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Geomorphologic evolution of a rapidly deteriorating barrier island system with multiple sediment sources: Eastern Isles Dernieres, Louisiana, 1887 to 2006

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Abstract

Trinity, East, and Wine Islands make up the eastern half of the Isles Dernieres barrier arc in south-central Louisiana. Formed following the abandonment of the Lafourche delta complex, subsidence and storm erosion have led to rapid deterioration of the system. Since 1887, the land area of the islands has decreased seventy-seven percent, and the gulf shoreline has retreated landward more than a kilometer. Wave ravinement on the shoreface of the islands is responsible for the most sediment loss; liberated sediment travels longshore to tidal inlets. The dominant ebb tidal currents then transport the sediment to where it is deposited in ebb tidal deltas or carried to the west, out of the system. A large lobe of sediment bypassing Cat Island Pass is entering the system from the eastern lower shoreface, which helps replace some of the sediment lost through wave ravinement to the upper shoreface.

Keywords: coastal geomorphology, coastal processes, barrier islands

Introduction

The Isles Dernieres barrier island chain in south-central Louisiana is a dynamic coastal system that has evolved rapidly since the late 1800s. Formation of the island chain began with the abandonment of the Bayou Petit Caillou delta of the Lafourche delta complex 420 years BP (Penland et al., 1988), and the recent evolution of the system is marked by extensive land loss and landward migration.

Four islands currently comprise the Isles Dernieres barrier arc, which is 32 km in length and located approximately 100 km west of the current Mississippi delta. From west to east, these are Raccoon, Whiskey, Trinity, and East Islands. Wine Island shoal is a former barrier island (Wine Island) that lies east of East Island. These islands are divided by tidal inlets that have all formed since Last Island Hurricane of 1856, including Coupe Colin, Whiskey Pass, and New Cut, from west to east, respectively. Trinity and East Island have been joined since the late 2000s, a result of a restoration project that filled the New Cut tidal inlet and strengthened island integrity.

This Isles Dernieres have undergone extreme land loss and shoreline retreat since the late 1800s, particularly following fragmentation. From 1906 to 1988, average retreat of the gulf-side shoreline was 11.1 m/yr, whereas bay-side shoreline retreat averaged 2.4 m/yr. These rates increased annually and resulted in 78% land loss (McBride and Byrnes, 1997).

The eastern Isles Dernieres (i.e. Trinity and East Islands) are unique in that sediment nourishing the islands is sourced from the erosional headland, as described by the model in Penland et al. (1988), as well as sediment bypassing Cat Island Pass to the east (Jaffe et al., 1989; Jaffe et al., 1997). This longshore-sourced sediment affects the islands' geomorphology and helps to replace sediment lost by erosion.

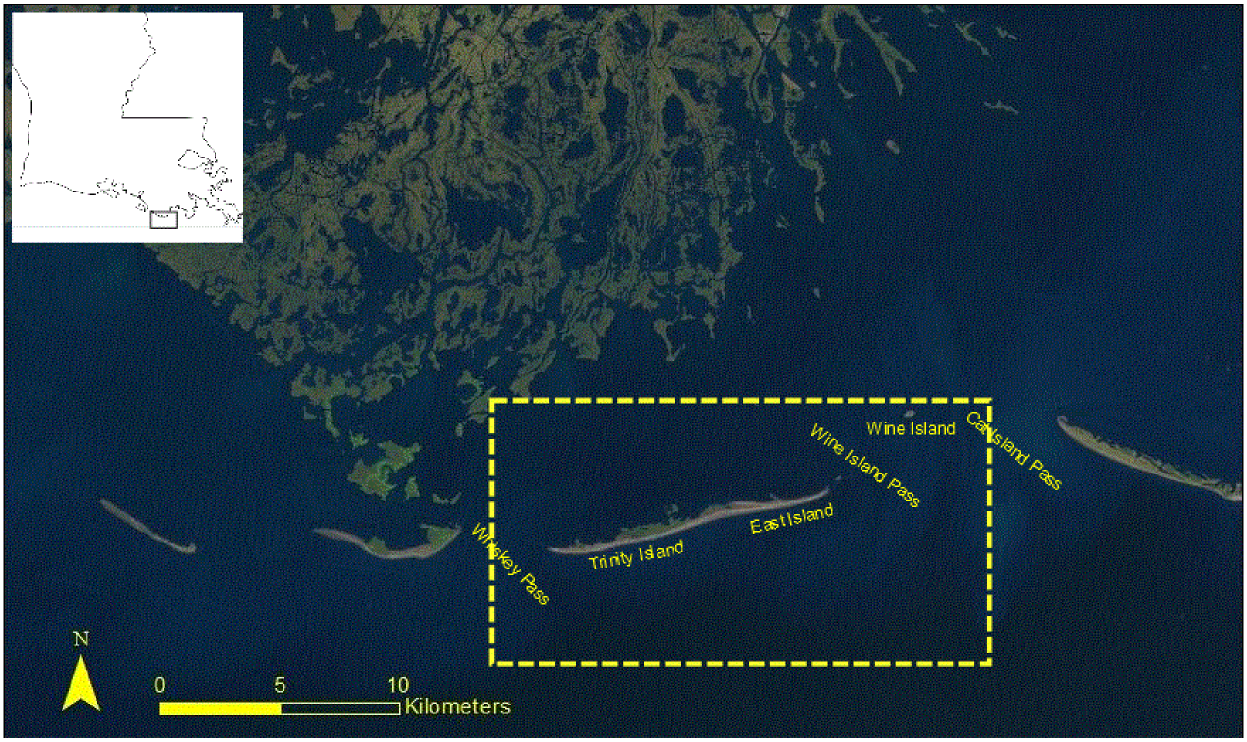


Figure 1 Study Area Location. This satellite image shows the location of the study area within the dashed box. The other two islands of the Isles Dernieres, Raccoon and Whiskey Islands, are immediately west of Trinity Island. Timablier Island lies to the east of Wine Island, across Cat Island Pass.

Hypothesis / Key Questions

The hypothesis proposed here is that sediment introduced to the eastern Isles Dernieres from longshore sources significantly affects the islands' evolving geomorphology. A large depositional lobe, just southeast of East Island and seaward of Cat Island Pass, is thought to consist of sediment eroded from the Timbalier system and the Bayou Lafourche headland. The lobe is thought to nourish Trinity and East Islands by providing an updrift sediment source (List et al., 1997; Georgiou et al., 2005; Miner et al., 2009a). It is hypothesized here that this sediment will be transported westward and into to the eastern Isles Dernieres system, leading to reduced rates of sediment loss. The questions to be answered are as follows:

1. Is there a significant amount of littoral transport that introduces sediment to the Isles Dernieres system from the east? Wave direction is predominantly from the northeast to southeast at this location, and longshore transport is toward the west (Georgiou et al., 2005). There is an adjacent sandy sediment source that contributes to inlet sediment bypassing and sediment load (Jaffe et al., 1997; List et al., 1997).
2. If significant longshore transport does exist, where is this sediment deposited and what are the geomorphological results? While sediment transport is westward in the system as a whole, individual inlets between barrier sand bodies are dominated by tidal processes due to the increasing tidal prism of Lake Pelto (Miner et al., 2007). Sediment transport at Trinity Island is bidirectional, whereas Whiskey Pass shows signs of very little to no net transport (Georgiou et al., 2005). Deposition of the longshore sediment will be limited to areas of east of Whiskey Pass or possibly even to areas east of the first localized eastward transport.
3. How is the evolutionary barrier model of Penland et al. (1988) influcenced by this secondary sediment source? The three-stage hypothetical model of Penland et al., 1988 accounts for the transport of sediment eroded from the central headland, but sediment input from longshore sources is not taken into account. Due to dominant westward sediment transport, the actual system may exist as a dynamic balance between Penland's model and some other mechanisms.

4. What implications do longshore transport and overall modes of island evolution have for barrier restoration projects? Restoration projects to help preserve or renourish the Isles Dernieres have had mixed success (Penland et al., 2003). With more information on sediment sources and transport, projects can be constructed most effectively.

Significance

The significance of this study is twofold: to increase scientific understanding of Louisiana barrier island evolution and generate practical information to increase effectiveness of restoration on Trinity and East Islands.

The Penland et al. (1988) model is applied to barrier island systems in Louisiana assuming a standardized suite of conditions; however, each barrier system contains unique conditions, processes, and complexities that affect model progression. In particular, sediment input from the east is not accounted for by the model, and longshore sediment is hypothesized here to have major implications on the geomorphology of the eastern Isles Dernieres. The role of this longshore sediment input can be analyzed and the effects noted on other Louisiana barrier systems receiving sediment input from sources other than the erosional headland.

Improving the current understanding of erosion and accretion patterns of the eastern Isles Dernieres would have great significance to restoration efforts. In the past, restoration projects have had mixed success, with results ranging from little impact to major land gain. However, some projects that did prove to be effective in increasing island area left existing salt marsh covered with sand, replacing an area of great biodiversity with bare land (Penland et al., 2003). If sediment could be introduced to natural depositional transport pathways or be used to fill pathways carrying sediment away from the system (Campbell et al., 2005), the islands may be able to sustain themselves by naturally building land.

Background

Holocene Delta Plain Evolution

The Mississippi River system drains into the Gulf of Mexico in southeast Louisiana and forms the Mississippi Delta, a continental-shelf delta extending across 28.6×10^3 km^2. As shown in Fig. 2, the modern, large delta plain was created by overlapping delta complexes that consist of smaller delta lobes, all of which were formed from distributaries of the Mississippi River. When progradation of the active delta decreased in efficiency, the depocenter would shift to a more efficient location, leaving the former headland subject to erosional coastal processes.

There have been many studies that identify and date the Holocene delta complexes, the names of these complexes used herein were identified and chronologically ordered by Frazier (1967) with modifications by Tornqvist et al. (1996). The complexes, from oldest to youngest as identified by Frazier (1967), are Teche, St. Bernard, Lafourche, and Modern/Plaquemines (also called Balize) deltas. Tornqvist et al. (1996) established dates of first sedimentation for the St. Bernard, Lafourche, and Modern/Plaquemines deltas as 3569, 1491, and 1322 years BP, respectively.

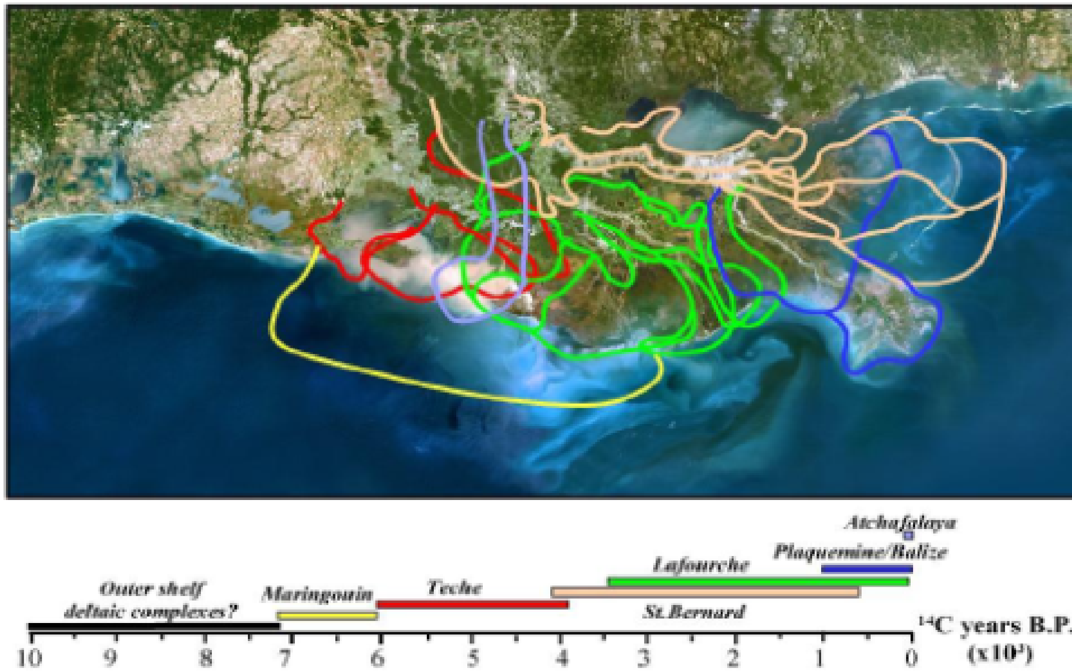


Figure 2 Holocene Mississippi River Delta Complexes. This map shows the areal extent of deposition for the various delta complexes that have been major depocenters of the Mississippi River in the Holocene. The Isles Dernieres are formed from a headland created by the Lafourche delta complex (green). (Kulp et atl., 2005)

Lafourche Delta Complex

The Lafourche delta complex first formed as an outlet of the Mississippi River approximately 1500 years BP (Tornqvist et al., 1996), nearly 2000 years after formation of the St. Bernard delta complex and approximately 100 years before the Plaquemines/Modern delta complex. Frazier (1967) suggested that the Lafourche delta complex was much older (~3500 years BP), but the updated study by Tornqvist et al. (1996) suggested a younger time frame for development.

Five delta lobes comprise the Lafourche delta complex, the fourth of which (chronologically) is the most extensive in area. This lobe formed the headland that would eventually form the Isles Dernieres (Frazier, 1967). Bayou Petit Caillou was a major distributary of this lobe, and beach ridges associated with this distributary progradation formed the core of the eastern Isles Dernieres prior to major degreadation (Penland et al., 1988). The Plaquemines/Modern delta complex and the Atchafalaya delta lobe have since become the main distributaries of the Mississippi River.

To attempt to identify the depositional history of this system, a variety of cores acquired from the University of New Orleans and the Louisiana Department of Natural Resources were used to develop the stratigraphic correlations included in Appendix I of this study. The temporal resolution of the cores is very poor; cores ranged in age from the early 1980s to the early 2000s. These initial correlations were included as an appendix, but they were not used in analysis of this study. Detailed stratigraphic correlation is an important area of future work.

Formation of the Isles Dernieres

The Isles Dernieres first began to form approximately 420 years BP following abandonment of the Bayou Petit Caillou delta lobe. The evolutionary model by Penland et al., (1988) and shown in figure 3, generally describes their evolution thus far.

The active delta stage of the model (top left in figure 3) evolves to Stage 1 with the switching of the Mississippi River depocenter. After sediment input has substantially declined or ceased, the active delta is left as a headland that is subjected to erosional wave and tidal processes. The active erosion of the headland supports the growth of the flanking barrier spits shown in Stage 1 due to longshore littoral transport. Subsidence also leads to relative sea-level rise in the marsh landward of the barrier spits, leading to an increase in tidal prism.

The transition to Stage 2 is marked by detachment of the barrier spits from the headland due to subsidence and backbarrier erosion. Wave action continues to disperse sediment toward the flanks of the barrier arc as well as cross-shore in the form of overwash during storm events. Tides transport sediment both landward and seaward as tidal delta deposits. In the case of the Isles Dernieres, ebb tidal deposits are much more extensive than flood tidal deposits.

The Isles Dernieres system is a Stage 2 barrier system during the period of time covered by this study, but it is rapidly approaching Stage 3: an inner shelf shoal. Continued subsidence and erosion will eventually lead to an entirely subaqueous barrier shoal. The Isles Dernieres were a continous island, known as “Last Island” or simply “Isles Derniere,” until 1856 when the island was initially fragmented by a strong hurricane. This initial tidal inlet was unnamed and likely had little tidal flux. With the formation of Whiskey Pass between 1856 and 1887, this initial inlet filled with sediment and became a continuous portion of Whiskey Island (Williams et al., 1992).

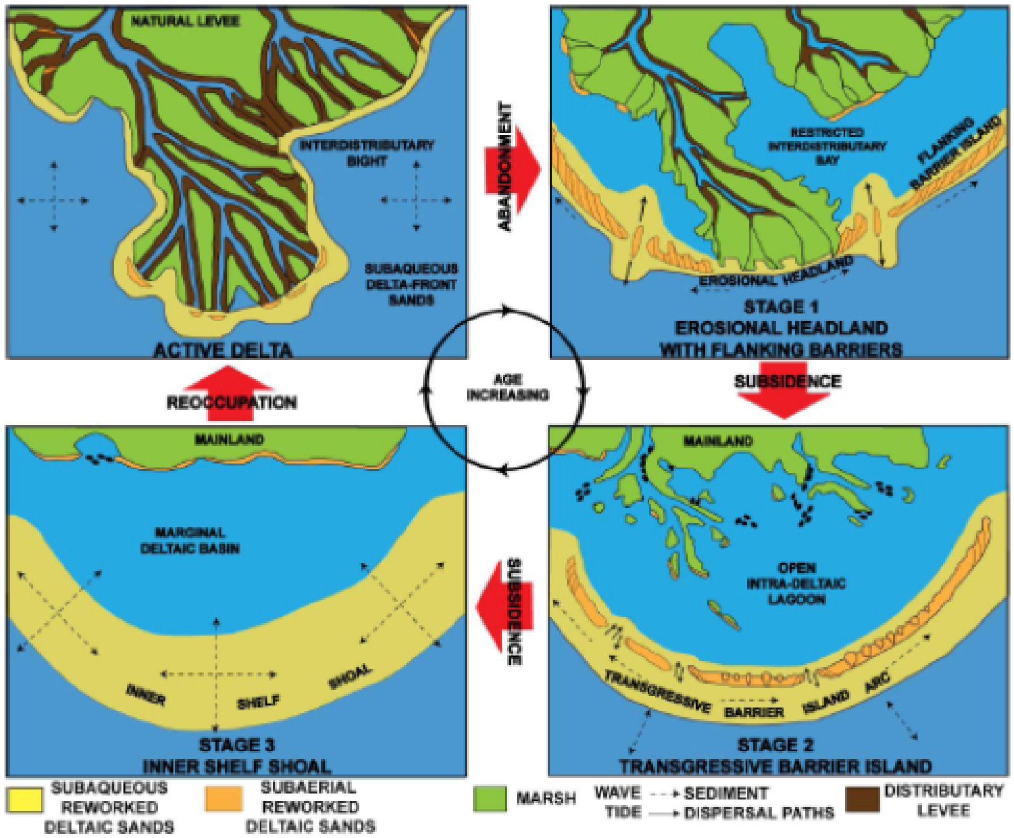


Figure 3 Penland et al. (1988) Model. Mississippi River Delta barrier systems follow this conceptual model, which starts with an active delta. As hydraulic efficiency decreases with continuing progradation, stream capture occurs at another lobe and leads to abandonment of the active delta. After abandonment, erosional processes take over and eroded sediment from the headland is transported longshore to form barrier spits, shown in Stage 1. Subsidence and erosion in the backbarrier eventually lead to a detached barrier island arc, shown in Stage 2. Finally, continued subsidence and erosion leave the barrier arc as a subaqueous shoal, shown in Stage 3.

Methods

In order to complete the objectives of this study, a suite of geomorphic data were required. In general, the data represented subaerial components of the barrier system as well as the subaqueous, nearshore barrier platform environments. Subaerial data included oblique aerial photography and satellite imagery. Subaqueous data included digitized shorelines derived from overhead photography and historical maps as well as bathymetric data obtained from single-beam surveys.

Data Sources

The single largest catalogue of data used in this study derived from a Barrier Island Comprehensive Monitoring Program (BICM). This online database contains Geographic Information System (GIS) data (bathymetry and digitized shorelines) and oblique aerial photography for the study area.

BICM oblique photography

Oblique aerial photography is included in BICM Volume I for the interval of 1984 to 2007 (Westphal, 2009; Penland and Westphal, 2009). Photos from 1984 to 1992 were collected from various sources with a range of goals and purposes. The remainder of the oblique aerial photos were taken by helicopter during simultaneous video capture along the Louisiana shoreline. Altitude at capture was generally 60-110 m.

Landsat satellite imagery

Satellite imagery used in this study is from LandSat satellites 1-7. Both multi-spectral scanner and thematic mapper images are used, and both were acquired from the US Geological Survey (USGS) digitally through the EarthExplorer online database.

BICM shoreline polygons

Shoreline GIS data was assembled as part of BICM Volume II (Martinez et al., 2009) and were digitized from a number of sources including historic National Oceanic and Atmospheric Administration (NOAA) topographic sheets (T-sheets) (1887, 1934), color infrared aerial photos (1996, 2005), and *Digital Globe Quickbird* satellite images (2004). The high-water line is used as the official shoreline in the database; see *Uncertainty* later in this section for more details.

BICM bathymetric data

BICM Volume III contains bathymetric digital elevation models (DEMs) for the study area. These bathymetric datasets represent four time periods: 1880s, 1930s, 1980s, and 2006 (Miner et al., 2009b). For the time periods 1890s, 1930s, and 1980s, the data were acquired digitally from the USGS, and it was also previously published as part of List et al. (1994). The 2006 data was collected by a team from the University of New Orleans (UNO) Pontchartrain Institute for Environmental Sciences (PIES) and USGS using single-beam sonar and GPS positioning. Miner et al. (2009b) contains an extensive description of bathymetric data collection methods, quality control analysis, and creation of bathymetric maps. Bathymetric data were adjusted for relative sea-level rise to depict true levels of erosion and accretion.

Data Analysis

The time period of interest for this study was from 1887 to 2006. The timeline in figure 6 diagrammatically shows all of the data sets that were used in this study. This timeline was used as a guide for data interpretation, and different results and discussion are presented in this context rather than specifically by type of data. It is worth noting that, as expected, there exists a larger number of datasets for the last thirty years compared to the beginning of the 20^{th} Century. These more recent data are also of higher quality with higher resolution and more tightly constrained errors.

Shoreline analyses

The shoreline datasets were of relatively low temporal resolution, with only five time periods. However, the spatial resolution is high; the shoreline datasets are GIS polygon shapefiles. These polygons were used to measure both change in position of shorelines and areal changes of the islands.

Shoreline change

Shoreline change was determined by noting the absolute positions on each of thirty-seven cross-shore transects drawn across the islands in the study area. Shoreline position was pinpointed on both the gulf and bay (backbarrier) sides of each transect at the farthest point seaward or landward, respectively. This was done for each of the time periods. The 1887 shoreline was used to determine the placement of transects; all are approximately 500 m apart and approximately normal to the shoreline. There are no transects beyond transect 37 on Wine Island, as they would not intersect more than one time period's shoreline.

Island area change

Island area was also measured for each of the five time periods. While Trinity Island and East Island were only separated in the 1996 and 2004 datasets, Transect 19 was used as a dividing line to measure the areas of the islands that would become Trinity and East Island. Because of this, the area of the joined island and the independent islands was able to be determined.

In addition to the total island areas, Transects 1-37 were used to divide the islands into zones labeled A-II, as well as WIP (Wine Island Pass) and CIP (Cat Island Pass). As shown in figure 8, zone WIP represents the land area between Transects 30 and 31 whereas CIP represents the area east of Transect 37. The area in all of these zones was measured, and the percentage of total area change was calculated between each of the datasets for each zone.

Bathymetric analyses

The bathymetric datasets used in this study were of the lowest temporal resolution of any datasets with only four time periods: 1890s, 1930s, 1980s, and 2006. Bathymetric data used in this study was particularly important as it was instrumental to being able to examine subaqueous patterns of deposition and erosion. A comparison of bathymetric datasets establishes the degree of seafloor change.

Bathymetry was used in three analyses: bathymetric profiles, patterns of erosion and accretion, and geomorphic volumetric change comparison. The results of these analyses are particularly important, as they involve the entire barrier system. The bathymetry explains many of the noted changes shown by the shoreline polygons.

Bathymetric profiles

Bathymetric profiles were taken cross-shore and at approximately 1300 m to 2000 m spacing along strike of the islands. Profiles were established at semi-irregular intervals, in a fashion that allowed for the greatest amount of anticipated change to be captured. There are twelve total cross-shore profiles, shown in figure 4, that are normalized to 4 km landward and 4 km seaward of the 1887 shoreline. The midpoint of the profiles is where the line of cross section intersects the 1887 polygon shoreline.

Vertical exaggeration on the cross-shore profiles is 150x and any values shown as positive (above mean sea-level) were normalized to zero. Because each bathymetric dataset was originally taken as part of a different study, different values were assigned for area representing land (Miner et al., 2009). There are also portions of some 2006 profiles that are cut off in the profile plots due to less robust data collection in that area.

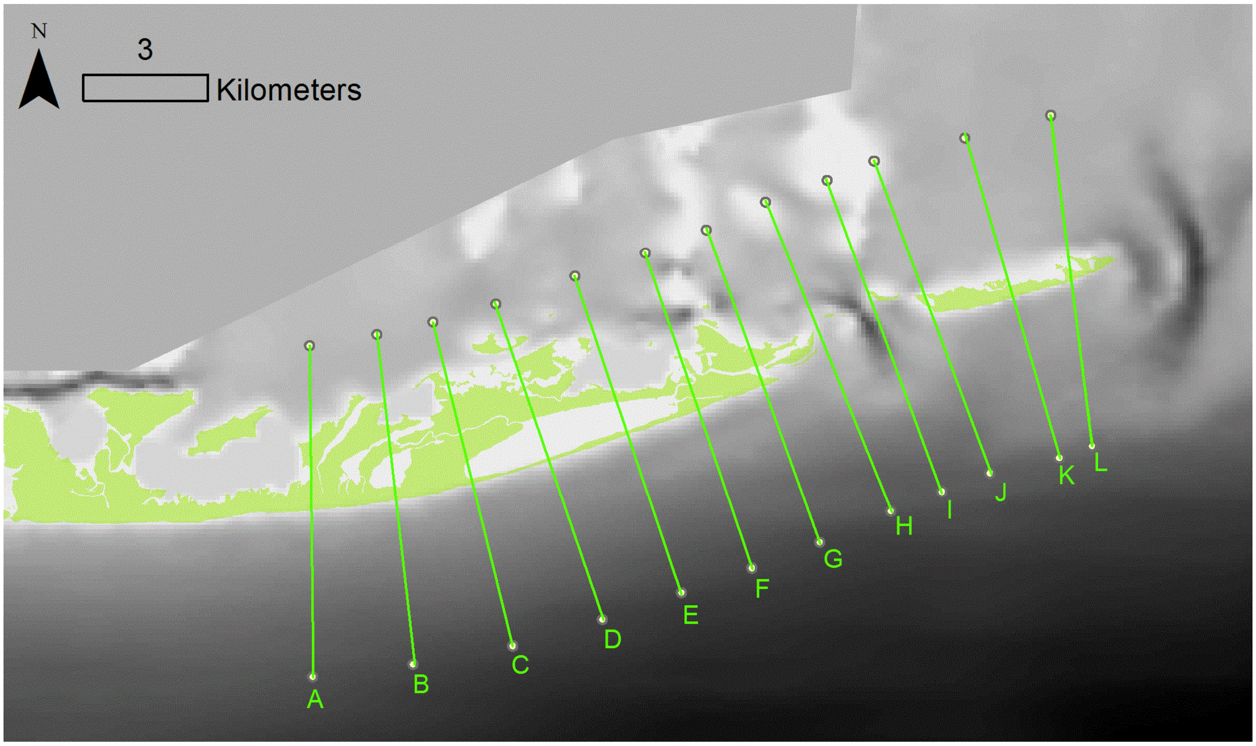


Figure 4 Bathymetric Profile Map. The lines of cross-shore profiles are shown here with the 1887 shoreline. Each profile extends 4 km landward and 4 km seaward of the intersection of the profile line and the 1887 gulf shoreline. These positions were chosen on the basis of predetermined significance rather than regular intervals. Each profile shows a comparison of all bathymetric datasets: 1890s, 1930s, 1980s, and 2006. Vertical exaggeration is 150x for each of the profiles included in Appendix III. The profiles are included in Appendix II.

Longshore profiles were also established for each time period; each is located approximately 100-200 m landward of the time respective gulf shoreline. The endpoints of the longshore profiles are Whiskey Island in the west and Timbalier Island in the east. The time periods with the widest tidal inlets were used to determine these end points; the position of Whiskey Island in 2006 and the position of Timbalier Island in 1887 were used. Vertical exaggeration for the longshore profiles is 500x.

Patterns of bathymetric change

Developed primarily for qualitative analysis, patterns and locations of erosion and accretion can be established by subtracting an older time period bathymetric DEM from a younger one (e.g. 1930s Z – 1890s Z = net bathymetric change) (Miner et al., 2009b). The resulting change maps produced by this method helped to indicate the relative role of coastal processes affecting geomorphic change. Maps showing these bathymetric changes were generated in *ArcMap*, using a color ramp that is fit to the minimum and maximum Z-value for the respective bathymetric change map. Z values between -0.5 m and 0.5 m were not displayed due to uncertainty; see the section regarding uncertainty for more details.

Geomorphic volumetric change

The bathymetric data was, however, used in a quantitative analysis. The change in the volume of geomorphic features was calculated for each time interval. The definitions for the features used in this analysis are shown in Table 1. In order to calculate the volumetric changes of specific geomorphic features, the previously mentioned raster-type bathymetric change maps were converted to 0.5 m contours as polyline shapefiles using the 3D Analyst extension in ArcMap (Fig. 5). These polylines were then enclosed around the extent of the survey area and converted to polygon shapefiles. Because of polygonal extent and labels showing each polygon's Z value, these polygon shapefiles contained quantitative values in three dimensions. Each of the areas bounded by contour lines was assumed to represent the lower value due to the previously mentioned ±0.5 m error. See the *Uncertainty* section for more details.

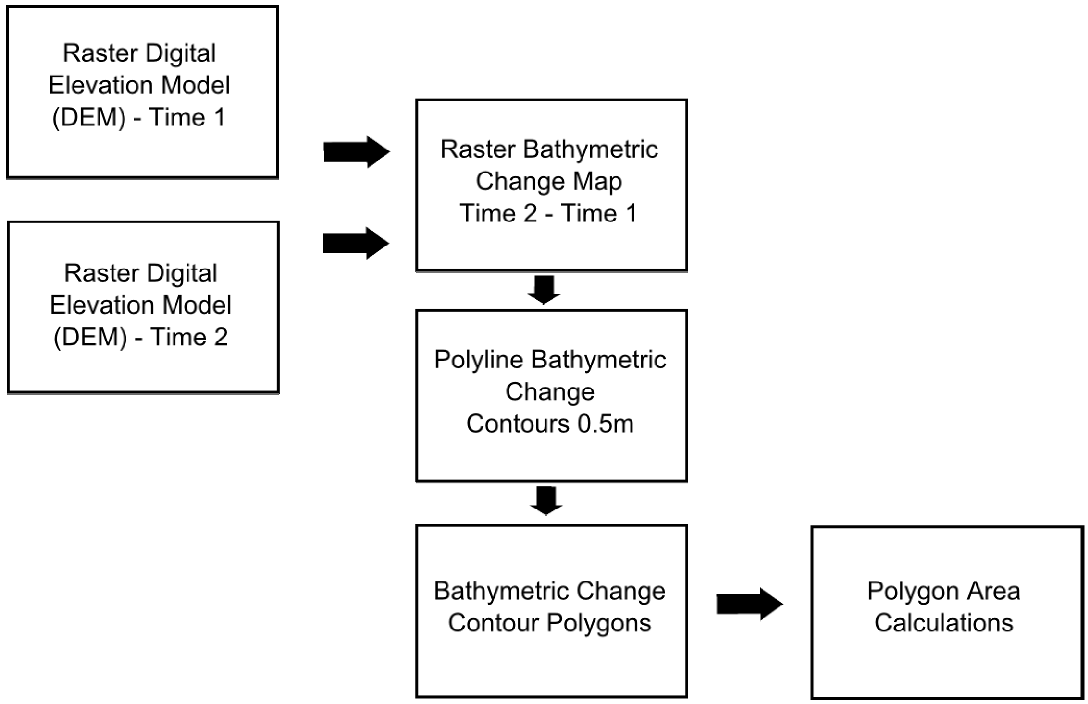


Figure 5 Bathymetric Volume Calculation Flow Chart. BICM DEMs were used to calculate volumetric change. The Z-values of the earlier DEM were subtracted from the later DEM; this yielded a map of bathymetric change across that interval (e.g. 1930s DEM – 1890s DEM = Time Period I bathymetric change). These raster bathymetric change maps were then contoured in *ArcMap* at 0.5 m intervals. The contours were then closed off at the edges of the survey area and converted to polygons. Then, in order to obtain a volume for each bathymetric feature, the area of each polygon within the feature was multiplied by the Z value of the contour. These volumes were then added together for a total volumetric change of each feature.

Oblique aerial photography and satellite imagery

Oblique aerial photography from the BICM database was used in conjunction with *LandSat* imagery to show localized morphologic changes, particularly before and after storm events. Figure 18 shows the approximate locations and directions of photography on LandSat thematic mapper images. This ties together large-scale island changes with the results of smaller-scale processes such as overwash.

Unit Name	*Definition for use in bathmyetric analyis*
Shoreface	*Coastal zone seaward of the mean water line that extends to the approximate maximum depth in which the seafloor is affected by the storm wave base*
Spit	*Depositional feature formed at the end of a barrier island; formed from accretion associated with a decrease in longshore current velocity*
Washover	*Group of depositional features representing cross-shore tranport; generally in the form of fans and terraces transported landward across the berm and/or dunes*
Marsh	*Portion of a barrier island located landward of the beach and dunes; generally heavily vegetated and consisting of organic mud*
Inlet	*Main channel seprating barrier islands; scoured and supported by tidal flux*
Ebb Tidal Delta	*Depositional feature seaward of a tidal inlet; formed from accretion associated with a decrease in ebb tidal current velocity*
Flood Tidal Delta	*Depositional feature landward of a tidal inlet; formed from accretion associated with a decrease in flood tidal current velocity*

Table 1 Definitions of features used in bathymetric analysis. To specifically identify the terminology used in the quantitative bathymetric analysis, definitions for the bathymetric features are included here. These are commonly accepted features of a coastal system, but some specifics are identified here as they relate to this

Uncertainty

Error assessment was not addressed in the original publication of BICM Volume II, from which the shoreline shapefiles are taken. As the BICM database is updated and corrected continually, it is likely to be addressed in the future. However, a similar study by Williams et al. (1992) did address uncertainty in shorelines digitized from paper maps. This includes the shorelines from 1887 and 1934. Uncertainty for these shapefiles is a result of several factors including pen width, map stretching, and map shrinkage. The maximum potential error in that study was ±26 m per shoreline or ±52 m when comparing shoreline change (Williams et al., 1992). The shoreline shapefiles for 1996, 2004, and 2005 in BICM were generated from aerial photography (Martinez et al., 2009), and this technique is addressed in another similar study by Morton et al. (2004). The uncertainty for shorelines generated in this manner is due to rectification of the photography as well as digitization of the shorelines themselves. The value given is ±4.1 m for one shoreline or ±8.2 m when comparing both shoreline positions. See Morton et al. (2004) for more details.

The error associated with the bathymetric datasets is detailed by List et al. (1994), which was the source of all BICM bathymetric datasets except 2006 (Miner et al., 2009). In the List et al. (1994) study, there was an indicated ±0.5 m for vertical uncertainty; this value was used in here for all time periods. The 2006 bathymetric dataset is actually much more accurate, but comparisons are made with the older data. The greater uncertainty was used for consistency.

To represent this uncertainty, areas representing Z value change between -0.5 m and 0.5 m were not included in calculations. In addition, a volumetric value for uncertainty was calculated for all areas by multiplying the total area of change for specific features by the error value of 0.5 m. This technique is similar to that used by Miner et al. (2009).

It should also be noted that due to such relatively high error, geomorphic zones with little change across one time period have a large percentage of the total volume within the uncertainty range. For example, between 1890s and 1930s the Whiskey Pass flood tidal delta showed net gain of 1,266,721.1 m^3. However, because it was widespread deposition of low positive Z value, the entire volume is within the error range (i.e. 100% error). Widespread deposition of low relief contains very large error, whereas more relief lowers the percentage of the total within the range of uncertainty. See Miner et al. (2009) for more information.

Results

The results of this study are discussed relative to three generalized time periods. Each time period has specific boundary years as seen in Fig. 6. By using three time periods, the data can be used to determine short-term change as individual intervals as well as long-term change when analyzed as a whole. It should be noted that the bathymetry and shoreline data from BICM are spaced at similar intervals, but the transition between Time Period II and Time Period III shows the availability of bathymetry from the 1980s but not shoreline data until 1996. This results in some overlapping boundaries. The maps showing patterns of erosion and accretion for Time Periods II and III use the 1996 shorelines as a reference point for the 1980s bathymetry.

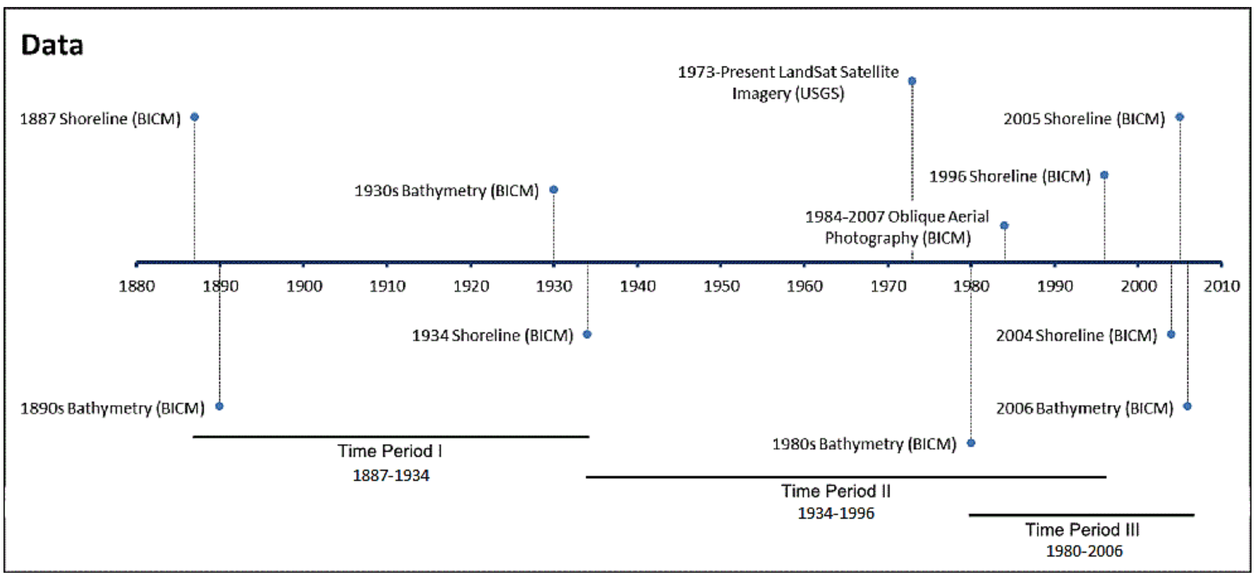


Figure 6 Timeline of data used in this analysis and its distribution. Dates covered by each dataset are shown here with the data source in parentheses. The range of each time period is shown on the bottom. Note the higher concentration of data in the latter half of Time Period II and in Time Period III. All data except for LandSat imagery is sourced from BICM; LandSat was obtained through USGS.

Time Period I

Time Period I covers the earliest interval of time – from 1887 to 1934. There are four datasets included in this time period: 1887 shoreline polygons, 1890s bathymetry, 1930s bathymetry, and 1934 shoreline polygons. All data in this time period is sourced from BICM (Miner et al., 2009b).

Shoreline analysis

The most substantial shoreline change in Time Period I occurred on western Trinity Island, as the continuous 1887 shoreline migrated landward along Transect 1 following the formation of Whiskey Pass in 1934 (Williams et al., 1992). As shown in Fig. 7, the gulf and bay shorelines migrated landward 1238 m and 789 m, respectively, and became the western spit of Trinity Island. The remaining change in gulf shoreline position on Trinity Island remained fairly consistent with an average of 585 m of landward retreat. The bay shoreline position change was generally much lower, with an average of 94 m seaward, but with more outlying values. Some of these outliers are a result of land loss, and do not represent the overall trend of shoreline change. Transect 9 in figure 7 is an example of this. The change in area was greatest on the western side of Trinity Island with a 77% decrease in Area A. The general trend is that the magnitude of land loss decreased eastward on Trinity Island, and land in Zone R (Fig. 8) in fact increased by 6% across this interval.

Transects 19-30 are part of the East Island analysis though New Cut had not yet formed in this time interval. East Island showed a generally comparable amount of gulf shoreline retreat as Trinity Island, with an average of 371 m of landward movement. The magnitude of cross-shore retreat also decreased from west to east. The bay shoreline change averaged 168.5

m seaward. A spit formed on the eastern end of East Island which resulted in the shoreline along Transect 28 prograding seaward. The area change, in the form of land loss, of East Island was generally greater than Trinity Island with percentage changes of -36% and -31%, respectively. Table 2 shows the results of the analysis of total island areas. The eastern spit, however, grew considerably; Zones BB and CC showed increases of 135% and 970%, respectively. A total of 203,348.3 m^2 of land was gained on this eastern spit.

Wine Island also showed rates of gulf shoreline change that were similar to Trinity and East Islands with an average of 462.9 m landward. However, unlike the other islands, Wine Island shoreline retreat increased from west to east. The bay shoreline also shifted landward an average of 293.9 m. Even though this shows island migration more than in-place land loss, Wine Island lost nearly double the percentage of land as the other two islands with -64.3%. The only zone that had an increase in land area on Wine Island was Zone DD a with 488% increase, which reflects the growth of the western spit of Wine Island.

The average gulf shoreline change for the entire study area was 499.3 m landward. The average for the bay shoreline change was 37.6 m seaward. The total area change was -35.1%, with an area of 16.62 km in 1887 and an area of 10.79 km in 1934. Yearly change was -.0124 km/yr, with Trinity Island showing the greatest rate of land loss. See Table 5 for more information on total island areal change.

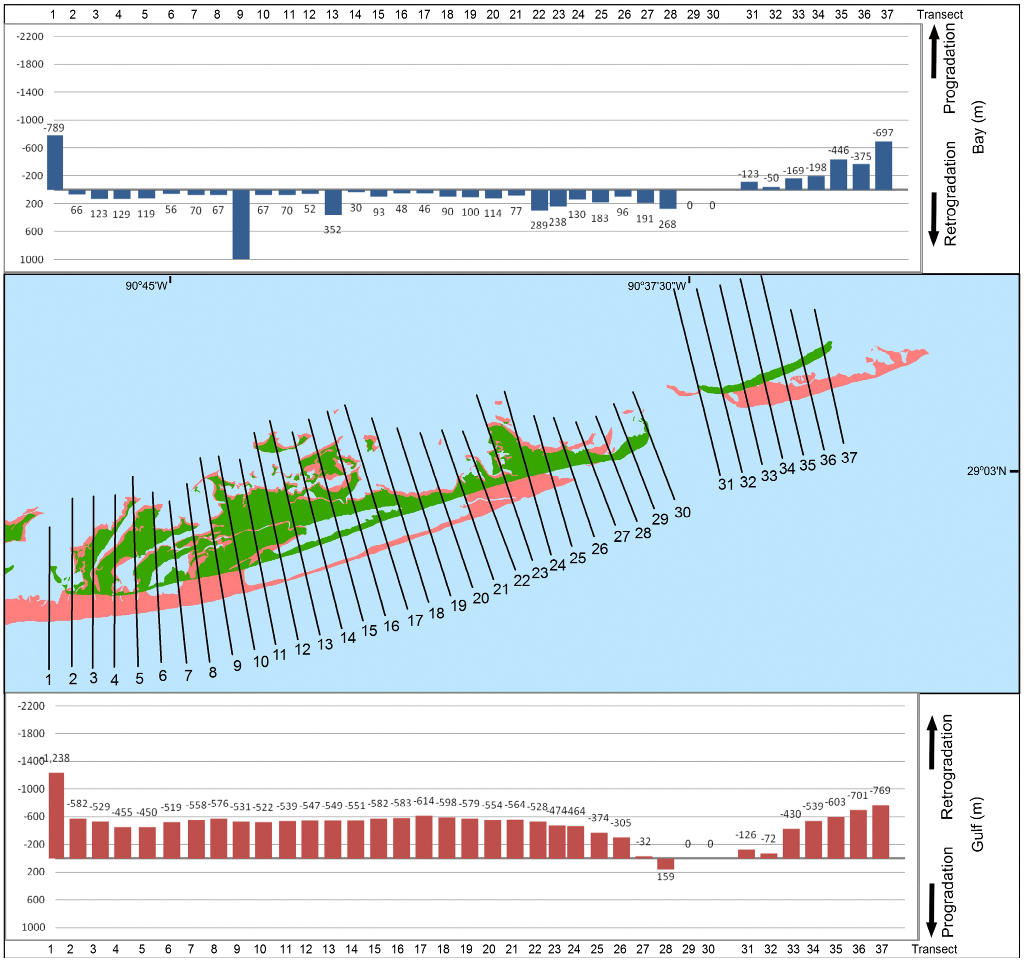


Figure 7 Time Period I: Shoreline change (1887-1934). Shoreline change on both the gulf and bay side is depicted here across Trinity, East, and Wine Islands for Time Period I. The values depicted in the graphs are one-dimensional changes along the individual transects labeled 1-37, and though connected across this time interval, Trinity and East Islands are treated as separate entities divided at Transect 19.The average change for this time period was 10.6 m/yr landward on the gulf side and 0.80 m/yr seaward on the bay side. The gulf shoreline change remained relatively consistent Trinity and East Islands except for the flanking spits. The western spit of Trinity Island migrated landward over double the average amount of change, and the eastern spit of East Island migrated seaward – the only seaward migration of a gulf shoreline in this time period. The bay shoreline of Trinity and East Islands shifted seaward varying amounts, with East Island having the higher rate. Both gulf and bay shorelines of Wine Island shifted landward, and the greater magnitude of change was in the eastern portion of the island. This resulted in the entire island migrating landward with a slightly counter-clockwise rotation.

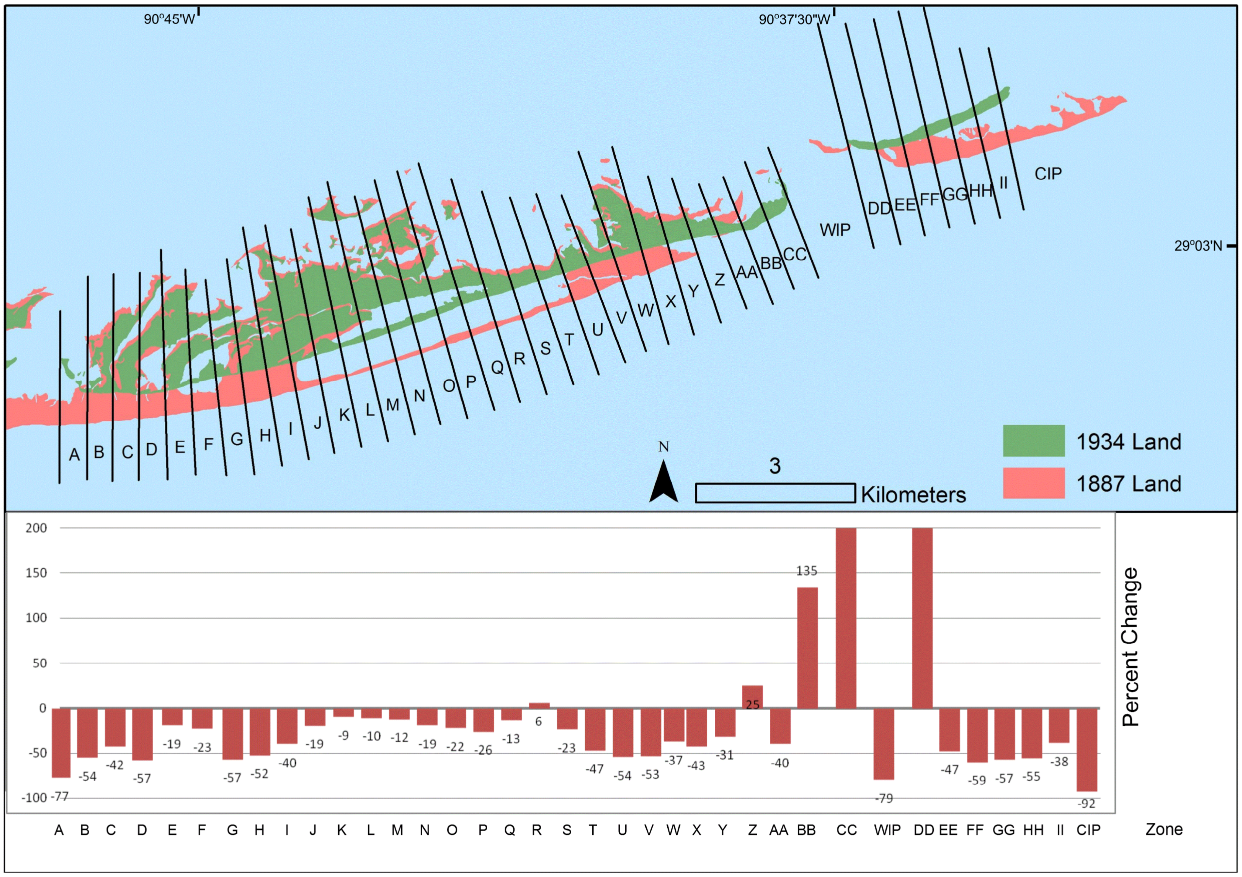


Figure 8 Time Period I: Area change (1887-1934). Change in area was determined for all areas labeled A-CIP, from west to east. The shoreline change transects were used as dividers; this analysis shows migration versus true land loss. An overall losing trend is seen across all islands, particularly Wine Island. The areal difference between the 1887 and 1934 shorelines is where the majority of land loss occurred, and the eastern spit over East Island is where land gain occurred. Major land loss occurred on Wine Island which resulted in a significant decrease in length, as shown by the 92% land loss in Area CIP.

Bathymetric analysis

Cat Island Pass was the most dynamic location in this study in terms of bathymetric change, which is not surprising as it was a rapidly migrating tidal inlet across all three time intervals. As seen in figure 9 and Table 2, there were 17.4x 10^6 m^3 of sediment deposited in the eastern side of the inlet and 17.9x 10^6 $m^3$of sediment scoured from the western side during Time Period I. A significant amount (2.2 x 10^6 m^3) was deposited west of the 1890s Cat Island Pass ebb tidal delta, but enough sediment was eroded from the eastern, older location that the ebb tidal delta actually showed net loss of sediment.

Table 2 shows that the greatest areas of net loss outside of Cat Island Pass were the shorefaces of Trinity and East Islands, with a loss of 17.6 x 10^6 m^3 and 5.5 x 10^6 m^3, respectively. As seen in Profiles A-H, the shoreface of each island became steeper whereas offshore bars increased in sediment volume. Other significant areas of net loss included the new Whiskey Pass inlet, Wine Island Pass inlet, and the Wine Island shoreface.

Features that had the greatest net sediment gain were the Wine Island Pass ebb tidal delta (6.8 km^3), East Island eastern spit (2.4 x 10^6 m^3), Wine Island overwash (2.2 x 10^6 m^3), and Whiskey Pass flood tidal delta (1.3 x 10^6 m^3). It should be noted that the amount of sediment eroded from the Wine Island shoreface was roughly similar to the accretion in the Wine Island overwash (3.0 x 10^6 m^3 to 2.2 x 10^6 m^3).

The total amount of accretion in the system from Cat Island Pass to Whiskey Pass in Time Period I was 29.5 x $10^6$$m^3$, and the total erosion was 58.0 x 10^6 m^3. The net sediment volume change was -28.4 x 10^6 m^3. See the uncertainty column in Table 2 for uncertainty values for each geomorphic feature/area.

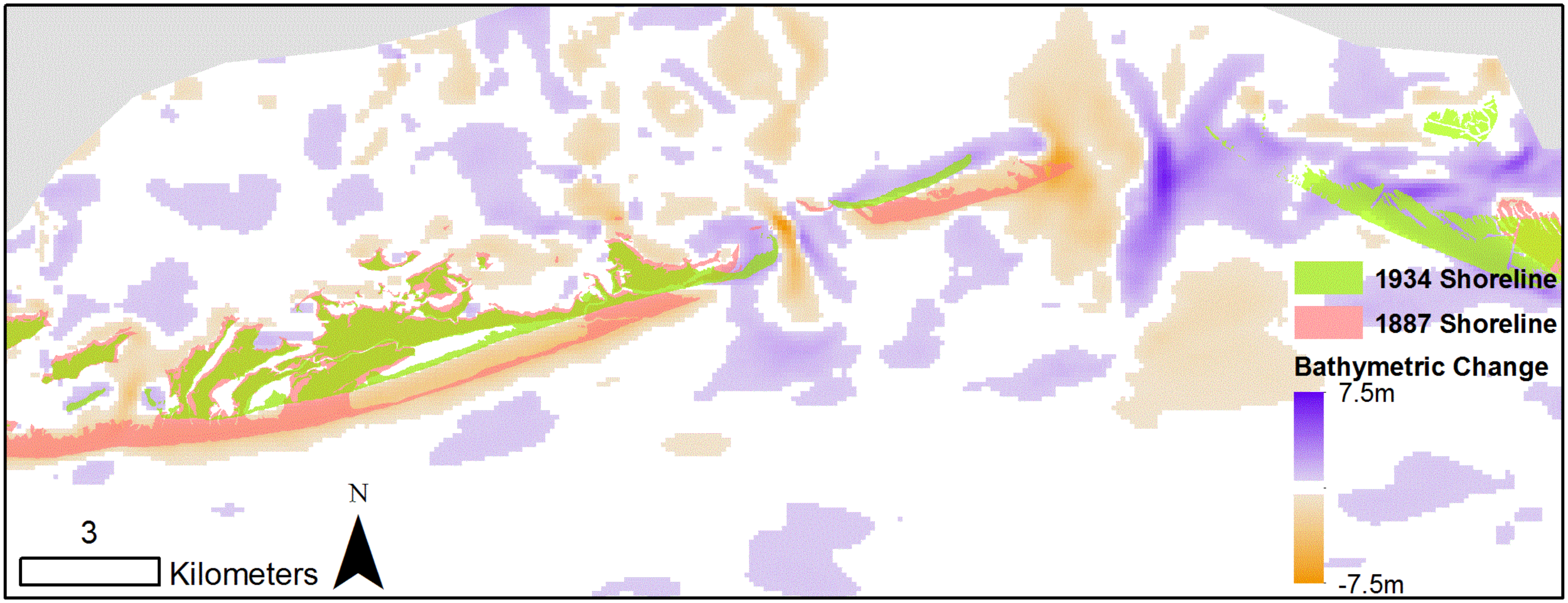


Figure 9 Time Period I: Bathymetric change map (1890s-1930s). Levels of erosion and accretion are shown here for the study area. See Fig. 1 for locations of islands and inlets and Table 1 for definitions of geomorphic features. Values of volumetric change for each feature are shown in Table 2. Note the pattern of fill in the east and scour in the west of tidal inlets in the system; all inlets showed this trend across all time intervals to some degree. As the inlet throats migrate west in both Cat Island Pass and Wine Island Pass, accretion in the eastern portion of the ebb tidal deltas ceases and increases in the west. In the Cat Island Pass ebb tidal delta, erosion takes place in the older location of the ebb tidal delta. Also note accretion in the eastern spit of East Island and the backbarrier of Wine Island as the island migrates landward. Large amounts of erosion took place on the shorefaces of Trinity and East Island as well, but relatively small amounts of accretion totok place in the marsh and backbarrier.

1890s-1930s	Accretion m^3	Erosion m^3	Net Volume Change m^3	Total Area m^2	Uncertainty $\pm m^3$
Whiskey Pass Ebb Tidal Delta	213,471.2	0	213,471.2	426,942.4	213,471.2
Whiskey Pass Flood Tidal Delta	1,266,721.1	0	1,266,721.1	2,533,442.2	1,266,721.1
Whiskey Pass Inlet	0	-3,386,912.5	-3,386,912.5	2,930,197.0	1,465,098.5
Trinity Island Western Spit	172,551.7	0	172,551.7	224,781.6	112,390.8
Trinity Island Shoreface	0	-14,641,197.1	-14,641,197.1	8,539,207.5	4,269,603.8
Trinity Island Marsh	481,491.0	-1,698,157.7	-1,216,666.7	3,653,967.8	1,826,983.9
Coup Carmen	0	0	0	0	0
East Island Shoreface	0	-5,485,747.5	-5,485,747.5	3,044,794.9	1,522,397.5
East Island Marsh	927,063.1	-2,399,434.6	-1,472,371.6	3,754,059.1	1,877,029.6
East Island Eastern Spit	2,368,790.2	-11,096.2	2,357,694.1	2,057,919.1	1,028,959.6
Wine Island Pass Ebb Tidal Delta	7,025,884.6	-200,773.3	6,825,111.3	8,968,086.5	4,484,043.3
Wine Island Pass Flood Tidal Delta	203,861.8	-291,658.5	-87,796.7	991,040.6	495,520.3
Wine Island Pass Inlet	1,197,104.2	-3,195,482.6	-1,998,378.4	3,250,342.6	1,625,171.3
Wine Island Western Spit	0	-57,708.5	-57,708.5	103,560.0	51,780.0
Wine Island Shoreface	0	-2,942,814.2	-2,942,814.2	1,838,541.3	919,270.7
Wine Island Overwash	2,157,292.7	0	2,157,292.7	2,300,216.5	1,150,108.3
Wine Island Eastern Spit	405,135.3	0	405,135.3	442,918.1	221,459.1
Cat Island Pass Ebb Tidal Delta	2,953,220.4	-5,709,588	-2,756,367.3	14,865,250.9	7,432,625.5
Cat Island Pass Flood Tidal Delta	0	0	0	0	0
Cat Island Pass Inlet	17,395,437.1	-17,948,462.5	-553,025.4	21,820,084.7	10,910,042.4
Totals	36,768,024.2	-57,969,032.6	-21,201,008.5		

Table 2 Time Period I: Volumetric change in geomorphic features (1890s-1930s). See Fig. 1 for locations of islands and inlets and Table 1 for definitions of geomorphic features. Specific locations of bathymetric change are shown in Fig. 9. Volumes of erosion and accretion are shown here with the net change for each feature. The totals for the entire study area are shown at the bottom; the system lost 21.2 x10^6 m^3 in Time Period I. The locations with the largest net loss were the shorefaces of Trinity and East Islands. The Wine Island ebb tidal delta had the largest net sediment gain with 6.8 x10^6 m^3. Uncertainty, in the last column, is very high for some features. Areas of widespread shallow accretion or erosion are most susceptible to large uncertainty.

Time Period II

Time Period II starts where Time Period I left off with the 1930s bathymetric data. There are five separate data available in this time period: 1930s bathymetry, 1934 shoreline, Landsat satellite imagery (from 1973-2006), 1980s bathymetry, oblique aerial photography (from 1984-2006), and 1996 shoreline. All data, except Landsat imagery, was sourced from BICM (Martinez et al., 2009; Miner et al., 2009b; Westphal, 2009). Landsat imagery was sourced from the USGS *EarthExplorer* website. Satellite imagery and photography is presented in the Discussion section of this study.

Shoreline analysis

The general trend of shoreline change was similar in Time Period II to that in Time Period I. The rates of gulf shoreline change were highest at the western ends of both Trinity and East Islands. Because Whiskey Pass formed before this time period, Transect 3 is the first transect from the west with values for both shorelines. Transects 3-5 all had high rates of gulf shoreline change (greater than 850 m), and the rate generally decreased across Trinity Island. The average rate of gulf shoreline change was 682 m landward, while the average rate of bay shoreline change was 346 m seaward. Fig. 10 shows that New Cut had formed by 1996, and Transect 18 on the eastern spit of Trinity Island showed landward change of both gulf and bay shorelines. The central portion of the island underwent the lowest amount of land loss; Zones A and B lost 100% and 97% of land, respectively. As shown in figure 11, most other zones on Trinity Island lost at least 50% land area (except Zones M and N), and that number reached

70% at Area P. The entire island decreased in area from 8.1 km^2 to 2.7 km^2; a total area loss of 66.7%.

On East Island, the highest rates of shoreline change were also due to the landward shift of both gulf and bay shorelines on the western side. Transect 19 did not have values due to the formation of New Cut, but Transects 20-22 showed landward movement of both gulf and bay shorelines as much as 902 m on the gulf-side and 844 m on the bay-side. The eastern side of the island also showed this landward shift of both shorelines, from Transects 27-30. Transect 28 showed values of 390 m landward for the gulf shoreline and 336 m for the bay. The change in area was similarly large on East Island as that on Trinity; however the greatest change occurred in the central portion of the island. The ends of the island were narrow in 1934 and remained so by 1996. The average rate of shoreline change on East Island was 385 m landward for the gulf shoreline and 94.8 m landward for the bay shoreline. The area of the island decreased 61% from 2.1 km^2 to 0.81 km^2.

Wine Island changed the most in terms of shoreline position and area in Time Period II. This was also the last time period that included shoreline polygon data for Wine Island. The shoreline change of the island was drastic with an average of 1887.8 m landward on the gulf side and 1836.3 m on the bay side. All zones covering the island decreased by nearly 100%, except for Zone GG. The total area of the island decreased from 0.57 km^2 to 0.12 km^2 – a loss of 75.4%.

The average change for the gulf shoreline of all islands in Time Period II was 693.8 m landward; the average for the bay shoreline was 33.7 m landward. The total area decreased from 10.8 km^2 in 1934 to 3.7 km^2 in 1996; the rate of area change was -0.12 km^2/year. Trinity Island decreased the most yearly.

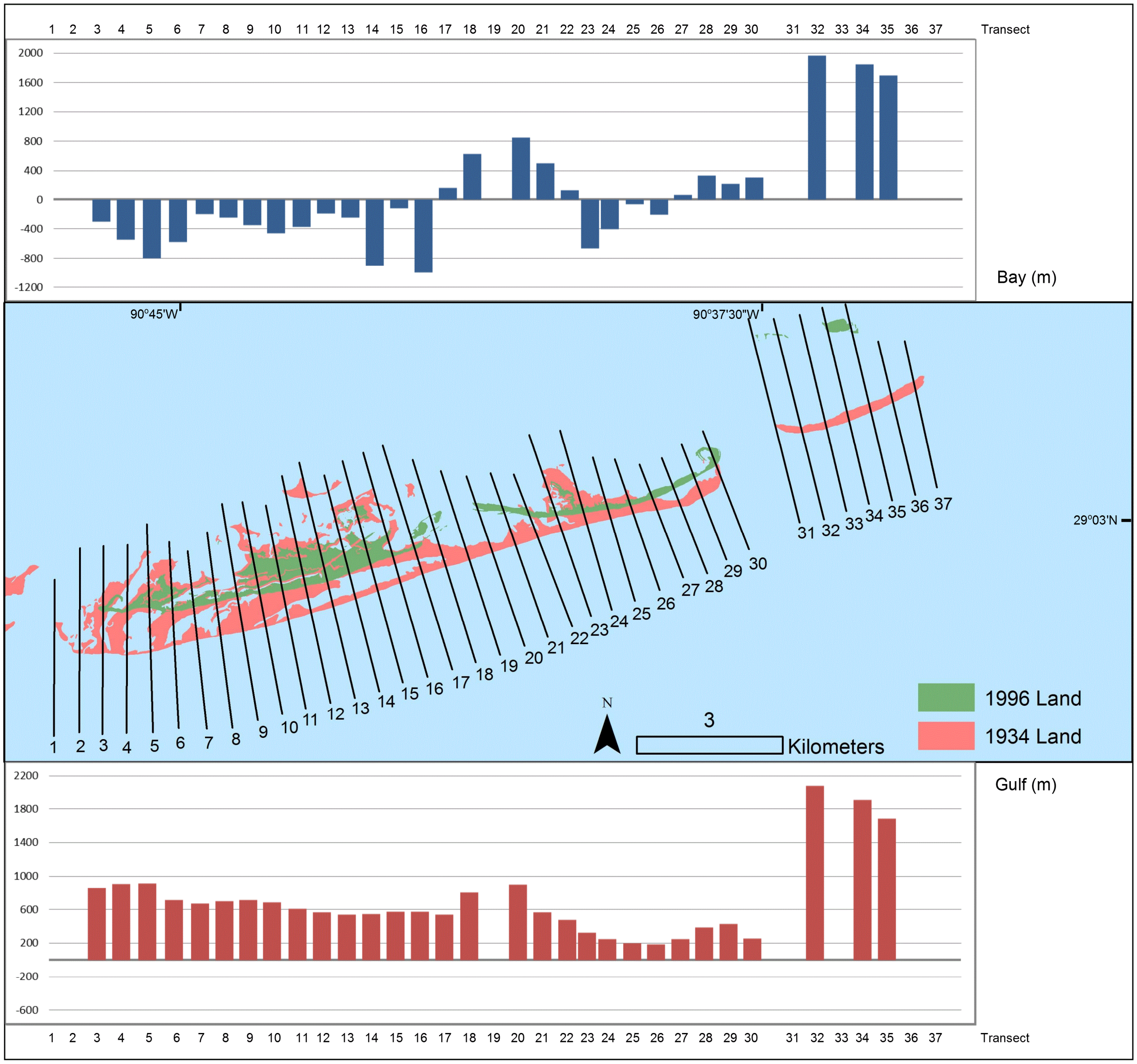


Figure 10 Time Period II: Shoreline change (1934-1996). Shoreline change from 1934 to 1996 was generally much greater than in Time Period I. The gulf shoreline shifted landward an average of 561.2 m landward across Trinity and East Islands, while the Wine Island gulf shoreline shifted an average of 1887.8 m landward. After Coupe Carmen formed between Trinity and East Islands in 1974 (Williams et al., 1992), both gulf and bay shorelines shifted landward (Transects 18-22). Aside from those transects, the magnitude of landward gulf shoreline movement was greatest in the west and decreased eastward across Trinity and East Islands. The bay shoreline shifted seaward across most of Trinity Island (except around New Cut), however the bay shoreline of East Island varied. In the middle of the island, the bay shoreline shifted seaward, but it shifted landward at the flanks where the spits migrated landward. Both gulf and bay shorelines of Wine Island shifted drastically landward.

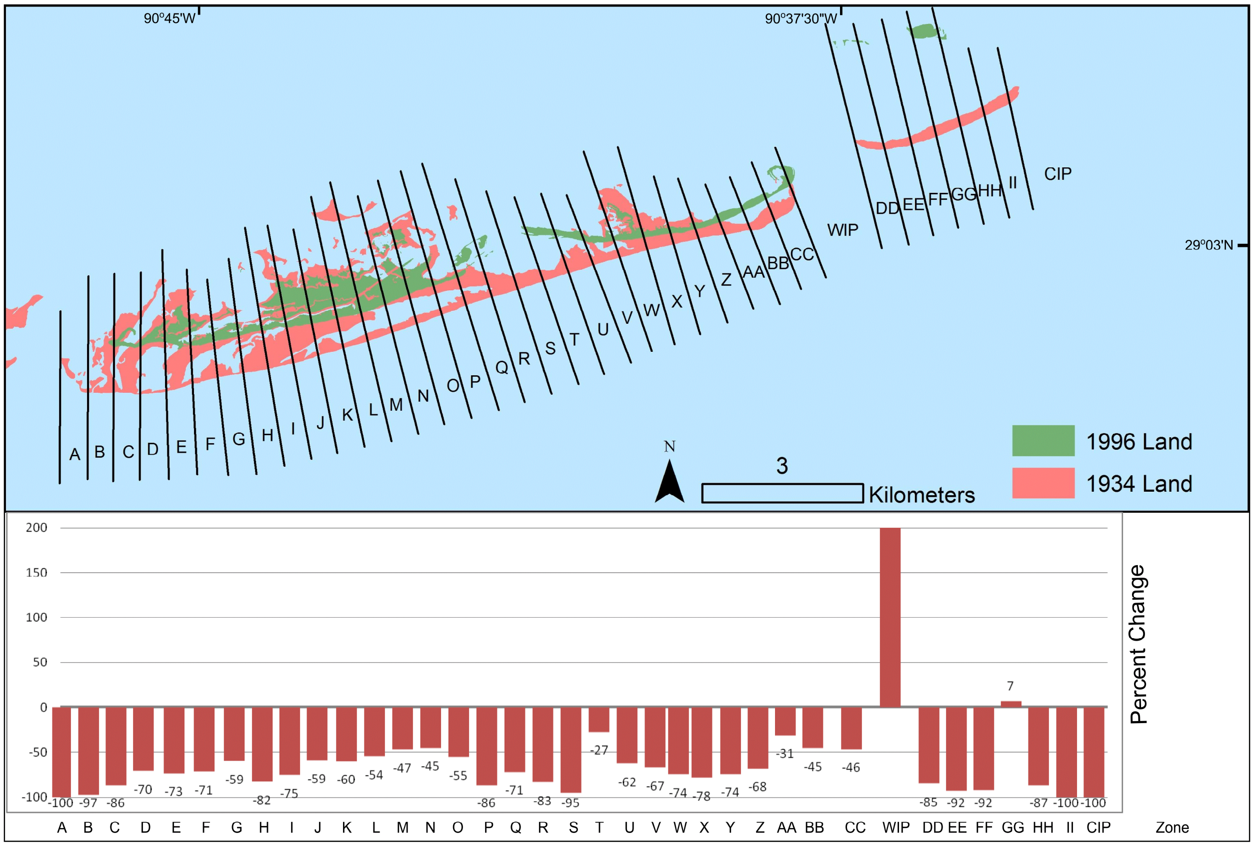


Figure 11 Time Period II: Area change (1934-1996). In Time Period II, land loss was extensive across all three islands, particularly the New Cut region and Wine Island. All zones except Zone GG on Wine Island decreased by 85% or more. Zones R and S also decreased by 83% and 95% with the opening of New Cut. Western Trinity Island underwent major land loss; Zone A lost 100% and Area B lost 97% of land from 1934 to 1996. The greatest land loss on East Island was also the Western portion as the island began to form a convex morphology. In all, the system decreased in area from 10.8 km^2 to 3.7 km^2 – a loss of 66%.

Bathymetric analysis

Similar to the shoreline analysis, the bathymetry analysis of Time Period II highlighted the presence of many of the same trends as were documented in Time Period I. Cat Island Pass was again the feature with the most combined erosion and accretion; however the amounts were of greater magnitude in Time Period II. The result was a more substantial net change (Table 3). The inlet throat had a net sediment gain of 3.9 x 10^6 m^3 and the ebb tidal delta had a net gain of 3.8 x 10^6 m^3. Cat Island Pass continued to fill toward the east and scour along the western edge in Time Period II. The ebb tidal delta shifted westward as well, approximately 2 km. Figure 12 shows that Whiskey Pass also filled in the east and scoured in the west; the inlet and the flood and ebb tidal deltas all underwent a net sediment loss. The inlet throat also shifted in orientation, rotating counter-clockwise approximately 30°. However, the location of the inlet throat itself did not change significantly.

Net sediment loss was greatest along the Trinity Island shoreface (17.2 x 10^6 m^3), Wine Island shoreface (5.0 x 10^6 m^3), Trinity Island marsh (4.2 x 10^6 m^3), and East Island shoreface (3.1 x 10^6 m^3). Every geomorphic feature west of New Cut had net sediment loss.

Features with the greatest net sediment gain included the Cat Island Pass inlet and ebb tidal delta, Wine Island Pass ebb tidal delta (3.4 x 10^6 m^3), Wine Island overwash (2.8 x 10^6 m^3), and New Cut (1.2 x 10^6 m^3). Because New Cut is located between Trinity and East Islands, it was treated as one depositional area rather than an eastern spit on Trinity and western spit on East Island. It is also notable that in Time Period II, the Wine Island shoreface and overwash had a greater discrepancy; the net change for both of them was erosional with a loss of 2.8 x 10^6 m^3.

The entire system within the study area had a net sediment change of -19.9 x 10^6 m^3 in Time Period II; total accretion was 33.6 x 10^6 m^3 and total erosion was 55.6 km^3. Areas of widespread shallow erosion or accretion are subject to high uncertainty, however – see Table 3.

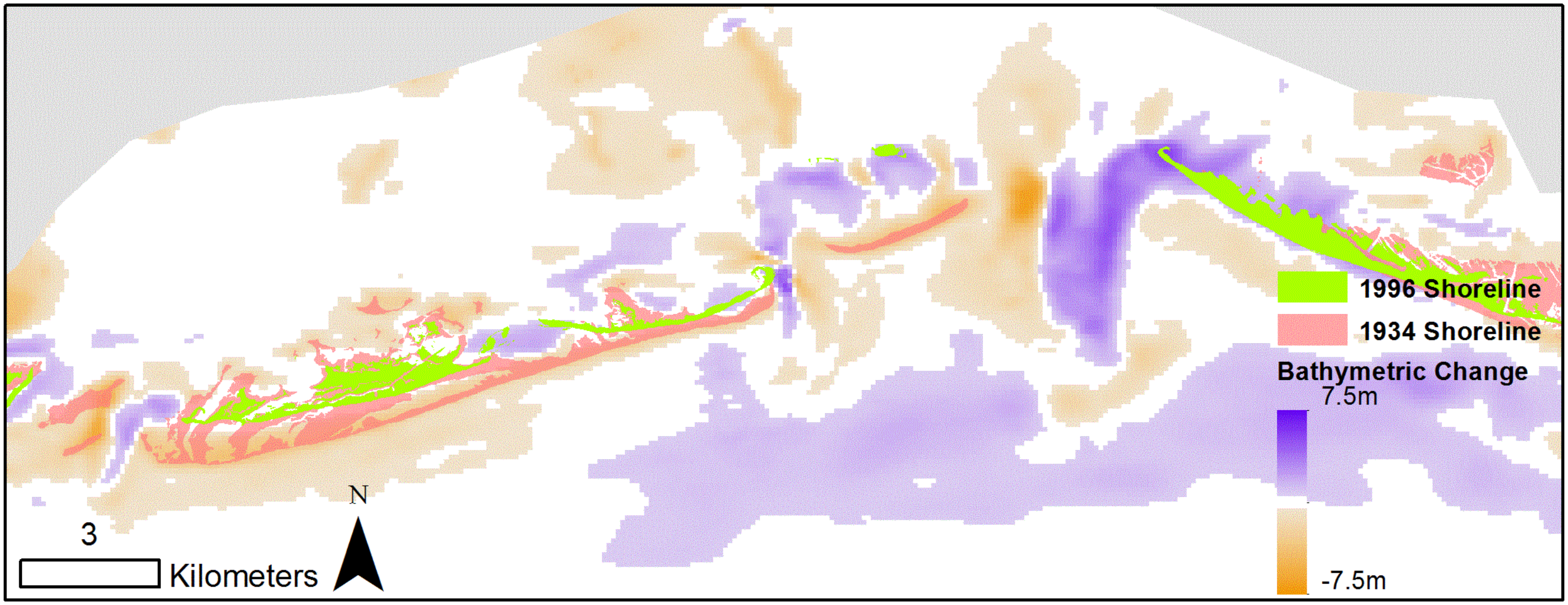


Figure 12 Time Period II: Bathymetric change map (1930s-1980s). (The time interval of this figure is from 1930s-1980s, though the 1996 shoreline is used for reference.) Values of volumetric change for each feature are shown in Table 3. Many of the same patterns in bathymetric change continued from Time Period I into Time Period II. The inlet throats of Cat Island Pass and Whiskey Pass continued to migrate westward due to inlet fill in the east and scour in the west. Wine Island Pass did not change location significantly, but the inlet throat did rotate counter-clockwise. The ebb tidal delta at Cat Island Pass also continued its pattern from Time Period I, with even more widespread accretion in the newer, western location. Shoreface erosion continued across all islands, and Wine Island became fragmented with a small area of scour between the fragments. A large area of accretion formed in the New Cut inlet, which would have been the area for spit accretion for both Trinity and East Islands.

1930s-1980s	Accretion m^3	Erosion m^3	Net Volume Change m^3	Total Area m^2	Uncertainty $\pm m^3$
Whiskey Pass Ebb Tidal Delta	*31,671.2*	*-340,325.7*	*-308,654.5*	*557,701.9*	*278,851.0*
Whiskey Pass Flood Tidal Delta	*184,869.3*	*-244,475.1*	*-59,605.8*	*858,688.7*	*429,344.4*
Whiskey Pass Inlet	*1,156,303.5*	*-5,714,632.2*	*-4,558,328.7*	*3,998,437.6*	*1,999,218.8*
Trinity Island Western Spit	*0*	*0*	*0*	*0*	*0*
Trinity Island Shoreface	*0*	*-17,163,434.9*	*-17,163,434.9*	*14,740,433.7*	*7,370,216.9*
Trinity Island Marsh	*0*	*-4,182,948.2*	*-4,182,948.2*	*4,259,637.9*	*2,129,819.0*
Coup Carmen	*1,216,328.3*	*0*	*1,216,328.3*	*1,244,924.5*	*622,462.3*
East Island Shoreface	*0*	*-3,147,896.4*	*-3,147,896.4*	*2,645,418.2*	*1,322,709.1*
East Island Marsh	*1,323,515.8*	*-580,395.1*	*743,120.7*	*3,060,495.9*	*1,530,248.0*
East Island Eastern Spit	*280,557.4*	*0*	*280,557.4*	*495,337.7*	*247,668.9*
Wine Island Pass Ebb Tidal Delta	*3,358,113.1*	*0*	*3,358,113.1*	*5,881,405.0*	*2,940,702.5*
Wine Island Pass Flood Tidal Delta	*0*	*-49,634.0*	*-49,634.0*	*95,880.7*	*47,940.4*
Wine Island Pass Inlet	*2,013,781.5*	*-3,167,856.4*	*-1,154,075.0*	*5,234,628.4*	*2,617,314.2*
Wine Island Western Spit	*0*	*-461,153.0*	*-461,153.0*	*381,611.8*	*190,805.9*
Wine Island Shoreface	*0*	*-5,001,600.8*	*-5,001,600.8*	*2,890,238.6*	*1,445,119.3*
Wine Island Overwash	*3,510,756.3*	*-688,979.8*	*2,821,776.6*	*3,915,022.5*	*1,957,511.3*
Wine Island Eastern Spit	*0*	*0*	*0*	*0*	*0*
Cat Island Pass Ebb Tidal Delta	*3,795,250.7*	*0*	*3,795,250.7*	*6,992,016.4*	*3,496,008.2*
Cat Island Pass Flood Tidal Delta	*0*	*0*	*0*	*0*	*0*
Cat Island Pass Inlet	*16,754,502.0*	*-12,817,936.6*	*3,936,565.4*	*17,951,933.1*	*8,975,966.6*
Totals	*33,625,648.9*	*-53,561,267.8*	*-19,935,619.0*		

Table 3 Time Period II: Volumetric change in geomorphic features (1930s-1980s). Specific locations of bathymetric change are shown in Fig. 12. The volumetric change in Time Period II is shown here for each geomorphic feature, and the same features had the greatest volumetric change. Cat Island Pass had the largest total sediment flux, and the net volume change of $+3.9 \times 10^6$ m^3 led to the inlet being the largest area of deposition in the system. The ebb tidal delta of Cat Island Pass had a net increase only slightly below the inlet itself. The Wine Island Pass ebb tidal delta also had a large increase in sediment volume. The largest areas of net sediment loss continued to be the shorefaces of all three islands as well as the marsh of Trinity Island.

Time Period III

Time Period III is the most recent and shortest time interval of the three that were examined in this study. However, the data in this time period is the most plentiful and generally of the highest quality because it was collected using state-of-the-art technologies and instruments. The earliest data in Time Period III is the 1980s bathymetric data set from BICM and Landsat satellite imagery. Oblique aerial photography is also available from BICM starting in 1984. The 1996 shoreline data that ended Time Period II is used as the earliest shoreline data in this time period, followed by shorelines from 2004 and 2005. The most recent data is bathymetry from 2006.

Shoreline analysis

The shoreline analysis of Time Period III was unique in that there were three shoreline datasets and the islands were at their smallest, whereas tidal inlets were at their largest. There was also no comparison for Wine Island; the last dataset in which the island maintained a subaerial footprint is from 1996. In line with trends from earlier time periods, most significant amount of linear shoreline change occurred at the west end of Trinity Island and the east end of East Island. Figure 13 shows that this was more pronounced from 1996 to 2004, when the gulf shoreline shifted 294 m landward on Trinity Island's western spit (Transect 3) and 175 m landward on East Island's eastern spit (Transect 29). The average across both islands was only 60 m landward. Figure 15 indicates that from 2004 to 2005, these spits again migrated the most relative to the rest of the island. The gulf shorelines in the middle of each island shifted landward fairly consistently; however the shoreline at Transects 18-22 prograded seaward as much as 324 m between 1996 and 2004 and 14 m between 2004 and 2005.

The bay shoreline change of Trinity Island was variable in Time Interval III across the two shoreline polygon data intervals. Fig. 13 shows that from 1996-2004, the bay shoreline migrated landward on the western spit and west-central portion of the island. The bay shoreline on the east-central portion of the island and especially the eastern spit shifted seaward; as much as 336 m on the eastern spit. After 2004, the majority of the island's bay shoreline was shifting seaward at rates generally consistent with rates from 1996 to 2004. East Island showed bay shoreline change that was less varied with an average of 84 m landward from 1996 to 2004. After 2004 however, most of the island's bay shoreline shifted seaward between 10 and 20 m. The exception to that is the eastern spit and New Cut (Transects 18-19); in this location the bay shoreline shifted 406 m landward along Transect 18.

These dynamic shoreline shifts resulted in equally dynamic area changes across the three islands in existence in 1996. Wine Island underwent 100% land loss, equating to a net loss of 0.14 km^2 from the system. The eastern spit of East Island also migrated and this coupled with the loss of Wine Island resulted in 100% land loss from every zone east of Zone CC between 1996 and 2004 (Fig. 14). This land loss trend continued toward the west during the 2004 to 2005 interval, as Zones BB and CC had net losses of 97.6% and 84.2% land area, respectively. Trinity Island gained land on its western half from 1996 to 2004 while losing land on the eastern half. All but one zone gained land from Zone P to Zone AA. Zones P and S especially showed large gains of 214% (+.091 km^2) and 809.1% (+.05 km^2), respectively. From 2004 to 2005, most areas in the islands began to lose land, especially the flanking spits. As seen in Fig. 16 however, zones in New Cut continued to have a net increase in land, with Zones Q, R, S and T increasing 99%, 590%, 163%, and 20%, respectively.

The average gulf shoreline change of the entire system was 60 m landward (1996-2004) and 34 m landward (2004-2005), and the average bay shoreline change was 36 m landward (1996-2004) and 19.8 m landward (2004-2005). The overall rate per year of Time Period III was 9.7 m/yr landward for the gulf shoreline and 6.04 m/yr landward for the bay shoreline. The area of Trinity Island was 2.70 km^2 in 1996, 2.65 km^2 in 2004, and 2.72 km^2 in 2005 – a gain of 7.4% across the entire time period. East Island was 0.81 km^2 in 1996, 1.29 km^2 in 2004, and 1.17 km^2 in 2005 – a gain of 44.3%. Wine Island was 0.14 km^2 in 1996 and decreased in land area by 100% before 2004.

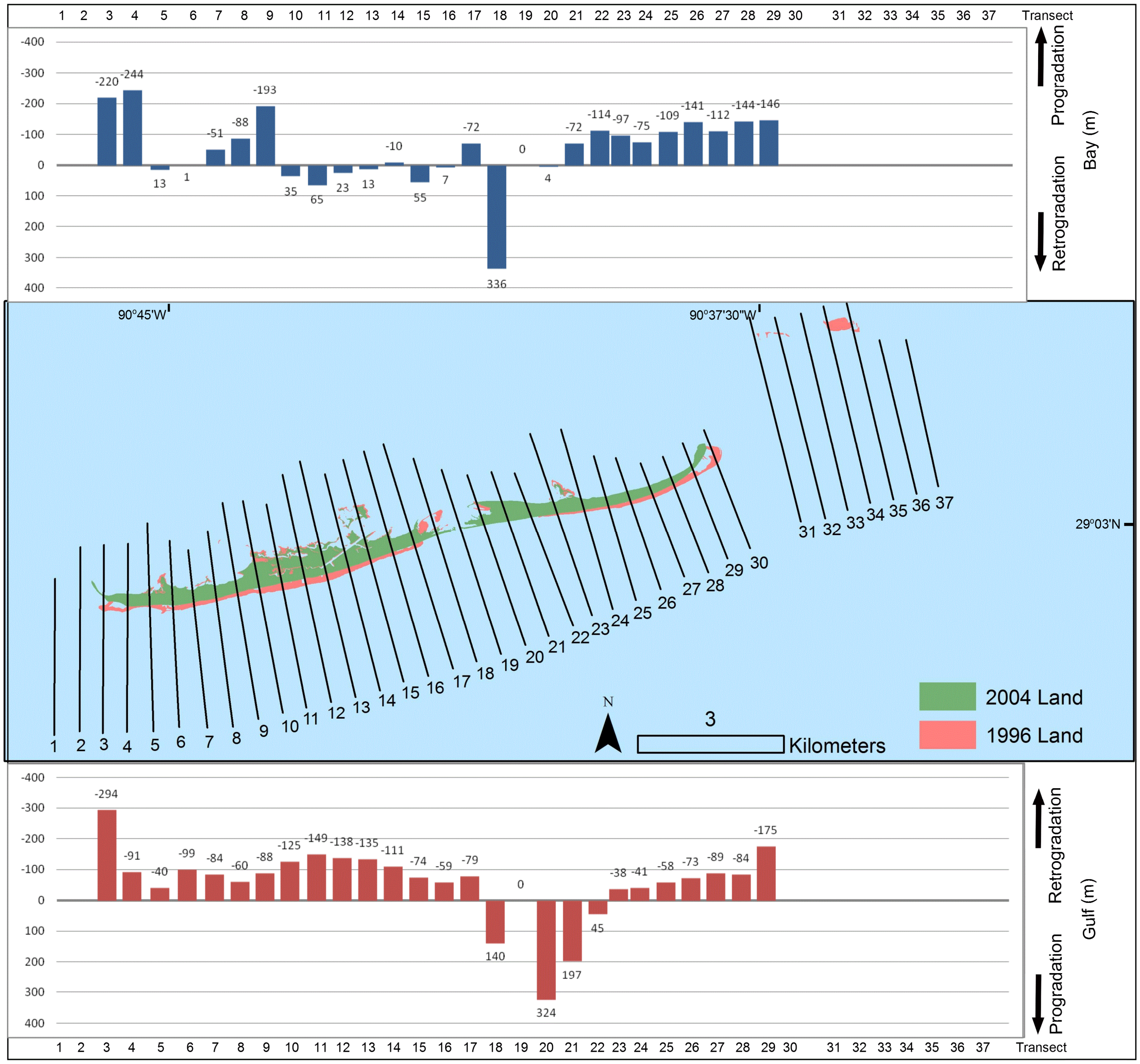


Figure 13 Time Period III: Shoreline change (1996-2004). The shoreline comparison in Time Period III covers a significantly shorter time than the previous two time periods, but there are some important features to note. First, Wine Island existed as a subaerial feature in 1996, but was entirely subaqueous by 2004. A shoreline comparison could not be made with just one dataset. Second, CWPPRA restoration projects*TE-20 and TE-24* (Penland et al., 2003) to restore land on East and Trinity Islandswere both completed in 1999. The seaward shift in the gulf shoreline along Transects 18-22 reflects these projects. The rest of the gulf shoreline along the islands continued to shift landward; the flanking spits had the greatest magnitude of change. The bay shoreline also shifted landward across the entirety of East Island and much of Trinity Island – also a result of the restoration projects in the late 1990s.

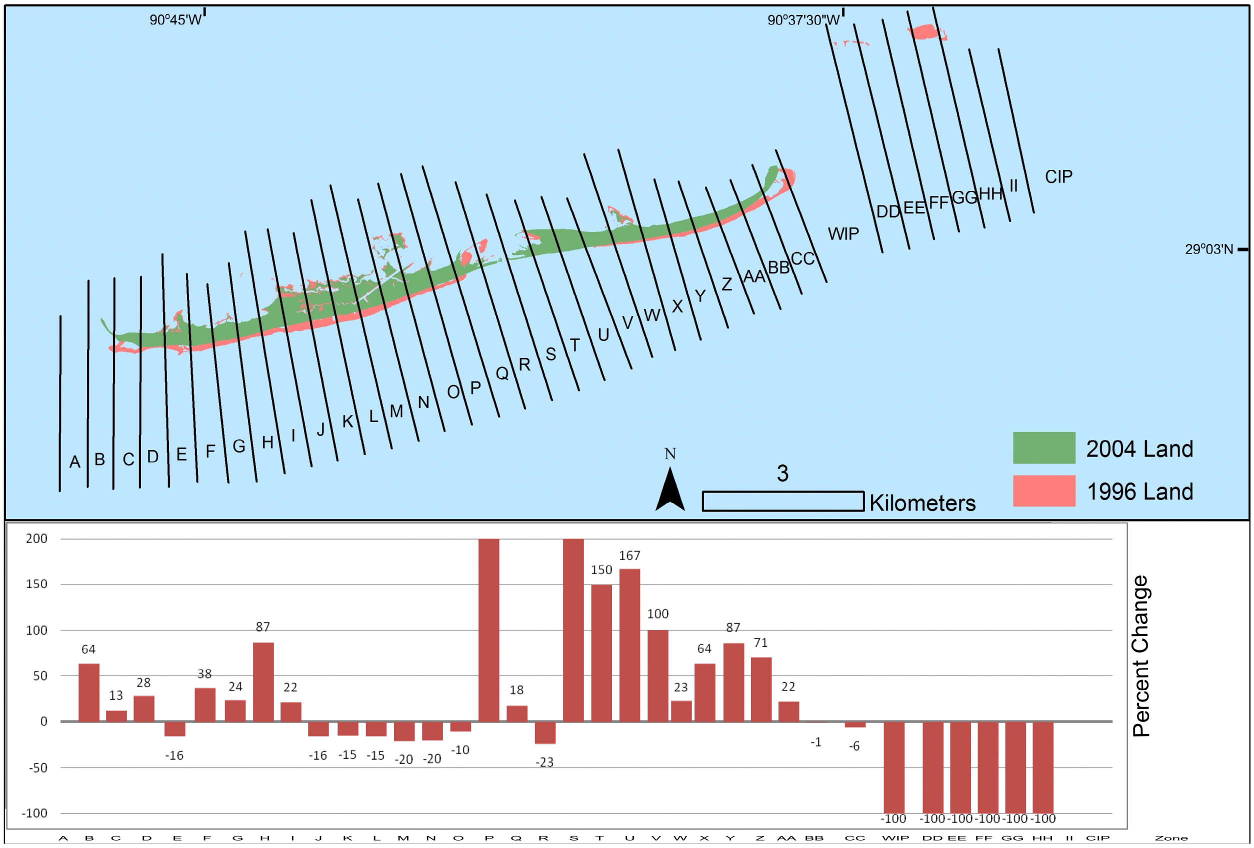


Figure 14 Time Period III: Area change (1996-2004). Due to CWPPRA restoration projects *TE-20* and *TE-24*, the barrier system increased in area by 0.3 km^2. This increase occurred despite the loss of 100% of land area on Wine Island and a loss of 0.05 km^2 on Trinity Island. The area of East Island increased by nearly 0.5 km^2, particularly on the western portion of the island.

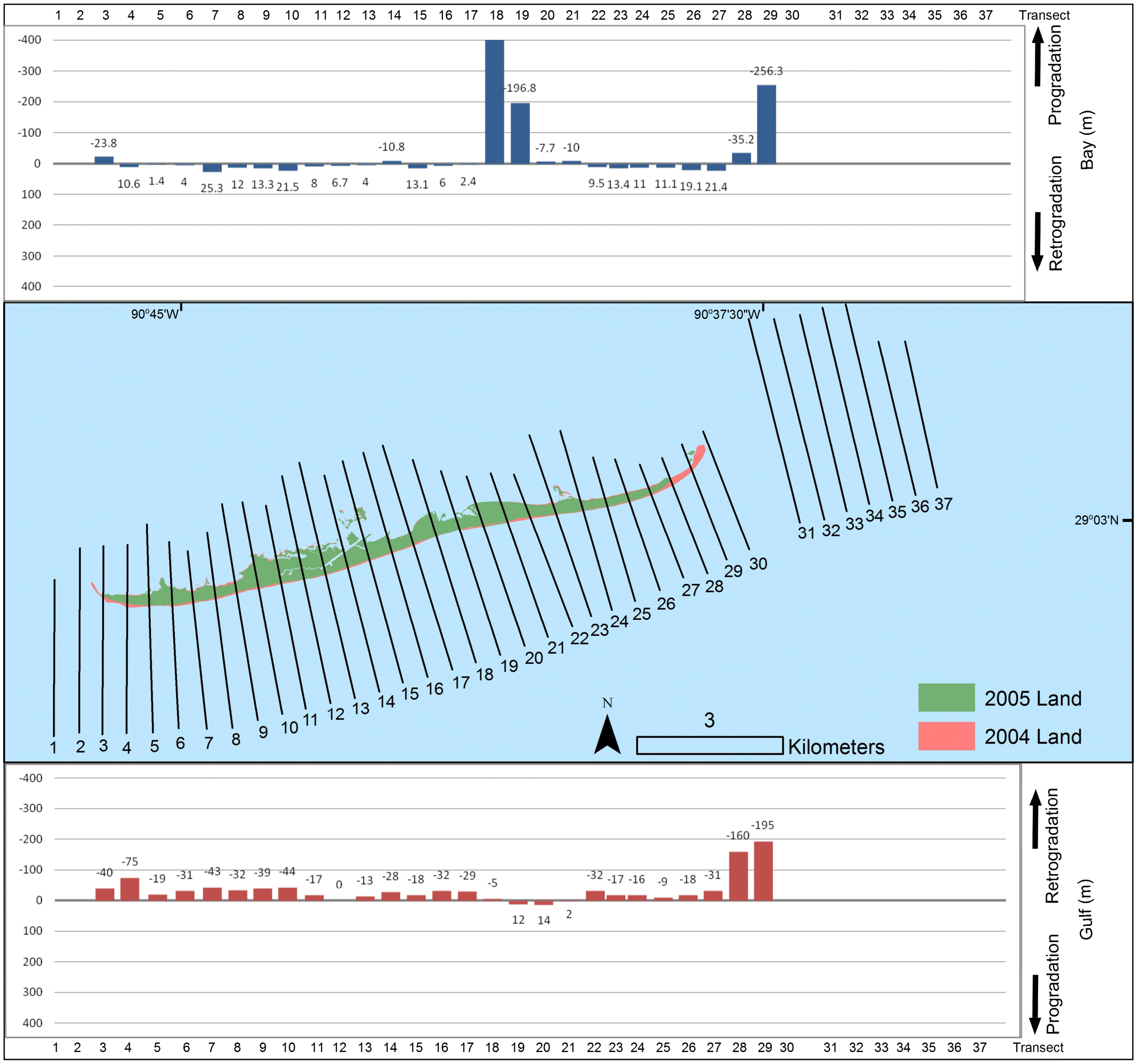


Figure 15 Time Period III: Shoreline change (2004-2005). The second shoreline change analysis of Time Period III covered only one year, but it offers a unique opportunity to see the yearly fluctuations in shoreline. The gulf shoreline across Trinity and East Islands generally shifted landward <50m; however, the New Cut area (Transects 18-21) and flanking spits varied. The gulf shoreline at New Cut shifted slightly seaward or very slightly landward, and it shifted landward as much as 75 m on the western spit of Trinity and as much as 195 m on the eastern spit of East Island. The bay shoreline shifted seaward <25 m except at New Cut and the eastern spit of East Island. The shift in bay shoreline at New Cut was as high as 406 m landward as a result of the restoration projects.

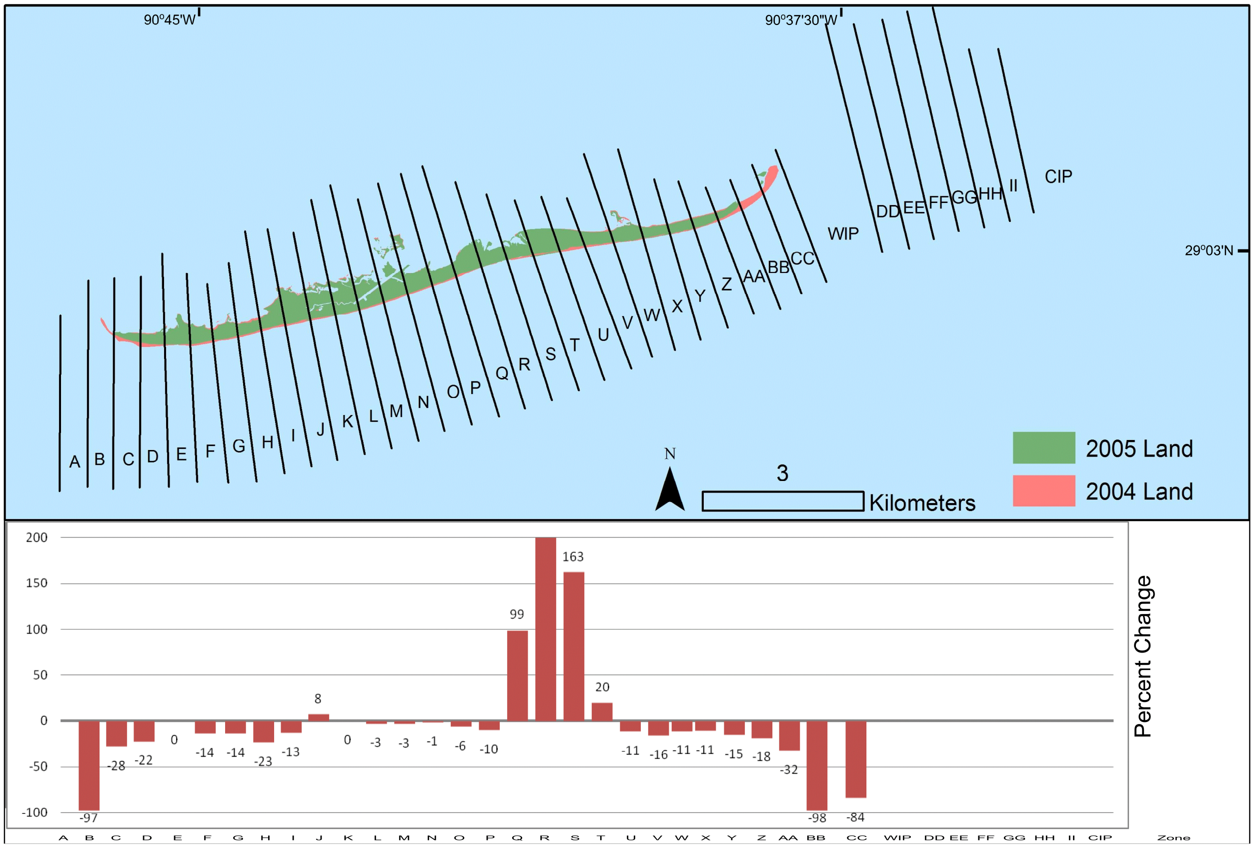


Figure 16 Time Period III: Area change (2004-2005). Within just one year, the area of both remaining islands changed a relatively large amount. Central Trinity Island (Zones K-N) was the only location that had negligible rates of change, whereas New Cut and both flanking spits changed dramatically. New Cut had a total gain of 0.38 km^2 of land in just one year. Both the western spit of Trinity Island and eastern spit of East Island lost large percentages of land, however. The total land change from 2004-2005 was -0.06 km^2, primarily from the flanking spits.

Bathymetric Analysis

During Time Period III the greatest sediment loss of the study period took place. Some features that had net accretion in earlier time periods (e.g. Wine Island Pass flood tidal delta, East Island eastern spit) underwent net erosion. Fig. 17 and the longshore profile in Appendix II show that the submergence of Wine Island led to the coalescence of Cat Island Pass and Wine Island Pass. In addition, the throat of Wine Island Pass filled with 1.9 x 10^6 m^3 of sediment, where there was a loss of 8.0 x 10^6 m^3 along the eastern side. Despite the inlet fill, this resulted in a net loss of 6.1 x 10^6 m^3 in the inlet. This scouring of higher elevation and filling of low elevation continued into Cat Island Pass, which had high amounts of accretion and erosion resulting in a net sediment loss of 4.0 x 10^6 m^3. Whiskey Pass also showed a similar pattern of erosion and accretion with a net loss of 4.3x 10^6 m^3. Outside of the inlets, the shorefaces of Trinity and East Islands continued to have the largest change in sediment volume of any feature with losses of 14.4 x 10^6 m^3 and 8.0 x 10^6 m^3, respectively. Each of the ebb tidal deltas, as well as the marshes on both Trinity and East Islands, also showed significant sediment loss. As indicated in Table 5, the uncertainty on these volumes is very high (some close to 100%) due to widespread shallow erosion. The only geomorphic feature where sediment volume actually increased was New Cut, which gained 1.0 x 10^6 m^3.

The overall change in sediment volume in Time Period III was -67.7x 10^6 m^3; total erosion was 77.4x 10^6 m^3 and total accretion was 9.7x 10^6 m^3. See Table 4 for information on uncertainty.

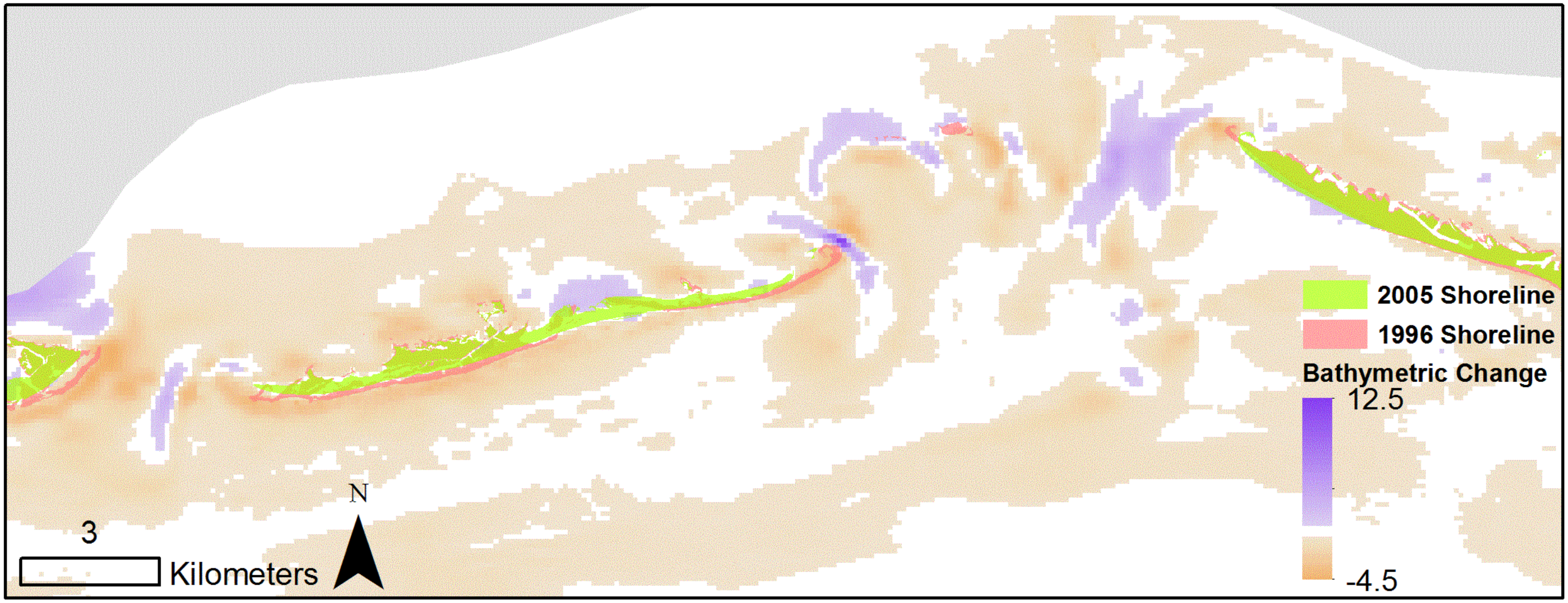


Figure 17 Time Period III: Bathymetric change map (1980s-2006). (Note the time interval of this figure is from 1980s-2006, though the 1996 and 2005 shorelines are used for reference.) Values of volumetric change for each feature are shown in Table 4. The bathymetry in Time Period III was dominated by widespread, shallow erosion and pockets of inlet fill. Cat Island Pass and Whiskey Pass continued the pattern of inlet fill in the east and scour in the west, but as both inlets became wider, the vertical change decreased and horizontal area increased. Wine Island Pass remained in approximately the same location, but the 1980s inlet throat was filled as Wine Island Pass and Cat Island Pass fully coalesced to one inlet. Erosion continued at the shorefaces of Trinity and East Island; it was most substantial at the western and eastern portions of Trinity and East Island, respectively. A large pocket of accretion formed at New Cut, leading to the shorelines of the islands joining.

1980s-2006	Accretion m^3	Erosion m^3	Net Volume Change m^3	Total Area m^2	Uncertainty $\pm m^3$
Whiskey Pass Ebb Tidal Delta	0	-6,346,777.4	-6,346,777.4	8,494,615.4	4,247,307.7
Whiskey Pass Flood Tidal Delta	0	-1,970,810.9	-1,970,810.9	2,264,886.6	1,132,443.3
Whiskey Pass Inlet	620,673	-4,879,245.5	-4,258,572.8	4,886,368.4	2,443,184.2
Trinity Island Western Spit	31,520.6	-485,555.0	-454,034.4	725,641.9	362,821.0
Trinity Island Shoreface	0	-14,444,873.4	-14,444,873	12,082,756	6,041,378
Trinity Island Marsh	0	-6,697,822.4	-6,697,822.4	12,082,755.7	6,041,377.9
Coup Carmen	1,012,864.2	0	1,012,864.2	1,237,100.6	618,550.3
East Island Shoreface	0	-7,990,087.5	-7,990,087.5	7,760,857.2	3,880,428.6
East Island Marsh	35,739.8	-2,527,625.3	-2,491,885.6	2,703,423.8	1,351,711.9
East Island Eastern Spit	1,332.6	-4,178,921.7	-4,177,589.1	3,155,159.3	1,577,579.7
Wine Island Pass Ebb Tidal Delta	0	-5,033,466.8	-5,033,466.8	6,715,196.7	3,357,598.4
Wine Island Pass Flood Tidal Delta	0	0	0	0	0
Wine Island Pass Inlet	1,849,152.1	-7,965,733.4	-6,116,581.3	9,887,920.1	4,943,960.1
Wine Island Western Spit	n/a	n/a	n/a	n/a	n/a
Wine Island Shoreface	n/a	n/a	n/a	n/a	n/a
Wine Island Overwash	n/a	n/a	n/a	n/a	n/a
Wine Island Eastern Spit	n/a	n/a	n/a	n/a	n/a
Cat Island Pass Ebb Tidal Delta	231,053.9	-4,894,020.1	-4,662,966.2	6,878,706.2	3,439,353.1
Cat Island Pass Flood Tidal Delta	0	0	0	0	0
Cat Island Pass Inlet	5,963,173.3	-10,005,049.2	-4,041,875.9	13,232,682.7	6,616,341.4
Totals	9,745,509.1	-77,419,988.3	-67,674,479.2		

Table 4 Time Period III: Volumetric change in geomorphic features (1980s-2006). Specific locations of bathymetric change are shown in Fig. 17. Total sediment loss from the system was greatest by far in Time Period III; the features that contributed to this most were the shorefaces of Trinity and East Island and the Trinity Island marsh. New Cut was the only feature with net sediment gain – even inlet fill was offset by widespread erosion in all three inlets. Wine Island was not considered a feature in Time Period III, so the shoals in the area previously occupied by the island were considered part of Wine Island Pass.

Shoreline (m)					
Gulf side (ave)	*1887-1934*	*1934-1996*	*1996-2004*	*2004-2005*	*1887-2005*
Trinity Island	*-584.59*	*-606.38*	*-82.57*	*-25.71*	*1198.13*
East Island	*-309.43*	*-353.09*	*0.66*	*-37.32*	*459.51*
Wine Island	*-462.86*	*-809.04*	*n/a*	*n/a*	*n/a*
Total	*-472.32*	*-562.57*	*-39.95*	*-24.61*	*731.90*
Bay side (ave)	*1887-1934*	*1934-1996*	*1996-2004*	*2004-2005*	*1887-2005*
Trinity Island	*93.79*	*307.76*	*-18.50*	*-17.35*	*405.87*
East Island	*140.40*	*-86.92*	*-83.73*	*-35.04*	*64.80*
Wine Island	*-293.94*	*-787.00*			
Total	*35.55*	*-27.36*	*-36.15*	*-19.81*	*218.46*
Rate/Year (Gulf)	*1887-1934*	*1934-1996*	*1996-2004*	*2004-2005*	*1887-2005*
Trinity Island	*-12.44*	*-9.78*	*-10.32*	*-25.71*	*10.15*
East Island	*-6.58*	*-5.70*	*0.08*	*-37.32*	*3.89*
Wine Island	*-9.85*	*-13.05*	*n/a*	*n/a*	*n/a*
Total	*-10.05*	*-9.07*	*-4.99*	*-24.61*	*6.20*
Rate/Year (Bay)	*1887-1934*	*1934-1996*	*1996-2004*	*2004-2005*	*1887-2005*
Trinity Island	*2.00*	*4.89*	*-2.31*	*-17.35*	*3.44*
East Island	*2.99*	*-1.38*	*-10.47*	*-35.04*	*0.55*
Wine Island	*-6.25*	*-12.49*	*n/a*	*n/a*	*n/a*
Total	*0.76*	*-0.43*	*-4.52*	*-19.81*	*1.85*

Table 5 Shoreline Change Totals. Shoreline change for each island is shown here across time intervals and as yearly averages. The greatest overall shoreline retreat was at Wine Island, followed by Trinity Island. Rates of retreat across the islands were relatively consistent for the first three time intervals, but they were much higher from 2004 to 2005 – likely a result of large hurricanes that occurred during 2005..

Area (km^2)	*1887*	*1934*	*1996*	*2004*	*2005*
Trinity Island	*11.682*	*8.096*	*2.700*	*2.655*	*2.720*
East Island	*3.325*	*2.124*	*0.811*	*1.294*	*1.170*
Wine Island	*1.605*	*0.574*	*0.141*		
Total	*16.618*	*10.794*	*3.652*	*3.949*	*3.891*
Change/Year (km^2)	*1887-1934*	*1934-1996*	*1996-2004*	*2004-2005*	*1887-2005*
Trinity Island	*0.076*	*0.087*	*0.006*	*-0.065*	*0.076*
East Island	*0.026*	*0.021*	*-0.060*	*0.124*	*0.018*
Wine Island	*0.022*	*0.007*	*0.018*	*0*	*0.014*
Total	*0.124*	*0.115*	*-0.037*	*0.058*	*0.108*
Percent Change	*1887-1934*	*1934-1996*	*1996-2004*	*2004-2005*	*1887-2005*
Trinity Island	*-30.696*	*-66.654*	*-1.659*	*2.441*	*-76.719*
East Island	*-36.130*	*-61.818*	*59.551*	*-9.576*	*-64.817*
Wine Island	*-64.250*	*-75.362*	*-100*		*-100*
Total	*-35.046*	*-66.165*	*8.130*	*-1.464*	*-76.584*

Table 6 Area Change Totals. The change in area by island is shown here, including yearly and percentage changes. Trinity Island consistently lost the greatest amount of land by area, but Wine Island lost the greatest percentage, eventually decreasing by 100%.

Interpretations and Discussion

Because the farthest updrift feature within the study area is Cat Island Pass, longshore sediment input from the east would be introduced first into this inlet system. Jaffe et al. (1989, 1997) have shown that a significant amount of sediment bypasses both Cat Island Pass and Wine Island Pass, but this sediment cannot be fully differentiated from the Cat Island Pass and Wine Island Pass ebb tidal deltas. As a consequence, this bypassing sediment is treated in this study as part of these ebb tidal delta features. The study area is discussed following the direction of longshore transport – from Cat Island Pass in the east to Whiskey Pass in the west.

Time Period I – 1887 to 1934

Because there was no evidence of sediment bypassing before the 1930s (Jaffe et al., 1989, 1997), sediment from longshore sources would first enter the Cat Island Pass inlet before nourishing the downdrift eastern Isles Dernieres. As shown in Fig. 9, a sediment volume of 17.4 x 10^6 m^3 was deposited in Cat Island Pass during Time Period I. This westerly-directed deposition forced the main tidal channel to migrate 2.3 km westward as Timbalier Island prograded westward into the inlet. The cross-sectional area of Cat Island Pass decreased from 32,221 m^2 to 22,625 m^2; correspondingly the CIP ebb tidal delta decreased in volume by 2.75 x 10^6 m^3. As the eastern area of the pass and the older inlet throat filled with sediment, tidal ravinement on the western side eroded the barrier lithesome of Wine Island and resulted in much of the island's land loss that is shown in Fig. 8. By the 1930s, the main tidal channel of Cat Island Pass was directly adjacent to Wine Island and curved slightly around the island, concave to the west. This curvature resulted in longshore tidal ravinement on the eastern shoreface of Wine Island that extended deeper than the shoreface ravinement surface, as shown in the longshore profile in Appendix II. An ebb tidal delta formed just seaward of this curved channel, as shown in Fig. 9. The curvature in this channel was typical of all inlets in the study area, and was most likely a result of wave-driven sediment input on the eastern side from the eroding eastern portion of the Cat Island Pass ebb tidal delta. During Time Period I, a relatively small amount of sediment from eastern, longshore sources was likely transported across Cat Island Pass by wave action and then deposited on the outer shoreface of Wine Island. This sediment may have then been reworked by wave action on the Wine Island shoreface, and it likely contributed a small volume to the Wine Island sand body.

Despite this sediment input, Wine Island underwent the most substantial land loss of the three islands in the study area. Land loss was particularly prevalent along the eastern portion of the island. Approximately the western third of the island has a core of bay/lagoon fine-grained mud deposits, whereas the eastern two thirds are barrier sands (Penland et al., 1988). It appears that the mud deposits were better able to resist tidal and shoreface ravinement. Fig. 8 shows the total land loss of Zone CIP as well as landward migration and approximately 50% land loss of the rest of the island. Despite this erosion, however, more than two thirds of the sediment remained as a submarine portion of the Wine Island sand body 500-700 m landward of the 1890s location. A small spit also developed on the western side.

To the west of Wine Island, Wine Island Pass decreased in cross-sectional area from 10,518.1 m^2 to 7318.2 m^2, mostly due to the progradation of the East Island eastern spit into the inlet. Sediment was deposited on both sides of Wine Island Pass in Time Period I from the spit accretion in the west and inlet fill in the east. A total of 4.36 x 10^6 m^3 of sediment was deposited in the inlet, scour occurred in the throat in response, and the depth of the thalweg increased from -6.7 m to -9.6 m.

The Wine Island Pass ebb tidal delta increased in volume by 6.83 x 10^6 m^3 – the most of any geomorphic feature in Time Period I. Erosion within the Wine Island Pass inlet only accounted for 3.20 x 10^6 m^3 of sediment; the additional volume deposited in the ebb tidal delta was likely a result of eastward longshore transport of sediment liberated from the shoreface of Trinity and East Islands.

Due to this erosion of the shoreface of Trinity and East Islands, the shoreline of the islands (which were continuous in Time Period I) retreated landward fairly consistently across the gulf side. Fig. 7 shows that shoreline retreat was lowest in two areas: the western side of Trinity Island (not including the spit) and the eastern spit of East Island. In fact, the eastern spit actually prograded slightly seaward due to the large accumulation of sediment; this large depositional area was then subjected to the tidal processes of Wine Island Pass. The geomorphology of the western part of Trinity Island (approximately Zones A-G in Fig. 8) is a result of the underlying beach ridge deposits known as Cheniere Caillou (Penland et al., 1988; McBride et al., 1989), and these deposits are likely more resistant to erosion than those underlying the rest of Trinity and East Islands.

The bay shoreline of Trinity and East Islands generally shifted seaward between 1887 and 1934, resulting in in-place drowning across much of both islands. However, a seaward shift in both gulf and bay shorelines occurred in the eastern spit of East Island, and land area generally increased.

The farthest down-drift feature in the study area is Whiskey Pass, which formed during Time Period I. This inlet divided the Isles Dernieres approximately in half, and it is suggested to have formed in the approximate location of a relict distributary channel (Penland et al., 1988). This process of tidal inlet reoccupation of formerly active distributaries may be a recurring process for the Mississippi River delta plain (Levin, 1993). There was net erosion of 3.39×10^6 m^3 of sediment as the cross sectional area of Whiskey Pass increased to 5555.6 m^2 by the 1930s. There was deposition in both ebb tidal deltas; Whiskey Pass was the only inlet in the study area with an expanding flood tidal delta in this time period. This may be an indication that Whiskey Pass was a more flood-dominated tidal inlet, whereas Wine Island Pass was more ebb-dominated. The inlet also started to follow the westward-migrating trend of Cat Island Pass and Wine Island Pass due to a small area of deposition in the western spit of Trinity Island. This spit accretion indicates bidirectional sediment transport on Trinity and East Islands, a process that is corroborated by numerical modeling (Georgiou et al., 2005).

Time Period II – 1934 to 1996

During Time Period II, Cat Island Pass and Wine Island Pass coalesced into an eastern and western channel complex within a larger inlet. During this time, Wine Island existed as a large sand body separating the two inlets with a small subaerial portion. As shown in the longshore profile in Appendix II, the main eastern channel, still considered here as Cat Island Pass, steepened along strike and increased in depth from -7.69 m to -8.19 m. While Cat Island

Pass consisted of several small channels separated by submarine bars in Time Period I, the main tidal channel increased in cross-sectional area to accommodate the encroaching aggradation of Timbalier Island into the inlet in Time Period II. Fig. 12 shows the lateral progradation of Timbalier Island and inlet fill associated with accretion in the eastern part of pass, as well as the scour that took place in the western portion as the inlet throat continued its western migration approximately 700 m by the 1980s. Sediment volume increased in Cat Island Pass by 3.94 x 10^6 m^3 in during Time Period II.

The Cat Island Pass ebb tidal delta again decreased in volume in the east and increased in the west. Sediment bypassing on the lower shoreface contributed to the volumetric increase in this period.

This bypassing sediment also contributed to the Wine Island sand body. In fact, sediment bypassing may have been the reason the sand body maintained subaerial integrity through Time Period II. The island and the associated shoal were pushed landward by tidal currents and severed by two tidal channels as Cat Island Pass migrated westward. The subaerial portion of Wine Island migrated landward approximately 2 km between the 1930s and 1980s, but the barrier island sands of the larger sand body sloped gently seaward approximately 1 km to the shoreface ravinement surface. The Wine Island sand body had a net loss of 2.64 x 10^6 m^3 across Time Period II.

Wine Island Pass occupied a fairly consistent location in Time Period II, but the direction of flow appears to have shifted counter-clockwise according to location of scour and inlet fill. As the Wine Island sand body was redistributed landward, the direction of flow of the Wine

Island Pass inlet was forced to align in a more longshore direction as shown in Fig. 12. This change in direction could also be evidence of a circular tidal pattern, corroborating evidence demonstrated by tidal deltas across Time Periods I and II. The existing ebb tidal delta of Wine Island Pass was largely dispersed, but a small accretionary lobe downdrift of the inlet may be a result of deposition from the ebb tidal jet pushed downdrift from stronger longshore current due to the deposition of the sediment bypassing Cat Island Pass.In addition, a depositional area in the backbarrier and marsh area of East Island was likely a flood tidal deposit – a result of additional sediment input into the inlet during Time Period II.

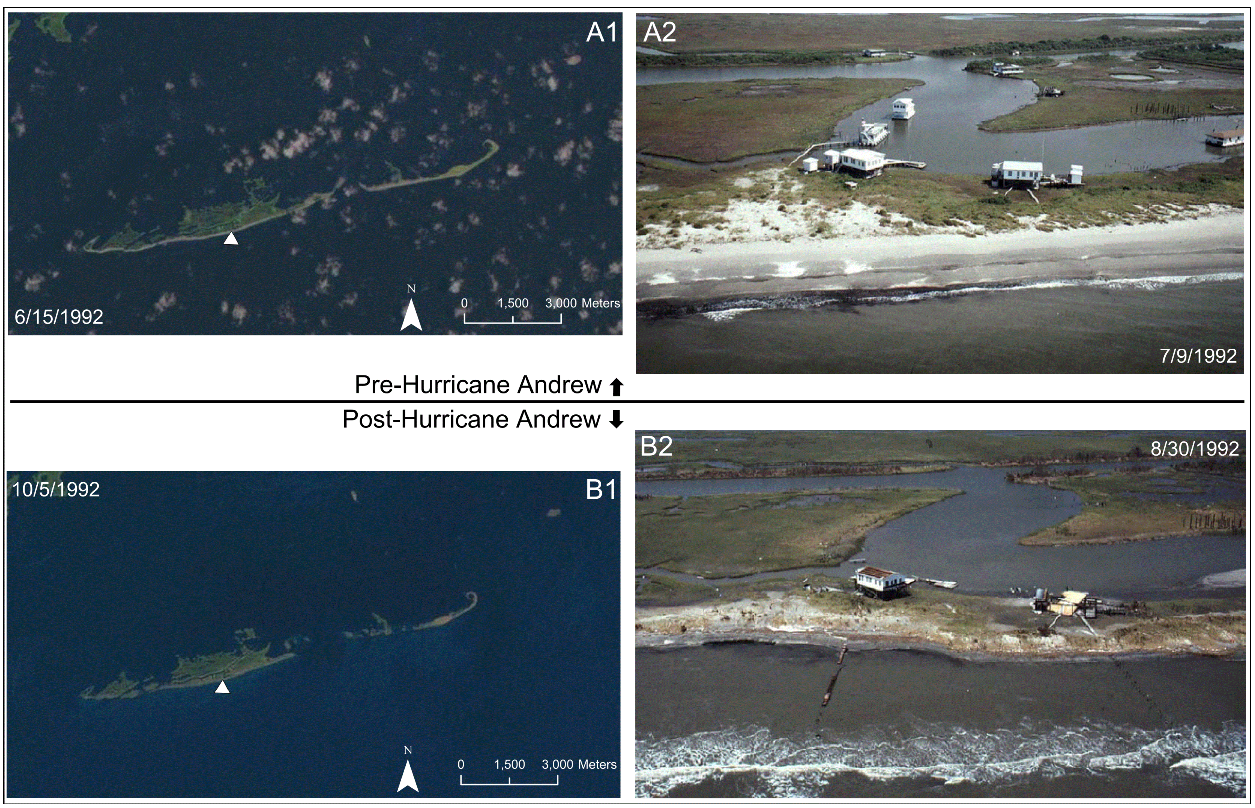


Figure 18 Shoreface Erosion of Trinity Island by Hurricane Andrew. Images of Trinity Island before and after Hurricane Andrew give an up-close view of the effects of hurricanes on the Isles Dernieres. The beach was completely eroded, and the only sand remaining was transported over and through the dunes (eroded in Fig. 17B2) and deposited as washover fans and terraces. While the marsh platform is then exposed to wave erosion, Dingler et al. (1993) found that overall shoreline retreat is retarded by large-scale Hurricane events. Cold fronts are a greater cause of shoreline retreat, and the reshaping of the beach gradient by Hurricanes slows erosion during cold fronts.

The large-scale sediment bypassing of Cat Island Pass and Wine Pass also had a large effect on the shoreface evolution of Trinity and East Islands, which were eroded during this interval. There is a truncation in the width of the band of shoreface erosion along both islands that is located at the western end of the lobe of sediment that bypassed Cat Island Pass. Western Trinity Island, which did not receive this additional sediment supply, had the most substantial shoreline retreat and the most extensive erosion.

The geomorphology of Trinity and East Islands also produced changes in sedimentation after 1974 when Hurricane Carmen breached the continuous shoreline and separated the islands (Williams et al., 1992). East Island was breached later in 1985 during Hurricane Juan; Fig. 19 shows the development of the inlet into what has been referred to here as New Cut. Shoreline rates of retreat on East Island were the highest on the western and eastern sides. In the west, retreat was a result of wave propagation through the inlet. The backbarrier of New Cut was also a major area of deposition in Time Period II; longshore currents and wave ravinement led to deposition just landward of the former island location. Despite the accretion in the backbarrier at New Cut, extensive land loss occurred in the backbarrier marsh environments of Trinity and East Islands.

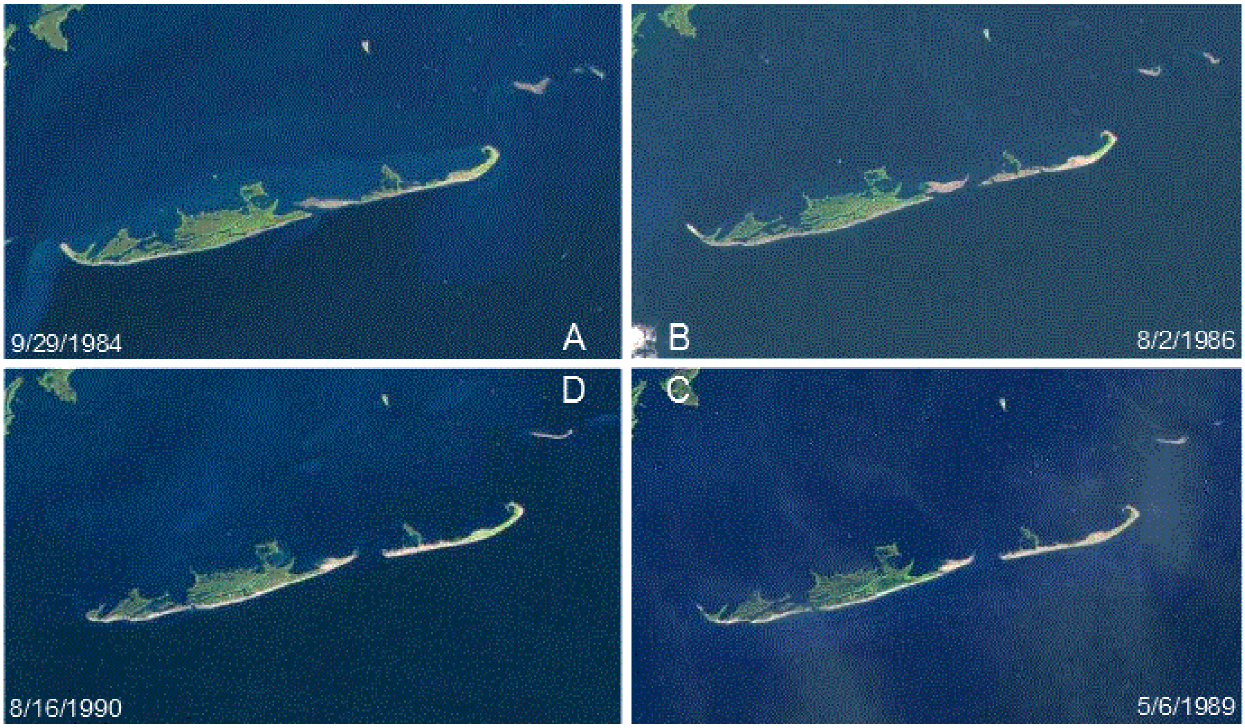


Figure 19 Formation of New Cut. Starting with a small inlet, known as Coupe Carmen, breeched by Hurricane Carmen in 1974, the inlet formation between Trinity and East Islands rapidly changed in five years. Fig. 18A shows this initial inlet, Coupe Carmen, before 1985 when Hurricane Juan hit the Louisianan coast. Fig. 18B shows the effects of Hurricane Juan: another, larger inlet formed by the separation of East Island's western spit from the larger island. It appears that wave propagation or tidal flux was more efficient through the new inlet, called New Cut, and it was sustained while Coupe Carmen was filled with sediment that was likely sourced from the Trinity Island shoreface. Figs. 18C and 18D show the final infill of Coupe Carmen, and the old East Island western spit was welded onto the eastern side of Trinity Island.

Additional processes controlling geomorphology in the western part of the study area were tidal ravinement and spit accretion in Whiskey Pass. The inlet continued westward migration as the inlet filled in the east and scour occurred in the west to a total depth between 6 and 7 m. The small islands that existed in the inlet in the 1930s were completely gone by the 1980s, and were replaced by the inlet throat. Total erosion was 5.71 x 10^6 m^3 whereas the total accretion associated with inlet fill as 1.16 x 10^6 m^3. The inlet increased in cross-sectional area from 5555.6 m^2 to 9553.7 m^2 and widened slightly.

Time Period III – 1996 to 2006

Time Period III was the only time period during which Timbalier Island did prograde significantly into Cat Island Pass; however, it is important to note that the 2005 shoreline data and the 2006 bathymetry data represent a time frame immediately after the active hurricane season of 2005. Two strong hurricanes, Katrina and Rita, significantly affected the study area in 2005. Dingler and Reiss (1995) suggested it may take more than one year for the Isles Dernieres' beaches to recover from large-scale storm events. Fig. 18 shows an example of storm damage following Hurricane Andrew. Despite a lack of subaerial spit growth on the west end of Timbalier Island, accretion did continue within the eastern portion of Cat Island Pass that filled in small tidal channels and formed a submarine platform west of Timbalier Island. The amount of sediment deposited in the inlet was 5.96×10^6 m^3, but this was only slightly more than over half of the sediment scoured from the western portion of the inlet, 10.0×10^6 m^3 (a difference of 4.04×10^6 m^3). Wine Island Pass and Cat Island Pass fully coalesced in Time Period III, and the Wine Island sand body continued to migrate landward. Erosion of the Wine Island sand body eliminated all subaerial portions, and tidal channels continued to disperse the remaining shoal. This opened up cross-sectional area in the central portion of the inlet. To maintain equilibrium with the cross-sectional area and tidal prism, the Wine Island Pass tidal channel filled with sediment. The entire inlet began to approach a more consistent long-shore depth as bathymetric highs in the inlet were eroded and bathymetric lows were filled with sediment. The massive ebb and flood currents associated with the 2005 storms likely encouraged this.

Erosion occurred across all tidal deltas associated with Wine Island Pass and Cat Island Pass as well as the lobe of sediment bypassing the inlets. Erosion to those depths was likely a result of wave action during the 2005 storms; the sediment appears to have been removed from the system. The lobe of bypassing sediment, as well as the tidal deltas, would likely recover given the time for which it had been accreting. There were a number of strong storms between the 1890s and 1980s during which the sediment bypassing continued, so it is likely to be a feature of shoreface equilibrium that had not yet recovered by 2006.

Through the first part of Time Period III, 1996 to 2004, East Island actually increased in area from 0.811 km^2 to 1.294 km^2 – a gain of 0.493 km^2 - due to CWPPRA restoration project *TE-20*. This project involved placement of 3.01 x 10^6 m^3 of sediment onto the island from offshore borrow sites, sand fencing, and planting of vegetation, and it was the largest scale restoration project attempted on East Island (Penland et al., 2003). Sediment was pumped onto the island across its entire length and was completed in October 1998, while vegetative planting was completed in June 1999. This relocation of sediment had major impacts on the island as well as on New Cut and likely on the tidal channel remaining from Wine Island Pass.

As shown in Fig. 17, the sediment placed onto the island was dredged from two separate sites, one in the backbarrier just landward of East Island's eastern spit and the other just north of the Wine Island Pass tidal channel. Approximately 3.0 x 10^6 m^3 was dredged from these sites (Rodrigue et al., 2008), which undoubtedly contributed to the slight rotation of the main tidal channel. This sediment was placed onto East Island resulting in a major increase in land area; however, much of the sediment was quickly eroded by day-to-day processes

(Penland et al., 2003) and transported longshore to the flanks of the island – particularly into New Cut. Hurricanes Katrina and Rita in 2005 continued to transport sediment into New Cut, but the eastern spit of East Island underwent massive erosion and was completely degraded.

Combined with the sediment input from restoration project *TE-24* on Trinity Island, New Cut was completely filled in 2005 and Trinity and East Islands again became one continuous island. Erosion on the shoreface of East Island continued to be much less in volume and extent than erosion on the shoreface of Trinity Island with 7.99 x 10^6 m^3 and 14.4 x 10^6 $m^3$of net loss, respectively. The lobe of sediment bypassing Cat Island Pass likely served to nourish the shoreface at East Island during cold fronts and dissipate wave energy during hurricanes.

Restoration project *TE-24* was performed on Trinity Island concurrently with *TE-20* on East Island, though dredging was done first for East Island. The goals and methods were largely the same for *TE-24* as they were with *TE-20*, including sediment placement and vegetative planting. There were five borrow sites used for dredging in this project, three of which were clustered in Whiskey Pass and two of which were in the backbarrier of Trinity Island, north of the west-central portion of the island (Penland et al., 2003). A total of approximately 3.7 x 10^6 m^3 was placed onto the island from the borrow sites, much of which was used to form an unnaturally high 2.7 m dune across much of the island (Penland et al., 2003; West and Dearmond, 2007).

The Trinity Island shoreface underwent massive erosion from 1996 to 2004, and due to bidirectional longshore transport seaward of the island (Georgiou et al., 2005), some of the sediment used for restoration was transported eastward into New Cut where Trinity Island increased in area. Despite this gain, Trinity Island decreased in area from 1996 to 2004 from 2.70 to 2.66 km^2, a result of shoreface erosion and in-place drowning of the backbarrier marsh. However the hurricanes in 2005 transported additional sediment into New Cut from Trinity Island, and as New Cut was closed, the island actually increased in area to 2.72 km^2, an approximate 0.02 km^2 increase in land area relative to 1996.

The western spit of Trinity Island fused with the main body of the island effectively following the restoration project, however a small recurved portion was eroded in 2005 as Whiskey Pass widened following Hurricanes Katrina and Rita. Longshore transport filled the inlet throat of Whiskey Pass, but much of the western and eastern sides of the inlet were scoured, giving the inlet the inlet a unique “U” shape in cross-section. The cross-sectional area increased from 9553 m^2 to 15,110 m^2.

The “U” shaped inlet of Whiskey Pass likely formed as a result of several processes, the first of which also occurred to a lesser degree at Cat Island Pass in Time Period III. The inlet throats filled and the bathymetric highs between smaller tidal channels were eroded, flattening the sea floor in the inlet. Concurrently, the sides of the channel steepened. Because this occurred at both inlets in the system, it is likely a result of a large-scale process such as storm surge flood and ebb associated with the strong hurricanes in 2005. Unique to Whiskey Pass, however, was the dredging directly in the middle of the inlet; sediment was simply removed for the restoration project *TE-24* in 1998. Finally, because dominant wave direction is from the southeast (Georgiou et al., 2005) and fetch increased as the inlet widened, shoreface ravinement may have started to shape the eastern end of Whiskey Island.

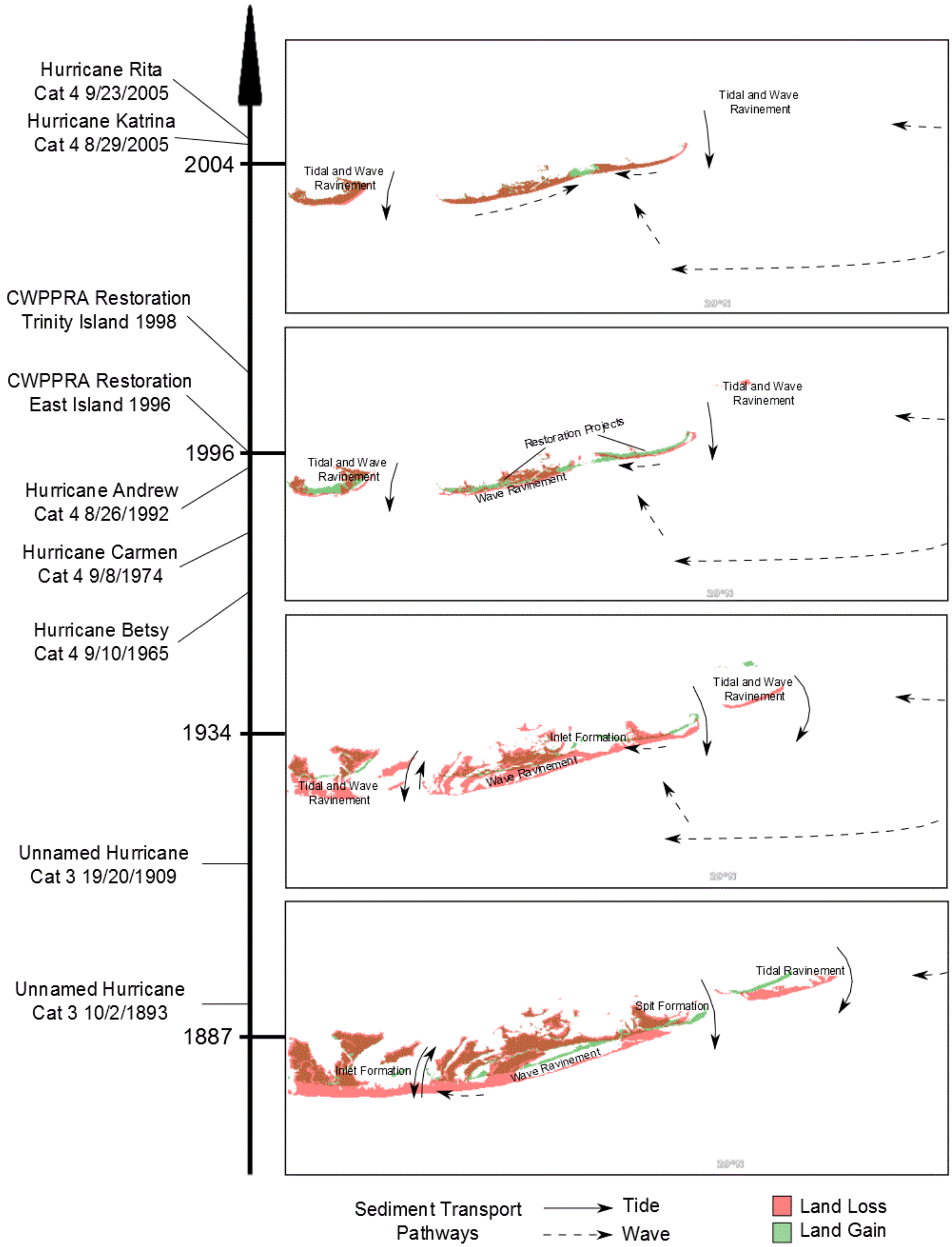
Implications for Barrier Island Development Theory

In terms of volume and areal change across all three islands in the eastern Isles Dernieres, shoreface wave ravinement is the dominant process affecting geomorphology. Gulf shoreline retreat due to wave ravinement has a greater effect on sediment volume loss and island area loss than any other process in the system. This is consistent with the model proposed by Penland et al. (1988) (Fig. 3), in which the source for downdrift sediment is the erosional headland.

This study confirms much of the Penland et al. (1988) model and serves as a practical application of the theory. The development of the system across the time period studied here (1887 to 2006) is a real-world documentation of a late Stage 2 barrier arc. Tidal inlet formation, expansion of the backbarrier bay, and spit growth at the downdrift ends of islands have all been documented in this study and are shown in Fig. 20. This figure is a conceptual model for the development of the Isles Dernieres that shows the processes and sediment transport pathways in the system.

There are processes and conditions in this system that differ from the idealized model in Penland et al. (1988), however. While shoreface wave ravinement is the process with greatest morphologic impact, the dominant direction of littoral sediment transport is to the west – toward the erosional headland (Georgiou et al., 2005).

The lobe of sediment bypassing Cat Island Pass nourishes East Island and significantly slows sediment loss through shoreface wave ravinement on that island. However, tidal ravinement was the driving process in the erosion of Wine Island, and the westward migration of the tidal channels in Cat Island Pass will likely begin to erode the eastern portion of East Island. It is likely then that the lobe of bypassing sediment will continue westward, and East Island will gradually receive less and less shoreface-nourishing sediment. This, combined with the westward migration of tidal channels, may result in increased rates of land loss at East Island and eventually eastern Trinity Island.



Hurricane Rita
Cat 4 9/23/2005
Hurricane Katrina
Cat 4 8/29/2005
2004
CWPPRA Restoration
Trinity Island 1998
CWPPRA Restoration
East Island 1996
1996
Hurricane Andrew
Cat 4 8/26/1992
Hurricane Carmen
Cat 4 9/8/1974
Hurricane Betsy
Cat 4 9/10/1965
1934
Unnamed Hurricane
Cat 3 19/20/1909
Unnamed Hurricane
Cat 3 10/2/1893
1887
Tidal and Wave Ravinement
Tidal and Wave Ravinement
Restoration Projects
Wave Ravinement
Inlet Formation
Tidal Ravinement
Spit Formation
Sediment Transport Pathways
Tide
Wave
Land Loss
Land Gain

Figure 20 Conceptual Model for Development of Eastern Isles Dernieres 1887-2006. This conceptual model was generated using the results of this study and shows the sediment transport pathways and associated processes. Two processes that are constant through the entire study period are wave shoreface ravinement on all islands and tidal ravinement on the eastern side of the Wine Island sand body. Sediment is also introduced into Cat Island Pass across the entire study period, which forces the tidal channels within the inlet westward, encouraging this tidal ravinement to the Wine Island sand body. Sediment input from the lobe of sediment bypassing Cat Island Pass from the east begins to enter the Isles Dernieres system after 1934, and it is transported through wave action to the East Island shoreface. This has helped to slow erosion of Wine Island, but as the bypassing sediment lobe continues west, it may have less effect in the future, leaving East Island more susceptible to erosion by waves and

Implications for Restoration Strategies

Because the Isles Dernieres are so rapidly deteriorating, the islands have been the focus of several restoration projects since the mid-1980s. The most successful of these were CWPPRA projects *TE-24* and *TE-20*, which aimed to restore land and mitigate future land loss on Trinity and East Islands, respectively. New Cut was filled within seven years of these projects by longshore sediment transport from the shoreface of both islands with sediment for the closure most likely attributable to that placed during *TE-24* and *TE-20.*

Because the shoreface and beach of these islands is the source of sediment introduced into New Cut, the islands were able to naturally build land by spit accretion until they were joined. This evolution shows that if sediment can introduced at the source of the transport pathways, natural processes will distribute sediment in a way that is the most sustainable.

Conclusions

In this study, the dynamic geomorphology and associated coastal processes of the eastern Isles Dernieres have been analyzed using a variety of methods. This barrier system is unique in that a significant amount of sediment is introduced to the system from multiple sources.

The Penland et al. (1988) model is the accepted conceptual guide for the formation of the Isles Dernieres, but the eastern islands (i.e. Trinity, East, and Wine) receive sediment from the east in addition to the erosional headland source. This sediment is introduced to the shoreface of East Island from a lobe of bypassing sediment seaward of Cat Island Pass. This sediment helps replace the volume that is lost due to wave ravinement on the shoreface, and it slows retreat of the gulf shoreline. Shoreface wave ravinement does not appear to have slowed significantly just west of the bypassing lobe on Trinity Island; this process continues to have the greatest effects on geomorphology on that island.

Sediment is also introduced into Cat Island Pass from the east, and inlet infilling forces the tidal channels westward. This westward-directed tidal channel migration means that tidal ravinement is a driving process in the erosion of Wine Island. As more sediment is introduced into the inlet from the east, tidal ravinement will likely increase on the eastern side of East Island.

The results of this study can be applied to the design of restoration projects, and may increase their effectiveness. Sediment that is introduced to the shoreface and beach of Trinity and East Islands will likely slow gulf shoreline retreat and also encourage spit growth at the ends of the islands. This would help sustain or increase island area and island dimensions as measured both longshore and cross-shore.

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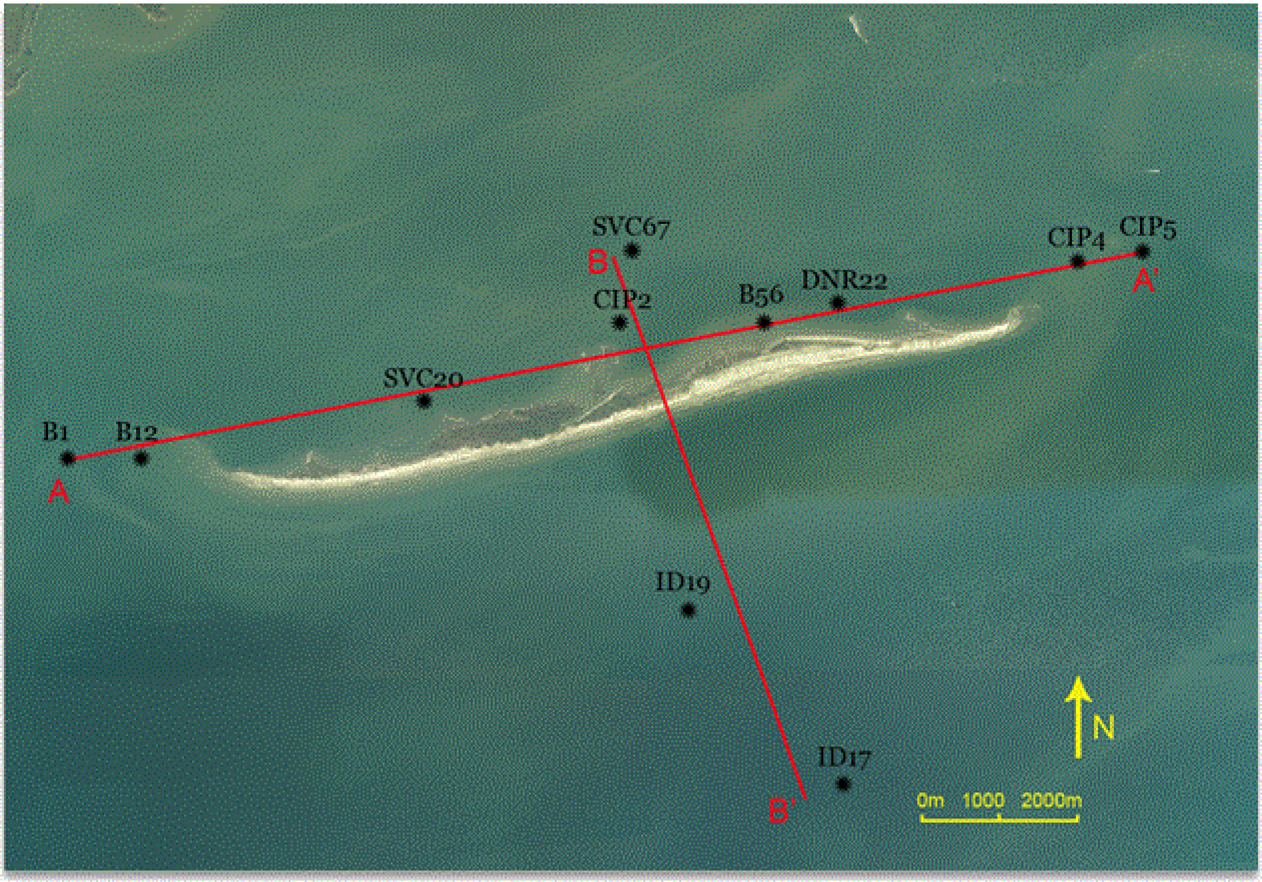
Appendix I


SVC67
B
CIP4
CIP5
A'
CIP2
B56
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SVC20
B1
B12
A
ID19
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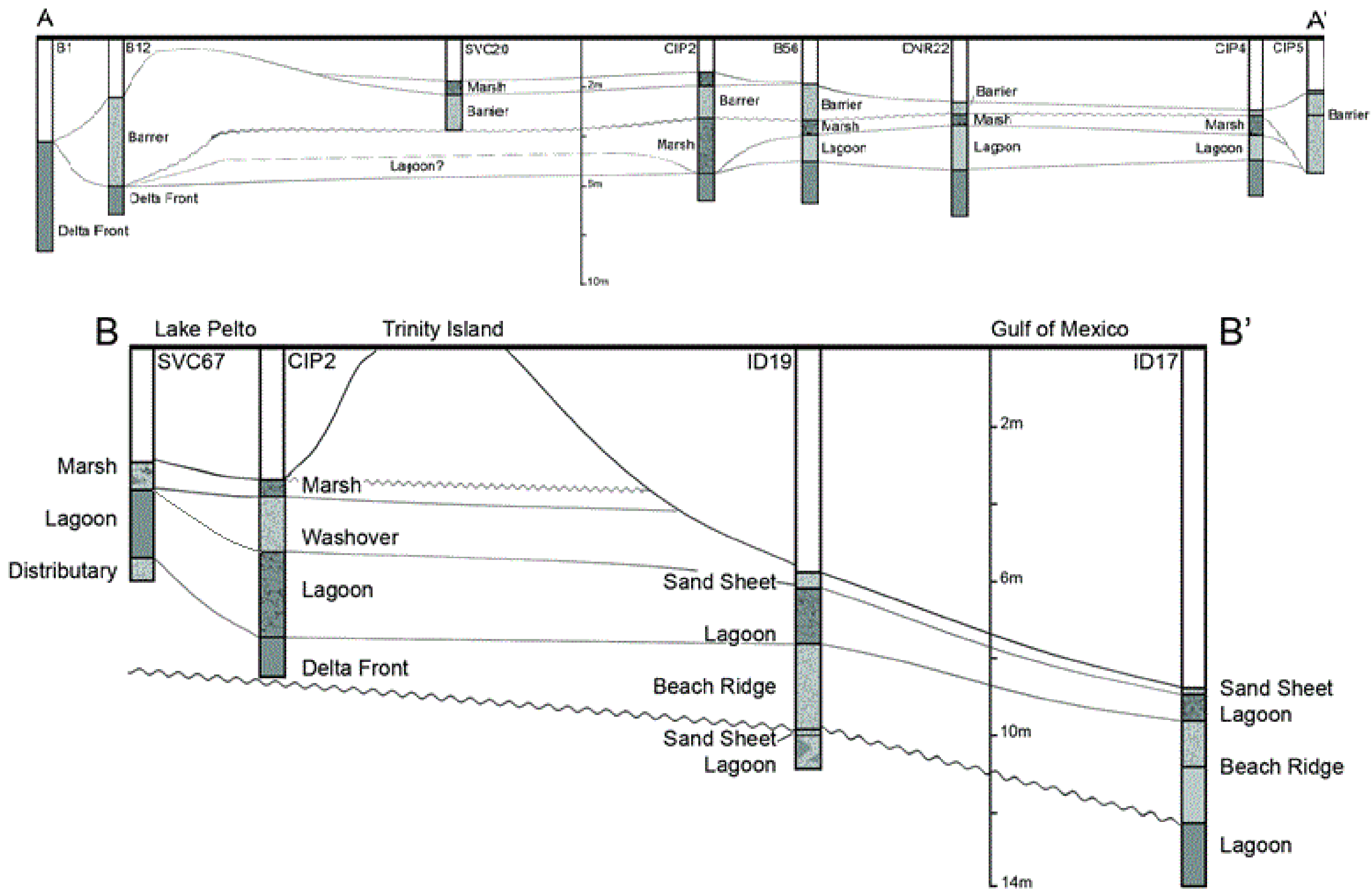
ID17
B'
0m 1000 2000m


A
A'
B1
B12
SVC20
CIP2
B56
DNR22
CIP4
CIP5
Marsh
Barrier
Barrier
Barrier
Barrier
Barrier
Barrier
Marsh
Marsh
Marsh
Marsh
Lagoon?
Lagoon
Lagoon
Lagoon
Delta Front
Delta Front
2m
6m
10m
B
Lake Pelto
Trinity Island
Gulf of Mexico
B'
SVC67
CIP2
ID19
ID17
Marsh
Lagoon
Distributary
Marsh
Washover
Lagoon
Delta Front
Sand Sheet
Lagoon
Beach Ridge
Sand Sheet
Lagoon
2m
6m
10m
14m
Sand Sheet
Lagoon
Beach Ridge
Lagoon

Appendix II

m		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1887-1934	Gulf	1238.0	582.1	529.2	455.1	449.9	519.3	558.1	576.3	530.7	522.1	538.6	547.0	549.3	550.6	581.5	583.0	614.3	597.6	579.0
	Bay	788.5	-65.5	-122.5	-128.6	-119.1	-56.3	-70.2	-66.9	-1000.4	-66.8	-70.2	-51.6	-351.7	-29.5	-93.1	-48.3	-46.2	-89.8	-100.4
1934-1996	Gulf	n/a	n/a	857.3	904.9	913.2	715.5	670.6	700.0	715.8	682.6	611.0	568.2	538.1	549.7	572.0	574.0	539.8	802.1	n/a
	Bay			-304.3	-550.9	-799.4	-577.4	-199.6	-245.2	-351.0	-459.8	-370.5	-192.6	-249.5	-901.0	-117.4	-999.2	154.6	623.5	
1996-2004	Gulf	n/a	n/a	293.8	91.3	40.0	99.3	83.7	60.0	88.1	125.3	148.8	137.8	134.8	110.7	74.1	59.0	79.1	-139.6	n/a
	Bay			220.2	244.4	-13.2	-0.5	51.2	88.0	193.1	-34.8	-64.6	-22.8	-12.5	9.6	-54.9	-6.5	72.3	-336.0	
2004-2005	Gulf	n/a	n/a	39.7	75.4	19.0	30.7	42.6	32.2	38.6	43.9	17.2	0.0	13.1	27.5	17.5	32.1	28.5	4.7	-12.0
	Bay			23.8	-10.6	-1.4	-4.0	-25.3	-12.0	-13.3	-21.5	-8.0	-6.7	-4.0	10.8	-13.1	-6.0	-2.4	406.0	196.8

m		20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1887-1934	Gulf	553.9	563.9	527.7	473.6	463.8	373.6	304.7	32.2	-159.2	n/a	n/a	125.8	72.0	430.0	539.0	603.3	700.8	769.1
	Bay	-113.5	-77.3	-288.8	-238.0	-129.8	-182.8	-96.1	-190.6	-267.5			122.5	49.5	169.4	198.3	446	375.4	696.5
1934-1996	Gulf	902.4	567.9	474.7	327.6	247.5	201.2	187.0	251.3	389.9	431.1	256.5	n/a	2076.1	n/a	1903.2	1684	n/a	n/a
	Bay	844.2	498.7	129.8	-663.7	-406.0	-61.9	-209.5	60.0	336.0	216.2	299.2		1968.4	n/a	1843.5	1697.1		
1996-2004	Gulf	-323.8	-197.0	-45.3	37.7	41.4	57.8	73.0	89.2	84.1	175.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Bay	-4.0	71.5	113.5	97.4	74.5	109.2	140.9	111.8	143.7	146.2								
2004-2005	Gulf	-14.4	-2.4	31.5	16.7	16.4	8.7	18.1	30.5	160.2	194.5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Bay	7.7	10.0	-9.5	-13.4	-11.0	-11.1	-19.1	-21.4	35.2	256.3								

Shoreline change data collected from *ArcMap* for each transect and time interval.

m^2	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1887	299814.9	685410.5	906043.7	713067.7	917326.9	459638.9	648813.1	717537.3	1044430.7	893240.6	773386.1	726424.7	569630.7	661823.6	686064.6	420237.9	345385.0	177411.3	173207.3
1934	68875.9	312596.0	521096.6	305331.4	742710.8	356076.0	282186.9	343514.7	628632.3	721738.0	702977.5	650237.3	502122.6	536527.9	536253.4	311441.4	300746.4	188555.7	132611.4
Net Change	-230939.0	-372814.5	-384947.1	-407736.3	-174616.1	-103562.9	-366626.2	-374022.6	-415798.4	-171502.6	-70408.6	-76187.4	-67508.1	-125295.7	-149811.2	-108796.5	-44638.6	11144.4	-40595.9
% Change	-77.0	-54.4	-42.5	-57.2	-19.0	-22.5	-56.5	-52.1	-39.8	-19.2	-9.1	-10.5	-11.9	-18.9	-21.8	-25.9	-12.9	6.3	-23.4

m^2	T	U	V	W	X	Y	Z	AA	BB	CC	WIP	DD	EE	FF	GG	HH	II	CIP
1887	202077.1	398928.2	471638.0	904613.3	520374.4	283389.2	134113.4	163601.9	47945.7	14310.2	67976.9	11443.4	144963.5	224830.1	226730.1	203318.7	174440.1	553980.4
1934	107486.0	184558.1	222319.7	570532.5	298851.4	194740.2	167368.5	98828.9	112486.3	153117.9	14083.9	67287.2	76155.2	91072.5	97867.4	91445.4	107621.0	41851.4
Net Change	-94591.1	-214370.1	-249318.3	-334080.8	-221523.0	-88649.0	33255.1	-64773.0	64540.6	138807.7	-53893.0	55843.8	-68808.3	-133757.6	-128862.7	-111873.3	-66819.1	-512129.0
% Change	-46.8	-53.7	-52.9	-36.9	-42.6	-31.3	24.8	-39.6	134.6	970.0	-79.3	488.0	-47.5	-59.5	-56.8	-55.0	-38.3	-92.4

m^2	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1934	68875.9	312596.0	521096.6	305331.4	742710.8	356076.0	282186.9	343514.7	628632.3	721738.0	702977.5	650237.3	502122.6	536527.9	536253.4	311441.4	300746.4	188555.7	132611.4
1996	0.0	8853.5	71757.9	90707.3	200876.8	103382.8	115371.9	61128.2	156884.8	299418.2	283049.9	299762.3	267623.6	296751.5	241590.3	42654.5	86057.4	32147.1	6571.0
Net Change	-68875.9	-303742.5	-449338.7	-214624.1	-541834.0	-252693.2	-166815.0	-282386.5	-471747.5	-422319.8	-419927.6	-350475.0	-234499.0	-239776.4	-294663.1	-268786.9	-214689.0	-156408.6	-126040.4
% Change	-100.0	-97.2	-86.2	-70.3	-73.0	-71.0	-59.1	-82.2	-75.0	-58.5	-59.7	-53.9	-46.7	-44.7	-54.9	-86.3	-71.4	-83.0	-95.0

m^2	T	U	V	W	X	Y	Z	AA	BB	CC	WIP	DD	EE	FF	GG	HH	II	CIP
1934	107486.0	184558.1	222319.7	570532.5	298851.4	194740.2	167368.5	98828.9	112486.3	153117.9	14083.9	67287.2	76155.2	91072.5	97867.4	91445.4	107621.0	41851.4
1996	78658.8	69890.3	73748.4	148612.4	66375.9	51366.3	54045.6	68602.8	61823.2	82241.5	159686.6	10316.9	5881.2	7662.3	105059.3	12164.7	0.0	0.0
Net Change	-28827.2	-114667.8	-148571.3	-421920.1	-232475.5	-143373.9	-113322.9	-30226.1	-50663.1	-70876.4	145602.7	-56970.3	-70274.0	-83410.2	7191.9	-79280.7	-107621.0	-41851.4
% Change	-26.8	-62.1	-66.8	-74.0	-77.8	-73.6	-67.7	-30.6	-45.0	-46.3	1033.8	-84.7	-92.3	-91.6	7.3	-86.7	-100.0	-100.0

m^2	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1996	0.0	8853.5	71757.9	90707.3	200876.8	103382.8	115371.9	61128.2	156884.8	299418.2	283049.9	299762.3	267623.6	296751.5	241590.3	42654.5	86057.4	32147.1	6571.0
2004	0.0	14545.4	80869.2	116496.2	169224.5	142191.4	142582.0	114440.2	190934.3	252434.8	240811.8	253444.0	212792.3	238134.1	217097.8	134054.6	101662.7	24663.2	59738.9
Net Change	0.0	5691.9	9111.3	25788.9	-31652.3	38808.6	27210.1	53312.0	34049.5	-46983.4	-42238.1	-46318.3	-54831.3	-58617.4	-24492.5	91400.1	15605.3	-7483.9	53167.9
% Change	0.0	64.3	12.7	28.4	-15.8	37.5	23.6	87.2	21.7	-15.7	-14.9	-15.5	-20.5	-19.8	-10.1	214.3	18.1	-23.3	809.1

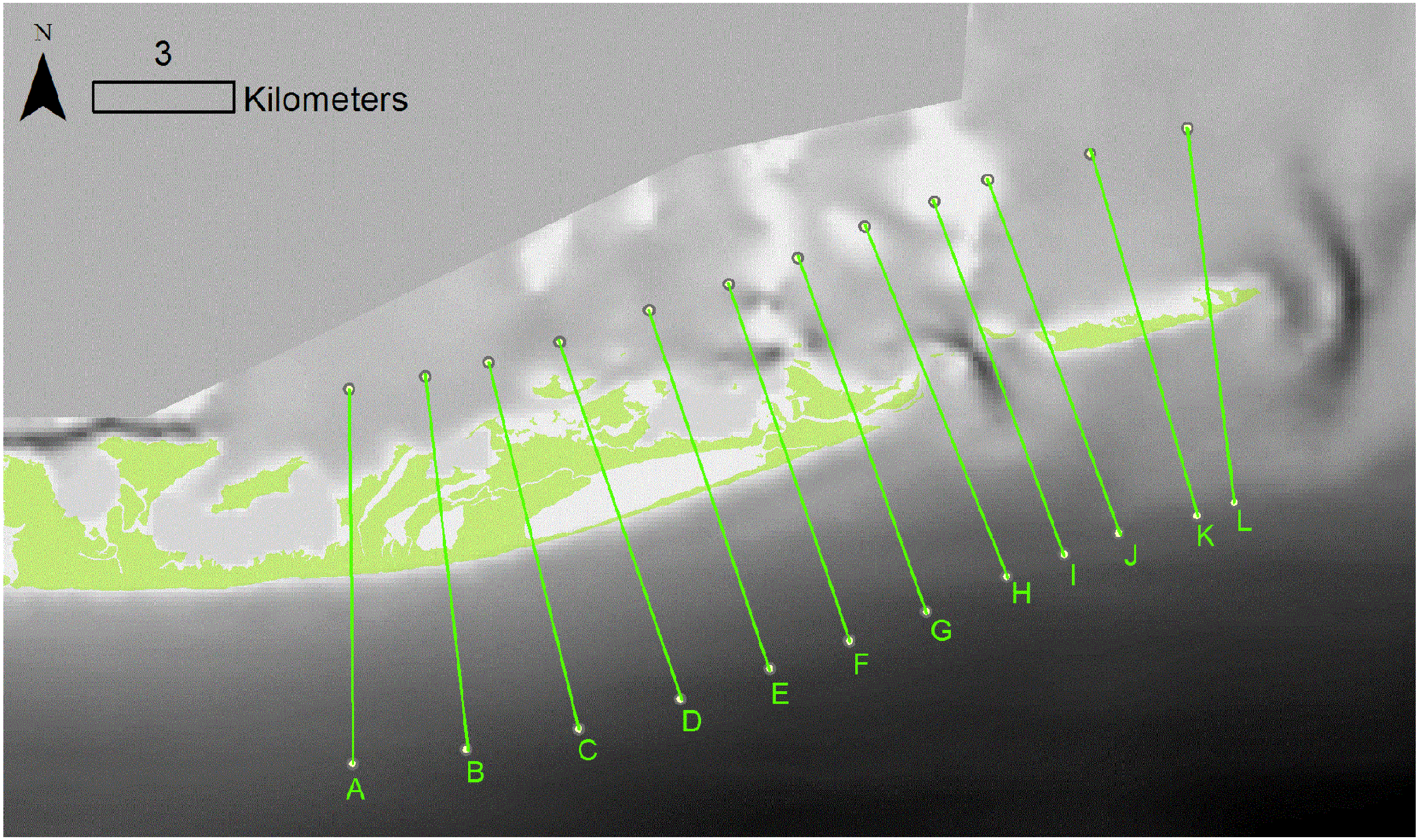
m^2	T	U	V	W	X	Y	Z	AA	BB	CC	WIP	DD	EE	FF	GG	HH	II	CIP
1996	78658.8	69890.3	73748.4	148612.4	66375.9	51366.3	54045.6	68602.8	61823.2	82241.5	159686.6	10316.9	5881.2	7662.3	105059.3	12164.7	0.0	0.0
2004	196734.2	186887.3	147629.8	182996.1	108862.8	95838.5	92267.6	83771.4	61262.3	77623.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net Change	118075.4	116997.0	73881.4	34383.7	42486.9	44472.2	38222.0	15168.6	-560.9	-4617.9	-159686.6	-10316.9	-5881.2	-7662.3	-105059.3	-12164.7	0.0	0.0
% Change	150.1	167.4	100.2	23.1	64.0	86.6	70.7	22.1	-0.9	-5.6	-100.0	-100.0	-100.0	-100.0	-100.0	-100.0	0.0	0.0

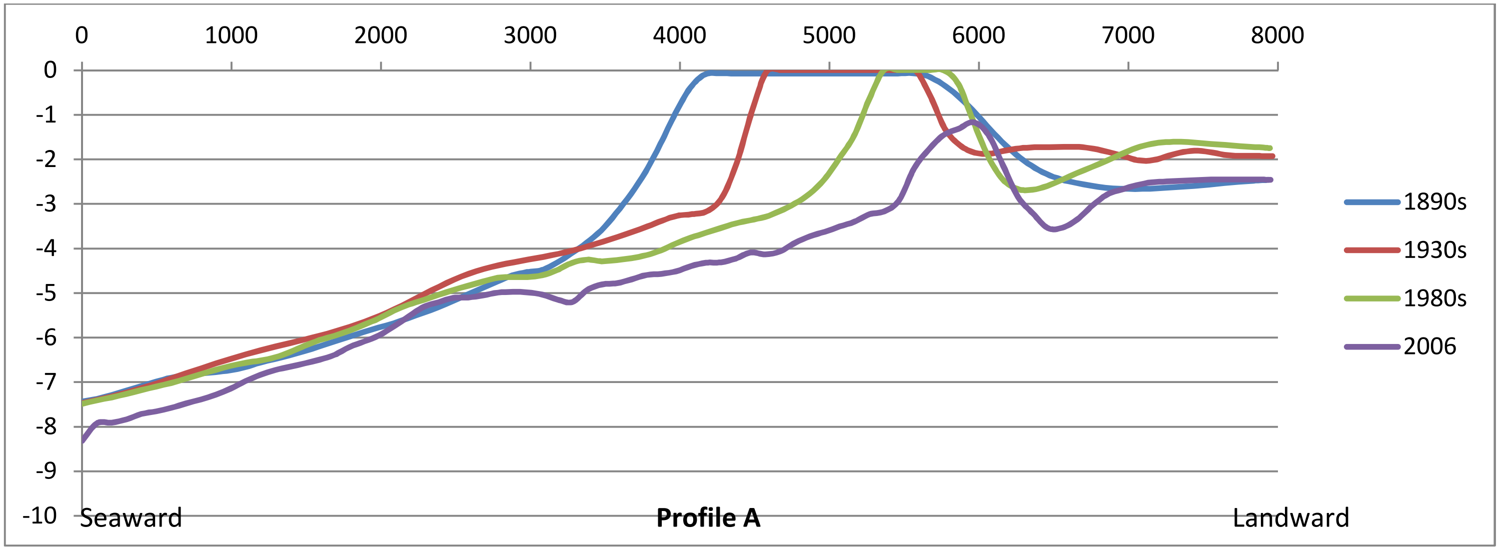
m^2	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
2004	0.0	14545.4	80869.2	116496.2	169224.5	142191.4	142582.0	114440.2	190934.3	252434.8	240811.8	253444.0	212792.3	238134.1	217097.8	134054.6	101662.7	24663.2	59738.9
2005	0.0	390.6	58553.9	90729.1	169725.5	122663.7	122990.0	87925.1	166554.8	271711.9	241520.0	246801.0	206027.6	235139.0	203853.9	120613.1	202057.0	170065.3	157104.3
Net Change	0.0	-14154.8	-22315.3	-25767.1	501.0	-19527.7	-19592.0	-26515.1	-24379.5	19277.1	708.2	-6643.0	-6764.7	-2995.1	-13243.9	-13441.5	100394.3	145402.1	97365.4
% Change	0.0	-97.3	-27.6	-22.1	0.3	-13.7	-13.7	-23.2	-12.8	7.6	0.3	-2.6	-3.2	-1.3	-6.1	-10.0	98.8	589.6	163.0

m^2	T	U	V	W	X	Y	Z	AA	BB	CC	WIP	DD	EE	FF	GG	HH	II	CIP
2004	196734.2	186887.3	147629.8	182996.1	108862.8	95838.5	92267.6	83771.4	61262.3	77623.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	236407.1	165768.8	124196.7	162863.8	97329.5	81634.7	75280.3	56968.0	1481.7	12281.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net Change	39672.9	-21118.5	-23433.1	-20132.3	-11533.3	-14203.8	-16987.3	-26803.4	-59780.6	-65342.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Change	20.2	-11.3	-15.9	-11.0	-10.6	-14.8	-18.4	-32.0	-97.6	-84.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Area change data collected from *Arcmap* for each zone and time interval.

Appendix III

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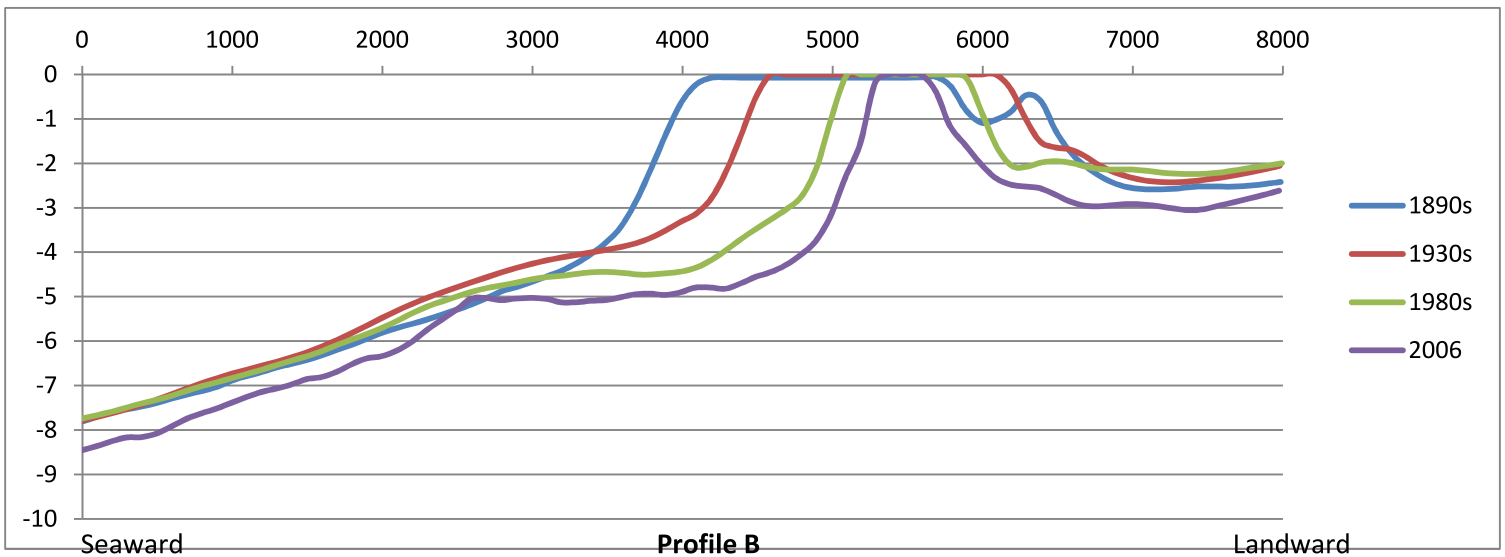
Seaward
Profile A
Landward
1890s
1930s
1980s
2006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Profile B
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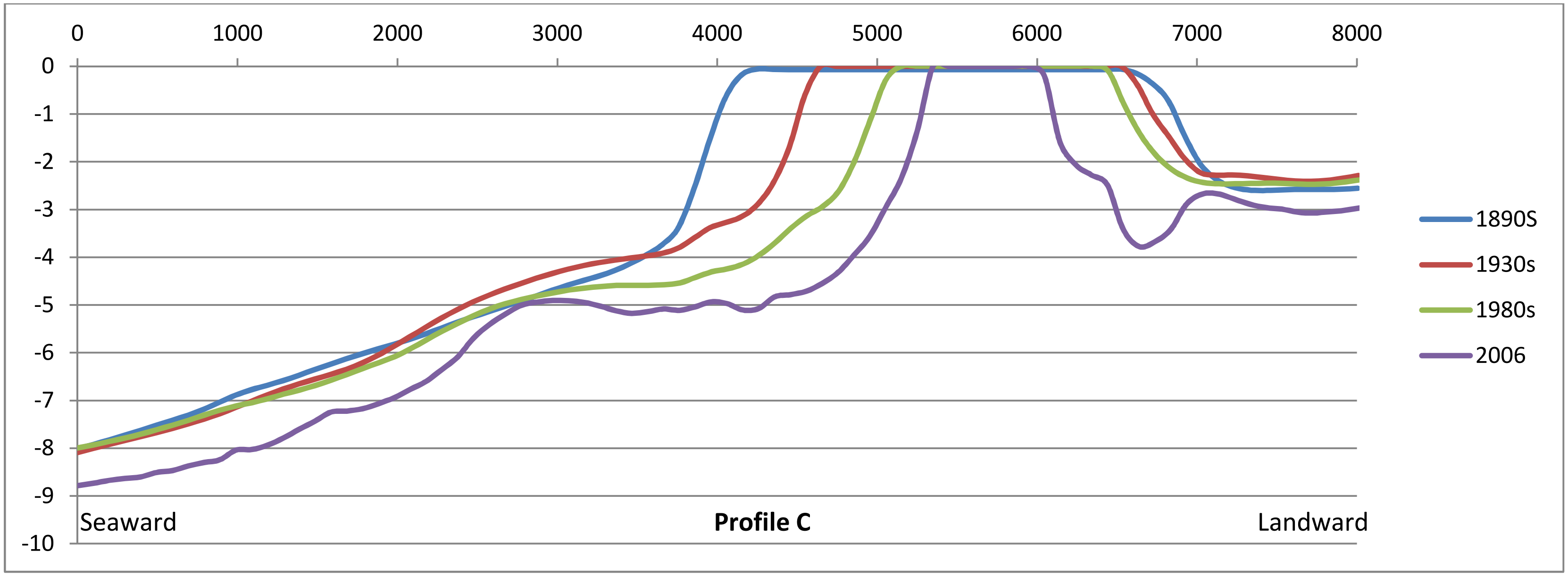

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Seaward
Profile C
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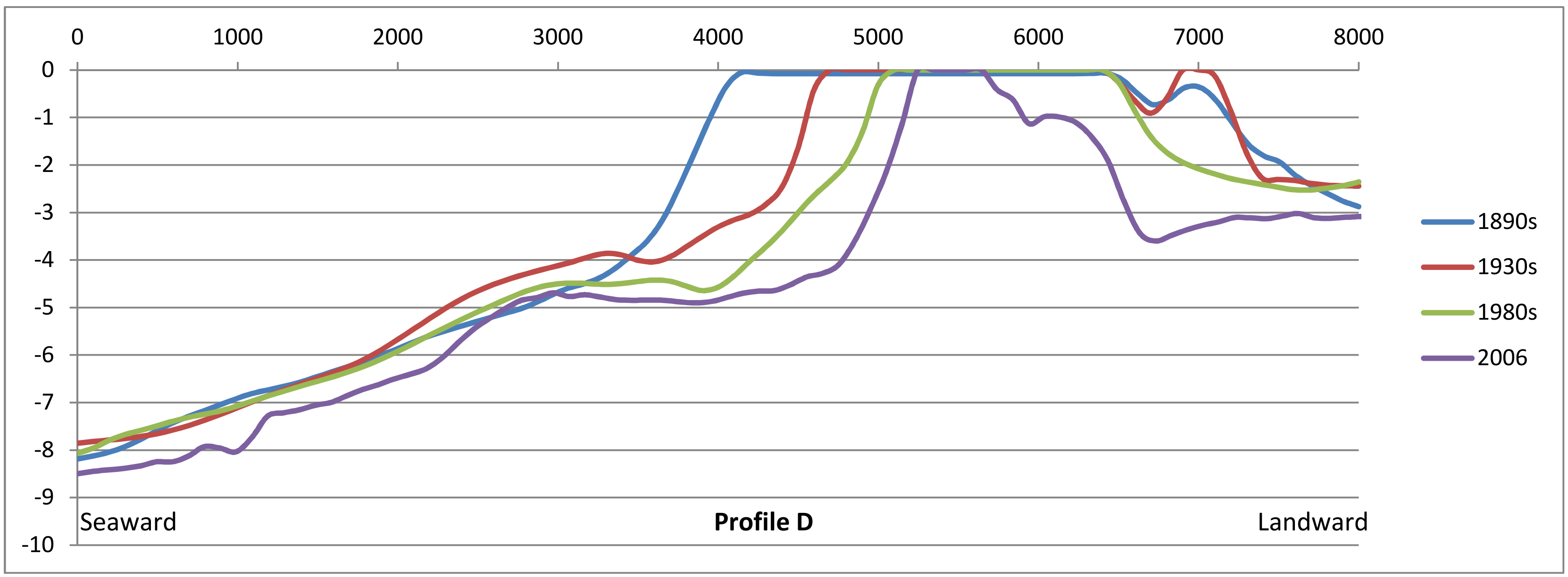
2006



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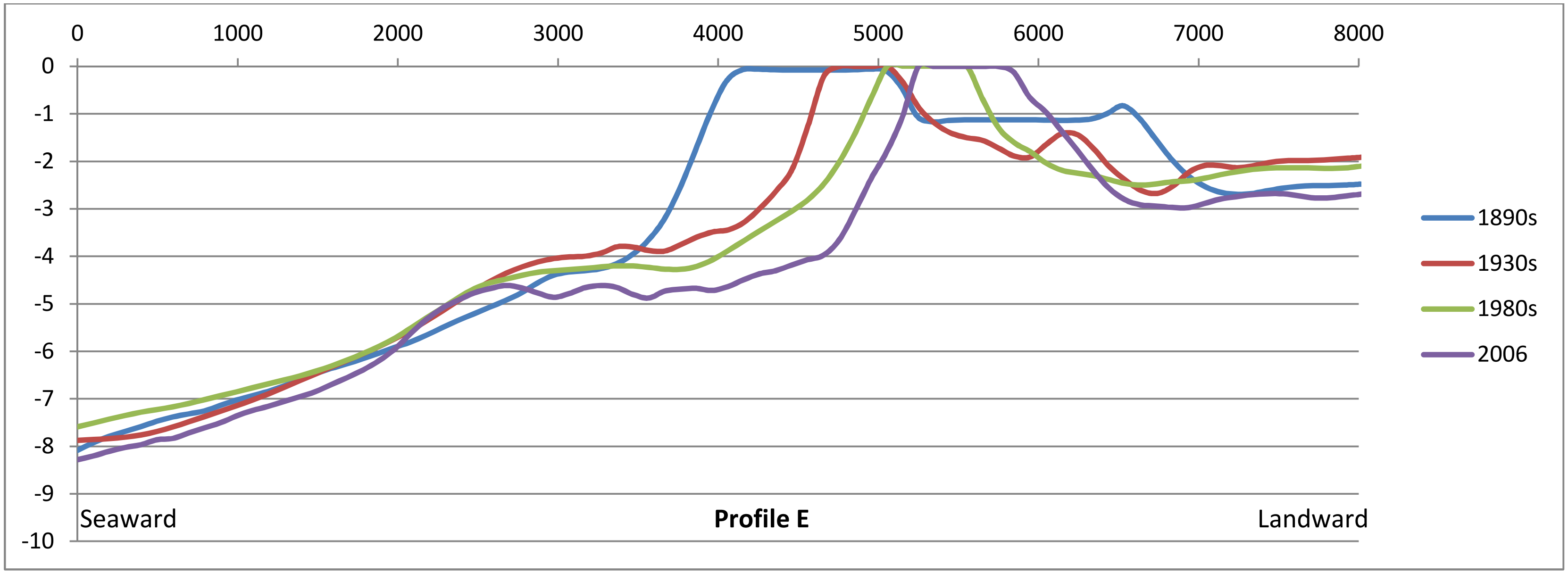

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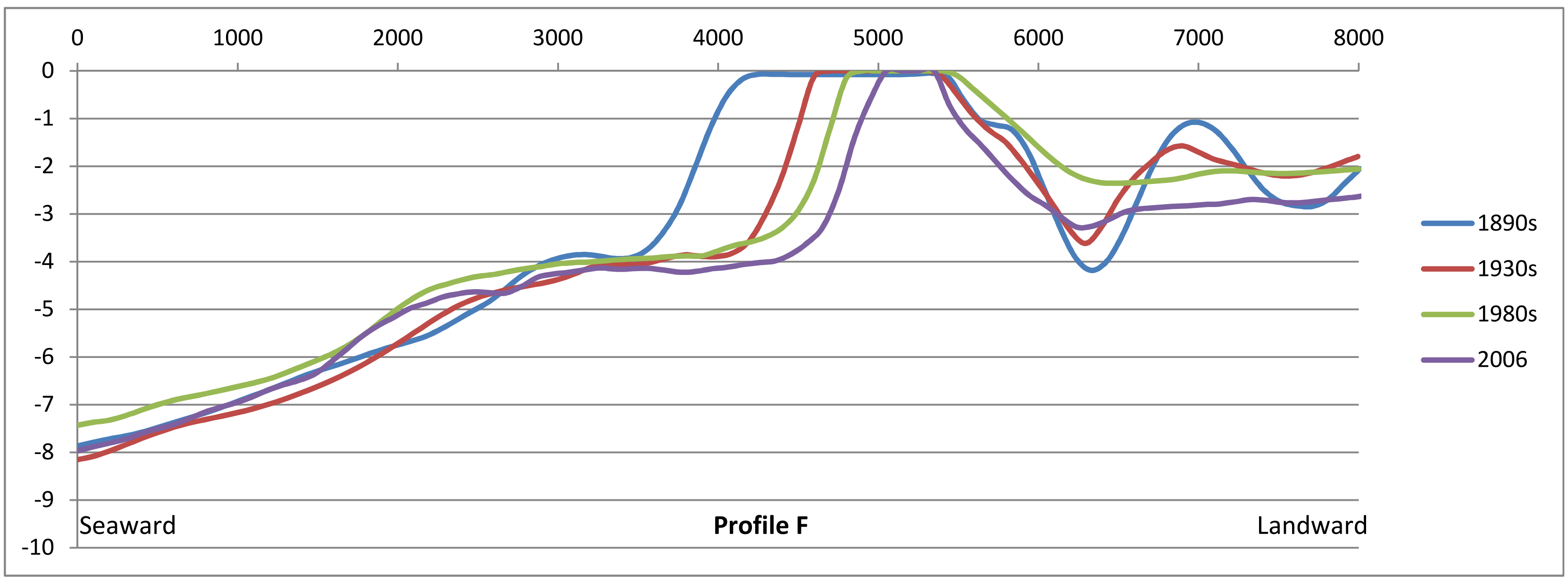

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Profile F
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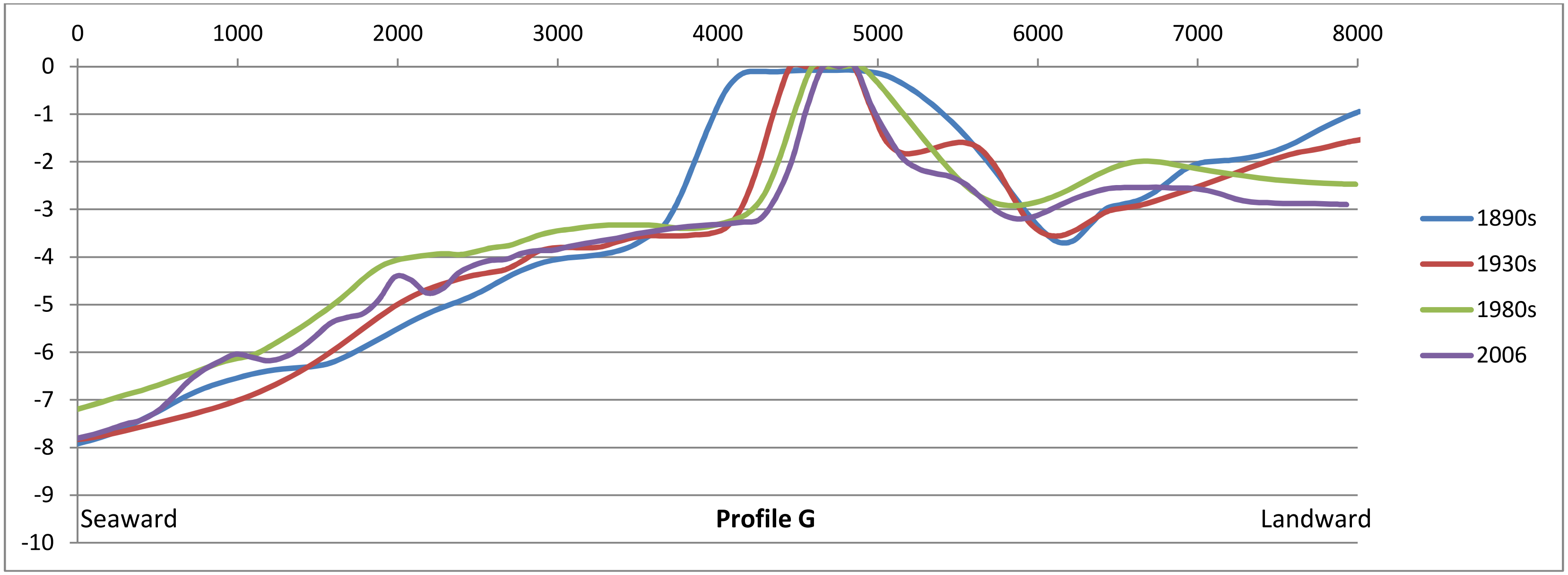
2006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Profile G
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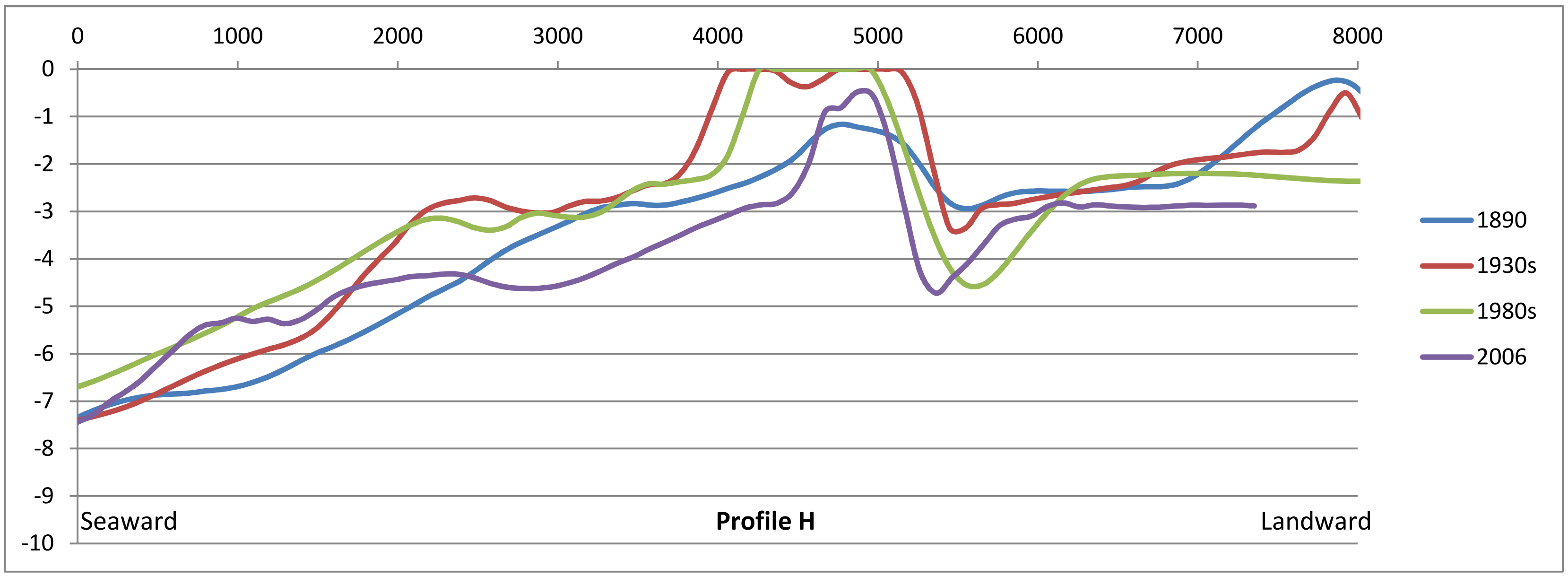
2006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Seaward
Profile H
Landward
1890
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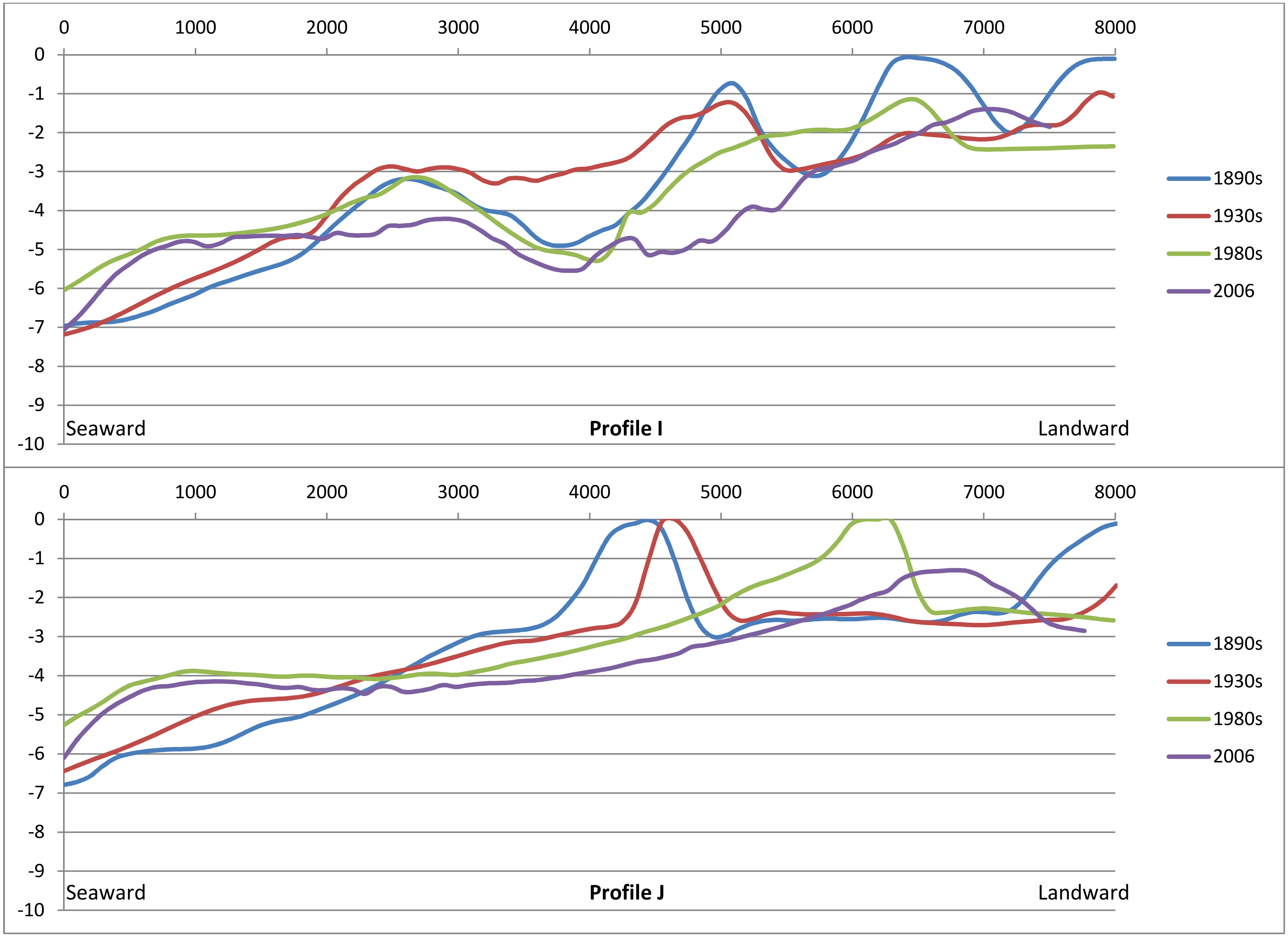
1980s
2006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Profile I
Landward
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Seaward
Profile J
Landward
1890s
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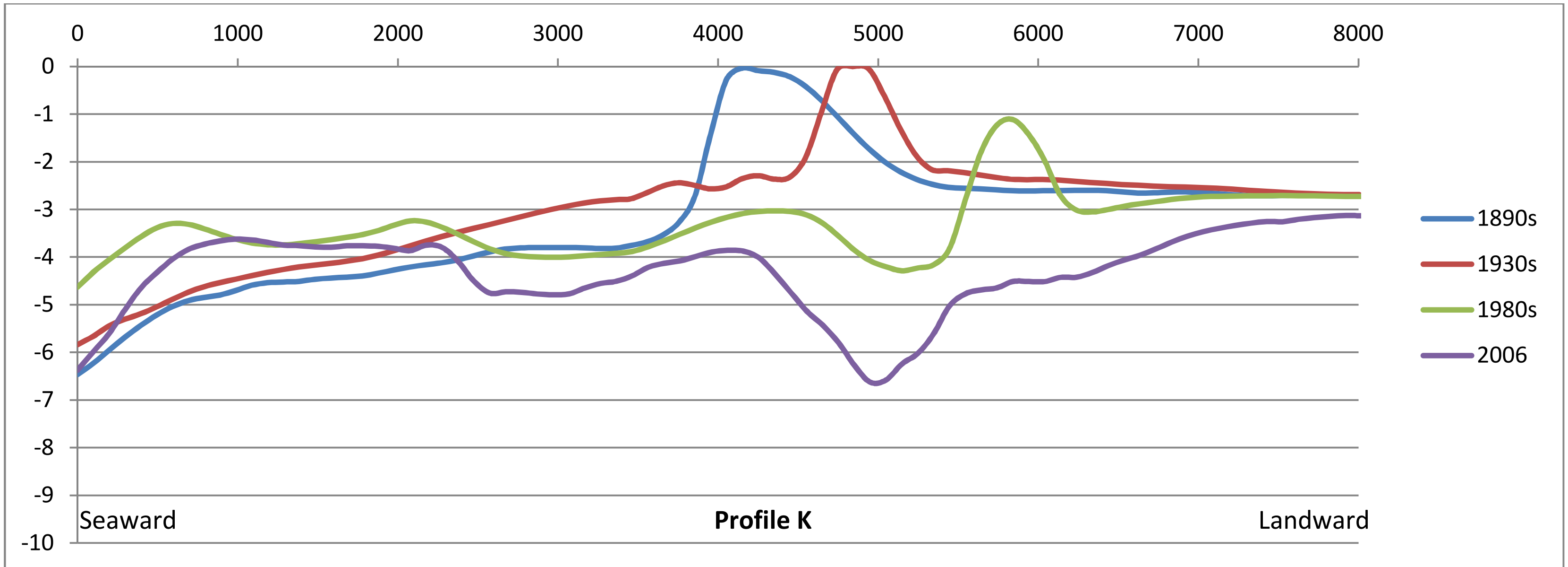
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Seaward
Profile K
Landward
1890s
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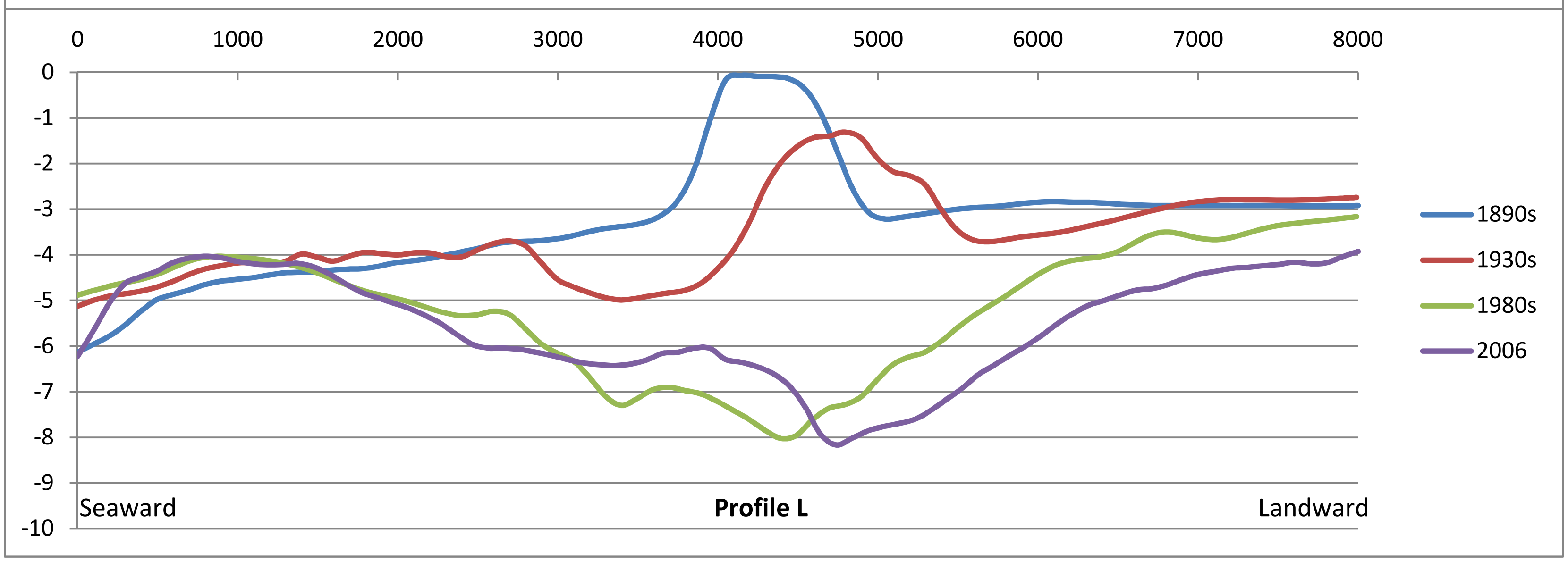
1980s
2006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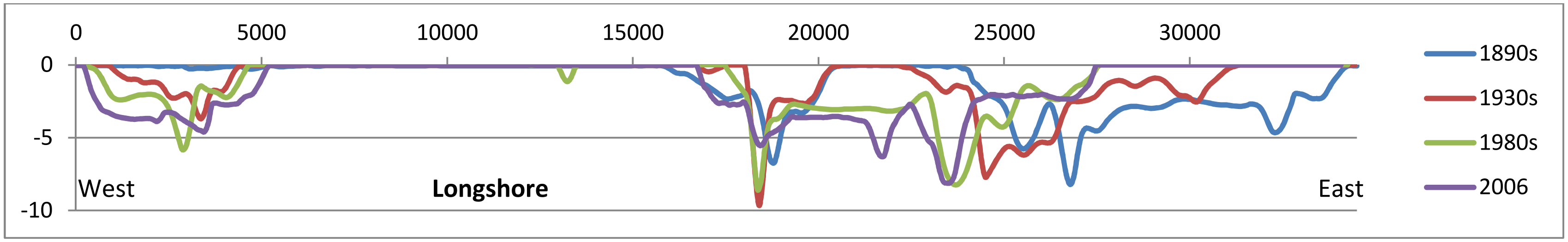
Seaward
Profile L
Landward
1890s
1930s
1980s
2006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West
Longshore
East
1890s
1930s
1980s
2006

Vita

Benjamin Kirkland was born in Charleston, WV and grew up in Vienna, near Parkersburg. He had an interest in politics from an early age, and was involved several political clubs from the local to national level. After graduating from Parkersburg High School in 2004, he chose to attend the University of Kentucky in Lexington to study political science. After a couple years, however, he decided to pursue a degree in geology with the intent of pursuing a career in oil and gas. After completing a B.S. in Geology in 2010, Ben chose to attend the University of New Orleans to pursue a M.S. in Earth and Environmental Sciences with a focus in coastal geology.