Chandeleur Islands:
A Post-berm Analysis and Island Renourishment Plan

Duncan FitzGerald, Ioannis Georgiou, Mark Kulp, Mike Miner
Department of Earth and Environmental Sciences

University of New Orleans

For the
Lake Pontchartrain Basin Foundation

Made possible by a grant from
National Wildlife Federation

February 8, 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PART 1. INTRODUCTION

The Chandeleur Islands are a well-studied barrier island complex extending 80-km along the eastern edge of southern Louisiana's coastal zone in the north-central Gulf of Mexico (Fig. 1). The barrier complex consists of a system of small (<2 km length) to larger (~10 km length) islands that historically have been divided into the northern islands (semi-continuous barrier arc), southern islands (Curlew, Grand Gosier, and Breton Islands) and western islands (North Harbor and Freemason Islands).

The basis of the division is geographical as well as geomorphological, with distinctly different geomorphological evolutionary histories in each of the three geographic domains. For example, throughout historical times the subaerial integrity of some of these islands has been ephemeral in nature. Within the southern partition the barriers such as Grand Gosier and Curlew Island have both disappeared and reformed during the past 50 years, whereas the northern islands have largely remained subaerial but undergone a significant reduction in area. A primary contributor to the loss of subaerial integrity historically has been elevation and area reduction stemming from the impact of large tropical cyclones, which have transported sand away from these barrier platforms. In the process subaqueous shoals are created and some transported sediment is stored in nearby sinks. During long-term, fair-weather conditions the shoals have re-built above mean sea level as sediment from nearby sinks is transported back to the linked barrier platform and shoal system. Consistently and regardless of the location however, the islands are diminishing in both vertical and horizontal dimensions with increasingly less likelihood for their natural recovery following a major cyclone.

Flanking the eastern side of the Mississippi River Delta Plain, these islands: 1) partially shelter the Biloxi saltmarsh from fair-weather wave swell, 2) regulate estuarine salinity and circulation (Reyes et al., 2005), 3) provide some buffer for New Orleans and its surrounding areas during the passage of tropical cyclones (Stone et al., 2005), and 4) the islands collectively represent the Breton National Wildlife Refuge, which is an important and unique habitat for wildlife such as the brown pelican [*Pelecanus occidentalis*], least tern [*Sterna antillarum*], piping plover [*Charadrius melodus*], loggerhead sea turtles [*Caretta caretta*]) (Lavoie et al., 2009), and sandwich terns (*Thalasseus sandvicensis*) (Shealer, 1999).

As coastal land loss continues to impact much of the Louisiana coast, the scientific community, government officials, and environmentalists have raised concerns about the longevity of the island chain. Fearnley et al. (2009) attributed the majority of land loss in the Chandeleurs to tropical cyclone frequency and intensity. On the basis of historical trends of a decreasing island footprint, Fearnley et al. (2009) extrapolated that the northern Chandeleur islands would be converted to an inner-shelf shoal sometime between 2013 and 2037.

However, this estimate was made before a sand berm was constructed between 2010 and 2011 along the northern part of the island system as a protective, oil-spill response measure following the MC252 Deepwater

Horizon oil spill. This study builds on the Fearnley et al. (2009) report using new post, berm-building data. Specifically, we provide insights concerning the evolution of the north and south barrier island chain, specifically considering in the analysis the alongshore versus across shore sand transport, vegetative patterns, sedimentation trends, and general historical data. On the basis of historic geomorphic evolutionary trends this report also presents a scenario of renourishment and preservation tools for the Northern Chandeleur Islands so that predictions of island collapse are extended into the future.

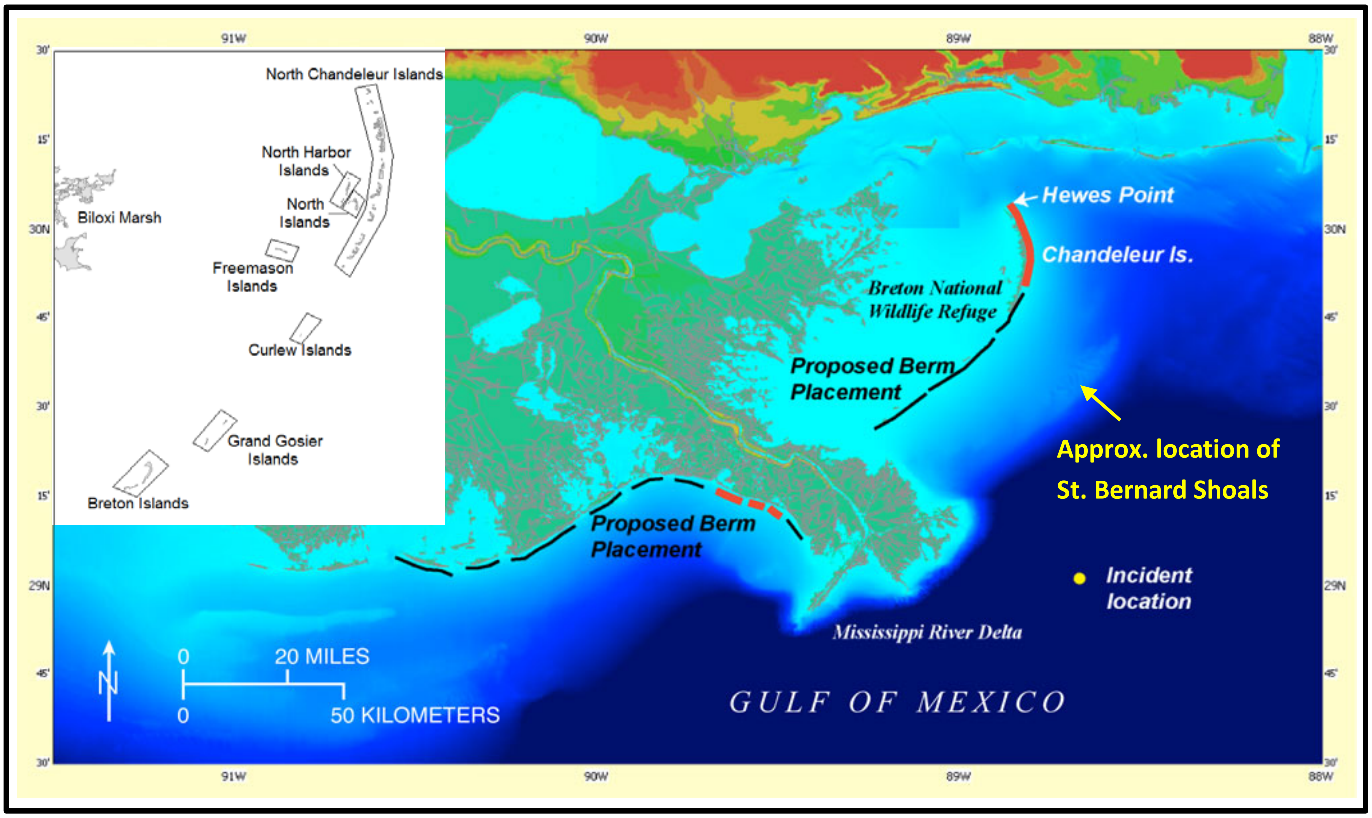


Figure 1. Regional map of the eastern Louisiana coast showing the location of the Chandeleur Islands and a labeled inset map of the island footprints in 2008. Map also shows the location of the proposed near-shore berm placements (black) and completed near-shore berms (red) following the 2010 Deepwater Horizon oil spill (map modified from Lavoie et al., 2010).

PART II: CHANDELEUR ISLAND FORMATION

Early Development- The Chandeleur Island chain represents the marine-reworking of the St. Bernard delta complex (Penland et al., 1988; Fig. 2), which was an active distributary of the Mississippi River between ~3,600 and ~1,500 years before present (Törnqvist et al., 1996). After avulsion of the lower Mississippi River to the Lafourche delta complex, the St. Bernard deltaic headland was eroded and reworked concentrating sand that developed into the proto-Chandeleur Islands. At the same time, much of the interior St. Bernard delta plain subsided and was eroded to form what is now Chandeleur Sound. This process detached the Chandeleur Islands from its fluvial sediment source thereby decreasing the sediment supply and ultimately forming a transgressive barrier arc.

A comprehensive model for the evolution of Chandeleur Islands must reconcile Frasier's (1967) delta lobe history, presence and extent of the St. Bernard Shoals (Fig. 1), and pathways of former distributary channels, which were excavated and added sand to the barrier system during Holocene shoreface retreat (Rogers et al., 2009). One model for Chandeleur evolution envisions the initial development of the Breton Islands resulting from the reworking of an early lobe of the delta associated with the southerly distributary system of Bayou Terre aux Beouf (Rogers et al., 2009). Frasier (1967) first defined the location of this distributary system on the basis of stratigraphic data. Later, Rogers et al., (2009) incorporated Frasier's (1967) delta lobe history into a four-stage model of the region (Fig. 3). The high angle beach ridges observed on Breton Island (Fig.4), prior to severe hurricane induced erosion during the 2004-2008 period that completely modified these islands, indicate an earlier progradational history and suggest a very different former shoreline orientation as compared to the rest of the Chandeleur arc. As seen in a 1788 map of the region (Fig. 5) Breton Island was once situated considerably landward of the northern Chandeleur barrier arc that extended south to Grand Gosier Island. In fact, the southern spit extension of Grand Gosier Island almost overlapped the eastern end of Breton Island producing a downdrift offset inlet configuration. The totality of the geomorphic and stratigraphic data, including: 1) beach ridge trends

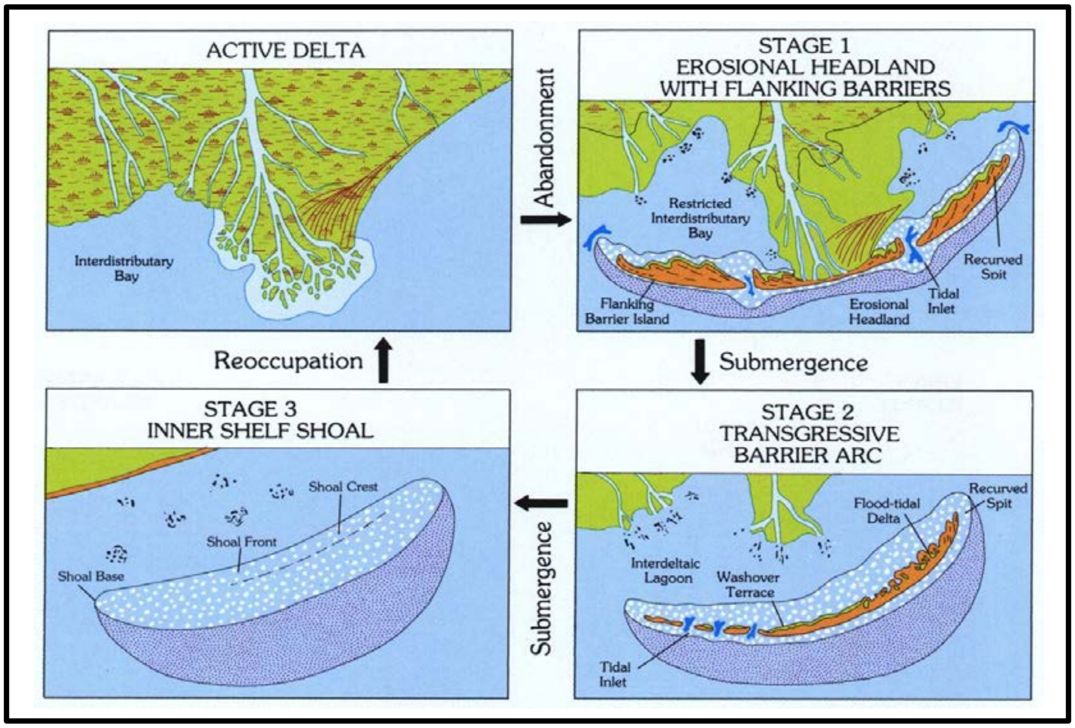


Figure 2. Transgressive-submergence model for barrier island development from deltaic headlands of the Mississippi River delta system (Penland et al., 1988). The Northern Chandeleurs are currently evolving as a Stage 2 system, whereas locally some of the more southern islands have already evolved into a Stage 3 system.

on Breton Island, 2) landward location of Breton Island compared to the northern Chandeleur barrier arc, 3) downdrift inlet configuration, and 4) early southern route of St Bernard distributary channel system (2,600 yrs BP, Fig. 3) suggests that the Chandeleurs (entire barrier chain) formed at different times and during at least two different phases of lobe abandonment, reworking, and barrier arc development (Penland et al., 1988; Fig. 2). As seen in Figure 3 (Rogers et al., 2009), it is probable that Breton Island formed first from the reworking of the Bayou Terre aux Beouf distributary system and the northern portion of the barrier arc developed through reworking of the Bayou La Loutre distributary. Given the alignment of the southern islands of the barrier arc as seen in the 1778 map (Fig. 5), it is likely that Curlew and Grand Gosier Islands initially developed from sand transported southward in the longshore transport system.

Present-day Trends- Surface sediment samples obtained during the State of Louisiana's 2008 Barrier Island Comprehensive Monitoring program (BICM) show that the Chandeleur shoreface is composed of well-sorted, fine sand (0.126 and 0.250 mm) (Kulp et al., 2011). The sheltered backside of the Northern Chandeleurs is largely vegetated and characterized by a platforms of Smooth Cordgrass (*Spartina alterniflora)* and Black Mangrove (*Avicennia germinans*).

The islands are currently located on the middle to inner Louisiana continental shelf, and the northern islands are in Stage 2 of the Penland et al. (1988)'s barrier model (Fig. 2). During the 1855-1989 period, the islands lost approximately 1000 hectares, which translates to nearly 475 m in average barrier width (McBride et al., 1992). This erosion constitutes some of the highest barrier island losses in the country. Fearnley et al. (2009) noted that the islands have decreased noticeably in subaerial extent, but have not moved landward appreciably within historic times compared to some other Louisiana barrier island systems. Historical relative sea-level rise rates along the Northern Chandeleurs average 0.5 cm/yr for the period 1880-2006 (Miner et al., 2007).

During an earlier evolutionary stage when the Chandeleur Islands contained more sand, had a more continuous and robust barrier footprint, and before the islands became segmented due to storm erosion and sand loss, a nodal point existed along the northern barrier arc that defined a divergence in longshore sediment transport directions (Figs. 6 and 7a). During this stage, sand moved northward accumulating at Hewes Point shoal and was transported southward to nourish Curlew, Grand Gosier, and Breton Islands. A digital rendering of the accumulation of sand at Hewes Point is shown in Figure 7b based on a comparison of bathymetric data for the years 1880 and 2006. The total volume of sand deposited during this period was 150 x 10^6 m^3, which averages 5.77 x 10^6 m^3/year (Kulp et al. 2007; Miner et al. 2009). As the sand reservoir at the nodal point and along the entire barrier system diminished, possibly due to fewer distributary sand-filled channels in the subsurface, sand transport to the south was greatly reduced and many of the southern islands periodically have been converted to subtidal shoals.

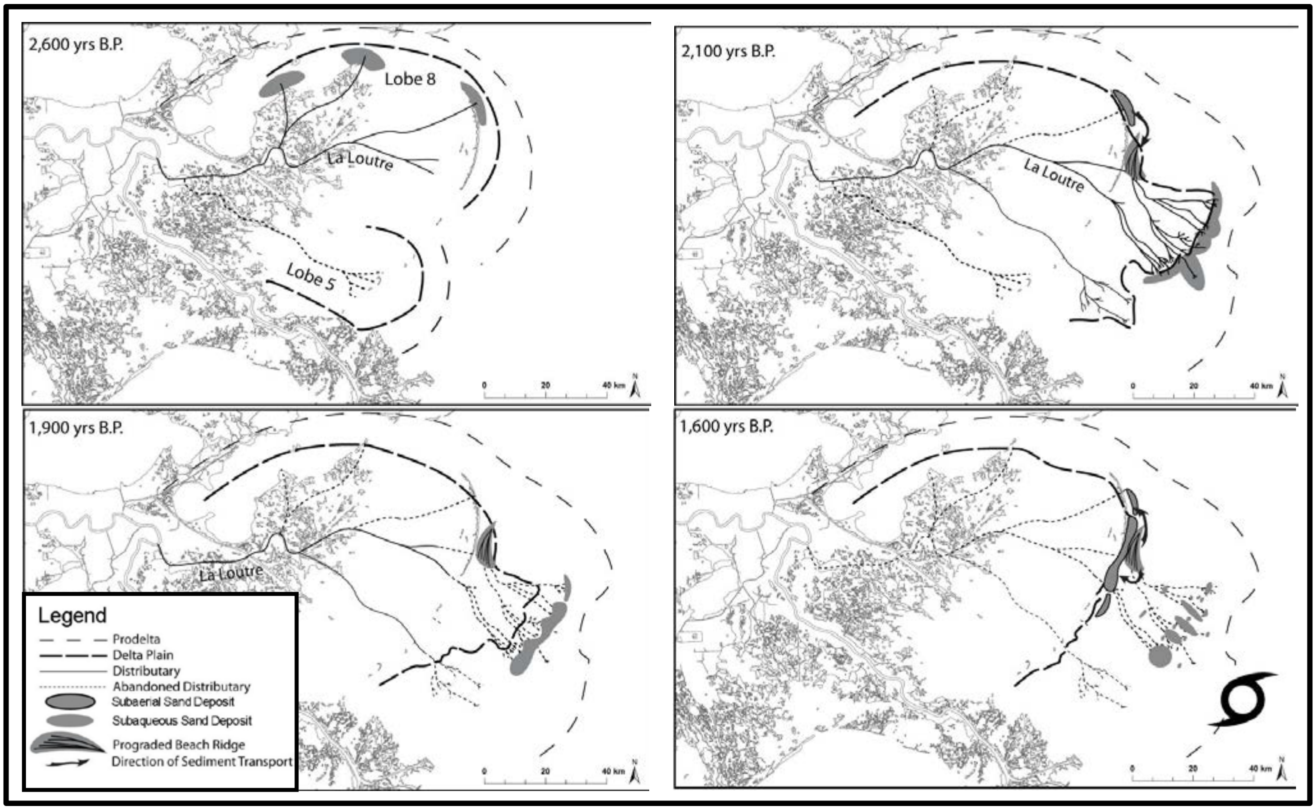


Figure 3. Geomorphic and chronologic evolutionary model of the St. Bernard delta complex distributary systems, St. Bernard shoals and Chandeleur Island system (from Rogers et al., 2009).

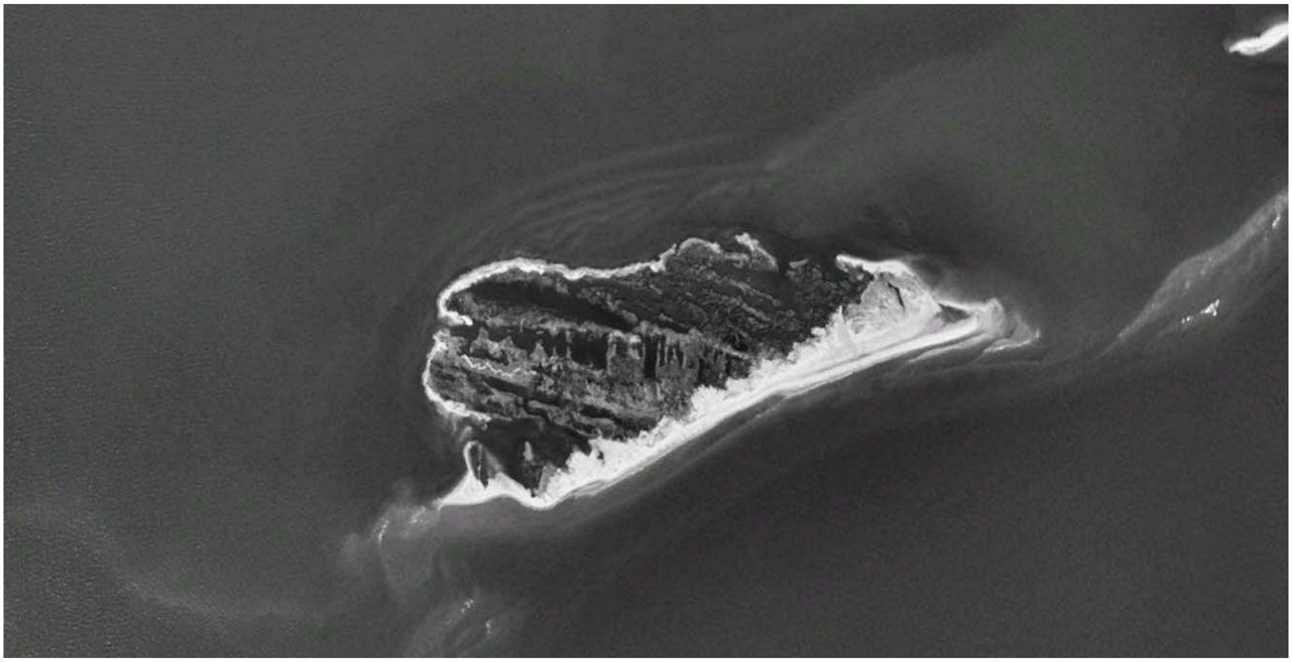


Figure 4. 1998 aerial photograph of a section of Breton Island. Note the high-angle, linear beach ridges compared to the trend of the present shoreline.

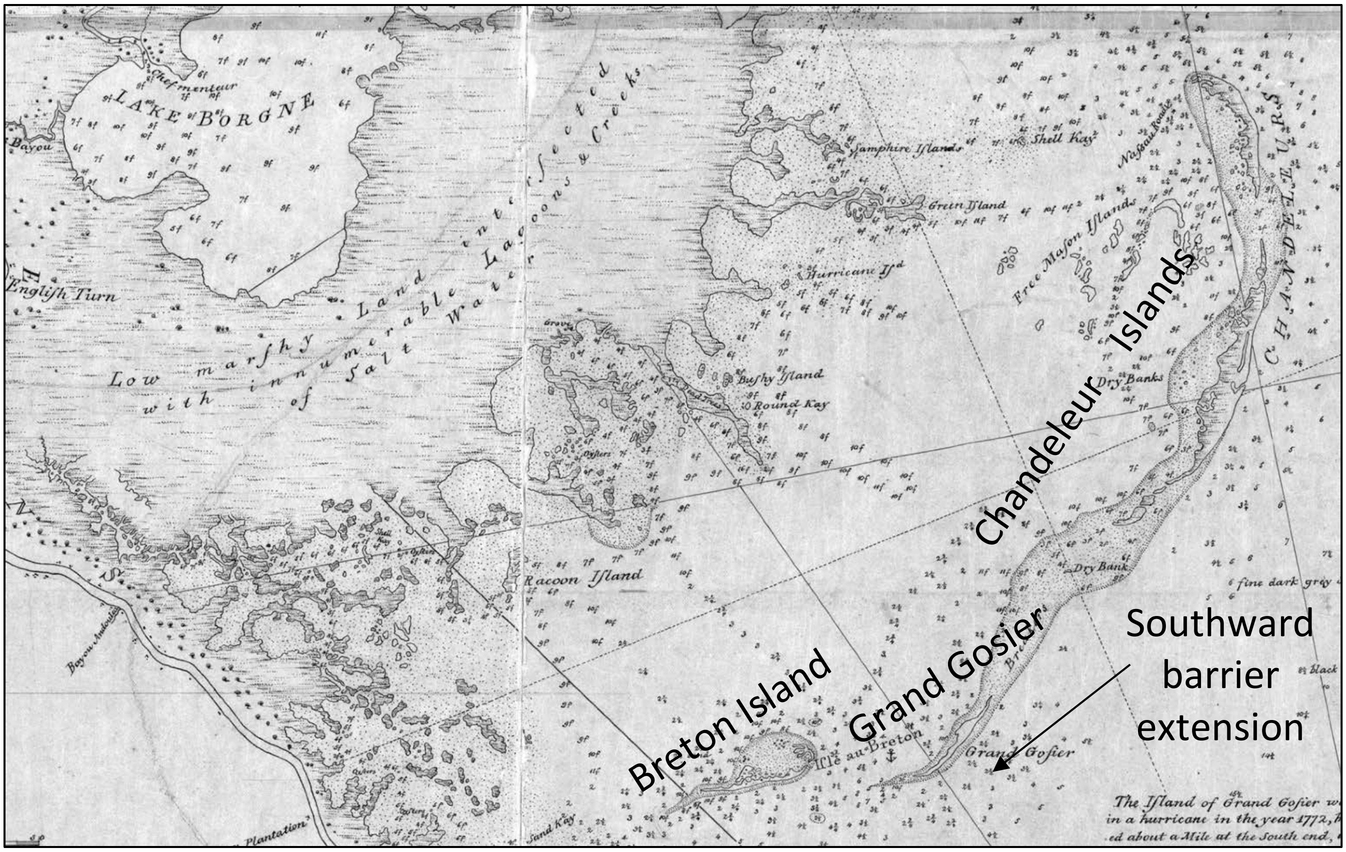


Figure 5. 1778 map of the eastern Louisiana coastal plain as surveyed by George Gauld. Note the large offset, overlap of the Grand Gosier and Breton Island shorelines that creates a north to northeast trending tidal inlet axis. One explanation for this inlet morphology is that Breton Island was an earlier barrier and the barrier to the north formed at a later time and gradually accreted southward.

Fearnley et al. (2009) asserted that historical changes to the Chandeleur system are event driven and the future long-term evolution and viability of the barrier chain will be controlled by the frequency and magnitude of tropical cyclones. Evidence of this trend is demonstrated by pre- and post-Katrina imagery (Sallenger et al, 2009). Kulp et al. (2007) noted that the islands were largely stripped of sand in 2005 during Hurricane Katrina and that by 2007 sand recovery had not approached pre-Katrina levels.

Projected future increases in the rate of relative sea-level-rise, hurricane frequency, and hurricane intensity will further threaten the islands' ability to contain its sand resources and maintain its integrity. The combined alongshore losses of sand to Hewes Point, offshore losses during storms, and onshore sand transport filling an increasingly deeper backbarrier water column due to subsidence will ultimately deplete the Chandeleur Islands of its sand reservoirs. Fearnley et al. (2009) estimated that the island system will be converted to an inner-shelf shoal (Stage 3 of Figure 2) during the next 20 years, on the basis of linear regressions of island areas coupled with projections of historical cyclone frequencies and analysis of high-resolution ortho-photos (Fig. 8).

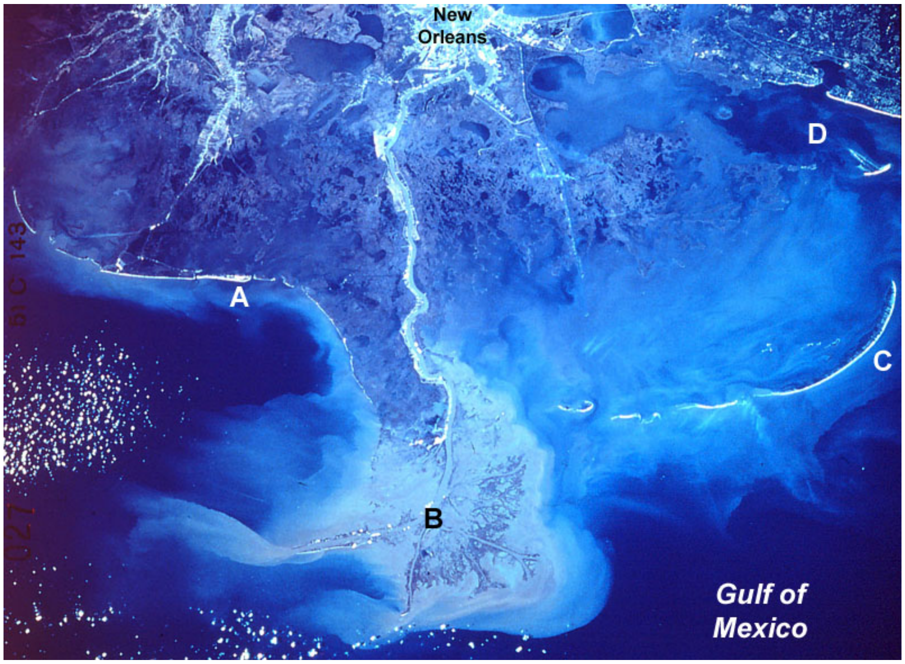


Figure 6. Satellite view of Louisiana coastal plain: A. Grand Isle, B. Head of Passes at the Birdfoot delta, C. Northern Chandeleur Islands. D. Mississippi Sound. Note the extension of sand shoals and barrier islands to the southwest of the northern Chandeleur Islands. The location C on the diagram approximately marks the location of a nodal point where sediment is transported alongshore to the north or south.

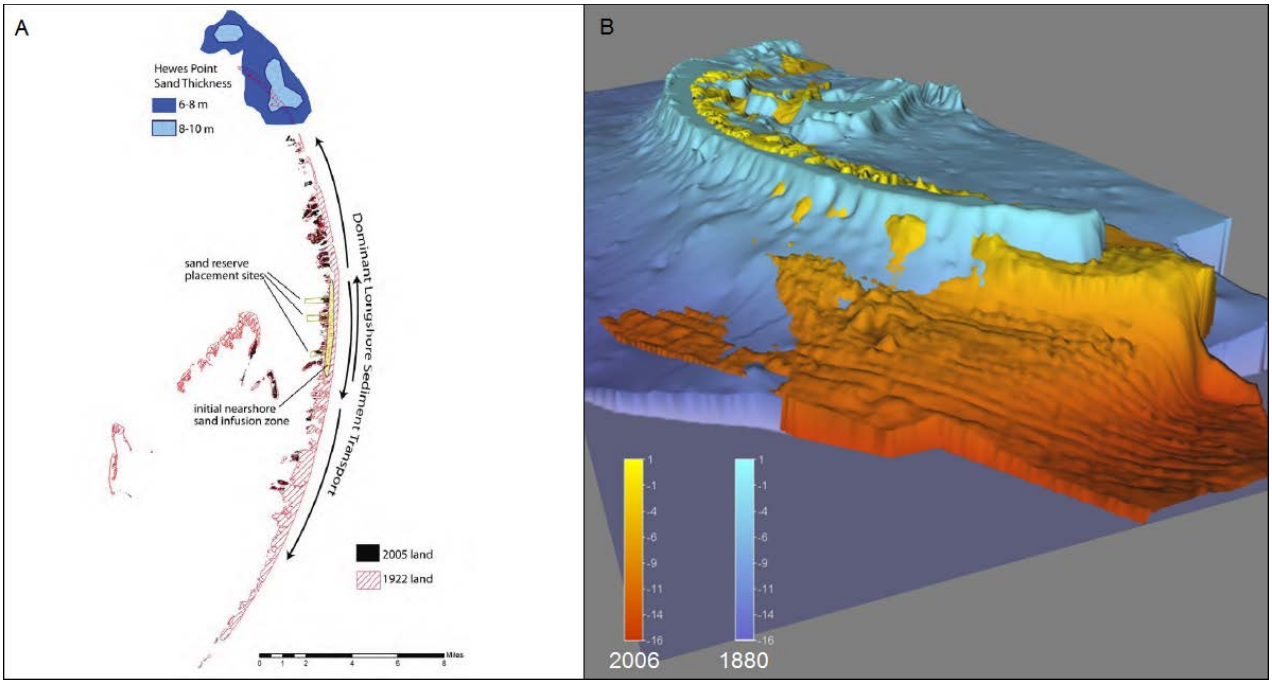


Figure 7. Diagram showing the dominant sediment transport patterns along the front side of the Chandeleur Islands. A. Schematic diagram of longshore transport patterns showing a zone of divergence near the middle of the Northern Chandeleur system (from Lavoie et al. 2009), and B. Along-strike superimposed Digital Elevation Models showing the accumulation of material at Hewes Point from 1880 to 2006 (adopted from Miner et al. 2007).

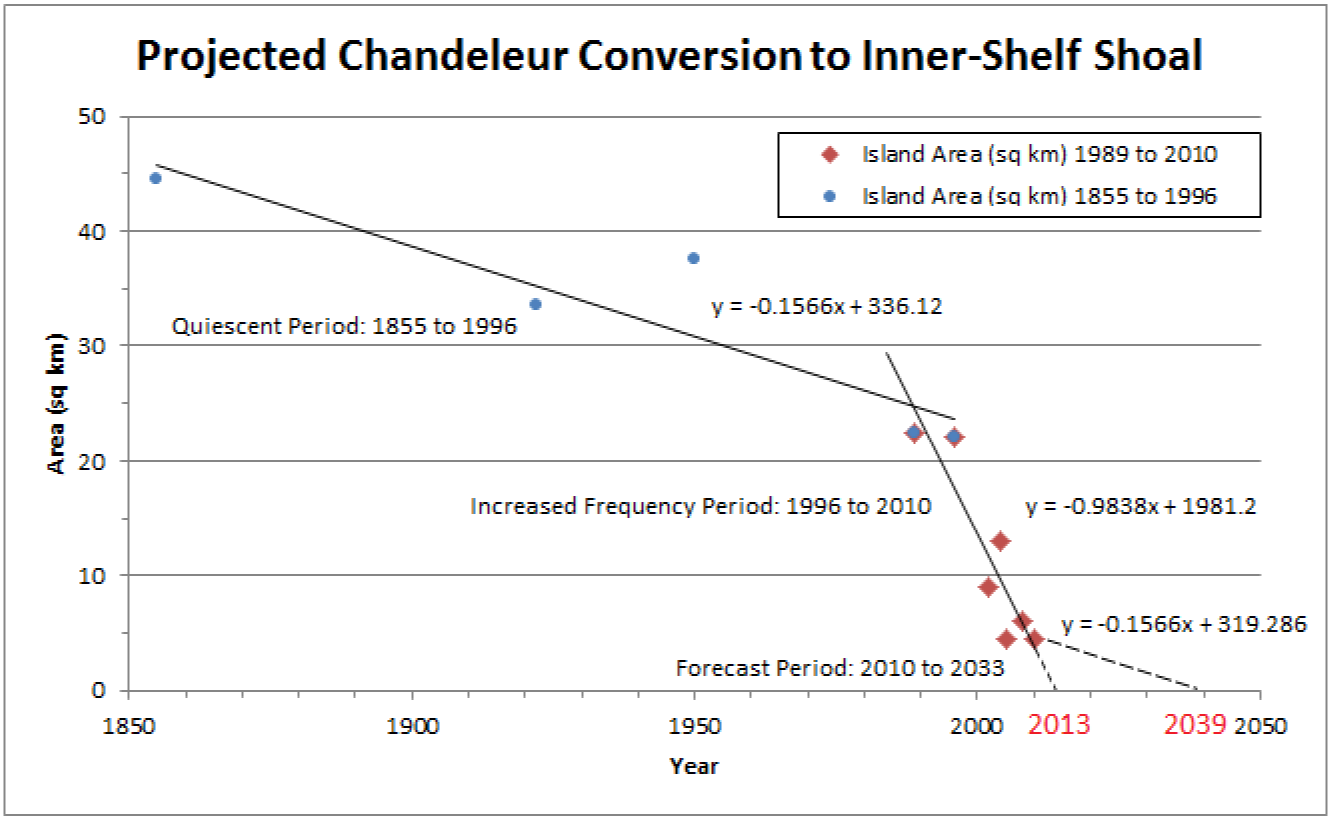


Figure 8. Linear analysis of historic island area showing a period of increased storm frequency beginning in approximately 1996, with projections for the future disappearance date of the North Chandeleur Islands assuming storm frequencies similar to either the modern trend (1989 to 2010, middle steeply sloping regression line) or the previous trend (1855 to 1996, uppermost regression line) (Fearnley et al. (2009) and appended with 2008 and 2010 data. The lower dashed regression line represents predicted change according to the slope of change during the 1855-1996 period.

PART III. PREVIOUS RENOURISHMENT SUGGESTIONS

Previous renourishment plans for the Northern Chandeleurs have advocated soft-engineering solutions similar to those that have been employed at the majority of other barrier island systems in Louisiana. In most of these projects the nearshore, beach, and supratidal portion of the barrier are artificially nourished using borrow sand with grain sizes similar to the native sand. Additionally, along some barrier systems mud-rich sediment has been pumped into back barrier locations and vegetated to build back barrier wetlands and help stabilize wash-over platforms (e.g. LCWCRTF, 2013).

Penland et al. (1992) presented three designs for using sediment and vegetation to restore coastal barriers, including: 1) beach nourishment and construction of a vegetated foredune ridge, 2) Adding sand to elevate the barrier and then vegetate the artificial dunes, and 3) backbarrier tidal flat and marsh construction followed by eelgrass planting (Fig. 9). Penland et al. (1992) intended Option 1 for amenity barrier islands that require a wide beach for tourism and high foredune ridge for storm protection, such as Grand Isle, LA. Options 2 and 3 were intended for uninhabited barrier islands that seek to reinstate barrier integrity and restore habitat diversity.

However, as emphasized by Martinez et al. (2011) in the context of modern rates of relative sea-level-rise and hurricane-induced erosion, any sedimentary modification will be relatively short-lived and will likely have to be repeated. It should also be noted that potential sediment sources for restoring the Chandeleurs, including the Hewes Point sand reservoir and offshore St. Bernard shoals, have finite sand reservoirs and cannot be used indefinitely for nourishment projects (150 x 10^6 m^3 and 135 x 10^6 m^3 respectively; Miner et al. 2007, and Rogers et al., 2009). However, sand could be dredged from the Head of Passes and other sections of the Mississippi as this is a renewable sand source and has the added benefit of being coarser grain sand than the barrier sand and therefore, more stable under storm conditions.

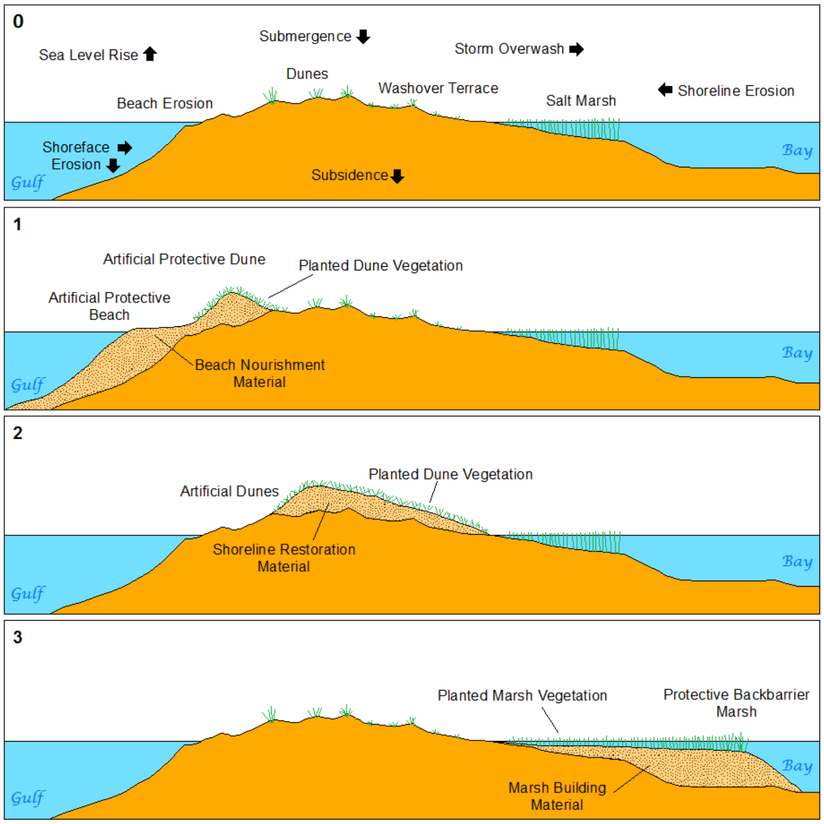


Figure 9. Possible restoration activities to apply to the Chandeleur Islands. 0. Conceptual model of the processes affecting the islands. 1. Beach nourishment and foredune ridge formation. 2. Elevating barrier through dune construction, 3. Development of backbarrier flat and marsh vegetation and eelgrass planting (redrawn from Penland et al. 1992),

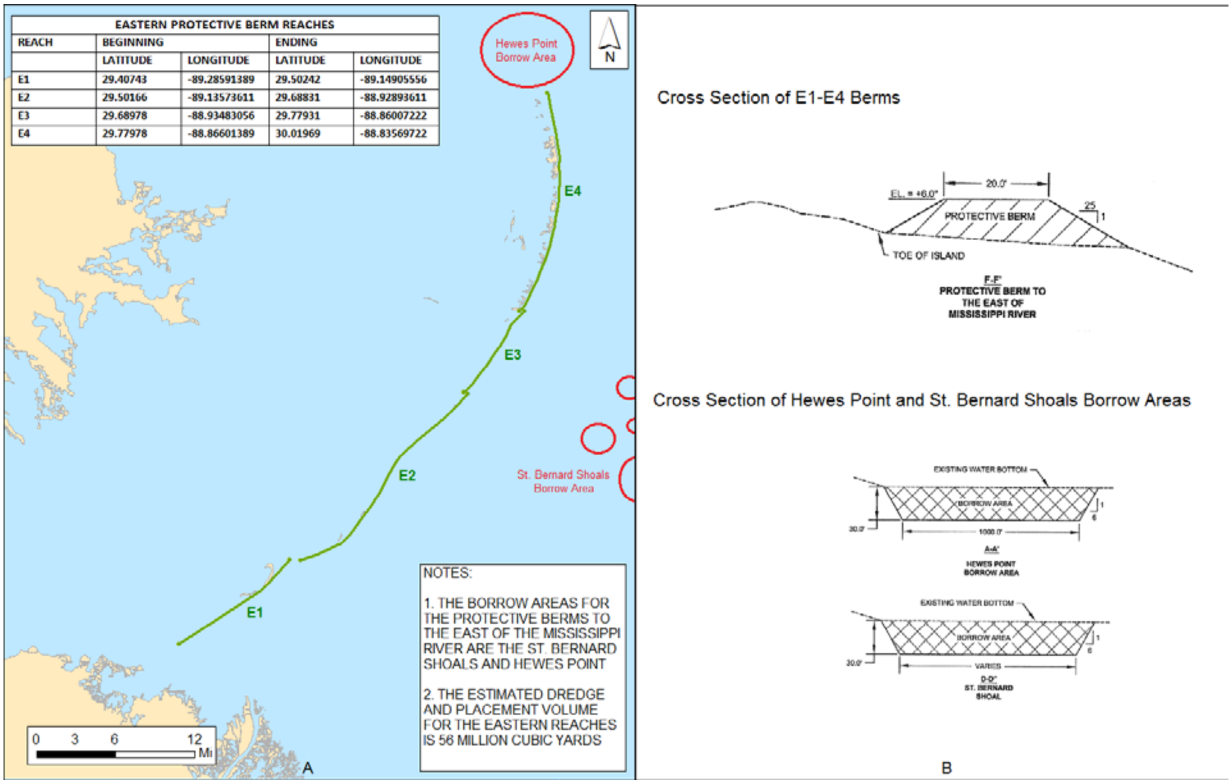
PART IV. CHANDELEUR ISLAND BERM CONSTRUCTION

Initial Conditions- On April 20, 2010 the offshore oil rig *Deepwater Horizon* exploded over the Macondo oil field offshore of the modern Mississippi River delta (Mississippi Canyon lease block 252 referred to as MC-252), initiating the largest oil spill on record in the United States. By May 5th of 2010 oil began stranding along sections of the Chandeleur Islands (Benton et al., 2011) and by May 11th heavy oiling conditions were being reported along many other sectors of the Louisiana coast.

Construction of protective berms is one method that can be used to prevent free floating oil from reaching intertidal and supratidal zones of sandy shorelines (Owens and Dubach, 2013). Concerned that the MC-252 release would result in widespread oiling of Louisiana coastal environments, the State of Louisiana submitted an emergency request (Barrier Island Plan) to the New Orleans District U.S. Army Corp of Engineers for the construction of approximately 100-miles of sandy barrier offshore of existing barrier islands. Borrow material was to be taken from within 1 mile of the barrier islands as designated by the State. On June 3, 2010 the State submitted a revised Barrier Island Plan aligned with the U.S. Army Corp decision of May 27 to authorize only six of the proposed areas where berms were originally designated. In the modified permit, four sections of berm construction were requested west of the Mississippi River in the vicinity of Scofield Island and Sandy Point (section W8 to W11) and two sections within the Chandeleur Islands (E4 and E3). State and Federal trustees, as well as by the USACE perceived that the permitted areas would receive immediate benefit from berm construction with minimal impact to the existing littoral system (Fig. 10). The fundamental rationale of the Barrier Island Plan proposal was that stranded oil would be easier to clean off sand berms than removing it from marshes. It would also minimize or eliminated oiling impacts to the sandy barrier shorelines.

Chandeleur Island E-3 and E-4 Berms- The design criteria of Chandeleur Berms E-3 and E-4 included: 1) sand composition of the sediment, 2) 50-m width above the mean high water mark, and 3) 2-m above the North American Datum of 1988 (Fig. 10; Plant and Guy, 2011). Sediment to construct the E-3 and E-4 berm sites was sourced from Hewes Point (Fig. 11), a site that had been previously identified as a potential borrow area by Lavoie et al. (2010). Moreover, the more southerly berm sites (E1 and E2) were to be constructed from sediment taken from the St. Bernard Shoals (Fig. 10), located in approximately 20 m of water (Rogers et al., 2009). The construction of the E-4 berm along the northern extent of the islands began on June 1, 2010.

Berm construction along the northern part of the Chandeleurs resulted in the construction of three fundamentally different sections: 1) a northern section that was built in open water on a submerged platform of the former northern Chandeleur system, 2) a middle section that was constructed 70-90 m seaward of the berm, and 3) a southern section built directly onto the beachface (Fig. 12) (Plant and Guy, 2011). Figure 12c shows a view of where the berm came ashore and how it changed through time. Additional photos depicting the construction of the berm are presented in Figures 13 and 14.



EASTERN PROTECTIVE BERM REACHES				
REACH	BEGINNING		ENDING	
	LATITUDE	LONGITUDE	LATITUDE	LONGITUDE
E1	29.40743	-89.28591389	29.50242	-89.14905556
E2	29.50166	-89.13573611	29.68831	-88.92893611
E3	29.68978	-88.93483056	29.77931	-88.86007222
E4	29.77978	-88.86601389	30.01969	-88.83569722

NOTES:

1. THE BORROW AREAS FOR THE PROTECTIVE BERMS TO THE EAST OF THE MISSISSIPPI RIVER ARE THE ST. BERNARD SHOALS AND HEWES POINT

2. THE ESTIMATED DREDGE AND PLACEMENT VOLUME FOR THE EASTERN REACHES IS 56 MILLION CUBIC YARDS

Figure 10. Proposed berm construction along the Chandeleur Islands. A. Map view of proposed berms shown in green. Borrow areas depicted by red circles at Hewes Point and St. Bernard Shoals. B. Engineering plans of proposed berms and borrow areas cross-sections (adapted from Emergency Permit NOD-20).

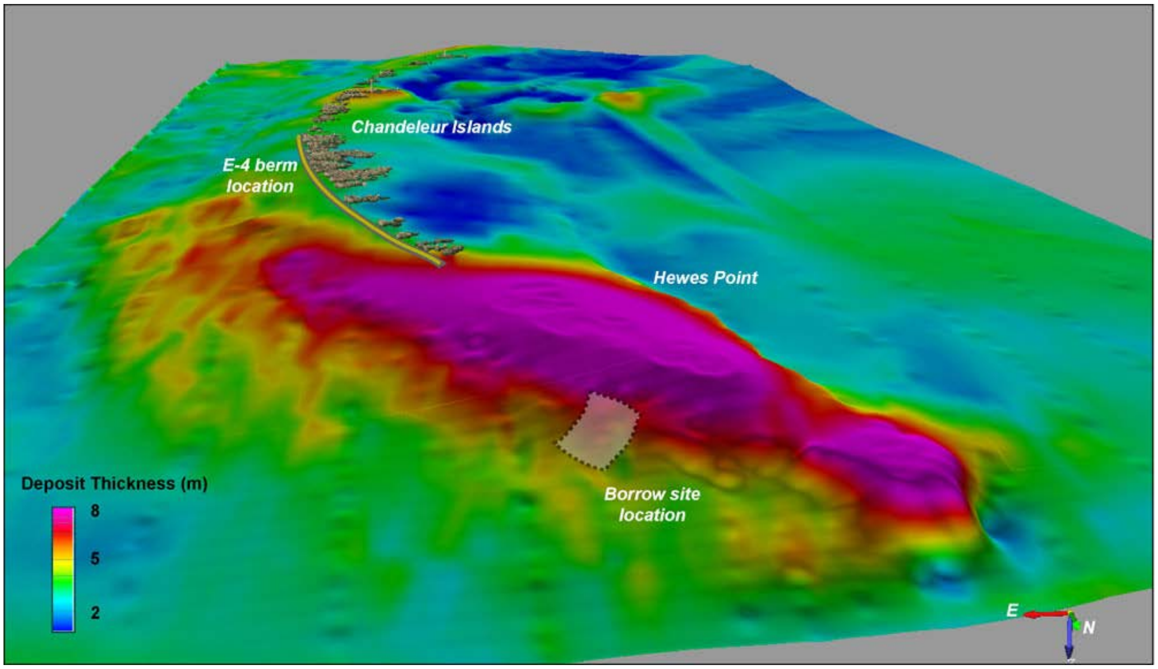


Figure 11. Digital elevation model of Northern Chandeleur elevation and bathymetry with a superimposed model of the Hewes Point sand thickness

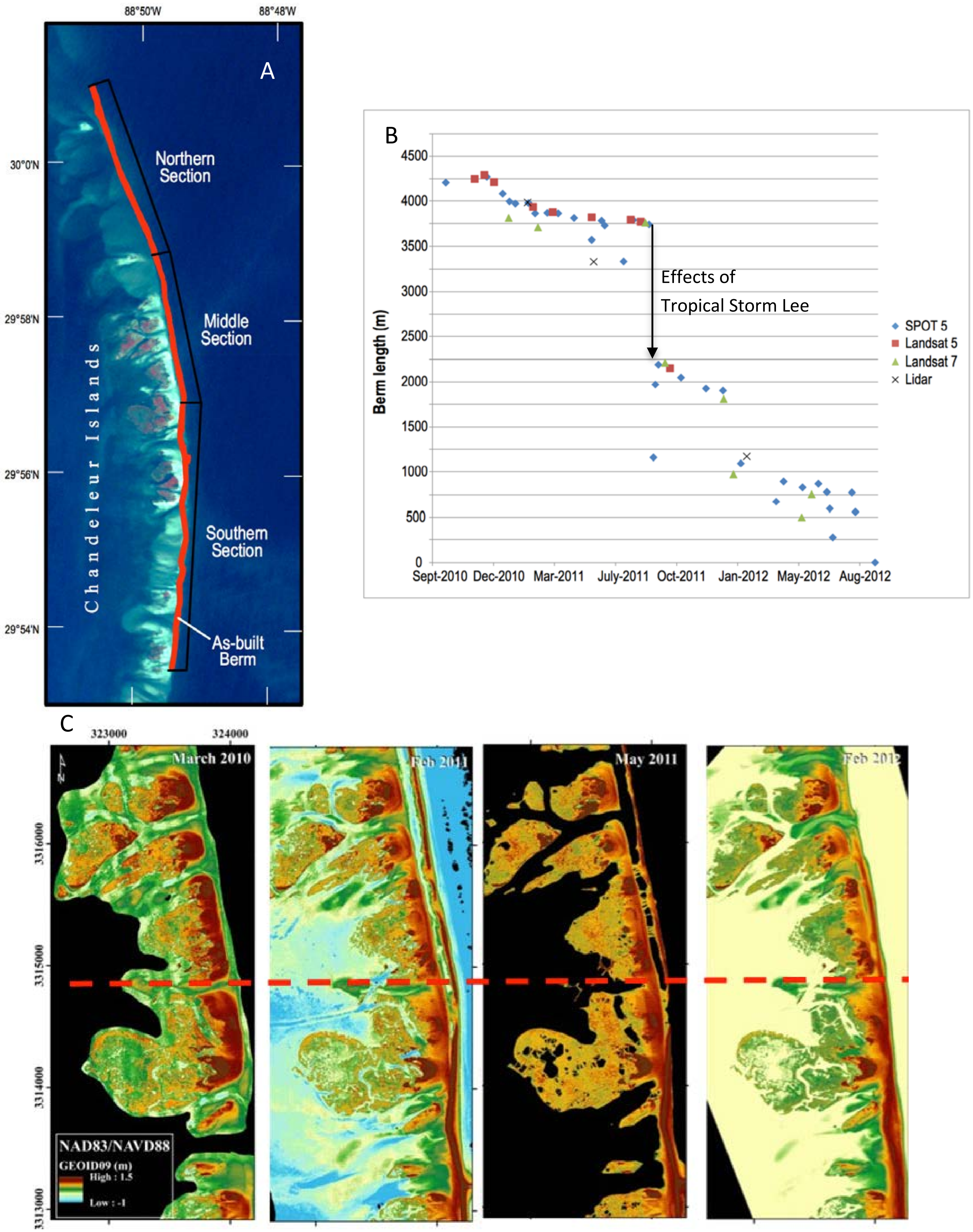


Figure 12. Berm physiography. A. Location of different sections of berm. B. Graph of northern berm erosion. Note the effects of TS Lee. C. Photo and LIDAR sequence showing how the middle section of berm was built and how it eroded from February 2011 through February 2012 (diagrams from the USGS, 2012).

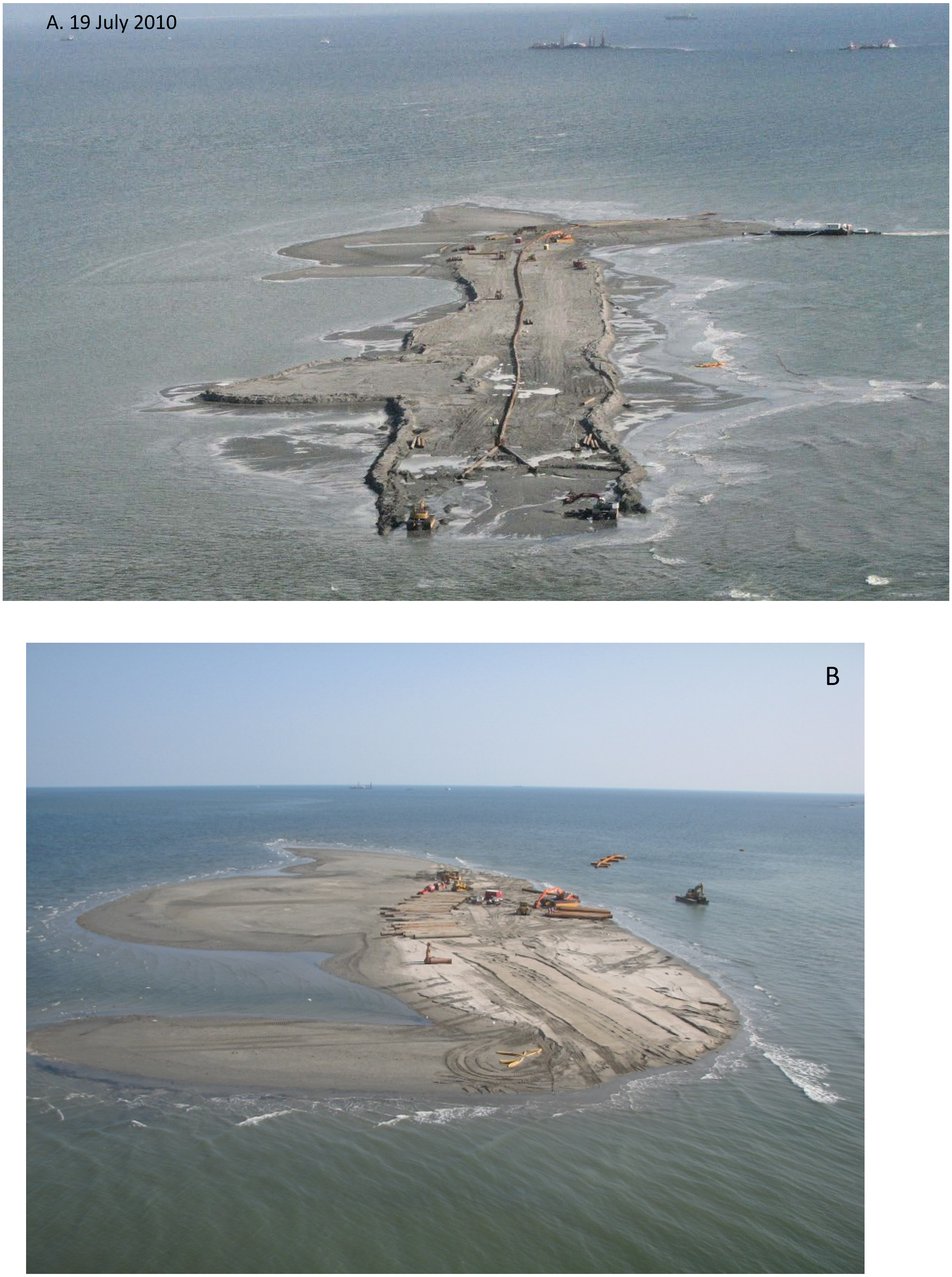


Figure 13. View of berm after several weeks of construction A. Berm in 19 July 2010. Note Dredge site at the top of the photo where sand was being sourced from Hewes Point. B. Crew is preparing to begin pumping sand after a small storm.

Figure 14. Photos of berm during different of construction. A. View looking north along entire length of berm north of where berm attached to the beach. B. View of middle section of the berm C. Photo of northernmost section of the berm on 3 Sept 2010 looking south.

Impacts of the E-3 And E-4 Berms- Berm construction was perceived by many as potentially harmful and capable of causing physical and biological impacts to the onshore barrier system. These suggested impacts were mostly based on the assumption that the berm would separate the barrier system and intervening tidal passes from the Gulf. The range of potential impacts included the following:

1. **Retarded circulation-** closure of tidal passes would diminish tidal circulation between Breton/Chandeleur Sounds and the Gulf of Mexico, reducing the exchange of nutrients and altering salinities and water temperatures.
2. **Obstructed wave energy**- wave energy along the Chandeleur Islands would be prevented or greatly reduced, possibly altering the natural longshore and across sand transport patterns.
3. **Interrupted turtle activities**- the movement, feeding, and egg-laying of a variety of sea turtles would be compromised because the berm would obstruct the turtle's natural movement onto and off the beach and impact natural turtle habitat.
4. **Disrupted reproductive cycles-** crabs and similar organisms that depend on onshore and nearshore barrier habitats for egg-laying and mating would be disrupted because the berm would cutoff their access to these environments.
5. **Restricted fish migrations**- the migration of fish and other species through natural cuts in the barrier system to the backbarrier shallows and broad sound would be prevented by the berm.
6. **Altered wrack development**- the berm would prevent the formation of wracklines along the lower and upper beach where birds such as the Piping Plover forage.
7. **Inhibited food sources-** the food sources of shore birds would be reduced because baitfish and nearshore infaunal animals would disappear or be reduced along the beach.

Despite these suggested impacts of the berm and protest against berm construction there remains no peer-reviewed study indicating that the berm affected the long-term physical and biological environments of the barrier island system.

Initial Berm Progress- According to reports that were issued by the Shaw Group, 4,824,472 yds^3 (3,688,574 m^3) of the proposed 9,978,900 yds^3 (7,630,000 m^3) of sediment (48%) had been pumped and molded into 32,295 linear feet (9,846 m) of the E4 berm on the gulf side of the North Chandeleurs when government officials halted construction in November 2010. Using the width dimension provided in NOD-20 and the completed linear feet value in the Shaw Group reports, the area of the E4 berm as of November 2010 was approximately0.35 mi^2 or 0.9 km^2. Figure 12b is a graph showing how the northern section of the berm reduced in length from 4,200 m in December of 2010 to its complete erosion and disappearance by August 2012. The most devastating loss of sand was associated with the passage of Tropical Storm Lee early in September of 2011 when approximately 1,500 m-length of berm was washed away (Fig. 12b).

Breaching of the E4 berm may have been similar to the model proposed by Lopez (2006) and Rosati and Stone (2007) whereby long, narrow barrier systems are breached because of the steep hydraulic slope associated with differential water levels on the bay and ocean sides of the barrier and narrow barrier widths. This suggests that stable barriers naturally have fixed length-width proportions, and the artificial berm structures did not comply.

If the average sediment accumulation rate for Hewes Point is used as an estimate of the northerly longshore transport rate (5.77 x10^6 m^3/year), then it is reasonable to assume that the entire equivalent volume of sediment placed on the E4 berm (3.69 x 10^6 m^3) should have been transported back to Hewes Point within one year. However, the long-term rate is based on a period that has included numerous large hurricanes whereas the 2010-2011 period experienced only a single moderate tropical cyclone. In contrast, if a rate of 70,000 m3/yr (Ellis and Stone, 2006) is used because it better characterizes transport during mostly non-storm conditions, then after three years most of the berm sand should still remain along the barrier. The fact that there is little obvious morphological evidence of the former berm in 2014, indicates that day-to-today processes and a number of small storms (Table 1) dispersed much of the berm sediment.

Table #1. Impacts of Tropical Storms on the Chandeleur Islands and berms.

Storm	**Date**	**Comments**
1. *Hurricane Alex*	30 June 2010	- Pre-berm erosional event - Brought oil ashore - Category #2 before making landfall in No. Mexico
2. *Tropical Storm Bonnie*	23 July 2010	- Path across delta region - Storm dispersed newly deposited sand
3. *Tropical Storm Lee*	3 September 2011	- Landfall across west-central Louisiana - Caused substantial erosion of berm
4. *Hurricane Isaac*	29 August 2012	- Category #1 when approaching Louisiana - Tracked across delta - Overwashed much of the barrier - Extensive erosion and shoreline retreat - Reoccupation of breaches & deposition of flood deltas
5. *Tropical Storm Karen*	3 October 2013	- Traveled west of delta. - Caused beach erosion and minor overwashed

Chandeleur Island area for 2010 was estimated by calculating the projected island area using a linear regression based on points for the period 1996 to 2008 on Figure 7, yielding an area of 3.48 km^2. Total island area, including the E4 berm, would be 4.52 km^2 (3.48km^2 + 0.9km^2). This calculated area is added as a new point in Figure 7, and was used to create the dashed projection lines. Assuming no human influence and that the frequency of storm conditions remains within the rates seen between 1855 to 1996, and 1989 to 2010, the Chandeleur Islands will disappear during the next 25 years (starting in 2014).

Assessment of Berm- The purpose of the berm project was to use nearby sediment sources to build a protective sand buffer in front of a highly vulnerable island chain that inevitably would be impacted by MC-252 oil. The Chandeleur Islands were located only 70 km from the Deepwater Horizon well and were the closest barrier island chain to the MC-252 oil slicks during the early stages of oil release. The sand berm was originally conceived to protect island habitats. In final assessment, because the oil had already come ashore prior to berm construction, the goal of protecting the Chandeleur Islands was not realized. However, the sediment-starved islands did benefit from the addition of 3.7 million m^3 of sand, although if nourishment has been the original intent of the project, placement of the sand could have been more judiciously located. For example, the northern berm section was built on a submerged island platform and not anchored to any existing island or marsh headland. The berm was steep-sided with slopes unlike nearby natural barrier nearshore areas. After the northern berm was completed, wave action served to redistribute sand forming a slope in equilibrium with the ambient wave conditions. This process consumed the entire subaerial portion of the northern berm rendering it to a subtidal shoal by August 2012 (Fig.12). The middle berm section was placed 70 to 90 m seaward of the beach, which is not an ideal location to nourish a beach, particularly when the seaward side was much steeper than along the adjacent natural beach. Much of this sand never moved onshore and prograded the landward beach, rather it was likely moved offshore and alongshore. Obviously, placement of the southern berm section on the existing beach was more ideally located for nourishing the beach.

PART V. BARRIER RECOVERY

A September 2014 over-flight of the Chandeleurs Island chain allowed an evaluation of the present barrier conditions and their future evolutionary trends (Figs. 15-20). This assessment is also based on numerous trips made to the northern island chain between 2006 and 2012, including some photo-flights of the southern chain. The widespread erosion and disintegration of the barrier chain resulting from the combined impacts of Ivan (2004), Katrina and Rita (2005), and Gustav and Ike (2008) are well chronicled by the USGS in their photographic and LIDAR surveys. In fact, after Gustav and Ike, it was suggested that the islands might disappear (Sallenger et al, 2009). However, in an overall regime of erosion and sand dispersion caused by frequent major storms, there was evidence of natural barrier rebuilding processes that were apparent during periods of quiescence (Kulp et al, 2007). For example, even before the berm construction project nourished the barrier with 3.69×10^6 m^3 of sand, most of the hurricane passes that severely segmented the northern barrier chain had closed as sand from nearshore reservoirs moved onshore.

Likewise, the southern chain (Curlew, Grand Gosier, and Breton Islands) that had largely been converted to subtidal shoals due to hurricane impacts and the effects of MRGO dredging, had begun to rebuild. Along a stretch of shoreline extending from Breton Island north to Curlew Island various stages of barrier construction and evolution exist ranging from subtidal shoals to supratidal incipient barrier islands. These evolutionary stages provide proof of concept of de Beaumont's (1845) and Johnson's (1919) mode of barrier island formation that envisioned shallow subtidal bars being driven onshore by shoaling and breaking waves eventually reaching an intertidal and then supratidal position seaward of the existing mainland shoreline. Penland and Boyd (1985) first proposed that the de Beaumont (1945) mode of barrier island genesis served a minor role in the reestablishment of barriers in the southern Chandeleurs following storm destruction (Fig. 21), but attributed most of reconstruction of the barriers due to Gilbert's (1885) prograding spits. Kahn (1986) studied changes to the Chandeleurs resulting from the category #4 Hurricane Frederick that passed east of islands and produced an 0.8-m high storm surge. He noted that three months after the storm, an island had built vertically from a subtidal shoal (Fig. 22) and after only one year, all but 12 of the 42 hurricane passes formed during Frederick had closed. The evolution of de Beaumont (1845) type barrier islands in various stages (Table 2) of formation are illustrated in Figures 23 through 27.

Table 2. Stages of barrier construction from sub-tidal shoals

Stage 1. Shallow shoal- experiencing breaking and shoaling waves, which transports sand landward toward center of shoal (Fig. 23).

Stage 2. Intertidal bar- vertical shoal accretion produces intertidal bar development (Figs. 24-26).

Stage 3. Incipient barrier- multiple bar weldings and vertical accretion generates supratidal barrier (Figs. 26-27).

Stage 4. Robust barrier- long-term beach accretion and dune building widens and builds barrier vertically.

Stages 1 through 3 require five to six years and a period of relative quiescence when there are no major storms, which can reset the clock by rendering incipient barriers and intertidal bars to subtidal shoals. As the barriers are reestablished, there is a parallel evolution in re-vegetation whereby grasses colonize incipient barriers and eelgrass vegetates backbarrier subtidal shoals. Dune grasses aid in growth and aggradation of the barrier. Once a stable and robust barrier is established, Smooth Cordgrass and Black mangrove colonize the rear portion of the barrier.

Figure 15. Oblique aerial image of the southernmost part of the Northern Chandeleur Islands on 19 September 2014. View is toward the north from the vicinity of what has been historically referred to as Monkey Bayou. Note the presence of back barrier marsh and the many breaking waves across shore parallel sand bars.

Figure 16. Oblique aerial image of the Northern Chandeleur Islands on 19 September 2014 (see Fig. 5 for approximate location). View is toward the north, Free Mason Island is visible in the upper left-hand side of the image, and the southern radio tower is in the backbarrier foreground.

Figure 17. Oblique aerial image of the Northern Chandeleur Islands on 19 September 2014, just south of Redfish Point. View is toward the north.

.

Figure 18. Oblique aerial image of the Northern Chandeleur Islands just south of Schooner Harbor on 19 September 2014. View is toward the north and the houseboat "The Pelican" is visible in the backbarrier.

Figure 19. Oblique aerial image of the Northern Chandeleur Islands at Schooner Harbor on 19 September 2014. View is to the west and the houseboat "The Pelican" is visible in the backbarrier of the image. Note the wash over deposits on the backbarrier marsh platform.

Figure 20. Oblique aerial image of the Northern Chandeleur Islands just north of Schooner Harbor on 19 September 2014. View is to the north. Note absence of a sandy berm as depicted in Figures 13 and 14.

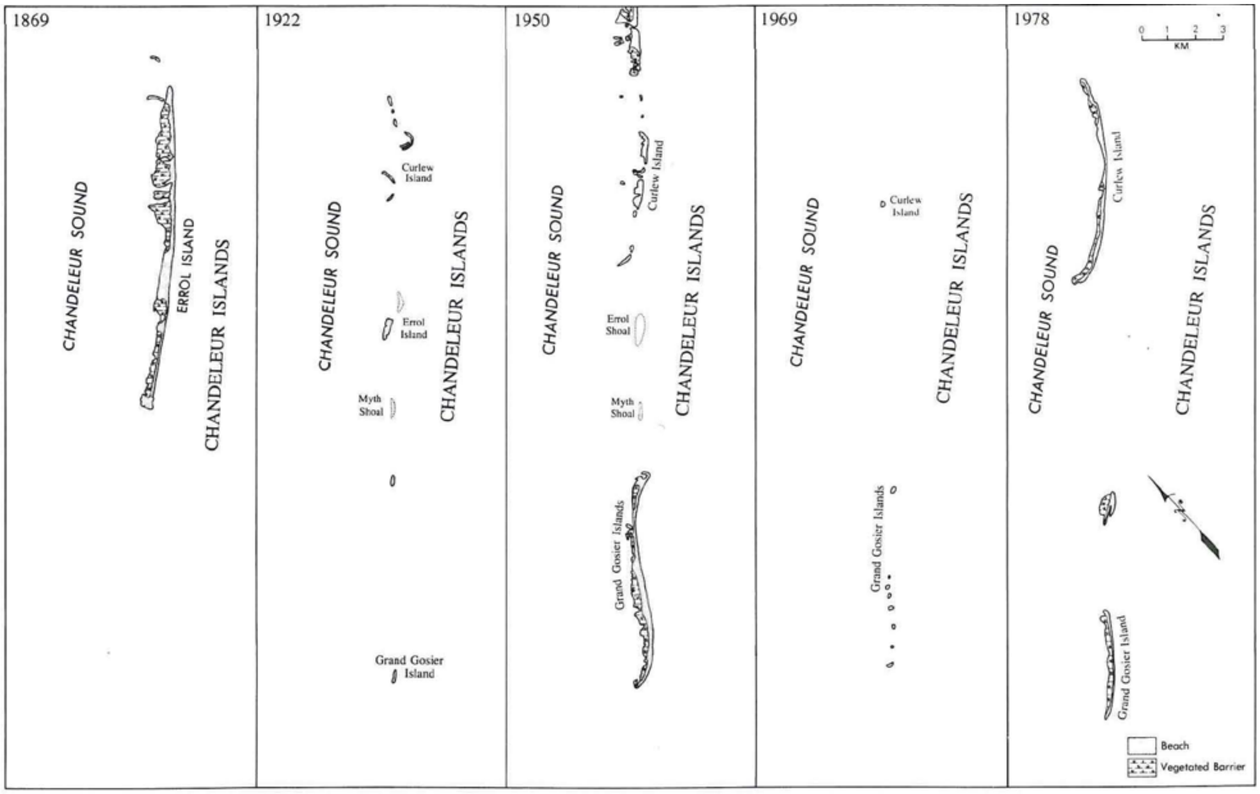


Figure 21. Historical barrier destruction and reconstruction along the southern portion of the Chanderleurs (from Penland and Boyd, 1985). Note that barriers extend southward through spit progradation, but it appears that barriers also must build vertically from subtidal shoals.

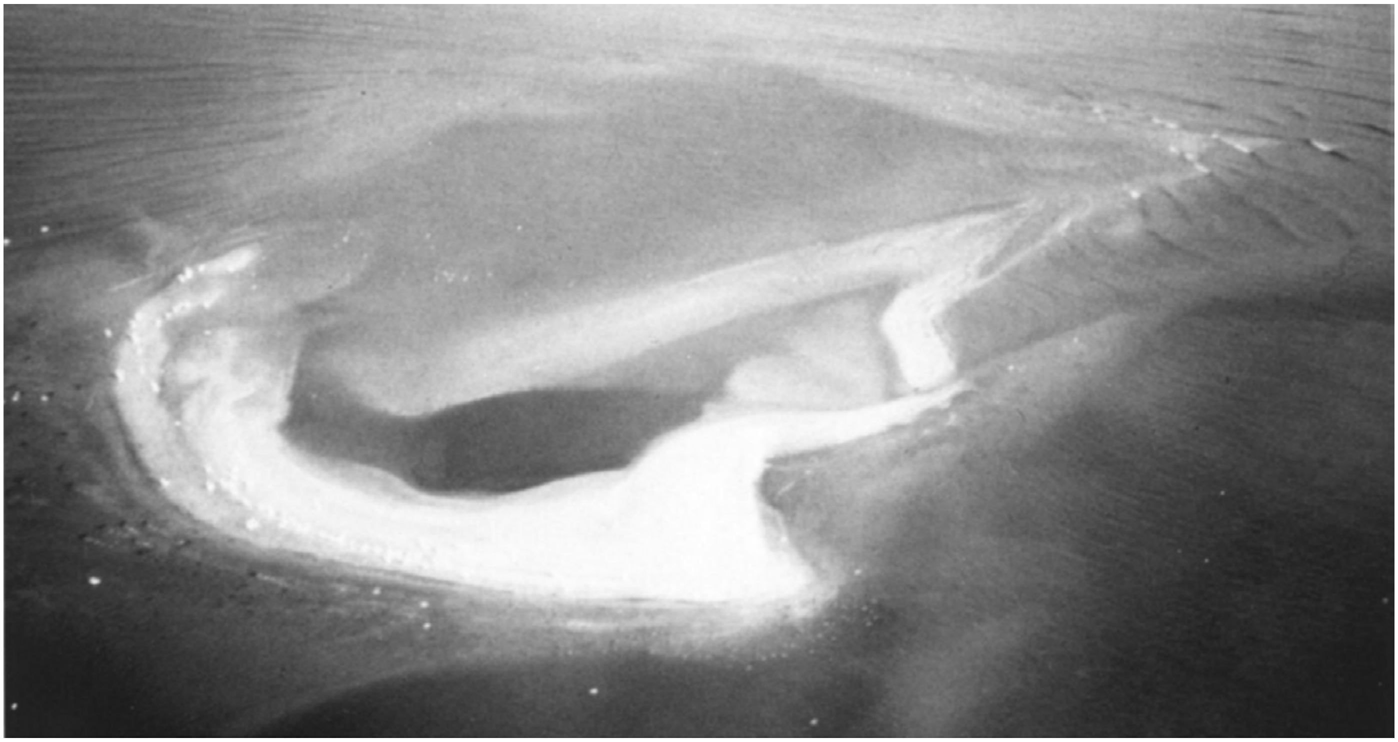


Figure 22. Island formed after Hurricane Frederick (from Kahn, 1986).

Figure 23. Breaking and shoaling waves across subtidal sand shoal. View is toward the west from the Gulf side.

Figure 24. Incipient bar formation by Gulf waves transporting sand westward and bay waves moving sand eastward.

Figure 25. Intertidal shoal development by waves in the southern Chandeleur Islands.

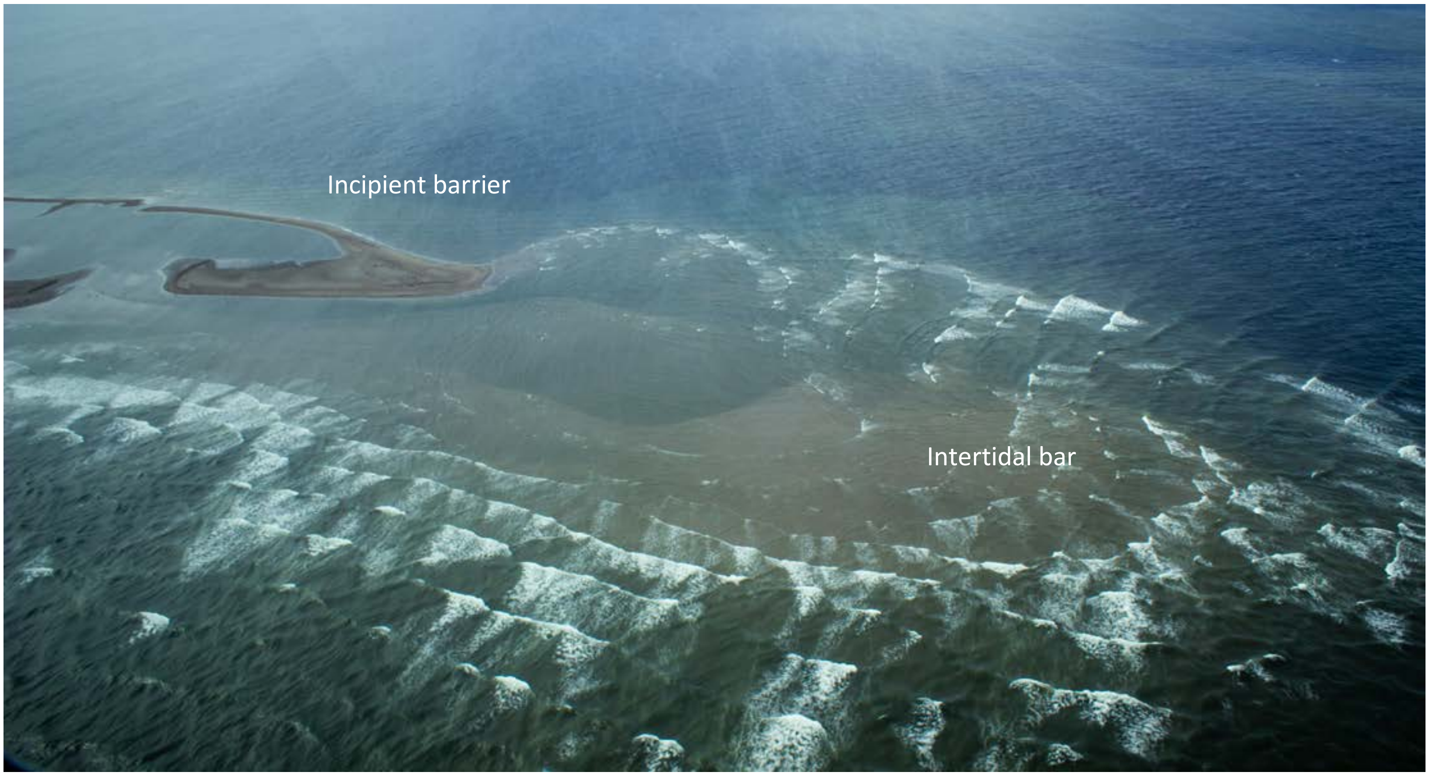


Figure 26. Intertidal shoal and incipient island formation in the southern Chandeleur Islands.

Figure 27. Newly developed barrier islands (A & B). Note the similarity of the two barriers with a more robust supratidal barrier on the Gulfside and a single thin bar formation on the bayside. The rise and fall of the tides produce tidal exchange (double arrow) keeping an inlet open at the north end of the incipient barrier.

PART VI. HYDRODYNAMICS AND SEDIMENT TRANSPORT PATHWAYS, EFFECT OF STORMS, AND SEDIMENT RETENTION STRUCTURES

Historical longshore transport studies

Longshore sediment transport (65,000 to 100,000 m^3/yr) along the Chandeleur Island chain is bi-directional with a node that can oscillate, depending upon the season, by as much as 3-5 km along the mid to southern end of the present barrier arc (Georgiou and Schindler, 2009; Fig. 28; Table 3). Wind climate analysis shows a persistent trend of southeasterly quadrant waves producing dominant northerly sand transport. Model-derived predictions of net LST rates and trends produce a seasonal imbalance in the transport gradients. The hurricane season creates additional asymmetry in the northerly transport component. Long-term trends in northerly transport alone do not explain the 150 x 10^6 m^3 of sand that resides at Hewes Point. Comparison of transport rates over decadal time scales demonstrate the importance of storms in controlling net sand transport patterns. Ellis and Stone (2006) suggested that during storms headland erosion and lateral transport helped rebuild flanking barriers following major erosional events. Sand that is not retained in barrier reconstruction is ultimately deposited at Hewes Point where there are no wave, tidal, or storm processes capable of returning this sand to the active littoral transport system (Georgiou and Schindler, 2009). Although our wave analyses provide a useful quantitative tool for estimating long-term sand transport rates and directions as well as assessing the relative importance of day-to-day versus storm transport processes, there are limitations in determining rates due to the lack of:

- detailed textural and compositional characterization of the nearshore substrate and beach system
- depth of shoreface reworking,
- detailed stratigraphy of the nearshore,
- identification of distributary channels intercepted by the barrier system
- determination of cross-shore sand movement.

Effect of Storms on Longshore Transport Rates

During storms, increased longshore transport rates occurs due to higher and steeper waves approaching the islands, which aid in the short-term, rapid development and reshaping of the barrier island spit as well as producing substantial north-northwestward transport (Grzegorzewski and Georgiou, 2011). This condition was examined through simulations of the relative sediment transport rates during high frequency events, such as a cold front, and rates produced by a low frequency event, such as a hurricane. Hurricanes have a 1% annual probability of occurrence at the Chandeleur Islands, based on the Joint Probability Method with Optimal Sampling (JPM-OS) methodology for estimating hurricane inundation probabilities (Resio, 2007). To simulate the time-dependent hydrodynamic forcing during both low energy and higher energy storm events, the advanced circulation (ADCIRC) hydrodynamic model (Westerink et al. 2008) was used which includes integrated full-plane waves from STWAVE-FP (Smith et al. 2001; Smith 2007). The Soulsby-Van Rijn formulation for combined transport under wave and tidal conditions (Soulsby, 1997) allowed comparison of lower energy cold fronts and higher energy storm events (Fig. 29). This analysis showed that near the northern terminus of the barrier arc, sediment flux during hurricanes was an order of magnitude greater than during cold fronts. Not only do hurricanes produce larger waves than during cold fronts, but due to the relatively deepwater that exists immediately offshore of the northern sector, there is less attenuation of hurricane wave energy compared to regions to the south.

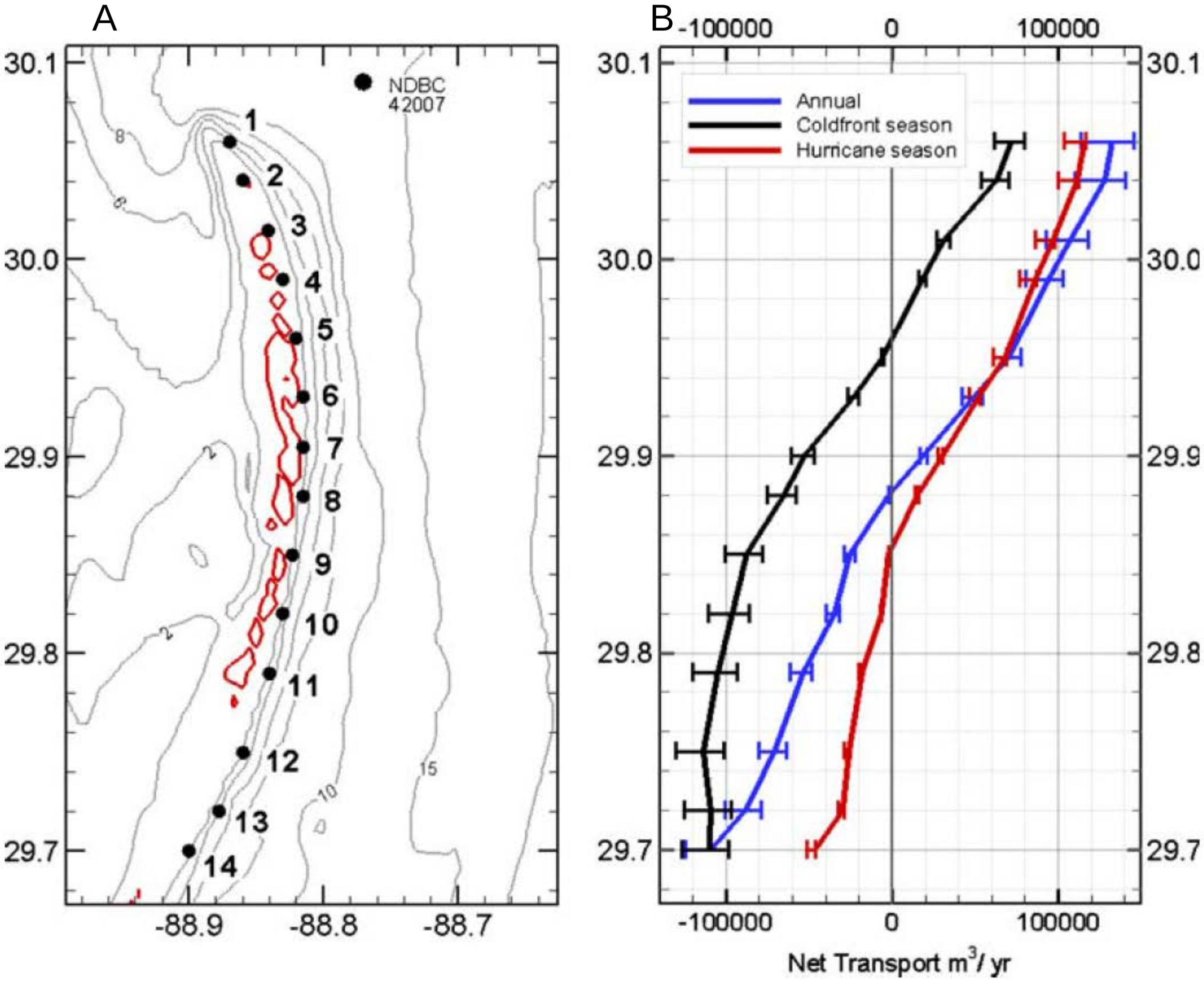


Figure 28. Longshore transport calculations. A. Regional bathymetry in the vicinity of the Chandeleur Islands and locations of longshore sediment transport calculations. B. Potential net longshore sediment transport in m^3/year as a function of different forcings: long-term annual average from 1985 to 2006 (blue), seasonal averaging during the cold front season (black), and seasonal averaging during the hurricane season (red). Error bars indicate fluctuations in the potential transport rate due to uncertainty in the parametric equations used for wave forecasting; they do not indicate the variance in the predictive capability of the CERC formula (from Georgiou and Schindler, 2009).

Table 3. Summary of seasonal changes in the net longshore sediment transport rates.

Pt	Latitude	Segment Distance (m)	Annual (long-term)		Cold front Season		Hurricane Season	
			Net Transport[1] (m^3/yr)	Gradient[2] (m^3/m/yr)	Net Transport (m^3/yr)	Gradient (m^3/m/yr)	Net Transport (m^3/yr)	Gradient (m^3/m/yr)
1	30.06		132,480		71,831		115,600	
2	30.04	2422	127,814	-1.9	63,086	-3.6	111,665	-1.6
3	30.01	3470	107,443	-5.9	31,494	-9.1	96,764	-4.3
4	29.99	2940	93,765	-4.7	18,359	-4.5	85,930	-3.7
5	29.95	4445	70,336	-5.3	-5,742	-5.4	67,955	-4.0
6	29.93	2222	49,147	-9.5	-23,113	-7.8	52,316	-7.0
7	29.90	3470	19,104	-8.7	-52,712	-8.5	30,561	-6.3
8	29.88	2422	-1,972	-8.7	-65,375	-5.2	15,589	-6.2
9	29.85	3334	-25,174	-7.0	-87,776	-6.7	-2,084	-5.3
10	29.82	3470	-34,932	-2.8	-96,383	-2.5	-6,530	-1.3
11	29.79	3334	-53,830	-5.7	-104,899	-2.6	-18,351	-3.5
12	29.75	4445	-70,690	-3.8	-113,475	-1.9	-25,761	-1.7
13	29.72	3470	-87,886	-5.0	-109,004	1.3	-29,412	-1.1
14	29.70	3650	-109,423	-5.9	-110,180	-0.3	-46,471	-4.7
		Average	15,442	-5.7	-41,706	-4.4	31,984	-3.9
		Standard deviation	82,305	2.3	67,158	3.2	56,065	2.0

Notes: 1. Positive transport is north, negative transport is south

2. Positive gradient indicates deposition, negative indicated erosion

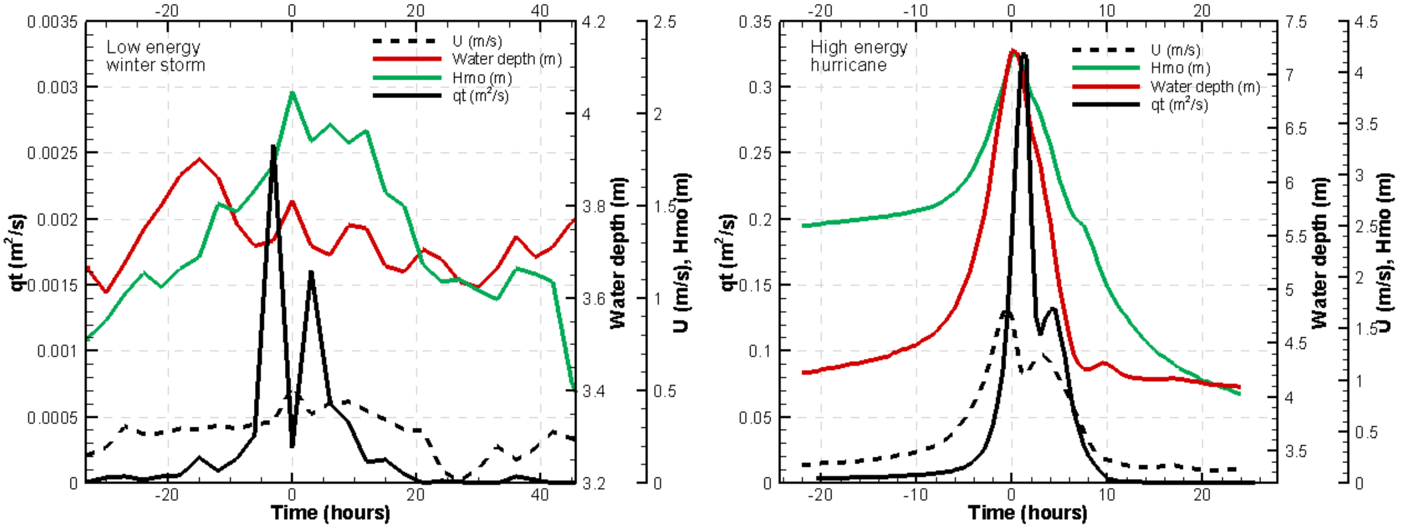


Figure 29. Time dependent sediment transport, storm surge, wave heights, and depth averaged velocity for the low energy (left panel) and high energy (right panel) storm for the southern transect of the island (from Grzegorzewski and Georgiou, 2011).

In addition to increased rates of longshore transport, storms control cross-shore transport over the barrier platform, initially during run-up overwash, and by inundation overwash, if water levels approach or exceed dune crests. Several methods are available to perform these estimates, but the lack of overwash volume data make application of these theories difficult to implement. These calculations also require a determination of storm breaker height and dune/berm elevation.

In the Chandeleur Islands, overwash volumes are also a function of island constructional/erosional state, sand versus shell content, presence of hurricane passes, existence of marsh/mangrove vegetation, dune continuity, and dune height. Moreover, the long-term degradation of the barrier due to storms and lack of sediment infusion suggest that inlets and overwash platforms, and hence volumes, are a function of the Islands' recent evolution. Observations following Hurricane Ivan (2004) and Hurricane Isaac (2012) showed that the barrier responds differently to overwash depending the level of storm, barrier morphology and type of rear barrier vegetation. For example, during Ivan the storm surge overwhelmed the barrier and overwash fans penetrated far onto the backbarrier platform, especially where there was no abutting marsh, but less so where the washover was deposited directly onto the marsh/mangrove vegetation. Hurricane Isaac was a less significant storm compared to Ivan and consequently washovers were less extensive. Measurements of washovers show that the length-to-width ratio (L/W) of the fan is ~ 0.8 for Hurricane Ivan and ~1.5 for Hurricane Isaac. The analysis suggests that overwash fans are increasingly wider, but not necessarily longer as the barrier degrades (Fig. 30).

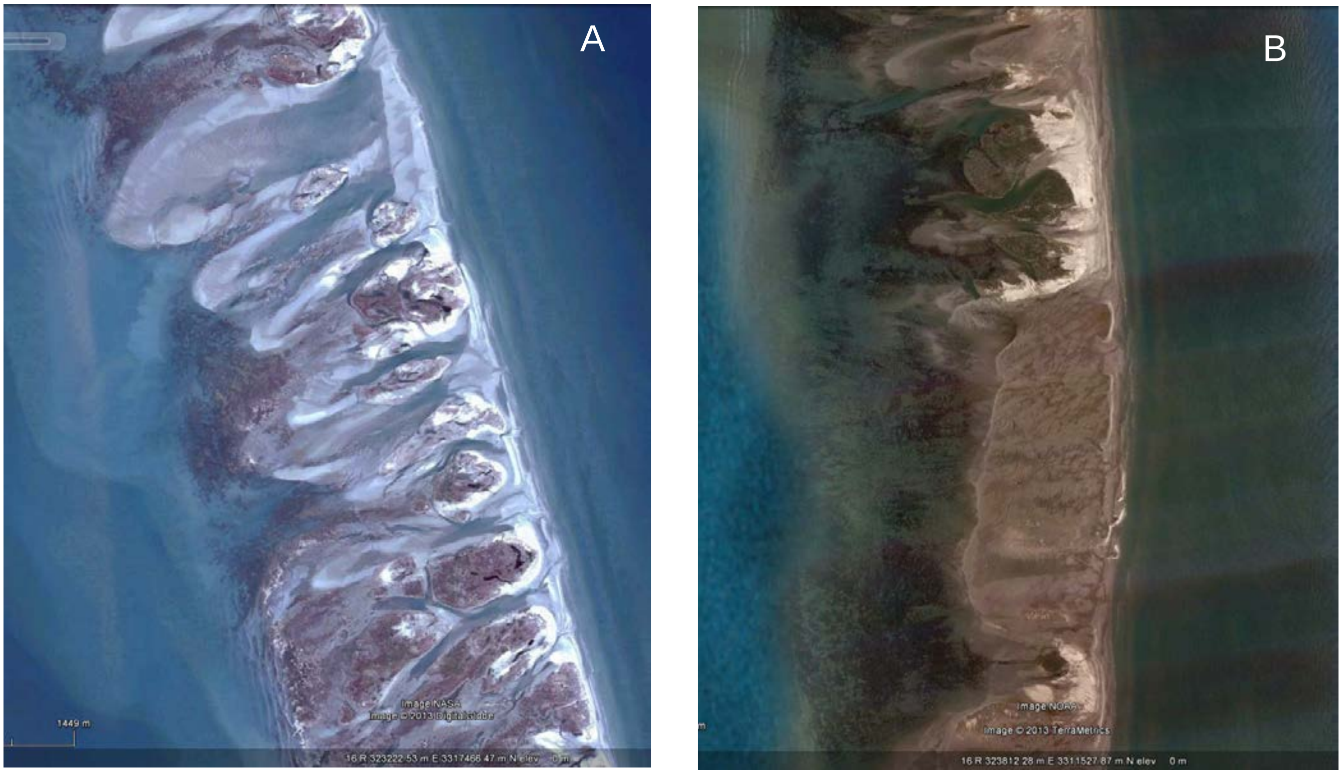


Figure 30. Overwash fans along the Chandeleur Islands. A. Section of barrier after Hurricane Ivan where overwash is confined to former inlets and extends to the back-barrier. Overwash onto marsh is evident, but not widespread. B. View after Hurricane Isaac where overwash consists of large sand sheets, but little penetration into the backbarrier. Overwash onto marsh is widespread.

Modern Longshore Transport Studies

The wave transformation to nearshore areas that was used in Ellis and Stone (2006) and Georgiou and Schindler (2009) was somewhat simplistic, and driven by offshore wave climate obtained from nearby buoy 42007, which no longer exists (22 NM SSE of Biloxi, MS). A more rigorous analysis now employs the wave model SWAN (Ris, 1997) and uses data from NOAA deepwater Buoy 42040 (64 NM south of Dauphin Island, AL). Annualized wave climate from buoy 42040 are used to propagate waves to the Chandeleur Islands and then longshore transport rates are calculated at selected overlapping points from the Georgiou and Schindler (2009) (Georgiou et al., 2013). This study confirmed the presence of a longshore transport nodal point reported by Georgiou and Schindler (2009). Furthermore, at selected locations in the northern Chandeleur Islands, transport gradients from this study show higher rates in the central portion of the Islands and reduced rates near the northern part close to Hewes point. Table 4 shows the comparison of the transport gradients between the two studies.

Table 4. Comparison of modern (this study) and historic (Georgiou and Schindler, 2009) transport gradients in the central and northern Chandeleur Islands.

Location	Longitude	Latitude	Transport gradients Georgiou and Schindler (2009) (m^3/m/year)	This study (m^3/m/year)	difference (%)
4 (North)	-88.83	29.99	-8.70	-7.45	-14%
7	-88.82	29.95	-7.00	-10.37	48%
10	-88.82	29.93	-5.70	-8.38	47%
13 (central)	-88.82	29.90	-5.00	-3.52	-30%

Sediment Retention and Effect of Groins

Often groins are built at the end of a nourished stretch of beach to diminish the loss of sand through longshore transport. The effect of a single groin is accretion of sand on the updrift side and erosion on the downdrift side; both effects extend some distance from the structure. Thus, a groin field (series of groins) results in a saw-tooth-shaped shoreline within the groin field (Fig. 31). Since sediment is continually moving north along the northern arc of the Chandeluer Islands toward the deepwater sink at Hewes Point and recognizing that storms contribute a significant amount of this sediment, groin construction has been considered to help retain some of this sand. Due to the segmented and transgressive nature of the barrier, a terminal groin would be a viable option as it is a single structure and would be as effective as a field of groins. Terminal groins have been used extensively in North Carolina and shown to be effective agents at trapping sand at the end of a littoral cell (Fig. 32).

To test the performance of groins in capturing sand, an analytical solution was solved for the transport near a groin with bypassing. Groins of various lengths (from 15 to 30 m) were tested to assess their effectiveness at sequestering sand and determine how long before they filled to capacity and then start bypassing sand. The analysis used wave heights, periods, and wave direction from the same annualized wave climate produced in this study. Grain-size data was taken from a previous study (Flocks et al., 2009). Results suggest that a 15-m groin will infill to ~12 m length within one year and will produce updrift accretion of nearly 1 m at least 200-300 m updrift from the groin. Similarly, a 30-m long groin would fill to 17 m within one year, causing updrift accretion of nearly 1 m at least 400 – 500 m updrift from the groin. When maximum wave climate conditions are used, both the 15 and the 30 m groins infilled completely within one year, with updrift beach accretion of the order of 1 m nearly 750 m away from the groin.

The results suggest that a terminal groin placed at the end of the northern Chandeleur islands would not be effective at sequestering more than one or two years of sediment from the longshore transport system. After one to two years sand would once again be lost to Hewes Point shoal. Considering the pristine nature of the Chandeleur Islands and the degree of erosion occurring during a substantial hurricane (e.g., Lighthouse lost during Katrina) constructing a hard structure along the barrier does not seem appropriate or practical. Breakwaters in front of the island system were not specifically modeled in this study for their effectiveness in trapping sediment along the island system. The likely outcome however of breakwater placement would be the eventual isolation of the breakwaters from the island as the system continues to overwash landward.

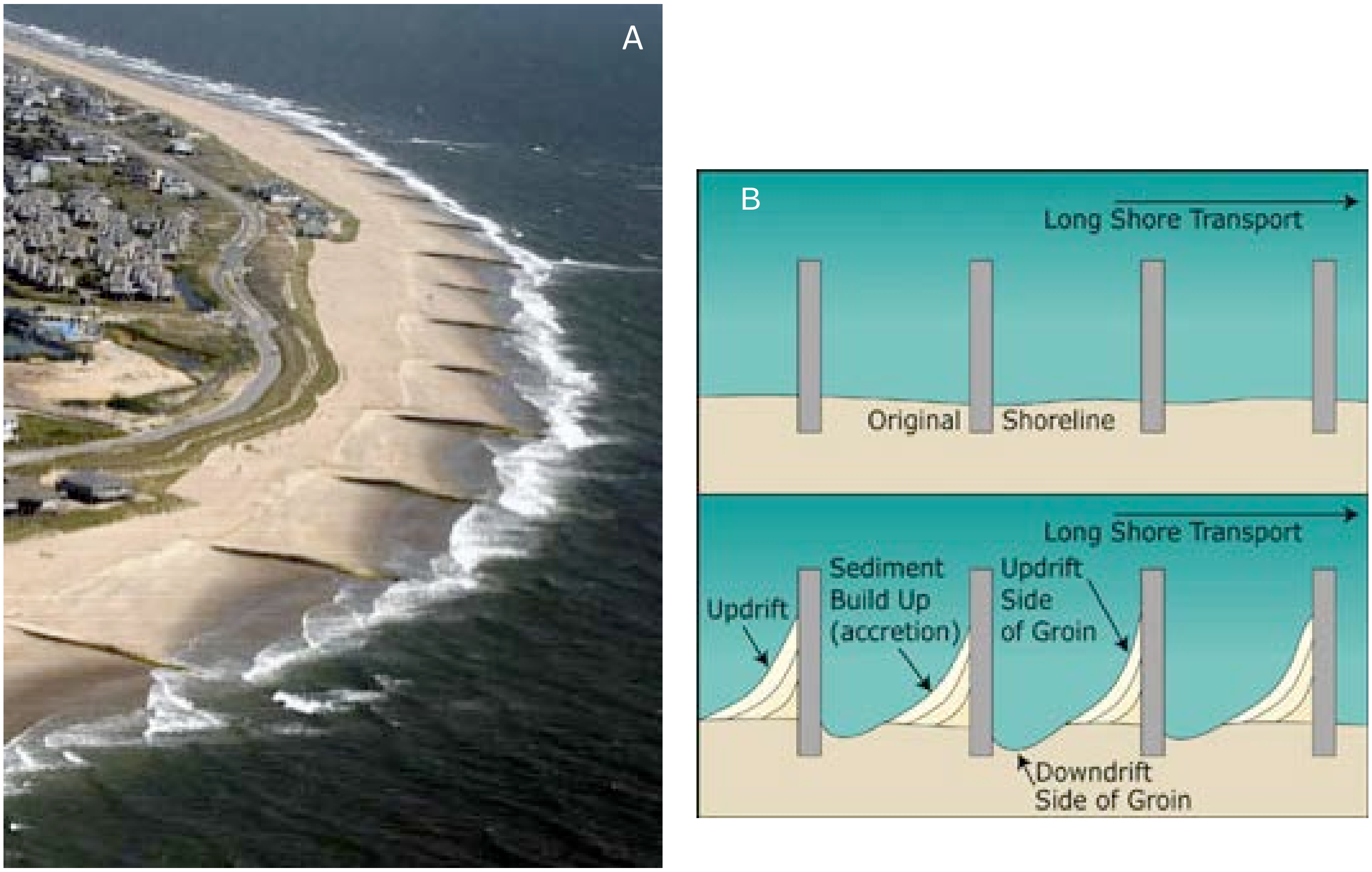


Figure 31. Groin field. A. View of groin field exhibiting saw-tooth beach erosion-deposition pattern.
B. Conceptualize drawing of how a beach respond to a groin field.

Figure 32. Terminal groin at Fort Macon State Park beach in North Carolina.

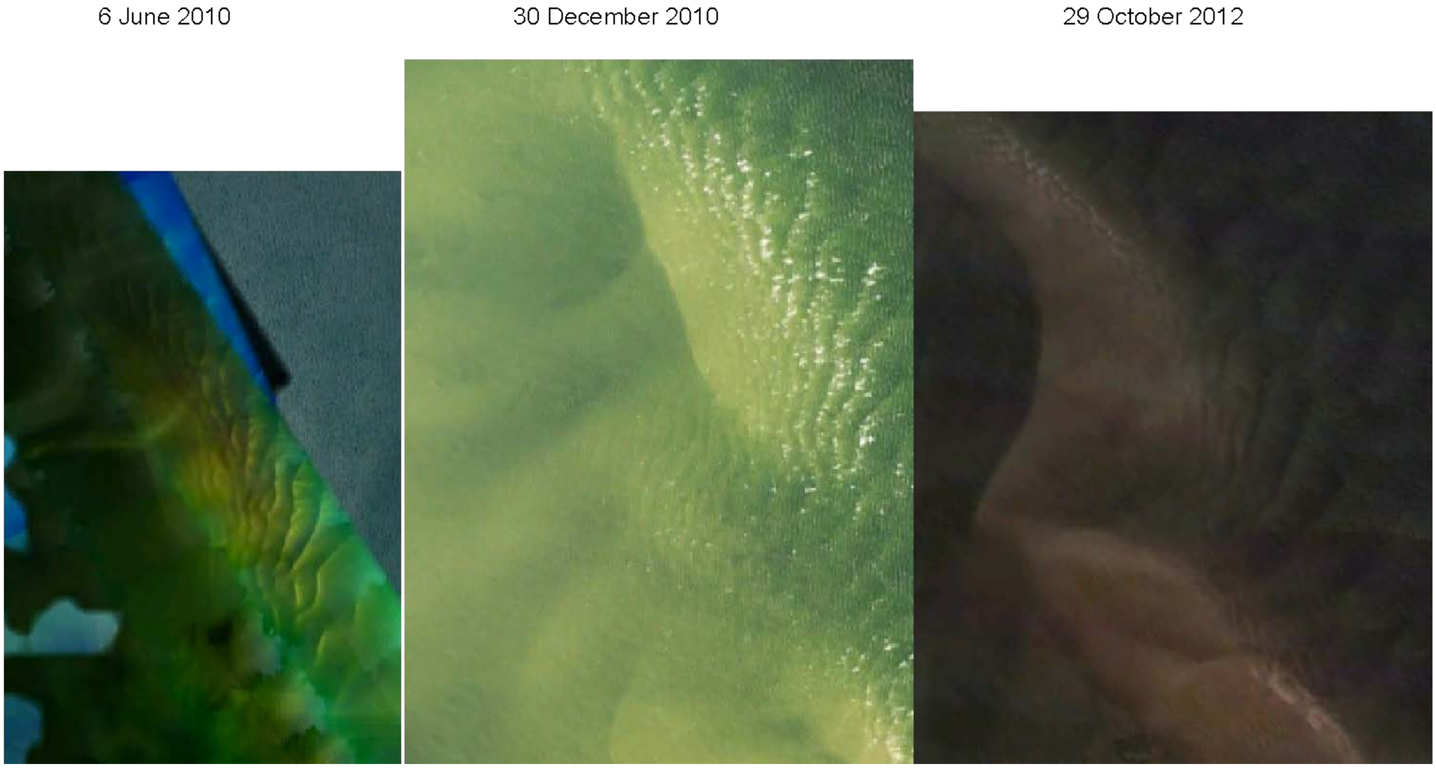
PART VII. PROPOSED RESTORATION MODELS

Future restoration of the Chandeleur Islands will require a substantial input of sediment and a sand input system that maximizes the longevity of the nourishment project by accounting for the major processes controlling sand dispersal vectors and providing a barrier architecture that encourages sand conservation. The major conditions that will impact a barrier-wide restoration project include:

1. A longshore sediment transport system volumetrically controlled by infrequent tropical storms and hurricanes.
2. Existence of a nodal point of diverging longshore transport along southern portion of barrier arc.
3. Overwash at vulnerable sites, extending to barrier-wide overwash depending on storm intensity and relief of northern barriers.
4. Overall landward barrier retreat.
5. High rate of sea level rise (5 mm/yr).
6. A deeply eroding shoreface (~ 8m).
7. Southern barrier arc consisting of broad sand shoals with intermittent intertidal and supratidal sand bodies separated by moderately deep tidal inlets.
8. Barriers anchored to marsh islands with eel grass beds in the north merging above water level to small stands and vestiges of marsh and mangrove.
9. Numerous former hurricane passes bordered by recurved spits and fronted by narrow barriers. Passes backed by extensive intertidal to subtidal flood deltas (0.2 – 1.0 km)
10. Existence of subsurface distributaries that contribute sand to the retreating barrier system.

One of the beneficial aspects of restoring the Chandeleur Islands is that there are abundant nearby sediment resources including 150 x 10^6 m^3 of sand at Hewes Point (Miner et al., 2007) and vast sand reservoirs contained in the Saint Bernard shoals (135 x 10^6 m^3; Rogers et al., 2010). The importance of maintaining a healthy sandy barrier complex was recognized more than 20 years by Penland et al. (1992) who provided a two dimensional view of various ways to rebuild the Chandeleur barriers (Fig. 9). However, this plan was intentionally piecemeal and site specific because in the early 1990's the barrier system was much more robust than it is today with extensive vegetated dunes, some ephemeral hurricane passes, and a vigorous rear barrier system of marsh and mangrove. The site-specific placement of nourishment sand was appropriately designed at that time, but a much more aggressive plan is required today due to the deteriorated nature of the barrier system. The plan presented below draws on other conceptual models for the Chandeleur Islands (Rosati and Stone, 2009; Lavoie et al., 2009; Thomson et al., 2010).

One measure of the magnitude of the restoration effort and the quantity of sand needed to restore the barrier complex is gaged by the almost complete dispersal of 3.7 million m^3 of sand that was placed in front and on top of the barrier during the "Berm Project" in the summer and fall of 2010. It is likely that much of this sand was removed during Hurricane Isaac in late August of 2012 and transferred onshore and along shore. During this time, storm waves drove substantial quantities of sand northward as evidenced by the patterns of bedforms observed along the northern Chandeleur coast (Fig. 33). Elevated tides and storm waves washing over the island moved berm sand onshore forming broad overwash fans and flood deltas as seen in Figure 34. Although these


6 June 2010

30 December 2010

29 October 2012

Figure 33. View of sand transport patterns along the northern portion of the barrier arc as seen in three sequential photos. Note the large sandwaves oriented to the north and northwest indicating northward transport in the nearshore zone. Their spacing had increased in 29 October 2012 photo (250-300 m) compared to those in the earlier photos, which likely reflects the large wave events and strong currents that occurred during Hurricane Isaac.

deposits represent sand eroded during the destruction of the berm, they are important sand reservoirs and contrast to the sediment lost offshore or to the longshore system, and ultimately to Hewes Point (Fig. 7). This onshore movement of sand remains in the system and will be excavated during shoreface erosion and retreat during the transgression. The fate of the berm sand provides lessons for a successful restoration plan.

Most importantly, a successful restoration plan must accommodate the strong longshore transport system and its divergent nodal point, as well as the susceptibility of the barrier system to hurricane overprinting. It will also be important that a large enough quantity of sand be placed along the barrier to ensure that a single storm event (erosional) does not completely remove or redistribute this sand resource.

Figure 34. Vertical aerial taken on 29 October 2012. The photo demonstrates the impact of Hurricane Isaac that overwashed the barrier forming a broad washover fan that was subsequently reworked by waves and current form the northwest and formed 10-m wave-length sand waves.

The restoration plan is conceptualized in Figure 35 and presented in detail in Figure 36 and Appendix 1. The plan depicts individual island segments, but is intended for the entire northern barrier arc. An aerial view of the Chandeleur is shown in five slightly overlapping November 2014 photographs. The southernmost segment of the barrier arc in Appendix 1 is used to illustrate the different components of the plan (Fig. 36); volumes of the individual components are also computed (Table 5). Our plan takes advantage of the existing tidal passes that characterize the much of northern barrier system. Sand would be placed along the upper portion of the barrier building a moderately wide beach and dune system. The beach would be overfilled with sand to allow for some wave transfer of sand to nearshore during the construction of an equilibrium foreshore. Locally, tidal inlets and small breaches would produce natural breaks in nourishment plan. Total width of renourished beach would be approximately 250 m with a thickness of approximately 1 m. Dune restoration would simultaneously be completed along barrier segments to create dunes 20-m wide at the base and 10-m wide at the top, with a height of 1.5 m (Figs. 35 and 36; Table 5). Dunes would be planted with appropriate vegetation to help capture the transport of aeolian sediment.

In some locations the foredune ridge should contain low areas that would permit overwashing during storms. In a regime of accelerating sea-level rise, it is beneficial to allow sand to move onshore during storms rather than solely offshore and alongshore where it may be lost from the barrier system. Tidal passes serve a similar function as the low areas in dune systems and provide large conduits through which sand can be transport landward, especially during storms where extensive flood-tidal delta shoals are formed. It is envisioned that waves will also transport sand along the sides of the inlets, building recurved spits. During the ongoing transgression it is expected that all of these deposits (washovers, flood-tidal deltas, recurved spits) will eventually become important sources of sand that will nourish the landward migrating barriers through reintroduction into the littoral zone.

Immediately behind the barriers, the lagoon/bay waters should be filled with sand to an intertidal elevation with a width of approximately 100 m. This intertidal, backbarrier apron would be approximately 0.5-m thick and vegetated with Smooth Cordgrass and stands of Black Mangrove . These plants will trap suspended sediment and overwash sand while their roots and rhizomes will help to bind and stabilize the sediment. Seaward of the intertidal apron a subtidal apron of sediment 400-m wide and 0.5-m thick would be constructed planted with beds of seagrass to stabilize the subtidal region. Not only will the seagrass beds add integrity to the backbarrier, but they will also provide an important habitat, food source, and feeding grounds for numerous faunal and infaunal species. Moreover, it has been shown that vegetation of all kinds will add resiliency to the Chandeleur Islands as well as anchoring points for sand accumulation during barrier reconstruction following major storm erosional events (Figure 30).

Another strategy we consider important in restoring the Chandeleur Islands, in addition to the plan described above, would be to emplace large sand reservoirs at several locations along the backside of the barrier arc as suggested by Lavoie et al. (2010). Using the Lavoie et al. (2010) plan as a guide, sand could be placed in troughs positioned perpendicular to the shoreline trend (Fig. 37). The troughs would be located, wherever possible, in existing low areas such as inactive channels to decrease excavation costs. Trough dimensions would vary according to the characteristics of the site (bathymetry, existing vegetation, stratigraphy, proximity to tidal passes, etc.) but would have general dimension of: 2-3 m thick, 300 to 400-m wide, and 1-km long with dikes constructed along the sides of the deposit. The 3-m deep troughs would be excavated mostly below mean low water to prevent mobilization of the sand during a major hurricane (Category #3-5 hurricanes). The dikes would perform a similar function and would help stabilize the sand during minor storm events as well as large ones. We envision that approximately 15 reservoir sand troughs be constructed along the barrier arc having a total sand volume of about approximately 15 million m^3 (Table 5, Fig. 37).

In summary, the advantages of our two-pronged plan to restore the northern Chandeleur barrier island include the following:

1. The ready availability of sand at Hewes Point and within the St. Bernard Shoals.
2. The plan takes advantage of the natural processes and existing morphology, stratigraphy, and vegetation that characterize the Chandeleur Islands, including:
    a. major storm events that produce high longshore and cross shore transport rates,
    b. micro-tidal range
    c. existing stands of supratidal, intertidal and subtidal vegetation
    d. overall low relief
    e. deep shoreface erosion in a regime of accelerating sea level rise
    f. limited sand influx
    g. ongoing transgression
    h. underlying mostly muddy stratigraphy
3. Long-term sand contribution to the individual barrier segments emphasizes placement of sediment in areas landward of the present shoreline at recurved spits, rear barriers sand aprons and backbarrier subtidal sand platforms.
4. Tidal passes and low areas along the foredune ridge are pathways provided in this plan to ensure that sand is transported landward during major storm events, thereby maximizing the longevity of keeping sand in the barrier system.
5. Deposition of sediment in overwash fans, flood-tidal deltas, and in recurved spits produce sand reservoirs that eventually will be intercepted by the ongoing transgression and input sand into the barrier system.
6. The elongated sand reservoirs positioned strategically along the barrier arc would extend 1 to 1.5 km landward from the present shoreline thereby providing a long-term sand feeder system to the barrier arc.
7. Most of the sand that would be deployed in the proposed restoration plan would be placed below mean low water (i.e., sand troughs, sand aprons, sand platform). This would ensure maximum protection of the sand reservoir and prevent mobilization and dispersion during major storm events. Our plan also takes advantage of natural storm processes whereby sand is transported

onshore into the backbarrier, less mobile subtidal and intertidal environments (overwash fans and flood-tidal deltas).

Closing Statement

The Chandeleur Islands are a unique barrier system and home to a wide variety of coastal plants and wildlife, including numerous endangered and protected species. The island chain also serves as important line of defense in protecting wetlands and onshore communities by diminishing the impacts of major storms. This unique habitat is in danger of being overwhelmed by accelerating sea level rise and increasing magnitude storms due to global warming and climate change. Also, this is one of the only areas along the Louisiana coast where there are abundant nearby sand resources that could be utilized to restore the islands with minimal impact to the environment. If a restoration plan in not put into operation soon, the islands are in danger of drowning in place.

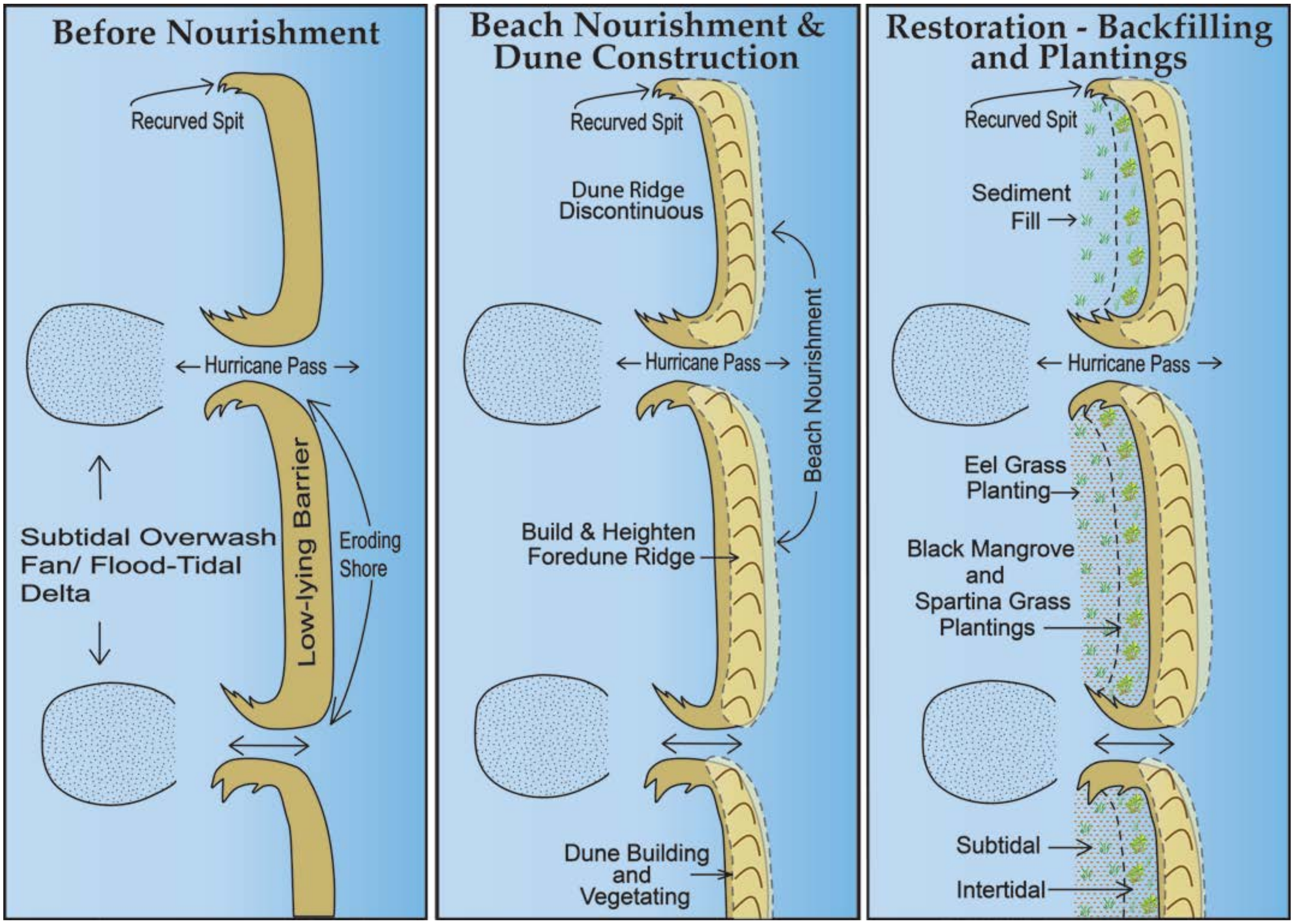


Figure 35. Model for restoring the individual, inlet separated island segments of the northern Chandeleur Islands.

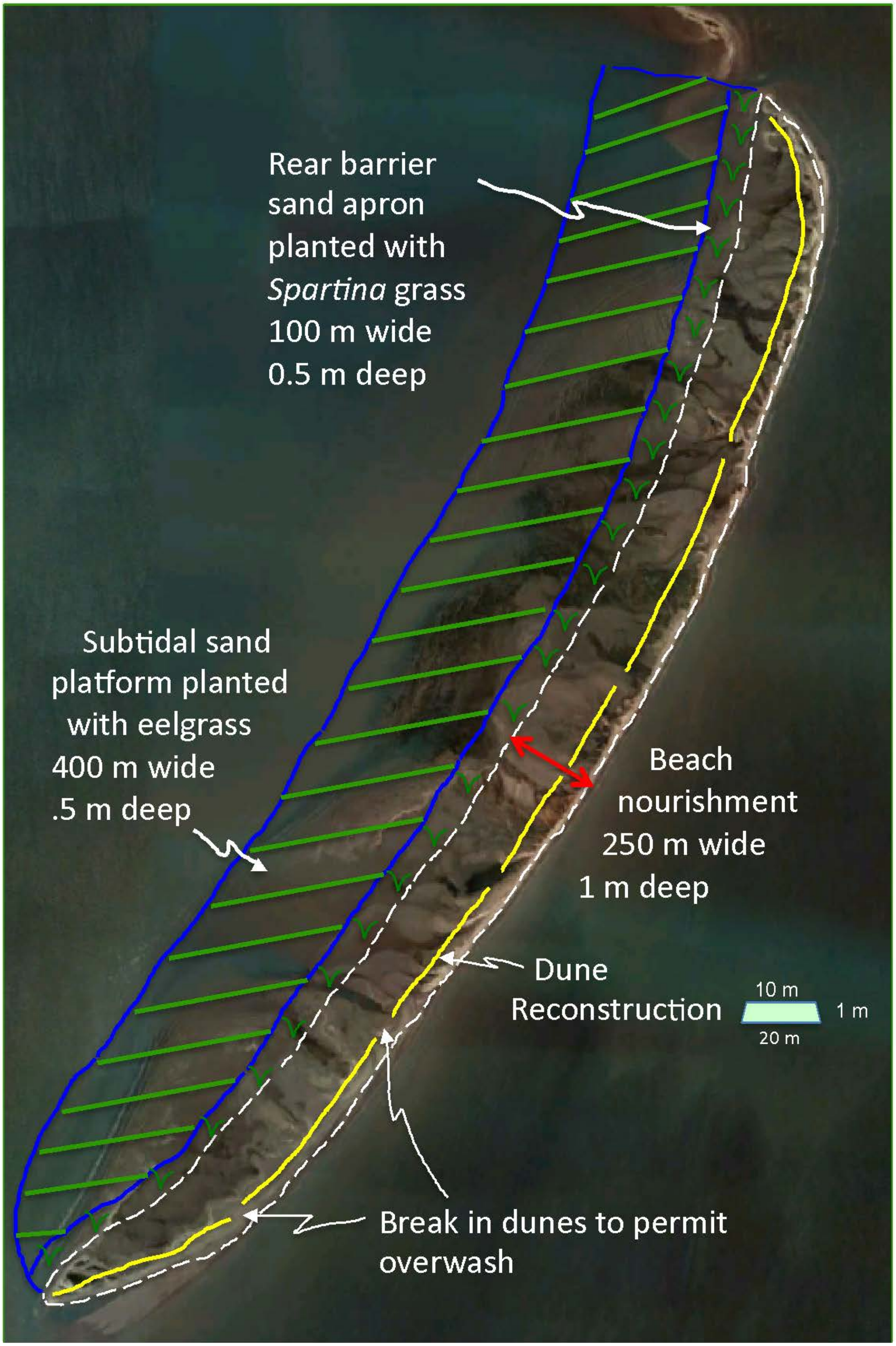


Figure 36. Components of restoration plan illustrated for a single barrier segment (see Appendix 1).

Table 5. Table describing the characteristics of restored barrier segments and the estimated volume of sediment required to complete the restoration plans as depicted in Figures 34 and 35.

	Beach Restoration	**Dune Restoration**	**Rear Barrier Sand Apron**	**Sand Trench Reservoirs**
Template Scale	5 segments ~ 5.5- km long	5 segments ~ 5.5-km long	5 segments ~ 5.5-km long	15 spaced 1 to 2-km apart
Fill dimensions	5.5-km long 250-m wide 1-m thick	5.5 km long 1.5-m high, 10-m high top, 20 m base, Average width = 15 m	100-m wide intertidal apron 0.5 m thick and planted with *Spartina;* 400-m wide subtidal platform, 0.5 m thick and planted with subaquatic vegetation	Variable and ~1000-m long, 400-m wide 2-3 m thick
Volume per Segment	1,375,000 m^3	123,750 m^3	1,375,000 m^3	1,000,000 m^3
Total Volume for Effort	**6,875,000 m^3**	**618,750 m^3**	**6,875,000 m^3**	**15,000,000 m^3**
Total Estimated of Fill Volume for Full Implementation of Sand Nourishment Program = ~ 30,000,000 m^3				

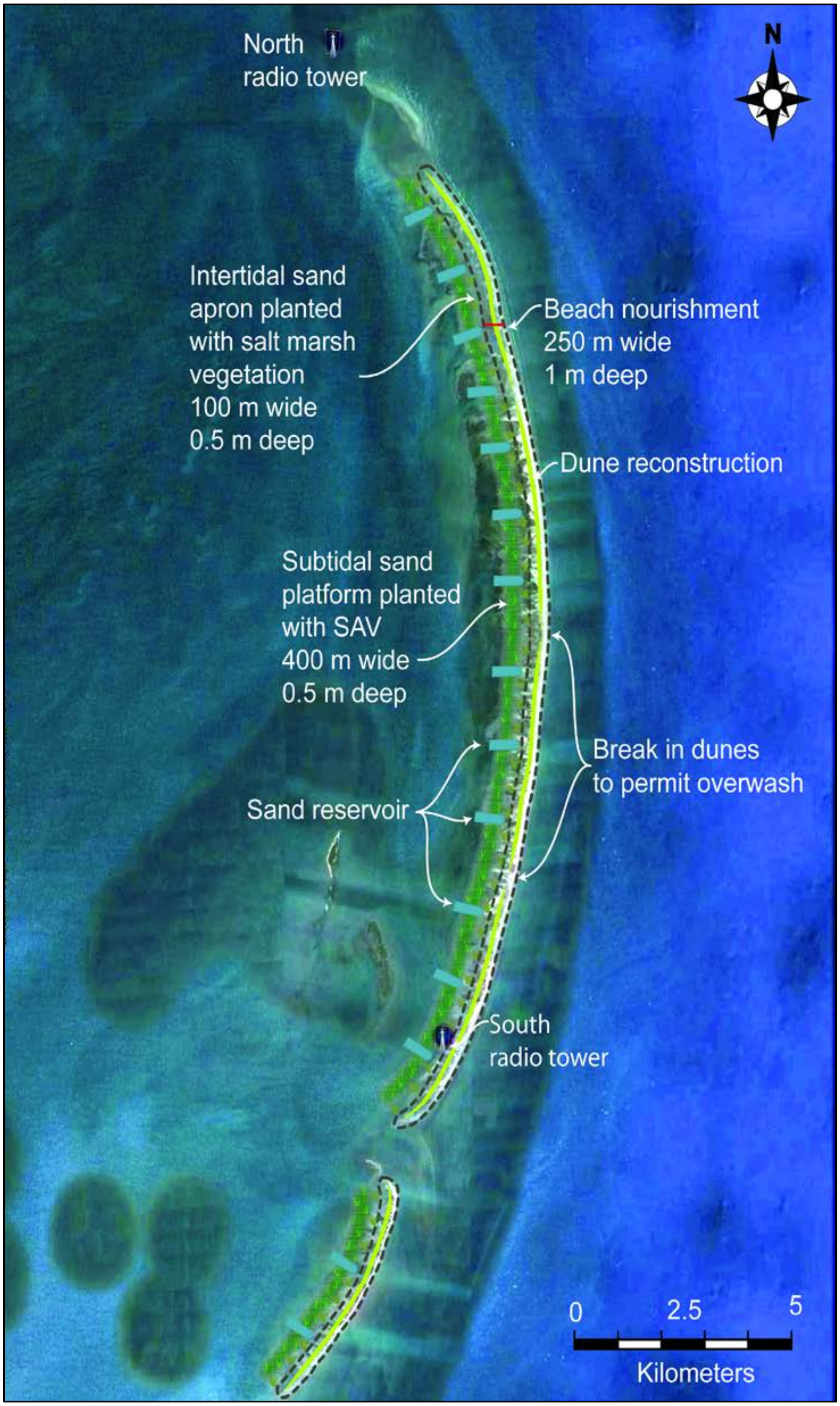


Figure 37. Regional map showing the distribution of restoration elements discussed in the text.

REFERENCES

Benton, L., Brown, J.S., Cook, L., and Mudge, S., 2011, Tracking oil samples from the MC252 Deepwater Horizon incident along the Louisiana/Texas coastlines, International Oil Spill Conference, Portland, Oregon.

de Beaumont, E., 1845, Lecons de geologic pratique, Paris: Bertrand, P.,

Donnelly, C., Larson, M., Hanson, H., 2009, A numerical model of coastal overwash, Proceedings of the Institution of Civil Engineers, Maritime Engineering, Thomas Telford Publishers, Lincolnshire, United Kingdom, v. 162, Issue 3, pp. 105–114.

Ellis, J. and Stone, G., 2006, Numerical simulation of net longshore sediment transport and granulometry of surficial sediments along Chandeleur island, Marine Geology, v. 232, p. 115-129.

Fearnley, S. M., Miner, M. D., Kulp, M. A., Bohling, C, and Penland, S., 2009, Hurricane impact and recovery shoreline change analysis of the Chandeleur Islands, Louisiana, USA: 1855 to 2005, Geo-Marine Letters, v. 29, no. 6, p. 455-466.

Georgiou, I.Y., FitzGerald, D.M., and Stone, G.W., 2005, The Impact of Physical Processes along the Louisiana coast. Journal of Coastal Research, SI (44), p. 72-89.

Georgiou, I.Y., Schindler, J., 2009, Wave forecasting and longshore sediment transport gradients along a transgressive barrier island; Chandeleur Islands, Louisiana, GeoMarine Letters, v. 29, p. 467-476.

Georgiou, I.Y., Hughes, Z.J., Trosclair, K., 2013, Application of Hydrodynamic and Sediment Transport Models for Cleanup Efforts Related to the Deepwater Horizon Oil Spill Along the Coast of Mississippi and Louisiana, Technical Report prepared for OSAT3, 44 p.

Gilbert, G.K., 1885, Lake Bonneville, U.S., Geological Survey Monograph, 1, 438 p.

Grzegorzewski, S.A., Georgiou, I.Y., 2011, Sediment transport trends along an island terminus; A model study during storms in the northern Chandeleur Islands, in Coastal Sediments, eds. Wang, P., Rosati, J.D., and Roberts, T.M., v. 3, p. 2198-221.

Hughes, S.A., 2004, Estimation of wave run-up on somooth, impermeable slopes using the wave momentum flux parameter, Coastal Engineering, no. 51, p. 1085-1104.

Hughes, S. A., 2004, Wave momentum flux parameter: A descriptor for nearshore waves, Coastal Engineering, Elsevier, 51(11), p. 1067-1084.

Kahn, J.H., 1986, Geomorphic recovery of the Chandeleur Islands, Louisiana, after a major hurricane, Journal of Coastal Research, v. 2, no. 3, p. 337-344.

Kulp, M. A., FitzGerald, D. M., Miner, M., Georgiou, I., and Penland, S., 2007, The demise of the Chandeleur Islands in southeastern Louisiana: Not Yet!, Geological Society of America Abstracts with Programs, v. 39, no. 6., p. 69.

Kulp, M.A, Miner, M., Weathers, D., Motti, J.P., McCarty, P., Brown, M., Labold, J., Boudreaux, D., Flocks, J.G., and Taylor, C., 2011, Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Volume 6, Part B: Characterization of Louisiana Coastal Zone Sediment Samples: Backbarrier through offshore samples of the Chenier Plain, South Central Barrier Island Systems and Chandeleur Islands, Louisiana Coastal Protection and Restoration Authority, 39 p.

Lavoie, D., Miner, M., Georgiou, I. Y., Fearnley, S., Sallenger, A. H., Williams, S. J., Twichell, D., Flocks, J., and Kulp, M., (2009) Chapter I. Summary and discussion, in Lavoie, D., ed., 2009, Sand resources, regional geology, and coastal processes of the Chandeleur Islands coastal system-an evaluation of the Breton National Wildlife Refuge: U.S. Geological Survey Scientific Investigations Report 2009-5252, 180 p.

Lavoie, D., Flocks, J.G., Kindinger, J.L., Sallenger, A.H., Jr., and Twichell, D.C., 2010, Effects of building a sand barrier berm to mitigate the effects of the Deepwater Horizon oil spill on Louisiana marshes, U.S., Geological Survey Open-File Report 2010-1108, 7 p.

Louisiana Coastal Wetlands Conservation and Restoration Task Force, 2013, Whiskey Island back barrier marsh creation (TE-50), http://lacoast.gov/reports/gpfs/TE-50.pdf.

Lee, A. B., 2010, Emergency permit NOD-20, US Army Corps of Engineers. Retrieved from <<www.mvn.usace.army.mil/pao/ issued%20permit.pdf>>

Lopez, J. A., 2006, The Multiple Lines of Defense Strategy to Sustain Coastal Louisiana, Lake Pontchartrain Basin Foundation, Metairie, LA. http://www.saveourlake.org

Martínez, M. L., Feagin, R. A., Yeager, K. M., Day, J., Costanza, R., Harris, J. A., Hobbs, R. J., López-Portillo, J., Walker, I. J., Higgs, E., Moreno-Casasola, P., Sheinbaum, J., Yáñez-Arancibia, A., 2011, Artificial modifications of the coast in response to the Deepwater Horizon oil spill: quick solutions or long-term liabilities? Frontiers in Ecology and the Environment, v. 10, p. 44-49.

McBride, R. A., Penland, S., Hiland, M. W., Williams, S. J., Westphal, K. A., Jaffe, B. E., and Sallenger, A. H., Jr., 1992, Analysis of barrier shoreline change in Louisiana from 1853 to 1989, in Williams, S. J., Penland, S., and Sallenger, A. H., Jr., eds., Louisiana barrier island erosion study-atlas of barrier island shoreline changes in Louisiana from 1853 to 1989: U.S. Geological Survey Miscellaneous Invest. Series I-2150-A, p. 36-97.

Miner, M., Kulp, M., Rogers, B., 2007, Historical Shoreline and Bathymetric Change of the Chandeleur Islands: Implications for Sediment Transport Trends and Hurricane Recovery and Preliminary Assessment of St. Bernard Shoals as a Potential Sand Resource for Barrier Nourishment.

Owens, E., and Dubach, H., 2013, Shoreline response and shoreline oiling assessment surveys for oil spills in the Gulf of Mexico, Owens Coastal Consulting Technical Manual, 58 p.

Penland, S., Boyd, R. , and Suter, J. R., 1988, Transgressive depositional systems of the Mississippi Delta Plain; a model for barrier shoreline and shelf sand development, Journal of Sedimentary Research, v. 58, no. 6, p. 932-949.

Penland, S., Williams, S. J., Davis, D. W., Sallenger, A. H., Jr., and Groat, C. G., 1992, Barrier island erosion and wetland loss in Louisiana, in Williams, S. J., Penland, S., and Sallenger, A. H., Jr., eds., Louisiana barrier island erosion study-atlas of barrier island shoreline changes in Louisiana from 1853 to 1989: U.S. Geological Survey Miscellaneous Investigations Series I-2150-A, p. 2-7.

Plant, N.G, and Guy, K.K., 2011, Change in length of the middle section of the Chandeleur Islands oil berm, November 17, 2010, through September 6, 2011, U.S. Geological Survey Open-File Report 2013-1075, 8 p.

Resio, D. T., 2007, White Paper on Estimating Hurricane Inundation Probabilities. U.S. Army Corps of Engineers Engineer Research and Development Center, Vicksburg, MS.

Reyes, E., Geogiou, I., Reed, D., and McCorquodale, A., 2005, Using models to evaluate the effects of barrier islands on estuarine hydrodynamics and habitats: a numerical experiment, Journal of Coastal Research, Special Issue no. 44, p. 176-185.

Ris, R.C., Holthuijsen, L.H., and Booij, N., 1999, A third-generation wave model for coastal regions—2. Verification: Journal of Geophysical Research, v. 104, no. C4, p. 7667–7681.

Rogers, B., Kulp, M.A., and Miner, M., 2009, Late Holocene chronology, origin and evolution of the St. Bernard Shoals, northern Gulf of Mexico, Geo-Marine Letters, v. 29, p. 379-394.

Rosati, J., and Stone, G., 2007, Critical width of barrier islands and implication for engineering design. Coastal Sediments 07, American Society of Civil Engineers, 14 p.

Shealer, D. 1999, Sandwich Tern (Thalasseus sandvicensis), The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online:http://bna.birds.cornell.edu/bna/species/405.

Soulsby, R., 1997, Dynamics of marine sands: a manual for practical applications, Thomas Telford Publishers, Lincolnshire, United Kingdom, 249 p.

Smith, J.M., 2007, Full-Plane STWAVE II: Model Overview. ERDC TN-SWWRP, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Smith, J.M., Jensen, R.E., Kennedy, A.B., Dietrich, C.J., and Westerink, J.J.W., 2010, Waves in Wetlands: Hurricane Gustav. Proceedings from the 32nd International Conference on Coastal Engineering. Shanghai, China.

Smith, J.M., Sherlock, A.R., and Resio, D.T., 2001, STWAVE: Steady-State Spectral Wave Model User’s Manual for STWAVE, Version 3.0. USACE Engineer Research and Development Center, Technical Report ERDC/CHL SR-01-1, Vicksburg, MS 80 p.

Stone, G.W., and Orford, J.D., 2004, Storms and their significance in coastal morph-sedimentary dynamics. Marine Geology, Special Issue No. 210.

Törnqvist, T. E., Kidder, T. R., Autin, W. J, van der Borg, K., de Jong, A. F. M., Klerks, C. J. W., Snijders, E. M. A., Storms, J. E. A., van Dam, R. L., and Wiemann, M. C. (1996) A revised chronology for the Mississippi River Subdeltas, Science, v. 273, no. 5282, p. 1693-1696.

Thomson, G., Miner, M., Wycklendt, A., Rees, M. Swigler, D., 2010, MRGO Ecosystem Restoration Feasibility Study – Chandeleur and Breton Islands. Boca Raton, Florida: Coastal Planning & Engineering, Inc. 96 p.

U.S. Army Corp of Engineers, 2010, Stakeholder Update Team New Orleans, U.S. Army Corp of Engineers Update, 2 p.

Westerink, J.J., Luettich, R.A., Feyen, J.C., Atkinson, J.H., Dawson, C., Roberts, H.J., Powell, M.D., Dunion, J.P., Kubatko, E.J., and Pourtaheri, H., 2008, A basin-to-channel-scale unstructured grid hurricane storm surge model applied to southern Louisiana. Monthly Weather Review, 136, p. 833-864.

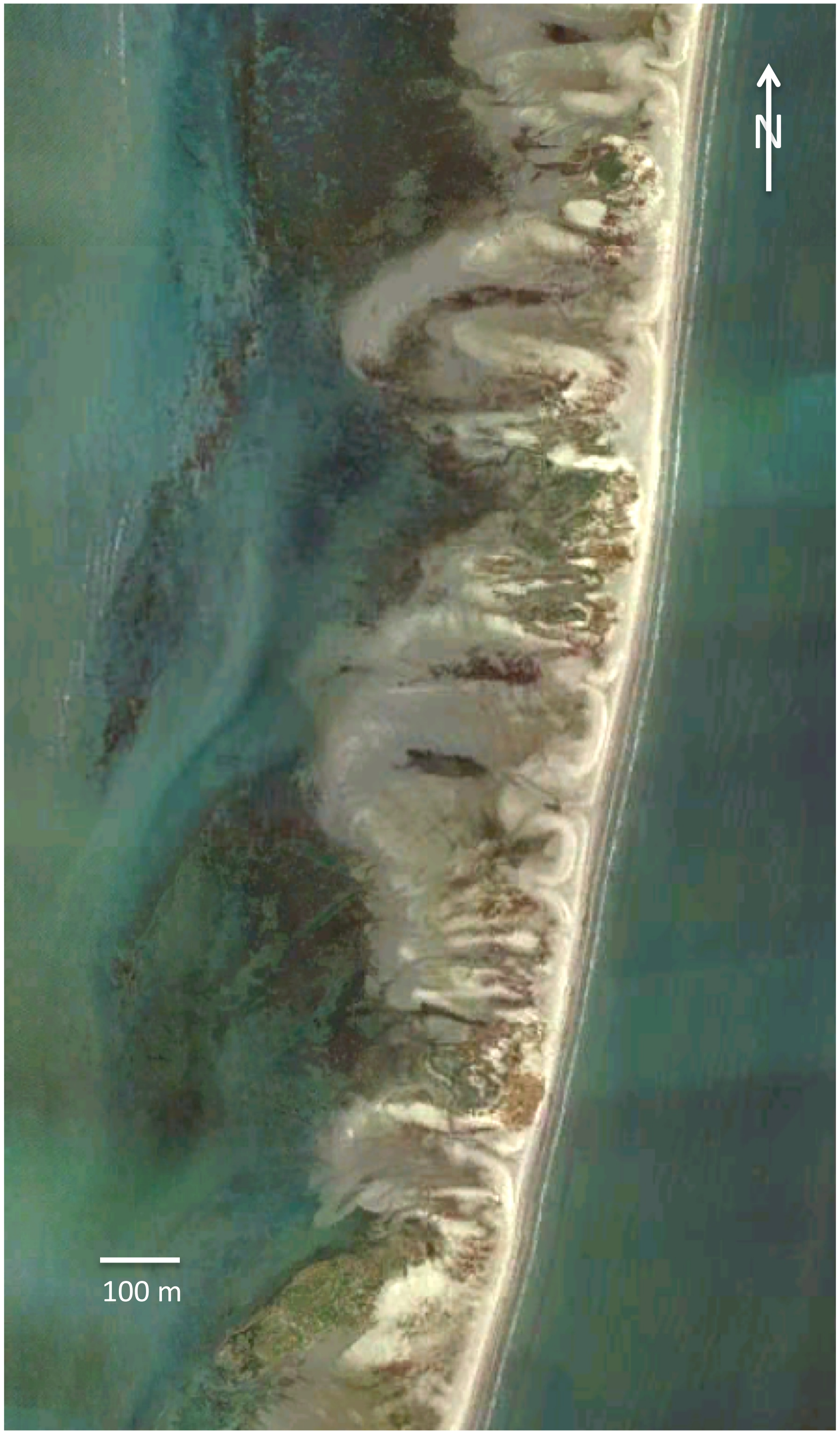
Appendix 1. Chandeleur Island Restoration Plan

The Chandeleur Islands are depicted in five slightly overlapping photographs using November 2014 aerial photography. The southernmost Chandeleur barrier section (last photograph) is used to illustrate the different components of the nourishment project, geometry of the sand deposits, and vegetation plantings. The volume of sand for each of the beach, dune, rear barrier nourishment components is computed.

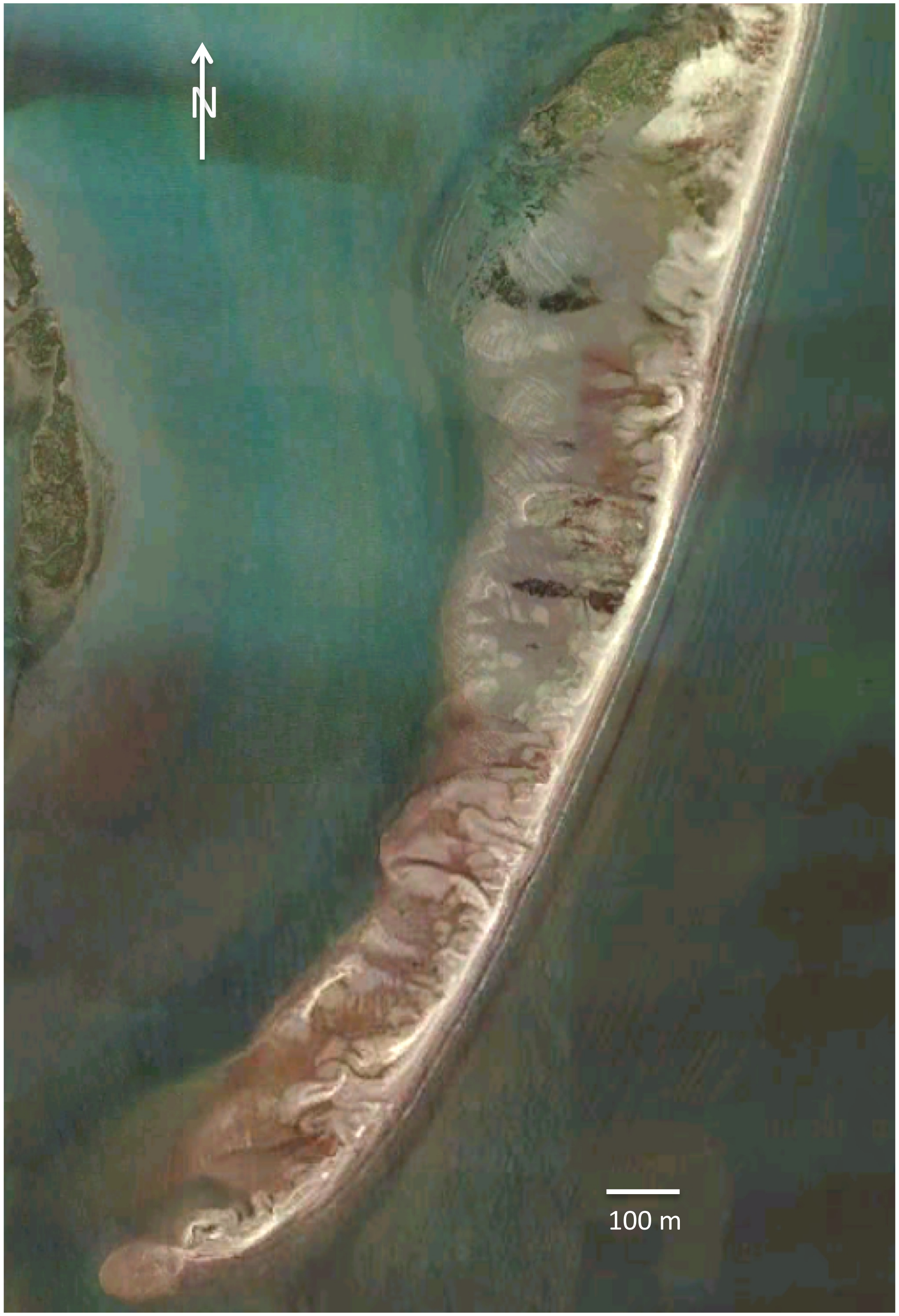
View of Chandeluer Islands
November 2014

Photos are arranged from north to south

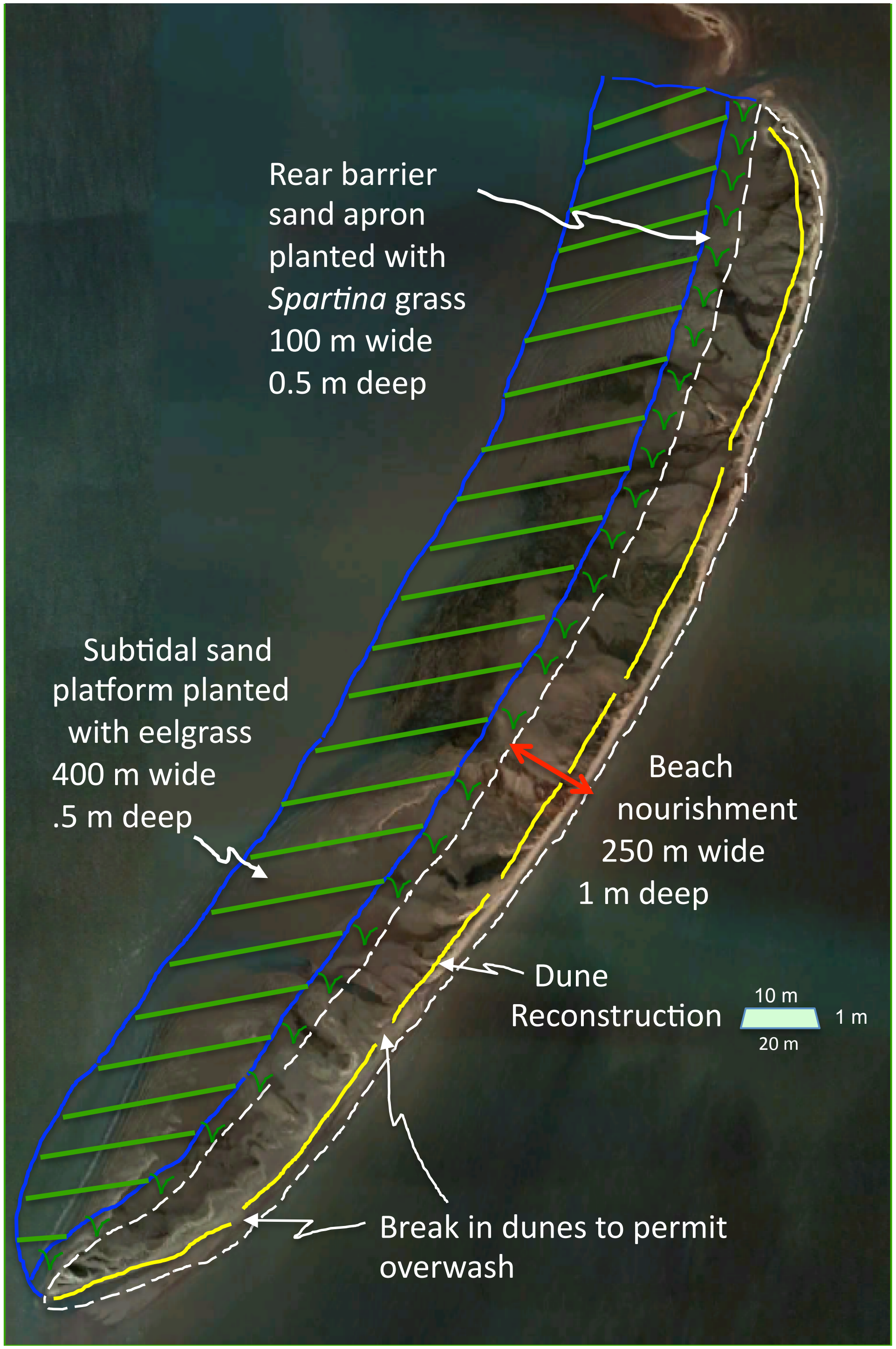

N
100 m



N
100 m


N
100 m


N
100 m


Rear barrier sand apron planted with *Spartina* grass 100 m wide 0.5 m deep
Subtidal sand platform planted with eelgrass 400 m wide .5 m deep
Beach nourishment 250 m wide 1 m deep
Dune Reconstruction
10 m
1 m
20 m
Break in dunes to permit overwash

Beach Restoration

Barrier chain divided into 5 segments, each about 5.5 km long

For rebuilding the beach we use 250 m wide and 1 m deep

Each barrier segment would be 5500 x 250 x 1 = **1,375,000 m^3**

Dune Restoration

5.5 km long, build dune 1.5 m high and 10 m wide at top and 20 m wide at base, yielding and average width of 15 m

Each barrier segment dune would be: 5500 x 1.5 x 15 = **123,750 m^3**

Rear Barrier Sand Apron

5.5 km long, 100 m wide sand intertidal apron that averages 0.5 m deep, this will be planted with Spartina grass

5.5 km long, 400 m wide sand subtidal platform that average 0.5 m deep, this will be planted with eelgrass or other subaquatic vegetation

Collectively, each barrier segment sand apron/platform: 5500 x 500 x 0.5 = **1,375,000 m^3**

Total Sand Required for Restoration

Beach restoration volume = 1,375,000 m^3

Dune restoration volume = 123,750 m^3

Rear beach apron/platform volume = 1,375,000 m^3

Total sand volume needed for each barrier segment = 2,873,750 m^3

Five barrier segments, Total sand volume for entire barrier length = 14,368,750 m^3

Total Volumes

Sand Trenches ~ 15,000,000 m^3 (see Figure 37, Table 5)

Barrier Restoration ~ 14,400,000 m^3

Total Sand Requirement ~ 30,000,000 m^3