East Ship Island Evolution, Morphology, and Hurricane Response – 1994 to 2001

Keil Schmid

Mississippi Department of Environmental Quality

Office of Geology

Open-File Report 134

S. Cragin Knox

State Geologist

Coastal Section

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January 2003

Cover photo: Picture taken of the shoreline in front of the central wooded portion of the island looking east in January 1999.

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Title page photograph: Picture of East Ship Island taken from the western spit in January 1999.

This work has been checked and approved for publication by:

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Abstract

East Ship Island is part of the Gulf Islands National Seashore in Mississippi; it is the eastern portion of the original Ship Island that was separated into East and West Ship Islands during Hurricane Camille. Hurricane Georges, a category 2 hurricane, passed just east of the island in late September 1998. This report has combined newly gathered data including LIDAR, Global Positioning System (GPS) surveys, and cross-shore profiles with existing data sources such as aerial photography, sediment cores, and bathymetry to describe island change in the period preceding Hurricane Georges, change caused by the hurricane, and change that occurred during recovery from the hurricane.

East Ship Island displayed a stable evolution prior to the storm's passage (1994-1997), with little change beyond the historical level (equilibrium). During the hurricane the island changed quickly as nearly 3 km of the island and a total of 81 acres (25% of the island) were lost. East Ship had the highest percent of area lost during Hurricane Georges for the entire chain of barrier islands in Mississippi. Equally impressive was the change during the recovery period when about half of the area lost was regained during the first year (40 acres); the entire 81 acres were recovered by the second year. Although much of the island area recovered following the hurricane, the low elevations on the spits, especially the western spit, and the lack of area recovery on the central wooded section of the island are critical indicators of a short future for the island.

The differences between the island's spits and central wooded core are evident in shoreline change as well as physical appearance. Moreover, the two spits behaved distinctly differently during the hurricane and recovery periods. A large factor in the difference between spit behaviors is the vegetation cover. The eastern spit had a fairly dense cover of dune grasses, the western spit did not, and during the hurricane the western spit was completely inundated while the eastern spit was only overwashed. The existence of Dog Key Shoals to the east of the island is an important sand source and also provides some protection to the island from east and southeast waves. The Pleistocene framework geology and surface elevation underlying the island appear to have controlled the location of the older central section of the island and may also be a secondary factor in the differences between spits. The island's longevity is heavily dependent on the central wooded portion of the island, which did not show any recovery following the hurricane, and the frequency of hurricane passage.

Introduction

The evolution of the Mississippi Barrier Islands from shoals (Otvos, 1970a; b; 1979) to present configuration is driven by natural interactions between relative sea level, sediment supply, and meteorological – oceanographic conditions (McBride and Byrnes, 1995), and human induced changes from dredging, sediment diversion and habitat control (Shabica et al., 1984). As meteorological conditions (energy) vary by orders of magnitude over short durations, changes in barrier island position and morphology typically happen at irregular and exaggerated rates (Byrnes et al., 1989). The Mississippi Barrier Islands are no exception, with average shoreline position changes in some areas as high as 90 meters/year (McBride and Byrnes, 1995; McBride et al., 1995).

These high rates make simple Global Positioning System (GPS) shoreline surveys, with accuracies of better than five meters (Hutchins and Oivanki, 1994), a viable way to document island evolution at yearly to semi-yearly scales. This is an important milestone in the study of hurricane change along the Mississippi Barrier Islands; at no time before could shoreline evolution be as densely and completely quantified prior to and following a hurricane's passage without incurring high costs. Previous studies have documented short temporal changes; however, they have been mainly qualitative (Byrnes et al., 1989). Temporally dense data also help highlight fine scale spatial trends and possible mechanisms that taken in total are important ingredients in island morphology and evolution.

Beyond satellite based surveying, the availability of Light Detection and Ranging (LIDAR) data to researchers has brought highly accurate elevation data sets to the greater research community. LIDAR has been successfully used in documenting seasonal change in coastal California as well as the Atlantic Coast (Morgan et al., 1999; Sallenger et al., 1998).

This report focuses on East Ship Island and is part of a series covering recent change on the Mississippi Barrier Islands in response to Hurricane Georges. East Ship was originally part of a larger Ship Island, which was last breached during Hurricane Camille in 1969 (Nummedal et al., 1980). Prior to Hurricane Camille the large Ship Island was breached several times, but the two "islands" re-attached. Following Hurricane Camille the two islands have appeared to evolve separately. As each island is relatively "new," they also offer some insight on inter-island processes and formation mechanisms.

Study Site

Coastal Mississippi stretches from Louisiana in the west to Alabama in the east (Figure 1) and contains five nearly shore-parallel barrier islands. The Mississippi Barrier Islands are an elongate east – west chain, located 15 to 20 kilometers from the mainland coast. From east to west, the islands are Petit Bois, Horn, East Ship, West Ship and Cat (Figure 2). Petit Bois, Horn, East Ship, and West Ship are presently part of the Gulf Islands National Seashore and Cat is in the stages of being acquired. All of the islands in Mississippi are broadly considered high profile, regressive barrier islands (Nummedal et al., 1980), although each island has extensive low profile areas that change rapidly. The eastern islands appear to exhibit a shoal to island geology (Otvos, 1970a;b) with the main source of sediment from the Alabama mainland coast (Otvos, 1985). Their early formation into islands has been placed in the Mid-Holocene (about 3-4 thousand years ago) (Otvos, 1979). Historically, within the last 300 years, the eastern islands (Petit Bois and Horn) have had a dominantly translational – longshore drift movement, such that they are not moving landward but rather from east to west along the coast. Cat Island, the westernmost island, has had very little translational movement and is instead eroding in place. The two Ship Islands are in the middle of the spectrum. In particular, West Ship Island is a rare island in that it has actually experienced shoreline advance and an area increase between 1966 (prior to Hurricane Camille) and 1986 (McBride and Byrnes, 1995).

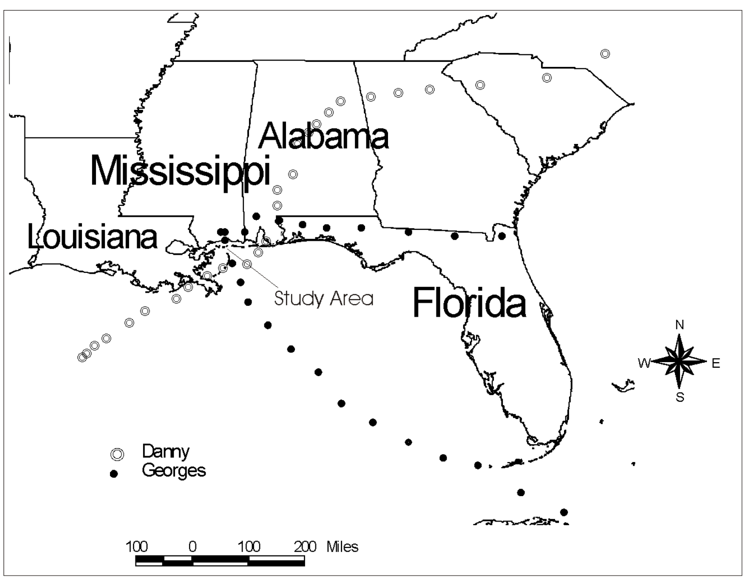


Figure 1. General Study site in Southeastern United States.

The importance of hurricanes on the formation and change of gulf coast barrier islands is undeniable (Nummedal et al., 1980). Each hurricane or storm is unique and its effect on individual barrier islands produces a distinct result (Morton, 1999; Sallenger, 2000). The eye of Hurricane Georges entered and passed through the Mississippi Sound between East Ship and Horn Islands on September 28, 1998 (Figure 1 and 2). It was a category 2 storm before making landfall near Biloxi, Mississippi. Although Hurricane Georges was only a category 2 storm when impacting the Mississippi Gulf Coast, its slow forward motion of about 5 mph (Otvos, 1999) caused significant damage to barrier islands in the area. In Louisiana island changes from Georges have been compared to those caused by Hurricane Camille, a category 5 storm (Penland et al., 1999). The only other tropical storm of note to pass fairly close to Mississippi during the study period was Hurricane Danny in 1997 (Figure 1); however, it only glanced the area and was substantially weaker.

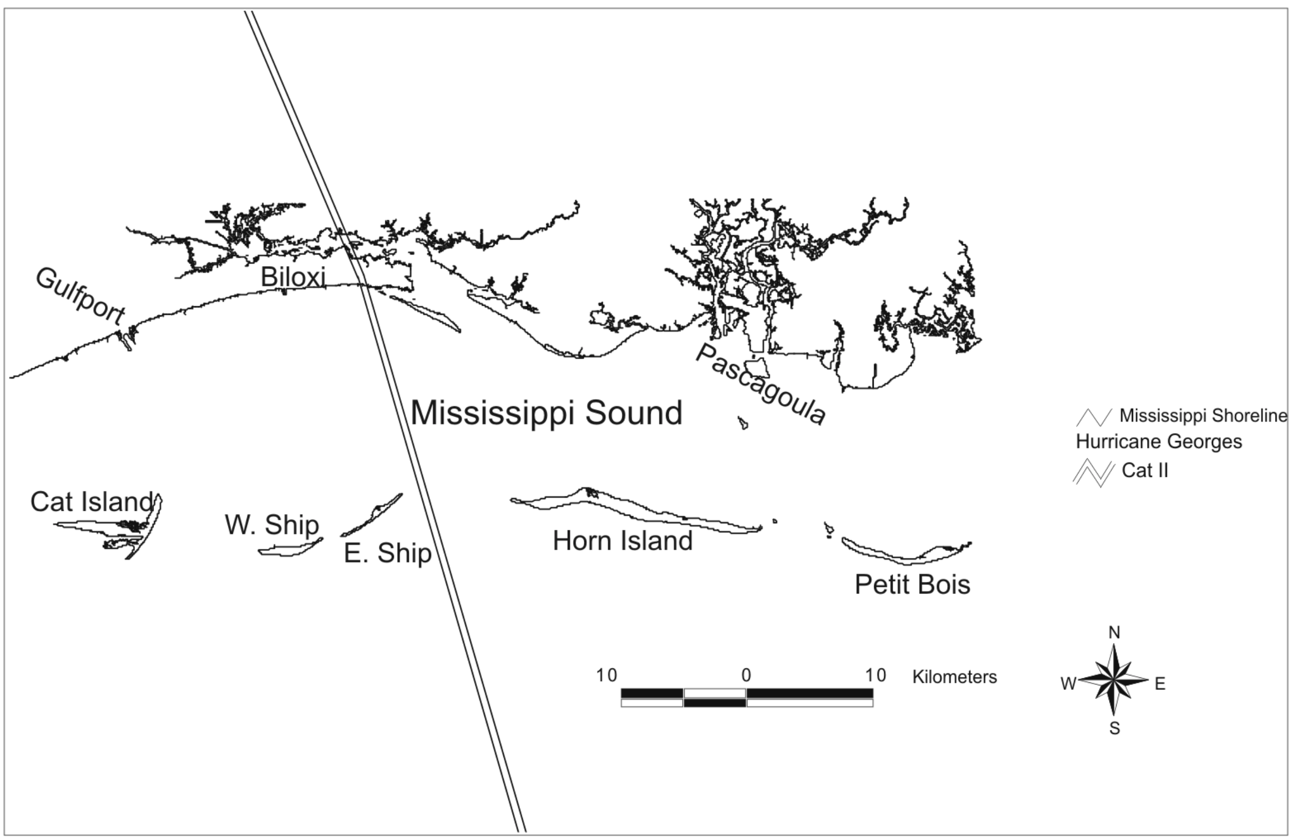


Figure 2. Study area with Hurricane Georges track.

Methods

Several different methods were used to document island evolution prior to, in response to, and following Hurricane Georges. Kinematic GPS surveying techniques were used to highlight shoreline changes in periods prior to Hurricane Georges (1994-1997), encompassed by Hurricane Georges (1997-1998), and following Hurricane Georges (1998-2001). To further document island changes, morphology from LIDAR elevation data sets collected following Hurricane Georges was analyzed in relation to hurricane-driven shoreline change. At representative locations, cross shore profiles generated from LIDAR elevations taken in 1998 were compared with profiles measured with conventional survey procedures in 2001 to highlight morphology changes during the period.

Yearly GPS shoreline surveys of the Mississippi Barrier Islands have been performed since 1993 by the Mississippi Office of Geology and semi-annually by the National Park Service since 1998. In each survey the high tide shoreline was mapped using kinematic GPS techniques. All data were post processed, yielding accuracies on the order of ± 2-5 meters (Hutchins and Oivanki, 1994). The high tide line, denoted by a wet-to-dry line, beach berm, or wrack line, has been chosen as the most repeatable datum and represents the state-owned boundary. Errors, both in interpreting the high-tide line and from differences in tide range, exist, although effort has been taken to insure a level of consistency between mapping parties. Tides are classified as microtidal and diurnal with a typical range of 0.5 m.

The GPS shorelines in 1994, 1997 and 2001 were surveyed during the June to early August period. The shoreline in 1998 was surveyed in October, following the passage of Hurricane Georges. Three separate time ranges are used to illustrate ambient or pre-hurricane conditions (1994-1997), hurricane caused change (1997-1998), and the recovery stage (1998-2001).

Locations of shoreline retreat and advance (shoreline change) beyond certain levels were computed using buffers on GPS shorelines. The buffer width was chosen to highlight areas of significant change within the confines of the survey accuracy. Otvos (Otvos, 1976) suggested that areas with more than 1.2 m/yr of retreat or advance are changing significantly. Any portions of the compared (later) shoreline landward of the base (earlier) shoreline buffers were highlighted as retreat; portions seaward of the buffers were highlighted as advance.

Buffer widths for each island were based on historic levels of shoreline change reported in Byrnes et al. (1991). East Ship Island has an average shoreline change of roughly 4.2 m/yr and a high of 7.2 m/yr. Buffers were assigned using average change (years x 4.2) and high change (years x 7.2) during the ambient, hurricane and recovery periods. Buffers help highlight areas of targeted change levels; they do not represent all areas of change, which would, in most cases, include the entire shoreline.

Total island area changes were also computed using GPS shorelines. This technique is especially useful in describing changes on the east and west ends of the island, which are low elevation spits with higher shoreline change rates than the central forested portion of the island. The buffer technique is too sensitive to the changes on this type of environment. The boundary between the eastern and western spits and the main island was established using elevation data.

Shoreline configurations prior to 1993 were taken from National Ocean Service (NOS) T-sheets and aerial photography (Byrnes et al., 1991). The maps were digitized by the Louisiana Geological Survey. These data are less accurate than GPS survey; they have accuracies on the order of ± 10 meters (Oivanki and Yassin, 1994) and are used only to document broad historic trends spanning several tens of years.

General analysis of morphology was preformed using LIDAR data flown in November 1998 (U.S. Geological Survey et al., 1998). Horizontal accuracies are on the order of 1 meter; vertical accuracies are ±15 to 20 centimeters. For general analysis of morphology, a 10 x 10 meter grid and the minimum value within each grid was used. The minimum value in the grid was specifically chosen to reduce the effects of vegetation. Elevation values were imported into AUTOCAD MAP (AutoDesk, 1998) and 10 x 10 meter gridded surface was generated using QUICKSURF (Schreiber Instruments, 1998). A triangulated grid method was chosen based on the normal spacing of data points (Schreiber Instruments, 1998).

Areas with representative morphology and shoreline change were further analyzed with a higher density of LIDAR elevation points; for these areas 2 x 2 meter grids and surfaces were chosen. The high-density data were used to produce cross-shore profiles. These LIDAR profiles were then compared to conventional profile surveys taken with a total station in 2001. Survey benchmark locations were GPS'ed and elevations taken from the 2 x 2 meter LIDAR grid. At some locations the benchmark elevation taken from the 1998 LIDAR survey was not completely accurate for 2001. In these cases, the benchmark elevations were adjusted vertically so that measured beach face morphology was consistent with respect to its elevation. LIDAR elevations over the subaqueous portions of the profiles (below sea level) are suspect so interpretations of the bathymetry changes are limited and tenuous.

Baseline historical wind and bathymetry data were obtained from the National Data Buoy Center (NDBC) and the National Geographic Data Center (NGDC). Both data sources were internally checked for errors by the providing agencies. Bathymetric data points were taken between 1935 and present and were provided in roughly 90-meter grids (6 arc seconds). The data were then contoured using 50 x 50 m grids.

Study Data

Ship Island

East and West Ship Islands, located ten miles (16 km) offshore of Biloxi, Mississippi, are quickly evolving Gulf Coast barrier islands that still bear the scars from Hurricane Camille. Ship Island (both East and West) has experienced rapid evolution in its extent (Figure 3), especially since being breached by the 1947 Hurricane and then permanently by Camille (Schmid, 1999). In fact, Ship Island has been breached five times since 1850 (1852, 1893, 1947, 1965, and then permanently in 1969) (Nummedal et al., 1980). Beyond change brought about by natural forces, an important factor in the combined island's evolution since 1948 has been maintenance of Ship Island channel. Sediment that would form the sand platform to the west of the West Ship is lost into the channel. Subsequent dredging removes sand from the system, unless it is pumped back onto the island, as it was in the 1970's (Henry and Giles, 1975).

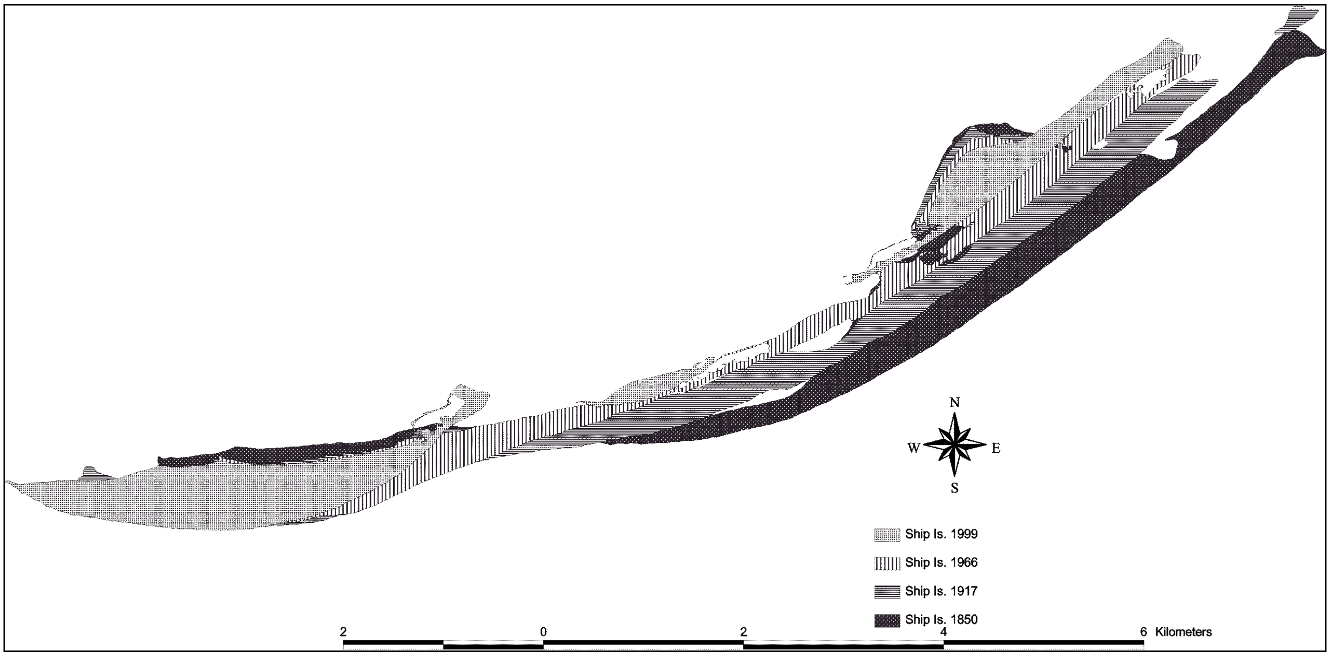


Figure 3. Historic configurations of Ship Island.

While West Ship has an historic fort – Fort Massachusetts – East Ship was the site of a quarantine station that operated until the 1930's. Both of the Ship Islands are important to the safety of the mainland as they shelter the highly developed Gulfport coastline and state port. Since Ship Island was severed, the two resulting islands seem to have evolved independently (Knowles and Rosati, 1989). West Ship Island has a higher elevation and a larger sand resource (dunes) than East Ship and is a more stable island. East Ship has experienced significant shoreline retreat (Figure 3). Neither island is moving laterally at rates comparable to Horn and Petit Bois islands.

East Ship Island

East Ship differs from West Ship, Petit Bois, and Horn Islands in that it has a central "core" with defined ridges running roughly NW – SE; the ridges are separated by low elevations, muddy peat sediments and wetland habitats. The ridges are somewhat similar to those on Cat Island, which run more east – west. These ridges are important in the evolution of the island, but difficult to explain using the longshore 'river of sand' idea; it has also been suggested that they are indicators of an earlier inlet location (Rucker and Snowden, 1990). Regardless of formation, these ridges lead to two distinctly different morphologies on the island: 1) low elevation elongated spits and 2) wooded ridges with adjacent swales typified by wetlands or coastal ponds. The ridge and swale morphology is associated with the wide portion of the island. On the north side of the island where the ridge and swale morphology was present (1850), or is currently present, there are linear subaqueous (underwater) features that are probably the continuation of the ridge sets (Figure 4).

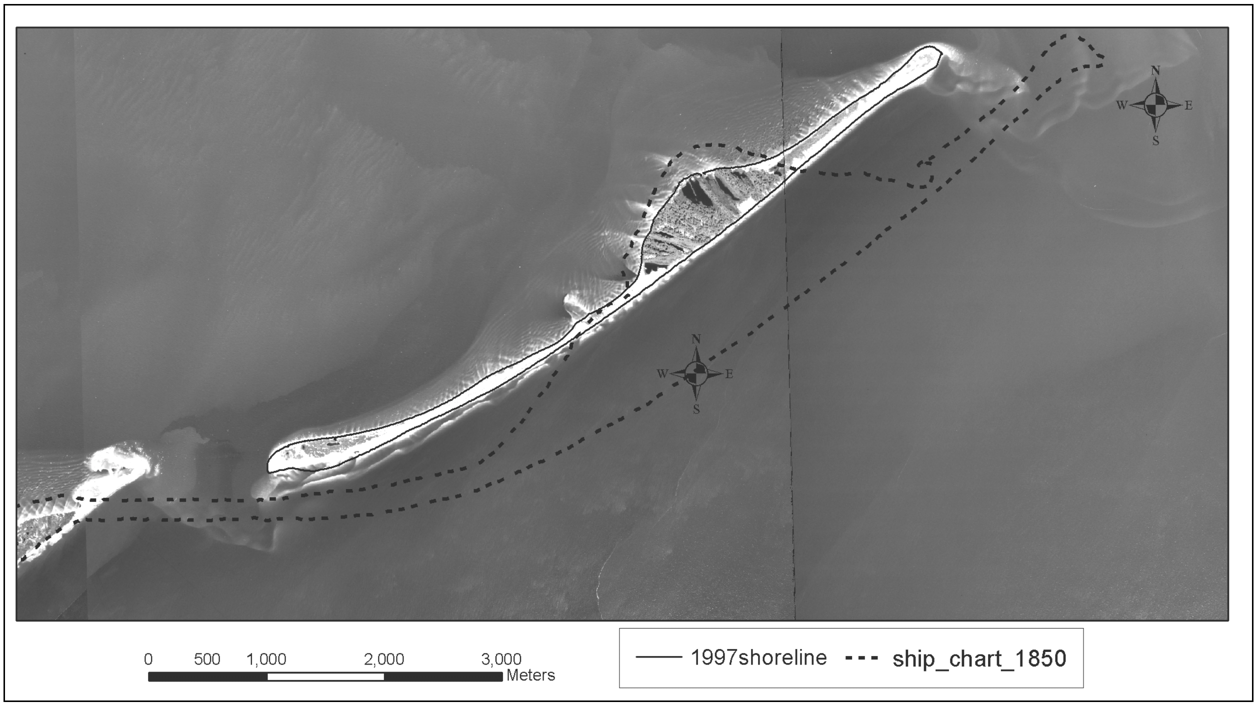


Figure 4. East Ship Island in 1997 as compared to the 1850 shoreline.

Yearly wind patterns from 1995 to July 2000 are fairly consistent (Figure 5), although the 1995-1997 and 1998-2000 windroses have a higher percentage of wind from the south to southeast than the 1997-1998 period. The shoreline of the two spits on East Ship (broken and solid lines in Figure 5) varies by about 10 to 15 degrees. The eastern spit is oriented slightly more normal to the southeast than the western spit. This orientation variation is common to West Ship and Petit Bois Islands. The northern shoreline runs northeast to southwest except the ridge and swale portion of the island, which extends outward and is affected by winds and waves from the northeast to west. As far as overall wind patterns might affect longshore drift, it would seem that during the 1995-1997 and 1998-2000 period there is more potential for east to west longshore transport on the southern shoreline than during the 1997-1998 period. On the north side, the same pattern is also observed, as a higher percentage of time the wind was blowing from the NE as opposed to the NW in the 1995-1997 and 1998-2000 periods. Average overall wind speeds during the 1995-2000 period are highest from the northeast to northwest (about 14 knots), and lowest from the south (about 10 knots).

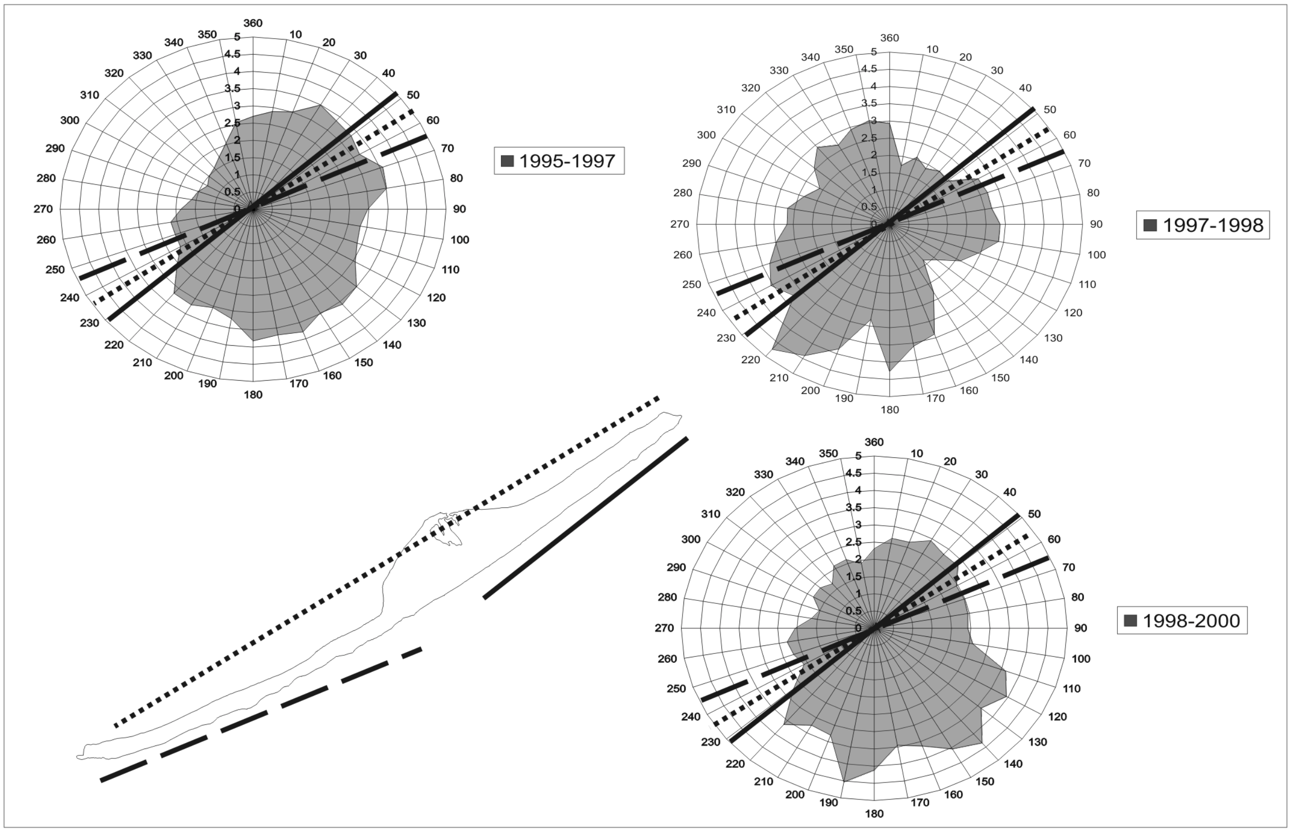


Figure 5. Wind data taken from National Data Buoy Center – buoy #42007, approximately 10 miles southwest of Ship Island. Shaded area is the percent of time the wind was from the specific direction.

The bathymetry works in tandem with the wind patterns (Figure 6) to shape the amount of energy reaching the shore. Bathymetry is both an important factor in the evolution of East Ship Island and a direct result of it. In general the contours on the south side of the island are aligned fairly uniformly, such that they parallel the shoreline, although there are some notable perturbations. The most striking is the highly shoal area to the east of the island, which is part of the Dog Key Shoal system that lies between Horn and Ship Islands. Secondary features are smaller cuspate-like variations in the –2 and –3 isobaths, which appear to be offshore continuations of beach ridge sets. To the west of the cuspates there is a wider nearshore (less than –3 m) platform. Bathymetry on the northern shoreline generally follows the shoreline pattern and is shoal in the area to the northeast of the island. Like West Ship Island (Schmid, 2001b), the northern side of the western end is deep right up to the shoreline. On West Ship Island this deep area served, historically, as a harbor.

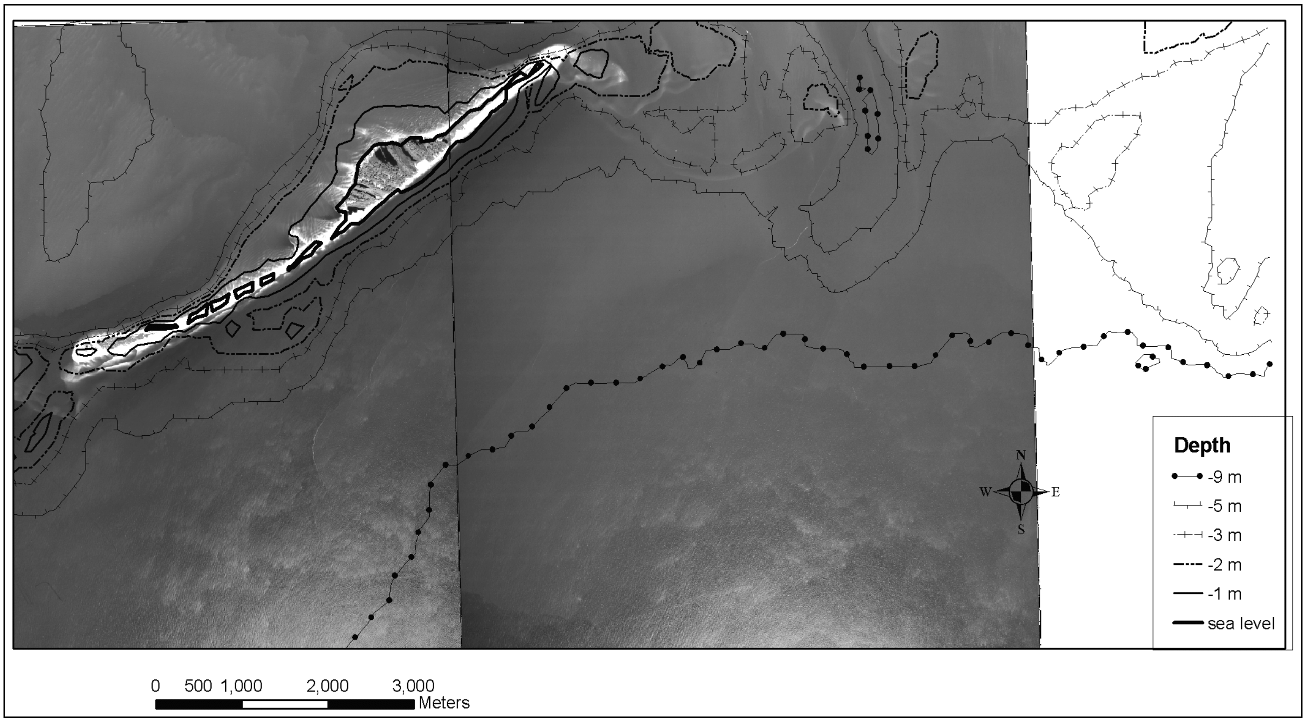


Figure 6. Bathymetric map of the East Ship Island overlaid on a digital orthophoto; the sea level contour is an outline of island location during the survey.

Shoreline Change

Historically, Ship Island (both E. and W.) has been associated primarily with rotational instability (Figure 3) as opposed to translation (Byrnes et al., 1991; McBride et al., 1995). Ship Island is the only Northeast Gulf of Mexico barrier island with this type of geomorphic classification, which was originally described by Leatherman (Leatherman et al., 1982). East Ship Island is eroding and retreating, while West Ship generally progrades toward the southwest. Ship Island's lateral movement is less than Horn and Petit Bois Island's but East Ship has more than double the rate of shoreline retreat as the eastern two islands.

East Ship Island had an average shoreline change of –4.2 m/yr between 1850 and 1986 and a 10-year high of –7.2 m/yr (1966 - 1976) (Byrnes et al., 1991). These values are significantly higher than at the other islands in Mississippi and suggest that the island is the most rapidly changing island in the barrier chain. Each of the values, average and high, were rounded up for the purpose of buffer analysis (Table 1). Buffer analysis was performed on the entire island; however, changes on the spits, especially the western one, are higher than can be documented using just buffer analysis. For the spits, change is also documented using area.

Table 1. East Ship Island shoreline inventory

Shoreline	Change (high, ave)
July, 1994	Baseline
July, 1997	22 m, 13 m
November, 1998	14 m, 7 m
July 2001	22 m, 13 m

1994-1997 GPS

Comparison of the 1994 and 1997 shorelines (Figure 7) using the average and high change buffers (Table 1) shows several basic trends. First, the vegetated end of the western spit has an overall trend towards shoreline accretion (widening) and westward movement. Second, the end of the eastern spit shows a westward movement trend, but little in the way of thinning. Third, the central portion of the southern shoreline (ridge and swale part of the island) has a pervasive erosion signature; and fourth, the northern shoreline shows little if any change, except on the ends of the spits. These general shoreline change trends appear to be associated with the morphology and westward sand transport regime, which ranges from 2,000 cubic meters per year (m^3/yr) at the eastern tip to 13,000 m^3/yr at the western end of the island (Cipriani and Stone, 2001). This range of sand transport values is the lowest for any of the Mississippi Barrier Islands.

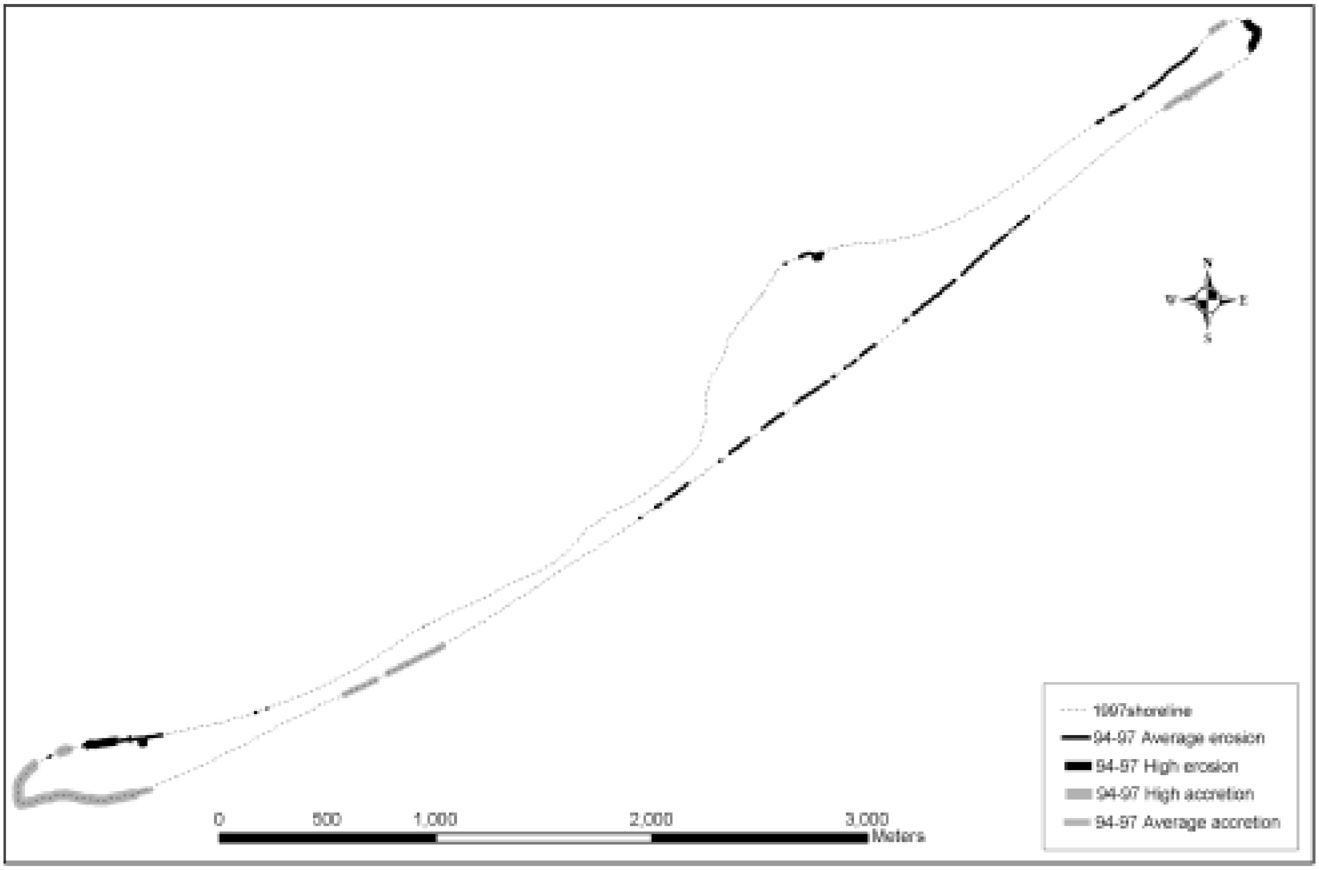


Figure 7. Shoreline change patterns during the 1994 to 1997 period.

Taken in total the island has a very moderate amount of shoreline change as compared to the long-term average values. For example only a combined (retreat + advance) 30% of the shoreline on the spit sections of the island changed at an 'average' level. Similarly, only 30% of the ridge and swale shoreline changed at average levels. The main difference between the ridge and swale and spit shorelines is the division of change. On the ridge and swale shorelines there is no shoreline advance; on the spit shorelines there is more advance than retreat, both at average and high levels. This suggests that erosion of the ridge and swale shoreline is contributing sediment to the spits during this period.

Table 2. Shoreline distances with certain levels of change for the island in meters.

1994-1997 Shorelines	total shoreline length (m)	retreat		advance	
		high	ave	high	ave
Spits	11650	375	1532	860	1826
Wooded	2715	0	798	0	0

Concomitant with the low level of shoreline change there was also only a very small change in island area (Table 3). While the west spit gained nearly 10 acres, both the east spit and ridge and swale region lost about 5 acres each. These area change trends are consistent with an overall westward migration regime. It is important to note that the ridge and swale region shows only shoreline retreat and negative area change and is, thus, operating differently than the spits.

Table 3. Island area change from 1995 to 1997.

1994-1997	1994 (sq m)	1997 (sq m)	change (sq m)	change (acre)
Total island	1286504	1287674	1170	0.3
East spit	285567	267529	-18038	-4.5
West spit	438009	477292	39283	9.7

1997 –1998 Post Georges GPS

Clearly the relative stability that the island experienced during the previous period was dramatically altered by the hurricane (Figure 8). Each of the three portions of the island, eastern spit, ridge and swale core, and western spit, behaved differently. While the ridge and swale portion of the island has a distinct morphology from the spits and would be expected to behave differently, the two spits have dramatically different shoreline change patterns even though they are similar landforms.

On the western spit high shoreline-retreat dominates as nearly ¾ of the west spit was completely overwashed and/or inundated. This is in contrast to the eastern spit, which displayed landward rollover with erosion on the south side and accretion on the north side. The difference in wave and surge heights alone should not have been large enough to create the observed responses. Moreover, the differences in elevation between the two spits before the hurricane were minimal (< 5 ft). Vegetated cover is the most notable difference between the two spits (Figure 9), and appears to have created the radical difference in response types. In fact, the 1998 shoreline following the hurricane corresponds almost perfectly to the dune line in 1997. This suggests that vegetation is an important factor in the evolution of the Mississippi Barrier Islands.

The ridge and swale portion of the island retreated during the storm period. Shoreline retreat on the gulf side is neither offset by sound side deposition nor accompanied by erosion. Morphology following the storm (Figure 20, page 40) is indicative of erosion of a non-equilibrium shoreline, such that the morphology reflects formation conditions that are out of phase with the present set. Once eroded, there is little chance that this shoreline will accrete. The northern shoreline shows that, even under high surges, the sediments and/or morphology are not prone to transport, probably because of the dense vegetation and the semi-consolidated sediments. The distinct outcomes from the different morphologies coupled with similar wave and wind conditions provides an interesting model, which will be discussed later in the text.

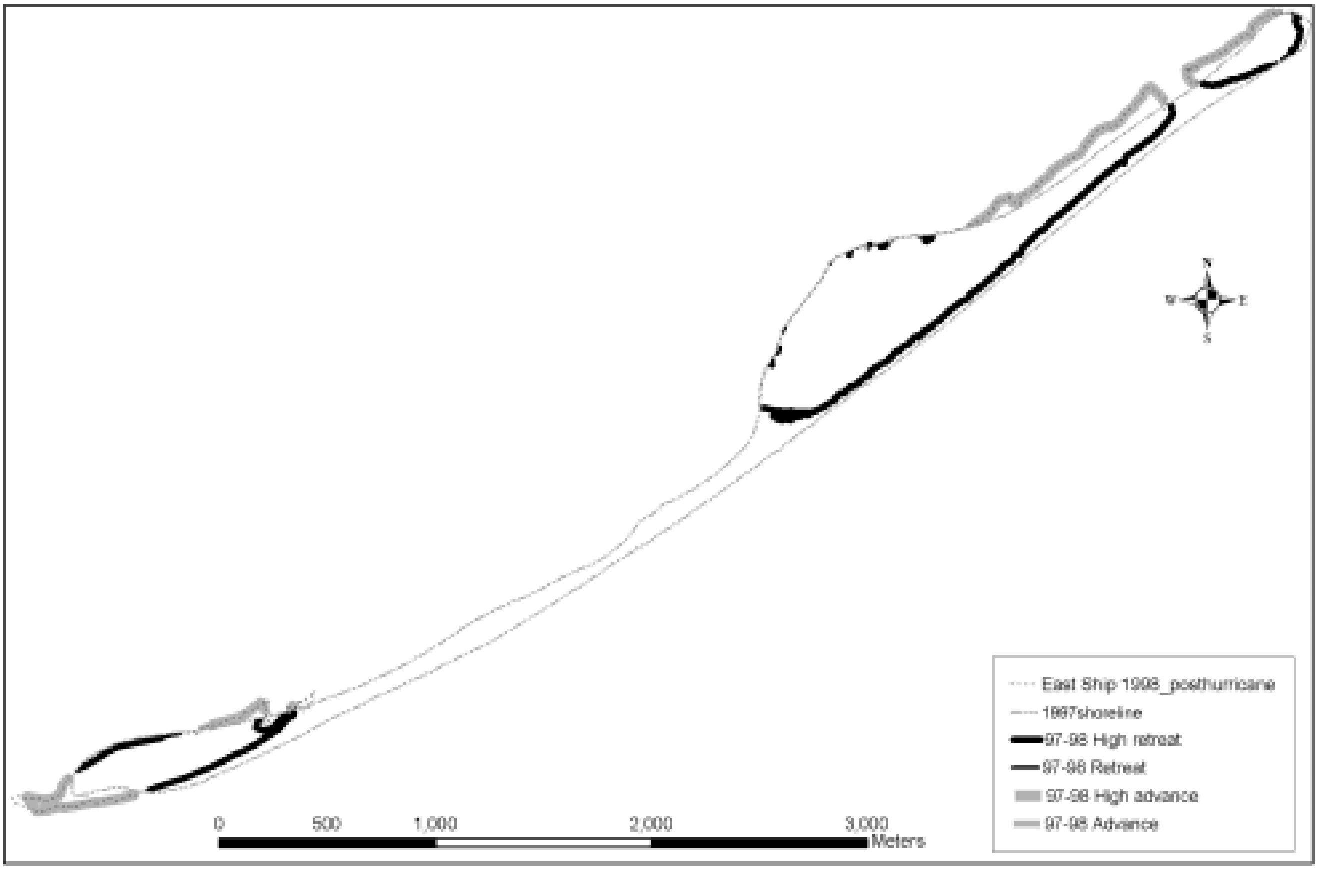


Figure 8. Shoreline change patterns during the 1997 to 1998 period; levels of change are given in Table 1.

It is somewhat difficult to analyze the degree of shoreline change using the same technique employed on the 1994-1997 period, as much of the shoreline on the western spit was completely removed during the hurricane. Shoreline segments present in 1997 and absent in 1998 are, not surprisingly, considered highly eroding segments although not highlighted (Figure 8). The dramatic difference in shoreline changes is verified by comparing the values for each morphology (Table 4) and with the 1994-1997 values (Table 2). On the western spit about 80% of the shoreline was classified as highly erosional or no longer existed. Compare this to 45% on the eastern spit. Moreover, about 50% of the eastern spit's shoreline was classified as highly advancing (toward the north). Averaging the two spits, about 70% the shoreline retreated at high levels and about 25% advanced at the same level. In contrast, 50% of the wooded shoreline retreated at high levels and only about 1% advanced at high levels. This reiterates the differences in the island's morphology.

Table 4. Shoreline distances with certain levels of change for the island in meters.

1997-1998 Shorelines	total shoreline length (m)	retreat		advance	
		high	ave	high	ave
Spits	**11993**	8100	275	2889	216
East	3640	1600	85	1758	110
West	8353	6500	190	1131	106
Wooded	**2716**	1300	186	40	68

In keeping with the dramatic shoreline retreat, the island area was reduced radically during the hurricane period. From 1997 to 1998 the island lost over 81 acres (Table 5), a dramatic change from the previous period when there was virtually no change. Of the total area lost, about 85% was lost from the western spit; loss from the eastern spit only amounted to 2%. This, like the shoreline change values, points out that slight differences, notably the vegetation, may account for the radically different responses between these two geomorphically very similar features. The ridge and swale portion of the island lost only 10.3 acres, but this loss is costly since the area is much more colonized and has a wide variety of habitats.

Aerial photographs of the island before and after the hurricane (Figures 9 and 10) highlight the changes that took place. The most impressive aspect was the conversion of the west spit to a wide sub-aqueous sand flat. Also notice the enlargement of the overwash feature on the Gulf shoreline near the eastern edge of the ridge and swale portion of the island. This area should be monitored closely as it represents a path for more overwashing events and destruction of the vegetation so important for maintaining this portion of the island. An important distinction between the east and west spits is the amount of vegetation, both before and after the hurricane. The eastern spit had a fairly robust cover of dune vegetation prior to the storm that was largely covered by sediment during the storm (Figure 10). This helped trap sand and probably kept the eastern spit from being inundated like the western spit.

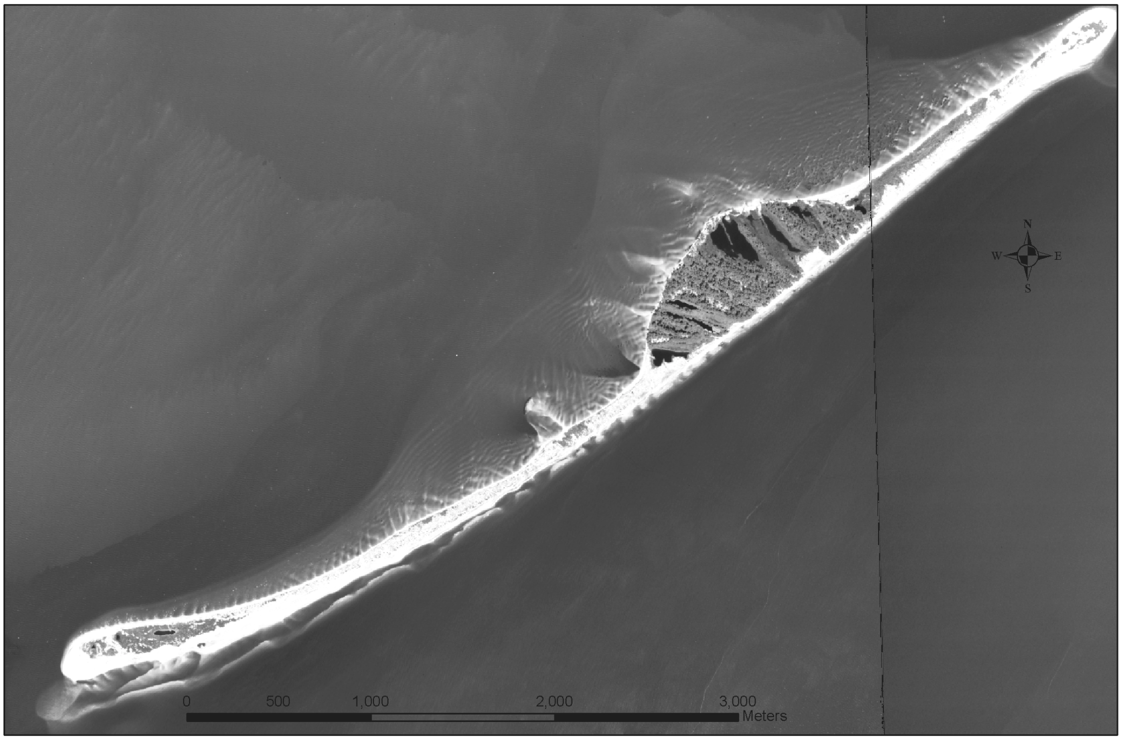


Figure 9. East Ship Island in 1997, before Hurricane Georges. (Photo courtesy of NOS)

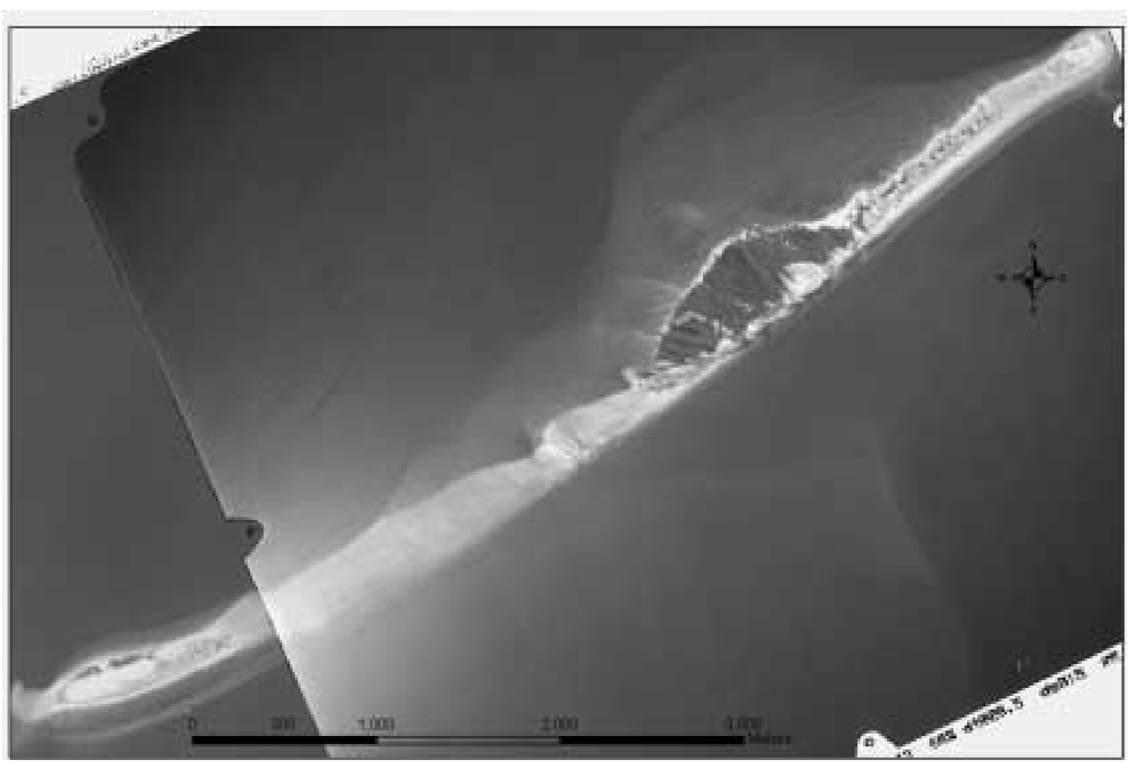


Figure 10. East Ship Island in 1998 after Hurricane Georges. (Photo courtesy of NOS)

Table 5. Island area changes from 1997 to 1998

1997-1998	1997 (sq m)	1998 (sq m)	change (sq m)	change (acre)
Total island	1287674	958144	-329530	-81.4
East spit	267529	260541	-6988	-1.7
West spit	477292	196470	-280822	-69.4

1998 Post Georges – 2001 GPS

The most interesting patterns from this period are where there has been no change. Basically, the ridge and swale portion of the island did not change since the hurricane. This is a fairly ominous pattern, given that on most barrier islands there is a significant amount of post-storm recovery. The western spit shows an extreme amount of recovery; the eastern spit returned, very nearly, to pre-hurricane position. The result of the differences in recovery is a trend towards island rotation, although in the opposite direction of West Ship Island's rotation. Once again the difference between the two genetically different morphologies is extremely evident in shoreline change patterns.

The western spit was for most of this period (1998 – 2001) segmented, such that there was an open water area between the extreme western tip and the main island. During the last survey (June, 2001) the spit had become continuous. The western spit's southern shoreline in 2001 is very nearly at the same location that its northern shoreline was in before the storm. It would appear that this is not a coincidence as this is the case for a stretch of about 2 km of uninterrupted shoreline. The present northern shoreline is controlled on the western half by deep water to the north. The northeastern portion of the shoreline is controlled to some degree by the remnants of a relict beach ridge located about 600 m from the junction between the spit and the wooded portion of the island.

The eastern spit, which showed landward rollover during the storm prograded seaward during the 1998 – 2001 period. This spit was also breached during the hurricane, but was continuous soon after (December, 1998). The location of the breach has created a kink in the spit's alignment, such that the eastern portion's axis runs more easterly than the western portion. The northern shoreline does show some retreat in localized areas that appear to have been washover fans formed during the hurricane.

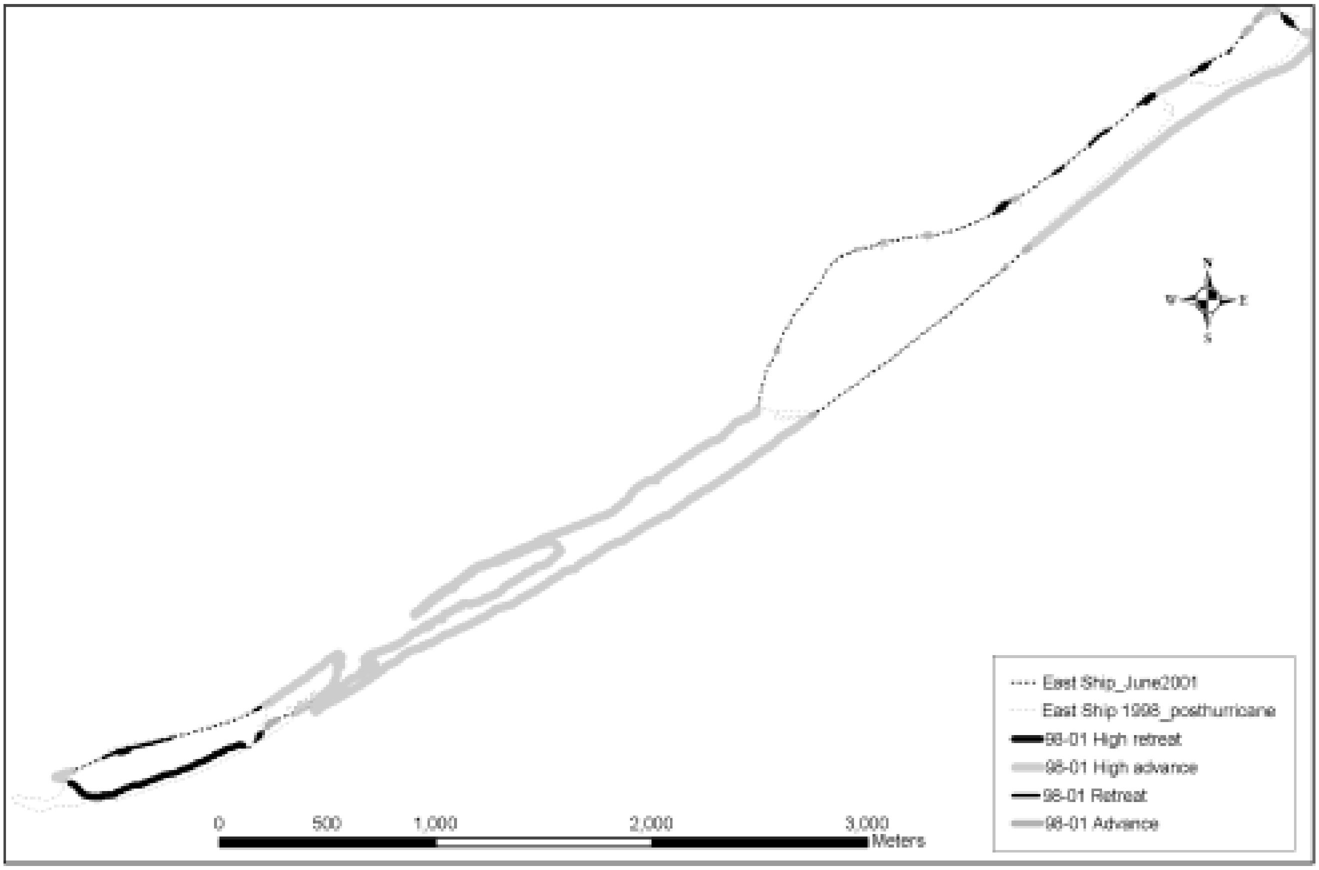


Figure 11. Shoreline changes from 1998 (after Hurricane Georges) to August 2000. Profile locations taken in 2001 are also included.

During the recovery period the western spit clearly showed the highest level of shoreline advance (80%) in conjunction with recovery of nearly the entire shoreline. Similarly, the eastern spit had about 55% of its shoreline classified as advancing. Shoreline classified as retreating on both spits was less than 15%. The ridge and swale section had only 20 m of shoreline that changed from 1998 by more than 13 m (Table 6).

Table 6. Shoreline retreat values from 1998 to 2001

1998-2001 Shorelines	total shoreline length (m)	retreat		advance	
		high	ave	high	ave
Spits	**14256**	1085	777	9994	420
East	3700	160	402	1804	270
West	10556	925	375	8190	150
Wooded	**2700**	0	0	0	20

From November 1998 to June 2001, East Ship Island gained 92 acres (Table 7), which is more than was lost during the previous period. Of the total recovery almost 80% occurred on the western spit. Both spits gained more than they lost during the hurricane period. The ridge and swale section gained less than an acre – below the resolution of the survey method. Taken in total the island actually gained area from 1997 to 2001; however, the change was largely on the low-elevation western spit that is only marginally above sea level (see following section).

Table 7. Island area change from 1998 to 2001

1998-2001	1998 (sq m)	2001 (sq m)	change (sq m)	change (acre)
Total island	958144	1329096	370952	91.7
East spit	260541	336675	76134	18.8
West spit	196470	488200	291730	72.1

A suite of shoreline surveys taken between October 1998 and June 2001 shows the rapid island recovery following the storm, followed by a gradual increase in island size. Recovery to or beyond the original island area (by 10 acres) is an unexpected outcome; neither of the western islands (West Ship or Cat) showed the same degree of recovery (Schmid, 2001a;b).

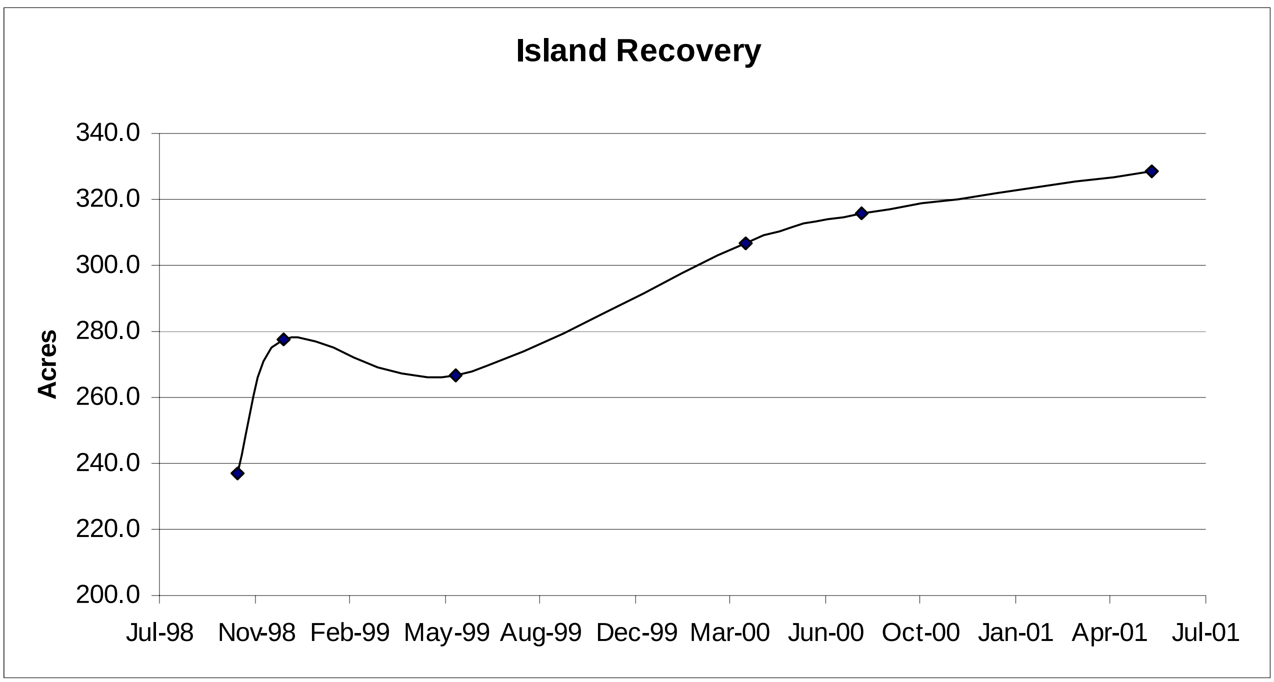


Figure 12. Island change between Hurricane Georges and June 2001.

Elevations and Profiles

Elevations

LIDAR elevation data clearly show the extent of the ridges and swales on the main island as well as the fairly robust nature of the dunes on the eastern spit (Figure 13). The island outline as depicted by the LIDAR survey in November 1998 is very nearly the same as the GPS island outline taken by the National Park Service in December 1998. The LIDAR survey accentuates the breach in the western spit, which is somewhat difficult to see in aerial photography. Note that the small breach about 2/3 of the way along the eastern spit has developed a small beach ridge on the gulf side. Similarly, a small beach ridge spit has developed on the western spit originating from the ridge and swale portion of the island.

There are no suggestions of any ebb flow features on the island. Although much of the western spit has been breached, there is no suggestion that sediment was displaced seaward. This is an interesting result, since Cat and West Ship Islands both have evidence of ebb flow features.

As East Ship is retreating landward more than translating, there is no indication of earlier beach ridge remnants preserved on the spits (unlike the central portion of the island). The only remnant of a previous shoreline on the spits is a depression (light grey color) running along the northern portion of the eastern spit that represents the location of the 1997 shoreline. It is interesting to note that formation of a beach ridge on the spit is in contrast to the typical formation mechanism, whereby sediment is added to the open coast (seaward facing) beach during island advance.

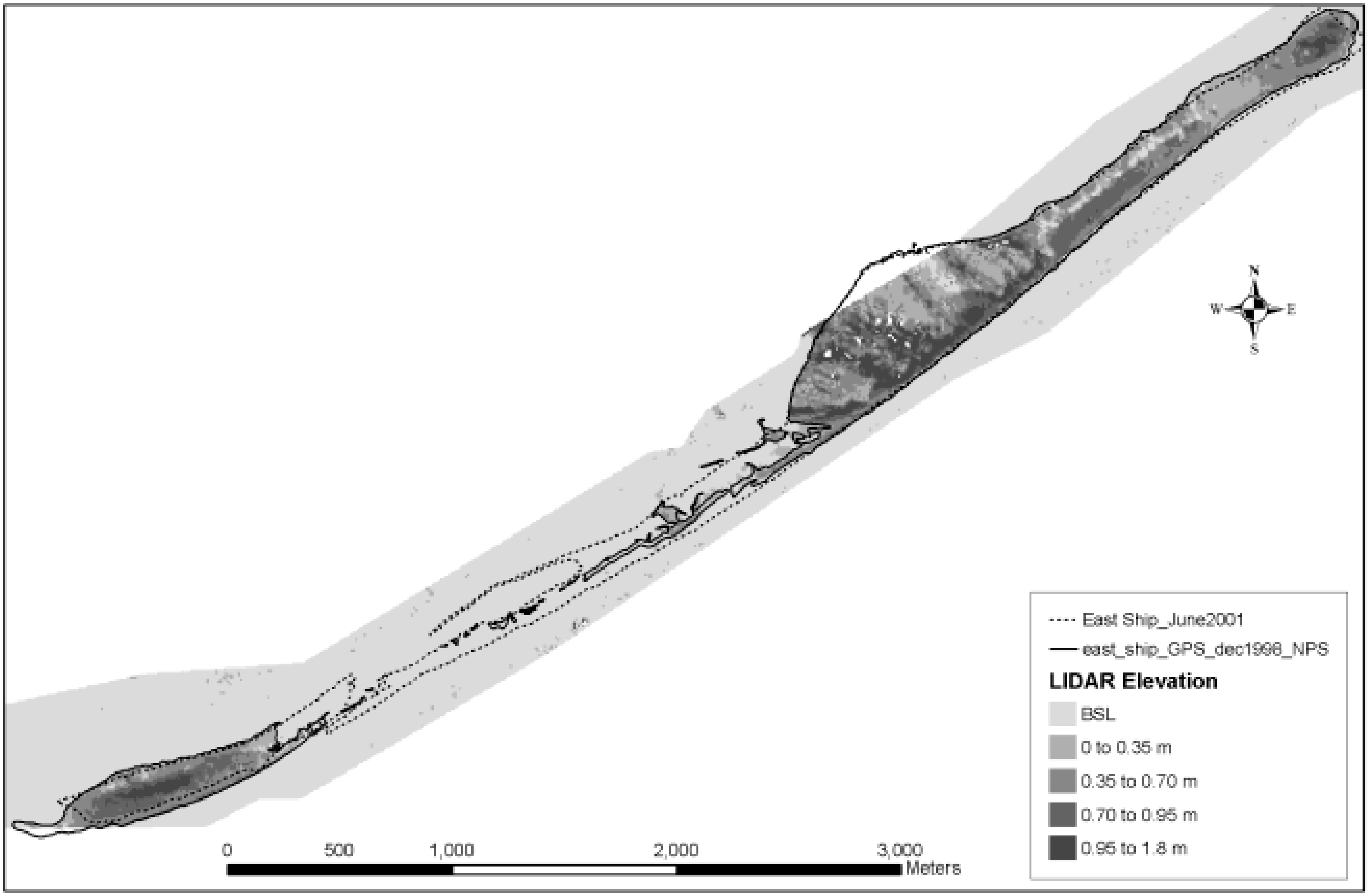


Figure 13. LIDAR elevation (m) for East Ship Island.

The extreme western end of the island (a small islet in 1998) is categorized by a central dune field running roughly parallel to the shoreline (east-west). With elevations of more than 1 m this portion of the western spit was apparently high enough to behave differently than the rest of the western spit.

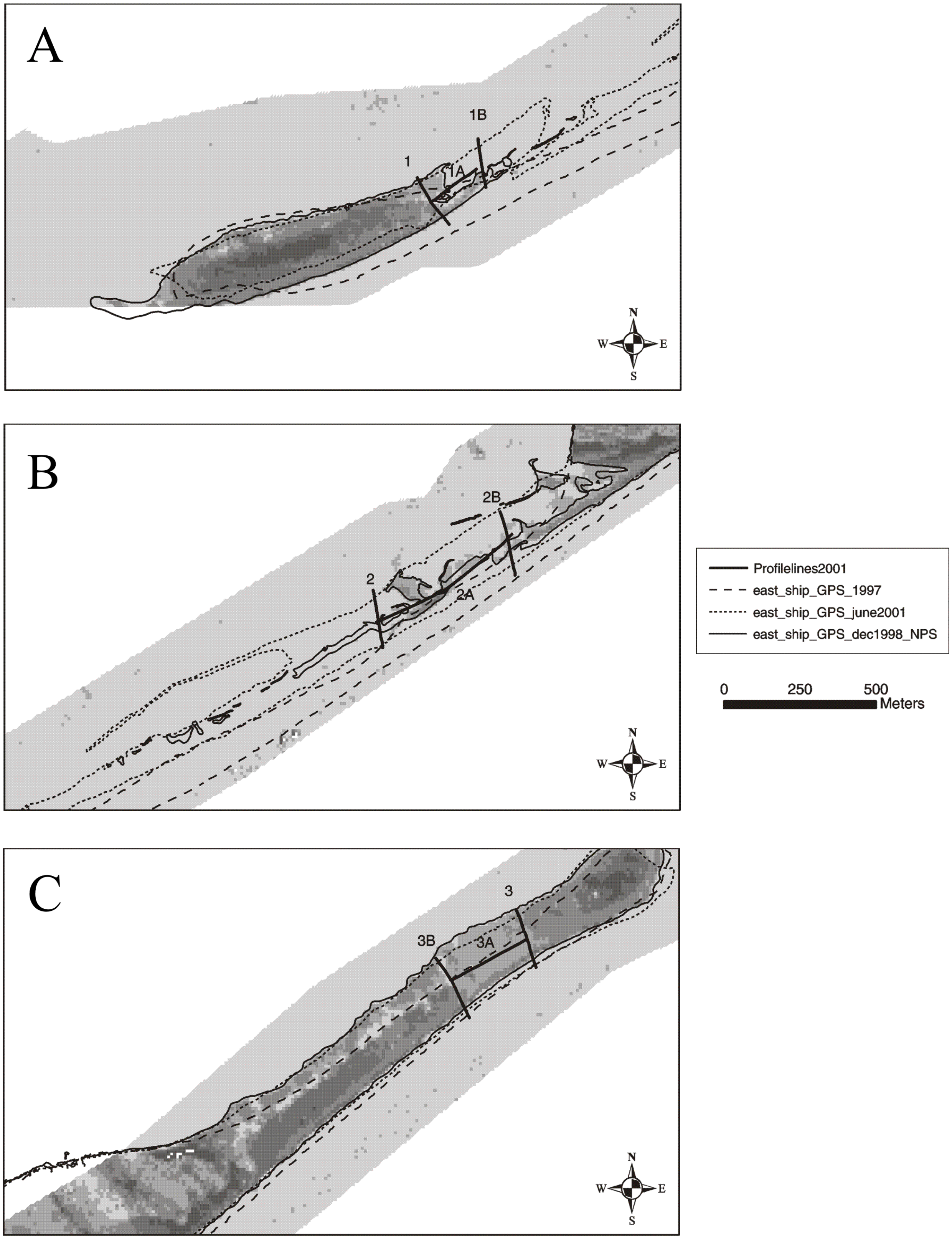
The ridge and swale portion of the island has a clear set of relict beach ridges that run NW-SE on the eastern half to nearly E-W on the western end. The remnant beach ridge at the western terminus of the island proper runs more nearly NW-SE. In addition to the well-defined beach ridges running at high angles to the present shoreline, there is an active beach ridge running parallel to the shoreline. This is the highest actively forming beach ridge on the island.

On the eastern spit there is again a well-defined large dune field that is lower than the beach ridge forming on the ridge and swale portion. Its northern edge is associated with the previous position of the shoreline (prior to the hurricane). The extreme eastern end of the island, like the western end, has a central dune core.

Profiles

Three profile groups were surveyed on East Ship Island in June 2001; each was compared to LIDAR generated profiles from data taken following Hurricane Georges. The profile groups were aligned to get two cross-shore profiles and one alongshore profile per group for a total of nine individual profiles. Two of the locations were on the western spit (Figure 14 A, B) and one was on the eastern spit (Figure 14 C).

Only changes above the zero (0) elevation (NAVD-88) were used to arrive at volume change in cubic yards per foot of beach length (island width for shore-parallel profiles) from November 1998 (LIDAR) to June 2001. In addition, changes in the southern shoreline (Gulf side) position, north shore (sound side) position, and dune heights was also computed. Cross shore profiles were taken across the entire spit out to a depth of ca. 3 ft with distances measured from north (sound side) to south (gulf side). Alongshore profiles have no shoreline change positions and distances are measured from west to east.



Figures 14A, B, C. Profile locations on East Ship Island.

Table 8. Across-shore profile changes

Profile	VolumeChange (c.yds/ft)	S. Shore Change (ft)	Dune Ht. Change (ft)	N. Shore Change (ft)
1	16.5	-81	3.9	-18
1B	4.0	-28	-0.6	121
2	27.4	72	3.0	390
2B	12.8	118	1.0	-36
3	7.2	61	-0.8	NA
3B	15.9	47	2.0	50

Table 9. Island-parallel profile changes

Profile	Volume Change (c. yds/ft)	S. Shore Change (ft)	Dune Ht. Change (ft)	N. Shore Change (ft)
1A	25.8	NA	5.2	NA
2A	11.5	NA	0.2	NA
3A	20.0	NA	1.9	NA

All profiles indicate a significant volume increase on the spits. All but the extreme western profiles also show island widening. The average for the western spit's cross shore profiles (Profiles 1, 1B, 2, 2B) is 15 cubic yds/ft of beach suggesting that a total of 174,000 (11,600 ft x 15 cubic yds/ft) cubic yards of sand have been redeposited (above 0 NAVD 88) on the western spit since the hurricane (November 1998). Similarly, the eastern spit gained an average of 11.5 cubic yds/ft of beach length, yielding an additional 65,500 cubic yards of sand. Taken in total the island gained about 240,000 cubic yards of sand between November 1998 and June 2001.

Island parallel profiles suggest that much of the gain took place on the middle portion of the island, as elevation increases and dune growth and not as island widening. This is opposite of the changes that took place on West Ship (Schmid, 2001b) where volume change was seen mostly on the active beach. It is evident that the ridge and swale portion of the island is not providing the sediment for the spits' regrowth during this period as its shoreline position (an indicative of volume change) has not varied since December 1998. This may signal a difference from the 1994-1997 period when there appeared to be potential sediment contribution by the ridge and swale region to the spits.

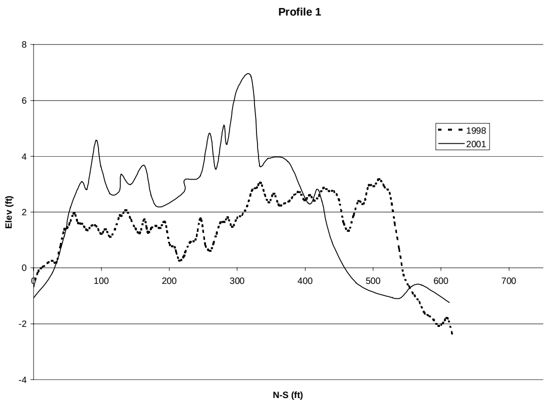


Figure 15a.

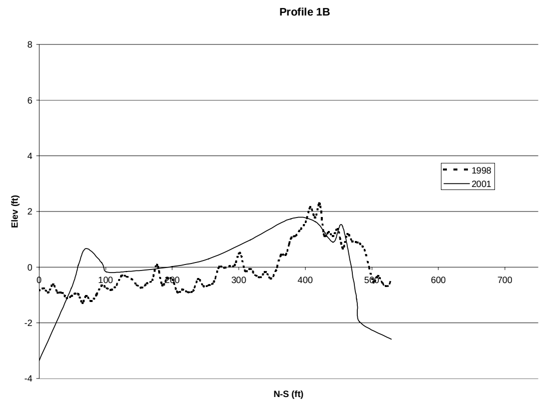


Figure 15b.

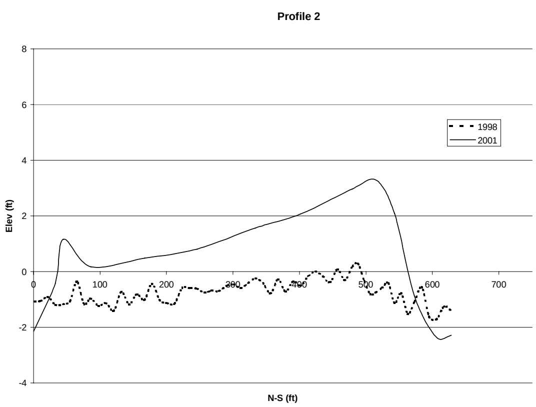


Figure 15c.

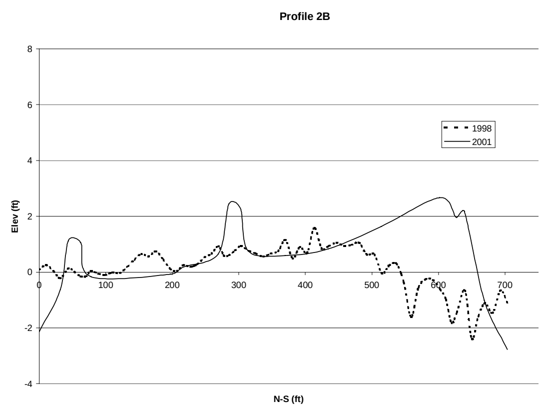


Figure 15d.

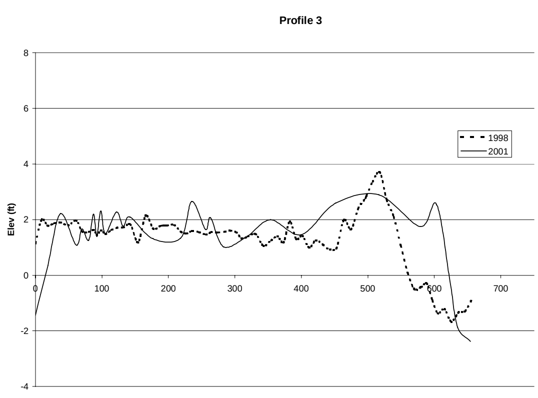


Figure 15e.

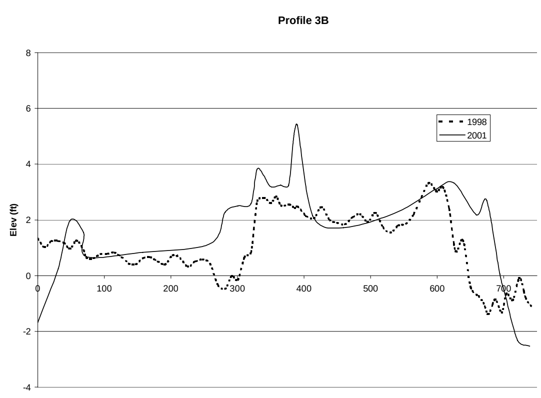


Figure 15f.

Figure 15. Cross-shore profiles on the two spits; north is on left.

The westernmost profiles (Figures 15a and 15b) had a fairly well developed beach berm following the hurricane that were the highest portions of the profiles. Although the southern shoreline has retreated (up to 81 ft), the inshore portion of the profiles has aggraded, most notably in Profile 1, where a fairly robust dune system remained after the hurricane. It is interesting to note that Profile 1's sound shoreline has remained extremely stable in the three ensuing years, suggesting that only a large storm is capable of changing this location (no gradual yearly change).

Profiles 2 and 2B are to the east of Profiles 1 and 1B. They are different in that this area was largely underwater during the LIDAR survey. Profile 2 is an example of how the spit has developed since the hurricane in the absence of remnant topology to grow upon. Profile 2B shows the same type of morphology, but has a central (small) dune that has developed on what existing morphology remained. In fact, the same shape can be seen in profile 1B, where little interior morphology remained. The growth of a dune field on these profiles is key for the spit's stability; it will be interesting to see if, where, and how quickly that occurs.

Profiles 3 and 3B (Figures 15e and 15f) are on the eastern spit, which was not completely breached during the hurricane – an important distinction. Profile 3 is the easternmost and is on the eastern side of the washover location on the spit that appears to have been active since at least the middle 1970's (Waller and Malbrough, 1976). Unlike the western spit profiles, very little change has occurred on the upland portion of the profile and there has been a measurable amount of southern shoreline advance here in the three years since the hurricane (Table 8). Profile 3B is near the western edge of the washover, but is more representative of the spit's general character. Here the upland volume (elevation) has increased, and there was advance of the southern shoreline. In both cases (Profiles 3 and 3B) the northern shoreline has retreated (Figures 15e and 15f). This regressive (seaward) shift is probably related to the prescribed (genetic) control on the shoreline angle that has remained nearly constant for the past 150 years (Figure 3).

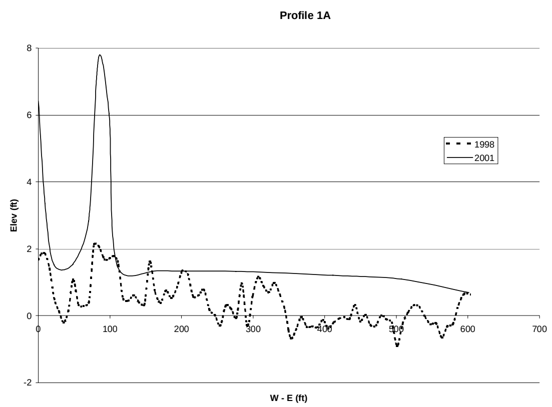


Figure 16a.

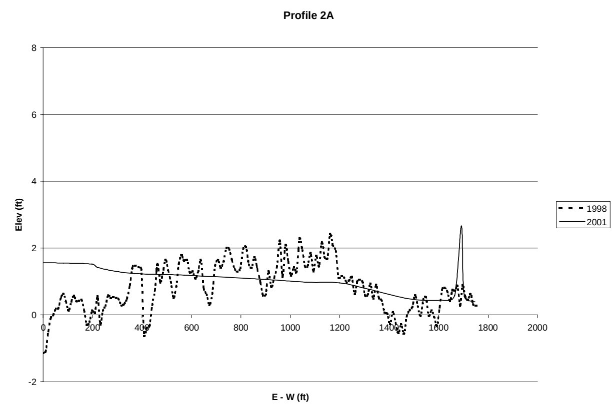


Figure 16b.

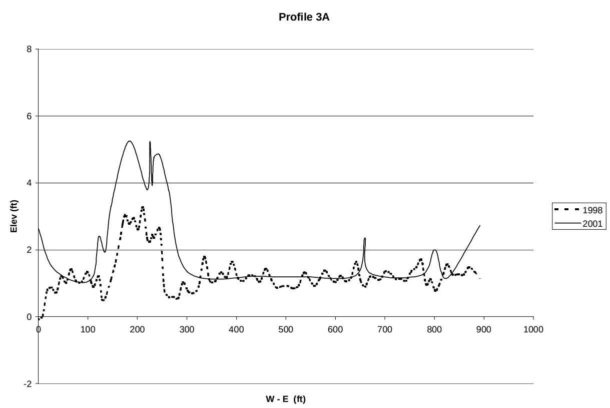


Figure 16c.

Figure 16. Transects between cross-shore profiles.

West to east transects (Figures 16a to 16c) were run between cross-shore profiles (Figures 15a to 15f). Transect 1A (Figure 16a) runs between Profile 1 and 1B and is about mid island. The most notable change is the large dune running perpendicular to the transect (about 30 ft wide) that formed from a small remnant dune. There is nearly 6 ft of aggradition at this particular location, yet the rest of the transect shows little change, even at locations with small remnant dunes. It appears that dune growth here is limited to remnant dunes with more than 1.5 ft of relief with an overall east to west increase in sediment supply.

Transect 2A (Profile 2A; Figure 16b) runs east to west (opposite of 1A and 3A) between profiles 2 and 2B; it shows very subdued elevation changes and no real dune growth. Only a small interior dune (same one as in 2B) formed on this transect that in combination with elevation decreases for much of the transect indicate a low sediment supply and/or difficult conditions for vegetation (beach grass) growth.

Transect 3A (Profile 3A; Figure 16c) runs between profiles 3 and 3B and across the washover channel on the eastern spit. Dune growth to the west of washover channel has occurred, but changes in the washover channel are minor. Like transect 2A, conditions do not seem to favor dune growth in areas totally breached. The formation of a sizeable dune suggests that there is a considerable sediment source, but that conditions in washover areas do not favor colonization of plants capable of capturing wind-blown sediments. It is possible that complete loss of rhizomes or a coarser underlying sediment texture (higher energy) makes colonization difficult and slow.

Discussion

Shoreline survey and island elevation data taken on East Ship Island between 1994 and 2001 suggest that the island's overall evolution can be separated into three phases: a stable-translational phase before the hurricane, a transgressive-translational phase during the hurricane period, and a regressive phase during the recovery period. In addition to the temporal evolution, there are three spatially controlled changes associated with the different morphological regions: spits and ridge and swale region. Additionally, the two spits behaved differently in two of the three time/change periods. Overall seven-year spatial change patterns in shoreline retreat-advance are consistent with the morphological regions; it is clear that the different morphology is controlling the island's evolution. The temporal and spatial characteristics of East Ship Island combine to create a unique barrier island among the Mississippi Barrier Islands.

Temporal Phases

To begin to analyze the island's evolution it is useful to describe the island's overall response in each of the three periods. Comparing shoreline changes on the Gulf and Sound sides of the island is one way to describe the temporal changes to the overall island, without separating out the individual morphological regions. In this analysis, the island's dominant trends reflect the sum of the individual responses of the spits and central ridge and swale portion of the island. This does not include the ends of spits; also, shorelines associated with lateral spit growth or retreat were not included. Total lateral spit change was measured from the previous island terminus to the latter terminus (total lateral movement).

Table 10. Overall shoreline change for the 1994 – 1997 pre-storm period

1994-1997	retreat (%)		advance (%)	
Shorelines	high	ave	high	ave
Gulf	0%	18%	0%	13%
Sound	3%	14%	1%	12%
Spit ends	East	-50 m	West	110 m

Table 11. Overall shoreline change for the 1997 – 1998 hurricane period

1997-1998	retreat (%)		advance (%)	
Shorelines	high	ave	high	ave
Gulf	91%	4%	0%	0%
Sound	45%	3%	32%	2%
Spit ends	East	-56 m	West	280 m

Table 12. Overall shoreline change for the 1998 – 2001 recovery period

1998-2001	retreat (%)		advance (%)	
Shorelines	high	ave	high	ave
Gulf	11%	0%	56%	10%
Sound	2%	8%	45%	2%
Spit ends	East	-45 m	West	-210 m

Between 1994 and 1997, 13% of the Gulf shoreline was classified as advancing (Table 10) and 18% was classified as retreating. Therefore, there is an overall difference of 5% retreating with 31% of the shoreline experiencing change beyond the long-term average. The same comparison on the Sound-facing shores nets a 4% retreat value (17% -13%) with 30% of the shoreline experiencing change. The island showed a fair amount of westward migration; the west end of the island grew about 35 m a year as the island’s length actually increased during this period. The small net shoreline changes (less than 5% total on each shoreline) along with the spit length changes suggest that the island was stable with westward lateral movement during the period. Area change during this period agrees with the stable behavior (Table 3).

Predictably, the island’s overall shoreline classification changed dramatically during the hurricane period (Table 11). The Gulf shoreline had a net of 95% retreating and the same value of overall change (no advance). The Sound shoreline had a more balanced net of 14% retreating, but also a high overall change of 82%. During this brief period, the island migrated rapidly to the west, and once again elongated. Area change for this period was highly negative (Table 5), as the island lost about 25% of its 1997 area during the hurricane period.

Like the hurricane period the amount of shoreline that changed was dramatically higher during the 1998 to 2001 than during the 1994-1997 period; however shoreline advance was dominant

(Table 12). The Gulf shoreline had a net of 55% advancing and an overall change of 77%. The sound shoreline, not including a small 750 m spit that developed on the sound side of western spit, had a net advance of 37% and an overall change of 57%. Because the small spit was not included the values are markedly different from the ones in Table 6. Like the previous examples, area change (Table 7) is in agreement with the highly advancing shoreline signature. One notable change during this period is the lack of westward translation; the western point actually retreated towards the east about 210 m. From 1994 to 2001 the western point of the island only moved about 160 to 180 m, yielding an overall rate of 25 m a year.

Predictably, the transgressive phase corresponds to the hurricane period (1997-1998), the stable phase corresponds to the ambient period (1994-1997), and the regressive phase corresponds to the recovery period (1998-2001). Unlike West Ship the difference between the recovery (1998-2001) and pre-hurricane periods (1994-1997) is distinct (Schmid, 2001b). Clearly the shoreline and area statistics provide a good measure of the island's behavior in qualitative terms; however, given that a consistent yearly change measure was used, it is possible to quantitatively describe morphologic changes between periods.

In terms of morphological response types (Figure 17) (McBride and Byrnes, 1995; McBride et al., 1995), calculated shoreline change percent values (Tables 10 to 12) on the Sound side and Gulf side can be used in different combinations to assign values (quantitative) for each response characteristic (landward rollover, advance, in-place narrowing, retreat, and equilibrium). For example, to describe landward rollover, the Gulf shoreline retreat and Sound shoreline advance are added and then divided by two ((% Gulf Retreat + % Sound Advance)/2); this produces a percent value from 0 to 100. In this example, 0 indicates that shoreline change is not associated with landward rollover; 100 indicates that shoreline change is completely associated with landward rollover. In addition to putting values on morphologic responses, the values can be compared between years.

Formulas for determining the morphologic response of the island are based on the total values of retreat and advance (high + average) in percent. The formulas are meant to describe as best as possible the overall shoreline response in terms of the morphologic response model adopted from McBride and others (McBride and Byrnes, 1995; McBride et al., 1995). As in the earlier descriptions of island shoreline change, 'net change' is the absolute value of the difference between retreat and advance for Gulf and Sound shorelines. Net change does not pertain to a specific morphologic response but is used in some computations.

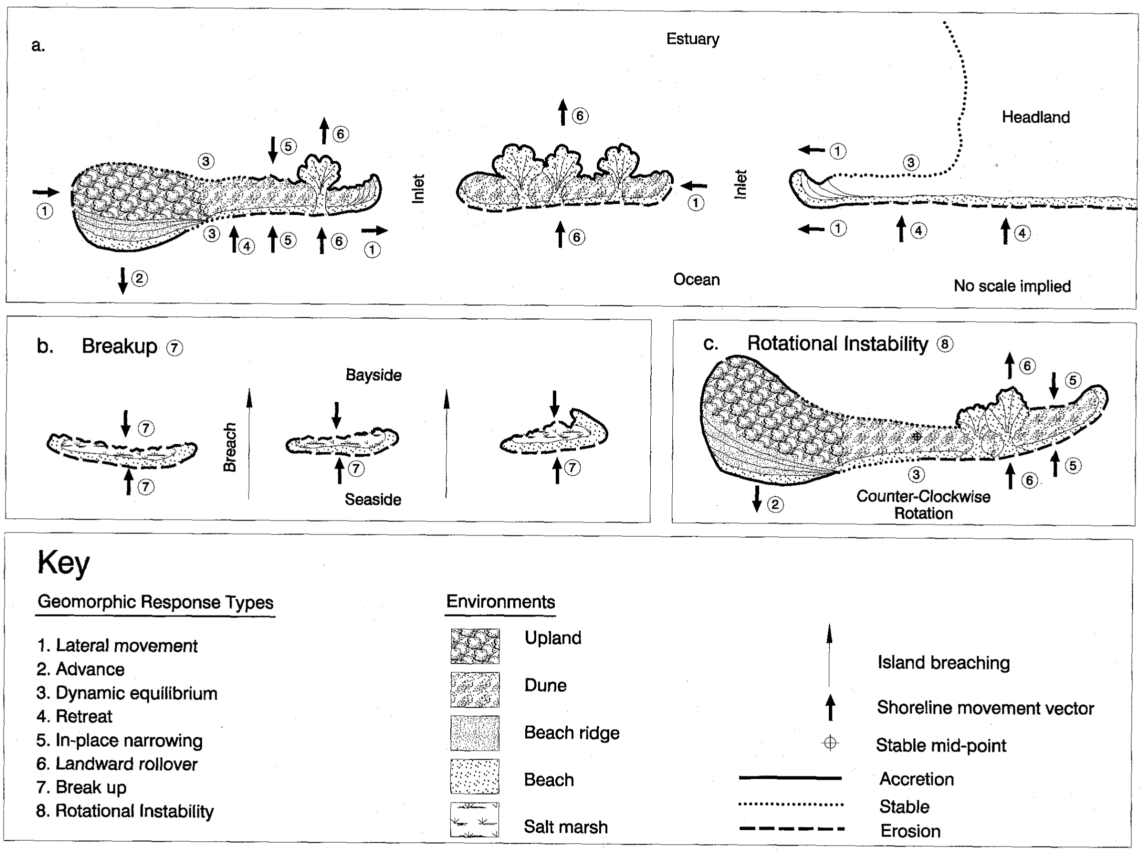


Figure 17. Geomorphic response types of McBride (taken from McBride et al., 1995).

'Landward rollover' has already been mentioned, and can be used to describe the degree of transgression. 'Equilibrium' is defined as the average of net change on the Sound and Gulf shores subtracted from 100%. The ranges are from 0% indicating total shoreline change (no equilibrium) to 100% indicating no shoreline change (equilibrium). 'Advance' is defined as the percentage of Gulf side shoreline advance minus the percentage of Gulf side shoreline retreat. The values range from -100% to 100%; -100% indicates complete retreat on the Gulf shoreline (no advance), 0% signifies equilibrium, and 100% indicates total seaward advance (regression). 'Retreat' is almost the opposite of 'advance' but also includes the behavior of the Sound shoreline (Figure 17). 'Retreat' is defined as the percentage of Gulf shoreline retreat minus the net change percentage on the Sound shoreline. Pure 'retreat' would occur if there was no change on the Sound shoreline and all of the Gulf shoreline retreated and indicates erosion of a static landmass such as a mainland beach. The range is between –100% and 100%. 'In-place narrowing' is the average of Gulf and

Sound shoreline retreat and describes the tendency of the island to be breached. The range is between 0% (no 'in-place narrowing') and 100% (breaching and breakup imminent). For East Ship Island this may be the most telling value of island response given the island's low elevations.

Table 13. Overall shoreline change for the 1986 – 1997 period.

1986-1997	retreat (%)		advance (%)	
Shorelines	high	ave	high	ave
Gulf		34%		0%
Sound		5%		0%
Spit ends	East	180 m	West	735 m

For quantitative comparison and to judge the average 'behavior' of the island, a longer-term average for the island was computed from 1986 to 1997. 1986 was chosen because it is a high-accuracy survey based on NGS data and 1997 because it was prior to Hurricane Georges. During this period (Table 13) the island experienced moderate to low amounts of change and an associated moderate to high level of equilibrium. The most notable characteristic was retreat and low advance, and it is mainly associated with the central wooded portion of the island. During this 11-year period the island lengthened about 1 km; 750 m on the west spit and 200 m on the east spit. Therefore the longer-term island behavior is associated with about 50 m/yr of westward translation (750 m-200 m /11 yrs). The shoreline advance (950 m on the Gulf shoreline and 820 m on the Sound shoreline) related to spit growth was not included in the values as they are only intended to measure cross-shore morphologic response. Shoreline advance was noticeably absent during the longer-term period.

Table 14. Response values of the island over the periods studied

Response Type	Formula	1986-1997	1994 to 1997	1997 to 1998	1998 to 2001
Total Change (Gulf or Sound)	Absolute value of Reteat % - Advance %	20% (G) 6% (S)	5% (G) 4% (S)	95% (G) 14% (S)	55% (G) 37% (S)
Equilibrium	100% - ((Gulf total change % + Sound total change %)/2)	80.5	95.5	45.5	54
Advance	Gulf Adv % - Gulf total retreat %	-34	-5	-95	55
Landward Rollover	(Sound Adv % + Gulf Ret %)/2	17	15	64.5	29
In-place Narrowing	(Gulf Ret % + Sound Ret %)/2	19.5	17.5	71.5	10.5
Retreat	Gulf Ret % - Sound total change %	29	14	81	-26
Translation/yr	+ = west, - = east	50	40	168	-40

The 1994-1997 period was very stable in comparison to the longer-term average (Table 14). The island's high equilibrium value highlights the lack of change. The average yearly translation was similar to the longer-term average. Thus, this period is a good measure of ambient change and may be described as stable with moderate in-place narrowing, retreat, and westward translation.

In direct contrast to the near-equilibrium during the previous period, 1997 to 1998 had high values for retreat, landward rollover, and in-place narrowing (Table 14). The high in-place narrowing value is indicative of the break-up and breach of the western spit. Westward translation is three times as high as the longer-term average. Using these values along with the net westward translation, this period can be broadly classified as island retreat (transgression) with in-place narrowing and rapid westward translation.

The three-year period following the hurricane can easily be described as highly regressive as the advance value clearly indicates (Table 14). It is interesting to note that landward rollover is higher than longer-term average even though retreat is significantly lower. This is associated with the regrowth of the western spit landward of its earlier location. Another major difference between this period and the two others is the eastward translation of the island, which may be related to the island's regressive response. Although this three year period shows an overall low equilibrium value (Table 14), based on the graph of area change (Figure 12), much of this can be accounted for in the first one to two years.

Morphological Regions

There are two distinct morphological regions on East Ship Island: the two spits and the ridge and swale portion. However, based on shoreline change and profiles, the two spits can also be subdivided; therefore, in this section East Ship Island has been divided into three separate morphological regions that will be compared and contrasted. The boundaries between the three regions are easily arrived at based on vegetation and island topography (Figures 13 and 18). The ridge and swale portion separates the two spits; its boundaries are based on the end of the pine tree hammocks and the start of dune grass vegetation.

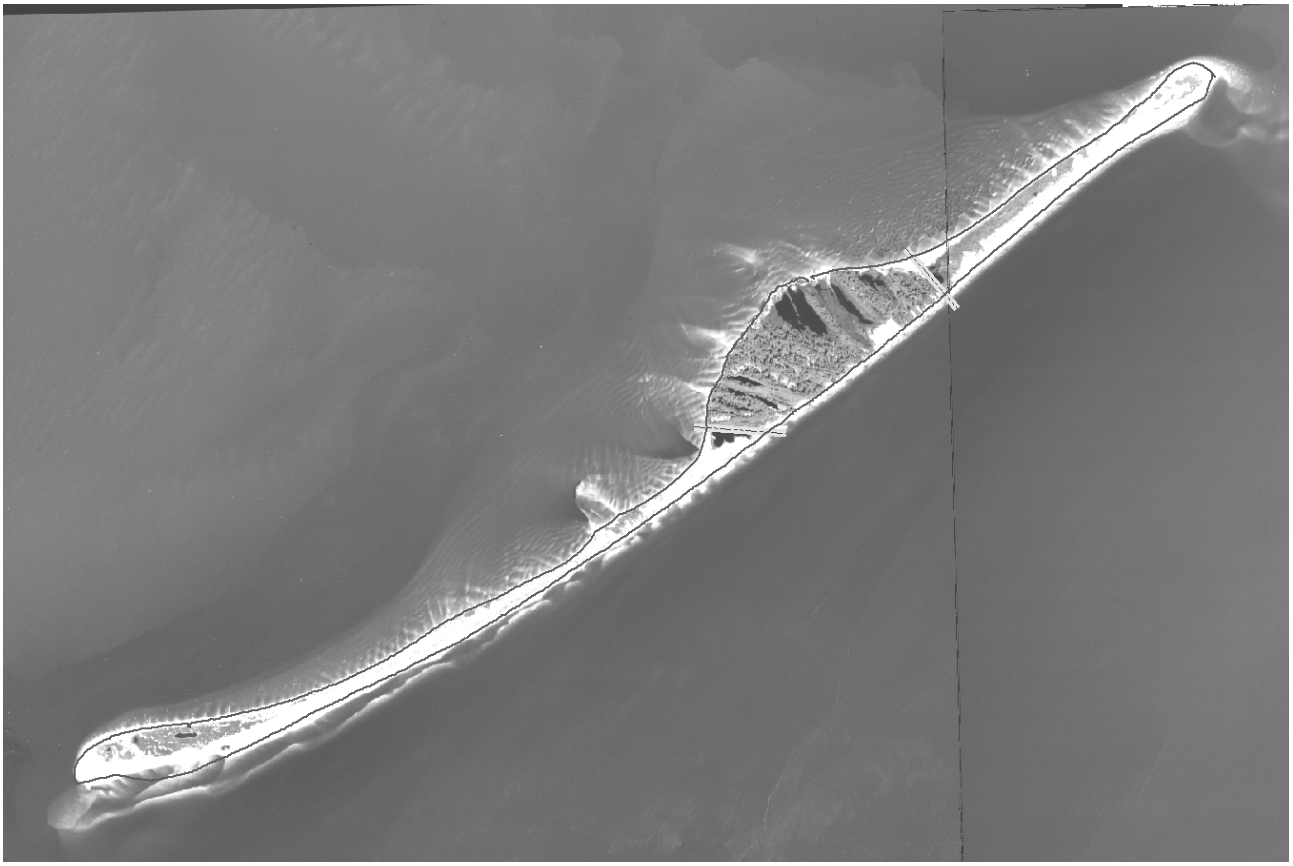


Figure 18. Geomorphic boundaries (hachured lines) based on island morphology and vegetation (1997 Color IR photo).

Ridge and Swale Region

The marked change in morphology, from spit to wooded relict ridges, is obvious whether walking on the island or viewing it from the air. The relict wooded ridges trend NW-SE and are clearly not related to the present shoreline configuration. Their linear extension can be seen both in the sound (white lineaments in Figure 18) and, although less obvious, offshore on the gulf side (Figure 6). A relict ridge is also present on the western spit, about 500 m west of the boundary between the spit and wooded ridges. Between the wooded ridges, the swales are mainly floored by mud and silts and thus wetland vegetation is common. Several inter-island ponds occupy the swales. The origin of the ridges and swales has been previously ascribed to re-curved beach ridges that formed the western end of a relict Ship Island (Otvos, 2002; Rucker and Snowden, 1989; Rucker and Snowden, 1990; Waller and Malbrough, 1976). Moreover, the exhumed peat deposits present in the swash zone have reported dates of 1205 years before present (Otvos, 1973). Given the high rates of westward translation (Tables 10 to 12) and the length of time involved, the wooded ridges cannot realistically be part of the present regime. The wooded ridge part of the island has an apparent genetic relationship with Cat Island, which has similar ridge and swale topography that is absent from present actively forming island areas (e.g. the west ends of Ship, Horn, and Petit Bois Islands).

It is obvious that this part of the island is a relict of earlier conditions; however, several questions remain. For example, why is the ridge and swale part of the island still unchanged by present conditions, what was its original configuration, and did it evolve under conditions different from the present? Based on core data analyzed by Otvos (Otvos, 1986) on and around East Ship Island, the the central portion of the wooded ridge area is underlain by approximately 27 feet of oxidized sandy (subaerial) sediment above nearshore (fine sand) and lagoonal (muddy) sediments (total Holocene = 48 feet). On the western and eastern flanks of the wooded ridge area the amount of subaerial sediment decreases to 5 and 17 feet respectively. Based on this evidence, the ridge and swale region has been in its present location for a significant portion of the Holocene.

Given the longevity of the ridge and swale portion of the island, it is logical to examine the Pleistocene surface and its make-up. Once again these data come from cores interpreted by Otvos (Otvos, 1986). There were 17 vibracores and rotary cores taken on or near East and West Ship Islands (Figure 19; cores MV 92 and 73 were not used). The Pleistocene surface generally dips to the west, with what appears to be a ridge running more or less parallel to the island. The Pleistocene geology in the eastern section, which also has the highest Pleistocene elevations (greater than -35 feet MSL) is composed of the Prairie Formation (Otvos, 1985), which are alluvial/fluvial muds and sands. At the lower elevations (below –35 ft), the Pleistocene surface is composed of the Biloxi Formation, which is nearshore to shallow marine mud with some sandy intervals. Given the interpreted Pleistocene surface and the earliest available island location (1850), there does seem to be a relationship between the island and the framework units. It is possible that the “Ancestral Ship Island” formed just seaward of the higher Prairie framework to the north and east.

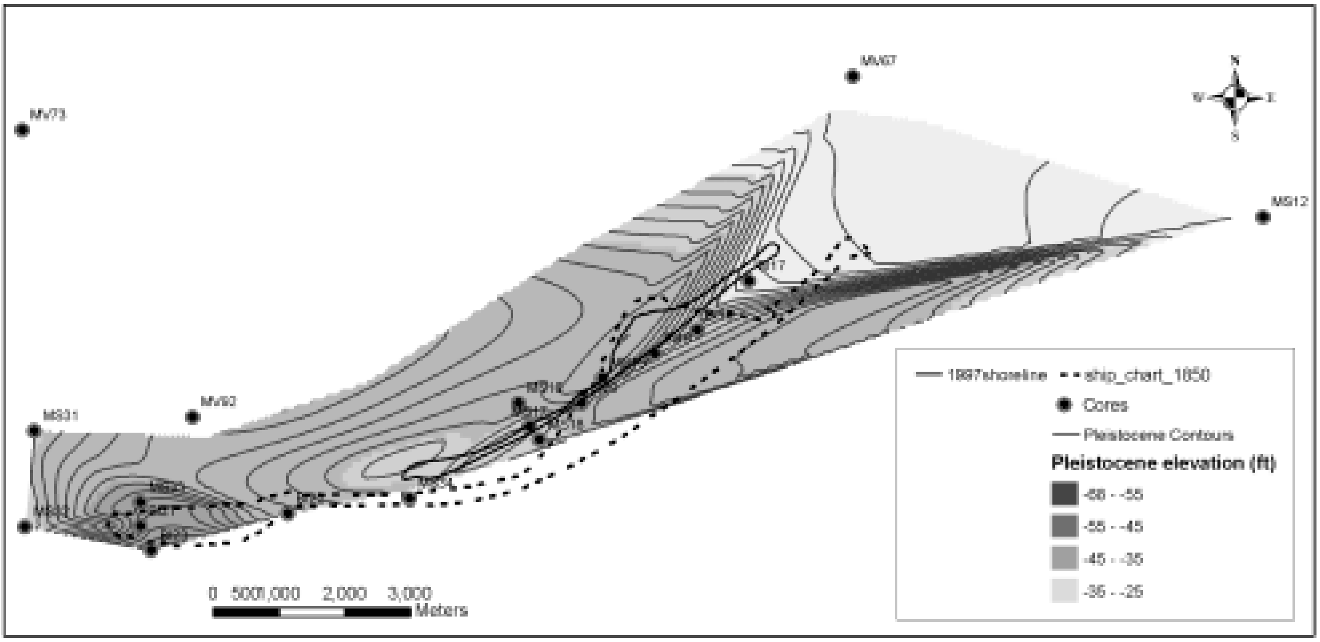


Figure 19. Shaded Pleistocene surface with contours.

Spits

Unlike the ridge and swale portion of the island, formation and evolution of the spits are directly related to the present physical processes. As such they are also indicators of these processes. The two spits behave differently, but share the same basic morphology. They differ in the amount of vegetation and dune prominence. As is evidenced in the infrared orthophoto (Figure 18), the eastern spit has a well developed grass and shrub community (gray); the western spit has only patchy cover, except for the extreme western tip. As a result or as a cause the eastern spit is significantly wider (about 50 to 60 m wider on average) than the western spit, even in areas with similarly wide sound-side nearshore platforms. Moreover, it appears that sea grasses are now (1997) only evident on the sound side of the eastern spit.

The differences raises several obvious questions: why are the spits different widths, especially given the dominant longshore drift direction, which would tend to favor the western spit in terms of sediment supply; why is the central part of the western spit so thin given the broader platform it is backed by; and why does the end of the western spit have more vegetation than the main part of the spit. Typically some of these answers can be connected to shoreline configuration; however, in this case the differences in shoreline configuration between the two spits are minimal (Figure 5, pg 10). This leaves sediment supply, sediment transport, and underlying geology as possible factors.

The dominant sediment supply is from the east (Waller and Malbrough, 1976) across Dog Key Shoals, which separates Ship and Horn Islands. Unlike the other island inlets (Horn and Ship), Dog Key Shoals has not been dredged and thus does not act as a sink (Cipriani and Stone, 2001). The shoals in turn overlie the higher elevation Prairie Formation. Other potential sources of sediment are the wooded ridges (Ancestral Ship Island), which given the dominant longshore direction would mainly feed the western spit, and onshore movement of sediment from offshore. An offshore source of sediment has been suggested to explain the increase in grain size and sorting coefficients from east to west along the Mississippi Barrier Islands (Cipriani and Stone, 2001).

The main loss of sediment based on longshore transport estimates (Cipriani and Stone, 2001) is from the western tip across Camille Cut to West Ship Island. It should be noted, however, that the rate of longshore transport on East Ship is about 1/3 of the other islands in the chain. Unique to Mississippi Barrier Islands, East Ship probably has a higher loss of sediment toward the Mississippi Sound (landward rollover). This process was exemplified by breaching of the spits during Hurricane Georges.

Once the sediment has passed from the shoals to the island or from the central wooded ridge portion of the island to the spits, the dominant westward longshore drift moves the sediment towards the western spit. Of course in some wave climates, south and southwesterly winds and waves (Figure 5), sediment is moved from the eastern spit to the shoals. Dog Key Shoals (ebb shoal) projects several kilometers (4 km for the 5 m isobath) seaward of East Ship Island (Figure 6) and provides, along with a sediment source, some measure of protection from waves out of the east and southeast (Cipriani and Stone, 2001). Refraction of the dominant southeast waves probably plays a part in creating a slightly more onshore sediment transport on the eastern spit as compared to the western spit (Cipriani and Stone, 2001). This interaction with Dog Key Shoals may account for some of the width difference of the two spits.

The influence of the Pleistocene framework may have some influence on the relative stability of the two spits. These findings are open to interpretation; however, there is a level of structure and a change in geology below the island (Figure 19), that to ignore would be an oversight. First and most obvious is the formation of Dog Key Shoals atop the higher elevation Prairie Formation. At the reported depths in the tidal channels, 33 feet (Rucker and Snowden, 1988), they would be within the Pleistocene and therefore, in this case, the interaction between the Holocene and Pleistocene is obvious. It may be suggested that the channels have an element of incision and are somewhat constricted in terms of westward migration.

At the present location of the island, the eastern spit is underlain by the shallower Prairie Formation. The rest of the island is underlain by a thicker Holocene package, a deeper Pleistocene elevation, and the Biloxi Formation. It also appears that there might be a small structural high near the western tip of the island (Figure 19). The relationship of the Pleistocene geology and surface elevation to the evolution and morphology of the spits warrants more investigation (as well as with the other islands in the chain).

Ground-water interaction is an interesting example of the potential effects from the different Pleistocene/Holocene arrangements. If there is ground-water interaction between the Pleistocene and the Holocene the thickness of the surface aquifer will vary. For example, the sandier Prairie Formation coupled with the overlying sandy Holocene would make a thicker surface aquifer than the muddier Biloxi Formation coupled with the overlying Holocene. This same principle would apply to the thickness of the Holocene itself in areas underlain by an aquiclude (low permeability sediments). In coastal aquifers where saltwater-freshwater interactions are occuring, the thickness of the surface freshwater lens (aquifer) and the density difference between the fresh and salt water are important factors because the fresh ground water ‘floats’ on the salt or brackish water (Heath, 1983). A thick lens (aquifer) of fresh water will have a higher elevation water table than a thin lens (aquifer). Moreover, a sandier (better) aquifer will have a higher water table than a poor (muddier) one. Given that there is a difference in the subsurface geology between the two spits, these ground-water processes may be responsible for some of the differences in vegetation.

Taking this a step further, it is possible that the robust vegetation on the eastern spit is somehow connected to a source of vertically moving ground water from the underlying formation(s). At the previous location of Isle of Caprice in the middle of Dog Keys Shoals (1917 shoreline on Figure 3, pg 8), there was an artesian well that survived after the island had been overwashed and converted to a shoal. This well tapped the Pliocene Graham Ferry Formation. Until it finally rusted away, the well flowed fresh water that fishermen used to replenish their supply (Powell, 1998; Rucker and Snowden, 1988). Given that the potentiometric surface of the formation used is or was several feet above sea level there may have been some subaqueous springs or leaky zones in areas overlying the formation. Leaky zones are more likely in the sandier Prairie Formation than in the muddier Biloxi Formation.

How the different factors, sediment supply, sediment transport, and framework geology, interact to create the different spit behavior is complex and further directed investigation is needed. The possible scenarios presented suggest that answers can be forthcoming and that longshore drift as an explanation in and of itself will leave the work unfinished. It is proposed that the interplay of the shoals and underlying geology/framework is largely responsible for the present spit configuration/behavior and that the Ancestral Ship Island is a relict feature that was created under a different set of conditions.

Morphological Regions and Shoreline Change – Qualitative Differences

East Ship Island's shoreline change over the seven year study period (1994 to 2001) is consistent with the morphological regions as determined from LIDAR generated topography, NGDC bathymetric data, and the Pleistocene framework. The most dramatic differences took place during the hurricane period (1997-1998) and recovery period (1998-2001) and as such will be highlighted below.

The most striking difference in shoreline change is between the spits and the relict Ancestral Ship Island (ridge and swale) shorelines. During the hurricane period the entire gulf shoreline of the ridge and swale portion and spits retreated at high rates (Figure 8). During the following period, however, there was no shoreline advance on the ridge and swale section (Figure 11) but the spits showed high levels of shoreline advance. Area changes reflect this difference; the spits regained all of the area lost during the hurricane period (Tables 5 and 7) while the ridge and swale portion regained only a small fraction of what was lost during the hurricane. It appears that the shoreface morphology created when the relict ridge and swale shoreline is eroded (Figure 20) does not favor sediment deposition. When the semi-indurated muddy sediments are exposed they can form steep to scarped shorelines that are highly reflective and do not promote sediment deposition.

Figure 20. Southwestern end of the wooded ridge section of East Ship Island looking east, picture taken in January 1999.

The spit shorelines had higher shoreline retreat than the ridge and swale shoreline during the hurricane period but had high levels of shoreline advance in the following period. The degree to which the spit shorelines advanced does appear to be related to the shoreline position of the ridge and swale shoreline. For example the spit shorelines do not extend beyond the wooded shorelines at the location where they intersect; they are effectively anchored by the ridge and swale shoreline. Shorelines on the spits (Figure 15) do not have the same type of highly reflective morphology as the ridge and swale portion of the island. This is a function of their evolution during the present day conditions.

Morphological Regions and Shoreline Change – Quantitative Differences

Like the whole-island analysis the shoreline behavior on the separate morphological regions can be described quantitatively. This highlights the differences between the two spits as well as the wooded ridge portion. The same equations used to describe the geomorphic response types in the earlier section were also used for this analysis.

During the hurricane period (1997-1998) all of the shorelines had low equilibrium and low advance values (Table 15) as expected. The landward rollover, in-place narrowing, and retreat responses are more telling of the individual regions. Landward rollover values on the ridge and swale and west spit regions were nearly identical; likewise, the values of in-place narrowing were similar for the ridge and swale and east spit regions, and the retreat values were similar for both spits (Table 15). From this analysis it is evident that during storm conditions the ridge and swale section is associated with a high retreat response, which is typical of a non-dynamic landform. The spits, on the other hand are associated with dynamic responses. East Spit is prone towards landward rollover; West Spit is associated with in-place narrowing, which ultimately leads to break-up (Figure 17).

Table 15. Hurricane response values for the three morphological regions

Hurricane Response Type	Formula	Ridge & Swale	E. Spit	W. Spit
Total Change (Gulf or Sound)	Absolute value of Reteat % - Advance %	100% (G) 12% (S)	98% (G) 84% (S)	84% (G) 76% (S)
Equilibrium	100% - ((Gulf total change % + Sound total change %)/2)	44	9	20
Advance	Gulf Adv % - Gulf total retreat %	-100	-98	-84
Landward Rollover	(Sound Adv % + Gulf Ret %)/2	53	95	52
In-place Narrowing	(Gulf Ret % + Sound Ret %)/2	59	53	90
Retreat	Gulf Ret % - Sound total change %	88	14	16
Translation/yr	+ = west, - = east	NA	+ 56	+ 221

During the recovery period (1998-2001) the shorelines displayed different equilibrium values, but similarly low in-place narrowing values. During this period the ridge and swale section showed high equilibrium, which further indicates that little recovery can be expected on this part of the island in future storm events. Like the ridge and swale section, East Spit is fairly well defined by one response, advance, during this period. This dynamic response is indicative of a healthy sediment budget and suggests that this spit is quite stable. West Spit is less defined by a single response during recovery, although it has the same equilibrium value as East Spit. In particular, the high landward rollover value may be a result of a lower sediment budget and/or a permanent change in the nearshore bathymetry caused by the storm.

Table 16. Recovery response values for the three morphological regions

Recovery Response Type	Formula	Ridge & Swale	E. Spit	W. Spit
Total Change (Gulf or Sound)	Absolute value of Reteat % - Advance %	0% (G) 2% (S)	95% (G) 11% (S)	49% (G) 58% (S)
Equilibrium	100% - ((Gulf total change % + Sound total change %)/2)	99	47	47
Advance	Gulf Adv % - Gulf total retreat %	0	95	49
Landward Rollover	(Sound Adv % + Gulf Ret %)/2	1	8	40
In-place Narrowing	(Gulf Ret % + Sound Ret %)/2	0	14	16
Retreat	Gulf Ret % - Sound total change %	-2	-11	-36
Translation/yr	+ = west, - = east	NA	-15	-70

From this analysis of shoreline evolution it is clear that the three regions of the island behaved differently during the hurricane and also in recovery. The result is expected for the ridge and swale section as it clearly has different morphology and historical evolution. What is more surprising are the differing responses of the spits given their similar morphologic lineage.

Recent work by Sallenger (Sallenger, 2000) has delineated several storm-impact regimes on barrier islands based on dune elevations, wave heights, and water levels (storm surge). Based on the western spit’s complete breach during the storm, the western spit experienced the inundation regime, which occurs when the average water level is higher than the dune or island elevation (i.e. the island is below water level). The eastern spit’s dominant landward rollover suggests that it experienced the overwash regime, which is when waves exceed the dune or highest elevation, but the average water elevation does not. No wave measurements were made on Ship Island during Hurricane Georges, although the wave heights and water levels on the two spits were probably similar; the recorded wave heights 10 miles south of the island were 15-20 ft before the buoy (42007) malfunctioned. Based on the differences in response, it is likely that the higher dune elevation and cohesion afforded by the dune vegetation created the dissimilar outcomes. This suggests that it is a self-repeating process as dune growth is limited if dune vegetation (sea oats, bitter panicum) is not present to stabilize the sediment. Regrowth of beach grass is much slower if no parent plants are present and sea oats naturally spread slowly so that island sections completely breached (inundation regime) are more prone to inundation in future storms. Dune grass planting on West Spit should be examined to extend the lifespan of the island.

Conclusion

East Ship Island has a combination of relict and dynamic morphology; the central core of the island is a remnant of an earlier island and/or a product of a different physical regime. Island change is controlled by and is a result of the different morphologies. Overall area change during the seven-year period was much higher than neighboring West Ship, both during Hurricane Georges and in the recovery period. However, the present location and size of East Ship Island is very nearly the same as in 1997, prior to the hurricane. The long, low-elevation spits are prone to high shoreline and area change during storms and to fairly rapid recovery to pre-storm levels. The ridge and swale section of the island (central core) has higher elevations, forested ridges, and wetland/lake habitats in the swales. It is not a dynamic feature and any area lost during storms does not appear to recover during the ensuing years. It anchors the two spits, such that the lifespan of the island is dependent on its presence. Overall, East Ship Island, controlled to a large degree by the ridge and swale section, is retreating landward.

Findings and suggestions for future studies based on the data collected include:

- Yearly and semi-yearly GPS surveys are a simple and economical way to study island evolution in temporally short periods with high accuracy. Given the long-term average shoreline change rate for East Ship (4.2 m/y), the accuracy of the technique is useful for year to year shoreline position comparisons. Area comparisons can probably be done at six-month intervals. Storm related changes are well within the technique's accuracy.
- East Ship Island shows different morphological responses through the seven-year period. During the ambient – pre-hurricane period the island exhibits a high degree of equilibrium, with slight rollover and in-place narrowing. During the hurricane period the island exhibits highly transgressive (retreat) behavior with in-place narrowing, retreat, and westward translation. Following the hurricane the island shows high change with shoreline advance and eastward translation and may be considered a regressive phase. Like most barrier islands, storms appear to be the driving force on East Ship Island's evolution, and may in this case be considered a natural progression rather than erosion, as the island shows a strong tendency to recover.
- East Ship has several morphological regions that correspond with unique shoreline and area change characteristics. The ridge and swale section of the island is a non-dynamic,

relict landform that is a remnant of earlier conditions. This part of the island is dominantly eroding, with little if any recovery following storms. The two spits are separated by the ridge and swale core of the island and are dynamic landforms that advance and retreat with the changing conditions. The difference between the east and west spits is more dramatic than may be expected. The eastern spit is more stable and has more pronounced dunes and dune vegetation. The western spit had little vegetation before the storm and was nearly devoid of vegetation following the storm. The level of vegetated dunes is both a result and cause of the difference in shoreline/area changes between the spits.

- Important factors in the island's evolution are Dog Key Shoals and the depth and type of underlying Pleistocene units. Dog Key Shoals appears to protect and feed the eastern spit, making it more stable than may be expected given the island's dominant westward migration trend. The Pleistocene surface mapped from previously taken cores suggests that the formation of the 'Ancestral Ship Island', which is represented by the central wooded section of the island, is associated with the edge of the higher elevation Prairie Formation. Moreover, the more stable eastern spit along with Dog Key Shoals overlie the Prairie Formation, but the less stable western spit overlies thick sequence of Holocene sediments and the lower elevation Biloxi Formation. Further work is needed to understand the relationship and/or control of the underlying framework geology to the evolution of the island.

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