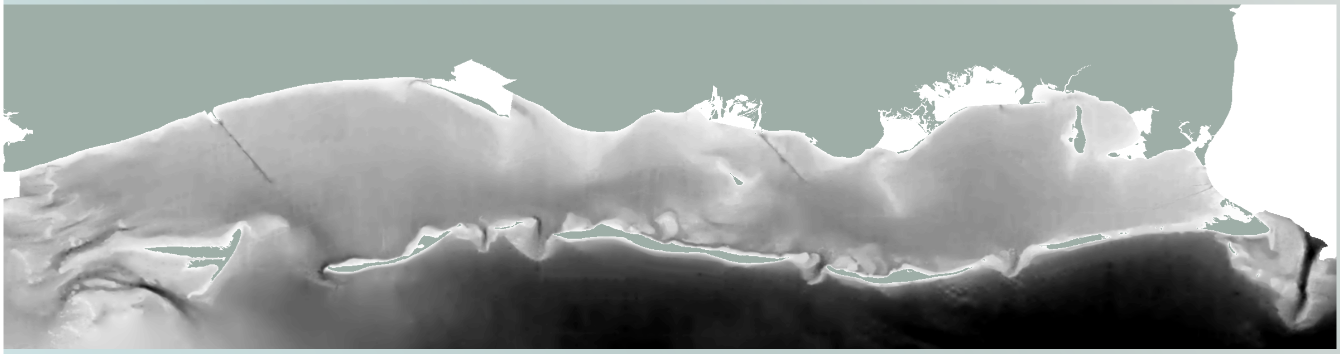
Historical Bathymetry and Bathymetric Change in the Mississippi-Alabama Coastal Region, 1847–2009

By Noreen A. Buster and Robert A. Morton



Pamphlet to accompany

Scientific Investigations Map 3154

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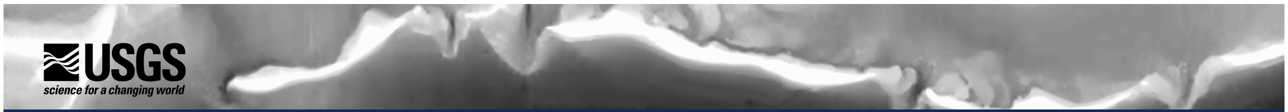

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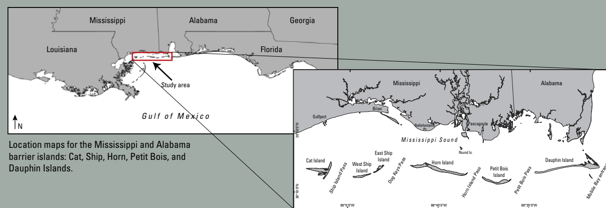

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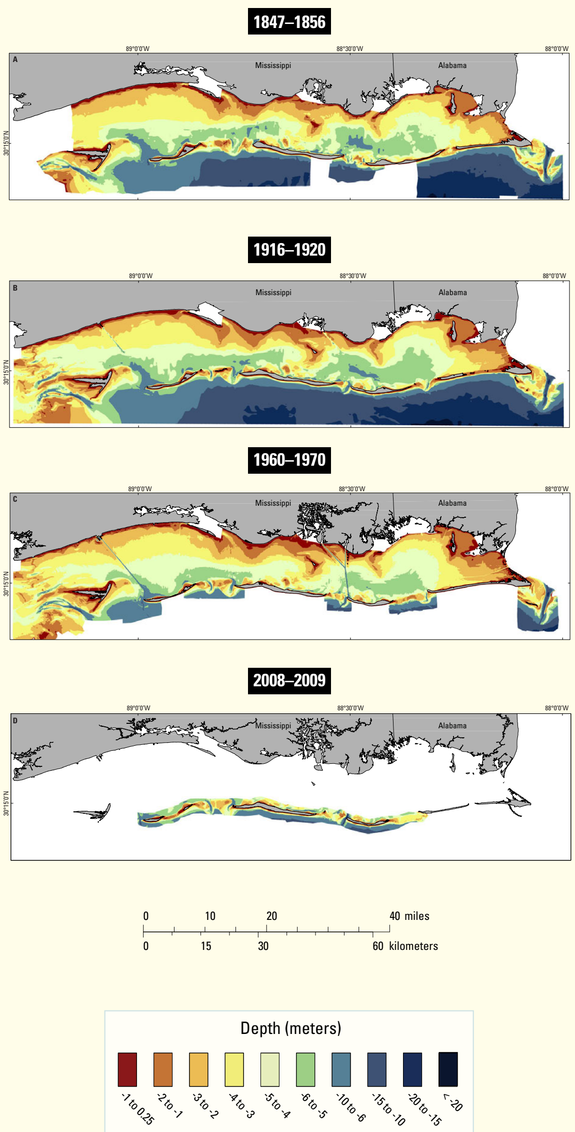

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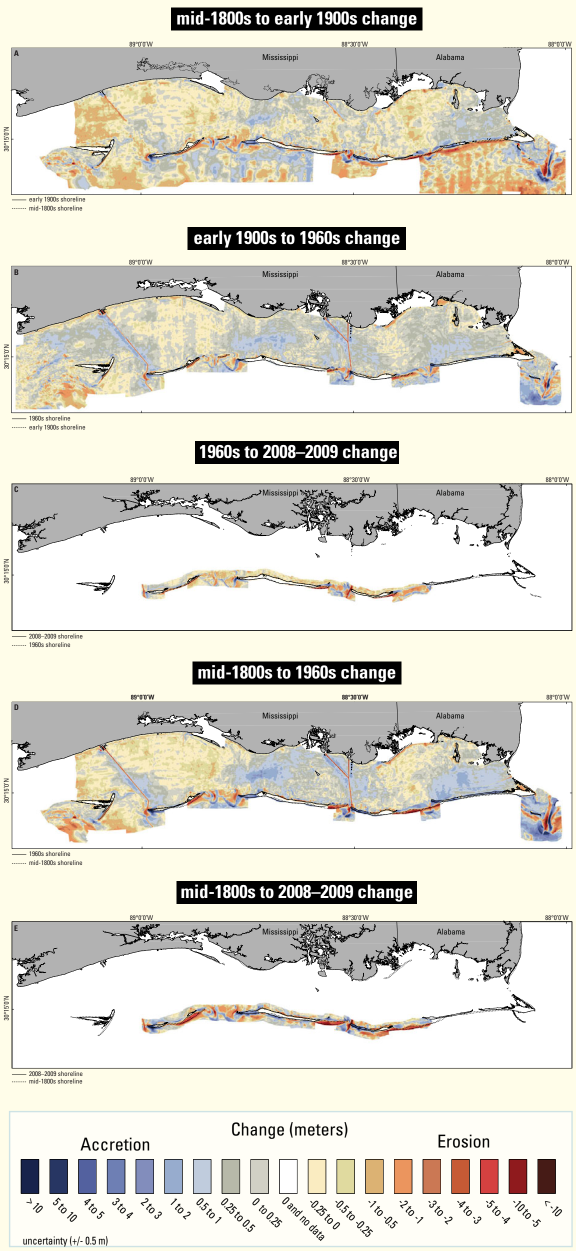

Figure 2. Bathymetric-change grids of the Mississippi and Alabama barrier islands from 1847 to 2009. (Projected using the GCS NAD 83 datum.)

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Introduction

Land loss and seafloor change around the Mississippi and Alabama (MS-AL) barrier islands are of great concern to the public and to local, state, and federal agencies. The islands provide wildlife protected areas and recreational land, and they serve as a natural first line of defense for the mainland against storm activity (index map on poster). Principal physical conditions that drive morphological seafloor and coastal change in this area include decreased sediment supply, sea-level rise, storms, and human activities (Otvos, 1970; Byrnes and others, 1991; Morton and others, 2004; Morton, 2008). Seafloor responses to the same processes can also affect the entire coastal zone. Sediment eroded from the barrier islands is entrained in the littoral system, where it is redistributed by alongshore currents. Wave and current activity is partially controlled by the profile of the seafloor, and this interdependency along with natural and anthropogenic influences has significant effects on nearshore environments. When a coastal system is altered by human activity such as dredging, as is the case of the MS-AL coastal region, the natural state and processes are altered, and alongshore sediment transport can be disrupted. As a result of deeply dredged channels, adjacent island migration is blocked, nearshore environments downdrift in the littoral system become sediment starved, and sedimentation around the channels is modified. Sediment deposition and erosion are reflected through seafloor evolution. In a rapidly changing coastal environment, understanding historically where and why changes are occurring is essential. To better assess the comprehensive dynamics of the MS-AL coastal zone, a 160-year evaluation of the bathymetry and bathymetric change of the region was conducted.

Data and Methods

The MS-AL barrier islands are separated from the mainland by the Mississippi Sound and include, from west to east, Cat, Ship (West and East), Horn, Petit Bois, and Dauphin Islands (index map on poster). Detailed historical bathymetric surveys conducted in the MS-AL coastal region by the U.S. Coast and Geodetic Survey are available from the National Oceanic and Atmospheric Administration (NOAA) and were used to compile a large dataset of seafloor elevations (NOAA, 2010a). In addition, the U.S. Geological Survey (USGS) conducted a limited bathymetric survey in 2008–2009 around the central barrier islands. Together the bathymetric surveys encompass four time periods: 1847–1856, 1916–1920, 1960–1970, and 2008–2009. Historical maps were georeferenced with horizontal positional corrections supplied by NOAA. All bathymetric soundings were either digitized for this study or downloaded in digital format from the National Geophysical Data Center (NGDC). All historical data were originally referenced to mean low water (MLW), and the 2008–2009 data were converted from North American Vertical Datum of 1988 (NAVD 88) to MLW. Shoreline data were taken from topographic sheets (T-sheets) and smooth sheets (hydrographic sheets). Adjustments for the relative rise of sea level were applied to each of the historical periods using a NOAA tide gage. Contours of the historical data were digitized after sea-level rise adjustments had been applied. Contours were also digitized for the most recent dataset. After all data were compiled, bathymetric grids and bathymetric-change maps were produced using geoprocessing tools in ESRI's ArcGIS 9.3.1 (figs. 1 and 2 on map poster). The methods used for this study closely follow those used in previous historical bathymetric-mapping and bathymetric-change studies (Foxgrover and others, 2004; Fregeso and others, 2008).

Data Collection

In the mid-1800s and early 1900s, soundings were collected using a graduated pole with a disk on the end for soundings up to 15 feet (ft). For depths greater than 15 ft, a handheld leadline was used, which consisted of "a graduated line attached to a lead weight called a sounding lead" (Shalowitz, 1964, v. 2, p. 218, 230). The method of determining horizontal position of the boat included "sextant angles taken in the survey boat upon three stations on shore, theodolite angles taken at two shore stations upon a flag hoisted in the boat and measuring the angle in the boat between the two shore stations for verification, and by running out ranges from shore and fixing the positions by time" (Shalowitz, 1964, v. 2, p. 231). Hydrographic descriptive reports, which accompanied the early 1900s and the 1960s smooth sheets, describe the surveys, data collection, and notable changes in navigation and seafloor from prior surveys. The reports state that the 1960s surveys were conducted using fathometers unless the depths were less than 3 ft, 6 ft, or "where the bottom shoaled" when they used graduated poles to measure depth. Horizontal control was obtained by standard visual three-point fix methods. The values on the smooth sheets for all three historical time periods were referenced to the vertical datum

MLW, and tidal reductions were performed prior to publication of the smooth sheet.

The 2008–2009 bathymetry data were collected by USGS scientists using single-beam and interferometric-sonar-swath bathymetry techniques (N. DeWitt, USGS, oral commun., 2010). The bathymetric measurements were recorded in meters using the Global Positioning System (GPS) Earth-centered coordinate system, World Geodetic System of 1984 (WGS 84), for horizontal and vertical positioning. The System for Accurate Nearshore Depth Surveying (SANDS) (DeWitt and others, 2007) was used for acquisition and processing single-beam data, and the swath data were acquired with the Systems Engineering and Assessment Ltd. (SEA) SWATH*plus*-H, 468 kHz interferometric sonar system (N. DeWitt, USGS, oral commun., 2010). Both single-beam and SWATH techniques were used in 2008, whereas only the swath system was used to collect 2009 data.

Georeferencing

The data presented in this study include all known surveys within each time period that were not considered supplemental or directed surveys (that is, small-scale post-hurricane pass inlet surveys). There are no areas where two separate surveys are superimposed, except for slight overlaps along edges of sequential surveys. For the overlaps, some data points were removed to retain original data density. The Geographic Information System (GIS) used to process the data was ESRI's ArcGIS 9.3.1 software. All T-sheet and smooth-sheet rectifications and consequent processing of all datasets were performed within the Universal Transverse Mercator (UTM) North American Datum of 1983 (NAD 83) zone 16N coordinate system and published here in Geographic Coordinate System (GCS) NAD 83.

All mid-1800s topographic surveys were obtained as rectified T-sheets from the Mississippi Department of Environmental Quality, Office of Geology (MDEQOG). All geographic information was removed from the T-sheets, and they were rectified using geographic horizontal transformations supplied by NOAA from the Bessel ellipsoid to GCS NAD 83 (table 1). NOAA was unable to provide a usable transformation for T-240 (Dauphin Island); therefore, T-240 was georectified to the overlapping T-sheet T-3711 from 1917, which was georectified using transformations from NOAA (table 1). T-sheets for the early 1900s, which were obtained from NOAA as nongeoreferenced images, were rectified using geographic horizontal transformations supplied by NOAA from U.S. Standard Datum to GCS NAD 83 (table 1).

Hydrographic smooth sheets for all time periods were downloaded from the NGDC as nongeoreferenced MrSID

Table 1. NOAA topographic sheets (T-sheets) used in this study, including horizontal transformations provided by NOAA.

	Year	T-sheets	Scale	Rectified for this report	NOAA horizontal transformations (seconds)	
					Latitude	Longitude
1847-1849 U.S. Coast Survey Topographic Sheets	1847	T240	1:20,000	X	-5.51	+83.63
	1848	T242	1:20,000	X	-5.48	+83.91
	1848	T244	1:20,000	X	-5.69	+83.91
	1848	T245	1:20,000	X	-5.50	+83.64
	1849	T274	1:20,000	X	-5.52	+83.78
1916-1922 U.S. Coast and Geodetic Survey Topographic Sheets	1916/17	T3701	1:40,000	X	+0.471	+0.524
	1917	T3702	1:40,000	X	+0.478	+0.486
	1917	T3703	1:40,000	X	+0.472	+0.519
	1917	T3711	1:40,000	X	+0.477	+0.496
	1922	T3917	1:40,000	X	+0.619	+0.507
1966 U.S. Coast and Geodetic Survey Topographic Sheets	1966	T11803	1:10,000			
	1966	T11804	1:10,000			
	1966	T11805	1:10,000			
	1966	T11807	1:10,000			
	1966	T11808	1:10,000			
	1966	T11809	1:10,000			
	1966	T11810	1:10,000			
	1966	T11813	1:10,000			
	1966	T11814	1:10,000			
	1966	T11815	1:10,000			
	1966	T11946	1:10,000			
	1966	T11947	1:10,000			
	1966	T13032	1:10,000			
	1966	T13033	1:10,000			
	1966	T13034	1:10,000			
	1966	T13035	1:10,000			
	1966	T13036	1:10,000			

(.sid) files (NOAA, 2010a). The list of smooth sheets used and a location map of smooth sheets for each time period are shown in table 2 and figure 1. An example of an original smooth sheet is shown in figure 2. All mid-1800s and early 1900s smooth sheets were georeferenced to spatially referenced T-sheets using at least four crosshairs, prominent shoreline features, and benchmarks (mapped on both T-sheets and smooth sheets). The 1960s smooth sheets were originally referenced to the North American Datum of 1927 (NAD 27). Therefore they were directly georectified using at least four

Table 2. NOAA smooth sheets (hydrographic (H) sheets) used in this study, including number of soundings.

	Year	Smooth sheets	Scale	Rectified for this report	Soundings digitized for this report	Soundings digitzed by NOAA	Number of soundings used for this study	Smooth sheet data coverage area (km^2)	Density of soundings (# pts/km^2)
1847 - 1856 U.S. Coast Survey Hydrographic Sheets	1847	H00191	1:20,000	X	X		3635	98	37
	1847/48	H00192	1:20,000	X	X		4808	192	25
	1848	H00194-1	1:20,000	X	X		4451	147	30
		H00194-2	1:20,001	X	X		5211	250	21
	1851	H00261	1:20,000	X	X		1931	235	8
	1853	H00328	1:20,000	X	X		4486	210	21
		H00328A	1:20,001	X	X		3273	130	25
	1852	H00329	1:20,000	X	X		4168	201	21
	1853	H00365	1:20,000	X	X		4251	183	23
	1854	H00430	1:20,000	X	X		534	742	1
		H00430C	1:20,001	X	X		1445	167	9
	1855	H00488	1:20,000	X	X		4504	169	27
	1855	H00489	1:20,000	X	X		7211	183	39
		H00489A	1:20,000	X	X		5399	173	31
						Total	**55307**	**Avgerage**	**23**
1916 - 1920 U.S. Coast and Geodetic Survey Hydrographic Sheets	1916/1917	H03960	1:40,000	X	X		6252	210	30
	1916/1917	H04020	1:40,000	X	X		15747	615	26
	1917/1918	H04023	1:40,000	X	X		2907	120	24
	1917	H04000	1:40,000	X		X	11228	722	16
	1917/18	H04021	1:40,000	X		X	13390	633	21
	1920	H04171	1:80,000	X		X	3772	651	6
						Total	**53296**	**Avgerage**	**20**
1960 - 1970 U.S. Coast and Geodetic Survey Hydrographic Sheets	1960	H08524	1:10,000	X		X	5068	20	253
	1960	H08526	1:10,000	X		X	17517	101	173
	1961	H08642	1:10,000	X		X	9832	48	205
	1961/62	H08643	1:10,000	X		X	11343	75	151
	1961/62	H08644	1:10,000	X		X	5010	47	107
	1961/62	H08645	1:10,000	X		X	8629	58	149
	1961/62	H08646	1:10,000	X		X	11505	70	164
	1961/62	H08647	1:20,000	X		X	11468	187	61
	1961/62	H08648	1:20,000	X		X	8502	145	59
	1962	H08649	1:10,000	X		X	232	1	232
	1962	H08650	1:10,000	X		X	11286	71	159
	1962	H08651	1:10,000	X		X	10317	66	156
	1962	H08652	1:10,000	X		X	9262	63	147
	1966/68	H08922	1:10,000	X		X	7505	26	289
	1966/68	H08923	1:10,000	X		X	12019	45	267
	1967/68	H08924	1:20,000	X		X	13274	201	66
	1967/68	H08925	1:10,000	X		X	16701	72	232
	1968	H08970	1:10,000	X		X	11081	56	198
	1968	H08971	1:20,000	X		X	13997	249	56
	1968/69	H09004	1:20,000	X		X	10023	151	66
	1970	H09028	1:20,000	X		X	26886	254	106
						Total	**231457**	**Average**	**157**
2008 - 2009 U.S. Geological Survey	2008						966192	127	7608
	2009						768306	111	6922
						Total	**1734498**	**Average**	**7265**

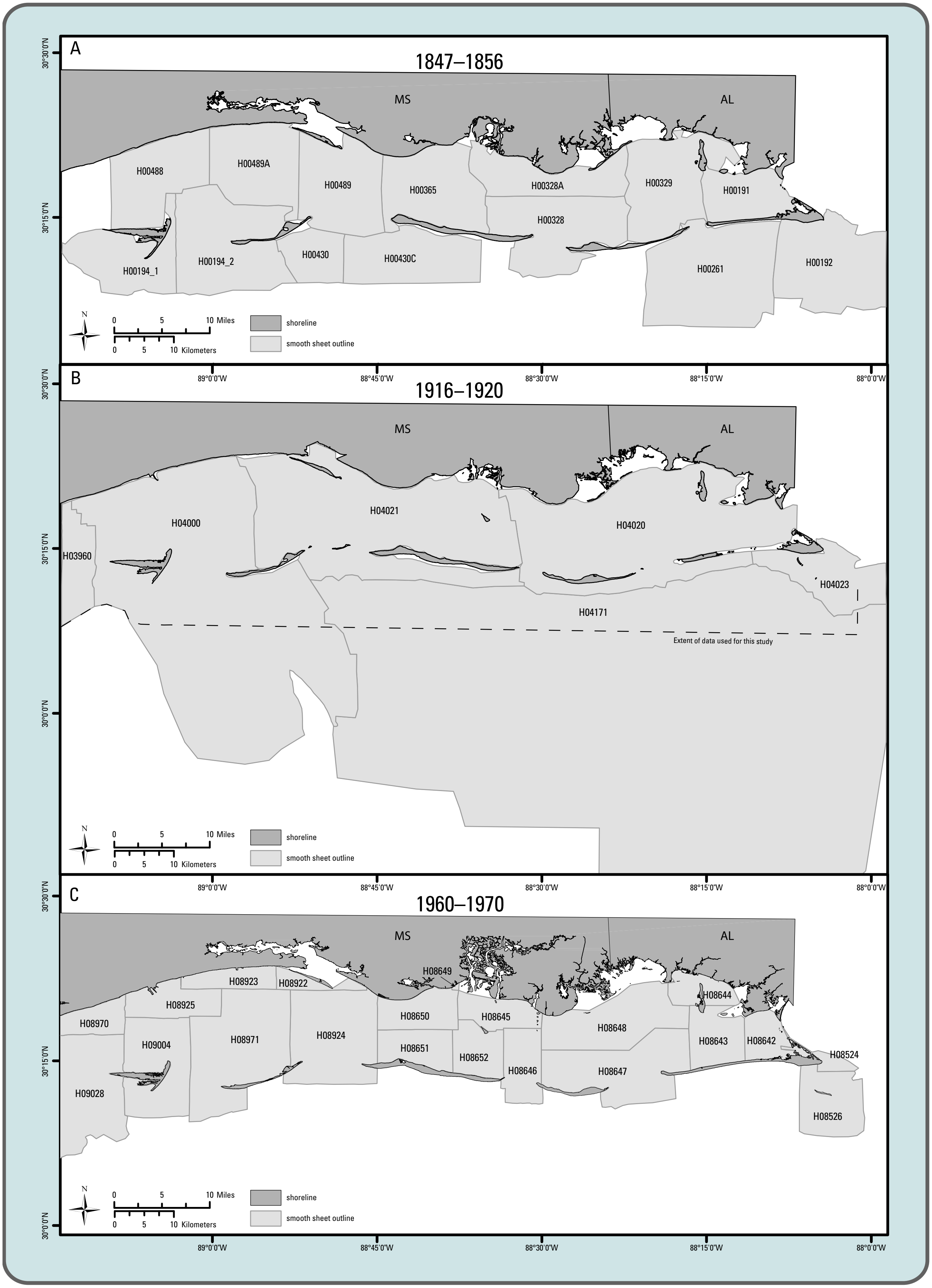

Figure 1. Location and data coverage of individual smooth sheets (H-sheets) for (A) 1847–1856, (B) 1916–1920, and (C) 1960–1970.

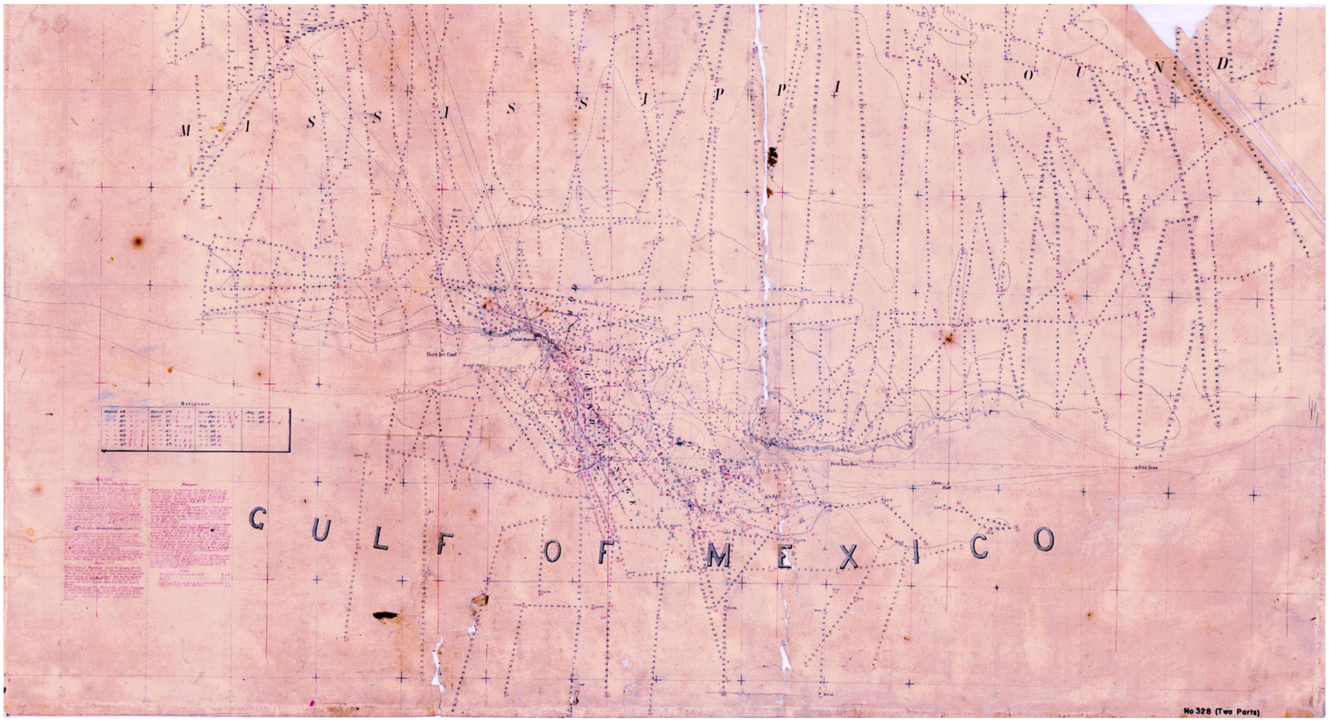

Figure 2. Example of a NOAA smooth sheet (1853).

sets of crosshairs to NAD 27 UTM zone 16N within ArcMap. They were then reprojected into UTM NAD 83 zone 16N. Bathymetric measurements for the 2008–2009 surveys were recorded using the GPS Earth-centered coordinate system WGS 84 for horizontal and vertical positioning.

Soundings

All legible soundings from the mid-1800s smooth sheets and from three early 1900s smooth sheets (H03960, H04020, H04023) were manually digitized, and depths were entered in feet. Original depths from the mid-1800s were reported in one-hundredth of a foot in increments of 0.25, 0.5, and 0.75 (although a few smooth sheets were reported to the nearest tenth of a foot). Depths marked in fathoms were entered to one-hundredth of a foot. All depths for the early 1900s and 1960s were originally reported in feet as integers. Soundings for three of the 1916–1920 smooth sheets (H04000, H04021, and H04171) and all of those for the 1960s had previously been digitized by a contractor for NOAA and were downloaded (NOAA, 2010a). The NOAA soundings were reported in meters rounded to the nearest tenth of a meter, representing values biased toward a shallower depth for navigation purposes (J. Campagnoli, NGDC, oral commun., 2010).

Duplicated soundings were deleted where the juxtaposed 1960s smooth sheets overlapped. In addition, the 1960s smooth-sheet data included zero and positive values that represented the depths above the mapped MLW line, and these data were removed to maintain consistency with the other time periods. All soundings for each smooth sheet were digitized separately, merged into one file for each time period, and converted to the nearest tenth of a meter (fig. 3A–D).

Soundings for the 2008–2009 time period include a combination of single-beam and swath bathymetry (N. DeWitt, USGS, oral commun., 2010). CARIS (Computer Aided Resource Information System, Geomatics Software Solutions, 2008), a swath-bathymetry-processing software package, was used to post-process the raw swath bathymetric soundings. After all offsets and corrections were applied to the data, a 5-meter (m) uninterpolated base surface was created in CARIS using the processed swath soundings reported in meters NAVD 88. This base surface was exported as an ASCII text file in x,y,z format and was used to create the 2008–2009 bathymetric grid. To compare these data with the historical datasets, the NAVD 88 data were converted to MLW using the NOAA Vdatum tool (NOAA, 2010b).

Shorelines

The mid-1800s shorelines for Cat, Ship, Horn, Petit Bois, and Dauphin Islands were manually digitized using the NOAA T-sheets rectified in this study. The mainland shoreline was obtained from MDEQOG (MDEQOG, 2010). The 1916/1917 shoreline was downloaded from the NOAA National Geodetic Survey (NGS) Shoreline Database (NOAA, 2010c). The 1960s shoreline represents a compilation of data from different sources. The 1966 western portion of the mainland and shorelines of Cat Island and Ship Island were provided by MDEQOG. NOAA provided 1966 T-sheets (created from aerial photos) of the western portion of the study area that matched the shorelines from the MDEQOG, yet extended more to the east. A 1950 mainland shoreline was also obtained from the MDEQOG and was edited to match the extension of the 1966 NOAA T-sheets. From where the NOAA T-sheets ended along the east-central portion of the study area, the mainland shoreline is merged with a NOAA 1958 mainland shoreline (NOAA, 2010c). Horn, Petit Bois, and Dauphin Island shorelines were manually digitized from the shorelines on the rectified NOAA smooth sheets. The mainland shoreline used for the 2008–2009 time period was a NOAA composite-vector shoreline (NOAA, 2010c). The shoreline for the MS-AL islands is a 2007 shoreline extracted as the zero meter elevation contour from EAARL data.

For gridding purposes, all shorelines were assigned an elevation value of 0.25 m to represent the mean high water (MHW) line because this is a typical value for the MS-AL coast (Morton and others, 2004). This value was used for all time periods to prevent the gridding algorithm from attempting to connect bathymetric values across the barrier islands.

Correction for Relative Sea-Level Rise

A systematic bias in the historical bathymetric data is caused by the long-term relative rise in sea level in the northern Gulf Coast region. The records of three tide gages provide a basis for estimating and evaluating the magnitude of the relative rise in sea level during the 1847–2009 period of bathymetric-change analysis. The historical tide-gage records include both land subsidence and the eustatic rise in sea level, if both processes are present. The longest continuous water-level history in the area of interest is from the U.S. Army Corps of Engineers gage at Biloxi, Miss., which recorded a relative rise in sea level of 1.80 millimeters per year (mm/yr) between 1896 and 1989 (Burdin, 1990). The relative rise in sea level at the NOAA gage at Dauphin Island, Ala., was 2.98 mm/yr

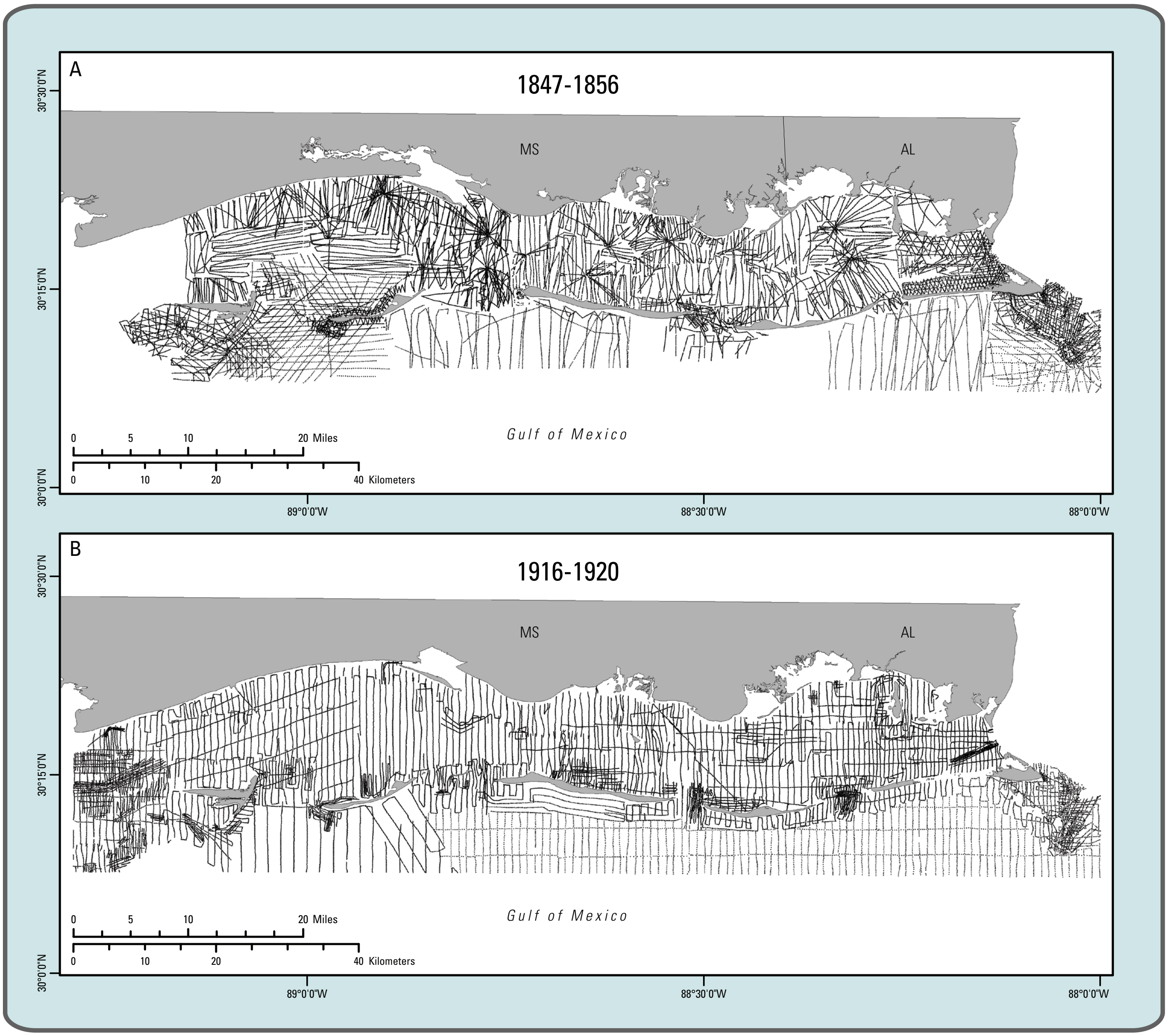

Figure 3. Digitized and (or) downloaded NOAA sounding data for (A) 1847–1856 and (B) 1916–1920.

between 1966 and 2006, whereas the rate at the NOAA gage at Pensacola, Fla., was 2.1 mm/yr between 1923 and 2006 (NOAA, 2010d). The Pensacola gage is at a geologically stable open-ocean location, so its long-term record should be a good estimator of the historical eustatic rise in sea level. In comparison to the Pensacola gage, the lower rate of relative sea-level rise at Biloxi probably reflects the low rates of subsidence (Shinkle and Dokka, 2004) and the protected location of the gage in Mississippi Sound, whereas the higher rate at Dauphin Island probably is caused by slow subsidence in the offshore region.

Rates of relative sea-level rise increase to the west toward the area of crustal loading and high rates of subsidence associated with deposition of the Mississippi Delta (Holdahl and Morrison, 1974). The bathymetric data were not corrected for subsidence because (1) the rates of subsidence in the MS-AL coastal area are low (Holdahl and Morrison, 1974; Shinkle and Dokka, 2004) and within the range of vertical error inherent in the bathymetric data and (2) subsidence rates are not constant across the study area. Furthermore, there were not enough data to calculate and apply a rate of relative sea-level rise that varied both temporally and spatially.

To account for the historical rise in sea level, linear regression was applied to the tide-gage data from Pensacola to obtain water-level corrections for each bathymetric-survey period, using 1992 as the midpoint of the most recent 19-year tidal epoch. For each survey period, there is a range of years during which the bathymetric surveys were conducted. The water-level corrections, which were averaged for the years

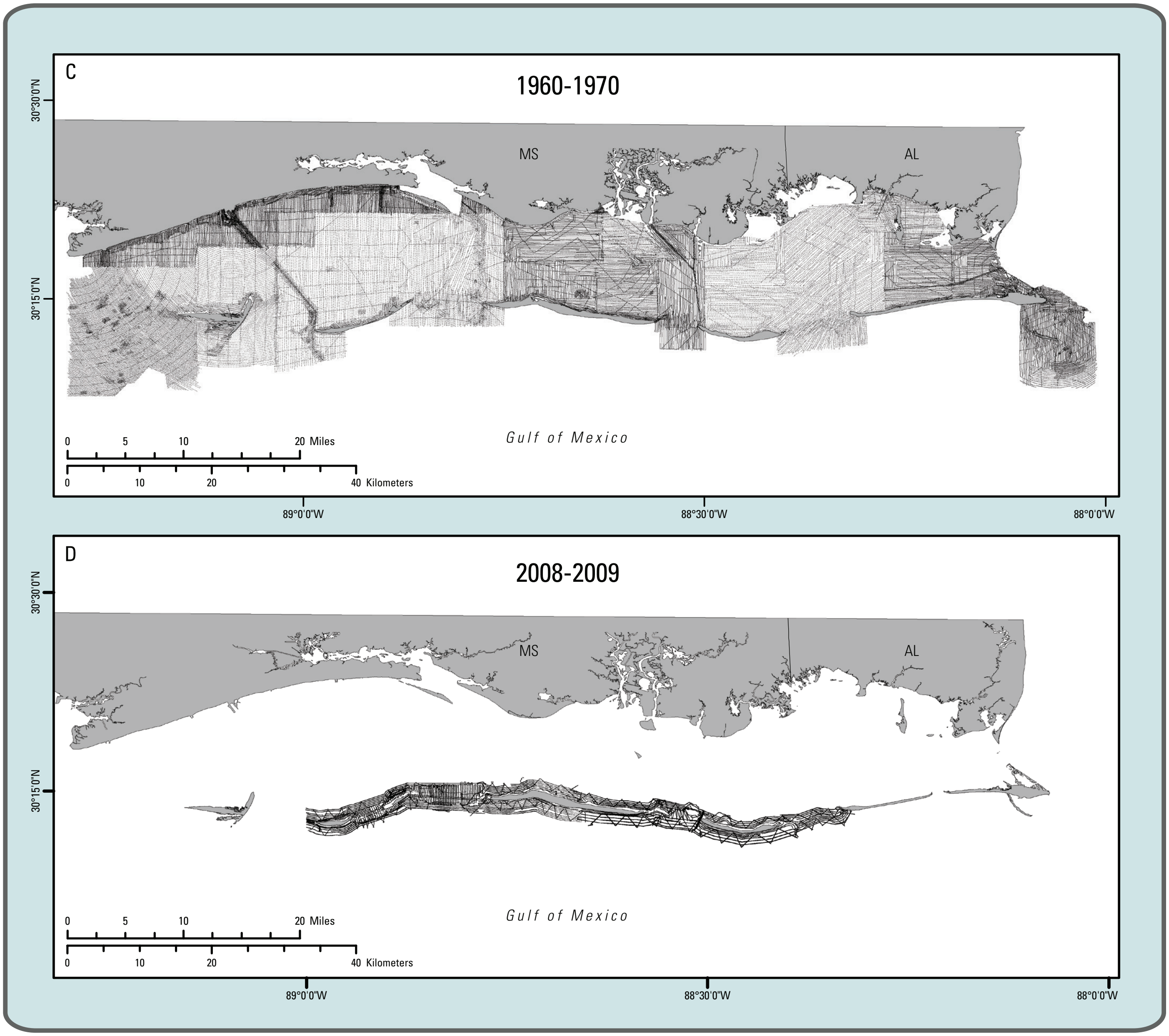

Figure 3 continued. Downloaded NOAA sounding data for (C) 1960–1970 and (D) U.S. Geological Survey soundings for 2008–2009.

included in each survey period, and the results, are as follows: 1847–1856 (0.23 m), 1916–1920 (0.16 m), and 1960–1970 (0.06 m). After the water-level corrections were added to depth values for each respective period, the final depths of the mid-1800s, early 1900s, and 1960s were taken to two decimal places. All sea-level corrections were applied prior to gridding.

Contours

Contours were digitized using depths of soundings after corrections for sea-level rise were applied. At most locations, the contours were constrained by soundings. However, in some places, contours were added between the shoreline and the nearest constrained contour. A gridded surface was created (see gridding section below) using only soundings and shorelines. This gridded surface, which was divided into colored classification boundaries, was used as a guide while digitizing contours where sounding data in the nearshore areas were absent. The gridding algorithm, with soundings alone, was unable to delineate the very steep gradients closest to shore where deep channels were adjacent to the ends and (or) Mississippi Sound sides of the islands. In these areas, where soundings were sparse and the gradient was steep, contours were hand drawn (digitized) as equally spaced as possible to represent the shape of the shoreline and the nearest soundings. Sounding coverage around the islands is shown in figures 1 and 3.

For the mid-1800s data, hand-drawn contours were added to a steep area on the central Mississippi Sound sides of Horn (approximately 2 kilometer (km) long) and Petit Bois Islands (approximately 3.5 km long), and the extreme western tips of Ship and Horn Islands. Similarly, for the early 1900s, hand-drawn contours were added to a steep area on the western-central sound side (approximately 2 km long) of Ship Island and the extreme western tip of Petit Bois Island. In the low-gradient nearshore zones, mid-1800s and early 1900s surveys ranged in distance from shore at approximately 150 m to 1 km but were typically 250 m away from the gulf shorelines of Ship, Horn, Petit Bois (only southwest shoreline in early 1900s), and Dauphin Islands in the mid-1800s (fig. 1A–B on map poster and fig. 1A–B and 3A–B, herein). In these particular areas, either one or all of the 1-, 2-, 3-, 4-, 5-, and 6-m contours were added following the sounding grid. The 1960s and 2008–2009 surveys covered nearshore areas, and the digitized contours were constrained with soundings (fig. 1C–D on map poster and figs. 1C–D and 3C–D, herein). Hand-drawn contours were only added to the extreme western tips of Ship, Petit Bois, and Horn Islands on the 2008–2009 map.

Gridding

The gridded data were created using the ArcGIS Topo to Raster analysis tool following the methods of Foxgrover and others (2004) and Fregeso and others (2008). Topo to Raster applies the Anudem 4.6.3 algorithm of Hutchinson (1988, 1989). The analysis tool allows the user to input point data, contour data, cell size, land boundaries, data-extent boundaries, shoreline elevation, and a snap raster (ensuring final grid-node placement). A detailed description of the Topo to Raster (Anudem 4.6.3) algorithm can be found within the help menu of ArcMap.

Bathymetric grids were produced for all four time periods (figs. 1A–D on map poster). All bathymetric grids were created with the same values for the shoreline (0.25 m), cell size (20 m), and snap raster. The 20-m cell size better represents the areas around the islands, but increases interpretation offshore where bathymetric tracklines can be as much as 1.5 km apart (mid-1800s and early 1900s) (fig. 3A–B). Mixed densities of sounding data on smooth sheets and between periods created a challenge for gridding (table 2, fig. 3). Topo to Raster was best suited for these issues because it is capable of using both point and contour data. The gridding process emphasized the point data and used the contour data as secondary input. Adding the digitized contours helped to stabilize the grid for the extreme western tips of the island shorelines along a steep gradient.

Error Estimates

The bathymetric data were collected with equipment and technologies that changed over time; therefore, the vertical and horizontal accuracy varies for each of the datasets. For an in-depth description of historical accuracy for bathymetric data, the reader is referred to Shalowitz (1964) and Byrnes and others (1991, 2002). The overall vertical uncertainty for this study is 0.5 m, which includes error inherent in collecting and reporting data and the standard deviations of how well approximately 90 percent of the gridded surface represented the original soundings.

Horizontal Error

Horizontal positioning in the mid-1800s and early 1900s introduced unknown uncertainties in positioning of the soundings (Shalowitz, 1964). However, in the mid-1900s, echo sounding and radio-acoustic ranging allowed for better navigation (Shalowitz, 1964). In addition to the unknown positional error during data collection, transposing sounding locations manually to a map, warping and stretching of sheets during storage, and map georectification all add to the horizontal-positioning error of the data. The root mean square (RMS) values for rectification of mid-1800s and early 1900s T-sheets were less than 20 m, and RMS values for mid-1800s, early 1900s, and 1960s smooth sheets were < 28 m (average 11 m), < 29 m (average of 18 m), and < 7 m (average 4 m), respectively. Horizontal accuracy for the 2008–2009 data is 0.01 to 0.03 m (DeWitt and others, 2007).

Vertical Error

The vertical error inherent in the sounding measurements occurs during data acquisition. The error of historical bathymetric data was measured at trackline crossings and "was not to be more than 3 percent of the depth, with a limiting error of 5 percent" (Shalowitz, 1964). According to Byrnes and others (2002), a 0.2-ft error was allowed at crossings for soundings below 15 ft, and a 1.5-ft error was allowed between 72 and 96 ft (no error was included for the 15 to 72 ft interval in the report). There is also an error associated with rounding of the historical soundings during acquisition (Byrnes and others, 2002). In this study, the water depths reported in feet were converted to the nearest tenth of a meter. The total error inherent in data acquisition for the majority of original depths used for this study ranges from 0.03 ft (0.01 m) to 0.75 ft (0.23 m). The vertical uncertainty for the 2008–2009 soundings is 0.11 m (N. DeWitt, USGS, oral commun., 2010).

Gridding Error

Before gridding, all soundings and contour values were classified and color coded to ensure that no data visually stood out, and after gridding, each grid was visually scanned to identify noticeable outliers. Additionally, the final grid values were compared to the original soundings by using the "extract values to points" tool within the Spatial Analyst tool of ArcMap. This allowed analysis of how well the surface represented the original sounding data. The average standard deviations for the difference between the original sounding values and the grid for the time periods 1847–1856, 1916–1920, 1960–1970, and 2008–2009 were 0.17, 0.16, 0.27, 0.28 m, respectively. For approximately 90 percent of the historical grid-to-point comparisons, the average standard deviations, for difference values between -0.1 and 0.1 m, were 0.03 m. For the 2008–2009 data, the standard-deviation value of 0.01 m within the same difference range (-0.1 to 0.1 m) represents 58 percent of the total number of soundings. The standard deviations are low for most of the historical and 2008–2009 soundings. However, the average standard deviation for all the soundings is higher because the gridding algorithm had difficulty with steep gradients, such as at dredged channels, around passes, and on the Mississippi Sound side of barrier islands where deep channels are close to the shoreline. This was especially true for the 2008–2009 bathymetry because it was focused on areas of greatest relief over a much smaller area than for the earlier time periods. Fregeso and others (2008) and Foxgrover and others (2004) also reported difficulty with gridding steep slopes.

Although the added contours helped stabilize the grid, they may not represent the actual bathymetry. For example, the bar offshore from Horn Island (Dolan and others, 1982) is not represented on the three historical maps (although it is unknown whether this bar existed in the past). Its absence is because the grid that the contours followed assumes a constant slope from the last sounding to the shoreline.

Bathymetric-Change Maps

Bathymetric-change maps represent changes in water depth between periods of data coverage (figs. 2A-E on map poster). For each change map, the older bathymetric data were subtracted from the younger bathymetric data in ArcGIS 9.3.1 using the ESRI raster calculator. Each bathymetric-change map boundary represents the area of the smallest data coverage between the compared maps. On the 1960s bathymetric-change maps, the ends of the barrier islands had moved from their historical positions, and surveys were not conducted in these areas. The lack of 1960s bathymetric data on the gulf side of the islands prevented a bathymetric-change analysis in the areas of no data. In these instances, the older shoreline is depicted as a dashed line on the bathymetric-change maps to show the change in shoreline position.

Discussion

The bathymetric datasets show changing seafloors and shorelines during approximately 160 years (figs. 1A–D and 2A–E on map poster). Notable change is seen through the natural migration patterns and disruption of migration of islands and island passes from east to west, and the changes in ebb- and flood-tidal deltas between the islands. The change maps show that due to predominant east-to-west littoral transport, the eastern ends of the islands eroded (excluding Dauphin Island), whereas their western ends accreted. The ebb- and flood-tidal shoals follow the migration of the islands and respond to changes in deposition, erosion, and tidal exchange between the Gulf of Mexico and Mississippi Sound.

Barrier Islands

Mid-1800s to early 1900s

Seafloor and shoreline changes were extensive between the mid-1800s and the early 1900s and resulted from a variety of processes (fig. 2A on map poster). Changes included complete overwash and breaching of the central portion of Dauphin Island as a result of the 1916 hurricane (Morton, 2010). During that time interval, the western end of Dauphin Island prograded westward, and in 1917 its western tip was in the same geographic location as the eastern tip of Petit Bois Island in the mid-1800s. A narrow, deep pass formed between these islands. The eastern three quarters of Petit Bois Island eroded during that period, and only a fraction of the length lost was gained on the downdrift western spit of the island. As Petit Bois Island migrated to the west, the eastern spit of Horn Island eroded. The ebb-tidal shoal between Horn and Petit Bois Islands showed significant change: in the mid-1800s, there was no distinct pass between the two islands, but the early 1900s maps showed the formation of Horn Island Pass. Deposition occurred on the west end of Horn Island onto the area of shoaling shown on the mid-1800s bathymetric map. The Dog Keys Pass area was present in the mid-1800s, but by the early 1900s, it was deeper with steeper slopes on either side. In addition, another channel to the west along the Dog Keys Pass area (later known as Little Dog Keys Pass) had also deepened and become better defined, as observed by Rucker and Snowden (1988). The maps show erosion along the gulf side of the eastern-to-central portion of Ship Island and seafloor accretion on the inner shelf and off the western spit. The increased deposition at the western tip of Ship Island forced migration of the channel westward. A large area eroded in the deeper water between Cat and Ship Islands. Deposition occurred to the west and south of the southern spit of Cat Island.

Early 1900s to 1960s

The period between the early 1900s and the 1960s showed continued erosion of the eastern portions of the islands and deposition to the west (fig. 2B on map poster). Continued deposition and elongation of Dauphin Island toward the west slightly narrowed the adjacent pass compared to the previous period. Petit Bois Island continued to erode on the eastern end almost to the island core. The shallow shoal area east of the core of Petit Bois Island, which was land in the mid-1800s and early 1900s, showed signs of northward accretion into Mississippi Sound. The west end of Petit Bois Island had migrated slightly west up to the point of encroachment on Horn Island Pass (Pascagoula Shipping Channel). Both the bathymetric map of 1960–1970 and the change map clearly show that a new and deep channel had been dredged from Pascagoula to and through Horn Island Pass since the early 1900s. The shoal west of Horn Island Pass (that was the west end of Horn Island in the mid-1800s) showed continuous reworking. The east end of Horn Island continued to erode, and deposition along the western spit had narrowed and deepened the eastern pass in the Dog Keys Pass area. The smaller Little Dog Keys Pass just west of the main pass area had also narrowed and deepened, being flanked on the western edge by a shoal remnant of the eroded east end of Ship Island. The eastern portion of Ship Island continued to retreat toward the northwest, the central portion of the island narrowed, and the gulf-side shoal, previously seen building between the mid-1800s and the early 1900s, was not included in the 1960s survey. The west end of Ship Island lengthened some; however, Ship Island Pass had become part of the dredged channel from Gulfport (Gulfport Shipping Channel), and westward extension of the island ceased because of dredging. The southern spit of Cat Island continued to erode, leaving an area of accretion west and to the south of the spit. The area southeast of Cat Island continued to erode, bringing deeper water closer to the southern tip of Cat Island and closer to the pass between Cat Island and Isle de Pitre to the southwest.

1960s to 2009

From the 1960s to 2009, deposition on Dauphin Island extended to the west, cutting off the small pass present in the 1960s at the west tip of the island (fig. 2C on map poster). The area where the east end of Petit Bois Island once existed on the early 1900s map and then shown as a shallow shoal in the 1960s deepened with no noticeable sign of a new, deeper pass forming between Dauphin and Petit Bois Islands. The eastern end of Petit Bois Island eroded to the core of the island, and the core eroded and retreated to the north-northwest with deposition just north and northeast of the eroded portion of the island and the new eastern end of Petit Bois Island. The west end of Petit Bois Island shifted slightly to the south but was no longer able to migrate farther west because dredging of Horn Island Pass (Pascagoula Shipping Channel) increased the channel depth and constrained its position. The Mississippi Sound side of Petit Bois Island deepened slightly. The ebb- and flood-tidal delta changed form with dredged material placed along the eastern side of the channel. Sediment redistributed between Petit Bois and Horn Islands produced both shallower and deeper areas compared to the 1960s, including a shoal of dredged material located northwest of the shipping channel. The deeper area was centrally located between the islands and was surrounded by areas of deposition. The east end of Horn Island continued to erode, but deposition extended off the northeast end of the island. The core of Horn Island narrowed overall except for the west-central gulf side, which widened slightly. The west spit of Horn Island was narrower, but extended westward naturally, forcing the adjacent inlet westward, narrowing the inlet, and reshaping the ebb- and flood-tidal delta in the east portion of Dog Keys Pass. The area of deposition just east of the new inlet was due to infilling of the old channel. The morphology of the shoals between Horn and East Ship Islands remained similar to the area in the 1960s. However the entire area deepened and the westernmost inlet increased in length and depth.

Ship Island was breached repeatedly by storms including Hurricane Camille (1969), which formed East and West Ship Islands (Morton, 2010). As a result of Hurricanes Camille and Katrina (2005), East Ship Island significantly eroded around its entire perimeter and the east end of West Ship Island transgressed and curved northward. The dredged Gulfport Shipping Channel was relocated to the west of the older dredged channel and was widened and deepened. The dredged material was placed west of the new channel. Because the dredged channel was moved westward, accommodation space was created at the western spit of West Ship Island, allowing alongshore currents to deposit sediment and resulting in elongation of the west end of the island and filling in of the old channel.

Mississippi Sound

Mid-1800s to early 1900s

Seafloor changes between the mid-1800s and the early 1900s also occurred within Mississippi Sound (fig. 2A on map poster). Two areas of increased deposition were located north of Dauphin Island and north of the hump in the northern shoreline of Horn Island. Increased deposition to the north of Dauphin Island was primarily due to overwash during and after storms breached this narrow central part of the island. As the spit grew on the western end of Horn Island, deposition of the subaerial portion of the island replaced a shallow shoaled area, deflecting flow in and out of Mississippi Sound and creating a deeper pass within the western portion of the Dog Keys Pass area. Flow was also altered into the sound in the Dog Keys

Pass area as the smaller, western pass deepened where there was previously only shallow flow. Although the Dog Keys Pass area became deeper and more defined (and was closer to the area of deposition in Mississippi Sound), the opening of the second pass to the west likely changed flow dynamics into and out of Mississippi Sound. A large section of the bay floor south of Bellefontaine Point (central part of Mississippi Sound) shoaled during this time. A portion of the seafloor behind Cat Island seems to have eroded. Also apparent in Mississippi Sound was the beginning of channel dredging off Gulfport and Pascagoula, Miss.

Early 1900s to 1960s

Between 1916 and 1920 and 1960 and 1970, Mississippi Sound showed an overall shallowing (fig. 2B on map poster). The areas behind Dauphin and Horn Islands, mentioned previously, continued to shoal, and these two depositional areas expanded in size. There was also an area of increased accretion between Cat Island and the mainland. Accretion occurred beside the channels where dredged sediment was deposited in spoil areas flanking the channel. Manmade accretion also explains increased sedimentation away from the flanks of the channels, as seen along the Pascagoula Shipping Channel and Gulfport Shipping Channel.

Entrance to Mobile Bay and Offshore

Between the mid-1800s to early 1900s, the deep channel at the entrance to Mobile Bay was dredged and shifted to the west with increased deposition (spoil) on its eastern flank and southern extent (Bisbort, 1957) (fig. 2A on map poster). From the early 1900s to 1960s, the deep channel at the entrance to Mobile Bay continued reworking its position (fig. 2B on map poster).

On the mid-1800s to early 1900s change map south of Dauphin Island, the grid shows depth artifacts from using a 20-m cell size for data analysis. With this small cell size, the grid had difficulty interpreting between the large distances where the distances between tracklines were up to 1.5 km (fig. 2A on map poster). However, the original early 1900s soundings consistently show deeper values in this area than the mid-1800s soundings.

Composite Change – Mid-1800s to 1960s and Mid-1800s to 2009

The seafloor and shoreline change that occurred from the mid-1800s to the 1960s included the combined changes mentioned in the previous sections for 1847 through the early 1900s (fig. 2D on map poster). The change map associated with this ~120-year period shows erosion and deposition more dramatically than the previous periods because the time span is longer and represents the total change for the historical portion of this study. Although this is not a composite change map to the present, it represents the latest available data to show overall change in Mississippi Sound and around Cat and Dauphin Islands since these areas are not represented in the 2008–2009 coverage.

The change map from the mid-1800s to the 2008–2009 time period includes a composite change over approximately 160 years (fig. 2E on map poster). Although the most recent data cover only a portion of the study area around Ship, Horn, and Petit Bois Islands, the migration of islands and passes is striking. The map shows significant erosion of the seafloor off the eastern ends of the islands and deposition on their western ends. What little land is left of an island core has remained generally fixed. The dynamic depositional and erosional forces of this coastal system have greatly changed the passes between islands as they have reacted to changes in sedimentation, sediment supply, tidal flow, and the impacts of hurricanes.

Summary

From the mid-1800s to 2009, the bathymetry surrounding the Mississippi and Alabama barrier islands and Mississippi Sound primarily reflects the processes that drive natural migration of a barrier-island chain. Littoral processes, sea-level rise, and storm activity control natural deposition and erosion of sediment in the nearshore environment, producing significant seafloor changes in tandem with island movement from east to west. The changes to various morphological coastal features include gains/losses of land, appearance/disappearance and locations/sizes of inlets and shoals, and reworking of shoals along island perimeters and within passes between the islands. Between the mid-1800s and the early 1900s, the majority of the system remained in its natural state of reforming as a result of natural processes. After channels were dredged, the dynamics of the island system changed. Migration of the islands was affected by the termination of natural migration of Petit Bois and Ship Islands and decreasing downdrift sediment availability. The channels dredged through Mississippi Sound prior to the surveys conducted in the 1960s show probable linkage to increased overall accretion within the sound, especially around the channels themselves. Other areas of accretion in the sound are probably due to natural processes, such as overwash of barriers from storm activity and natural sediment accumulation in the deeper central portion of Mississippi Sound, which acts as a sediment sink. The sediment entering Mississippi Sound and being deposited just to the southeast of Biloxi Bay and to the north of Horn Island may be trapped by the bathymetric highs around and to the south of Round Island.

The compilation, rectification, and digitization of data collected by the Office of Coast and Geodetic Survey and the USGS have allowed historical analysis of a barrier-island system that is currently in a state of change due to a combination of increased human activity, decreased sediment supply, sea-level rise, and storm activity. Understanding historical processes and responses of this coastal system will provide a greater perspective that will form the basis for predicting future change and management of its natural resources.

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