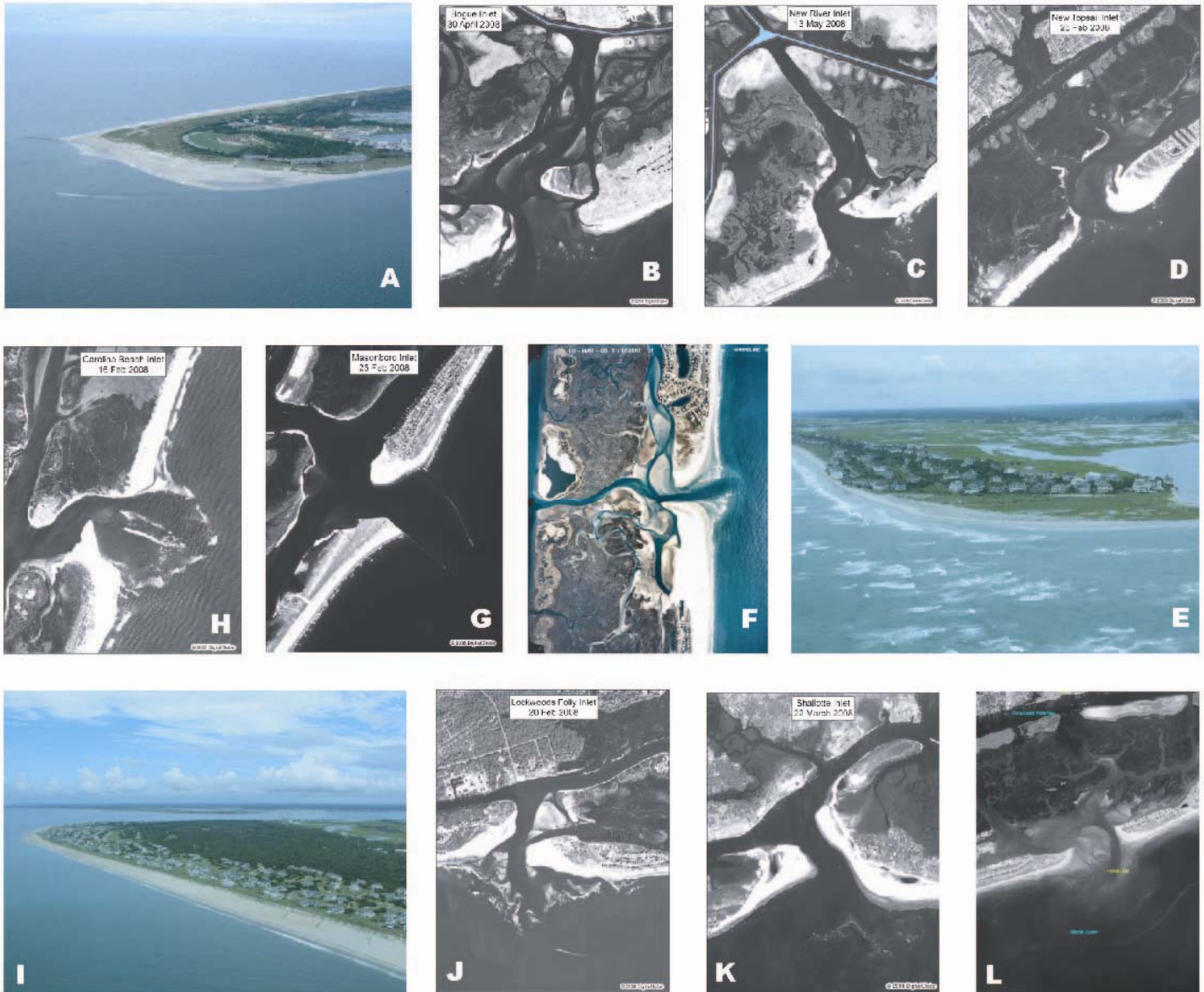


# INLET HAZARD AREA BOUNDARIES UPDATE:

## Recommendations to the North Carolina Coastal Resources Commission



### **Final Report Prepared and Submitted by:**

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North Carolina Division of Coastal Management

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## AVAILABILITY OF THIS REPORT

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## SUGGESTED CITATION

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## ABOUT THE COVER

The aerial photographs on the cover of this report represent a montage of the twelve developed inlets along North Carolina's oceanfront. Each inlet is labeled with a letter (A-L), and the corresponding inlet name and the source of the imagery is as follows: A) Beaufort Inlet (NC Division of Coastal Management, September 2007), B) Bogue Inlet (US Army Corps of Engineers Wilmington District, April 2008), C) New River Inlet (US Army Corps of Engineers, May 2008), D) New Topsail Inlet (US Army Corps of Engineers Wilmington District, February 2008), E) Rich Inlet (Division of Coastal Management, September 2007), F) Mason Inlet (US Army Corps of Engineers Wilmington District, March 2003), G) Masonboro Inlet (US Army Corps of Engineers Wilmington District, February 2008), H) Carolina Beach Inlet (US Army Corps of Engineers Wilmington District, February 2008), I) Cape Fear River Inlet (NC Division of Coastal Management, September 2007), J) Lockwood Folly Inlet (US Army Corps of Engineers Wilmington District, February 2008), K) Shallotte Inlet (US Army Corps of Engineers Wilmington District, March 2008), and L) Tubbs Inlet (US Geological Survey / National Oceanic and Atmospheric Administration, Sept/Oct 2003). The US Army Corps of Engineers Wilmington District imagery was downloaded from <http://www.saw.usace.army.mil/nav/Inletindex.htm>. The US Geological Survey / National Oceanic and Atmospheric Administration imagery is available as base photography on the NC Division of Coastal Management Interactive Mapping website at [http://www.nccoastalmanagement.net/Maps/shoreline\\_mapintro.htm](http://www.nccoastalmanagement.net/Maps/shoreline_mapintro.htm).

## ACKNOWLEDGMENTS

The authors wish to acknowledge Loie Priddy and Rick Carraway whose work with the NC Division of Marine Fisheries Technical Services Section thirty years ago provided the NC Coastal Resources Commission (CRC) with the State's first inlet hazard area boundaries. The efforts of Steve Benton (Division of Coastal Management, retired), Julia Knisel (former NOAA Coastal Services Center Fellow with the Division of Coastal Management), and the CRC Science Panel on Coastal Hazards catalyzed the assembly and analysis of appropriate technology, data, and knowledge of inlet processes necessary to update the original Priddy and Carraway (1978) study. The boundary amendments presented in this report are based primarily on the technical expertise of the CRC Science Panel on Coastal Hazards, which is reflected in the methodologies they developed and contributed to during this effort. This project would not have achieved its goals without the Science Panel's input and direct involvement. The Division of Coastal Management (DCM) would like to recognize the volunteered efforts of the Science Panel: Mr. Steve Benton (DCM retired); Mr. Bill Birkemeier (USACE Field Research Facility, Duck, NC); Dr. Bill Cleary (UNC Wilmington emeritus); Mr. Tom Jarrett, PE (Coastal Planning and Engineering); Dr. Dave Mallinson (East Carolina University); Dr. Margery Overton (current Science Panel Chair, NC State University); Dr. Charles "Pete" Peterson (UNC Chapel Hill Institute for Marine Science); Dr. Stan Riggs (East Carolina University); Dr. Tony Rodriguez (UNC Chapel Hill Institute for Marine Science); Mr. Spencer Rogers (NC Sea Grant); Dr. Beth Sciaudone, PE (NC State University); Dr. Greg Williams, PE (USACE Wilmington District); and Dr. Rob Young (Western Carolina University). The authors also express their gratitude to former members of the Science Panel who were involved in the early portions of this investigation: Dr. Walter Barnhardt (US Geological Survey); Dr. John Fisher (former Science Panel Chair, NC State University emeritus); Dr. Orrin Pilkey (Duke University emeritus); and Dr. John Wells (Virginia Institute of Marine Science). The authors also extend gratitude to the NC Department of Transportation Photogrammetry Unit whose collaborative efforts provided much of the historical aerial orthophotos necessary to study historical shoreline trends. This study could not have been completed without the dedicated support and input provided by the DCM staff, including Bonnie Bendell, Jim Gregson, Charles Jones (retired), Mike Lopazanski, Tancred Miller, Guy Stefanski, Ted Tyndall, Steve Underwood, and former NOAA Coastal Service Center (CSC) Fellows Patrick Limber and Lauren Theodore. Appreciation is extended to the numerous and diverse stakeholders that contributed ideas and concepts that certainly added to the quality and accuracy of what this report intends to achieve.

## **LIST OF ACRONYMS / ABBREVIATIONS USED IN THIS REPORT**

|                |                                                 |
|----------------|-------------------------------------------------|
| <b>AEC</b>     | Area of Environmental Concern                   |
| <b>AIWW</b>    | Atlantic Intracoastal Waterway                  |
| <b>CAMA</b>    | NC Coastal Area Management Act of 1974          |
| <b>CRC</b>     | NC Coastal Resources Commission                 |
| <b>CSC</b>     | NOAA Coastal Services Center                    |
| <b>DCM</b>     | NC Division of Coastal Management               |
| <b>ft</b>      | feet                                            |
| <b>GIS</b>     | Geographic Information System                   |
| <b>GS</b>      | General Statute                                 |
| <b>IHA</b>     | Inlet Hazard Area                               |
| <b>km</b>      | kilometers                                      |
| <b>LiDAR</b>   | Light Distance and Ranging                      |
| <b>m</b>       | meters                                          |
| <b>mi</b>      | miles                                           |
| <b>MLW</b>     | Mean Low Water                                  |
| <b>MHW</b>     | Mean High Water                                 |
| <b>NC</b>      | North Carolina                                  |
| <b>NCAC</b>    | NC Administrative Code                          |
| <b>NOAA</b>    | National Oceanic and Atmospheric Administration |
| <b>NOS</b>     | National Ocean Service                          |
| <b>T-sheet</b> | Topographic Sheet                               |
| <b>US</b>      | United States                                   |
| <b>USACE</b>   | US Army Corps of Engineers                      |
| <b>USGS</b>    | US Geological Survey                            |
| <b>yds</b>     | yards                                           |

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## 1.0 INTRODUCTION

The purpose of this study is to recommend amendments to the Priddy and Carraway (1978) Inlet Hazard Area (IHA) boundaries adjacent to the State's 12 developed inlets (Tubbs, Shallotte, Lockwood Folly, Cape Fear River, Carolina Beach, Masonboro, Mason, Rich, New Topsail, New River, Bogue, and Beaufort inlets).

The establishment of Areas of Environmental Concern (AECs) is the responsibility of the North Carolina Coastal Resources Commission (CRC) as authorized under the North Carolina Coastal Area Management Act (CAMA) of 1974 (GS 113A-100 et seq.) for the purposes of regulating coastal development. The CRC defines four specific ocean hazard AECs in their rules (Title 15A, Chapter 7, Subchapter H, Section 300 of the North Carolina Administrative Code, alternatively referred to as 15A NCAC 07H.0300). The four ocean hazard AECs are: 1) ocean erodible, 2) high hazard flood, 3) inlet hazard, and 4) unvegetated beach. The IHA AEC boundaries, which are the subject of this report, are defined in 15A NCAC 07H.0301(3) as locations that "are especially vulnerable to erosion, flooding and other adverse effects of sand, wind, and water because of their proximity to dynamic ocean inlets."

The existing IHA boundaries were defined by Priddy and Carraway (1978) based primarily on statistical analysis (and to a lesser extent previous inlet territory) of historic shoreline movement defined on multiple aerial photosets. For the purposes of this report, a shoreline is the approximate location of mean high water (MHW) along the oceanfront defined by either the wet/dry line from aerial photographs, MHW defined from National Oceanic and Atmospheric Administration (NOAA) National Ocean Service Topographic Sheets (NOS T-sheets), or MHW defined from Light Distance and Ranging (LiDAR) surveys.

The IHA boundary recommendations developed by Priddy and Carraway (1978) for all of the State's then-active inlets were adopted by the CRC in 1979. Minor amendments by the CRC followed in 1981. Of the 23 active tidal inlets studied by Priddy and Carraway (1978), specific inlet AEC boundaries were not designated for Masonboro Inlet, Drum Inlet, the southwestern side of Ocracoke Inlet, and Oregon Inlet because they were, at the time, excluded from requirements listed in the NC Coastal Plan (NC Department of Natural Resources and Community Development, 1977). Currently, 19 of the original 23 inlets analyzed by Priddy and Carraway (1978) are still active tidal inlet complexes. Although Drum Inlet has since expanded from one to three independent inlets (i.e., definable ebb and flood tidal deltas), the third of which opened as a result of Hurricane Ophelia in 2005, it is being considered as a single inlet complex for the purpose of this report. Three of the tidal inlets from the 1978 study have closed naturally: Mad Inlet, Old Topsail Inlet, and New/Corncake Inlet. One tidal inlet (New River Inlet) has migrated into South Carolina and is maintained by the US Army Corps of Engineers (USACE) to remain in its current general location.

In most cases, the statistical methods used by Priddy and Carraway (1978) identified the landward-most shoreline position (99% confidence interval) projected to occur between 1978 and 1988. Therefore, 1988 represented the point where the statistical significance of inlet shoreline trend predictions decreased. The CRC Science

Panel, a group of coastal engineers and geologists appointed by the CRC, identified the need to change the methodology for defining the IHA (Oct 21, 1998 Science Panel meeting minutes) and addressed this goal in their short-term recommendations to the CRC (Fisher, 1999):

*Inlet Hazard Areas are coastal zones that are especially vulnerable to migration, erosion, flooding, and other adverse effects of sand, wind, and water because of their proximity to dynamic tidal inlets. Each of North Carolina's inlets is unique and there are distinct differences in the history and behavior of inlets in different coastal compartments of the state. Current Inlet Hazard Areas are based upon original studies conducted over twenty years ago. The Inlet Hazard Areas need revision to incorporate updated knowledge.*

*The Panel recommends that the delineation of the Inlet Hazard Areas be revised after a review of site-specific studies of each inlet by a group of experts. The hazard zone delineation shall consider such factors as previous inlet territory, structurally weak areas along migration pathways, unusually low and narrow sections of barriers prone to breaching, external influences such as jetties and channelization, and increased erosion extending along adjacent shorelines.*

This specific recommendation fits well within the scope of the Science Panel's initial charge by the CRC, which included general directives to provide recommendations to the CRC and DCM, including: 1) studies to better describe North Carolina's coastal processes for management purposes, 2) specific methodology changes needed for DCM to better determine coastal hazards and 3) the consideration of new hazard identification methodologies (Coastal Resources Commission, 1997).

## **2.0 METHODS**

### ***2.1 Previous Investigation***

The Priddy and Carraway (1978) methodology utilized a geographically stationary grid system superimposed onto appropriately scaled, commercially available aerial photographic prints spanning 1940 through 1977. The number of photos used at each inlet ranged from six to 32. The grid system applied to the photographs was oriented parallel to the predominant ocean shoreline and facilitated the detection of lateral movement of the inlet shoreline with a spatial resolution of 300 feet. Measurements were made on the photos themselves, scaled accordingly, and tabulated for each grid on the photograph. The shorelines along each side of the inlet were treated separately and individual grids were regressed both linearly and quadratically to determine the best-fit shoreline migration trends of each inlet. On accepted curve fits, the landward most 99% confidence interval projected to occur between 1978 and 1988 along a given transect represented the limit of the inlet hazard area at that transect (i.e., a 1% chance that shoreline position exceeds the designated hazard area at any time within the decade following the analysis). When inlets or grids did not conform to attempted regression methods, strong emphasis was placed on previous inlet territory as determined by relict inlet ridge locations, using the methods of Fisher (1962, 1967).

Priddy and Carraway (1978) only applied basic linear and quadratic regressions due to the scarcity of computing resources at that time. They noted that their approach limited a total regression analysis because any inlet is the product of many complex factors that are not necessarily polynomial in form. Future efforts were suggested to examine higher order polynomials, cyclic or transcendental patterns, and time-series forecasting. Priddy and Carraway (1978) also underscored the importance of applying common sense and good judgment in the establishment of inlet hazard areas.

### ***2.2 Current Investigation***

To facilitate the IHA update, the DCM collaborated extensively with the CRC Science Panel to develop methodologies for updating the original IHA boundaries. Lockwood Folly inlet was chosen as a test case by the Science Panel in order to establish an accurate method for hazard delineation (DCM, 2000; 2002), and the Science Panel proceeded with IHA re-delineation by looking at two major variables: 1) the spatial and temporal variability of the shoreline positions adjacent to the inlet, and 2) the application of simple statistical models based on shoreline variability to help determine the hazard areas. The Panel felt that defining the portions of oceanfront shoreline adjacent to inlets influenced by inlet processes was a major factor in delimiting the overall hazard area. By analyzing statistical shoreline trends (i.e., linear regression of shoreline rate of change and standard deviation of shoreline position), Panel members Drs. Margery Overton and John Fisher produced an objective assessment of the extent of inlet influence along the oceanfront shoreline (Overton and Fisher, 2004). This statistical methodology was applied to Hatteras Inlet by Overton and presented to the full Science Panel (DCM, 2004), which used it as the starting point to couple

shoreline trends with other factors including, inlet-specific processes and geomorphology, island-specific geomorphology, underlying geology, meteorological forcing (i.e., storms) and man-made interactions to all of the above (e.g., dredging, beach fill, engineered structures, creation of the AIWW). Although the IHA boundary to Hatteras Inlet was outside the scope of this study, it provided a valuable testing ground for synthesizing the aforementioned variables. Four major methods, discussed below, were used to carry out this study: 1) shoreline statistics (section 2.2.1), 2) the creation of a hybrid shoreline (section 2.2.2), 3) the consideration of beach width (section 2.2.3), and 4) barrier-island geomorphology (primarily topography of more stable upland regions). Additional factors such as anthropogenic influence were also considered and are discussed in the results on an inlet-by-inlet basis (see section 3.0).

### **2.2.1 Shoreline Statistics**

Shorelines used in this investigation spanned 1933 through 2004. The earlier shorelines from the 1930s and early 1940s were digitized from NOS T-sheets, and most represented digitized wet/dry lines from historical orthophotos (with the exception of a USGS LiDAR-derived MHW shoreline from 1997). Two studies carried out by DCM (Limber et al., 2007a; 2007b) provided evidence that the 1997 USGS LiDAR-derived MHW could be used interchangeably with the wet/dry lines generated from historical aerial orthophotos. The Science Panel agreed that no shoreline before 1930 should be used due to the construction and maintenance dredging of the AIWW and other waterways and the influence these waterways had on the hydrodynamics of the inlets, particularly those in the southern portion of the State (i.e., south of Cape Lookout). A dataset of between nine and 14 shorelines was used at each inlet for statistical trend analysis. The final analysis of Tubbs Inlet ultimately relied on a subset of five shorelines, which was chosen to eliminate bias related to the man-made alteration (i.e., wholesale movement) of the inlet in the early 1970s, although the preliminary work considered the full 11-shoreline dataset.

The spatial and temporal variability of each inlet was analyzed using two statistical calculations: 1) compute linear shoreline change rate using simple regression techniques, and 2) compute sample standard deviation of shoreline position. These methods were applied to this study at the request of DCM by Fisher and Overton (2004) using the following methods:

1. Digitize shoreline.
2. Extract coordinates of the intersection of the transects and shoreline outlined in Benton et al. (2004). These transects are approximately 90 degrees to the shoreline and are evenly spaced at 50 m (164 ft) intervals (although, in some cases, supplemental analyses were conducted using additional transects created to span current inlets, where transects previously had not been established, or to wrap around the throat of an inlet to account for non-parallel and/or radial shoreline morphologies).
3. Compute relative change in shoreline position along each transect. For example, let one of the endpoints of each transect be the reference point for measurement. Compute distance from this endpoint using the coordinates (Benton et al., 2004).
4. Create a spreadsheet with relative shoreline position, time and transect number.

5. Use the Microsoft Excel spreadsheet function SLOPE to compute the linear shoreline change rate (the y variable is relative position, the x variable is time) for each transect.
6. Plot shoreline change with respect to location (or transect).
7. Use the Microsoft Excel spreadsheet function STDEV to compute the sample standard deviation of shoreline position for each transect.
8. Plot standard deviation with respect to location (or transect).

Overton and Fisher (2004) provided a simple dataset to illustrate the techniques described above (see Tables 2.1 and 2.2). The tabulated data are plotted in Figures 2.1 and 2.2. The data for the first dataset (dataset A, Table 2.1) follow a linear trend with a shoreline change rate of 14.4 m/yr (47.2 ft/yr) and  $R^2$  of 0.95 (Figure 2.1). The  $R^2$  value is a correlation coefficient that indicates the strength and direction of a linear relationship between two random variables (in this case, shoreline location and time). A higher  $R^2$  value (maximum value = 1) indicates a higher correlation. The standard deviation is the average shoreline change around the mean shoreline position. For dataset A (defined above), the standard deviation is 307 m (1,007 ft). Considering dataset B (Table 2.2), the shoreline positions are the same but occur at different points in time (Figure 2.2). Because the position data are the same, the standard deviation is the same for the datasets in both Table 2.1 and 2.2. However, the trend in shoreline rate of change (i.e., erosion rate) is quite different (Figure 2.2). The shoreline change rate for dataset B is 1.0 m/yr (3.3 ft/yr) with an  $R^2$  of 0.005.

In addition to the method discussed above, which considers raw data only, spatial smoothing was applied to shoreline change rate data using a simple moving average or running mean technique described by Davis (1986). For shoreline segments consisting of at least five transects (250 m, 820 ft), a “smoothed” average was calculated for the five transects and positioned on the third. Standard deviation data were not smoothed. Figure 2.3 plots smoothed shoreline trend data and standard deviation data for each transect along the Ocean Isle Beach side of Shallotte Inlet (western shoulder of inlet) to illustrate where the transect used to anchor the IHA polygon was defined. The graphs for the statistical analysis calculated for each of the twelve developed inlets are presented in the appendix.

The difference in rate and standard error are important for determining trends and predicting future shoreline positions. However, the standard deviation provides a measure of variability in shoreline position around the mean, one indicator of vulnerability for the delineation of the Inlet Hazard Area. For this reason, the Science Panel considered both the shoreline rate of change (linearly regressed) and standard deviation of shoreline position to establish the point along the oceanfront shoreline where inlet-related hydrodynamics no longer dominate coastal processes. Primarily, this was defined by obvious breaks in slope of the lines generated for each of the two distinct statistical datasets. This point, once defined, anchored the oceanfront portion of the IHA. From this point, a suite of additional methodologies were considered to define the IHA polygon (see sections 2.2.2, 2.2.3, and 2.2.4).

### **2.2.2 Hybrid Shoreline**

The hybrid shoreline represents the landward-most position of all the shorelines in each inlet-specific dataset. Establishing this line from historical datasets (i.e., during the past 60 to 70 years) is a proxy for the potential landward migration of the shoreline and related geomorphology (i.e., dry sand beach, primary and front dunes, first line of stable and natural vegetation, etc.) due to the impact of a major storm event or shoreline-migration trend related to inlet processes. The hybrid shoreline is designated as a point along each of the 50-m (164-ft) spaced, shore-perpendicular transects that were used for the shoreline statistics described above as well as the long-term annual erosion rate calculations used for setback determinations in the Ocean Erodible AEC adjacent to the IHA (Benton et al., 2004). Figure 2.4 illustrates how the hybrid shoreline is established at each transect. The hybrid shoreline was used in conjunction with measurements of maximum and average beach widths determined along each transect (discussed below).

### **2.2.3 Beach Width**

Beach width was calculated for all shorelines used in this study that were defined using historical aerial orthophotos by defining the wet/dry line on the beach. The width of the beach was measured as the distance between the shoreline (wet/dry line) and the first line of stable, natural vegetation (vegetation line) for each transect (see Figure 2.5). As discussed in section 2.2.1, the transect locations were the same ones used by DCM for long-term erosion rate calculations (Benton et al., 2004). Transects are approximately 90 degrees (i.e., shore perpendicular) to the shoreline and are evenly spaced at 50 m intervals. In some cases, supplemental beach width analyses were conducted using additional transects created to span current inlets, where transects previously had not been established, or to wrap around the throat of an inlet to account for non-parallel and/or radial shoreline morphologies. A beach width was calculated for each transect for every set of historical aerial orthophotos in each inlet's dataset. Beach widths could not be established using NOS T-sheets (which only delineated shoreline) or LiDAR surveys (which only delineate MHW).

Maximum beach width was transect specific in that it was determined by taking the highest width through the comparison of the same transect from each aerial orthophoto in the dataset. For example, consider the illustrative dataset provided in Table 2.3 for a transect A, which is a fixed reference line and occurs in the same geographic location regardless of photo date. The beach width at transect A for a multi-photo dataset acquired in 1971, 1974, 1983, 1995, 1998, and 2004 provides a set of hypothetical values of 120 ft or 37 m (1971 photo), 145 ft or 44 m (1974 photo), 263 ft or 80 m (1983 photo), 299 ft or 91 m (1995 photo), 316 ft or 96 m (1998 photo), and 357 ft or 109 m (2004 photo) (see Table 2.3). The maximum beach width for transect A from this dataset is 357 ft or 109 m (2004 photo). An average beach width was also calculated at each transect wherein all widths were summed specific to that transect and a mean

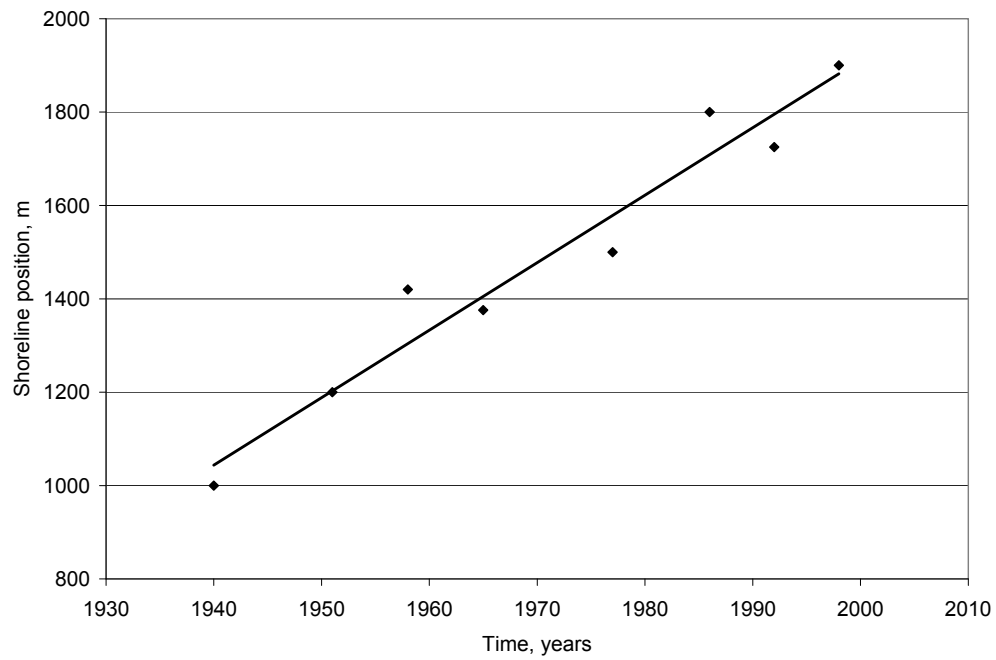
value calculated. Using the same hypothetical dataset, the average value is defined as (120 ft + 145 ft + 263 ft + 299 ft + 316 ft + 357 ft = 1,500 ft or 457 m) divided by six observations, or (1,500 ft / 6) which equals 250 ft (76 m). Therefore, while the maximum beach width equals 357 ft (109 m) for transect A, the average beach width equals 250 ft (76 m). Both of these values were then plotted along each transect using GIS as a distance landward from the hybrid shoreline (see section 2.2.2) for each transect.

| Time | Relative position  |
|------|--------------------|
| 1940 | 1,000 m (3,280 ft) |
| 1951 | 1,200 (3,937 ft)   |
| 1958 | 1,420 m (4,659 ft) |
| 1965 | 1,376 m (4,511 ft) |
| 1977 | 1,500 m (4,921 ft) |
| 1986 | 1,800 m (5,906 ft) |
| 1992 | 1,725 m (5,659 ft) |
| 1998 | 1,900 m (6,234 ft) |

**Table 2.1.** Sample shoreline dataset A (from Overton and Fisher, 2004).

| Time | Relative position  |
|------|--------------------|
| 1940 | 1,725 m (5,659 ft) |
| 1951 | 1,376 m (4,511 ft) |
| 1958 | 1,420 m (4,659 ft) |
| 1965 | 1,200 m (3,937 ft) |
| 1977 | 1,900 m (6,234 ft) |
| 1986 | 1,800 m (5,906 ft) |
| 1992 | 1,000 m (3,280 ft) |
| 1998 | 1,500 m (4,921 ft) |

**Table 2.2.** Sample shoreline dataset B (from Overton and Fisher, 2004).



**Figure 2.1.** Shoreline position as a function of time (from Overton and Fisher, 2004).

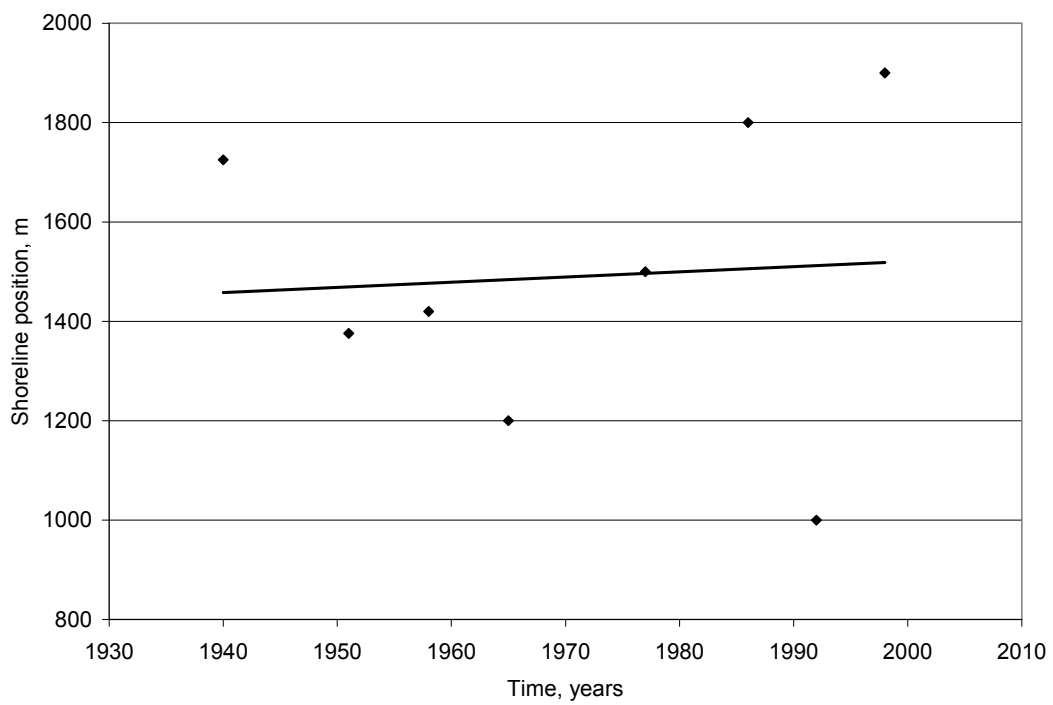
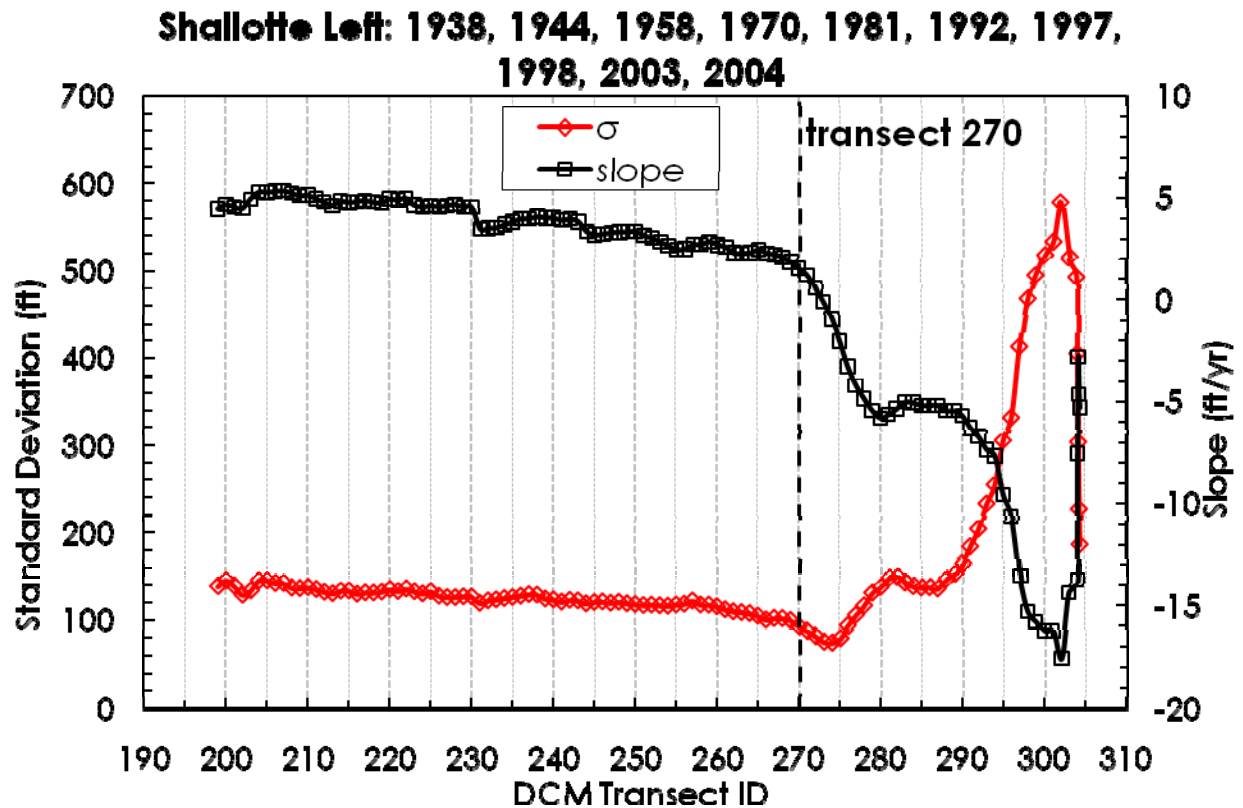
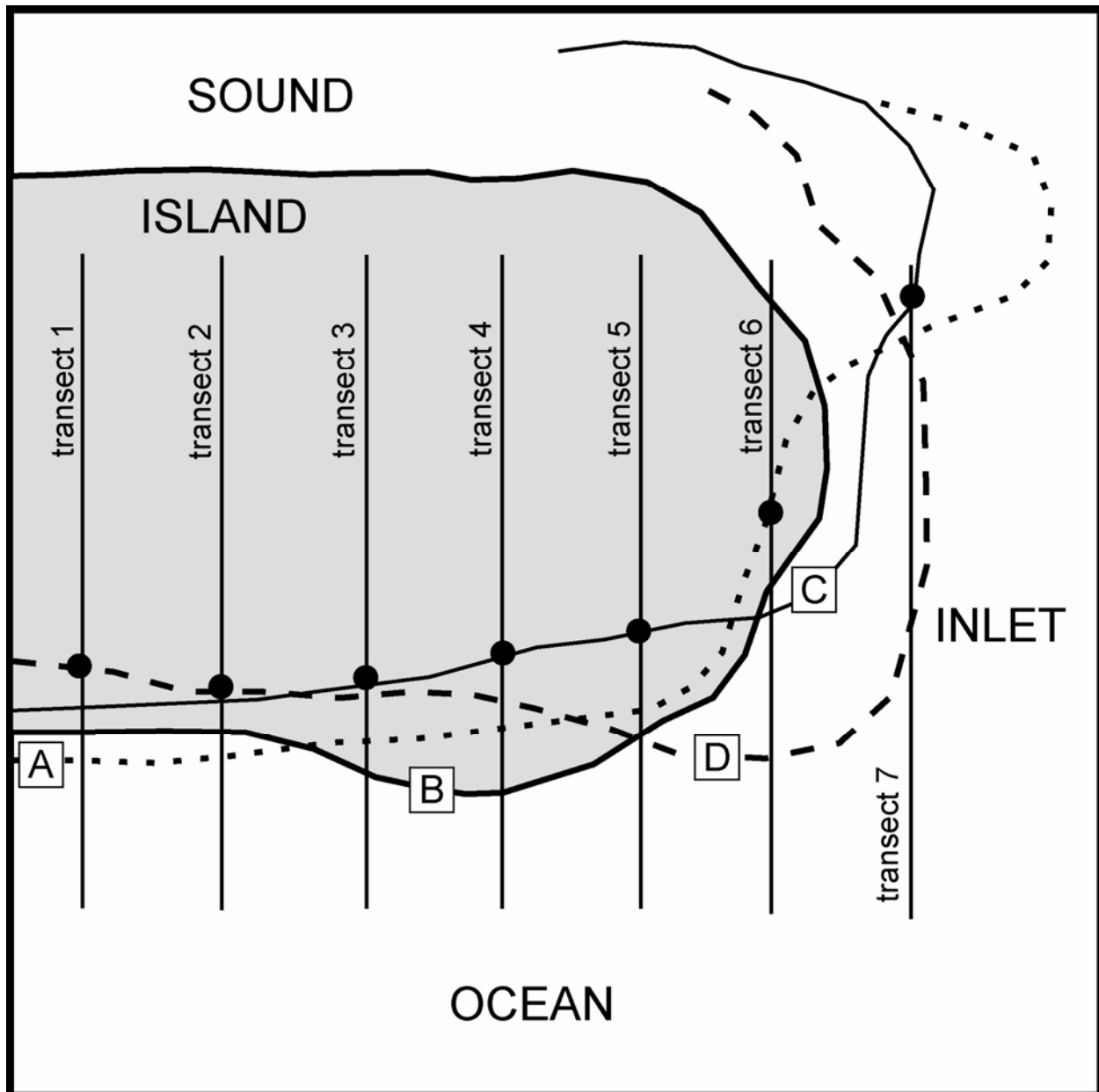


Figure 2.2. Shoreline position as a function of time (from Overton and Fisher, 2004).

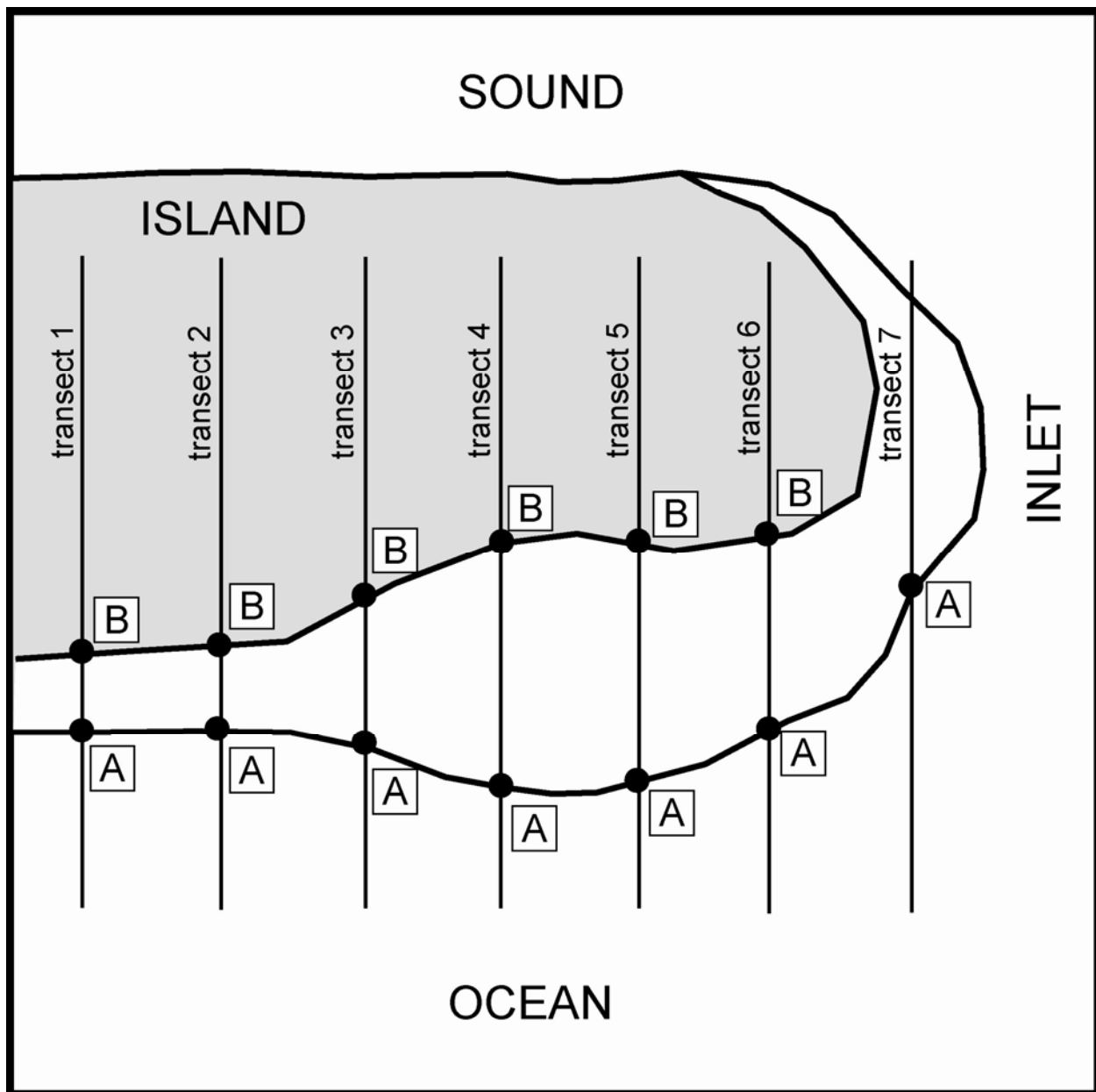


**Figure 2.3.** The linear regression of shoreline change rate (labeled as “slope”) defines the average rate of shoreline change for the dataset (10 shorelines spanning 1938 to 2004) at each transect. The slope data are plotted with a black line with squares superimposed, and the units for the slope data are reported in feet per year and are found on the right vertical axis. The standard deviation of shoreline position (labeled as “ $\sigma$ ”) quantifies the extent of shoreline variation (i.e., back and forth movement) at each transect. The standard deviation data are plotted with a red line with diamonds superimposed, and the units for the standard deviation data are reported in feet and are found on the left vertical axis. The data along the horizontal axis (bottom) are unique transect ID numbers. Transect spacing is at 50 m (164 ft) intervals although the units in this graph are presented in feet. The graph is oriented with east being to the right, therefore, Shallotte Inlet is on the right hand side whereas the left hand side of the graph represents the central portion of the barrier island (the ocean can be visualized as being on the bottom portion of the graph). For this particular location, portions of the shoreline to the right of transect 270 (labeled) are dominated by inlet hydrodynamics, and portions of the shoreline to the left of transect 270 are dominated by oceanfront processes. Therefore, transect 270 is the anchor for the IHA polygon boundary. These

data, as well as similar graphs for each of the other 11 inlets studied, are included in the appendix of this report.



**Figure 2.4.** The establishment of a hybrid shoreline represented the landward position of all wet/dry shorelines in the dataset specific to each transect. Four shorelines are depicted here (labeled A through D) where B is the current shoreline and A, C, and D are historical. The black circles on transects 1 through 6 depict the landward most position of all shorelines in the dataset. In this example, the landward most shoreline at transect 1 is shoreline D, transect 2 is shoreline D, transect 3 is shoreline C, transect 4 is shoreline C, transect 5 is shoreline C, transect 6 is shoreline A, and transect 7 is shoreline C.



**Figure 2.5.** For this investigation, beach width was established on digital aerial orthophotos by determining the distance between the wet/dry shorelines and the vegetation line. In this example, the width is defined as the distance between points A and B at each transect. Where vegetation was not present at a transect (i.e., transect 7), width could not be determined. After a width was calculated for each transect in each orthophoto in the dataset, the widest beach width at a specific transect from all orthophotos established the maximum beach width at that transect for the photography dataset. All widths at each transect were then summed and a mean width calculated in order to establish the average beach width for that transect for the photography dataset. Beach widths could not be established using NOS T-sheets (which only delineated shoreline) or LiDAR surveys (which only delineate MHW).

| Year | Beach Width    |
|------|----------------|
| 1971 | 37 m (120 ft)  |
| 1974 | 44 m (145 ft)  |
| 1983 | 80 m (263 ft)  |
| 1995 | 91 m (299 ft)  |
| 1998 | 96 m (316 ft)  |
| 2004 | 109 m (357 ft) |

**Table 2.3.** Sample beach width dataset. In this example, the maximum beach width is 357 ft (109 m) and the average is 250 ft (76 m).

The results of this approach provide a general approximation of average and maximum beach conditions based on historical data at each transect by considering the landward-most shoreline position (hybrid shoreline), the average beach width at the same transect as measured landward of the hybrid shoreline, and the widest (maximum) beach width that occurred at said transect. Establishing beach width ranges from historical datasets (i.e., during the past 60 to 70 years) is a proxy for the potential response of coastal geomorphology (i.e., dry sand beach, primary and frontal dunes, first line of stable and natural vegetation, etc.) to a major storm event or shoreline migration trend related to inlet processes.

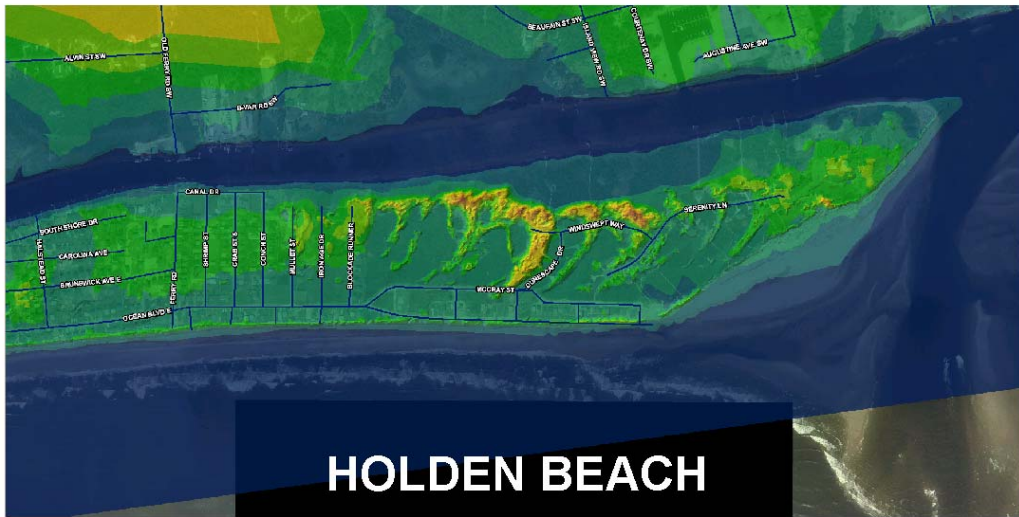
#### **2.2.4 Geomorphology**

In addition to considering hybrid shoreline locations and beach width relative to the hybrid shoreline on a transect-by-transect basis, the CRC Science Panel also considered geomorphological features at each inlet including paleo shorelines, dune ridges and other topography, ebb delta morphology, paleo river channels influencing inlet location, past inlet locations, inlet migration trends, meteorological (storms) forcing of shorelines and island morphology, as well as the underlying geology. An example of how geomorphological concepts were used in this investigation can be seen in Figure 2.6, which uses LiDAR-derived elevation data to show the topographic expression of geomorphic features such as dune ridges and paleo shorelines.

### ***2.3 Summary of Methods used in this Investigation***

Revised IHA boundaries are presented in this report for the State's 12 developed inlets: Tubbs, Shallotte, Lockwood Folly, Cape Fear River, Carolina Beach, Masonboro, Mason, Rich, New Topsail, New River, Bogue, and Beaufort. No boundary changes are

proposed for Brown's, Bear, Barden, Ocracoke, and Hatteras inlets, which were developed using the methods established by Priddy and Carraway (1978). No boundaries are proposed for Drum and Oregon inlets, which were excluded from the Priddy and Carraway (1978) study. The revised boundaries developed during this investigation rely on statistical analysis of shoreline change along the oceanfront shoreline (i.e., linearly regressed shoreline change rates and standard deviation of shoreline position) to establish the point along the shoreline, moving away from the inlet, where the inlet processes no longer dominate shoreline response. This point serves as the anchor for the proposed IHA boundary, which is defined on an inlet-by-inlet basis using a suite of methodologies, including the consideration of the hybrid shoreline, the average and maximum beach widths at each transect (as measured in a landward direction from the hybrid shoreline), and general considerations of geomorphology and other geological factors identified by the CRC Science Panel. In most cases, the transects used were those defined by Benton et al. (2004), although in specific cases, additional transects were considered in order to span inlets where transects did not exist or to follow radial shoreline trends along the shoulders of each inlet shoreline. DCM further refined the CRC Science Panel IHA boundaries, where appropriate, to follow geographic or other features such as lot lines, parcel boundaries, and roads to aid in the implementation of the IHA boundaries. A description of what methods were applied and where they were applied is presented in the following section (see section 3.0 Results).



**Figure 2.6.** An example of a color image showing LiDAR-derived topography used to analyze island geomorphology from Holden Beach (Lockwood Folly Inlet), Bald Head Island (Cape Fear River Inlet), and Bear Island (Bogue Inlet).

## 3.0 RESULTS

### 3.1 Tubbs Inlet

#### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- References to the inlet opening date at least as far back as 1856
- Migratory inlet (overall westward movement)
- Average rate of movement (westward) between 50 and 65 ft (15 to 20 m) per year between 1865 and 1970
- Relocated by private interests in January 1970 (approximately 3,000 ft or 914 m eastward) shifted migration from westward to an eastward trend (dredging of lagoon channels, principally Jinks Creek, presumed to have altered hydrodynamics)
- Shoaling in Jinks Channel behind Ocean Isle Beach could shift current migration back to west
- Relocation of inlet (1970) and potential effect(s) of dual jetty system installed at Little River Inlet, SC (approximately four mi or six km to the west) makes this a complex inlet

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Sunset Beach)***

Shorelines analyzed (5): 1981, 1992, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 93
- Proposed IHA boundary @ DCM transect 92 (IHA boundary movement 165 ft or 50 m west)

Based on analysis of statistical shoreline trends and man-made interference with inlet processes (the inlet was relocated in 1970), the CRC Science Panel determined that the behavior of Tubbs Inlet is complex. Statistical shoreline trend analysis (standard deviation of shoreline position and average rate of shoreline change) excluded pre-1971 shorelines in order to identify the effect of inlet relocation on the Sunset Beach shoreline (down-drift from pre-project inlet migration trend). Consideration was given to the existing IHA boundary (Priddy and Carraway, 1978) and the complex nature of the inlet's recent history. In addition, the location of the 1970 shoreline (aerial orthophoto), which runs diagonally from the back-barrier lagoon near the intersection of Canal St. and Cobia St. to DCM transect 92, was used to help modify the western (left) boundary of the existing IHA (i.e., the inlet had occupied that location in the past and potentially could occupy that position in the future). Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Therefore, in locations where the proposed IHA boundary (1970 shoreline) crossed any portion of a parcel, the entire parcel was included. Refer to Figure 3.1 for

proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

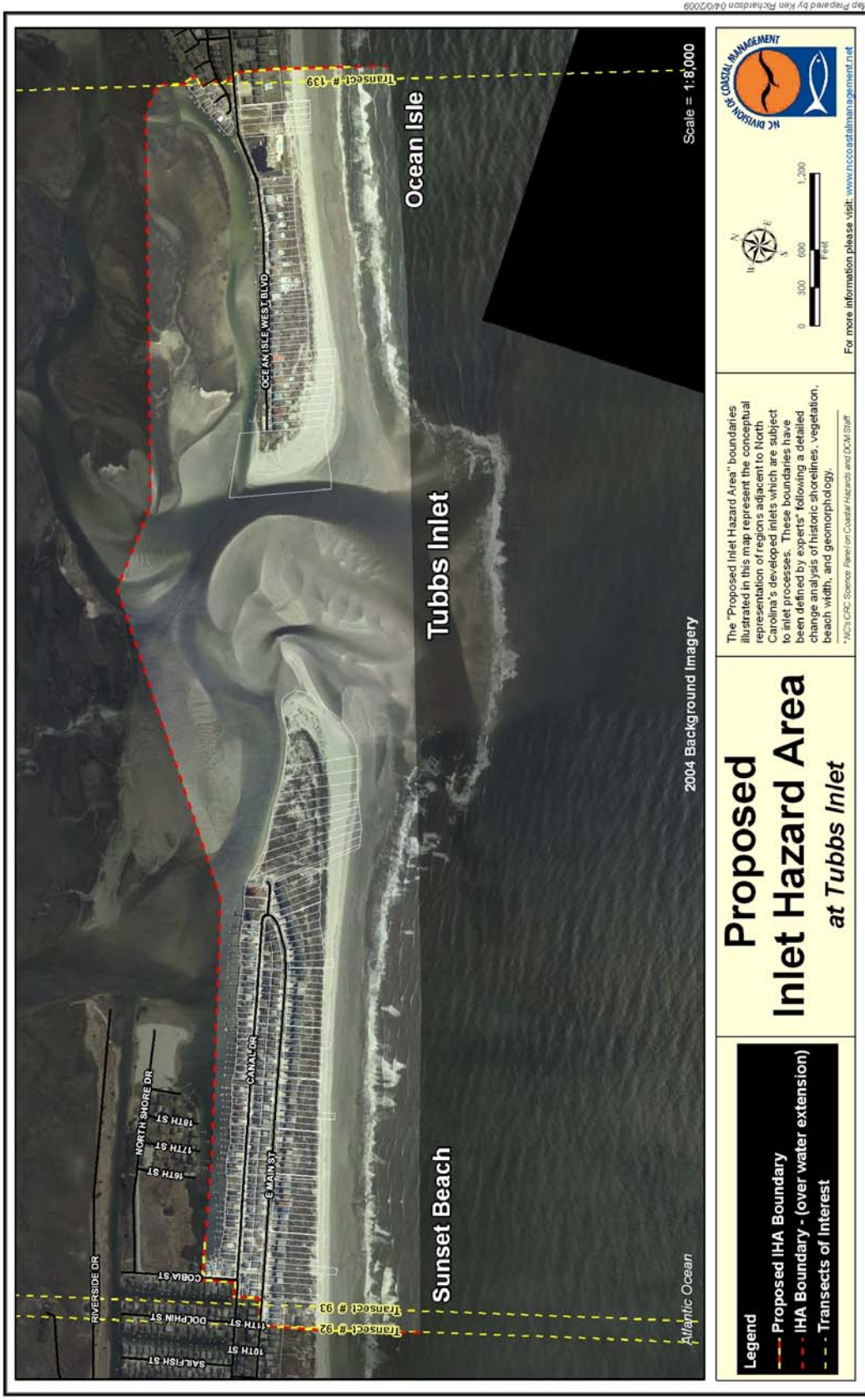
### ***RIGHT SIDE OF INLET (Ocean Isle Beach)***

Shorelines analyzed (5): 1938, 1944, 1954, 1961, 1970

- Original IHA boundary @ DCM transect 139
- Proposed IHA boundary @ DCM transect 139 (no movement of IHA boundary)

Based on analysis of statistical shoreline trends and man-made interference with inlet processes, the CRC Science Panel defined the behavior of Tubbs Inlet as complex. Statistical shoreline trend analysis (standard deviation of shoreline position and average rate of shoreline change) excluded post-1970 shorelines in order to identify the natural shoreline trends on Ocean Isle (up-drift from pre-project inlet migration trend) prior to the inlet relocation. Consideration was given to the existing IHA boundary (Priddy and Carraway, 1978) and the complex nature of the inlet's recent history. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Therefore, in locations where the current IHA boundary (which is also the proposed boundary) crossed any portion of a parcel, the entire parcel was included. Refer to Figure 3.1 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.1.** Proposed IHA boundary for Tubbs Inlet.



## 3.2 Shallotte Inlet

### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- Inlet in existence for at least the past 300 years
- Oscillatory inlet
- When the ebb channel shifts orientation toward Holden Beach, the updrift shoulder of Ocean Isle experiences erosion (and vice versa)
- Bulbous shape of Holden Beach shoreline present since 1974. If ebb channel becomes more westerly then this accreted sand will erode. Ocean Isle had the same bulbous shape between 1938 and 1958 before the ebb channel shifted and caused erosion at the eastern end of Ocean Isle. If the ebb channel once again re-orient itself towards Ocean Isle, the bulbous shape will return (and the Holden Beach side will erode).

### **BOUNDARY SUMMARY**

#### ***LEFT SIDE OF INLET (Ocean Isle Beach)***

Shorelines analyzed (10): 1938, 1944, 1958, 1970, 1981, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 289
- Proposed IHA boundary @ DCM transect 270 (IHA boundary movement 3,135 ft or 950 m west)

Proposed IHA boundaries were delineated based on statistical shoreline trends, maximum historical beach width (as measured landward from the hybrid shoreline), width of the Ocean Erodible Area (OEA), recent stable vegetation, inlet processes, and geomorphology. Statistical shoreline analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 270 as the point along the oceanfront where inlet processes were no longer dominant. Although maximum historical beach width decreased towards the inlet, the width of the OEA (measured landward from the vegetation line delineated on 2006 digital aerial orthophotos) remained both constant and shore parallel. In addition, the low elevation along this portion of the island, coupled with the fact that inlet-related hazards increase toward the inlet, also justified that the IHA should not become narrower as the transects approach the inlet. Therefore, the proposed IHA follows the 2006 OEA boundary to transect 282. At transect 282, the most current long-term oceanfront erosion rates (calculated from 1998 aerial orthophotos) increased to 4.5 ft (1.4 m) per year, and, in turn, the OEA width increased to 570 ft (174 m). The proposed IHA boundary followed the OEA boundary between transect 282 and 285 where, at Shallotte Boulevard, it turns shore perpendicular and crosses the barrier island to the back-barrier lagoon. Man-made

landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Therefore, in locations where the proposed IHA boundary (including those tied to shore-perpendicular measurement transects) crossed any portion of a parcel, the entire parcel was included. Refer to Figure 3.2 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

### ***RIGHT SIDE OF INLET (Holden Beach)***

Shorelines analyzed (10): 1938, 1944, 1958, 1970, 1981, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 327
- Proposed IHA boundary @ DCM transect 370 (IHA boundary movement 7,095 ft or 2,150 m east)

Proposed IHA boundaries were delineated based on statistical shoreline trends, maximum historical beach width (as measured landward from the hybrid shoreline), historical storm-induced inlet shorelines, inlet processes, and geomorphology. Statistical shoreline analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 370 as the point along the oceanfront where inlet processes were no longer dominant. In addition, transect 370 was the approximate site where Hurricane Hazel caused severe overwash and breached the island. Maximum historical beach width was used between transects 370 and 340 at which point the island narrowed and the proposed shore parallel IHA boundary intersected the back-barrier lagoonal wetlands. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. In locations where the proposed IHA boundary crossed any portion of a parcel, the entire parcel was included with one exception. One parcel along the back-barrier estuarine shoreline just east of transect 340 was not included because the maximum beach width line cut across only a few feet of a portion of the parcel line along Ocean Boulevard. The adjacent parcel (immediately to the west) was included because the historical maximum beach width included more than 50% of the parcel inside the proposed IHA boundary. Refer to Figure 3.2 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.2.** Proposed IHA boundary for Shallotte Inlet.



### 3.3 Lockwood Folly Inlet

#### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- Inlet in existence since at least 1672
- Oscillatory inlet
- Geographic position of the inlet is relatively unchanged since 1938 although ebb channel position and orientation has experienced significant change
- Midpoint of the channel has migrated approximately 500 ft (152 m) east since 1938

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Holden Beach)***

Shorelines analyzed (12): 1933, 1938, 1944, 1958, 1970, 1971, 1978, 1988, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 552
- Proposed IHA boundary @ DCM transect 530 (IHA boundary movement 3,630 ft or 1,100 m west)

Proposed IHA boundaries were delineated based on statistical shoreline trends, maximum historical maximum beach width (as measured landward from the hybrid shoreline), inlet processes, and geomorphology. Statistical shoreline analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 530 as the point along the oceanfront where inlet processes were no longer dominant. Between transects 530 and 538, the proposed IHA boundary followed the line of maximum historical beach width. At transect 538, the base of numerous parabolic dunes was mapped (generally between the 11 and 15 ft, or three and five m, contours) to define the remaining boundary that eventually is projected shore perpendicular back to the AIWW. These dunes are not relict beach ridges (i.e., shoreline related) but rather eolian in nature and indicate relative stability compared to the adjacent shoreline. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Therefore, the topographic trend of the dunes follows McCray Street to where it intersects Ocean Blvd East, cuts shore parallel along parcel boundaries to Serenity Lane and eventually turns shore perpendicular along a parcel boundary to intersect the AIWW. Refer to Figure 3.3 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

### ***RIGHT SIDE OF INLET (Oak Island)***

Shorelines analyzed (12): 1933, 1938, 1944, 1958, 1970, 1971, 1978, 1988, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 588
- Proposed IHA boundary @ DCM transect 605 (IHA boundary movement 2,805 ft or 850 m east)

Proposed IHA boundaries were delineated based on statistical shoreline trends, maximum historical beach width (as measured landward from the hybrid shoreline), inlet processes, and geomorphology. Statistical shoreline analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 605 as the point along the oceanfront where inlet processes were no longer dominant. Maximum historical maximum beach width encompassed the majority of the island toward the inlet (west) from transect 605 to approximately 66<sup>th</sup> Place West. The thin, bar-like nature of the entire western end of Oak Island, added to the fact that the proposed IHA is adjacent to the location of the inlet breach during Hurricane Hazel (1954), justified the inclusion of the entire barrier island within the proposed IHA from transect 605 westward to the inlet. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figure 3.3 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.3.** Proposed IHA boundary for Lockwood Folly Inlet.



### 3.4 Cape Fear Inlet

#### **BACKGROUND** (*summarized from Cleary and Marden, 2001*)

- Largest inlet system in southeastern North Carolina
- Dredging of the river and estuary began in 1829 with modifications in 1871 (channel dimensions increased to 12 ft or four m deep and 100 ft or 30 m wide)
- Inlet has been modified for commercial traffic to the NC State Port in Wilmington City and continues to be maintained by the USACE
- Entrance channel to the Cape Fear River progressively deepened, widened and re-oriented since late 1800s to its current depth of 44 ft  $\pm$  two ft (13 m  $\pm$  one m) and approximate width of 600 ft or 183 m (current data provided by USACE)
- Increased volume of the navigation channel in the Cape Fear River from dredging has increased the tidal prism (volume of water exchanged during flood and ebb tides) but there is a net loss in the ebb tidal delta sediments (even though larger tidal prisms usually correlate to larger tidal deltas)
- Between 1855 and 1962, the South Beach (Bald Head Island) shoreline has accreted between 1,800 ft or 549 m (western portion) and 2,400 ft or 732 m (central portion). Since 1962, South Beach has experienced chronic erosion due to a lack of sand bypassing and the continued reconfiguration of the flood tidal channel.

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Oak Island, Town of Caswell Beach)***

Shorelines analyzed (14): 1944, 1970, 1971, 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004

- Original IHA boundary @ DCM transect 970
- Proposed IHA boundary @ DCM transect 901 (IHA boundary movement 11,385 ft or 3,450 m west)

Proposed IHA boundaries were delineated based on statistical shoreline trends, average historical beach width (as measured landward from the hybrid shoreline), inlet processes, and geomorphology. The western boundary of the proposed IHA (transect 901), although coincident with the siphon channel associated with the Brunswick Nuclear Power Plant located on the mainland, is related to numerous geomorphologic features: 1) a subsurface shore-perpendicular geologic ridge, 2) the low elevation of the island related to the paleo delta of the Elizabeth River, 3) the undulate nature of the shoreline and 4) the location where the edge of the ebb tidal delta welds to the shoreline. It was noted by the CRC Science Panel that the statistical shoreline trends were complex with no major shift in standard deviation of shoreline position. (Data analysis included, and omitted, shorelines from 2003 and 2004 in order to understand the effect of the 2001 beach fill project on the shoreline positions. It was concluded that

there was no significant shoreline effect from these beach fill projects.) Although the average shoreline rate-of-change increased dramatically at transect 901, the eastern boundary of the proposed IHA was defined primarily by expert knowledge of the island's geomorphology (see the four specific factors identified above). From transect 901 toward the inlet, the majority of the proposed IHA boundary was based on maximum historical beach width up to transect 956 (approximate entrance to Ft. Caswell) and then followed topography (ridge of frontal and primary dunes) around Ft. Caswell. Areas along the back-barrier portion of the island along the Cape Fear River with a potential for inlet-related spit development were also included in the proposed IHA boundary. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Therefore, the parcels along the oceanfront were included in their entirety. Refer to Figure 3.4 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

### ***RIGHT SIDE OF INLET (Bald Head Island)***

Shorelines analyzed (14): 1944, 1970, 1971, 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004

- Original IHA boundary @ DCM transect 998
- Proposed IHA boundary @ DCM transect 1025 (IHA boundary movement 4,455 ft east)

Proposed IHA boundaries were delineated based on statistical shoreline trends, average historical beach widths (as measured landward from the hybrid shoreline), inlet processes, and geomorphology. This inlet complex is the largest in the State (e.g., the ebb delta of the Cape Fear River Inlet contains hundreds of millions of cubic yards of sediment) and operates on longer-term cycles (100 to 200 years) than the other inlets (decadal). Statistical shoreline analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 1025 as the point along the oceanfront (South Beach) where the processes affecting the shoreline transition from inlet-dominated to being influence more by processes associated with Cape Fear. In addition to this eastern boundary position along South Beach, a northern boundary was also defined as the tidal creek (Bald Head Creek). Although transects did not extend along west beach parallel to the Cape Fear River, the CRC Science Panel identified the western shoreline of the river (West Beach) and the sand spit on which the marina sits as being heavily influenced by inlet-related processes. This particular IHA boundary is defined currently in 15A NCAC 07H.0304(3) as not extending northeast of the Bald Head Island marina entrance channel. This was done, in part, due to the groin field that existed north of the marina entrance. However, similar to the CRC Science Panel recommendations, the Priddy and Carraway (1978) report also used Bald Head Creek as its recommended IHA boundary. Inclusion of inlet-related sand spits has been consistent for all twelve of the proposed IHAs presented in this report.

Historically, net shoreline accretion occurred (primarily on West Beach) in the early 1900s followed by a trend reversal in the 1920s. This net erosion was related to the collapse (i.e., redistribution and/or removal) of nearshore shoal systems. The western portion of South Beach (Bald Head Island) has experienced erosion since the 1960s at least in part due to the USACE dredging projects associated with the Cape Fear River (Military Operations Terminal Sunny Point and the State's Port of Wilmington). The long-term (approximately 50 to 60 years) average erosion rates referenced in 15A NCAC 07H.0304(1)(a) for the western portion of South Beach are between two and eight feet per year for the oceanfront within the proposed IHA, while the more robust dataset used for this investigation produces erosion rates between two and in excess of 15 feet per year. Not coincidentally, the island's terminal groin field (installed under a CRC variance in the 1990s and reconstructed in 2004) was placed along the higher erosion rate "hot spots" along western-most South Beach and southern-most West Beach in an effort to mitigate the erosion hazard.

Owing to the magnitude of the inlet and inlet-related processes on Bald Head Island, both recent and historic, the CRC Science Panel felt that historical maximum beach width methods used on the other inlets did not provide a large enough IHA, especially along South Beach. Instead, the ridgeline across the middle of the island (easily observed in 1978 color infrared aerial photos as well as 1998 and 2003 NC Floodplain Mapping topographic data) became the preferred boundary for the majority of the IHA. The CRC Science Panel felt determined that the proposed boundary on Bald Head Island is applicable due to the magnitude of the inlet size, its processes and the extensive area affected by these processes, and that it represented the location of the 1855 shoreline. Oceanward of the 1855 shoreline is accreted sand related to USACE-engineered dredging projects, which is vulnerable to inlet-related erosion (such as what happened in the 1920s shoal collapse).

The CRC Science Panel noted that the width of their proposed Bald Head Island IHA boundary, although based on historical inlet accretion trends and resultant geomorphology (i.e., the topographic high of the paleo dune ridge), was extreme and that, because of its large area, development inside of this boundary was not exposed to the same degree of risk. For example, the portion of the golf course and its support facilities contained within the majority of the proposed IHA may not need to be governed with the same restrictions as the other, smaller IHAs within this report due to its more landward location. Although the CRC Science Panel continued to support their initial boundary recommendation, DCM staff developed an alternative IHA boundary proposal that used a combination of the CRC Science Panel's boundary coupled with linear regressed erosion rates generated during the course of this investigation. These shoreline trends (i.e., erosion rates) were multiplied by a setback factor of 90, which is consistent with the maximum setback factor adopted by the CRC in September 2008. The resulting distance was then measured landward from the Village's current static vegetation line from transect 1025 westward to transect 1001, at which point it intersected the Science Panel's geomorphological line. The proposed IHA boundary follows this line east until it intersects with the existing IHA boundary (Priddy and Carraway, 1978) near the intersection of Green Teal Trail and West Bald Head Wynd. Where the existing IHA boundary approaches the intersection of Marina Wynd and

Keelson Row, the proposed boundary turns shore perpendicular (i.e., perpendicular to West Beach) and heads due west toward the Cape Fear River Inlet. As with all other inlet boundary proposals in this report, man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the recommended IHA boundary. This DCM-amended IHA boundary, as described above, was presented to the CRC in November 2008 and subsequently approved by the CRC for inclusion in this report (Warren, 2008). Refer to Figure 3.5 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.4.** Proposed IHA boundary for the western side (Caswell Beach, Oak Island) of Cape Fear River Inlet.



Map Prepared by Ken Richardson 04/14/2009

North Carolina DEIR - Division of Coastal Management - 2008

**Figure 3.5.** Proposed IHA boundary for the eastern side (Bald Head Island) of Cape Fear River Inlet.



### 3.5 Carolina Beach Inlet

#### **BACKGROUND** (*summarized from Cleary and Marden, 2001*)

- Opened by private interests in 1952
- Width of inlet varied as it reached equilibrium (a process disrupted by numerous storms between 1954 and 1962): 380 ft or 116 m (1966); 1,400 ft or 427 m (1985); 660 ft or 201 m (1999)
- High erosion rates occurred along Pleasure Island (Carolina Beach) and Masonboro Island in response to the opening of the inlet

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Pleasure Island, Carolina Beach)***

Shorelines analyzed (11): 1933, 1971, 1973, 1974, 1977, 1984, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 1623
- Proposed IHA boundary @ DCM transect 1575 (IHA boundary movement 7,920 ft or 2,400 m south)

Proposed IHA boundaries were delineated based on statistical shoreline trends, maximum historical beach widths (as measured landward from the hybrid shoreline), inlet processes, and geomorphology. Statistical shoreline analysis along the northeastern-most portion of Pleasure Island (Carolina Beach) is complex due to 1) numerous historical and recent beach fill projects and 2) the lapse in large-scale beach fill projects during the 1970s and 1980s. The highest erosion rates in this area occurred at the end of Canal Drive during the period without large-scale beach fill maintenance. In addition, a rock (rip-rap) revetment (wall) was emplaced in 1970 and 1972 (the south end of this wall is near transect 1584). Therefore, although statistical shoreline analysis (standard deviation of shoreline position and average rate of shoreline change) was completed and reviewed, the proposed southern IHA boundary primarily was chosen based on the following factors: 1) erosion rates associated with the location of a historical inlet (opened in 1954 just south of the Carolina Beach Fishing Pier but within the proposed IHA), 2) the existence of the rock revetment (and its effect on the adjacent shoreline), 3) the effect of the numerous large-scale beach fill projects and their effect on the adjacent shoreline and 4) the location of the naturally vegetated dunes relative to those constructed and planted (which were washed out during Hurricane Hazel in 1954).

Between transects 1575 and 1583, the CRC Science Panel determined that the historical average beach width was not wide enough (oceanward of Carolina Beach Avenue) but the historical maximum beach width was too wide (landward of Carolina Beach Avenue). Therefore, the boundary was defined by Carolina Beach Avenue,

which incorporated no more than the oceanfront lots (a compromise between average and maximum historical beach widths. At transect 1583, the use of historical maximum beach width and the low-lying nature of the topography defined the boundary towards the estuary (west) and the Carolina Beach Yacht Basin. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figure 3.6 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

### ***RIGHT SIDE OF INLET (Masonboro Island, North Carolina Coastal Reserve)***

Shorelines analyzed (11): 1933, 1971, 1973, 1974, 1977, 1984, 1992, 1997, 1998, 2003, 2004

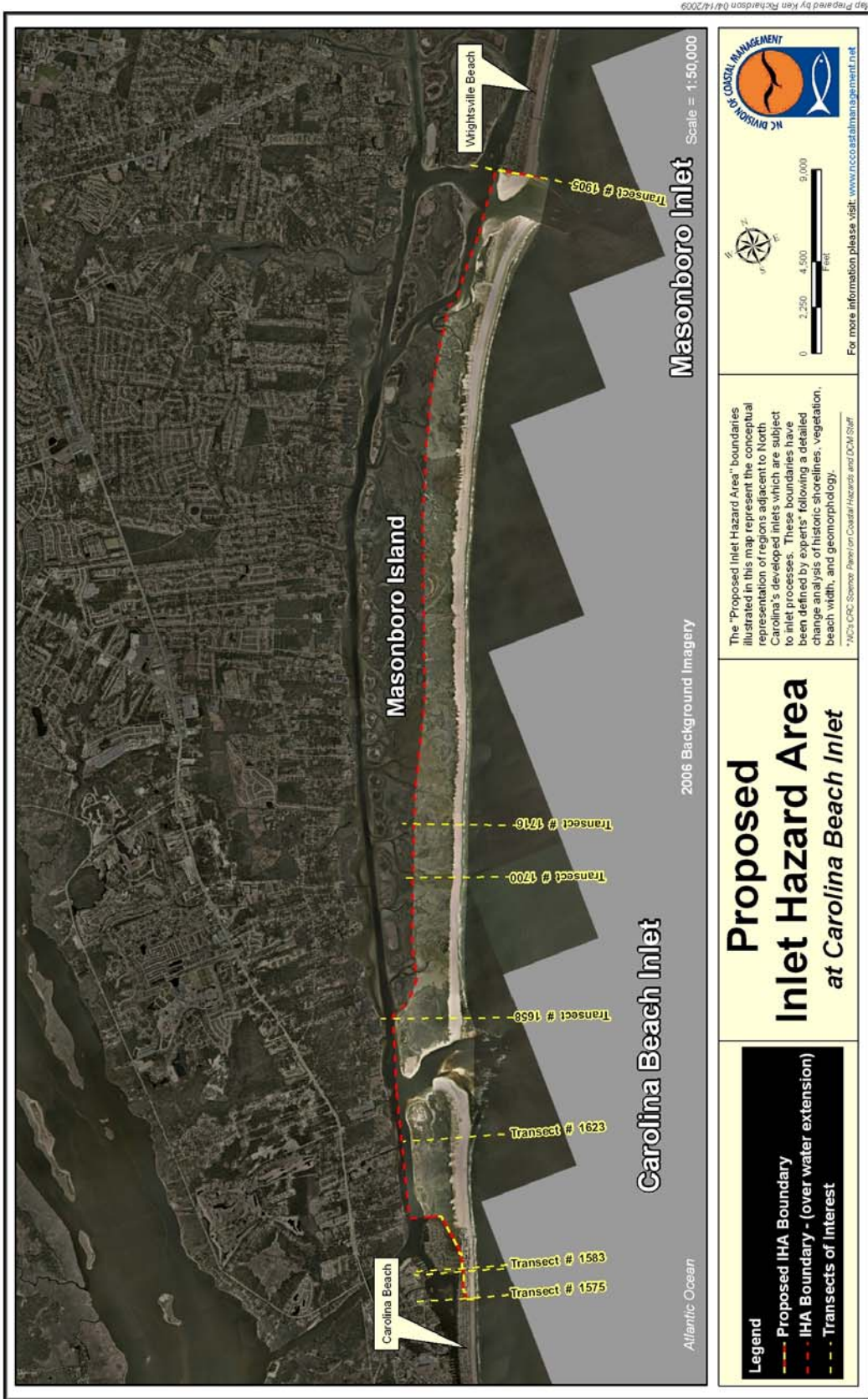
- Original IHA boundary @ DCM transect 1658
- Proposed IHA boundary @ DCM transect 2023 (IHA boundary movement 60,225 ft or 11.4 mi (18,357 m or 18.3 km) north to include Masonboro Island in its entirety, Masonboro Inlet and the southern-most portion of Wrightsville Beach)

Masonboro Island is heavily influenced by both Carolina Beach Inlet as well as Masonboro Inlet. Based on the narrow and low-lying topography of the island (e.g., extensive overwash, 1954 breach during Hurricane Hazel near transect 1700), its offshore geology, and the southern jetty at adjacent Masonboro Inlet (constructed in 1981), it was proposed that the Carolina Beach Inlet IHA include Masonboro Island in its entirety. The location of the southern jetty at Masonboro Inlet, while having a net gain of sand within the groin fillet (a positive effect at the inlet), has caused an erosional bight along the island (a negative effect along the Masonboro shoreline). This convex bight is also controlled by offshore sandstones (the shoreline “bump” observed northward of transect 1716) that, if removed from the shoreface, could create a convex shoreline and change the planform of the island. A planform change could also be expected if the southern jetty at Masonboro Inlet was removed or failed (the island is expected to rotate counterclockwise as it has adjusted to regain equilibrium conditions). Therefore, the proposed Carolina Beach/Masonboro IHA extends to Wrightsville Beach (the northern proposed IHA boundary of Masonboro Inlet). Refer to Figure 3.7 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.6.** Proposed IHA boundary for the southwestern side (Carolina Beach) of Carolina Beach Inlet.



**Figure 3.7.** Proposed IHA boundary for the area spanning Carolina Beach Inlet and Masonboro Inlet.



Map Prepared by Ken Richardson 04/14/2009

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### 3.6 Masonboro Inlet

#### **BACKGROUND** (*summarized from Cleary and Marden, 2001*)

- Historical charts from 1733 first document the inlet, which opened in the early 1700s two km (6.562 ft) north of its present location
- Fifteen years after the completion of the Atlantic Intracoastal Waterway (AIWW) in 1932, the inlet's channel was relocated at the southern end of the barrier spit extending northward from Masonboro Island (designed to mitigate erosion to Wrightsville Beach)
- The northern jetty was completed in June 1966 with a weir to allow sand bypassing into the inlet
- The southern jetty was completed in April 1981
- A comparison of 1964 and 1985 bathymetry indicates an increased ebb-tidal delta volume from 6.2 million cubic meters or 8.1 million cubic yards to 9.4 million cubic meters or 12.3 million cubic yards (changes to depths of 20 ft or six m)
- Jetty construction and the consequent enlarged tidal prism have increased sediment entrapment where little or no sediment bypasses naturally (some material is transported over weir of the northern jetty into inlet)

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Masonboro Island, North Carolina Coastal Reserve)***

Shorelines analyzed (12): 1933, 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004

- No original IHA boundary designated due to northern jetty (constructed in 1965) and the southern jetty (proposed when IHA report published in 1978 but not constructed until 1981)
- Proposed IHA boundary @ DCM transect 1575 (includes southern-most portion of Wrightsville Beach, Masonboro Island in its entirety and extends across Carolina Beach Inlet into the southern-most portion of Carolina Beach)

Masonboro Island is heavily influenced by both Carolina Beach Inlet as well as Masonboro Inlet. Based on the narrow and low-lying topography of the island (e.g., extensive overwash, 1954 breach during Hurricane Hazel around transect 1700), its offshore geology, the southern jetty at adjacent Masonboro Inlet, inlet processes, and island geomorphology, it was proposed that the Masonboro Inlet IHA include Masonboro Island in its entirety. The location of the inlet's southern jetty (constructed in 1981), while having a net gain of sand within the groin fillet (a positive effect at the inlet), has caused an erosional bight along the island (a negative effect along the Masonboro shoreline). This convex bight is also controlled by offshore sandstones (the shoreline

“bump” observed northward of transect 1716) that, if removed from the shoreface, could create a convex shoreline and change the planform of the island. A planform change could also be expected if the southern jetty at Masonboro Inlet was removed or failed (i.e., the island is expected to rotate counterclockwise as it adjusts to regain equilibrium conditions). Therefore, the proposed Carolina Beach/Masonboro IHA extends all the way to Carolina Beach (the southern proposed IHA boundary of Carolina Beach Inlet). Refer to Figure 3.7 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

### ***RIGHT SIDE OF INLET (Wrightsville Beach)***

Shorelines analyzed (12): 1933, 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004

- No original IHA at this inlet due to jetties
- Proposed IHA boundary @ DCM transect 1905 (IHA includes northern-most portion of Carolina Beach, Carolina Beach Inlet, Masonboro Island in its entirety and the southern-most portion of Wrightsville Beach)

The northern jetty at Masonboro Inlet (constructed in 1965) has created a net gain of sand as the jetty's fillet has filled. The statistical shoreline analysis for this proposed IHA was not considered because it identified shoreline trends associated with the engineered structure and not the natural system. With the assumption that the jetty remains in place and does not fail, the CRC Science Panel determined that this portion of the island will be influenced by the twin jetties flanking the inlet. Therefore, the proposed IHA boundary starts where the jetty intersects the shoreline (transect 1905) and follows transect 1905 across the island to Banks Channel. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figure 3.8 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.8.** Proposed IHA boundary for the northeastern side (Wrightsville Beach) of Masonboro Inlet.



Map Prepared by Ken Richardson 04/09/2009

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### 3.7 Mason Inlet

#### **BACKGROUND** (*summarized from Cleary and Marden, 2001*)

- Historical maps confirm the existence of inlets in this area in the early 18<sup>th</sup> century
- The inlet's southwestern migration and related erosion in the mid 1990s led to the inlet's northern relocation closer to Figure Eight Island
- The inlet relocation project moved the inlet approximately 3,000 ft or 914 m to the north and was completed in April 2002

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Wrightsville Beach)***

Shorelines analyzed (12): 1933, 1949, 1958, 1971, 1973, 1977, 1987, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 2030
- Proposed IHA boundary @ DCM transect 2023 (IHA boundary movement 1,155 ft or 350 m southwest)

Proposed IHA boundaries were delineated based on statistical shoreline trends, historical inlet migration rates, inlet processes, and geomorphology. Because Mason Inlet was relocated in 2002 and is subject to future engineering, the CRC Science Panel determined that the alteration of the inlet, and subsequent shoreline response to the resultant inlet processes, make the system complex. The inlet historically migrated south and, prior to its closure and movement in 2003, was migrating at a rate of one foot per day. Members of the CRC Science Panel provided estimates that, without relocation, the inlet would have continued to migrate to the south before closing and re-opening back to the north. Statistical shoreline trend analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 2023 as the point along the oceanfront where inlet processes were no longer dominant. The position of the inlet shoreline in 2003 at the southern boundary of the existing IHA (Priddy and Carraway, 1978) and the rate at which the shoreline was migrating to the south at the time of inlet relocation prompted the CRC Science Panel to move the IHA boundary farther south. The proposed IHA boundary at transect 2023 follows the transect to the backside of the island, and man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figure 3.9 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

##### ***RIGHT SIDE OF INLET (Figure Eight Island)***

Shorelines analyzed (13): 1933, 1944, 1949, 1958, 1971, 1973, 1987, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 2061
- Proposed IHA boundary @ DCM transect 2074 (IHA boundary movement 2,133 ft or 650 m northeast)

Proposed IHA boundaries were delineated based on statistical shoreline trends, historical inlet migration directions, inlet processes, and geomorphology. Mason Inlet was relocated in 2002 and is subject to future engineering. The CRC Science Panel determined that the alteration of the inlet, and subsequent shoreline response to these inlet processes, make the system complex. Statistical shoreline trend analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 2074 as the point along the oceanfront where inlet processes were no longer dominant. Between transects 2074 and 2069, the proposed IHA boundary follows the historical maximum beach width and then follows topography to transect 2061 where it intersects with the existing IHA boundary. The CRC Science Panel determined that Mason Inlet was unlikely to migrate north (although the inlet had occupied positions farther northward in the past) due to numerous changes affecting the back-barrier side of the island (e.g., dredging of finger canals, creation of highlands for development, inlet relocation) so the existing IHA boundary was deemed appropriate. The northern extension of the proposed IHA along the oceanfront was justified due to the inlet-induced processes along the shoreline unrelated to lateral migration. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figure 3.9 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.9.** Proposed IHA boundary for Mason Inlet.



### 3.8 Rich Inlet

#### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- Inlet drains an expansive marsh area where two large tidal creeks, Nixon and Green channels, connect the AIWW
- Inlet's large tidal prism and historic stability are primarily responsible for the size of the ebb-tidal delta
- The ebb delta has been estimated to contain eight million cubic meters of sediment to a depth of six m (19.7 ft)
- Compared to other inlet systems found in this region, Rich Inlet is a relatively large inlet and depths in the main channel range from five to seven m (16 to 23 ft)

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Figure Eight Island)***

Shorelines analyzed (9): 1938, 1958, 1973, 1980, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 2173
- Proposed IHA boundary @ DCM transect 2151 (IHA boundary movement 3,630 ft or 1,100 m southwest)

Proposed IHA boundaries were delineated based on statistical shoreline trends, inlet processes, and geomorphology. Statistical shoreline trend analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 2151 as the point along the oceanfront where inlet processes were no longer dominant. At transect 2151 the historical average beach width was used to define the landward extent of the proposed IHA boundary and transitioned to the maximum historical beach width between Clamdigger Point and the private drive that connects Beach Road to Surf Court. The proposed IHA boundary continued to follow maximum beach width along Beach Road and back to Oyster Catcher Road where it intersected the existing IHA boundary and followed that boundary to the backside of the island. A sand spit on the back-barrier portion of the island, the formation of which was driven by inlet processes, was also included in the proposed IHA. Inclusion of inlet-related spits has been the standard for all of the proposed IHAs presented in this report. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figure 3.10 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

### ***RIGHT SIDE OF INLET (Lea/Hutaff Island complex)***

Shorelines analyzed (9): 1938, 1958, 1973, 1980, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 2208
- Proposed IHA boundary @ DCM transect 2370 (proposed IHA moved 26,730 ft or 5 mi (8,038 m or 8 km) to the northeast to include the northeastern-most portion of Figure Eight Island, Rich Inlet, the Lea/Hutaff Island complex – joined after the closure of Old Topsail Inlet, New Topsail Inlet and the southwestern-most portion of Topsail Island)

Similar to Masonboro Island, the Lea/Hutaff Island complex (also referred to as Coke and No-Name islands) was created as Old Topsail Inlet closed in 1997 and is heavily influenced by Rich Inlet as well as New Topsail Inlet flanking it to the north. Based on the narrow and low-lying geomorphology of the island complex (e.g., lack of dune ridges and extensive overwash) and inlet processes, the CRC Science Panel determined that the Rich Inlet IHA should include the Lea/Hutaff Island complex in its entirety.

Therefore, the proposed Rich/New Topsail IHA extends to Topsail Island (the northern proposed IHA boundary of New Topsail Inlet). This IHA includes the existing IHA for Old Topsail Inlet (spanning transects 2259 to 2301). Refer to Figure 3.11 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.10.** Proposed IHA boundary for the southwestern side of Rich Inlet (Figure Eight Island).



**Figure 3.11.** Proposed IHA boundary for the area between Rich Inlet and New Topsail Inlet.



### 3.9 New Topsail Inlet

#### **BACKGROUND** (*summarized from Cleary and Marden, 2001*)

- Land grants record the existence of New Topsail Inlet as early as 1726
- Maps indicate that the inlet has migrated to the southwest at an average rate of 38 m (125 ft) per year during the past 275 years and an 11-km (6.8-mi) chain of 20 low-relief marsh islands lies in the lagoon, recording the inlets movement
- The ebb-tidal delta is estimated to contain 9 million cubic m (11.8 cubic yds) of sand
- The inlet's width has fluctuated considerably from a minimum width of 295 m (968 ft) in 1984 to a maximum width of 690 m (2,264 ft) in 1995

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Lea/Hutaff Island complex)***

Shorelines analyzed (12): 1971, 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004

- Original IHA boundary @ DCM transect 2251
- Proposed IHA boundary @ DCM transect 2151 (proposed IHA moved 16,404 ft or 3.12 mi (5,000 m or 5 km) to the southwest to include the Lea/Hutaff Island complex – joined after the closure of Old Topsail Inlet in 1997, Rich Inlet and the northeastern-most portion of Figure Eight Island)

Similar to Masonboro Island, the Lea/Hutaff Island complex (also referred to as Coke and No-Name islands) was created as Old Topsail Inlet closed in 1997 and is heavily influenced by Rich Inlet as well as New Topsail Inlet flanking it to the north. Based on the narrow and low-lying geomorphology of the island complex (e.g., lack of dune ridges and extensive overwash) and the inlet processes, the CRC Science Panel determined that the New Topsail Inlet IHA include the Lea/Hutaff Island complex in its entirety. Therefore, the proposed/New Topsail/Rich IHA extends to Figure Eight Island (the northern proposed IHA boundary of Rich Inlet). This IHA includes the existing IHA for Old Topsail Inlet (spanning transects 2259 to 2301). Refer to Figure 3.11 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

##### ***RIGHT SIDE OF INLET (Topsail Island, Topsail Beach)***

Shorelines analyzed (12): 1971, 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004

- Original IHA boundary @ DCM transect 2347
- Proposed IHA boundary @ DCM transect 2370 (IHA boundary movement 3,795 ft or 1,150 m northeast)

Proposed IHA boundaries were delineated based on statistical shoreline trends, geomorphology, and inlet processes. Statistical shoreline trend analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 2370 as the point along the oceanfront where inlet processes were no longer dominant. The CRC Science Panel recognized that the inlet likely is the longest-lived migrating inlet in the State (and currently migrating south at rates approaching 90 ft per year), and the planform of the shoreline will continue to change along with inlet migration. From these observations, the CRC Science Panel expects continuing erosion along the oceanfront shoreline adjacent to the inlet. Between transects 2370 and 2352 the historical maximum beach width was used to define the landward extent of the proposed IHA boundary. Historical maximum beach width was used between transects 2352 and 2370 and where the boundary followed Trout Street to the back side of the island. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figure 3.12 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.12.** Proposed IHA boundary for the northeastern side of New Topsail Inlet (Topsail Beach, Topsail Island).



### 3.10 New River Inlet

#### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- Historical coastal charts indicate that the inlet has migrated within a two-kilometer zone since 1856; the migration zone width is controlled by the ancestral channel of the New River, the majority of which is located on the Onslow Beach (northeastern) shoulder of the inlet
- In recent history, the inlet's width has varied considerably ranging from 66 m (217 ft) in 1938 (prior to dredging) to a maximum width in 1987 of 304 m (997 ft)
- Although the inlet has generally moved southwest, it has periodically reversed direction (this northeastward movement was directly related to the enlargement of the marginal flood channel on the North Topsail Beach shoulder)

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Topsail Island, North Topsail Beach)***

Shorelines analyzed (14): 1934, 1952, 1971, 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004

- Original IHA boundary @ DCM transect 3017
- Proposed IHA boundary @ DCM transect 2996 (IHA boundary movement 3,465 ft or 1,050 m southwest)

Proposed IHA boundaries were delineated based on statistical shoreline trends, inlet processes, and geomorphology. Statistical shoreline trend analysis (standard deviation of shoreline position and average rate of shoreline change) identified transect 2996 as the point along the oceanfront where inlet processes were no longer dominant. Although shoreline accretion occurred in this area between the 1960s and 1990s, the shoreline has experienced inlet-induced erosion for the past decade. The historical maximum beach widths were used to establish the proposed IHA boundary between transects 2996 and 3017. The CRC Science Panel determined that the island geomorphology, primarily the low-lying topography of the island (i.e., lack of dune ridge), required an IHA boundary that followed Sea Gull Lane where it intersected with Oyster Lane (the approximate boundary of the existing IHA). From this point it followed Oyster Lane across the island through the back-barrier marsh and included a sand spit and extensive overwash along the inlet's southern shoreline. The formation of this spit was driven by inlet processes. Inclusion of inlet-related spits has been the standard for all of the proposed IHAs presented in this report. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figures 3.13 and 3.14 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

### ***RIGHT SIDE OF INLET (Onslow Beach, Camp Lejeune)***

Shorelines analyzed (14): 1934, 1952, 1971, 1973, 1974, 1977, 1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004

- Original IHA boundary @ DCM transect 3069
- Proposed IHA boundary @ DCM transect 3101 (IHA boundary movement 5,280 ft or 1,600 m northeast)

The Onslow Beach proposed IHA boundary, which is shoreline perpendicular, stops at transect-3101. The CRC Science Panel determined that beach width data were insufficient and did not illustrate an adequate hazard boundary. The proposed IHA boundary follows the back-barrier canal based on the relative position of shorelines, inlet processes, and geomorphology. Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figure 3.14 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.13.** Proposed IHA boundary for New River Inlet (North Topsail Beach, Topsail Island).



**Figure 3.14.** Proposed IHA boundary for New River Inlet (North Topsail Beach, Topsail Island and Camp LeJeune, Onslow Beach).



### 3.11 Brown's Inlet

#### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- Relatively stable inlet; evidence suggests that the inlet has migrated within a two-kilometer zone straddling the existing inlet
- Width has fluctuated dramatically; in 1938 the minimum width was only 154 m (505 ft) and the inlet reached a maximum width of 389 m (1,276 ft) in 1995
- While the position of the inlet has changed comparatively little during the past 50 years, the orientation of the ebb channel and the adjacent shorelines have altered significantly
- The migration of the channels within the inlet throat have governed the accretion and erosion on adjacent shorelines

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Onslow Beach, Camp Lejeune)***

Shorelines analyzed : none\*

- Original IHA boundary @ DCM transect 3370
- Proposed IHA boundary @ DCM transect 3370

\*Because of the undeveloped nature of this inlet, DCM recommends no change to the boundary of Priddy and Carraway (1978) in conjunction with applicable IHA boundary amendments in 1981 until further analysis can be completed (Figure 3.15).

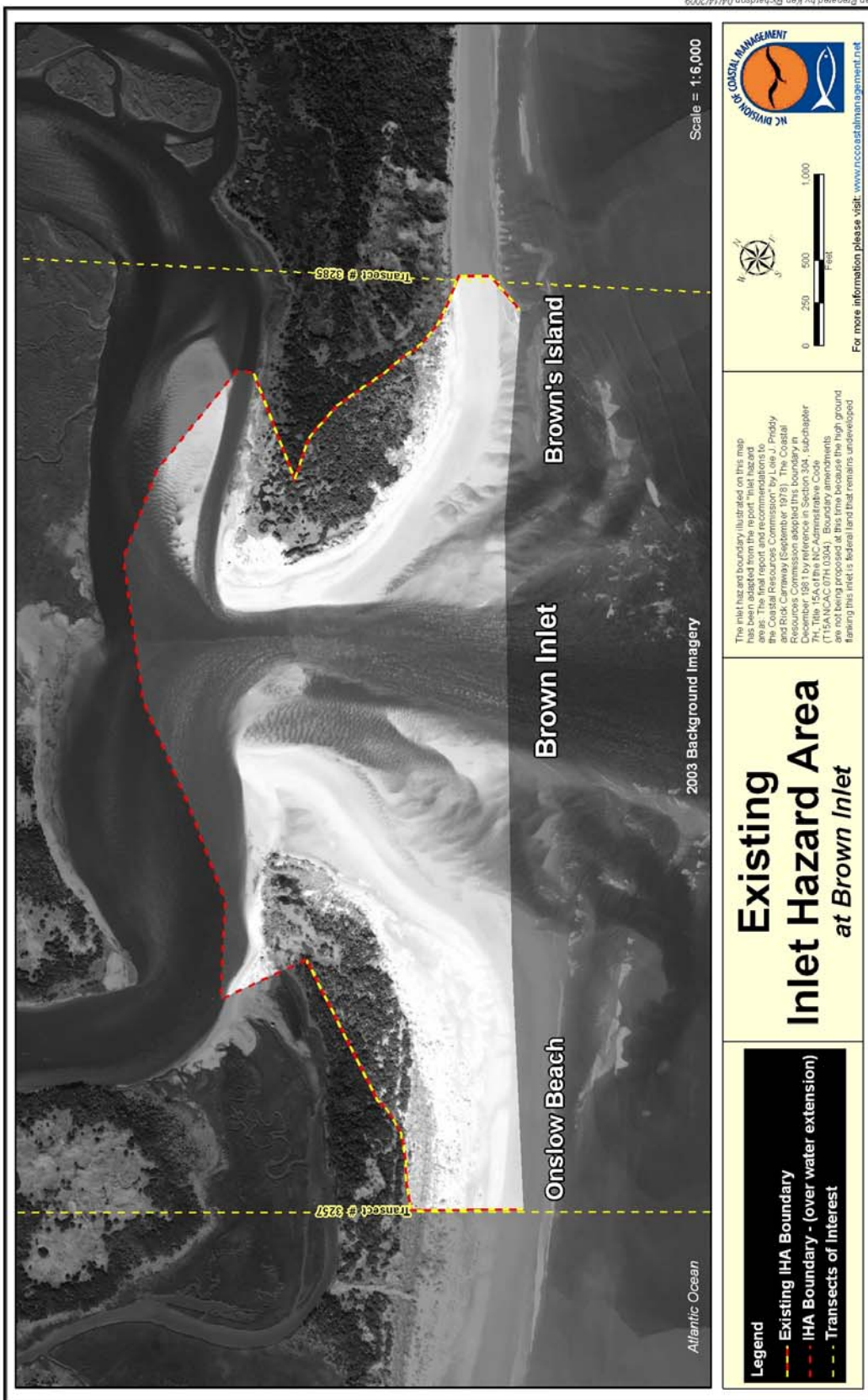
##### ***RIGHT SIDE OF INLET (Brown's Island, Camp Lejeune)***

Shorelines analyzed: none\*

- Original IHA boundary @ DCM transect 3394
- Proposed IHA boundary @ DCM transect 3394

\*Because of the undeveloped nature of this inlet, DCM recommends no change to the boundary of Priddy and Carraway (1978) in conjunction with applicable IHA boundary amendments in 1981 until further analysis can be completed (Figure 3.15).

**Figure 3.15.** Existing IHA boundary for Brown's Inlet. No changes to this boundary are proposed at this time.



### 3.12 Bear Inlet

#### **BACKGROUND** (*summarized from Cleary and Marden, 2001*)

- Maps and aerial photographs suggest the inlet has migrated about two kilometers to the northeast from its original position on Brown's Island (seaward of Shacklefoot Creek)
- Initial position of the inlet channel was controlled by the position of an ancestral river channel
- During the past several thousand years, the estuary has filled in and water exchange through the inlet has decreased resulting in the migration of the inlet in the direction of the dominant eastward sediment transport
- Since 1938, inlet has remained relatively stable moving to the northeast approximately 65 m or 213 ft, during which time the throat of inlet has ranged in width from 300 m or 984 ft (1956) to 780 m or 2,559 ft (1938) with an average width of 500 m (1,640 ft)

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Bear Island, Camp Lejeune)***

Shorelines analyzed : none\*

- Original IHA boundary @ DCM transect 3257
- Proposed IHA boundary @ DCM transect 3257

\*Because of the undeveloped nature of this inlet, DCM recommends no change to the boundary of Priddy and Carraway (1978) in conjunction with applicable IHA boundary amendments in 1981 until further analysis can be completed (Figure 3.16).

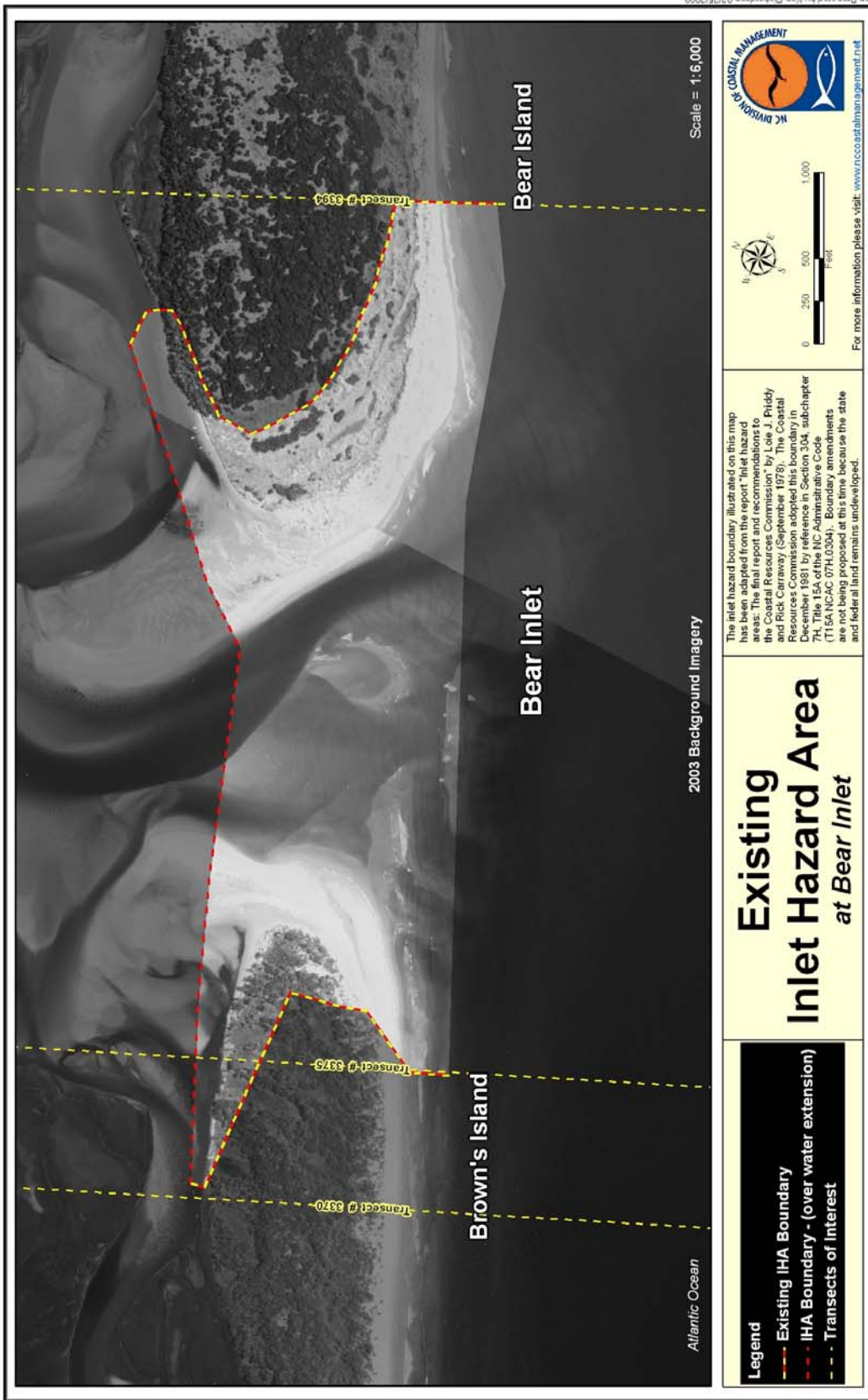
##### ***RIGHT SIDE OF INLET (Brown's Island, Hammocks Beach State Park)***

Shorelines analyzed: none\*

- Original IHA boundary @ DCM transect 3285
- Proposed IHA boundary @ DCM transect 3285

\*Because of the undeveloped nature of both sides of this inlet, DCM recommends no change to the boundary of Priddy and Carraway (1978) in conjunction with applicable IHA boundary amendments in 1981 until further analysis can be completed (Figure 3.16).

**Figure 3.16.** Existing IHA boundary for Bear Inlet. No changes to this boundary are proposed at this time.



Map Prepared by Ken Richardson 03/25/2009

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### 3.13 Bogue Inlet

#### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- Records indicate that this inlet has served as a port of entry for the Town of Swansboro during the early 1700s
- Inlet width has fluctuated between 400 m (1,312 ft) to 1.9 km (1.2 mi) during the past 60 years, while depths in the ebb channel have fluctuated between 5 to 9 m (16 to 30 ft)
- Since 1946, the USACE has maintained a five-kilometer-long, two-m (7-ft) deep channel connecting the inlet to the AIWW
- Ebb tidal delta is estimated to contain approximately 13 million cubic m (17 million cubic yds) of sand
- Inlet is relatively stable with location controlled by ancestral location of White Oak River
- Ebb channel moved under private contract in 2005 from eastern-most portion of inlet to center

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Bear Island, Hammocks Beach State Park)***

Shorelines analyzed (11): 1949, 1956, 1960, 1971, 1973, 1974, 1987, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 3447
- Proposed IHA boundary @ DCM transect 3440 (IHA boundary movement 1,148 ft or 350 m west)

Based on maximum beach width, geomorphology, and inlet processes, the CRC Science Panel defined the Bear Island proposed shoreline-perpendicular IHA boundary to stop at transect 3440. The proposed IHA boundary follows historical maximum beach width between transects 3440 and 3459. The boundary continues to follow the trend of maximum beach width as it approaches transect 3471, but also takes into consideration dune-ridge topography near the back side of the island. From this point, maximum beach width defines the proposed IHA boundary until it reaches the back-barrier shoreline. Refer to Figure 3.17 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

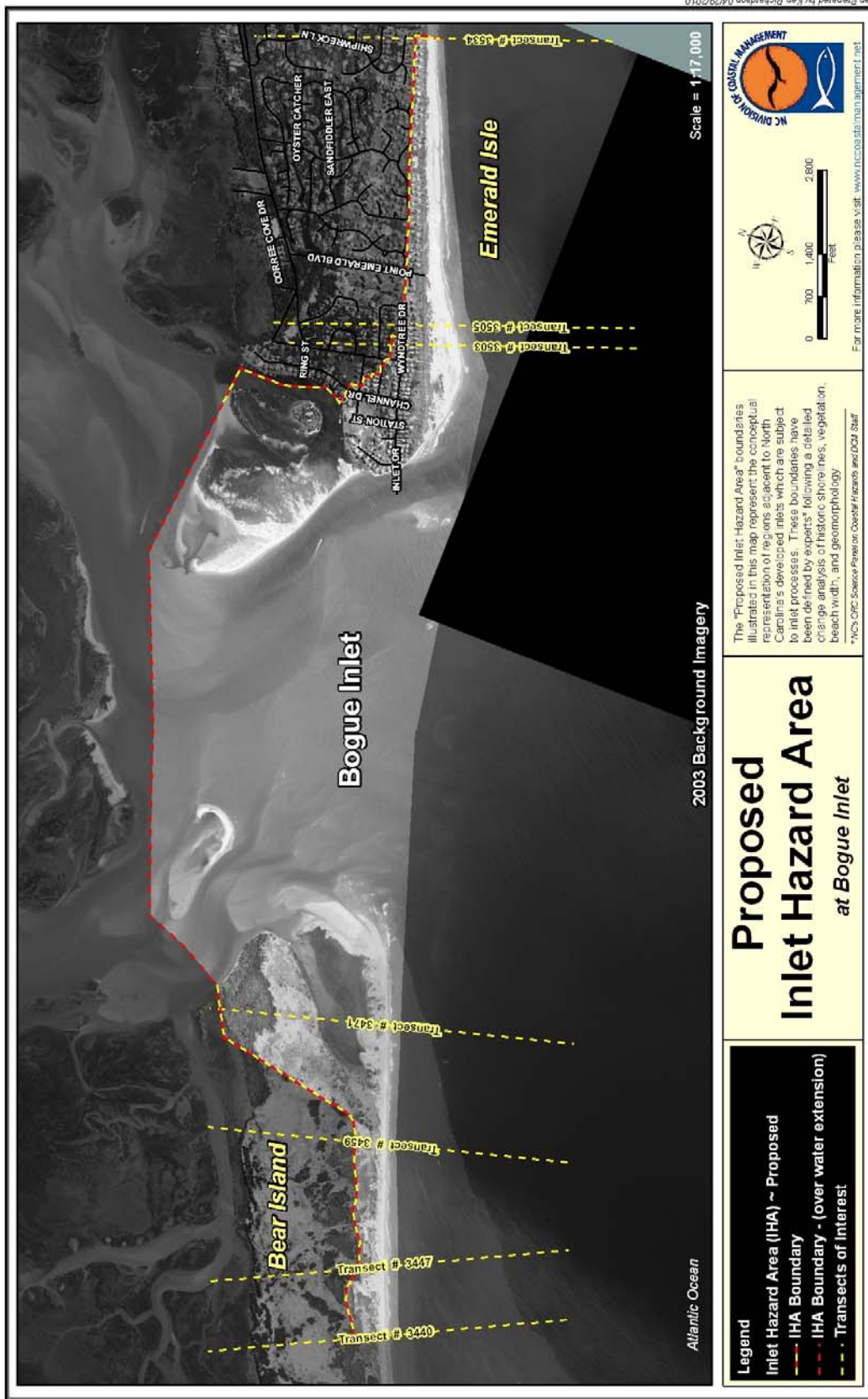
### ***RIGHT SIDE OF INLET (Bogue Banks, Emerald Isle)***

Shorelines analyzed (13): 1949, 1956, 1958, 1960, 1971, 1973, 1976, 1987, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 3505
- Proposed IHA boundary @ DCM transect 3534 (IHA boundary movement 4,757 ft or 1,450 m east)

Based on average beach width, maximum beach width, geomorphology, and inlet processes, the CRC Science Panel defined the Emerald Isle shoreline-perpendicular proposed IHA boundary to stop at transect 3534. Between transects 3534 and 3505 the proposed IHA boundary follows parcel boundaries, placing the landward extent of the boundary between the average and maximum beach widths. The CRC Science Panel determined that the application of the average beach width was too conservative and the maximum beach width was too far landward. Therefore, at transect 3503 the proposed IHA boundary simply follows the existing IHA boundary (Priddy and Carraway, 1978). Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figures 3.17 and 3.18 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.17.** Proposed IHA boundary for Bogue Inlet.



Map Prepared by Ken Richardson 04/29/2010

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**Figure 3.18.** Proposed IHA boundary for the eastern side of Bogue Inlet (Emerald Isle, Bogue Banks).



### 3.14 Beaufort Inlet

#### **BACKGROUND** (*summarized from Cleary and Marden, 2001*)

- Ancestral river channel controls inlet position
- Historical maps from 17<sup>th</sup> century confirms the inlet was in the same general location as today
- The large tidal prism associated with the Newport and North Rivers contributes to the inlet's relative stability
- Inlet has been modified for commercial traffic to the NC State Port in Morehead City by the USACE
- Inlet width fluctuates in conjunction with storm cycles with a maximum width of 2.5 km or 1.6 mi (1953) and a minimum of 1.1 km or 0.7 mi (1993), and the average width has been 1.4 km or 0.9 mi since 1939 (prior to changes made by the USACE for navigational purposes, which include dredging and the construction of a terminal groin at Ft. Macon on Bogue Banks, the average width was 2.1 km or 1.3 mi, as compared to 1.2 km or 0.7 mi over the past 40 years)
- Channel's average depth increases as width decreases, thereby maintaining similar cross-sectional flow characteristics (depth increase from 4 meters at turn of 19<sup>th</sup>/20<sup>th</sup> century to 7.5 m or 25 ft in 1974)

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Bogue Banks, Ft. Macon State Park)***

Shorelines analyzed (9): 1971, 1974, 1976, 1979, 1984, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 4276
- Proposed IHA boundary @ DCM transect 4231 (IHA boundary movement 7,382 ft or 2,250 m west)

Based on geomorphology, and inlet processes, the CRC Science Panel defined the proposed shoreline-perpendicular IHA boundary at Fort Macon on Bogue Banks to stop at transect 4231. The proposed IHA boundary primarily follows historical maximum beach width and, to a lesser extent, topography (i.e., dune ridge). Man-made landmarks (e.g., existing streets and parcel lines) were taken into consideration by DCM staff to refine the proposed IHA boundary. Refer to Figure 3.19 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

### ***RIGHT SIDE OF INLET (Shackleford Banks, Cape Lookout National Seashore)***

Shorelines analyzed (11): 1949, 1956, 1960, 1971, 1973, 1974, 1987, 1992, 1997, 1998, 2003, 2004

- Original IHA boundary @ DCM transect 3505
- Proposed IHA boundary @ DCM transect 3440 (IHA boundary movement 5,741 ft or 1,750 m east)

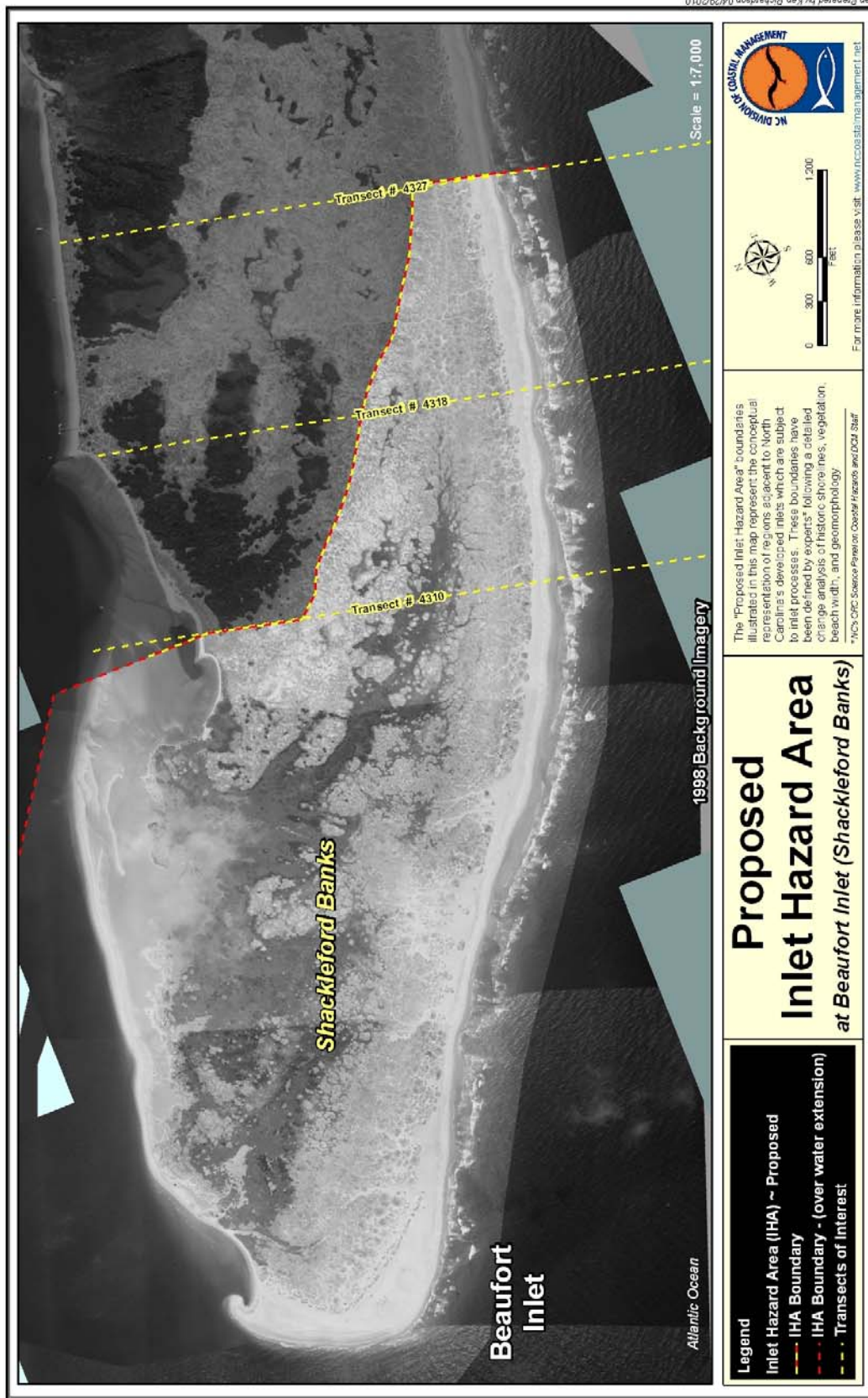
Based on maximum beach width, geomorphology, and inlet processes, the CRC Science Panel defined the proposed shoreline-perpendicular IHA boundary at Shackleford Banks to stop at transect 4327. Between transect 4327 and 4310, the proposed IHA boundary follows the maximum beach width and merges with the existing IHA boundary (Priddy and Carraway, 1978) due to engineering of this inlet (i.e., dredging of shipping channel by USACE for State Port in Morehead City). Refer to Figure 3.20 for proposed IHA boundary. Additional data figures for this inlet are included in the appendix.

**Figure 3.19.** Proposed IHA boundary for the western side of Beaufort Inlet (Ft. Macon State Park).



Map Prepared by Ken Richardson 04/29/2010

**Figure 3.20.** Proposed IHA boundary for the eastern side of Beaufort Inlet (Shackleford Banks, Cape Lookout National Seashore).



### 3.15 Barden Inlet

#### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- Relatively small inlet that opened in 1933 and migrates to the east
- Inlet throat has alternatively constricted and expanded, the general trend has been towards expansion with the minimum width increasing from 280 meters in 1945 to 710 m or 2,329 ft in 1993 (average width of inlet has been 575 m or 1,886 ft since 1945)
- Inlet unique due to the large 300 by 500 m (984 by 1,640 ft) sand shoal extending from Shackleford Banks into the inlet throat

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Shackleford Banks, Cape Lookout National Seashore)***

Shorelines analyzed : none\*

- Original IHA boundary @ DCM transect 4560
- Proposed IHA boundary @ DCM transect 4560

\*Because of the undeveloped nature of this inlet, DCM recommends no change to the boundary of Priddy and Carraway (1978) in conjunction with applicable IHA boundary amendments in 1981 until further analysis can be completed (Figure 3.21).

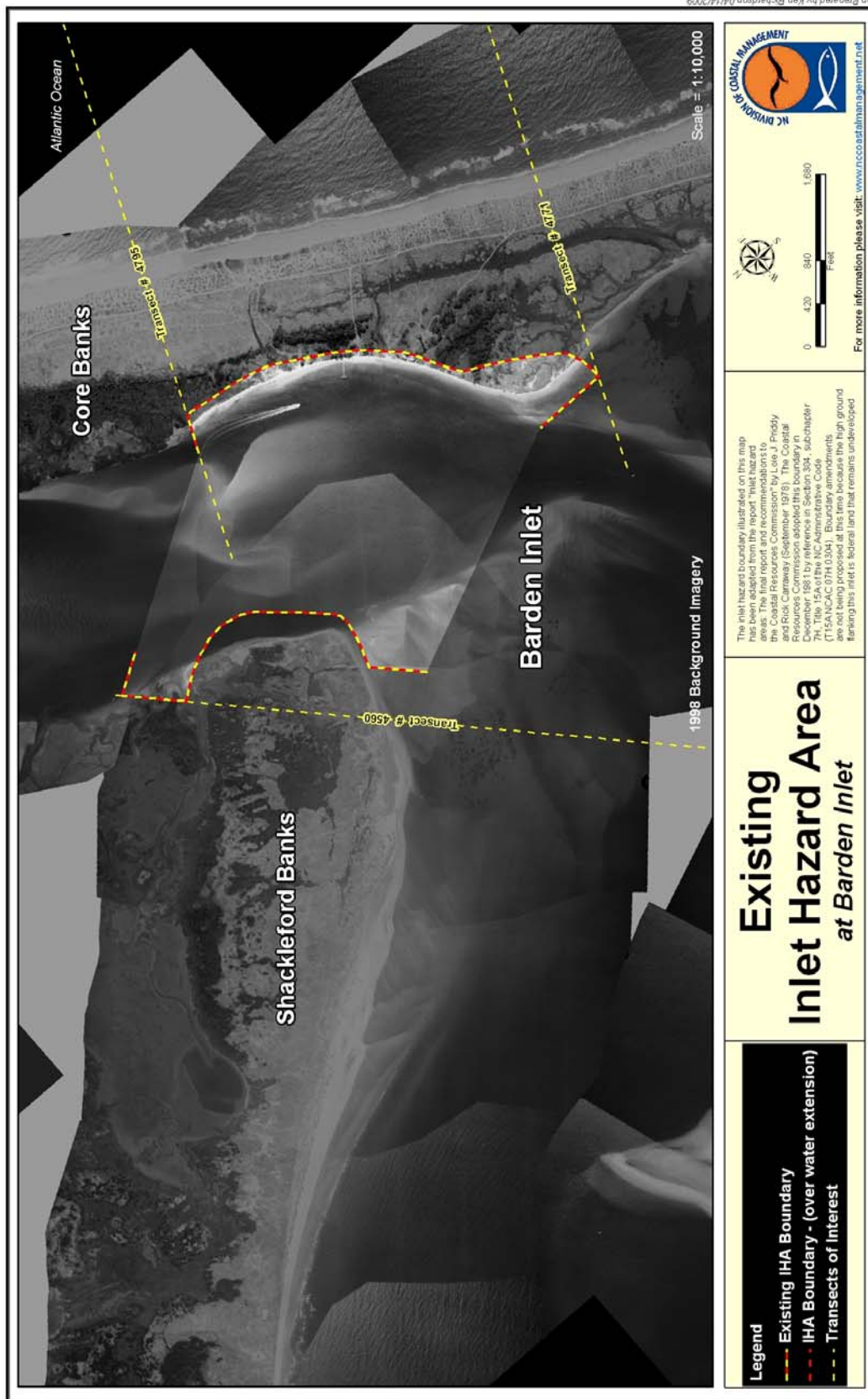
##### ***RIGHT SIDE OF INLET (Core Banks, Cape Lookout National Seashore)***

Shorelines analyzed: none\*

- Original IHA boundary @ DCM transect 4771 and 4795 (two transects listed because of the configuration of transects along this section of coastline relative to Cape Lookout)
- Proposed IHA boundary @ DCM transect 4771 and 3795 (two transects listed because of the configuration of transects along this section of coastline relative to Cape Lookout)

\*Because of the undeveloped nature of this inlet, DCM recommends no change to the boundary of Priddy and Carraway (1978) in conjunction with applicable IHA boundary amendments in 1981 until further analysis can be completed (Figure 3.21).

**Figure 3.21.** Existing IHA boundary for Barden Inlet. No changes to this boundary are proposed at this time.



### 3.16 Drum Inlet Complex

#### **BACKGROUND** (*summarized from Cleary and Marden, 2001*)

- Since the turn of the 18<sup>th</sup>/19<sup>th</sup> century, Drum Inlet and its predecessors have had a history of opening and closing several times, and this area has been prone to inlet formation in the recent past
- A 61 m or 200 ft wide and 12 m or 39 ft deep channel was dredged in 1939 to connect Old Drum Inlet with the Core Sound Waterway but shoaled and became unnavigable by the early 1960s
- Old Drum Inlet migrated almost two kilometers between 1940 and its closure in 1971 at an average rate of 61 m or 200 ft per year
- The inlet was re-opened in 1971 several months after the old inlet closed; new inlet located approximately 3.5 km or 2.1 mi south of old inlet
- Characterized by a large flood-tidal delta extending across Core Sound and a small ebb-tidal delta fronting the inlet

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Core Banks, Cape Lookout National Seashore)***

Shorelines analyzed : none\*

- No existing IHA boundary
- No proposed IHA boundary

\* No inlet hazard area recommendations were made by Priddy and Carraway (1978) or in conjunction with subsequent 1981 amendments (Figure 3.21). Because of the undeveloped nature of these inlets, DCM recommends that no inlet hazard area be created for the three inlets of the Drum Inlet complex until further analysis can be completed. Note that photographic imagery in Figure 3.22 is ca. August/September 2004 and does not capture the third inlet opened during Hurricane Ophelia (September 2005).

##### ***RIGHT SIDE OF INLET (Core Banks / Portsmouth Island, Cape Lookout National Seashore)***

Shorelines analyzed : none\*

- No existing IHA boundary
- No proposed IHA boundary

\* No inlet hazard area recommendations were made by Priddy and Carraway (1978) or in conjunction with subsequent 1981 amendments (Figure 3.22). Because of the undeveloped nature of these inlets, DCM recommends that no inlet hazard area be

created for the three inlets of the Drum Inlet complex until further analysis can be completed. Note that photographic imagery in Figure 3.22 is ca. August/September 2004 and does not capture the third inlet opened during Hurricane Ophelia (September 2005).

**Figure 3.22.** No IHA boundaries currently exist for Drum Inlet, and none are being proposed at this time.

# Drum Inlets



Atlantic Ocean

2004 Background Imagery

Scale = 1:19,000

|  |                                                               |                                                                                                                                                                      |                                                                                                                                                                                                          |
|--|---------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | <p><b>No IHA boundary currently exists for this inlet</b></p> | <p>The creation of an inlet hazard area is not being proposed at this time because the high ground flanking this inlet is federal land that remains undeveloped.</p> |  <p>For more information please visit: <a href="http://www.nccostatmanagement.net">www.nccostatmanagement.net</a></p> |
|--|---------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

### 3.17 Ocracoke Inlet

#### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- The largest of the current inlets north of Cape Lookout along the Outer Banks
- Maps show the existence of Ocracoke Inlet as early as 1585 and Ocracoke is one of the more stable inlets, as well as the deepest, in North Carolina
- The location of the inlet is governed by old river channel and stability is presumably related to large tidal prism associated with Pamlico Sound and the Pamlico River
- In the late 1950s, aerial photographs and bathymetric surveys of Pamlico Sound determined the enormous flood-tide delta extended into the sound for more than 10 kilometers; the corresponding ebb-tide delta is small by comparison (as are all ebb-tidal deltas along the Outer Banks)
- Since the mid-1800s, Ocracoke Inlet has migrated over 2.9 km or 1.8 mi to the southwest
- A USACE study from the 1950s indicated that the inlet was 610 m or 2,001 ft narrower in 1948 than it was in the early 1800s
- Since 1984, maintenance dredging has not been required by the USACE to maintain the authorized channel depth of 6 m or 20 ft
- The USACE monitors the depth of the channel to ensure continued operation of the Ocracoke-Cedar Island ferry run by the North Carolina Department of Transportation

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Core banks / Portsmouth Island, Cape Lookout National Seashore)***

Shorelines analyzed : none\*

- No existing IHA boundary
- No proposed IHA boundary

\* No inlet hazard area recommendations were made by Priddy and Carraway (1978) or in conjunction with subsequent 1981 amendments (Figure 3.23). Because of the undeveloped nature of this side of the inlet, DCM recommends that no inlet hazard area be created for the southwestern side of Ocracoke Inlet until further analysis can be completed.

***RIGHT SIDE OF INLET (Ocracoke Island, Cape Hatteras National Seashore)***

- Original IHA boundary @ DCM transect 6219
- Proposed IHA boundary @ DCM transect 6219

\* Because of the undeveloped nature of this inlet, DCM recommends no change to the boundary of Priddy and Carraway (1978) in conjunction with applicable IHA boundary amendments in 1981 until further analysis can be completed (Figure 3.23).

**Figure 3.23.** Existing IHA boundary for northeastern side of Ocracoke Inlet (Ocracoke Island, Cape Hatteras National Seashore), and no changes to this boundary are proposed at this time. No IHA boundaries currently exist for the southwestern side of Ocracoke Inlet (Core Banks / Portsmouth Island, Cape Lookout National Seashore), and none are being proposed at this time.



### 3.18 Hatteras Inlet

#### **BACKGROUND** (*summarized from Cleary and Marden, 2001*)

- Inlet opened during a major hurricane in September 1846, the same time as Oregon Inlet to the north (the southwestern reach of Hatteras Island has historically been the site of recurring storm breaches, the most recent of which occurred during Hurricane Isabel in 2003 – an inlet that subsequently was closed by the NC Department of Transportation to restore access to NC Highway 12)
- Old Hatteras Inlet was located 16 kilometers to the west of the current inlet as early as 1585 and remained open until the late 1700s
- The inlet system has migrated to the southwest at varying rates, although the Hatteras Island shoulder (eastern side) has not migrated as much as the Ocracoke Island shoulder
- Following the Ash Wednesday Storm of March 1962, the inlet was approximately 2.6 km or 1.6 mi wide and has decreased to its current approximate width of 500 m or 1,530 ft

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Core banks / Portsmouth Island, Cape Lookout National Seashore)***

Shorelines analyzed : none\*

- Original IHA boundary @ DCM transect 6584
- Proposed IHA boundary @ DCM transect 6584

\* Because of the undeveloped nature of this inlet, DCM recommends no change to the boundary of Priddy and Carraway (1978) in conjunction with applicable IHA boundary amendments in 1981 until further analysis can be completed (Figure 3.24).

##### ***RIGHT SIDE OF INLET (Hatteras Island, Cape Hatteras National Seashore)***

Shorelines analyzed : none\*

- Original IHA boundary @ DCM transect 6697
- Proposed IHA boundary @ DCM transect 6697

\* Because of the undeveloped nature of this inlet, DCM recommends no change to the boundary of Priddy and Carraway (1978) in conjunction with applicable IHA boundary amendments in 1981 until further analysis can be completed (Figure 3.24).

**Figure 3.24.** Existing IHA boundary for Hatteras Inlet. No changes to this boundary are proposed at this time.



Map Prepared by Ken Richardson 04/14/2009

### 3.19 Oregon Inlet

#### **BACKGROUND** *(summarized from Cleary and Marden, 2001)*

- Maps dating back to 1585 show inlets in the vicinity of Oregon Inlet until 1808, but the present inlet did not open until September 1846
- Since its opening, the inlet has migrated 3.7 km or 2.3 mi to the south at an average rate of 15 m or 49 ft per year until the construction of a terminal groin on the southern shoulder of the inlet (Pea Island), which was constructed in 1990 to protect the Herbert C. Bonner Bridge that crosses the inlet
- The inlet's maximum width was 2 km or 1.2 mi following the Ash Wednesday Storm of 1962 and its minimum width of 450 m or 1,476 ft occurred in 1862; the inlet was 850 m or 2,789 ft wide in April 1999
- As the inlet has decreased in width, the channel has deepened to maintain cross-sectional area and flow; the current cross-sectional area and tidal prism have changed little over the past 50 years
- Oregon Inlet is the only outlet for the enormous volume of sound water along the northern stretch of the Outer Banks
- The navigability of the inlet is maintained by the USACE

#### **BOUNDARY SUMMARY**

##### ***LEFT SIDE OF INLET (Hatteras Island, Pea Island National Wildlife Refuge)***

Shorelines analyzed : none\*

- No existing IHA boundary
- No proposed IHA boundary

\* No inlet hazard area recommendations were made by Priddy and Carraway (1978) or in conjunction with subsequent 1981 amendments (Figure 3.25). Because of the undeveloped nature of this inlet, DCM recommends that no inlet hazard area be created for the southern side of Oregon Inlet until further analysis can be completed.

##### ***RIGHT SIDE OF INLET (Bodie Island, Cape Hatteras National Seashore)***

Shorelines analyzed : none\*

- No existing IHA boundary
- No proposed IHA boundary

\* No inlet hazard area recommendations were made by Priddy and Carraway (1978) or in conjunction with subsequent 1981 amendments (Figure 3.25). Because of the undeveloped nature of this inlet, DCM recommends that no inlet hazard area be created for the northern side of Oregon Inlet until further analysis can be completed.

**Figure 3.25.** No IHA boundaries currently exist for the Oregon Inlet. None are being proposed at this time.



## 4.0 RECOMMENDATIONS

**DCM recommends the adoption of this report by reference in rule 15A NCAC 07H.0304.**

The effect of this action will amend the IHA boundaries for the State's 12 developed inlets (Tubbs, Shallotte, Lockwood Folly, Cape Fear River, Carolina Beach, Masonboro, Mason, Rich, New Topsail, New River, Bogue, and Beaufort). Five of the original IHA boundaries developed by Priddy and Carraway (1978) will remain unchanged. DCM and the CRC Science Panel have determined that the original boundaries developed by Priddy and Carraway (1978) for Brown's, Bear, Barden, Ocracoke (northeastern boundary on Ocracoke Island), and Hatteras inlets (primarily due to the lack of existing and potential development at these locations) are sufficient until further analysis can be completed. Similarly, it is unnecessary to develop IHA boundaries for Drum Inlet, the southwestern side of Ocracoke Inlet (Core Banks), and Oregon Inlet at this time. Adoption of this report by the CRC will also remove existing IHA boundaries from three inlets (Mad and Corncake) because they have closed. DCM and the CRC Science Panel have determined that the threat of these two inlets reopening is no higher than the creation of new inlets through the breaching process associated with storms that historically have occurred along the State's barrier islands. (Although Old Topsail has also closed, its location and its original IHA boundaries will be included in the proposed IHA boundary for New Topsail Inlet presented herein). Adoption of this report will also remove the existing IHA boundary associated with Little River Inlet because it has migrated into South Carolina and is being stabilized by engineered structures maintained by the USACE and no longer poses a direct coastal hazard to Bird Island (which is owned by DCM and will continue to remain an undeveloped Coastal Reserve site).

It should be noted that while this report is a major effort in re-visiting the original IHA investigation study by Priddy and Carraway (1978), it does not represent the final word in defining hazardous areas relative to development flanking tidal inlets. The Division recommends that all of the State's tidal inlets continue to be analyzed and monitored as data and resources become available or, at least, within ten years of the incorporation of this report into CRC rules. It may be appropriate to review inlets based on a pre-determined set of priorities to maximize efforts rather than attempting a wholesale review of the entire State. Regardless of the approach, continuing studies of the interaction between background natural coastal processes and human activities must be planned and executed to develop better understandings of inlet and island process-response relationships. The non-linear influence of storms and sea level rise must also be considered. Therefore, continued data collection (e.g., shoreline locations, ebb and flood tide delta volumes, ebb and flood channel locations, bathymetry, dredge volumes and frequencies in and near inlets, as well as any other anthropogenic influences) and timely review and synthesis by coastal experts is appropriate and necessary. DCM also recommends that the review and amendment of development policy adjacent to inlets should occur concurrently with the scientific and engineering assessment and quantification of inlet processes and related hazards.

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Overton, M.F. and Fisher, J.S., 2004, Methodology for the analysis of shoreline change for the purpose of delineating the Inlet Hazard Area. Prepared for the NC Division of Coastal Management, December 13, 3 pp.

Priddy, L.J. and Carraway, R., 1978, Inlet hazard areas: The final report and recommendations to the Coastal Resources Commission. Prepared by the NC Division of Marine Fisheries Technical Services Section, NC Department of natural Resources and Community Development., September, 60 pp.

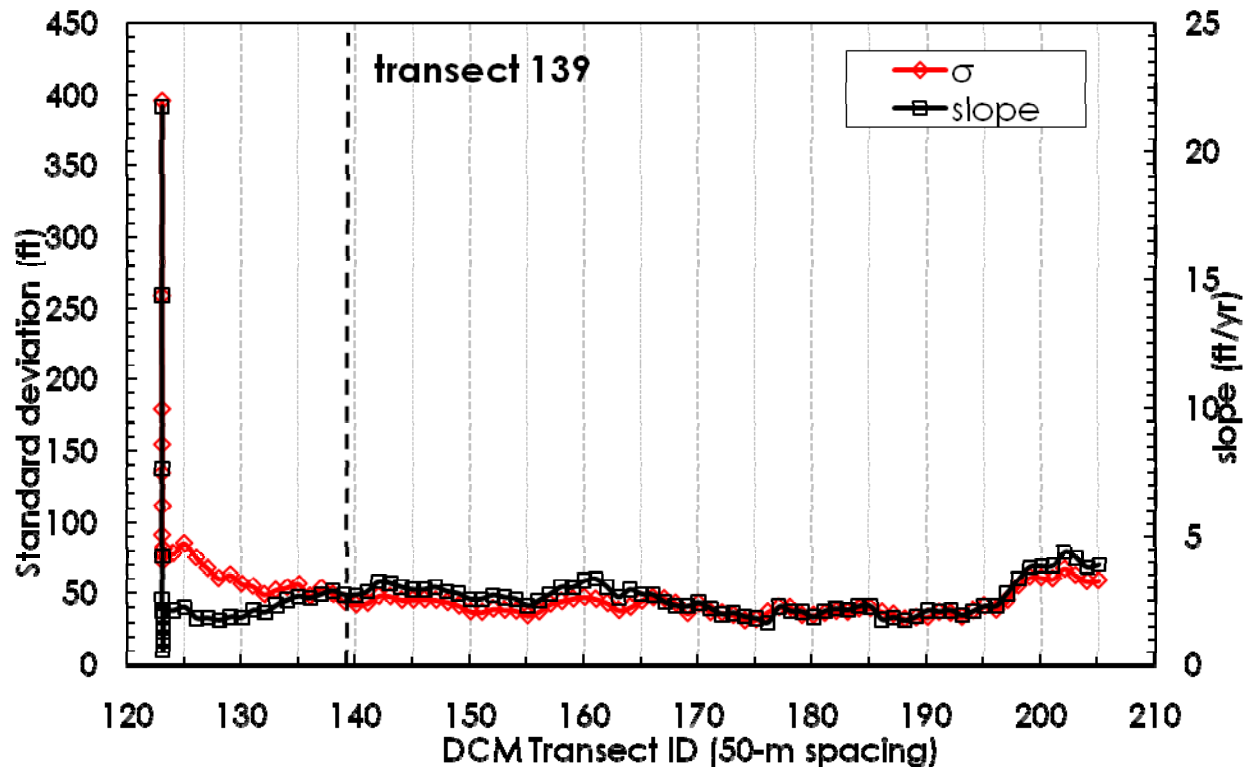
Warren, J.D., 2008, Inlet hazard area policy recommendations. NC Division of Coastal Management memo CRC 08-48, November 6, 2 pp.

## **APPENDIX**

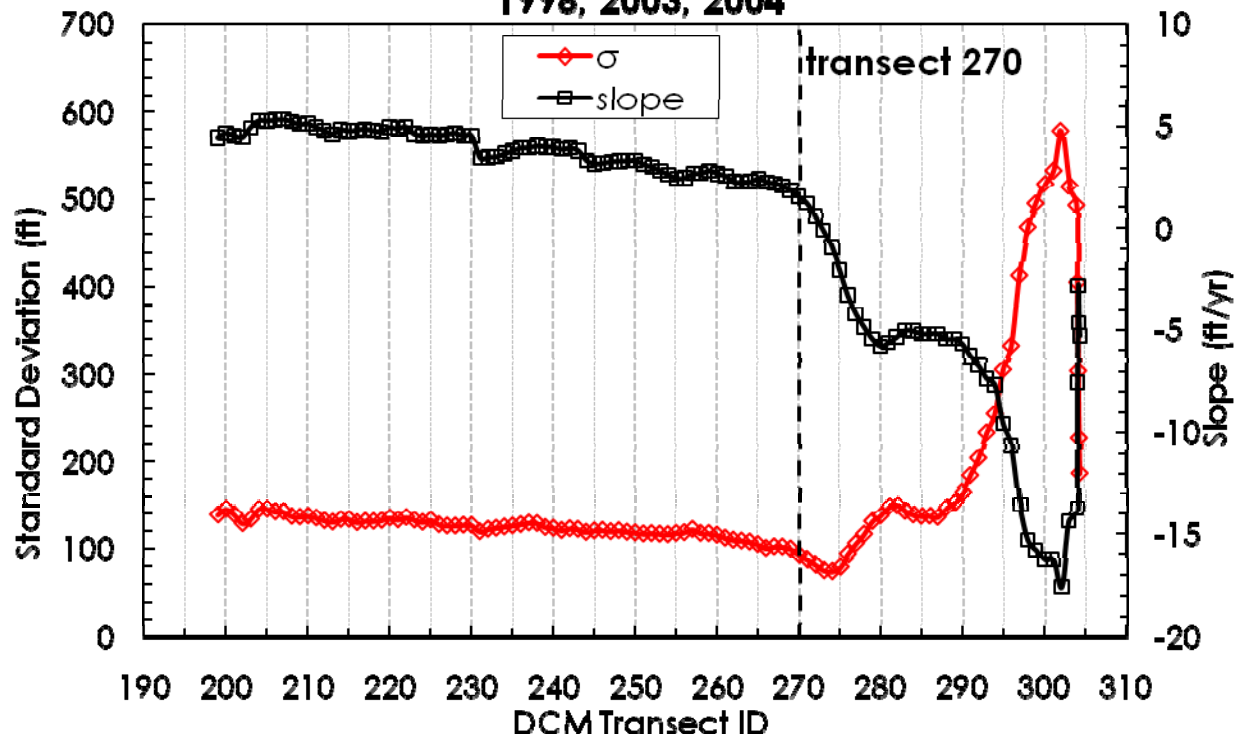
For convenience, the data in this appendix is arranged by inlet, geographically from south to north for the twelve developed inlets defined and analyzed in this study (Tubbs, Shallotte, Lockwood Folly, Cape Fear River, Carolina Beach, Masonboro, Mason, Rich, New Topsail, New River, Bogue, and Beaufort).

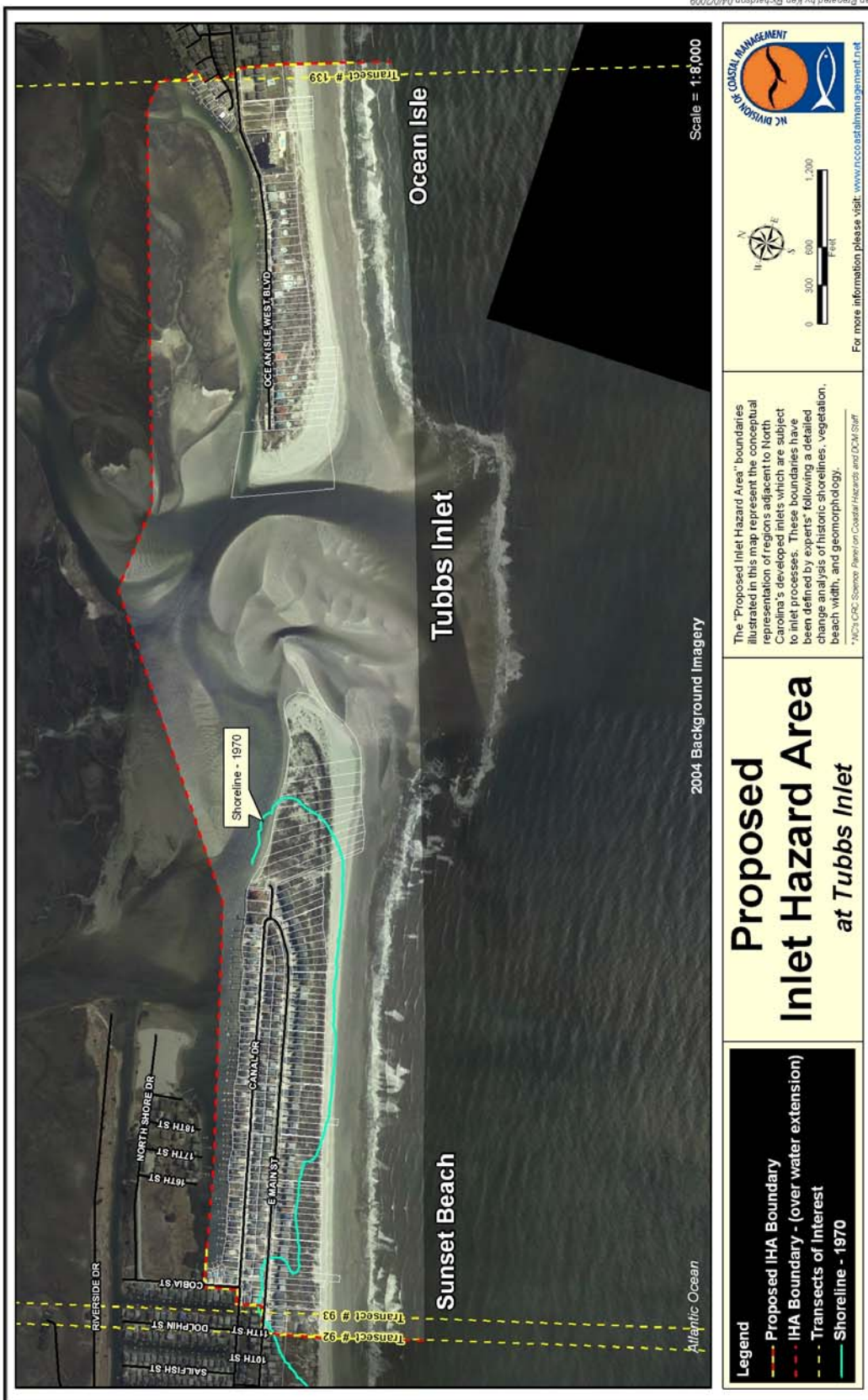
**TUBBS INLET**

**Tubbs Right: 1938, 1944, 1954, 1961, 1970**

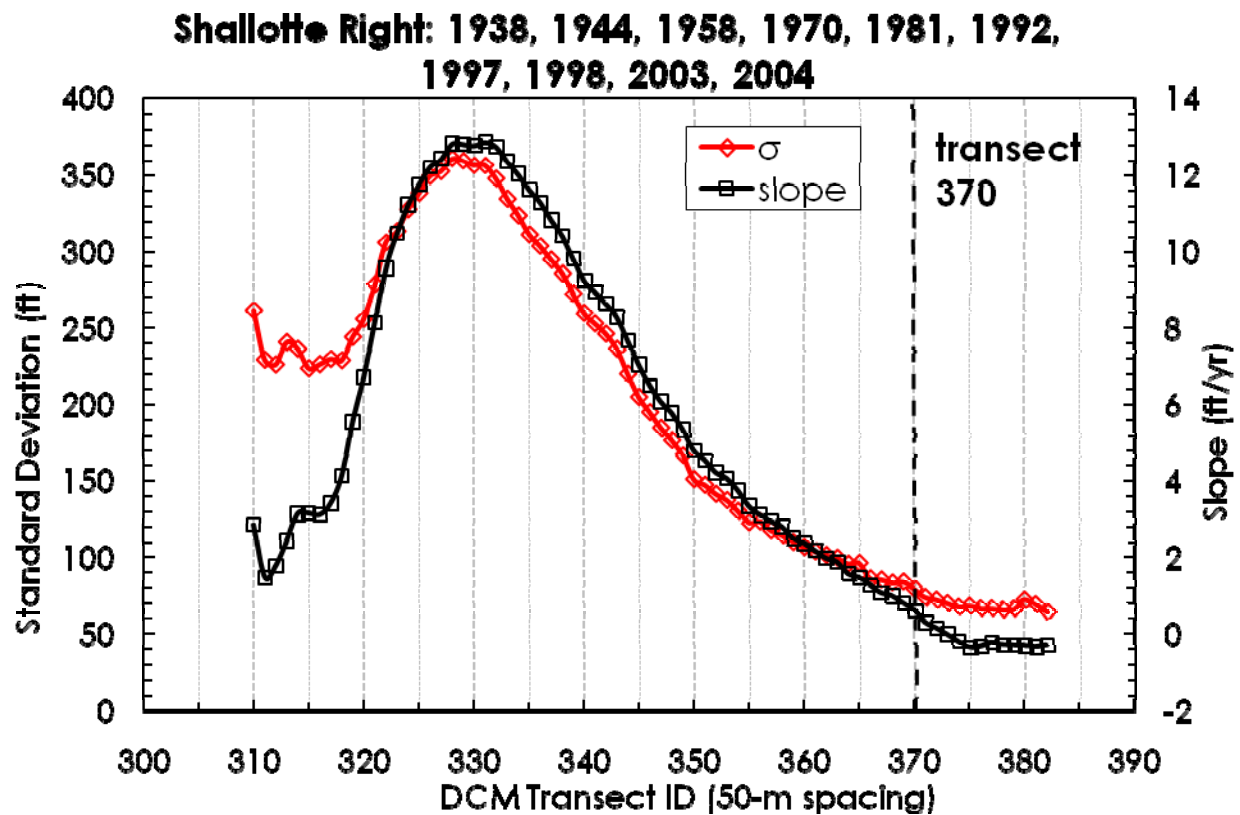
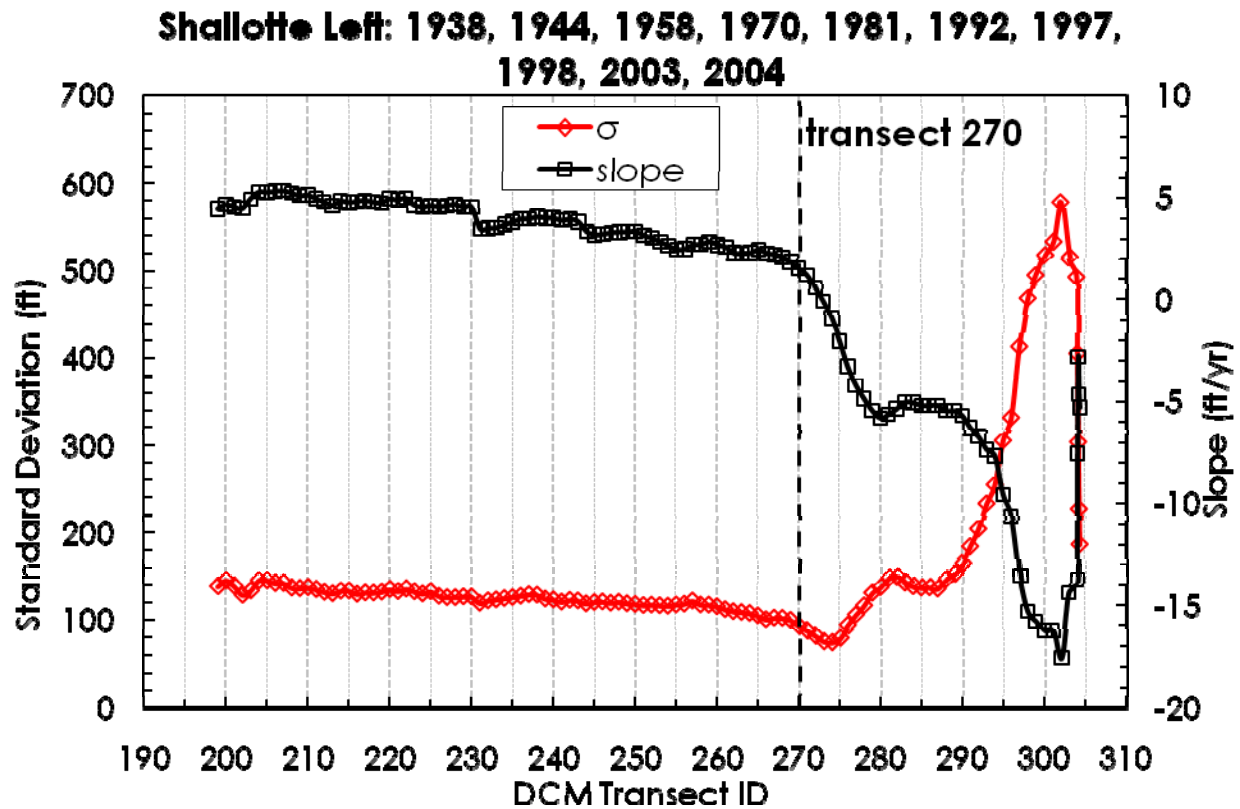


**Shallotte Left: 1938, 1944, 1958, 1970, 1981, 1992, 1997, 1998, 2003, 2004**



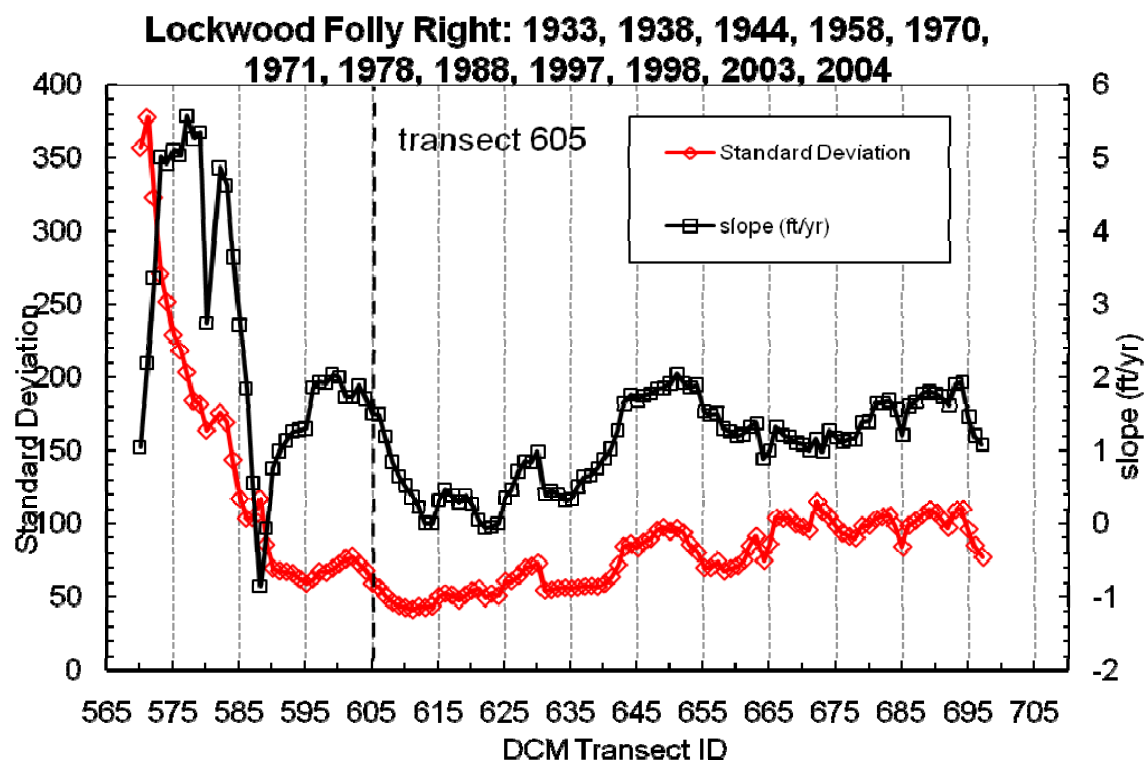
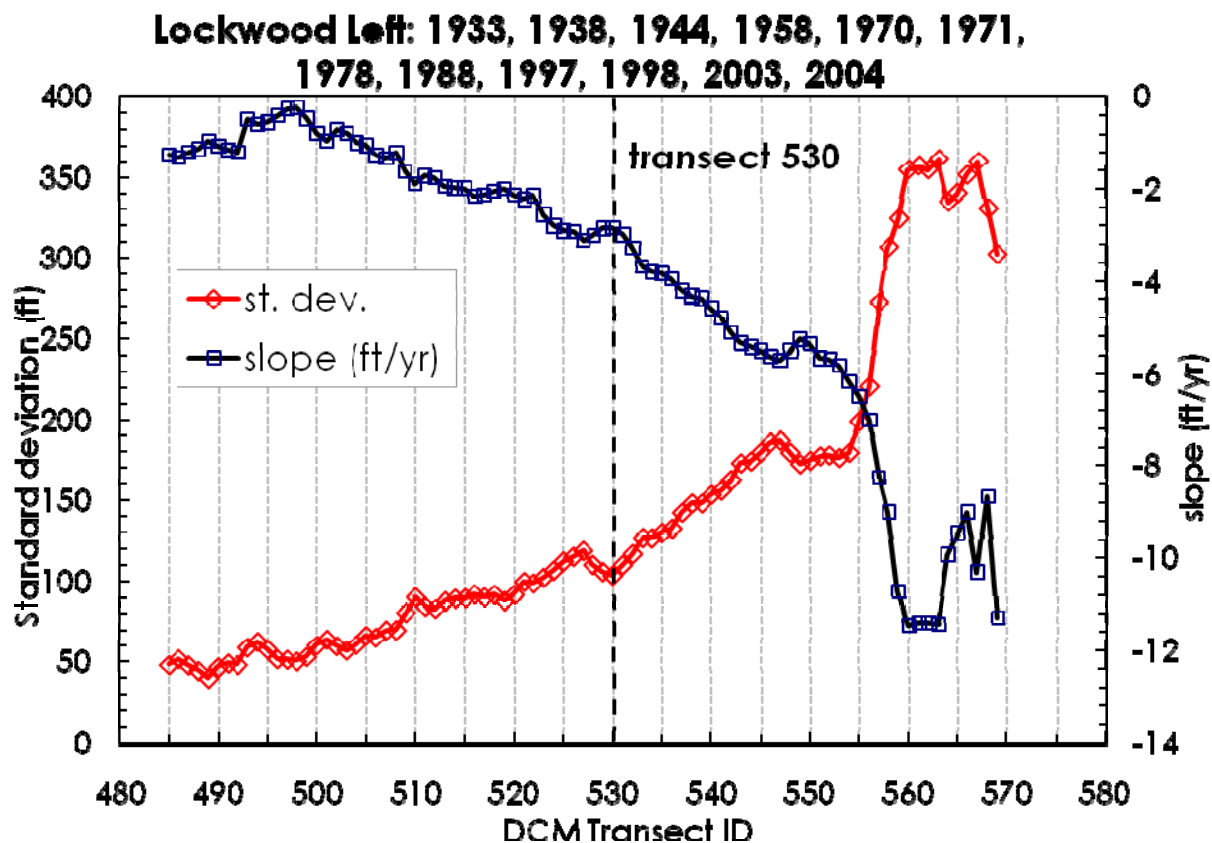


## SHALLOTTE INLET





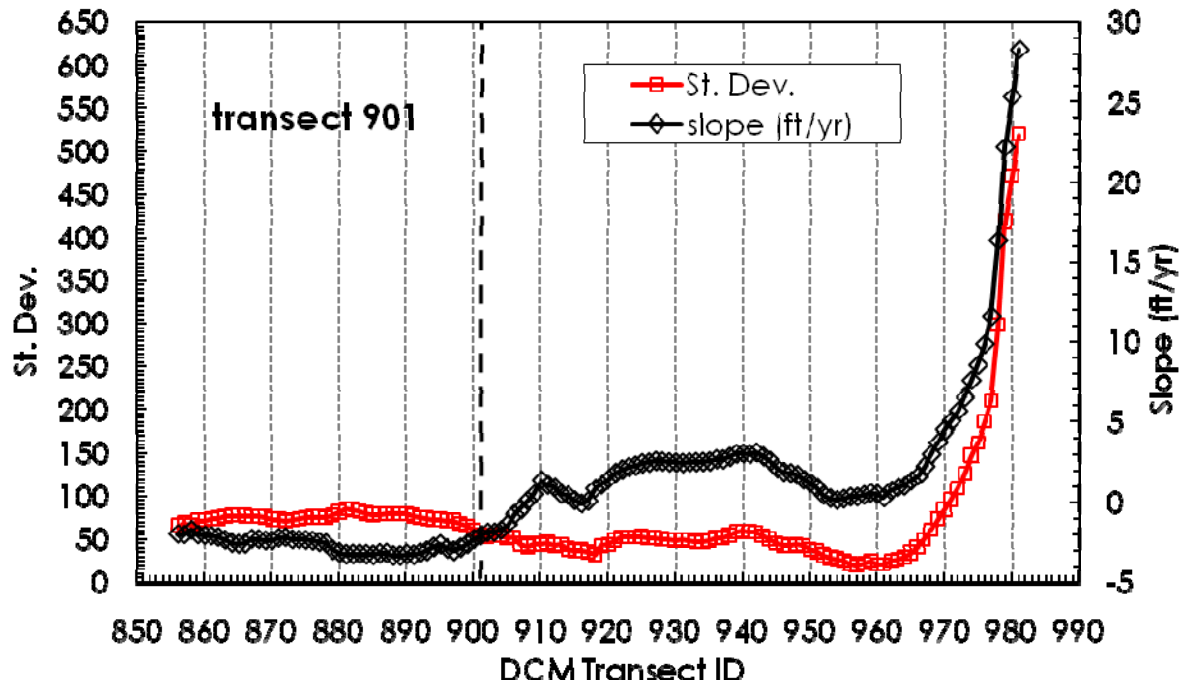
## **LOCKWOOD FOLLY INLET**



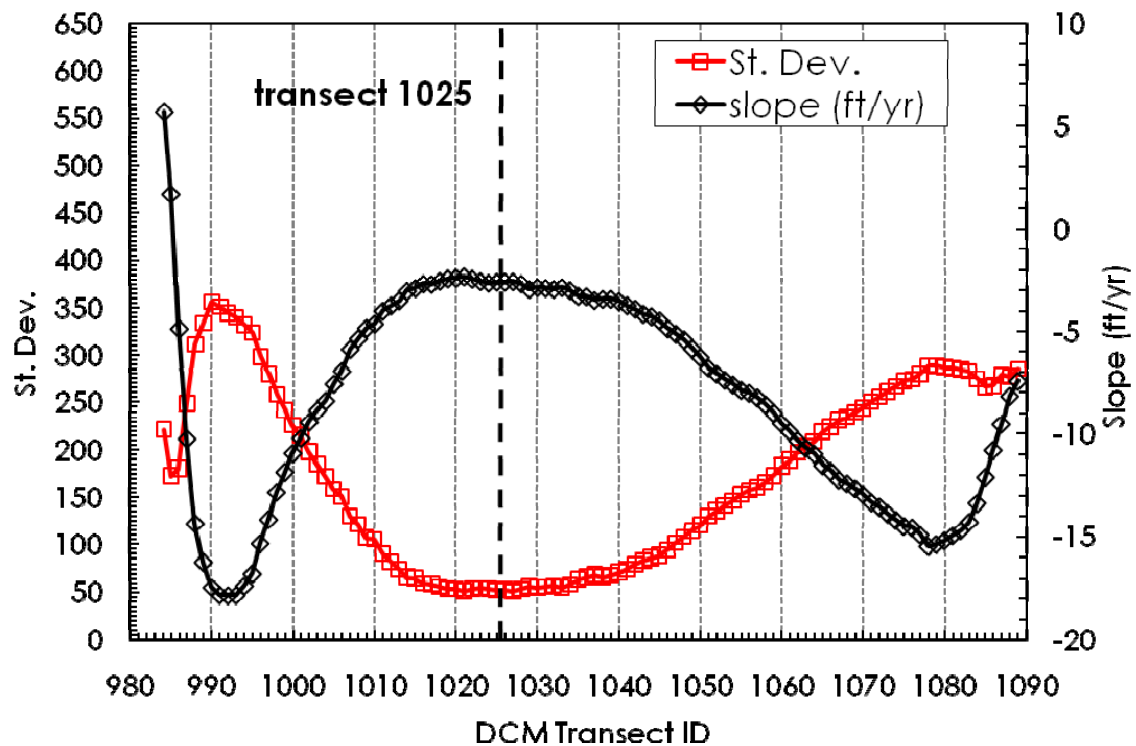


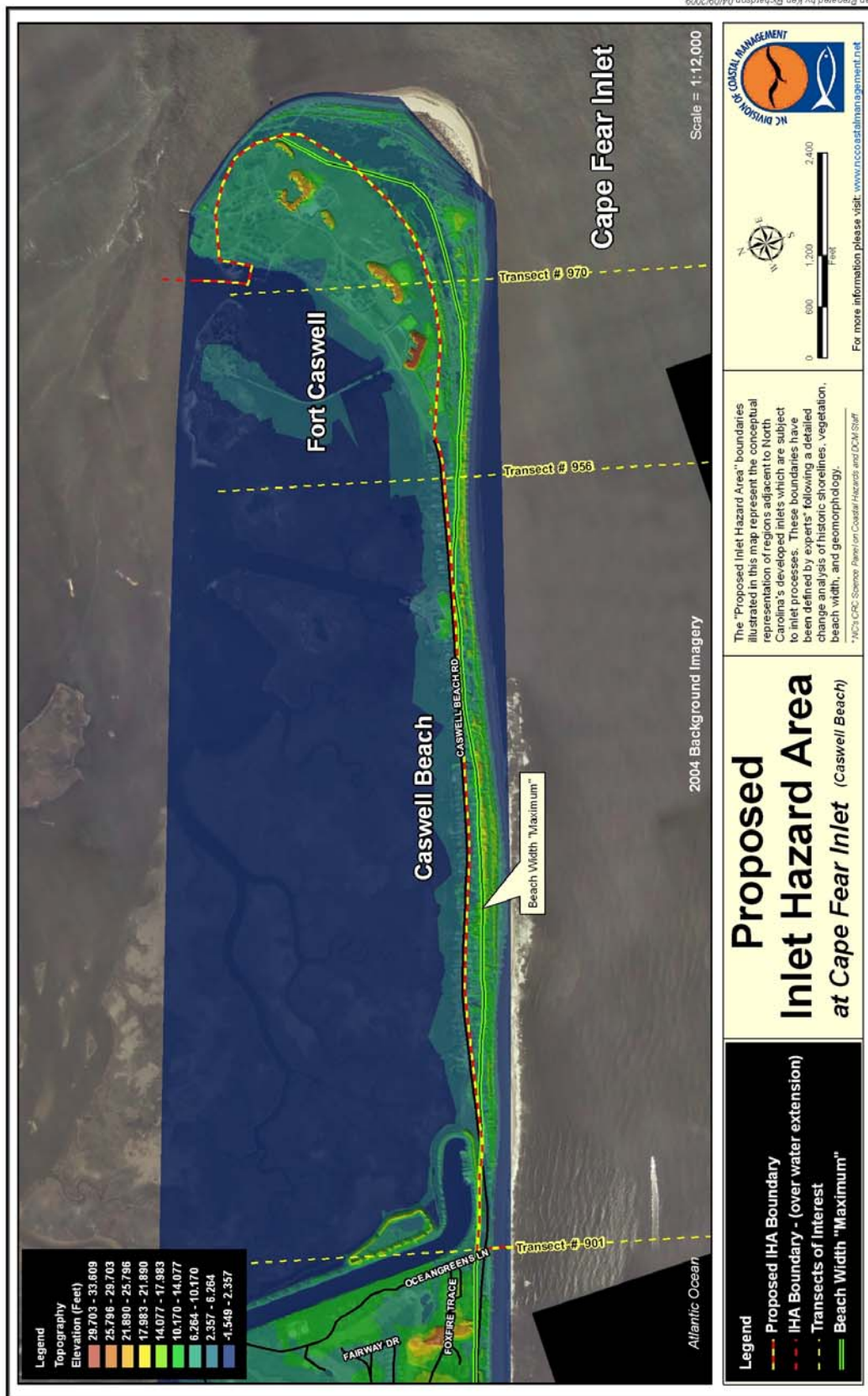
## **CAPE FEAR RIVER INLET**

**Cape Fear Left: 1944, 1970, 1971, 1973, 1974, 1977,  
1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004**



**Cape Fear Right: 1942, 1970, 1971, 1973, 1974, 1977,  
1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004**



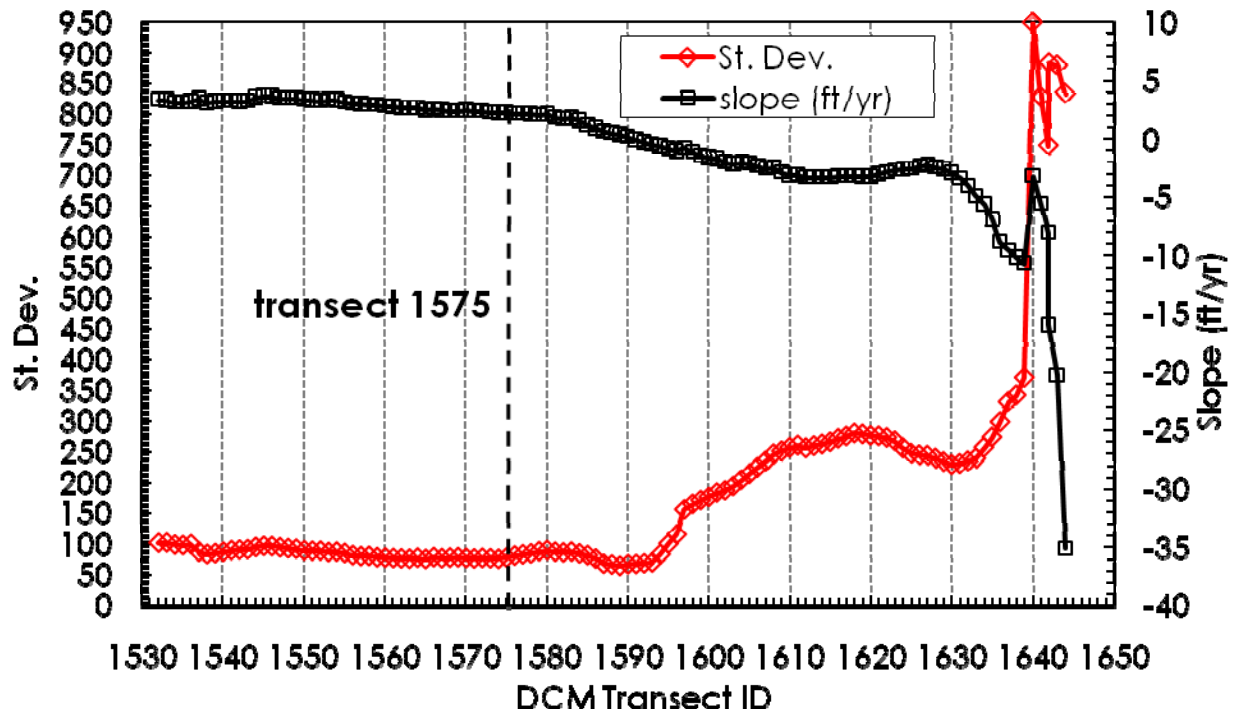


Map Prepared by Ken Richardson 04/09/2009

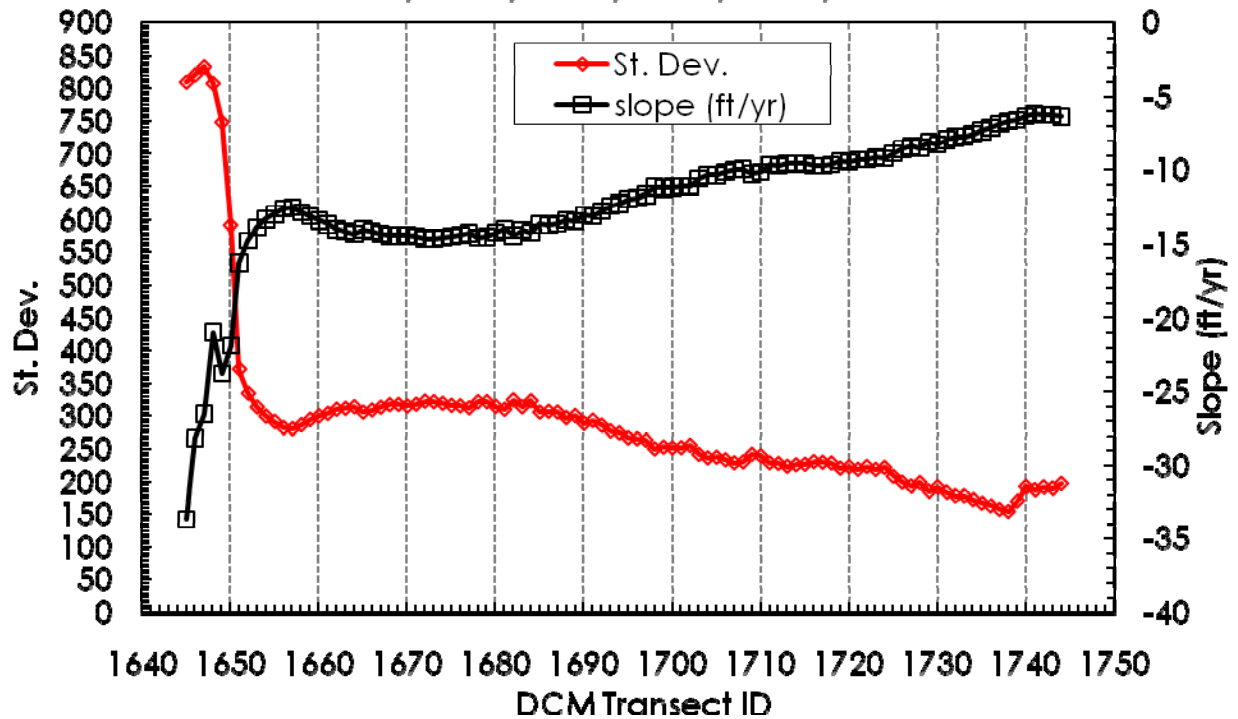


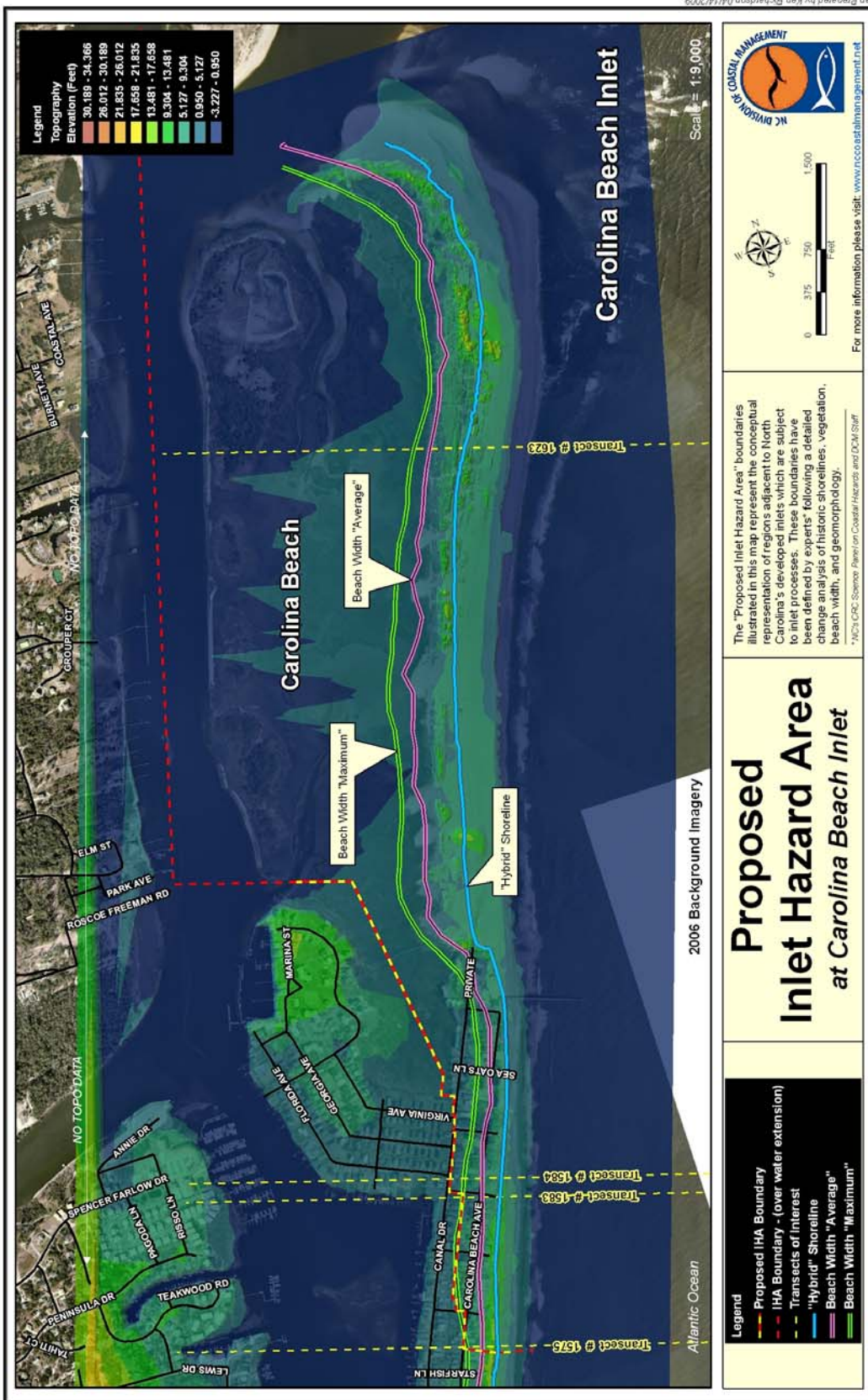
## **CAROLINA BEACH INLET and MASONBORO INLET**

**Carolina Beach left: 1933, 1971, 1973, 1974, 1977,  
1984, 1992, 1997, 1998, 2003, 2004**



**Carolina Beach Right: 1933, 1971, 1973, 1974, 1977,  
1984, 1992, 1997, 1998, 2003, 2004**

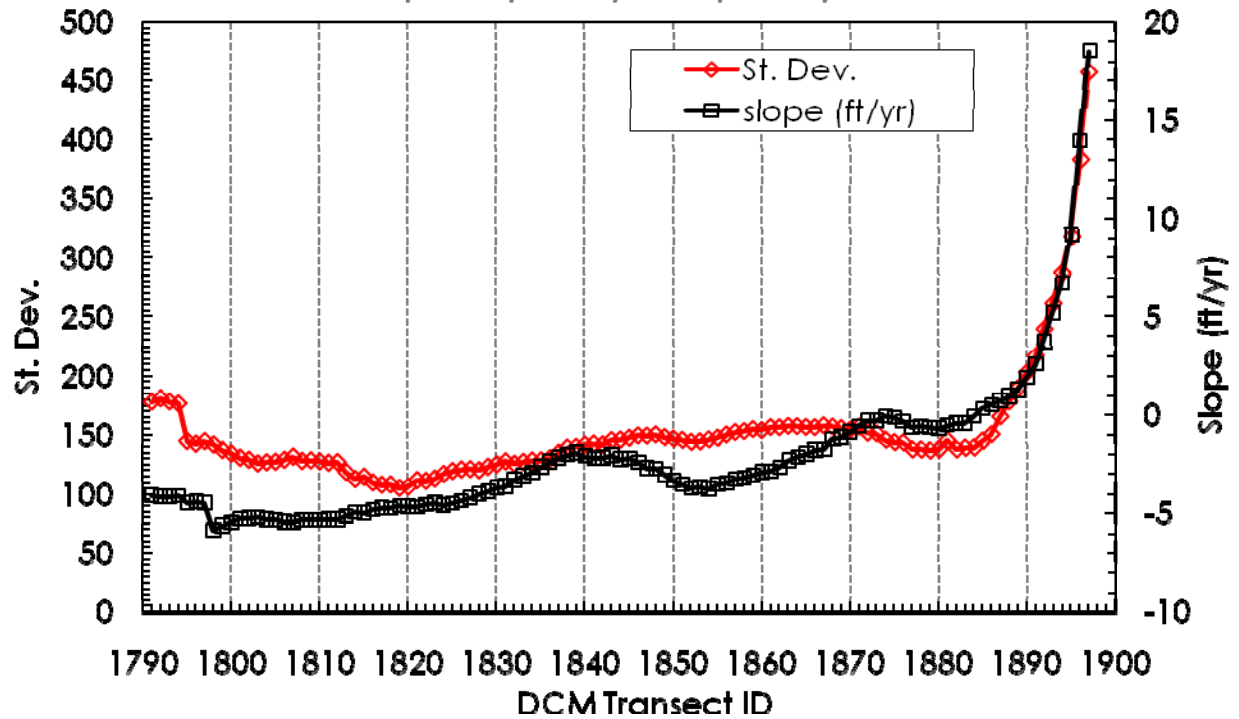




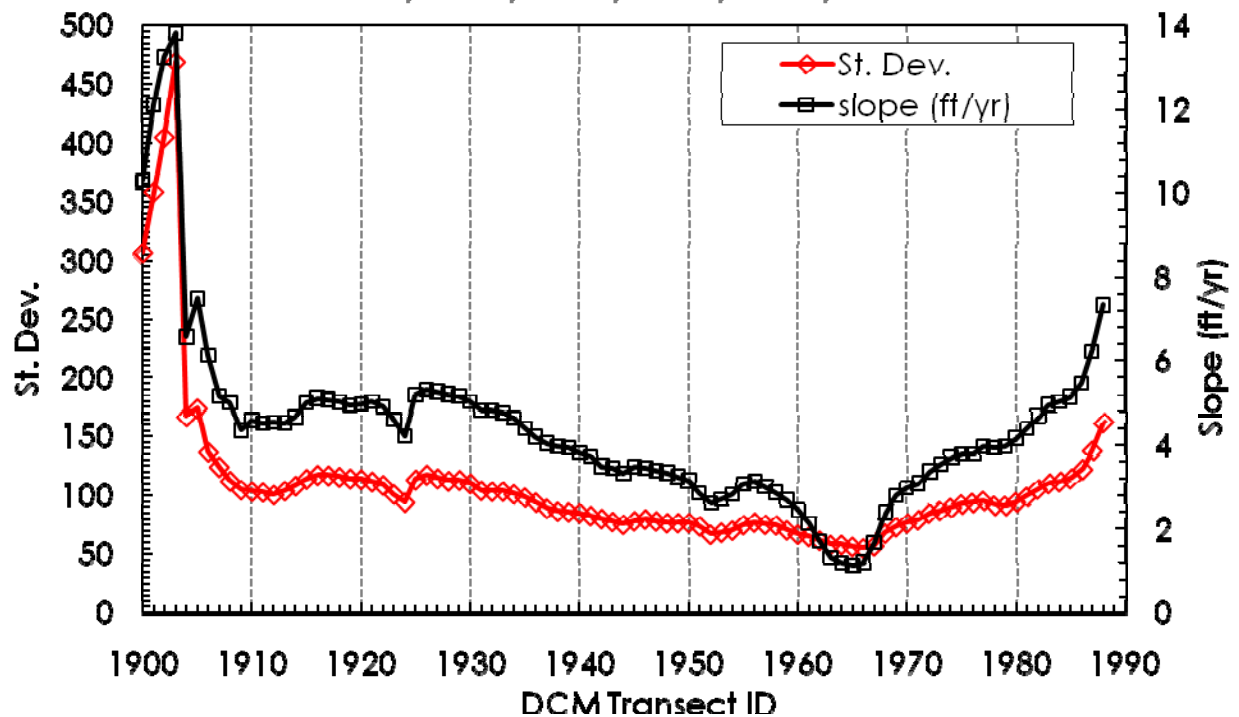
Map Prepared by Ken Richardson 04/14/2009

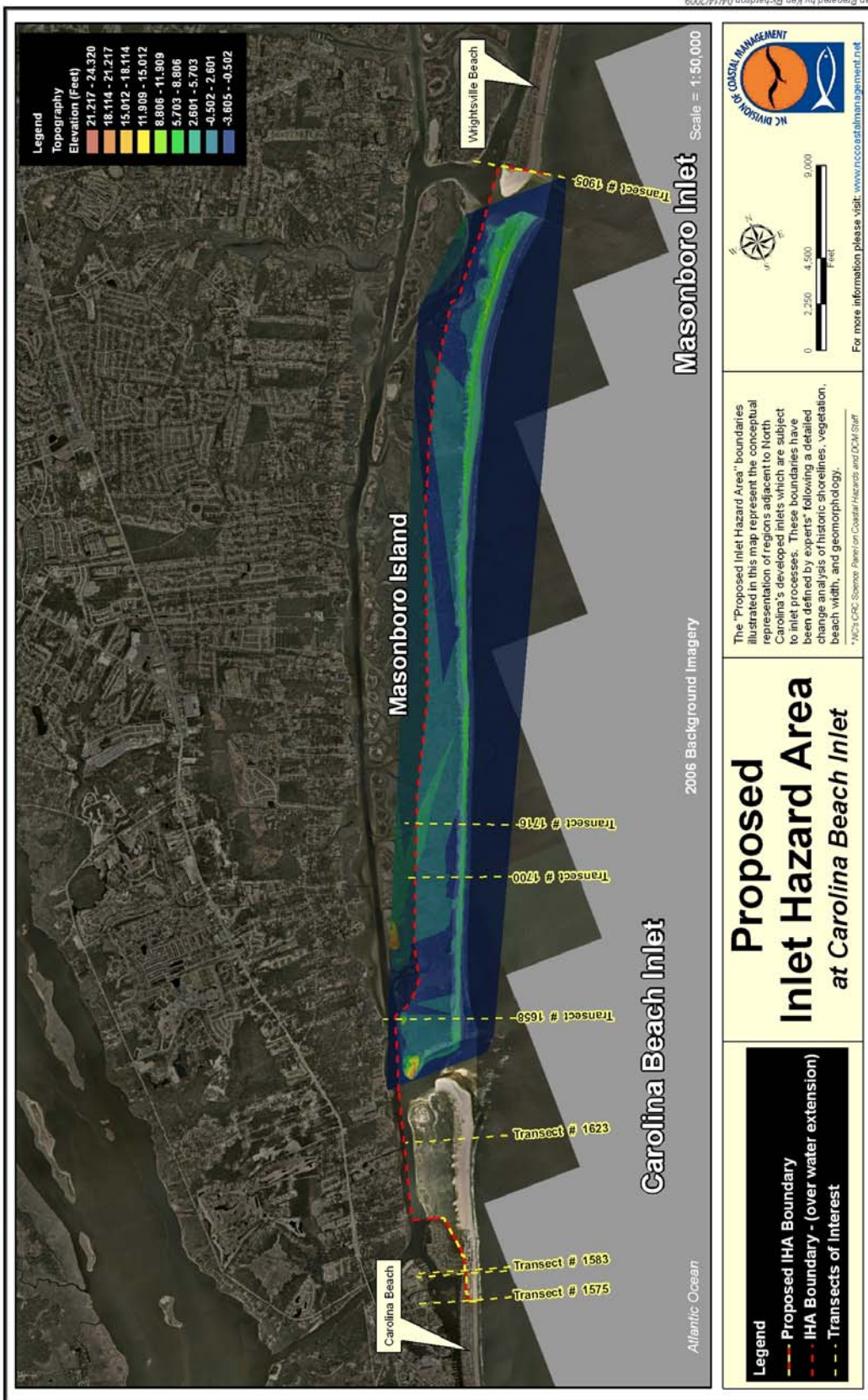
North Carolina DEIR - Division of Coastal Management - 2009

**Masonboro Left: 1933, 1973, 1974, 1977, 1984, 1992,  
1995, 1997, 1998, 2000, 2003, 2004**



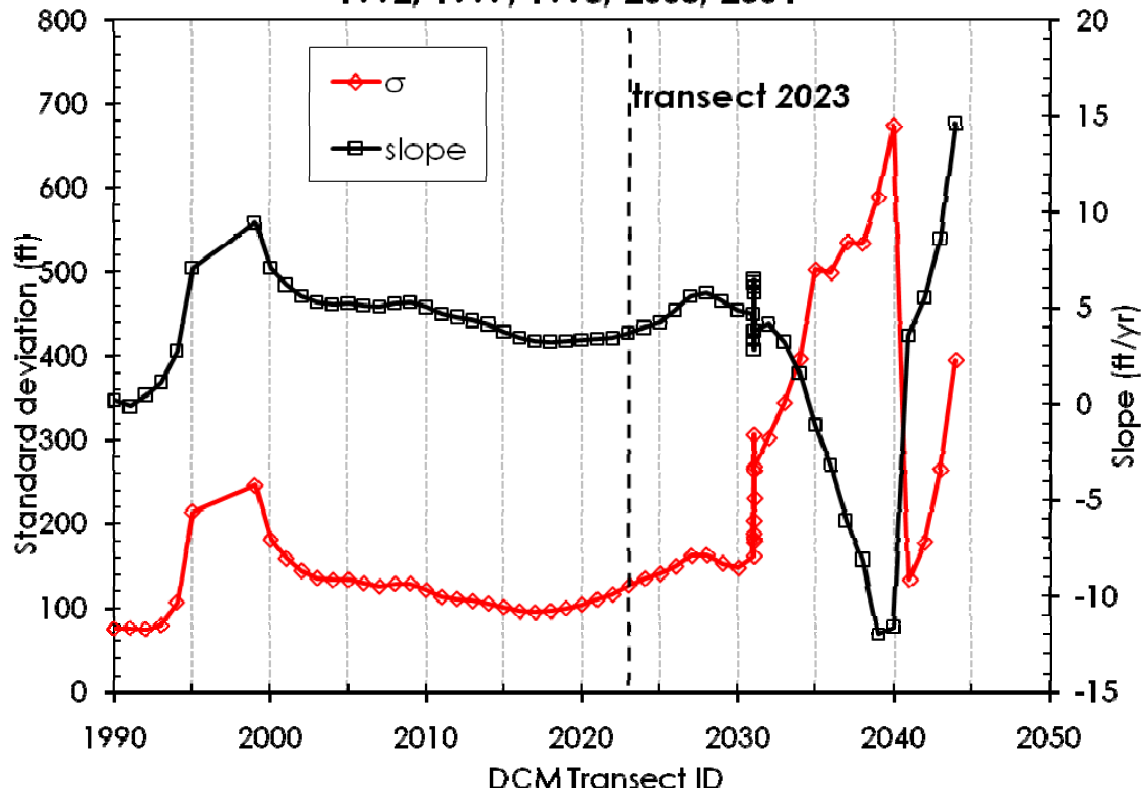
**Masonboro Right: 1933, 1973, 1974, 1977, 1984, 1992,  
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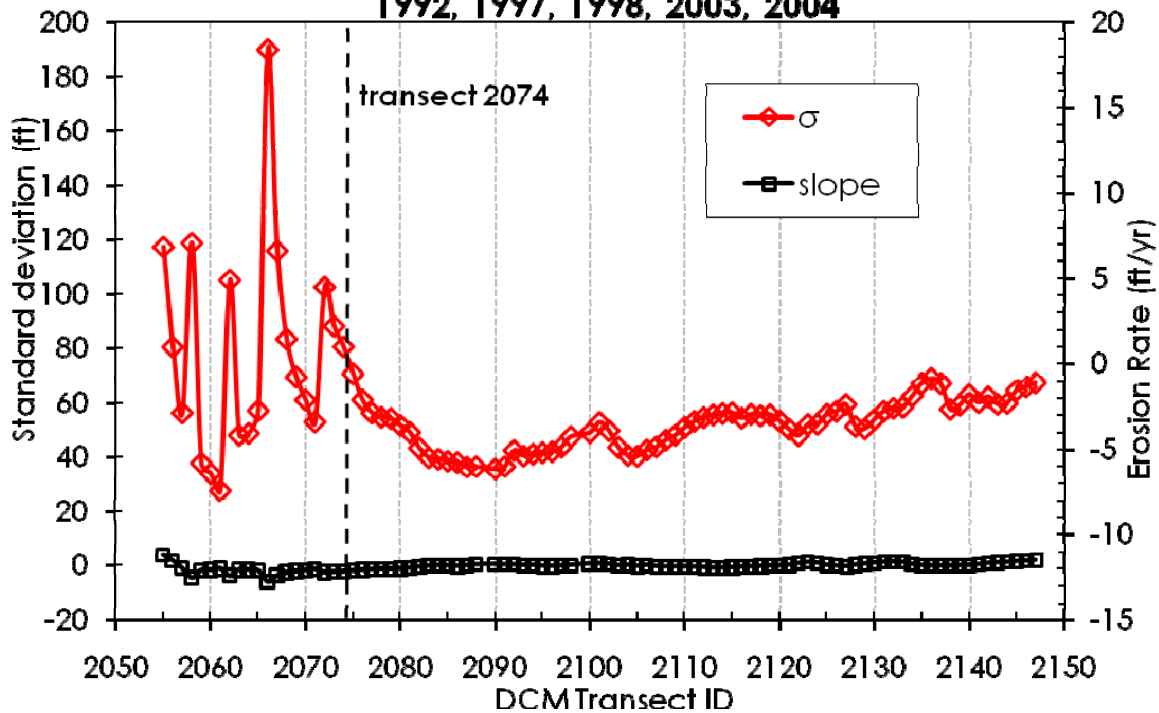


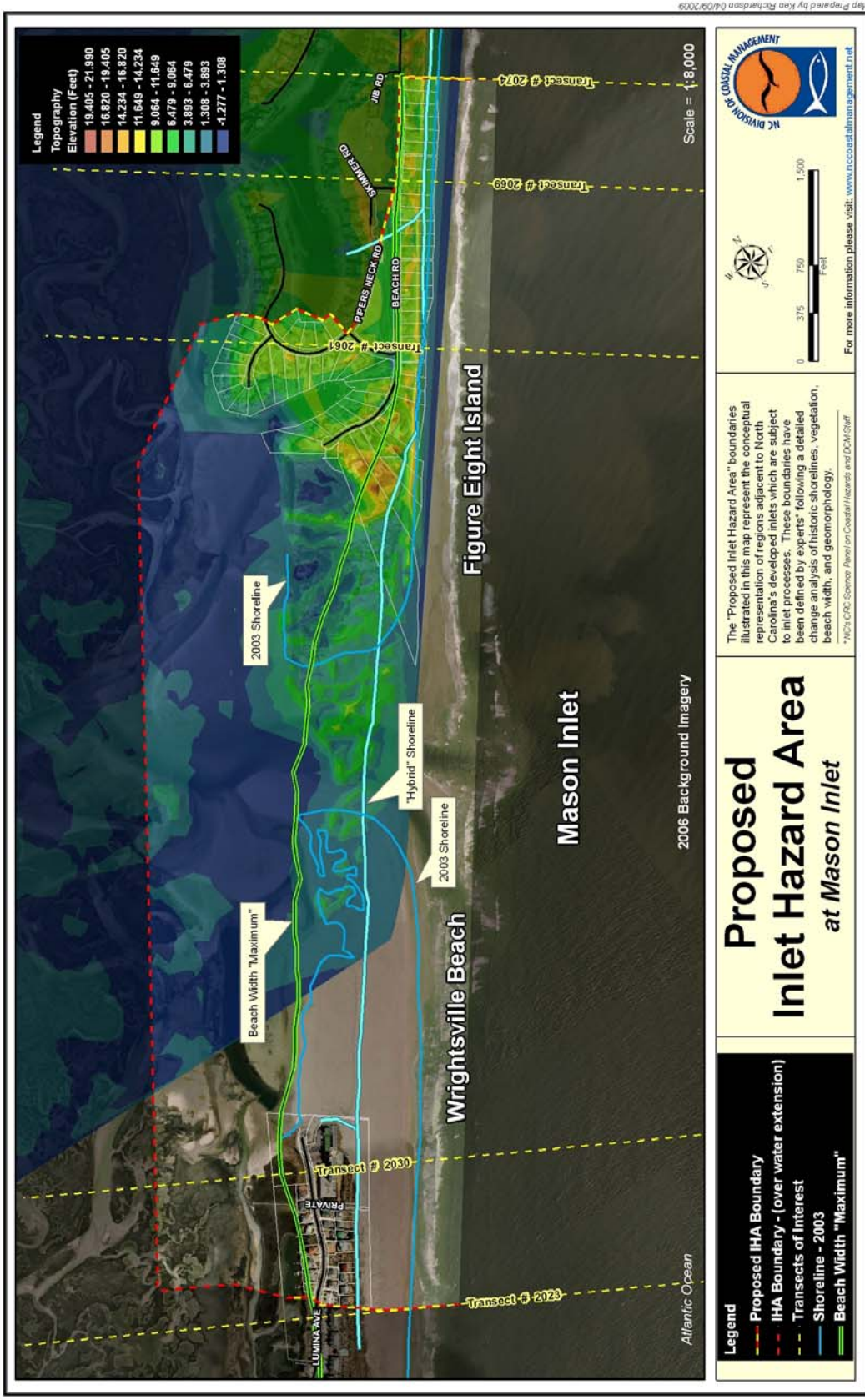
**MASON INLET**

**Mason Left: 1933, 1949, 1958, 1971, 1973, 1977, 1987,  
1992, 1997, 1998, 2003, 2004**



**Mason Right: 1933, 1949, 1958, 1971, 1973, 1977, 1987,  
1992, 1997, 1998, 2003, 2004**



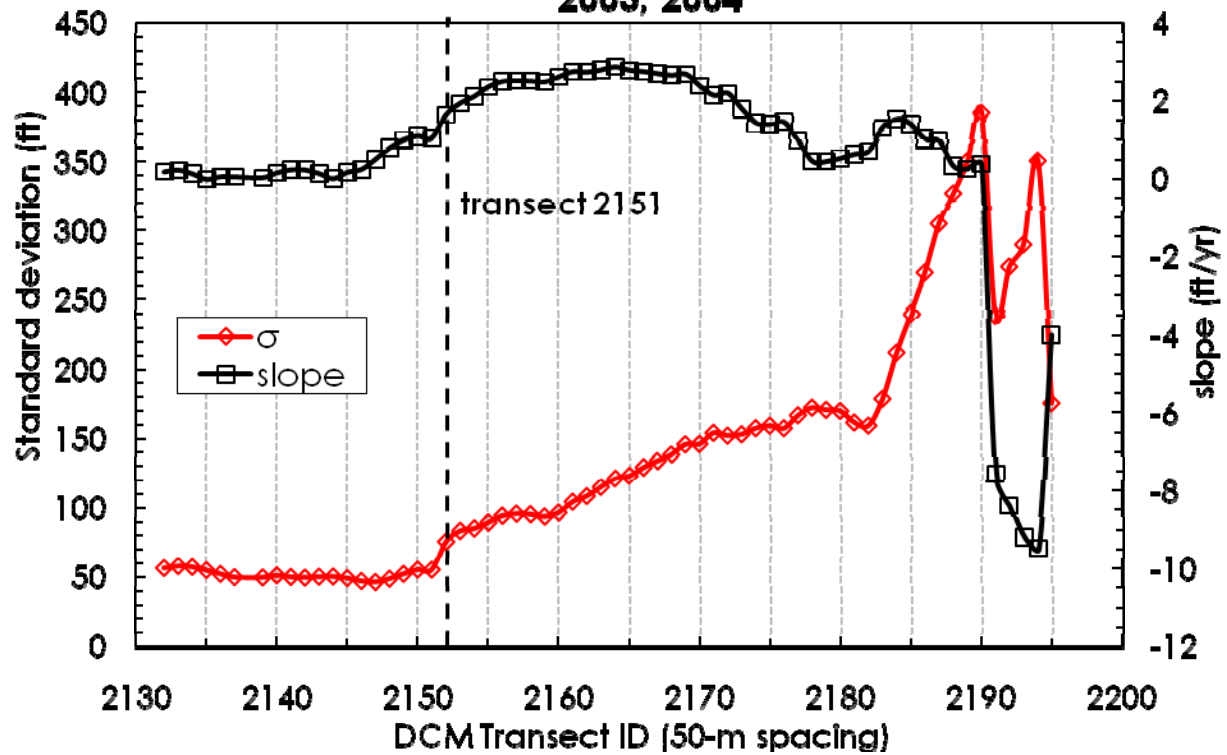


Map Prepared by Ken Richardson 04/09/2009

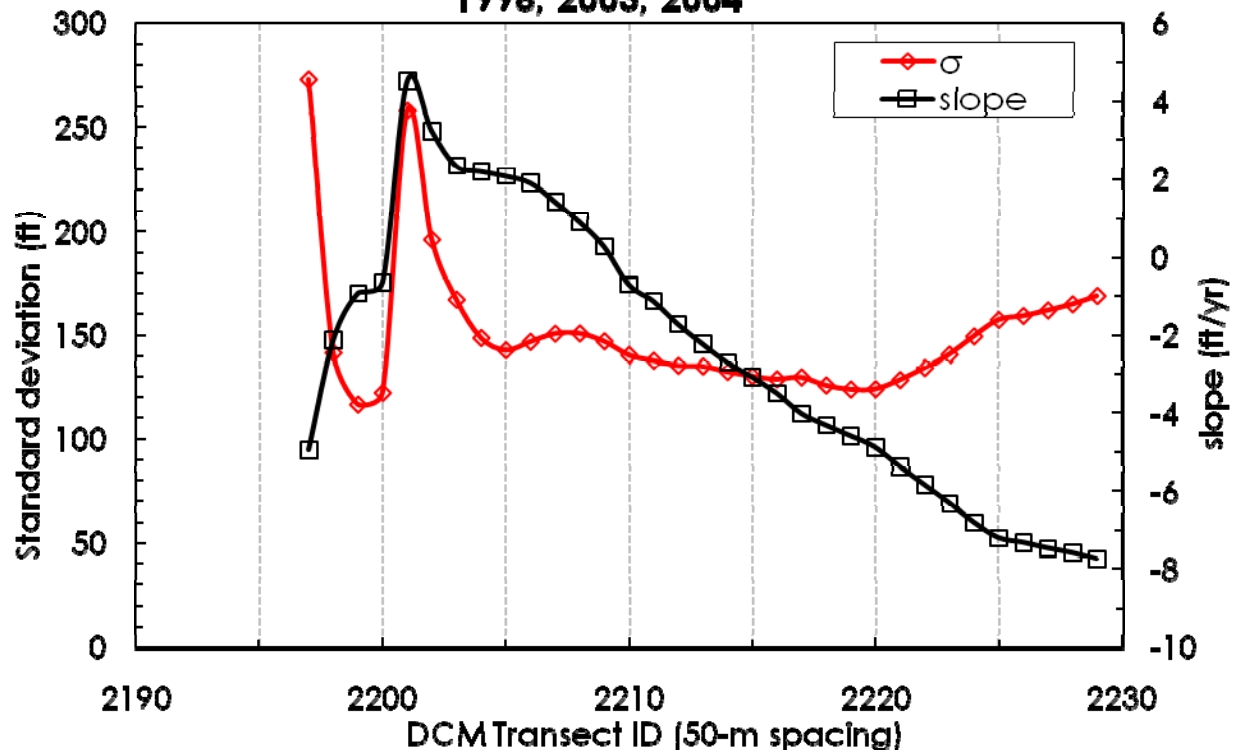
North Carolina DEIR - Division of Coastal Management - 2008

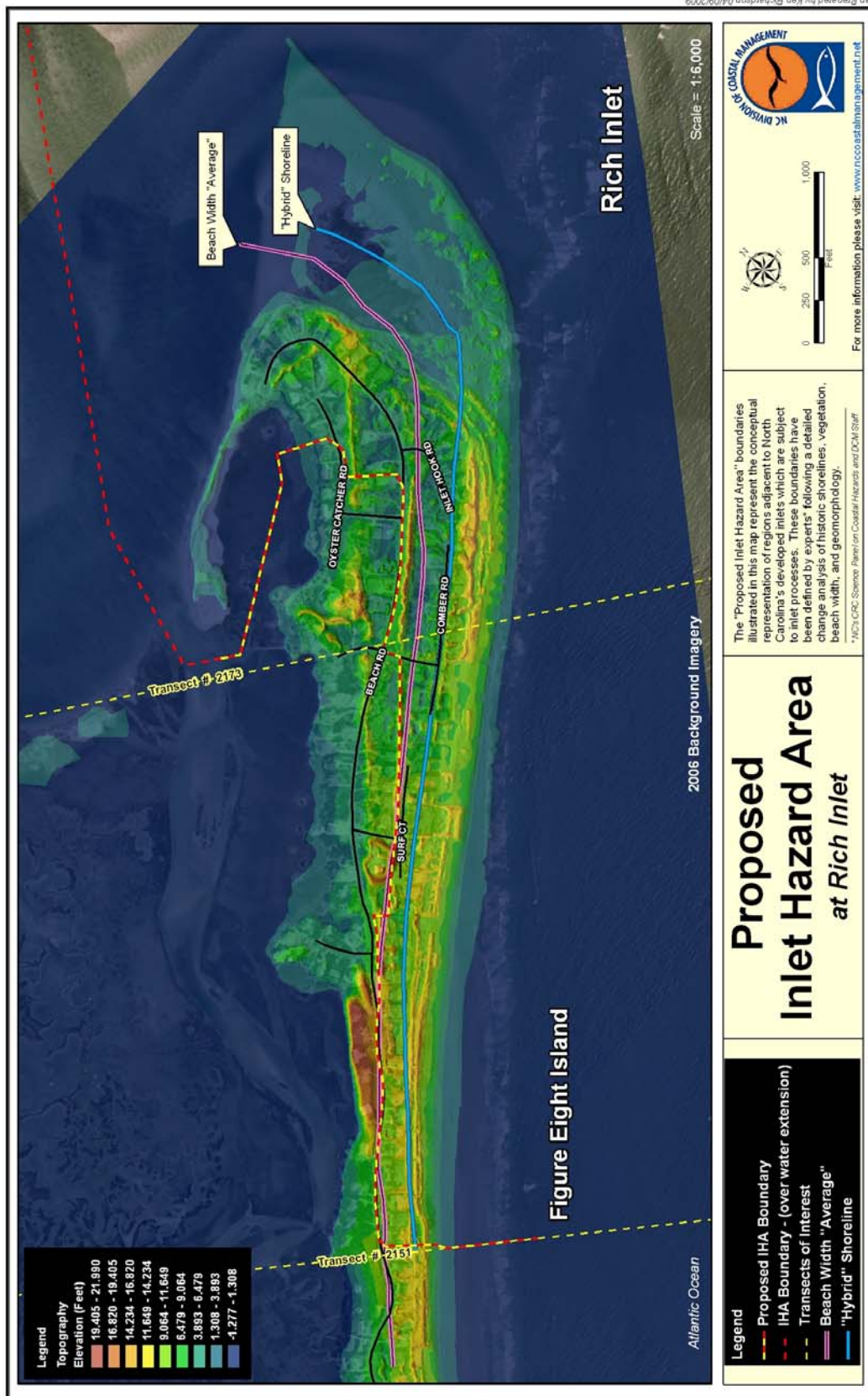
## **RICH INLET and NEW TOPSAIL INLET**

**Rich Inlet Left: 1938, 1958, 1973, 1980, 1992, 1997, 1998, 2003, 2004**



**Rich Inlet Right: 1938, 1958, 1973, 1980, 1992, 1997, 1998, 2003, 2004**

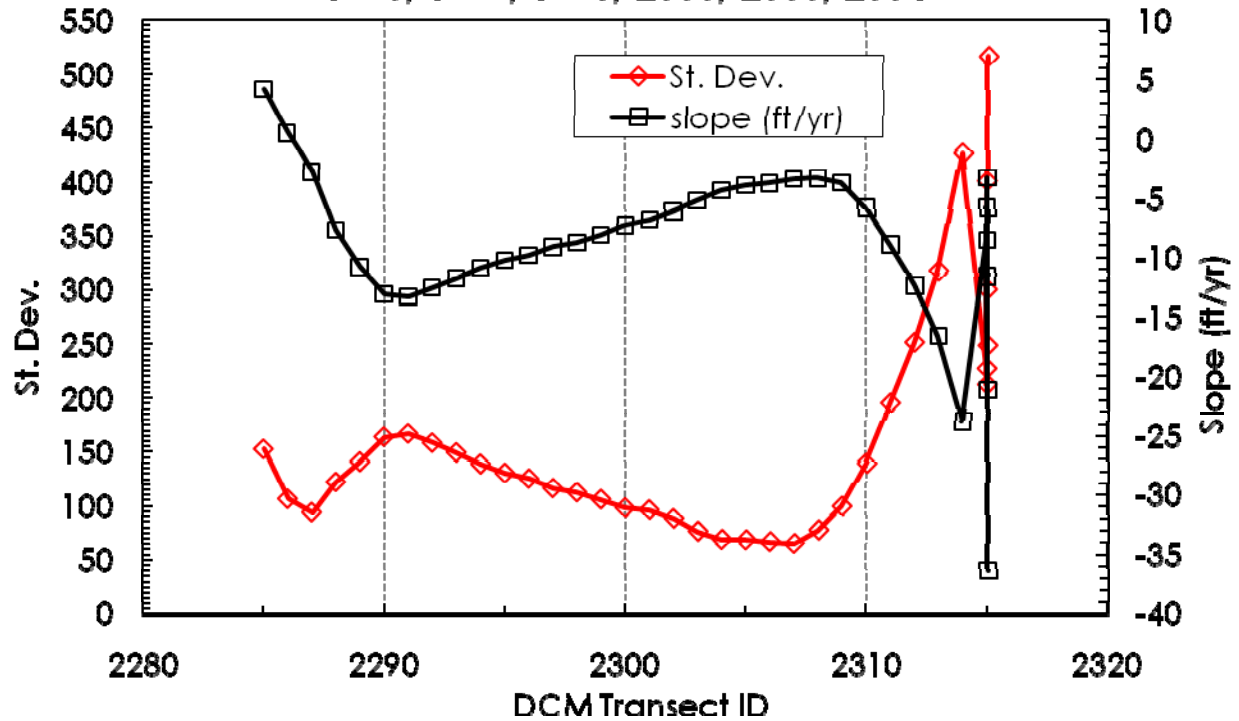




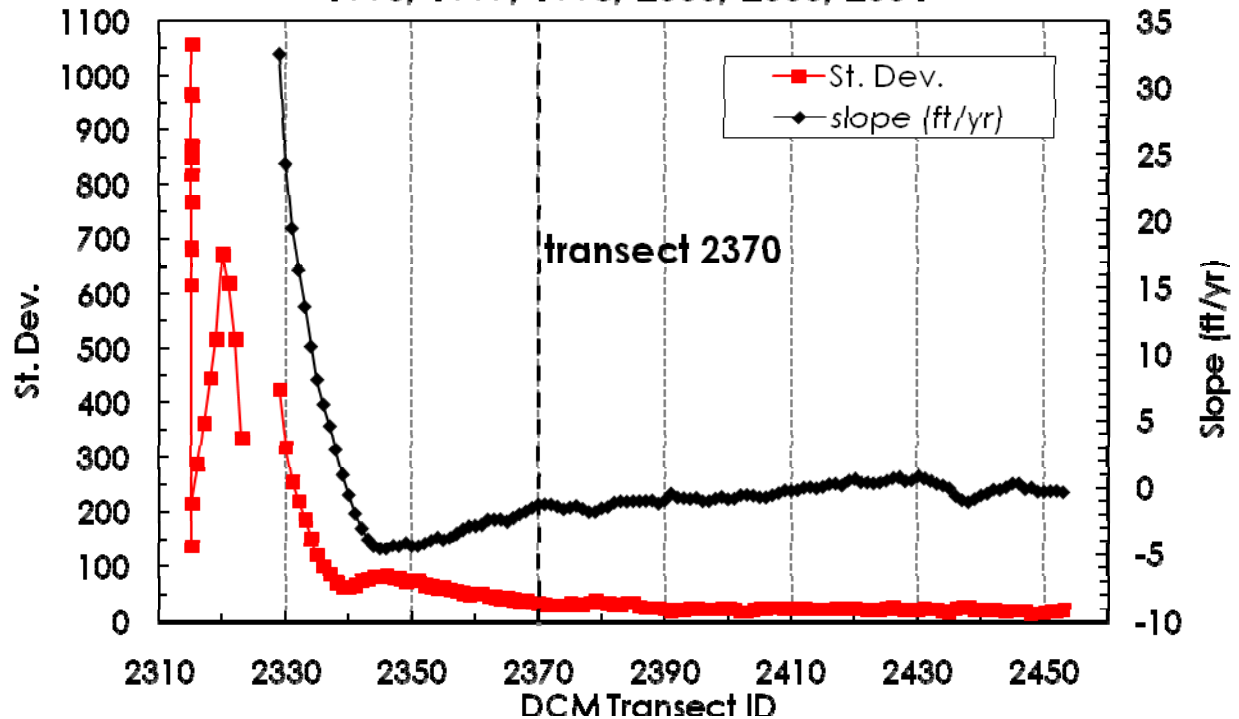
Map Prepared by Ken Richardson 04/09/2009

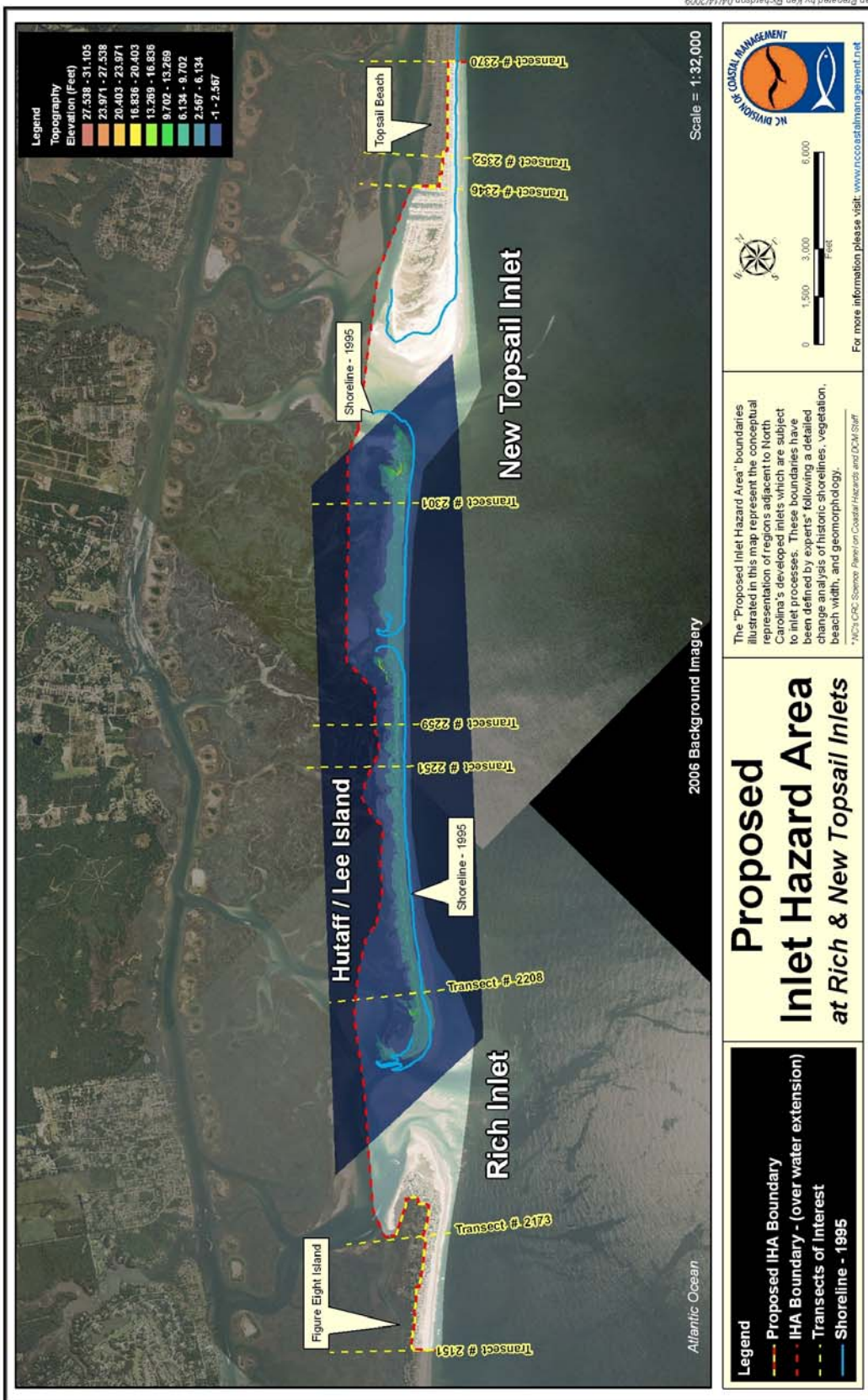
North Carolina DEIR - Division of Coastal Management - 2008

**New Topsail Left: 1971, 1973, 1974, 1977, 1984, 1992,  
1995, 1997, 1998, 2000, 2003, 2004**



**New Topsail Right: 1971, 1973, 1974, 1977, 1984, 1992,  
1995, 1997, 1998, 2000, 2003, 2004**





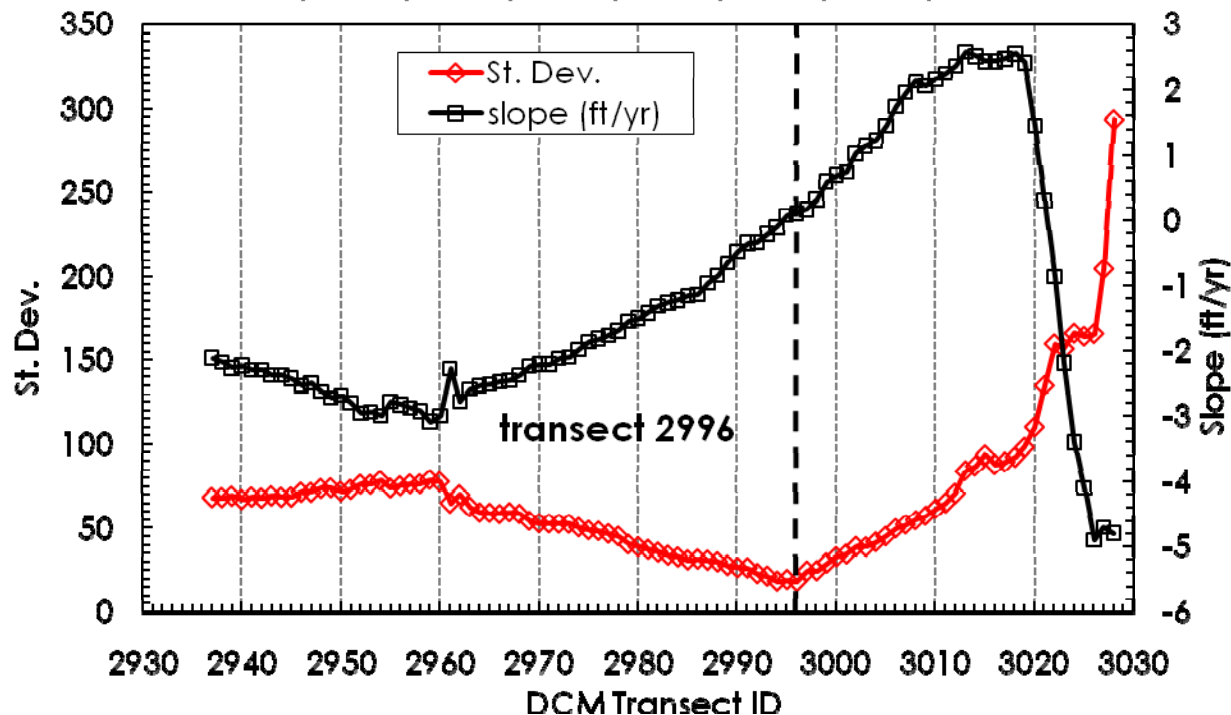
Map Prepared by Ken Richardson 04/14/2009

North Carolina DEIR - Division of Coastal Management - 2008

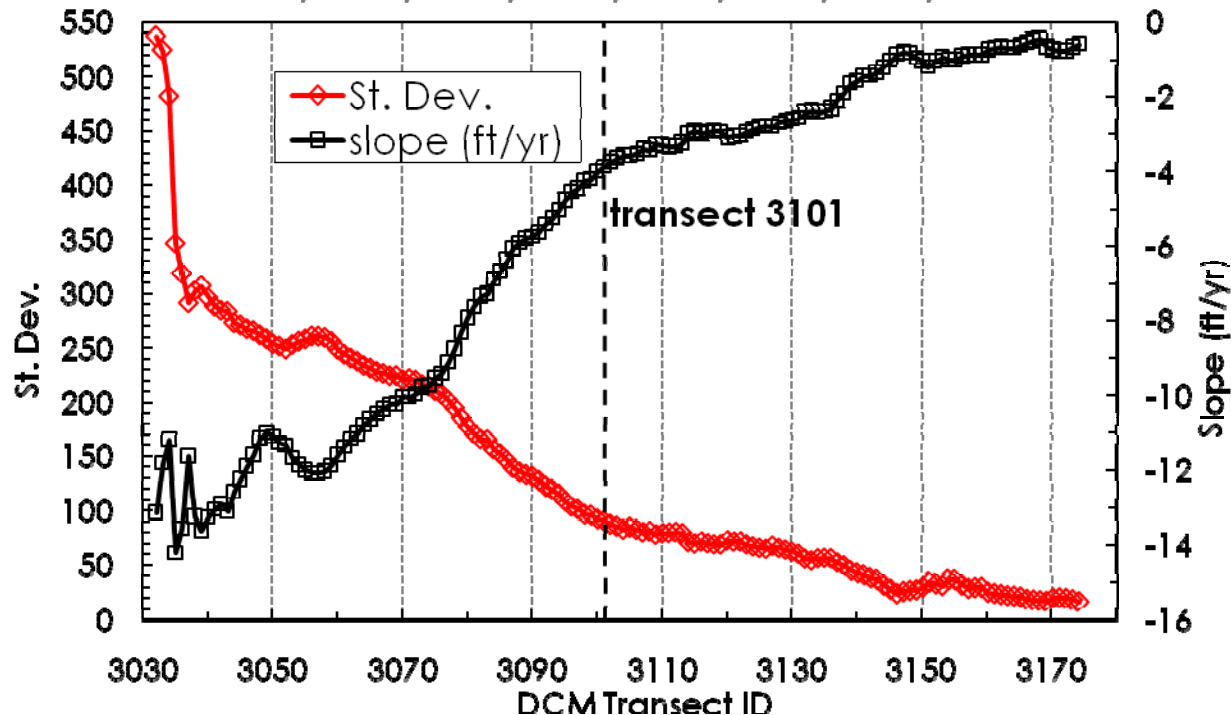


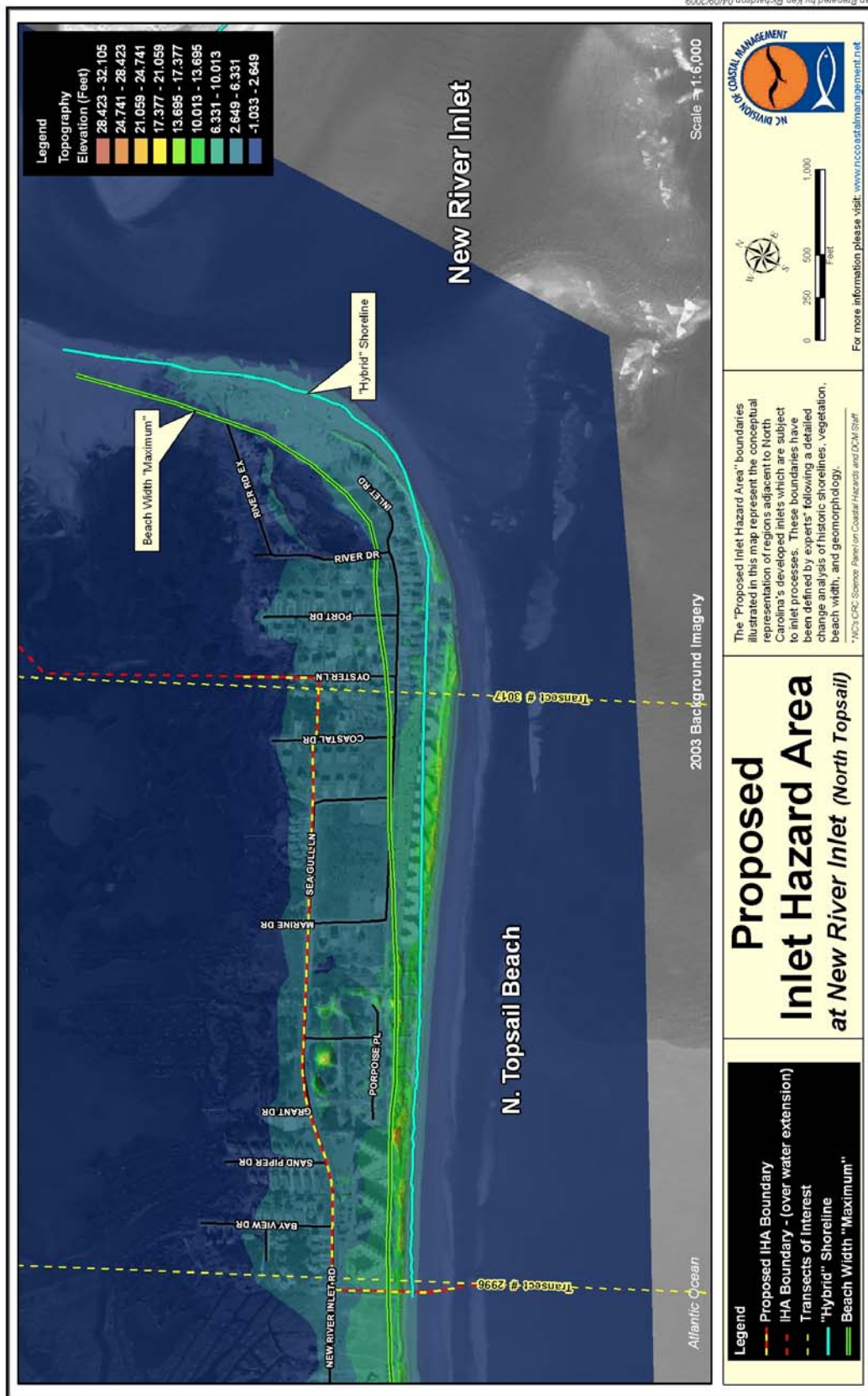
## **NEW RIVER INLET**

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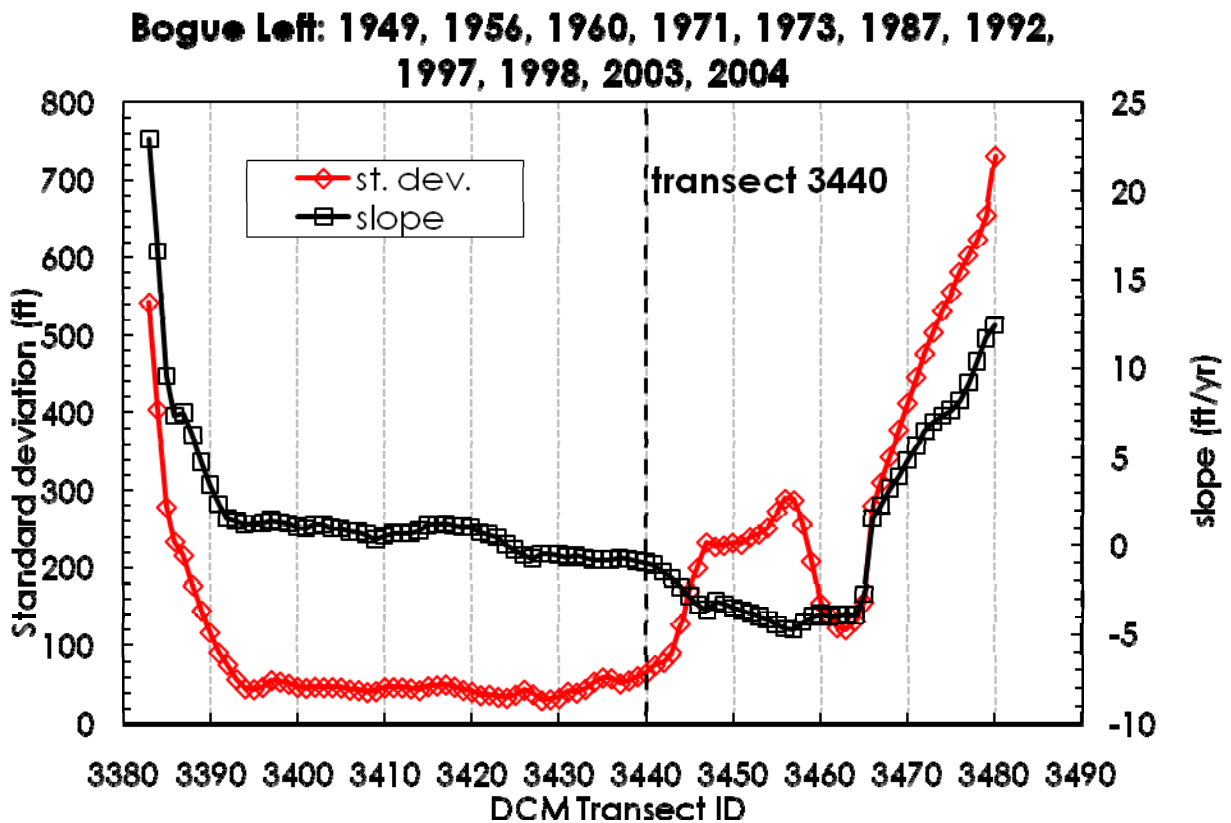
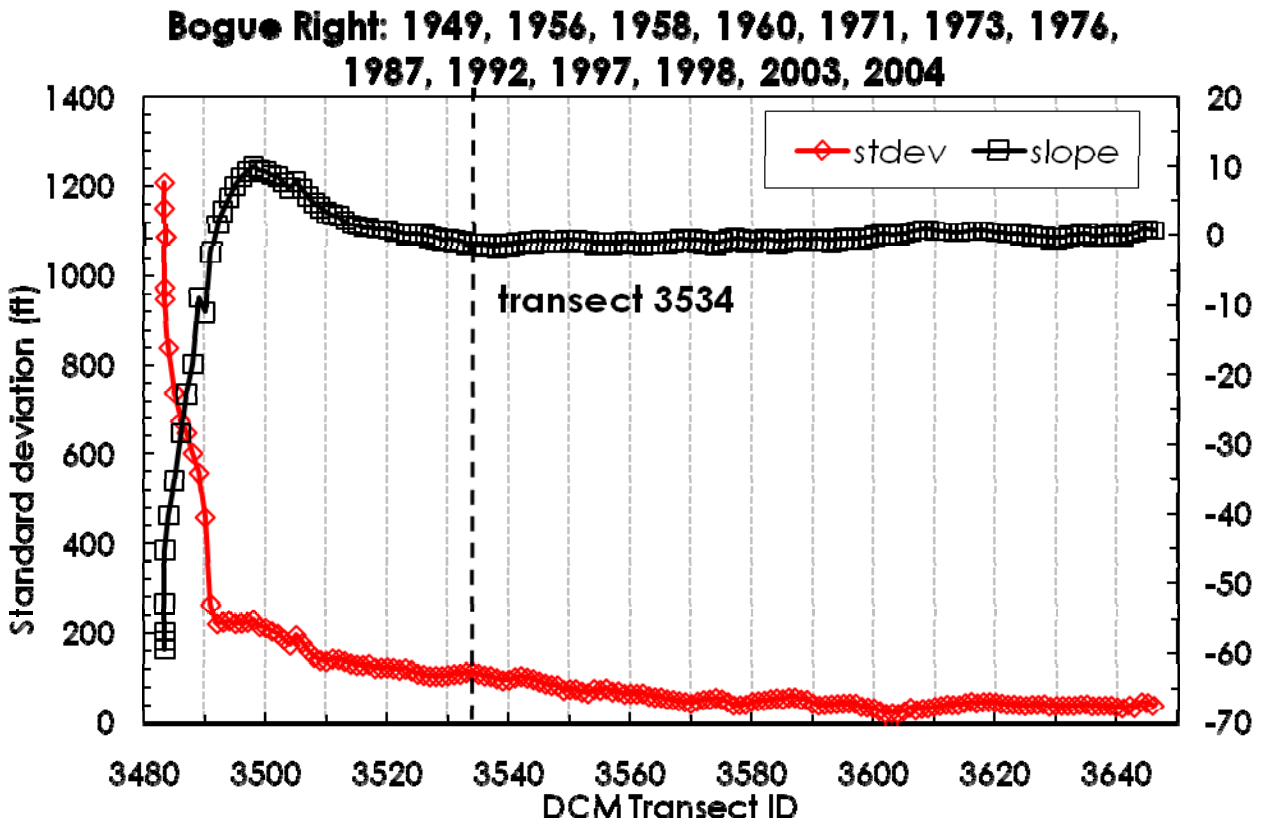


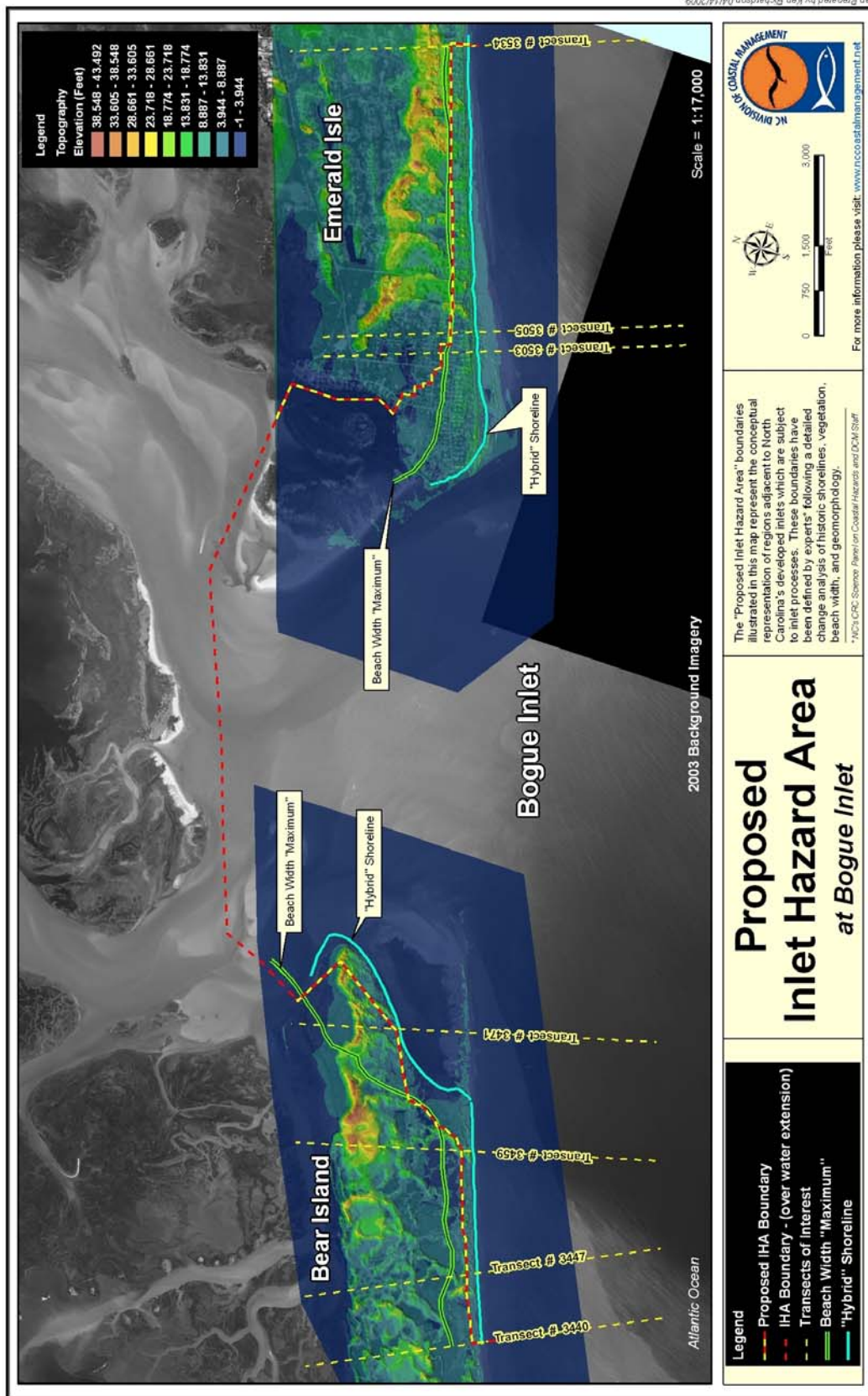
**New River Right: 1934, 1952, 1971, 1973, 1974, 1977,  
1984, 1992, 1995, 1997, 1998, 2000, 2003, 2004**





## **BOGUE INLET**

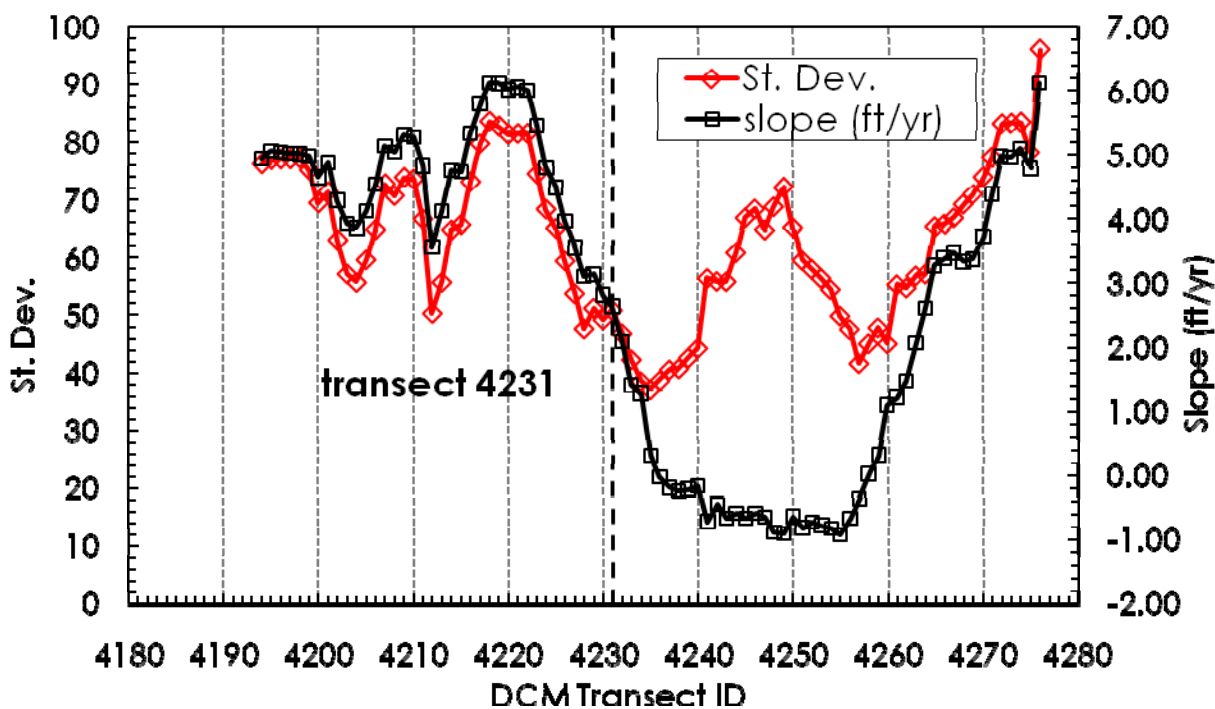






## **BEAUFORT INLET**

**Beaufort Left: 1971, 1974, 1976, 1979, 1984, 1997, 1998,  
2003, 2004**



**Beaufort Right: 1971, 1974, 1976, 1979, 1984, 1997,  
1998, 2004**

