Assessment of South Carolina Offshore Sand Resources with Emphasis on Community Needs and Data Gaps

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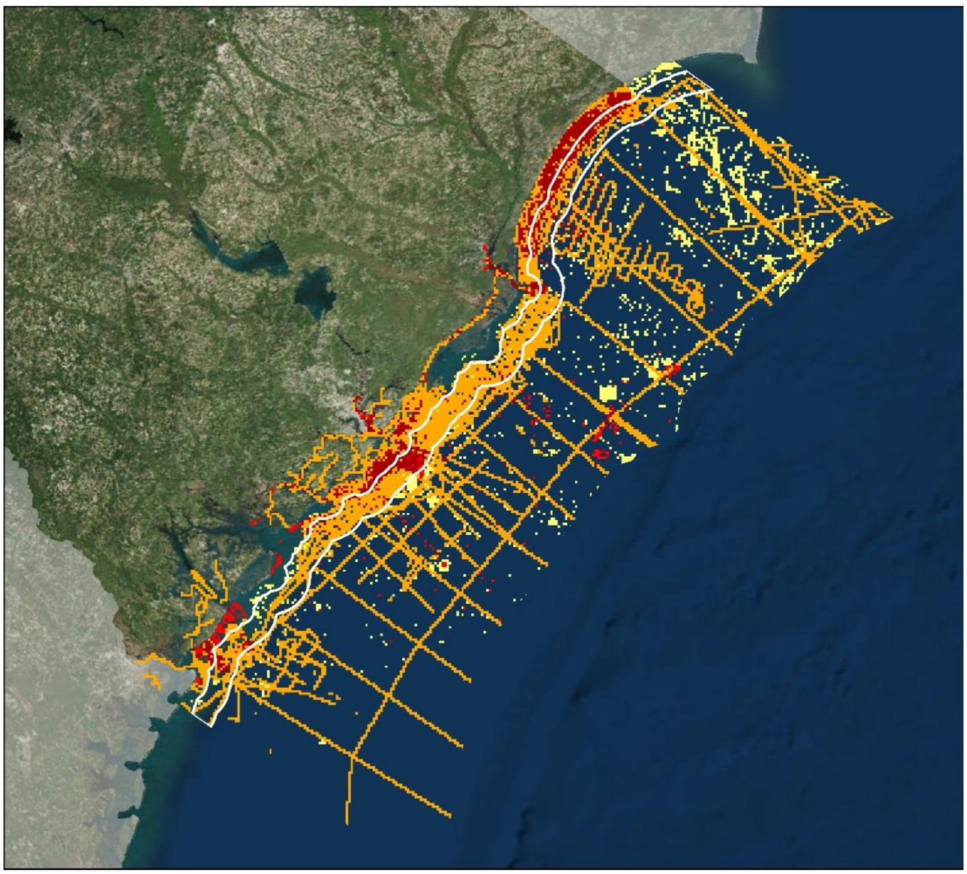

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Abstract

The need for offshore sand resources to nourish beaches and counter the impacts of chronic and storm-driven erosion has increased significantly in the state of South Carolina since the 1990's. Historically, nourishment quality sand material has been borrowed from areas within state waters (0-3 nautical miles (nm) offshore); however, as these resources become depleted in certain areas, having access to and knowledge of Outer Continental Shelf (OCS) sand resources is becoming increasingly important. This Bureau of Ocean Energy Management (BOEM) Hurricane Sandy state cooperative project was undertaken to update and expand on known geophysical and geotechnical datasets offshore of South Carolina, evaluate gaps in data coverage, and assess the spatial distribution of data in relation to the nourishment needs of coastal beach communities. A comprehensive beach nourishment database was also compiled to provide information on past community needs and project these needs into the future as return intervals, measured in years. Borrow distances were calculated to consider trends and examine the potential future need for OCS sand, and over 6,000 geotechnical samples and 18,800 km of trackline datasets were compiled for the analysis. Data density and quality tends to correlate to proximity of nearby beach communities with nourishment needs, particularly Folly Beach, Hilton Head Island, and areas of the Grand Strand. In Long Bay, data densities are high in state waters but sparse in the OCS study area, particularly between 5 and 8 nautical miles offshore. Although some of South Carolina's beach communities, most notably Hilton Head Island, have been able to take advantage of borrow areas that naturally refill with beach-compatible sediment, many of the eroding beaches in South Carolina are reliant on the identification of new resources to maintain beach width, stability, and resilience to storm impacts.

Introduction

Recent storm events have revealed a need to further assess offshore sand resources and potential community demand for beach-compatible sand. While beach nourishment has been practiced for decades to combat erosion, there has been renewed interest in the identification of sand sources for such projects following Hurricane Sandy in 2012, which resulted in widespread erosion of Atlantic coast beaches from Florida to New York. In addition to the ongoing threat from hurricanes, South Carolina's low-lying coast, naturally and unnaturally erosional beaches, and rising sea levels may further amplify the potential for coastal damages. Beaches along coastal South Carolina have been nourished at least 79 times since 1968, totaling approximately 58 million cubic yards of sediment. With few exceptions, these projects seek sand at increasing distances, and therefore cost, from where placement is desired. Because of this trend, an increasing need for sand resources from the Outer Continental Shelf area (OCS) is anticipated. This study presents an assessment of sediment data availability in the OCS, and aims to identify areas with partial data coverage where more thorough exploration may be warranted, as well as areas where data gaps exist.

The erosion of sand by storms and coastal processes has led to extensive beach nourishment projects along North Myrtle Beach, Arcadian Shores, Myrtle Beach, Garden City Beach, Pawley's Island, DeBordieu Beach, Folly Beach, Seabrook Island, Edisto Beach, Hunting Island and Hilton Head Island. All of these beaches are periodically nourished on varying cycles. Isle of Palms, Sullivan's Island, Kiawah Island and Daufuskie Island have also been nourished. These projects protect beachfront property and provide a wider recreational beach that supports the state's tourism industry. All of these large-scale projects require offshore sand resources. To date, most offshore borrow sites have been identified within the 3 nautical mile (nm) state water boundaries; however, as known sand resources become scarce, new borrow sites will need to be identified in federal waters. As an example of this emerging need, the U.S. Army Corps of Engineers (USACE) dredged sand from federal waters for the nourishment of Folly Beach in 2014 (Crowe et al., 2015).

Numerous investigations of sand resources have been conducted in South Carolina, primarily for specific nourishment projects (e.g., Van Dolah et al., 1992; Katuna et al., 1993; Morton and Miller, 2005), but also to support regional mapping efforts such as the United States Geological Survey (USGS) South Carolina Coastal Erosion Study (Barnhardt, 2009). The South Carolina Department of Natural Resources (SCDNR) has also conducted research on sediment and benthic community recovery of borrow and intertidal beach areas following beach nourishment for several decades (e.g., Van Dolah et al., 1992; Jutte et al., 1999 and 2001; Bergquist et al., 2008; Bergquist, Crowe, and Levisen, 2009 and 2011; Wren et al., 2010; Crowe and Sanger, 2014; Crowe et al., 2015). SCDNR also conducted a regional-scale data synthesis as part of the South Carolina Task Force on Offshore Resources, a collaboration between the State of South Carolina and the Minerals Management Service (MMS) (Bury and Van Dolah, 1995; Weinbach and Van Dolah, 2001). These data syntheses were further refined for projects conducted for the South Carolina Energy Office and Governor's South Atlantic Alliance (GSAA) (Van Dolah et al., 2011; Boynton et al., 2013).

This analysis builds upon these previous data syntheses by including more recent datasets, as well as a more comprehensive assessment of data types and data gaps. An additional component is the inclusion of beach nourishment history along the South Carolina coast, which aids in identifying locations and volumes of potential future projects. The merging of the offshore and beach datasets helps ensure that the utility and benefit of future data collection is maximized.

Objectives

Specifically, this project builds on previous work by adding value to existing data sets through the construction of a comprehensive spatial database of sand-resource data to be used in evaluating OCS sand resources. This effort was divided into three main objectives:

Data Accumulation efforts focused on understanding what data sets of OCS sand resources exist, where the data sets are located, what format the data sets are in, and whether the data sets were used in previous evaluations. This objective consisted of developing an up-to-date inventory of existing data pertinent to South Carolina in the 3-8 nm OCS.

Data Management centered on organizing data based on the nature and format of the different data sets being compiled. This primarily built upon an existing inventory used by SCDNR in an offshore resource evaluation done in the late 1990s (Weinbach and Van Dolah, 2001) that was updated in 2010 during a comprehensive evaluation of resources off the coast of South Carolina (Van Dolah et al., 2011). In order to add new data from a variety of sources, it was necessary to develop a data model that was simple and flexible. The data were accepted in their original, unaltered format and metadata records were developed based on the information available.

Needs Assessment was used to evaluate the data inventory and to assess the needs for future data acquisition. This spatial synthesis was carried out once the inventory accumulated a sufficient amount of new data sets that would complement the original studies. The needs assessment identified: 1) areas with potential sand resources for further exploration, and 2) areas lacking data. A second component of the needs assessment evaluated the potential for beach communities to utilize offshore sand resources, specifically those beyond the 3 nm boundary. This included an assessment of nourishment histories, frequencies, volumes, and sediment sources.

Methods

Data Accumulation

Identifying and then acquiring existing datasets located within the 3-8 nm OCS (Figure 1) was the first step toward the analysis and synthesis of needs for future data acquisition. This area of interest spans approximately 300 km between North Carolina and Georgia, with depths averaging 10 m. The bottom type is predominantly characterized by soft sediments, with scattered hard bottom habitat occupying a relatively small proportion of the total area. Prevailing currents generally transport surficial sediment from north to south.

Following a review of known data sources, databases, and existing reports and studies conducted in both state and federal waters offshore of South Carolina, data gap areas and potential data sources for inclusion in the database were identified. Data requests were made for location information (tracklines or shotpoints for geophysical data, latitude and longitude locations for geotechnical cores and grabs), core logs, and raw and interpreted data files. Data located outside of the 3-8 nm and within the 0-3 nm zones was still included if identified during the data review process, but its acquisition was not a priority.

Geotechnical Data

Geotechnical data were derived from vibracores and grab samples primarily collected for beach nourishment and monitoring studies. Most of the data were collected by private companies or the USACE. These data are generally concentrated in borrow sites or potential borrow areas for the following beach communities and associated investigators: DeBordieu Beach (Coastal Science Associates, Applied Technology and Management (ATM), Tidewater Atlantic Research, Inc., and Athena Technologies), Folly Beach (USACE, Athena Technologies) Hunting Island (Coastal Science & Engineering, USACE, CSE-Baird), Hilton Head Island (Olsen and Associates), and Daufuskie Island (ATM, Athena Technologies). The USACE, Charleston District, also provided additional vibracore data concentrated in vicinity of Charleston Harbor and Folly Beach. Where available, descriptive core-log information for offshore vibracores has been compiled for future reference.

Location information for 19 vibracores and 11 surficial grabs were also obtained from BOEM Atlantic Sand Assessment Project (ASAP) contractor Chicago Bridge and Iron Company (CB&I) from field data collected for this study. Final core-log data and surficial grab sample information will be added to the database for South Carolina when available.

Geophysical Data

Geophysical trackline data were acquired and integrated into the database for surveys conducted by universities, federal and state agencies, and private companies. Much of the cruise data that was found from the 1970's, 1980's, and 1990's was collected using navigation technology such as LORAN-C and the differential geographic positioning system (DGPS) to provide positions. These data proved more difficult to integrate into ArcGIS than recent surveys, which commonly use high-accuracy Real-Time Kinematic (RTK) GPS with centimeter horizontal and vertical resolution. Several trackline shapefiles from U.S. Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA) cruises were created using raw navigation data in ASCII-file format to create point and line files. Some of the older seismic data have not yet been converted to a digital format. Tracklines for these cruises (for example, a survey route for a cruise conducted aboard the USGS R/V Fay in 1976) are included in the database so that their spatial extent is known should the need to convert the raw seismic reflection data arises in the future. Where available, georeferenced sidescan sonar backscatter mosaics were included in the database. Any raw geophysical data were also compiled for database inclusion.

Trackline data for CB&I geophysical data collected in 2015 are included (sidescan sonar, subbottom profiler, and swath bathymetry) data from this survey will be processed and analyzed under the second iteration of state cooperative funding.

Online data portals were also used extensively in this project as a means of identifying new geophysical and geotechnical data for inclusion in the database. Several of these are federal data viewers created and maintained by NOAA and USGS. Others are state-specific and provided jurisdictional boundaries and information for past beach nourishment projects. A list of the most useful online data sources for this project, along with a description of the available data and a link to the resource, is outlined in Appendix 1.

Data Management

The geographic data layers collected for this project were stored in an ArcGIS geodatabase. The inventory geodatabase includes the data in their original form as they were received from the source or previous study.

The inventory geodatabase is structured into six feature datasets and a collection of spatially-referenced geophysical imagery. The feature datasets are: Avoidance, Beach, Boundaries, Bottom, Geophysical, and Geotechnical. All feature classes are in a geographic coordinate system, which was common to a majority of the native data incorporated. The exception was the Beach dataset, which is uses the State Plane coordinate system.

The **Avoidance** feature dataset includes areas where dredging is likely not possible because of: offshore artificial reefs, dredged-material disposal locations, as well as hardbottom and potential hardbottom habitats.

The **Beach** feature dataset includes layers available from South Carolina Department of Health and Enivironmental Control-Ocean and Costal Resource Management's GIS Clearinghouse (SCDHEC) (Figure 2). Feature classes delineate the adopted setback and baselines for every developed beachfront; adopted long-term erosion rates for points along the coast; information on past nourishment projects; classification of beaches into standard, stabilized, or unstabilized zones; and inshore and offshore sand-borrow areas. All of the layers remain unchanged from their original format with the exception of the sand-borrow areas. Borrow areas contained in this inventory are a compilation of spatial information from SCDHEC and SCDNR, and tend to represent the permitted area rather than the actual dredged areas for which spatial information is less available.

The **Boundaries** feature dataset includes lines showing 3 nm, 5 nm, 8 nm, 12 nm, and -50 m bathymetric contour and areas delimiting state waters, BOEM's stated area of interest, and finally the larger project area where data was found and inventoried (Figure 1).

The **Bottom** feature dataset includes the South Carolina portion of SEAMAP-SA (2001) data inventory and bottom characterization as both point and line feature classes.

The **Geophysical** feature dataset to date has twenty-eight feature classes representing locations for at least sixteen separate projects from a variety of sources (Appendix 2) both private and public. Some of the layers were already compiled, and a number of trackline datasets appeared in multiple files, so the exact number of surveys and projects represented is difficult to determine. These feature classes represent mostly tracklines from sidescan sonar backscatter and high-resolution seismic data acquisitions, as well as a few bathymetric and magnetic contours. Some of the tracklines have associated sidescan sonar raster mosaics, included in the final data package, but they were not available for all trackline datasets.

The **Geotechnical** feature dataset has twelve feature classes representing locations for both specific surveys as well as datasets that represent compilations of several datasets. The geotechnical data are point feature classes representing the locations of sediment grabs or vibracores. The feature class attributes vary in complexity, which is another reason the structure of each dataset was left intact. Some geotechnical point data contain associated vibracore logs. These were maintained as PDF documents to accompany the spatial data package.

Metadata were maintained for every feature class and raster layer using Federal Geographic Data Committee metadata standards. The required metadata elements were imported as xml and upgraded to editable ArcGIS metadata. Metadata include as much pertinent information as possible, but for some of the older datasets, certain metadata components were not available. The file naming convention for the geophysical and geotechnical data was standardized as Source_Date_Location_Type (e.g., USGS_2007_MB_grabs; Appendix 3). The date most often refers to the year the data set was published, which can include data collected prior to that year. In some cases the date represents the year the data was collected if no particular report was available.

Needs Assessment

Sediment Data

Once the inventory database was assembled, the sediment data were compiled in a manner that would allow the identification of data gaps and areas of high data density. A number of source datasets contained duplicate data. This was expected, as some of the source data consisted of meta-analyses (e.g., Van Dolah et al., 2011; SEAMAP-SA, 2001), or were derived from researchers that included previously collected data to support their analyses (e.g., College of Charleston and Coastal Carolina University). Therefore, the first step in assessing data coverages, was to parse out these duplicate records.

The 'select by location' tool in ArcMap 10.2 was used to select data that shared identical spatial locations. Often these duplicate data could be confirmed by shared attributes such as sampling date or result value. To avoid overestimating data densities, duplicate data were excluded from the needs analysis. Most of these duplicates existed as geophysical trackline polylines or trackline vertices.

A second step in the preparation of data was to separate geophysical point data (often navigational data) from geotechnical point data. The earlier SEAMAP-SA dataset, for instance, contains 1,192 geophysical points. All but 37 of these are accounted for by later data syntheses such as Van Dolah et al. (2011). The data set from this study contained several point values (CC03-CC18, CC33-CC35) that represented interpretations from geophysical surveys, and therefore these data were excluded from the geotechnical data analysis. Many of these point values were also included in another trackline dataset already included in the analysis (Harris, 2000), but the point-value interpretations were maintained as supplemental information. Appendix 2 summarizes total number of records and the number of records used for the needs assessment. Because some of these datasets contained duplicate information a second needs assessment geodatabase was created to house filtered datasets that were used in the analysis (Appendix 2).

To facilitate combining multiple datasets into a single layer, point and polyline vector data were merged into raster datasets that are stored in the needs assessment geodatabase. This was conducted to allow a greater variety of analyses and data depiction than could be accomplished with shapefiles. Much of the native data were stored in a geographic projection. These data were projected into an Equal Area projection (USA Contiguous Albers Equal Area Conic) prior to analysis, to ensure that distances were measured accurately and precisely in space. Analysis was explored at two primary grid sizes: 1 km × 1 km and 2 km × 2 km. These were selected to provide good interpretation at a coast-wide level, while still allowing detailed interpretation for specific areas of interest. The most recent similar analysis utilized a 1-minute grid. Because the linear distance of 1-minute varies across the study area, but averages 1.7 km, the 1 km × 1 km and 2 km × 2 km grids utilized here are comparable in size but more consistent in a projected coordinate system. The 1 km^2 grids are presented here, as they were determined to provide greater utility than the larger grids.

The sediment data needs assessment consisted of two primary components: 1) an assessment of available data types (e.g., geophysical, geotechnical) and coverages offshore of coastal South Carolina (with emphasis on the 3-8 nm OCS), and 2) an analysis of data density within these respective data types. The data type coverages were assembled using the following methodology. First, the 'select by location' tool was used to identify cells that contained a given data type. These were saved as individual coverages. To combine these into a single layer, a hierarchy was developed under the assumption that geotechnical and geophysical coverage is optimal, followed by geotechnical, then geophysical, and then bottom type only (hardbottom or soft bottom without sediment data). Each pixel was then assigned a score representing the data types contained within that pixel. The second component utilized a spatial join to sum the number of geotechnical points within a given pixel, or the length of trackline within that pixel for geophysical data, to assess data density in points/km^2 or km trackline/km^2.

Beach Data

To assess the potential for utilization of offshore sand resources by various beach communities along the South Carolina coast, a comprehensive beach nourishment database was compiled from various sources (Van Dolah et al., 2011; SCDHEC, 2016; Western Carolina University, 2016). This contains information relating to nourishment volume, cost, spatial extent, and borrow areas. In most cases, borrow-area polygons, where available, represent the permitted borrow area, which may vary from the area actually dredged if only a portion was suitable material (e.g., Surfside Beach borrow area), or if the permitted area contained more material than was needed for a specific project (e.g., Folly Beach borrow areas A and B). Some listed projects were excluded from the synthesis if they were potentially a by-product of existing dredging projects (such as channel dredging at Folly River, Huntington Beach State Park and Waites Island, or the Isle of Palms marina dredging).

Beach nourishment data were analyzed to assess the approximate return interval (years) and annualized volumes used by beach communities in cubic yards per year (CY/y). These calculations assume an active period from the first nourishment for each respective beach through the year 2016. Because of the project emphasis on offshore sand resources and volumes, beach statistics were not adjusted for beach length or presented per linear unit, although many nourishment project lengths, as provided by SCDHEC, were included in the database. Borrow distances were calculated to look for trends and to examine the potential need for OCS sand. These distances were calculated conservatively from the nearest beach point to the nearest point of the borrow area used for nourishing the associated beach. In cases in which multiple borrow locations were permitted for a single nourishment, the nearest borrow was used for distance calculation. Inland pit and channel dredging distances were calculated, but these were excluded from the bulk of the analysis in that the emphasis was primarily offshore sediment. Additionally, some nourishment events were excluded from the cost- and sand-deposition analysis because of missing or incomplete data.

Results and Discussion

The final inventory database contains a wide variety of data representing offshore bottom type information derived from both geophysical and geotechnical samples collected between the 1960s and present day (Appendices 2-4). Over 6,000 geotechnical samples and 18,800 km of trackline datasets were compiled for the analysis (Figures 3-4). While the emphasis of data collection and analysis was on the three to eight nautical mile area, the spatial coverage of data ranges from inshore bays to the -50 m depth contour. Bottom type and avoidance information were also considered (Figures 5-6). Spatial data were organized and ranked in 1 km^2 grids according to data density and data type (Figures 7-9), which were subsequently used to identify data gaps (Figure 10).

Data densities and data quality are generally proportional to patterns of sand resource use (Figures 7-9). In general, most geotechnical and geophysical data occurs within the 0-3 nm state waters, but the geophysical data coverage also extends over a much larger area (Figures 11 and 12). Between the beachfronts and the 3 nm boundary, the database contains 7,100 km of trackline data. In the 3-8 nm zone, 5,600 km of trackline data were compiled. For geotechnical data, there are approximately 3,200 records in the 0-3 nm zone, and 2,080 in the 3-8 nm OCS zone. These datasets are shown in greater detail for subsets of coastal South Carolina in Figures 13 and 14.

The most continuous data coverage for both primary data types occurs in a 75 km stretch along the Grand Strand (DeBordieu Beach to Waites Island), ranging 0-5 nm (0-9 km) from shore. Despite its history of large nourishment projects, however, the Grand Strand OCS just inside of 8 nm is data poor, and several areas contain no data. This most likely results from the availability of usable sand closer to placement areas. Central South Carolina between Winyah Bay and Dewees Island is lacking coverage of geotechnical data, but there are no populated beaches in this stretch, and therefore little demand, at this time, for nourishment. Folly Beach OCS has the greatest data density and quality, but also a high demand for sand resources, as these borrow areas have historically refilled with sediments too fine to use in future projects (Bergquist et al., 2008; Bergquist et al., 2009a). Within state waters, Folly Beach contains the highest density of geophysical data, with some 1 km^2 pixels containing over 25 km of trackline data. Investigation at finer resolution reveals several areas in or near the OCS that may warrant further analysis. South of Folly Beach, data quality and density becomes more limited, matching the fewer nourishment events that have occurred in this area. Geophysical and geotechnical data coverage in this area tends to be regional geological studies rather than detailed surveys of potential borrow areas. Data coverage then increases near Hilton Head Island, although it is sporadic, and geotechnical data is lacking in a large portion of the 3-8 nm OCS area. Previous nourishment projects at Hilton Head, including a planned 2016 nourishment, have utilized the ebb tidal deltas near inlet mouths, well inside of the OCS, and previous monitoring studies have demonstrated that these types of borrow areas have a greater tendency to fill with beach compatible sand and can often be used more than once (Bergquist et al., 2009b).

Because these datasets may be used to identify areas of sand extraction or future data exploration, avoidance areas representing hardbottom habitat, artificial reefs, and offshore dredged material disposal sites were also considered in this analysis (Figures 6, 14). Avoidance areas in the 3-8 nm zone tended to be most prevalent near Charleston, as there is a 40 km^2 area permitted for the Charleston Ocean Dredged Material Disposal Site (ODMDS) and 27 1 km^2 pixels that contain hardbottom or potential hardbottom habitat. Near the Grand Strand, hardbottom and potential hardbottom habitats, where bottom-type data were available, tend to occur within the 0-3 nm state waters. Artificial reefs occupy a relatively small area of bottom and are well distributed along the coast, occurring in both state and federal waters.

Beach nourishment data were analyzed to provide approximate return frequencies and average volumes for various areas. Beach communities with the highest annualized sand usage were Folly Beach and Hilton Head Island (Figures 15-16). Total volume for all nourishment events at Folly Beach is 7.5×10^6 CY excluding channel maintenance dredging, or 10.3×10^6 CY in total, between 1979 and 2014. For Hilton Head Island, the total nourishment volume is 12.8×10^6 CY since nourishment began in 1969. Not surprisingly, Folly Beach and Hilton Head Island also exhibit the shortest return interval for nourishment events, with both communities experiencing nourishment every four to five years on average (Figure 17). Spacing of nourishments events at these same communities, however, is variable, reaching up to 13 years between events. As a region, the Grand Strand has placed the most sand along its beaches, but this region is also much larger than the barrier island beaches along the southern South Carolina coast, and has consequently drawn from sand resources along a 75 km stretch of state and OCS bottoms, as well as several terrestrial borrow areas. Total sand placement for this region is approximately 19.0×10^6 CY over 28 events since 1979. Within the Grand Strand, annualized sand placement is greatest at Myrtle Beach, but return frequencies are similar, ranging from 5-9 years between events.

The inflation-adjusted per-unit cost for beach nourishment (2016 \$/CY) has increased significantly since the earliest record in 1954 (Figure 18, $r^2 = 0.34$, $p = 0.01$). Borrow distance has also increased significantly over this same timespan (Figure 19, $r^2 = 0.23$, $p = 0.03$), suggesting that at least part of the increase in per-unit cost may be driven by the increase in dredging distances. However, directly testing borrow distance against per-unit cost does not yield a significant relationship, so factors other than inflation and borrow distance are likely also driving the increase in cost. Nourished beaches and corresponding borrow areas are detailed in Figures 20-22.

Recent detailed beach profile surveys have identified a number of beaches with sand deficits that are characterized by minimal dry-sand beach at high tide (D. Burger, SCDHEC-OCRM, 2016, personal communication). These areas are, in order from North to South, Garden City-Surfside, Pawleys Island, Isle of Palms, Sullivan's Island, Harbor Island, and Hunting Island. Garden City, Pawleys Island, and Hunting Island have all exceeded their time-averaged nourishment window by three to four years (date of last nourishment + average return interval, Table 1). Isle of Palms, Sullivan's Island, and Harbor Island do not have enough records to calculate a nourishment return rate. Folly Beach, Hilton Head Island, and other beach communities with a history of short nourishment return intervals should also be considered as highly erosional. With Folly Beach recently completing its nourishment in 2014, and a project at Hilton Head Island underway, the nourishment planned for Garden City starting in the fall of 2016 is the next major nourishment project for South Carolina. It is likely that with increasing nourishment costs, funding these projects will become increasingly challenging, especially as nearshore borrow areas become exhausted. Sand resource use in the OCS area is likely to increase as interest in beach nourishment projects remains high. Future sediment data collection and analysis should focus on areas where nourishment is anticipated.

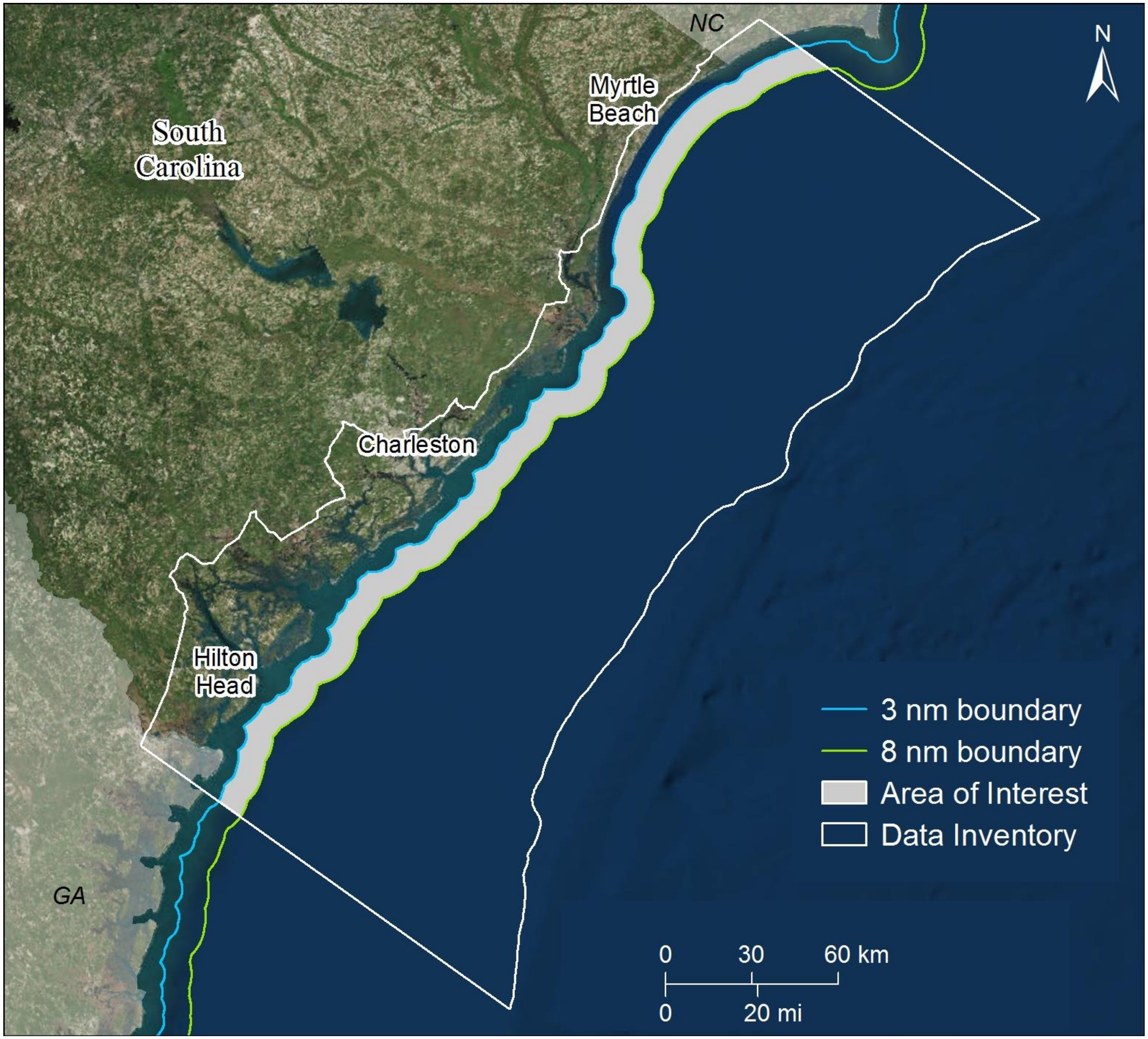

Figure 1. The area of interest is between the 3-8nm of the OCS. The data inventory extends east from the inland SCDHEC - OCRM critical area boundary to the -50 bathymetric contour offshore.

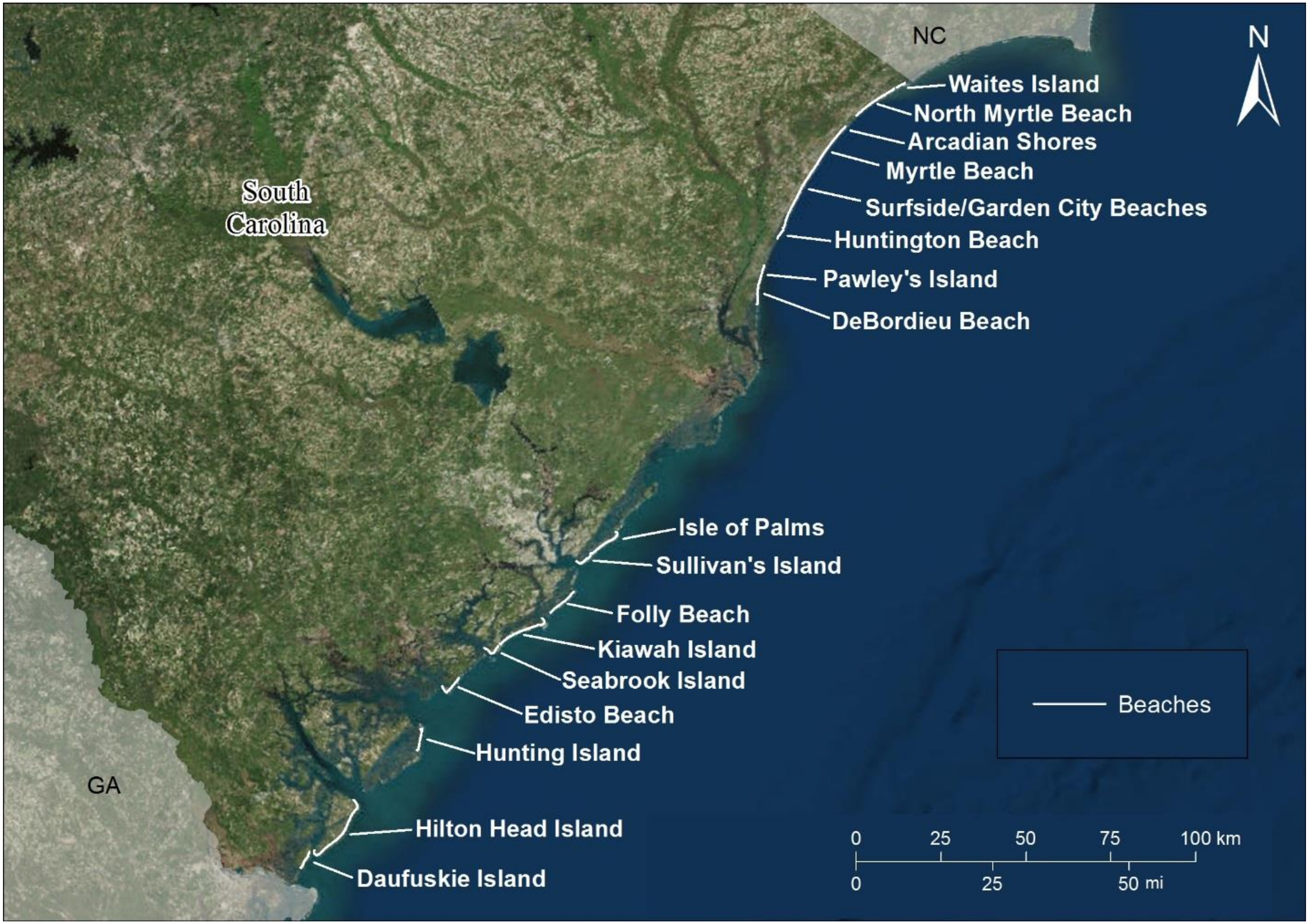

Figure 2. White lines depict beaches in South Carolina with associated nourishment projects.

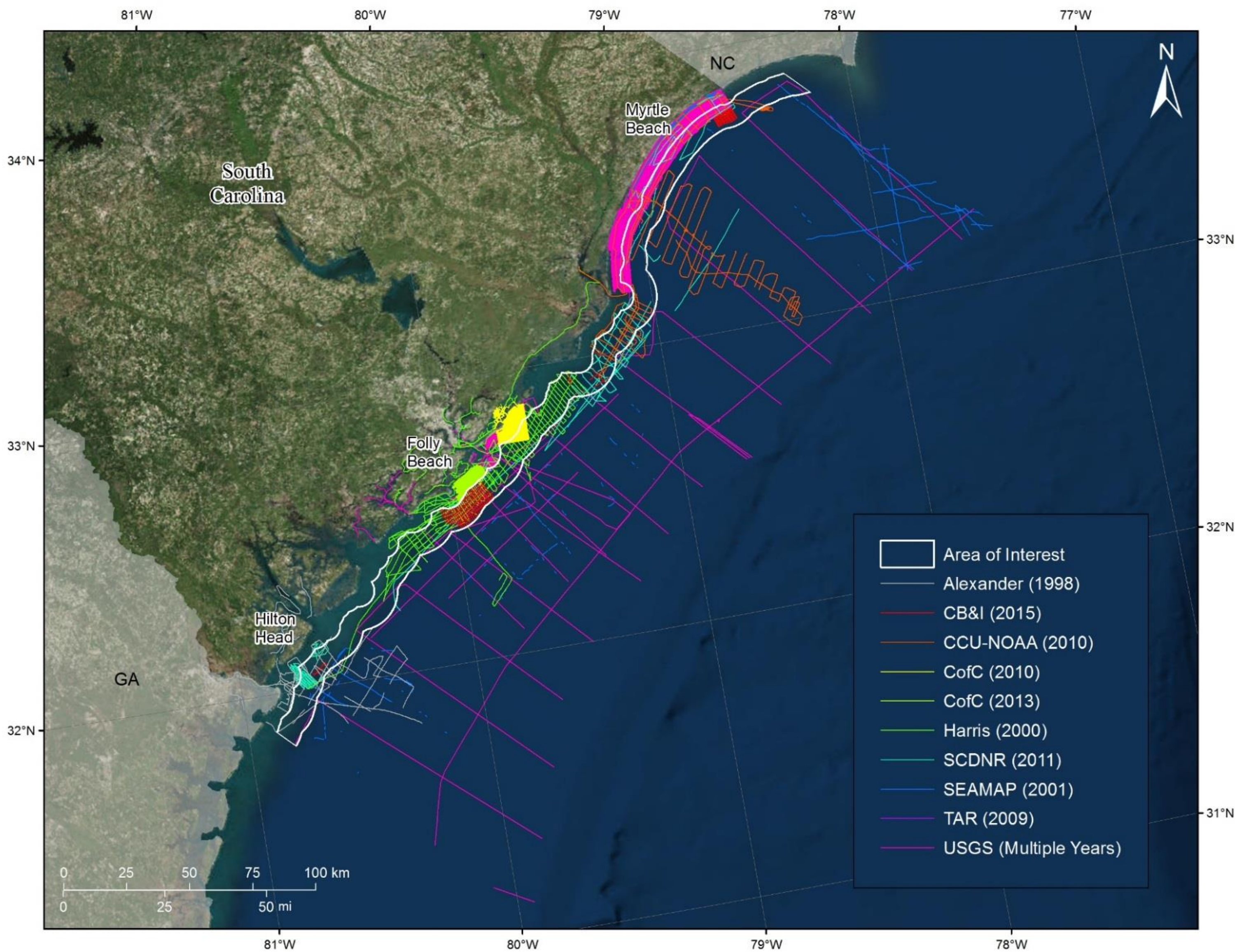

Figure 3. Colored lines represent geophysical surveys that are compiled in the inventory, by source. The USGS survey years are 1976, 1994, 1996, 1997 and 2007.

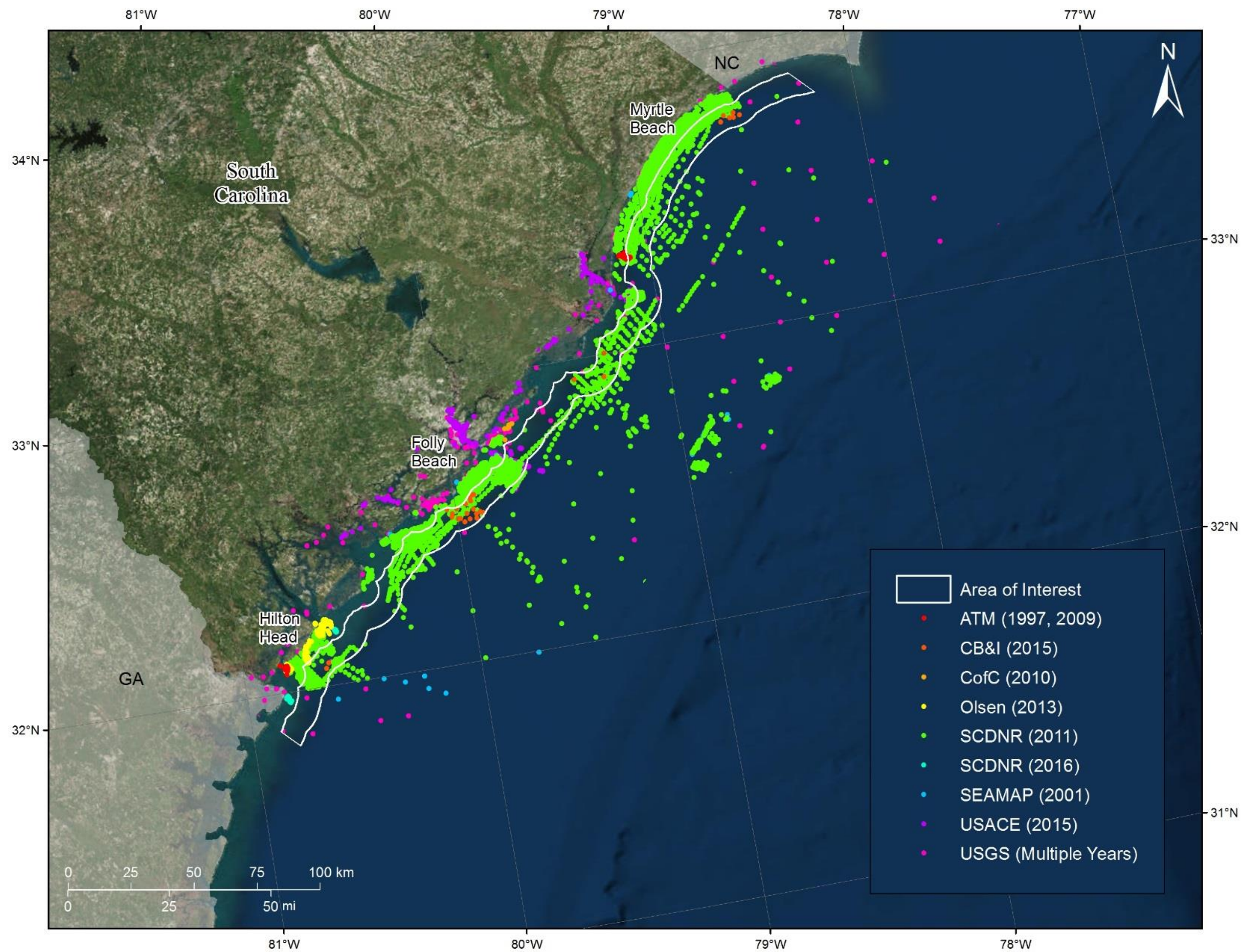

Figure 4. Colored points represent geotechnical data sources that are compiled in the inventory. Years indicate year of publication or year of last data point. In some cases (e.g., SEAMAP-SA, 2001) datasets contain records dating to the 1960s.

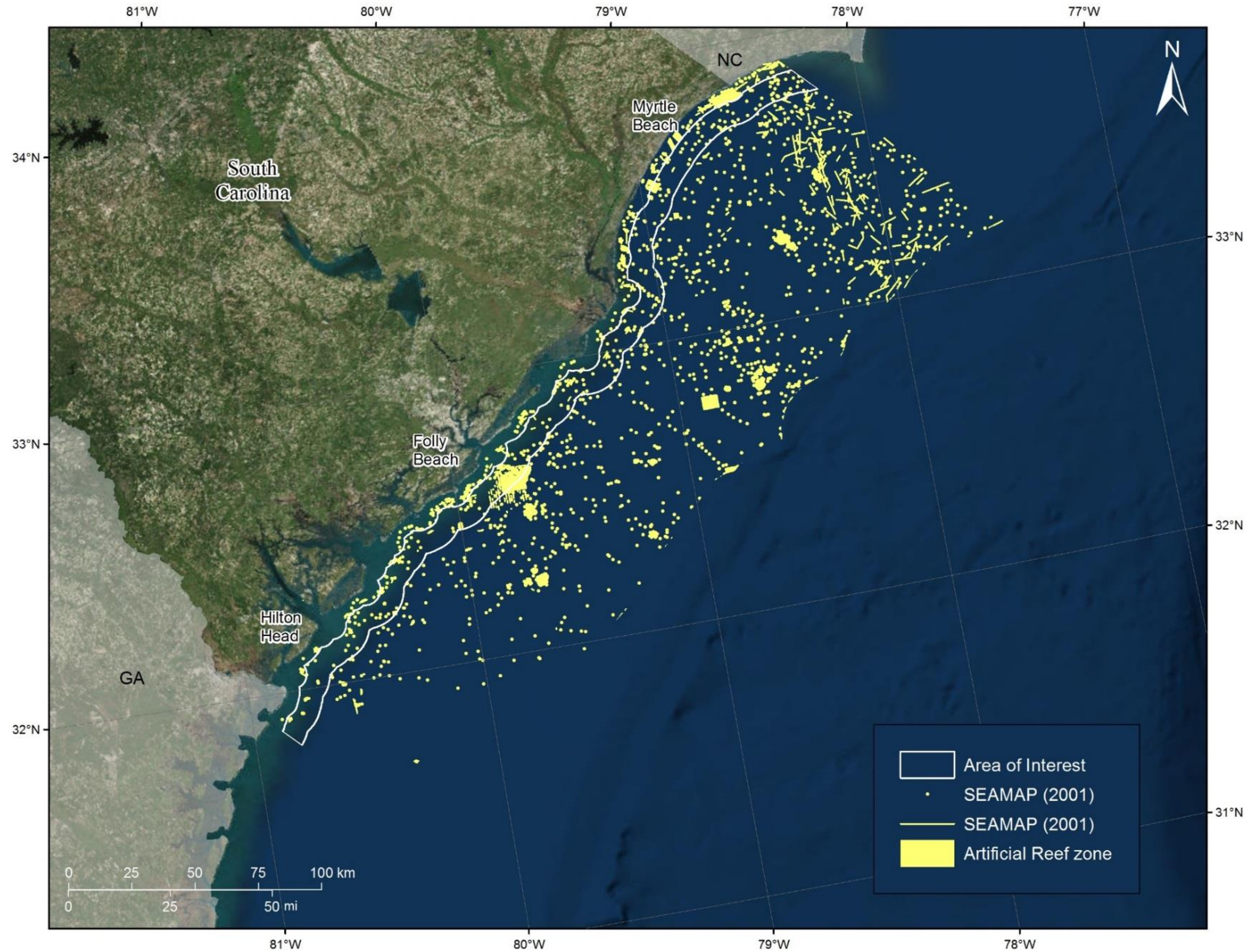

Figure 5. Yellow shading marks bottom type data that are included in the inventory. Data represent point, polyline, and polygon data types.

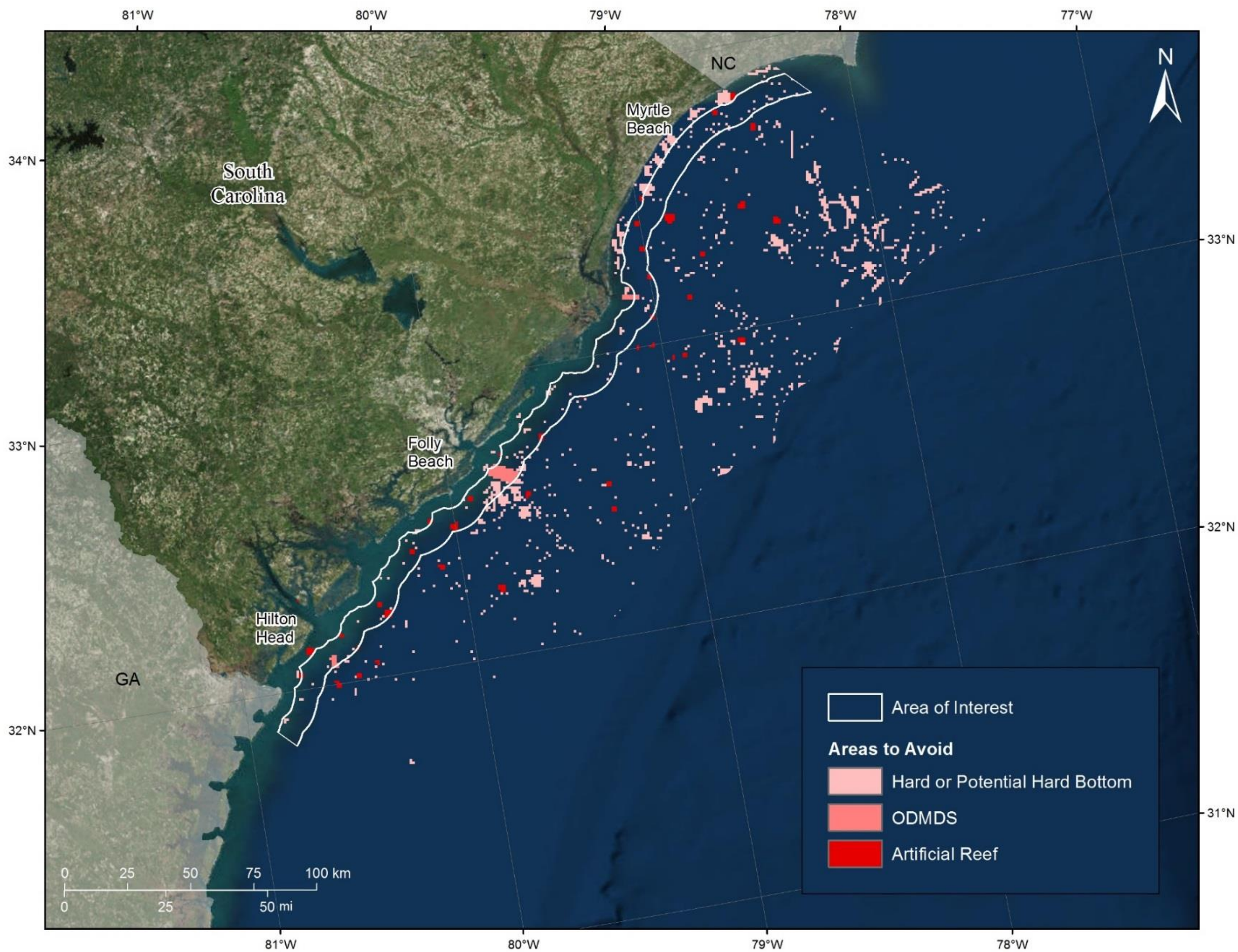

Figure 6. Red shading depicts the locations of probable avoidance areas. These areas contain hard bottom, potential hard bottom, artificial reefs, or ocean dredged material disposal sites.

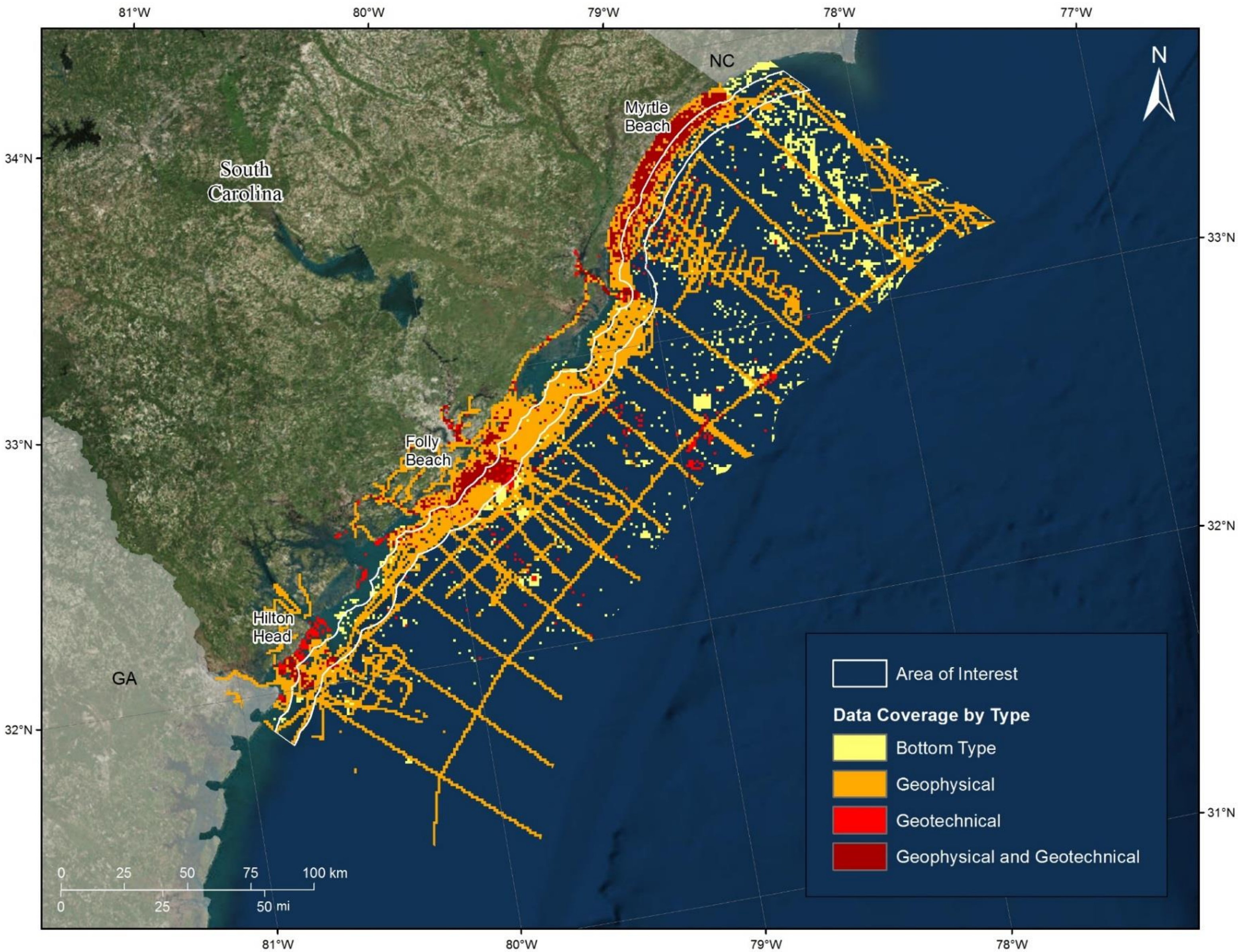

Figure 7. Grid analysis results showing data coverage by data type (1 km^2 grid). The darker colors represent higher quality data.

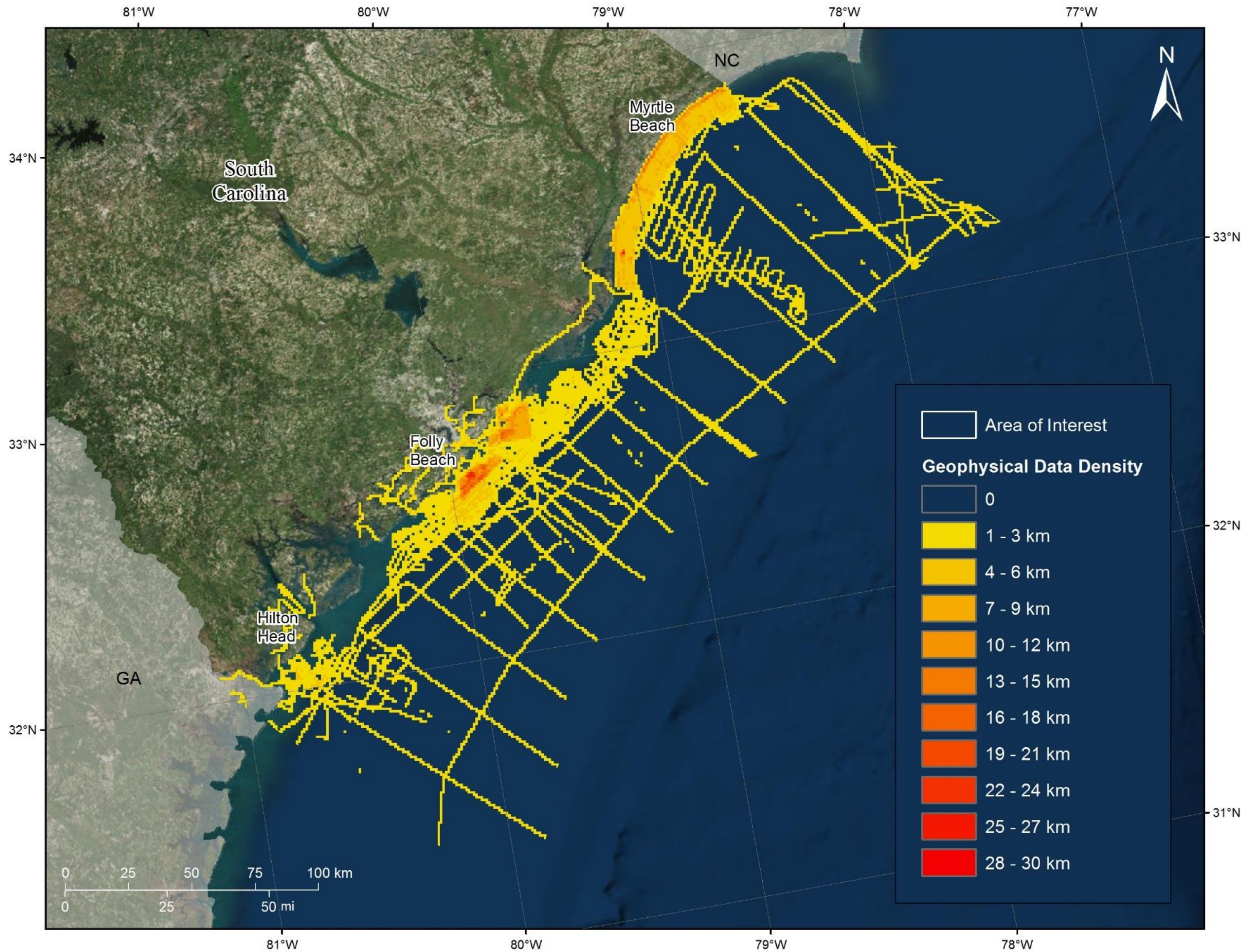

Figure 8. Results from geophysical data density analysis (km trackline per 1 km^2 grid cell). Darker colors represent greater data density.

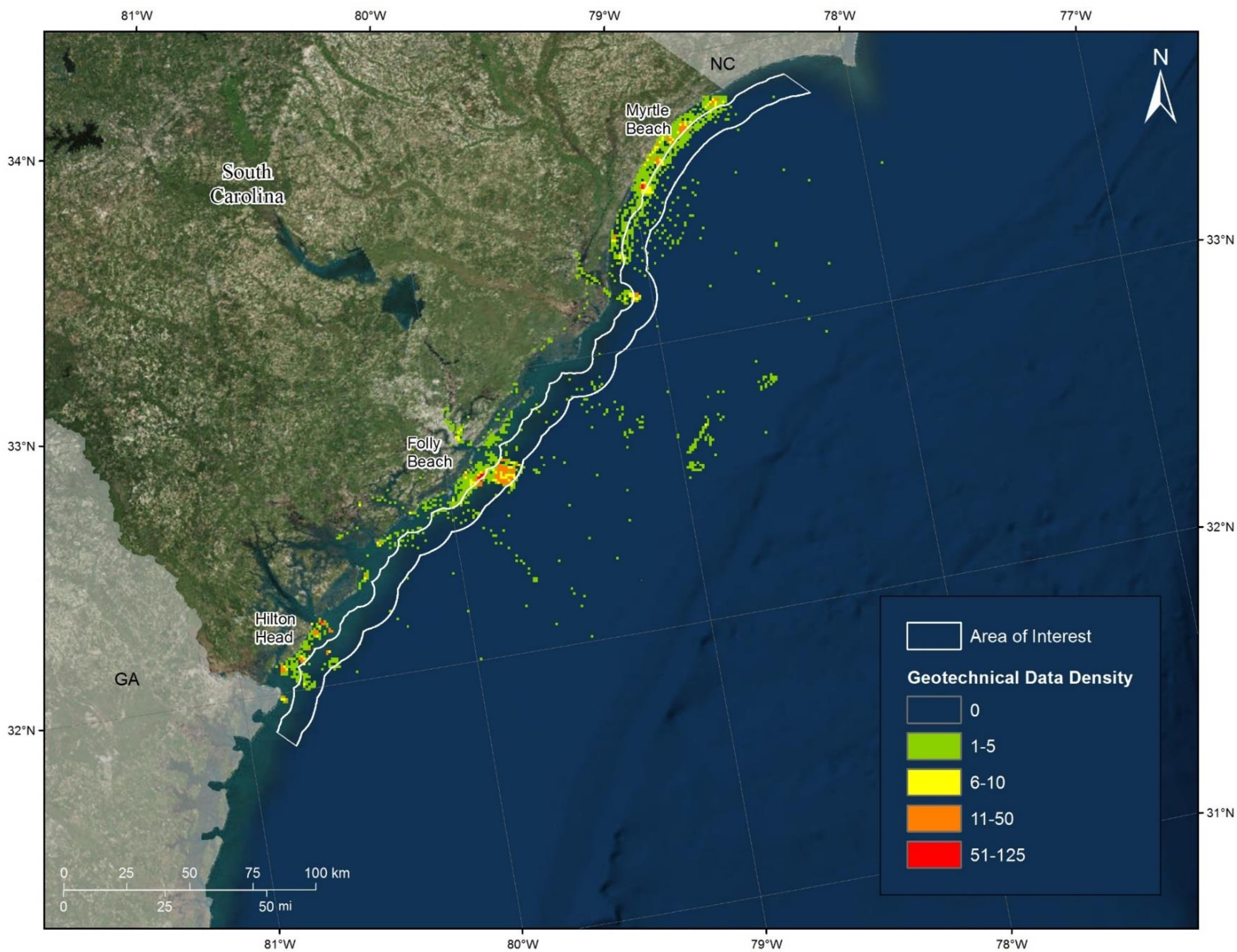

Figure 9. Results from geotechnical data density analysis depicting areas of high (red) and low (green) data density (points per 1 km^2 grid cell).

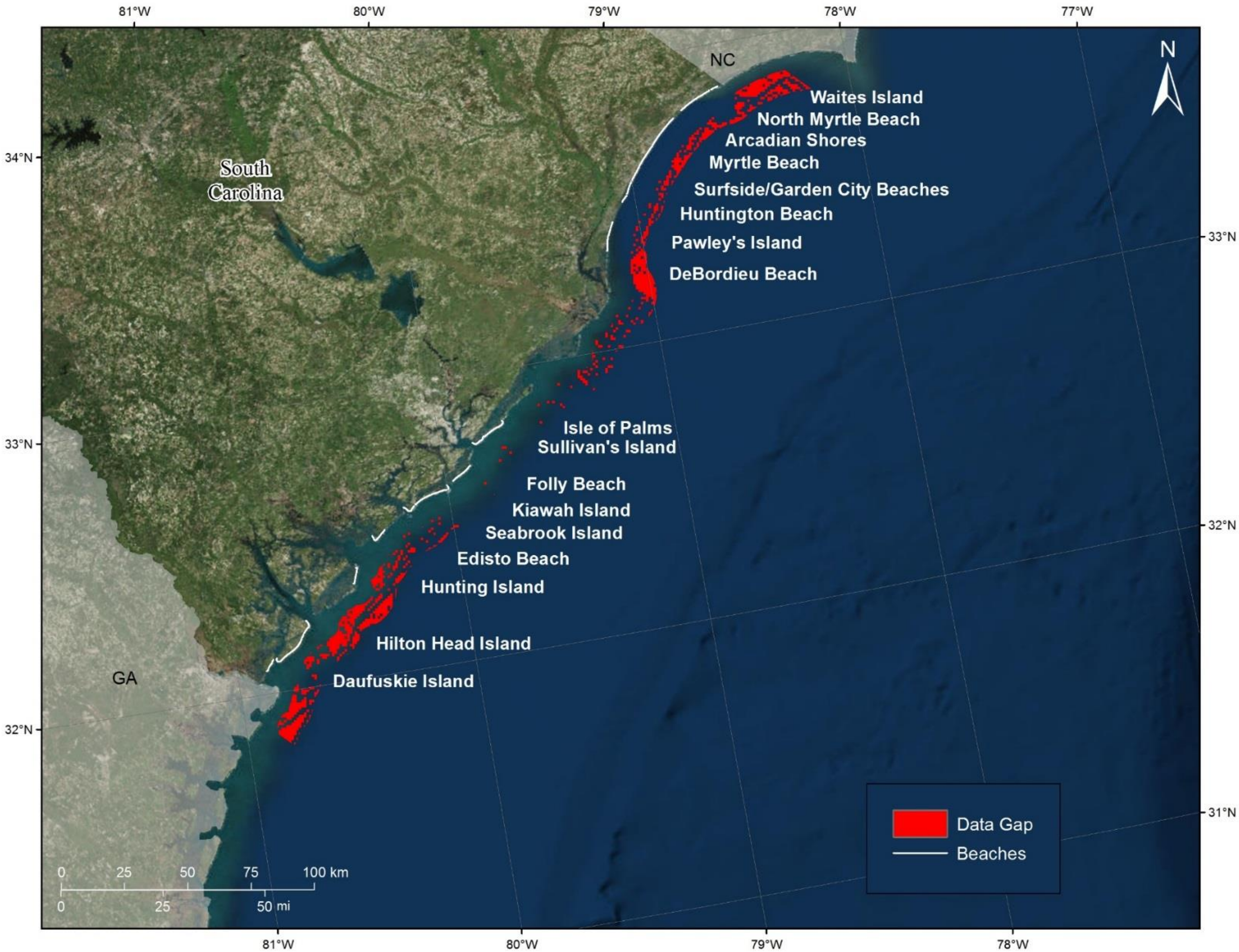

Figure 10. Red shading indicates 1 km^2 areas where no sediment or bottom type data were available. Data gap analysis shown only for the 3-8 nm area of interest.

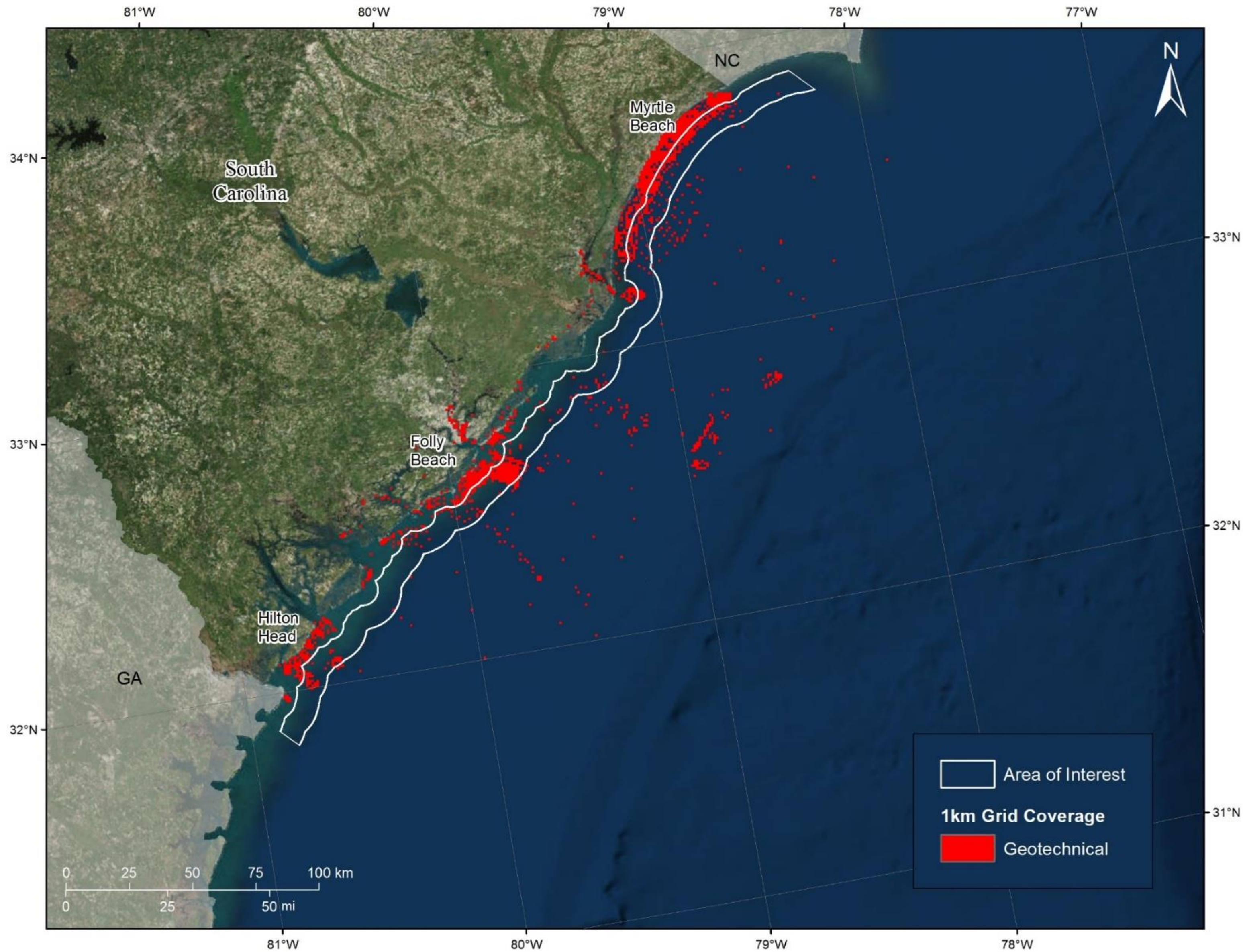

Figure 11. Results from geotechnical data coverage analysis are depicted by red shading (1 km^2 grid).

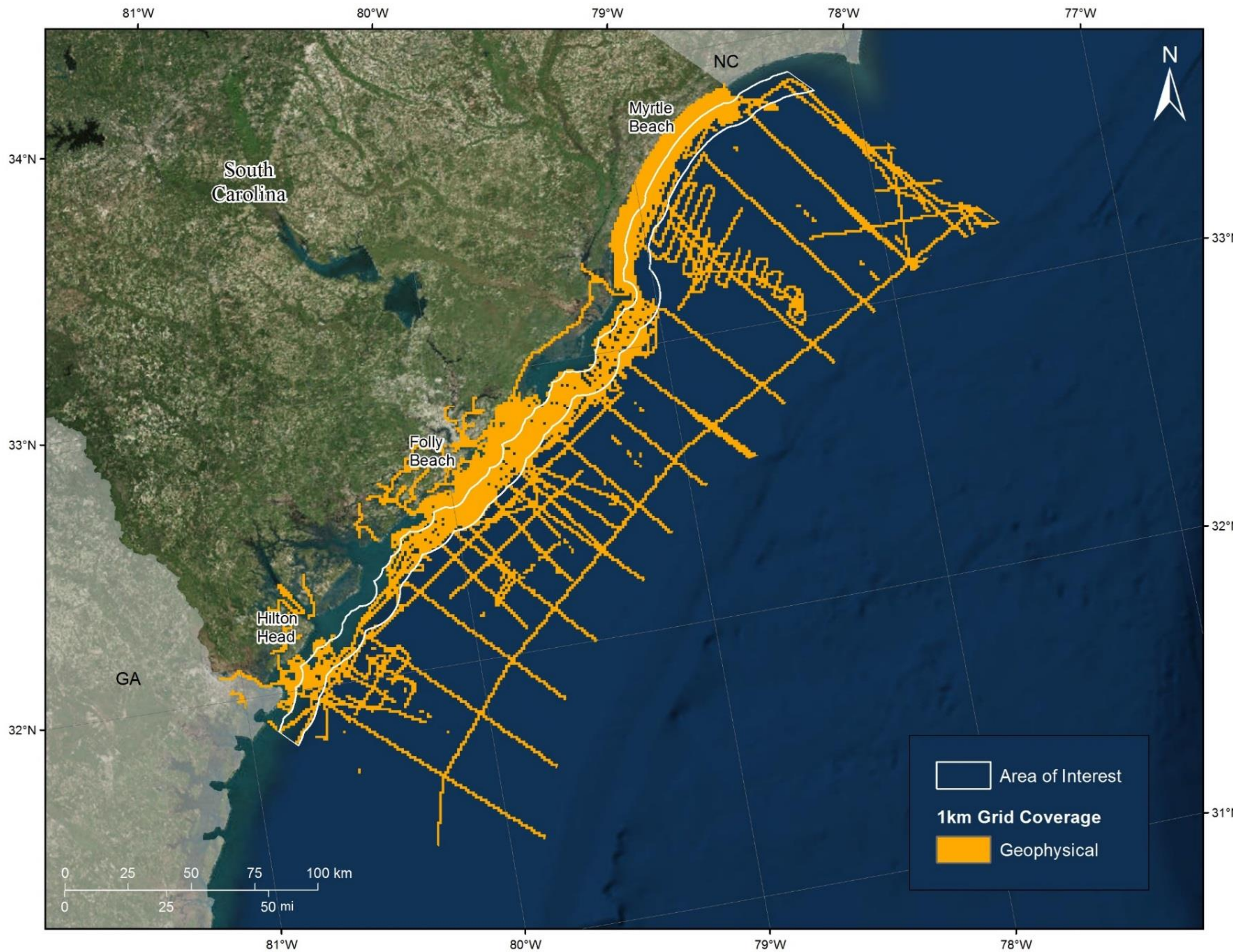

Figure 12. Results from geophysical data coverage analysis are depicted by orange shading (1 km^2 grid).

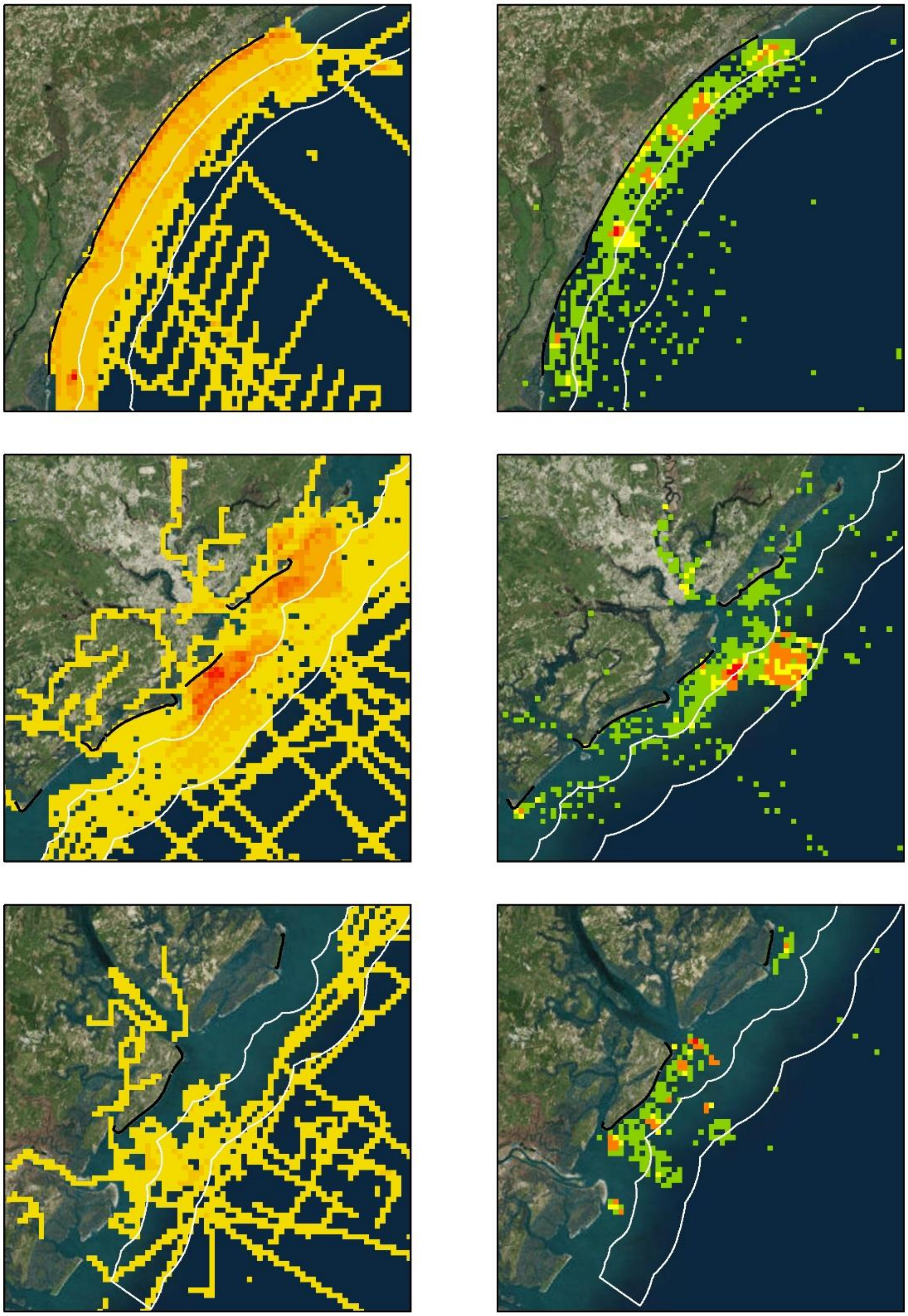

Figure 13. Detail maps of geophysical (left) and geotechnical (right) data densities for the Grand Strand (top), Charleston (middle), and Beaufort (bottom) regions.

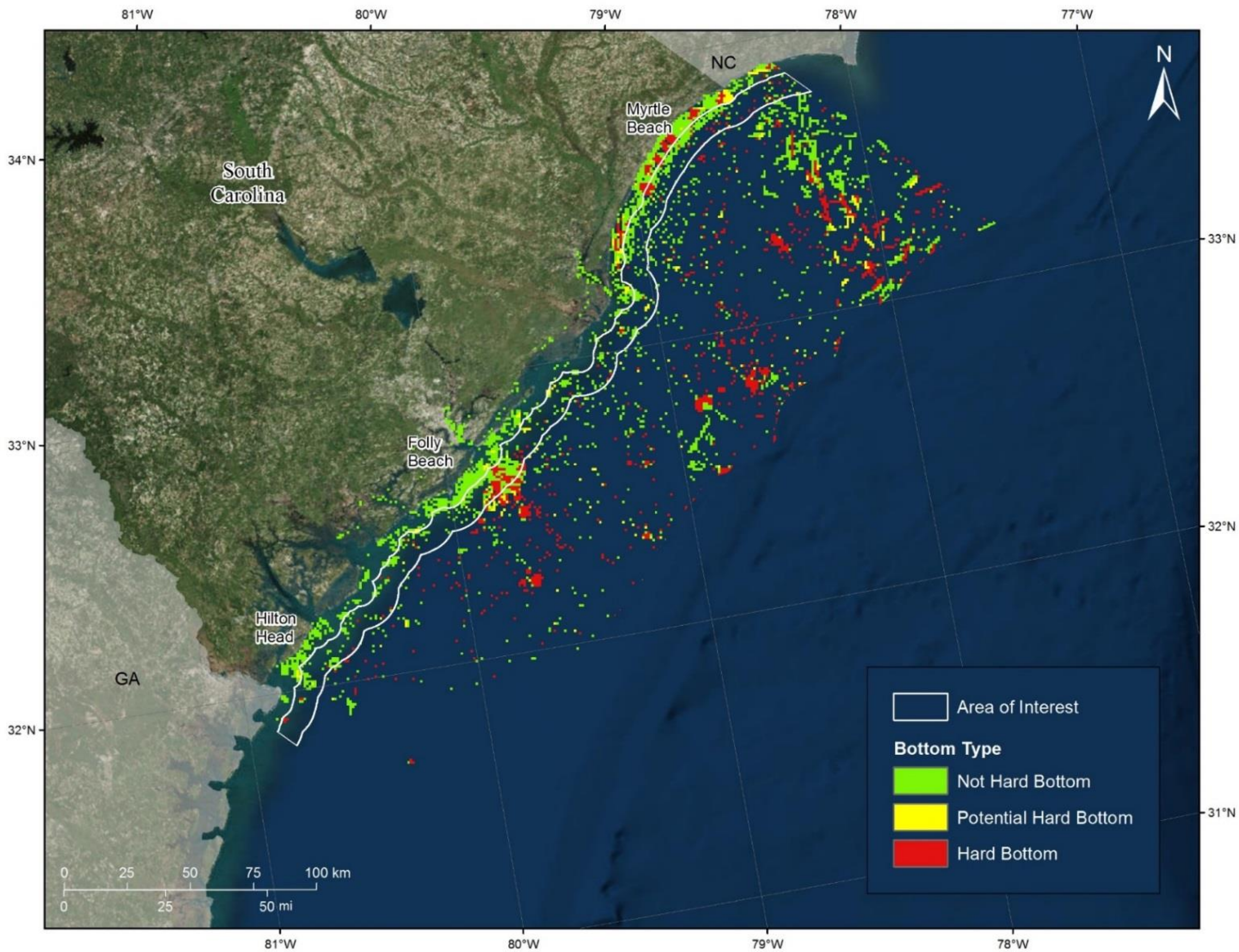

Figure 14. Coverage of bottom type data for coastal South Carolina. Within the 8 nm zone, most hard bottom in the Grand Strand occurs within state waters, whereas in Charleston and south, hard bottom tends to occur within the OCS zone. Data were sourced from SEAMAP-SA (2001), as well as areas where sediment grabs have been collected.

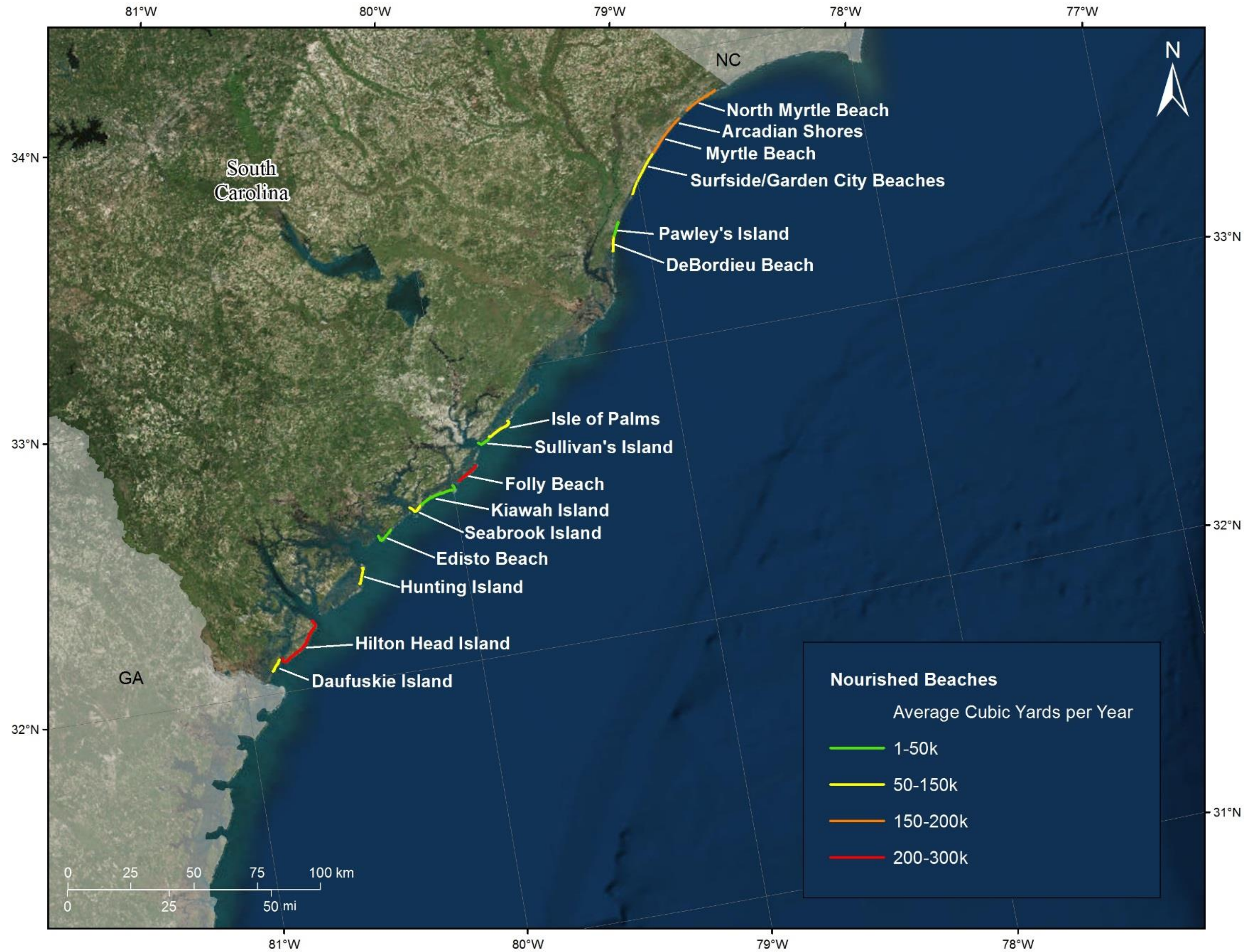

Figure 15. Colored lines indicate nourished beaches in South Carolina where calculation of sand placement rate was possible using available data. Beach segments depict entire beach length, not necessarily the portion nourished.

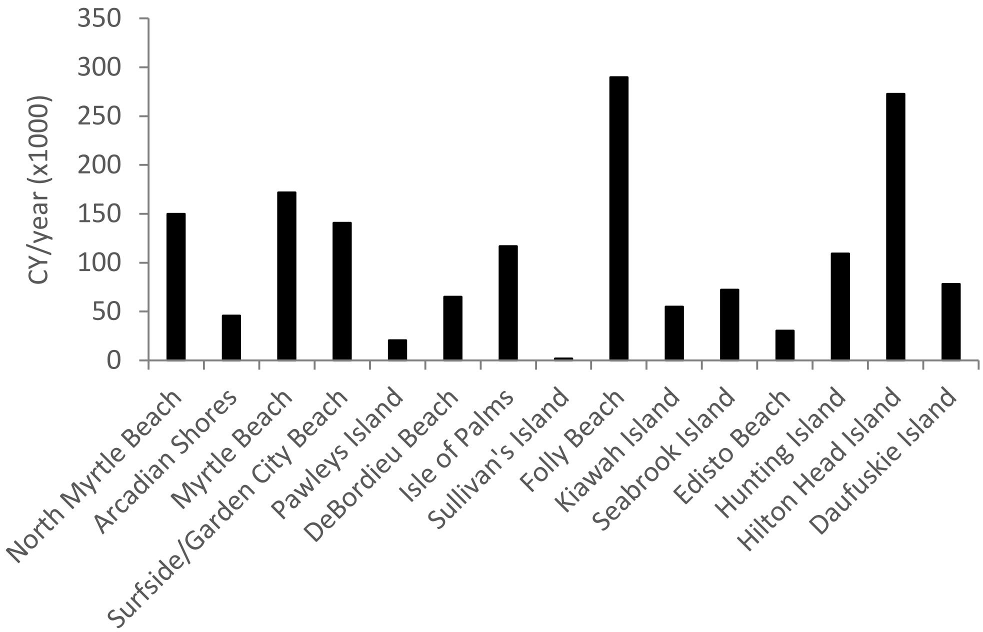

Figure 16. Bars indicate time-averaged annual sand usage (CY/yr x1000). Beach communities are listed in order from north (left) to south (right).

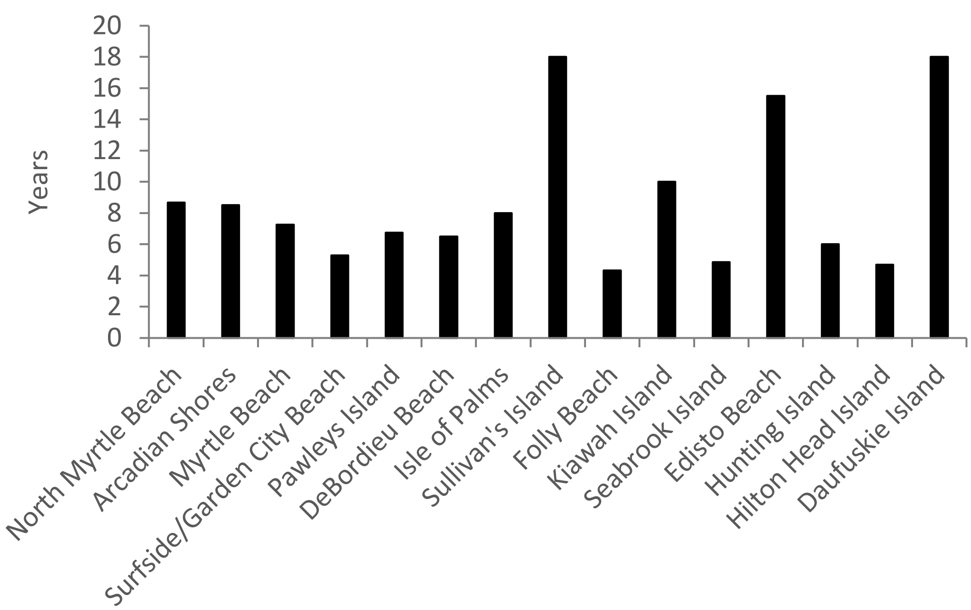

Figure 17. Bars indicate average time span between nourishment events, calculated as total nourishment period (2016 - start year) divided by number of events in database. Beach communities are listed in order from north (left) to south (right).

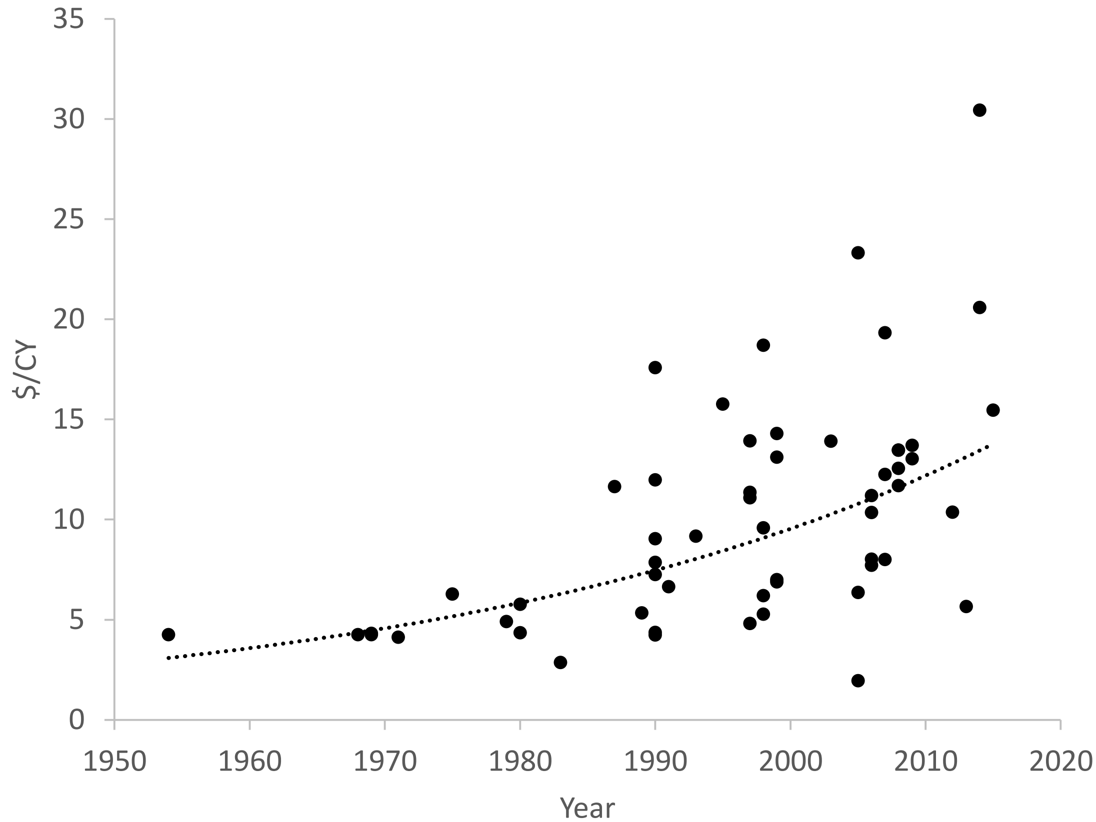

Figure 18. Points depict increasing trend in per-unit cost of beach nourishment over time (2016 $/cy, offshore borrow areas only). The relationship becomes more variable over time and is statistically significant (p = 0.01).

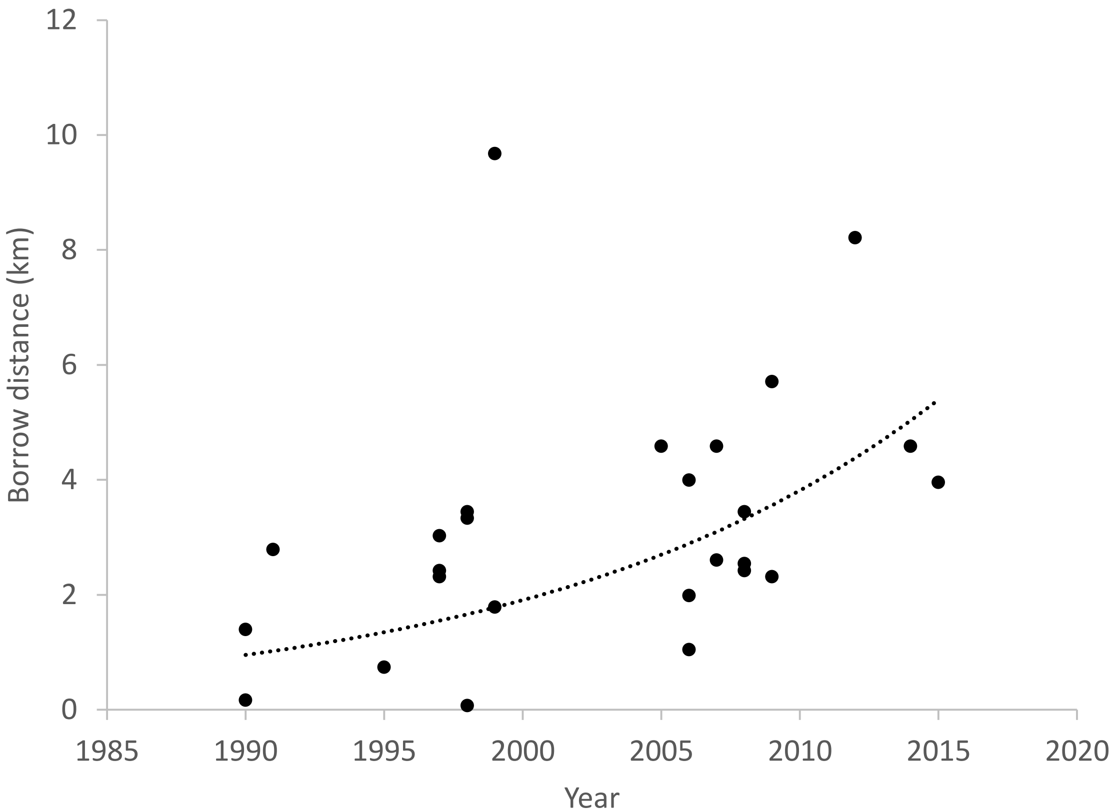

Figure 19. Points depict increasing distances to borrow areas, where spatial borrow data were available. The relationship is statistically significant (p = 0.03).

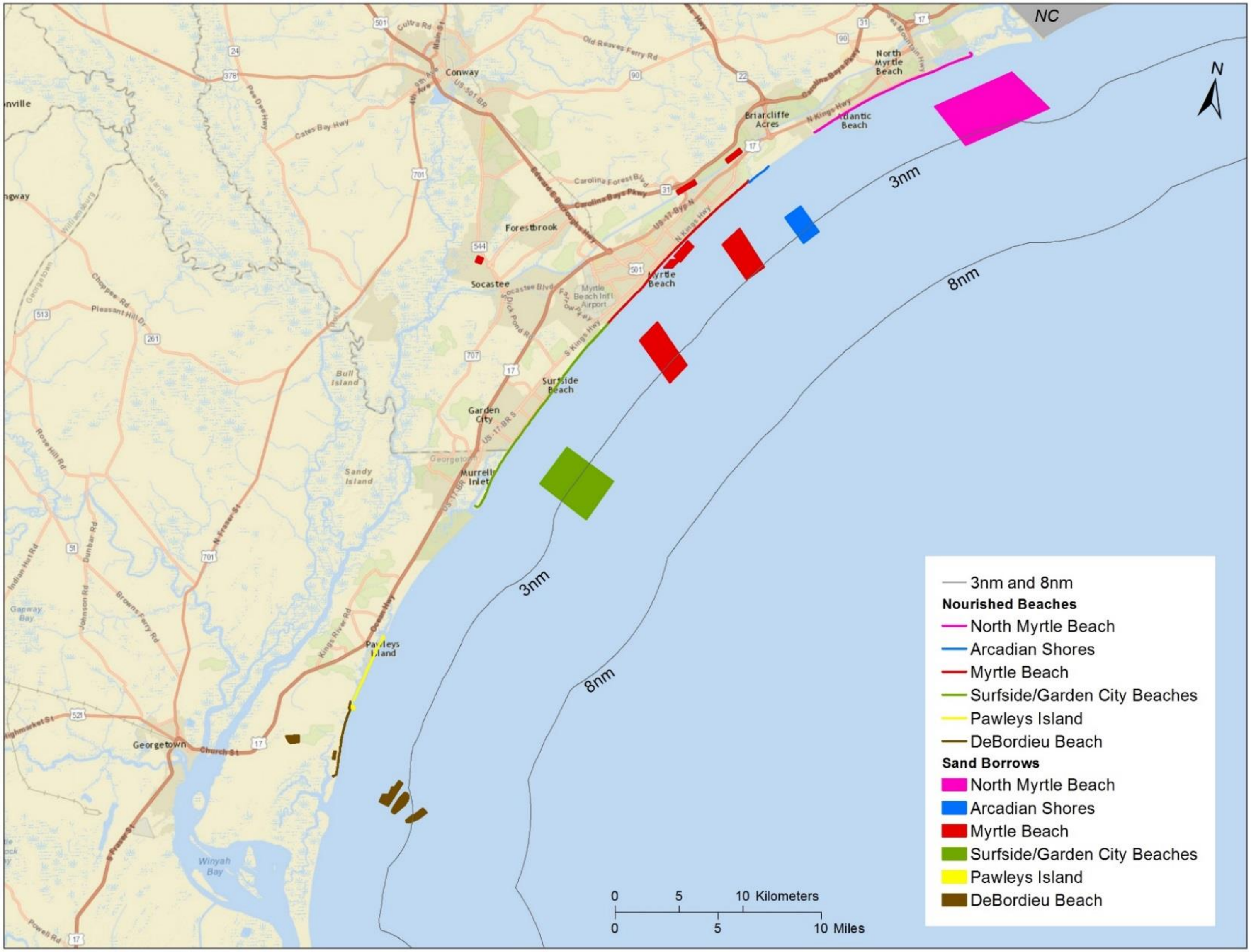

Figure 20. Beach communities and corresponding borrow areas (onshore, inshore, and offshore) in the Grand Strand area of South Carolina where spatial data were available. Lines represent the entire beach community and not the specific nourishment extent, because many historical nourishment projects do not have associated extents.

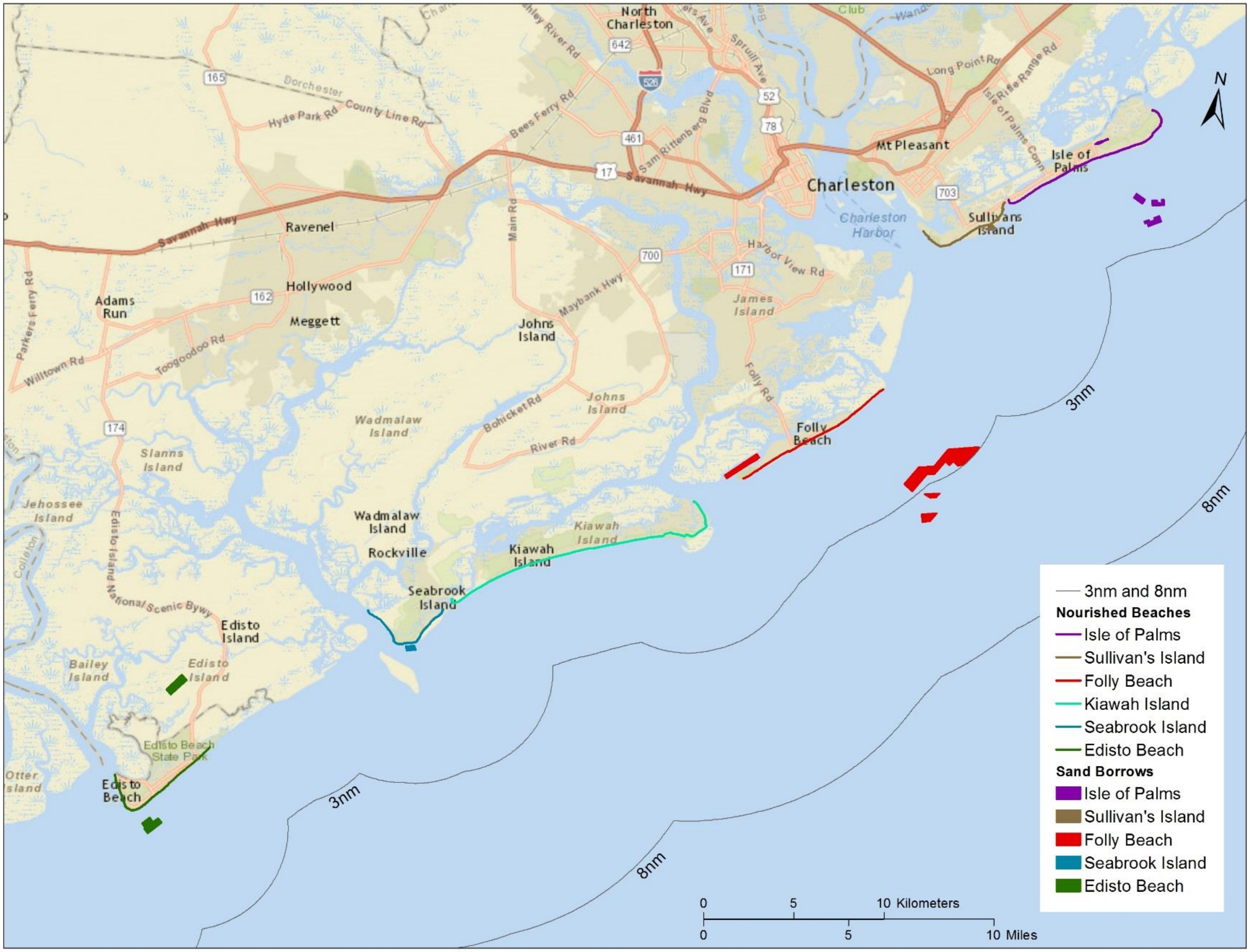

Figure 21. Beach communities and corresponding borrow areas (onshore, inshore, and offshore) in the Charleston area of South Carolina where spatial data were available. Lines represent the entire beach community and not the specific nourishment extent, because many historical nourishment projects do not have associated extents.

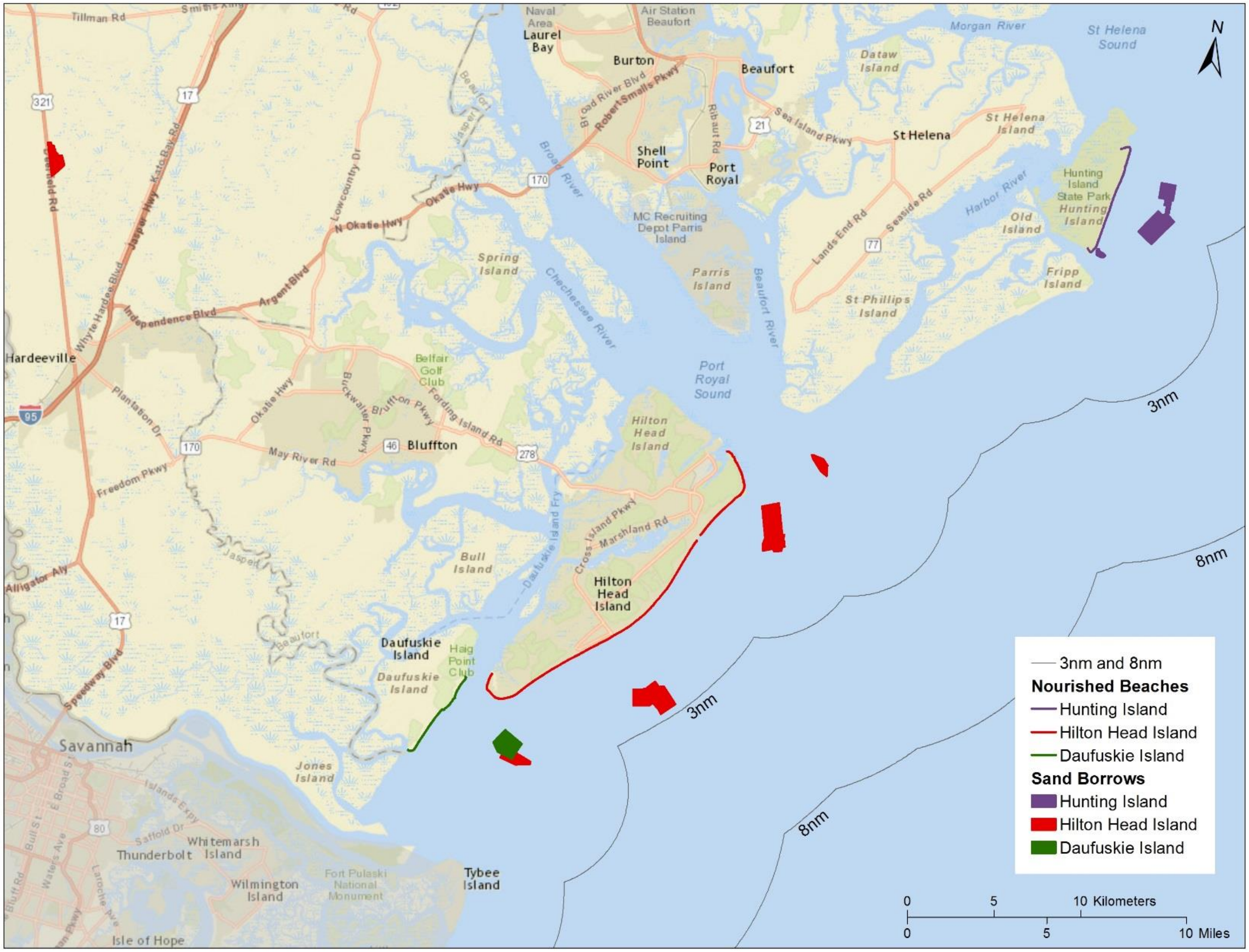

Figure 22. Beach communities and corresponding borrow areas (onshore, inshore, and offshore) in the Grand Strand area of South Carolina where spatial data were available. Lines represent the entire beach community and not the specific nourishment extent, because many historical nourishment projects do not have associated extents.

Table 1. Table summarizing beach nourishment summary data. Data sources and calculation methods are described in text. Summary statistics are shown only where relevant.

	Base metrics					Spatial metrics		Cost metrics (2016$)				Volume metrics			
Beaches	Events[1]	First Year	Last Year	Years Active	Return Interval (years)	Events[2]	Avg Borrow Distance (Km)	Events[3]	Total Cost	Average Cost	$/Year	Events[4]	Total Sand (CY)	Avg CY/Event	Avg CY/Year
North Myrtle Beach	3	1990	2008	26	8.67	2	2.42	3	43797579	14,599,193	1,684,522	3	3,902,829	1,300,943	150,109
Arcadian Shores	2	1999	2009	17	8.50	2	7.69	2	10403237	5,201,619	611,955	2	777,574	388,787	45,740
Myrtle Beach	4	1987	2009	29	7.25	3	1.62	4	59006985	14,751,746	2,034,724	4	4,981,241	1,245,310	171,767
Surfside/Garden City Beach	7	1979	2008	37	5.29	2	3.45	7	71117991	10,159,713	1,922,108	7	5,215,126	745,018	140,949
Pawleys Island	4	1989	2007	27	6.75	1	0.41	3	3524604	1,174,868	130,541	4	559,160	139,790	20,710
DeBordieu Beach	4	1990	2015	26	6.50	4	4.43	4	19558315	4,889,579	752,243	4	1,694,079	423,520	65,157
Isle of Palms	1	2008	2008	8	8.00	2	1.63	1	11725664	11,725,664	1,465,708	1	933,895	933,895	116,737
Sullivan's Island	1	1998	1998	18	18.00	1	0.08	1	335766	335,766	18,654	1	35,000	35,000	1,944
Folly Beach	6	1990	2014	26	4.33	5	2.95	6	82805804	13,800,967	3,184,839	6	7,532,200	1,255,367	289,700
Kiawah Island	1	2006	2006	10	10.00	0	no data	4	4250295	1,062,574	425,030	1	550,000	550,000	55,000
Seabrook Island	7	1982	2005	34	4.86	1	0.17	1	3806591	3,806,591	111,959	6	2,462,574	410,429	72,429
Edisto Beach	4	1954	2006	62	15.50	2	0.89	4	15328479	3,832,120	247,234	4	1,881,414	470,354	30,345
Hunting Island	8	1968	2006	48	6.00	4	1.26	8	32700571	4,087,571	681,262	8	5,243,313	655,414	109,236
Hilton Head Island	10	1969	2014	47	4.70	6	9.22	9	78551794	8,727,977	1,671,315	10	12,825,900	1,282,590	272,891
Daufuskie Island	1	1998	1998	18	18.00	1	3.34	1	8759124	8,759,124	486,618	1	1,410,000	1,410,000	78,333
Min	1	1954	1998	8	4.33		0.08		335,766	335,766	18,654		35,000	35,000	1,944
Max	10	2008	2015	62	18.00		9.22		82,805,804	14,751,746	3,184,839		12,825,900	1,410,000	289,700
Sum	63					36		58	445,672,800		15,428,709	62	50,004,305		1,621,047
Average	4.2			28.87	8.82		2.82		29,711,520		1,028,581		3,333,620		108,070

[1] All nourishment events excluding channel dredging
[2] Nourishment events with spatial data excluding inland and inlet borrows
[3] Nourishment events with associated cost data
[4] Nourishment events with associated sand data

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Appendices

1. Online resources for spatial and geological data
2. Geodatabase structure and outline of records used in needs assessment
3. Abbreviations used in naming locations and data sources
4. Annotated bibliography of data sources
5. Beach nourishment raw data