 km^2 of marsh, an increase of about 0.5% of the total area in the region since 1971. Section IV contained about half as much marsh or, 1.38 km^2. Section IV also experienced marsh growth over the period gaining at a rate comparable to Section V. There was approximately 1.12 km^2 of marsh in Section III, and about 0.93 km^2 of marsh in Section II. Section I contained slightly less marsh than Sections II or III, or 0.89 km^2 of marsh despite an increase in marsh area in that Section of 0.8% per year since 1971.

High fragmentation marsh occupied approximately 52% of the total marsh area in Section V. The remaining high fragmentation marsh was found in Sections IV, III, and II. There was no high fragmentation marsh located in Section I. No medium fragmentation marsh was found in Sections V and III, but about 35% was found in Section IV. Section II contained about 17% of the medium fragmentation marsh and the remaining 47% was located in Section I. There was no low fragmentation marsh found in Sections V, IV, or III. Sections II and I contained 21% and 79% low fragmentation marsh, respectively. High fragmentation marsh dominated Sections V, IV, III, and II, accounting for all of the marsh in Sections V and III, and 85.5% and 75%, respectively, in IV, and II. Medium fragmentation marsh did not dominate any of the physiographic sections. Low fragmentation marsh was the dominant marsh type in Section I comprising about 75.5% of the marsh area.

1998 Marsh Distribution

Total island/sound area in 1998 was about 3% less than in 1984, with 14.90 km^2 of area (Figure 14). Approximately 7% of the marsh area was lost since 1984, decreasing in marsh area to 6.55 km^2. Of the total marsh area, 76 % consisted of high fragmentation marsh. Approximately 15%, was medium fragmentation marsh and 9% was low fragmentation marsh.

A highly significant difference ($p<0.0001$) in marsh area per section occurred in Sections II, III, IV, and V from 1984 to 1998. Section V contained 2.51 km^2 of marsh, filling almost half of the backbarrier area. Section IV again contained about half as much as Section V or 1.29 km^2. Section III contained approximately 1.12 km^2 of marsh. Sections II and I contained equal areas of marsh; 0.81 km^2 and 0.81 km^2, respectively.

Fifty-four percent of the high fragmentation marsh occurred in Section V, 28% in Section IV, and 17% in Section III. There was no high fragmentation marsh in Section II and Section I contained only 1%. All of the medium fragmentation marsh was located in the two southern-most sections, Sections II and I, with twice as much in Section I than Section II. The majority of the low fragmentation marsh, 78%, occurred in Section II. The remaining portion was divided between Section III and Section I. No low fragmentation marsh existed in Sections V and IV. High fragmentation marsh comprised more than 90% of the marsh type for Section V, IV, and III. For Sections II and I, 57% of the marsh in Section II was low fragmentation marsh and 90% of the marsh in Section I was medium fragmentation marsh.

2002 Marsh Distribution

By 2002, the total island/sound complex was 2% smaller than it was in 1998, covering 14.62 km^2 of area (Figure 14). Backbarrier marsh covered 6.09 km^2 of the total area, or about 42% of the island/sound system. About 24% of the total marsh was highly fragmented, covering an area of 1.46 km^2. Medium fragmentation accounted for 59% of the marsh and low fragmentation marsh accounted for the remaining 17% of the total marsh area. From 1998 to 2002, the extent of high fragmentation marsh area significantly increased ($p<0.0317$). None of the other fragmentation types exhibited significant change.

Physiographic Section V contained about 2.35 km^2 of marsh, slightly less than in 1998. Significant differences ($p<0.0001$) in marsh area were observed for Section II, III, IV, and V from 1998 to 2002. Section V experienced a loss of marsh area since 1998 at a rate of 0.9% per year. Section IV contained approximately 1.18 km^2 of marsh, and experienced a relatively rapid rate of loss, 1.3% per year, since 1998. There was about 1.10 km^2 of marsh located in Section III and approximately 0.70 km^2 in Section II. There was very little change in marsh area in Section III since 1998, however, the rate of marsh area loss in Section II was 0.5% per year. Section I contained approximately 0.76 km^2 of marsh, or slightly less than in 1998.

Approximately 90% of the high fragmentation marsh existed in the northern-most portion of the island/sound, Section V. The remaining 10% existed in the southern-most section, Section I. The majority of the medium fragmentation marsh occurred in Sections V, IV, and III. Section II contained 13% and Section I contained 3% medium fragmentation marsh. About 62% and 53% of the low fragmentation marsh occurred in Sections V and I, respectively. Sections IV, III, and II each contained less than 15%. High fragmentation marsh was the dominant fragmentation type of Section V, comprising 52% of the section's total marsh area. Medium fragmentation marsh accounted for the majority (>75%) of total marsh by section in Sections IV, III, and II. Low fragmentation marsh was the dominant type in Section I comprising 69% of the total marsh area in the section.

Change Detection

1938-1959 Change

The results from the change detection for the 1938 to 1959 time period comparison shows that the greatest change was the conversion of approximately 1.32 km^2 of low fragmentation marsh to medium fragmentation marsh over the length of the island/sound complex (Figure 15). About 1.01 km^2 of high fragmentation marsh changed to medium fragmentation marsh. Over this same period, other types of noteworthy coverage change include conversion of 'other' areas, either open water or uplands, to overwash (0.34 km^2) and medium fragmentation marsh (0.51 km^2), and overwash (0.19 km^2) and low fragmentation marsh (0.27 km^2) changing to areas of the 'other' category. All types and areas of change results for the 1938 to 1959 time period are in Tables 1and 2.

1959-1962 Change

For the time period from 1959 to 1962, the largest amount of change was 1.32 km^2 of medium fragmentation marsh converting to low fragmentation marsh. The only other types of notable coverage change were overwash converting to areas of 'other' (0.11 km^2), and areas of 'other' converting to low fragmentation marsh (0.49 km^2) (Figure 15). Tables 1 and 2 show all results from the change detection for the 1959 to 1962 time period.

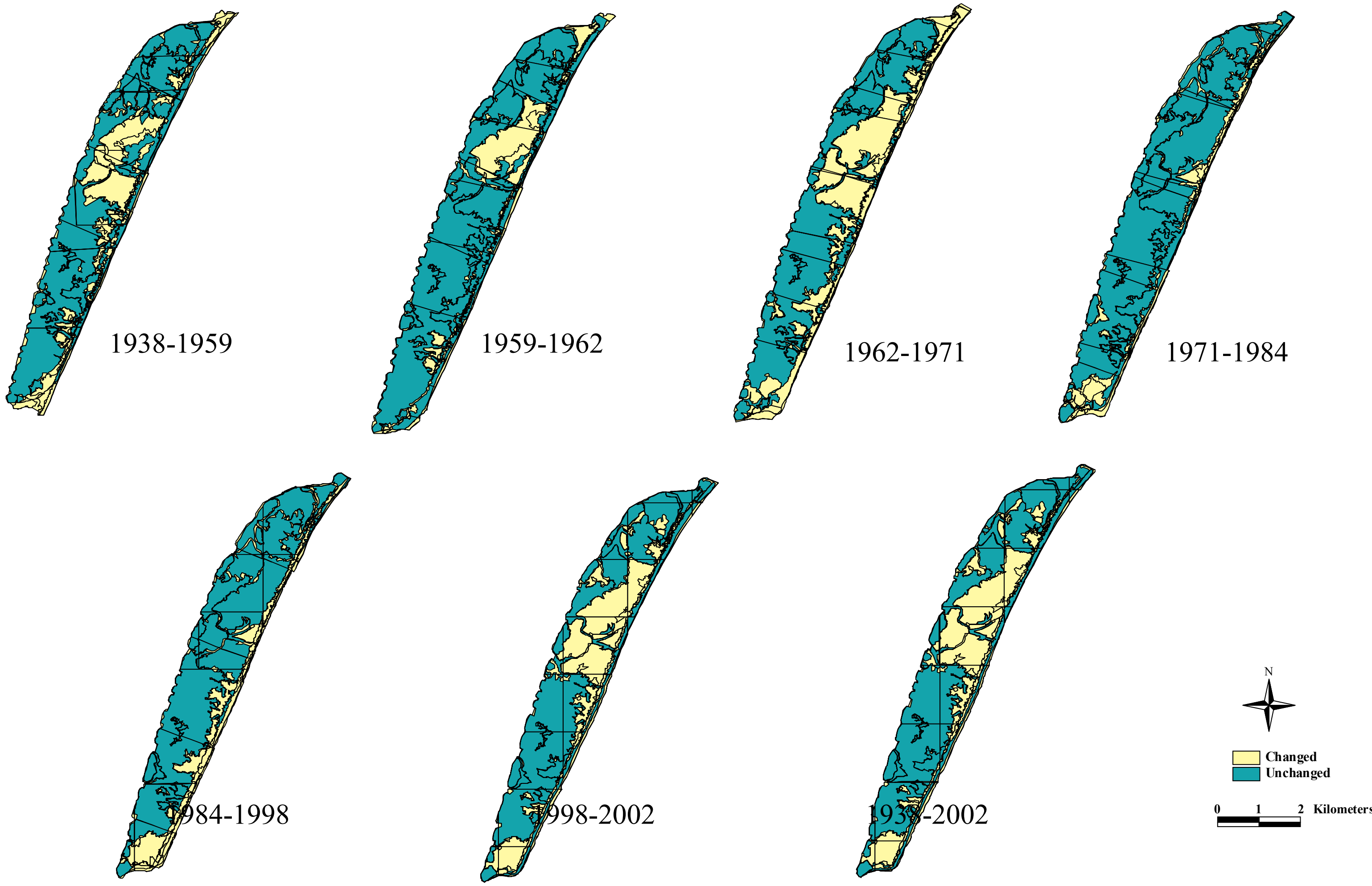


Figure 15: Maps of each year comparison showing areas of change and no change

Table 1: Matrices of change detection results (in km^2) for each year comparison

59(is) 38(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	8.16	0.19	0.25	0.12	0.27
overwash	0.34	0.84	0.04	0.06	0.18
high frag marsh	0.17	0.02	1.31	0.10	0.01
med frag marsh	0.51	0.01	1.01	0.51	1.32
low frag marsh	0.17	0.00	0.01	0.17	0.25

62(is) 59(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	8.00	0.11	0.10	0.15	0.07
overwash	0.18	1.17	0.04	0.04	0.03
high frag marsh	0.17	0.00	1.15	0.00	0.00
med frag marsh	0.22	0.01	0.28	1.84	0.06
low frag marsh	0.49	0.00	0.02	1.32	0.42

71(is) 62(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	7.69	1.05	0.07	0.20	0.22
overwash	0.04	0.13	0.00	0.00	0.00
high frag marsh	0.32	0.00	1.15	2.01	1.80
med frag marsh	0.36	0.00	0.00	0.19	0.14
low frag marsh	0.04	0.00	0.00	0.00	0.09

84(is) 71(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	7.47	0.01	0.24	0.06	0.02
overwash	0.25	0.04	0.01	0.00	0.02
high frag marsh	0.80	0.00	4.95	0.00	0.00
med frag marsh	0.12	0.00	0.12	0.26	0.00
low frag marsh	0.31	0.00	0.00	0.38	0.07

98(is) 84(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	6.61	0.02	0.34	0.01	0.06
overwash	0.41	0.13	0.43	0.13	0.05
high frag marsh	0.42	0.00	4.38	0.18	0.00
med frag marsh	0.12	0.00	0.22	0.17	0.50
low frag marsh	0.06	0.00	0.36	0.00	0.15

02(is) 98(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	6.51	0.01	0.40	0.04	0.05
overwash	0.17	0.84	0.20	0.10	0.05
high frag marsh	0.14	0.00	1.24	0.08	0.00
med frag marsh	0.08	0.00	2.93	0.27	0.33
low frag marsh	0.17	0.00	0.21	0.51	0.13

02(is) 38(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	6.41	0.01	0.21	0.07	0.19
overwash	0.72	0.31	0.08	0.15	0.23
high frag marsh	0.28	0.00	1.07	0.12	0.00
med frag marsh	0.75	0.00	1.19	0.47	1.20
low frag marsh	0.70	0.00	0.05	0.01	0.26

Table 2: Change detection results (% landcover of 1938 total island/sound area)

59(is) 38(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	48.77	1.13	1.49	0.69	1.64
overwash	2.01	5.02	0.23	0.37	1.09
high frag marsh	1.02	0.10	7.83	0.57	0.03
med frag marsh	3.03	0.00	6.01	3.06	7.89
low frag marsh	1.01	0.00	0.00	1.01	1.49

62(is) 59(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	47.85	0.64	0.61	0.90	0.42
overwash	1.10	7.00	0.27	0.23	0.16
high frag marsh	0.45	0.00	6.86	0.00	0.00
med frag marsh	1.30	0.03	1.69	11.02	0.35
low frag marsh	2.92	0.00	0.09	7.86	2.53

71(is) 62(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	45.95	6.28	0.45	1.22	1.30
overwash	0.23	0.76	0.00	0.00	0.02
high frag marsh	1.89	0.00	6.87	12.03	10.73
med frag marsh	2.13	0.03	0.00	1.15	0.81
low frag marsh	0.24	0.00	0.00	0.00	0.54

84(is) 71(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	44.62	0.05	1.44	0.33	0.11
overwash	1.49	0.21	0.04	0.00	0.11
high frag marsh	4.77	0.01	29.56	0.00	0.00
med frag marsh	0.74	0.00	0.71	1.55	0.00
low frag marsh	1.86	0.00	0.00	2.25	0.39

98(is) 84(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	39.51	0.14	2.01	0.08	0.34
overwash	2.45	0.78	2.57	0.77	0.29
high frag marsh	2.48	0.00	26.17	1.07	0.00
med frag marsh	0.70	0.01	1.33	1.00	2.97
low frag marsh	0.34	0.00	2.17	0.00	0.89

02(is) 98(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	38.91	0.08	2.37	0.26	0.31
overwash	1.03	5.31	1.18	0.61	0.30
high frag marsh	0.85	0.00	7.42	0.48	0.00
med frag marsh	0.46	0.00	17.51	1.63	1.99
low frag marsh	1.02	0.00	1.28	3.04	0.79

02(is) 38(was)	other	overwash	high frag marsh	med frag marsh	low frag marsh
other	38.28	0.06	1.26	0.43	1.13
overwash	4.32	1.87	0.49	0.88	1.40
high frag marsh	1.67	0.00	6.38	0.71	0.00
med frag marsh	4.49	0.00	7.11	2.81	7.19
low frag marsh	4.16	0.01	0.32	0.05	1.56

1962-1971 Change

During the time period from 1962 to 1971, three types of change contributed to identifiable changes in land cover. About 1.05 km^2 of overwash converted to areas of 'other' (Figure 15). Approximately, 2.01 km^2 of medium fragmentation marsh converted to high fragmentation marsh, and 1.80 km^2 of low fragmentation marsh converted to high fragmentation marsh. No other types of significant change occurred. All results of the change detection for the 1962 to 1971 time period are listed in Tables1 and 2.

1971-1984 Change

From 1971 to 1984, the most noteworthy change consisted of 0.80 km^2 of other changed to areas of high fragmentation marsh (Figure 15). Also, approximately 0.38 km^2 of medium fragmentation marsh converted to low fragmentation marsh. Other types of change and their corresponding areas for the 1971 to 1984 time period are listed in Tables 1 and 2.

1984-1998 Change

During the time period from 1984 to 1998, one major type of change occurred. This was the conversion of 4.38 km^2 of high fragmentation marsh to medium fragmentation marsh. In addition, about 0.43 km^2 of high fragmentation marsh changed to overwash. Also, approximately 0.12 km^2 of areas of 'other' changed to medium fragmentation marsh, and about 0.41 km^2 of areas of other changed to overwash (Figure 15). All types of change for the 1984 to 1998 time period are listed in Tables 1 and 2.

1998-2002 Change

The most appreciable change that occurred from 1998 to 2002 was the conversion of 2.93 km^2 of high fragmentation marsh to medium fragmentation marsh. Also, approximately 0.51 km^2 of medium fragmentation marsh converted to low fragmentation marsh, and 0.40 km^2 of high fragmentation marsh converted to areas of the 'other' category (Figure 15). Tables 1 and 2 show the remaining types of change and areas for the 1998 to 2002 time period.

Long-term Change

Over the entire study period from 1938 to 2002, approximately 0.72 km^2 of 'other' areas consisting of upland, open water, or unvegetated tidal flat converted to overwash, and about 0.75 km^2 of areas of 'other' changed to medium fragmentation marsh (Figure 15). Approximately 0.70 km^2 of areas of 'other' changed to low fragmentation marsh. About 0.19 km^2 of low fragmentation marsh changed to areas of 'other'. Over the 64-year period, 1.20 km^2 of low fragmentation marsh converted to medium fragmentation marsh, and about 1.19 km^2 of high fragmentation marsh converted to medium fragmentation marsh. The remaining types of change and their corresponding areas are listed in Tables 1 and 2. In addition, over the long term, the amount of marsh located in Section III changed significantly ($p<0.0206$). In addition, the amount of total marsh that occupied the island/sound complex changed significantly ($p<0.0238$) from 1938 to 2002.

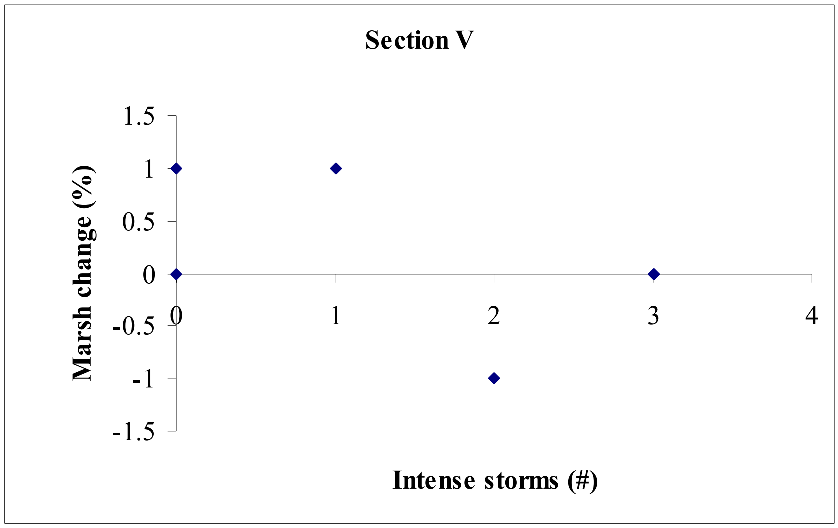
Storm Event Correlation

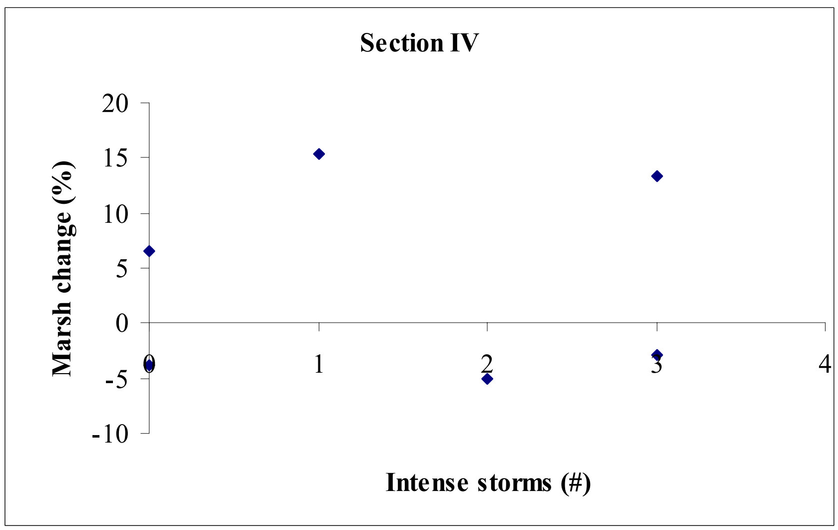
Nine storm events, including four major hurricanes, Hurricane of 1944, Hazel, Diane, and Helene, impacted the study site during the time period from 1938 to 1959, at an average rate of 0.4 storms per year during the 21 year period (Appendix A). From 1959 to 1962, four storms events impacted Masonboro Island at a rate of 1.3 storms per year. One of the four storms, Donna, was a major hurricane, and one was a major nor'easter, the Ash Wednesday Storm of '62. There were four storms during the 1962 to 1971 time period, though most of these events were of minimal intensity. The frequency of storms to affect the island during the nine year time period between 1962 and 1971 was 0.4 storms per year. From 1971 to 1984, seven storms impacted the island with a frequency of 0.5 storms per year over the 13-year period. Hurricane Diana occurred after the 1984 aerial photograph set was taken and so is included in the 1984 to 1998 time period. No major hurricanes occurred from 1971 to 1984. From 1984 to 1998, three major hurricanes struck Masonboro Island, Hurricanes Diana, Bertha and Fran. There were a total of eight storm events during the time period yielding at a rate of 0.6 storms per year. During the short, four year time period from 1998 to 2002 two hurricanes, Bonnie and Floyd, impacted the study site. A total of four storm events occurred over the four-year period at a frequency of one storm per year.

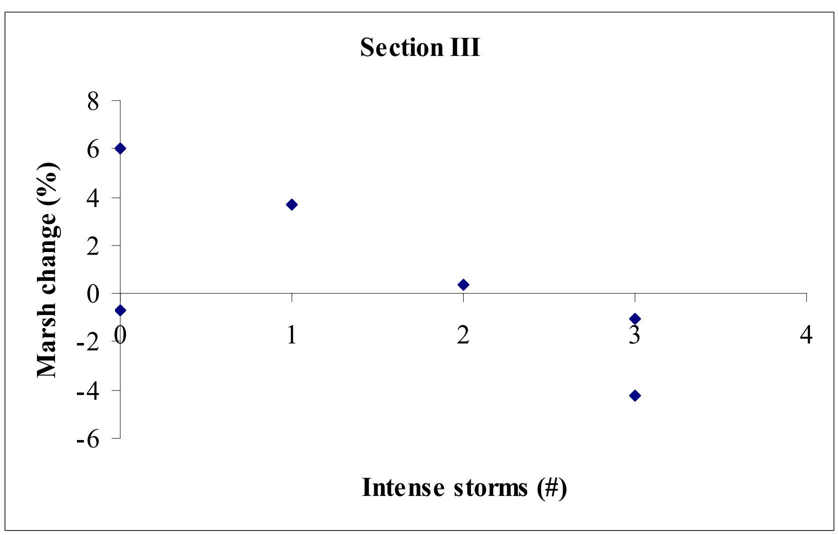
The percent change in marsh area, percent change in marsh area per year, the number of storm events and frequency of storm events per year were examined to determine potential correlations between storm activity and marsh change. No significant correlations were identified so the data were re-examined including, only intense storms, category 3 and higher hurricanes. For these analyses, no significant correlations were found, impart due to the limited number of data points. Therefore, these data were examined qualitatively. The qualitative evaluation did not identify any obvious trends in Sections V and IV (Figure 16 and 17). However, when the percent change in marsh area was plotted with the number of intense storm events, percent marsh change appears to decrease with number of storms in Section III, II, and I, with the trend in II and I being more pronounced than in Section III (Figures 16, 17, 18, and 19).

Being a physiographic section that is highly overwashed, the marsh in Section V appeared to respond to storm frequency as expected (HOSIER and CLEARY, 1977). As the section was overwashed and sediments were transported into the marshes, expected gains in marsh area occurred. A delayed effect in marsh change was also visible in the storm correlation. During the period from 1959 to 1962, a high frequency of storms impacted Masonboro Island and the marshes behind the island. Following the period of overwashing from 1959 to 1962, which created extensive washover deposits and infilling of marsh and open water areas with sediments, extensive revegetation and colonization was visible in the quiescent period from 1962 to 1984. The subsequent period of high storm frequency from 1984 to 2002 again resulted in an increase in percentage of marsh loss and marsh burial by overwash.

Though not a section initially experiencing much overwash as observed by HOSIER and CLEARY (1977), Section IV responded in much the same way as Section V. The gains in marsh area in the section from 1938 to 1962 were rapid which is consistent with the frequency of storms over that time period. Because of the lack of marsh in the section prior to the study and the amount of open water areas in the sound, infilling occurred and new marsh was established thus increasing the rate of marsh


Section V
Marsh change (%)
1.5
1
0.5
0
-0.5
-1
-1.5
0
1
2
3
4
Intense storms (#)


Section IV
Marsh change (%)
20
15
10
5
0
-5
-10
0
1
2
3
4
Intense storms (#)


Section III
Marsh change (%)
8
6
4
2
0
-2
-4
-6
0
1
2
3
4
Intense storms (#)

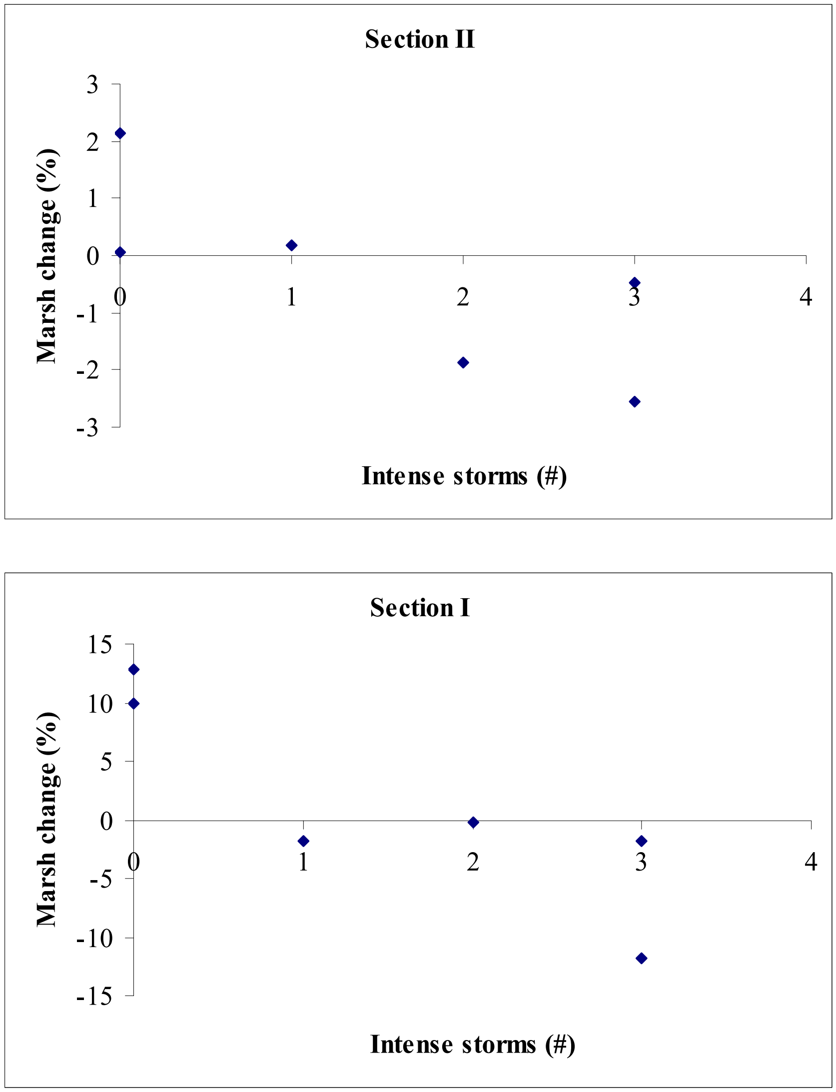
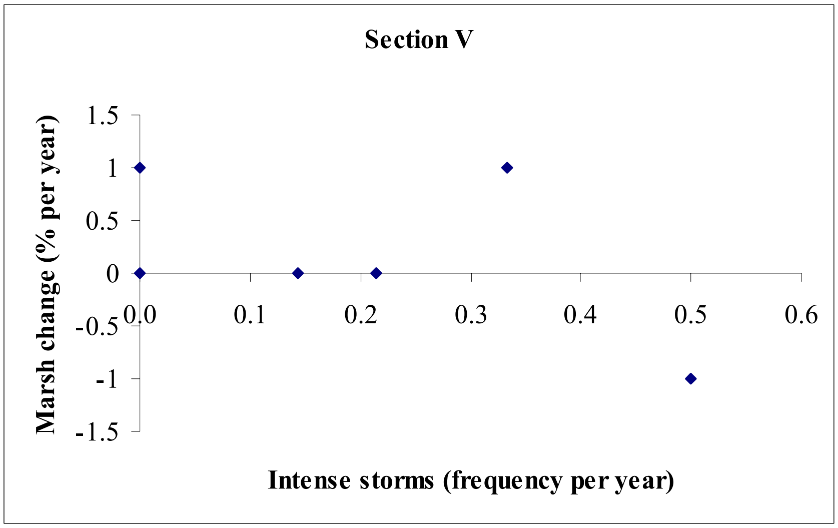
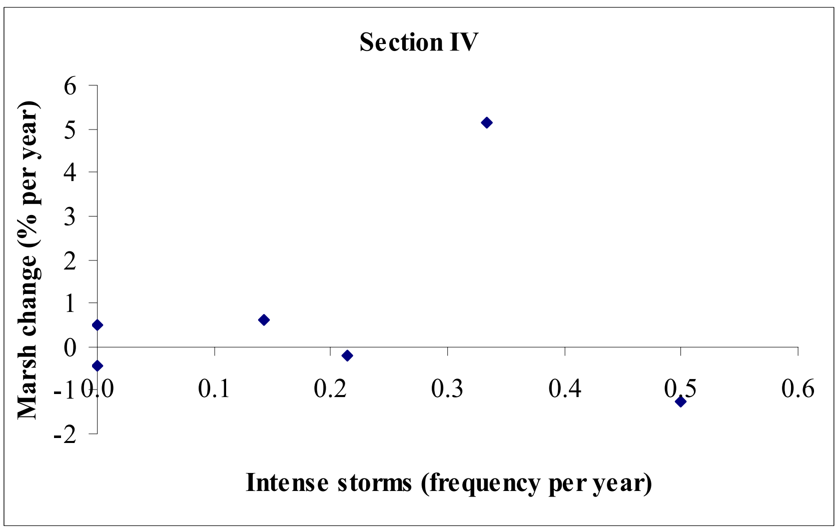


Figure 16: Percent change in marsh area compared to number of intense storm events per time period for each physiographic section


Section V
1.5
1
0.5
0
-0.5
-1
-1.5
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Marsh change (% per year)
Intense storms (frequency per year)


Section IV
6
5
4
3
2
1
0
-1
-2
0.0
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0.2
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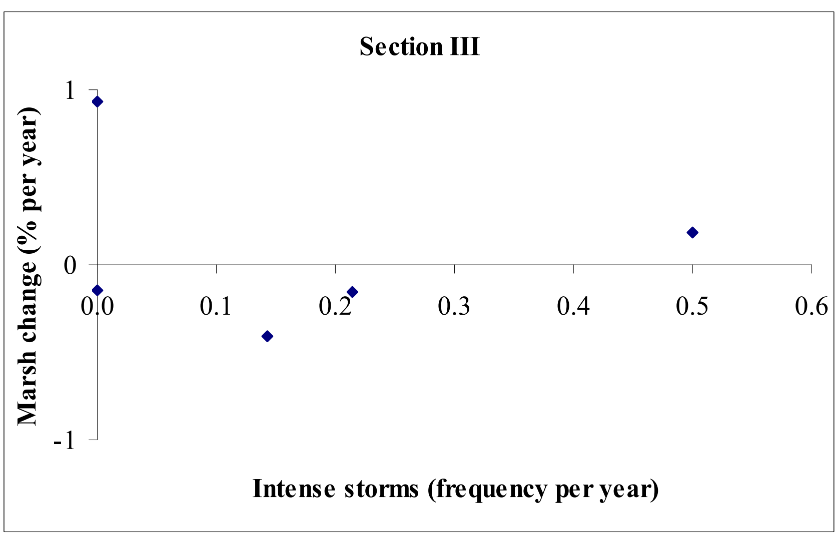
0.5
0.6
Marsh change (% per year)
Intense storms (frequency per year)


Section III
1
0
-1
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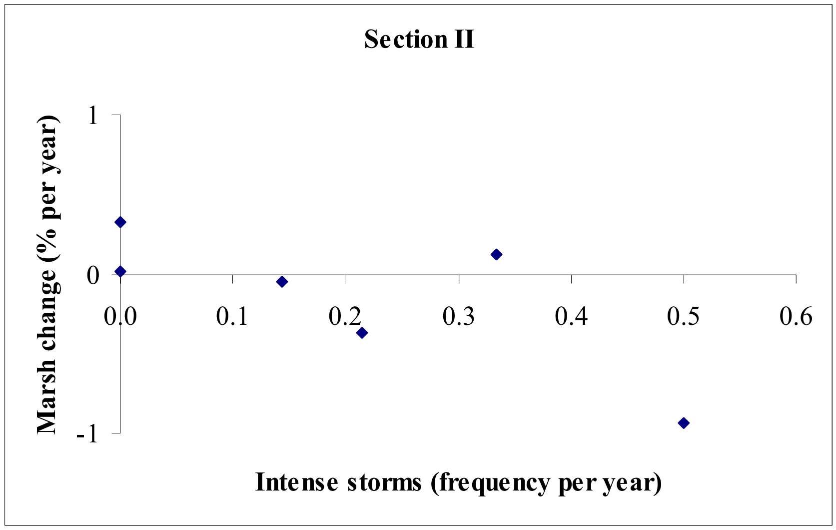
0.1
0.2
0.3
0.4
0.5
0.6
Marsh change (% per year)
Intense storms (frequency per year)



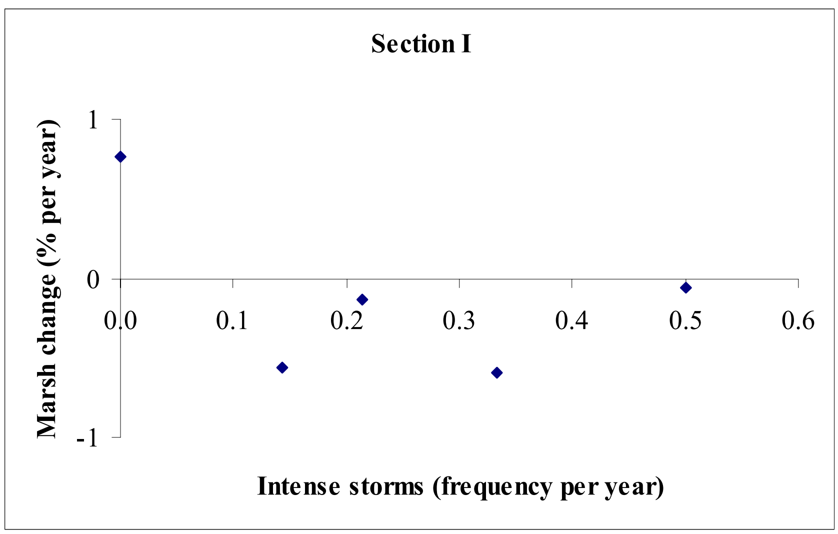
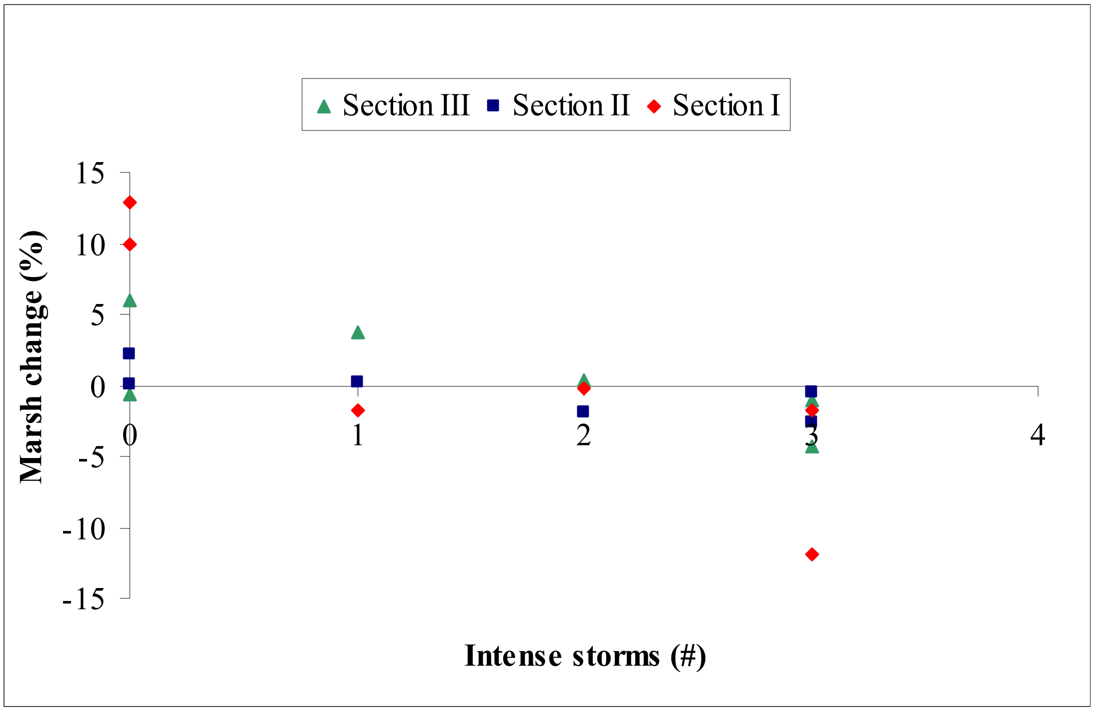


Figure 17: Percent change in marsh area per year compared to frequency of intense storms per year for each physiographic section



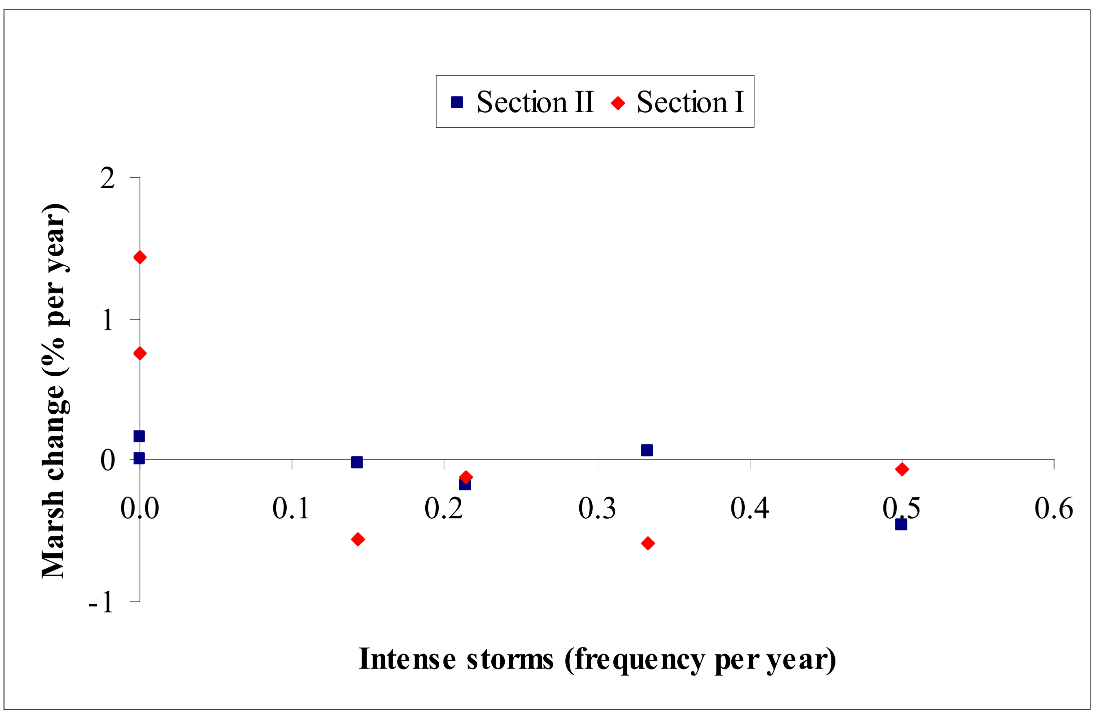
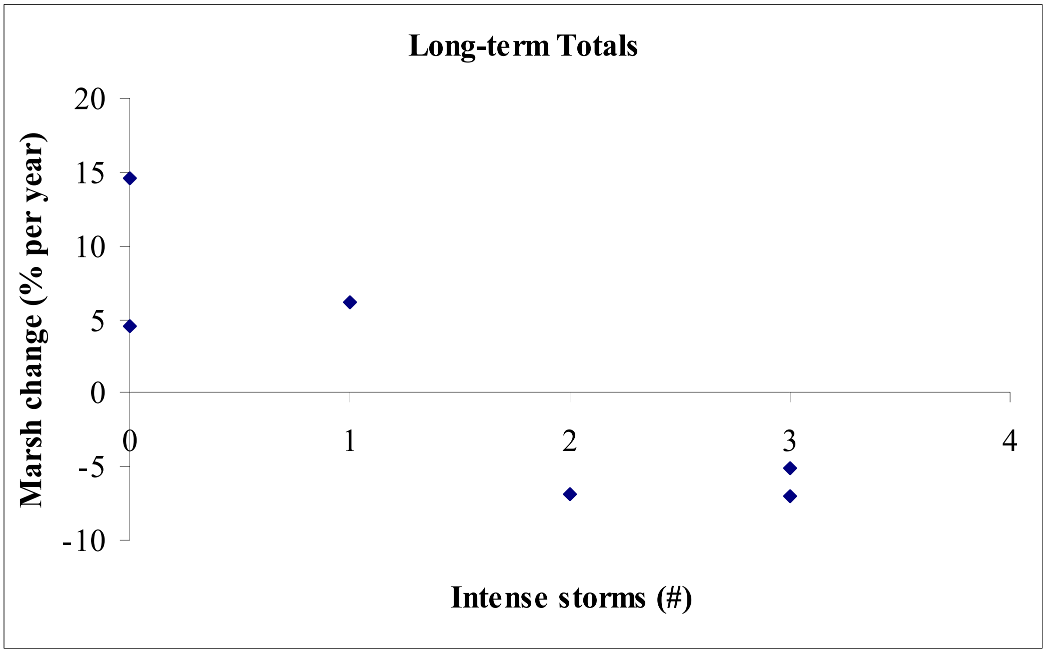


Figure 18: Trends for comparison of percent change in marsh area and number of intense storms per time period and percent change in marsh area per year and frequency of intense storms per year



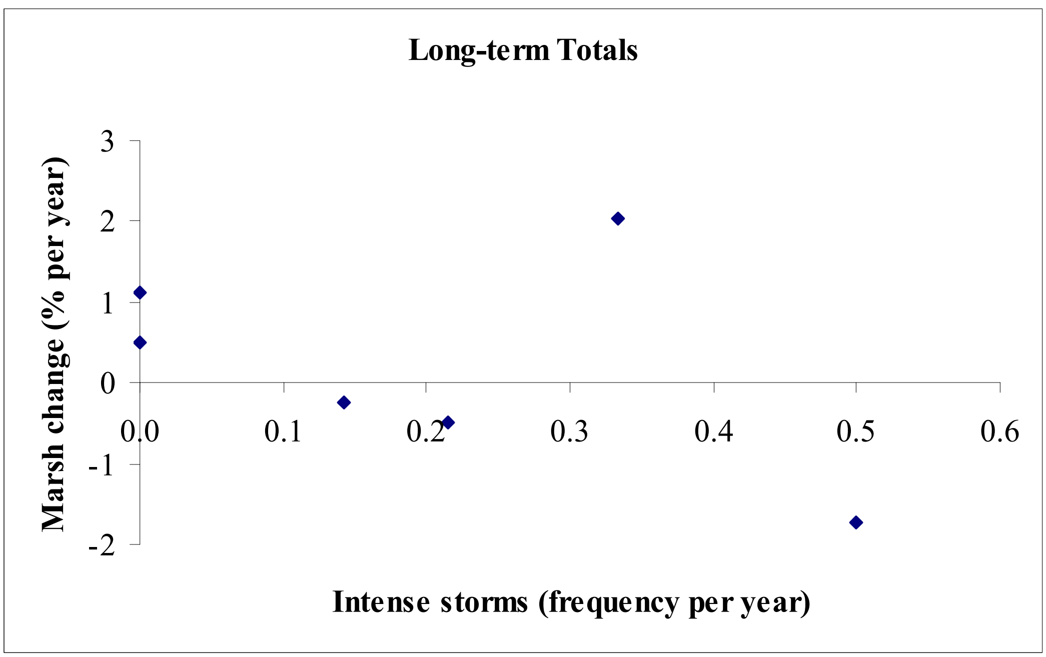


Figure 19: Percent change in marsh area compared to number if intense storm events per time period and percent change in marsh area per year compared to frequency of intense storm events per year

gain. During the period from 1962 to 1971 a loss of marsh occurred probably because the newly established marsh could not maintain stability without the input of storm sediments, which were lacking during the period. Hurricane Diana's impact added sediments to the marsh system by overwashing and helped in restabilizing marsh areas. Then, from 1984 to 2002, losses of marsh area corresponded to the increased storm frequency as overwash sediments buried marsh. During the study period, marsh areas in Section IV were strongly impacted by storm events and overwashing, especially later in the study as the island narrowed and this section became more susceptible to overwashing.

Section III was not frequently overwashed during storm events because of the relatively higher topography (HOSIER and CLEARY, 1977). Therefore, the marshes in the section remained somewhat protected. This physiographic section contains the abandoned inlet shoulders of Old Cabbage Inlet and contained mostly low and medium fragmentation marsh. Although the response was not significantly correlated with storm frequency, changes in marsh area as a function of storm activity were identified that were different from other sections of the island. For example, during the high storm frequency period from 1938 to 1959, a loss of marsh area occurred, likely the result of burial by washover deposits. Then from 1959 to 1962, the section was not significantly overwashed, despite a high frequency of storms, and marsh recovery occurred as washover fans were revegetated. No significant changes in marsh area occurred in Section III from 1962 to 1971 and from 1984 to 2002. Susceptibility to overwashing probably decreased over time as the section gained elevation and washover deposits were vegetated by upland vegetation. The increase in marsh area in Section III was likely a delayed effect of infilling of existing marsh and establishment of new marsh, by the infilling of open water or revegetation of overwash.

Section II did not experience any significant changes in marsh area from 1938 to 1971. The biggest losses of marsh area in this section were likely the result of island retreat as the south end of the island/sound narrowed and retreated landward. The quiescent period from 1971 to 1984 allowed for marsh stabilization in this section as new marsh infilled open water and revegetated overwash sediments. Initially, Section II was not very susceptible to overwashing at the beginning of the study; however, due to high storm frequency and narrowing of the south end of the island overwash sediments did bury marsh causing losses of marsh area (HOSIER and CLEARY, 1977). Overall, marshes in Section II were overwashed more frequently later in the study as the island/sound complex narrowed and marsh was available to be overwashed that had been created by infilling of open water areas of the sound.

Section I responded as expected. This highly susceptible section of the island was overwashed more frequently as the frequency of storms increased (HOSIER and CLEARY, 1977). From 1938 to 1959 a high frequency of storm events impacted the highly susceptible south end of the island, and marsh area was lost due to burial by overwash sediments. The majority of losses of marsh in the south end during this time, however, do not appear to be solely the result of storm overwashing. Instead, these losses may be associated with the opening of Carolina Beach Inlet, which resulted in considerable conversion of marsh to open water. The creation of this inlet, however, appears to have increased the susceptibility of Section I to overwashing. For example, four storms impacted the study area between 1959 and 1962 at a frequency of one storm event per year. During this time, overwashing was identified as the cause of the documented losses of marsh in Section I. In the following years from 1962 to 1984, when storm frequency decreased dramatically, marsh area experienced an overall gain, as washover deposits were revegetated. When storm frequency increased again from 1984 to 1998, losses of marsh area occurred in Section I due to marsh burial by overwash sediments and permanent losses of marshes closest to the ocean as the island retreated over and beyond them. No significant changes in marsh area occurred in Section I from 1998 to 2002. Overall, Section I became more susceptible to overwashing following the creation of Carolina Beach Inlet. Further, marsh growth increased as the distance between the marsh and ocean narrowed due to island retreat and new sediments more readily reached and infilled backbarrier lagoons.

DISCUSSION

Overall Island/Sound Changes

There were several processes identified that affect marsh change in response to storm events. Marsh gain occurred mostly due to infilling of the open water areas of highly fragmented marsh which then converted to low fragmentation marsh as overwash sediments were transported into the marshes (PARSONS, 1998). Washover deposits caused both marsh loss due to direct burial and marsh gains when sufficient time had elapsed to allow recolonization or reemergence of vegetation on overwash deposits (HOSIER and CLEARY, 1977; MOUNDALEXIS, 1999). Also, when deposited in open water areas, washover deposits provided substrate for development of new marsh over these deposits reached elevations suitable for vegetation growth (LEONARD, 1997). Losses of marsh area not attributed to overwash burial were more prevalent during quiescent periods, thus suggesting deterioration due to a reduction in inorganic sediment supply (REED, 1989). Increases in marsh fragmentation during quiescent periods also suggest deterioration due to lack of sediment inputs. Although not directly observed from the aerial photograph analyses, some edges of marsh areas were probably lost due to storm erosion or due to erosion associated with inlet dynamics (CLEARY *et al*., 1979; SAULT *et al*., 1999; BAUMANN *et al*., 1984), especially at the northern and southern ends of the island.

Although marsh fragmentation categories were used for this study to qualitatively analyze marsh change, not all marsh fragmentation was considered negative change or degradation of marsh (REED, 1989). For example, the highly fragmented marshes in the northern section of the island/sound complex remained highly fragmented throughout the study. This section of the island was also very wide and less susceptible to overwash than other sections of the island. It is possible that this section remained highly fragmented because it received relatively little overwash, however, very little net marsh acreage loss was observed. Therefore, marshes in this section must have acquired the necessary sediment inputs from another source. One likely source is the many channels that dissected the marsh and caused it to be classified as highly fragmented. These channels can act as conduits for sediments, which are then deposited on the marsh surface in close proximity to tidal creeks and channels and help maintain marsh elevation and stability (STUMPF, 1983; LEONARD, 1995; LEONARD, 1997; DELAUNE *et al*., 1990; REED, 1995). In fact, close visual inspection of very small channels indicates undocumented infilling over the study area and study period. So, although the marshes in the northern end of the island, specifically Sections V and IV, remained highly fragmented over the study period, they appear to have changed little and appear stable.

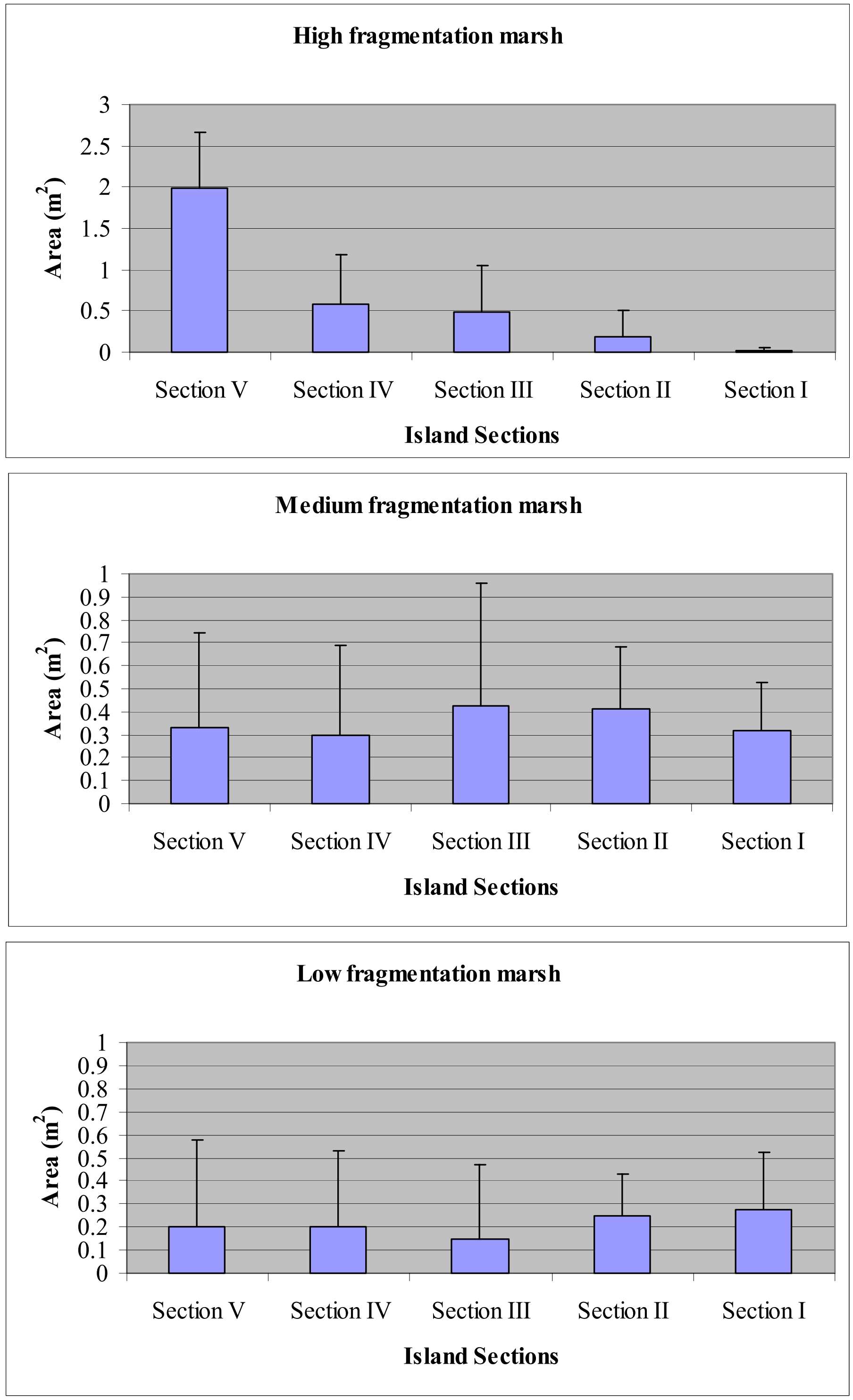
A total of 3.17 km^2 in area that was overwash fans, dunes, and beach were lost to the inner shoreface as the island retreated landward. Another factor in the decrease of island/sound area was the opening of Carolina Beach Inlet in 1952, which reconfigured the southern end of the island's geomorphology. It can clearly be seen when comparing the 1938 photographs to the 1959 photographs that the opening of the Carolina Beach Inlet altered this portion of the island as new sedimentation patterns became established. It also demonstrates that, even though inlet-supplied sediments are beneficial to the marsh system, they are only beneficial locally near the inlet (CLEARY *et al*., 1979; SAULT *et al*., 1999). Overwash sediments are more important on the whole because they are distributed more widely along the island and can be transported further into the marsh (PARSONS, 1998; LEONARD, 1997; GOODBRED and HINE, 1995; MORTON and SALLENGER, 2003; NYMAN *et al*., 1995).

Overwashing during storm events was an important cause of beach erosion and island retreat. Island retreat was especially pronounced where the island was frequently overwashed, such as, Sections I and II in the southern end of the island (HOSIER and CLEARY, 1977). Although Section V was also frequently overwashed, the installation of the southern jetty on Masonboro Inlet created a wide accretionary prism, consequently discontinuing island retreat at the north end of the island (CLEARY *et al*., 1979; HOSIER and CLEARY, 1977). Although, no overwashing was evident during the quiescent nine year period from 1962 to 1971, total island/sound area still decreased at a rate of 0.2% per year, though not as quickly as it did during the active storm period from 1959 to 1962. The loss in island area during quiescent times was likely due to shoreline retreat associated with inlet processes and retreat of the beach face due to natural wave erosional processes (CLEARY *et al*., 1979; SAULT *et al*., 1999).

Over the period of 1938 to 2002, a cyclic pattern of marsh loss due to overwash, followed by gains associated with revegetation of the overwash fans and colonization of newly infilled areas was observed. Following a storm event, winds and tides transport recently deposited sediments further into the backbarrier marsh areas. Provided that sufficient time elapsed between overwashing events, healthy stands of marsh grass can be established. Further, marsh can be established in areas that were previously open water, but infilled by overwash sediments. Nearly 5.73 km^2 of new marsh area was established over the 64 year study period as backbarrier lagoons and channels were infilled, while approximately 1.47 km^2 of marsh is now buried by overwash deposits, and another 3.24 km^2 of area that was marsh in 1938 is now some other non-marsh land cover class. These processes operate over much different temporal scales. In the case of marsh burial, the loss was instantaneous, whereas the successive gain of marsh, as washover deposits were recolonized by marsh vegetation, occurred over a period of months or years (HOSIER and CLEARY, 1977; MOUNDALEXIS, 1999).

Physiographic Sections

According to the study by HOSIER and CLEARY (1977), the physiographic sections of Masonboro Island are impacted by storm events by responding differently to overwash. During their study in 1977, HOSIER and CLEARY observed that Sections V, III, and I are overwashed more frequently than Sections IV and II. These observations were attributed to differences in topography, proximity to inlets, and dune structure and stability (HOSIER and CLEARY, 1977). However, during the course of this study, these observations shifted to Sections III, II, and I being more susceptible to overwashing. The island and backbarrier marshes of Sections II and I were specifically influenced by overwash as the southern end of the island decreased in elevation and narrowed in width as the island retreated landward. Sections II and I contained more medium and low fragmentation marsh areas as open water infilled than the northern end of the island (Figure 20). Sections V and VI did not experience as much overwashing, and thus contained mostly high fragmentation marsh, as this study progressed, due to widening of the island as sediments accrete south of the jetty (Figure 20).



- Note: Scale of high fragmentation marsh graph is larger than medium and low fragmentation graphs

Figure 20: Average area in square meters of high, medium, and low fragmentation marsh in each physiographic section (shown with standard deviation error bars)

Even though Section V was susceptible to overwashing no notable changes in marsh area occurred in the section between 1938 and 1959 (HOSIER and CLEARY, 1977). For the most part, high fragmentation marsh was the type marsh that occupied Section V of the island (Figure 20). This was constant throughout the study time period with the exception of a notable gain in medium fragmentation marsh. This gain was enough to increase the percentage of total island area occupied by medium fragmentation marsh by 12% per year (Figure 20). Although most of the marshes in Section V were highly fragmented, or channelized, these channels acted as conduits for transporting sediments into the marsh and likely provided the sediment needed for the interior marshes in this section to remain fairly stable over the study. Further evidence for this is the gradual conversion of small areas of medium fragmentation marsh (more channels) to convert to low fragmentation marsh (less fragmented). Where marsh losses occurred in this section they were almost exclusively associated with burial by overwash sediments.

Section V was highly susceptible to overwash during the earlier periods of the study (prior to 1971), but as sediments accreted behind the southern jetty of Masonboro Inlet, and shoreface width increased, overwashing decreased in this section (HOSIER and CLEARY, 1977). It is likely the case that while being highly overwashed, the high fragmentation marshes developed at the north end of the island due to infilling of the open water sound. Then, as overwashing decreased, but inlet-related sedimentation processes continued, the highly fragmented marshes remained stable because of high channelization (LEONARD, 1997). Any storm sediments that infiltrated Section V were probably reworked and deposited within the highly fragmented marsh, maintaining stablization as suggested by LEONARD (1997).

Dune and upland width in Section IV was relatively narrow with very little marsh and a large amount of open water existing directly behind the island. This morphology and the high amount of overwash experienced with storm events, especially over short periods of time, allowed for infilling of open water and establishment of new marsh. As evidenced by the gains in medium fragmentation marsh and conversion of non-marsh land cover classes to fragmented marsh following stormy periods. As marsh areas were established in the sound behind the island, losses of marsh area also occurred from continued burial by overwash. Small areas of low fragmentation marsh behind the dunes, which were likely denser marsh from continuous overwashing, were lost in Section IV from burial by washover deposits. Like Section V, Section IV contained mostly high fragmentation marsh over the entire study. Small areas of low fragmentation marsh in some areas also converted to medium fragmentation marsh in Section IV suggesting an increase in channelization or open water areas (especially during time intervals with low storm activity). Similar changes have been associated with marsh degradation due to inorganic sediment deficits in a study by REED (1989).

Because of the relatively higher topography and insusceptibility of overwashing of Section III, major changes in marsh area did not occur (HOSIER and CLEARY, 1977). The high topography of Section III, especially near the foreshore, protected the marshes in the sound from overwashing and prevented major losses. Therefore, over the long-term, Section III did not experience a significant change in marsh area. As the island continued to be impacted by storms and overwashing and beach erosion scoured the dunes during island retreat, some of the dunes and topography of Section III began to destabilize (HOSIER and CLEARY, 1977). Over time, this allowed for increased overwashing over time. The increased availability of sediment due to overwash facilitated infilling as evidenced by the observed gain in low fragmentation marsh types as high and medium fragmentation type marsh was lost. Further, considerable losses of marsh areas near the dune line were buried as the section became more frequently overwashed over time.

Section II experienced little change in marsh area from 1938 to 1959, probably because this section was not very susceptible to overwashing during the early periods of this study (HOSIER and CLEARY, 1977). Therefore, in Section II, a loss or complete degradation of high fragmentation marsh occurred between 1938 and 1959 because sediments were not sufficiently supplied to the backbarrier marsh interior. However, this situation changed over time as the island retreated landward causing this section to narrow and become more susceptible to overwash. Another factor influencing marsh change in this section was the opening of Carolina Beach Inlet. Section II experienced a large gain in low fragmentation marsh as sediments carried through the inlet were transported to the backbarrier and provided substrate for new marsh growth.

As observed for the other physiographic sections, marshes in this section also exhibited evidence of slight degradation during less storm-impacted intervals. for example, from 1962 to 1971 medium fragmentation marsh in Section II increased slightly as low fragmentation marsh converted to denser areas of marsh, especially for the more interior areas. At the same time, medium fragmentation marsh degraded and converted high fragmentation marsh with more open water areas, again presumably due to reduced sediment inputs. From 1971 to 1984, another period of low storm activity, higher fragmentation marsh infilled and converted to low fragmentation marsh, but these gains were less than those occurring during stormy intervals. Further, the area of low fragmentation marsh located behind the dune line did not experience major losses from 1971 to 1984 because appreciable overwashing did not occur and bury marsh.

Section I was highly susceptible to overwashing due to its proximity to the inlet, low topography, and narrow width (SAULT *et al*., 1999). Most of the losses of marsh area in Section I were associated with the displacement of marsh area by the new inlet, which was opened in 1952 (CLEARY *et al*., 1979; SAULT *et al*., 1999). The creation of the new inlet at the south-end of Masonboro Island caused some direct loss of low and medium fragmentation marsh in Section I by occupying areas that were once established marsh at the inlet location. As observed in a study by CLEARY *et al*. in 1979, the increased sediment supply from the new inlet, specifically from the flood tidal delta, also resulted in some burial of low and medium fragmentation marsh in Section I. Similar processes have been observed in other Southeastern North Carolina marsh systems (GAMMILL and HOSIER, 1992). At the same time, the inlet provided a conduit for delivery of sediments to provide a base for new marsh development. Section I experienced a gain in low fragmentation marsh as the southern inlet continued to supply sediments, despite no storm overwashing from 1962 to 1971. Thus, gains were likely due to the creation of substrate and subsequent colonization of marsh vegetation. A total of 1.29 km^2 of new low fragmentation marsh was established across the island during this time period. Following the infilling of the sound with marsh, storms transported large amounts of sediments from Carolina Beach Inlet into the sound and marsh in Section I causing burial of existing marsh while also providing new substrate for additional marsh colonization. As with Section V, there was some loss of low fragmentation marsh in Sections II and I as washover deposits buried considerable areas of marsh. Further into the marsh interior, increases in low fragmentation marsh occurred as medium fragmentation converted to low fragmentation marsh area due to the infilling of medium fragmentation marsh with overwash sediments. Overall, low fragmentation marsh increased at a very high rate of 93% per year from 1959 to 1962 and continued at a comparable rate until 2002.

The amount of total marsh area in Section I increased at a rate of 1.4% per year from 1962 to 1971. This relatively slow rate of increase may reflect the lack of major storm events and overwashing during this period, which tended to inhibit marsh development in this section. Instead slow infilling from inlet-derived sediments and resulted in a gain of medium fragmentation marsh as flood tidal delta sediments or jetty-trapped sediments became colonized by marsh vegetation, and as high fragmentation marsh was infilled. Between 1984 and 1998, a stormy interval, Physiographic Section I experienced major losses of low fragmentation marsh as overwashing sediments and inlet dynamics buried marsh. Approximately 0.17 km^2 of low fragmentation marsh were buried by overwash sediments over the 14 year time period. Section I exhibited an increase of 0.60 km^2 in low fragmentation area from 1998 to 2002, another period of frequent storms, as storm sediments infilled the sound and higher fragmented marsh types produce new areas of low fragmentation marsh. At the same time, the low-lying southern end of the island experienced a high amount of overwashing at a higher rate, thus causing a decrease in marsh area mostly from burial, especially in areas closest to the dune line and inlet.

Storm Impacts and Marsh Response

When percent change in marsh area per section was compared to the number and frequency of intense storms, Sections V and IV showed little correlation (Figure 16). In Section III, a historically stable stretch of island, marsh changes displayed a subtle decrease in marsh area as the number of intense storms increased. For Sections II and I, areas historically susceptible to overwash, an even more obvious decreasing trend was observed suggesting that as the frequency of intense storms impact the island, losses of marsh area occur, likely as a result of burial by overwash sediments (Figure 18).

Much of the changes in marsh area from 1938 to 1959 can be attributed to the passing of the Hurricane of 1944, Hazel, Diane, and Helene. The Hurricane of 1944 and Hazel both had a northward track as they passed over the study site allowing a northward direction for sediment transport. The northward tracks of the storms pushed sediments away from the south end and middle of the island causing a loss in marsh area with conversion of low and medium to medium and high fragmentation marsh. This process was demonstrated by BAUMANN et al. (1984) in a study showing how high velocity flows induced from hurricane surge can cause both lateral and vertical erosion of marsh substrate.

The overwash from the Hurricane of 1944, Hazel, Diane, and Helene was sufficient to noticeably affect wide areas of marsh in the sound between 1938 and 1959. Although most of the overwash deposits can only be seen near the dune line on aerial photographs, very thin layers of sediment not visible on photographs does reach areas further in the sound. MOUNDALEXIS (1999) showed that a thin veneer of sediments from overwashing does filter through the marsh vegetation and becomes incorporated into the marsh substrate. These deposits are an important component of the marsh's vertical accretion budget and may account for up to ten years worth of deposition after just one event (NYMAN *et al*., 1995).

Although not an appreciable amount when compared to the overall changes of marsh area, approximately 3.44 km^2 of marsh area was lost by degradation or erosion and converted to open water areas during the quiescent non-storm period from 1962 to 1984, suggesting that the lack of sediment inputs from overwash was allowing for marsh deterioration in some areas of the sound. In the interval of 1962 to 1971 some marsh area was gained as previously open water areas was slowly infilled and as overwash fans produced by the Ash Wednesday Storm were revegetated. Even though marsh area increased, the slow rate of increase was most likely due to reduced sediment inputs because of fewer storms and reduced overwash. The latter also provided the time needed for revegetation of overwash deposits.

The high frequency of major storm events in the short three-year time period between 1959 and 1962 caused a decrease in the area of the island/sound complex and an increase in marsh area. Erosion associated with these storms caused retreat of the beach face and immediate burial of marshes near the dune line. However, as recolonization of overwash sediments occurred, new marsh areas were established, thereby increasing the area of marsh (HOSIER and CLEARY, 1977). Hurricane Donna and the Ash Wednesday Nor'easter of 1962 produced ample substrate, which allowed for gains in marsh area as open water areas infilled and became more established and as overwash deposits were revegetated. One unexpected result during this period was a decrease in acreage of marsh coverage given the high storm frequency. It is likely, however, that the majority of overwashing that occurred during the three year time period was due to Hurricane Donna in 1960. Therefore, by the time the 1962 aerial photographs were taken, some revegetation of washover deposits had already occurred, thus causing the areas of washover deposits to be classified as marsh.

In general, the paucity of storm activity during the time period from 1962 to 1971 shows the importance of quiescent periods for marsh to revegetate and stabilize. At the same time, without the important inorganic sediments supplied from storm overwash, marsh areas degrade or disappear completely. The lack of storm activity and overwashing allowed 0.15 km^2 of washover deposits to be revegetated and converted to marsh areas during this time. Similarly, because little storm activity occurred from 1971 to 1984, little overwashing occurred, and thus some of the higher fragmented marsh degraded. The lack of storms provided the quiet conditions needed for the growth and stabilization of new and revegetated marsh as the overall marsh area increased by 15% over the 13 year time period.

Hurricane Diana occurred immediately after the 1984 photographs were taken and in 1996, Hurricane Bertha was followed by Hurricane Fran, with both making direct landfall in the Masonboro Island area. All three of these storms caused major beach erosion and overwashing. In fact more than 3.53 km^2 of the island was converted from other land cover types to overwash during this interval. Of this change, more than half was the conversion of marsh to overwash. Burial of marsh by washover deposits was high during the time from 1984 to 1998, but by the time the 1998 photographs were taken sufficient time had elapsed to allow for some revegetation, which was evident on the photographs. Although three major storms occurred during the period from 1984 to

1998, all five physiographic sections experienced a loss in total marsh areas per section, likely a result of burial by overwashing. Due to the high frequency of major storms and the amount of overwash, 2.09 km^2 of marsh was lost or buried by washover sediments. While storm frequency was high from 1984 to 1998, the 14-year period allowed enough quiescent time between storm events for sediments to be distributed and marsh restabilization to occur. This was also the situation during the stormy, but longer time period from 1938 to 1959. As overwash sediments infiltrated through the marsh vegetation and tidal channels, highly fragmented marsh converted to lower fragmented marsh areas and supported the benefits of storm sediments to marsh stability (LEONARD, 1997). On the other hand, the decrease of marsh area from 1998 to 2002 can be partially attributed to the short time period in which overwashing occurred, but the little time between the two photograph sets to allow for revegetation of washover deposits.

The two major storm events between 1998 and 2002, Hurricanes Bonnie and Floyd, and two minor storms did not create the same extent of overwashing as Hurricanes Bertha and Fran, but were destructive, nonetheless. Hurricane Bonnie produced mostly sound-side flooding, which would have been most detrimental to the unprotected edges of marsh areas in the sound and may have contributed to the observed conversions of low and medium fragmentation marsh to higher fragmented marsh.

In general, over the entire study period from 1938 to 2002, the five physiographic sections became more susceptible to overwashing and thus the marshes were more strongly affected by storms over time. Since the HOSIER and CLEARY study in 1977, Sections IV and II, in particular, have experienced more overwashing during periods of high storm frequency. As a result, these two sections appear to be more impacted by overwash than previously documented. Changes in total marsh area for the island generally decreased as the number of intense storms within the examined time interval increased. Also since HOSIER and CLEARY 1977, a jetty system was constructed at Masonboro Inlet at the north end of the island, the accretionary prism in Section V helped decrease the section's susceptibility to overwashing as time passed. Overall, the results of this study are consistent with the results of the HOSIER and CLEARY (1977) and changes in marsh acreage could be related to the frequency of storm events, especially category 2 or higher hurricanes that impacted the study site.

Overall, the major storm events, which have impacted Masonboro Island, proved to be beneficial to the backbarrier marsh system. As overwashing occurred, open water areas were infilled and highly-fragmented marsh areas converted to less-fragmented marsh areas. Overwash sediments delivered to the marsh during storm events increased marsh surface elevation and provided substrate for vegetation growth. These inputs appear to offset losses that occur during quiescent periods when inorganic inputs are greatly reduced (GOODBRED and HINE, 1995; REED, 1989; LEAONARD *et al*., 1995; MOUNDALEXIS, 1999).

CONCLUSIONS

The study found several processes in which marsh change occurred. During high storm frequency periods highly fragmented marsh infilled with overwash sediments and became less fragmented. Open water areas in the sound were filled with overwash sediments and new substrate was made for establishment of new marsh areas. Also, areas of marsh were buried by washover deposits and dynamic inlets. Marsh areas were also lost due to erosion from storms and inlet dynamics. During quiescent periods low fragmentation marsh degraded and converted back to highly fragmented due to the lack of inorganic sediments necessary to maintain stability. With no storms impacting the island, a period of recovery occurred too, with washover deposits being recolonized by marsh vegetation or the re-emergence of marsh vegetation that survived burial.

The first hypothesis of the study was, on the short-term, marsh loss will occur from the burial of marsh vegetation by washover deposits. This was found to be true from the many examples of marsh loss during several time periods experiencing overwashing. In most cases burial was limited to small areas of low and medium fragmentation marsh near the dune line. Major burial did occur at the south end of the island where overwashing was considerable and frequent near the unstable inlet. A recovery of marsh area was also observed as these buried areas of marsh were recolonized by marsh vegetation and attributed to a gain in marsh in later years.

The second hypothesis was that existing areas of marsh will become less fragmented over time with the passage of storm events, and areas of open water will become more fragmented as the sound infills and new marsh develops. Areas of highly fragmented marsh did show a decrease in fragmentation as open water areas infilled with overwash sediments. The opposite was also true, that when no storm events occurred, transporting sediments into the marshes, degradation occurred and low fragmentation marsh converted to highly fragmented marsh. Also, as overwash sediments were transported into areas of the sound not previously occupied by marsh, new marsh eventually formed, but remained highly fragmented until stabilization occurred with more sediments.

The third hypothesis was in the long-term, washover deposits will renourish backbarrier marshes with inorganic sediments, which can then be recolonized by marsh grasses, converting back to areas of stable marsh. This concept essentially occurred on the short-term as well, but the long-term preservation of the backbarrier marshes was the results of the inorganic overwash sediments transported during storm events. Recolonization of washover deposits did occur and especially aided in maintaining marsh area as the island retreated from shore face erosion with rise in sea level and storm events.

Marsh area values were overestimated due to the methods used in this study, but do not affect the final results or conclusions of this study. Overwashing processes are beneficial to marsh areas by providing inorganic sediment substrate and thus, elevation, allowing the island to compete with rising sea level. However it also affects the island topography by decreasing the overall height/elevation and therefore increasing the vulnerability to overwashing in the future. The results of overwashing can be seen in changes in the backbarrier marshes behind barrier islands. Backbarrier marshes appear to respond rapidly and dramatically to storm overwashing events by either degrading from a lack of inorganic overwash sediments or by prograding and/or stabilizing with the introduction of inorganic overwash sediments.

From the time period 1938 to 2002, the backbarrier marshes behind Masonboro Island, North Carolina responded noticeably to periods of high storm frequency as well as quiescent periods. A positive response of marsh change was visible as major storm events impacted the island and marshes, while a negative response occurred when no storm events occurred. During the 64-year time period of the study, an almost cyclic pattern of marsh changes between gains and losses in area was noticed. This pattern was most likely attributed to the length of the recovery period for marsh areas as they returned back to stable marsh after being influenced by overwash sediments.

Although, both positive and negative marsh changes occur with the passage of major storm events, a pattern of degradation and progradation will continue as long as the marshes receive the necessary inorganic sediments provided by overwashing events. Overwashing that occurs in response to storm events, coupled with island retreat and narrowing is an important factor as open water sound areas infills with sediments and new marsh substrate and maintains overall marsh area. Overall, because Masonboro Island remains undeveloped, the marshes will likely maintain stability and growth as sea level rises and storm events impact the island.

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Appendix A: Hurricane Track Data Table

Rec	YEAR	MONTH	DAY	STORM ID	STORM NAME	LAT	LONG	WIND SPEED(KTS)	PRESSURE(MB)	WIND SPEED(MPH)	CATEGORY	BASIN
1	1938	10	24	624	NOTNAMED	32.2	-79.8	40	0	45	E	North Atlantic
2	1944	8	1	667	NOTNAMED	32.6	-78.2	80	990	90	H1	North Atlantic
3	1944	8	2	667	NOTNAMED	34.2	-78.3	60	0	70	TS	North Atlantic
4	1945	6	25	676	NOTNAMED	32.8	-78.1	60	0	70	TS	North Atlantic
5	1945	6	25	676	NOTNAMED	33.5	-77.5	60	0	70	TS	North Atlantic
6	1946	7	6	688	NOTNAMED	33.4	-78.9	40	0	45	TS	North Atlantic
7	1946	7	6	688	NOTNAMED	34	-78.4	40	0	45	TS	North Atlantic
8	1946	7	6	688	NOTNAMED	34.6	-77.7	40	0	45	TS	North Atlantic
9	1953	9	27	761	FLORENCE	32.5	-80.2	35	0	40	E	North Atlantic
10	1953	9	28	761	FLORENCE	33.8	-77.1	35	0	40	E	North Atlantic
11	1954	10	15	776	HAZEL	32.8	-78.7	110	937	125	H3	North Atlantic
12	1955	8	17	781	DIANE	32.8	-76.9	75	0	85	H1	North Atlantic
13	1955	8	17	781	DIANE	33.5	-77.5	75	0	85	H1	North Atlantic
14	1955	8	17	781	DIANE	34.3	-78	60	986	70	TS	North Atlantic
15	1956	9	26	797	FLOSSY	34.8	-78.4	30	0	35	E	North Atlantic
16	1956	9	27	797	FLOSSY	35	-78	30	0	35	E	North Atlantic
17	1958	9	27	814	HELENE	33.1	-78.2	115	938	135	H4	North Atlantic
18	1958	9	27	814	HELENE	33.9	-77.5	115	943	135	H4	North Atlantic
19	1960	7	29	830	BRENDA	32.9	-79.7	45	0	50	TS	North Atlantic
20	1960	7	30	830	BRENDA	34.6	-78	50	0	60	TS	North Atlantic
21	1960	9	12	832	DONNA	33.1	-78	95	958	110	H2	North Atlantic
22	1961	9	14	840	UNNAMED	33	-78.1	30	0	35	TD	North Atlantic
23	1961	9	14	840	UNNAMED	34.7	-77.9	35	0	40	TS	North Atlantic
24	1964	9	13	865	DORA	33.7	-79.8	45	0	50	TS	North Atlantic
25	1964	9	13	865	DORA	34.4	-77.9	45	0	50	TS	North Atlantic

26	1968	6	11	897	ABBY	33.4	-78.5	25	0	30	TD	North Atlantic
27	1968	6	12	897	ABBY	33.6	-78.2	25	0	30	TD	North Atlantic
28	1968	6	12	897	ABBY	33.8	-78	25	0	30	TD	North Atlantic
29	1968	6	12	897	ABBY	34	-77.8	25	0	30	TD	North Atlantic
30	1968	10	20	904	GLADYS	32.9	-78.2	75	0	85	H1	North Atlantic
31	1970	8	17	926	UNNAMED	32.5	-78	30	1013	35	TD	North Atlantic
32	1970	8	17	926	UNNAMED	33.5	-78	30	0	35	TD	North Atlantic
33	1971	10	1	940	GINGER	34.7	-77	60	991	70	TS	North Atlantic
34	1971	10	1	940	GINGER	34.8	-77.5	55	997	65	TS	North Atlantic
35	1971	10	1	940	GINGER	34.9	-78	45	1000	50	TS	North Atlantic
36	1972	6	21	947	AGNES	34.4	-79	30	990	35	TD	North Atlantic
37	1975	6	28	972	AMY	33.3	-78	25	1011	30	TD	North Atlantic
38	1975	6	28	972	AMY	34	-77	30	1006	35	TD	North Atlantic
39	1975	10	26	979	HALLIE	32.5	-78.7	35	1003	40	TS	North Atlantic
40	1975	10	27	979	HALLIE	33.5	-77.5	45	1002	50	TS	North Atlantic
41	1977	9	5	993	CLARA	33.2	-79	20	1014	25	TD	North Atlantic
42	1977	9	6	993	CLARA	33.6	-78.2	20	1013	25	TD	North Atlantic
43	1977	9	6	993	CLARA	33.8	-77.6	25	1012	30	TD	North Atlantic
44	1977	9	6	993	CLARA	34	-77	25	1011	30	TD	North Atlantic
45	1981	8	20	1032	DENNIS	33.4	-78.8	50	999	60	TS	North Atlantic
46	1982	6	19	1042	SUBTROP1	32.5	-79.2	60	992	70	SS	North Atlantic
47	1982	6	19	1042	SUBTROP1	33.9	-77.8	60	992	70	SS	North Atlantic
48	1984	9	11	1055	DIANA	33.4	-78	110	952	125	H3	North Atlantic
49	1984	9	12	1055	DIANA	33.9	-77.7	115	949	135	H4	North Atlantic
50	1984	9	12	1055	DIANA	34	-77.4	95	963	110	H2	North Atlantic
51	1984	9	12	1055	DIANA	34	-77.2	95	967	110	H2	North Atlantic
52	1984	9	12	1055	DIANA	33.9	-77.1	90	970	105	H2	North Atlantic
53	1984	9	13	1055	DIANA	33.8	-77.4	85	972	100	H2	North Atlantic

54	1984	9	13	1055	DIANA	33.9	-77.9	80	978	90	H1	North Atlantic
55	1984	9	13	1055	DIANA	34	-78.3	65	990	75	H1	North Atlantic
56	1984	9	13	1055	DIANA	34.3	-78.5	55	999	65	TS	North Atlantic
57	1984	9	14	1055	DIANA	34.6	-78.5	45	1003	50	TS	North Atlantic
58	1984	9	14	1055	DIANA	35	-78	40	1005	45	TS	North Atlantic
59	1985	11	22	1074	KATE	33.7	-79.2	45	996	50	TS	North Atlantic
60	1987	8	8	1082	ARLENE	34.3	-77.5	10	1016	10	L	North Atlantic
61	1995	6	6	1155	ALLISON	33.6	-80	35	995	40	E	North Atlantic
62	1995	6	6	1155	ALLISON	34.5	-78.1	40	995	45	E	North Atlantic
63	1996	6	19	1174	ARTHUR	33.2	-78.1	40	1005	45	TS	North Atlantic
64	1996	6	19	1174	ARTHUR	33.9	-77.3	40	1005	45	TS	North Atlantic
65	1996	7	12	1175	BERTHA	32.2	-78.4	85	975	100	H2	North Atlantic
66	1996	7	12	1175	BERTHA	33.6	-78.1	90	974	105	H2	North Atlantic
67	1996	7	13	1175	BERTHA	35	-77.6	65	993	75	H1	North Atlantic
68	1996	9	5	1179	FRAN	32.3	-77.8	100	952	115	H3	North Atlantic
69	1996	9	6	1179	FRAN	33.7	-78	100	954	115	H3	North Atlantic
70	1996	10	8	1183	JOSEPHINE	34	-79	45	988	50	E	North Atlantic
71	1998	8	26	1196	BONNIE	32.7	-77.8	100	965	115	H3	North Atlantic
72	1998	8	26	1196	BONNIE	33.4	-77.8	100	962	115	H3	North Atlantic
73	1998	8	27	1196	BONNIE	34	-77.7	95	963	110	H2	North Atlantic
74	1998	8	27	1196	BONNIE	34.5	-77.5	85	965	100	H2	North Atlantic
75	1999	9	16	1214	FLOYD	32.1	-78.7	90	950	105	H2	North Atlantic
76	1999	9	16	1214	FLOYD	33.7	-78	90	956	105	H2	North Atlantic
77	2001	6	13	1236	ALLISON	34	-79.6	25	1006	30	SD	North Atlantic
78	2001	6	14	1236	ALLISON	34.3	-78.5	25	1006	30	SD	North Atlantic
79	2001	6	14	1236	ALLISON	34.6	-77.9	25	1006	30	SD	North Atlantic
80	2001	6	14	1236	ALLISON	34.7	-77.7	25	1007	30	SD	North Atlantic
81	2001	6	14	1236	ALLISON	34.6	-77.6	25	1008	30	SD	North Atlantic

82	2001	6	15	1236	ALLISON	34.6	-77.2	25	1008	30	SD	North Atlantic
83	2002	10	11	1261	KYLE	33.2	-79.3	35	1011	40	TS	North Atlantic
84	2002	10	12	1261	KYLE	34.2	-78	30	1012	35	TD	North Atlantic

Source: http://hurricane.csc.noaa.gov/hurricanes/viewer.htm

APPENDIX B

1944 Hurricane

The Hurricane of 1944 made landfall as a category 1 storm on August 1 at eight o'clock in the evening at Southport, NC. Wind speeds in Wilmington, NC were recorded at 72 mph. Carolina Beach, south of Masonboro Island, sustained the greatest damage from the storm's 30 feet waves (BARNES, 1998). Just to the north of Masonboro Island at Wrightsville Beach, the water was measured at 18 feet at the City Hall in the center of the island (BARNES, 1998). Though only a category 1 hurricane on the Saffir-Simpson Scale, storm surge and high waves caused damage to the coastline.

Hazel

Hurricane Hazel formed as a low-pressure trough over the warm, tropical waters of the Atlantic Ocean. The storm made landfall at the North Carolina – South Carolina border on October, 15, 1954. The storm surge recorded at Calabash, NC was 18 feet above mean low water and 12 feet at Wrightsville Beach, NC. By the time the storm reached Wrightsville Beach, the winds were measured at 125 mph, making Hazel a Category 3 hurricane. The storm surge was said to be the highest and most damaging surge in North Carolina's recorded history (BARNES, 1998). This severity was due to the angle the storm struck the coastline, with the northeast quadrant slamming into Carolina Beach, NC (BARNES, 1998). The storm surge was also exaggerated because of the storm's timing, reaching the North Carolina coast just in time for the highest lunar tide during the full moon of October (BARNES, 1998). The high winds and storm surge of Hazel caused massive destruction to Brunswick and New Hanover County beaches (BARNES, 1998).

Diane

Not even a year later, Hurricane Diane struck the North Carolina coast, making landfall on August 17, 1955, again at Carolina Beach. This storm was especially damaging because it landed just five days after Hurricane Connie, which left the ground fully saturated, amplifying damage from Diane (BARNES, 1998). Diane was a Category 2 hurricane delivering 74 mph winds to Wilmington as well as heavy rains and a storm surge of 5-9 feet above mean low water. Although this storm was relatively weak, the saturated ground and slow movement of the storm to the northwest caused severe beach erosion (BARNES, 1998).

Helene

Hurricane Helene was the most intense storm event to threaten southeastern North Carolina during the 1950's (BARNES, 1998). Hurricane Helene was a category 4 hurricane that did not make landfall, but it came within 20 miles of Cape Fear on September 27, 1958. Even though this hurricane remained offshore, 135 mph wind gusts were recorded in Wilmington and 8-10 inches of rain fell. The storm surge was only 3-5 feet due to the storm's arrival during low tide. There were 2.5 to 3 swells per minute on the coast which indicates "exceptional intensity" of the storm (BARNES, 1998). The low topography and vulnerable location of Masonboro Island most likely allowed this storm to impact the island with wind and waves even though Helene did not make landfall.

Donna

Southeastern North Carolina experienced a lull of five years before another major storm, Hurricane Donna, hit on September 11, 1960. Like other hurricanes, Donna developed as a tropical wave at the Cape Verde Islands off the coast of Africa and headed for the Caribbean Sea. Donna struck Florida and moved to the Gulf of Mexico, where it made a 90° turn and headed back across Florida to the Atlantic (BARNES, 1998). As the storm headed back into the Atlantic and reached the warm waters of the Gulf Stream, Donna strengthened again and made a turn for North Carolina. Donna made landfall at Topsail Island, three islands north of Masonboro Island, as a Category 3 storm with a 4-8 feet storm surge. Wind gusts in Wilmington, North Carolina were measured at 97 mph.

Ash Wednesday Nor'easter

The Ash Wednesday storm of '62 struck the Eastern seaboard of the United States from March 7-9, 1962 (BARNES, 1998). Although the Ash Wednesday storm was a winter-time nor'easter, it ranks among the worst of North Carolina's hurricanes (BARNES, 1998). Beach erosion was severe in many places because the storm occurred during the highest lunar tide of the year (BARNES, 1998).

Ginger

The North Carolina coast felt no major hurricane impact for almost a decade following Hazel and Donna. During the night of September 30, 1971 Hurricane Ginger made landfall on Atlantic Beach, North Carolina as a Category 1 storm. Although this storm did not directly impact the southeastern North Carolina coast, 58 mph winds and a storm surge of four feet were recorded at Topsail Island. Hurricane Ginger was an extremely slow-moving storm with a record 31 days of tracking, a National Weather Service record for longest-lived storm (BARNES, 1998).

Diana

After drifting off the Cape Fear coast for two days, Diana made landfall at Bald Head Island on September 9, 1984, as a minimal Category 2 storm. While Hurricane Diana drifted off the coast, winds were clocked at 135 mph, but at landfall winds had dissipated to 92 mph and the storm had a barometric pressure of 28.02 inches. Even though Diana was only a weak Category 2 storm, it was the first significant storm to hit North Carolina since Donna in 1960 (BARNES, 1998). Storm surge effects were minor due to the low tide at the storm's landfall and a surge of five and a half feet impacted Carolina Beach (BARNES, 1998). Any beach erosion that did occur was mostly not from storm surge, but rather, the northeast winds that affected the coast in addition to 13.72 inches of rain that fell in Wilmington, NC (BARNES, 1998). Again, as in the past, Brunswick and New Hanover Counties were the hardest hit by Diana (BARNES, 1998).

Hurricane Bertha

The eye of Hurricane Bertha passed over Kure Beach, North Carolina on July 12, 1996. This was the first Hurricane to strike North Carolina in July since 1908 (BARNES, 1998). Winds in this category 2 storm reached 92 mph from the northeast while the storm traveled north along the coast, where it quickly lost strength (DEL GRECO and HINSON, 1996; BARNES, 1998). South of Masonboro Island, Carolina Beach was heavily flooded and three feet of sand covered the roads (BARNES, 1998). Wrightsville Beach and Figure 8 Island, to the north of Masonboro Island, received little damage although the storm surge in Pender and Onslow County was 5-8 feet (DEL GRECO and HINSON, 1996; BARNES, 1998). The extensive beach erosion that was felt in places like Carolina Beach was due to storm surge (BARNES, 1998).

Hurricane Fran

Hurricane Fran, which began as a tropical wave off the coast of Africa, was a minimal Category 3 storm when it made landfall at Bald Head Island, North Carolina on September 5, 1996. Hurricane Fran struck southeastern North Carolina less than three months after Bertha hit in the same area. This was the first time in 41 years that two hurricanes hit North Carolina in the same hurricane season and both occurred in the Cape Fear region (BARNES, 1998). This Category 3 hurricane had sustained winds of 115 mph with gusts of 126 mph at Wrightsville Beach and a barometric pressure of 28.14 inches. Wrightsville Beach, Figure 8 Island, and Topsail Island experienced the highest storm surge at 8-12 feet (BARNES, 1998). New Hanover, Pender, Onslow, and Carteret Counties were the hardest hit and had extensive beach erosion and overwash (BARNES, 1998). Hurricane Fran had a greater impact than Bertha as the damaging east side of the storm swept along the coast. In addition to the angle of approach of the storm, heavy rains fell prior to the hurricane's arrival with nearly a foot of rainfall recorded in Brunswick and Pender Counties (BARNES, 1998).

Hurricane Bonnie

Hurricane Bonnie was a low-grade category 3 storm that made landfall, just south of Masonboro Island, at Bald Head Island on August 26, 1998. In New Hanover County, wind gusts were 100 mph along the coast and around ten inches of rain fell. Storm surge on the islands was 7-9 feet, but flooding occurred from the sound side allowing for minimal beach erosion (DEL GRECO and HINSON, 1998).

Hurricane Floyd

Hurricane Floyd struck southeastern North Carolina on September 15, 1999 dumping record-setting rainfall on the area. This storm was a category 2 hurricane on the Saffir-Simpson Scale, with wind gusts reaching 90 mph at landfall. At the Wilmington International Airport in New Hanover County, a record 14.84 inches of rain fell in a 24 hour period, delivering a total of 19.06 inches for the storm (DEL GRECO and HINSON, 1999). At other beaches in New Hanover County, Carolina Beach to the south, and Wrightsville Beach to the north, storm surge was recorded at 9-10 feet (DEL GRECO and HINSON, 1999). This surge inundated the islands and overwashed several areas of dunes.

Appendix C: Total area of marsh type and island/sound per section and year in km^2

		Physiographic Section				
Year	**Type**	**V**	**IV**	**III**	**II**	**I**
1938	**Total Island/Sound**	4.92	2.11	1.95	4.45	3.29
	Total Marsh	2.16	0.81	1.13	0.89	0.85
	Low Frag	0.07	0.26	0.86	0.55	0.47
	Med Frag	0.29	0.00	0.00	0.33	0.33
	High Frag	1.87	0.50	0.27	0.03	0.00
1959	**Total Island/Sound**	4.78	2.07	1.95	4.51	2.84
	Total Marsh	2.14	1.07	1.04	0.88	0.40
	Low Frag	0.13	0.15	0.00	0.14	0.17
	Med Frag	0.71	0.71	1.01	0.78	0.13
	High Frag	1.51	0.00	0.00	0.00	0.09
1962	**Total Island/Sound**	4.68	2.05	1.89	4.47	2.84
	Total Marsh	2.19	1.37	1.08	0.88	0.35
	Low Frag	1.05	0.91	0.00	0.23	0.06
	Med Frag	0.23	0.23	0.97	0.74	0.23
	High Frag	1.22	0.00	0.00	0.00	0.00
1971	**Total Island/Sound**	4.56	2.00	1.89	4.23	2.65
	Total Marsh	2.29	1.27	1.07	0.84	0.67
	Low Frag	0.00	0.00	0.00	0.06	0.07
	Med Frag	0.00	0.00	0.00	0.17	0.53
	High Frag	2.53	1.10	1.20	0.49	0.00
1984	**Total Island/Sound**	4.69	1.97	1.85	4.26	2.54
	Total Marsh	2.67	1.38	1.16	0.93	0.89
	Low Frag	0.00	0.00	0.00	0.16	0.59
	Med Frag	0.00	0.18	0.00	0.09	0.24
	High Frag	2.81	1.05	1.15	0.76	0.00
1998	**Total Island/Sound**	4.53	1.93	1.82	4.17	2.43
	Total Marsh	2.51	1.29	1.12	0.81	0.81
	Low Frag	0.00	0.00	0.10	0.44	0.03
	Med Frag	0.00	0.00	0.00	0.34	0.67
	High Frag	2.68	1.40	0.85	0.00	0.05
2002	**Total Island/Sound**	4.53	1.91	1.78	4.02	2.30
	Total Marsh	2.35	1.18	1.10	0.70	0.76
	Low Frag	0.14	0.11	0.09	0.14	0.54
	Med Frag	1.07	0.98	1.01	0.46	0.10
	High Frag	1.32	0.00	0.00	0.00	0.01