MAPPING COASTAL EROSION HAZARDS ALONG SHELTERED COASTLINES IN SOUTH CAROLINA
1852 to 2006

Summary Report Submitted to:

U.S. Army Corps of Engineers (Charleston District)

South Carolina Department of Health and Environmental Control
Office of Ocean and Coastal Resource Management

Prepared by:

Chester W. Jackson Jr., Ph.D.

Department of Geology and Geography
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EXECUTIVE SUMMARY

Estuarine shoreline erosion is becoming more of a focus of coastal managers as waterfront development continues to grow and both residential and commercial properties are threatened by shifting shorelines. The U.S. Army Corps of Engineers (Charleston District) and South Carolina's Office of Ocean and Coastal Resource Management (SC-DHEC) conducted a pilot study within Jasper, Beaufort, and Colleton counties to ascertain the extent and potential drivers of historical shoreline change in order to assist with local and state planning efforts. Shoreline mapping and analysis efforts were conducted at the Applied Coastal Research Lab at Georgia Southern University. Historical shorelines were assembled and changes analyzed using AMBUR for shorelines from the 1800s, 1930s, and 2000s. The 2000s high-resolution shoreline was created by digitizing highly controlled aerial and LiDAR imagery and contains over 4000 miles of shore along the marsh-water and upland-water boundary. Over 6400 anthropogenic shoreline features (e.g. docks, seawalls, bulkheads) were also mapped and/or compiled from existing GIS databases and imagery. New mapping protocols and tools were created to assist with analyzing shoreline datasets within AMBUR. Almost two-thirds of shorelines along major streams and waterways, sampled at 23,695 transect locations, experienced net erosion during the 1800s to 2000s time period. The average long-term erosion rate was approximately -0.36 m/yr (± 0.10 m/yr). Shorelines located adjacent to, or near bays/sounds/inlets and stream confluences typically had higher shoreline change rates. Apart from sea level rise and storm impacts, which could not be resolved in this study, six other factors are identified that likely drive shoreline erosion within the study area: estuarine meander processes, tidal current dynamics at stream confluences, wind/wave exposure (fetch), boat activity, shoreline armoring and alterations, and dredging activity.

This report is organized into 6 sections that provide basic information for planners to gain a general understanding of the state of shoreline erosion along major streams and waterways. Semi-detailed information is presented that chronicles complex shoreline changes that have occurred along estuarine shorelines and identifies erosion hotspots. The shoreline change data presented depict up-to-date information on the erosion and accretion trends for the study area and can be used for future shoreline change and coastal vulnerability analyses.

1.0 SHORELINE CHANGE REPORT

1.1 Introduction

Under the Silver Jackets Program, the Applied Coastal Research Lab at Georgia Southern University, in conjunction with the Charleston District U.S. Army Corps of Engineers, SCDHEC-OCRM and NOAA Coastal Services Center, assessed estuarine shoreline positions, erosion rates and hotspots, and potential drivers to assist in risk assessments and economic studies to help coastal communities develop and prioritize responses to shoreline change projections. This work develops additional shoreline data inland of oceanfront areas, estimates erosion rates along major coastal estuarine streams, and develops improved information products for local governments. Some areas within the region are experiencing considerable amounts of shoreline erosion, which ultimately poses a threat to natural and cultural resources, as well as anthropogenic structures along portions of the shore. Prominent erosional scarps exist along portions of estuarine shorelines as cutbanks of tidal streams have migrated into tidal marsh and upland landscapes. Current adverse conditions along a considerable length of the shoreline include exposed upland bluffs slumping into adjacent tidal streams, undermined trees/vegetation, and loss of marsh shoreline.

Historically, regional shoreline change studies have focused mostly on oceanfront beaches and some tidal inlets (U.S. Army, 1971; Morton and Miller, 2005). Very few studies exist that quantify estuarine shoreline erosion along the South Carolina coast and very little is known about the lateral movements of tidal channels in general (Frey, 1973). In order to delineate and understand the erosion trends along estuarine shorelines, a GIS-based investigation was conducted to determine how extensive the erosion is over the length of the shorelines of major tidal streams and to quantify the rate of shoreline loss. Although some work has been done at specific ground locations for studies conducted by various coastal researchers (academic and non-academic), the problem has not been studied over a large area in South Carolina with high resolution shoreline data. There were four main objectives to achieve for this shoreline change study:

- Digitize three historical shorelines in the study region
- Digitize shoreline alterations in the study region
- Use AMBUR to determine long-term erosion rates
- Determine erosion "hotspots," erosion drivers, and management implications

This study focuses on the "Lowcountry" of South Carolina, or the coastal area extending from the Savannah River to Edisto Island, SC (mainly in Jasper, Beaufort, and Colleton Counties) that is dominated by three large estuarine systems around Calibogue Sound, Port Royal Sound, and St. Helena Sound (Figure 1-1). The landward extent of the study area is the SCDHEC-OCRM Critical Area Line, beyond which the agency no longer has direct permitting authority for shoreline alterations. Shorelines and shoreline structures (e.g. docks, seawalls, bulkheads etc) were mapped within ArcGIS 10.0 and analyzed using AMBUR software (Jackson, 2012)

The results of this study will allow coastal researchers/managers to further investigate the potential natural and/or anthropogenic factors influencing shoreline erosion, focus their attention on critical areas or "hotspots", and develop plans to mitigate adverse impacts of erosion.

1.2 Report Organization

This report is organized into a series of inter-related sections. These sections provide information for use in gaining an understanding of shoreline erosion problems facing South Carolina's estuarine system, including erosion hotspots related to long- and short-term coastal dynamics. The shoreline change data presented represents information on the erosion and accretion trends along estuarine shorelines up to the year 2006.

The specific subject matter covered in each of the sections of the report is summarized below. The multi-faceted approaches utilized in acquiring the various data sets that were used during the conduct of this study are described in Section 2 (Methodology). Sections 3 and 4 report the results of shoreline change analyses in AMBUR and discuss erosion hotspots and potential drivers. This report provides a general overview of shoreline erosion and establishes some baseline data that can be utilized to assist with technical decisions involving management of estuarine shorelines.

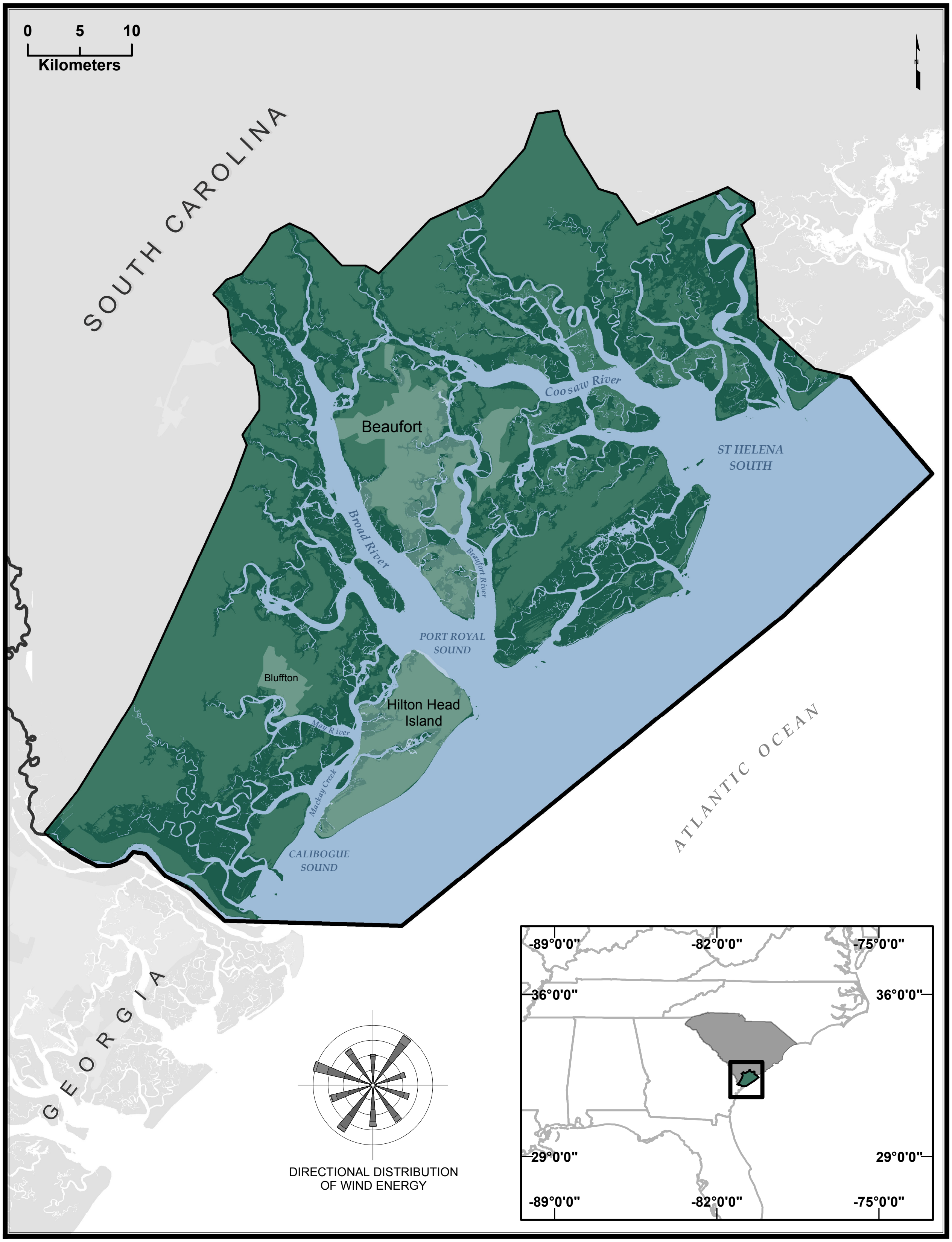

Figure 1-1. Location map of study area within the southern portion of South Carolina's coast. Wind rose based on data recorded at Savannah from 1961 to 1990.

2.0 METHODOLOGY

Three historical shorelines (2 shorelines between the 1800s to 1930s; 1 modern shoreline from the 2000s) in the study area were digitized along with shoreline structures within a GIS framework based on established mapping protocols, some of which were partially modified during the project (Figure 2-1). The shorelines represent three distinct time periods and can be directly compared for shoreline change analysis within reasonable error (Table 2-1). Since spatial data (i.e. shoreline positions) obtained from aerial photographs and maps hinge on the accuracy by which imagery is georectified, different precautions were taken to make certain these data meet or exceed the National Standard for Spatial Data Accuracy (NSSDA) and ensure mappable change. These shorelines were subsequently analyzed to determine the distances and rate-of-change using AMBUR software.

2.1 Digitization of Historical T-sheet Shorelines (1800s & 1930s)

Controlled historic aerial photographs, coastal charts, and survey maps can provide a wealth of shoreline and morphologic data. Representative sets from these data sources were obtained from the USGS, U.S. Coast and Geodetic Survey (now the National Ocean Service), and other agencies (Table 2-1). Digital historical shorelines from the 1800s and 1930s were obtained from NOAA's Coastal Services Center along with the original T-sheet maps they were extracted from within ArcGIS. Two composite (multiple dates for one time period) shorelines were assembled: 1 for the mid-to-late 1800s, and, 1 for the 1930s. However, the 1930s shoreline provided more detail and extensive coverage of the study area. Furthermore, given the rigor of methods used to map the 1930s shoreline, it is perhaps the oldest, most accurate shoreline map of the coast. The 1930s T-sheet shoreline maps were originally derived from some of the first aerial photography of the coast and used highly controlled benchmarks throughout each map for ground surveys. Some of these survey markers are still present today along the coast and are maintained by the National Geodetic Survey.

2.2 Digitization of Modern Shoreline Positions (2000s)

To produce a modern shoreline to compare with the 2 historical shorelines, a combination of NOAA high resolution surveys, orthophotography, and LiDAR imagery were used to extract data from. Aerial photographs were chosen that primarily depicted estuarine shorelines for the entire study area. The USGS High Resolution color orthoimagery provided coverage for the entire study area at 1 meter/pixel to 0.5 meter/pixel. The SC Oyster Imagery provided high resolution (0.5 meter/pixel or lower) CIR orthoimagery flown at mostly low tide. However, it did not cover the entire study area and was flown at various dates from 2003 to 2005. Both imagery datasets had horizontal accuracies of about ± 5 meters.

Two primary methodologies were used to digitize shorelines from aerial photography that were developed by North Carolina's Division of Coastal Management (Geis, and Bendell, 2008) and South Carolina's Department of Natural Resources (Howard et al., 2011). Both protocols provided a good framework for digitizing estuarine shorelines from imagery; however, they have some limitations given that their protocols do not address various shoreline environments that were encountered in this study. During the process of digitizing shorelines from imagery, the high-water line (HWL) or swash terminus, bluff toe, and marsh edge were selected as the primary indicators of shoreline position. In some cases, the movement of the shoreline was restricted by seawalls and other engineered structures. The shoreline positions depicted on orthoimagery were digitized onscreen in ArcGIS at a scale of 1:300 up to 1:1000 and converted into an ESRI polyline shapefile for each image and its GIS table was populated with attributes uniquely identifying the shoreline segment and prepared with fields/attributes to make them compatible with AMBUR software.

Shoreline segments were attributed with their location: upland or apparent mean high-water line, marsh, and anthropogenic (shoreline armoring). Table 2-2 summarizes the lengths of the features digitized for the modern 2000s shoreline with over 4000 miles of digital shore mapped. These primary shoreline classifications are based on newer protocols being currently established by a regional partnership of coastal researchers from North Carolina, South Carolina, Georgia, and Florida as part of the Governors South Atlantic Alliance. This group of researchers is currently funded by NOAA to perform coastal vulnerability analyses of estuarine and upland environments of selected areas in each state. The shorelines in this project are compatible with future vulnerability studies and comparisons with estuarine shoreline change results from researchers who are currently adopting similar methods. Finally, the most recent land/use, land/cover (LULC) geospatial dataset available at SCDNR was used to create an approximate LULC classification for shoreline segments. These classifications are approximations at best, given the mapping resolution of the LULC shoreline is lower than that of the high resolution modern shoreline and the methods used to assign a class to a shoreline segment. The shorelines were intersected with the LULC dataset to obtain the LULC attributes within the GIS. Not all shorelines intersected properly because the shoreline of the LULC was too generalized in areas. Nevertheless, the results provide potentially useful information and can be refined in the future with updated LULC data. Appendix A1 contains these additional classifications and a summary of shoreline change rates. Additional summaries for individual tidal streams and baselines are found in Appendix A2.

Once all shorelines were digitized and exported as shapefiles, they were compiled into a central GIS database. All shoreline shapefiles were projected to a UTM projection, Zone 17, NAD-1983 datum, and GRS-1980 spheroid and combined into one shapefile (Figure 2-1). The new shapefile containing all historical shoreline positions for the study was checked for possible errors due to processing and GIS table inconsistencies.

2.3 Shoreline Position Error

Studies have also shown that a number of factors such as map or photo scale, line-width of a plotted shoreline on a map, and interpretation of the high-water line also limit shoreline accuracy (Dolan et al., 1980; Crowell et al., 1991; Moore, 2000; Thieler and Danforth, 1994 a & b). Studies have proposed worst-case error estimates between 1 and 30 m for shoreline positions derived from various sources, such as aerial photos and T-sheets, to estimate mapping inaccuracies (Table 2-2). Nevertheless, subsequent error analyses conducted by the same authors of several case studies show the level of error is likely far less than the worst-case estimate (Crowell et al., 1991; Jackson, 2004). Shoreline accuracies of T-sheets were assessed by comparing benchmarks located on the maps with the National Geodetic Survey's benchmark shapefile. Some shoreline positions were adjusted to reduce horizontal error below a target of 10 meters. A summary of shoreline data sources and their worst-case error estimates are provided in Table 2-1. In the current study, worst-case position error estimates ranged from 5 to 9 m for historical shorelines.

2.4 Calculation of Shoreline Change

Given that there has yet to be an accepted method adopted by both industry and academia for analyzing shoreline change, AMBUR was employed to calculate changes and produce a variety of statistical data (Jackson et al., 2012). The program calculates shoreline change by measuring the position differences of two or more historic shorelines along transects. Transects were cast at orientations approximately normal to, or in the direction of shoreline movement along a baseline at a spacing interval of 50 m for this study.

The delineation process of a baseline involved creating polygons of all of the tidal streams from each historical shoreline and intersecting them together using within GIS. Next, polygons were extracted that remained water throughout the time period and never intersected marsh or land. This polygon layer is referred to as “stable water” and helped to delineate major streams of study area that have not had channel movements that could complicate shoreline analyses. A centerline was constructed in ArcGIS for the “stable” water polygon and used as a baseline for the study area. A map of baseline locations and ID numbers are provided in Figure 2-2 and Table 2-3

The baselines used for the study did not include smaller, more active tidal streams because they are problematic for transect-based analyses. For example, if a tidal channel meanders and experiences a meander cutoff within the historical time period, it becomes problematic to ascertain erosion rates of those shorelines which are no longer active. Also, shifting geometries of meanders can greatly complicate determining shoreline change rates using transect methods because of marked shifts in their movements and curvature. Small tidal stream/creeks tend to have these complex geometries and can be difficult to assess using older transect casting techniques. These techniques cannot compensate for alternating trajectories of shoreline movements as meanders become more curved over time and/or switch curvature direction. Newer transect methods are being developed and are currently being tested in AMBUR to analyze such tidal streams. However, in this study, tidal streams were analyzed using another new technique developed during this project using a function called 'ambur.channeltran'. This function is not yet released in the current version of AMBUR (v.1.03-17) and is planned for a future release. This function allow for transects to be cast from both sides of a stream centerline and can adjust the orientations to better approximate shoreline curves and movements. It is different from the double-baseline approach that is central to AMBUR, however, it has its advantages and reduced analysis time and subjectivity of baseline placement.

In the historical shoreline dataset, streams typically larger than 90-meters wide had "stable waters" where no shoreline moved through it for the entire study period, and had adequate shoreline data analyzed. Transects were intersected with shorelines in AMBUR and analyzed using the 'ambur.analysis' function in order to perform shoreline change calculations. From these calculations, regions of shoreline exhibiting erosion, accretion, or no apparent change were identified. The “end-point rate” (EPR) calculation, widely used by state and local agencies, was the primary method used to estimate both long-term and short-term shoreline change rates. Transects were removed from the dataset where there was incomplete shoreline data or where transects fell into smaller tidal channel openings off of the main stream’s shoreline being analyzed. When transects “shoot through” these openings into smaller adjacent tidal creeks, the rate of shoreline change appears to be more rapid in these areas when it is not because the shorelines are incompatible for analysis together.

2.5 Digitization of Shoreline Structures

Shoreline structures were digitized in the study area based on mapping protocols established by SCDNR and NCDCM and modified to incorporate a new classification scheme and hierarchy. Although some structures were previously mapped for a portion of the study area by SC-DHEC, efforts were expanded to include additional structures for the entire study region. Additional GIS-based methods of digitizing shoreline structures were evaluated that follow those of Alexander (2010) where armoring was mapped along estuarine and oceanfront shorelines along the Georgia coast to ensure compatibility between datasets in Georgia, South Carolina, and North Carolina. However, Pictometry imagery analysis and field verification were not performed during this study, as was done in the Alexander 2010 study.

Previous GIS shapefiles were initially viewed inside ArcGIS and only those features within the study were extracted and retained. Structures were not mapped again if they followed the North and South Carolina methodology, however, if they did not follow those methodologies or had quality issues they were deleted and remapped. The imagery was subsequently examined for missing shoreline structures. Shorelines were searched using a viewing scale of approximately 1:1,000 in ArcGIS. Once a feature resembling a shoreline structure was found, the viewing scale was increased to the range of 1:300 to 1:500. Where available, alternative imagery datasets were examined to confirm the type of structure and to obtain a better indication of its shape. Once the structure was identified it was digitized according to its type. Structures were mapped by following the "Definitions and Example Photos of Modified Structures" section of the South Carolina Digital Mapping Protocol in order to decide if a polygon, polyline, or point was best used to delineate the feature. Both SC and NC methodologies' digitizing rules were followed. They were recorded into the shapefile's attribute table using the same fields discussed in the North Carolina Mapping Protocol. The "StrucType" field of the GIS shapefile's attribute table was changed to a Float field in ArcGIS and the representative values were slightly changed so that the field was more expandable and adaptable to include more types of shoreline structures using a decimal number system. Bridges and causeways were separated so that they had two different classifying values in order to make them useful for future LiDAR corrections of flow models. Examples of mapped structures within the new classification system are found in Appendix B. Table 2-4 provides the new classification scheme and a summary of the features mapped. Figure 2-3 provides a map depicting the general locations of shoreline structures. Table 2-5 provides a summary of structures used for shoreline armoring.

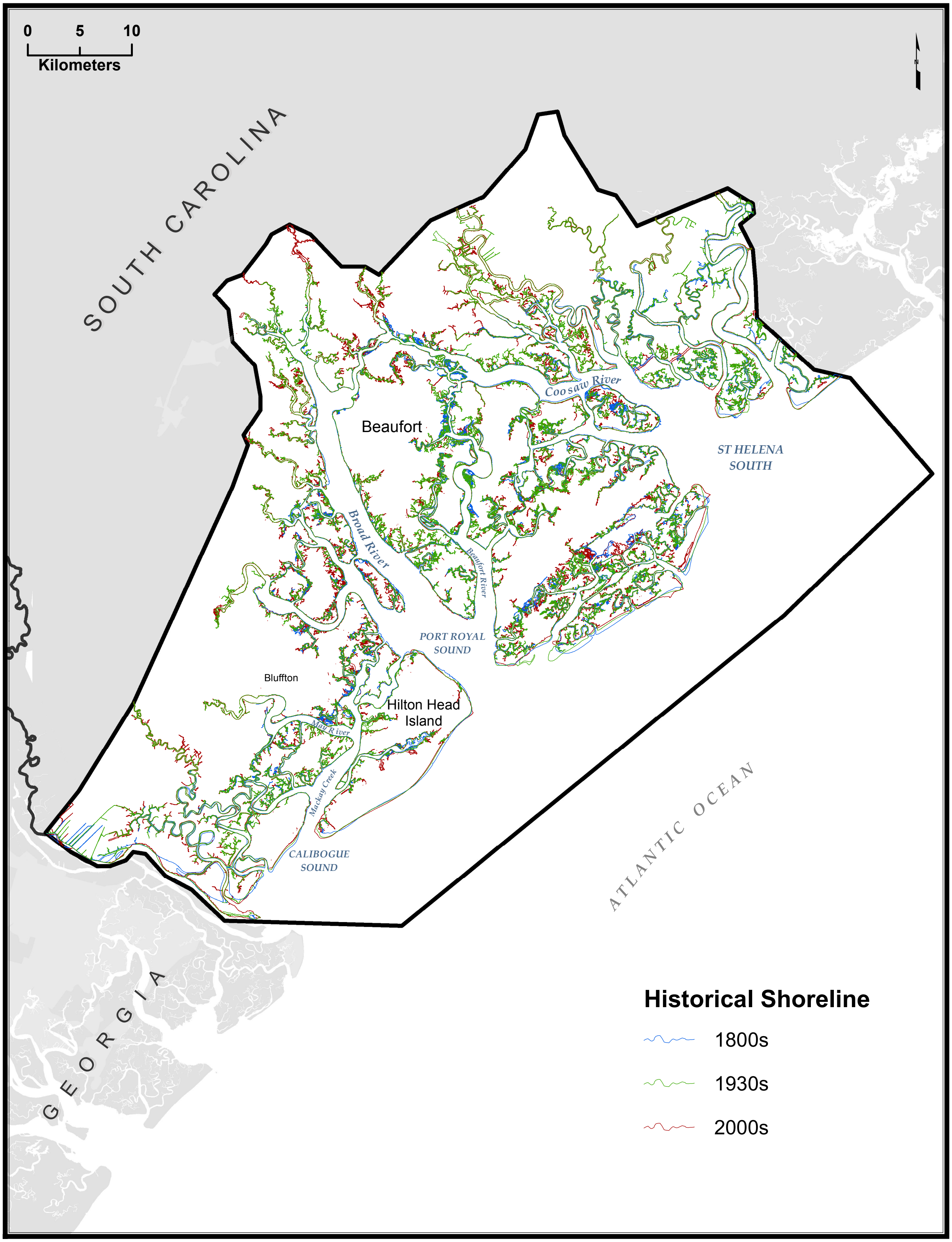

Figure 2-1. Location map of historical shorelines from 1852 to 2006.

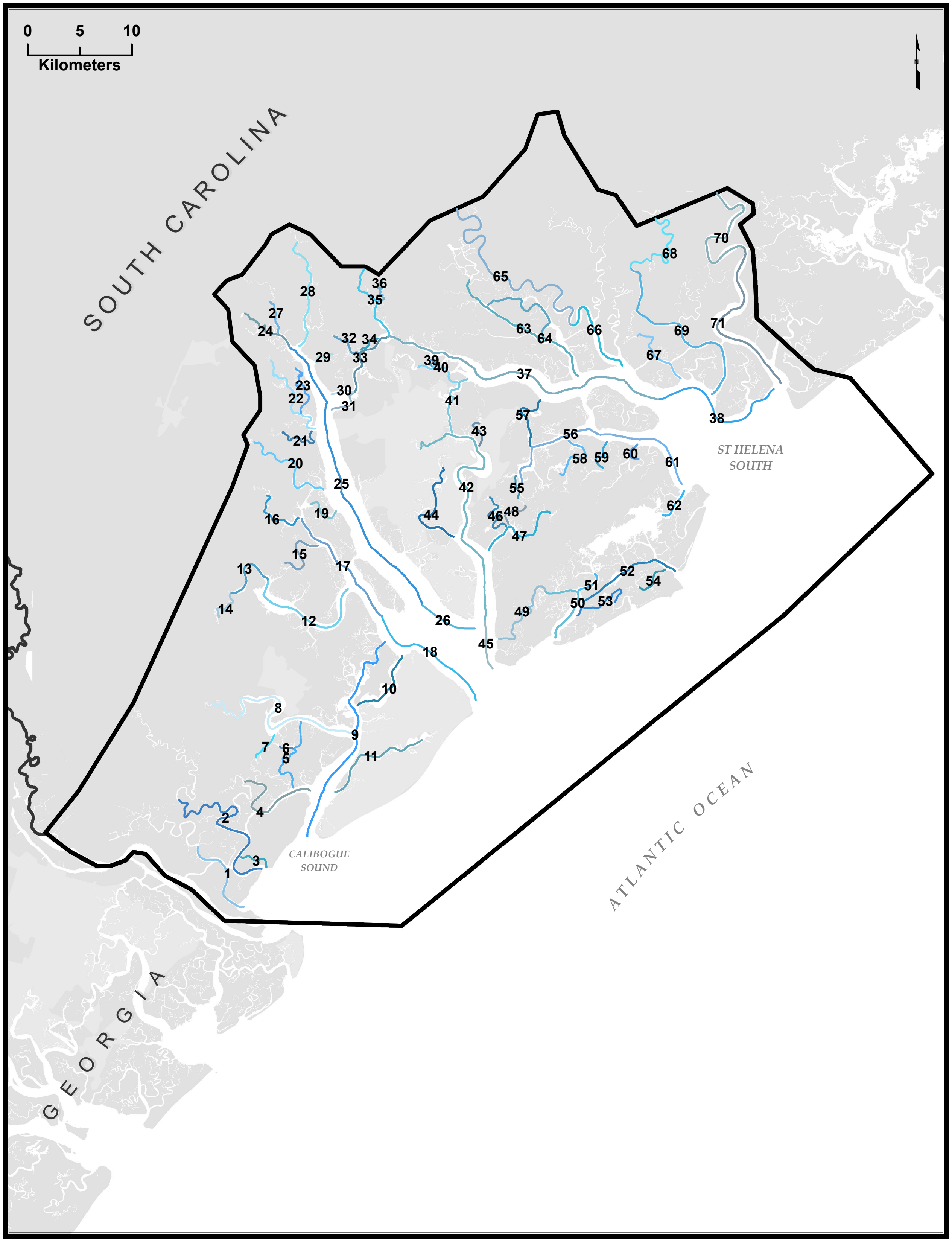

Figure 2-2. Location map of baselines for AMBUR analyses and Map ID numbers that correspond with those found inTable 2-3.

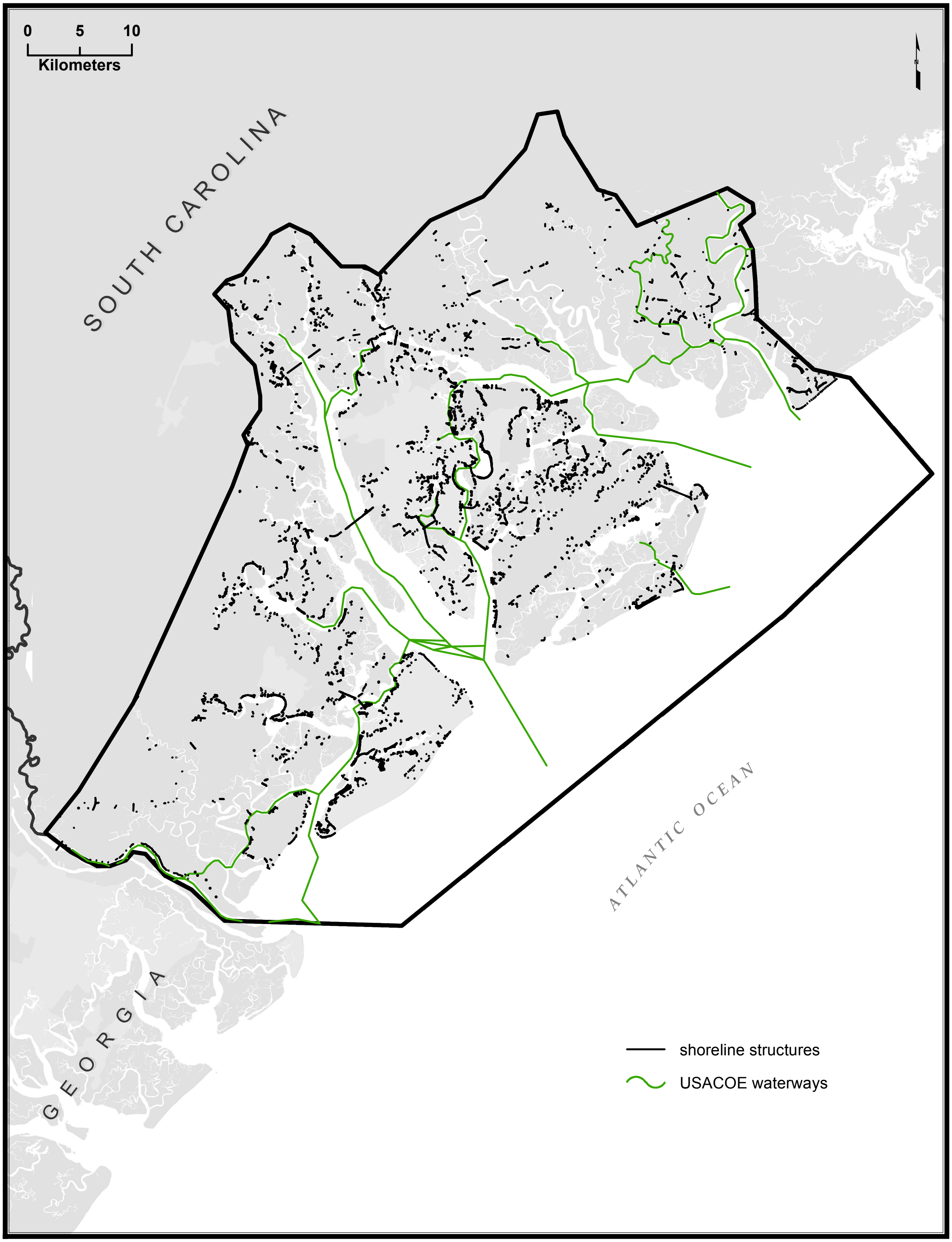

Figure 2-3. Location map of shoreline structures and U.S. Army Corps of Engineers navigable waterway routes.

Table 2-1. Historical shoreline data sources and worst-case accuracy estimates.

Year(s)	Agency	Source Type	Map or Project ID	Accuracy (m)
1852	U.S. Coast and Geodetic Survey	T-sheet	T00379_1	9
1852	U.S. Coast and Geodetic Survey	T-sheet	T00379-2	9
1852	U.S. Coast and Geodetic Survey	T-sheet	T00383-2	9
1852	U.S. Coast and Geodetic Survey	T-sheet	T00385-2	9
1852	U.S. Coast and Geodetic Survey	T-sheet	T00508	9
1856	U.S. Coast and Geodetic Survey	T-sheet	T00611	9
1856	U.S. Coast and Geodetic Survey	T-sheet	T00679	9
1859	U.S. Coast and Geodetic Survey	T-sheet	T00803	9
1859	U.S. Coast and Geodetic Survey	T-sheet	T00809	9
1859	U.S. Coast and Geodetic Survey	T-sheet	T00840	9
1864	U.S. Coast and Geodetic Survey	T-sheet	T00998	9
1865	U.S. Coast and Geodetic Survey	T-sheet	T00996	9
1865	U.S. Coast and Geodetic Survey	T-sheet	T00997	9
1865	U.S. Coast and Geodetic Survey	T-sheet	T01006	9
1868	U.S. Coast and Geodetic Survey	T-sheet	T01070	9
1870	U.S. Coast and Geodetic Survey	T-sheet	T01195	9
1870	U.S. Coast and Geodetic Survey	T-sheet	T01196	9
1871	U.S. Coast and Geodetic Survey	T-sheet	T01275	9
1872	U.S. Coast and Geodetic Survey	T-sheet	T01307_B	9
1873	U.S. Coast and Geodetic Survey	T-sheet	T01307_A	9
1933	U.S. Coast and Geodetic Survey	T-sheet	T05134	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05135	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05136	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05138	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05142	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05143	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05144	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05147	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05148	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05155	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05156	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05162	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05163	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05168	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05169	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05186	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05187	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05188	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05189	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05190	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05206	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05207	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05208	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05209	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05210	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05211	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05212	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T05213	6
1933	U.S. Coast and Geodetic Survey	T-sheet	T06103A	6
2002	NOAA/National Geodetic Survey	high resolution shoreline survey	GA0201	1
2002	Beaufort County GIS	LiDAR	-	5
2003-2005	NOAA/NOS	CIR orthophotography	South Carolina Oyster Mapping	5
2006	USGS	orthophotography	USGS High Resolution Orthoimagery	5

Table 2-2. Summary of primary feature types digitized for the 2003-2006 'modern' shoreline.

Feature Type	n	Total Length (km)	Total Length (miles)
anthropogenic	970	90	56
marsh	45,658	6,219	3,864
upland or apparent mean high water	8,025	578	359
all	54,653	6,886	4,279

Table 2-3. Summary of AMBUR baseline attributes and mean shoreline change rate errors for each era.

Location	Baseline Parameters				Mean Shoreline Change Rate Error ± (m/yr)		
	Length (km)	n Transects	Type	Map ID	1800s to 1930s	1930s to 2000s	1800s to 2000s
Ashepoo River	19.99	763	major stream	69	0.16	0.12	0.08
Ashepoo River north	12.76	502	major stream	68	NA	0.12	0.15
Battery Creek	11.08	398	minor stream	44	0.16	0.11	0.08
Beaufort River	28.11	1009	major stream	42	0.16	0.12	0.08
Beaufort River Bay	4.74	88	bay	45	0.14	0.11	0.07
Bird Island Creek	3.81	128	minor stream	19	0.17	0.11	0.08
Boyd Creek	10.50	394	minor stream	22	0.16	0.11	0.13
Brickyard Creek	6.84	227	minor stream	41	0.16	0.11	0.08
Broad Creek	11.16	345	intrabarrier	11	0.15	0.11	0.07
Broad River	29.03	1072	major stream	25	0.16	0.12	0.08
Broad River Bay	5.68	103	bay	26	0.16	0.11	0.07
Broad River north	6.50	228	major stream	24	0.16	0.12	0.09
Broomfield Creek	3.19	119	minor stream	43	0.16	0.11	0.10
Bull Creek	8.98	348	minor stream	5	0.17	0.11	0.08
Chechessee Creek	6.76	264	minor stream	15	0.17	0.11	0.08
Chechessee River	12.65	479	major stream	17	0.17	0.12	0.08
Chechessee River Bay	12.95	255	bay	18	0.16	0.11	0.07
Coles Creek	5.37	199	minor stream	21	0.16	0.11	0.12
Colleton River	13.23	513	major stream	12	0.17	0.12	0.08
Combahee River	9.73	378	major stream	66	0.17	0.12	0.08
Combahee River north	27.56	1095	major stream	65	0.18	0.12	0.14
Cooper River	11.30	413	minor stream	4	0.17	0.11	0.08
Coosaw River	29.72	1058	major stream	37	0.16	0.12	0.08
Coosaw River Bay	14.45	269	bay	38	0.14	0.11	0.07
Cowen Creek	9.14	345	minor stream	47	0.17	0.11	0.08
Cowen Creek branch	3.42	132	minor stream	48	0.16	0.11	0.08
Distant Island Creek	6.91	256	minor stream	46	0.16	0.11	0.11
East Branch Boyd Creek	6.38	243	minor stream	23	NA	0.11	0.16
Eddings Point Creek	3.63	137	minor stream	59	0.17	0.11	0.08
Euhaw Creek	10.98	419	minor stream	20	0.17	0.11	0.13
Harbor River	3.44	125	intrabarrier	62	0.14	0.11	0.07
Harbor River Branch 1	2.75	109	intrabarrier	51	0.14	0.11	0.07
Haulover Creek	3.65	141	minor stream	32	0.16	0.11	0.14
Hazzard Creek	6.23	233	minor stream	16	0.17	0.11	0.12
Huspa Creek	8.02	303	minor stream	35	0.18	0.11	0.14
Jenkins Creek	6.32	240	minor stream	58	0.16	0.11	0.09
Little Huspa Creek	3.70	127	minor stream	36	NA	0.11	0.16
Little May River	2.90	111	minor stream	7	0.17	0.11	0.09
Mackay Creek	22.53	790	major stream	9	0.16	0.12	0.08
May River	21.52	846	major stream	8	0.17	0.12	0.11
McCalleys Creek	5.05	173	minor stream	40	0.17	0.11	0.08
McCalleys Creek Branch	1.38	27	minor stream	39	0.18	0.11	0.08
Morgan River	17.05	615	major stream	56	0.16	0.12	0.08
Morgan River Bay	5.09	106	bay	61	0.14	0.11	0.07
Morgan River Branch	2.32	80	minor stream	55	0.17	0.11	0.08
Mungen Creek	3.31	127	minor stream	3	0.17	0.11	0.08
New River	22.08	855	major stream	2	0.17	0.12	0.09
Okatee River	6.53	257	major stream	13	0.17	0.12	0.16
Okatee River west	4.21	161	major stream	14	NA	0.12	0.16
Old House Creek	3.67	144	intrabarrier	54	0.14	0.11	0.07
Pocotaligo River	11.64	448	minor stream	28	0.16	0.11	0.33
Point Creek	6.75	246	minor stream	57	0.17	0.11	0.08
Rock Creek	7.20	277	minor stream	67	0.16	0.11	0.07
Savage Creek	1.33	50	minor stream	6	0.17	0.11	0.08
Skull Creek	7.50	274	intrabarrier	10	0.15	0.11	0.07
Skull Creek Pritchards Island	6.95	261	intrabarrier	53	0.14	0.11	0.07
South Edisto River	17.91	694	major stream	71	0.14	0.12	0.07
South Edisto River north	15.05	590	major stream	70	0.14	0.12	0.08
South Haulover Creek	2.30	89	minor stream	29	0.16	0.11	0.14
Station Creek	8.36	314	intrabarrier	50	0.14	0.11	0.08
Station Creek west	9.90	363	intrabarrier	49	0.14	0.11	0.07
Story River	10.62	399	intrabarrier	52	0.14	0.11	0.08
Tulifiny River	3.42	131	minor stream	27	0.16	0.11	0.09
Village Creek	2.32	81	minor stream	60	0.14	0.11	0.07
Whale Branch	7.43	281	major stream	33	0.16	0.12	0.08
Whale Branch North 1	2.17	83	minor stream	34	0.16	0.11	0.08
Whale Branch North 2	2.35	46	major stream	30	0.16	0.12	0.10
Whale Branch South	3.48	50	major stream	31	0.16	0.12	0.08
Williman Creek	10.36	359	minor stream	64	0.18	0.11	0.11
Wimbee Creek	15.60	604	major stream	63	0.17	0.12	0.11
Wright River	8.93	306	minor stream	1	0.16	0.11	0.07
total:	*660*	*23,695*		*mean:*	0.16	0.11	0.10

Table 2-4. Shoreline classification hierarchy and summary of digitized features.

Classification ID	Subclass 1 ID	Subclass 2 ID	Type	n Features (Classification ID)	n Features (Subclass 1 and 2)	% within Classification ID	% of Total Structures
11			Boat Ramp	95			1.48
21			Breakwater	10			0.16
31			Bridge	414			6.45
	31.1		Non-vehicular		41	9.90	0.64
	31.2		Vehicular		173	41.79	2.70
	31.3		Culvert		200	48.31	3.12
33			Causeway	577			8.99
35			Water Control Structure	107			1.67
	35.1		Dam		105	98.13	1.64
	35.2		Levee		0	0.00	0.00
	35.3		Lock		2	1.87	0.03
41			Groin/Jetty	54			0.84
	41.1		Groin		50	92.59	0.78
	41.2		Jetty		4	7.41	0.06
51			Pier/Floating Dock/Wharf/Dock/Gangway/Walkway	4196			65.38
	51.1		Pier		37	0.88	0.58
	51.2		Walkway		254	6.05	3.96
	51.3		Wharf		4	0.10	0.06
	51.4		Gangway		2	0.05	0.03
	51.5		Dock		3712	88.47	57.84
		51.51	Boat Storage Dock		2	0.05	0.03
		51.52	Commercial Dock		25	0.60	0.39
		51.53	Community Dock		14	0.33	0.22
		51.54	Joint use dock		4	0.10	0.06
		51.55	Private Dock		108	2.57	1.68
		51.56	Floating Dock		34	0.81	0.53
53			Commercial Complex	4			0.06
61			Sill	9			0.14
	61.1		Living Shoreline		9	100.00	0.14
71			Sloped Structure	255			3.97
	71.1		revetment (sloped)		94	36.86	1.46
	71.2		Riprap		154	60.39	2.40
	71.3		Concrete Slope		7	2.75	0.11
81			Unknown	62			0.97
91			Vertical Structure	553			8.62
	91.1		Bulkhead		444	80.29	6.92
	91.2		Seawall		109	19.71	1.70
	91.3		Gabion		0	0.00	0.00
101			Hybrid Structure	25			0.39
	101.1		Vertical Structure fronted by Sloped Structure		24	96.00	0.37
	101.2		T-Groin		1	4.00	0.02
111			Abandoned/ Historic Structure	57			0.89
		111.11	Abandoned/Historic Boat Ramp		1	1.75	0.02
		111.21	Abandoned/Historic Breakwater		0	0.00	0.00
		111.31	Abandoned/Historic Bridge		0	0.00	0.00
		111.33	Abandoned/Historic Causeway		47	82.46	0.73
		111.35	Abandoned/Historic Water Control Structure		0	0.00	0.00
		111.41	Abandoned/Historic Groin/Jetty		0	0.00	0.00
		111.51	Abandoned/Historic Pier/Floating Dock/Wharf/Dock/Gangway/Walkway		9	15.79	0.14
		111.53	Abandoned/Historic Pier Complex		0	0.00	0.00
		111.61	Abandoned/Historic Sill		0	0.00	0.00
		111.71	Abandoned/Historic Sloped Structure		0	0.00	0.00
		111.81	Abandoned/Historic Unknown		0	0.00	0.00
		111.91	Abandoned/Historic Vertical Structure		0	0.00	0.00
		111.101	Abandoned/Historic Hybrid Structure		0	0.00	0.00
			Total:	6418			

Table 2-5. Summary of shoreline armoring and dock features.

Classification ID	Type	# Digitized		
			Total Area (m^2)	Average Area (m^2)
51.5	Dock	3712	568,493	153
51.51	Boat Storage Dock	2	182	91
51.52	Commercial Dock	25	50,944	2,038
51.53	Community Dock	14	6,149	439
51.54	Joint use dock	4	858	215
51.55	Private Dock	108	8,324	77
51.56	Floating Dock	34	2,117	62
			Total Length (m)	Average Length (m)
71.1	Revetment	94	16,426	175
71.2	Riprap	154	13,913	90
71.3	Concrete Slope	**7**	649	93
91.1	Bulkhead	444	37,106	84
91.2	Seawall	109	6,772	62
101.1	Vertical Structure fronted by Sloped Structure	24	4,079	170

3.0 SHORELINE CHANGE

Lowcountry estuarine shores, though not as active a feature as oceanfront shorelines, have changed considerably in areas such as those adjacent to bays/sounds and continue to do so under different natural and artificial drivers. The estuarine system, when viewed in terms of decades and/or century-long timeframes, is ultimately shaped by a complex set of factors operating in concert with one another. The position of the shoreline today ultimately represents the cumulative impacts of a number of factors including sea-level change, storms, tidal channel dynamics, inlet dynamics, human activity, and the inherited geologic framework. For that reason, from a management perspective, it is important to have adequate historical shoreline data to investigate trends of estuarine erosion and eventually relate the changes to the dominant factors influencing the observed trends.

Some studies have suggested that a minimum of 10 years of relatively continuous historic shoreline data are needed to interpret short-term trends and at least 50 years of data are needed for deciphering long-term trends (Camfield and Morang, 1996). However, these studies mostly concentrated on oceanfront shorelines where the distance of shore movement exceeded horizontal accuracy errors and allow for dense, almost yearly datasets where a researcher could be certain to attain mappable change at smaller time intervals. Such is not necessarily the case of estuarine shorelines, where movements are in general relatively slow, sometimes less than a third of the rates and distance of an oceanfront shoreline. The dataset for the Lowcountry provides only snapshots in time of the shoreline position(s), which represents the cumulative effects of all factors influencing change. Therefore, only apparent shoreline change trends and influences may be ascertained from statistical analyses of the dataset and visual inspections of maps and historical aerial photographs. A field campaign to ascertain factors driving erosion trends observed in the dataset fell outside the scope of this project. However, there is enough data from this study to identify some potential factors/drivers.

All shoreline change rates reported below, unless otherwise noted, are in terms of the EPR calculation method. The EPR calculation is simply the distance from the oldest to the youngest shoreline divided by the elapsed time to yield a rate-of-change. The oldest and youngest shorelines are referred to as the "end points". It also should be noted that shoreline change data presented in this manuscript as "negative" numbers indicate erosion and "positive" numbers indicate accretion. Shoreline rates utilizing alternative calculation methods such as Linear Regression Analyses (LRR) and "Weighted Linear Regression" (WLR), and other AMBUR model outputs were also generated but were not included in this report due to limitations of the dataset and uncertainty in the reliability of the rate models using only 3 shoreline. However, these shoreline change rate calculations are provided in the digital AMBUR output files accompanying this report. Results are broken down for each of the following eras: 1800s to 1930s, 1930s to 2000s, and 1800s to 2000s (net change). The percentages of shoreline erosion and average change rates for baseline locations (major stream, minor stream, bay, and intrabarrier) and shoreline types/classification are tabulated in Tables 3-1 and 3-2 for each era. Major streams baseline locations represent primary navigable waterways based on USACOE waterway routes (Figure 2-3), and/or, the first primary channel extending from a major sound or inlet that originates in the upland. Minor streams are typically smaller sections of major streams or the first smaller branches off of the stream that encounters an upland. Baselines that are at bay locations represent shorelines adjacent to sounds or inlets. Intrabarrier baselines are those located within a barrier island complex. Figures 3-1, 3-2, and 3-3 display the spatial extents (envelope of change) of shoreline change along with erosion and accretion rate trends for each era for all locations.

3.1 Era I (1800s to 1930s)

The earliest series of detailed maps accurately depicting the study area are U.S. Coast and Geodetic Survey T-sheets from field surveys conducted in 1852, 1856, 1859, 1864, 1865, 1868, 1870, 1871, 1872, and 1873. Combined, these maps provide a nearly complete coverage of the shore within the study area with the exception of the western portion of the project area. Shoreline positions extracted from these T-sheets were merged together into the one estuarine shoreline, representing the oldest historical shoreline in the dataset. The shoreline is denoted in this manuscript as “1800s” to represent the combination of the multiple T-sheet years. Subsequently, a mixture of aerial photographic and ground surveys from different dates were used to construct the NOS T-sheets from 1933 (referred to as “1930s” shoreline). The noticeable difference between these maps and their older counterparts, aside from increased accuracy, is the detailed mapping of smaller marsh channels and other coastal features as previously noted.

During the 1800s to 1930s era, which spanned 70+ years, approximately 62 % of the estuarine shoreline experienced net erosion (Figure 3-1, Table 3-1). Although the average rate of change for all 18,757 transects measured for this era was -0.16 m/yr (± 0.16 m/yr), the average rate among transects recording only erosion values was -0.66 m/yr. Accretion occurring at transects recording only accretion during the era averaged approximately 0.66 m/yr (exactly opposite of the erosion rate). Although the erosion rate appears to be offset by the accretion rate, the spatial extent of erosion was greater (62 %).

The most notable shoreline erosion occurred primarily along major and intrabarrier streams, and bays (Figure 3-1 and 3-2). Over two-thirds of these shoreline locations experienced net erosion. Shoreline recession was far greater along these segments and appeared to be greater at segments closest to the inlets and sounds. The shoreline eroded along bay locations an average of -1.39 m/yr and accreted at rates of 2.6 m/yr in St. Helena and Port Royals Sounds.

Shoreline movements adjacent to St. Helena Sound are noticeably greater than others in the study area (Figure 3-1), especially along Pine and Otter Islands. These areas comprised of a mixture of morphologic features including vegetated dredge spoil islands, upland, and tidal marsh. Overall, for the entire study area, mean erosion rates along marsh and anthropogenic shorelines were approximately -0.62 and -0.65 m/yr respectively. Upland or apparent mean high water shorelines had slightly higher erosion rates of -0.70 m/yr and a greater percentage of erosion (~70 %)

3.2 Era II (1930s to 2000s)

When compared with the previous era, it appears that both the spatial extent and rates of erosion decreased (Figure 3-2, Table 3-1). Rates of shoreline erosion for the 1930s to 2000s era (~ 70-year time period) averaged approximately -0.35 m/yr (± 0.11 m/yr). These rates were nearly half of mean erosion rates for the previous era. It should be noted however, that there were more transect locations during this era (23,359 transects) because the 1930s and 2000s shorelines extended farther in to the study area toward the western boundary and had more detail. Interestingly, the percentage of shoreline accretion along bay and intrabarrier shorelines increased markedly from the previous era and had rates averaging nearly 0.94 m/yr and 0.28 m/yr respectively. Although upland shorelines had mean erosion rates of -0.53 m/yr along slightly more than half of the shore, anthropogenic or armored shorelines experienced 80 % of erosion along the shoreline. This is likely due to an increase in the amount of shoreline armoring within already erosion pronged areas.

Still, what is uncertain about this era is the overall decrease of erosion rates. One might point toward the accuracy of the shoreline position data from 1933 survey maps and 2000s aerial/LiDAR imagery. However, analyses of stable features, such as seawalls and other historical landmarks, reveal horizontal displacements below the projected worst-case error estimates for the era. Another explanation could be the difference between shoreline proxies of the T-sheets versus those mapped from the 2000s imagery. Given the mapping protocols used in this study, the 2000s shoreline is a conservative estimate of shoreline position along some areas, especially where the upland is fronted by a thin marsh platform. In the 1930s, the upland/marsh boundary or high tide level might have been mapped in these areas and not the edge of the marsh platform as present on low tide aerial photography as was the case in some of the 2000s imagery. If a 2000s marsh-water boundary at the platform edge is compared against a 1930s marsh-upland shoreline, then it might show up as accretion or a smaller distance of erosion (leading to a smaller rate). Future work is needed to determine the appropriate shoreline proxy to reduce potential errors in erosion rates. Recently, automated digitizing experiments were conducted within the study area using 2009 NAIP high tide, color infrared aerial photography to delineate shorelines in test areas and hold promise, along with LiDAR, for delineating a shoreline approximately equal to the mean high water line along uplands. Such techniques will be beneficial for future shoreline mapping efforts and assist with resolving the location of the mean high tide shoreline and reduce mapping errors.

If shoreline position inaccuracies are partially ruled out, the mechanism(s) influencing reduced erosion rates is uncertain. Since increased sedimentation is essential for the progradation of shorelines and the establishment of new marsh, it is reasonable to assume that sediment supply during this period increased substantially. Such an increase might be attributed to increased development in South Carolina's Piedmont and Coastal Plain provinces, thus increasing the sediment loads of coastal rivers/streams. It could also be attributed to anthropogenic activities taking place within close proximity of the shoreline, such as dredging and new development, which have the potential to alter the sedimentary system. However, the actual mechanism(s) remains unclear.

3.3 Long-term Trends (1800s to 2000s)

Shoreline change along the South Carolina's Lowcounty is anything but uniform. Throughout the study period spanning from 1852 to 2006, shoreline change has varied both in magnitude and spatial extent along segments of the marsh and upland (Figures 3-1, 3-2, & 3-3). Graphs of percent erosion and average annual shoreline change rates for each tidal stream/bay/waterway location in Figures 3-4 and 3-5 illustrate both the short- and long-term behavior of each baseline segment depicted in Figure 2-2. Although the overall average shoreline change rate was approximately -0.11m/yr (± 0.10 m/yr) for all calculated transects (23,695 transects), almost two-thirds of transects had an average shoreline erosion rate of -0.36 m/yr for transects with only net erosion (Table 3-1). Furthermore, inspection of Figure 3-3 reveals that bay shorelines and larger tidal streams, such as the Chechessee, Broad, Beaufort, Coosaw, and Combahee Rivers, are most susceptible to chronic erosion and have a number of transects with higher rates of erosion that are greater than -1 m/yr. When viewed from a coastal management standpoint, these areas could be considered "hotspots" or "areas of concern". This is especially true for shorelines within close proximity to bays/inlets/sounds where the frequency and magnitude of erosion appears to be greater. The highest rates of shoreline appear to occur erosion occur along upland/sandy and anthropogenic shorelines. Mean erosion rates along these shorelines were approximately -0.5 m/yr throughout the 1800s to 2000s era.

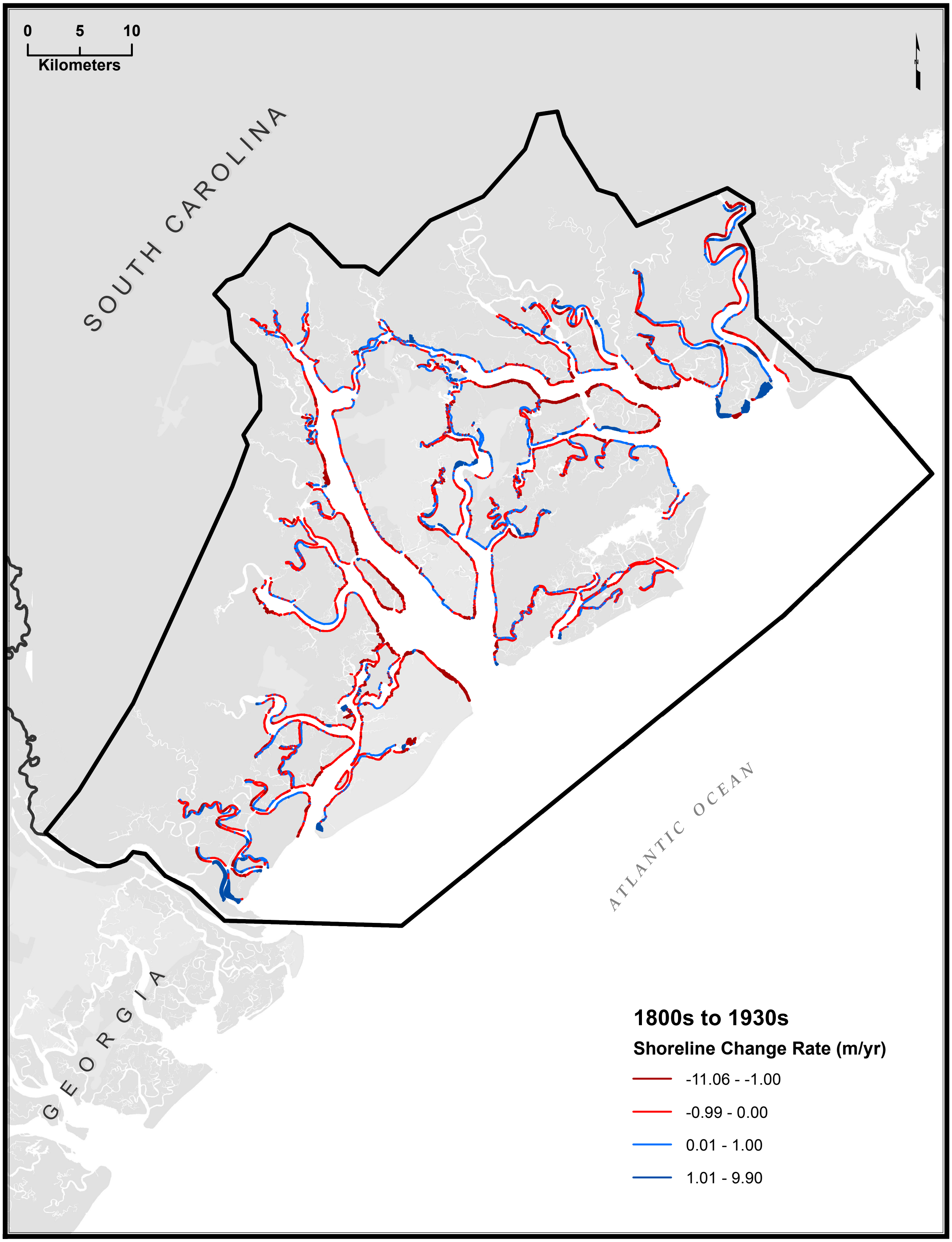

Figure 3-1. Map depicting shoreline change rates from 1800s to 1930s. Rate calculations are based on the EPR method. Positive values indicate accretion and negative values are erosion.

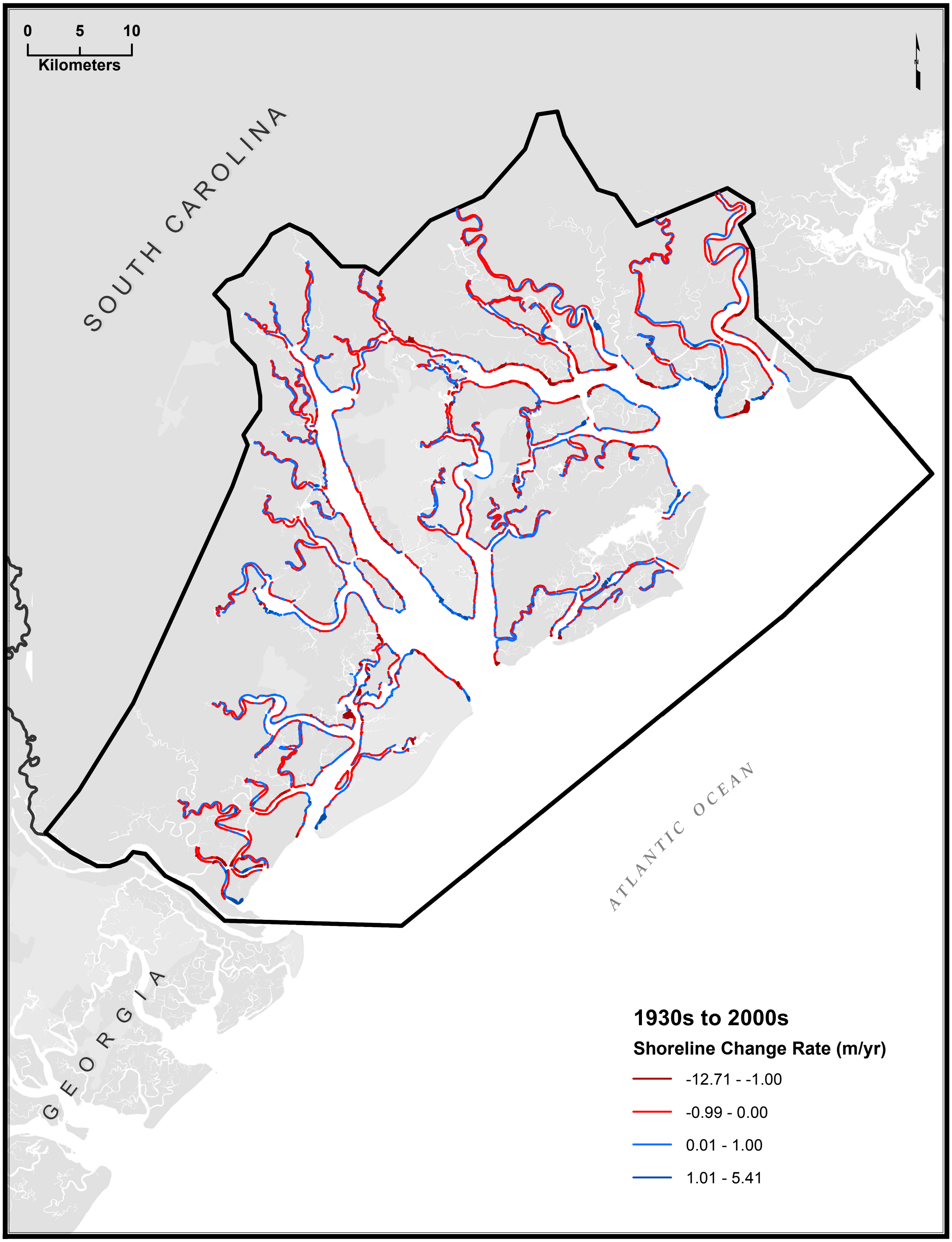

Figure 3-2. Map depicting shoreline change rates from 1930s to 2000s. Rate calculations are based on the EPR method. Positive values indicate accretion and negative values are erosion.

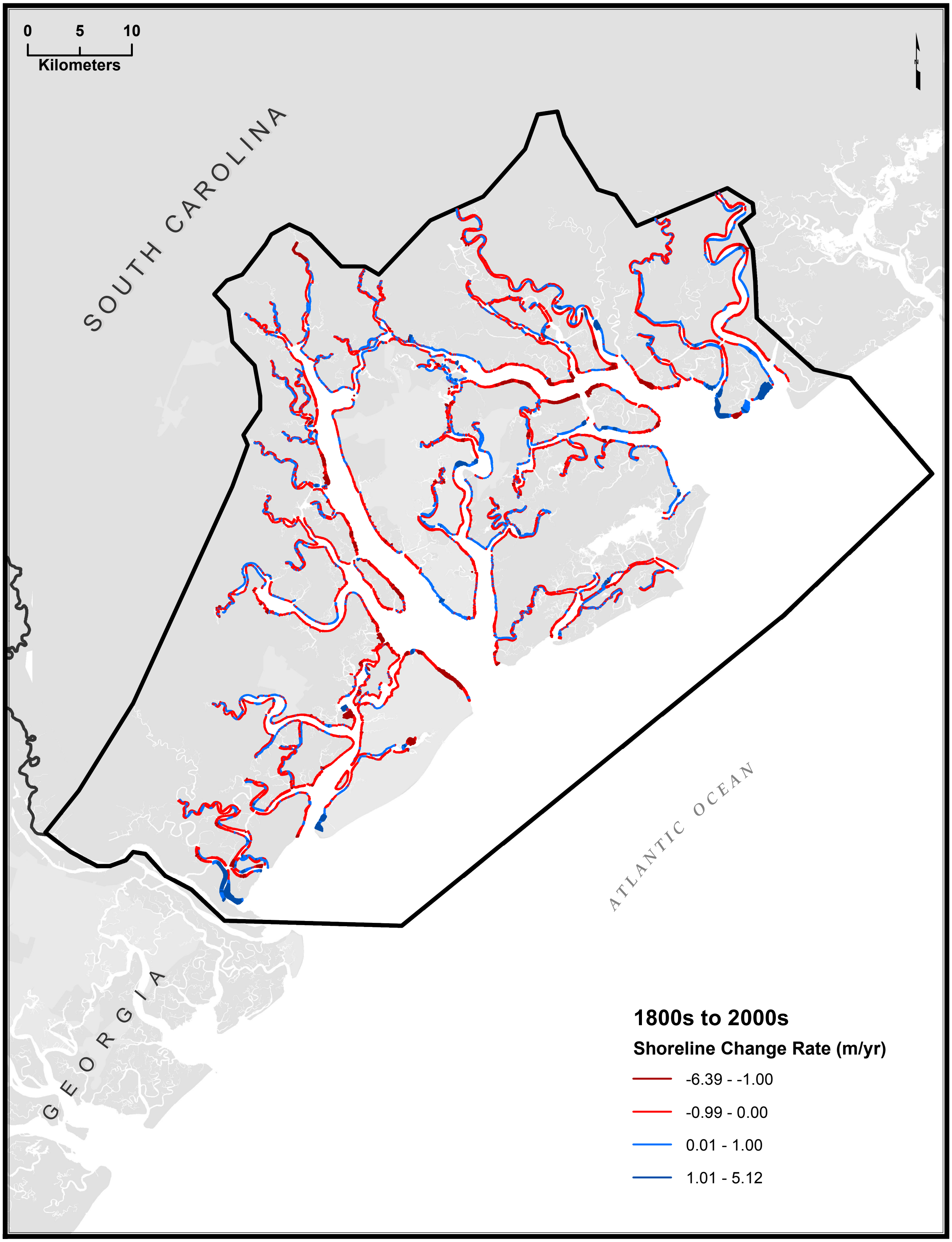

Figure 3-3. Map depicting shoreline change rates from 1800s to 2000s. Rate calculations are based on the EPR method. Positive values indicate accretion and negative values are erosion.

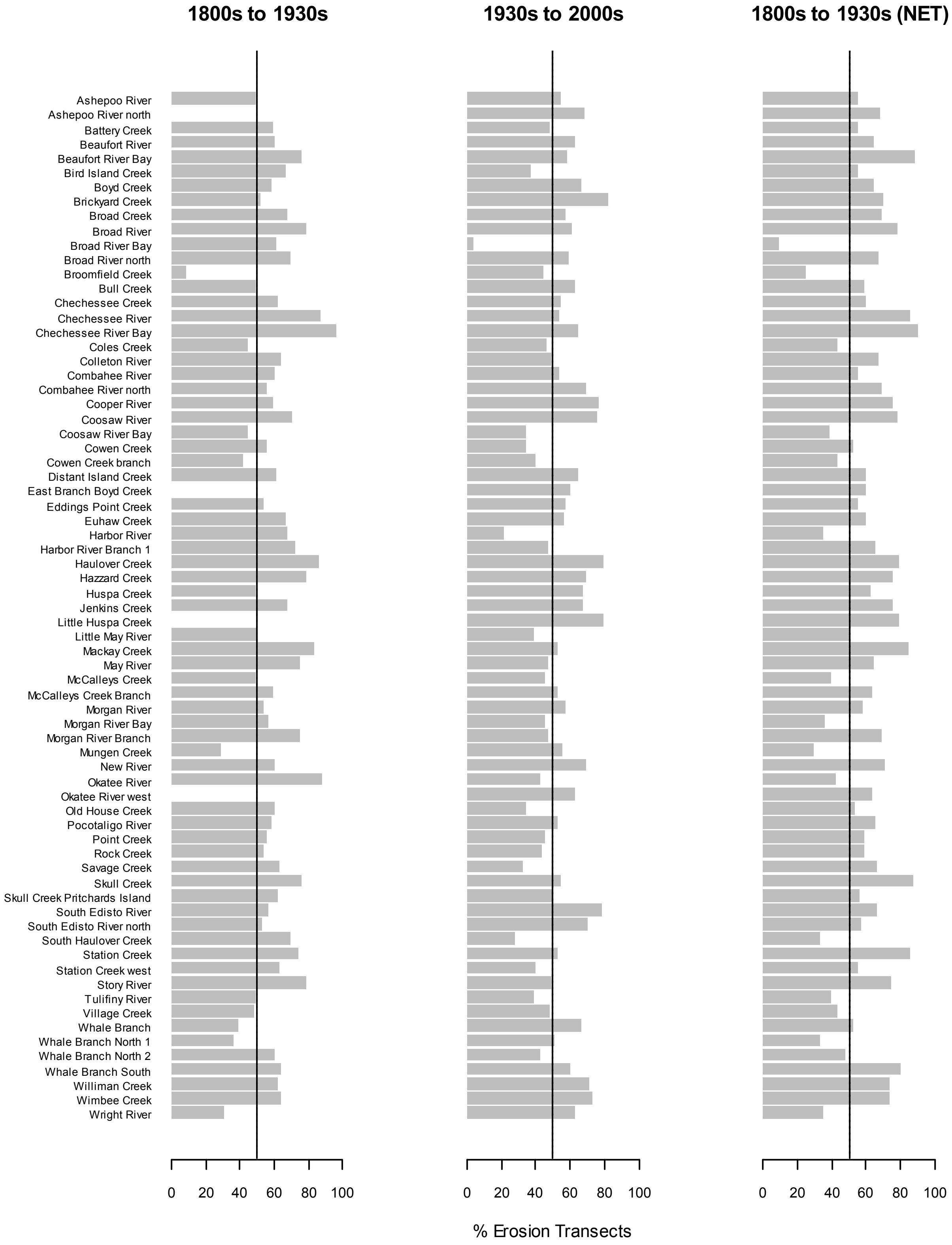

Figure 3-4. Graph of the percentage of erosion transects at each location.

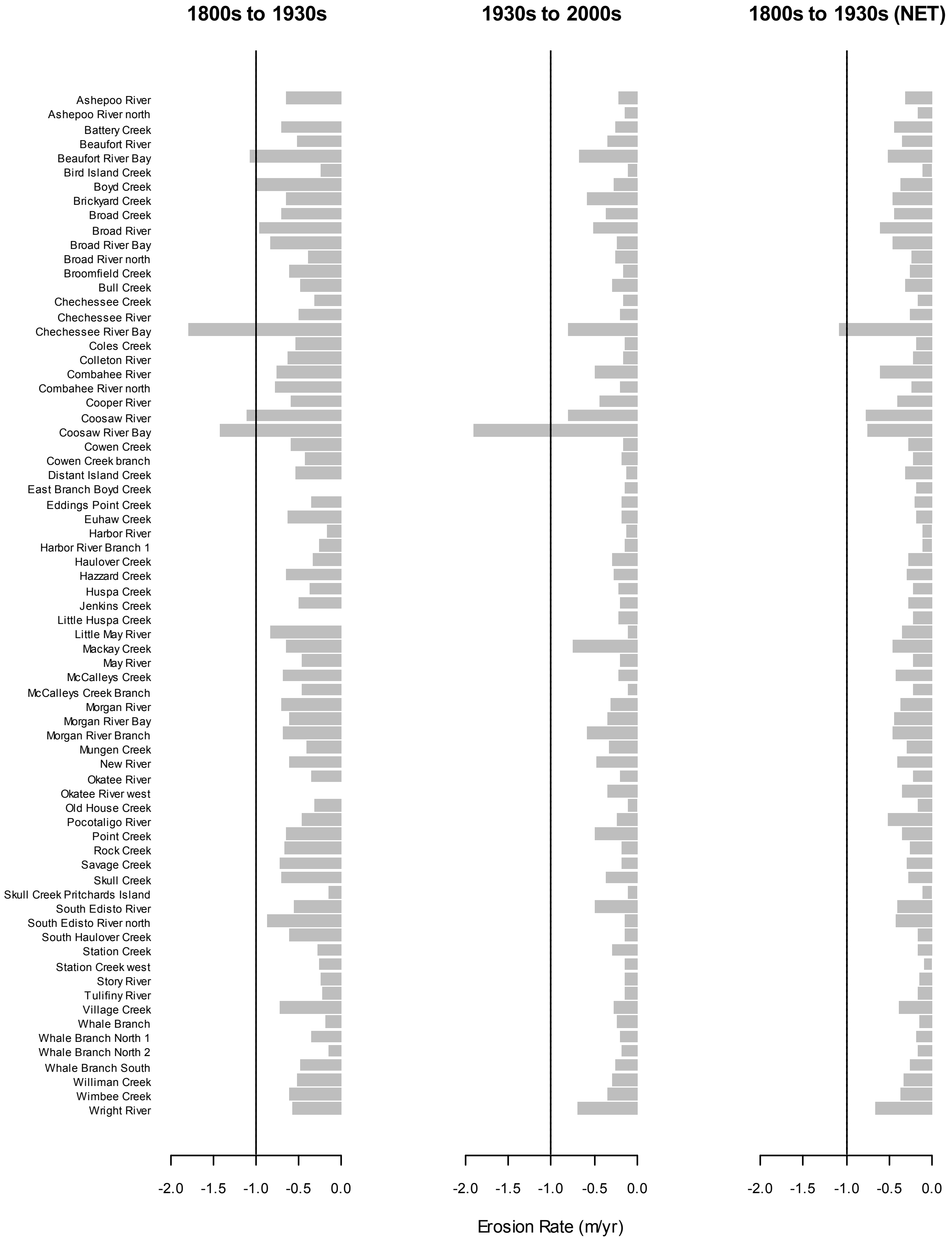

Figure 3-5. Graph of the mean erosion rate at each location. Erosion rates calculated using the EPR method.

Table 3-1. Summary of shoreline change rates for baseline locations during each era.

Classification	Mean Rate (m/yr)	% Erosion	Mean Erosion Rate (m/yr)	Mean Accretion Rate (m/yr)
1800s to 1930s (± 0.16 m/yr rate error)				
major stream	-0.25	65	-0.70	0.58
bay	-0.08	67	-1.39	2.60
minor stream	0.01	54	-0.56	0.68
intrabarrier	-0.19	70	-0.37	0.24
all	-0.16	62	-0.66	0.66
1930s to 2000s (± 0.11 m/yr rate error)				
major stream	-0.12	62	-0.38	0.32
bay	0.10	44	-1.00	0.94
minor stream	-0.05	57	-0.28	0.26
intrabarrier	0.04	47	-0.23	0.28
all	-0.07	58	-0.35	0.32
1800s to 2000s (± 0.10 m/yr rate error)				
major stream	-0.17	68	-0.39	0.32
bay	0.03	56	-0.85	1.13
minor stream	-0.05	58	-0.32	0.33
intrabarrier	-0.08	67	-0.20	0.18
all	-0.11	64	-0.36	0.35

Note: Rates with positive values indicate accretion and negative is erosion.

Table 3-2. Summary of shoreline change rates for feature types during each era.

Classification	Mean Rate (m/yr)	% Erosion	Mean Erosion Rate (m/yr)	Mean Accretion Rate (m/yr)
1800s to 1930s (± 0.16 m/yr rate error)				
marsh	-0.14	61	-0.62	0.62
upland or apparent mean high water	-0.26	70	-0.77	0.93
anthropogenic	0.30	38	-0.65	0.87
all	-0.16	62	-0.66	0.66
1930s to 2000s (± 0.11 m/yr rate error)				
marsh	-0.06	58	-0.31	0.29
upland or apparent mean high water	-0.11	58	-0.53	0.48
anthropogenic	-0.29	80	-0.41	0.20
all	-0.07	58	-0.35	0.32
1800s to 2000s (± 0.10 m/yr rate error)				
marsh	-0.09	63	-0.32	0.31
upland or apparent mean high water	-0.20	70	-0.51	0.51
anthropogenic	-0.44	91	-0.50	0.15
all	-0.11	64	-0.36	0.35

Note: Rates with positive values indicate accretion and negative is erosion

4.0 EROSION HOTSPOTS AND POTENTIAL FACTORS INFLUENCING CHANGE

A number of erosion hotspots have been identified along the estuarine shorelines within the study area (Figure 4-1). For the purpose of this study, erosion hotspots are defined as shoreline segments that have erosion rates that exceed a threshold rate of -1 m/yr throughout the 1800s to 2000s era; a rate threshold nearly three times the mean annual erosion rate calculated during this era. Erosion hotspots identified in this study are related to a number of factors with varying spatial and temporal extents. Understanding the nature and principle causes of the shoreline erosion in these hotspot areas, which are characterized by higher erosion rates, is critical to developing a sound shoreline management and preservation plan. This study only provides a brief overview of these hotspots and potential drivers of erosion based on cursory inspections of the data output from AMBUR analyses. A detailed literature review of previous site-specific locations and an extensive field campaign are needed to truly link erosion trends with these potential drivers and map the spatial and temporal extents of their influence.

Based on trends found in the data and depicted in Figure 4-1, erosion hotspots appear to be generally found along 4 main shoreline areas: bay/sounds/inlets, stream confluences, estuarine tidal meander cutbanks, and highly dissected (fragmented) tidal marsh/ mudflats. The Chechessee, Broad, Beaufort, Coosaw, and Combahee Rivers contain a number of hotspots where shoreline erosion averages between -1 to -6 m/yr and is of primary concern. Furthermore, these streams appear to show net widening or dilation throughout the study period (Figure 3-3). These larger tidal streams are also used as primary navigation channels for recreation and commercial vessels (Figure 4-1). It can be reasonably assumed that vessel traffic is potentially impacting these shorelines through boat wake activity in addition to natural processes such as sea level rise. It is unclear if net channel widening (net erosion) in some of the larger streams is primarily linked to sea level rise or anthropogenic activity. However, apart from sea level rise and storm impacts which are difficult to ascertain from this dataset alone, six other factors are identified that likely drive shoreline erosion within the study area: estuarine meander processes, tidal current dynamics at stream confluences, wind/wave exposure (fetch), boat activity, shoreline armoring and alterations, and dredging activity. Example locations where these factors are playing role in influencing the behavior of the shoreline can be found in Figures 4-2 and 4-3.

Changing current directions during ebb and flood tides within tidal streams influence the pattern of shoreline erosion, especially within meanders. Such reversals of flow directions in tidal streams are different from their inland counterparts uninfluenced by tides. In a typical non-tidal stream, erosion occurs along the cutbank or outer bend of the stream and deposition (accretion) occurs along the inner bend or point bar. In tidal meanders, given differences in flow velocities and durations of ebb and flood tides, erosion can become concentrated along a portion of the cutbank and widen the channel along one side or half of a given meander. Additionally, the inner point bar or section of the meander becomes sharpened and sometimes pointy in nature. In some cases, the inner side of the meander becomes a box-like shape. Anhert (1960) observed the estuarine meanders in the Chesapeake Bay and how differences in ebb and flood flow contribute to their shapes. Jackson (2010) observed them along the Georgia coast and quantified erosion patterns using AMBUR. The study found that these tidal meanders had erosion that is typically greater on the ebbdrift (downdrift) side of the meander due to ebb tidal velocities being greater than that of the flood (Jackson, 2010). The estuarine meanders identified in Figure 4-2 show that erosion is concentrated on the ebbdrift side (the side toward the sound/inlet/ocean). If one were to split the meander loop in half, the outer part of the loop will typically have more erosion in the downstream half (ebbdrift direction). Erosion rates can easily exceed -1 m/yr in some meanders. Although this erosion pattern is recognizable in a number of streams in the study area, not all tidal meanders exhibit this behavior and further work is needed to ascertain their complex morphologies.

Another stream related process where erosion can be prominent is at the confluence of two tidal streams (Figure 4-2). The shorelines appear to be quite active within these regions given the complexity of tidal currents entering and exiting multiple streams with differing widths and geometries. In Figure 4-2, two tidal streams (Wimbee Creek and Combahee River) are identified that join with the Coosaw River and contain larger areas of erosion concentrated at their respective confluences. These active shorelines have erosion rates that were mostly between -1 to -2 m/yr in these areas. The study area is punctuated with stream confluences that involve streams with various widths, depths, and shoreline compositions where shoreline movements appear to be more active than adjacent areas.

Shorelines within close proximity to bays/inlets/sounds, where the frequency and magnitude of erosion appears to be greater, have erosion rates between -1 to -5 m/yr. Linking these active shorelines to one particular process is difficult using this dataset alone. Factors influencing erosion likely involve a linkage between fetch and tidal inlet processes. Fetch, or wind/wave exposure, is typically greater in these areas and shorelines are subjected to increased wave activity than their more sheltered counterparts. Furthermore, changes in inlet dynamics can promote considerable shoreline change to adjacent shorelines through shoaling and sediment bypassing events.

Anthropogenic activity has also clearly shaped the behavior of some estuarine shoreline areas. Through dredging new and existing channels for the Atlantic Intracoastal Waterway (AIWW) as seen in Figure 4-2, and increased construction of shoreline armoring and other structures (Figure 4-3), the footprint of human activity on estuarine shorelines is visible and growing. Commercial and recreational vessel use and the need for adequate waterways and docking facilities is likely enhancing erosion through increased boating activity and associated boat wakes (Figure 4-3). This study cannot definitively link boat activity with shoreline erosion. It is likely a combination of anthropogenic activity and processes mentioned above that promote erosion in these areas. However, given the amount of erosion occurring along some of these major waterway routes, these areas should be of primary concern to managers and attempts should be made to lessen human impacts. Furthermore, shoreline erosion enhanced by armoring the shore with seawalls, bulkheads, and revetments should also be of a primary concern because they have the potential to translate erosion to adjacent, unprotected shorelines.

Finally, given the number of shoreline structures present along estuarine and upland shorelines and that it is increasing yearly, it is important for managers to 1.) recognize the vulnerability of existing shoreline structures to erosion, and, 2.) use shoreline erosion data in decisions to permit new structures or maintenance of existing structures. Using shoreline erosion data from AMBUR for only the streams analyzed for this study, an example analysis was conducted to show how managers could prioritize the monitoring of potentially vulnerable structures due to shoreline erosion. Transect locations along the modern shoreline were buffered to a distance of 50 years times the mean erosion rate. The resulting buffered areas were subsequently used to extract shoreline structures that would encounter an eroding shoreline within 50 years (Figure 4-4). Approximately, 615 structures are estimated to be threatened by potential shoreline erosion over the next 50 years. These types of analyses using AMBUR are useful for coastal managers/scientists trying to determine potentially vulnerable sites based on projected erosion rates. These techniques have also been used by the author to determine archaeological sites vulnerable to shoreline erosion along the Georgia coast. With nearly two-thirds of estuarine shorelines analyzed in this study experiencing net erosion since the 1800s, it is critical that additional shoreline studies are conducted to assess potential impacts of future sea level rise and increasing development along the shore. Likewise, studies of the upland-marsh boundary, a shoreline that could not be fully analyzed by this study, should be conducted with a sense of urgency given the density of development in these areas and pressure for future development.

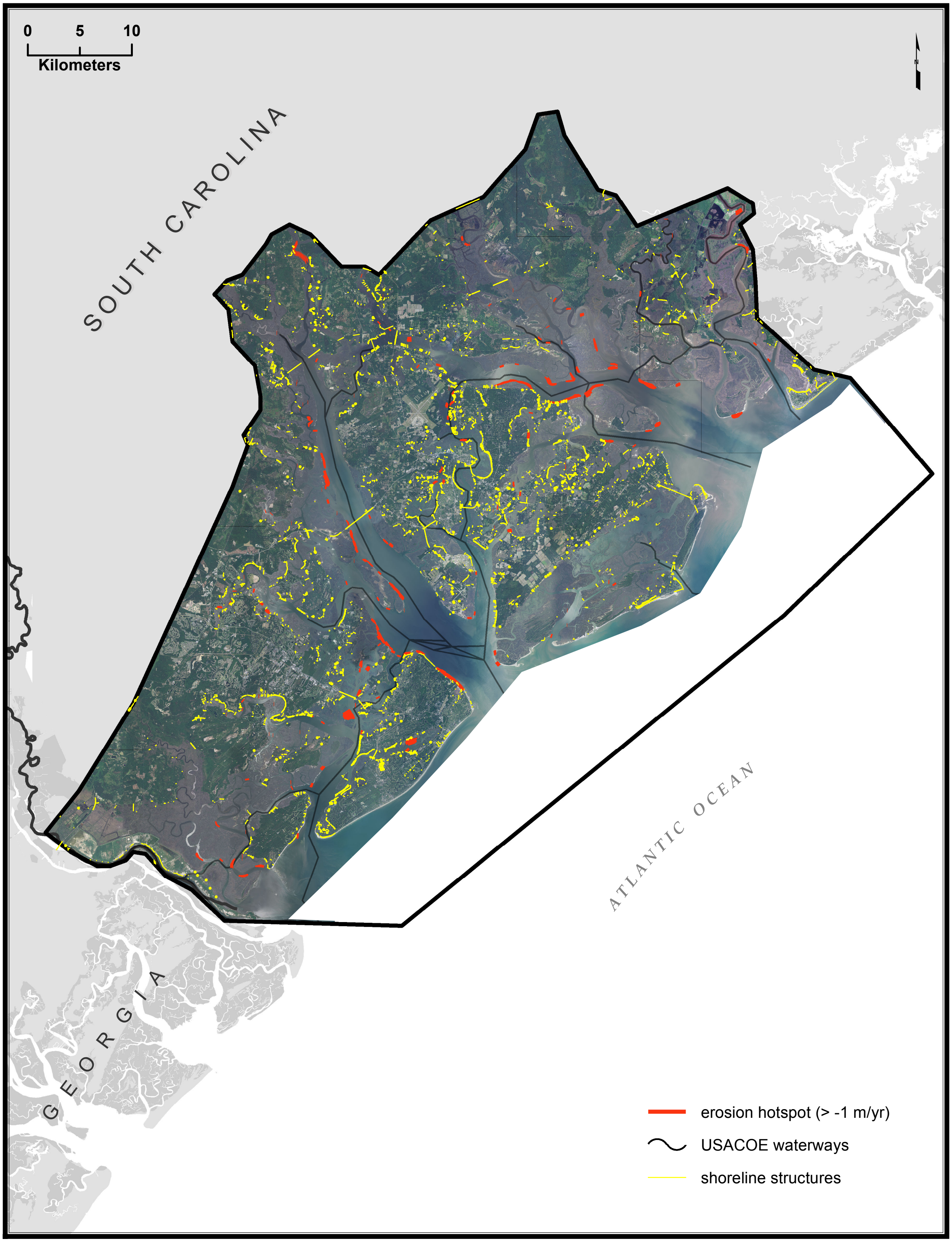

Figure 4-1. Map depicting erosion "hotspots" from 1800s to 2000s with shoreline structures and USACOE navigable waterway routes.

Figure 4-2. Map depicting erosion (red) with shoreline structures (yellow) and factors potentially influencing erosion patterns at specific areas.

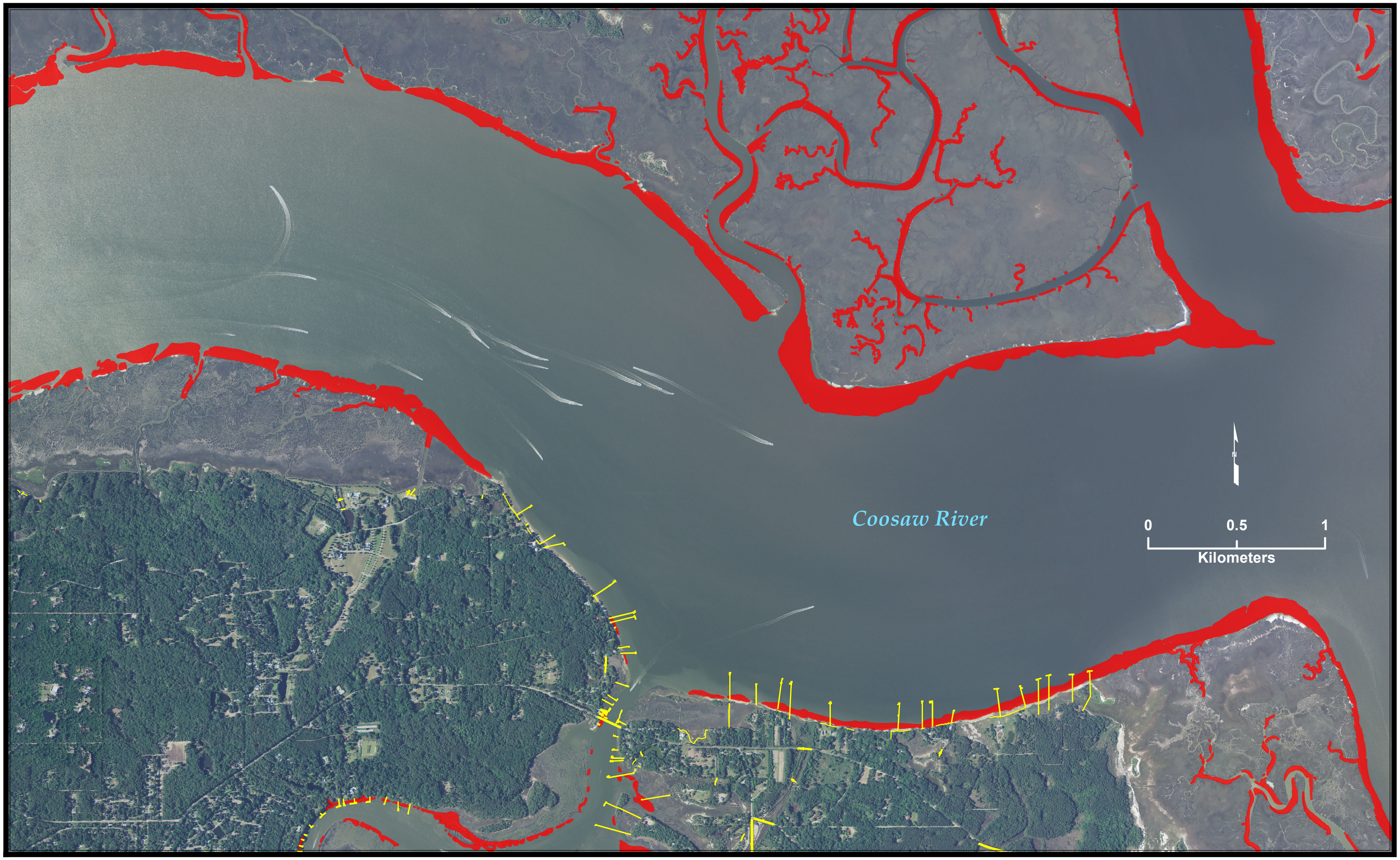

Figure 4-3. Map depicting erosion (red) with shoreline structures (yellow) and boating activity along the "Coosaw River Hotspot."

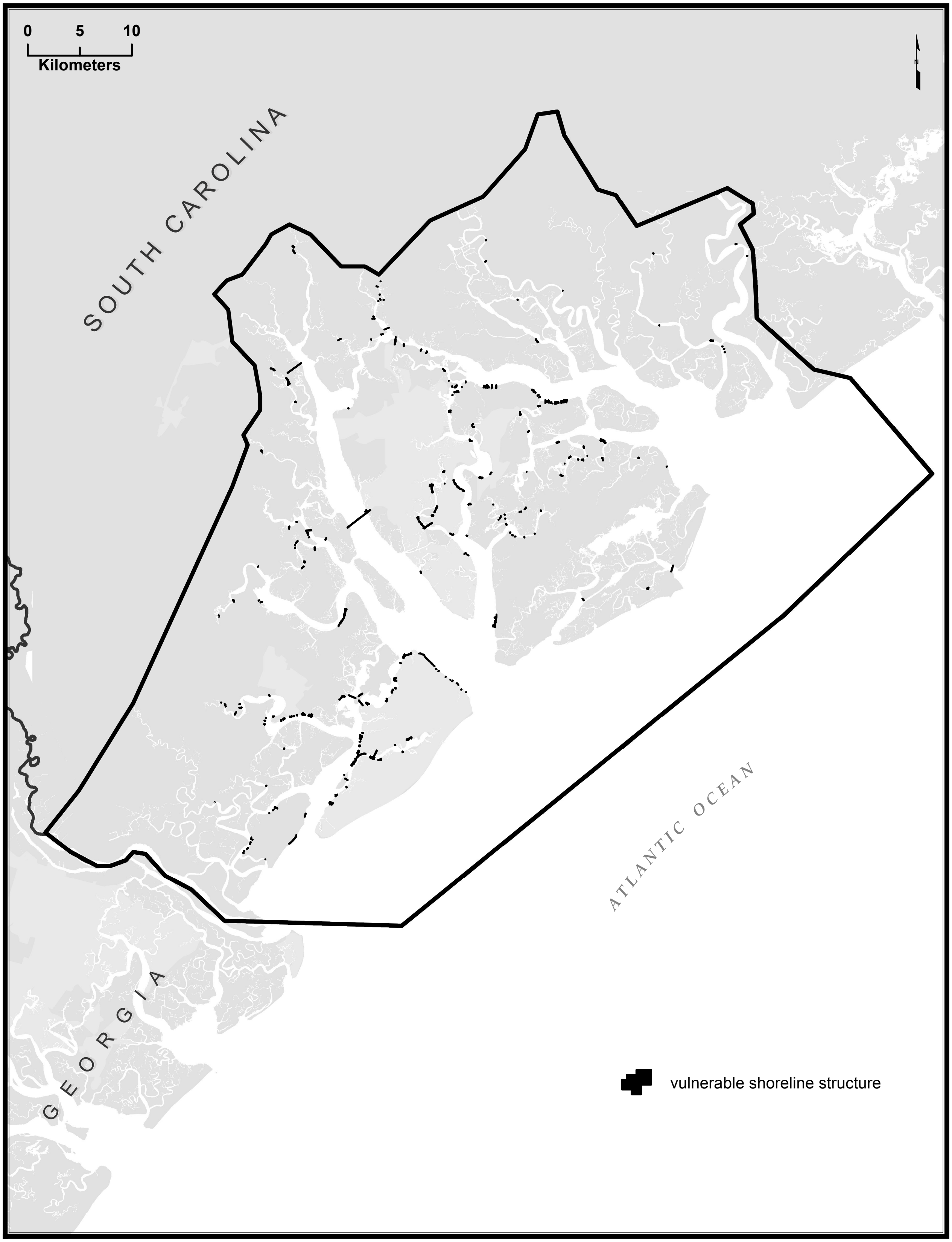

Figure 4-4. Shoreline structures vulnerable to erosion within 50 years based on extrapolation of erosion rates. Approximately 615 structures are threatened based on available erosion data.

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APPENDIX A – Additional Shoreline Change Summary Tables

Appendix A1. Summary of shoreline change rates for approximated 2006 land-use/cover classifications.

Location	Mean Rate (m/yr)	% Erosion	Mean Erosion Rate (m/yr)	Mean Accretion Rate (m/yr)
BAY/ESTUARY	-0.03	59	-0.30	0.35
NON-FORESTED WETLAND	-0.18	69	-0.39	0.29
FORESTED WETLAND	-0.50	80	-0.72	0.36
CROPLAND/PASTURE	-0.20	75	-0.30	0.11
EVERGREEN UPLAND FOREST	-0.21	75	-0.34	0.19
SANDY AREA	-0.03	58	-0.62	0.77
TRANSPORTATION/UTILITIES	0.12	43	-0.14	0.33
MIXED UPLAND FOREST	-0.17	69	-0.30	0.13
RESIDENTIAL	0.05	58	-0.30	0.53
COMMERCIAL/SERVICES	-0.16	76	-0.28	0.20
BEACHES	0.16	56	-0.97	1.63
OTHER URBAN	-0.13	73	-0.41	0.63
UPLAND PLANTED PINE	-0.11	76	-0.21	0.22

Note: Rates with positive values indicate accretion and negative is erosion

Appendix A2. Summary of shoreline change rates for stream location during each era.

Location	1800s to 1930s (n transects = 18,757)				1930s to 2000s (n transects = 23,359)				1800s to 2000s (NET) (n transects = 23,695)			
	Mean Rate (m/yr)	% Erosion	Mean Erosion Rate (m/yr)	Mean Accretion Rate (m/yr)	Mean Rate (m/yr)	% Erosion	Mean Erosion Rate (m/yr)	Mean Accretion Rate (m/yr)	Mean Rate (m/yr)	% Erosion	Mean Erosion Rate (m/yr)	Mean Accretion Rate (m/yr)
Ashepoo River	-0.06	49	-0.65	0.50	0.09	54	-0.21	0.44	0.01	55	-0.31	0.42
Ashepoo River north	no data	no data	no data	no data	-0.07	68	-0.15	0.11	-0.07	68	-0.16	0.11
Battery Creek	-0.10	59	-0.70	0.77	0.02	48	-0.25	0.26	-0.05	55	-0.44	0.42
Beaufort River	-0.04	60	-0.53	0.69	-0.11	63	-0.34	0.28	-0.08	64	-0.34	0.38
Beaufort River Bay	-0.64	76	-1.07	0.73	-0.18	58	-0.67	0.49	-0.42	88	-0.52	0.32
Bird Island Creek	-0.07	66	-0.25	0.28	0.04	37	-0.10	0.13	-0.01	55	-0.10	0.10
Boyd Creek	-0.40	58	-1.01	0.45	-0.12	66	-0.27	0.19	-0.16	64	-0.36	0.20
Brickyard Creek	-0.10	52	-0.66	0.52	-0.39	82	-0.58	0.46	-0.25	70	-0.45	0.22
Broad Creek	-0.33	67	-0.70	0.42	-0.13	57	-0.36	0.17	-0.23	69	-0.44	0.22
Broad River	-0.68	78	-0.96	0.33	-0.19	61	-0.51	0.31	-0.42	78	-0.60	0.21
Broad River Bay	-0.30	61	-0.84	0.54	1.13	4	-0.24	1.18	0.45	9	-0.46	0.53
Broad River north	-0.18	69	-0.40	0.30	-0.07	59	-0.25	0.18	-0.12	67	-0.24	0.14
Broomfield Creek	0.47	8	-0.61	0.57	0.02	44	-0.16	0.16	0.15	25	-0.25	0.28
Bull Creek	-0.04	49	-0.49	0.40	-0.10	63	-0.28	0.20	-0.08	59	-0.31	0.23
Chechessee Creek	-0.11	62	-0.32	0.23	0.00	54	-0.16	0.19	-0.05	60	-0.17	0.12
Chechessee River	-0.42	87	-0.51	0.16	-0.02	53	-0.20	0.18	-0.21	85	-0.26	0.09
Chechessee River Bay	-1.66	96	-1.79	1.11	-0.21	64	-0.81	0.82	-0.92	90	-1.08	0.61
Coles Creek	0.22	44	-0.55	0.82	0.01	46	-0.15	0.15	0.05	43	-0.19	0.23
Colleton River	-0.31	64	-0.64	0.28	0.11	49	-0.16	0.37	-0.09	67	-0.21	0.16
Combahee River	-0.18	60	-0.77	0.71	0.10	53	-0.50	0.78	0.01	55	-0.60	0.76
Combahee River north	-0.01	55	-0.79	0.92	-0.09	69	-0.20	0.16	-0.09	69	-0.23	0.23
Cooper River	-0.19	59	-0.59	0.40	-0.26	76	-0.44	0.31	-0.22	75	-0.40	0.30
Coosaw River	-0.59	70	-1.12	0.62	-0.49	75	-0.80	0.45	-0.54	78	-0.77	0.28
Coosaw River Bay	1.69	44	-1.42	4.16	0.10	34	-1.90	1.15	0.94	38	-0.75	1.97
Cowen Creek	-0.04	55	-0.60	0.64	0.05	34	-0.16	0.15	0.00	52	-0.28	0.31
Cowen Creek branch	0.05	42	-0.43	0.40	0.05	40	-0.17	0.19	0.04	43	-0.21	0.23
Distant Island Creek	-0.15	61	-0.55	0.48	-0.02	64	-0.13	0.18	-0.11	60	-0.32	0.20
East Branch Boyd Creek	no data	no data	no data	no data	-0.04	60	-0.15	0.12	-0.06	60	-0.18	0.12
Eddings Point Creek	-0.06	54	-0.35	0.30	-0.02	57	-0.18	0.19	-0.05	55	-0.20	0.15
Euhaw Creek	-0.24	66	-0.63	0.50	0.00	56	-0.17	0.22	-0.03	60	-0.19	0.20
Harbor River	-0.05	67	-0.17	0.20	0.45	21	-0.12	0.60	0.19	35	-0.10	0.35
Harbor River Branch 1	-0.17	72	-0.27	0.11	0.15	47	-0.14	0.40	-0.02	65	-0.11	0.15
Haulover Creek	-0.27	86	-0.34	0.18	-0.18	79	-0.28	0.21	-0.18	79	-0.27	0.21
Hazzard Creek	-0.47	78	-0.65	0.16	-0.13	69	-0.27	0.17	-0.19	75	-0.30	0.14
Huspa Creek	-0.01	49	-0.37	0.35	-0.10	67	-0.22	0.13	-0.08	62	-0.22	0.14
Jenkins Creek	-0.25	67	-0.50	0.27	-0.10	67	-0.20	0.10	-0.17	75	-0.28	0.16
Little Huspa Creek	no data	no data	no data	no data	-0.14	79	-0.21	0.11	-0.15	79	-0.22	0.11
Little May River	-0.15	50	-0.83	0.53	0.03	39	-0.10	0.12	-0.06	50	-0.35	0.23
Mackay Creek	-0.33	83	-0.65	1.19	-0.13	52	-0.75	0.55	-0.23	84	-0.46	0.98
May River	-0.25	75	-0.47	0.41	0.03	47	-0.20	0.24	-0.08	64	-0.22	0.19
McCalleys Creek	0.02	49	-0.69	0.71	0.14	45	-0.22	0.44	0.07	39	-0.43	0.39
McCalleys Creek Branch	-0.08	59	-0.46	0.47	0.08	52	-0.10	0.28	0.01	63	-0.21	0.38
Morgan River	-0.10	54	-0.71	0.63	-0.04	57	-0.31	0.31	-0.07	58	-0.36	0.35
Morgan River Bay	-0.08	56	-0.61	0.59	0.06	45	-0.34	0.39	-0.01	36	-0.44	0.23
Morgan River Branch	-0.34	75	-0.69	0.72	-0.12	47	-0.59	0.29	-0.22	69	-0.45	0.29
Mungen Creek	0.42	29	-0.42	0.76	-0.02	55	-0.33	0.35	0.19	29	-0.30	0.39
New River	-0.11	60	-0.61	0.64	-0.21	69	-0.48	0.38	-0.17	71	-0.41	0.43
Okatee River	-0.30	88	-0.35	0.00	0.04	42	-0.20	0.21	0.03	42	-0.21	0.21
Okatee River west	no data	no data	no data	no data	-0.15	63	-0.34	0.16	-0.16	63	-0.35	0.16
Old House Creek	-0.11	60	-0.33	0.22	0.06	34	-0.11	0.15	-0.03	53	-0.16	0.12
Pocotaligo River	-0.10	58	-0.47	0.42	0.00	52	-0.23	0.26	-0.26	65	-0.51	0.20
Point Creek	-0.19	55	-0.66	0.39	-0.05	45	-0.50	0.32	-0.12	59	-0.35	0.21
Rock Creek	-0.12	54	-0.67	0.51	0.09	43	-0.18	0.30	-0.01	59	-0.25	0.34
Savage Creek	-0.22	63	-0.73	0.65	0.18	32	-0.17	0.35	-0.03	66	-0.29	0.47
Skull Creek	-0.48	76	-0.70	0.23	0.06	54	-0.37	0.56	-0.22	87	-0.27	0.13
Skull Creek Pritchards Island	-0.06	62	-0.16	0.10	0.02	50	-0.10	0.14	-0.02	56	-0.10	0.07
South Edisto River	-0.03	56	-0.56	0.64	-0.31	78	-0.49	0.31	-0.16	66	-0.41	0.30
South Edisto River north	-0.11	53	-0.88	0.78	-0.04	70	-0.14	0.21	-0.07	57	-0.42	0.39
South Haulover Creek	-0.37	69	-0.61	0.18	0.09	28	-0.14	0.18	0.06	33	-0.16	0.16
Station Creek	-0.14	74	-0.29	0.27	-0.05	52	-0.28	0.20	-0.11	85	-0.17	0.23
Station Creek west	-0.08	63	-0.26	0.22	0.06	40	-0.15	0.21	-0.01	55	-0.09	0.08
Story River	-0.13	78	-0.25	0.29	0.08	49	-0.15	0.30	-0.03	74	-0.15	0.30
Tulifiny River	0.08	49	-0.23	0.37	0.06	39	-0.15	0.20	0.07	39	-0.16	0.22
Village Creek	-0.10	48	-0.72	0.49	0.11	48	-0.27	0.47	0.00	43	-0.38	0.29
Whale Branch	0.15	39	-0.19	0.37	-0.12	66	-0.24	0.12	0.01	52	-0.14	0.18
Whale Branch North 1	0.19	36	-0.35	0.50	-0.03	51	-0.19	0.14	0.08	33	-0.18	0.21
Whale Branch North 2	0.01	60	-0.16	0.25	0.03	42	-0.18	0.18	0.00	48	-0.16	0.14
Whale Branch South	-0.25	64	-0.48	0.16	-0.12	60	-0.26	0.10	-0.18	80	-0.26	0.12
Williman Creek	-0.14	62	-0.52	0.49	-0.07	71	-0.28	0.44	-0.13	73	-0.33	0.41
Wimbee Creek	-0.24	64	-0.62	0.42	-0.21	73	-0.34	0.16	-0.21	73	-0.36	0.20
Wright River	1.62	31	-0.57	2.62	-0.02	63	-0.69	1.14	0.81	35	-0.66	1.60
all	-0.16	62	-0.66	0.66	-0.07	58	-0.35	0.32	-0.11	64	-0.36	0.35

Note: Rates with positive values indicate accretion and negative is erosion

APPENDIX B – Examples of Digitized Anthropogenic Shoreline Structures

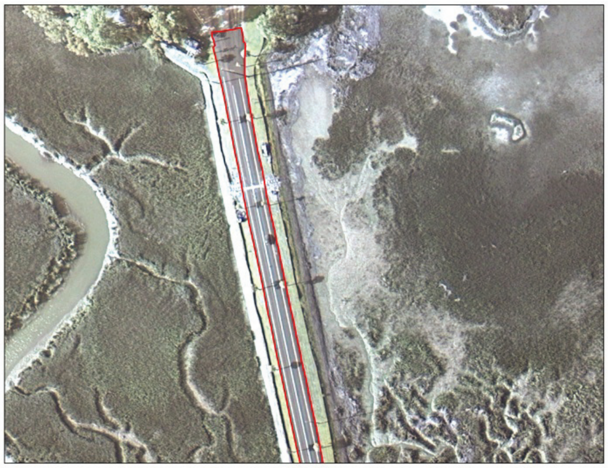
Boat Ramp (11)

Breakwater (21)

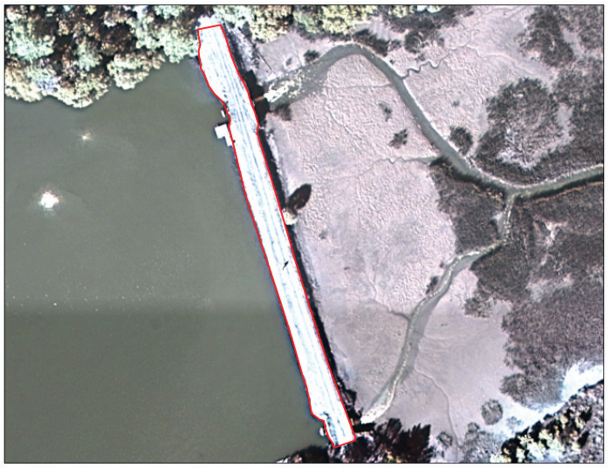
Non-Vehicular Bridge (31.1)

Vehicular Bridge (31.2)

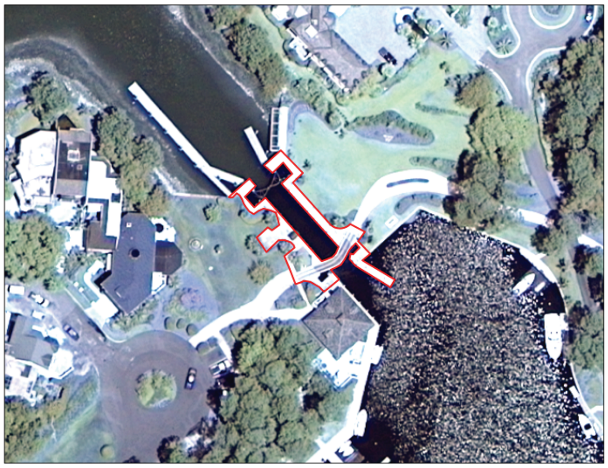
Culvert (31.3)



Causeway (33)



Dam (35.1)



Lock (35.3)

Groin (41.1)

Jetty (41.2)

Pier (51.1)

Walkway (51.2)

Wharf (51.3)

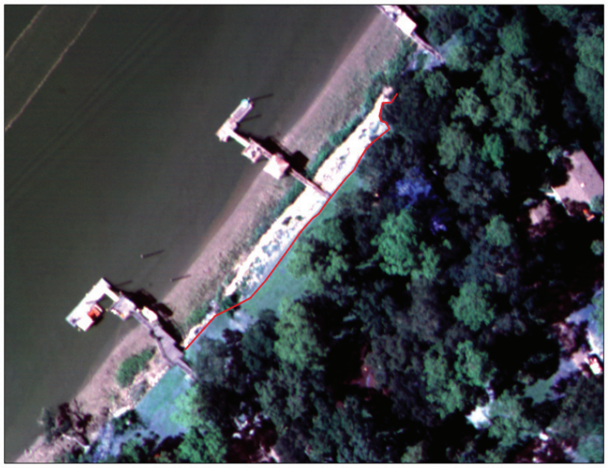
Gangway (51.4)

Dock (51.5)

Commercial Complex (53)

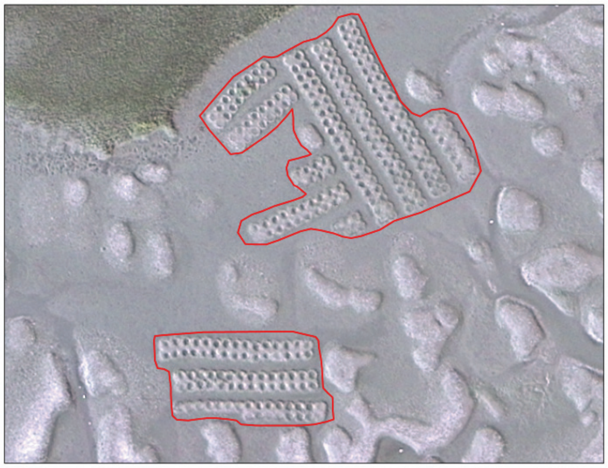
Sill (61.1)

Revetment (71.1)



Riprap (71.2)

Concrete Slope (71.3)



Unknown (81)

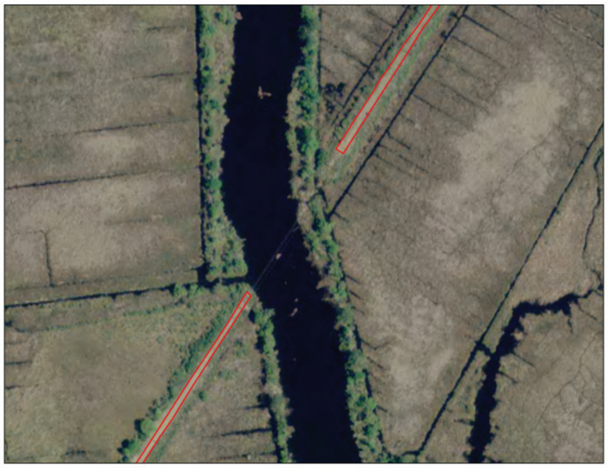
Bulkhead (91.1)

Seawall (91.2)

Vertical Structure fronted by Sloped Structure (101.1)

T-groin (101.2)

Abandoned/Historic Boat Ramp (111.11)



Abandoned/Historic Causeway (111.33)

Abandoned/Historic Dock (111.51)