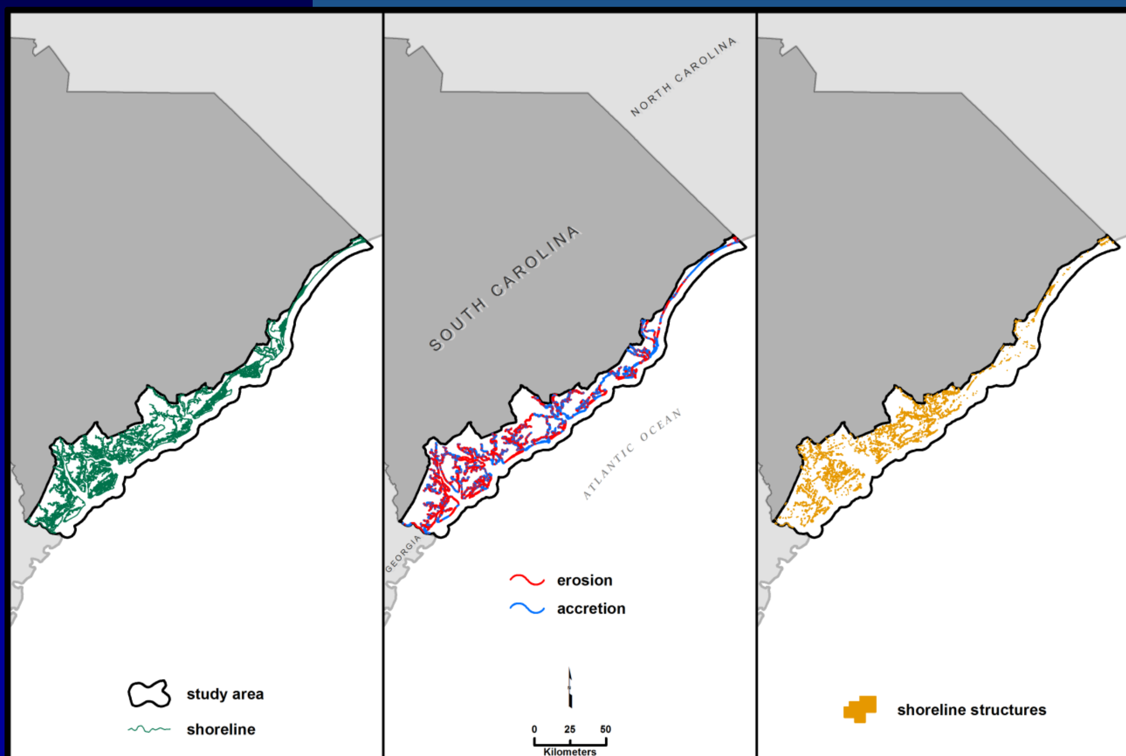
MAPPING COASTAL EROSION HAZARDS ALONG SHELTERED COASTLINES IN SOUTH CAROLINA 1849 to 2015



Summary Report Submitted to:

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

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

Prepared by:

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MAPPING COASTAL EROSION HAZARDS ALONG SHELTERED AND OCEANFRONT COASTLINES IN SOUTH CAROLINA
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EXECUTIVE SUMMARY

Estuarine shoreline erosion, in addition to oceanfront erosion, is becoming more of a focus for coastal managers as waterfront development continues to grow, and both residential and commercial properties are threatened by shifting shorelines. In 2012, the U.S. Army Corps of Engineers (Charleston District) and the South Carolina Department of Health and Environmental Control, Ocean and Coastal Resource Management (SCDHEC-OCRM) conducted a pilot study within Jasper, Beaufort, and Colleton counties to map shorelines, calculate shoreline change, and ascertain the extent and potential drivers of historical shoreline change in order to assist with local and state planning efforts. Following that pilot study, SCDHEC-OCRM contracted with the Applied Coastal Research Lab at Georgia Southern University in 2014 to complete this work along the South Carolina coast. This project assessed the remaining estuarine, oceanfront, and inlet shoreline positions, calculated shoreline change rates, and identified erosion hotspots, as well as potential drivers to assist in risk assessments and economic studies to help coastal communities develop and prioritize responses to shoreline change projections. The project also digitized all anthropogenic shoreline features (e.g. docks, seawalls, bulkheads) within the study area.

Historical shorelines were assembled and changes analyzed using Analyzing Moving Boundaries Using R (AMBUR) for shorelines from the 1800s, 1930s, and 2000s. The 2000s high-resolution shoreline was created by digitizing from highly controlled aerial and LiDAR imagery, and contains 14,103 km (8,763 miles) of shore along the marsh-water, upland-water boundary, and approximate high water line on beaches. Both the 1800s and 1930s shorelines were derived from U.S. Coast and Geodetic Survey, now National Ocean Service (NOS), topographic or T-sheets.

There were 17,775 anthropogenic shoreline features 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. Over half (~57%) of all shorelines sampled at 53,552 transect locations experienced net erosion during the 1800s to 2000s time period. The average long-term erosion rate was -0.55 m/yr (± 0.11m/yr). Estuarine shorelines located near bays/sounds/inlets and stream confluences typically had higher shoreline change rates. Oceanfront shorelines had higher rates near inlets. Apart from sea level rise and storm impacts, which were not addressed, six other factors were identified as likely drivers of 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.

The shoreline change data presented in this report depict information on the erosion and accretion trends for the study area from the 1800s through 2015, and can be used for future shoreline change and coastal vulnerability analyses. This report is an update of the original Phase I report and includes oceanfront and inlet shoreline data, in addition to estuarine shoreline change data for the entire coastline of South Carolina. Similar findings to Phase I, in terms of processes and drivers of erosion, are presented throughout the coast. This report also provides an updated methodology section, in addition to shoreline change and structures data.

This study ultimately found that some areas within the region are experiencing considerable shoreline erosion, which 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. Some of the highest erosion rates are found along the oceanfront and inlet-facing shorelines, since they are unsheltered from open ocean processes.

1.0 SHORELINE CHANGE REPORT

1.1 Introduction

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).

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.

Between 2012 and 2014, 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 the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, performed a pilot study to assess estuarine, oceanfront, and inlet shoreline positions, calculate shoreline change rates, and identify erosion hotspots. The pilot study also identified potential drivers to assist in risk assessments and economic studies to help coastal communities develop and prioritize responses to shoreline change projections. This work developed shoreline data inland of oceanfront areas, estimated erosion rates along major coastal estuarine streams, and developed improved information products for local governments. The project area focused on the coastline from the Georgia/South Carolina border to Capers Inlet, just north of Charleston.

In 2014, SCDHEC-OCRM contracted with the Applied Coastal Research Lab at Georgia Southern University to complete the rest of the South Carolina coast, and to create seamless coast-wide datasets for digitized shorelines, shoreline change, and shoreline structures.

There were four main objectives of this shoreline change study:

- Digitize three historical shorelines in the study region (Figure 1.1)
- Digitize shoreline alterations in the study region
- Use AMBUR to determine long-term shoreline change rates
- Determine erosion hotspots, erosion drivers, and management implications

The southern portion of the study area in the ACE Basin tends to be tidal-dominate and transitions to a lower tide range along the Myrtle Beach/Grand Strand area. 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, such as docks, seawalls and bulkheads, were mapped within ArcGIS 10.3.1 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.

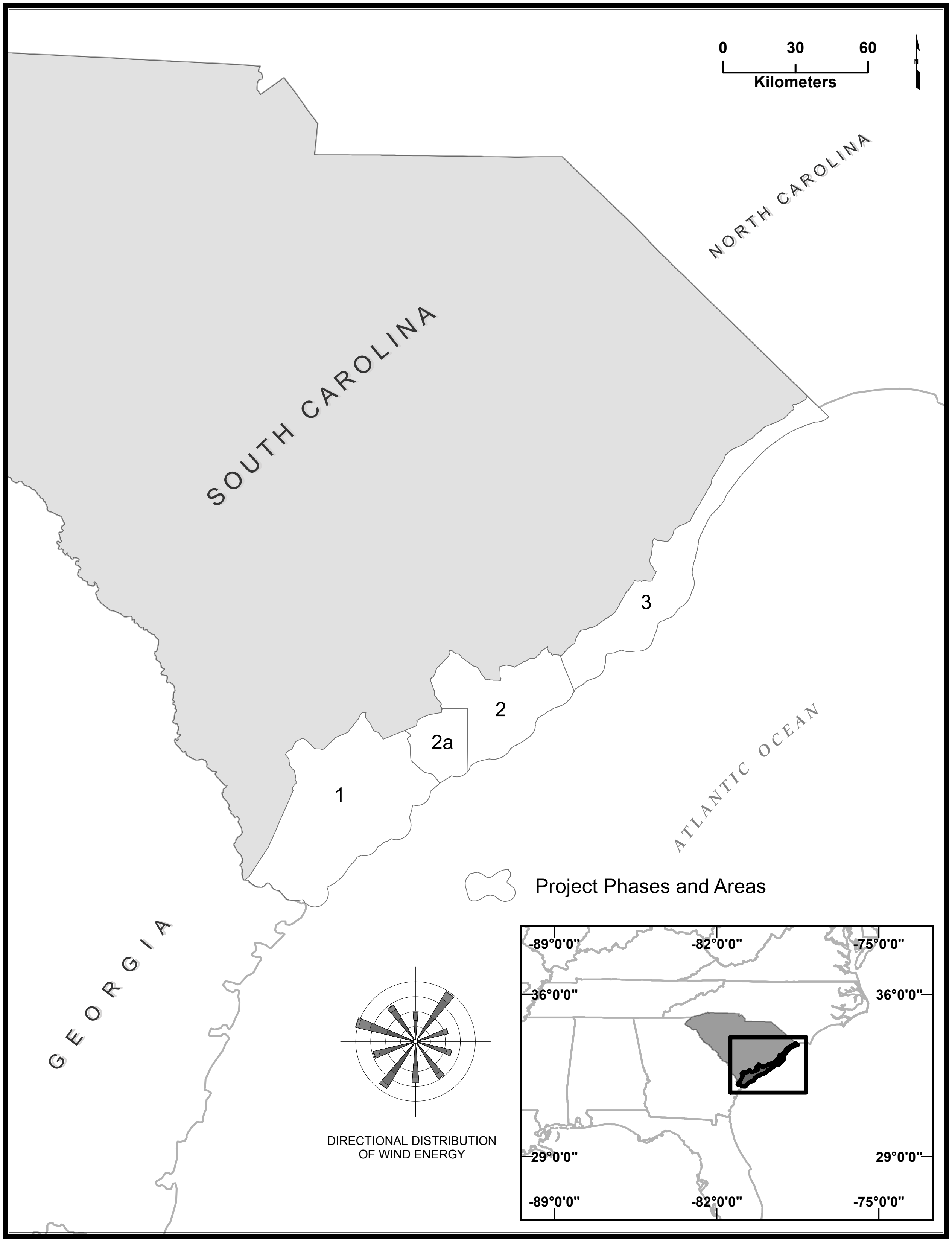

Figure 1-1. Location map of study area within South Carolina's coast. Wind rose based on data recorded at Savannah from 1961 to 1990.

2.0 METHODOLOGY

Three historical shorelines, one from the 1800s, 1930s and 2000s, were digitized in the study area, along with shoreline structures within a GIS framework based on established and partially modified mapping protocols (Figure 2-1). The shorelines represent three distinct time periods and can be directly compared for shoreline change analysis within reasonable shoreline position error (Table 2-1). Since 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)

Historical aerial photographs, coastal charts, and survey maps provide a wealth of shoreline and morphologic data. Representative sets from these data sources were obtained from the U.S. Geological Survey (USGS), the U.S. Coast and Geodetic Survey, now the NOS, 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 shorelines were assembled from multiple dates: one for the mid-to-late 1800s, and one for the 1930s. The 1930s shoreline provided more detail and extensive coverage of the study area. 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. Given the rigor of methods used to map the 1930s shoreline, it provides the most complete and detailed shoreline map of the coast.

2.2 Digitization of Modern Shoreline Positions (2000s)

To produce a modern shoreline to compare with the two historical shorelines, a combination of NOAA high resolution aerial photography surveys, orthophotography, and LiDAR imagery were used. 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 resolution. Aerial photography obtained from the South Carolina Department of Natural Resources (SCNDR), 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. Additional National Aerial Imagery Program (NAIP) orthophotography, obtained through the U.S. Department of Agriculture (USDA) Geospatial Data Gateway (https://datagateway.nrcs.usda.gov/) and the USDA's Farm Service Agency for various years between 2010 to 2015, had comparable accuracies of approximately ± 5 meters.

Two primary methodologies were used to digitize shorelines from aerial photography. The first was developed by the North Carolina Division of Coastal Management (NCDCM) (Geis, and Bendell, 2008), and the second was developed by SCDNR (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 all of the 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 1:1,000. They were then converted into an ESRI polyline shapefile for each image and the attribute table was populated with fields and attributes uniquely identifying the shoreline segments and making them compatible with AMBUR software.

Shoreline segments were attributed by the following locations: upland or apparent mean high-water line, marsh, anthropogenic (shoreline armoring), and unknown if the shoreline was unable to be identified. Table 2-2 summarizes the lengths of the features digitized for the modern 2000s shoreline with 8,763 miles of digital shore mapped. The primary shoreline classifications used here have been adopted by coastal researchers from North Carolina, South Carolina, Georgia, and Florida as part of the Governors' South Atlantic Alliance. These groups of researchers were 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 using AMBUR-Hazard Vulnerability Assessment (HVA) software developed by the author. Maintaining consistent methodology will provide consistent analyses between locations.

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 including map or photo scale, line-width of a plotted shoreline on a map, and interpretation of the high-water line can affect 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 meters for shoreline positions derived from various sources, such as aerial photos and T-sheets, to estimate mapping inaccuracies. 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 position error estimates of T-sheets were assessed by comparing benchmarks located on the maps with the National Geodetic Survey's benchmark shapefile. Some shoreline positions were corrected to reduce horizontal error below a target of 10 meters. The corrections improved the alignment of benchmarks on the T-sheets with the National Geodetic Survey's most recent surveys of those matching benchmarks and thus improved the spatial accuracy of shoreline features. However, some older maps exceeded the horizontal error target of 10 meters due to a number of factors such as shrinking or warping of the original paper maps that can cause features to become distorted and difficult to correct. A summary of shoreline data sources and their worst-case shoreline position error estimates are provided in Table 2-1. In the current study, worst-case shoreline position error estimates ranged from 1 to 15 meters for historical shorelines.

2.4 Calculation of Shoreline Change

AMBUR was employed to calculate shoreline change by measuring the position differences of two or more historic shorelines along transects (Jackson et al., 2012). Transects were cast at orientations in the direction of shoreline movement along a baseline at a spacing interval of 50 meters.

The creation of a baseline involved buffering each side of the historical shorelines 25 meters in ArcGIS. The resulting polygon buffers were buffered again using a negative value of 24 meters. Performing both the positive and negative buffers filtered out smaller tidal streams less than 50 meters wide where accuracy might be an issue or only one shoreline was present. For example, the modern shoreline was digitized at such a high resolution that smaller streams not found on other datasets proved to complicate the analysis process. These small streams had to be either manually removed or removed through a more automated and less subjective way. Additional shoreline change data can be extracted with streams that are smaller than 50 meters wide, but the process is time consuming and exceeded the scope of this project. Finally, utilizing the negative buffers, an offshore and an onshore baseline were extracted and prepared. This is the double baseline technique described in Jackson, 2012. A map of baseline locations is provided in Figure 2-2, and a summary of their attributes are in Table 2-3. Baseline locations were placed primarily in navigable waterways (Figure 2-2), and/or, in the first primary channel extending from a major sound or inlet that originates in the upland. Major tidal streams that branched off larger river systems (e.g. Broad River) that encountered upland areas were include in the analysis. Minor streams, such as those that branched off into marsh-only areas, were also included in the analysis where the data and methodology permitted. Baselines were also located at shorelines adjacent to sounds or inlets and oceanfront.

Another reason this study did not use smaller, more active tidal streams in establishing baselines is that 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 or present. Also, shifting geometries of meanders can complicate determining shoreline change rates using transect methods because of marked shifts in their movements and curvature. Small tidal streams/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.

In the historical dataset containing the 1800s, 1900s, and 2000s shorelines, all stream shorelines were overlaid to ensure the following: 1.) There was a minimum width between each side of the streams at least 50 meters wide, and 2.) No shoreline moved through that 50-meter wide swath of water for the entire study period. All shorelines meeting these criteria were analyzed. Transects were intersected with shorelines in AMBUR and analyzed using the *ambur.analysis* function to perform shoreline change calculations using the double baseline technique. Transects were cast from the offshore baseline to the onshore baseline as describe in the AMBUR manual and above. 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. The EPR calculation is 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*. Transects were removed from the dataset where there was incomplete shoreline data (e.g. only 1 year). In addition, transects sometimes fell into smaller tidal creek openings branching off the main stream. When transects 'shoot through' these openings into smaller adjacent tidal creeks, the rate of shoreline change artificially appears to be more rapid in these areas because the shorelines are incompatible for analysis together. These transects were removed. Transects with highly oblique orientations to the shoreline's movement/trajectory were also removed manually.

Finally, the most recent coastal classification, based on a geospatial dataset created by SCDHEC (*Coastal Zone Feature Classifications*), was used to assign additional classifications for shoreline transects generated from AMBUR's shoreline change analysis output. The dataset used to provide the additional coastal zone feature classifications is available at: http://www.scdhec.gov/HomeAndEnvironment/maps/GIS/GISDataClearinghouse/. A method was used to classify shoreline change transects generated in AMBUR that involved intersecting transects with the SCDHEC dataset to obtain the coastal classification attributes within the GIS.

The results provide additional shoreline change trends based on a more detailed classification scheme and can be refined in the future with updated, more detailed coastal classification data. Appendix A1 contains these additional classifications and a summary of shoreline change rates.

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 SCDHEC-OCRM, 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 USDA NAIP (2015) imagery was subsequently examined for missing shoreline structures. Shorelines were searched using a viewing scale of ~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. 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 North Carolina Digital Mapping Protocol in order to decide if a polygon, polyline, or point was best used to delineate the feature. The type of structures was recorded into the shapefile's attribute table using the same fields discussed in the North Carolina Digital 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 or coastal development.

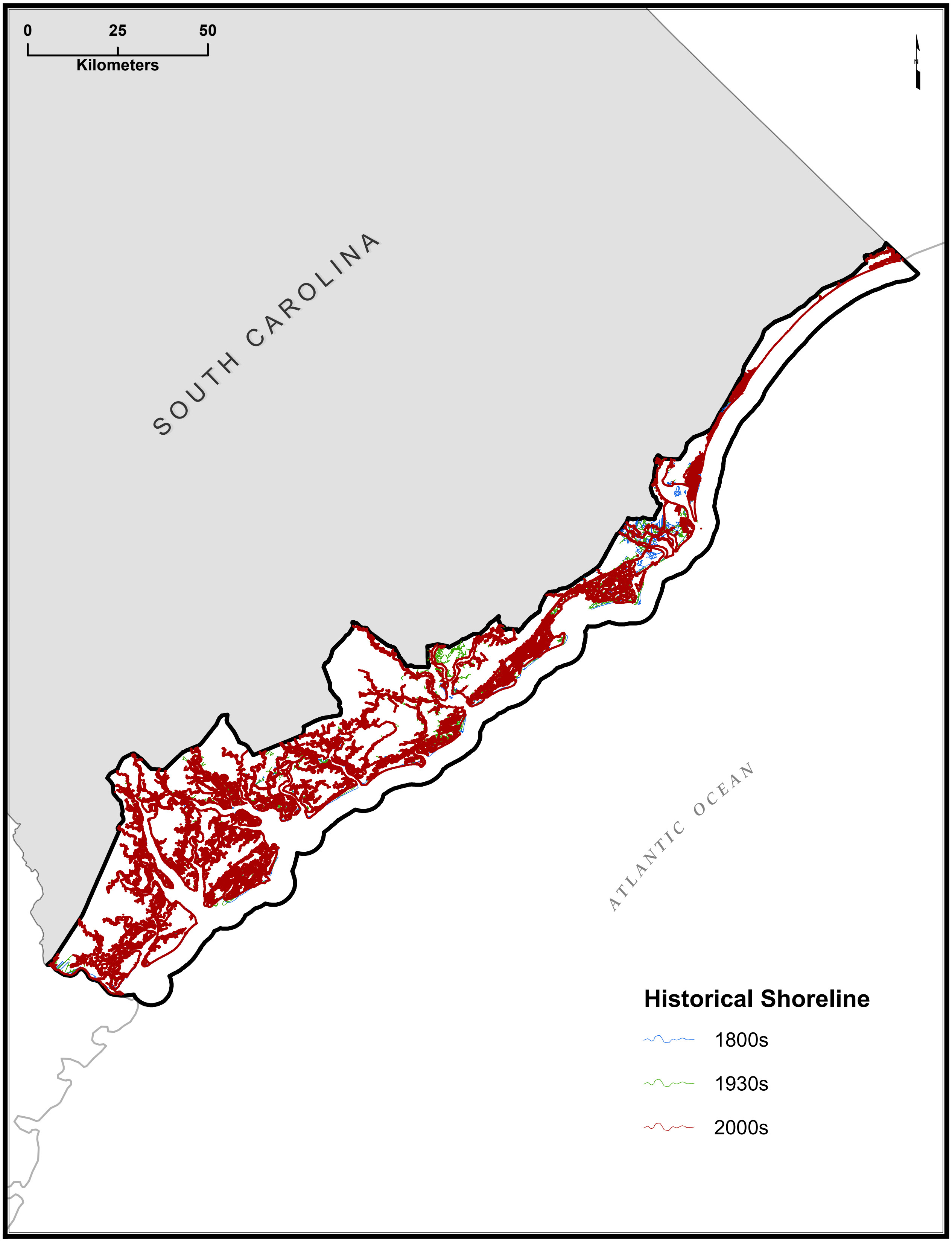

Figure 2-1. Location map of historical shorelines from 1849 to 2015.

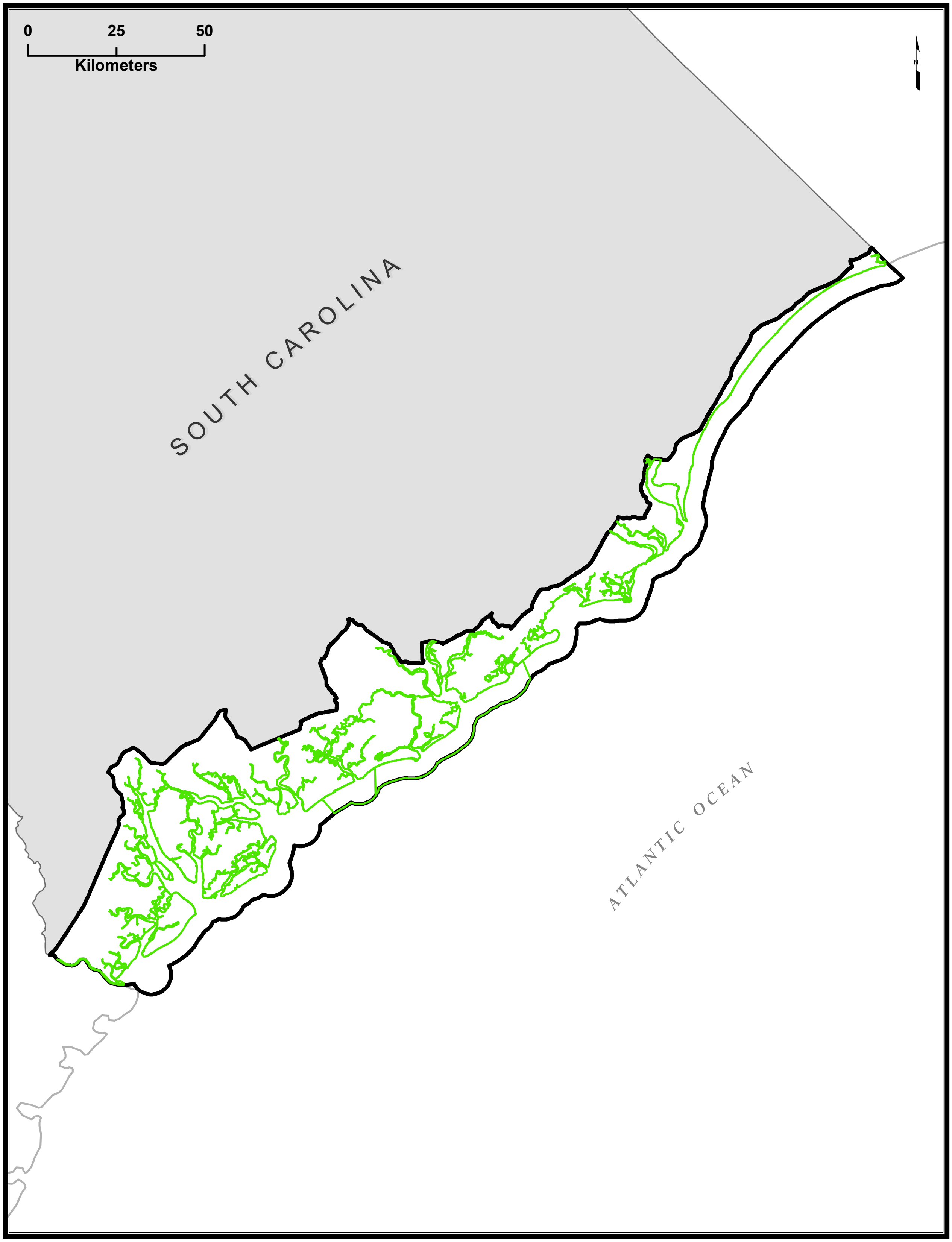

Figure 2-2. Location map of baselines for AMBUR analyses.

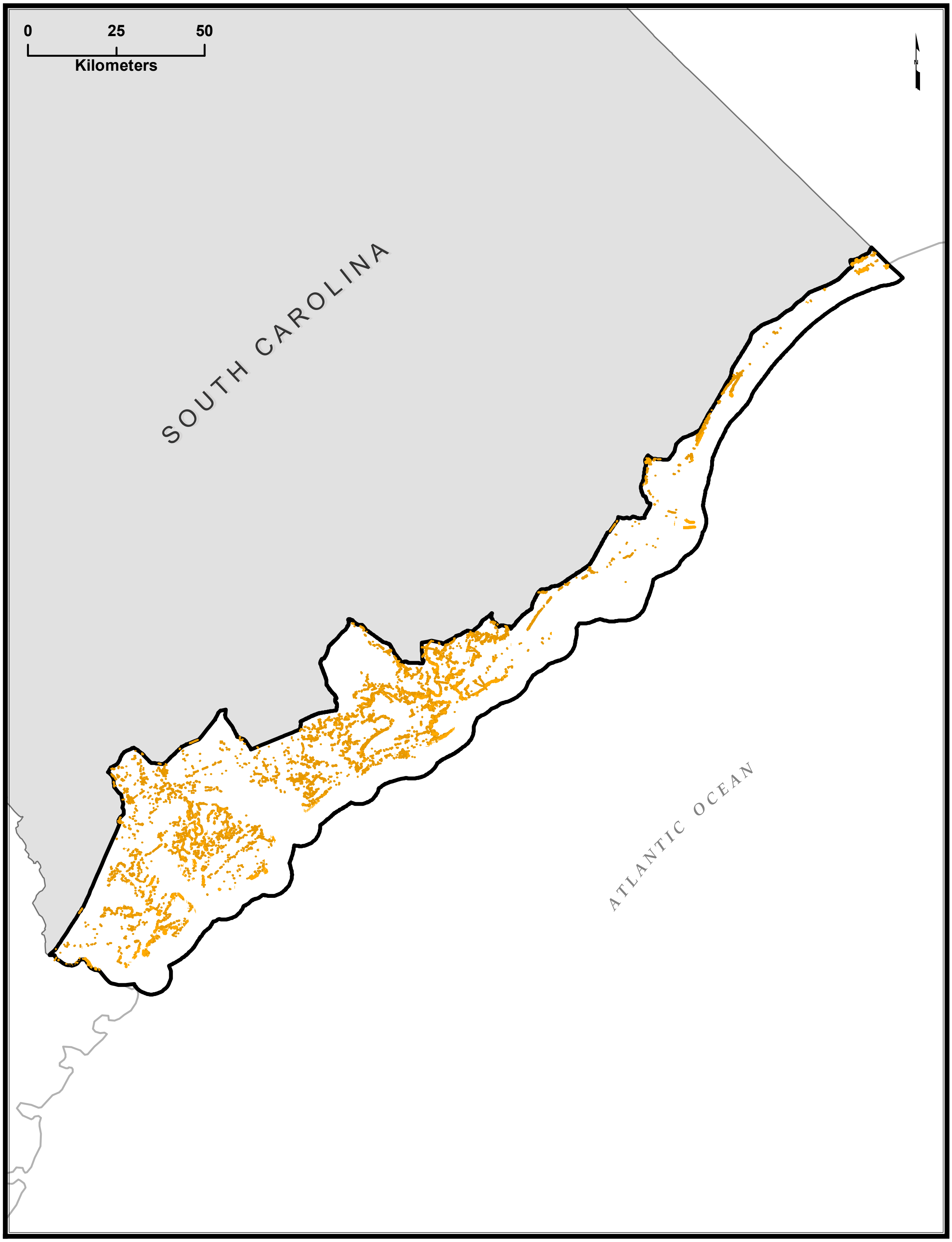

Figure 2-3. Location map of shoreline structures.

Table 2-1. Historical shoreline data sources and shoreline position error estimates.

Year(s)	Agency	Source Type	Map or Project ID	Error (m)
1849	U.S. Coast and Geodetic Survey	T-sheet	T00262	15
1851	U.S. Coast and Geodetic Survey	T-sheet	T00322	15
1851	U.S. Coast and Geodetic Survey	T-sheet	T00327	15
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
1852	U.S. Coast and Geodetic Survey	T-sheet	T00508	15
1854	U.S. Coast and Geodetic Survey	T-sheet	T00491-1	15
1854	U.S. Coast and Geodetic Survey	T-sheet	T00491-2	15
1856	U.S. Coast and Geodetic Survey	T-sheet	T00611	9
1856	U.S. Coast and Geodetic Survey	T-sheet	T00679	9
1856	U.S. Coast and Geodetic Survey	T-sheet	T00679	15
1857	U.S. Coast and Geodetic Survey	T-sheet	T00710	15
1858	U.S. Coast and Geodetic Survey	T-sheet	T00714	15
1858	U.S. Coast and Geodetic Survey	T-sheet	T00715	15
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
1872	U.S. Coast and Geodetic Survey	T-sheet	T01276	15
1872	U.S. Coast and Geodetic Survey	T-sheet	T01280A	15
1872	U.S. Coast and Geodetic Survey	T-sheet	T01280B	15
1873	U.S. Coast and Geodetic Survey	T-sheet	T01307_A	9
1873	U.S. Coast and Geodetic Survey	T-sheet	T01295B	15
1873	U.S. Coast and Geodetic Survey	T-sheet	T01308	15
1874	U.S. Coast and Geodetic Survey	T-sheet	T01347	15
1875	U.S. Coast and Geodetic Survey	T-sheet	T01400A	15
1875	U.S. Coast and Geodetic Survey	T-sheet	T01400B	15
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
1933	U.S. Coast and Geodetic Survey	T-sheet	T05153	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05154	5

Table 2-1. Historical shoreline data sources and shoreline position error estimates. (continued)

1933	U.S. Coast and Geodetic Survey	T-sheet	T05155	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05156	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05157	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05159	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05164	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05165	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05166	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05167	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05170	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05171	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05172	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05173	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05174	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05175	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05176	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05177	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05178	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05179	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05180	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05181	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05182	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05183	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05184	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T05185	5
1933	U.S. Coast and Geodetic Survey	T-sheet	T5243	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05244	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05245	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05246	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05252	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05254	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05255	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05256	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05376	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05377	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05378	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05379	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05380	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05381	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05382	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05383	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05384	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05385	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05386	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05387	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05388	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05390	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05391	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05392	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05393	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05394	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05548	5
1934	U.S. Coast and Geodetic Survey	T-sheet	T05549	5
2002	NOAA/National Geodetic Survey	high resolution shoreline survey	GA0201	1
2002	Beaufort County GIS	LiDAR	-	5
2002	South Carolina Geologic Survey	2D georeferenced aerial photo	aerial photo	5
2003-2005	NOAA/NOS	CIR orthophotography	South Carolina Oyster Mapping	5
2006	USGS	orthophotography	USGS High Resolution Orthoimagery	5
2006	NOAA	LiDAR	-	10
2006	NOAA	orthophotography	Satellite Imagery	10
2010	USDA	orthophotography	NAIP Aerial Photography	11
2014	NOAA	LiDAR	Hurricane Sandy LiDAR	5
2014	NOAA	LiDAR	-	5
2015	USDA	orthophotography	NAIP Aerial Photography	5

Table 2-2. Summary of primary feature types digitized for the 2002-2015 'modern' shoreline. Anthropogenic features are shoreline-parallel structures that were estimated to be coincident with the approximate mean high water shoreline.

Feature Type	n	Total Length (km)	Total Length (miles)
anthropogenic	1,323	141	88
marsh	60,787	12,885	8,006
oceanfront or inlet	700	359	223
upland	8,352	718	446
all	**71,162**	**14,103**	**8,763**

Table 2-3. Summary of AMBUR baselines for each study phase.

Phase	Baseline Parameters		
	Length (km)	n Baselines	n Transects
1	1,451.53	27	27,413
2	666.43	23	10,081
2a	346.46	15	5,786
3	583.64	8	10,272
total:	**3,048**	**73**	**53,552**

Table 2-4. Shoreline structure classification scheme and hierarchy. Classifications are based on features located in aerial imagery.

Classification ID	Subclass 1 ID	Subclass 2 ID	Type
1			Undefined
11			Boat Ramp
21			Breakwater
31			Bridge
	31.1		Non-vehicular
	31.2		Vehicular
	31.3		Culvert
33			Causeway
35			Water Control Structure
	35.1		Dam
	35.2		Levee
	35.3		Lock
41			Groin/Jetty
	41.1		Groin
	41.2		Jetty
51			Pier/Floating Dock/Wharf/Dock/Gangway/Walkway
	51.1		Pier
	51.2		Walkway
	51.3		Wharf
	51.4		Gangway
	51.5		Dock
		51.51	Boat Storage Dock
		51.52	Commercial Dock
		51.53	Community Dock
		51.54	Joint use dock
		51.55	Private Dock
		51.56	Floating Dock
53			Commercial Complex
61			Sill
	61.1		Living Shoreline
71			Sloped Structure
	71.1		revetment (sloped)
	71.2		Riprap
	71.3		Concrete Slope
81			Unknown
91			Vertical Structure
	91.1		Bulkhead
	91.2		Seawall
	91.3		Gabion
101			Hybrid Structure
	101.1		Vertical Structure fronted by Sloped Structure
	101.2		T-Groin
111			Abandoned/ Historic Structure
		111.11	Abandoned/Historic Boat Ramp
		111.21	Abandoned/Historic Breakwater
		111.31	Abandoned/Historic Bridge
		111.33	Abandoned/Historic Causeway
		111.35	Abandoned/Historic Water Control Structure
		111.41	Abandoned/Historic Groin/Jetty
		111.51	Abandoned/Historic Pier/Floating Dock/Wharf/Dock/Gangway/Walkway
		111.53	Abandoned/Historic Pier Complex
		111.61	Abandoned/Historic Sill
		111.71	Abandoned/Historic Sloped Structure
		111.81	Abandoned/Historic Unknown
		111.91	Abandoned/Historic Vertical Structure
		111.101	Abandoned/Historic Hybrid Structure
		999	Unknown due to imagery quality

Table 2-5. Summary of shoreline armoring, docks, and other structures.

Classification ID	Type	# Digitized	
	Polygon Mapped Structures		Total Area (m^2)
1.00	undefined	14	11,652
11.00	Boat Ramp	303	38,694
31.00	Bridge	94	249,437
31.10	Non-vehicular	79	16,292
31.20	Vehicular	304	1,143,057
31.30	Culvert	9	3,063
33.00	Causeway	1,014	1,776,818
35.10	Dam	172	274,427
35.30	Lock	2	1,350
51.00	Pier/Floating Dock/Wharf/Dock/Gangway/Walkway	76	54,243
51.10	Pier	76	33,742
51.20	Walkway	4	4,104
51.30	Wharf	11	333,714
51.50	Dock	6,768	924,764
51.51	Boat Storage Dock	19	1,832
51.52	Commercial Dock	143	261,645
51.53	Community Dock	80	29,982
51.54	Joint use dock	177	44,072
51.55	Private Dock	5,519	800,362
51.56	Floating Dock	58	5,127
53.00	Commercial Complex (Includes restaurants, amusement parks, factory/industrial complexes etc.)	21	42,722
71.10	Revetment	1	8,082
71.20	Riprap (small rock)	1	19
81.00	Unknown	122	56,609
111.11	Abandoned/Historic Boat Ramp	2	97
111.31	Abandoned/Historic Bridge	4	1,544
111.33	Abandoned/Historic Causeway	82	81,517
111.51	Abandoned/Historic Pier/Floating Dock/Wharf/Dock/Gangway/Walkway	73	13,141
111.53	Abandoned/Historic Pier Complex	1	3,738
111.81	Abandoned/Historic Unknown	8	12,744
	Totals:	**15,237**	**6,228,591**
	Polyline Mapped Structures		Total Length (m)
1.00	undefined	1	23
21.00	Breakwater	15	5,811
41.10	Groin	110	6,531
41.20	Jetty	11	15,093
51.00	Pier/Floating Dock/Wharf/Dock/Gangway/Walkway	14	235
51.10	Pier	2	46
51.20	Walkway	504	18,907
51.40	Gangway	14	56
51.52	Commercial Dock	1	0
51.55	Private Dock	6	343
61.10	Sill with Living Shoreline	9	56
71.10	Revetment	194	25,233
71.20	Riprap (small rock)	293	30,775
71.30	Concrete Slope	8	685
81.00	Unknown	26	1,627
91.00	Vertical Structure	98	18,755
91.10	Bulkhead	980	89,335
91.20	Seawall	119	8,541
101.10	Vertical Structure fronted by Sloped Structure	55	7,175
101.20	T-groin (breakwater/revetment/groin)	1	53
111.41	Abandoned/Historic Groin/Jetty	1	214
111.51	Abandoned/Historic Pier/Floating Dock/Wharf/Dock/*	1	23
111.91	Abandoned/Historic Vertical Structure	1	48
999.00	Unknown due to imagery quality	54	2,146
	Totals:	**2,518**	**231,711**

3.0 SHORELINE CHANGE

The main focus of this study has centered on estuarine or sheltered shorelines, and although oceanfront shorelines are included, there is more discussion of estuarine shorelines. Lowcountry estuarine shorelines found in Phase 1, 2, and 2a areas, 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 a number of 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 positions of today's oceanfront, inlet, and estuarine shorelines ultimately represent the cumulative impacts of a number of factors including sea-level change, storms, tidal channel dynamics, inlet dynamics, human activity, wind/wave climate, 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 shoreline change in order to 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 allowed researchers to use almost yearly datasets to calculate mappable change at much smaller time intervals. Such is not the case for estuarine shorelines, where movements are, in general, relatively slow, sometimes less than a third of the rates and distance of oceanfront shorelines. The dataset for this project provides only snapshots in time of estuarine and oceanfront shoreline position(s), which represents the cumulative effects of all factors influencing change. Therefore, longer periods of time between shoreline position data sources are more appropriate for estimates of shoreline change trends and influences; especially those estimates that might be ascertained from statistical analyses of the dataset and visual inspections of maps and historical aerial photographs, such as those in this study. However, there is sufficient data from this study to identify a number of potential factors/drivers.

All shoreline change rates reported below, unless otherwise noted, are in terms of the EPR calculation method. It also should be noted that shoreline change data presented in this manuscript as *negative* numbers indicate erosion and *positive* numbers indicate accretion. Shoreline change rates using calculation methods, such as Linear Regression Analyses (LRR), Weighted Linear Regression (WLR), and other AMBUR model outputs, were also generated. However, these rates were not included in this report due to uncertainty in the reliability of these rate models using only three shorelines. These metrics would be useful for inlet and oceanfront shorelines where more historical shorelines could be added to provide these models with sufficient data to produce a more statistically sound output. 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 and shoreline types/classification are tabulated in Table 3-1 for each era along with error estimates. Classifications in Table 3.1 are based on simplified classes found in Table 2-2 and include: 'upland', 'marsh', 'anthropogenic', and 'oceanfront or inlet'. The 'estuarine sandy beach' classification in Table 2-2 was merged with the 'marsh' classification in Table 3-1. This is because it was was originally mapped as narrow strip of sand in front of the marsh and immediately adjacent to the tidal channel, and, considered to be a feature that is part of composition of some marsh shorelines. Figures 3-1, 3-2, and 3-3 display the shoreline 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 the 1800s. Combined, these maps provide a nearly complete coverage of the shore within the study area, with the exception of the smaller tidal streams that were present in the project area but not mapped in detail or missing on the T-sheet maps in the 1800s. 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 photography 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 the 1930s versus the 1800s maps, aside from increased accuracy, is the detailed mapping of smaller marsh channels and other coastal features as previously noted. The 1930s shoreline included far more detail than the 1800s shorelines, and therefore, had extraneous features that could not be analyzed. Furthermore, the 1930s shorelines covered the entire study area, whereas the 1800s maps sometimes did not reach as far inland.

During the 1800s to 1930s era, which spanned 70+ years, ~58% of all shoreline types (upland, estuarine/marsh, anthropogenic, and oceanfront or inlet) experienced net erosion (Figure 3-1,

Table 3-1). Although the average rate of change for all 41,915 transects measured for this era was -0.10 m/yr (± 0.23 m/yr), the average rate among transects with only erosion values was -0.89 m/yr. Accretion occurring at transects with only accretion during the era averaged 0.98 m/yr (slightly higher than the erosion rate). Although the erosion rate appears to be offset by the accretion rate, the spatial extent of erosion was greater and was ~58% during this time period.

The most notable shoreline erosion occurred primarily along major and intrabarrier streams, bays/inlets, and oceanfront shorelines (Figures 3-1, 3-2, & 3-3). However, estuarine shoreline locations experienced net erosion, particularly in the Phase 1, 2, and 2a areas that contain a large amount of estuarine shoreline. Shoreline erosion was greater at segments closest to the inlets and sounds, as well as the oceanfront. Accretion and erosion rates in these areas often exceed 1 m/yr and -1 m/year, respectively.

Estuarine shorelines adjacent to sound areas included a mixture of morphologic features including vegetated dredge spoil islands, vegetated/sandy uplands, and tidal marsh in addition to anthropogenic structures. Oceanfront shorelines typically included sandy shorelines and anthropogenic structures. Overall, for the entire study area, mean erosion rates along marsh and anthropogenic shorelines were -0.63 and -0.42, m/yr respectively. Upland (or the apparent mean high water line) shorelines had slightly higher erosion rates of -0.74 m/yr and a greater percentage of erosion (~68%).

3.2 Era II (1930s to 2000s)

Table 3.1 shows that oceanfront/inlet shorelines alone contain mean erosion rates ~6.8 times higher than the rates of marsh shorelines for the 1930s to 2000s era (the era containing the most detailed/accurate shorelines of the coast). During this era, just over half (~54%) of the coast experienced net erosion with a general reduction in rates of change. Shoreline change data from this most recent era provided the most spatially complete, accurate dataset. There were more transect locations during this era (52,397 transects) because the 1930s and 2000s shorelines extended farther into the study area toward the western boundary and had more detail. The rates of shoreline change for all shoreline types were overall lower than the previous era (Table 3.1). Rates of shoreline erosion for the 1930s to 2000s era (~70-year time period) averaged -0.59 m/yr (± 0.09 m/yr). These rates were one-third less than mean erosion rates for the previous era. The mean accretion rate for all shoreline types during this period was 0.67 m/yr (± 0.09 m/yr). However, ~55% of marsh shoreline experienced net erosion whereas ~44% of the oceanfront/inlet shoreline eroded during the 1930s to 2000s era (Table 3.1). There are a number of factors that could contribute to overall lower rates of change during this era. First, there was an increase in the amount of shoreline armoring within already erosion-prone areas along oceanfront and estuarine shorelines. Second, beach nourishment projects along the oceanfront during this period could also create the appearance of lower erosion rates as the shoreline became artificially altered. For future studies, it would be beneficial to determine the dates and locations of beach nourishment projects and compare pre- and post-nourishment rates.

Next, the cause of this era's overall decreased erosion rates could be explained by differences in shoreline mapping techniques of the data sources. One might point toward the accuracy of the shoreline position data from 1930s 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 shoreline position error estimates for the era, eliminating this option. Another explanation could be the difference between shoreline proxies (datum or location identified based on visual or mathematical approximations) 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, instead of 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 shorter 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. These experiments 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, 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 most likely due to shoreline armoring and renourishment. Finally, 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. In summary, while there are a number of possible mechanisms, including armoring, renourishment, and sediment supply increase, determining the main driving factor will require more study in the future.

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

Shoreline change along the South Carolina coast is not uniform. Throughout the study period with data spanning from 1849 to 2015, shoreline change has varied both in magnitude and spatial extent (Figures 3-1, 3-2, & 3-3). The overall average shoreline change rate was -0.05 m/yr (± 0.11 m/yr) for all calculated transects (53,552 transects). However, ~57% of all transects were erosional. For transects experiencing only net erosion, the average shoreline erosion rate was -0.55 m/yr (± 0.11 m/yr). For transects experiencing accretion only (Table 3-1), there was an average accretion rate of 0.63 m/yr (± 0.11 m/yr) for transects. Inspection of Figure 3-3 reveals that oceanfront, inlet, and larger tidal stream shorelines are most susceptible to chronic erosion, and have a number of transects with higher rates of erosion that exceed -1 m/yr. When viewed from a coastal management standpoint, these areas could be considered hotspots. 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 erosion appear to occur along oceanfront and inlet shorelines. Mean erosion rates along these shorelines were -2.12 m/yr from the 1800s to 2000s era (Table 3-1). The lowest erosion rates were in estuarine/marsh shorelines and were -0.34 m/yr.

3.4 Data Compatibility and Future Shoreline Studies

Georgia has recently completed a shoreline change project for all coastal counties for both oceanfront and estuarine shorelines that will fit seamlessly with the South Carolina dataset, which was created using comparable methodologies and tools. However, the oceanfront and inlet facing shorelines in the South Carolina study, especially for barrier islands, should be re-analyzed, as additional shorelines become available, given the dynamic nature/magnitudes of their movements relative to estuarine shorelines. Automated techniques developed in the current study are better suited for estuarine shorelines, whereas other techniques using AMBUR are more suitable for oceanfronts and inlets. Using existing and newly developed techniques in AMBUR would allow for more shorelines to be analyzed in greater detail in the future. Although some of these techniques are more time consuming for estuarine shorelines, it will produce more shoreline change data. The analysis of oceanfronts and inlets is far less time consuming and more historical shorelines could easily be analyzed, which would be particularly useful for the rapid assessment of shoreline change from pre- and post-storm aerial photography and/or imagery.

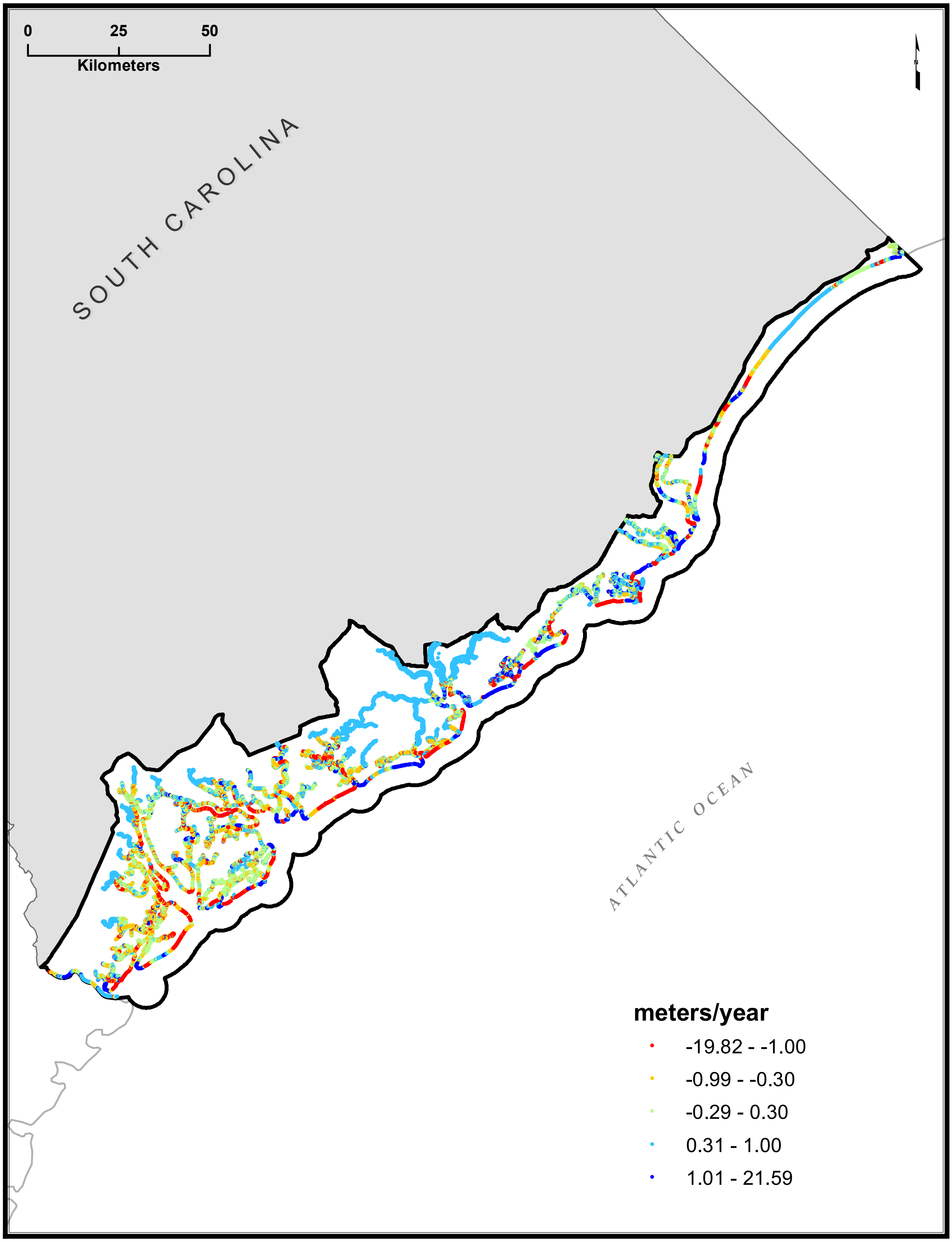

Figure 3-1. Map depicting shoreline change rates from 1800s to 1930s. Rate calculations are based on the EPR method. Positive values indicate accretion and negative values are erosion.

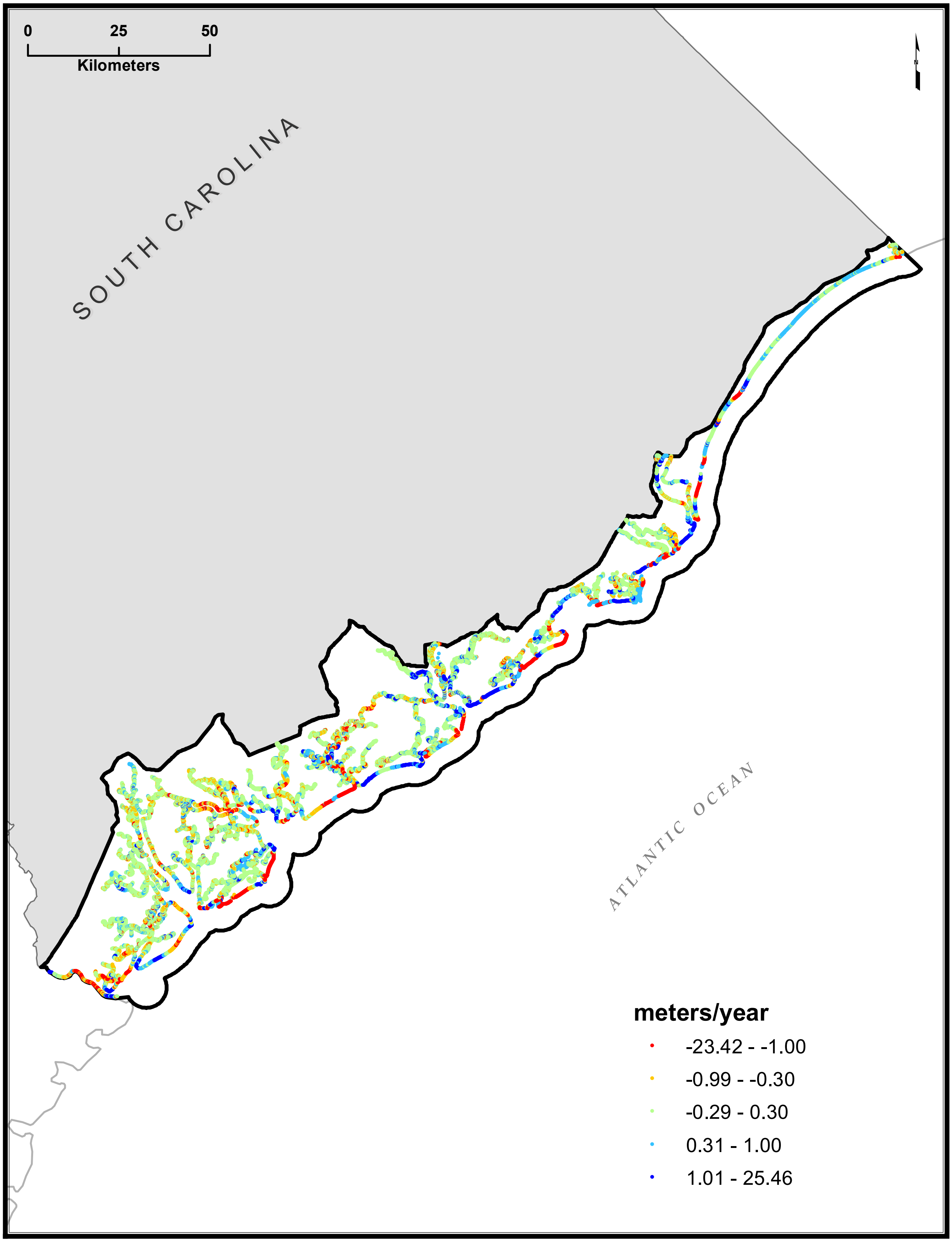

Figure 3-2. Map depicting shoreline change rates from 1930s to 2000s. Rate calculations are based on the EPR method. Positive values indicate accretion and negative values are erosion.

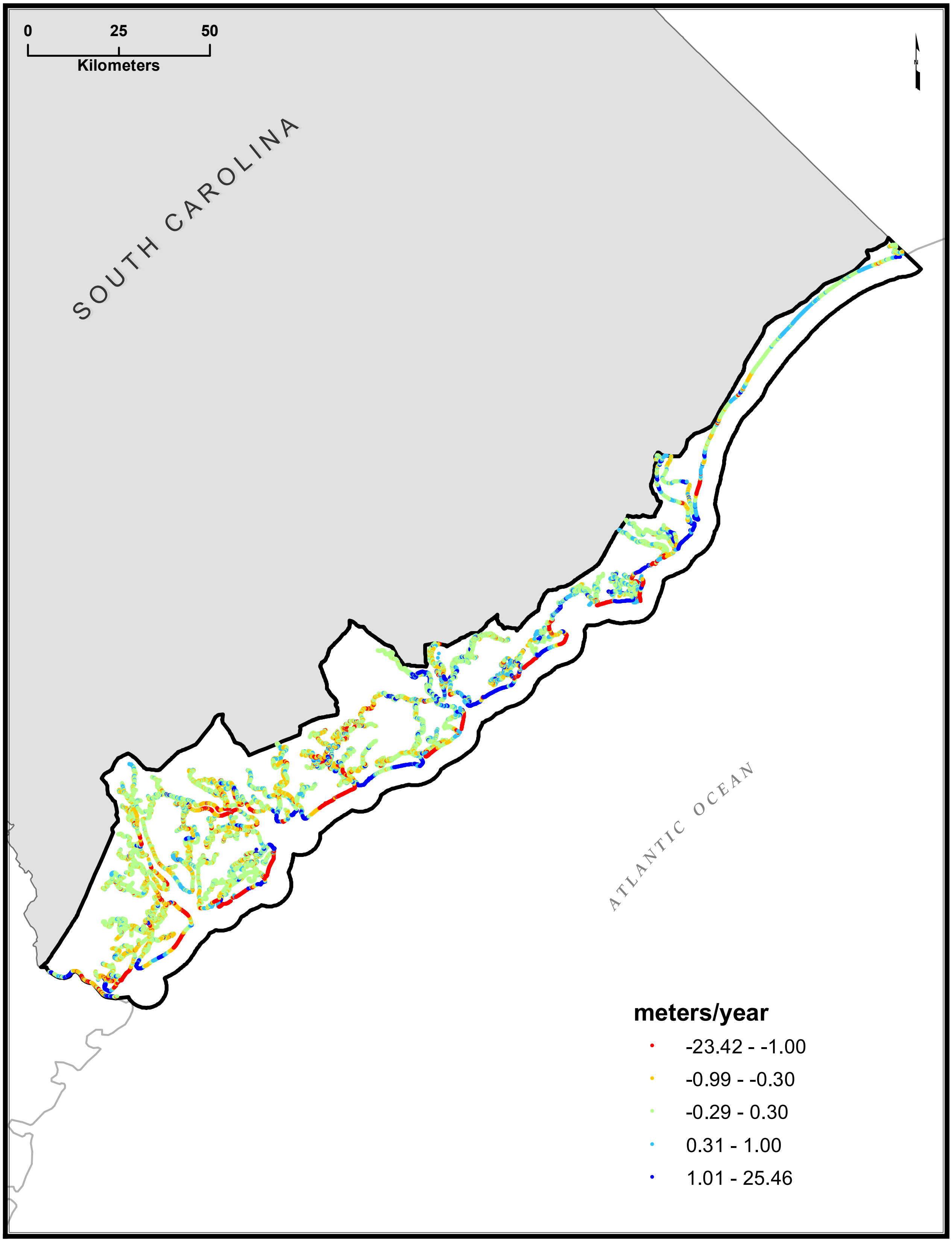

Figure 3-3. Map depicting shoreline change rates from 1800s to 2000s. Rate calculations are based on the EPR method. Positive values indicate accretion and negative values are erosion.

Table 3-1. Summary of shoreline change rates for feature types during each era. Classifications are based on the modern shoreline (2000s).

Classification	Mean Rate (m/yr)	% Erosion	Mean Erosion Rate (m/yr)	Mean Accretion Rate (m/yr)
1800s to 1930s (± 0.23 m/yr mean shoreline rate error)				
n Transects = 41,915				
upland	-0.28	67.94	-0.74	0.68
marsh	-0.08	57.33	-0.63	0.64
anthropogenic	0.47	28.74	-0.42	0.82
oceanfront or inlet	-0.12	56.39	-2.36	2.78
all	**-0.10**	**57.90**	**-0.89**	**0.98**
1930s to 2000s (± 0.09 m/yr mean shoreline rate error)				
n Transects = 52,397				
upland	-0.09	57.10	-0.49	0.45
marsh	0.01	55.04	-0.36	0.45
anthropogenic	0.03	53.88	-0.59	0.75
oceanfront or inlet	-0.05	44.31	-2.44	1.85
all	**-0.01**	**53.85**	**-0.59**	**0.67**
1800s to 2000s (± 0.11 m/yr mean shoreline rate error)				
n Transects = 53,552				
upland	-0.22	69.03	-0.51	0.42
marsh	-0.02	57.92	-0.34	0.41
anthropogenic	0.16	47.37	-0.51	0.76
oceanfront or inlet	-0.14	48.20	-2.12	1.70
all	**-0.05**	**57.47**	**-0.55**	**0.63**

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. This rate threshold is nearly double the mean annual erosion of -0.55 m/yr (± 0.11m/yr) 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 is critical to developing a sound shoreline management and preservation plan. This study provides a brief overview of these hotspots and potential drivers of erosion based on initial inspections of the data output from AMBUR analyses. A detailed literature review of previous site-specific locations and extensive field data collection are needed to fully 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 on oceanfronts, and along four main shoreline areas within the estuarine system: bays/sounds/inlets, stream confluences, estuarine tidal meander cutbanks, and highly dissected (fragmented) tidal marsh/mudflats. For example, the Chechessee, Broad, Beaufort, Coosaw, and Combahee Rivers contain a number of hotspots where average shoreline erosion rates exceed -1 m/yr. A number of larger tidal streams in the dataset appear to show net widening or dilation throughout the study period. These larger tidal streams are also used as primary navigation channels for recreation and commercial vessels. It can be reasonably assumed that vessel traffic is potentially impacting these shorelines through boat wake activity. 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), dredging activity, boat/vessel activity (e.g. boat wakes), and shoreline armoring and alterations. Example locations where these factors are 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 bend in half at the apex of the curve, the outer part (cutbank) of the bend 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 dynamic 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. The study area is punctuated with stream confluences that involve streams with various widths, depths, and shoreline compositions. At these stream confluences, shoreline movements appear to be more active than adjacent areas.

The frequency and magnitude of erosion appears to be greater on shorelines within close proximity to bays/inlets/sounds. These erosion rates are frequently greater than -1 m/yr, and can have rates that exceed -30 m/yr depending on the conditions and processes occurring in these locations. 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 these types of estuarine shorelines are subjected to increased wave activity, similar to what would be experienced on oceanfront shorelines. Furthermore, changes in inlet dynamics can lead to shoreline change impacts on 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 (Figures 4-1 & 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 a primary concern because these structures have the potential to translate erosion to adjacent, unprotected shorelines. Some of the greatest amount of shoreline armoring can be found in the Phase 2 study area, which includes Charleston and surrounding areas with heavily developed shoreline. These shorelines have been armored in the interest of protecting residential development and stabilization of the shoreline for military and commercial purposes where docks and marinas need protection.

Finally, given the increasing number of shoreline structures present along estuarine and upland shorelines, it is important for managers to 1.) recognize the vulnerability of existing shoreline structures to erosion, and 2.) use shoreline change data in assessment and planning decisions for new structures and infrastructure in proximity to dynamic estuarine shorelines. Using shoreline change data from AMBUR for all shoreline types 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 times the erosion rate at each location. The resulting buffered areas were subsequently used to extract shoreline structures that would encounter an eroding shoreline within 50 years (Figure 4-4). Based solely on long-term shoreline change rates at each transect and projecting or extrapolating where the shoreline might be located over the next 50 years, 1,412 structures are estimated to be potentially threatened or impacted by shoreline erosion. Short-term erosion rates could also be used to look at structures potentially threatened over shorter time periods in the future. 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 over half 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 in this study, should be conducted with a sense of urgency given the density of development in these areas and pressure for future development. Finally, additional imagery of oceanfront and inlet-facing shorelines should be used to extract more shoreline data to better resolve the dynamics of these areas. Inlet shorelines are of critical importance as they have the capacity to influence change on both estuarine and oceanfront shorelines. Additional data in these areas would be useful in delineating inlet hazard zones. Furthermore, existing shoreline change rates in this dataset can be used to identify potential shoreline/habitat restoration areas, or areas not suitable for development.

In summary, this project found that 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. Some of the highest shoreline change rates and erosion are found along the oceanfront and inlet-facing shorelines given they are unsheltered from open ocean processes.

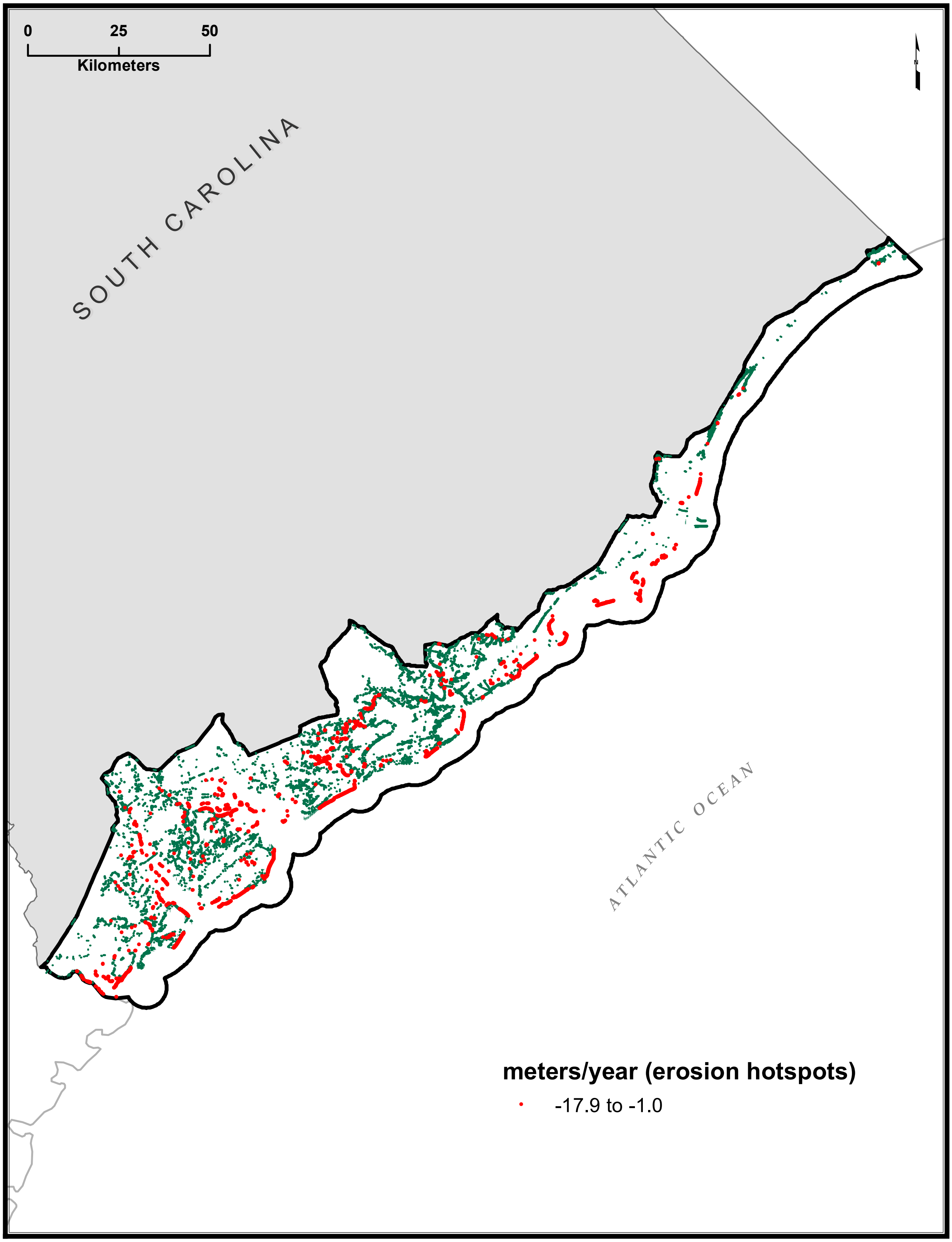

Figure 4-1. Map depicting erosion hotspots from 1800s to 2000s with shoreline structures shown in green.

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

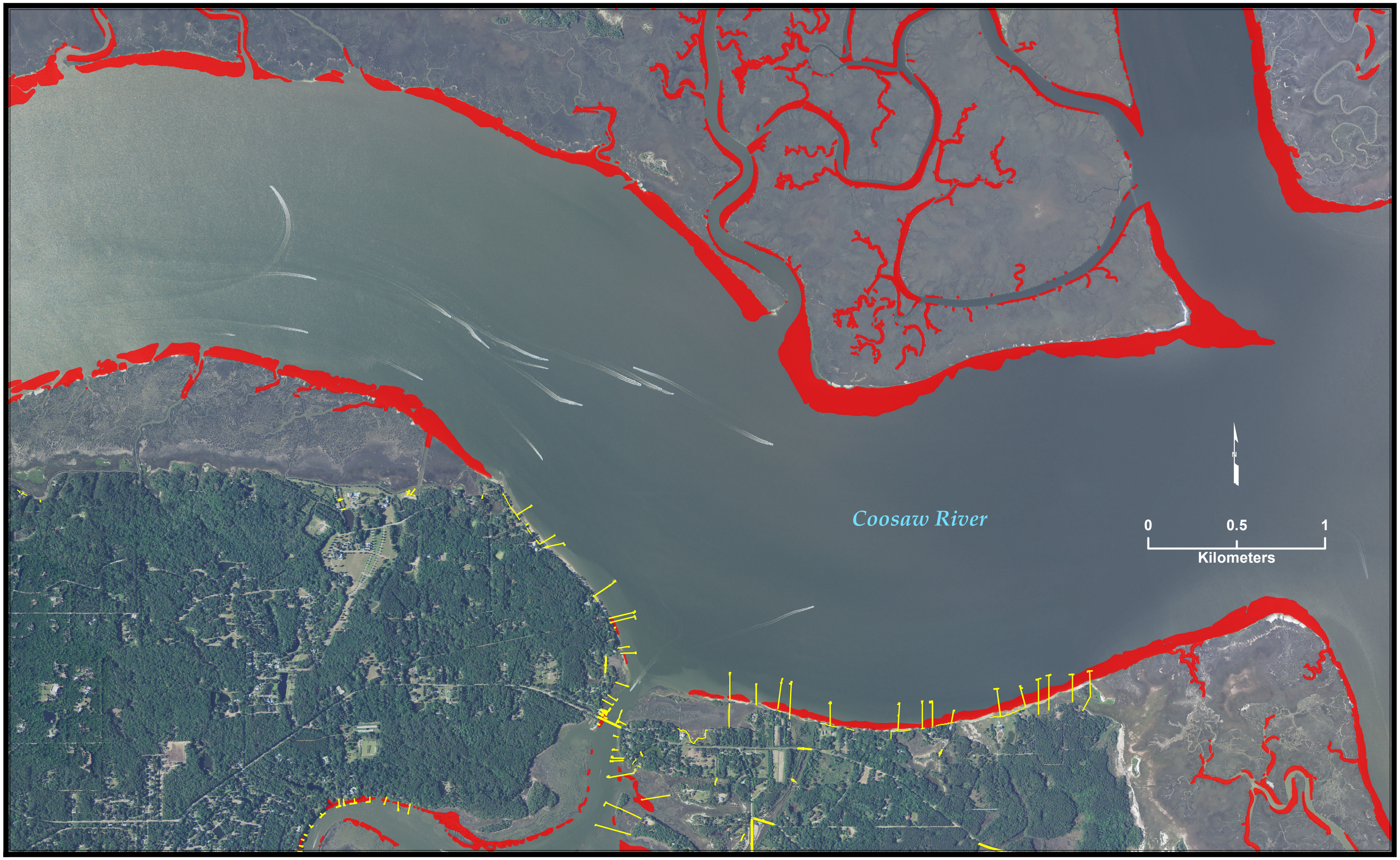

Figure 4-3. Map depicting erosion (red) with shoreline structures (yellow) and boating activity along the Coosaw River Hotspot.

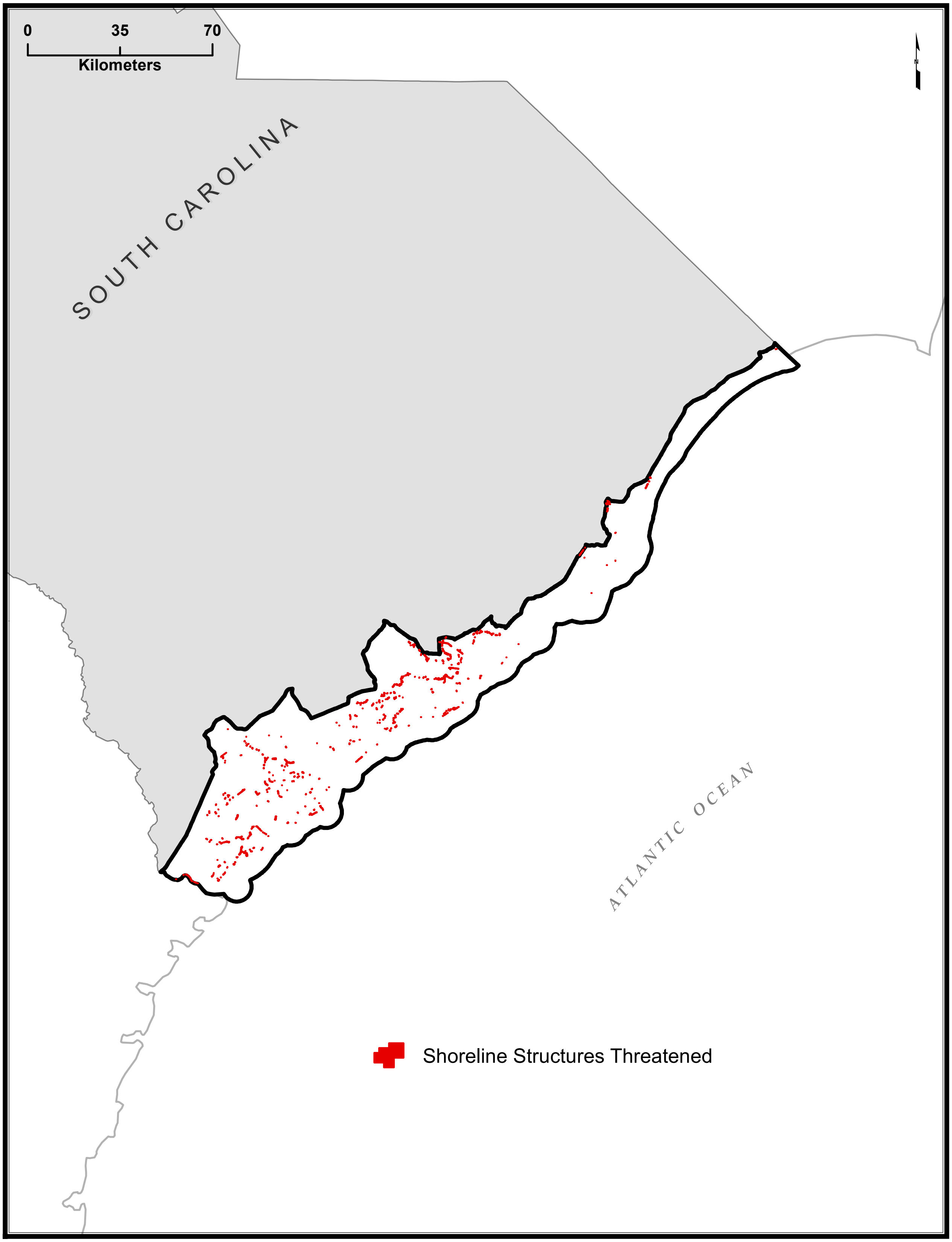

Figure 4-4. Shoreline structures vulnerable to erosion within 50 years based on extrapolation of erosion rates. There are 1,412 threatened structures based on available erosion data.

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APPENDIX A – Additional Shoreline Change Summary Tables

Appendix A1. Summary of shoreline change rates for SCDNR's coastal classifications from 1800s to 2000s. These classifications are provided in AMBUR's shoreline change geospatial (GIS) data for the 1800s to 2000s era. Classifications were assigned to the column named 'TYPE' in the GIS shapefile's attribute table.

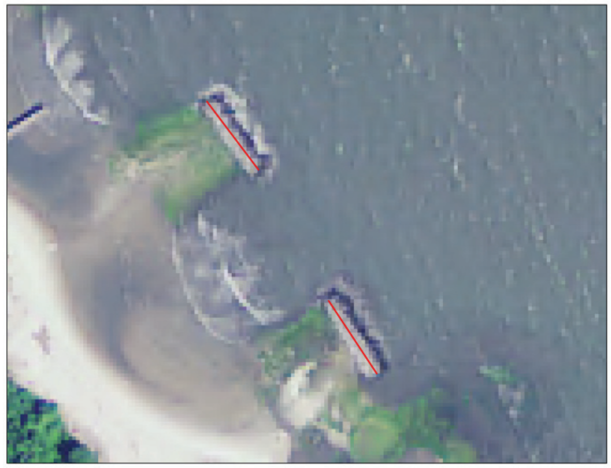
Location	Mean Rate (m/yr)	% Erosion	Mean Erosion Rate (m/yr)	Mean Accretion Rate (m/yr)	n Transects
RIVER/CREEK	-0.21	78.38	-0.39	0.44	22316
MARSH	0.16	35.42	-0.21	0.37	17806
BEACH/SANDY SHORE	-0.55	53.98	-2.24	1.42	5028
ANTHROPOGENIC	0.53	36.07	-0.46	1.08	754
SOUND	-0.52	92.65	-0.59	0.46	490
MARSH ISLAND	0.46	40.97	-0.38	1.04	903
BARRIER ISLAND	1.00	25.79	-2.09	2.07	1105
TIDAL/MUD FLAT	-0.24	71.50	-0.61	0.70	1979
INLET	-0.09	81.03	-0.66	2.39	427
SEA ISLAND	0.22	26.40	-0.19	0.36	659
IMPOUNDMENT/SPOIL	1.83	11.11	-0.49	2.12	315
MAINLAND	0.32	22.85	-0.18	0.46	547
SPOIL ISLAND	0.48	26.47	-0.85	0.96	68
AIWW	-0.36	90.00	-0.44	0.36	280
UNCLASSIFIED WETLAND	0.06	0.00	NA	0.06	1
HARBOR	-0.25	63.33	-0.84	0.77	300
BAY	-0.03	57.49	-0.60	0.75	574

Appendix A2. Summary of shoreline change rates for each project phase from 1800s to 2000s.

Phase	Mean Rate (m/yr)	% Erosion	Mean Erosion Rate (m/yr)	Mean Accretion Rate (m/yr)	n Transects
1	-0.14	63.78	-0.46	0.41	27413
2a	-0.26	62.95	-0.72	0.51	5786
2	0.15	49.14	-0.56	0.84	10081
3	0.11	45.75	-0.79	0.87	10272

APPENDIX B – Examples of Digitized Anthropogenic Shoreline Structures

Boat Ramp (11)

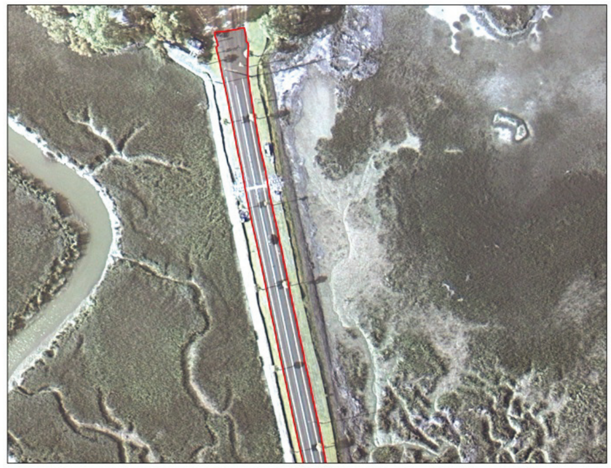


Breakwater (21)

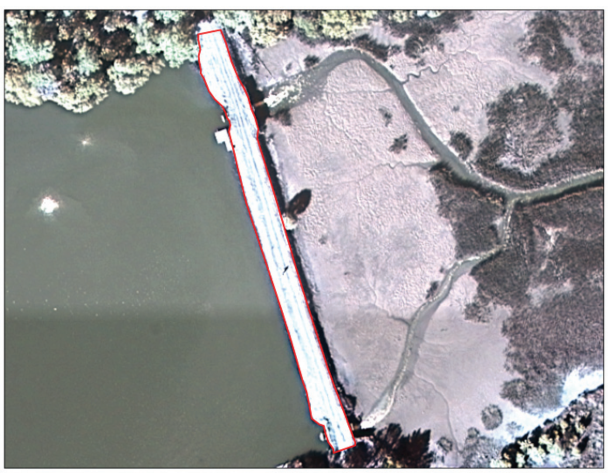
Non-Vehicular Bridge (31.1)

Vehicular Bridge (31.2)

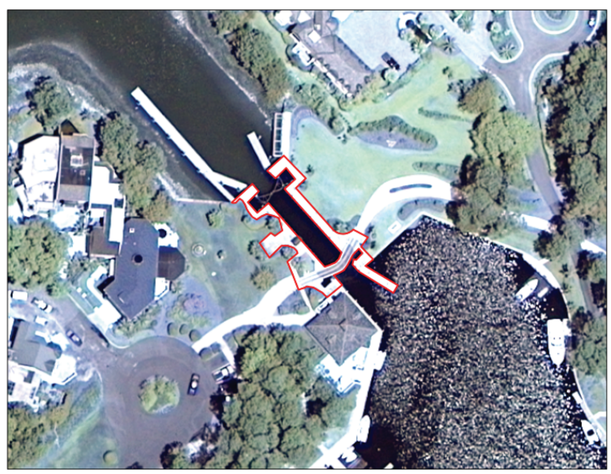
Culvert (31.3)



Causeway (33)



Dam (35.1)



Lock (35.3)

Groin (41.1)

Jetty (41.2)

Pier (51.1)

Walkway (51.2)

Wharf (51.3)

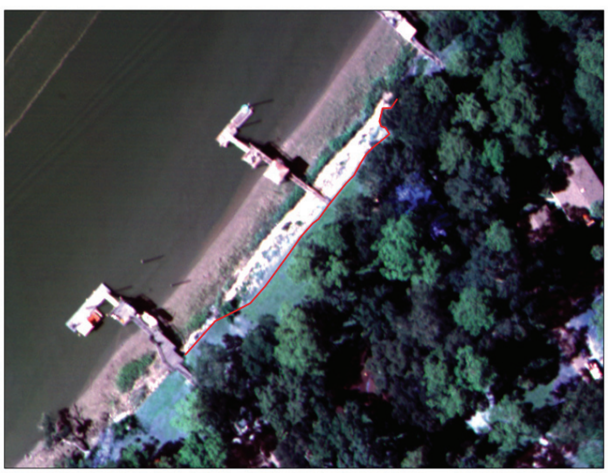
Gangway (51.4)

Dock (51.5)

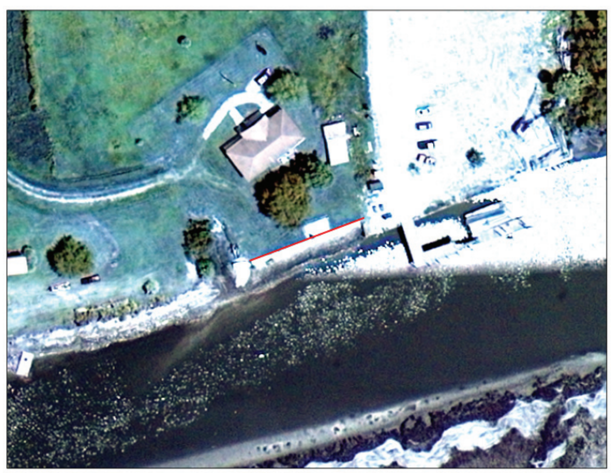
Commercial Complex (53)

Sill (61)

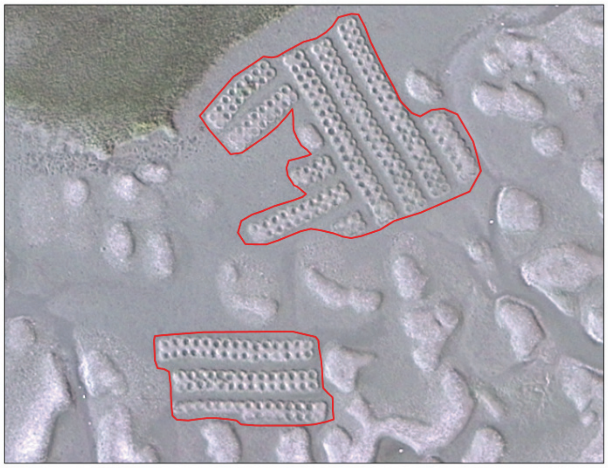
Revetment (71.1)



Riprap (71.2)



Concrete Slope (71.3)



Unknown (81)

Bulkhead (91.1)

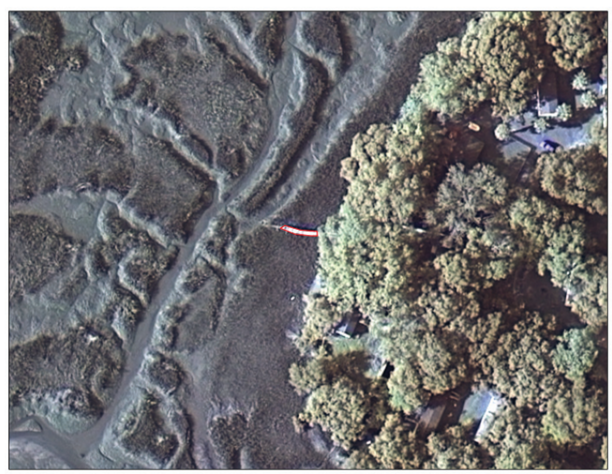
Seawall (91.2)

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)