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A 15-YEAR EVALUATION OF THE MISSISSIPPI AND ALABAMA COASTLINE BARRIER ISLANDS, USING LANDSAT SATELLITE IMAGERY

By

Ryan T. Theel

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A 15-YEAR EVALUATION OF THE MISSISSIPPI AND ALABAMA COASTLINE BARRIER ISLANDS, USING LANDSAT SATELLITE IMAGERY

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The Mississippi and Alabama barrier islands are sensitive landforms that are affected by hurricanes, longshore currents, and available sediment, yet these effects are difficult to quantify with traditional ground-based surveying. Landsat satellite imagery was used to evaluate changes in barrier island area and centroid position from 1990 and 2005. When hurricanes are infrequent (1999–2003), barrier islands generally increased in total area and showed moderate repositioning of their centroid locations. However, when hurricanes were frequent (1994–1999 and 2004–2005), the barrier islands substantially decreased in area and their centroids dramatically repositioned. This was especially true following Hurricane Katrina (2005). Generally, from 1990 to 2005, the movement of barrier islands was westerly and most islands experienced an overall reduction in area (-18%). The results of this research are similar to findings reported in the literature and illustrate the suitability of using Landsat imagery to study geomorphic changes.

DEDICATION

I would first and foremost like to thank my wife and lifelong fishing partner Heather, whom I love dearly for always standing by my side when times got tough and keeping me on track, when the track was at its hardest to stay on. To my mother, Mollie Theel, who instilled the importance of education and always keeping your goals in sight, no matter where they may lead you. To my father, John Theel, for showing me the importance of persistence and hard work, whenever, wherever, and whatever you are working toward. Also, thank you to my parents for giving me an appreciation and love for the outdoors, by showing me the quiet beauty of a northern Minnesota lake in the early morning, to a beautiful sunset in the wilderness of the Grand Tetons. To my grandparents, Virginia and the late Joseph Blakley, for your love, and foremost, for always being there to support me at <u>every</u> hockey and baseball game…or whatever I was doing. I would also like to thank my grandparents, the late Herbert and Lorraine Theel, where, at their farm, my love for the outdoors grew, and they also showed me the importance of hard work.

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INTRODUCTION

Hurricane Ivan (2004) and Hurricane Katrina (2005) struck the northern Gulf of Mexico and resulted in substantial reworking of barrier island sediment on the Mississippi and Alabama coasts. Ship Island, Mississippi, in particular, was significantly affected by the 8.5+ m storm surge generated by Hurricane Katrina. Although these recent hurricanes were quite profound, barrier islands routinely experience morphological and vegetative changes due to fluctuations in sediment distribution (Davis and Fitzgerald, 2004; Hesp and Short 1999). They are, by all accounts, transitory geomorphic features. This is especially true during large storm events when wave energy is high (United States Department of the Interior, 1985). The reworking of northern Gulf Coast barrier island sediment might be unprecedented within recent years, yet the amount of redistribution and the degree to which these barrier islands have shifted position over the last couple of decades has yet to be quantified.

The barrier islands along the Mississippi and Alabama coastlines receive the bulk of their sediment from longshore transport, and to a lesser degree, from offshore sources (Waller and Marlborough, 1976). Longshore transport along the northern Gulf Coast typically shifts the general barrier island position in an east to west direction by eroding sediments on the eastern edge and redepositing it down-drift on the western edge of the island. This longshore transport and the associated redistribution of sediment is an integral and necessary process for maintaining barrier island stability. Factors that alter the longshore drift or that alter the distribution of sediment in any other manner, such as from storm waves or from sea level rise, may result in islands retreating landward (transgression) and may reduce the overall island area. These morphological changes in barrier island position and area are difficult to quantify on the ground. As a result, opinions vary about the influence of storms and other coastal processes on barrier island morphology (Schwartz, 1971).

Barrier island vegetation has to be extremely tolerant of ever changing conditions and saline stress on the barrier islands (Ehrenfeld, 1992). Generally, the most tolerant species are found on the ocean-facing side of the barrier island, and the least tolerant species are found further inland where they are more protected from the winds, waves, saltwater inundation, and salt spray. Breaching of barrier island dunes by storm waves may greatly alter these vegetation patterns. Some vegetative areas may be buried by sand. Alternatively, newly-deposited sand may become colonized by vegetation. Because hurricanes are frequent within the northern Gulf of Mexico, spatial vegetation patterns have shifted throughout time. Measuring vegetation changes, such as those on the barrier islands following major storm events, is especially difficult to quantify over large spatial scales with traditional ground-based surveying because of the complex logistics, the amount of time required, and the amount of monetary resources needed (Aniya et al., 1985; Sakai et al., 1985). Moreover, calculating the changes in land cover from vegetated to non-vegetated areas, and visa-versa, takes long periods of time to accomplish with traditional field sampling techniques. The use of satellite imagery to monitor changes in barrier island position preceding and following storm events allows for broad-scale assessments of vegetation change. Change-detection models applied to satellite imagery offer a means to assess alterations in barrier island vegetation over a large area within a short time frame.

This research uses Landsat satellite imagery acquired over a sixteen-year time frame, 1990–2005 to monitor changes in Mississippi and Alabama barrier island position and vegetation. Specifically, the spatial arrangement of barrier islands was examined during the early 1990's when major land-falling hurricanes were infrequent (Schmid, 2001a; Schmid, 2001b; Schmid, 2003). Also, barrier island morphological changes were examined during the more recent periods when major storms (e.g., Hurricane Ivan and Hurricane Katrina) were more frequent. Similarly, the spatial patterns of vegetation change will be assed through Landsat imagery by using change-detection algorithms on satellite images taken before and after major land-falling hurricanes. The advantages of Landsat imagery over other data sources, such as aerial photographs, includes the following: 1) Landsat is generally lower in cost; 2) it has more frequent repeat coverage (16-day repeat period); and 3) it has an extensive, readily-available archive. The results of this project provide an estimate of how much change occurs on the Gulf Coast barrier islands during periods of active hurricanes and during periods when hurricanes are less frequent. This project also provides insight into the role of hurricanes and how they influence the Mississippi and Alabama barrier island shape and vegetation cover.

CHAPTER II

RESEARCH OBJECTIVES

The overall goal of this thesis research is to determine the amount of change in barrier island morphology and vegetation over a 16-year period. A secondary goal of this research is to determine if it is applicable to use Landsat satellite imagery to accurately determine how the barrier islands along the Mississippi and Alabama coast change position and vegetation cover over a 15-year period. Previous studies of barrier islands and their processes have focused on the use of high-resolution aerial photography, LIDAR (Schmid, 2001a; Schmid, 2001b; Schmid, 2003), and historic charts and maps (Waller and Malbrough, 1976). The specific objectives of this research are:

1. Compare and quantify the changes in vegetation and sand on the Mississippi and Alabama barrier islands between 1990 and 2005 using Landsat imagery. The ability to quantify broad-scale change on barrier islands may provide insight into understanding their dynamic geomorphic nature. Also, determining change over a 16-year period could possibly help pinpoint variables that affect barrier island morphology.
2. Determine the locations of barrier island erosion and accretion from 1990 until 2005. It has been noted that the barrier islands of the

3. Mississippi and Alabama coastlines are slowly moving in a westward direction. By examining locations where barrier islands have changed the most or the least, it may be possible to quantify the rate of barrier island movement.
4. Compare changes in vegetation and sand land-cover types before and after major land-falling hurricanes. Examining changes in these land cover types may shed light on the importance of vegetation in stabilizing barrier island sediments.
5. Determine the accuracy of using coarse-resolution Landsat images to detect morphological and vegetation changes on the barrier islands. It is important to compare the accuracy of the Landsat imagery land cover categorizations to corresponding high-resolution aerial photography. When the Landsat image classification results are proven comparable to the more-expensive and more-detailed aerial photographs, this research aided in determining if using Landsat imagery is a viable and more economic geospatial solution for monitoring barrier island morphology and vegetation.

CHAPTER III

BACKGROUND INFORMATION AND LITERATURE REVIEW

Barrier islands are sensitive, elongated landforms that parallel the world's coastlines and are generally found in chains or are separated by channels or tidal inlets (Hoyt, 1967). They have also become some of the most popular areas of residential and tourist developments (Woodroffe, 2002). They are called "barrier islands" because they act as barriers or buffers and lessen the effects of landward storm events and their associated storm surges. Barrier islands are found around only 12% of the world's coastlines and every continent except Antarctica (Davis and Fitzgerald, 2004; Pilkey, 2003). Many of the world's barrier islands occur around the United States Atlantic and Gulf of Mexico coastlines where relative sea level rise is occurring (United States Department of the Interior, 1985). The U.S. coastline (lower contiguous 48 states) contains over 400 barrier islands, and approximately 4,345 km of shoreline (United States Department of the Interior, 1985). Generally formed and manipulated by sediment being transported by wave and wind action, barrier islands tend to be found on continental shelves that are wide, have a low gradient (Hoyt, 1967), and have a medium to small tidal range (Bird, 2000; United States Department of the Interior, 1985). Barrier islands are dynamic environments, as they are constantly being shaped and reshaped, eroded an accreted by normal ocean conditions as well as tropical and extra-tropical storm surges. It is important to understand how barrier islands are manipulated during storm and normal ocean (non-storm) periods.

Barrier Island Formation

Barrier islands tend to be a function of their environment, and are morphologically controlled by such factors as tidal range, wave energy, currents, sediment supply, sea-level trends, and climate (Davis and Fitzgerald, 2004; Hesp and Short 1999; United States Department of the Interior, 1985). Barrier islands are generally separated from the coastline by bays, lagoons, saltwater marshes, or tidal creek systems (Hoyt, 1967). Many different theories have come to light when attempting to explain barrier island formation, but generally, all can be grouped into three major theories: offshore-bar theory, spit accretion theory, and the submergence theory. It has been shown through lab and field experimentation (McKee and Sterrett 1961; Hoyt, 1969; Otvos, 1970; Otvos, 1979) that all barrier islands can not be described by one formation process alone; each formation theory can explain different barrier islands. Although all three barrier island formation theories are different, Schwartz (1971) points out that barrier islands are formed by multiple processes.

The offshore-bar theory, also called submarine bar up-building, is a barrier island formation process that theorizes that, as landward moving waves brake and lose energy, their transported sediments are deposited, forming an underwater offshore bar. These underwater bars continually accrete vertically and grow large enough to surpass the present sea level. This was theorized by L.E. de Beaumont (1845) and supported by

Johnson (1919) and Otvos (1970, 1979), who also believed that the Mississippi and Alabama barrier islands were formed by this process. McKee and Sterrett (1961), however, showed in laboratory tank experiments that offshore bars could not be built higher than the sea level. Hoyt (1967) stated that barrier islands formed by the offshore-bar theory tend to be very small and short lived, and pointed to the fact that there is no offshore bar development presently occurring. Hoyt (1967) also stated that if the offshore-bar theory were true, an open-ocean coast would have existed during underwater bar formation, whereas in most situations, an open-ocean coast never existed. Otvos (1979) argues that low salinities near shore and coastal marshes explain the absence of open-ocean sediments and organisms providing significant evidence for the offshore-bar theory. Otvos (1979) also claims that Ship Island, which currently resides as two separate islands, was also split in the 1700's and again in 1965 before being reconnected by the longhshore sediment transport from wave action, supporting the offshore-bar theory.

The spit accretion theory states that barrier islands are formed (specifically near bays) when sediment moving through the breaker zone is agitated by wave action, and produces elongated, finger-like sediment deposits paralleling the coast, also known as beach spits (Gilbert, 1885; Fisher, 1968). At this stage, the beach spits are still connected to the shore, and would only become disconnected or breached during strong wave action from storm events. According to Hoyt (1967), the spit accretion theory does not account for large barrier island systems, and is generally limited to small areas of coastlines where littoral longshore transport of river-generated sediments occurs. Again, the lack of evidence of open-ocean sediments and deposits points away from the spit accretion theory (Hoyt, 1967).

Sea levels around the world are continuously rising (Davis and Fitzgerald, 2004). In some situations, the rising waters submerge offshore coastal ridges, forming barrier islands; this is commonly known as the submergence theory (McGee, 1890). Prior to their submergence, barrier islands exist as only wave and wind-created beach ridges or dunes, and contained constituents such as coarse sand, gravel, or shells (Davis and Fitzgerald, 2004). Submergence of these offshore landforms began during the early Holocene, when melting of the North American continental glaciers increased the ocean volume, thus increasing sea levels. Hoyt (1967) specifically pointed to the Gulf of Mexico as being a prime example of coastal submergence forming barrier islands. Core samples were taken from coastal barrier islands to support the submergence theory (Hoyt, 1967). Barrier islands, like those in the northern Gulf of Mexico are made of fine constituents, such as sand and coarse gravel, being composed of such small material makes them subject to constant and continuous alteration and movement by ocean conditions.

Barrier Island Sediment Dynamics

Barrier islands, especially those located in the Gulf of Mexico, are dynamic landforms due to their composition (mostly sands and silts); they are constantly reshaped, eroded, and accreted. Wave and storm surge events associated with cold fronts, tropical storms, or hurricanes can have significant and detrimental effects on barrier islands. For example, in 1992, Hurricane Andrew eroded approximately 30% of Isles Dernieres, which is located off of the Mississippi River delta (Penland et al., 2003). In 1969, Hurricane Camille split Ship Island, which is located adjacent to the Mississippi coastline, forming the present day East and West Ship Islands. Wave action associated with “normal” ocean conditions also affect barrier islands, where longshore currents erode and transport sediments down-drift (Meadows, 1998). The Mississippi and Alabama barrier islands are no different; it has been shown that Horn and Petit Bois Islands have moved westward in excess of 5 km in the past century, whereas little shift is seen in a landward direction (Otvos, 1970).

Sediment supply plays a large role in how barrier islands change and migrate through time. Numerous sediment types are found comprising barrier islands. Sand and gravel are their most common sediment sizes because finer sediments are too easily eroded (Davis and Fitzgerald, 2004; Hoyt, 1967). Sediment, specifically sand, is supplied to the barrier islands by means of: river systems carrying sediment loads, the shoreface, erosion of coastal beaches and dunes, offshore ridges, or longshore transport (Pilkey, 2003; Finkl et al., 2004). The longshore transport of sediments has been altered along the Mississippi and Alabama coastline by dredging of tidal canals and other beach structures (Oltman, 1997). Loss of sediment has caused the barrier islands to be more susceptible to hurricane events (Oltman, 1997; Finkl, 2004). Sand for beach nourishment of barrier islands and mainland beaches are in such short order that it is common practice for dredging of underwater offshore sand ridge fields to take place for nourishment of these beaches (Finkl et al., 2004; Finkl et al., 2007) The amount of sediment an island receives generally determines the island size and how the barrier island moves with tide fluctuations and wave action (Pilkey, 2003). Generally, a barrier island that receives a large amount of sediment will expand in a seaward direction. This type of barrier island is known as a regressive barrier island and is recognizable by a succession of dune ridges (Davis and Fitzgerald, 2002; Woodroffe, 2002; Pilkey, 2003). Transgressive barrier islands, similar to the islands located along the Mississippi and Alabama coastlines, are characterized as narrow and having a general landward movement, caused by the relatively low amount of sediment supply received (Pilkey, 2003; United States Department of the Interior, 1985). The barrier islands of the Mississippi and Alabama coasts are transgressive because of the overwash processes that take place during hurricanes or other storm events (Bird, 2000). Due to the storm surge associated with hurricane events, and because the barrier islands are low in gradient (close to sea level), the storm surge has a great effect on barrier island morphology. For example, Cat Island, Ship Island, Horn Island, and Petit Bois Island erode on average 3.1 meters per year, whereas Dolphin Island has a slightly slower erosion rate of 2.1 meters per year (Shabica et al., 1984; Byrnes et al., 1991).

Barrier Island Vegetation

Although most barrier islands are in a constant state of flux due to natural processes, beach vegetation can be abundant and provide stability to the barrier islands. There are three general functional types of beach vegetation present on barrier islands, and they are characterized by their growth form and the ability to stabilize constituents. These traits in turn can modify the topography of a barrier island (Stallins, 2002). Vegetation functional types include dune builders, burial-tolerant stabilizers, and burial-intolerant stabilizers. Dune builder species are characterized by their positive response to burial, vertical growth, and the ability to produce steep, sandy dune slopes. Sea oats (*Uniola paniculata, L.)* characterize the dune builder species, and they are commonly found on the foredune. They are tolerant to sand burial, strong winds, and continual salt spray. Burial-tolerant stabilizers, also respond positively to being buried, act only as substrate stabilizers, and do not promote vertical dune growth. They are generally located on the protected lee side a sand dune, and include grasses such as beach and bunch grass. Burial-tolerant stabilizers are the third functional vegetation type found on barrier islands, have a negative response to burial, tend to inhabit protected areas of barrier islands, and are noted for their compact growth, facilitating substrate binding (Stallins, 2002). Species characteristic of this functional group include *Juncus scirpoides,* which in general, is a freshwater aquatic that lives in the dune swale environment, panic grasses (*Panicum spp.*), and other species associated with inland marsh areas. Other species that are located on the innermost and highest elevations of the barrier islands are woody vegetation, such as the live oak, rosemary, slash pine, and sand pine. Established forest systems exist on certain barrier islands of the northern Gulf of Mexico, but generally do not promote dune building. Three of the six barrier islands (Cat Island, Horn Island, and Dauphin Island) along the Mississippi and Alabama coastline have extensive forest systems in the interior. Ship Island and Petit Bois Island lack these extensive forest systems and are dominated by shrubby vegetation, dune grasses and marsh grasses (Eleuterius, 1998). Generally, barrier islands lacking established forest systems have low gradients and therefore more prone to washover damage from storm surge. Also, because the islands are narrower, they have less protection from marine influences, such as salt spray and saltwater inundation. Hurricane events can both greatly alter and maintain certain plant communities (Stoneburner, 1978). Overwash associated with hurricanes has prevented under story growth on the barrier islands in the Northern Gulf of Mexico, creating forest areas dominated by slash pine forest due to their salinity tolerances (Stoneburner, 1978).

Barrier islands provide the “last lines of defense” between landward-moving storm events and the mainland, yet they can be significantly altered by such storm waves. The impact of hurricanes and other large storms on barrier islands is dependent upon the storm surge and wave runup heights, but also on the geometry of the island nearest to the storms landfall (Sallenger, 2000). When islands become narrower from storm-generated erosion, they have diminished abilities to protect the mainland and nearshore estuaries and wetlands (Penland et al., 2003). As an example, the Louisiana coast barrier islands are experiencing severe erosion due to sea level rise and hurricane events. This erosion of the barrier islands is causing increased rates of saltwater intrusion and overall loss of important sensitive wetland areas along the entire gulf coast (Penland et al., 2003). The importance of barrier islands to coastal systems cannot be understated. Barrier islands protect nursery grounds for fisheries, saltwater marshes, and protect from future eroding of the coastline.

The physical and temporal changes of barrier islands are due largely to hurricanes and tropical storms which are common in the warm waters of the Gulf of Mexico (United States Department of the Interior, 1985). Hurricane events that affect the Gulf of Mexico are generally spawned from Atlantic Ocean tropical depressions that form off the western coast of Africa. Tropical depressions grow into tropical storms then into hurricanes by the continued uptake of the warm waters of the Atlantic Ocean and Caribbean Sea.

Major hurricanes account for approximately 20% of the African-spawned tropical storm events, but cause more than 80% of the damage to the United States (Goldenberg et al., 2001).

Hurricanes along the United States Gulf Coast

The substantial effect and importance of hurricanes on Gulf Coast barrier island morphology is irrefutable (Nummedal et al., 1980). Since 1900, there have been 34 hurricanes that have made landfall along the northern Gulf of Mexico (NOAA, 2006). Since 1990, 11 hurricanes have made landfall between the western panhandle of Florida and the Texas/Louisiana boarder (Andrew, Erin, Opal, Danny, Earl, Georges, Lili, Ivan, Cindy, Dennis, and Katrina; Figure 1 and Table 1). A hurricane's strength is defined by the five category Saffir-Simpson hurricane scale, which categorizes hurricanes by their intensities relative to their sustained winds.

Hurricane Andrew formed on 14 August 1992 in the north Atlantic Ocean and was officially classified as a hurricane on 22 August (Mayfield et al., 1994). Quickly becoming a category 4, Hurricane Andrew made landfall in central Florida. After crossing peninsular Florida, then entered into the Gulf of Mexico making landfall again in south–central Louisiana as a category 3 storm. Hurricane Andrew had a storm surge that ranged from 0.3 meters to 2.4 meters (Mayfield et al., 1994). In early August, 1995, Hurricane Erin made landfall near the Alabama and Florida state line as a category 1, and it generated a storm surge between 0.3 and 1.2 meter (Lawrence et al., 1998). Three months later, in early October, Hurricane Opal reached its maximum strength as a category 4 hurricane in the Gulf of Mexico. It finally weakened to a category 3 before making landfall near Pensacola, Florida. Associated storm surge from Hurricane Opal ranged from 1.5 to 6.4 meters along the northern Gulf Coast (Lawrence et al., 1998). In July 1997, Hurricane Danny formed from an upper-air disturbance heading in a southerly direction from the Great Lakes to the Gulf of Mexico. Hurricane Danny made landfall as a category 1 hurricane near Mobile Bay, Alabama, and had storm surges ranging between 0.6 to 1.9 meters in height (Rappaport, 1999). In early September, 1998, Hurricane Earl, which grew to hurricane strength southeast of New Orleans, Louisiana, made landfall near Panama City, Florida, as a category 1 hurricane with a storm surge ranging from0.6 to 2.4 meters. Again in late September, 1998, Hurricane Georges made landfall as a category 2 near Biloxi, Mississippi, bringing a storm surge ranging between 1.2 and 3.7 meters (Pasch et al., 2001). Hurricane Lili made landfall on the Louisiana coast early October 2001 as a category 1. While trekking across the Gulf of Mexico, Hurricane Lili grew to a strong category 1 before diminishing shortly before landfall to a weak category 1 storm. Storm surge associate with Lili ranged from 2.8 to 4.0 meters along the Louisiana coast (Pasch et al., 2004).

The 2004 and 2005 Atlantic hurricane seasons were two of the four most active hurricane seasons since 1950 (NOAA, 2006). The year 2004 had six major hurricanes. Hurricane Ivan was the strongest Gulf Coast hurricane of the 2004 season, which reached category 5 status (Franklin et al., 2006). However, as it neared the United States coastline, it weakened to a category 3 hurricane before making landfall and causing extensive damage near Gulf Shores, Alabama (Franklin et al., 2006). In 2005, there were a total of 27 tropical storms. Of these, fifteen became hurricanes and seven strengthened into category 3 or larger hurricanes, making this the most active hurricane season on record (NOAA, 2006).

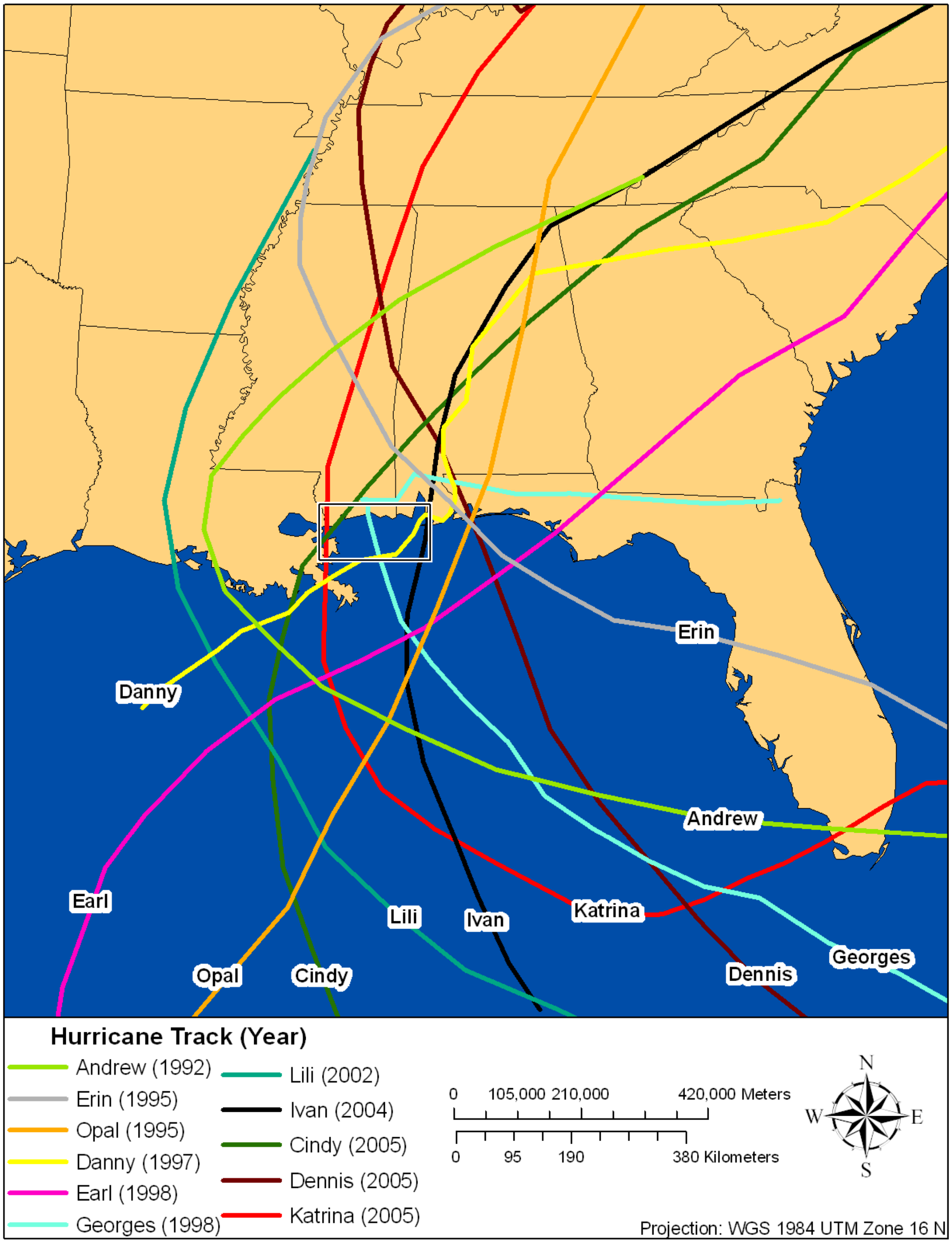

Figure 1. Hurricane events making landfall between the west central portion of peninsular Florida and the Louisiana/Texas border between August 1990 and September 2005.

Table 1. Hurricanes making landfall between western peninsular Florida and the Louisiana/Texas state line between August 1990 and September 2005.

Date of last landfall	Hurricane name	Landfall area	Saffir-simpson scale at landfall	Minimum pressure (mb)	Storm surge (m)
8/26/1992	Andrew	FL & Morgan City, LA	3	922	0.3 - 2.4
8/1/1995	Erin	FL panhandle	1	973	0.3 - 1.2
10/4/1995	Opal	Pensacola, FL	3	916	1.5 - 6.4
7/18/1997	Danny	Buras, LA	1	984	0.6 - 1.9
9/3/1998	Earl	Panama City, FL	1	985	0.6 - 2.4
9/28/1998	Georges	Biloix, MS	2	937	1.2 - 2.9
10/3/2002	Lili	Intercoastal City, LA	1	938	2.8 - 4.0
9/16/2004	Ivan	Gulf Shores, AL	3	910	3.0 - 4.6
7/6/2005	Cindy	Grand Isle, LA	1	992	0.6 - 1.8
7/10/2005	Dennis	FL Panhandle	3	930	1.0 - 2.7
8/29/2005	Katrina	Buras, LA	3	902	3.0 - 8.5

In early July 2005, a tropical depression located just south of Grand Isle, Louisiana quickly formed into Hurricane Cindy, a category 1 storm. Cindy it tracked in a northeastern direction and made landfall near Waveland, MS (Stewart, 2006). Storm surge associate with Cindy ranged from 0.6 to 1.8 meters near the Florida panhandle. Later, in mid–July 2005 another hurricane, Hurricane Dennis made landfall on the southern tip of Florida as a category 3 storm (Beven, 2005). Hurricane Dennis quickly weakened into a tropical depression as it crossed into Alabama and Mississippi on the 11th of July, 2005. Along the Florida, Alabama, and Mississippi coastlines Hurricane Dennis had associated storm surge ranging from 1.0 to 2.7 meters. Hurricane Katrina (2005) was the costliest hurricane in U.S. history (Graumann et al., 2005). Like Hurricane Ivan in 2004, Katrina grew to a category 5 before decreasing slightly and making landfall across, Florida, near Buras-Triumph, Louisiana. Like Ivan, Katrina regained intensity after passing across Florida into the Gulf of Mexico and made landfall once again, but this time if came ashore along the Mississippi/Louisiana coastline as a category 3 hurricane (Knabb et al., 2005). Both Hurricane Ivan and Katrina had substantial effects on the barrier islands along the Mississippi and Alabama coastlines. Ivan had storm surges that ranged from 3.0 to 4.6 meters where Katrina had storm surge that ranged from 3.0 to 8.5 meters. The storm surge associated with Hurricanes Ivan and Katrina greatly altered the barrier islands along the Mississippi and Alabama coastlines.

The ability to assess the amount of change that takes place on barrier islands as a result of hurricane events and during "normal" ocean conditions in a timely fashion is very important due to their non-static nature. Satellite imagery covers the Earth's surface on a consistent basis, making these remotely-sensed data a very useful tool in detecting change on the barrier islands and on landscape in general. Specifically, the Landsat sensor, which has a 16-day repeat period, makes it a possibility for use to assess the effects that hurricanes have on barrier islands.

Satellite Imagery

The United States Geological Survey (USGS) Landsat satellite program has satellites that orbit the earth and capture data from a particular spot approximately once every 16 days. Remotely-sensed data are commonly used in land use/land cover change detection studies (Lillesand et al., 2004). However, few investigations have taken place comparing barrier island morphological changes during "normal" and hurricane events. Evolution, genesis, morphology, ocean, and hurricane effect studies have been performed on barrier islands, but these studies used other geospatial tools, such as GPS, very high resolution aerial photography, and LIDAR technologies (Schmid, 2001a; Schmid, 2001b; Schmid, 2003). It is expected that the medim resolution (30 meters) of the Landsat satellite imagery will be able to detect change on barrier islands. Optimally, the use of higher resolution imagery (aerial photography, SPOT, and LIDAR) is preferred because of the ability to detect subtle changes to the islands and their vegetation. Landsat satellite imagery is advantageous for investigating barrier island change due to its 16-day repeat time, large amounts of available archived data, and relative low cost, when compared to other remotely-sensed imagery, such as LIDAR and aerial photography. One major goal of this research is to compare the accuracy of barrier island morphological and vegetative change between coarser Landsat imagery and finer aerial photographs.

Change Detection

Change detection using satellite imagery, is a powerful application of remote sensing. It involves the use of multi-temporal data sets to discern areas of significant or minute changes over time (Singh, 1989; Lillesand et al., 2004; Jin and Sader, 2005). Change detection has four important aspects when monitoring natural resources: 1) detecting changes that have occurred, 2) identifying the nature of the change, 3) measuring the aerial extent of the change and 4) assessing the spatial pattern of change (Brothers and Fish, 1978; Malila, 1980; Macleod and Congalton, 1998). Selecting a single change detection method to address a specific problem is incredibly difficult, but necessary, due to differing spectral responses of landcover types to disturbances of varying degrees, ecosystem type, and other environmental factors (Collins and Woodcock 1996; Michener and Houhoulis, 1998). When acquiring satellite imagery for change detection in any ecosystem, especially coastal areas, due to their non-static nature, consideration should be taken for differences in season (i.e. vegetation phenology), tide stage, or scene wetness. All of these factors can influence the interpretation of change areas (Burkhalter et al., 2005). Satellite imagery and high spatial resolution photography can be used to classify and detect change in these coastal areas (Ramsey and Laine, 1997). Landsat imagery has been used to classify coastal urban areas (O’Hara et al., 2003) and identify landcover change within coastal watersheds to identify possible sedimentation sources (Cartwright, 2002). The ability to detect change in any ecosystem is affected by the spatial, spectral, thematic, and temporal constraints of the sensors being used; consequently, the selection of a suitable change-detection methodology is of highest importance (Coppin and Bauer, 1994).

Many techniques for detecting change on the landscape using remotely sensed data have been developed (Singh, 1989; Lu et al., 2004). Techniques such as temporal image differencing, temporal image ratio, change vector analysis and, post-classification comparison are all commonly used to detect changes occurring on the landscape (Singh, 1989). Temporal image differencing is the most widely used change detection technique and utilizes at least two images from the same area, the images are subtracted pixel by pixel, band by band, resulting in a difference distribution for each respective band (Singh, 1989). Commonly, single band vegetation indices are differenced to highlight changes on the landscape (Singh, 1989). The advantage of this technique is that it is simple and quick to complete, the disadvantages are that that output highlights areas of change, but gives no information as to what a particular land cover type changed to or from. It is also difficult to determine an appropriate change threshold value, to allow the user to determine where change on the landscape actually occurred. Often the mean and standard deviation (Singh, 1984) are used or thresholds can be set interactively while reviewing image differencing results (Woodwell et al, 1983). Image differencing has been successful at determining change along the Texas coast (Weismiller et al., 1977), mapping changes in tropical rainforest (Miller et al., 1978), and forest defoliation (Williams and Stauffer, 1978).

Image ratioing simply produces that ratio of the data from the two dates of imagery (Lillesand et al., 2004). Areas where change has not occurred tend to be near or equal to one, where change will have higher or lower ratio values. Similar to temporal image differencing, image ratioing is simple and quick to compute, however it lacks the ability to produce information as to what areas changed to or from.

When the land undergoes change over time, its spectral signature changes, causing the vector describing the direction and magnitude of change during that same time period (Lillesand et al., 2004). This vector describing that change is determined using the vector analysis approach (Singh, 1989; Lu et al., 2004). Data from date one are plotted against data from date two, the resultant vector which connects each data point and the direction of the vector tend to describe the nature of the change (Lillesand et al., 2004). Generally a threshold on magnitude of change (vector length) is determined to pin point areas where change and no-change have occurred, whereas, the direction of the vector describes that nature of the change (i.e. forest to field) (Singh, 1989). Change vector analysis is commonly used to determine changes in forest (Malila, 1980; Colwell and Weber, 1981; Muchoney and Haack, 1994). Disadvantages of this technique are that it is very time consuming, however it has the ability to classify land cover change into different classes (Lillesand et al., 2004).

Another method for determining change between time periods is a post-classification comparison. This technique compares two images that have been first independently classified using a supervised or unsupervised classification methodology (Lillesand et al., 2004). This method is useful in studies that are designed to identify a complete matrix of changes (i.e. amount of hectares of forest converted to bare ground) that occur between the compared dates (Singh, 1989). Like other change detection techniques, errors are associated with post-classification comparison, however, errors may be greater because the errors associated with the image classification become compounded in the change detection process (Lillesand et al., 2004). Despite its disadvantages, the post-classification comparison provides detailed qualitative and quantitative explanation of changes that may have occurred between two time periods.

A challenge of change detection and land cover classification studies using satellite imagery is removing and/or normalizing noise associated with atmospheric effects, sun angle, and instrument error (Wharton, 1989; Lillesand et al., 2004). Image transformations such as spectral rationing or other linear regression methods are commonly performed on satellite imagery data to remove these undesirable effects (Yuan and Elvidge, 1996; Lillesand et al., 2004). Many image transforms and vegetation indices can minimize these atmospheric effects that commonly occur on satellite imagery. The use of vegetation indexes can not only strengthen associations between spectral data and biophysical characteristics of vegetative cover, but also provide a means for data reduction (Coppin and Bauer, 1994). For example the tasseled-cap transformation (Crist and Cicone, 1984; Crist and Kauth, 1986) reduces the original six bands of a Landsat image to three bands which highlight the areas of brightness, greenness, and wetness of the image, respectively. Also vegetation indices such as the Normalized Difference Vegetation Index (NDVI) highlight areas of dense, green vegetation.

Image Transforms

Tasseled Cap Transformation

The tasseled-cap transformation is a commonly-used method for enhancing spectral information content of Landsat TM satellite imagery. Monitoring landcover change and vegetative mapping are commonly derived from the outputs of the tasseled-cap transformation (Crist and Cicone, 1984; Crist and Kauth, 1986). It not only provides an avenue of data reduction, but its spectral features have been linked to physical parameters of the earth's surface (Christ & Cicone, 1984; Crist & Kauth, 1986). Six bands of the TM satellite imagery (bands 1–5 and 7) are related in the tasseled-cap to measures of vegetation, soil, and canopy moisture or brightness, greenness and wetness respectively (Crist and Cicone, 1984). The tasseled-cap transformation works by applying linear transformation to the six original bands from empirically-derived coefficients (Crist and Cicone, 1984). The output is three tasseled-cap transformed bands, derived from the original six, representing brightness, greenness, and wetness, which generally convey a majority of the image variability. The tasseled-cap transformation is commonly used in forested ecosystems to monitor and detect forest change (Coppin and Bauer, 1994; Collins and Woodcock, 1996; Coppin et al., 2001).

Principal Components Analysis (PCA)

The PCA reduces the redundancy of the data by explaining the data's variance (Rogerson, 2001; Lillesand et al., 2004). In this case, the data are bands of the satellite image. The original seven satellite bands are reduced to a user-defined number of bands, or principal component factors, which is generally less than the satellite images' original number of bands. The first principal component factor places an axis through the data such that it explains the largest amount of the data's variability and generally explains the most variance of all the principal component factors (Rogerson, 2001). The following principal component factors are placed orthogonal to each subsequent principal component factor in order to have the majority of the variance explained (Rogerson, 2001). As the number of principal components increases there is a higher likelihood that noise will come into the data. In order to determine the appropriate number of principal components that will be useful for normalization and change-detection, the eigenvalue (length of principal component factor axis through data explaining variance) is plotted on a vertical axis against its relative principal component factor (Rogerson, 2001) for satellite imagery. Regions of change that exist between multi-temporal, multi-spectral satellite images are commonly highlighted by the use of PCA, because of the low correlation that exists between areas of change (Byrne and Crapper 1979; Byrne et al., 1980). The PCA has been used successfully over a wide array of ecosystems to determine change, for instance broad land cover change (Byrne et al., 1980; Kwarteng and Chavez, 1998), urban expansion (Li and Yeh, 1998), and various forest alterations (Jha and Unni, 1994; Muchoney and Haack, 1994; Collins and Woodcock, 1996)

Normalized Difference Vegetation Index (NDVI)

The NDVI (Rouse et al., 1973) is the most widely-used vegetation index and is most often used to determine the presence of, or vigor of, vegetation (Jiang et al., 2006). It works under the premise that healthy vegetation absorbs most of the visible light spectrum that hits it, whereas the majority of the near-infrared spectrum wavelengths are reflected by healthy vegetation. The NDVI is computed by:

$$\mathrm{NDVI} = \frac{(\mathrm{Near - Infrared}) - (\mathrm{Red})}{(\mathrm{Near - Infrared}) + (\mathrm{Red})}$$

Where the near-infrared wavelength range is 0.76µ – 0.90µ and the red wavelength is 0.63µ–0.69µ (Lillesand et al., 2004). The NDVI is a very popular mechanism for detecting change, it is generally used to highlight areas where changes in vegetative greenness have occurred over time (Coppin and Bauer, 1994; Lyon et al., 1998; Hayes and Sader, 2001). Lyon et al. (1998), found when comparing vegetation indices to characterize and determine vegetation change, that the NDVI was the best at the characterization and determining change occurring in the vegetation.

The Normalized Difference Moisture Index (NDMI)

The NDMI is similar to the NDVI, except for the fact that the mid-infrared band is more sensitive to moisture that leaves absorb. The NDMI has shown to be highly correlated with forest canopy water content, closely tracked plant biomass changes, and water stress (Hardisky et al., 1983). In studies looking at change detection in forested areas, the NDMI had high accuracies due to its ability to detect smaller forest changes, including areas that were partially cut (Wilson and Sader, 2002).The NDMI is calculated by:

$$\mathrm{NDMI} = \frac{(\text{Near - Infrared}) - (\text{Mid - Infrared})}{(\text{Near - Infrared}) + (\text{Mid - Infrared})}$$

Where the near-infrared wavelength range is 0.76µ – 0.90µ and the mid–infrared wavelength is 1.55µ – 1.75µ (Lillesand et al., 2004).

Current Geospatial Research on Barrier Islands

Geospatial surveys of barrier islands have taken place in the past, but most used aerial photographs (Waller and Malbrough, 1976), high resolution light detection and ranging (LIDAR), walking GPS surveys (Schmid, 2001a; Schmid, 2001b; Schmid, 2003), and historical maps and charts (Waller and Malbrough, 1976). Along with remote sensing, geographic information systems have been used to characterize barrier island vegetation patterns (Morgan, 1998), mapping of barrier island sand and vegetation landscapes (Shao et al., 1998; Hoffman and Shroyer, 2003), identify offshore sediment supplies for beach nourishment to promote barrier island building (Finkl et al., 2004; Finkl et al., 2007), and quantify and characterize barrier island movement (Schmid, 2000). These reports show that geospatial techniques can be successful in monitoring morphological change in barrier island environments. This current thesis research utilizes similar geospatial techniques to monitor changes in the Mississippi and Alabama barrier islands.

CHAPTER IV

MATERIALS AND METHODS

Study Area

The longest and best-defined chain of barrier islands in the world resides along the Atlantic and Gulf coasts of the United States (United States Department of the Interior, 1985). The Mississippi coast, in particular, contains the Gulf Islands National Seashore (GINS), which encompasses approximately 15,378 hectares of coastline and barrier islands in the Gulf of Mexico. The barrier islands of the GINS run nearly parallel to shore and are located approximately 15 to 20 km from the mainland coast (Schmid, 2001a). Barrier islands of the Mississippi and Alabama Gulf coasts are located in a wave-dominated environment, where they are characterized by being long and narrow (United States Department of the Interior, 1985). In the Mississippi Sound where the barrier islands are located, diurnal tides generally range less than 0.5 meters (Waller and Malbrough, 1976; Davis and Fitzgerald, 2004). The barrier islands of the GINS are primarily composed of quartz sand that has been eroded from the southeastern Appalachian Mountains (Waller and Malbrough, 1976), where alongshore currents sweep the sand westward forming the barrier islands (Waller and Malbrough, 1976; United States Department of the Interior, 1985). The barrier islands of interest include (from west to east) West Ship Island, East Ship Island, Horn Island, Petit Bois Island, and

Dauphin Island (Figure 2). Cat Island, which is not included in the GINS, was also included in this current study. Cat Island has a different morphology and is uncharacteristically “T”-shaped instead of being linear and elongate (Barnhart, 2003). Cat Island, however, was originally elongate in form but experienced a change in morphology from the addition of sediment from the St. Bernard Delta of the Mississippi River (Penland et al., 1985). Specifically, Cat Island transformed into its current form when the St. Bernard Delta Lobe of the Mississippi River was abandoned (Barnhart, 2003). The group of barrier islands from this study can be separated into the eastern islands, including Horn Island, Petit Bois Island, and Dauphin Island and western islands, including Cat Island, and Ship Island. The western group, exclusive of Dauphin Island, is dominated by western migration. The eastern group is typified not by their westward migration, but their in-place erosion (Schmid, 2000). The abandonment of the St. Bernard Delta lobe, some 2000 years ago is the main cause in the groups of islands (Schmid, 2000). The area located landward of the barrier islands is known as the Mississippi Sound and it has an average depth of approximately 3.0 meters (Meadows, 1998). The Pearl, Pascagoula, and Alabama Rivers empty into the Mississippi Sound creating an extensive estuarine system with a mud, and silt-covered bottom. The Mississippi and Alabama barrier islands have undergone significant changes in morphology over time. As stated, this change is precipitated during storm events. Yet, few investigations have quantified this change at the island-level scale. Therefore, the focus of this study is to evaluate changes in barrier island morphology for the GINS along with Cat Island, during the time period of 1990 to 2005

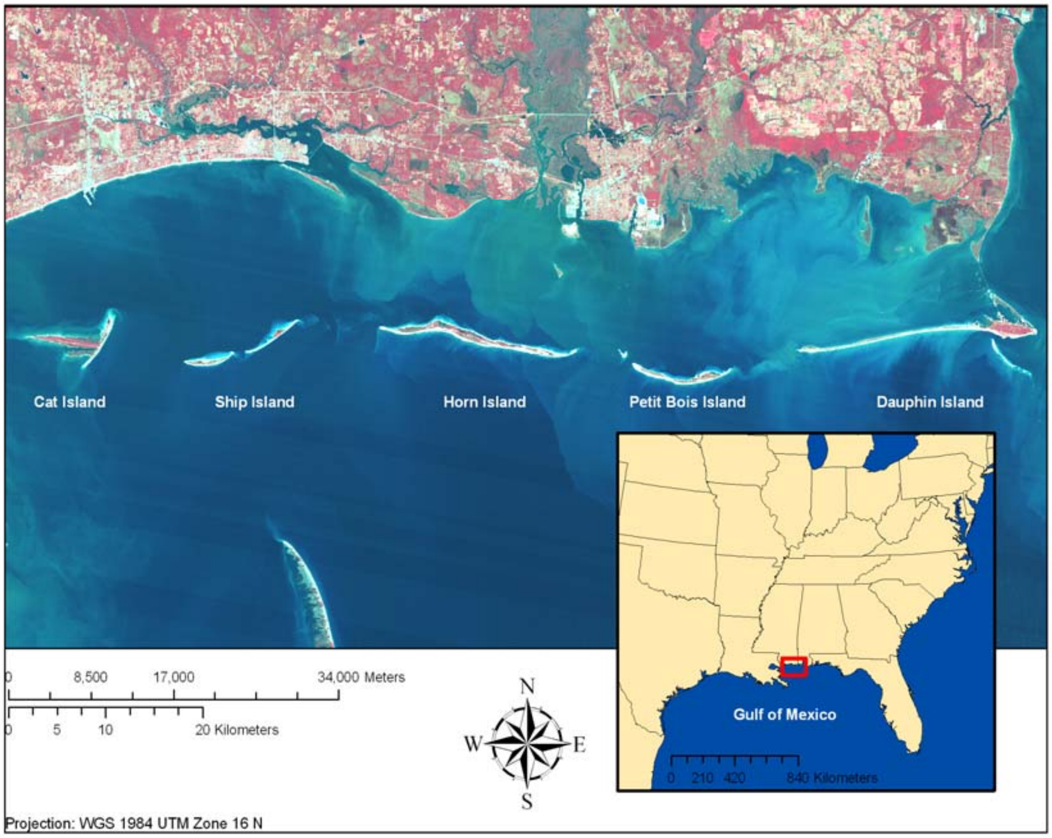

Figure 2. The barrier islands located off the Mississippi and Alabama coastlines from west to east include; Cat Island, Ship Island, Horn Island, Petit Bois Island and Dauphin. All barrier islands were included in this study during the time period between August 1990 and September 2005

Data Acquisition

The satellite imagery used for the morphological change detection study of the Mississippi and Alabama barrier islands were obtained from the United States Geological Survey (USGS) EROS Data Center and consisted of 10 total satellite images (all from path 21 row 39); eight Landsat 5 TM and two Landsat 7 ETM+ (Table 2). Each satellite image was resampled to a common resolution of 29 m. Satellite imagery used to cover the 16-year period, ranged in date from 22 August 1990, to 7 September 2005. All satellite images that were used are in the possession of the Mississippi State University, Department of Geosciences and were geometrically corrected to the 8 June 2000, Landsat 7 ETM+ image. This particular satellite image was chosen for registration, due to its lack of cloud cover and high radiometric quality. A total of 60 ground control points were used on each satellite image for geometric correction. Total root mean squared (RMS) errors on all geometrically corrected satellite images were less than 0.3 pixels. Keeping the RMS error under 0.3 pixels met the condition that whatever resampling technique applied must result in a rectified image being no greater than half the pixel size of the reference data (Jensen, 1981). Keeping total RMS error under half the pixel size of the reference data is critical, especially when performing change detection utilizing image differencing (Jensen, 1981). The nearest neighbor resampling method was used for geometric correction. Nearest neighbor was chosen because it gives real, rather than calculated, pixel values, and works by assigning the digital number for the corrected pixel from the nearest input pixel center (Lillesand et al., 2004).

Table 2. Satellite images from path 21 row 39 with sensor type, date and time of images used during the study period (August 1990 (T_1) to September 2005 (T_{10})). "*" indicates that satellite image occurred within three months of a hurricane.

Satellite Image Date		Sensor	Image time (CST)
1990 August 22	(T_1)	Landsat 5	15:46
1991 July 24	(T_2)	Landsat 5	15:49
1994 September 2	(T_3)	Landsat 5	15:42
1999 September 8	(T_4)	Landsat 7	16:18
2000 July 8	(T_5)	Landsat 7	16:17
*2002 August 7	(T_6)	Landsat 5	16:00
2003 January 6	(T_7)	Landsat 7	16:14
*2004 December 18	(T_8)	Landsat 5	16:11
*2005 March 24	(T_9)	Landsat 5	16:12
*2005 September 16	(T_{10})	Landsat 5	16:14

Weather and Tide Data

Barrier island morphology is strongly related to wave energy, and large-scale changes in island morphology are precipitated during instances when wave energies are high, like that during hurricanes (Davis and Fitzgerald, 2004). Thus, hurricanes are a major influence on the outcome of the current study, and for that reason, a significant portion of this thesis research investigated barrier island change before and after tropical cyclone events (category 1 through category 5 hurricanes). All hurricanes that made landfall between the western panhandle of Florida and the east-central portion of Louisiana were considered (Table 1). Hurricane track data were obtained from the NOAA National Hurricane Center (www.nhc.noaa.gov). In order to determine the distance from each storm to each barrier island an invisible line was created (from the eastern Mississippi River delta to the panhandle of Florida) which bisected each island and crossed each hurricane track of interest. Where the created line crossed each hurricane tack a point representing each hurricane was created. The centroid of each barrier island, which was created to determine barrier island shift/sediment reorganization, was used to determine distance of each hurricane to each island. The centroid for each barrier island used was from the date prior to each hurricane event, for example if a hurricane occurred in August 1995, barrier island centroids generated from the September 1994 classified satellite were used to determine the distance to the hurricane. Along with distance to each barrier island, the magnitude (Saffir-Simpson category, pressure and storm surge) of the hurricanes were also collected.

Another important controlling variable of barrier island morphology is the tidal range (Davis and Fitzgerald, 2004). The influences of tides might be important when determining morphological changes in sand and vegetation, especially in the foreshore beach environment. Therefore archived tidal data were obtained from NOAA Tides and Currents (tidesandcurrents.noaa.gov). The Mississippi and Alabama coasts are classified as microtidal (Davis and Fitzgerald, 2004), meaning that they have a minimal tidal range (<2 m). The tidal range is most likely insignificant when detecting changes at the 29 m resolution; however ranges were determined for each of the Landsat scenes to make sure that the tidal flux did not affect the changes in barrier island morphology. Dates of large tidal ranges, such as those during spring and neap tide or during perigee/apogee, were investigated and related to the times when the images were taken (Table 3).

Table 3. Tide heights recorded during the study period (August 1990 to September 2005). Tide heights are measured in meters, and were collected from the Pascagoula Point, Mississippi Sound, Station identification number: 8741196.

Tide measurement date	Tide measurement time (CST)	Tide height (m)	Tide stage	Tide difference from previous measurement
8/22/1990	15:48	0.30	rising	N/A
7/24/1991	15:48	0.48	falling	0.18
9/2/1994	15:42	0.40	falling	-0.08
9/8/1999	16:18	0.42	falling	0.02
7/8/2000	16:18	0.20	rising	-0.22
8/7/2002	16:00	0.54	falling	0.34
1/6/2003	16:12	0.01	steady/rising	-0.53
12/18/2004	16:12	0.14	falling	0.13
3/24/2005	16:12	0.17	rising	0.04
9/16/2005	16:12	0.45	falling	0.28

Selecting accurate image categorization and change-detection methodologies are of great importance for this study, as certain methodologies may perform better in different ecological regimes (Lillesand et al., 2004). A pilot study (Figure 3) was performed where an accuracy assessment was completed to determine the most accurate categorization procedure for the barrier islands' land cover (sand, vegetation and water). A single Landsat image, 16 September 2005 (post-Hurricane Katrina) and high-resolution aerial photography were used together to determine a remote sensing methodology that would: 1) accurately categorize the sand, vegetation, and water land cover categories and 2) produce the most accurate estimate of change occurring on the barrier islands. Results from the pilot study indicated the best objective means to categorize the images and were applied to the remaining images.

Landsat Image Pre-Processing

In order to prepare each Landsat image for normalization and subsequent change-detection all images were subset to the study area, which included all five barrier islands (Cat Island, Ship Island, Horn Island, Petit Bois Island, and Dauphin Island). The great variability in pixel values that included water and land was reduced by masking out (eliminating) water outside that perimeter of each barrier island. A water mask was applied to each image, which took the ratio of the mid-infrared to green band of the Landsat image. The resultant "water-masked" image was converted to binary format. Each "water-masked" image, using image algebra, was applied to its respective original subset Landsat image, masking out the easily identifiable water category.

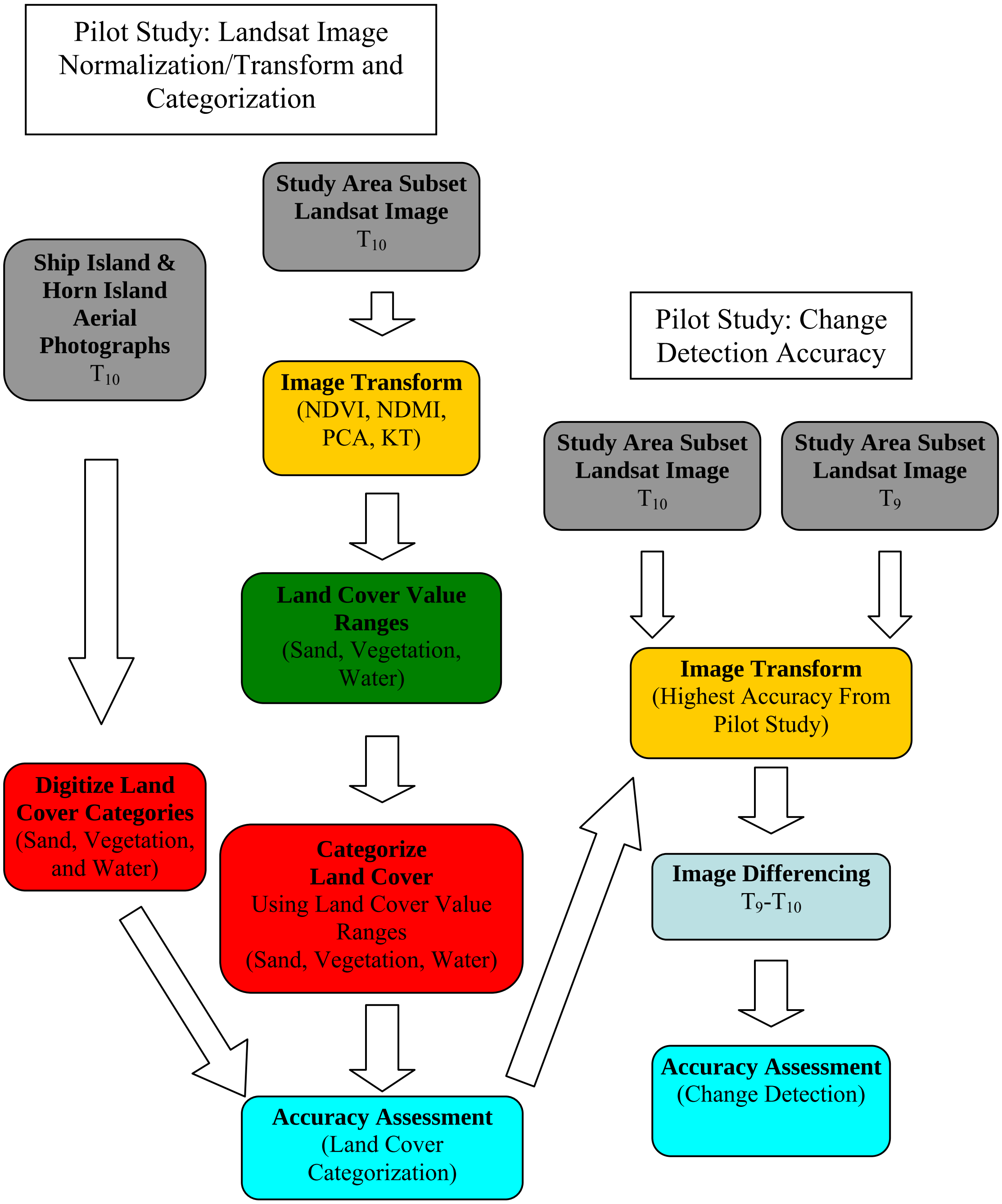

Figure 3. Pilot study methods for determining the most accurate image normalization/transformation technique that was used to categorize the entire set of Landsat images.

Pilot Study: Landsat Image Transform/Normalization

Developing a methodology that accurately categorized the land cover types of the barrier islands along the Mississippi and Alabama coastlines using Landsat satellite imagery, is of utmost importance for this study. The 16 September 2005 Landsat image was used in conjunction with aerial photography from early September 2005 to determine an accurate method of image normalization (Figure 3). The early to mid-September time period was chosen for the pilot study because it represented the only satellite image that was acquired at the same time period as aerial photographs. Only, Ship Island (West Ship Island) and Horn Island were used because their vegetation, sand, and water environments were representative of those present on all remaining barrier islands (Cat Island, Petit Bois Island and Dauphin Island). Four commonly used image transforms were compared to aerial photographs (which were used as truth), to determine the most accurate method of normalization. The normalized difference vegetation index (NDVI), normalized difference moisture index (NDMI), principal components analysis (PCA), and tasseled-cap image transforms, which are frequently used in change detection studies (Lillesand et al., 2004), were all applied to the post-Hurricane Katrina Landsat image. Each image transform applied to the original Landsat image resulted in a separate image, with each transform was subsequently compared to the aerial photographs. In order to properly apply the tasseled-cap transformation, values of brightness, greenness, and wetness, raw image pixel values that represent reflectance were converted into at-sensor-reflectance.

Pilot Study: Image Categorization

After applying the four image normalization techniques to the post-Hurricane Katrina image, the land cover value ranges for sand, vegetation and water were extracted from each transformed Landsat image, and categorized based upon their respective value ranges. In order to extract each land cover categories' value range, polygons were visually digitized around known areas of sand, vegetation and water on the non-transformed Landsat image. Each resultant categorized image would be compared to aerial photographs to determine its accuracy.

Pilot Study: Aerial Photographs

High-resolution, geocorrected, aerial photography was obtained free of charge from the National Oceanic and Atmospheric Administration (NOAA) and the National Geodetic Survey. The most recent aerial photographs available were from post-Hurricane Katrina along the Mississippi Gulf coast (1–3 September 2005), these photographs corresponded to the 16 September 2005 Landsat image. The aerial photographs for Ship Island and Horn Island were composed and mosaicked separately, creating a separate image for each barrier island. Each of the land cover types (sand, vegetation, and water) were visually digitized on Ship Island and Horn Island separately and land cover areas calculated. These digitized land cover types and area calculations were used as truth, and were compared to each categorized Landsat image.

Pilot Study: Image Transform/Normalization Accuracy Assessment

After applying the four image normalization techniques (NDVI, NDMI, PCA, and tasseled-cap) and categorizing each of the four resultant images, an accuracy assessment was performed. The accuracy assessment compared each categorized image to the digitized aerial photographs. One-thousand points were randomly generated separately over both Ship Island and Horn Island. These points were categorized according to what land cover type they occurred on, in each categorized Landsat image. For comparison purposes, the randomly generated points were then categorized according to the digitized aerial photographs for Ship Island and Horn Island. Once point categorization was done, a simple comparison was done to determine the accuracy of each of the four image transforms. An accuracy assessment was performed by creating an error matrix, which compared point categorizations. This provided an overall accuracy assessment of each image transform, and accuracy of each land cover category. The KHAT statistic, which serves as an indicator of the percent of correct values within the error matrix, was also used to determine the "true" agreement versus "chance" agreement (Lillesand et al., 2004).

Pilot Study: Comparing Landsat Land Cover Category Areas to Aerial Photograph Land Cover Category Areas.

The area of each land cover category on the categorized Landsat image was calculated by summing the number of pixels within each category and multiplying that value by the area of each pixel, which was 29m x 29m. Total barrier island area was calculated as the sum of the sand and vegetation classes together. These areas were then compared to the digitized aerial photograph areas.

Pilot Study: Change Detection Accuracy Assessment

It was not only important to determine the accuracy of the initial land cover categorization, but also the ability to detect changes between the transformed satellite images from two different time periods needs to be evaluated (Figure 3). In order to determine the accuracy of the change detection, two satellite images were used; the previously used post-Hurricane Katrina image (16 September 2005), and the pre-Hurricane Katrina image from 24 March 2005. First, the pre-Hurricane Katrina Landsat image was transformed using the most accurate image transform, as described earlier (i.e. NDVI). Simple image differencing was performed between the transformed pre and post Hurricane Katrina images. The resultant image (pre-post Hurricane Katrina) showed pixels that were associated with areas of change and no-change. After visual inspection of the pre-post Hurricane Katrina image and determining the pixel values were normally distributed, the mean ± 2 standard deviations, which generally explains ≈ 95% of the data (Freund and Wilson, 2003), was used to determine where the most significant land cover change occurred (Jensen, 1996). This assumption of land cover change states that values close to or equal to zero represent areas of no-change, whereas values falling in the "tails" of the distribution represent significant change (Figure 4; Jensen, 1996). The previously used, randomly generated points that were categorized correctly (when comparing the aerial photographs to each initial image transform) were overlaid on the pre-post Hurricane Katrina image. Of those points, only points which occurred in areas

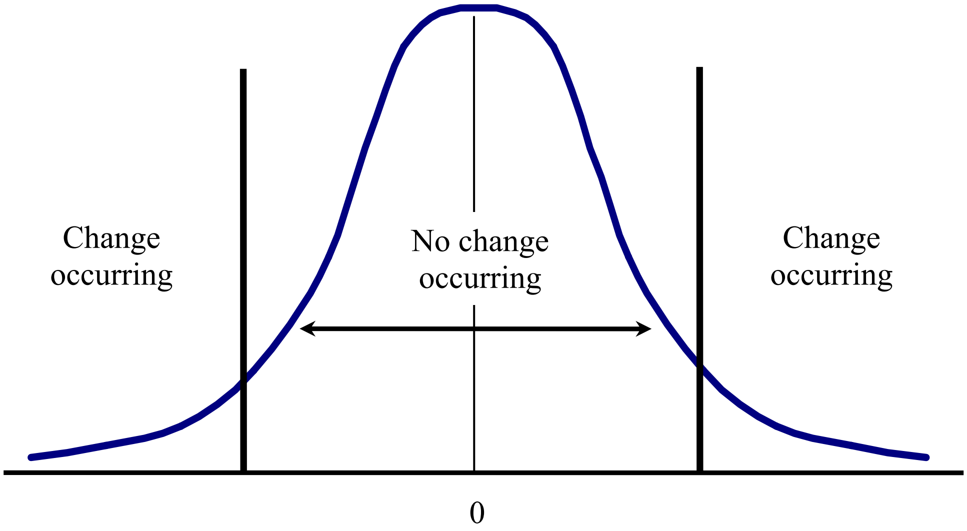

Figure 4. A normal curve derived from Jensen (1996) showing where areas of change and no change generally take place when investigating land cover change on a satellite image.

of no-change were kept for the change detection accuracy assessment. The assumption here is that points that showed no significant change from pre-Hurricane Katrina to post-Hurricane Katrina, should have an agreement between the pre-Hurricane Katrina land cover (Landsat derived) and the land cover from the 2005 aerial photography. It is expected that the land cover should be similar between the two sets of imagery.

Barrier Island Multi-Temporal Change Detection

After determining the most accurate method for land cover categorization and applying that method to the remaining Landsat images, a post-categorization change detection of the barrier islands was performed on 10 images. The post-categorization change detection method was chosen because measurement of the amount of change to and from each land cover category (sand, vegetation, and water) between each time period was desired. After performing the image transform, each image was categorized by extracting each land covers value range (as described earlier). A simple image differencing technique was employed to determine the amount of change in sand, vegetation, and water on each barrier island between 1990 and 2005. Differencing was done on images which occurred consecutively, (i.e. 1990 minus 1991, 1991 minus 1994) (Table 4). Images that did not occur in consecutive time periods were not differenced. By limiting the time period between images as much as possible it may be possible to identify the environmental variables that were most influential on the barrier islands during each time period.

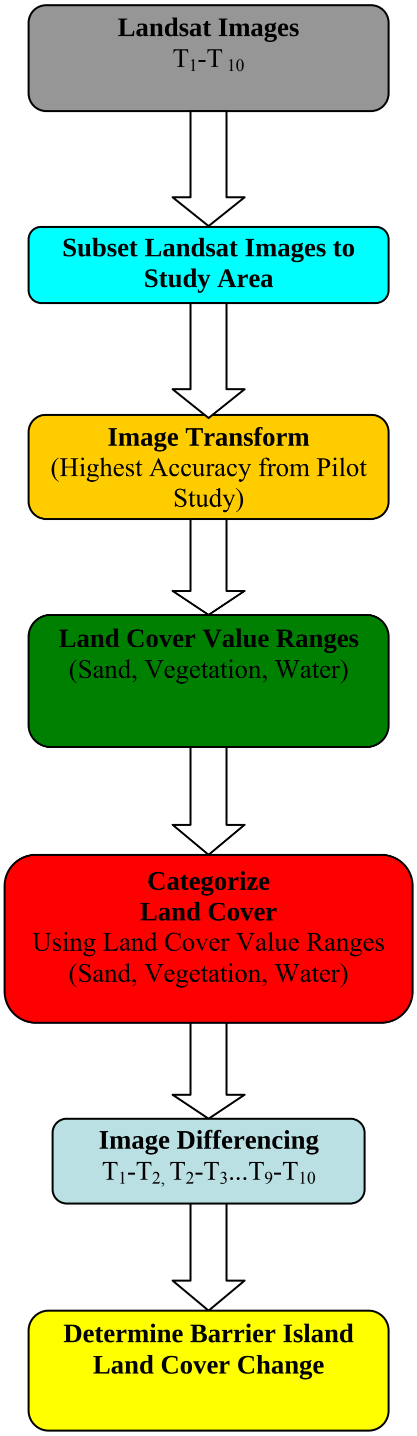

Figure 5. Methods used to determine the amount of change occurring on the Mississippi and Alabama barrier islands between August 1990 and September 2005.

Table 4. Satellite image differencing that took place for analysis during the study; all image dates occurred between August 1990 and September 2005.

Comparison number	Images compared
1	22 August 1990 - 24 July 1991
2	24 July 1991 - 2 September 1994
3	2 September 1994 - 8 September 1999
4	8 September 1999 - 8 July 2000
5	8 July 2000 - 7 August 2002
6	7 August 2002 - 6 January 2003
7	6 January 2003 - 18 December 2004
8	18 December 2004 - 24 March 2005
9	24 March 2005 - 16 September 2005

Barrier Island Shift/Reorganization

In order to determine the general direction (north, south, east or west) that each barrier island shifted, points were visually digitized, representing the eastern and western-most boundaries of each barrier island on the categorized satellite images. East and West Ship Island were combined for calculation of barrier island area, however for determining island shift; they were separated as East Ship Island and West Ship Island. Because island area was calculated as just the area of vegetation and sand, the intervening water in between East and West Ship Island is considered in the area calculation. This was done in order to make accurate comparisons to earlier imagery. The straight line distance between each consecutive year's boundary points was measured. Also, barrier island centroid shift was identified by creating a centroid for each island for each year. This was done by converting each categorized satellite image (raster) into a polygon (feature) layer and converting that file into a point file, in ArcMap 9.x this feature generates a point representing the centroid of the representative polygon. The straight line distance between each island centroid was measured to determine the general shift of the barrier island from one image to the next. It should be noted that a change in centroid can represent at least one of three events. A shift in centroid may represent an overall net movement of the entire island. Second, a centroid shift may represent a change in barrier island area; sediment loss or sediment gain around the earlier centroid will appear to shift its position even though the island has not physically moved. Third, a shift in the centroid may represent both actual island movement and reorganization of sediment around the barrier island. Regardless of which factor is responsible, a shift in centroid location will be used in this thesis to indicate substantial reorganization of barrier island sediments.

Since West Ship Island and East Ship Island were treated as one island for area calculations, their total centroid distance movement was averaged. The ratio of barrier island erosion (loss) to migration (Schmid, 2000) was used to determine if the barrier islands were migrating or eroding in place. This was calculated by taking the ratio of the net amount of movement of the barrier island centroid to the calculated total area lost between 1990 and 2005.

CHAPTER V

RESULTS

Pilot Study: Image Transform/Normalization Accuracy Assessment

Results of the image transform accuracy assessments showed that the NDVI transform had the highest accuracy (78.6%) (Figure 6, Tables 5, 6, 7, 8, 9 and 10) when compared with tasseled cap bands 1 (56.0%), band 2 (36.3%), band 3 (22.5%); PCA band 1 (58.4%) band 2 (0.0%) and band 3 (0.0%); and the NDMI (6.8%). The NDVI image transform also had a higher KHAT statistic (0.65) than tasseled cap bands 1 (0.39), band 2 (0.21), and band 3 (0.14); PCA band 1 (0.41), band 2 (0.00) and band 3 (0.00); and the NDMI (0.05). Bands 2 and 3 of PCA resulted in no accuracy (0.0%) and KHAT statistics of 0.00. Each of the calculated landcover statistics overlapped extensively with PCA producing broad misclassifications. Not only did the NDVI have higher overall accuracies and KHAT statistics, accuracies of each land cover type: sand (75.2%), vegetation (85.4%), and water (69.2%) were also higher than all other image transform techniques. Because of the high overall and individual landcover accuracies, the NDVI image transform methodologies were applied to the remaining images.

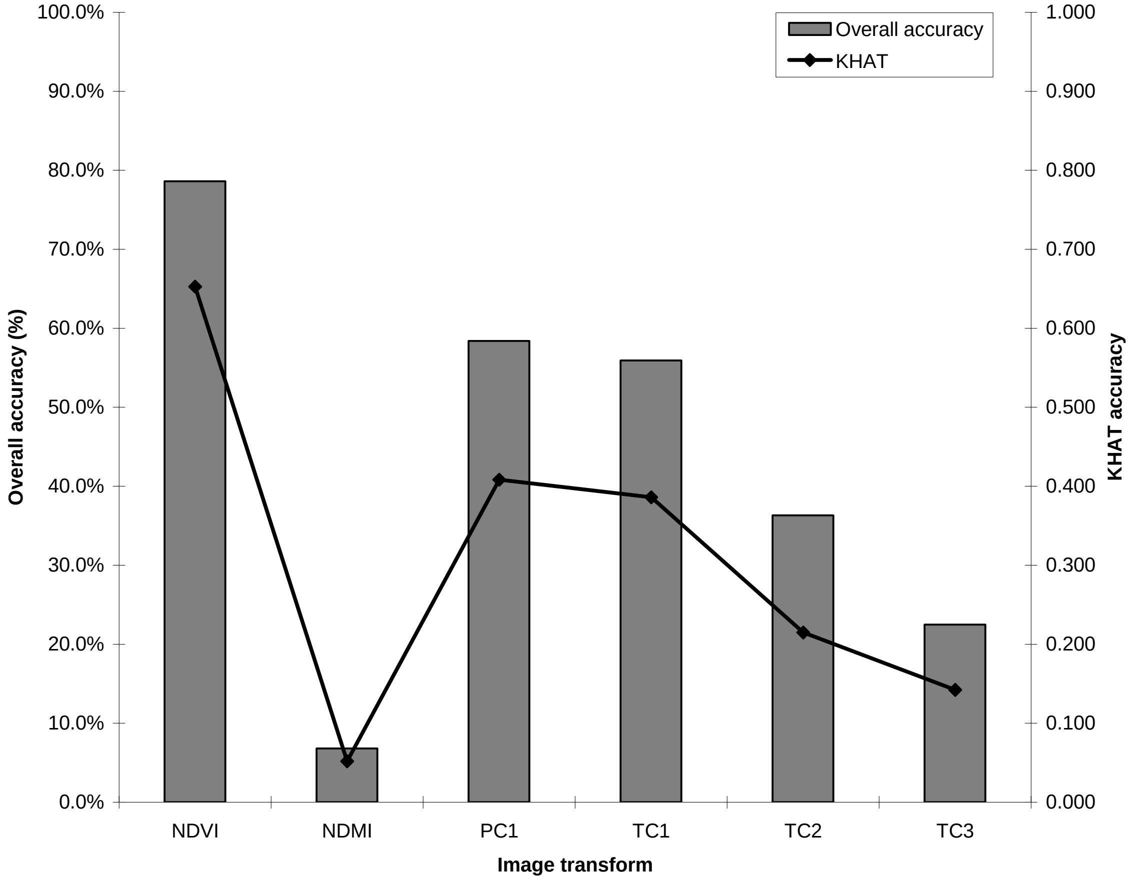

Figure 6. Overall accuracy (%) and KHAT values for NDVI, NDMI, Principal Component 1 (PC1), Tasseled Cap 1 (TC1), Tasseled Cap 2 (TC2), and Tasseled Cap 3 (TC3). Principle components 2 and 3 were not included because each had accuracies and KHAT values of 0.

Table 5. Accuracy assessment for the NDVI categorization performed on the 16 September 2005 (post-Hurricane Katrina) satellite image.

Classified (Satellite imagery)	Reference (Aerial photography)				Total points	Users accuracy	Comission errors
	Sand	Vegetation	Water	Unclassified			
Sand	641	107	70	0	818	78.4%	21.6%
Vegetation	144	720	24	0	888	81.1%	18.9%
Water	67	16	211	0	294	71.8%	28.2%
Unclassified	0	0	0	0	0	0.0%	0.0%
Total points	852	843	305	0	2000	**Overall accuracy**	
Producers accuracy	75.2%	85.4%	69.2%	0		**78.6%**	
Omission errors	24.8%	14.6%	30.8%	100.0%		**KHAT**	**0.653**

Table 6. Accuracy assessment for the Tasseled cap band 1 categorization performed on the 16 September 2005 (post-Hurricane Katrina) satellite image.

Classified (Satellite imagery)	Reference (Aerial photography)				Total points	Users accuracy	Comission errors
	Sand	Vegetation	Water	Unclassified			
Sand	461	72	22	0	555	83.1%	16.9%
Vegetation	99	556	79	0	734	75.7%	24.3%
Water	6	16	102	0	124	82.3%	17.7%
Unclassified	287	199	101	0	587	0.0%	0.0%
Total points	853	843	304	0	2000	**Overall accuracy**	
Producers accuracy	54.0%	66.0%	33.6%	0		**56.0%**	
Omission errors	46.0%	34.0%	66.4%	100.0%		**KHAT**	**0.386**

Table 7. Accuracy assessment for the Tasseled cap band 2 categorization performed on the 16 September 2005 (post-Hurricane Katrina) satellite image.

Classified (Satellite imagery)	Reference (Aerial photography)				Total points	Users accuracy	Comission errors
	Sand	Vegetation	Water	Unclassified			
Sand	96	28	55	0	179	53.6%	46.4%
Vegetation	74	630	10	0	714	88.2%	11.8%
Water	0	0	0	0	0	0.0%	0.0%
Unclassified	683	185	239	0	1107	0.0%	0.0%
Total points	853	843	304	0	2000	**Overall accuracy**	
Producers accuracy	11.3%	74.7%	0.0%	0		**36.3%**	
Omission errors	88.7%	25.3%	100.0%	100.0%		**KHAT**	**0.215**

Table 8. Accuracy assessment for the Tasseled cap band 3 categorization performed on the 16 September 2005 (post-Hurricane Katrina) satellite image.

Classified (Satellite imagery)	Reference (Aerial photography)				Total points	Users accuracy	Comission errors
	Sand	Vegetation	Water	Unclassified			
Sand	240	62	12	0	314	76.4%	23.6%
Vegetation	6	24	6	0	36	66.7%	33.3%
Water	64	38	186	0	288	64.6%	35.4%
Unclassified	543	719	100	0	1362	0.0%	0.0%
Total points	853	843	304	0	2000	**Overall accuracy**	
Producers accuracy	28.1%	2.8%	61.2%	0		**22.5%**	
Omission errors	71.9%	97.2%	38.8%	100.0%		**KHAT**	**0.142**

Table 9. Accuracy assessment for the principle component band 1 categorization performed on the 16 September 2005 (post-Hurricane Katrina) satellite image.

Classified (Satellite imagery)	Reference (Aerial photography)				Total points	Users accuracy	Comission errors
	Sand	Vegetation	Water	Unclassified			
Sand	482	78	25	0	585	82.4%	17.6%
Vegetation	114	581	78	0	773	75.2%	24.8%
Water	5	13	105	0	123	85.4%	14.6%
Unclassified	252	171	96	0	519	0.0%	0.0%
Total points	853	843	304	0	2000	**Overall accuracy**	
Producers accuracy	56.5%	68.9%	34.5%	0		**58.4%**	
Omission errors	43.5%	31.1%	65.5%	100.0%		**KHAT**	**0.408**

Table 10. Accuracy assessment for the NDMI categorization performed on the 16 September 2005 (post-Hurricane Katrina) satellite image.

Classified (Satellite imagery)	Reference (Aerial photography)				Total points	Users accuracy	Comission errors
	Sand	Vegetation	Water	Unclassified			
Sand	0	0	0	0	0	0.0%	0.0%
Vegetation	0	1	2	0	3	33.3%	66.7%
Water	38	43	135	0	216	62.5%	37.5%
Unclassified	815	799	167	0	1781	0.0%	0.0%
Total points	853	843	304	0	2000	**Overall accuracy**	
Producers accuracy	0.0%	0.1%	44.4%	0		**6.8%**	
Omission errors	100.0%	99.9%	55.6%	100.0%		**KHAT**	**0.052**

Pilot Study: Change Detection Accuracy Assessment

The 24 March 2005 (pre-Hurricane Katrina) image was transformed using NDVI and landcover classes were classified using the same thresholding techniques as mentioned earlier. In chapter IV, it was stated that a point layer was created that contained the land cover values from the 2005 aerial photography and the land cover values from the pre-Katrina minus post-Katrina image. The points being compared included only those that fell in the area of no change. The comparison of the land cover types showed high agreement between the aerial photographs and the satellite images. The pre-Hurricane Katrina image had an overall accuracy of 76.2% and a KHAT statistic of 0.58, which was similar to that of the 16 September 2005 (post-Hurricane Katrina) image accuracy (78.6%) and KHAT statistic (0.65) (Table 11). The resultant high classification accuracy ensures confidence that subsequent change detection calculations are valid.

Table 11. Change detection accuracy assessment of the 24 March 2005 (pre-Hurricane Katrina) satellite image.

Classified (Satellite imagery)	Reference (Aerial photography)			Total points	Users accuracy	Comission errors
	Sand	Vegetation	Water			
Sand	528	81	65	674	78.3%	21.7%
Vegetation	105	425	18	548	77.6%	22.4%
Water	41	3	51	95	53.7%	46.3%
Total points	674	509	134	1004	**Overall accuracy**	
Producers accuracy	78.3%	83.5%	38.1%	1317	**76.2%**	
Omission errors	21.7%	16.5%	61.9%		**KHAT**	**0.5830**

Pilot Study: Comparing Landsat Land Cover Category Areas to Aerial Photograph Land Cover Category Areas

Slight differences were seen in barrier island area (Table 12) when comparing the digitized aerial photographs from Ship Island and Horn Islands to the classified satellite images. The sand class was underestimated by 60.5 ha on Ship Island and 382.7 ha on Horn Island when compared with the digitized aerial photograph area for Ship Island (82.4 ha) and Horn Island (552.3 ha). For each barrier island, the classified satellite image vegetation class overestimated the corresponding area calculations from the aerial photographs. From the satellite image, Ship Island and Horn Island vegetation classes were calculated to have an area of 117.7 ha and 916.1 ha, respectively. This was not equal to the digitized aerial photos areas of 75.6 ha and 612.7 ha, respectively. Overall barrier island area (sand + vegetation areas) was overestimated for the classified satellite image on both Ship Island (+20.2 ha) and Horn Island (133.8 ha; Figure 7 and 8).

Table 12. Comparison of total barrier island area from Ship Island and Horn Island between satellite (raster) and aerial photographs (polygon). A negative value in the difference column indicates an underestimate by the raster data, percentage of each land cover type is recorded.

Barrier island	Landcover class	Raster area (ha) (%)	Polygon area (ha) (%)	Difference (ha)
Ship Island				
	Sand	60.5 (14.2%)	82.4 (19.3%)	-21.9
	Vegetation	117.7 (27.7%)	75.6 (17.7%)	42.1
	Water	246.5 (58.1%)	269.3 (63.0%)	-22.8
	Total area	424.6	427.2	-2.6
Horn Island				
	Sand	382.7 (12.9%)	552.3 (18.6%)	-169.6
	Vegetation	916.1 (30.8%)	612.7 (20.6%)	303.4
	Water	1672.7 (56.3%)	1806.1 (60.8%)	-133.5
	Total area	2971.5	2,971.1	0.4

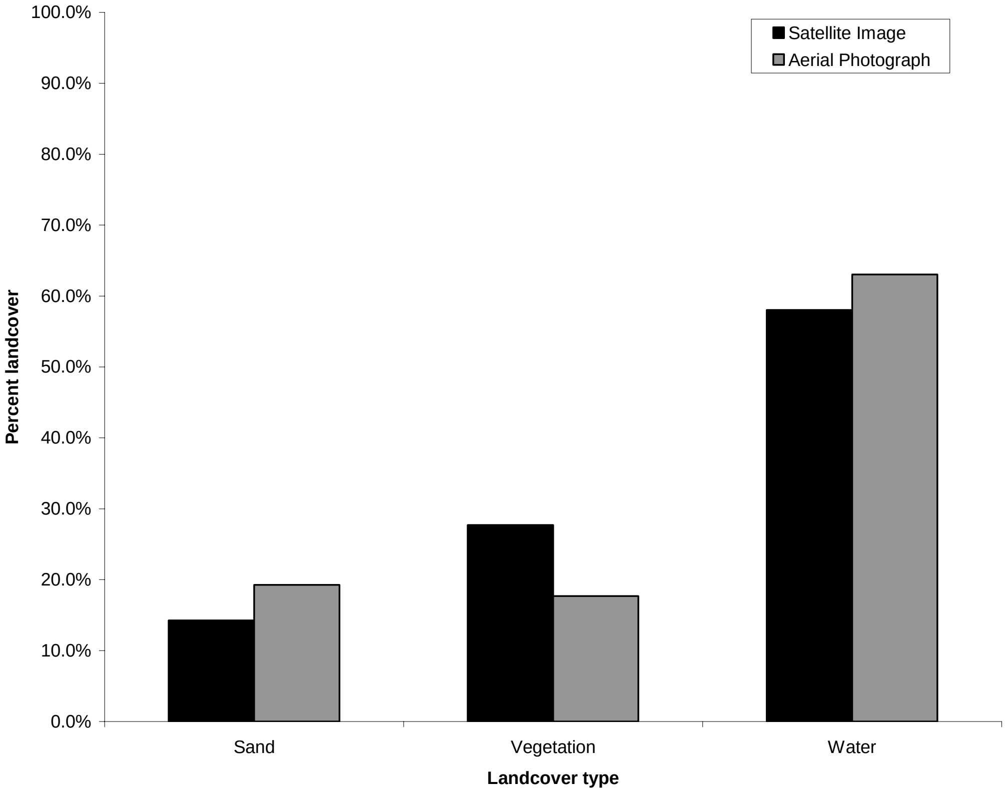

Figure 7. Ship Island comparison of satellite image calculated percent land cover to aerial photograph derived percent land cover for the post-Hurricane Katrina time period.

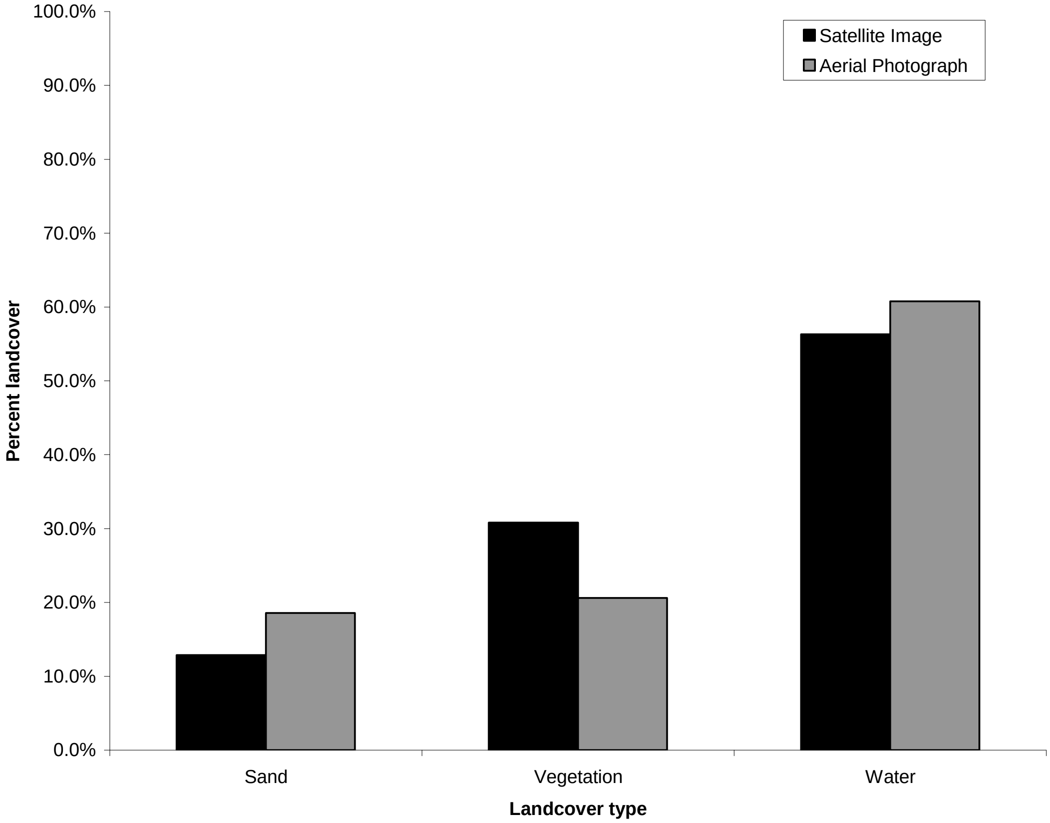

Figure 8. Horn Island comparison of satellite image calculated percent land cover to aerial photograph derived percent land cover for the post-Hurricane Katrina time period.

Barrier Island Multi-Temporal Change Detection

Cat Island

In the 22 August 1990 image, it was calculated that Cat Island (Figure 14, Appendix A) had approximately 509.6 hectares (ha) of vegetative cover, 376.3 ha of sand, and 791.7 ha of surrounding water (Table 32, Table 33, Figure 15, Appendix A). "Surrounding water," is the area of water around the island that was included when sub-setting each barrier island during image processing. During the time from 1990 to 1991 images, it was calculated that the largest changes were seen within vegetated areas, where there was a net vegetative loss of 28.6 % (Table 13, Figure 9). The majority of the vegetation was converted into sand (96.7 %) and a small portion to water (3.3 %). The sand class gained in area by approximately 33.0 %, with most of the gain coming as a conversion from vegetation (80.8%) and only a small amount from water (19.2%) (Table 14). Overall on Cat Island, total island area (sand and vegetation) lost approximately 2.4 % of its area (Figure 10).

Between 1991 and 1994 Cat Island had an increase in vegetation by 71.9 % (Table 32, Figure 9). Most of the gain came as conversion from the sand class (89.0 %) and a small portion from water (11.0 %) (Table 14). The sand class had a loss of 45.2 % of the 1994 area, with most being converted to vegetation (88.9 %) and a small amount to water (11.1 %) (Table 13). Total island area increased by 4.1 % (Figures 15 and 10).

Net vegetation loss on Cat Island from 1994 to 1999 was approximately 58.1%. Most of the vegetation loss was from conversion to sand (66.1 %), followed by conversion to water (33.9 %; Table 13). There was a net gain of sand on Cat Island by

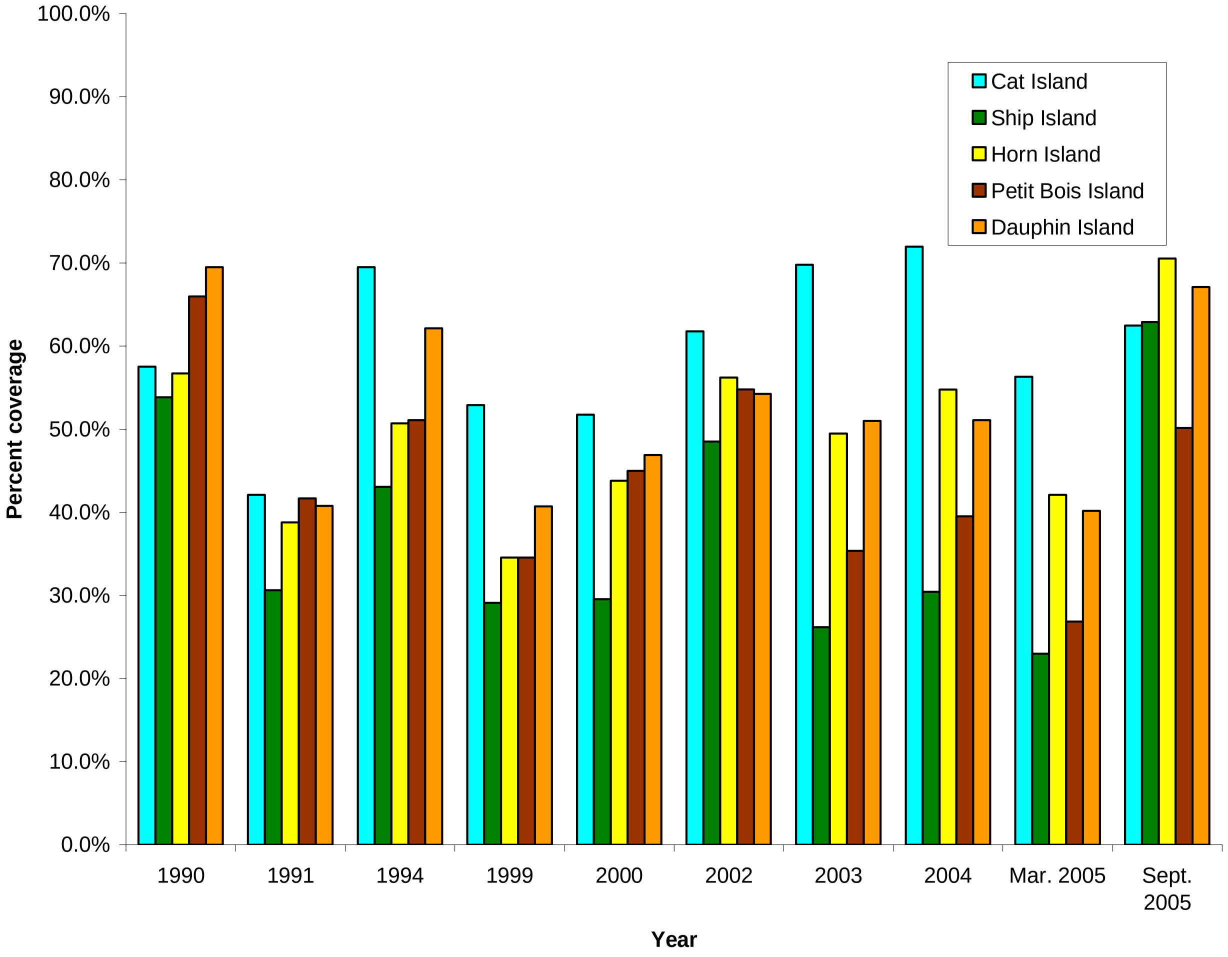

Figure 9. Percent vegetation of the total barrier island area on the Mississippi and Alabama barrier islands between August 1990 and September 2005.

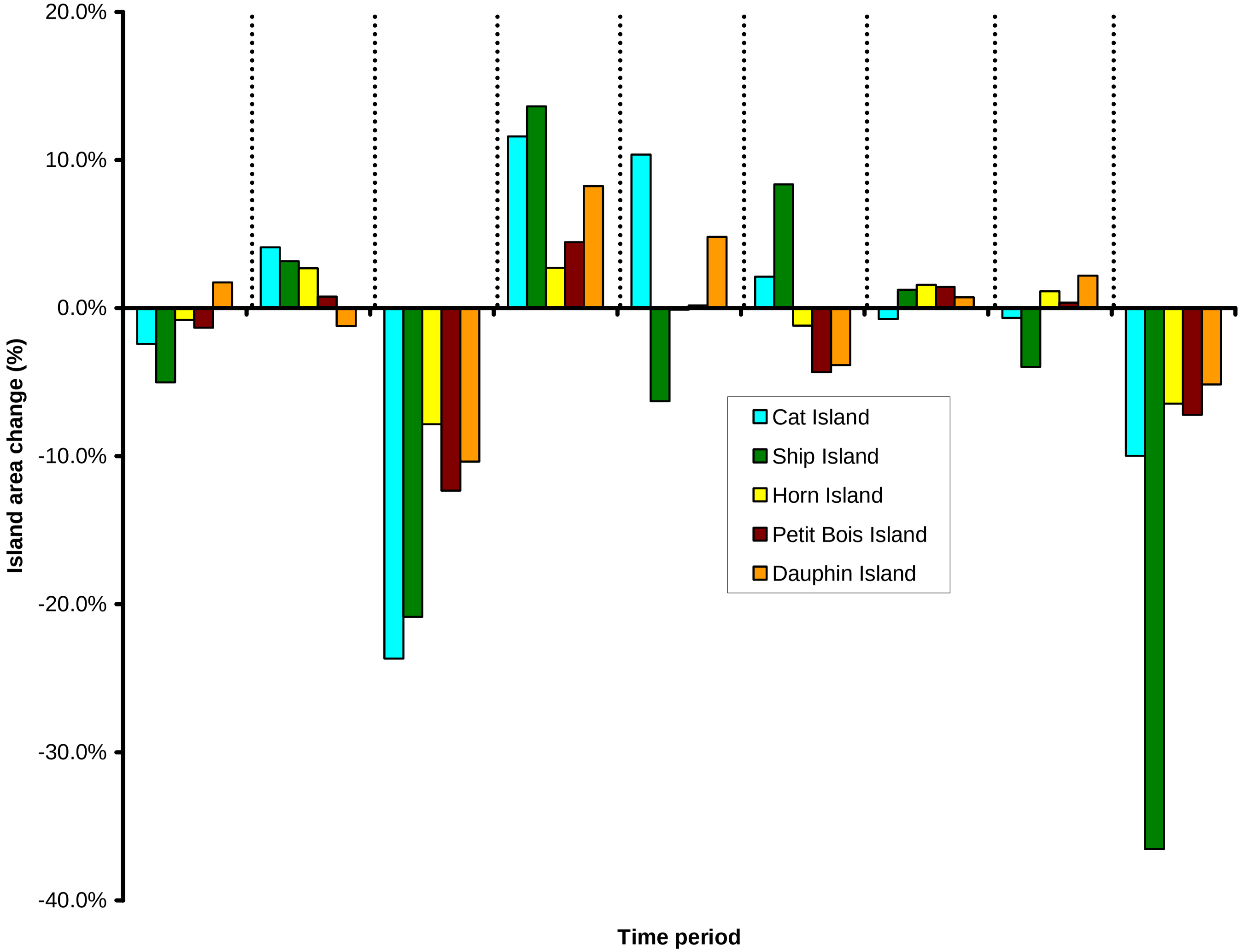

Figure 10. Change in total barrier island area between August 1990 and September 2005.

Table 13. Cat Island percent loss from each land cover class, and its subsequent conversion to, between August 1990 and September 2005.

	Time period								
Change class	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	64.1%	11.1%	95.4%	34.0%	28.1%	20.4%	38.0%	65.3%	47.6%
Sand to vegetation	35.9%	88.9%	4.6%	66.0%	71.9%	79.6%	62.0%	34.7%	52.4%
Vegetation to water	3.3%	7.2%	33.9%	13.7%	9.3%	12.2%	4.5%	3.9%	16.1%
Vegetation to sand	96.7%	92.8%	66.1%	86.3%	90.7%	87.8%	95.5%	96.1%	83.9%
Water to vegetation	9.2%	22.4%	0.0%	10.2%	30.2%	16.2%	6.3%	0.3%	7.0%
Water to sand	90.8%	77.6%	100.0%	89.8%	69.8%	83.8%	93.7%	99.7%	93.0%

Table 14. Cat Island percent gain from each land cover class and its subsequent conversion from between August 1990 and September 2005.

Change class	Time period 8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Water to Sand	19.2%	80.5%	4.7%	79.0%	74.4%	52.2%	40.0%	18.0%	22.1%
Vegetation to Sand	80.8%	19.5%	95.3%	21.0%	25.6%	47.8%	60.0%	82.0%	77.9%
Water to Vegetation	11.0%	5.6%	0.0%	17.8%	24.5%	6.9%	3.2%	0.5%	1.8%
Sand to Vegetation	89.0%	94.4%	100.0%	82.2%	75.5%	93.1%	96.8%	99.5%	98.2%
Vegetation to water	9.0%	3.0%	41.0%	13.4%	6.3%	15.9%	5.4%	15.8%	15.4%
Sand to Water	91.0%	97.0%	59.0%	86.6%	93.7%	84.1%	94.6%	84.2%	84.6%

17.9 %; most of this gain was conversion from vegetation 95.3 % ha (Table 14). Although the sand class gained in total area, the large portion of sand loss was converted to water (95.4 %). During this time period, Cat Island lost approximately 23.7 % of its total island area, which was the greatest loss during the study period from 1990 to 2005 (Figure 10).

Between August 1999 and July 2000, vegetated areas had a net increase of 9.1 % (Figure 9), with most of the gain coming from sand (66.0 %), the largest portion of vegetated loss was conversion to the sand class (86.3 %) (Table 13). Sand also had a net increase by 14.3 %, with the majority of the gain coming from water (79.0 %), losses were noted to vegetation (66.0 %) and water (34.0 %). Cat Island increased in total area by 11.6 % (Figures 10 and 15).

Following the same trend of 1999 to 2000, July 2000 to August 2002 also showed an increase in vegetated area by 31.7 % (Figures 9 and 15), whereas losses were seen in both sand (-12.5 %) and water (-8.7 %) (Table 32). The majority of the area gain in vegetation was conversion from sand (75.5 %) and from water (24.5 %). Again, total island area increased on Cat Island by 10.4 % (Figure 10).

Vegetation change patterns on Cat Island were similar from August 2002 to January 2003, where there was an increase in vegetated area by 15.4 % and net area losses were again seen in sand (-19.3 %) and water (-2.2 %) (Table 32, Figure 9 and Figure 15). Similar to the July 2000 to August 2002 time period, the largest gain in vegetated area came from sand (93.1 %) (Table 14). Since July 2000, Cat Island increased in total area (Figure 10). Similarly, between August 2002 and January 2003 Cat Island increased by approximately 2.1% (Figure 10).

The January 2003 to December 2004 time period had vegetated area grow by 2.3 % (Figure 9). Most of the gain came from a conversion from sand (96.8 %) (Table 14). Water showed a slight increase in area as well (0.8%), whereas sand underwent a loss of approximately 7.9 %. This time period was one the most stable periods for Cat Island, even though the island lost approximately 0.7 % of its total area from January 2003 (Figure 10).

For the first time since 1994 to 1999 time period, December 2004 to March 2005 showed a net decrease in vegetated cover (-22.3 %; Figure 14) whereas both sand (54.8 %) and water (0.7 %) showed net increases. The majority of the sand gain came from loss of vegetated area (82.0 %). Similar to the January 2003 to December 2004 time period, Cat Island had a loss of total island area (0.7 %). These two time periods represented the most stable time on Cat Island (where the least amount of change occurred; (Figures 10 and 15).

Following consecutive periods of stability on Cat Island, the time period between March 2005 and September 2005 had large amounts of change with the island losing approximately 10.0 % of its total area (Figures 10 and 15). Areas of sand on Cat Island saw the greatest decrease (-22.6 %) between March 2005 and September 2005. Vegetated areas decreased during this time period as well (-0.2 %; Figure 9). The only increase was noted in the water class, which increased by 10.3 %. The majority of the gains in water area came from the loss of sand (84.6 %) (Table 14).

Ship Island

On 22 August 1990, Ship Island (Figure 16, Appendix A) had approximately 187.5 ha of sand and 218.7 ha of vegetation (Figure 17; Table 34; Appendix A). Between August 1990 and July 1991 Ship Island lost a large net amount of vegetation (-46.0 %), with most of it being converting to sand (96.6 %) (Table 15). Both sand (+42.8 %) and water (+1.3 %) had net gains in area. Sand gained most of the area as a conversion from vegetation, where water had most of its gains coming from sand (90.0 %). Total island area (sand and vegetation only) decreased by 5.0 % (Figure 10).

Between July 1991 and August 1994, Ship Island increased in vegetation by 45.1 % (Figure 14), whereas both sand (-15.3 %) and water (-0.8 %) lost area from the previous year (Table 34). The majority of the vegetative gain came as conversion from sand (87.5 %), this was also the largest loss for the sand class (68.0 %). The water class on Ship Island lost the majority of its area to sand (97.2 %). Ship Island during this time period had an overall increase in island area by 3.2 % (Figure 10).

During the five year time span from September 1994 to September 1999, Ship Island had losses in vegetative area (-46.5 %; Figure 9) and sand (-1.4 %). Net water area had an increase of 5.2 % (Table 34). Most of the vegetative loss was converted to sand (77.5 %), whereas sand lost most of its area to water (97.8 %). Total island area also decreased by 20.9 % (Figure 10).

From August 1999 to July 2000 on Ship Island the only measured net loss was in the water class (-2.6 %). Most of the loss of water area was conversion to sand (97.4 %); this was also the largest gain for sand, which had a total net gain of 13.0 % (Table 34). Similar to the sand class, vegetated area had a slight net increase of 15.3 % (Figure 9),

Table 15. Ship Island percent loss from each land cover class, and its subsequent conversion to class, between August 1990 and September 2005.

Change class	Time period								
	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	91.5%	32.0%	97.8%	36.1%	50.1%	94.1%	63.3%	83.9%	67.9%
Sand to vegetation	8.5%	68.0%	2.2%	63.9%	49.9%	5.9%	36.7%	16.1%	32.1%
Vegetation to water	3.4%	9.3%	22.5%	8.2%	2.1%	4.9%	1.3%	3.3%	5.5%
Vegetation to sand	96.6%	90.7%	77.5%	91.8%	97.9%	95.1%	98.7%	96.7%	94.5%
Water to vegetation	2.8%	3.9%	0.0%	2.6%	14.1%	1.3%	1.7%	0.7%	8.5%
Water to sand	97.2%	96.1%	100.0%	97.4%	85.9%	98.7%	98.3%	99.3%	91.5%

with most of the gain being conversion from sand (93.6 %). Unlike the previous time period (August 1994 to September 1999) where Ship Island lost area (-20.9 %), an increase of approximately 13.6 % was seen between August 1999 and July 2000 (Figures 10 and 17).

Between July 2000 and August 2002, vegetated area on Ship Island again had an increase in area (+53.9 %; Figure 9), with most of the gain coming via conversion from the sand class (92.1 %). The water class (+1.4 %) also showed a net gain, where sand (-31.5 %) had a measured net loss between 2000 and 2002. Total island area decreased by 6.3 % (Figure 10).

Between August 2002 and January 2003 on Ship Island, the sand class showed a large net increase of 55.3 %, where both vegetation (-41.5 %) and water (-1.7 %) had net losses (Table 34). The sand class gained area from the loss of vegetated area (49.6 %), this was the largest loss of the vegetation class (95.1 %). Sand also gained in area from water (50.4 %), which was the largest loss of the water class (98.7 %). The overall increase in total island area was 8.4 % (Figure 10).

During the time period between January 2003 and December 2004 on Ship Island, the only measured net increase was in vegetation (+17.7 %; Figure 9), with most of its gain in area coming as conversion from sand (96.8 %) (Table 16). Both the sand class (-4.6 %) and water class (-0.3 %) had measured net losses, with sand loosing 63.3 % of its total area lost to the water class, where water lost 98.3 % of its measured losses to the sand class. Even with the loss of sand, most of its measured gains were from the water class (81.1 %), which in turn led to an increase in total island area by 1.2 % (Figure 10). This was also the most stable period during the study period on Ship Island.

Table 16. Ship Island percent gain from each land cover class and its subsequent conversion from class, between August 1990 and September 2005.

Change class	Time period								
	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Water to sand	12.5%	84.3%	36.6%	87.7%	88.3%	50.4%	81.1%	40.2%	60.2%
Vegetation to sand	87.5%	15.7%	63.4%	12.3%	11.7%	49.6%	18.9%	59.8%	39.8%
Water to vegetation	12.5%	2.6%	0.0%	6.4%	7.9%	28.2%	3.2%	2.2%	1.5%
Sand to vegetation	87.5%	97.4%	100.0%	93.6%	92.1%	71.8%	96.8%	97.8%	98.5%
Vegetation to water	10.0%	2.6%	15.4%	5.4%	0.1%	8.4%	0.3%	3.2%	0.3%
Sand to water	90.0%	97.4%	84.6%	94.6%	99.9%	91.6%	99.7%	96.8%	99.7%

Vegetation on Ship Island between December 2004 and March 2005 decreased by 27.5 % (Figure 9), whereas both sand and water increased by 6.3 % and 0.9 % respectively (Table 34). The majority of vegetative loss was seen as conversion to sand (96.7 %), the largest gain for the sand class came from vegetation (59.8 %) (Table 15). The sand class although it had a net gain, also provided the largest gain in the water class (96.8 %). Unlike the previous two time periods (August 2002 to January 2003 and January 2003 to December 2004), Ship Island had an overall loss of total island area by 4.0 %, with 92.5 % of the loss coming from loss of sand (Figure 10).

Ship Island underwent the greatest amount change between March 2005 and September 2005 (Figure 10), where it lost approximately 36.5 % of its total island area. The greatest change on the island took place in the sand class with a loss of 69.4 %, with 68.0% of that loss being converted to water (Table 15). Vegetated area saw a net increase in area by 73.6 % (Figure 9), with most of the gain coming as conversion from sand (98.5 %; Table 16).

Horn Island

On the 22 August 1990 image, sand had an area of 614.5 ha and vegetation had an area of 804.8 ha on Horn Island (Figure 18, Appendix A). The calculated total island area was 1419.3 (Table 36; Figure 19; Appendix A). It was calculated that the vegetative class between August 1990 and July 1991 decreased by 32.1 % and sand increased by 40.2 % (Figure 9). The total area of Horn Island decreased by 0.8 % (Table 36; Figure 10) between August 1990 and September 1991.

After having large vegetative losses between August 1990 and July 1991, the time period from July 1991 to September 1994 had an increase by 34.2 % in the vegetation class (Figure 9), most of the increase came from the sand class (98.7 %) (Table 18). Both Sand (-17.3 %) and water (-2.4 %) had calculated net losses. The majority of the sand loss came from the conversion to vegetated area (79.9 %), whereas the largest area of water loss was to sand (97.0 %) (Table 17). Total area increased by 10.5% (Figure 10).

During the longest time span between Landsat images for the duration of the study period (September 1994 to September 1999), it was calculated on Horn Island that vegetated area decreased by -37.2 %, whereas there were gains in both sand (+22.3 %) and water (+7.4 %) (Table 36). The largest loss of vegetation was in the conversion to sand (96.2 %; Table 17), this was also the largest gain in the sand class (85.9 %; Table 18). The total area of Horn Island decreased by 7.8 %, with conversion of sand to water resulting in 90.4% of the total island area loss between 1994 and 1999.

Table 17. Horn Island percent loss from each land cover class.

Change class	Time period								
	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	46.4%	20.1%	90.5%	24.4%	26.8%	63.3%	28.9%	71.4%	27.2%
Sand to vegetation	53.6%	79.9%	9.5%	75.6%	73.2%	36.7%	71.1%	28.6%	72.8%
Vegetation to water	3.0%	4.7%	3.8%	4.9%	3.4%	2.3%	0.9%	1.5%	7.8%
Vegetation to sand	97.0%	95.3%	96.2%	95.1%	96.6%	97.7%	99.1%	98.5%	92.2%
Water to vegetation	4.0%	3.0%	0.6%	6.4%	5.6%	2.6%	3.5%	0.1%	7.6%
Water to sand	96.0%	97.0%	99.4%	93.6%	94.4%	97.4%	96.5%	99.9%	92.4%

Table 18. Horn Island percent gain from each landcover class.

Change class	Time period								
	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Water to sand	16.4%	81.1%	14.1%	76.1%	78.7%	30.0%	70.0%	27.8%	62.8%
Vegetation to sand	83.6%	18.9%	85.9%	23.9%	21.3%	70.0%	30.0%	72.2%	37.2%
Water to vegetation	3.3%	1.3%	1.6%	3.4%	2.0%	3.6%	2.1%	0.4%	1.0%
Sand to vegetation	96.7%	98.7%	98.4%	96.6%	98.0%	96.4%	97.9%	99.6%	99.0%
Vegetation to water	13.2%	1.9%	7.0%	2.5%	0.9%	4.3%	0.6%	5.0%	1.6%
Sand to water	86.8%	98.1%	93.0%	97.5%	99.1%	95.7%	99.4%	95.0%	98.4%

Between September 1999 and July 2000 net losses were calculated in both sand (-11.8 %) and water (-2.2 %), whereas vegetated area gained by 30.2 % (Table 36). The largest losses of sand and water were to vegetation (75.6 %; Figure 9) and sand (93.6 %) respectively (Table 17). Total island area increased by 2.7 % (Figure 10).

Similar trends were seen between July 2000 and August 2002. Vegetated area (+28.2 %) and water (+0.1 %) had net increases, whereas sand (-22.2 %) decreased (Table 36). The biggest gain to the vegetated class came from the conversion of sand (98.0 %; Table 18); this was the largest loss to the sand class (73.2 %; Table 22). Even with the great loss of sand area, Horn Island's total area only decreased by 0.1 % (Figure 10); this was the smallest total island area change during the study period.

Vegetated area was calculated to have decreased by approximately 13.0 % during the time period of August 2002 to January 2003, whereas both sand (+14.0 %) and water (+1.0 %) both had gains on Horn Island (Table 36). The largest loss in the vegetation class came as a conversion to sand (97.7 %; Table 17), this was also the largest gain for the sand class (70.0 %; Table 18). The water class gained the most area from the sand class (95.7 %). Similar to the previous time period of July 2000 to August 2002, Horn Island lost approximately 1.2 % of its total island area (Figure 10).

Unlike the previous two time periods where island area was lost, the time period of January 2003 to December 2004, saw an increase in Horn Island area by 1.6 % (Figure 9). Following a similar trend as the September 1999 to July 2000; the January 2003 to December 2004 time period had a decrease in sand (-9.0 %), whereas the vegetation class gained by approximately 12.4 % (Table 36). As with other comparisons, the vegetation class gained the most area as a conversion from the sand class (97.9 %; Figure 9; Table 18), this was the biggest loss to the sand class (71.1 %; Table 17), whereas the biggest calculated loss of water was in the conversion to sand (96.5 %; Table 17).

The vegetation class decreased by 22.2 % between December 2004 and March 2005 on Horn Island (Figure 9). Most of the vegetated loss was a conversion to sand (98.5 %; Table 17). With a large amount of conversion coming from the vegetation class, sand increased by 29.4 %. Water showed little change in respect to both vegetation and sand, only loosing 1.0 % of its area, with most of the loss being conversion to sand (99.9 %; Table 17). Total island area increased by 1.1 % during this time period as well (Figure 10).

Between March 2005 and September 2005 Horn Island underwent a great deal of change, where total island area decreased by 6.4 % (Figure 10). The largest calculated change was a net loss in the sand class (-52.4 %) with 72.8 % of sand converting to vegetation. At the opposite end of the spectrum the vegetated class saw a large net increase of 56.7 %, with most coming from sand being converted to vegetation (99.0 %) (Table 18).

Petit Bois Island

Petit Bois Island (Figure 20, Appendix A) had calculated landcover areas, for sand, of 192.8 ha and 374.0 ha for vegetation during 22 August 1990 Landsat satellite image (Table 38; Appendix A). Between August 1990 and July 1991, Petit Bois Island had a decrease in vegetation by 37.6 %, with 96.9 % of the loss being to sand (Table 19). The sand class area had the largest net gain (+69.1 %), with the majority coming as a conversion from the vegetative class (82.3 %; Table 20). Water had a slight gain in area (+0.5 %) with most coming from sand converting to water (88.2 %; Table 20). Total island area changed by less than 2% (Figure 10).

Vegetation during the time period of July 1991 to September 1994 on Petit Bois Island increased by 23.5 % (Figure 9), with 98.3 % of the gain coming as a conversion from sand (Table 20). Both sand (-15.5 %) and water (-0.3 %) lost total area (Table 38). Most of the water lost was converted to sand (96.6 %), whereas the majority of sand loss was converted to vegetation (69.9 %; Table 19). The total island area of Petit Bois Island increased by 0.8 % between the 1991 to 1994 time period (Figure 10).

During the five year time period between September 1994 and September 1999 on Petit Bois Island, vegetated area decreased by 40.7 % (Table 38; Figure 9). Most of the vegetation loss was converted to sand (81.2 %; Table 19). Net increases were noted in both sand (+17.4 %) and water (+4.3 %), most of the sand increase came from vegetation (71.8 %), whereas most of the increase in water area came from sand (97.8 %) (Table 20). As seen with the August 1990 to July 1991 time period, Petit Bois had an overall decrease of island area by 12.3 %, which represented the largest loss during the study period.

Table 19. Petit Bois Island percent loss from each land cover class.

Change class	Time period								
	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	87.5%	30.1%	85.7%	32.1%	54.8%	77.0%	39.6%	80.5%	42.5%
Sand to vegetation	12.5%	69.9%	14.3%	67.9%	45.2%	23.0%	60.4%	19.5%	57.5%
Vegetation to water	3.1%	4.6%	18.8%	32.9%	9.8%	16.5%	0.0%	1.3%	0.2%
Vegetation to sand	96.9%	95.4%	81.2%	67.1%	90.2%	83.5%	100.0%	98.7%	99.8%
Water to vegetation	4.0%	3.4%	4.2%	6.4%	38.4%	3.5%	4.5%	0.0%	28.2%
Water to sand	96.0%	96.6%	95.8%	93.6%	61.6%	96.5%	95.5%	100.0%	71.8%

Table 20. Petit Bois Island percent gain from each land cover class.

	Time period								
Change class	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Water to sand	17.7%	70.2%	28.2%	76.2%	54.4%	28.9%	62.9%	32.0%	48.1%
Vegetation to sand	82.3%	29.8%	71.8%	23.8%	45.6%	71.1%	37.1%	68.0%	51.9%
Water to vegetation	20.3%	1.7%	11.1%	5.1%	33.3%	10.0%	3.6%	0.0%	11.4%
Sand to vegetation	79.7%	98.3%	88.9%	94.9%	66.7%	90.0%	96.4%	100.0%	88.6%
Vegetation to water	11.8%	2.2%	22.1%	20.3%	5.7%	30.9%	0.0%	3.0%	0.1%
Sand to water	88.2%	97.8%	77.9%	79.7%	94.3%	69.1%	100.0%	97.0%	99.9%

Unlike the previous five year time span, vegetation on Petit Bois Island increased by 36.0 % (Figure 9), whereas both sand (-12.2 %) and water (-1.3 %) had losses between September 1999 and July 2000 (Table 38). Most of the gain in vegetation came as a conversion from sand (94.9 %; Table 20), this was the largest loss for the sand class (67.9 %; Table 19). Total island area increased during this time period as well (+4.5 %; Figure 15). Again, between July 2000 and August 2002 there was a gain in vegetation (+22.1 %) and losses in both sand (-17.7 %) and water (-1.3 %). The largest gain in vegetation came as a conversion from sand (94.9 %; Table 20), whereas the largest losses in sand (54.8 %; Table 19) and water (61.6 %; Table 19) were to the water and sand classes respectively. Also the time period of July 2000 to August 2002 represented the most stable period of the island with an overall area increase of only 0.2 % (Figure 21, Appendix A; Figure 10).

Vegetation on Petit Bois Island from August 2002 to January 2003 decreased by 38.3 % (Figure 9). Approximately 83.5% of the vegetative loss was converted to sand (Table 19); this represented the largest gain in sand area (71.1 %; Table 20), which subsequently showed a net increase of 36.8 % (Table 38). Water area also increased 1.4 % on Petit Bois Island between August 2002 and January 2003. Following the most stable time period during the study, the island lost approximately 4.3 % of its total area.

Between January 2003 and December 2004, Petit Bois Island increased in total island area by 1.4 % (Figure 10), which was one of the most stable periods during the entire study period. Some change did occur on the island however, with vegetation increasing by 13.4 %, whereas both sand and water had losses of 5.1 % and 0.4 %, respectively. The change in island area was minor (<2%, Figure 10 and Figure 21).

Between December 2004 and March 2005 vegetation (-31.8 %) and water (-0.1 %) decreased, where the only class gaining in area was sand by 21.4 % (Table 38) on Petit Bois Island. The biggest losses to vegetation (98.7 %) and water (100.0 %) classes were converted to sand. Since early 2003 Petit Bois Island had undergone little change, until the time period of March 2005 to September 2005, when it lost approximately 7.2 % of its total area (Figure 10). Most of the change that occurred on the island was in the sand class decreasing by approximately 36.7 % and vegetation increasing by 73.3 %. Vegetation gained most of its area from conversion from sand (88.6 %; Table 20), where sand lost the most being converted to vegetation (57.5 %; Table 19).

Dauphin Island

Dauphin Island (Figure 22, Appendix A) is the eastern most barrier island of the five in the study area and it had 484.5 ha of sand and 1131.8 ha of vegetation on the 22 August 1990 satellite image (Table 40, Appendix A). Between August 1990 and July 1991 vegetated area decreased by 40.3 %, (Figure 9) and sand increased by 97.5 %. The majority of the vegetation loss (96.0 %) was converted into sand (Table 21). Total island area increased by 1.7 % during this time period as well (Figure 10 and Figure 23, Appendix A).

From July 1991 to September 1994 on Dauphin Island, there were increases in both vegetation (+50.6 %) and surrounding water (+0.5 %), whereas the sand class decreased by 36.9 % (Table 40). The major contributing factor to the large increase in vegetative cover was the loss of sand (71.9 %; Table 22). The loss of sand (28.1 %; Table 21) also contributed to the increase in water area. Total island area decreased by 1.2 % (Figure 10).

Similar to the August 1990 to July 1991 time period, the September 1994 to September 1999 time period had a decrease in vegetation (-41.3 %) and an increase in sand (40.1 %) and water (4.0 %) (Table 40). Vegetation converting to sand (82.2 %) was the cause of sand increase, however, the increase in water was mostly due to loss of sand (97.6 %) around the shoreline (Table 21). Similar to the previous time period, Dauphin Island lost 10.4 % of its total area, which was the largest loss on the island during the study period (Figure 10).

Dauphin Island, between September 1999 to July 2000, had an increase of total island area by 8.2 % and also had an increase in vegetation (+24.7 %) and decreases in both sand (-3.1 %) and water (-2.7 %) (Table 40). Most of the calculated loss of sand (74.8 %) was converted to vegetation, whereas 95.1% of the water loss was converted to sand (Table 21). The island increased by 8.2 %, which was the most area gained for Dauphin Island during the study (Figure 10).

The July 2000 to August 2002 time period showed Dauphin Island having an increase in vegetative cover (+21.2 %) and losses in sand (-9.7 %) and water (-1.8 %). Approximately 89.4% of the gain in vegetated area was from sand (Table 22), whereas 88.2% of the calculated water loss was converted to sand (Table 21). Similar to the September 1999 and July 2000, the total area of Dauphin Island increased by 4.8 % (Figure 10).

Table 21. Dauphin Island percent loss from each land cover class.

	Time period								
Change class	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	87.7%	28.1%	97.5%	25.2%	36.6%	60.9%	49.9%	72.8%	37.6%
Sand to vegetation	12.3%	71.9%	2.5%	74.8%	63.4%	39.1%	50.1%	27.2%	62.4%
Vegetation to water	4.0%	12.9%	10.0%	5.1%	4.0%	7.4%	6.0%	3.9%	14.3%
Vegetation to sand	96.0%	87.1%	90.0%	94.9%	96.0%	92.6%	94.0%	96.1%	85.7%
Water to vegetation	3.1%	7.7%	0.5%	4.9%	11.8%	18.5%	5.7%	0.4%	17.1%
Water to sand	96.9%	92.3%	99.5%	95.1%	88.2%	81.5%	94.3%	99.6%	82.9%

During the time period of August 2002 to January 2003, both sand (+3.0 %) and water (+1.5 %) increased but vegetation decreased by 9.7 % (Table 21). Most of the vegetation loss was converted to sand area (92.6 %). Water gained most its area as a conversion from sand (91.1 %). The total area of Dauphin Island decreased by 3.9 % during this time period as well (Figure 10).

During the time period of January 2003 to December 2004 vegetation increased slightly by 0.9 % (Figure 9). Between December 2004 and March 2005 vegetation decreased by 19.6 % (Table 21). Sand showed a slight increase between January 2003 and December 2004 by 0.5 %, whereas, between December 2004 and March 2005, it had an increase of 25.0 %. Water, during both time periods, showed an overall net decrease. Overall island area increased by 2.9 %, with 75.6 % of the total island increase was during the December 2004 to March 2005 time period.

After two and a half years of increasing in total island area, Dauphin Island lost approximately 5.2 % of its total island area (Figure 10). The largest change was with the loss of sand (-47.9 %), most of which (62.4 %) was converted to vegetation (Table 40). At the other end of the spectrum, vegetation increased by 58.4 %, most of which came as a conversion from sand (93.5 %; Table 22). Water area increased by 2.0 %, most of which coming as a conversion from sand (97.6 %; Figure 10).

Table 22. Dauphin Island percent gain from each land cover class.

Change class	Time period								
	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Water to sand	24.7%	83.4%	17.8%	91.3%	77.7%	31.5%	53.8%	41.7%	79.0%
Vegetation to sand	75.3%	16.6%	82.2%	8.7%	22.3%	68.5%	46.2%	58.3%	21.0%
Water to vegetation	24.3%	2.6%	7.4%	5.2%	10.6%	16.6%	6.2%	1.7%	6.5%
Sand to vegetation	75.7%	97.4%	92.6%	94.8%	89.4%	83.4%	93.8%	98.3%	93.5%
Vegetation to water	15.3%	2.4%	16.8%	1.6%	1.8%	8.9%	5.7%	7.7%	2.4%
Sand to water	84.7%	97.6%	83.2%	98.4%	98.2%	91.1%	94.3%	92.3%	97.6%

Individual Barrier Island Area Comparisons

Between August 1990 and July 1991, most of the barrier islands showed a decrease in area with the exception being Dauphin Island, which had a gain of 1.7 % (Figure 10). Losses on the other barrier islands ranged from -0.8 % on Horn Island to -5.0 % on Ship Island. July 1991 to September 1994 showed area increases in all islands, however, Dauphin Island was the exception by having a 1.2 % of its total area. Gains on the other barrier islands ranged from +0.8 % on Petit Bois Island to +4.1 % on Cat Island.

The time period of September 1994 to September 1999 had a lot of change to the barrier islands. Combined, the islands lost an average of 21.3% of their total area. Losses ranged from 7.8 % on Horn Island to 23.7 % on Cat Island. The September 1999 to July 2000 time period showed an increase in total area for all barrier islands. Horn Island had the smallest gain at +2.7 %, where Ship Island had the largest increase at +13.6 %. Ship Island and Horn Island both had losses between July 2000 and August 2002, losing -6.3 % and -0.1 %, respectively. The remaining three islands all had increases ranging from 0.2 % on Petit Bois Island to 10.4 % on Cat Island. August 2002 to January 2003 saw Horn Island (-1.2 %), Petit Bois Island (-4.3 %), and Dauphin Island (-3.9 %) all losing total area, whereas both Cat Island (+2.1 %) and Ship Island (+8.4 %) had increases in island area. Following the increase in area on Cat Island, January 2003 to December 2004 saw Cat Island (-0.7 %) again losing area. All other barrier islands during this time period saw an increase in total area, ranging from 0.7 % on Dauphin Island to 1.6 % on Horn Island (Figure 10).

Between December 2004 and March 2005, Cat Island (-0.7%) and Ship Island (-4.0 %) lost island area, whereas, Petit Bois Island (+0.4 %), Horn Island (+1.1 %) and

Dauphin Island (+2.2 %) all increased in total area. The time period of March 2005 to September 2005 saw a great deal of change on all of the barrier islands. On average the islands lost approximately 17.8% of their total island area. The largest loss was from Ship Island, which lost 36.5 % of its total area, to Dauphin Island which lost approximately 5.2 % (Figure 10).

Overall, the most stable island, as an average percent of change (both gain and loss), was Dauphin Island, where, on average, only 0.6% of its total area underwent change. The remaining islands in order of most stable were Horn Island (1.1%), Cat Island (2.2%), and Petit Bois Island (2.3 %). Ship Island (8.5%) underwent the most area change of all the islands in the study throughout the study period.

In addition to investigating barrier island loss as a percentage, the barrier island area to perimeter ratio was determined for each island (Figure 11). The ratio standardized change taking place on the islands, making it easily comparable. The general trend was that on the islands that following hurricane events the area/perimeter ratio decreased, immediately following that time period (higher hurricane frequency) the ratio for each island began increasing as the islands recovered lost area following the subsequent hurricane period.

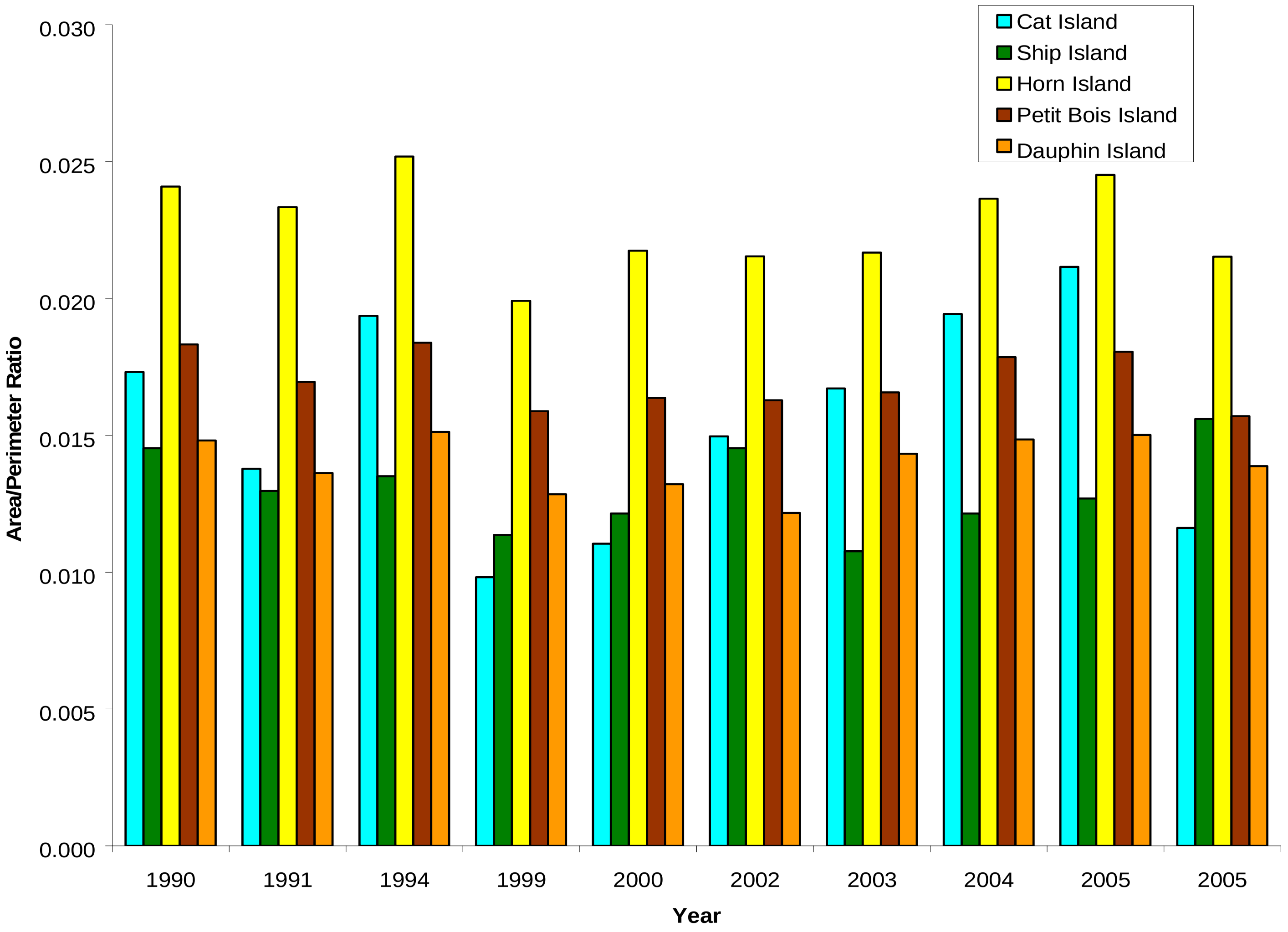

Figure 11. The area to perimeter ratio for all barrier islands along the Mississippi and Alabama coastlines for each time period between August 1990 and September 2005.

Barrier Island Shift/Reorganization

Cat Island is different from the other barrier islands in this study by being elongate in a north-south direction compared to the other islands that are elongated in an east-west direction. Points were digitized which represented the northernmost and southernmost connected area of the island. In general, over the study period the northernmost point on the island shifted in a southerly direction by 219.6 meters whereas the southern most point of the island moved in a northerly direction by 50.6 meters (Table 23). The centroid of Cat Island, at the end of the study period, had shifted in a northwestern direction by 39.2 meters (Table 24 and Table 25). However, before the March 2005 to September 2005 time period, most of the island centroid movement had been in the south-east direction (Figure 1; Table 24 and Table 25).

The western end of West Ship Island, throughout the study period, moved in a westerly direction. However, between March 2005 and September 2005, the western tip had moved approximately 171.7 m to the east (Table 26). The eastern tip of West Ship Island moved in a westerly direction during 8 out of the 9 time periods, however during the last time period the eastern tip moved approximately 1,123.2 m to the west, making a total movement net to the west of 1,609.2 m. The centroid of West Ship Island also followed a similar trend to that of its western point, where it had a calculated net western shift of 393.1 m (Figure 12; Table 24 and Table 25). East Ship Island showed similar trends to that of West Ship Island. East Ship Island's western tip frequently grew in a western direction, however, one large movement to the east occurred during the March

Table 23. Movement in meters of Cat Island points representing the northern and southern most point between August 1990 and September 2005.

Time period	Northern point movement	Movement direction	Southern point movement	Movement direction
8/1990 to 7/1991	40.9	South-west	107.4	East-south
7/1991 to 9/1994	0.0	0	29.0	South
9/1994 to 9/1999	91.7	South-east	220.9	West-south
9/1999 to 7/2000	0.0	0	0.0	0
7/2000 to 8/2002	29.0	North	82.0	North-west
8/2002 to 1/2003	0.0	0	0.0	0
1/2003 to 12/2004	29.0	North	0.0	0
12/2004 to 3/2005	58.0	South	29.0	South
3/2005 to 9/2005	87.0	South	246.1	North-east

Table 24. Movement of the Mississippi and Alabama barrier islands centroid, with the general direction of the centroids' movement, between August 1990 and September 2005. All measurements are in meters.

	Time period								
	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Cat Island	34.8	57.8	101.2	108.2	36.2	25.5	25.3	38.1	118.2
Movement direction	west-north	east-south	north-west	south-east	west	south-east	east	east-south	north-west
West Ship Island	72.9	13.1	133.9	58.8	141.0	108.2	48.6	27.2	242.4
Movement direction	west-south	east-north	west	east-north	east	west	west-north	south	west-south
East Ship Island	15.1	170.4	340.5	181.5	63.6	349.0	249.1	106.8	417.6
Movement direction	west-south	west-south	north-east	west-south	east-south	west-south	east-north	east	east-north
Horn Island	52.0	68.4	16.4	16.1	63.0	16.3	128.7	22.3	20.7
Movement direction	west	west	west	north	west	east	west	south	east
Petit Bois Island	25.1	73.3	582.7	28.6	131.8	54.9	100.2	60.4	205.6
Movement direction	west-south	west-north	west	south-west	north-west	south-east	west-north	east-south	west
Dauphin Island	12.9	95.0	140.3	135.0	208.2	82.0	206.0	62.7	43.2
Movement direction	east	west	south	east	east	west	west-north	south-east	north-west

Table 25. Cumulative shift in magnitude and direction of the Mississippi and Alabama barrier islands centroids from 1990 to 2005, all measurements are in meters.

Barrier Island	August 1990 to March 2005	March 2005 to September 2005	August 1990 to September 2005
Cat Island	83.1 (south-east)	118.3 (north-west)	39.2 (north)
West Ship Island	147.3 (west)	242.2 (west-south)	384.0 (west)
East Ship Island	154.4 (north)	417.6 (east-north)	478.2 (north-east)
Horn Island	311.7 (west)	20.7 (east)	291.4 (west)
Petit Bois Island	788.0 (west)	205.9 (west)	993.2 (west)
Dauphin Island	109.1 (south)	43.2 (north-west)	74.22 (south)

Table 26. Movement in meters of West Ship Island points representing the islands western and eastern most point during each time period.

Time period	Eastern point movement	Movement direction	Western Point movement	Movement direction
8/1990 to 7/1991	97.2	West-north	116.2	West
7/1991 to 9/1994	105.6	West-south	58.0	East
9/1994 to 9/1999	214.8	West-north	59.6	West
9/1999 to 7/2000	44.8	North-west	91.7	West
7/2000 to 8/2002	74.3	West-south	116.8	East
8/2002 to 1/2003	107.1	West-south	28.1	South
1/2003 to 12/2004	157.8	North-east	99.9	North-west
12/2004 to 3/2005	31.1	South	78.7	South-east
3/2005 to 9/2005	1123.2	West-south	285.5	East

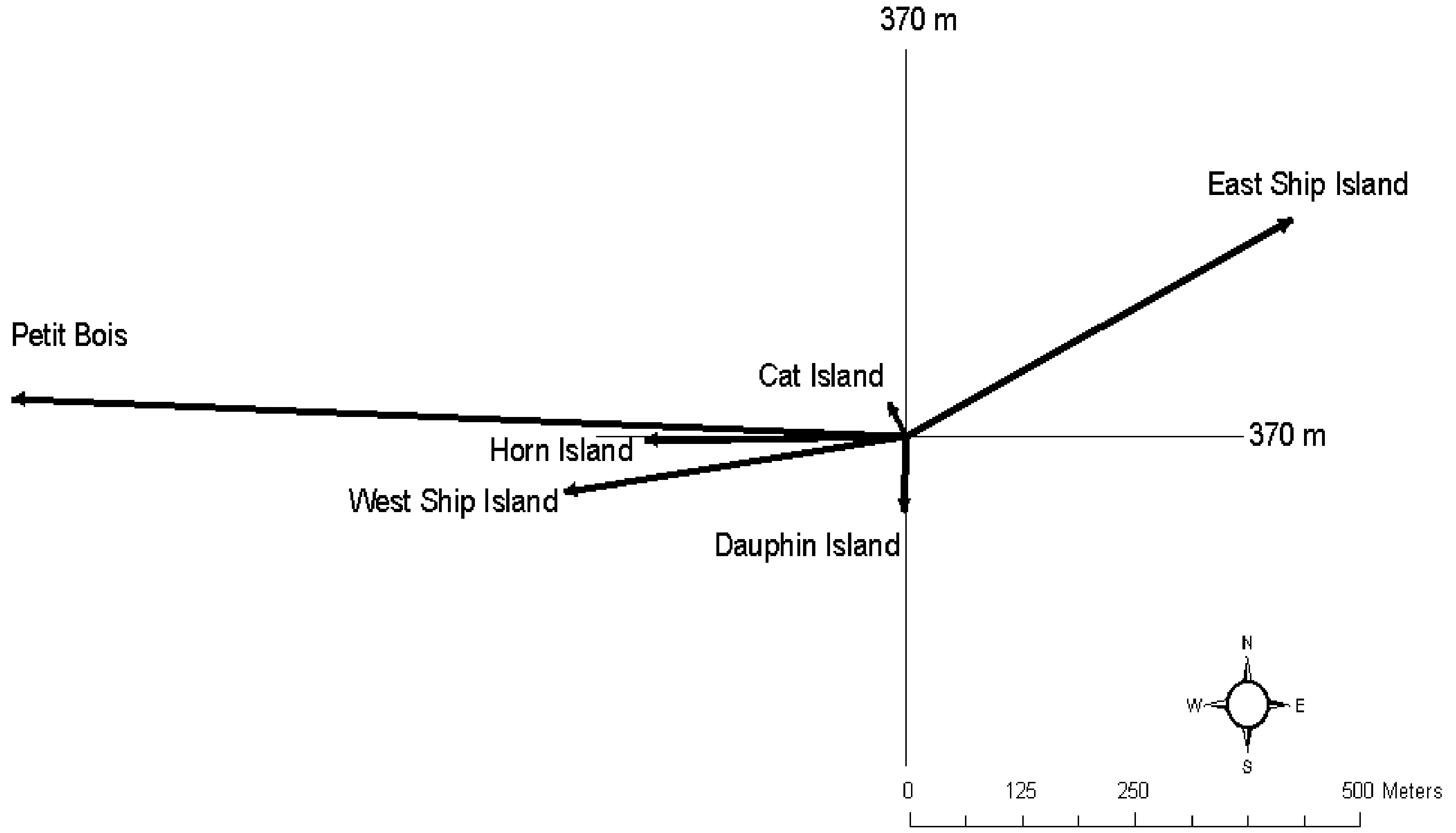

Figure 12. Cumulative magnitude and direction of each barrier islands' centroid shift between August 1990 and September 2005.

2005 and September 2005 time period. This caused an overall net movement to the east of East Ship Islands western tip of 3,231.7 m (Table 27). Similar to the eastern tip of West Ship Island, the East Ship Island eastern tip consistently shifted eastward for the duration of the study (Figure 12). However, one large movement to the west occurred during the March 2005 to September 2005 time period causing a net movement to the west of 1,487.6 m to the west of eastern tip of East Ship Island. Unlike West Ship Island, East Ship Island's centroid had a net eastern movement of 461.7 m, most of which was accrued during the March 2005 to September 2005 time period (Table 24).

The eastern portion of Horn Island had a net western movement of 1,649.4 m, however five of the nine time periods showed the island moving in a eastern direction (Table 28). The Horn Island western end had a net movement of approximately 715.8 m east, with the majority of the movement east coming following the March 2005 to September 2005 time period. The centroid of the island moved in a westerly direction each year, for a total net western movement of 291.4 m (Figure 12; Table 24).

Like the other barrier islands in the study area, the eastern end of Petit Bois Island had a net movement in the western direction of 1,379.4 m (Table 29). However, the western end of Petit Bois Island had a net movement of 1,493.8 m to the west, which is different than all other barrier island in the study. The centroid of the island also had a net movement in the western direction of 1,032.0 m (Figure 12; Table 24 and Table 25).

Unlike Petit Bois Island, Ship Island, and Horn Island, the eastern end of Dauphin Island showed little change during the study, having only a net shift of 9.5 meters east (Table 30). Whereas, similar to Petit Bois, Dauphin Island's western end had a net

Table 27. Movement in meters of East Ship Island points representing the islands western and eastern most point during each time period.

Time period	Eastern point movement	Movement direction	Western Point movement	Movement direction
8/1990 to 7/1991	58.3	East	70.7	South-west
7/1991 to 9/1994	58.0	East	191.8	West-south
9/1994 to 9/1999	101.3	West-south	445.1	West-south
9/1999 to 7/2000	47.9	North-east	103.3	West-north
7/2000 to 8/2002	30.5	East-south	252.3	East-south
8/2002 to 1/2003	29.4	East	274.6	West
1/2003 to 12/2004	58.0	East	422.0	West-south
12/2004 to 3/2005	29.0	West	91.6	East-north
3/2005 to 9/2005	1639.4	West	4395.4	East-north

Table 28. Movement in meters of Horn Island points representing the islands western and eastern most point during each time period.

Time period	Eastern point movement	Movement direction	Western Point movement	Movement direction
8/1990 to 7/1991	126.3	North-east	77.8	South-west
7/1991 to 9/1994	257.5	North-east	0.0	0
9/1994 to 9/1999	307.2	East-south	235.9	East
9/1999 to 7/2000	29.0	West	0.0	0
7/2000 to 8/2002	29.0	East	58.0	West
8/2002 to 1/2003	29.0	West	178.5	South-west
1/2003 to 12/2004	1066.0	West	64.8	West-north
12/2004 to 3/2005	69.8	East-north	61.8	South-east
3/2005 to 9/2005	1315.1	West	797.2	East

Table 29. Movement in meters of Petit Bois Island points representing the islands western and eastern most point during each time period.

Time period	Eastern point movement	Movement direction	Western Point movement	Movement direction
8/1990 to 7/1991	59.5	west	90.1	west
7/1991 to 9/1994	60.6	east	116.6	northwest
9/1994 to 9/1999	963.6	west	166.2	northwest
9/1999 to 7/2000	60.9	east	29.0	west
7/2000 to 8/2002	403.9	northeast	656.8	south west
8/2002 to 1/2003	308.6	southwest	56.4	west
1/2003 to 12/2004	154.4	south-west	202.5	south west
12/2004 to 3/2005	230.8	northeast	63.4	northwest
3/2005 to 9/2005	649.6	west	112.8	northwest

Table 30. Movement in meters of Dauphin Island points representing the islands western and eastern most point during each time period.

Time period	Eastern point movement	Movement direction	Western Point movement	Movement direction
8/1990 to 7/1991	31.4	West	34.3	West
7/1991 to 9/1994	51.5	South-east	139.7	North-west
9/1994 to 9/1999	73.5	0	233.6	West
9/1999 to 7/2000	39.9	West-south	82.1	West-south
7/2000 to 8/2002	28.9	East	81.2	East-north
8/2002 to 1/2003	57.7	West	0.0	0
1/2003 to 12/2004	29.1	East	28.9	East
12/2004 to 3/2005	0.0	0	104.3	West-south
3/2005 to 9/2005	29.0	East	195.1	East-south

western shift of 288.8 meters. The centroid of Dauphin Island differed from the other island by shifting in a southward direction (74 m; Figure 12).

Barrier Islands and Hurricanes

Hurricane Georges (September, 1998), which made landfall between the western boarder of Louisiana and the eastern panhandle of Florida, was on average the closest of all hurricane events evaluated for this study. The average distance of Hurricane Georges was 30.4 km to all of the barrier islands along the Mississippi and Alabama coastline, with Hurricanes' Danny (61.4 km) and Ivan (77.2 km) being the next closest in average distance to the barrier islands (Table 31).

Changes in barrier island area and centroid position were strongly related to the occurrence of major land-falling hurricanes (Figure 1, Figure 10). The most noted effect was on barrier island area. From 1990 to 1994, hurricanes were infrequent (Table 1). The corresponding satellite imagery shows very little area changes (<5%) from 1990 to 1994. During the time period from 1994 to 1999, there were five major hurricanes (Table 1) that passed near the study area. Corresponding in time to the hurricanes, the barrier islands had the greatest decrease in area throughout this time period for all islands, suggesting a causal relationship. It should be noted that the time period from 1994 to 1999 has the largest temporal gap, and the tremendous decrease in sediment may be a function of the longer time period. However, no other five-year time frame throughout the 15-year study period has both this degree of decrease and this frequency of hurricanes. From September 1999 to 2000, all barrier islands increased in area. No hurricanes were recorded during this time frame with the previous hurricane occurring in

1998 (Hurricane Georges) and the subsequent hurricane occurring in 2002. Interestingly, in this four-year hiatus, all barrier islands show the greatest increase in area.

Most of the hurricanes from 2002 to 2004 were far away from the barrier island centroid locations. This time period is characterized by low amounts of barrier island area increases and decreases with individual islands showing varied responses (Figure 12). The exception is Hurricane Ivan (2004), which had an almost direct hit on Dauphin Island (Table 31). Surprisingly, Dauphin Island showed a minor increase in area between January 2003 and December 2004. The 2005 hurricane season was very active and several storms passed near the study area (Table 31). The most significant of these storms was Hurricane Katrina (August 2005), which came within 64 km of Ship Island. Similar to the 1994–1999 time period, an intense hurricane season corresponds with major decreases in barrier island area. This decrease is especially prominent on Ship Island. All islands in the study area showed decreases following Hurricane Katrina. Not only did Hurricane Katrina reduce island area, it also causes major shifts in the barrier island centroids (Figure 13). Cat Island, East Ship Island, Horn Island, and Dauphin Island had different centroid directional shifts before and after Hurricane Katrina (Figure 23). West Ship Island shifted by almost twice as much after Hurricane Katrina as it did for the entire study period up to March 2005. Petit Bois appears to have shifted the least. The differences in the vector magnitudes and directions suggest a substantial reworking of sediment around the island following Hurricane Katrina.

Table 31. Hurricane distance in meters to each barrier island's centroid for each occurrence, in kilometers.

Hurricane year	Hurricane name	Barrier island				
		Cat Island	Ship Island	Horn Island	Petit Bois Island	Dauphin Island
1992	Andrew	251.0	266.8	291.3	312.6	341.6
1995	Erin	190.2	174.4	149.9	128.7	99.7
1995	Opal	189.2	173.4	148.9	127.7	98.7
1997	Danny	102.9	87.2	62.7	41.6	12.4
1998	Earl	352.7	336.9	312.4	291.2	262.2
1998	Georges	24.8	9.0	15.5	36.9	65.7
2002	Lili	309.3	325.0	349.4	370.1	400.1
2004	Ivan	118.7	102.8	78.5	57.9	27.9
2005	Cindy	48.8	50.2	74.5	95.3	125.1
2005	Dennis	34.5	178.6	154.4	133.6	103.7
2005	Katrina	194.4	64.5	88.8	109.6	139.4

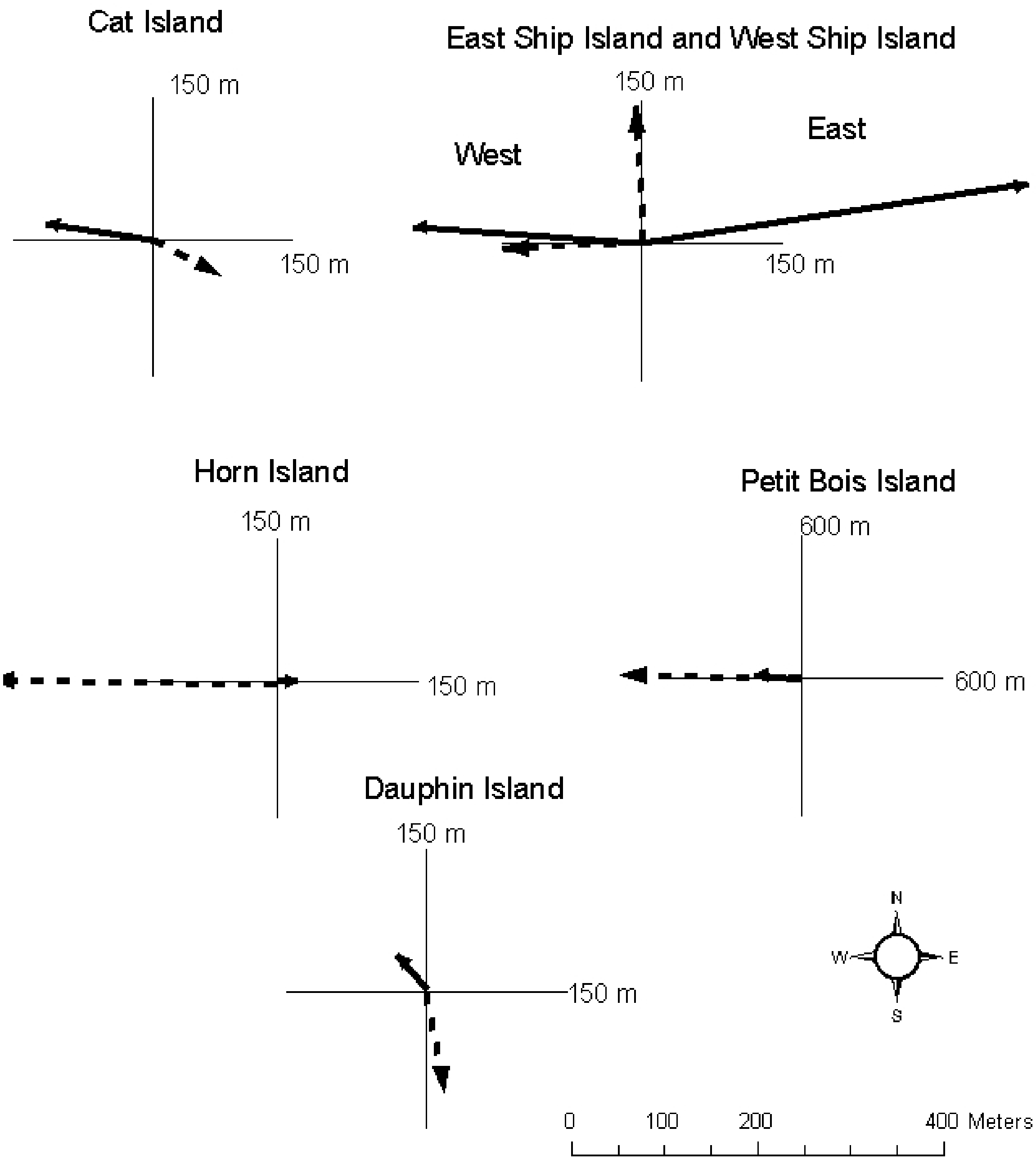

Figure 13. Magnitude and direction of barrier island centroid shift for cumulative August 1990 to March 2005 (dashed line) and for shift following Hurricane Katrina (September 2005, solid line). Note the difference in scale for Petit Bois Island (600 m; i.e. 150 m x

CHAPTER VI

DISCUSSION

Although hurricanes appear to be the largest driving factor affecting barrier islands, Waller and Malbrough (1976) point out that along with hurricanes, sea level rise and sediment supply to the barrier island are of high importance as well.

Hurricane Events and the Barrier Islands

Morton et al. (2004) characterized the barrier islands along the northern Gulf of Mexico as a "storm dominated region that is constantly changing as a result of active coastal processes that are directly related to meteorological events". These same barrier islands are generally in one of three phases at any time: 1) a stable-translational phase before hurricane events, 2) a transgressive-translational phase during the hurricane period or 3) a regressive phase following a hurricane event (Schmid, 2001a; Schmid, 2001b; Schmid, 2003).

Hurricane events impacted the study area during the 1992, 1995, 1997, 1998, 2002, 2004 and 2005 Atlantic hurricane seasons. Loss was calculated on all barrier islands between September 1994 and September 1999, where five hurricanes (Erin, Opal, Danny, Earl, and Georges) occurred. Losses of total island area between 1994 and 1999 ranged from -7.8 % on Horn Island to -23.7 % on Cat Island. Also, between March 2005 and September 2005, three hurricanes (Cindy, Dennis, and Katrina) occurred, and loss was seen on all barrier islands, ranging from -5.2 % on Dauphin Island to -36.5 % on Ship Island. These two periods account for approximately 83.1% of the total amount of loss experienced by all the barrier islands. Also these two time periods accounted for 8 of the 11 total hurricane events that occurred during the 16-year study period. This trend of barrier island loss follows Schmid (2001a, 2001b and 2003) and Waller and Malbrough (1976), where they effectively showed that the barrier islands were more sensitive to hurricane events and that they have the ability to experience large losses of island area. There were time periods over the duration of the study period, however, when hurricanes occurred and barrier islands did not show loss. Hurricane Ivan made landfall on September 2004, within 2.7 km from Dauphin Island, however, each barrier island, with the exception of Cat Island, had gains in total island area. During the time period between December 2004 and March 2005, both Cat Island and Ship Island had losses in total island area, whereas Horn Island, Petit Bois Island, and Dauphin Island all had gains in total area. These two time periods highlight the fact that although hurricanes have a great effect on barrier islands, how barrier islands are affected is related to a variety of hurricane factors such as storm surge, waves, wave runup, and other non-hurricane related factors like, island geometry (Sallenger, 2000).

The barrier islands' ability to recover from these devastating events is most evident during the July 1991 to September 1994 time period, where Hurricane Andrew tracked across the northern Gulf of Mexico in August 1992. The only island to experience loss during this time was Dauphin Island, whereas Cat Island, Ship Island, Horn Island, and Petit Bois Island all experienced gains in total island area. This is more than likely due to what Schmid (2001a, 2001b, and 2003) refers to as the regressive period, where the barrier islands have the ability to quickly recover lost area, with most of these losses generally occurring on the eastern and western portions or spits of the islands. Schmid (2001b) noted that area lost on West Ship Island during Hurricane Georges was recovered in less than 8 months. These "growing" phases were also noted during the August 2002 to January 2003 time period when Hurricane Lili caused losses in island area to Horn Island, Petit Bois Island, and Dauphin Island, whereas both Cat Island, and Ship Island showed increases in island area. These gains in island area are likely due to their ability to rebound quickly after moderate hurricane events. Alternatively, the hurricane tracks were perhaps at too great a distance from the study area to cause substantial changes in island area. In this study, only those hurricane tracks that were nearby (<200 km) seem to cause the greatest changes. Generally, after the barrier islands experienced loss due to hurricane events, area was recovered. Following the most active hurricane period (1994 to September 1999), all barrier islands saw an increase in total island area. Between September 1999 and July 2000, no hurricanes occurred and all islands increased in area.

Periods of stability (Schmid, 2001a; Schmid, 2001b; Schmid, 2003) on the Mississippi and Alabama barrier islands were difficult to characterize during the study. Due to the fact that during each time period, all barrier islands underwent change in total area, being gains or losses, points to the fact that these islands are constantly undergoing change. However, 5 out of 20 total times during less frequent hurricane periods, the barrier island lost or gained less than 1 % of their total island area. This highlights the dynamic nature of the Gulf Coasts' barrier islands and suggests that periods of "stability" may be rare.

Historically, hurricanes have frequented the northern Gulf of Mexico, however, hurricane rates appear to be slightly higher than historical occurrences. Waller and Malbrough (1976) evaluated the Mississippi barrier islands (Cat Island, Ship Island, Horn Island, and Petit Bois Island) between 1848 and 1973, where there was an average of 0.4 hurricanes/year over the 125-year study. The frequency of hurricanes during this study period (16 years) had an average hurricane occurrence of 0.7 hurricanes/year, which is substantially higher. Results from the Waller and Malbrough (1976) study period showed that Cat Island lost an average of 2.1 ha/yr, Ship Island lost an average of 1.5 ha/yr of island area, Horn Island lost an average of 0.8 ha/yr, and Petit Bois lost an average of 1.4 ha/yr. My results illustrate on average, Cat Island lost 7.4 ha/yr, Ship Island lost 11.4 ha/yr, Horn Island lost 7.5 ha/yr, and Petit Bois lost an average of 6.2 ha/yr. Waller and Malbrough (1976) utilized vintage charts, maps, and aerial photographs to measure loss taking place on the barrier islands during their study. The earlier study showed slower rates of area change. It should be noted that the difference in island area change rates may be a function of the different methodologies employed and the differences in the resolution of the imagery. However, the impact that hurricane events have on the Mississippi and Alabama barrier islands is evident from both studies.

Barrier Island Vegetation

The relationship of vegetation area to total island area has been suggested to be related to the evolution of the Mississippi barrier islands (Waller and Malbrough, 1976; Schmid, 2003). Schmid (2003) noted that the shoreline of East Ship Island, following Hurricane Georges, correlates well to the location of high vegetation cover before the storm. When relating vegetative cover to island area, approximately 71.1% of the comparisons (time periods, e.g. 1990 to 1991) showed an increase in vegetative cover and an increase in total island area. The reverse was also true with decreases in vegetative cover corresponding to decreases in island area. On a simple level, this makes sense because with area loss there would be less space for vegetation to occupy, thus the two should be highly correlated. It is interesting to point out, though, that the only time when the island area-vegetation cover had a negative correlation was after Hurricane Katrina. In this case, the percent cover of vegetation increases while the total island area decreases. This trend was not the case during the 1994–1999 time period when hurricanes were frequent. The negative correlation of total island area to area of vegetative cover may be a function of the substantial redistribution of barrier island sediments following the enormous storm surge that was produced by Hurricane Katrina. Another interesting trend with the island area-vegetation cover comparisons is that the islands with established forest areas (Cat Island, Horn Island, and Dauphin Island) had the least overall island change (5.1 %) throughout the study period. This contrasts with the high amounts of change on the non-forested islands, Ship Island and Petit Bois. Although this study does not have direct evidence to suggest that the forest helped stabilize the island (or to suggest that the more stable islands have forests), the positive relationship between the vegetation and island stability is worth noting.

Barrier Island Shift/Reorganization

Along with loss of total barrier island area from hurricane events, Cat Island, Ship Island, Horn Island, Petit Bois Island, and Dauphin Island showed subtle indications that their centroid shifted in a westerly direction, perhaps due to the east to west longshore currents present in the northern Gulf of Mexico, some rates being as high as 30 m/yr (Byrnes et al., 1991). This is most obvious during time periods of no hurricane events. Calculated barrier island movement shows that each island's western tip, excluding Cat Island, had the propensity to "grow" or shift in a western direction similar to Schmid (2001a, 2001b and 2003). Morton et al. (2004) characterized the barrier islands by stating that erosion is more pronounced on the eastern ends of the barrier islands. Similarly, this study showed that when change occurred on the eastern ends of the barrier islands, 76.6% of the time it was from loss of area, perhaps suggesting sediment erosion. On the western ends of the islands however, only 59.1% of the movement was erosion related. The eastern end of Dauphin Island throughout the study period showed the least amount of change, with no net movement after the study period. This is likely due to the fact that the eastern end of Dauphin Island is armored with riprap to prevent erosion (Froede, 2006). During the 125-year time period that Waller and Malbrough (1976) studied, accretion took place on the western ends of the islands and the north end of Cat Island, ranging from 4.9 m/yr to 38.1 m/yr. While accretion was taking place on the barrier islands' western end, erosion took place on the eastern ends. Erosion rates ranged from 13.4 m/yr to 98.1 m/yr on the Mississippi barrier islands (Waller and Malbrough, 1976). Calculating the shifting centroids of each barrier islands and comparing this movement across time periods shows that each island is migrating in a westerly direction.

East Ship Island was the only island that showed a slight eastern movement, which may be related to the extensive island area readjustment between March 2005 and September 2005. In this situation, the repositioning of the centroid is probably related to the disappearance of sediment after the storm rather than an actual physical movement or rollover event. For Horn Island, and Petit Bois Island Schmid (2000), characterized these islands as dominated by western movement, whereas, he classified Cat Island and both Ship Islands as being dominated by erosion rather than migration. This trend was seen when taking the ratio of total barrier island loss through the entire study period and dividing it by the amount of net movement, as done by Schmid (2000). Cat Island had the highest ratio of loss to movement of 3.4, followed by Ship Island (2.7), whereas both Horn Island (0.4) and Petit Bois Island (0.1) had lower ratios, pointing toward more movement than erosion (Table 28). Dauphin Island, which was not characterized by Schmid (2000), had the highest ratio of erosion to movement (9.0), however, it also had the least amount of total island change during the study period (0.6%). This suggests that Dauphin Island may be operating under different coastal processes than the other barrier islands along the Mississippi and Alabama coasts. The barrier islands, between August 1990 and September 2005, grew in a slight western direction. The findings of this study support the earlier results of barrier island movement reported by Schmid (2001a, 2001b, 2003), Morton et al (2004), Waller and Malbrough (1976) and Byrnes et al., (1991).

Barrier Island Area Calculation Accuracy

Using the categorized satellite image area and comparing it to the digitized polygon area, area calculations were off by approximately 11.0 %, with the classified satellite image overestimating Ship Island and Horn Island's total island area. Schmid (2001b, 2003) evaluated both East and West Ship Island numerous times between 1995 and 2000, using ground GPS surveys and LIDAR. Combined calculated areas of both East and West Ship Island were approximately 332.1 ha during 1995. When comparing the categorized satellite image barrier island area from the September 1994 image to the findings of Schmid (2001b, 2003), there was a difference of approximately 65 ha (16.6 %). Differences could be due to human bias for determining the definite boundary of sand and water during on-the-ground surveying, and also the coarse 29 m resolution of the satellite imagery. The 29 m spatial resolution of the satellite imagery tended to overestimate barrier island area due to the same land/shallow clear water interface that can easily cause confusion during the classification process when compared to the aerial photography. Time of the GPS survey may also play a roll as tide height may cause both the human and the automated classification process to over or underestimate total island area.

Sediment Supply to the Barrier Islands

Hurricane events along the northern Gulf of Mexico are not the only cause for the loss of barrier islands. Beaches eroding on the mainland shores and the continental shelf are the primary sources of sand that maintain the barrier islands along the Gulf coast today (Morton et al., 2004). Historically, the barrier islands along the Mississippi and Alabama coast received the majority of their sediments from the Mississippi River (Morton et al., 2004) and the Mobile Bay, which contains the Mobile and Tensaw Rivers (National Park Service, 2006). Reductions of sand supplies from these rivers have decreased tremendously due to human activities such as damming, dredging river channels, and jetty construction (Morton et al., 2004). Also, jetty construction along the shore breaks up the alongshore currents that transport the sand and other particulates in a westward direction. Over the entire time period of the study, all of the barrier islands lost a great amount of area, the factor that hurricanes play in that loss is seen, however loss of barrier island area can also be linked to a decrease in sediment supply.

Sea Level Rise and the Barrier Islands

Along with decreases in sediment supply, Waller and Malbrough (1976) named increases in sea level as one of the most important factors impacting barrier islands. Sea level along the Mississippi and Alabama coasts is rising by approximately 2.0 mm per year (Davis and Fitzgerald, 2004). Generally, barrier islands will react to rising sea levels by continued migration (Johnson, 1919) or drowning/eroding in place (Gilbert, 1885). Based on the results from this study it is hard to determine conclusively if the islands are migrating or are eroding in place. However, after examining the data and looking at the ratio of erosion to movement, it can be concluded that Cat Island, Ship Island, and Dauphin Island are characterized more by erosion than movement of constituents, whereas Horn Island and Petit Bois Island are characterized by more constituent movement over erosion of total area.

The results of this study point to the fact that the Mississippi and Alabama barrier islands are undergoing a great deal of change, with most of the change occurring during hurricane events. Even though the barrier islands generally lost a large amount of area following hurricane events, they showed the propensity to recover a large amount of the area lost quickly. The results also show that the barrier islands sediments are eroding on the eastern ends of the islands and accreting on the western ends, meaning that the islands may be migrating in a westward direction. The satellite imagery used for this study was able to convey the varying states that the barrier islands are undergoing during any one instance in time. Vegetation on the barrier islands provided support to their fine constituents, which ultimately lessened the impacts that the barrier islands underwent during hurricane events.

CHAPTER VII

CONCLUSIONS

This study used satellite imagery to investigate changes in the Mississippi and Alabama barrier islands from 1990 to 2005. The most important findings of this study are that total barrier island area and island spatial position are strongly related to hurricane frequency. During periods when hurricanes are infrequent, such as from 1999 to 2003, barrier islands generally increased in total area and showed only moderate repositioning. During periods when hurricanes are frequent (1994-1999 and 2004-2005), barrier islands along the Gulf Coast, showed substantial decreases in area and demonstrated dramatic repositioning of their island centroid. This was especially true following Hurricane Katrina, the most intense hurricane with the greatest storm surge. After Hurricane Katrina, every barrier island in the study decreased in total area. Several of the island centroid locations actually shifted in directions opposite to that of the 15-year trend. Ship Island and Petit Bois Island showed the most amount of change. Ship Island, especially, had tremendous changes in island area and position after Hurricane Katrina. Although no causal relationship was determined from this study, it is interesting to point out that the non-forested islands had the greatest change in island area and position. Lastly, this study showed that the general movement of the Gulf Coasts' barrier islands is westerly and that most of the islands have experienced an overall reduction in island area over the course of the study period (ca. -15 %). These results are similar to findings reported in the literature, which used ground-based surveying and higher-resolution imagery (Waller and Malbrough, 1976; Schmid, 2001a, Schmid, 2001b; Schmid, 2003). Thus, using Landsat imagery to detect changes in barrier islands, with its coarser 29 m resolution, may be an appropriate and more cost-effective geospatial solution.

It is important that this study was able to show that hurricane events have a tremendous impact on the Mississippi and Alabama barrier islands and that the use of Landsat satellite imagery is a suitable geospatial solution. This fact can open the door to future study of these same barrier islands, or other barrier island systems throughout the world using Landsat satellite imagery. The limitations of the Landsat satellite images' coarse resolution were mostly seen at the sand shore/clear water and vegetation/sand interfaces, causing an overestimate of total barrier island area and vegetative area, respectively. This uncertainty in actual area of the barrier islands is a limitation of this study, especially when attempting to compare the results to previous studies, which used higher-resolution imageries. However, Landsat satellite imagery may prove to be an effective and efficient method to measure change taking place on the barrier islands of the northern Gulf of Mexico, due to its relative low cost, large amount of archived data and short repeat time.

Ideally, data would have been available for every year consecutively from 1990 to 2005 during the same season of the year to evaluate the barrier islands along the coasts of Mississippi and Alabama. However, due to lack of funds to purchase more satellite imagery and excessive cloud cover images, images were used that did not occur in the same season. Continued research should focus on increasing the accuracy of classifying the landcover types of the barrier islands either by an unsupervised classification, with cluster busting, or a hybrid classification. In order to overcome the limitations of the coarse resolution of the Landsat sensor, more comparisons to higher-resolution imagery should be made to increase confidence barrier island area calculations. Less emphasis should be put on determining vegetative change on the barrier islands, but focus on accurately classifying the vegetation/sand and sand/shallow clear water interfaces. Also, to be able to better explain changes that occur on the barrier islands on a routine basis, additional weather data, such as paths and strengths of tropical storms, the occurrence of such as el niňo and la niňa events, and winter storm events which often bring strong winds and damaging storm surge should be done to make the study more complete. However, despite the limiting factors for this study, it is one of few of its kind, and the results of this research will be able to be used as a tool for future investigations of not just the northern Gulf of Mexico barrier islands, but other barrier islands as well.

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APPENDIX A

ADDITIONAL BARRIER ISLAND DATA AND INFORMATION

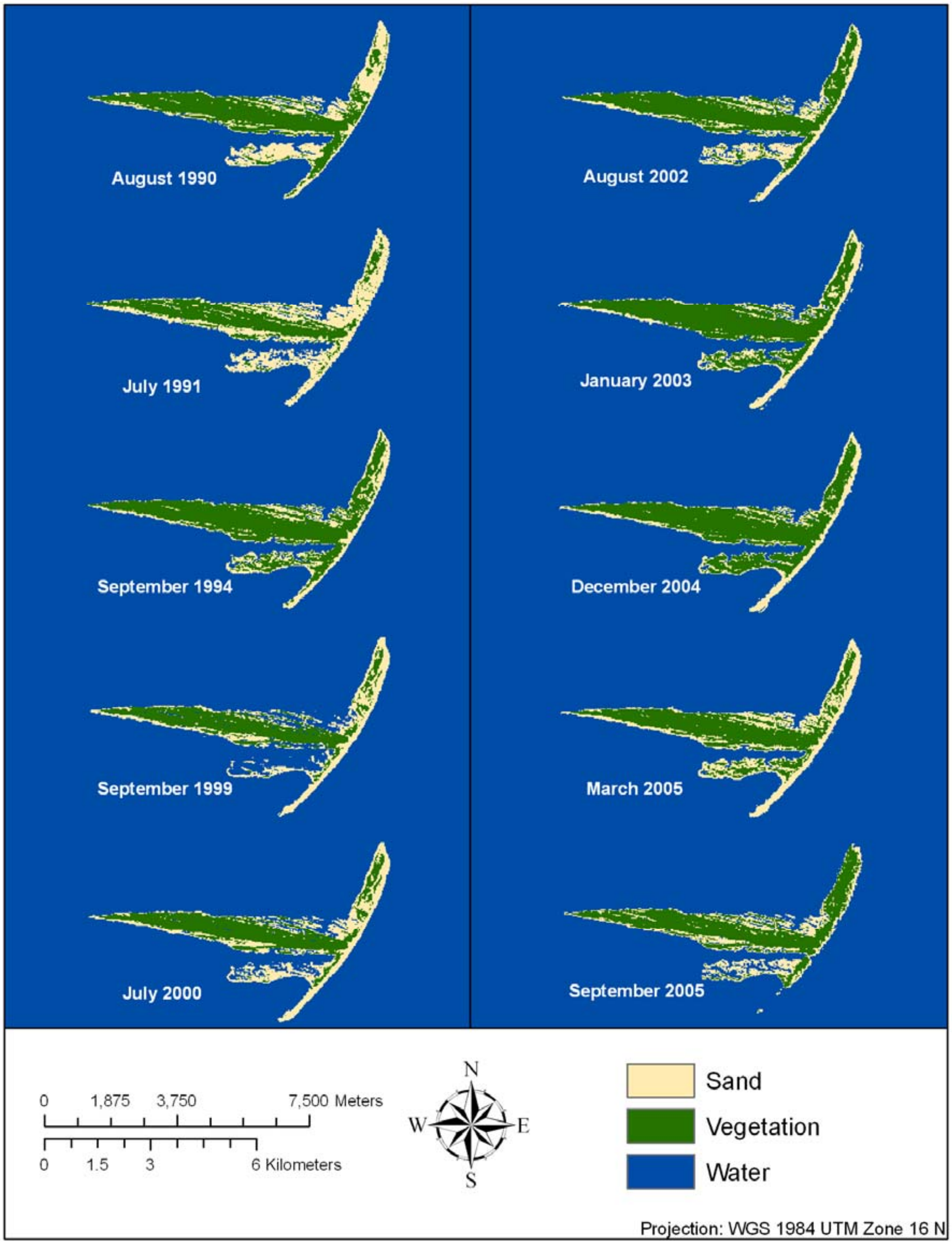

Figure 14. Change occurring on Cat Island between August 1990 and September 2000

Table 32. Cat Island class area calculations in hectares (ha) between August 1990 and September 2005.

Land cover class	Image date									
	August 1990	July 1991	September 1994	September 1999	July 2000	August 2002	January 2003	December 2004	March 2005	September 2005
Sand	376.3	500.6	274.5	323.5	369.9	323.5	261.0	240.4	372.1	288.0
Vegetation	509.6	363.7	625.4	363.4	396.6	522.5	603.1	617.1	479.8	478.9
Water	791.7	813.2	777.8	990.7	911.1	831.6	813.6	820.1	825.7	910.7

Table 33. Cat Island change classification matrix. All areas are measured in hectares (ha), between August 1990 and September 2005.

Change class	Time period								
	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	62.1	32.5	130.7	27.1	47.3	30.6	33.9	32.3	95.2
Sand to vegetation	34.7	260.1	6.3	52.5	121.1	119.3	55.3	17.2	104.8
Vegetation to water	6.1	1.0	90.9	4.2	3.2	5.8	1.9	6.1	17.3
Vegetation to sand	178.7	13.0	177.4	26.4	31.3	41.8	41.2	148.5	90.2
Water to vegetation	4.3	15.5	0.0	11.4	39.3	8.8	1.9	0.1	1.9
Water to sand	42.5	53.5	8.7	99.5	90.7	45.6	27.5	32.6	25.6
No change	1,349.1	1,302.1	1,263.7	1,456.6	1,344.8	1,425.7	1,515.9	1,440.9	1,342.6

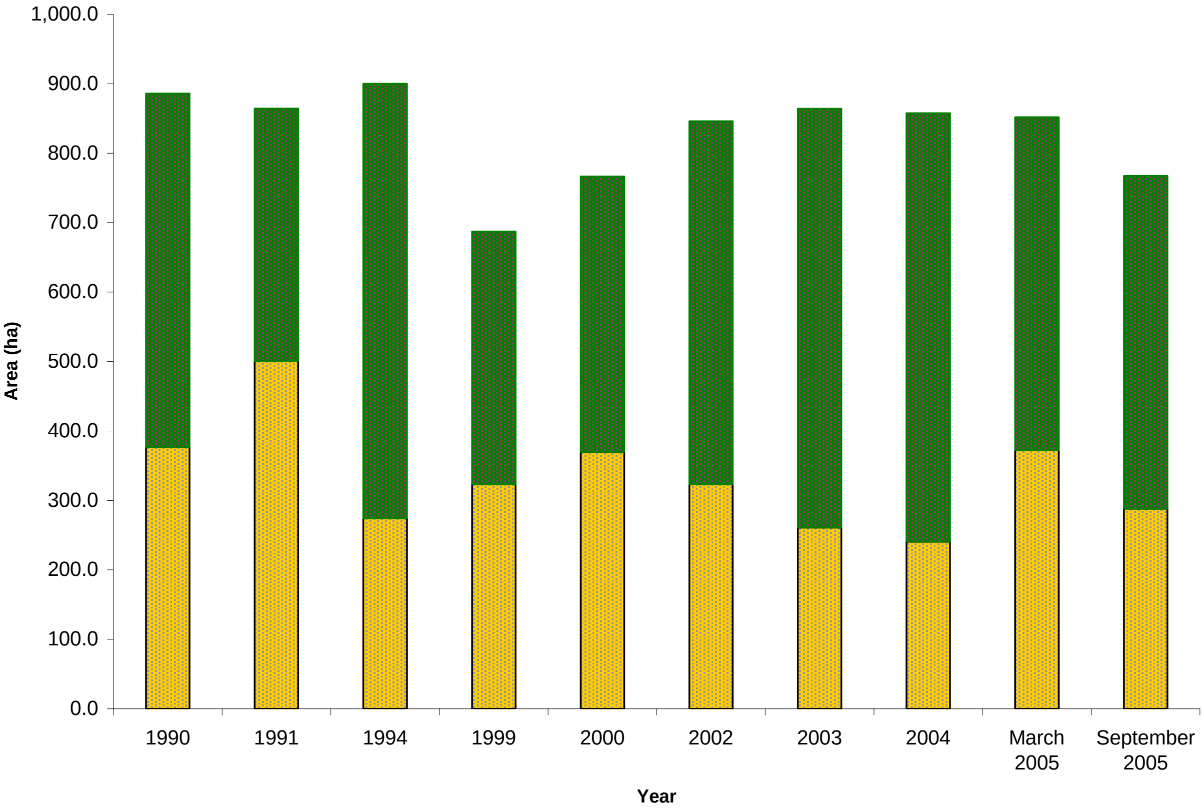

Figure 15. Total vegetation area (top of bar, dark) and total sand area (bottom of bar, light) of Cat Island from August 1990 to September 2005. Total island area is calculated as the summation of vegetation and sand.

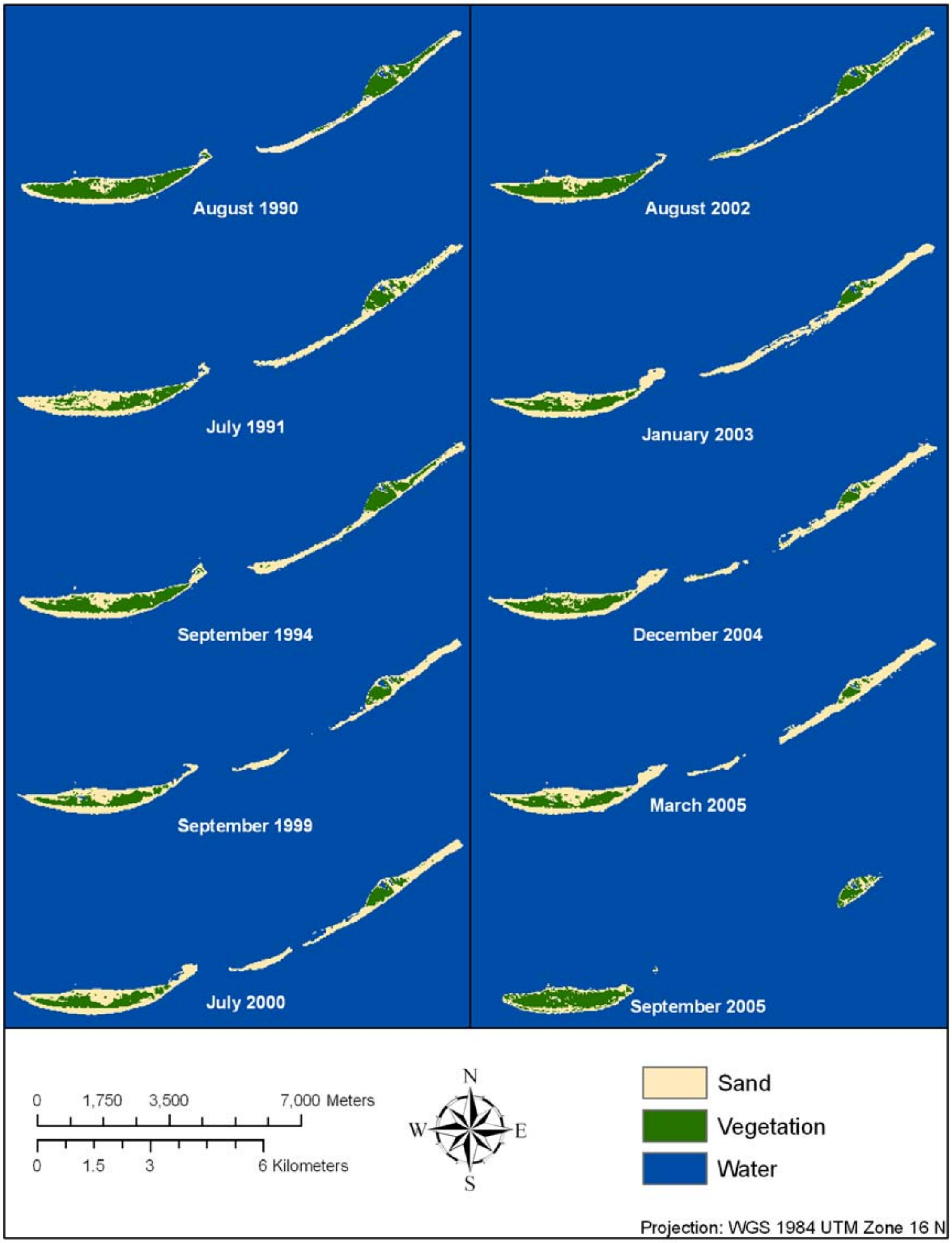

Figure 16. Change occurring on Ship Island between August 1990 and September 2005.

Table 34. Ship Island class area calculations, in hectares (ha) between August 1990 and September 2005.

Land cover class	Image date									
	August 1990	July 1991	September 1994	September 1999	July 2000	August 2002	January 2003	December 2004	March 2005	September 2005
Sand	187.5	267.6	226.6	223.3	252.2	172.7	268.2	255.9	272.1	83.2
Vegetation	218.7	118.2	171.5	91.7	105.7	162.7	95.2	112.0	81.2	141.0
Water	1590.0	1610.4	1598.2	1681.2	1638.3	1660.8	1632.8	1628.3	1642.9	1772.0

Table 35. Ship Island change to from classification matrix. All areas are measured in hectares (ha), between August 1990 and September 2005.

Change class	Time period								
	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	31.7	28.2	101.3	11.8	56.4	37.8	49.1	38.4	140.6
Sand to vegetation	2.9	59.9	2.3	20.9	56.2	2.4	28.4	7.4	66.4
Vegetation to water	3.5	0.8	18.5	0.7	0.1	3.4	0.2	1.3	0.4
Vegetation to sand	100.4	7.4	63.6	7.6	3.9	67.4	12.4	37.1	7.2
Water to vegetation	0.4	1.6	0.0	1.4	4.8	0.9	0.9	0.2	1.0
Water to sand	14.4	39.6	36.7	54.0	29.2	68.4	52.9	24.9	10.9
No change	1,842.8	1,858.8	1,773.9	1,899.9	1,845.7	1,815.9	1,852.3	1,887.0	1,769.5

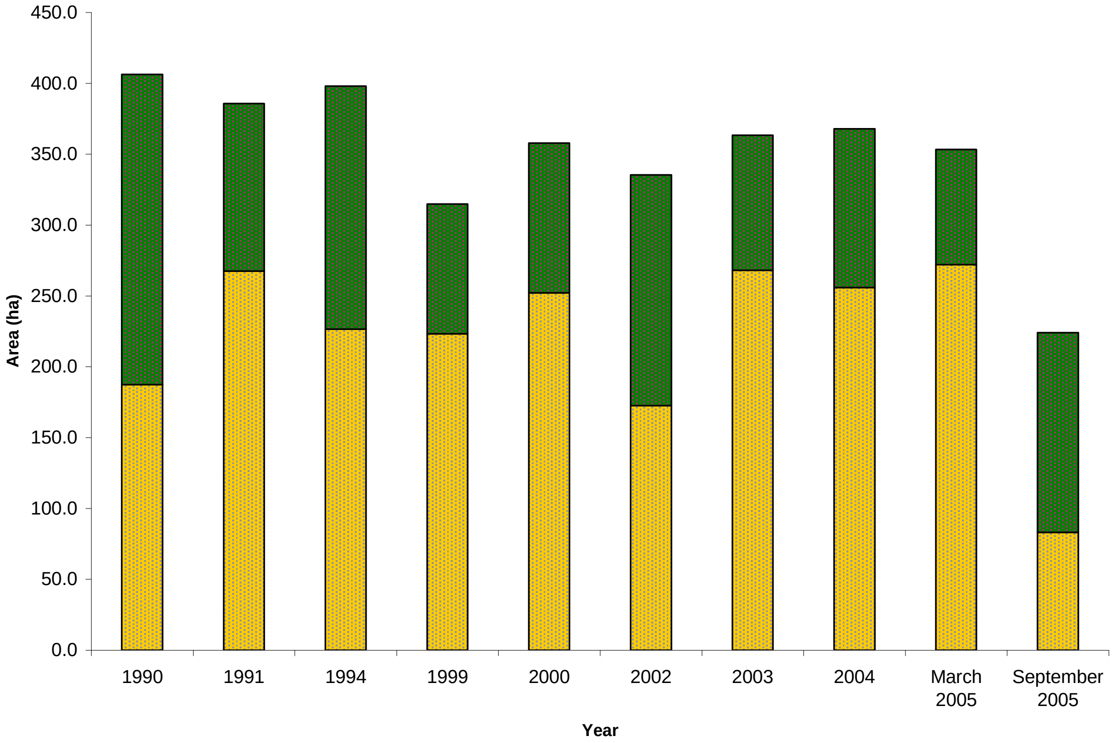

Figure 17. Total vegetation area (top of bar, dark) and total sand area (bottom of bar, light) of Ship Island from August 1990 to September 2005. Total island area is calculated as the summation of vegetation and sand.

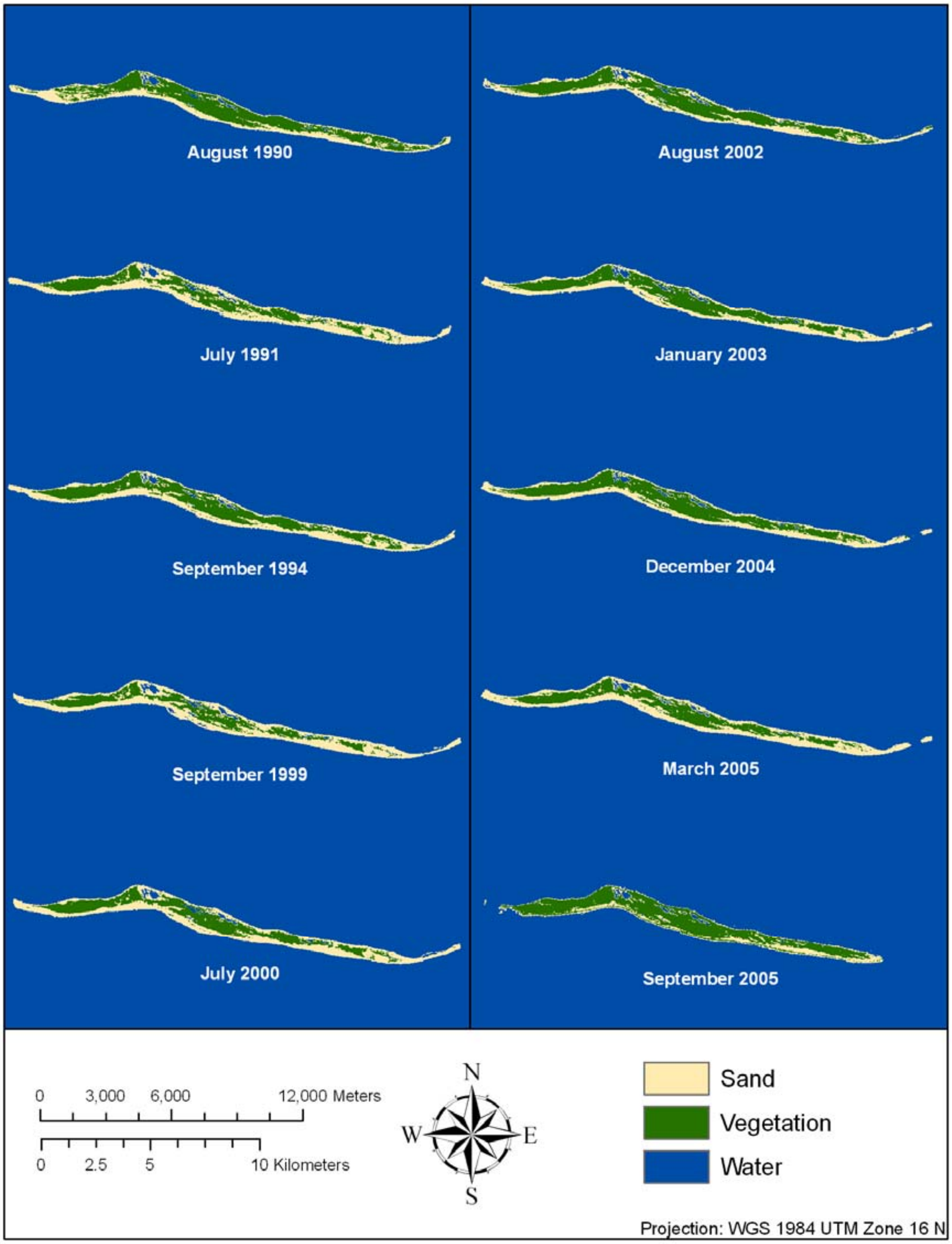

Figure 18. Change occurring on Horn Island between August 1990 and September 2005.

Table 36. Horn Island class area calculations, in hectares (ha) for the duration of the study period.

Class	Image date									
	August 1990	July 1991	September 1994	September 1999	July 2000	August 2002	January 2003	December 2004	March 2005	September 2005
Sand	614.5	861.9	712.8	872.1	769.3	598.7	682.7	621.0	803.7	382.7
Vegetation	804.8	546.3	733.1	460.4	599.5	768.8	668.7	751.7	584.6	916.1
Water	1552.1	1563.3	1525.6	1638.9	1602.6	1604.0	1620.1	1598.8	1583.2	1672.7

Table 37. Horn Island change to from classification matrix. All areas are measured in hectares (ha).

	Time period								
Change class	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	68.0	51.6	148.1	52.1	66.9	74.9	44.0	53.2	132.6
Sand to vegetation	78.6	205.5	15.5	161.1	183.0	43.4	108.2	21.4	354.9
Vegetation to water	10.3	1.0	11.1	1.3	0.6	3.4	0.3	2.8	2.1
Vegetation to sand	329.5	20.4	277.3	26.3	16.9	141.7	27.2	185.8	24.7
Water to vegetation	2.7	2.7	0.3	5.7	3.7	1.6	2.3	0.1	3.4
Water to sand	64.4	87.7	45.6	84.0	62.3	60.6	63.2	71.6	41.8
No change	2,418.0	2,602.5	2,473.7	2,641.0	2,638.1	2,645.9	2,726.4	2,636.7	2,411.9

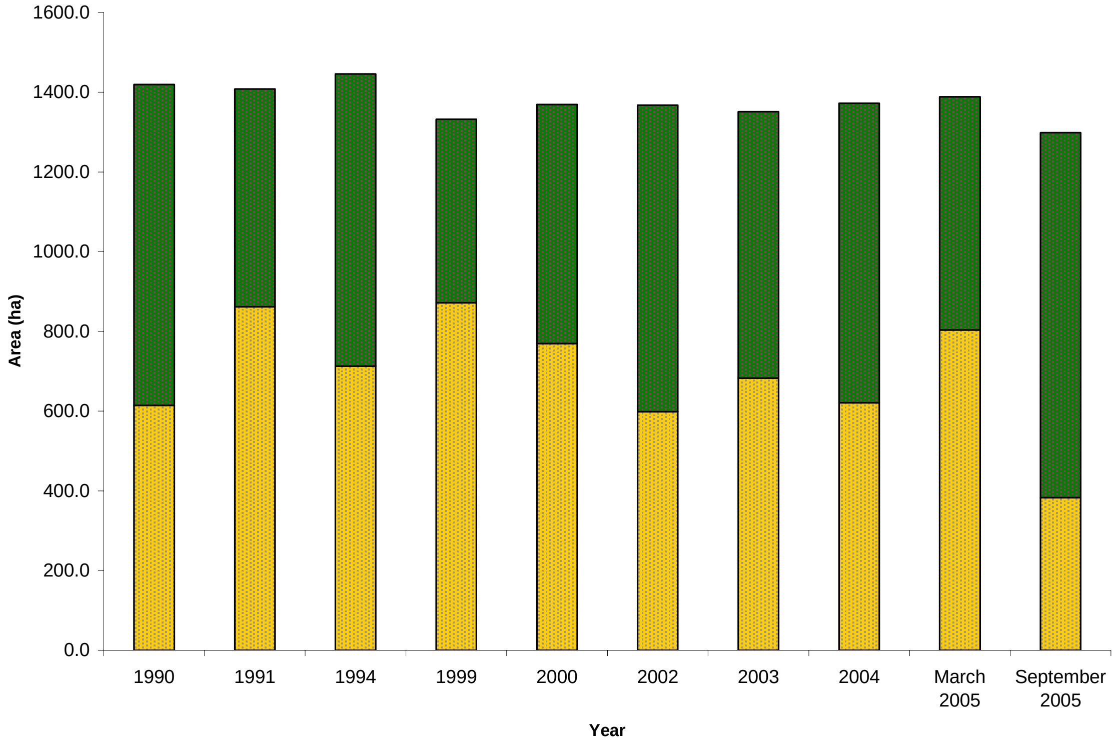

Figure 19. Total vegetation area (top of bar, dark) and total sand area (bottom of bar, light) of Horn Island from August 1990 to September 2005. Total island area is calculated as the summation of vegetation and sand.

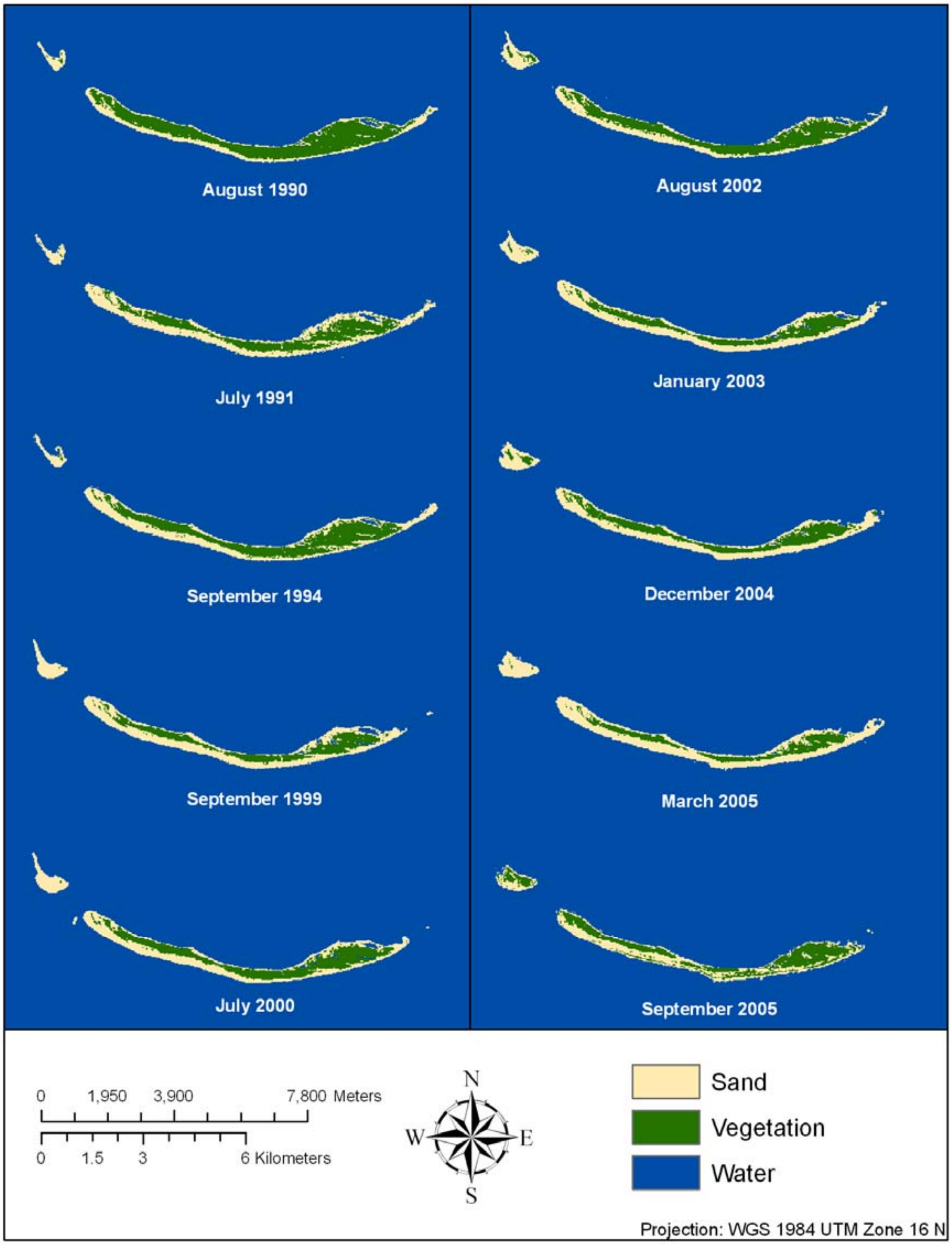

Figure 20. Change occurring on Petit Bois Island between August 1990 and September 2005.

Table 38. Petit Bois Island class area calculations, in hectares (ha) for the duration of the study period.

Class	Image date									
	August 1990	July 1991	September 1994	September 1999	July 2000	August 2002	January 2003	December 2004	March 2005	September 2005
Sand	192.8	326.1	275.6	323.4	284.0	233.7	319.7	303.4	368.4	233.0
Vegetation	374.0	233.2	288.0	170.6	232.1	283.3	174.8	198.2	135.2	234.3
Water	1596.5	1604.0	1599.8	1669.2	1647.2	1646.3	1668.7	1661.6	1659.7	1696.0

Table 39. Petit Bois Island change to/from classification matrix. All areas are measured in hectares (ha).

	Time period								
Change class	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	34.7	29.4	88.8	42.2	82.3	45.5	26.9	29.8	94.4
Sand to vegetation	5.0	68.3	14.8	89.4	67.9	13.6	41.0	7.2	127.8
Vegetation to water	4.6	0.7	25.2	10.8	5.0	20.4	0.0	0.9	0.1
Vegetation to sand	142.4	14.0	108.7	22.0	45.6	103.3	19.2	69.3	45.1
Water to vegetation	1.3	1.2	1.9	4.8	33.9	1.5	1.5	0.0	16.4
Water to sand	30.5	33.1	42.7	70.2	54.3	41.9	32.5	32.6	41.8
No change	1,944.8	2,016.6	1,881.1	1,924.0	1,874.3	1,937.2	2,042.2	2,023.4	1,837.8

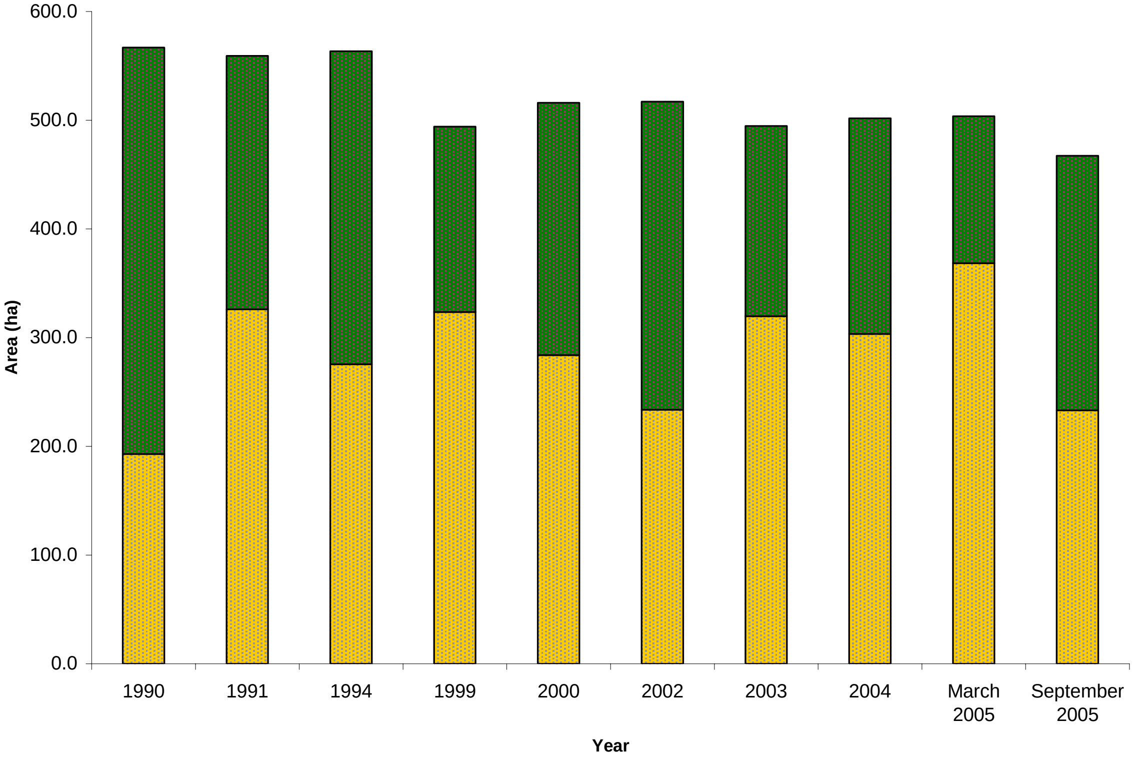

Figure 21. Total vegetation area (top of bar, dark) and total sand area (bottom of bar, light) of Petit Bois Island from August 1990 to September 2005. Total island area is calculated as the summation of vegetation and sand.

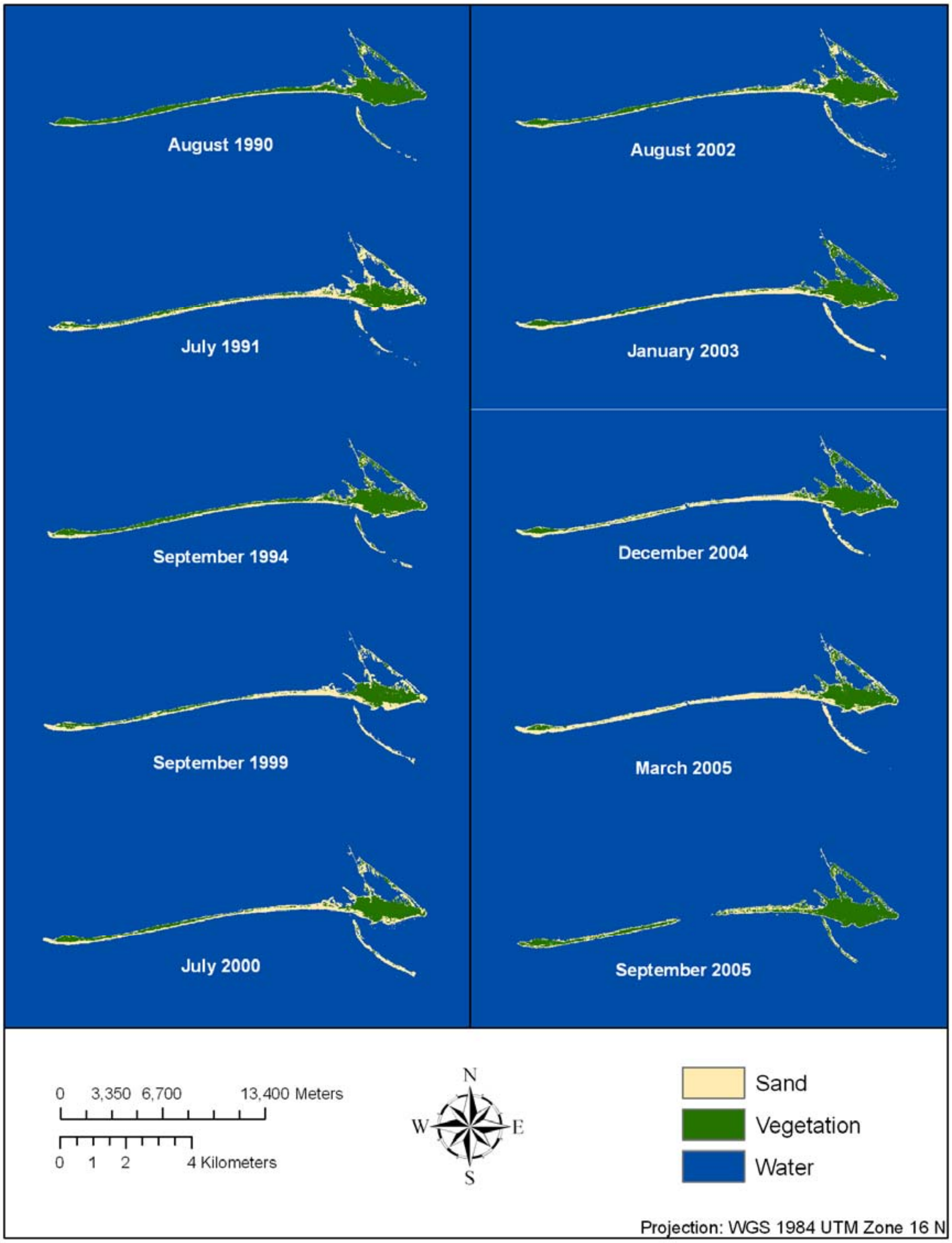

Figure 22. Change occurring on Dauphin Island between August 1990 and September 2005.

Table 40. Dauphin Island class area calculations, in hectares (ha) for the duration of the study period.

	Image date									
Class	August 1990	July 1991	September 1994	September 1999	July 2000	August 2002	January 2003	December 2004	March 2005	September 2005
Sand	496.7	981.2	619.3	869.6	842.9	761.1	784.2	788.3	985.0	513.6
Vegetation	1131.8	675.6	1017.3	597.3	744.8	902.9	815.6	823.0	661.6	1048.0
Water	4297.6	4269.3	4289.5	4459.2	4338.4	4262.1	4326.3	4314.8	4279.5	4364.5

Table 41. Dauphin Island change to from classification matrix. All areas are measured in hectares (ha).

	Time period								
Change class	8/1990 to 7/1991	7/1991 to 9/1994	9/1994 to 9/1999	9/1999 to 7/2000	7/2000 to 8/2002	8/2002 to 1/2003	1/2003 to 12/2004	12/2004 to 3/2005	3/2005 to 9/2005
Sand to water	107.0	139.8	210.6	52.4	106.8	157.8	111.0	92.5	241.0
Sand to vegetation	15.0	358.2	5.3	155.6	184.9	101.3	111.3	34.5	400.3
Vegetation to water	19.3	3.4	42.5	0.8	1.9	15.4	6.7	7.7	6.0
Vegetation to sand	456.7	22.6	383.2	15.7	46.8	193.3	104.5	188.7	35.7
Water to vegetation	4.8	9.5	0.4	8.5	21.9	20.2	7.4	0.6	27.8
Water to sand	149.7	113.5	82.9	165.6	163.2	88.8	121.8	135.0	134.2
No change	5,173.7	5,279.2	5,201.2	5,527.5	5,400.6	5,349.3	5,463.4	5,467.1	5,081.1

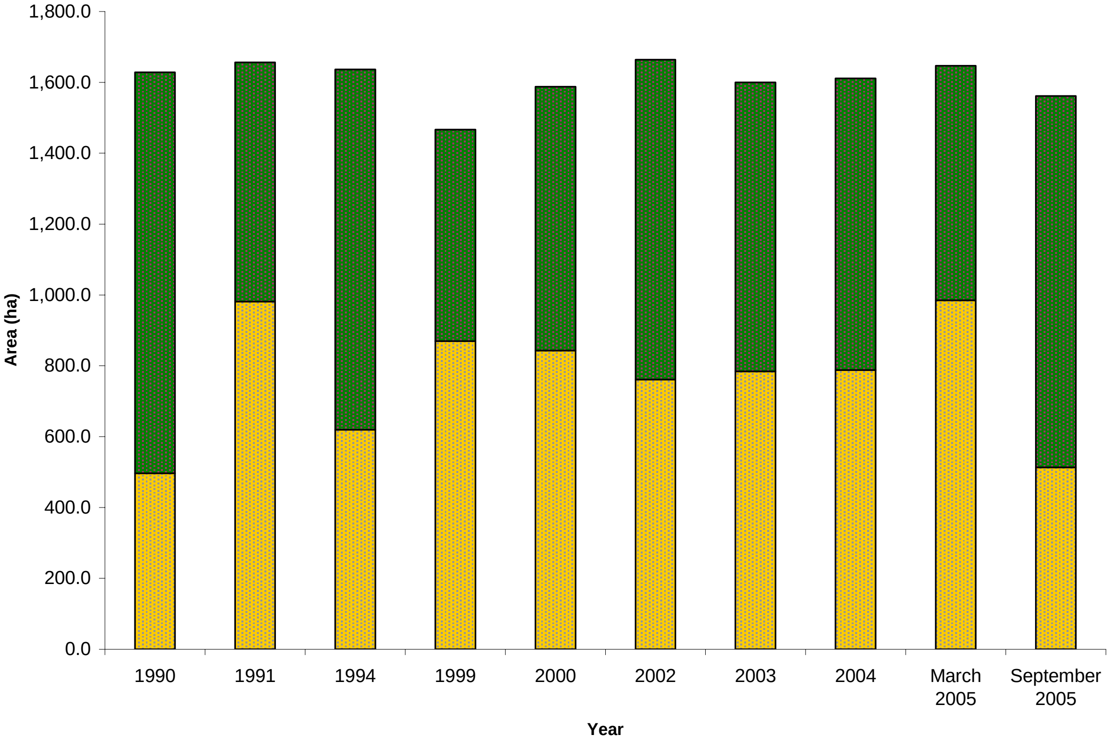

Figure 23. Total vegetation area (top of bar, dark) and total sand area (bottom of bar, light) of Dauphin Island from August 1990 to September 2005. Total island area is calculated as the summation of vegetation and sand.

Table 42. Barrier island area (ha) comparisons for each time period between August 1990 and September 2005

Satellite image date	Barrier island Cat Island	Ship Island	Horn Island	Petit Bois Island	Dauphin Island	Total all Islands
August 1990	885.9	406.2	1,419.4	566.8	1,628.5	4,906.8
July 1991	864.4	385.8	1,408.2	559.3	1,656.8	4,874.5
Area Change	-21.5	-20.4	-11.2	-7.5	28.3	-32.3
% Change	-2.5%	-5.3%	-0.8%	-1.3%	1.7%	-0.7%
July 1991	864.4	385.8	1,408.2	559.3	1,656.8	4,874.5
Sept.1994	899.9	398.0	1,445.9	563.6	1,636.6	4,944.0
Area Change	35.5	12.2	37.7	4.3	-20.2	69.5
% Change	3.9%	3.1%	2.6%	0.8%	-1.2%	1.4%
Sept. 1994	899.9	398.0	1,445.9	563.6	1,636.6	4,944.0
Sept.1999	686.9	315.0	1,332.6	494.1	1,466.9	4,295.5
Area Change	-213.0	-83.0	-113.3	-69.5	-169.7	-648.5
% Change	-31.0%	-26.3%	-8.5%	-14.1%	-11.6%	-15.1%
Sept.1999	686.9	315.0	1,332.6	494.1	1,466.9	4,295.5
July 2000	766.5	357.9	1,368.9	516.1	1,587.7	4,597.1
Area Change	79.6	42.9	36.3	22.0	120.8	301.6
% Change	10.4%	12.0%	2.7%	4.3%	7.6%	6.6%
July 2000	766.5	357.9	1,368.9	516.1	1,587.7	4,597.1
August 2002	846.0	335.4	1,367.5	517.0	1,664.0	4,729.9
Area Change	79.5	-22.5	-1.4	0.9	76.3	132.8
% Change	9.4%	-6.7%	-0.1%	0.2%	4.6%	2.8%
August 2002	846.0	335.4	1,367.5	517.0	1,664.0	4,729.9
January 2003	864.0	363.4	1,351.4	494.6	1,599.8	4,673.2
Area Change	18.0	28.0	-16.1	-22.4	-64.2	-56.7
% Change	2.1%	7.7%	-1.2%	-4.5%	-4.0%	-1.2%
January 2003	864.0	363.4	1,351.4	494.6	1,599.8	4,673.2
Dec. 2004	857.6	367.9	1,372.7	501.7	1,611.3	4,711.2
Area Change	-6.4	4.5	21.3	7.1	11.5	38.0
% Change	-0.7%	1.2%	1.6%	1.4%	0.7%	0.8%
Dec. 2004	857.6	367.9	1,372.7	501.7	1,611.3	4,711.2
March 2005	851.9	353.3	1,388.3	503.6	1,646.6	4,743.7
Area Change	-5.7	-14.6	15.6	1.9	35.3	32.5
% Change	-0.7%	-4.1%	1.1%	0.4%	2.1%	0.7%
March 2005	851.9	353.3	1,388.3	503.6	1,646.6	4,743.7
Sept. 2005	766.9	224.2	1,298.8	467.3	1,561.6	4,318.8
Area Change	-85.0	-129.1	-89.5	-36.3	-85.0	-424.9
% Change	-11.1%	-57.6%	-6.9%	-7.8%	-5.4%	-9.8%

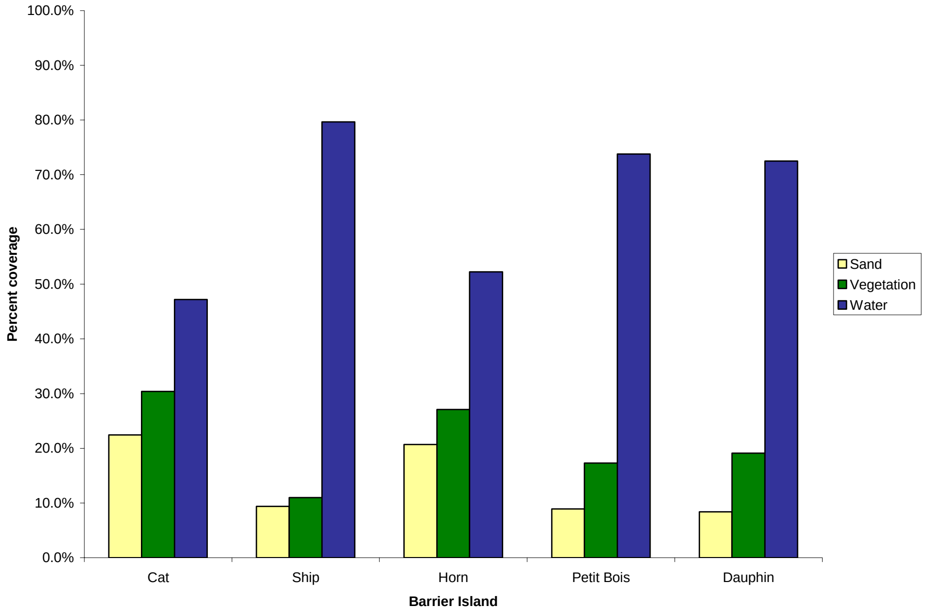

Figure 24. August 1990 comparisons of percent coverage of sand, vegetation and water on each barrier island.

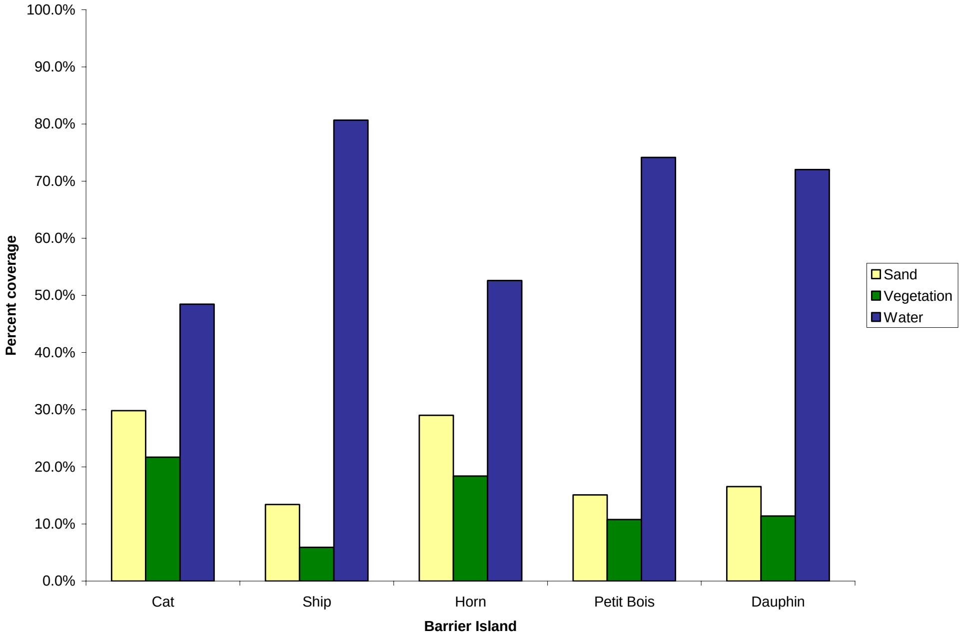

Figure 25. September 1991 comparisons of percent coverage of sand, vegetation and water on each barrier island.

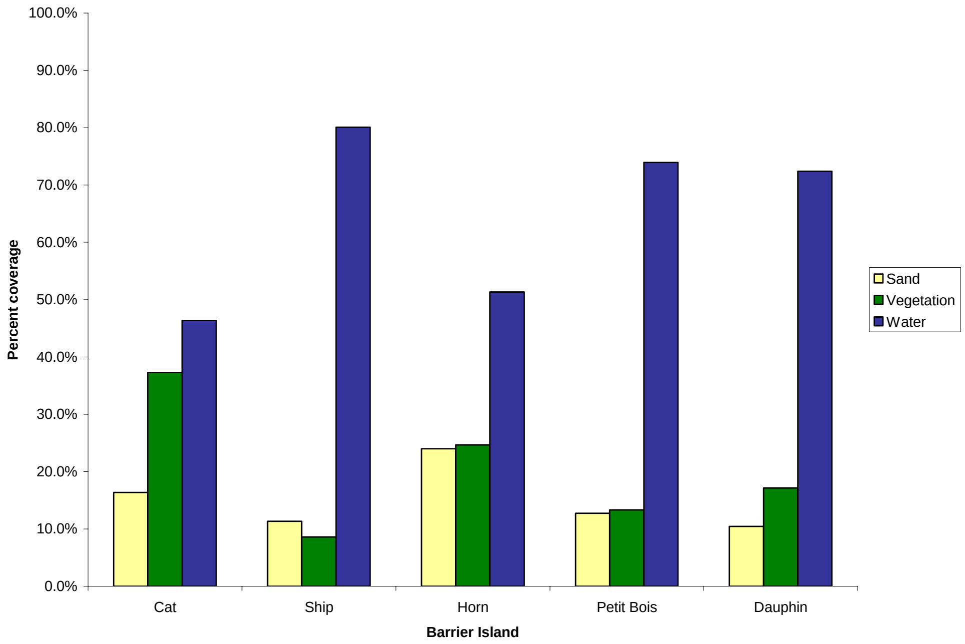

Figure 26. September 1994 comparisons of percent coverage of sand, vegetation and water on each barrier island.

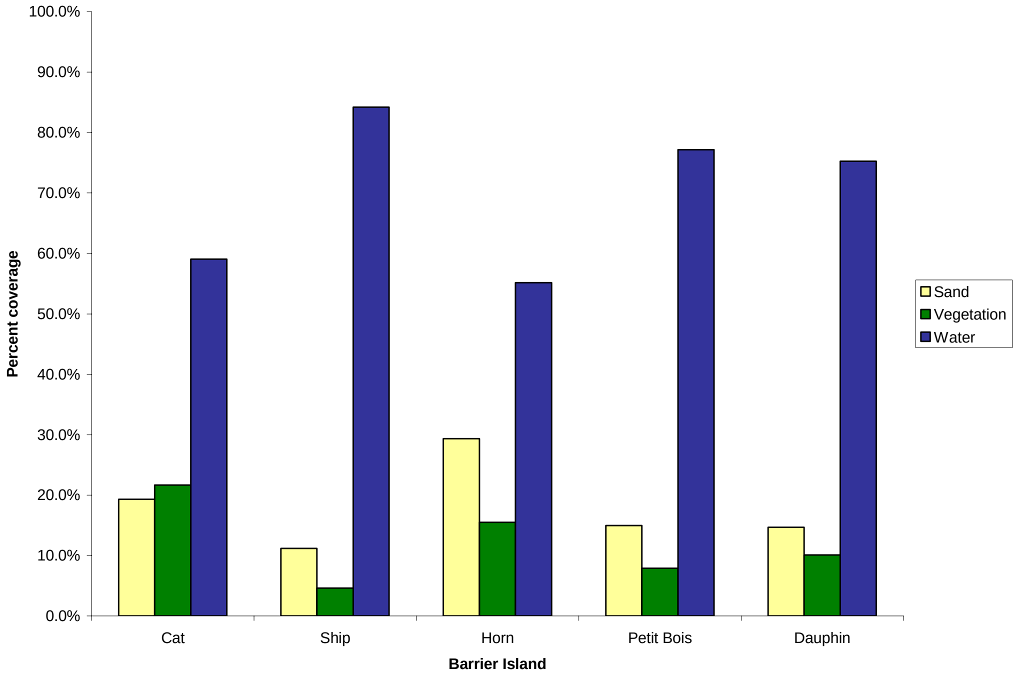

Figure 27. September 1999 comparisons of percent coverage of sand, vegetation and water on each barrier island.

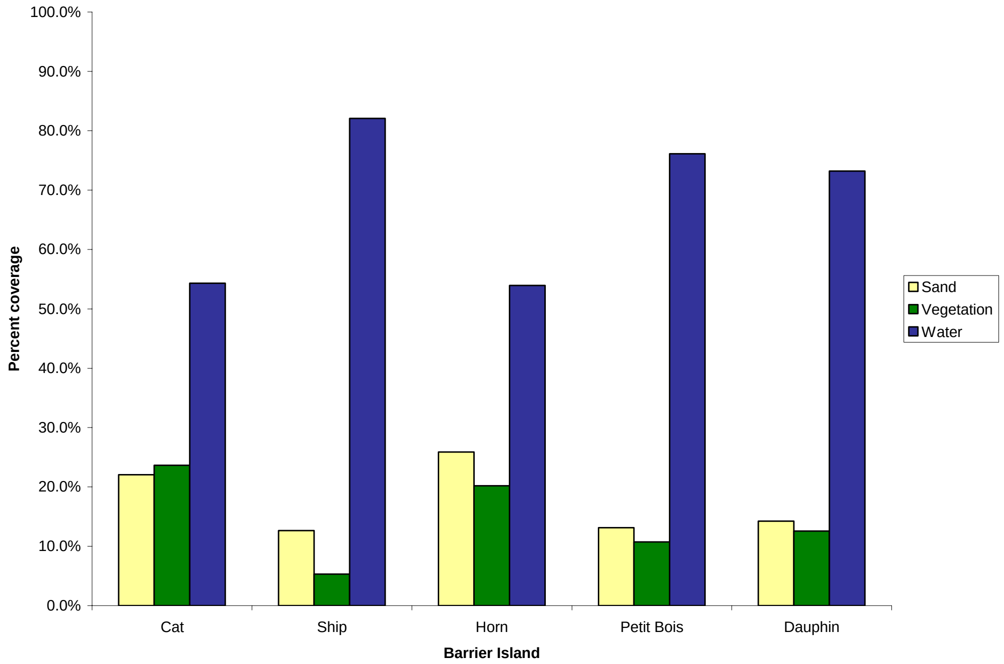

Figure 28. July 2000 comparisons of percent coverage of sand, vegetation and water on each barrier island.

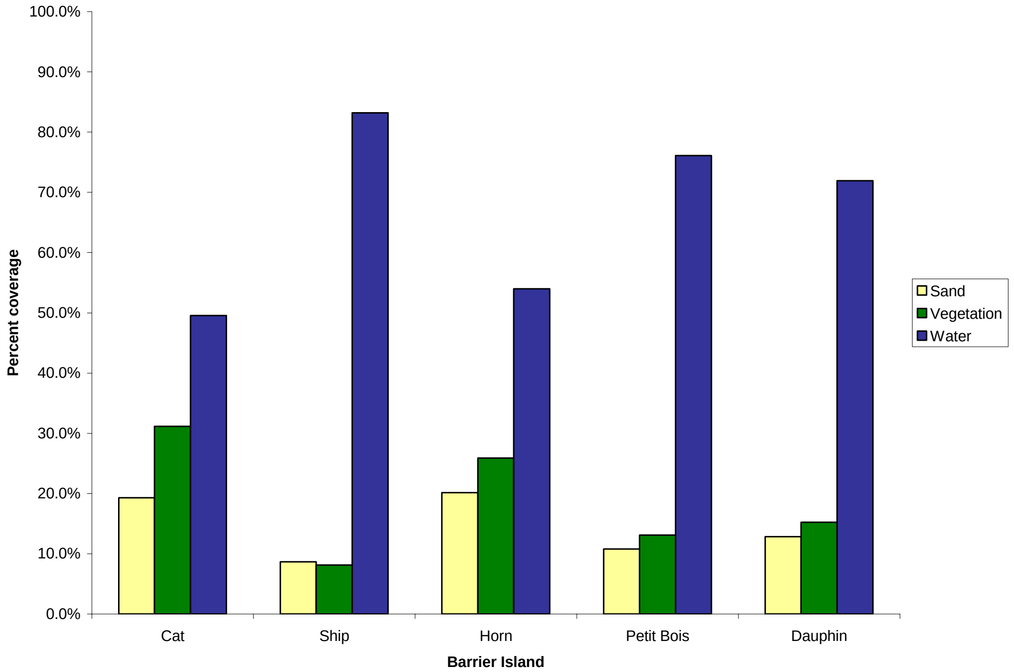

Figure 29. August 2002 comparisons of percent coverage of sand, vegetation and water on each barrier island.

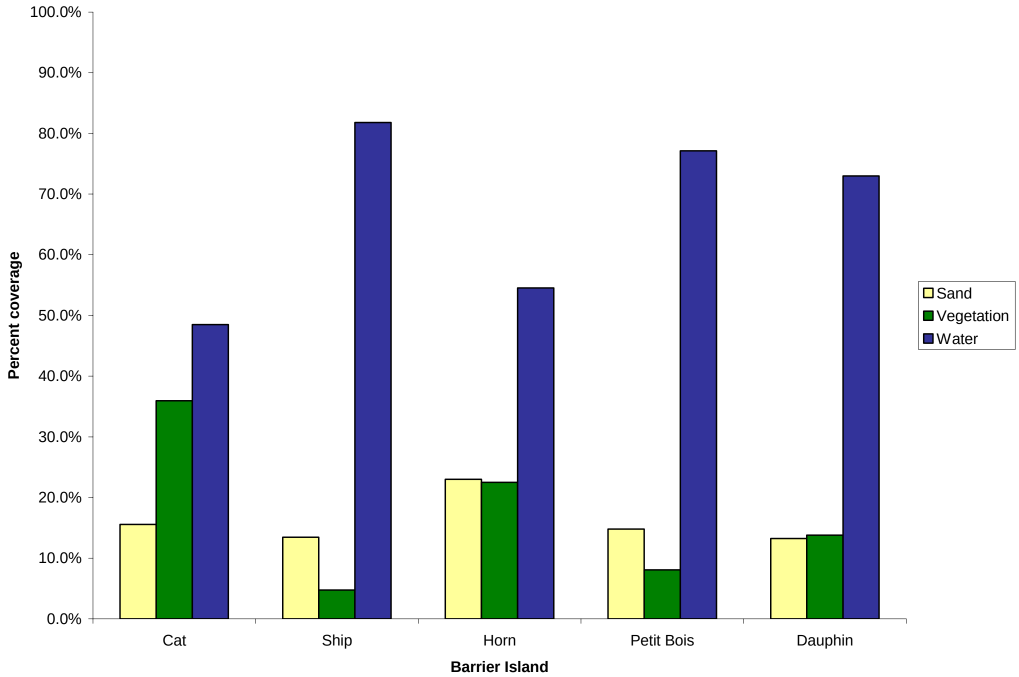

Figure 30. January 2003 comparisons of percent coverage of sand, vegetation and water on each barrier island.

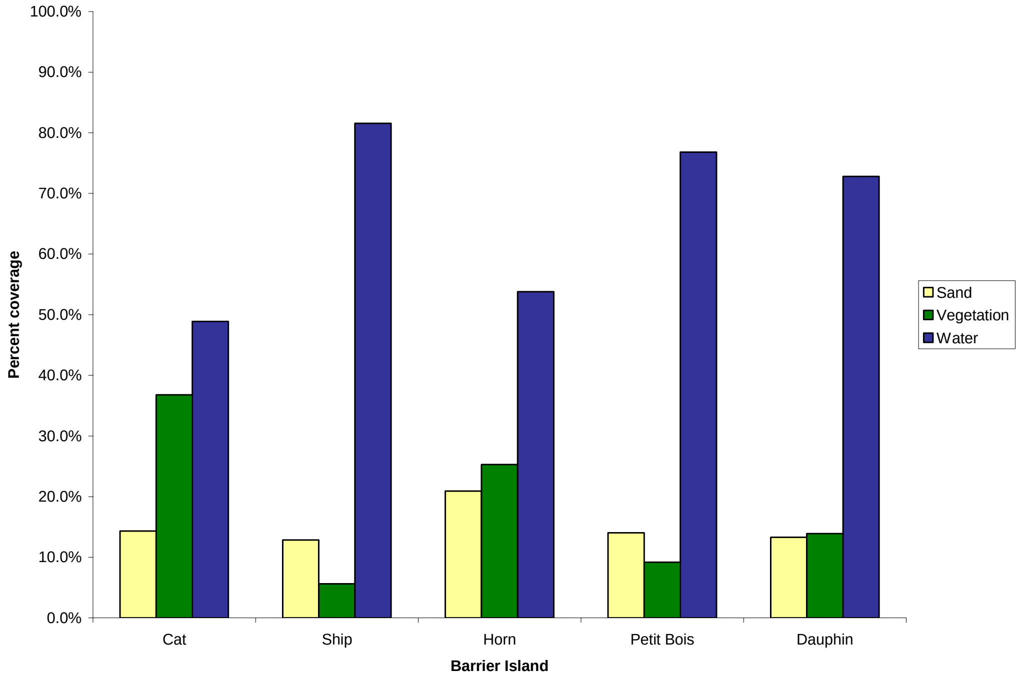

Figure 31. December 2004 comparisons of percent coverage of sand, vegetation and water on each barrier island.

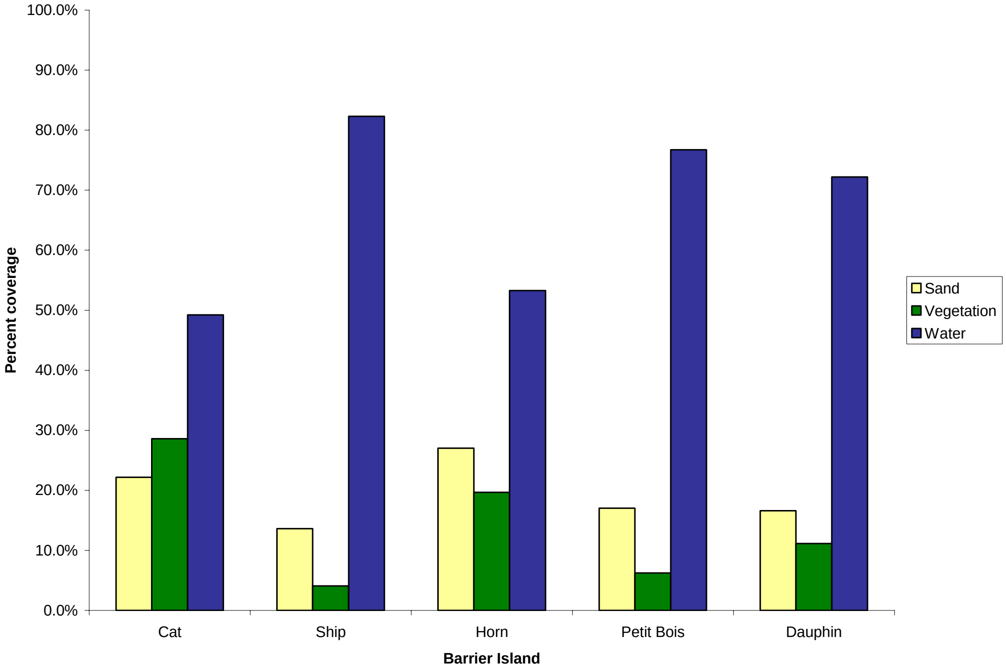

Figure 32. March 2005 comparisons of percent coverage of sand, vegetation and water on each barrier island.

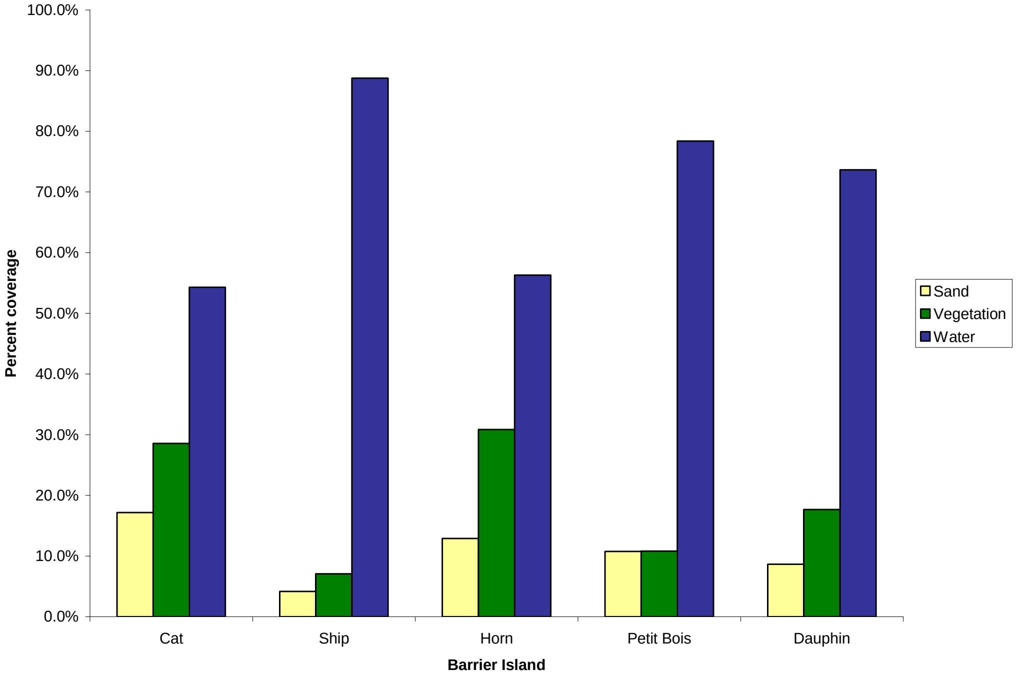

Figure 33. September 2005 comparisons of percent coverage of sand, vegetation and water on each barrier island.