Coastal Protection and Restoration Authority of Louisiana

2021
Monitoring Close-out Report

for

Isles Dernieres Restoration Whiskey Island (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50) Projects

State Project Numbers TE-27 & TE-50,
Priority Project Lists 3 & 13

April 2022

Terrebonne Parish

Prepared by: Joshua Sylvest, Glen Curole, Todd Hubbell & Elaine Lear

Coastal Protection and Restoration Authority
Thibodaux Regional Office
1440 Tiger Drive
Thibodaux, LA 70301
www.coastal.la.gov

Suggested Citation:

Sylvest, J., G. Curole, E. Lear, and T. Hubbell. 2022. 2021 Monitoring Close-out Report for Isles Dernieres Restoration Whiskey Island (TE-27) and the Whiskey Island Back Barrier Marsh Creation (TE-50) Project. Thibodaux, Louisiana: Coastal Protection and Restoration Authority of Louisiana, 88p.

Table of Contents

List of Figures

List of Tables

Chapter 1 – Historical and Project Background

Historical Background

The Louisiana deltaic plain is fronted by a series of headlands and barrier islands that were formed as a result of the Mississippi River deltaic cycle. The Isle Derniere was a barrier island arc formed along the central Louisiana coast during abandonment of the Caillou headland portion of the Early Lafourche Delta complex approximately 500 years before present (B.P.) (Frazier 1967, Penland and Boyd 1985). Following deltaic abandonment, longshore deposition of headland sands formed flanking barriers (Penland et al. 1988). Submergence of the abandoned Early Lafourche Delta lobe separated the former headland from the back barrier wetlands creating the water bodies which are known today as Caillou Bay, Lake Pelto, and Terrebonne Bay. This created an island arc called Isle Derniere measuring approximately 24 miles in length (figure 1-1).

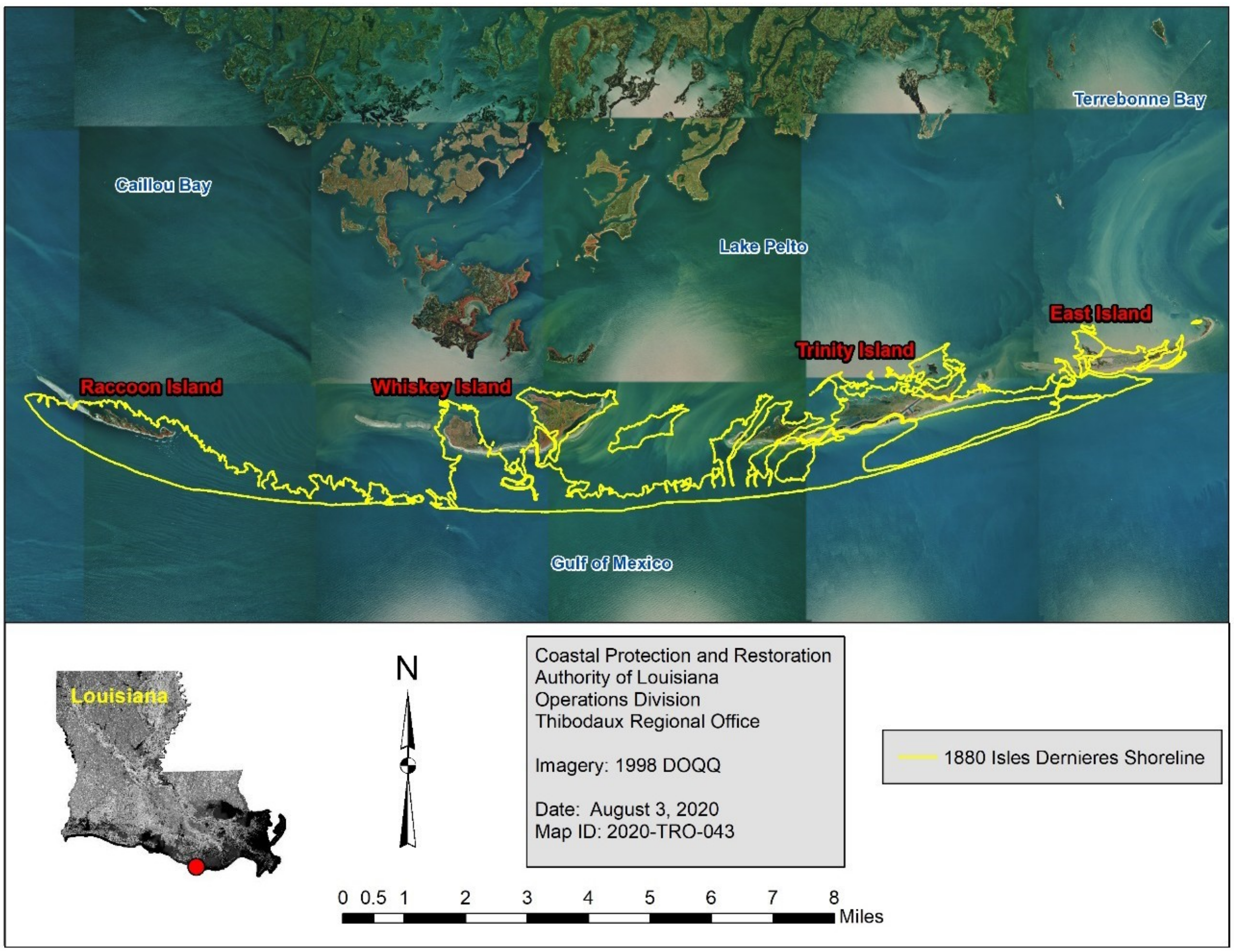

Figure 1-1 . Isle Derniere 1880s shoreline position digitized from US Coast & Geodetic Survey (USC&GS) topographic maps (T-sheets) (Byrnes et al 2018).

On August 10, 1856, a hurricane impacted the Isle Derniere to the extent that the island was breached. The area continued to be affected by tropical cyclones as well as other natural and anthropogenic disturbances such that the Isle Derniere was eventually segmented into four islands:

Raccoon Island, Whiskey Island, Trinity Island, and East Island (McBride et al. 1989) (figure 1-1). Like all of Louisiana's barrier islands, these islands are experiencing narrowing and land loss as a consequence of complex interactions among global sea level rise, subsidence, wave and storm processes, inadequate sediment supply, and anthropogenic disturbances (Penland et al. 1988, McBride et al. 1989, Penland and Ramsey 1990, List et al. 1997). This report focuses on two restoration efforts occurring on the portion of the Isles Dernieres known as Whiskey Island.

Numerous studies have documented land loss and shoreline erosion trends in this area. McBride et al. (1991) reported land loss rates in the Isles Dernieres as a whole that approached 69.6 ac/yr between 1887 and 1988, and the Barrier Island Comprehensive Monitoring (BICM) Program documented shoreline erosion rates from 1880s through 2015 at the Whiskey Island reach at 52.2 ft/yr (Byrnes et al. 2018). Whiskey Island exhibited landward erosion of the gulf side shoreline and seaward erosion on its bayside. Between 1853 and 1988, erosion on the bayside of Whiskey Island occurred at an average rate of 18.4 ft/yr (McBride et al. 1989). The results of this fragmentation and disintegration have been a decrease in the ability of the island chain to protect the adjacent mainland marshes and wetlands from the effects of storm surge, saltwater intrusion, increased tidal prism, and energetic storm waves (McBride and Byrnes 1997). Erosional models have estimated that the Isles Dernieres would gradually narrow, fragment, and transgress through time, eventually becoming subaqueous sand shoals. Estimates, including data developed by the BICM program, estimate the disappearance of Isles Dernieres between 2007 (McBride et al. 1991) and 2019 (Penland et al. 1988) without implementing restoration efforts; analyses specific to Whiskey Island in this report estimate its disappearance by 2014 without restorative measures.

In an effort to combat the natural and anthropogenic processes causing the islands to become shoals, the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA, Public Law 101-646, Title III) constructed two (2) projects: The Whiskey Island Restoration (TE-27) project, which is a Project Priority List (PPL) 3 project, and the Whiskey Island Back Barrier Marsh Creation (TE-50) project, which is a PPL 13 project. Each CWPPRA project is sponsored by the U.S. Environmental Protection Agency (EPA) in conjunction with the former Louisiana Department of Natural Resources, Coastal Restoration Division, currently the Coastal Protection and Restoration Authority (CPRA) of Louisiana.

Project Background

The Whiskey Island Restoration (TE-27) project was constructed between February 1998 and the spring of 1999 (West and Dearmond 2004). Whiskey Island is located 18 miles southwest of Cocodrie in Terrebonne Parish, Louisiana (figure 1-2). The overall objective of the project was to strengthen and stabilize the island through goals of increasing both the elevation and width of Whiskey Island using dredged sediments and reducing the loss of sediments through the growth of vegetation (Townson 1998). Upon project completion, approximately 2.5 million cubic yards (MCY) of sediment had been dredged from Whiskey Pass, most of which was placed on the bay side to help restore the back barrier portion of the island. Smaller quantities of dredged sediments were pumped onto central portions of the island in the vicinity of several breaches, as well as eastern portions of the island. Target elevations ranged from +1 ft to +4 ft North American Vertical

Datum of 1988 (NAVD88) (Rodrigue et al. 2008). The sediment created approximately 355 ac of supratidal and intertidal habitats. In the spring of 1999, a second phase of construction utilizing planting of several native plant species along the newly created supratidal terrace and back barrier shoreline (Rodrigue et al. 2008). Planted vegetation consisted of *Spartina patens* (marshhay cordgrass) and *Panicum amarum* (bitter panicum) installed on the supratidal platform, with *Spartina alterniflora* (smooth cordgrass) and *Avicennia germinans* (black mangrove) installed along the back bay shoreline of the project fill area.

The Whiskey Island Back Barrier Marsh Creation (TE-50) project was constructed between March and November of 2009 (figure 1-2). The goals of the project per the monitoring plan were to create approximately 300 acres of back barrier intertidal marsh, to create a minimum of three 1-acre tidal ponds and approximately 5,800 ft of tidal creeks, and to increase the longevity of the natural and previously restored portions of the island by increasing the width of the island in order to retain sand volumes and elevations (Curole 2007).

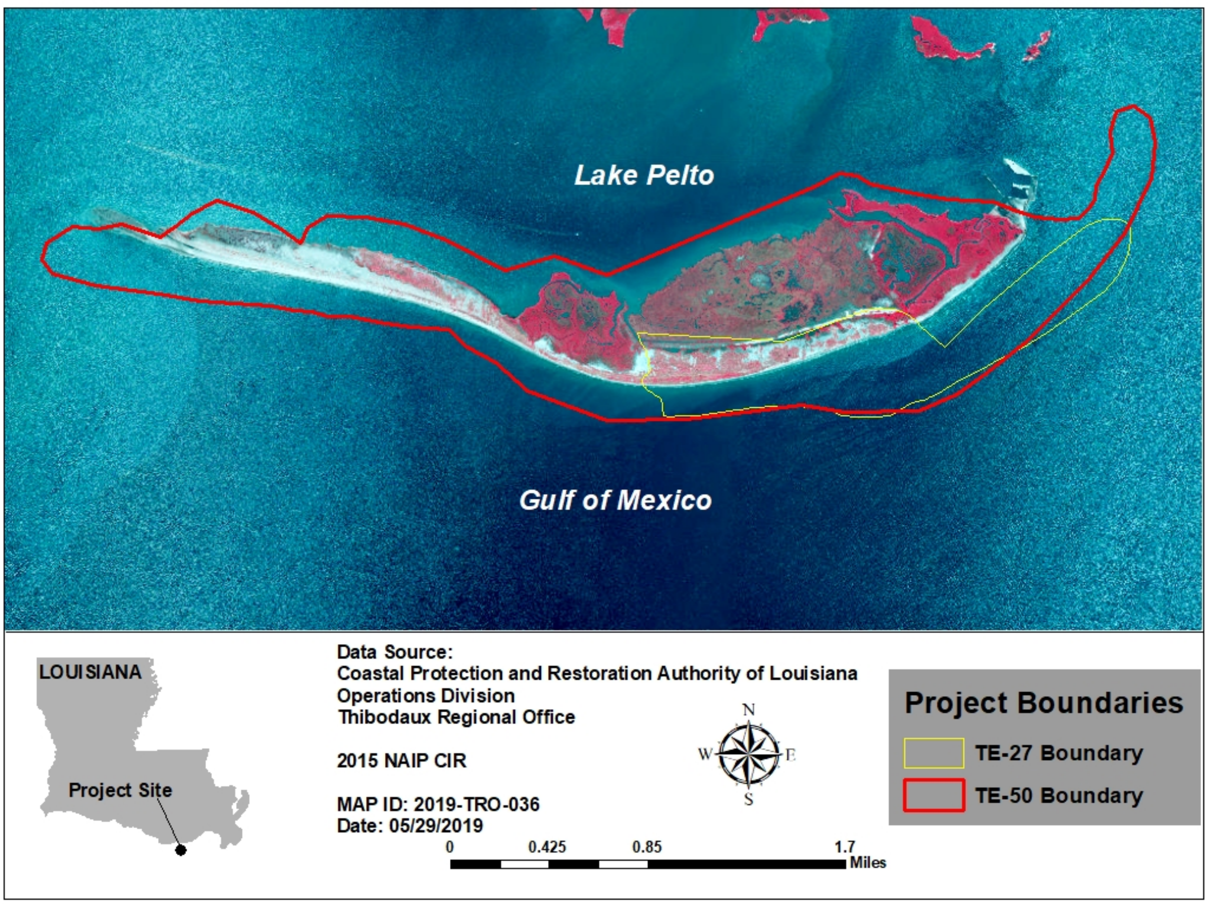

Figure 2-2. Whiskey Island Restoration (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50) project boundaries.

Upon project completion in November of 2009, approximately 2.9 MCY of sediment had been dredged from a borrow area located in Ship Shoal Blocks 43 and 67. The sediment created approximately 319 ac of intertidal marsh platform and nourished approximately 95 ac of elevation classes conducive to creating beach habitats (T. Baker Smith & Sons, Inc. 2010 TE-50 Project Completion Report). The target elevations ranged from +2.5 ft to +4.5 ft NAVD88 with an anticipated marsh platform height of 2.18 ft NAVD88 following consolidation (Curole 2007). As part of initial construction, 13,000 ft of sand fencing was installed 20 ft north from the toe of the newly constructed dune of the same length. Once sediments were consolidated, vegetative plantings were installed in phases and included *Spartina alterniflora* (smooth cordgrass) plugs and *Avicennia germinans* (L.) L (black mangrove) saplings in an effort to stabilize the newly created marsh platform. A total of 250,000 *Spartina alterniflora* (smooth cordgrass) plugs and 5,000 *Avicennia germinans* (L.) L (black mangrove) saplings were installed.

As part of the CWPPRA program, an Operation and Maintenance (O&M) Plan and a Monitoring Plan are developed for each project if funds are allocated. The O&M Plan for barrier island projects provides guidance for activities such as sand fencing repairs and initial or supplemental vegetative plantings. Monitoring plans are developed prior to project construction. The monitoring plan outlines the goals and objectives for the project and how data will be collected to assess project performance. Both plans are written to provide guidance on the potential needs and timing of these activities throughout the project's twenty (20) year life. There was no O&M Plan developed for the TE- 27 project, but one was developed for the TE-50 project; however, there have not been any repairs or maintenance events conducted. Monitoring plans which documented goals and objectives for project performance throughout its 20 year life were developed for each of the projects. All monitoring and O & M plans can be found in the document library on CPRA's Coastal Information Management System (CIMS) database: https://cims.coastal.louisiana.gov/Default.aspx.

This 2021 monitoring report serves as the close-out report for both the Whiskey Island Restoration (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50) projects. Although the TE-50 project has not reached its end of life (20 years), the monitoring plan included the final report for the project to be produced in 2021 and no further monitoring activities will take place.

Chapter 2 – Project Goals and Objectives

The stated goals of the Whiskey Island Restoration (TE-27) project were (1) to increase the elevation and width of the island using dredged sediments and (2) to reduce the loss of sediments through the growth of vegetation; the overall objective of the project was to strengthen and stabilize the island (Townson 1998). The stated goals of the Whiskey Island Back Barrier Marsh Creation (TE-50) project were (1) to create approximately 300 acres of back barrier intertidal marsh, (2) to create a minimum of three 1-acre tidal ponds and approximately 5,800 ft of tidal creeks, and (3) to increase the longevity of the natural and previously restored portions of the island by increasing the width of the island to help retain sand volumes and elevations (Curole 2007).

The goals and objectives outlined in the monitoring plans are ill-defined and can be difficult to assess. For example, phrases such as "island stability" and "reduce the loss of sediment" are vague and problematic to empirically measure; even goals and objectives related to creating a defined number of acres are troublesome to assess as there is no definitive time frame referenced. The approximately 300 acres to be created by TE-50, for example, leaves open for interpretation whether this goal is expected to be met shortly following construction completion or at the end of the 20 year project life. Objectives such as increased heights and widths could be implicitly evaluated, but other stated project goals or objectives which lacked specificity were evaluated based on changes in trends (shoreline erosion and land loss rates post-restoration), and the success of the projects based on the land area change data predicting that Whiskey Island would be completely subaqueous by 2014.

Chapter 3 – Project Performance

Data analysis for this report used project specific data in conjunction with products from the Barrier Island Comprehensive Monitoring (BICM) program (Kindinger et al. 2013) administered by the Coastal Protection and Restoration Authority (CPRA) of Louisiana. The BICM program encompasses a wide variety of datasets and analyses that include: 1) shoreline assessment photography and period comparisons, 2) coast-wide shoreline delineation and change analysis, 3) topography data and elevation change, 4) bathymetry data and elevation change, 5) habitat delineation with habitat and land/water changes, and 6) surficial sediment composition and change. One goal of the BICM program is to aggregate and standardize data sets for comparability over time, and so data sets that pre-date CWPPRA have also been assembled and formatted for this purpose. The analysis results of each BICM variable used to assess the success of the projects appear in subsequent chapters; details concerning data analysis methodologies and specific time interval changes can be found in Chapters 4 – 9.

Land Area Change

The trend in land area change during the post restoration period (1998 - 2016) differed from that observed in the pre-restoration period (1978-1998). The post-restoration period shows a reversal in loss rates, such that during the 1998 to 2016 period, the island experienced an average gain of just over 14 acres per year. The effects of both the TE-27 and TE-50 projects, which contributed 2.9 and 2.5 million cubic yards of fill material to the island, respectively, are evident in figure 3-1. Immediately prior to TE-27 project construction in 1998, Whiskey Island had been reduced in land area to 411 acres. The difference in the two land area calculations is due to the hurricanes in the fall of 2002 and highlights the importance of tropical cyclones on erosion and sediment transport processes.

Figure 3-1. Land area changes from 1978 through 2016 at Whiskey Island, Isles Dernieres, Terrebonne Parrish, LA.

Regarding project goals and objectives related to island stability, the additional sediment added to the system by this project likely sustained it through the 2002 hurricane season and ensured its continued existence in the post-construction period between 1998 and 2008. The 2002 post-storms land area estimate remained 29% above the pre-restoration estimate, and even by 2008 following several hurricanes, Whiskey Island was 22 acres larger than it had been prior to TE-27 project completion. Considering that the 433 acres estimated in 2008 is only 5% larger than the pre-restoration acreage, it is questionable whether or not TE-27 would have lasted its 20 year project life.

The TE-50 project was completed in 2010, two years after Hurricane Gustav impacted the island. In 2012, land area was calculated at 803 acres, the highest calculation of subaerial land at any point in the post-restoration period and 88% of the earliest land area examined, which occurred at the beginning of the analysis period in 1978. The 2012 land area estimate represents an 85% increase compared to the 433 acres estimated in 2008 prior to the TE-50 project, even without accounting for potential land loss that is likely to have occurred on some scale between project completion in 2010 and the 2012 land area calculation; this is particularly noteworthy considering that the island was projected to become subaqueous by 2014 (figure 3-1). From 2012 to 2015, the land area of the island was reduced from 803 to 729 acres, a 10% reduction. By 2016, another 9% of subaerial land was calculated to have been lost, which represents a cumulative loss of 17% between 2012 and 2016. Still, the subaerial land portion of Whiskey Island was 38% larger in 2016 than it was in 1998 before either project had been constructed.

Given that the pre-construction period was characterized by a below average number of storms and that the post-construction period experienced an above average number of storms, including several powerful storms in close proximity, the difference in land loss trends between these two periods is significant. Whiskey Island was losing on average almost 25 acres each year during a period of below average tropical activity in the 20 years prior to 1998, whereas land area increased on average of 14.5 acres per year in the 20 years that followed. As stated earlier, the goals and objectives of each project related to both island stability and land creation, both projects were successful as measured by their contributions to the subaerial land area of Whiskey Island verses projected disappearance of the sub-aerial land by 2014.

Island Change: Shoreline Position, Length, and Width

The initial post-construction time period (1998-2008) exhibited shoreline recession at a rate of 61.1 ft/yr, while the complete post-restoration time period (1998-2015) had a recession rate of 46.8 ft/yr. Compared with an average recession rate of 63.4 ft/yr reported by Byrnes et al (2018) prior to restoration (1950s – 1998), there was a ~4% reduction in recession rates during the initial 10 years following TE-27 construction and a ~26 % reduction during the full post-restoration period (1998-2015). Additional time periods were examined to potentially illuminate project-specific effects. In examining the 2008-2012 time period, the shoreline recession rate was calculated at 17.9 ft/yr. The effects of several significant storms on shoreline recession rates during this period were likely mitigated by construction of TE-50 in 2010 and the additional sediment which it added to the system. The final time period we examined extended the previous one by an additional three years to include the 2015 shoreline. During the 2008-2015 time period, Whiskey Island experienced no additional storms than it had in the 2008-2012 time period. The shoreline recession rate during this period was calculated at 30.8 ft/yr. While this is an increase from the abbreviated

2008-2012 period, it still represents a ~50% decrease in shoreline recession rates as calculated for the first 10 year period following TE-27 project construction (1998-2008).

Whiskey Island exhibited an overall reduction in length during the pre-restoration period (figure 3-2). In 1978, 20 years prior to restoration, the length of Whiskey Island totaled approximately 26,411 feet and by 1998 had shortened to approximately 20,341 feet, equating to an average shortening rate of –303.5 ft/yr. Following the completion of TE-27 in 1999, the island exhibited an initial increase in length such that between 1998 and 2002 there was an additional 1,640 feet even after Hurricanes Lili and Isidore had severely impacted Whiskey Island in 2002 as discussed above. At that point in 2002, the island was 21,981 feet long, having experienced a modest increase from the 1998 length of 20,341 feet due to the combined and opposing effects of both a restoration event and significant storm impacts. Island length varied during the 2004-2008 period, but had ultimately shortened to 16,732 feet by 2008. In 2010 TE-50 was completed, and by 2012, the length of Whiskey Island had increased to 19,521 feet even after being affected by Hurricane Isaac that same year. The island lengthened again in 2015 to 20,669 feet, and by the end of the analysis period in 2016 it was 21,817 feet. The overall trend in island length in the post-restoration period was positive, and between 1998 and 2016 the island exhibited increases in length at an average of 82 ft/yr.

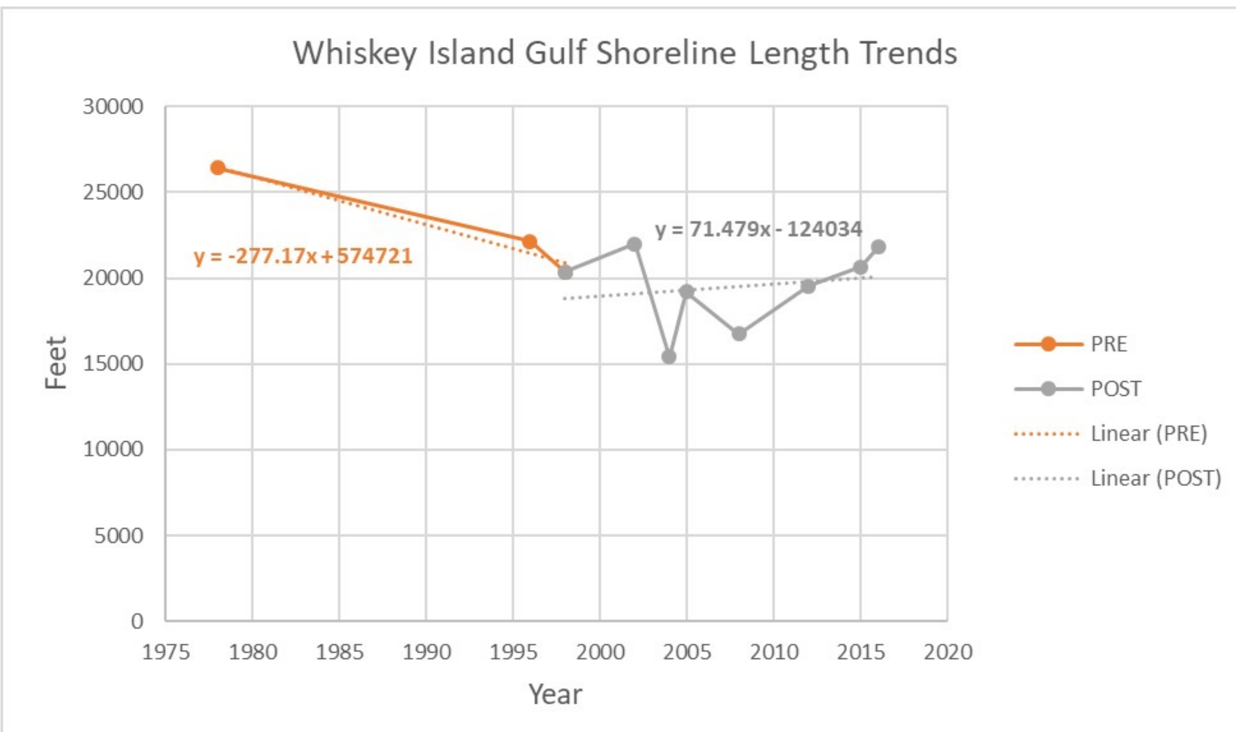

Figure 3-2. Trends in average island length at Whiskey Island from 1978 to 2016.

Island widths were examined for the same years that the lengths had been, and the overall trends observed in width in the pre- and post-restoration time periods were generally the same as those observed in length; the pre-restoration period exhibited narrowing of the island at a rate of approximately 16.5 ft/yr while the post-restoration period exhibited widening at a rate of approximately 22 ft/yr (figure 3-3). Following TE-27 construction, the average width of the island increased from 1,037 feet in 1998 to 1,722 feet in 2002, a difference of 685 feet which translates to a widening rate of approximately 171 ft/yr in this 4-year period immediately following that project. Examined on a longer time horizon, the widening rate becomes 14.7 ft/yr between 1998 and 2008. TE-50 was completed in 2010 and was responsible for the widening observed in figure 3-3 between 2008 and 2012 when the average width increased from 1,184 feet to 1,841 feet, which would translate to a rate of approximately +164 ft/yr. Once again, soon after the restoration event occurred, there was a significant storm to affect the island in Hurricane Isaac, which occurred in 2012. As expected, as a result of Hurricane Isaac and other system drivers in the years that followed, the island began to narrow and by 2016, the average width was 1,437 feet. Between 2008 and 2016, however, the island still exhibited an overall increase in average width of 253 feet, at a rate which translates to 31.6 ft/yr.

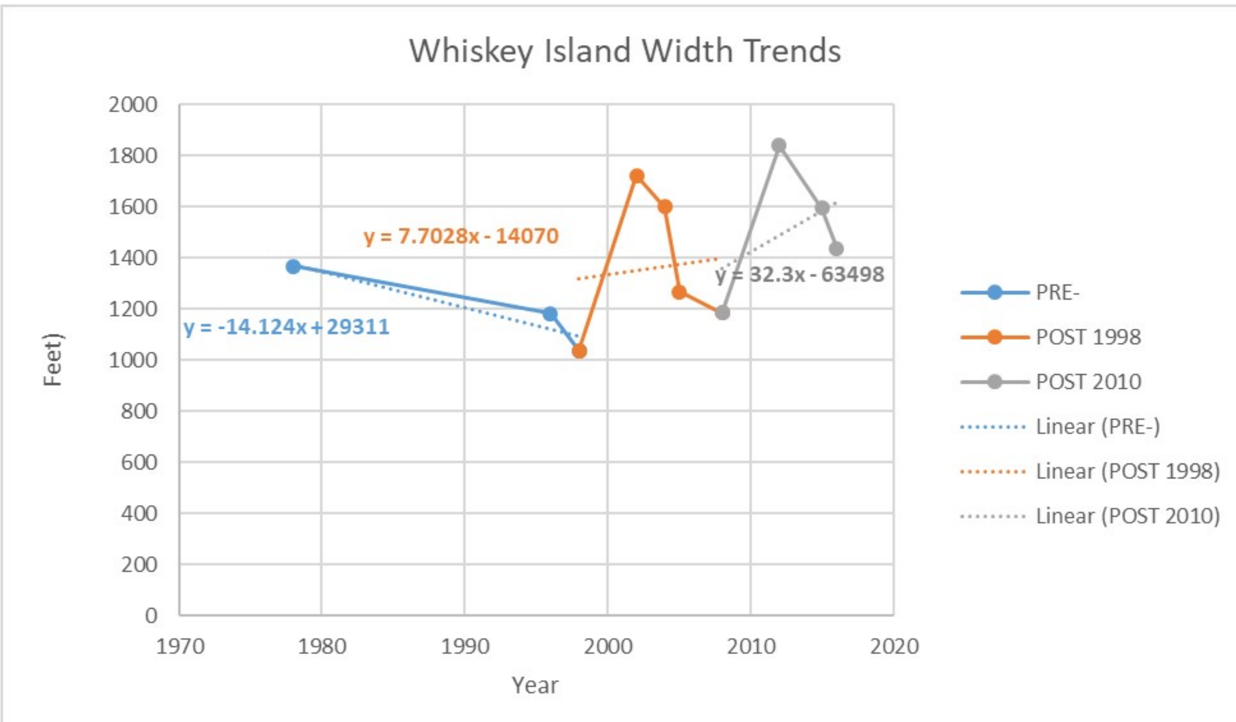

Figure 3-3. Trends in average island width at Whiskey Island from 1978 to 2016. The cumulative effect of the projects on the width of the island is evident when comparing the trend lines before and after the 1998 restoration effort as the narrowing was reversed. The 2010 restoration effort is especially prominent due to several active storm seasons immediately preceding it, compounding other island stressors.

All metrics that were examined revealed the positive impacts that the two restoration events had on the island in the various post-restoration time periods evaluated in this analysis. The common goals and objectives of the projects related to stabilization, increased width and prolonged longevity each appear satisfied following the construction of each of the projects individually, and especially when their cumulative effects are considered. Trends in length, width, as well as shoreline position were each favorable, although the processes which act on barrier islands in general were not altered by either project, and the initial benefits of the projects eventually succumb to natural coastal processes. Still, positive trends in erosion rates as well as island length and width were evident from these analyses, and project contributions to stabilizing Whiskey Island and increasing its longevity are thusly considered to have been achieved.

Elevation and Sediment Volume

Whiskey Island experienced considerable expansions in supratidal habitats once construction of the TE-27 project was completed in September 1998. Approximately, 251.70 acres of supratidal and 2.19 acres of dune habitats were created (Figure 3-4). During and/or shortly after construction, the breach separating the island and the spit was infilled and a long, narrow eastern spit was geomorphically shaped through longshore transport processes. For the initial post-construction period (Mar 2000), supratidal habitats slightly declined and intertidal habitats correspondingly expanded (figure 3-4).

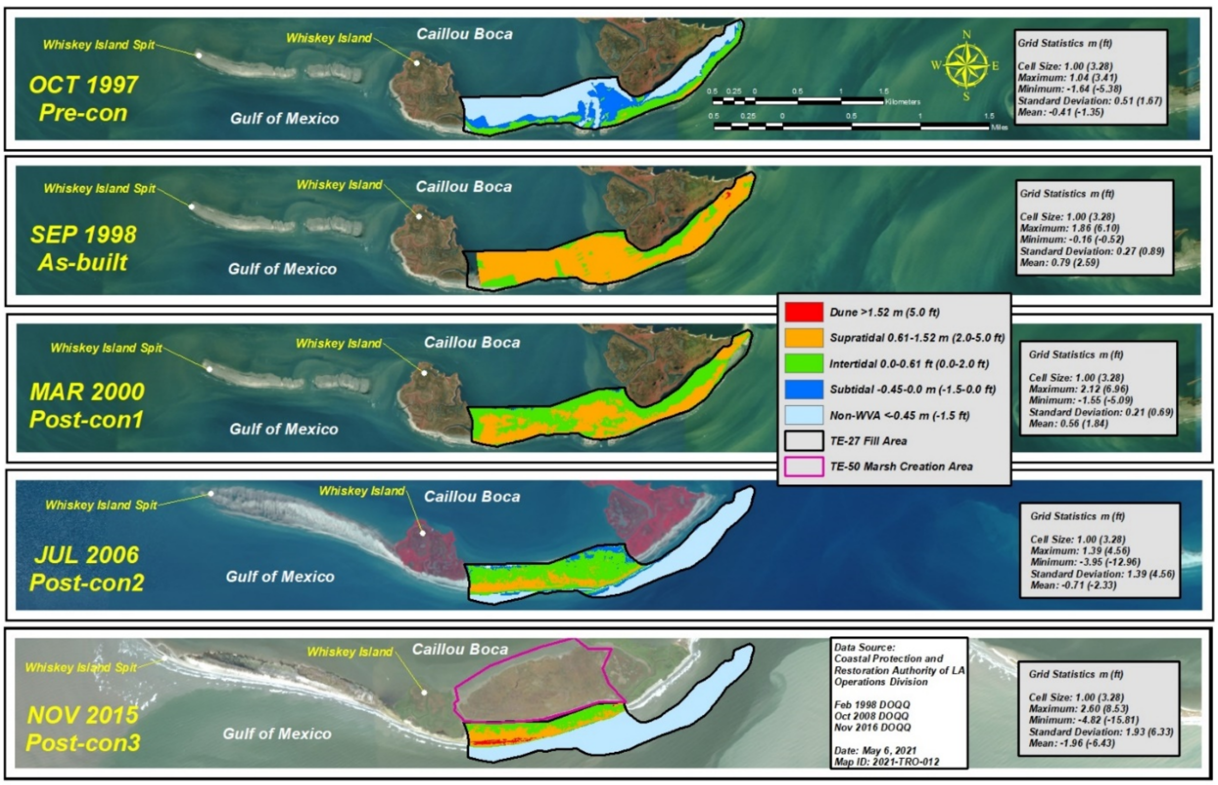

Figure 3-4. Elevation classification of the analysis area for the Whiskey Island Restoration (TE-27) project for five time periods from pre-construction (1998) to seventeen years post-construction (2015).

In the second (Jul 2006) and third (Nov 2015) post-construction periods, elevations within the TE-27 analysis area sizably declined. Supratidal habitats were reduced in 2006, and the non-WVA class formed inside the TE-27 analysis area. By 2015, the non-WVA class had the greatest habitat gain and became the foremost habitat class in the TE-27 analysis area (figure 3-4). Sediment volume decreased by -125% (second interval) and -233% (third interval) creating a sediment volume deficit within the TE-27 analysis area (figure 3-4). The dominant causes of these substantial volume losses in the analysis area were eastern reach shoreline erosion induced during the passage of the 2002, 2005, and 2008 hurricane seasons and longshore transport (figure 3-4).

However, tropical storms are not the only cause of the substantial volume losses that occurred by 2016 because the eastern reaches transgressed an additional 800 ft since these hurricanes.

The expanded 2006-2015 BICM change model shows aggradation in the Whiskey Island system for this defined interval. Figure 3-5 delineates the trends in sediment transport surrounding Whiskey Island for the period from 2006-2015 and displays a sediment accruing trend. Although the general trend reveals sediment aggradation, Figure 3-5 also exhibits reaches with marked erosional activity. The most prominent of these erosional hot spots is the TE-27 analysis area. Other erosional hot spots include the bay shoreline of the island and Whiskey Pass. Whiskey Pass is widening to the west and migrating closer to the island. The westward drift of this pass is outlined in figure 3-5 and shows the pass encroaching very close to the island. Interestingly, the pass is aggrading along its eastern banks and a flood shoal is forming west of the pass and northeast of the island. Besides the areas in the vicinity of Whiskey Pass, several other reaches show intense aggradation (figure 3-5). These accretionary reaches include the TE-50 marsh creation area, the bay behind the island, the Whiskey Island Spit, and an ebb shoal that is forming south of this shoreline on the western terminal end of the island. The shaping of the eastern flood shoal, the western ebb shoal, and the nourishing of the spit show that a proportion of the sediments eroded from the eastern TE-27 analysis area have been conserved within the island system.

The TE-27 analysis area has incurred sizeable volume and elevation deficits over time. Whiskey Island was extremely narrow before the construction of the TE-27 project (figure 3-4) and was projected to become an inner shelf shoal early in the 21st century (McBride et al. 1989; McBride and Byrnes 1997; Penland et al. 2003), so the project extensively expanded island width in the project area and re-joined the island to the spit causing the island to elongate. Without the added width and elevations provided by the TE-27 project in 1998, Whiskey Island would have likely reverted to an inner shelf shoal or have a considerably lower profile with reduced acreages of barrier island habitats. As a result, the elevation and width goal of the TE-27 project has been attained because the project enhanced the longevity of Whiskey Island and sediments were conserved in the spit, the eastern flood shoal, and the western ebb shoal.

The construction of Whiskey Island Back Barrier Marsh Creation (TE-50) marsh and dune features in October of 2009 resulted in the enlargement of supratidal and dune habitats on Whiskey Island. Approximately, 305.23 acres of supratidal habitats were created within the TE-50 marsh analysis area by the project (figure 3-6). Within the dune analysis area, the TE-50 project transformed supratidal and intertidal habitats to dune elevations (figure 3-6). During the initial marsh post-construction period (April 2010), supratidal habitat settled in the TE-50 marsh analysis area to create intertidal marsh habitats (figure 3-6). Sediment volume decreased by 22% from October 2009-April 2010 (figure 3-6). The reason for the volume declines throughout the marsh analysis area is primary settlement and desiccation of the dredged sediments.

For the second (February 2014) and third (November 2015) marsh post-construction intervals, habitats in the marsh analysis area remained dominated by the intertidal class. By 2015, the non-WVA habitat class appeared and the subtidal habitat class expanded along the Caillou Boca shoreline. The sediment volume in the marsh analysis area were diminished by 32% (second interval) and 40% (third interval) (figure 3-6). The increased transgressions along the Caillou

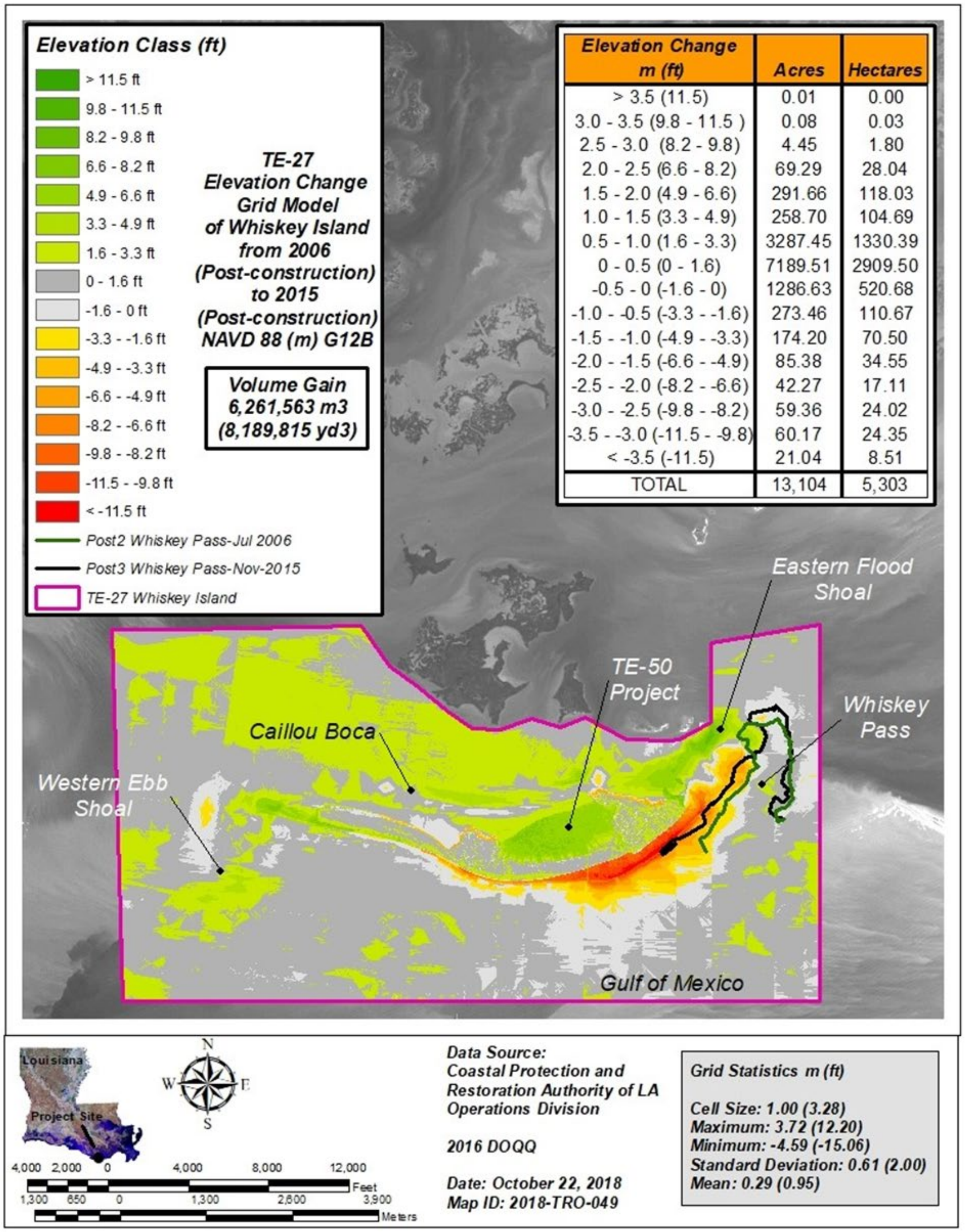

Figure 3-5. Elevation and volume change grid model for the Whiskey Island system from Jul 2006 to Nov 2015. Yellows and reds illustrate erosion areas; greens illustrate deposition areas. Grey areas represent areas within model uncertainties and are excluded from the volume calculations.

Boca shoreline seem to be driving the sediment volume changes in the marsh analysis area for these intervals.

For the first dune post-construction interval (November 2015), habitats in the dune analysis area transitioned to the non-WVA class The eastern and central reaches of the dune analysis area eroded to form the non-WVA class while the western reaches remained dune and supratidal habitats (figure 3-6). For this period, the sediment volume within the dune analysis area declined by 362% creating a large sediment deficit (figure 3-6). The TE-50 dune analysis area change models supports the TE-27 conclusions that longshore transport and the widening of Whiskey Pass are likely forcing the Whiskey Island Gulf of Mexico shoreline northward.

In conclusion, these results reveal that the TE-50 project is currently attaining its intertidal marsh acreage and longevity goals. Though the intertidal marsh acreage has dipped below the 300 acres stated in the goal, approximately 270 acres of functioning marsh habitats remain. In addition, the longevity of Whiskey Island has also been enhanced through the widening provided by the TE-50 project.

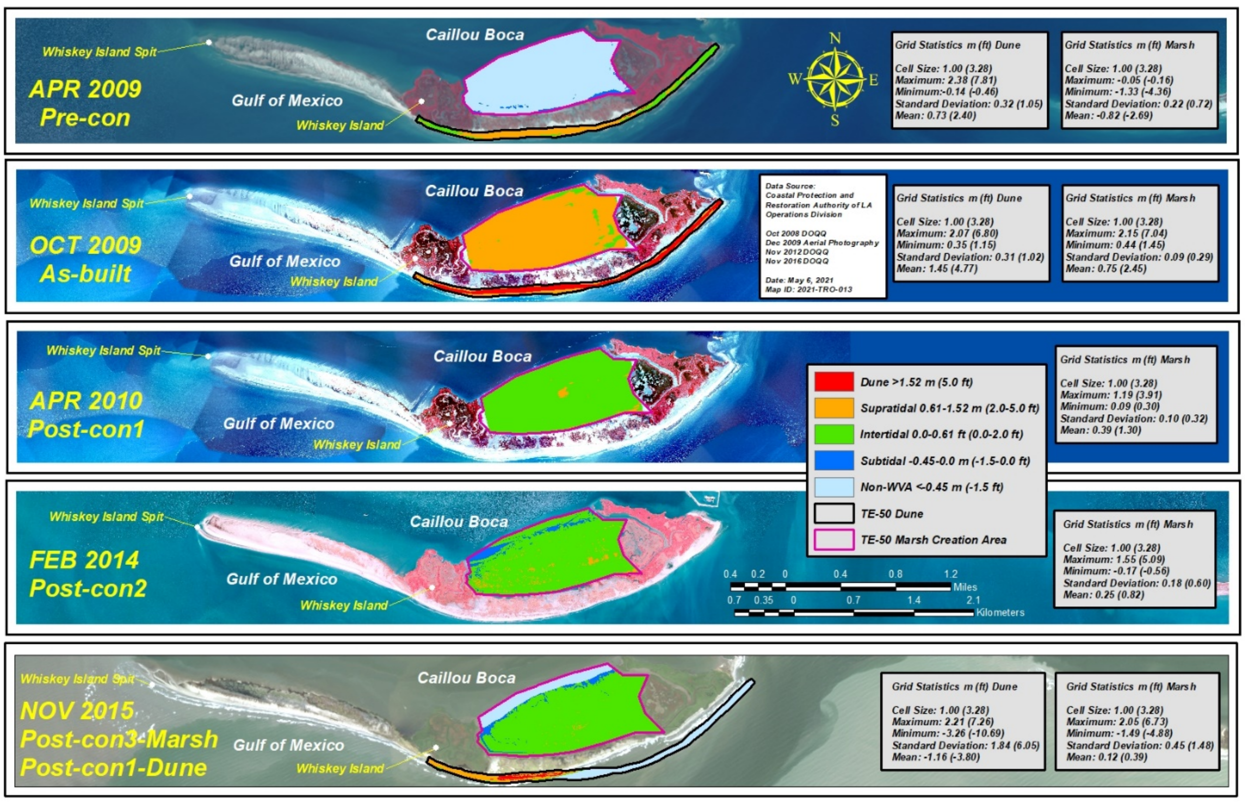

Figure 3-6. Elevation classification of the analysis area for the Whiskey Island Back Barrier Marsh Creation (TE-50) project for five time periods from pre-construction (2009) to six years post-construction (2015).

The TE-50 tidal creek and pond areas and their reference area detailed minor reductions in sediment volume since the as-built surveys of these areas were completed in 2010. The sediment volume reductions in the creek and pond project and reference areas are primarily attributable to erosion along the Caillou Boca shoreline (figure 3-7). By 2015, virtually all of the primary creeks eroded into Caillou Boca and became subaqueous. Segments of the reference area have also transgressed into Caillou Boca (figure 3-7). Figure 3-8 delineates the positions where creeks formed in the project and reference areas overlaid on the surface of 2012 and 2016 aerial images.

Creeks did not form in all of the pre-dug locations, but they seem to maintain the shape of the pre-dug channels where they did form. A total of 5,887 ft of creeks formed in the project area. In the reference area a network of 5 creeks were shaped creating 8,502 ft of tidal channels (figure 3-8). The creeks in the reference area seem to have formed more extensive creek networks especially RC 4, which has developed multiple branches. Although some of the creeks formed can be partially discerned from the post-construction change models (figure 3-7), the creeks should be more sharply outlined in the change models. The TE-50 creek and pond goal is currently being attained at this time because the creek length exceed the 5,800 ft benchmark and extensive creek networks were developed in the reference area.

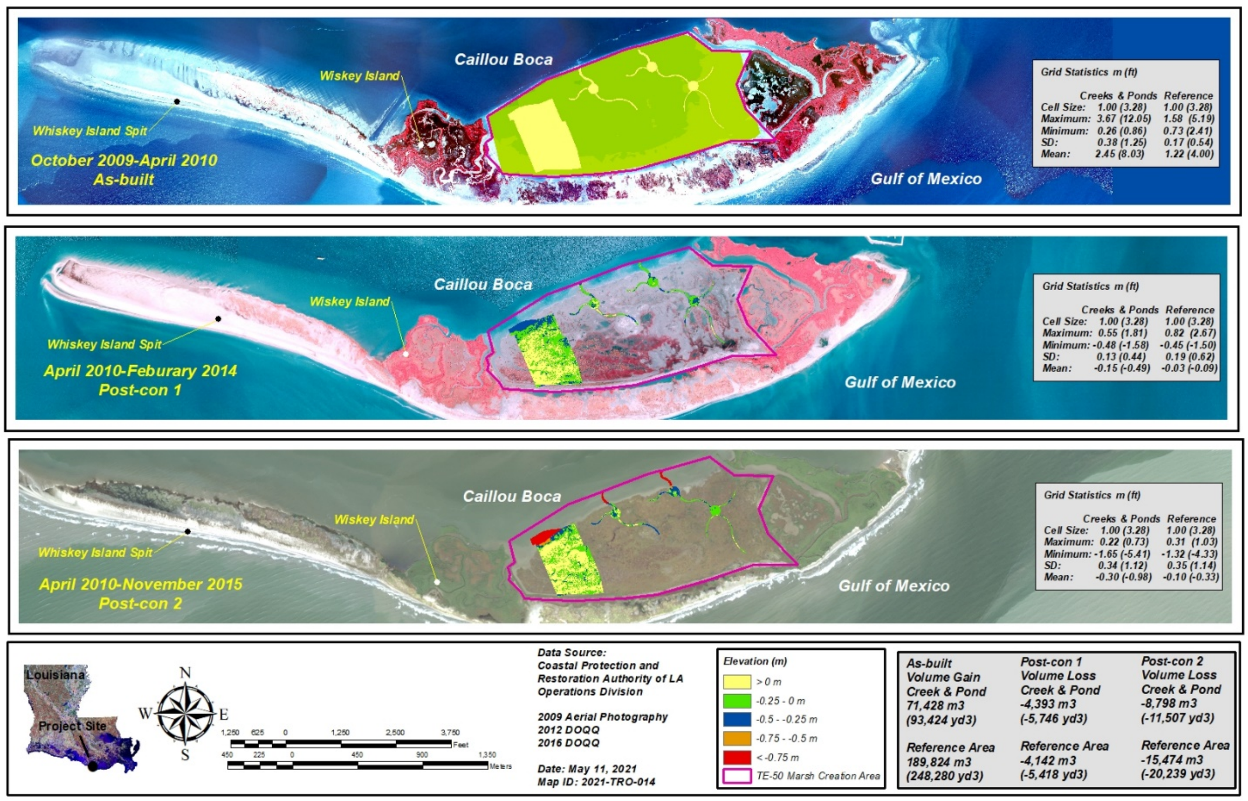

Figure 3-7. Elevation and volume change grid models for the TE-50 creek, pond, and reference areas from pre-construction (Apr 2009) to as-built (Apr 2010), from as-built (Apr 2010) to post-construction (Feb 2014), and from as-built (Apr 2010) to post-construction (Nov 2015) at the Whiskey Island Back Barrier Marsh Creation (TE-50) project.

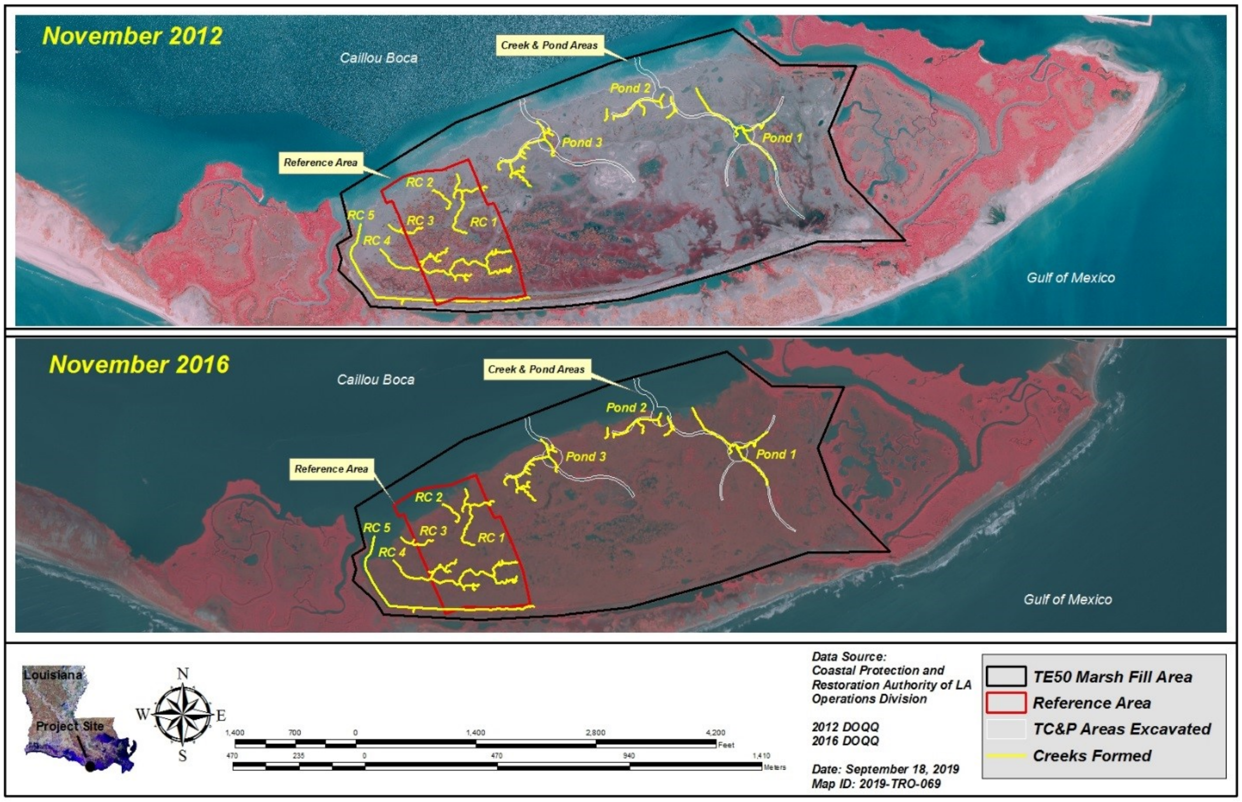

Figure 3-8. Creeks formed in the TE-50 creek, pond, and reference areas displayed over post-construction Nov 2012 and Nov 2016 CIR imagery at the Whiskey Island Back Barrier Marsh Creation (TE-50) project.

Habitat

Habitat classification datasets for Whiskey Island were available for six time periods between 1996 and 2016 (figure 3-9). This 20-year period includes a pre-restoration analysis of the 1996 aerial imagery and five additional years following the initial restoration: 2002, 2004, 2005, 2008, and 2016. The habitat change trends revealed an overall increase in land area, as substantiated by the area, length, and width analyses in previous sections and in more detailed discussions in later chapters. Each project had goals and/or objectives related to creating marsh and dunes and establishing vegetation. The changes in habitat classes over time exhibited favorable trends in each of these regards. Emergent marsh, which would fall into the category of vegetated wetland, remained fairly stable throughout the 1996 to 2008 period. Between 2008 and 2016, vegetated wetlands had increased by 331 acres. Total land habitat in that same period increased by 233 total acres as intertidal flat and bare land vegetated and beach habitats were reworked. The 666 total land acres in 2016 represents a 40% increase in total land habitat area when compared to the pre-restoration habitat data. Vegetated wetlands more than doubled in acreage during that period, increasing from 304 acres in 1996 to 617 acres in 2016. Goals related to increasing marsh acreage are considered to have been achieved as evaluated here, while individual habitats showed increases or stability post-restoration as desired in the project goals.

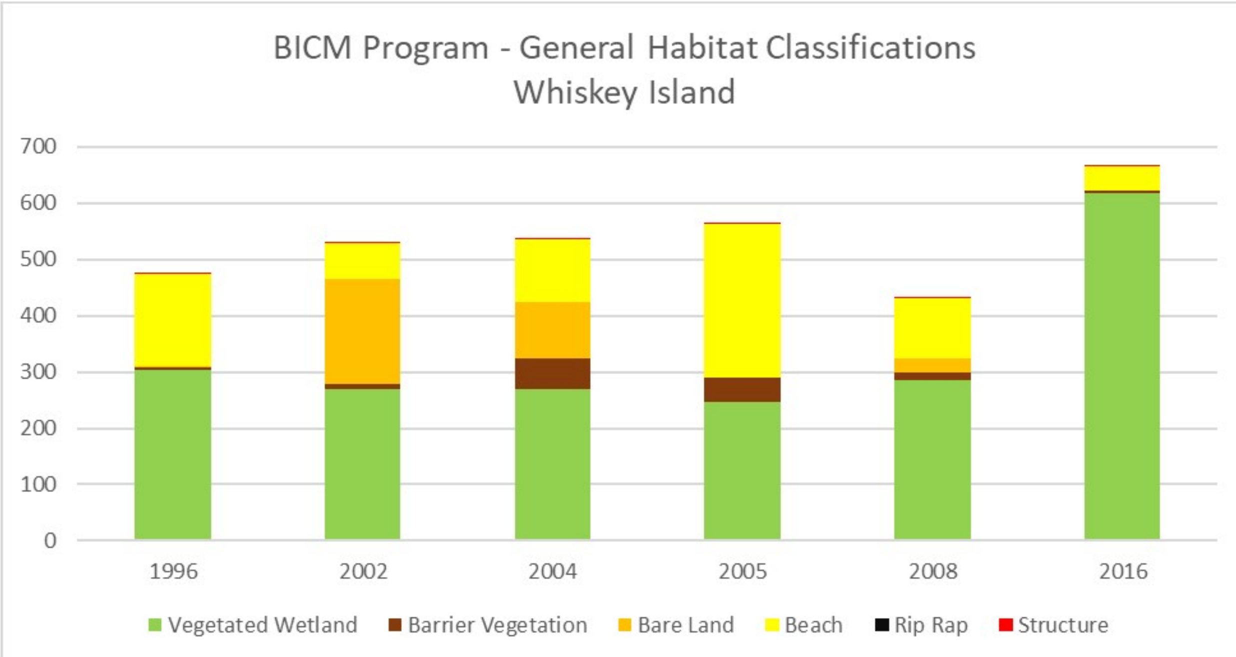

Figure 3-9. BICM habitat classifications showing total acres of 6 land cover types at Whiskey Island, Terrebonne Parish, LA. Changes in habitat classes indicate impacts of restoration events and storms over time. (Areas classified as water were removed for the purposes of displaying the data graphically and parsing out land classification changes.

Land area was defined as any general habitat class other than water or intertidal flat. The barrier vegetation and bare land habitat classes are the categories that map dunes within the BICM general classifications, and these categories were examined to help evaluate how well the projects performed relative to the goals and objectives related to creating, establishing or maintaining dunes. In 1996 prior to restoration, there was only 3 acres of barrier vegetation and only 2 acres of bare land (table 3-1), and those 5 acres account for only 1% of the total land area at that time. By 2002, following the construction of TE-27, the barrier vegetation and bare land habitat categories had increased to 8 and 188 acres, respectively, totaling 196 acres or about 37% of the total land habitat of the island. The increase in these categories and the extensive coverage of bare land is attributed to the initial material placed in 1998. There was also a large increase in intertidal flat which resulted from the 1998 restoration and as some of these areas began to vegetate, intertidal flat decreased by 2004 as barrier vegetation increased from 8 to 55 acres between 2002 and 2004. Bare land also decreased during this period from 188 acres to 101 acres as it also began to vegetate.

Table 3-1. Habitat acreages by BICM general habitat class between 1996 and 2016 for Whiskey Island, Isles Dernieres, Terrebonne Parish, LA.

Habitat Classes	1996	2002	2004	2005	2008	2016
Water	4388	4086	4337	4121	3551	3455
Intertidal Flat	73	321	64	252	177	39
Vegetated Wetland	304	270	269	247	286	617
Barrier Vegetation	3	8	55	44	13	6
Bare Land	2	188	101	0	26	0
Beach	165	64	111	273	107	42
Rip Rap	0	0	0	0	0	0.7
Structure	1	1	1	1	1	1
Total Land Area [1]	**475**	**531**	**537**	**564**	**433**	**666.7**

1 *Land Area defined as sum of all habitat classes other than Water or Intertidal Flat.*

Most fluctuations observed in various habitat categories can be attributed to both storm and restoration impacts and the vegetative colonization and other successional processes which follow those disturbances. Beach and bare land exhibited the most variability of the land class categories and they were each highly responsive to disturbance events whether they were from restoration events or storms. Compared to the much more frequent storm impacts to the island during the initial 10 years post construction, the relatively low number of tropical cyclones and resulting overwash events over the last 8 years of the analysis period likely provided for vegetation to increase as natural succession progressed.

In 2010, the TE-50 project added another 2.5 million cubic yards to the system. Between 2008 and 2016, the island showed an increase in total land area of nearly 54%. As 6 years had passed between the second restoration event and the next and final year of habitat data, evidence of increases in intertidal flat and bare land were much reduced compared to the initial restoration in 1998, this due to the increased amount of time that these areas had to vegetate between mapping efforts. By 2016, vegetated wetlands made up 92% of the area considered land, which represents an increase of 102% in that category compared to the 1996 data. Only 6 acres of barrier vegetation was mapped in 2016 and bare land had been reduced to zero, so habitat categories which map dunes made up only 0.9% of the total land area by 2016, very similar to the 1% that it had been in 1996. While each project made contributions to habitats containing dunes, the ephemeral nature of these habitats, their sensitivity to various disturbances or lack thereof, and propensity to quickly transition caused large fluctuations between analysis years. It is fair to assess that the projects did achieve dune stabilization/maintenance by providing material to the system such that these habitats continue to exist beyond the predicted island life and the island system is fortified to withstand future disturbance events that will variously affect not only these habitat categories but also each of the others comprising the island.

Vegetation

Vegetation stations fell into 3 different geomorphic regions: upslope, swale, and marsh. The upslope region was the area closest to the Gulf of Mexico where the sand/water interface begins and rises upward in elevation until reaching the dune. The swale region is the area on the back side of the dune and slopes downward toward the bayside of the island. The marsh region begins where the swale elevation has decreased as it nears the bay. Each region is characterized by a unique composition of emergent vegetation. Upslope region stations on Whiskey Island had a relative mean vegetation cover of 63% in 2007 (figure 3-10) and sixteen species were documented at that time, dominated by *Spartina patens*. The planted species, *Panicum amarum*, accounted for almost one-third of the upslope vegetation cover. By 2016, the physical location of the 2007 upslope stations had transitioned out of that geomorphic region and into open water due to a combination of shoreline erosion and island migration. Relative mean vegetation cover inside the swale region stations slightly increased from 2007 to 2016 and remained above 65%. S. patens was the dominant species with 23% and 25% relative mean cover in 2007 and 2016, respectively (figure 3-11). In 2007 *P. amarum* and *Sesuvium portulacastrum* both had over 10% relative mean cover, but by 2016 *P. amarum* had disappeared and *S. portulacastrum* was reduced to 4% cover due to station lost from erosion. Diversity remained high through 2016 even as the species composition shifted from predominately swale species to a larger number of salt pan and low back barrier marsh species. Relative mean vegetation cover inside of the three marsh region stations remained above 65% in 2007 and 2016 (figure 3-10) and species richness increased from 8 to 13. In 2007, *S. patens* and *Salicornia bigelovii* had high relative mean cover values, each with 18%. By 2016, the species composition shifted to a low back barrier marsh assemblage consisting of *S. alterniflora*, *Avicennia germinans*, and *Batis maritima* co-dominating.

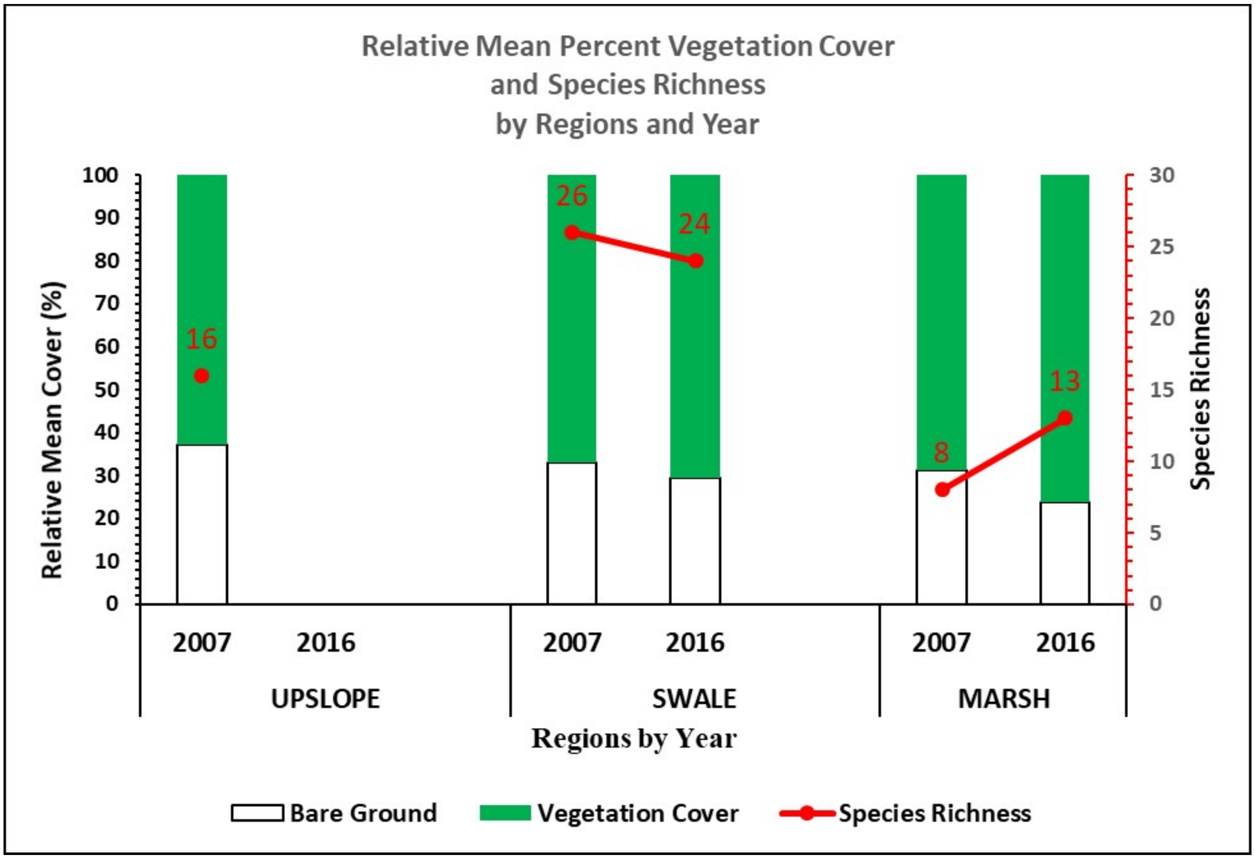

Figure 3-10. Relative mean cover of vegetation and species richness by region and year on Whiskey Island.

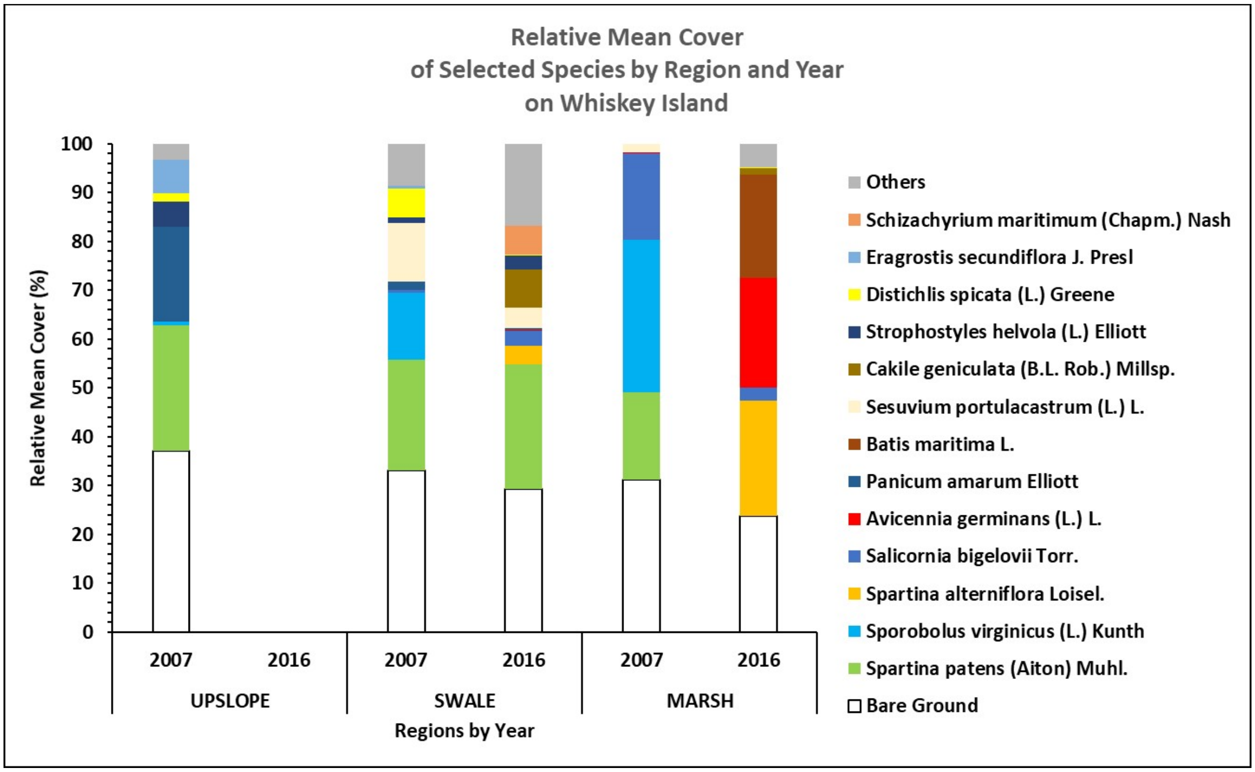

Figure 3-11. Relative mean percent vegetation cover of selected species inside the 4m^2 stations by region and year on Whiskey Island.

The goal to reduce loss of dredged sediments on the eastern half of Whiskey Island through the growth of vegetation was realized as measured by the health of the vegetation community and the extent of its cover. Despite sampling limitations and station loss, it was evident from this analysis that vegetative growth and coverage was occurring and sufficient to aid in island stabilization as relative mean vegetation cover was maintained above 65%. Species richness also remained high, speaking to the health of the vegetation community. There was evidence of a shift in the species composition of the swale region as more salt-pan and low back-barrier marsh species began to occur, but this community shift is not unexpected on barrier islands and in this instance may indicate a natural geomorphic transition.

Sediment Properties

The results of the sediment properties analysis demonstrate that surficial sand deposits were present along the Whiskey Island shoreface, beach, dune, marsh, bay, and passes in 2008 and 2015 (figures 3-12 and 3-13). The percentage of sand (%) in 2008 ranged from < 70 to 95% for sediments extracted from the middle of shoreface to the marsh with the greatest concentrations of sand recovered from the western end of the spit (figure 3-12). The < 70 and 70-75% classes that encroach onto Whiskey Island were partially calculated from interpolation of distant points due to inadequate point spacing and may not be a representative depiction of the actual surficial sand percentages in this area. Moreover, the 75-80% and 80-85% classes in the bay behind the island and spit were also interpolated from distant points because no surficial samples were extracted from this area. The median grain sizes of these sediments fell within the very fine sand (62.5–125 µm) or fine sand (125–250 µm) size classes (figure 3-12). In 2015, the sand percentage (%) ranged from < 70 to 90% for sediments extracted from the middle of shoreface to the bay. The highest proportions of sand (85-90%) were observed along the eastern reaches of the island. Unlike the 2008 sampling, the 2015 event did collect samples in the bay behind the island. These surficial samples showed Caillou Boca to contain considerable concentrations of silty sediments. The point spacing in the shoreface reaches continues to be too distant for accurate model interpolations. The median grain sizes for the 2015 sediments fell within the very fine sand (62.5–125 µm) or fine sand (125–250 µm) size classes. The courser 2015 sediments followed the subaerial contour of the island and did not venture far into the shoreface (nearshore littoral zone) or the bay (figure 3-13). The longshore model demonstrates that a reasonable volume of westward transport occurred from 2006 to 2015 in the nearshore littoral zone, and the 2015 surficial sediment data suggest part of this transport was granular (figure 3-13). While elevation data illustrate that an enlarging (horizontal and vertical growth) shoal migrated to the west and marginally to the south since 2006, while the 2015 data appears to suggest that these sediments have restricted granular constitutes (figure 3-13). Although moderate quantities of surficial sand deposits are available, the Isles Dernieres and Timbalier Barrier Islands have been characterized as having thin sand layers overlying silt and/or clay substratums (Peyronnin 1962; Penland et al. 1985; Kulp et al. 2005). Therefore, the depth of the granular deposits are projected to be predominantly surficial and the volume available for transport is probably limited. In the future, sediment cores should be extracted to establish a detailed sediment budget for Whiskey Island. These cores should extend 15-20 ft (5-6 m) below the ground surface (bgs) and stretch from Whiskey Pass to the Coupe Colin Inlet and include shoreface, beach, dune, marsh, and bay habitats like the surficial samples.

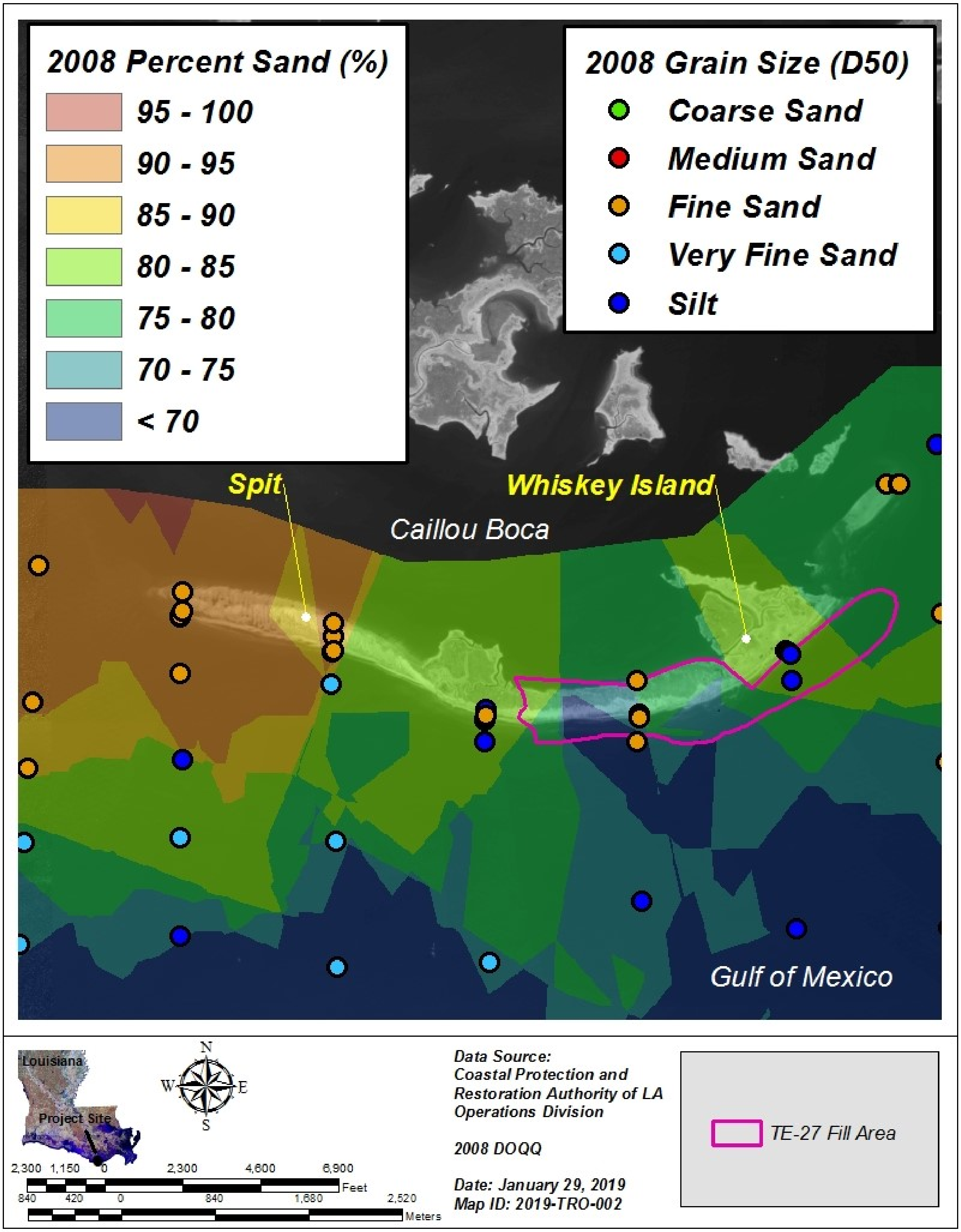

Figure 3-12. Median grain size (D50) and percent sand (%) distributions for Whiskey Island in July 2008.

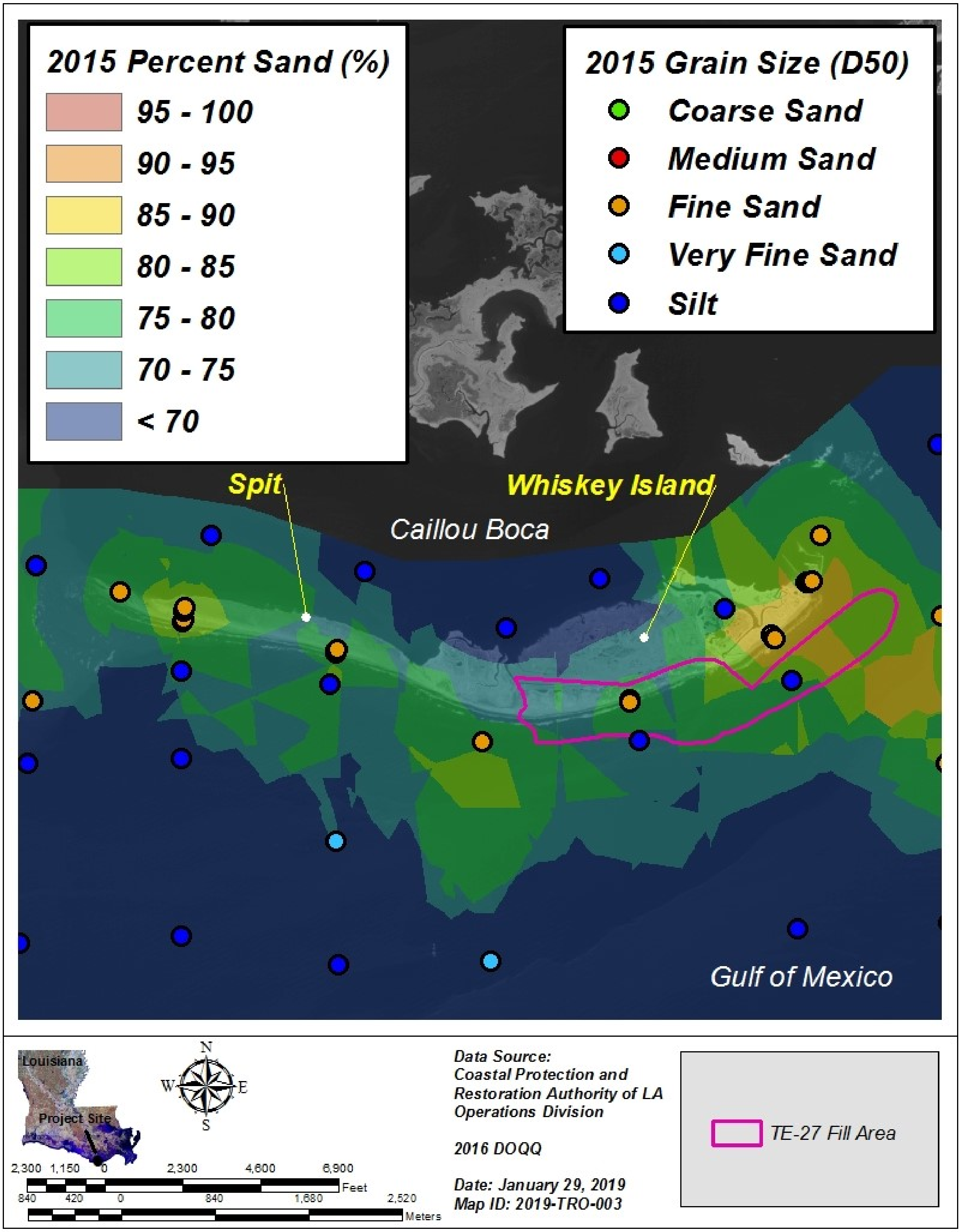

Figure 3-13. Median grain size (D50) and percent sand (%) distributions for Whiskey Island in August 2015.

Chapter 4 - Land Area Change at Whiskey Island due to the Whiskey Island Restoration (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50) projects

Introduction

In order to assess aspects of the restoration efforts on Whiskey Island, a combination of digitized shorelines and habitat mapping datasets were compiled from various sources to determine land area change rates both prior to and following two Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) Program restoration projects. These projects were the Whiskey Island Restoration (TE-27) project, which was completed in 1999, and the Whiskey Island Back Barrier Marsh Creation (TE-50) project, which followed in 2010. This assessment of land area change will help to evaluate some common goals and objectives between the two projects including aspects of island strengthening and stabilization, marsh creation and increased longevity by examining and comparing changes in loss rates prior to and following the construction of each project.

Methods

Land area changes have been utilized extensively to assess barrier island erosion and deterioration (Morgan and Larimore, 1957, Williams et al. 1992). Several data types including maps, charts, aerial photographs, satellite imagery, and elevation surveys have been used to determine land area as well as land area changes through time. However, comparisons of various datasets and types is complex due to the differing methodologies, scales, datums, projections, etc utilized to create them (McBride et al. 1989). This assessment will use a combination of habitat classification data developed from imagery and digitized shoreline data in order to include a sufficiently robust set of data points to examine land area before and after construction of each project and help determine their respective impacts.

The Coastal Protection and Restoration Authority's (CPRA) Barrier Island Comprehensive Monitoring Program (BICM) has compiled a series of nine shorelines for the Louisiana coast through adjustment and revision of existing datasets, as well as the digitization of new time periods. The shoreline periods compiled by BICM include: 1) 1880s, 2) 1930s, 3) 1950s, 4) 1998, 5) 2004, 6) 2005, 7) 2008, 8) 2012, and 9) 2015. The 1880s, 1930s, and 1950s US Coast & Geodetic Survey (USC&GS) topographic maps (T-sheets) encompassed multiple years. Because 1930s and 1950s USC&GS shorelines were limited in the Acadiana Bays and Pontchartrain Basin, data gaps in the 1930s were filled using United States Geological Survey (USGS) topographic maps where appropriate, and those in the 1950s were filled using aerial photography.

The time range for orthorectified imagery used to develop shorelines between 1998 and 2015 was much narrower than map data. Because of this, data gaps were filled with USGS topographic quadrangle maps or aerial photography where appropriate. For detailed information on data sources and compilation procedures of the BICM shoreline see Byrnes et al. (2018).

Habitat datasets for 1996/1998, 2001/02, 2004, and 2005 were developed by the University of New Orleans - Pontchartrain Institute for Environmental Sciences (UNO - PIES) using supervised and unsupervised classification of ortho-photography. The classification methods currently used by USGS Wetland and Aquatic Research Center (USGS-WARC) for the 2008 and 2015/16 periods generate habitat datasets from high-resolution ortho-photography using object-based analyses in the Trimble eCognition software. Detailed information on the sources and methods used to create these datasets can be found in Fearnley et al. (2009) and Enwright et al. (2020). While additional categories are delineated by the Trimble eCognition software to generate habitat classifications at a finer scale than had been delineated in the earlier datasets from UNO - PIES, comparability with previous datasets was maintained and the 6 datasets have been analyzed and assessed using the BICM general classification scheme (table 4-1).

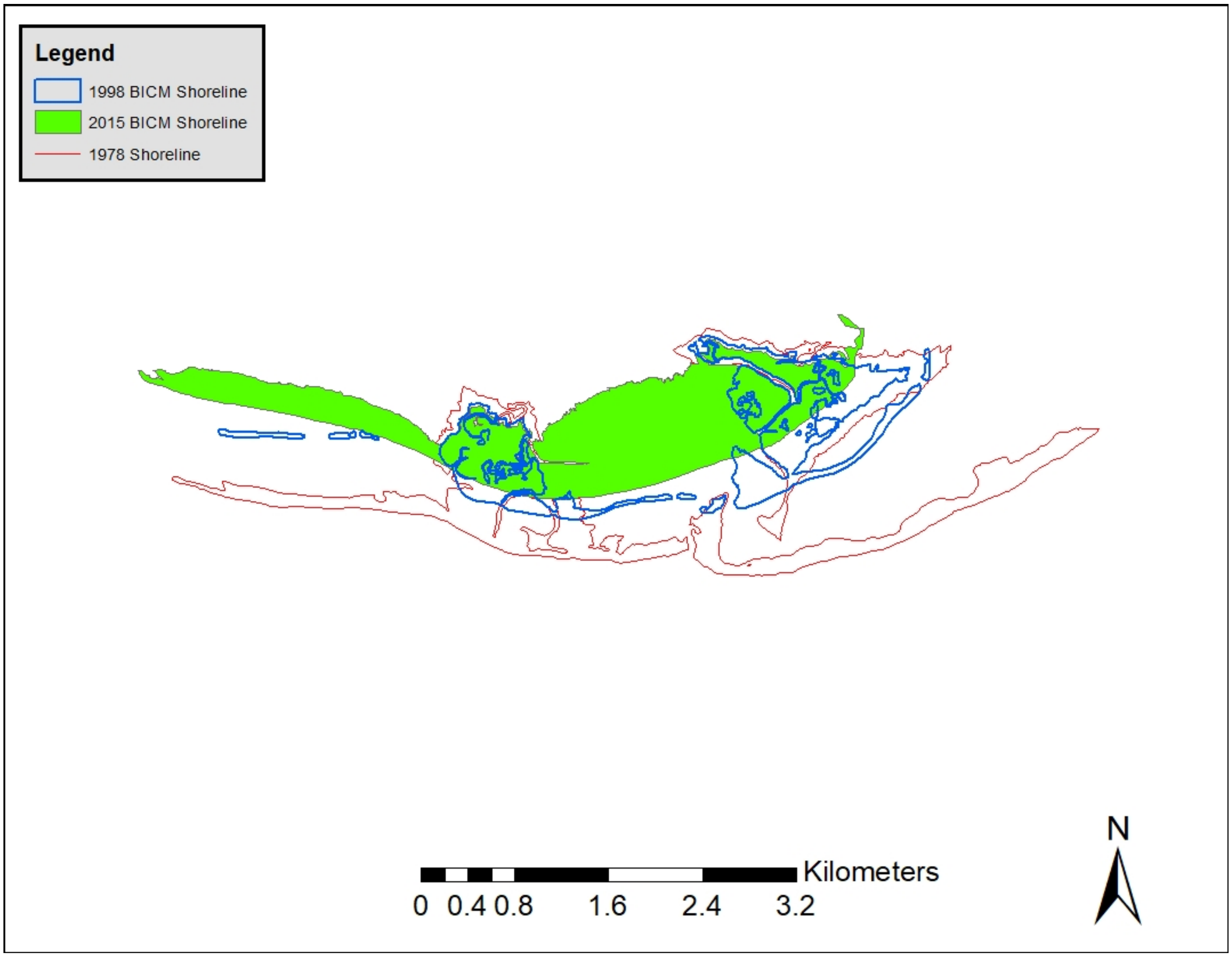

Figure 4-1. Three example land area representations of Whiskey Island developed from either digitized shorelines or habitat classification datasets available from various sources.

In addition to the nine shorelines and six habitat classification datasets complied by BICM, various publications provided supplemental land area datasets (table 4-1). These supplemental datasets were compiled from both shoreline digitization and habitat classification procedures similar to those described above. Land area calculations reported in publications provided additional time periods both prior to and after construction of each project, allowing for the inclusion of additional data points to better parse out trends in land area change. Five of the datasets were digitized shorelines and one was a habitat classification dataset produced using the BICM methodology. For detailed information on the sources and methods used for these datasets, see Penland et al. 2003.

Table 4-1. Land area as reported in Penland et al. (2003). 1996 and 2002 areas are calculated from habitat classification datasets and all others are from digitized shorelines. Area in acres.

Island	1978	1988	1992	1992	1993	1996	2002
Raccoon	368.2	200.2	167.8	112.8	99.2	127.2	145.5
Whiskey	**904.4**	**564.2**	**505.6**	**440.8**	**428.4**	**474.8**	**642.8**
Trinity	1317.1	894.6	796.5	678.5	651.4	617.4	710.1
East	368.2	202.2	173.4	93.4	88.5	193.1	380.4
East Timbalier	1223.2	588.1	533.7	350.9	316.3	226.2	334.7

The land area change analysis utilized the BICM general habitat classification scheme by using the habitat descriptions to appropriately categorize and condense the finer-scale datasets (table 4-2). The water category contains two habitat classes, water and intertidal, while the remaining four classes are aggregated into the land category. Intertidal is defined as bare or sparsely vegetated areas located between the extreme low water and extreme high water spring tide levels, with vegetation cover generally less than 30 percent. Due to the lack of vegetation cover and the intertidal nature of this classification, it was not considered land in this analysis. This is opposed to the beach class that while also low in vegetated cover, is typically mapped above extreme high-water spring tide levels. The marsh classification was likewise considered land due to the dense cover of emergent vegetation.

Using the high-water spring tide levels to define the aggregation of habitat classes into land or water matches well with the shoreline digitization methods utilized to delineate the various shorelines and allows comparison of the different data types. As noted in Byrnes et al. (2018), high-water shoreline position determined from orthoimagery represents the upper limit of average wave runup at high tide; relative to geomorphology, this position generally is recognized as the berm crest or an active scarp at the toe of a dune. It is also recognized as the wet/dry boundary on the beach at high water, or as a debris line marking the position of wave uprush (Leatherman, 2003). For south Louisiana, the wet/dry boundary on the beach at high tide was the primary shoreline marker. Where marsh shoreline type was dominant, shoreline position was mapped as the vegetation/water boundary, consistent with USC&GS historical shoreline mapping (Shalowitz, 1964).

Final compilation of land acreages for the Whiskey Island assessment included fifteen data points from 1978 through 2016. Land areas were determined from 11 digitized shorelines and 4 habitat classification datasets. The BICM program developed 9 of the datasets with 6 provided through other sources (Penland et al. 2003, Byrnes et al. 2018, Enwright et al. 2020).

Table 4-2. Louisiana Barrier Island Comprehensive Monitoring (BICM) Program detailed and general habitat classification schemes used in habitat mapping efforts for the Louisiana Gulf of Mexico shoreline (from Enwright at al. 2020).

Detailed class	**Description**	**Description source**	**General class (Fearnleyet al., 2009)**
Beach	Beach habitat includes supratidal bare or sparsely vegetated areas (that is, above the extreme high water springs tide level) located along coastlines with high wave energy (that is, gulf-facing shorelines). Vegetation cover is generally less than 30 percent. Beach transitions into dunes, meadow, or unvegetated flat where overwash is evident. Beach includes the backshore zone of a beach.	Modified from Cowardin et al. (1979)	Beach
Unvegetated dune	Dunes are supratidal features (that is, above the extreme high water springs tide level) developed via Aeolian processes. Dunes are often located above typical storm water levels and have a well-defined relative elevation (that is, upper slope or ridge). Unvegetated dune includes dune habitat that has less than 10 percent vegetation cover.	Modified from Psuty (1989)	Bare land
Vegetated dune	Dunes are supratidal features (that is, above the extreme high water springs tide level) developed via Aeolian processes. Dunes are often located above typical storm water levels and have a well-defined relative elevation (that is, upper slope or ridge). Vegetated dune includes dune habitat that has greater than 10 percent vegetation cover.	Modified from Psuty (1989)	Barrier vegetation
Unvegetated flat	Unvegetated barrier flat includes flat or gently sloping supratidal unvegetated or sparsely vegetated areas (that is, areas located above extreme high water springs tide level) that are located on the backslope of dunes, unvegetated washover fans, and along low- energy shorelines. Vegetation cover should be generally less than 30 percent.	Modified from Leatherman (1979)	Beach
Meadow	Meadow includes supratidal areas (that is, above the extreme high water springs tide level) with sparse to dense herbaceous vegetation located in areas leading up to dunes and on the barrier flat (that is, backslope of dunes and supratidal, back-barrier habitat). Vegetation coverage should generally be greater than 30 percent. Classification of meadow habitat is restricted by geomorphic settings. Meadow is reserved for areas located on barrier flats of barrier islands, backslopes of dunes, or transitional vegetated areas in dune/beach habitats.	Modified from Lucas and Carter (2010)	Barrier vegetation
Intertidal	Intertidal includes bare or sparsely vegetated areas located between the extreme low water springs and extreme high water springs tide levels. Vegetation cover should generally be less than 30 percent. Intertidal includes the foreshore zone of a beach.	Cowardin et al. (1979)	Intertidal
Estuarine emergent marsh	Estuarine emergent marsh includes intertidal saline emergent marsh (that is, located above extreme low water springs and below extreme high water springs tide levels) and supratidal brackish emergent marsh. Vegetation cover should be generally 30 percent or greater cover by erect, rooted, herbaceous hydrophytes. Note, supratidal emergent vegetation that is located on the backslopes of dunes will be classified as meadow.	Cowardin et al. (1979)	Estuarine vegetated wetland
Mangrove	Mangrove habitat includes areas with black mangrove (*Avicennia germinans*). Mangrove vegetation coverage should generally be greater than 30 percent.	--	Estuarine vegetated wetland
Bare land	Bare land includes bare or sparsely vegetated areas that are often located above typical storm water levels and are associated with unvegetated spoil or inland ridges. Vegetation cover should generally be less than 30 percent.	Modified from Fearnley et al. (2009)	Bare land
Grassland	Grassland includes upland areas covered by herbaceous vegetation often located above typical storm water levels and associated with inland spoil banks with herbaceous vegetation, freshwater emergent marsh, and upland areas along the mainland in the BICM regions along the Chenier Plain geomorphic zone.	Modified from Homer et al. (2015)	Barrier vegetation
Scrub/shrub	Scrub/shrub includes areas where woody vegetation height is greater than about 0.5 meter, but less than 6 meters. Woody vegetation coverage should generally be greater than 30 percent.	Cowardin et al. (1979)	Barrier vegetation
Forest	Forest includes areas where woody vegetation height is greater than 6 meters. Woody vegetation coverage should generally be greater than 30 percent.	Cowardin et al. (1979)	Barrier vegetation
Shoreline protection	Shoreline protection includes any material used to protect shorelines against erosion (for example, breakwater, groins, and jetties).	Fearnley et al. (2009)	Rip-rap
Developed	Developed includes areas dominated by constructed materials (that is, transportation infrastructure and residential and commercial areas) and open developed areas.	Modified from Homer et al. (2015)	Structure
Water	Water includes areas of open water with vegetation cover generally less than 30 percent.	Modified from Cowardin et al. (1979)	Water

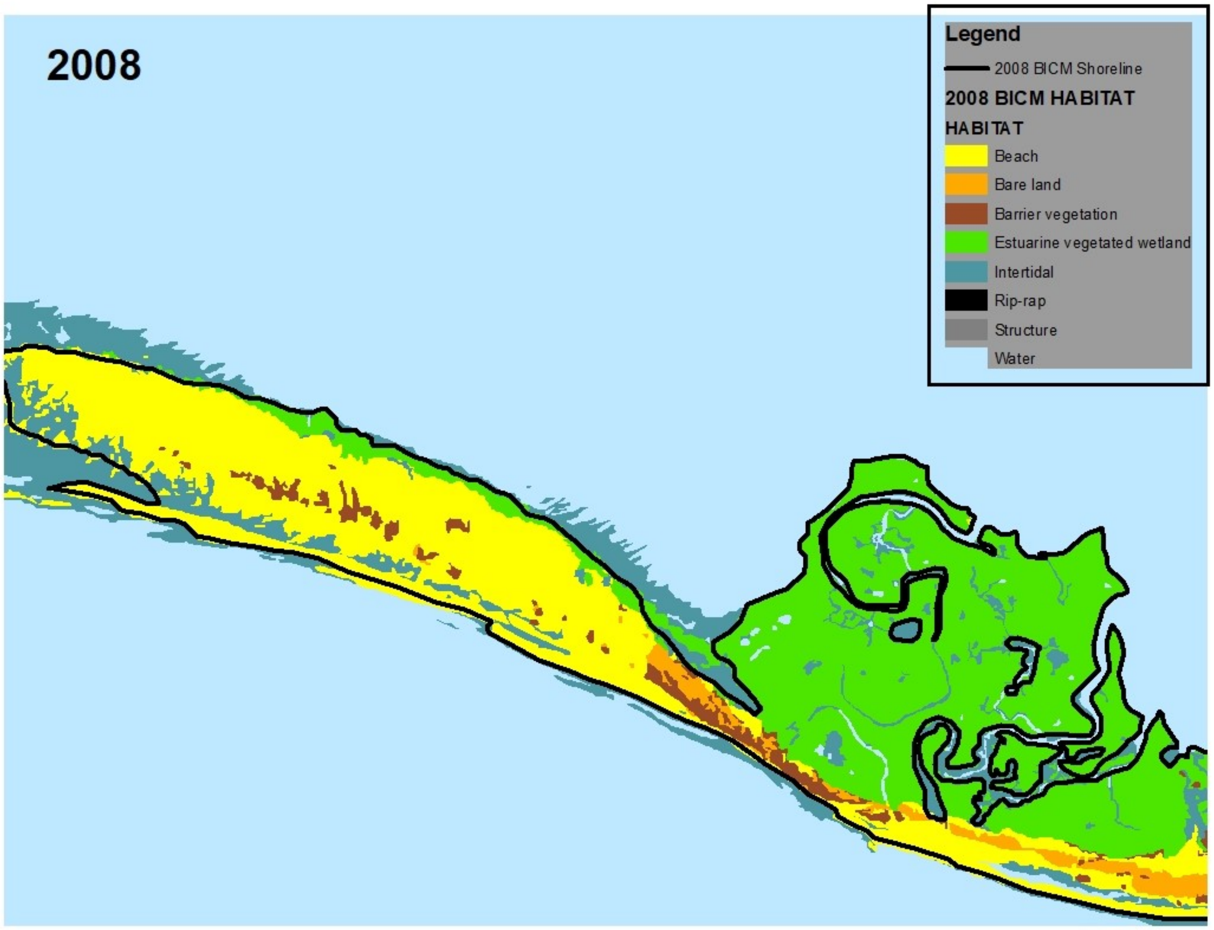

Figure 4-2. Example of the potential for land area derived from shoreline datasets to differ from that derived from habitat datasets. Note how finer scale habitat data are not perfectly delineated by the shoreline data within emergent marsh zones which can slightly skew the area classified as land by capturing additional intertidal areas.

Results and Discussion

Whiskey Island land area data were available for 15 different time periods between 1978 and 2016. The period between 1978 and 1998 is examined as the pre-construction period, while the period between 1998 and 2016 represents the post-construction periods in which the TE-27 (1999) and TE-50 (2010) projects were impacting the island system. A time series plot of land areas was created and a linear regression line was fit to the data points during both prior to (1998), as well as post restoration periods (figure 4-3).

From 1978 to 1998, the land area of Whiskey Island decreased from 904 acres to 411 acres, which averages out to a loss of approximately 25 acres per year. At that rate of land loss, the remaining 411 acres of Whiskey Island at that time would have become subaqueous by 2014. McBride et al. (1989) used a more extensive dataset dating back to the 1880s and projected Whiskey Island's disappearance to occur in 2007 without restorative measures. The prediction of island disappearance according to our results compared with that of McBride et al. (1989) is similar, within 7 years, and that disparity is likely a result of the longer time horizon examined to produce the latter prediction coupled with the fact that our analysis utilized more recently developed datasets.

The trend in land area change during the post restoration period (1998 - 2016) differed dramatically from that observed in the pre-restoration period (1978-1998). The post-restoration period reflected not only a reduction in land loss but a reversal in loss rates such that during the 1998 to 2016 period, the island experienced an average gain of just over 14 acres per year. The effects of both the TE-27 and TE-50 projects, which contributed 2.9 and 2.5 million cubic yards of fill material to the island system, respectively, are evident in figure 4-1. Immediately prior to TE-27 project construction, Whiskey Island had been reduced in land area to 411 acres in 1998. Two land areas were calculated in 2002 following project construction, one from Penland et al. (2003) using shoreline datasets and one produced from BICM habitat data. Penland et al. (2003) indicated a 56% land area increase of 643 acres while the BICM habitat data indicated a more modest increase of 29% and 530 acres. The disparity in the two land area calculations is due to Hurricanes Isidore and Lili in the fall of 2002. Hurricane Isidore was a slow moving storm that passed approximately 30 miles to the east of Whiskey Island in the last week of September (NOAA 2002a). Hurricane Lili passed approximately 90 miles to the south and west of the island, bringing additional storm surge only one week later (NOAA 2002b). These observations would indicate that the 2002 hurricane season caused ~113 acres to be lost from Whiskey Island, or a nearly 18% reduction in subaerial land.

Figure 4-3. Land area changes from 1978 through 2016 at Whiskey Island, Isles Dernieres, Terrebonne Parrish, LA.

Additional hurricanes to affect the Gulf of Mexico after the 2002 season were Hurricanes Ivan (2004), Katrina & Rita (2005), as well as Gustav and Ike (2008). Hurricane Gustav affected Whiskey Island most directly, passing within 20 miles of the island in September of 2008 (NOAA 2009). By 2008, the land area of Whiskey Island had decreased to 433 acres, only 22 acres larger than it was in 1998 before the construction of TE-27. This highlights not only the importance of tropical cyclones on barrier island systems, but also how important barrier island restoration is to ensuring that the islands remain functional as storm barriers to populated inland areas. Regarding goals and objectives of the TE-27 project related to island stability, the additional sediment added to the system by this project likely sustained it through the 2002 hurricane season and ensured its continued existence in the post-construction period between

1998 and 2008. The 2002 post-storms land area estimate remained 29% above the pre-restoration estimate, and even by 2008 following several hurricanes, Whiskey Island was 22 acres larger than it had been prior to TE-27 project completion. Considering that the 433 acres estimated in 2008 is only 5% larger than the pre-restoration acreage, it is questionable whether or not TE-27 would have lasted its 20 year project life.

The TE-50 project was completed in 2010, two years after Hurricane Gustav impacted the island. In 2012, land area was calculated at 803 acres, the highest calculation of subaerial land at any point in the post-restoration period and second only to the earliest land area examined in this analysis, which occurred at the beginning of the analysis period in 1978. This represents an 85% increase in land area, even without accounting for potential land loss that is likely to have occurred on some scale between project completion in 2010 and the 2012 land area calculation (figure 4-3). Hurricane Isaac made landfall in southeast Louisiana less than 50 miles to the east of Whiskey Island in late August of 2012. While Whiskey Island was spared the worst of Isaac's effects due to it being situated to the west of the storm's center, the slow moving cyclone had a very large wind field and associated storm surge. The nearest measurement of Isaac's storm surge was taken in Grand Isle, LA and measured 4.3 feet above normal tide levels while another reading taken farther away and to the west of Whiskey Island near the Atchafalaya delta was 2.2 feet above normal tide levels (NOAA 2013). Tropical Storm Karen was the only other tropical cyclone to affect Whiskey Island through the end of the analysis period in 2016. From 2012 to 2015, the land area of the island was reduced from 803 to 729 acres, a 10% reduction. Another 9% of subaerial land was calculated to have been lost by the following year in 2016, which represents a cumulative loss of 17% between 2012 and 2016. Still, the subaerial land portion of Whiskey Island was 38% larger in 2016 than it was in 1998 before either project had been constructed.

The number of tropical cyclones observed by NOAA to have passed within 150 nautical miles of the center of the Isles Dernieres was 9.4 per decade during the post-construction period (1999-2016). The long term (1842-2016) average number of tropical cyclones in the same vicinity is 8.2 per decade, while the pre-construction period (1978-1998) experienced only 6.7 storms per decade. Given that the pre-construction period was characterized by a below average number of storms and that the post-construction period experienced an above average number of storms, the difference in land loss trends between these two periods is significant. Whiskey Island was losing on average almost 25 acres each year during a period of below average tropical activity in the 20 years prior to 1998, whereas land area increased on average of 14.5 acres per year in the 20 years that followed. As earlier stated regarding the goals and objectives of each project related to island stability as well as creating island, both TE-27 and TE-50 were successful in this regard as measured by their contributions to the subaerial land area of Whiskey Island.

Chapter 5 - Restoration Impacts on Shoreline Position, Island Length, and Island Width at Whiskey Island due to the Whiskey Island Restoration (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50) projects

Introduction

Following the Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) Program's implementation of the TE-27 (1999) and TE-50 (2010) projects at Whiskey Island, a combination of digitized shorelines and habitat mapping datasets were compiled from various sources to determine shoreline erosions rates as well as island lengths and widths. This assessment examines these components to help evaluate some common goals and objectives between the two projects, including aspects of island "stabilization" as well as increasing island width and maintaining the island/ extending its life. By comparing dimensional changes and changes in shoreline erosion rates prior to and following the construction of each project, cumulative effects were also examined relative to the projected disappearance of the island by 2014 as predicted in Chapter 4.

Methods

Shoreline Erosion

The Coastal Protection and Restoration Authority's (CPRA) Barrier Island Comprehensive Monitoring Program (BICM) has compiled a series of nine shorelines for the Louisiana coast through adjustment and revision of existing datasets, as well as the digitization of new time periods. The shorelines compiled by BICM include: 1) 1880s, 2) 1930s, 3) 1950s, 4) 1998, 5) 2004, 6) 2005, 7) 2008, 8) 2012, and 9) 2015. The 1880s, 1930s, and 1950s US Coast & Geodetic Survey (USC&GS) topographic maps (T-sheets) encompassed multiple years. Previously available datasets for the 1930s and 1950s period were limited in some regions and as such, data gaps were filled by the BICM Program with US Geological Survey (USGS) topographic quadrangle maps or aerial photography as deemed appropriate. The time range for orthorectified imagery used to develop shorelines between 1998 and 2015 was much narrower than map data and required no gaps to be filled with alternate sources. For detailed information on data sources and compilation procedures of the BICM shorelines see Byrnes et al. (2018).

After shoreline datasets were compiled and attributed, they were brought into ESRI® ArcMap™ where the USGS Digital Shoreline Analysis System (DSAS version 5) was used to quantify changes in shoreline position (Himmelstoss et al. 2018). The analysis was performed by establishing a baseline south of the island and shore-perpendicular transects which were set at 50 meter (164 feet) longshore intervals (figure 5-2). Rates of change were determined by subtracting the shoreline positions from the previously established baseline for distinct time periods and then dividing by the exact acquisition period for each shoreline location. For detailed information on the sources and methods used for these analyses, see Byrnes et al. 2018. Figure 5-1 represents Whiskey Island shorelines from three different time periods as an example.

This analysis used the shorelines, analysis transects and baseline established by the BICM program to help assess project impacts on the shoreline change rates at Whiskey Island before and after restoration. The time periods chosen for analysis were: 1) 1950s to 1998, 2) 1998 to 2015, 3) 1998 to 2008, 4) 2008 to 2012, and 5) 2008 to 2015. These time periods represent both a significant period prior to restoration (1950s to 1998), as well as the seventeen years after restoration efforts began (1998 to 2015). The other three periods are examined in an attempt to parse out the post-restoration impacts of TE-27 and TE-50, completed in 1999 and 2010, respectively. These time periods were also delineated to look at any possible changes in erosion rates as various natural processes impacted the island over the life of the projects.

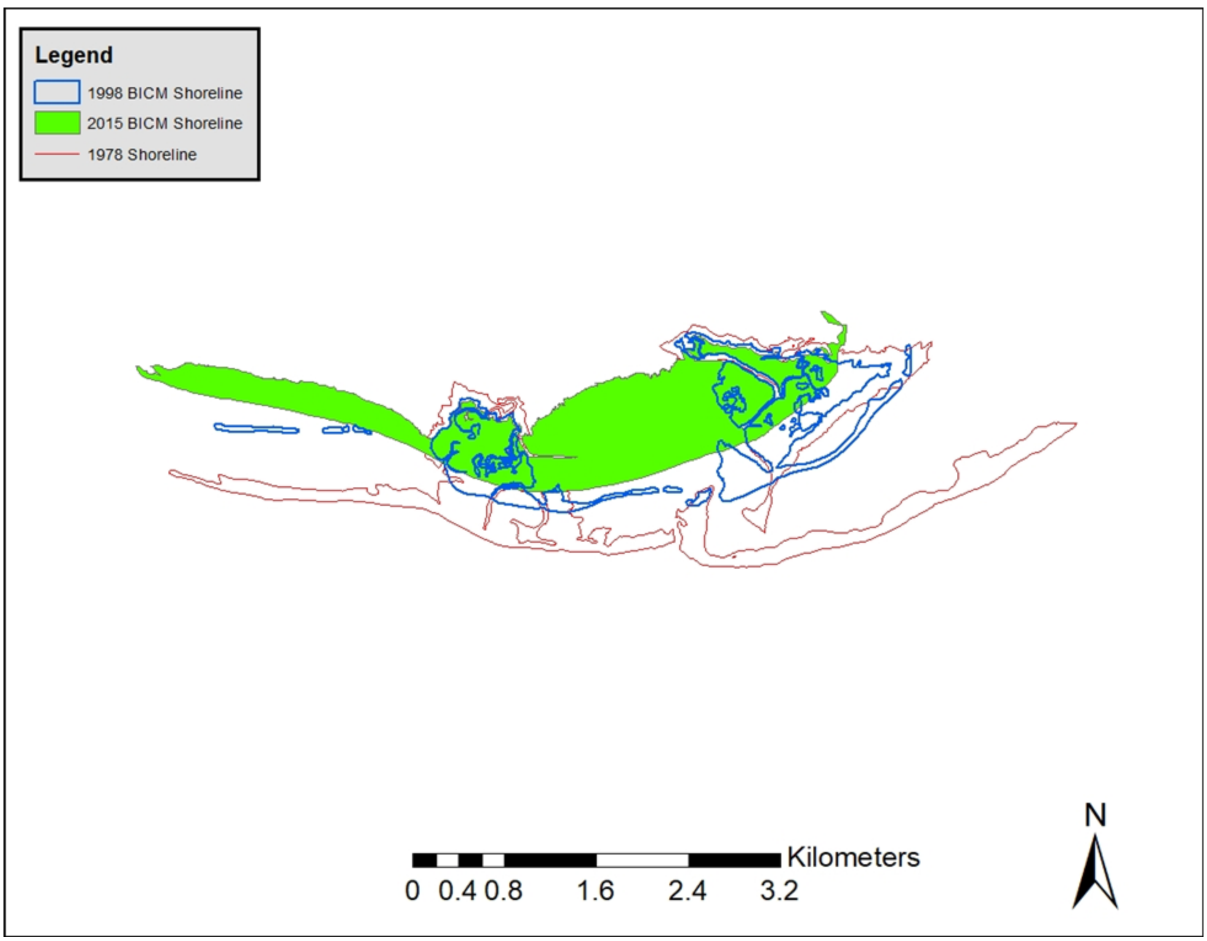

Figure 5-1. Whiskey Island shorelines represented in three different years. The shorelines were developed from digitization or habitat classification datasets available from various sources.

Island Length

In order to determine how the length of Whiskey Island changed over time as well as to assess potential project effects of this metric prior to and following restoration, 10 datasets were examined. These include 6 of the aforementioned BICM shoreline datasets: 1998, 2004, 2005, 2008, 2012, and 2015. An additional shoreline dataset was available from USGS for 1978 (Morton et al. 2004) and was utilized as an initial pre-restoration data point to help characterize the 20-year period prior to the first restoration in 1999. BICM produces habitat classification datasets as described in Fearnley et al. (2009) and Enwright et al. (2020). This analysis used 3 of these habitat datasets in order to determine the land area and calculate the island length for three additional years: 1996, 2002, and 2016. This was achieved by aggregating classes to land and water as was done in the land area change analysis in Chapter 4.

Island lengths were determined using the same method for both habitat classification datasets as well as digitized shoreline data. Island length was determined from a compilation of all island fragments during each time period. Each fragments length was defined from the first BICM shore-perpendicular measurement transects noted above until the last transect that intersected the digitized line and the total number of transects was multiplied by the 50m distance between them (figure 5-2).

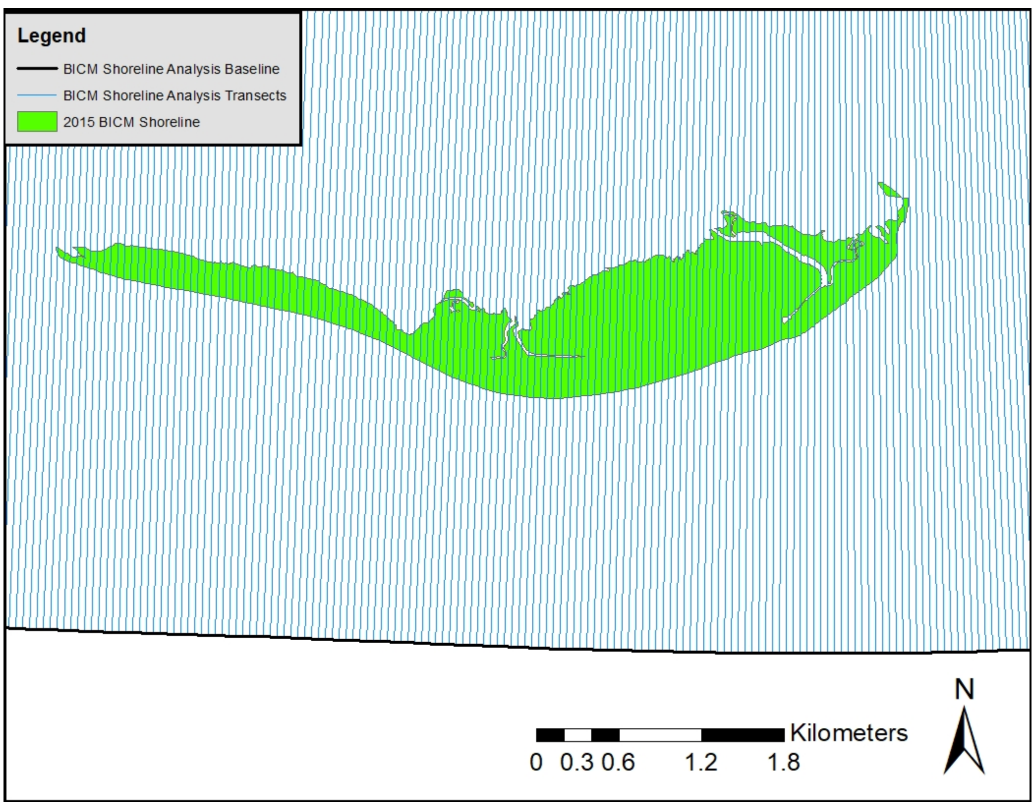

Figure 5-2. Example of BICM shoreline measurement transects used to define the length of Whiskey Island in 2015, Isles Derniers, Terrebonne Parrish, LA.

The use of the BICM shoreline change baselines and shore-perpendicular transects provided an unbiased determination of the beginning and end of each island fragment and was felt to be more representative of the island length as opposed to a direct computation of shoreline length, which could be affected by an area of deeply convoluted shoreline. Once the lengths had been compiled for all 10 periods, a time series plot of island length was created and linear regression lines were fit to the data points before and after the initial restoration project was completed in 1999.

Island Width

The BICM program created island polygons for periods after 1978 using the digitized shoreline datasets which allowed for the calculation of island widths to be determined using the previously described BICM shore-perpendicular measurement transects. Island areas available were 1978, 1998, 2004, 2005, 2008, 2012, and 2015. The transects, at 50-m (164-ft) longshore intervals, were clipped to the shoreline polygons (figure 5-3). Because the BICM datasets are grid based projections, the starting and ending coordinates of the clipped lines were used to determine the line distance geometrically. This allowed the maximum distance to be calculated and it includes ponds, canals, and small bays to be considered part of the island's width. Once maximum distance was calculated for each transect, they were averaged to determine the island width for each period.

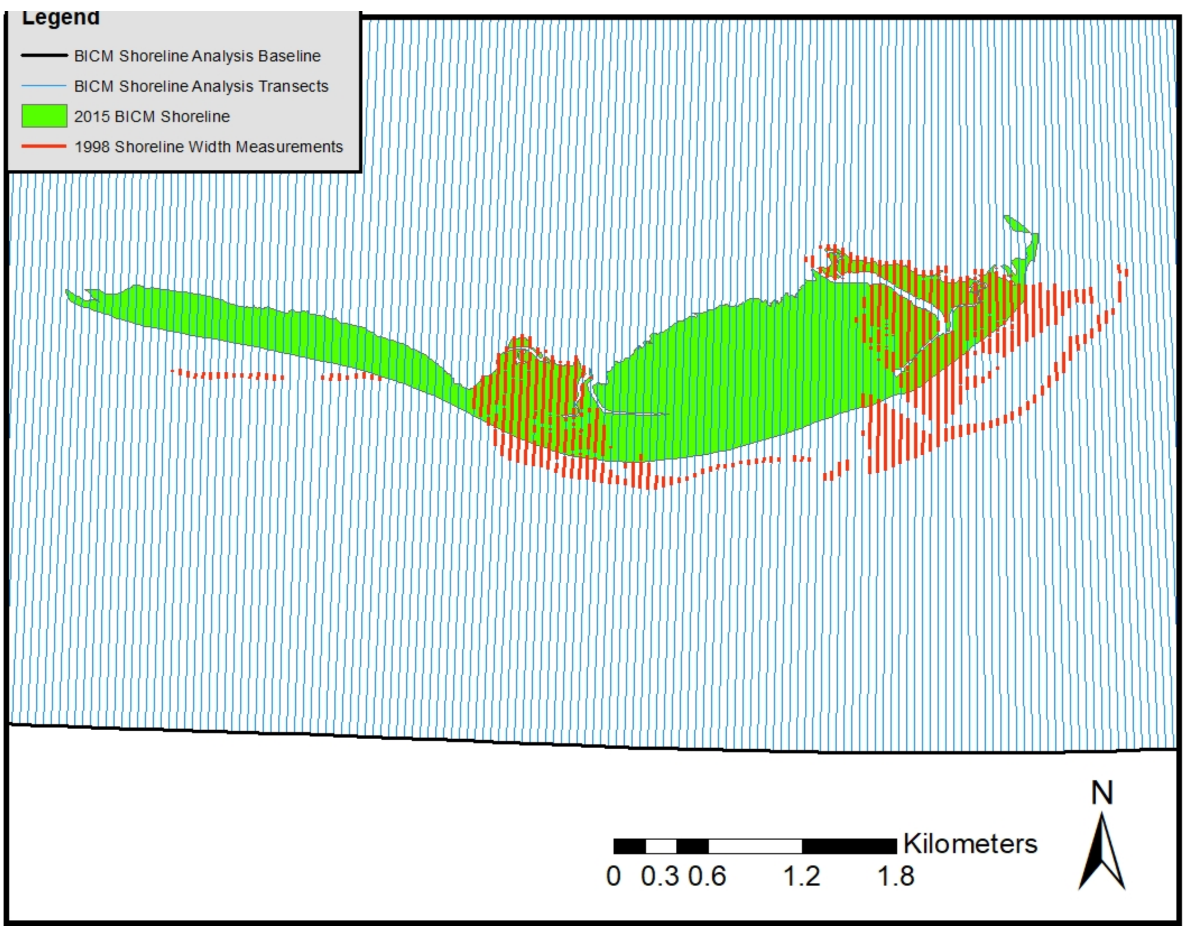

Figure 5-3. Example showing the 1998 verses 2015 BICM shorelines of Whiskey Island, as well as the BICM Baseline and measurement transects. Note the measurement transects clipped to the island outline and used to calculate the average island width in 1998.

Additionally, the 2016 BICM habitat dataset was also used to determine island width. Using the dissolve tool in ESRI® ArcMap™, the individual habitat classification polygons of this datasets were merged into single polygons by habitat class. The polygons classified as water and intertidal were then removed and the remaining habitat polygons were dissolved to produce a single polygon classified as land. This land polygon represents a shoreline as described in the land area change analysis (Chapter 4). This polygon was used to determine island width in the same manner as the 7 other BICM shoreline polygons described above. A time series plot of average island width was created and linear regression lines were fit to the data points for various time periods.

Results and Discussion

Shoreline Erosion

Shoreline recession at Whiskey Island in the time period prior to restoration (1950s-1998) as reported by Byrnes et al (2018) averaged 63.4 ft/yr, the highest rate for any period examined at Whiskey Island (figure 5-4). The post restoration time period from 1998 through 2015 exhibited a reduced shoreline recession rate of 46.8 ft/yr. While this rate is still fairly high, it is worth noting that it is measured during a period of above average tropical storm activity in the vicinity of the north coast of the Gulf of Mexico (NOAA 2019). Three additional time periods were examined after the initial restoration effort of TE-27 was completed in 1999. These were 1998-2008, 2008-2012, and 2008-2015. These periods were chosen based on data availability and to examine on a finer scale how changes in shoreline recession rates at Whiskey Island may have been impacted by the TE-50 project completed in 2010 as well as the various tropical cyclones which occurred during these periods.

The 1998-2008 time period exhibited shoreline recession at a rate of 61.1 ft/yr (table 5-1). Compared to the complete post-restoration time period (1998-2015) rate of 46.8 ft/yr, this is a ~31% increase in recession rates during the initial 10 years following TE-27 construction. Several storms that were particularly impactful to Whiskey Island during this period included Hurricanes Isidore and Lili in 2002, Ivan in 2004, Katrina and Rita in 2005, and Gustav and Ike in 2008. Hurricane Isidore was a slow moving storm that passed approximately 30 miles to the east of Whiskey Island in the last week of September (NOAA 2002a). Hurricane Lili passed approximately 90 miles to the south and west of the island, bringing significant additional storm surge only one week later (NOAA 2002b). As reported in Chapter 3 and 4, these storms significantly affected the island such that they contributed to a ~18% reduction in subaerial land in 2002.

In examining the 2008-2012 time period, the shoreline recession rate was calculated at 17.9 ft/yr. Hurricane Gustav is accounted for in this period, having passed within 20 miles of Whiskey Island in September of 2008 (NOAA 2009). Hurricane Isaac again affected the island in August of 2012 when it passed within 50 miles to the east of the island. Isaac's storm surge was measured to be over 4 feet above normal tide levels as close to Whiskey Island as Grand Isle, LA, and to be over 2 feet above normal tide levels as far east as the Atchafalaya delta (NOAA 2013). The effects of these significant storms on shoreline recession rates during this period were likely mitigated by construction of TE-50 in 2010 and the additional sediment which it added to the system. The final time period we examined extended the previous one by an additional three years to include the 2015 shoreline. During the 2008-2015 time period, Whiskey Island experienced no additional storms than it had in the 2008-2012 time period. The shoreline recession rate during this period was calculated at 17.9 ft/yr. While this is an increase from the abbreviated 2008-2012 period, it is a 49% decrease in shoreline recession rates calculated for the 1998-2008 period, which spans a more comparable length of time during which both restoration and storm events were occurring.

Table 5-1. Shoreline position changes during various time periods at Whiskey Island, Isles Dernieres, Terrebonne Parish, LA.

TIME PERIOD	CHANGE RATE (FT/YR)	STANDARD DEVIATION (FT)
1950S TO 1998 (PRE)	-63.4	23.1
1998 TO 2015 (POST)	-46.8	32.0
1998 TO 2008	-61.1	47.1
2008 TO 2012	-17.9	41.2
2008 TO 2015	-30.8	39.9

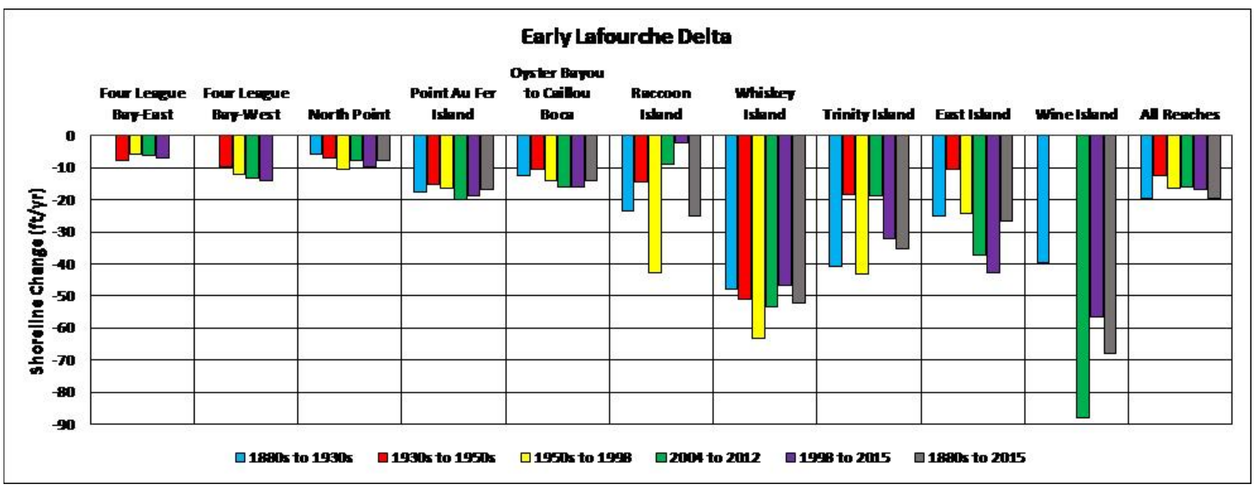

Figure 5-4. BICM shoreline change for the Early Lafourche Delta (from Byrnes et al. 2018).

Island Length

Whiskey Island exhibited an overall reduction in length during the pre-restoration period (figure 5-5). In 1978, 20 years prior to restoration, the length of Whiskey Island totaled approximately 26,411 feet and by 1998 had shortened to approximately 20,341 feet, equating to an average shortening rate of 303.5 ft/yr. Interestingly, this rate is identical to that of the Trinity/East system of the Isles Dernieres just to the east of Whiskey Island reported for this same period (Sylvest et al. 2020). Following the completion of TE-27 in 1999, the island exhibited an initial increase in length such that between 1998 and 2002 there was an additional 1,640 feet even after Hurricanes Lili and Isidore had severely impacted Whiskey Island in 2002 as discussed in Chapter 4 of this report. At that point in 2002, the island was 21,981 feet long, having experienced a modest increase from the 1998 length of 20,341 feet due to the combined and opposing effects of both a restoration event and significant storm impacts. Five additional hurricanes between 2004 and 2008 variously affected the length of the island due to their respective tracks, strength and proximity, along with various winter storms and other system drivers. Island length likewise varied during this period, but had ultimately shortened to 16,732 feet by 2008. In 2010 TE-50 was completed, and by 2012, the length of Whiskey Island had increased to 19,521 feet even after being affected by Hurricane Isaac that same year. The island lengthened again in 2015 to 20,669 feet, and by the end of the analysis period in 2016 it was 21,817 feet. The overall trend in island length in the post-restoration period was positive, and between 1998 and 2016 the island exhibited increases in length at an average of 82 ft/yr.

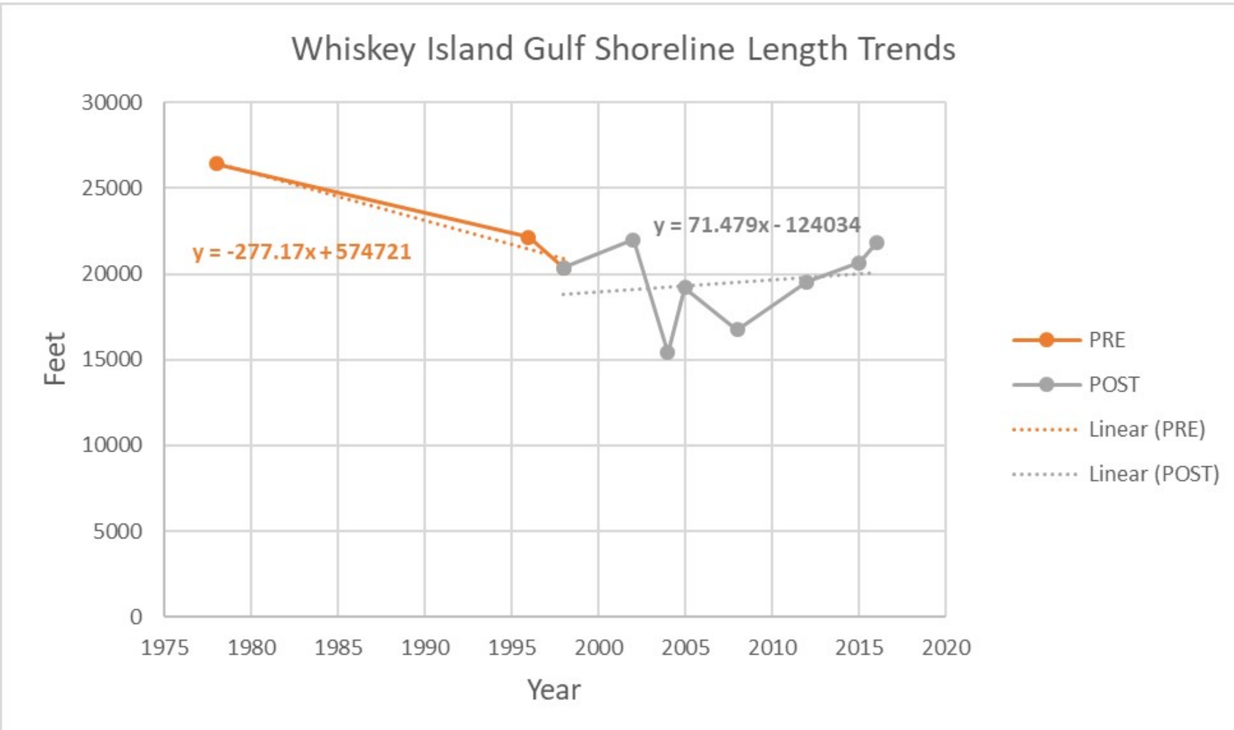

Figure 5-5. Trends in average island length at Whiskey Island from 1978 to 2016.

Island Width

Island widths were examined for the same years that the lengths had been, and the overall trends observed in width in the pre- and post-restoration time periods were generally the same as those observed in length; the pre-restoration period exhibited narrowing of the island at a rate of approximately 16.5 ft/yr while the post-restoration period exhibited widening at a rate of approximately 22 ft/yr (figure 5-6). Following TE-27 construction, the average width of the island increased dramatically from 1,037 feet in 1998 to 1,722 feet in 2002, a difference of 685 feet which translates to a widening rate of approximately 171 ft/yr in this 4-year period immediately following that project. Examined on a longer time horizon, the widening rate becomes 14.7 ft/yr between 1998 and 2008. TE-50 was completed in 2010 and was responsible for the widening observed in figure 5-6 between 2008 and 2012 when the average width increased from 1,184 feet to 1,841 feet, which would translate to a rate of approximately 164 ft/yr. Once again, soon after the restoration event occurred, there was a significant storm to affect the island in Hurricane Isaac, which occurred in 2012. As expected, as a result of Isaac and other system drivers in the years that followed, the island began to narrow and by 2016, the average width was 1,437 feet. Between 2008 and 2016, however, the island still exhibited an overall increase in average width of 253 feet, at a rate which translates to 31.6 ft/yr.

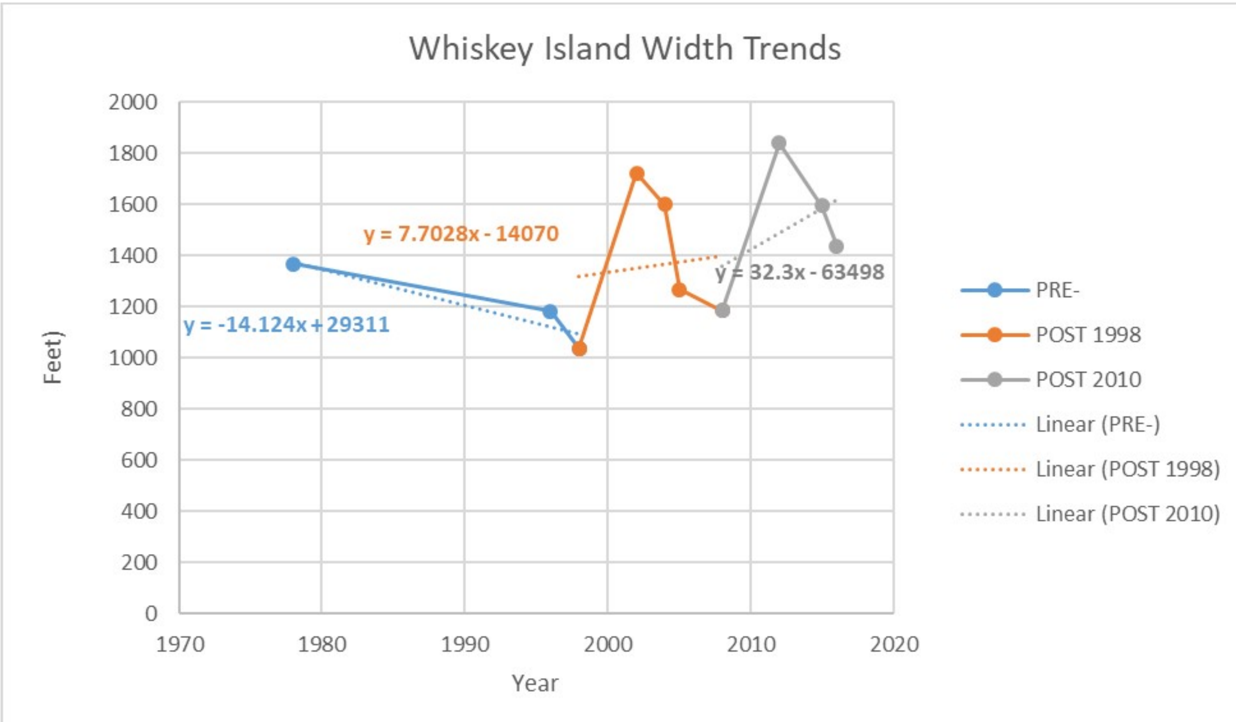

Figure 5-6. Trends in average island width at Whiskey Island from 1978 to 2016. The cumulative effect of the projects on the width of the island is evident when comparing the trend lines before and after the 1998 restoration effort as the narrowing was reversed. The 2010 restoration effort is especially prominent due to several active storm seasons immediately preceding it, compounding other island stressors.

All metrics that were examined revealed the positive impacts that the two restoration events had on the island in the various post-restoration time periods evaluated in this analysis. The common goals and objectives of the projects related to stabilization, increased width and prolonged longevity each appear satisfied following the construction of each of the projects individually, and especially when their cumulative effects are considered. Trends in length, width, as well as shoreline position were each favorable, although the processes which act on barrier islands in general were not altered by either project, and the initial benefits of the respective projects eventually succumb to natural coastal processes. Still, positive trends in erosion rates as well as island length and width were evident from these analyses, and project contributions to stabilizing Whiskey Island and increasing its longevity are thusly considered to have been achieved.

Chapter 6 - Restoration Impacts on Elevation and Sediment Volume Changes at Whiskey Island due to the Whiskey Island Restoration (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50) projects

Introduction

To assess project changes to the Whiskey Island Restoration (TE-27) project, the Whiskey Island Back Barrier Marsh Creation (TE-50) project, and Whiskey Island system (area), nine (9) elevation data sets were analyzed (table 6-1). Temporal modifications to island heights and volumetric changes in sedimentation were assessed within a portion of the TE-27 and TE-50 project areas. These areas will be referred to as the analysis areas in this report. For TE-27 there is only one analysis area. Conversely, TE-50 has two analysis areas – the marsh creation and dune analysis areas. Within the TE-50 marsh creation area, there are two nested analysis areas - a tidal creek and pond area and a creek and pond reference area. Additionally, elevation and volume changes will be evaluated for the entire Whiskey Island system to determine elevation trends within the island system not just the TE-27 and TE-50 project areas. The TE-27 project has goals related to increasing the elevation and width of Whiskey Island by using dredged sediments. Similar to TE-27, the TE-50 project also has a goal to increase the width of the island. TE-50 has additional goals to create intertidal marsh, intertidal creeks, and intertidal ponds. For this assessment, acreages for the five (5) WVA elevation classes were determined along with the overall average elevations, and the sediment volume changes for the available surveys.

Methods

In order to assess individual project impacts as well as the overall impact to Whiskey Island, elevation data was analyzed to quantify heights, classify those heights into predefined Wetland Value Assessment (WVA) elevation classes, and calculate the area of each class. The analysis also determined the average/overall height and volumetric changes within the analysis areas. The analysis area is a limited portion of the project area where elevation data was collected during every survey (time period). Upon completion of individual projects, each project had sediment deposited within a more limited construction footprint. These footprints were surveyed at various spatial coverages and common analysis areas were developed that covered as much of the construction footprint as possible. The analysis area represents as much of the initial sediment deposition as possible but only indicates trends in sediment and elevation changes within the initial construction footprint. For the TE-27 project, the analysis area represents 68% of the project area and the TE-50 analysis area represents 22% of the project area. The low percentage for TE-50 is a result of the large project area polygon outside of the marsh and dune analysis areas.

Topographic and bathymetric surveys were employed to document elevation. Surveys utilized for this report were collected pre-construction for engineering and design, upon completion of a project (as-built), and at various times post-construction through various funding sources (Table 6-1). Depending on the funding source and purpose, each survey had a slightly different spatial coverage. Project specific surveys typically only reoccupy the constructed footprint whereas BICM surveys are more regional in scope and cover entire island systems including inlets, bays and shorefaces. The bathymetric portion of BICM surveys have less resolution (1,500 ft transect spacing) than more detailed project funded surveys (250–500 ft transect spacing), but BICM bathymetric surveys have considerably more spatial coverage. BICM topographic LiDAR collects elevation data with centimeter spacing and provides higher resolution than transect surveys. The combination of BICM topographic LiDAR and BICM bathymetric surveys provide a detailed analysis of island systems and detects geomorphic modifications in these systems.

When comparing older data sets to newer data sets, transformations between various datums used at the time of each survey were needed in order to ensure datasets were comparable. All data were adjusted to the Universal Transverse Mercator (UTM) North American Datum of 1983 (NAD83) coordinate system and the North American Vertical Datum of 1988 (NAVD88) in meters using Corpscon® software. Detailed information on the various surveys can be found in individual survey reports or project completion reports. Table 6-1 summarizes when surveys were conducted, the project(s) associated, the project phase, and the associated source for the data.

Table 6-1. Topography and bathymetry survey data acquisition dates, associated projects and time periods, method of data collection, and the funding source.

Survey Acquisition Date	Project(s)	Project Period	Data Type	Funding Source
October 1997	TE-27	Pre-construction	RTK cross-sectional	Project
September 1998	TE-27	As-Built	RTK cross-sectional	Project
March 2000	TE-27	Post-construction	LiDAR	Project
July 2006	TE-27	Post-construction	LiDAR & Bathymetry	BICM
April 2009	TE-50	Pre-Construction	RTK cross-sectional	Project
October 2009	TE-50	As-Built	RTK cross-sectional	Project
April 2010	TE-50	Post-construction	RTK cross-sectional	Project
February 2014	TE-50	Post-construction	LiDAR	Project
November 2015	TE-27 & TE-50	Post-construction	LiDAR & Bathymetry	BICM

The adjusted data were imported into ESRI®ArcMap™ software for surface interpolation. Triangulated irregular network (TIN) models were produced from the point data sets. Next, the TIN models were converted to raster grid models (3.3 ft^2 cell size), and the spatial distribution of elevations were mapped into five (5) elevation classes: 1) dune, which is any elevation >5.0 ft; 2) supratidal, consisting of elevations between 2.0 – 5.0 ft; 3) intertidal, consisting of elevations between 0 – 2 ft; 4) subtidal, consisting of elevations between -1.5 – 0 ft; and 5) non-WVA, consisting of elevations <-1.5 ft (Roy 2002). The grid models were clipped to the TE-27 and TE-50 analysis area polygons to estimate elevation and volume changes within each analysis area. One other polygon was produced to assess the greater spatial distributions of the combined BICM Light Detection and Ranging (LiDAR) and bathymetric surveys in 2006 and 2015 – a Whiskey Island polygon. The Whiskey Island polygon was utilized to evaluate elevation and volume changes to the whole island system (from pass to pass) due to the BICM surveys more extensive spatial coverage.

The 2006 BICM LiDAR and bathymetric surveys were joined to form a single continuous elevation model of this barrier island as described above, however, the 2015 BICM LiDAR and 2015 bathymetric data were joined by merging grid models to form a single continuous surface. The February 2015 LiDAR and the November 2015 bathymetric data were merged to form a single continuous elevation grid model, referred to as the November 2015 dataset, of Whiskey Island. The first step in this process was to create two separate grid models for topography and bathymetry using the methodology from the previous paragraph. Next, a hole was created in the bathymetric grid at the island position (location of the LiDAR grid) by creating a polygon that is slightly smaller than the LiDAR grid to allow the two grids to be blended seamlessly. This procedure was completed with the Mask Function of the Image Analysis Tool of ESRI®ArcMap™. Next, the grids were merged using the Mosaic to New Raster function of the Data Management Tools extension of ESRI®ArcMap™. This created a single grid with both the LiDAR and bathymetric data incorporated.

Elevation changes were calculated for TE-27 and TE-50 by subtracting the various combinations of grid models using the Minus Tool utility of the Spatial Analyst extension of ESRI® ArcMap™. Volume changes were calculated in cubic meters (m3) using the Cut/Fill Calculator function of the 3D Analyst extension of ArcMap™. Once calculated, volume changes were summarized in a tabular format (yd3 and %) to display project and area trends. In addition, the volume changes (yd3) and grid model mean elevations (ft) were graphically illustrated for each analysis area. Note, these elevation and volume calculations are valid only for the extent of analysis areas based on the availability of corresponding survey areas.

For the larger comprehensive BICM survey analysis area, an error estimate was applied to elevation and volume changes in order to remove volume changes based on survey and model uncertainty. When calculating elevation changes and corresponding volumes over large areas, minor differences in elevations can contribute to large volume changes. These changes are within the estimates of survey and model error and are therefore removed from change calculations. We reviewed the model and survey data and applied a 1.6 ft uncertainty estimate to all volume change calculations. This was similar to ACRE (2020) estimate of 1.97 ft using the same BICM data over a larger area and longer time period.

The 2008 Operations, Maintenance, and Monitoring reports for the TE-27 project analyzed and reported on the survey data collected in September 1997, December 1998, and March 2000 (Rodrigue et al. 2008). This report focuses on more recent data sets and the larger Whiskey Island system, particularly the period after addition of sediment from the TE-50 project in 2009. As noted above, the elevations presented in this report are representative of the NAVD88 Geoid12B model, whereas the previous reports used the NAVD88 Geoid99 model. Hence, there may be slight differences amongst heights and volumes presented here for the same time periods presented by Rodrigue et al. (2008).

Results and Discussion

Whiskey Island Restoration (TE-27) Project

Whiskey Island experienced considerable expansions in supratidal habitats once construction of the TE-27 project was completed in September 1998. Figure 6-1 spatially illustrates the growth of supratidal habitats and Table 6-2 quantifies the acreages of supratidal habitats constructed by the addition of sediments to the TE-27 analysis area. Approximately, 251.70 acres of supratidal and 2.19 acres of dune habitats (table 6-2) were created within the TE-27 analysis area by the deposition of 1,978,851 yd^3 of granular sediments (table 6-3). As can be seen in the 1997 (pre-construction) and 1998 (as-built) WVA elevation models, Whiskey Island was substantially elevated and widened by construction of the TE-27 project (figure 6-1). During and/or shortly after construction, the breach separating the island and the spit was infilled and a long, narrow eastern spit was geomorphically shaped through longshore transport processes.

For the initial post-construction period (Mar 2000), supratidal habitats slightly declined and intertidal habitats correspondingly expanded (figure 6-1 and table 6-2). Sediment volume decreased by -19% from September 1998 to March 2000 leaving 81% of the as-built volume remaining within the TE-27 analysis area (table 6-3). For this interval, small changes in elevation were documented throughout the analysis area. However, no large sediment volume losses occurred within the project footprint and the shorelines remained in place (figure 6-1). Moreover, this was a quiescent period with very little tropical storm activity along Louisiana's Gulf of Mexico shoreline.

In the second post-construction period (Jul 2006), elevations within the TE-27 analysis area sizably declined. Supratidal habitats were reduced by 139.27 acres, and very small increases were found in the intertidal and subtidal elevation classes while the non-WVA class formed and created 110.22 acres of habitat at elevations below -1.5 feet within the TE-27 analysis area (figure 6-1 and table 6-2). Sediment volume decreased by 125% from September 1998 to July 2006 creating a sediment volume deficit within the TE-27 analysis area (figure 6-1 and table 6-3). The total sediment volume loss in the analysis area from September 1998 to July 2006 was approximately

2,470,873 yd^3. The dominant causes of this substantial volume loss in the analysis area were eastern reach shoreline erosion induced during the passage of the 2002 and 2005 hurricane seasons and longshore transport (figure 6-1). Hurricanes Isidore and Lili (September 2002) reduced sediment volumes, altered shorelines, shortened the narrow eastern spit, and induced considerable spit overwash on Whiskey Island (Georgiou et al. 2005; West and Dearmond 2007; Morton and Barras 2010). In 2005 Hurricane Cindy (July), Hurricane Katrina (August), and Hurricane Rita (September) impacted Whiskey Island causing the eastern reaches to truncate westward and rotate towards the northwest (Barras 2006; Rodrigue et al. 2008; Fearnley et al. 2009; Martinez et al. 2009). Since construction through 2005, the TE-27 analysis area's eastern shorelines truncated and rotated approximately 1,000 ft primarily due to transgressions incurred during the 2005 hurricane season. Although only qualitative longshore transport evidence exists for the early years of the TE-27 project (breach infilling and spit formation), it is highly likely that this transport mechanism influenced the shoreline and volume changes that transpired because net longshore transport drifts westward on all the Isles Dernieres barriers (Peyronnin 1962; Ritchie and Penland 1988; Stone and Zhang 2001; Georgiou et al. 2005) while Whiskey Island is eroding along its eastern reaches.

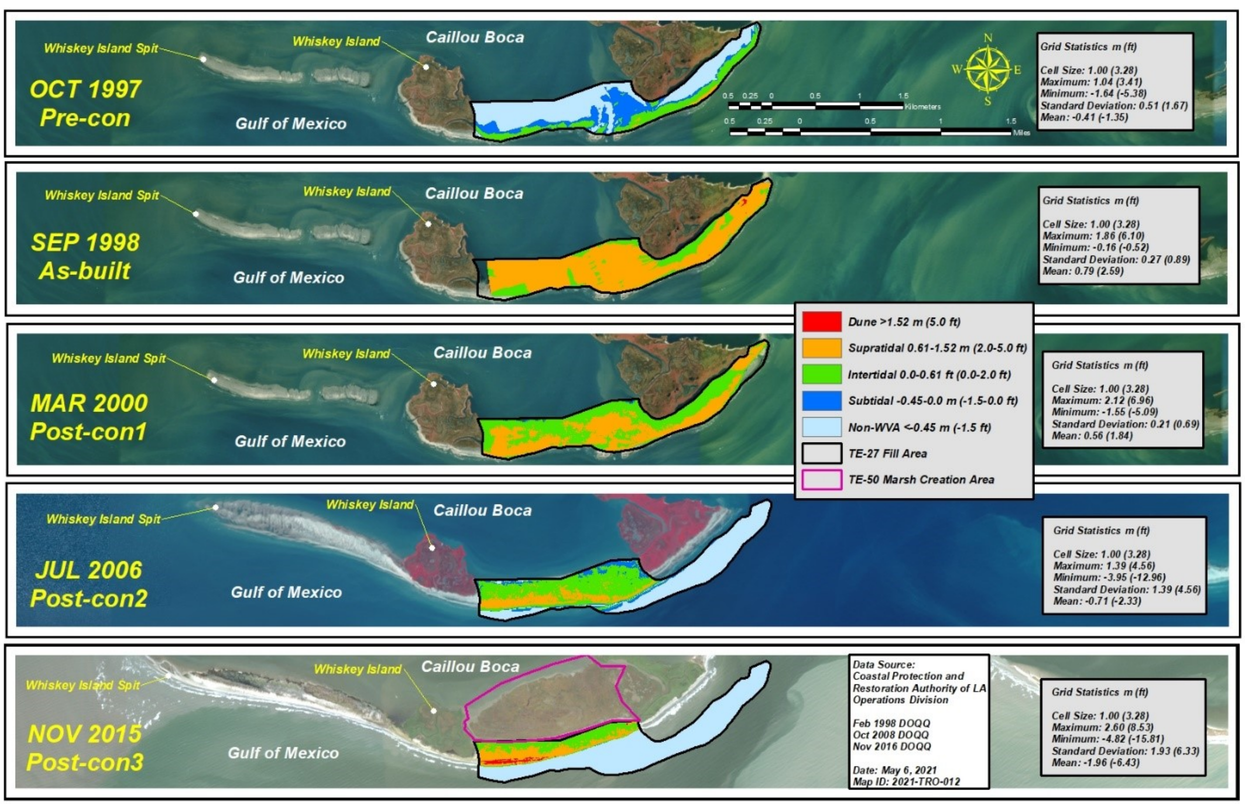

Figure 6-1. Elevation classification of the analysis area for the Whiskey Island Restoration (TE-27) project for five time periods from pre-construction (1998) to seventeen years post-construction (2015).

Table 6-2. Area within each WVA Elevation Classification for the TE-27and TE-50 projects between 1997 and 2015 along with the Whiskey Island system areas in 2006 and 2015. Note, the acreage totals column list the acreage within the clipped raster images. Figure 6-1 graphically displays the TE-27 analysis area while the Whiskey Island system analysis area is exhibited in figures 6-2 and 6-3. Figure 6-4 delineates the TE-50 marsh and dune analysis areas.

Project	Area Analyzed (Clipped)	Year	> 5.0 ft (Dune Acres)	2.0-5.0 ft (Supratidal Acres)	0.0-2.0 ft (Intertidal Acres)	-1.5-0.0 ft (Subtidal Acres)	< -1.5 ft (Non-WVA Acres)	Acreage Totals	Analysis Area Elevation (ft)
TE-27	Analysis Area	1997	0.00	8.85	76.94	68.69	136.27	**290.7**	-1.35
TE-27	Analysis Area	1998	2.19	251.70	36.54	0.25	0.00	**290.7**	2.59
TE-27	Analysis Area	2000	0.00	200.26	90.15	0.14	0.00	**290.5**	1.84
TE-27	Analysis Area	2006	0.00	60.99	97.67	21.91	110.22	**290.8**	-2.33
TE-27	Analysis Area	2015	7.78	46.12	36.61	0.01	200.25	**290.8**	-6.43
TE-50	Marsh (Pre)	2009	0.00	0.00	0.00	72.57	233.32	**305.9**	-2.69
TE-50	Marsh (As)	2009	0.35	305.23	0.35	0.00	0.00	**305.9**	2.45
TE-50	Marsh	2010	0.00	35.25	270.51	0.00	0.00	**305.8**	1.30
TE-50	Marsh	2014	0.00	27.63	277.96	0.29	0.00	**305.9**	0.82
TE-50	Marsh	2015	0.00	12.31	246.29	7.22	40.06	**305.9**	0.39
TE-50	Dune (Pre)	2009	1.47	55.05	20.34	0.01	0.00	**76.9**	2.40
TE-50	Dune (As)	2009	47.42	29.45	0.01	0.00	0.00	**76.9**	4.77
TE-50	Dune	2015	8.75	16.56	3.94	0.46	46.91	**76.6**	-3.80
Whiskey Island	WI System Analysis Area	2006	0.00	88.33	469.93	163.94	12,383.52	**13,105.7**	-9.06
Whiskey Island	WI System Analysis Area	2015	9.18	256.75	533.10	71.44	12,233.99	**13,104.5**	-8.10

Table 6-3. Pre, as-built, and post-construction sediment volume changes in the TE-27 fill area over time. Volume changes are recorded in yd³ (cubic yards), percent removed (%), and percent remaining (%).

TE-27 Elevation Intervals	Project Timeline	Volume Change (yd3)	Percent Volume Removed (%) From Analysis Area	Percent Volume Remaining (%) in Analysis Area
1997-1998	*Pre-As-built*	1,978,851	-	-
1998-2000	*As-built-Post1*	-372,073	-19	81
1998-2006	*As-built-Post2*	-2,470,873	-125	0
1998-2015	*As-built-Post3*	-4,610,829	-233	0

For the third post-construction period (Nov 2015), elevations along the shoreline edge continued to convert to then non-WVA class. Approximately, 14.87 acres of supratidal habitat were converted to other habitat types. Dune habitats comprised 7.78 acres of the supratidal habitat conversion primarily due to cross-shore transport of sediments during storm events. Intertidal habitats declined by 61.06 acres, and the subtidal habitat became essentially nonexistent. The non-WVA class had the greatest habitat gain, 90.03 acres, and became the foremost habitat class in the TE-27 analysis area (figure 6-1 and table 6-2). Sediment volume declined by 4,610,829 yd^3 for Sep 1998 to Nov 2015 interval resulting in considerably more sediment losses than added during construction (in place as-built volume). This translates into a sizable sediment volume deficit in the analysis area (figure 6-1 and table 6-3). A portion of this large sediment volume loss was sustained due to Hurricanes Gustav (September) and Ike (September) in 2008. Hurricane Gustav passed within 10 mi of Whiskey Island and eroded the eastern reaches another 200 ft to the northwest continuing the northwest rotation of these reaches. Other sandy shorelines in the Terrebonne Basin have also reported extensive land loss as a result of these 2008 storms (Morton and Barras 2010; Rodrigue et al. 2011; Curole and Lee 2013; Curole et al. 2017; Sylvest et al. 2020). However, the 2008 storms are not the major cause of the substantial volume losses that occurred by 2016 because the eastern reaches transgressed an additional 800 ft since these hurricanes. Furthermore, segments of the eastern reaches of the TE-27 analysis area are in approximately -12.0 ft deep water and the shoreline transgressions extend to the western end of the analysis area leaving very little subaerial land within the project margins (figure 6-1). Therefore, the large TE-27 volume losses are a result of the large changes in elevation within the analysis area.

Whiskey Island System

Elevation and volume change analysis for the TE-27 project discussed in the preceding paragraphs details temporal and spatial changes within a limited analysis area. Outside of the analyzed area, the fate of granular sediments transported out of the box has a high degree of uncertainty because all that is known is that sediments have left the analysis area. Fortunately, the July 2006 and November 2015 BICM elevation surveys have expanded the analysis area to include the entire Whiskey Island system – the entire island (including the back-barrier areas and spits), the shoreface, the passes, and the bay behind the island (figure 6-2). The WVA classes show that dune, supratidal, and intertidal habitats all increased their acreages on Whiskey Island from 2006 to 2015. This increase in elevated classes is primarily due to the construction of the TE-50 project (marsh and dune) and longshore transport to the spit (figure 6-2 and table 6-2).

The expanded 2006-2015 BICM change model shows aggradation in the Whiskey Island system for this defined interval. Figure 6-3 delineates the trends in sediment transport surrounding Whiskey Island for the period from 2006-2015 and displays a sediment accruing trend. Although the general trend reveals sediment aggradation, Figure 6-3 also exhibits reaches with marked erosional activity. The most prominent of these erosional hot spots is the TE-27 analysis area. This reach is described in the prior analysis of the TE-27 analysis area and is illustrated with the dark red tone. Figure 6-3 also shows that the volume losses extended to the east and west of the analysis area. Other erosional hot spots include the bay shoreline of the island and Whiskey Pass. The shoreline transgressions on the bay side of the island were likely derived through winter storm activity (Boyd and Penland 1981; Dingler and Reiss 1990; Ritchie and Penland 1998; Georgiou et al. 2005). Whiskey Pass is widening to the west and migrating closer to the island. The westward drift of this pass is outlined in figure 6-3 and shows the pass encroaching very close to the island. Interestingly, the pass is aggrading along its eastern banks and a flood shoal is forming west of the pass and northeast of the island. The surficial sediments of the flood shoal are comprised of 80-90% fine sand deposits (figure 9-2). Moreover, no earlier expanded bathymetric surveys were available to document pass migration, only movement of the eastern reaches out of the TE-27 analysis area were available (shoreline and volume changes). Therefore, Whiskey Pass may have been migrating westward for a longer period than documented and be the primary mechanism forcing the shoreline erosion and volume changes along the eastern reaches. Besides the areas in

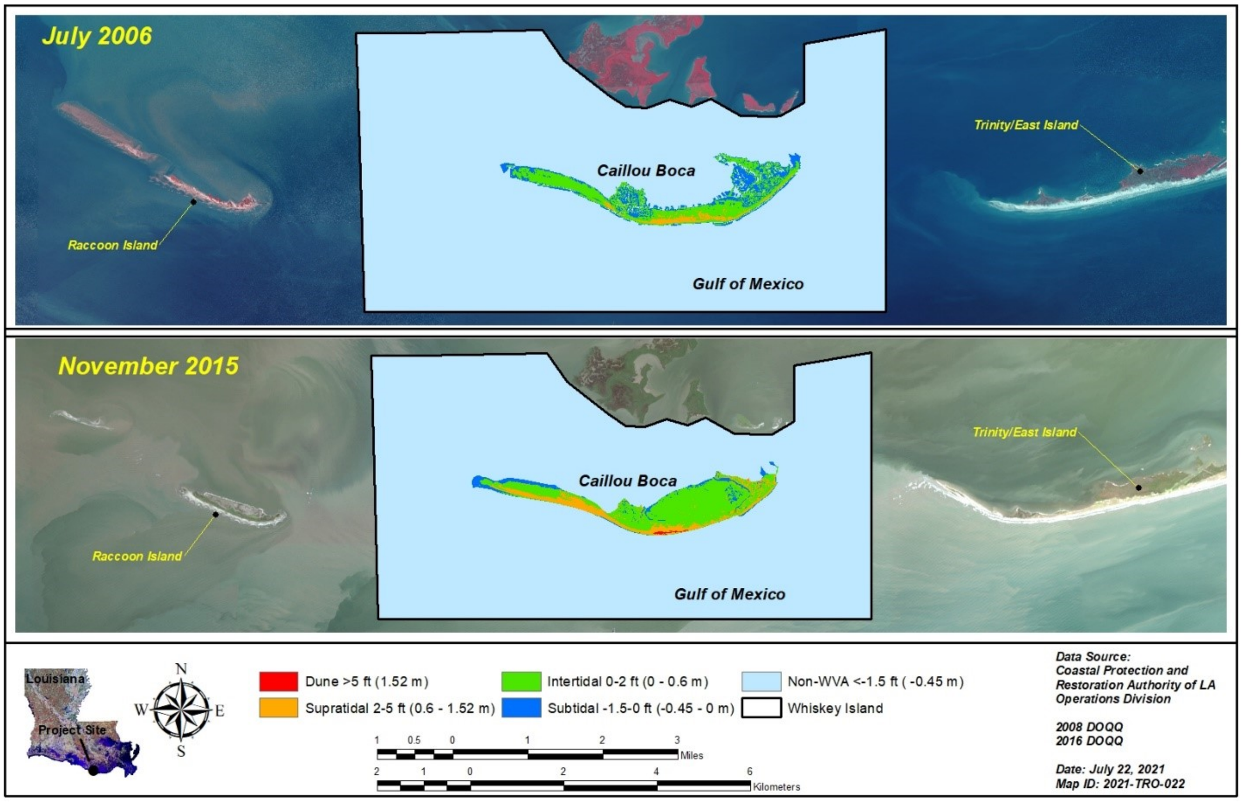

Figure 6-2. Elevation WVA classification of the Whiskey Island Restoration (TE-27) and the Whiskey Island Back Barrier Marsh Creation (TE-50) projects using the July 2006 and November 2015 BICM Surveys. Data for larger spatial coverage obtained from the BICM program.

the vicinity of Whiskey Pass, several other reaches show intense aggradation and are outlined with dark green colors (figure 6-3). These accretionary reaches include the TE-50 marsh creation area, the bay behind the island, the Whiskey Island Spit, and an ebb shoal that is forming south of this shoreline on the western terminal end of the island. This spit and the shoal are aggrading through longshore transport processes. Additionally, the ebb shoal has enlarged and migrated southward since 2006 (figures 6-3, 9-1, and 9-2). The surficial composition of the ebb shoal consists of 70-85% fine sands in close proximity to the shoreline, but silts are abundant slightly further offshore (figures 6-3 and 9-2). The shaping of the eastern flood shoal, the western ebb shoal, and the nourishing of the spit show that a proportion of the sediments eroded from the eastern TE-27 analysis area have been conserved within the island system. ACRE (2020) corroborates the creation of the depositional shoals and further stipulates that 602,000 yd^3/year were eroded from the eastern shoreline of Whiskey Island by the westward migration of Whiskey Pass from 2006 to 2015.

The TE-27 analysis area has incurred sizeable volume and elevation deficits over time. Moreover, the sediment volume losses within the project margins were considerably larger than the in place as-built volume due to shoreface erosion and transport of sediments out of the project box. When assessing the overall systemic impacts of the project, the existence of 53.90 acres of dune and supratidal elevations in 2015 is a strong indication that the project goal of increasing elevations in the project area have been met. Although this is a low acreage of elevated habitats relative to the

253.89 acres of dune and supratidal habitats created in 1998 by the project (as-built), the acreage is noticeably higher than the 8.85 pre-construction (1997) acres (Table 6-2). Furthermore, Whiskey Island was extremely narrow before the construction of the TE-27 project (figure 6-1) and was projected to become an inner shelf shoal early in the 21st century (McBride et al. 1989; McBride and Byrnes 1997; Penland et al. 2003), so the project extensively expanded island width in the project area and re-joined the island to the spit causing the island to elongate. Over the life history of the TE-27 project, Whiskey Island has withstood the substantial impacts of three (2002, 2005, and 2008) catastrophic hurricane seasons and the western migration of Whiskey Pass while nourishing the spit and the eastern and western shoals. In addition, the remnants of the TE-27 project buffer the TE-50 marsh creation area from Gulf of Mexico wave energy. As of 2015, Whiskey Island consisted of 265.93 acres of dune and subtidal habitats (mostly on the spit) and 533.10 acres of intertidal habitats (figure 6-2 & Table 6-2). Without the added width and elevations provided by the TE-27 project in 1998, Whiskey Island would have likely reverted to an inner shelf shoal or have a considerably lower profile with reduced acreages of barrier island habitats. As a result, the elevation and width goal of the TE-27 project has been attained because the project enhanced the longevity of Whiskey Island and sediments were conserved in the spit, the eastern flood shoal, and the western ebb shoal.

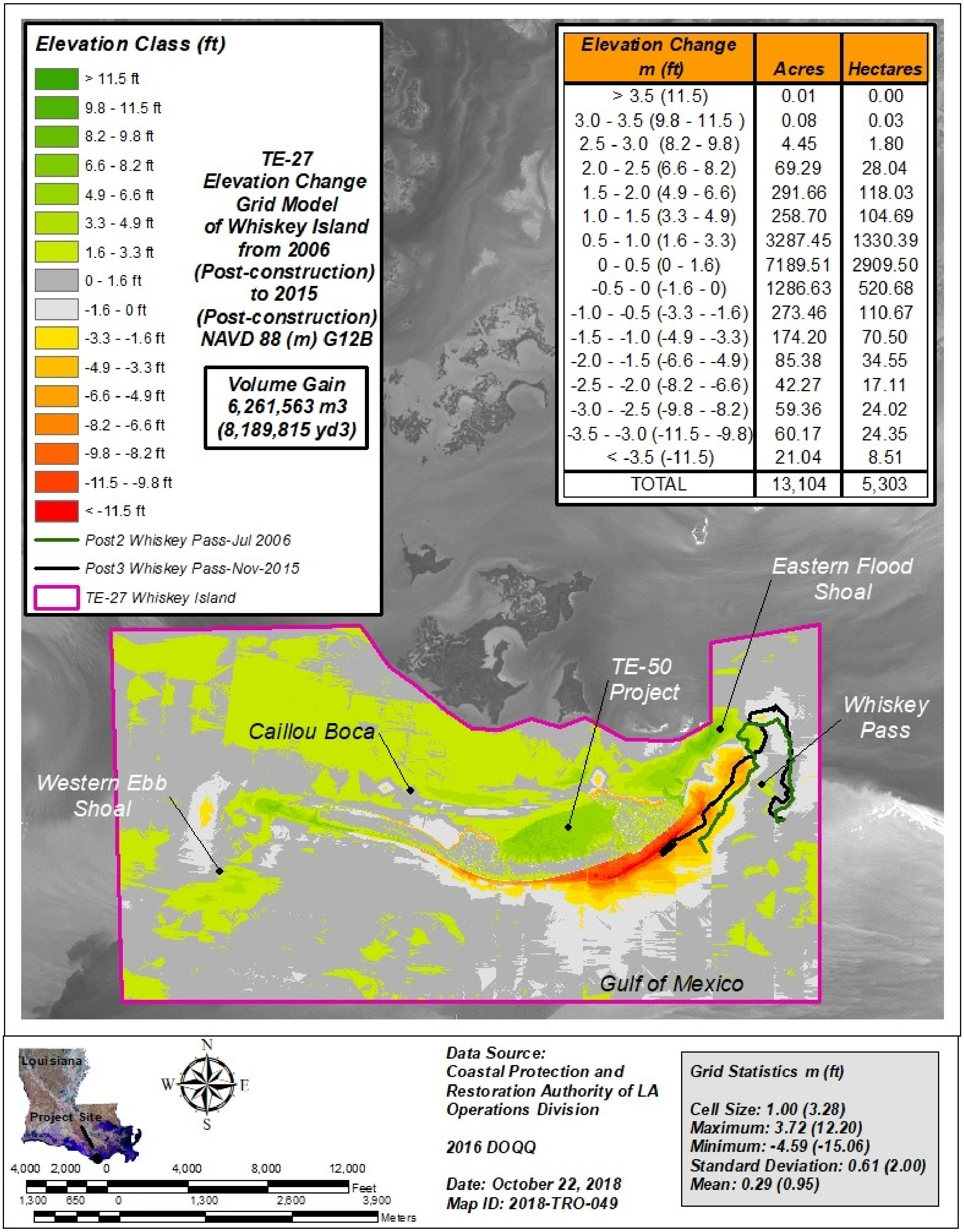

Figure 6-3. Elevation and volume change grid model for the Whiskey Island system from Jul 2006 to Nov 2015. Yellows and reds illustrate erosion areas; greens illustrate deposition areas. Grey areas represent areas within model uncertainties and are excluded from the volume calculations.

Whiskey Island Back Barrier Marsh Creation (TE-50) Project – Marsh & Dune Creation

The construction of Whiskey Island Back Barrier Marsh Creation (TE-50) marsh and dune features in October of 2009 resulted in the enlargement of supratidal and dune habitats on Whiskey Island. Figure 6-4 spatially illustrates the growth of supratidal and dune habitats and table 6-2 quantifies the acreages of supratidal and dune habitats constructed by the placement of dredged sediments in the TE-50 analysis areas. Approximately, 305.23 acres of supratidal habitats were created within the TE-50 marsh analysis area by the project elevating former non-WVA habitats with an average elevation of -2.69 ft NAVD88 to supratidal habitat with an average elevation of 2.45 ft NAVD88. Within the dune analysis area, the TE-50 project transformed supratidal and intertidal habitats to dune elevations (figure 6-4 and table 6-2). Tables 6-4 and 6-5 lists the volume changes (yd3 and %) in the marsh and dune analysis areas over the project timeline. Volume distributions for the TE-50 marsh analysis area are shown for the following intervals: April 2009-October 2009, October 2009-April 2010, October 2009-February 2014, October 2009-November 2015. The dune analysis area change is only shown for two intervals because the dune was not surveyed for the other post-construction periods. Approximately, 2,535,112 yd3 of clay and silt sediments were deposited during construction in the marsh analysis area (figure 6-4 and table 6-4), and 293,040 yd3 of sand were placed on the existing beach to form the dune habitats (figure 6-4 and table 6-5).

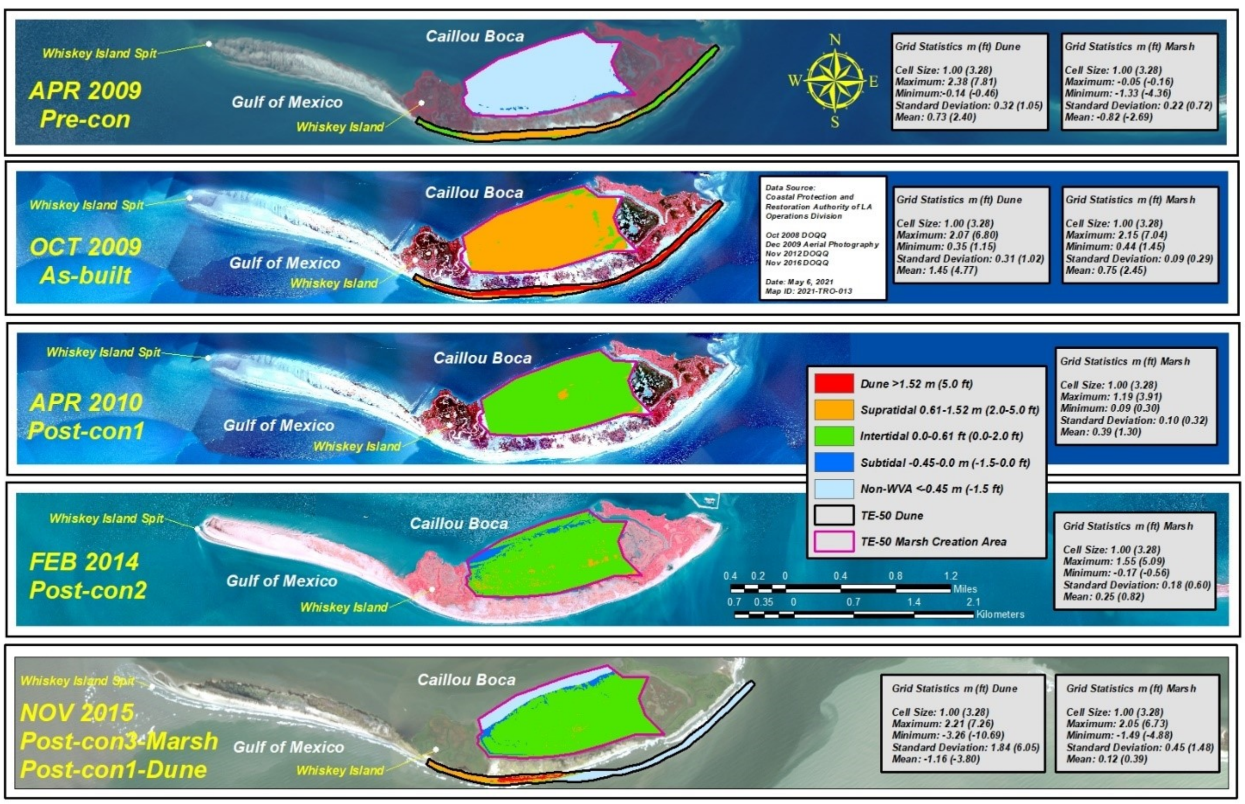

Figure 6-4. Elevation classification of the analysis area for the Whiskey Island Back Barrier Marsh Creation (TE-50) project for five time periods from pre-construction (2009) to six years post-construction (2015).

During the initial marsh post-construction period (April 2010), supratidal habitat settled in the TE-50 marsh analysis area to create intertidal marsh habitats. The average elevation within this area consolidated over one foot from 2.45 ft NAVD88 to 1.30 ft NAVD88. This led to the conversion of approximately 270.51 acres of supratidal habitat to intertidal habitat (figure 6-4 and table 6-2).

Table 6-4. Pre, as-built, and post-construction sediment volume changes in the TE-50 marsh fill area over time. Volume changes are recorded in yd3 (cubic yards), percent removed (%), and percent remaining (%).

TE-50 Elevation Intervals	Project Timeline Marsh	Volume Loss/Gain (yd3)	Percent Volume Removed (%) From Fill Area	Percent Volume Remaining (%) in Fill Area
2009-2009	Pre-As-built	2,535,112	-	-
2009-2010	As-built-Post1	-568,930	-22	78
2009-2014	As-built-Post2	-806,816	-32	68
2009-2015	As-built-Post3	-1,007,483	-40	60

Table 6-5. Pre, as-built, and post-construction sediment volume changes in the TE-50 dune fill area over time. Volume changes are recorded in yd3 (cubic yards), percent removed (%), and percent remaining (%).

TE-50 Elevation Intervals	Project Timeline Dune	Volume Change (yd3)	Percent Volume Removed (%) From Analysis Area	Percent Volume Remaining (%) in Analysis Area
2009-2009	Pre-As-built	293,040	-	-
2009-2015	As-built-Post1	-1,061,411	-362	0

Sediment volume decreased by 22% from October 2009-April 2010 leaving 78% of the as-built volume remaining within the TE-50 marsh analysis area (figure 6-4 and table 6-4). For this interval, small changes in elevation were documented throughout the analysis area. However, small acreages within the marsh creation area incurred more sizeable volume losses. These larger sediment volume changes were particularly prominent on the northern edge of the created marsh along the Caillou Boca shoreline (figure 6-4). The reason for the volume declines throughout the marsh analysis area is primary settlement and desiccation of the dredged sediments. The April 2010 survey occurred six months after the as-built survey and illustrates that the marsh was still settling after the as-built period. Moreover, this primary settlement was predicted in the Eustis (2007) settlement curve. The dune analysis area was not surveyed in April 2010, so no data is available.

For the second marsh post-construction period (February 2014), settlement of the marsh surface continued in the marsh analysis area but only minor habitat switching occurred. The average elevation in the marsh analysis area declined to 0.82 ft NAVD88 during this time period. Moreover, intertidal habitats continued to dominate the marsh landscape and small acreages of subtidal habitats began to appear along the Caillou Boca shoreline (figure 6-4 and table 6-2). Sediment volume decreased by 32% from October 2009-February 2014 allowing 68% of the as-built volume to remain within the TE-50 marsh analysis area. The total sediment volume loss in the analysis area for this interval was approximately 806,816 yd^3 (figure 6-4 and table 6-4). The primary triggers of this increased volume decline in the marsh analysis area were erosion along the Caillou Boca shoreline (northern edge of the marsh fill area) and secondary settlement within this analysis area. The shoreline receded at least 250 ft during this period (2009-2014) reducing the sediment volume along the Caillou Boca shoreline. In addition, greater secondary settlement can be seen in the center of the marsh analysis area resulting in increased sediment volume losses. The dune analysis area was not surveyed in February 2014, so no data on this area is available.

For the third marsh and first dune post-construction interval (November 2015), habitats in the marsh analysis area remained dominated by the intertidal class and habitats in the dune analysis area transitioned to the non-WVA class. During this time period, the average elevation in the marsh analysis area fell to 0.39 ft NAVD88 while the average elevation in the dune analysis area was substantially reduced to 3.8 ft NAVD88 (Figure 6-4 and table 6-2). In addition to the intertidal habitats within the marsh analysis area, the non-WVA habitat class appeared, and the subtidal habitat class expanded along the Caillou Boca shoreline. Along the Gulf of Mexico shoreline, the eastern and central reaches of the dune analysis area eroded to form the non-WVA class while the western reaches remained dune and supratidal habitats (figure 6-4 and table 6-2). The sediment volume in the marsh analysis area was diminished by 40% from October 2009 to November 2015 interval allotting 60% of the as-built volume to remain within the TE-50 marsh analysis area (figure 6-4 and table 6-4). The deepening of eroded areas and increased transgressions along the Caillou Boca shoreline seem to be driving the sediment volume changes in the marsh analysis area for this interval. The northern shoreline of the marsh analysis area retreated approximately 400 ft southward during this period. Figure 6-4 illustrates these areas with light and dark blue tones. Settlement does not appear to have visibly increased since the second post-construction interval, and the change in the average elevation is likely driven by Caillou Boca shoreline erosion. In contrast, the dune analysis area recorded sediment volume reductions of a considerably larger magnitude. For this period, the sediment volume within the dune analysis area declined by 362% creating a large sediment deficit (figure 6-4 and table 6-5). Indeed, a substantial proportion of the dune analysis area has become subaqueous. Moreover, this area is currently part of the shoreface and is exhibited in figure 6-4 with the light blue color. These results are not that surprising because the TE-27 elevation change models (figures 6-1 and 6-3) produced very similar outcomes albeit on larger scales and differing timelines (intervals). The TE-50 dune analysis area change models supports the TE-27 conclusions that longshore transport and the widening of Whiskey Pass are likely forcing the Whiskey Island Gulf of Mexico shoreline northward. Although the greater proportion of the dune analysis area is part of the shoreface, it is highly likely that the granular sediments placed in this area are being conserved within the Whiskey Island spit or shoals (figures 9-1 & 9-2). In conclusion, these results reveal that the TE-50 project is currently attaining its intertidal marsh acreage and longevity goals. Though the intertidal marsh acreage has dipped below the 300 acres stated in the goal, approximately 270 acres of functioning marsh habitats remain. In addition, the longevity of Whiskey Island has also been enhanced through the widening provided by the TE-50 project.

Whiskey Island Back Barrier Marsh Creation (TE-50) Project – Creek & Pond Formation

The following discussion on creek and pond formation in the TE-50 marsh analysis area utilizes only elevation change models to determine the shaping of these tidal features. The reason for this is very small changes in elevation are required to distinguish early creek and pond formations and elevation change analysis provide a better platform to detect small differences in elevation. The TE-50 tidal creek and pond areas and their reference area detailed minor reductions in sediment volume since the as-built surveys of these areas were completed in 2010. Tables 6-6 (creek and pond areas) and 6-7 (creek and pond reference area) lists the volume changes (yd^3 and %) in these areas over the project timeline. Elevation change and volume distributions for the TE-50 creek and pond areas and their reference area are shown in figure 6-5: April 2009 (pre) - April 2010 (as-built), April 2010 (as-built) - February 2014 (post 1), and (April 2010 (as-built) - November 2015 (post 2). Approximately, 93,424 yd^3 of sediment were deposited during construction in the creek and pond areas (figure 6-5 and table 6-6), and 248,280 yd^3 of sediment were placed in the creek and pond reference area (figure 6-5 and table 6-7).

Table 6-6. Pre, as-built, and post-construction sediment volume changes in the TE-50 creek and pond areas over time. Volume changes are recorded in yd^3 (cubic yards), percent removed (%), and percent remaining (%).

TE-50 Elevation Intervals	Project Timeline Creeks & Ponds	Volume Loss/Gain (yd3)	Percent Volume Removed (%) From Fill Area	Percent Volume Remaining (%) in Fill Area
2009-2010	Pre-As-built	93,424	-	-
2010-2014	As-built-Post1	-5,746	-6	94
2010-2015	As-built-Post2	-11,507	-12	88

Table 6-7. Pre, as-built, and post-construction sediment volume changes in the TE-50 creek and pond reference area over time. Volume changes are recorded in yd^3 (cubic yards), percent removed (%), and percent remaining (%).

TE-50 Elevation Intervals	Project Timeline Creeks & Ponds Reference	Volume Loss/Gain (yd3)	Percent Volume Removed (%) From Fill Area	Percent Volume Remaining (%) in Fill Area
2009-2010	Pre-As-built	248,280	-	-
2010-2014	As-built-Post1	-5,418	-2	98
2010-2015	As-built-Post2	-20,239	-8	92

During the post-construction intervals, the creek and pond project and reference areas recorded marginal declines in sediment volume. The sediment volume in the creek and pond areas decreased by 6% (2010-2014) and 12% (2010-2015) since 2010 (table 6-6 and figure 6-5). The post-construction sediment volume changes to the creek and pond reference area were similarly minimal (table 6-7 and figure 6-5). The sediment volume reductions in the creek and pond project and reference areas are primarily attributable to erosion along the Caillou Boca shoreline (figure 6-5). By 2015, virtually all of the primary creeks eroded into Caillou Boca and became subaqueous. Additionally, the most northern pond is currently coalescing into Caillou Boca. Segments of the reference area have also transgressed into Caillou Boca (figure 6-5). The dark red tones depicted in figure 6-5 correspond to an elevation regression of over 2.5 ft NAVD 88. Secondary settlement is also illustrated in the post-construction change models (figure 6-5). The green colors in these elevation change grids are likely derived through settlement while the blue color represents creek or pond formations, advanced settlement, or the early stages of shoreline erosion. The red and orange colors outline progressive stages of shoreline erosion, and the tan colors demarcate areas with little elevation variation over time. Figure 6-6 delineates the positions where creeks formed in the project and reference areas overlaid on the surface of 2012 and 2016 aerial images. Creeks did not form in all of the pre-dug locations, but they seem to maintain the shape of the pre-dug channels where they did form. A total of 5,887 ft of creeks formed in the project area. As for the ponds, only one small pond formed in the Pond 3 area creating a 0.15 acre pond while 0.65 acres of Pond 2 merged with Caillou Boca. In the reference area a network of 5 creeks were shaped creating 8,502 ft of tidal channels (figure 6-6). Although some of the creeks formed can be partially discerned from the post-construction change models (figure 6-5), the creeks should be more sharply outlined in the change models. The reason for the low creek resolution is likely the method of elevation data collection. The 2014 survey only used LiDAR data, and the 2015 survey used LiDAR and bathymetric (ends at Caillou Boca shoreline edge) data to establish elevations in the marsh creation area. LiDAR data does not penetrate water and appears to have not demarcated the shape of the smaller creeks. In addition, water depth cannot be determined from LiDAR data. Therefore, visible channels in the project and reference area should be topographically surveyed to enhance the delineation of the channels and to determine channel depth.

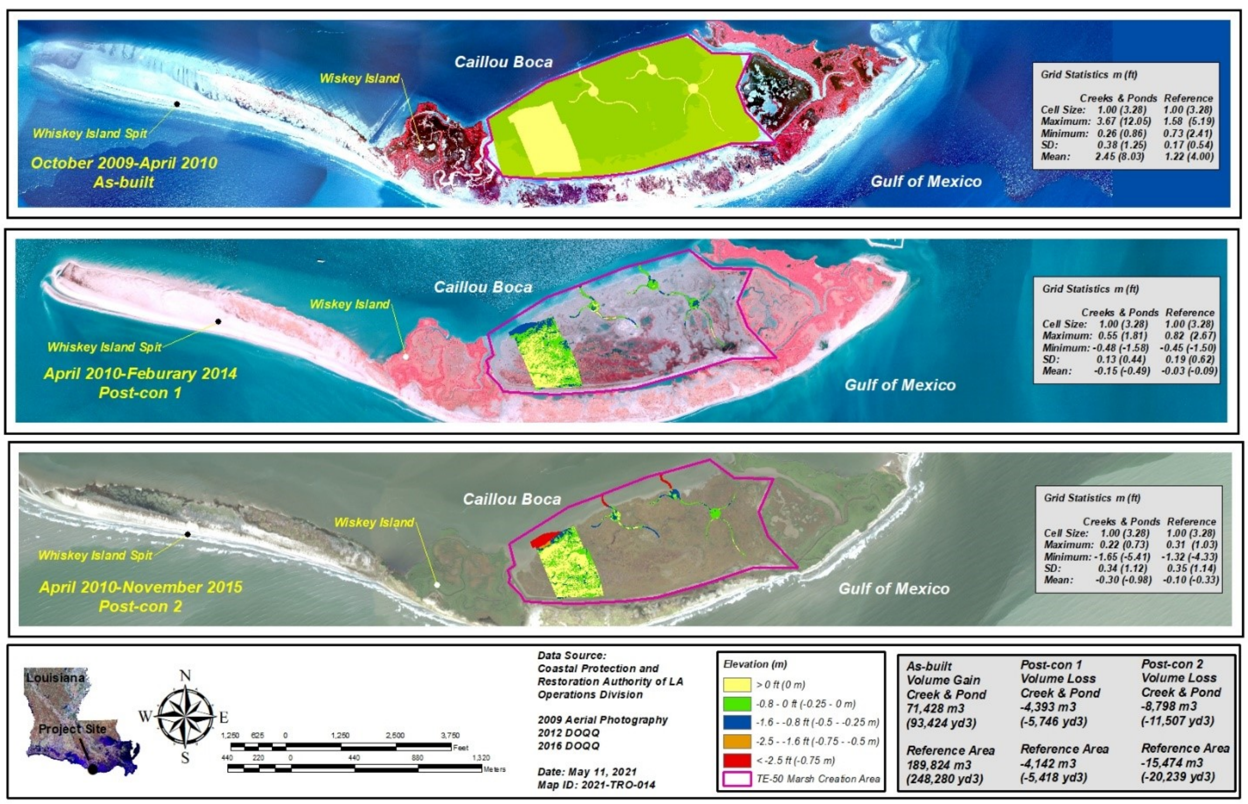

Figure 6-5. Elevation and volume change grid models for the TE-50 creek, pond, and reference areas from pre-construction (Apr 2009) to as-built (Apr 2010), from as-built (Apr 2010) to post-construction (Feb 2014), and from as-built (Apr 2010) to post-construction (Nov 2015) at the Whiskey Island Back Barrier Marsh Creation (TE-50) project.

The formation of tidal creeks in salt marshes has been described as being guided by local geomorphology and hydrology (Tyler and Zieman 1999; Novakowski et al. 2004; Wallace et al. 2005; Hughes et al. 2009; Perillo 2009). Crab burrows have also been implicated in creek formation and evolution (Hughes et al. 2009; Perillo 2009; Vu 2016). Creek formations have been postulated as being initiated when erosional thresholds have been reached leading to the shaping of incipient grooves. However, only a few of these embryonic grooves actually evolve into functioning creeks (Perillo 2009), which grooves get selected for further creek development is difficult to predict and has been proclaimed as topographically random events (Novakowski et al. 2004). Typically, creeks form in topographically depressed locations with low vegetation cover

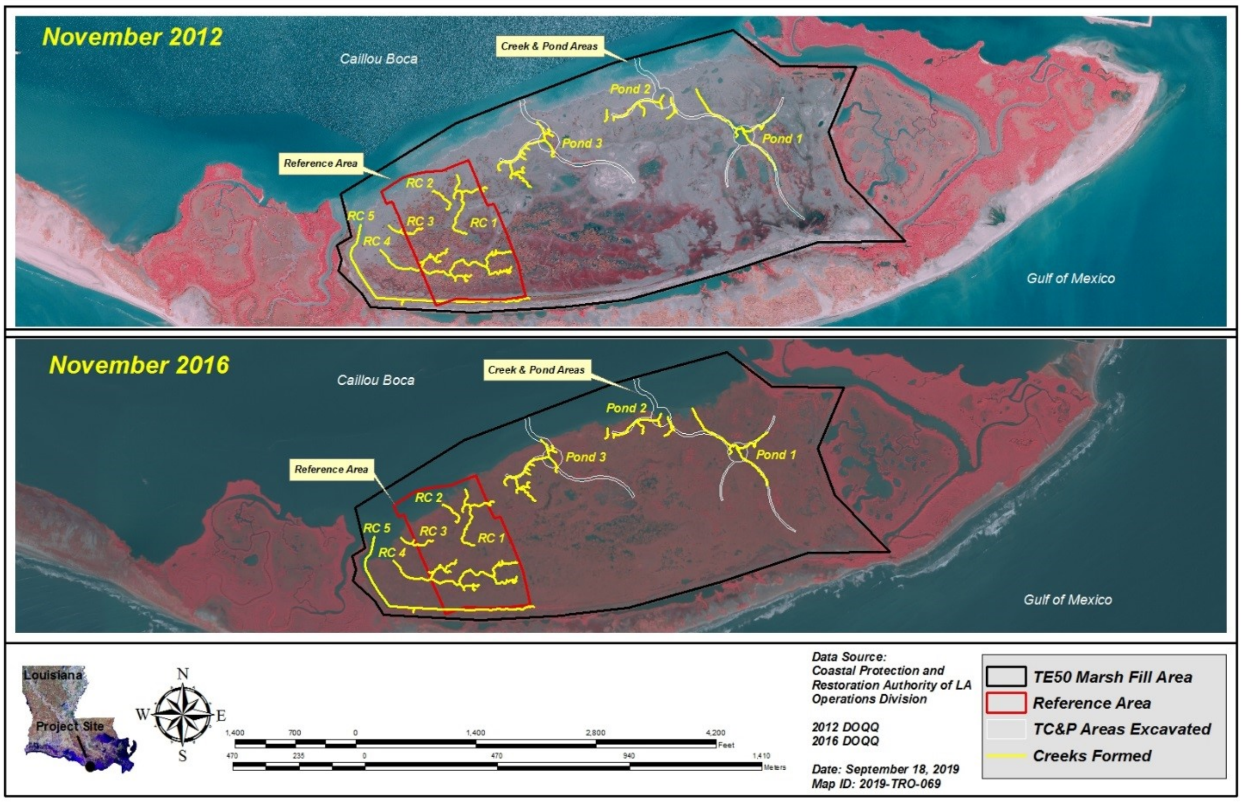

Figure 6-6. Creeks formed in the TE-50 creek, pond, and reference areas displayed over post-construction Nov 2012 and Nov 2016 CIR imagery at the Whiskey Island Back Barrier Marsh Creation (TE-50) project.

(Wallace et al. 2005; Hughes et al. 2009) due to the surface flow resistance and sedimentation provided by densely vegetated marshes (Perillo 2009; Choi and Harvey 2014). The origin and development of the creeks that formed in the constructed TE-50 marshes appear to follow the scenario listed above. All of the creeks that formed can be seen as either incipient grooves or depressions in the Nov 2012 imagery, and these creeks were shaped in areas with low vegetation cover (figure 6-6). The high rate of erosion along the Caillou Boca shoreline and quick demise of the primary containment dike likely aided creek development by increasing the rate of water exchange. RC 5, one of the creeks that elongated in the reference area, was shaped in a deep depression produced by the containment dike borrow ditch. Once the containment dikes eroded, this depression became a functioning creek. Another factor that led to creek elongation is salt marsh pans. Numerous salt marsh pans (Neumeier et al. 2013) were created throughout the TE-

50 constructed marshes, and these pans likely aided in creek elongation (figure 6-6). Salt marsh pans have been shown to extend creeks (Perillo 2009). Although no data on crab burrows were collected, the presence of so many salt marsh pans suggest that crab burrows may have assisted in creek and pan expansion (Perillo 2009; Vu 2016). The creeks shaped in the creek and pond areas typically did not expand past their pre-dug boundaries. Only one location in the Pond 1 and Pond 3 areas did the creeks extend outside these boundaries. In the Pond 1 area a creek formed connecting this area to Caillou Boca while a creek extended the Pond 3 area southward (figure 6-6). The creeks in the reference area seem to have formed more extensive creek networks especially RC 4, which has developed multiple branches. One possible cause for the greater creek elongation in the reference area is sediment grain size. The reference area was further from the dredge pipe outfall during construction and finer sediments were deposited in this part of the marsh creation area. In addition, greater water exchange could be occurring in the reference area due to the narrow width of the marsh creation area at this location leading to expanded creek elongation. The TE-50 creek and pond goal is currently being attained at this time because the creek length exceed the 5,800 ft benchmark and extensive creek networks were developed in the reference area. All these creeks form a considerable amount of marsh edge, which enhances fisheries productivity (Minello et al. 1994; Peterson and Turner 1994). Furthermore, Minello et al. (1994) and Wallace et al. (2005) report greater marsh functioning with constructed creeks. However, did the TE-50 project need to pre-dig creeks to enhance tidal connectivity? This question cannot be answered until more extensive topographic creek surveys are undertaken.

Chapter 7 - Habitat Changes at Whiskey Island due to the Whiskey Island Restoration (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50) projects

Introduction

Following the Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) Program's implementation of the TE-27 (1999) and TE-50 (2010) projects at Whiskey Island, habitat classification datasets were compiled to determine habitat acreages and changes in order to help assess the restorative effects of the respective projects. The TE-27 project had goals related to enhancing stability and restoring coastal dunes (Rodrigue et al. 2008), while the TE-50 project had goals related to creating dunes and marsh (Curole 2007). For this assessment, we will evaluate project effectiveness by comparing pre project habitat datasets with five other habitat datasets collected over the lives of the projects.

Methods

Habitat datasets provide a snapshot of the various habitats which make up a given land area at a given time and can be compared with historical and/or future datasets to evaluate barrier islands and other natural resources over time. Habitat datasets have been developed for the Barrier Island Comprehensive Monitoring (BICM) program by researchers at the University of New Orleans – Pontchartrain Institute for Environmental Sciences (UNO – PIES) for 1996/1998, 2001/02, 2004, and 2005 (Fearnley et al., 2009). In 2016, the BICM program partnered with the U.S. Geological Survey - Wetland and Aquatic Research Center (USGS-WARC) to develop habitat datasets for 2008 and 2015/2016 (Enwright et al. 2020).

Habitat datasets for 1996/1998, 2001/02, 2004, and 2005 were developed by the UNO - PIES using supervised and unsupervised classification of ortho-photography. The classification methods used by USGS-WARC for the 2008 and 2015/16 periods generate habitat datasets from high-resolution ortho-photography using object-based analyses in the Trimble eCognition software. Detailed information on the sources and methods used to create these datasets can be found in Fearnley et al. (2009) and Enwright et al. (2020). While additional data are utilized by the Trimble eCognition software to generate habitat classifications at a finer scale than had been delineated in the earlier datasets from UNO - PIES, comparability with previous datasets was maintained and the 6 datasets have been analyzed and assessed using the BICM general classification scheme (table 7-1, figure 7-1).

Table 7-1. Louisiana Barrier Island Comprehensive Monitoring (BICM) Program detailed and general habitat classification schemes used in habitat mapping efforts for the Louisiana Gulf of Mexico shoreline (from Enwright at al. 2020).

Detailed class	Description	Description source	General class (Fearnley et al., 2009)
Beach	Beach habitat includes supratidal bare or sparsely vegetated areas (that is, above the extreme high water springs tide level) located along coastlines with high wave energy (that is, gulf-facing shorelines). Vegetation cover is generally less than 30 percent. Beach transitions into dunes, meadow, or unvegetated flat where overwash is evident. Beach includes the backshore zone of a beach.	Modified from Cowardin et al. (1979)	Beach
Unvegetated dune	Dunes are supratidal features (that is, above the extreme high water springs tide level) developed via Aeolian processes. Dunes are often located above typical storm water levels and have a well-defined relative elevation (that is, upper slope or ridge). Unvegetated dune includes dune habitat that has less than 10 percent vegetation cover.	Modified from Psuty (1989)	Bare land
Vegetated dune	Dunes are supratidal features (that is, above the extreme high water springs tide level) developed via Aeolian processes. Dunes are often located above typical storm water levels and have a well-defined relative elevation (that is, upper slope or ridge). Vegetated dune includes dune habitat that has greater than 10 percent vegetation cover.	Modified from Psuty (1989)	Barrier vegetation
Unvegetated flat	Unvegetated barrier flat includes flat or gently sloping supratidal unvegetated or sparsely vegetated areas (that is, areas located above extreme high water springs tide level) that are located on the backslope of dunes, unvegetated washover fans, and along low- energy shorelines. Vegetation cover should be generally less than 30 percent.	Modified from Leatherman (1979)	Beach
Meadow	Meadow includes supratidal areas (that is, above the extreme high water springs tide level) with sparse to dense herbaceous vegetation located in areas leading up to dunes and on the barrier flat (that is, backslope of dunes and supratidal, back-barrier habitat). Vegetation coverage should generally be greater than 30 percent. Classification of meadow habitat is restricted by geomorphic settings. Meadow is reserved for areas located on barrier flats of barrier islands, backslopes of dunes, or transitional vegetated areas in dune/beach habitats.	Modified from Lucas and Carter (2010)	Barrier vegetation
Intertidal	Intertidal includes bare or sparsely vegetated areas located between the extreme low water springs and extreme high water springs tide levels. Vegetation cover should generally be less than 30 percent. Intertidal includes the foreshore zone of a beach.	Cowardin et al. (1979)	Intertidal
Estuarine emergent marsh	Estuarine emergent marsh includes intertidal saline emergent marsh (that is, located above extreme low water springs and below extreme high water springs tide levels) and supratidal brackish emergent marsh. Vegetation cover should be generally 30 percent or greater cover by erect, rooted, herbaceous hydrophytes. Note, supratidal emergent vegetation that is located on the backslopes of dunes will be classified as meadow.	Cowardin et al. (1979)	Estuarine vegetated wetland
Mangrove	Mangrove habitat includes areas with black mangrove (*Avicennia germinans*). Mangrove vegetation coverage should generally be greater than 30 percent.	--	Estuarine vegetated wetland
Bare land	Bare land includes bare or sparsely vegetated areas that are often located above typical storm water levels and are associated with unvegetated spoil or inland ridges. Vegetation cover should generally be less than 30 percent.	Modified from Fearnley et al. (2009)	Bare land
Grassland	Grassland includes upland areas covered by herbaceous vegetation often located above typical storm water levels and associated with inland spoil banks with herbaceous vegetation, freshwater emergent marsh, and upland areas along the mainland in the BICM regions along the Chenier Plain geomorphic zone.	Modified from Homer et al. (2015)	Barrier vegetation
Scrub/shrub	Scrub/shrub includes areas where woody vegetation height is greater than about 0.5 meter, but less than 6 meters. Woody vegetation coverage should generally be greater than 30 percent.	Cowardin et al. (1979)	Barrier vegetation
Forest	Forest includes areas where woody vegetation height is greater than 6 meters. Woody vegetation coverage should generally be greater than 30 percent.	Cowardin et al. (1979)	Barrier vegetation
Shoreline protection	Shoreline protection includes any material used to protect shorelines against erosion (for example, breakwater, groins, and jetties).	Fearnley et al. (2009)	Rip-rap
Developed	Developed includes areas dominated by constructed materials (that is, transportation infrastructure and residential and commercial areas) and open developed areas.	Modified from Homer et al. (2015)	Structure
Water	Water includes areas of open water with vegetation cover generally less than 30 percent.	Modified from Cowardin et al. (1979)	Water

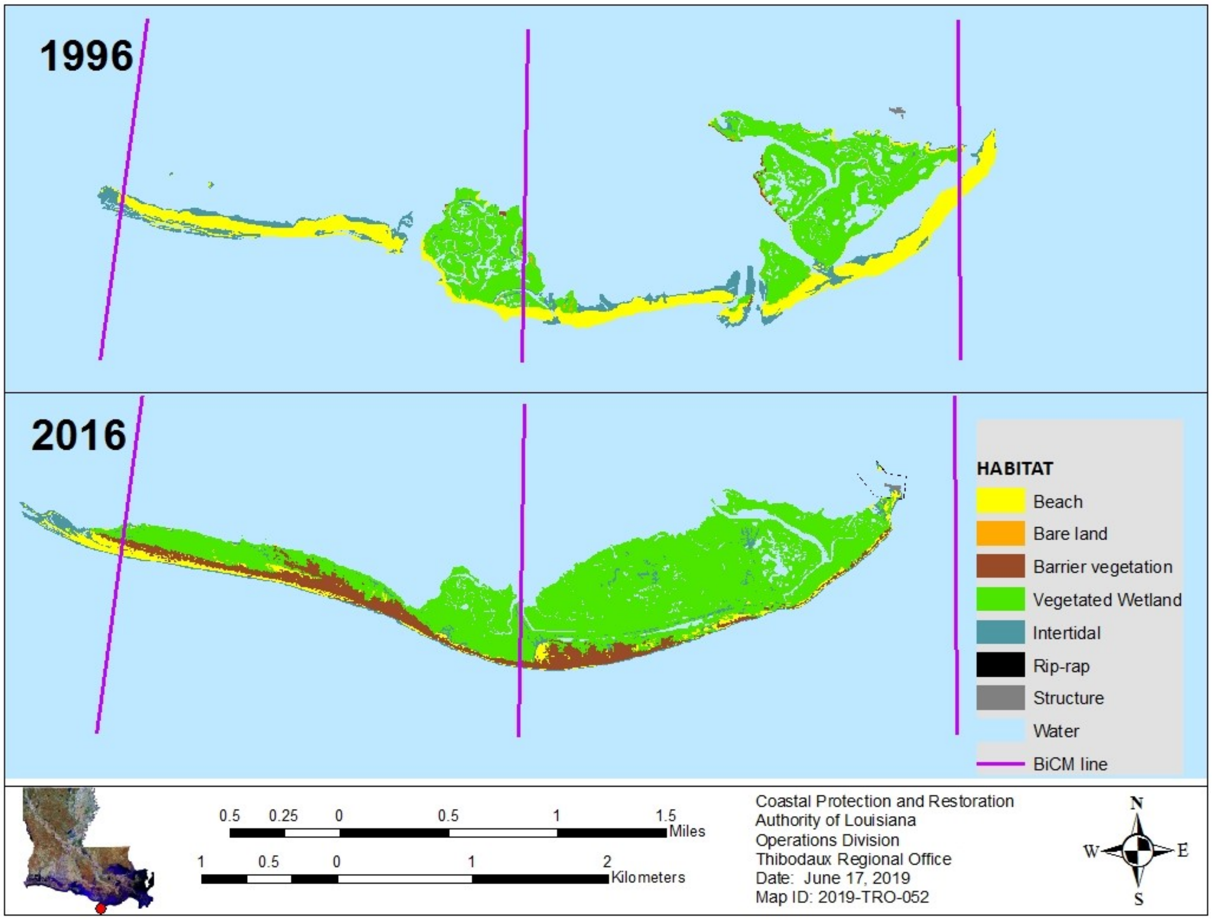

Figure 7-1. BICM general habitat classification maps for 1996 and 2016 at Whiskey Island, Isles Dernieres, Terrebonne Parish, LA.

Results and Discussion

Habitat classification datasets for Whiskey Island were available for six time periods between 1996 and 2016 (figure 7-2). This 20-year period includes one 1996 dataset acquired prior to restoration and five additional datasets compiled over the subsequent 18 years following the initial restoration event in 1999 and the one that followed in 2010. The habitat change trends revealed an overall increase in land area, as described in the more extensive analysis of land area change in Chapter 4. Each project had goals and/or objectives related to creating marsh and dunes and establishing vegetation. The changes in habitat classes over time exhibited favorable trends in each of these regards. Emergent marsh, which would fall into the category of vegetated wetland, remained fairly stable throughout the 1996 to 2008 period. The minor reduction of vegetated wetland observed between 1996 and 2002 occurred as a result of a combination of tropical cyclone activity and TE-27 project construction, each resulting in a large increase in the bare land category. The sediments added via TE-27 project construction which initially aided in the creation of bare land began to vegetate over time, and increases in beach and barrier vegetation categories were observed between 2002 and 2005. Active hurricane seasons in each of these years likewise contributed to fluctuations in habitat composition, particularly in the bare land and beach habitat classes. These habitats exhibited overall decreases in acreage as they began to vegetate and transition. Between 2008 and 2016, vegetated wetlands had increased by 331 acres. Total land habitat in that same period increased by 233 total acres as intertidal flat and bare land vegetated and beach habitats were reworked. The 666 total land acres in 2016 represents a 40% increase in total land habitat area when compared to the pre-restoration habitat data. Vegetated wetlands more than doubled in acreage during that period, increasing from 304 acres in 1996 to 617 acres in 2016. Goals related to increasing marsh acreage are considered to have been achieved as evaluated here, while individual habitats showed increases or stability post-restoration as desired in the project goals.

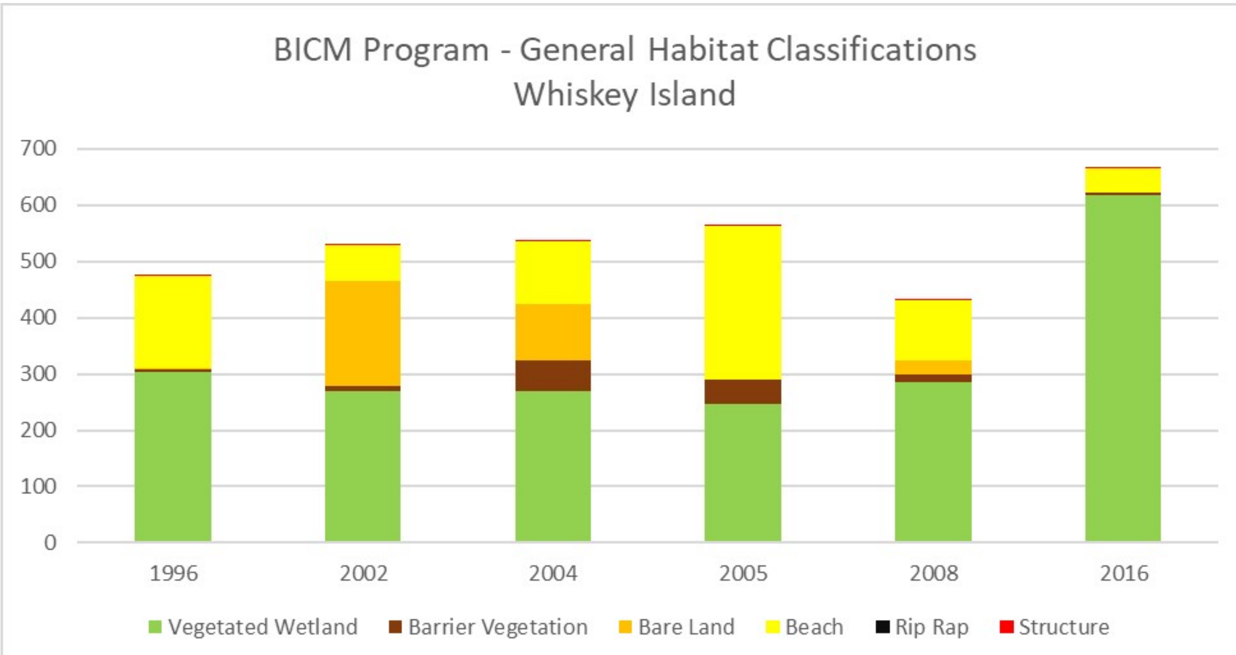

Figure 7-2. BICM habitat classifications showing total acres of 6 land cover types at Whiskey Island, Terrebonne Parish, LA. Changes in habitat classes indicate impacts of restoration events and storms over time. (Areas classified as water were removed for the purposes of displaying the data graphically and parsing out land classification changes.

Land area is defined in Chapter 4 as any general habitat class other than water or intertidal flat. The barrier vegetation and bare land habitat classes are the categories that map dunes within the BICM general classifications (table 7-1), and we examine these categories to help evaluate how well the projects performed regarding the goals and objectives related to creating, establishing or maintaining dunes. In 1996 prior to restoration, there was only 3 acres of barrier vegetation and only 2 acres of bare land (table 7-2), and those 5 acres account for only 1% of the total land area at that time. By 2002, following the construction of TE-27, the barrier vegetation and bare land habitat categories had increased to 8 and 188 acres, respectively, totaling 196 acres or about 37% of the total land habitat of the island. The increase in these categories and the extensive coverage of bare land is attributed to the initial material placed in 1998. There was also a large increase in intertidal flat which resulted from the 1998 restoration and as some of these areas began to vegetate, intertidal flat decreased by 2004 as barrier vegetation increased from 8 to 55 acres between 2002 and 2004. Bare land also decreased during this period from 188 acres to 101 acres as it also began to vegetate.

Table 7-2. Habitat acreages by BICM general habitat class between 1996 and 2016 for Whiskey Island, Isles Dernieres, Terrebonne Parish, LA.

Habitat Classes	1996	2002	2004	2005	2008	2016
Water	4388	4086	4337	4121	3551	3455
Intertidal Flat	73	321	64	252	177	39
Vegetated Wetland	304	270	269	247	286	617
Barrier Vegetation	3	8	55	44	13	6
Bare Land	2	188	101	0	26	0
Beach	165	64	111	273	107	42
Rip Rap	0	0	0	0	0	0.7
Structure	1	1	1	1	1	1
Total Land Area [1]	**475**	**531**	**537**	**564**	**433**	**666.7**

1 Land Area defined as sum of all habitat classes other than Water or Intertidal Flat.

Most fluctuations observed in various habitat categories can be attributed to both storm and restoration impacts and the vegetative colonization and other successional processes which follow those disturbances. Between 2004 and 2005 for example, which were each active storm seasons, the total land area increased by only 27 acres; however, significant changes in habitat composition were occurring in individual categories during this period. Intertidal flats, which are not considered land in this analysis, increased by 188 acres, effectively removing that area from the total land calculations presented in table 7-2. Vegetated wetlands decreased by 22 acres, barrier vegetation decreased by 11 acres, and areas mapped as bare land were reduced from 101 acres down to zero in the same period, all primarily due to storm effects. At the same time, however, beach habitat increased by 162 acres to 273 acres, or 48% of the total land area in 2005, the highest percent of beach acreage in the analysis period. Beach acreage continued to decrease through the remainder of the analysis period, however, and contributed only 42 acres or about 6% of the land area by 2016. Beach and bare land exhibited the most variability of the land class categories as measured by standard deviation (SD= 75.95 and 70.09, respectively), and they were each highly responsive to disturbance events whether they were from restoration events or storms. Sediment placement can cause reductions in emergent vegetation across various habitat types and can result in rapid transitions to different categories. These rapid transitions can likewise happen as a result of vegetation establishment due to natural succession, seeding, and/or plantings in the absence of disturbance. Also contributing to the ephemeral nature of beach habitat in particular and its drastic reduction by 2016 is the potential that the BICM general classification system lumps together unvegetated flats and meadows. Compared to the much more frequent storm impacts to the island during the initial 10 years, the relatively low number of tropical cyclones and resulting overwash events over the last 8 years of the analysis period likely provided for vegetation to increase as natural succession progressed.

In 2010, the TE-50 project added another 2.5 million cubic yards to the system. Between 2008 and 2016, the island showed an increase in total land area of nearly 54%. As 6 years had passed between the second restoration event and the next and final year of habitat data, evidence of increases in intertidal flat and bare land were much reduced compared to the initial restoration in 1998, this due to the increased amount of time that these areas had to vegetate between mapping efforts. By 2016, vegetated wetlands made up 92% of the area considered land, which represents an increase of 102% in that category compared to the 1996 data. Only 6 acres of barrier vegetation was mapped in 2016 and bare land had been reduced to zero, so habitat categories which map dunes made up only 0.9% of the total land area by 2016, very similar to the 1% that it had been in 1996. While each project made contributions to habitats containing dunes, the ephemeral nature of these habitats, their sensitivity to various disturbances or lack thereof, and propensity to quickly transition caused large fluctuations between analysis years. It is fair to assess that the projects did achieve dune stabilization/maintenance by providing material to the system such that these habitats continue to exist beyond the predicted island life and the island system is fortified to withstand future disturbance events that will variously affect not only these habitat categories but also each of the others comprising the island.

Chapter 8 - Vegetation Community at Whiskey Island due to the Whiskey Island Restoration (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50) projects

Introduction

In order to assess the vegetation community at Whiskey Island Restoration (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50), both Coastal Wetlands Planning Protection and Restoration Act (CWPPPRA) projects, shore perpendicular cross-island transects upon which an initial fifty-seven (57) vegetation stations were randomly placed for sampling in 1999. The sampling approach was redesigned in 2007 to address station loss due to erosion through the years. The CWPRRA program implemented the Whiskey Island Restoration (TE-27) in 1999 and the Whiskey Island Back Barrier Marsh Creation (TE-50) project in 2010. Both the TE-27 and TE-50 projects have goals of reducing sediment loss through the use of vegetative plantings thereby increasing the stability of the island. Another goal is to determine the species composition and diversity of the vegetation within the habitat types on the island. These goals were assessed in the earlier TE-27 project report (Rodrigue et al. 2008) prior to portions of the construction fill areas and subsequently some plantings being eroded away, and will not be repeated here. Only the data collected from 2007 and 2016 are presented in this report. For this assessment the authors determined species composition, the overall relative percent cover of vegetation, the relative percent cover by species, and the species count for the post 2003 datasets in order to assess if the goals of stabilizing dunes and establishing vegetative cover were accomplished. It is important to note that due to budget limitations, vegetation monitoring occurred only where TE-27 overlapped with the eastern half of TE-50 beginning in 2007.

Methods

The Coastal Protection and Restoration Authority (CPRA) of Louisiana has used the Braun-Blanquet method (Mueller-Dombois and Ellenberg 1974; Folse et al. 2008, rev. 2014) for collecting vegetation data at TE-27 and TE-50. This method records visual estimates of percent cover for each species observed within a four (4) square meter sample plot by vegetative layers which include; 1) tree, 2) shrub, 3) herbaceous, and/or 4) carpet. Estimates of percent cover use the following classifications: solitary, <1%, 1-5%, 6-25%, 26-50%, 51-75%, and 76-100%, although observations are recorded to the nearest 5% when cover is above 5% and to the nearest whole number when below 5%. Vegetation outside of each sample plot, but within 15 feet are also identified and recorded. Over the course of the project life, the method for establishing the vegetation stations changed as a result of changes to the original project footprint and station loss due to erosion. Sampling the TE-27 and TE-50 projects in 2007 and 2016 was conducted utilizing shore perpendicular cross sections for the establishment of 25 stations as described below to better ascertain barrier island community composition and cover as vegetative succession occurred, and as the fill areas were impacted by natural processes. Determination of species composition was a component of the new sampling scheme, but documenting planting success was not.

Vegetation sampling was conducted in 2007 and 2016 for the two projects on Whiskey Island. As mentioned above, the method of station establishment changed in 2007. Shore perpendicular Barrier Island Comprehensive Monitoring (BICM) bathymetric track lines are spaced approximately 1,500 feet apart along most of the Louisiana gulf shoreface. Where these lines intersect the respective subaerial project areas of TE-27 and TE-50, they were digitally extended via ESRI® ArcMap™ such that they would completely cross the island. Points were generated every 2 meters along these lines and assigned a numerical value to facilitate random locations of vegetation stations. Files generated in ArcMap™ were then transferred to a handheld Trimble GeoXT Global Positioning System (GPS) unit for mobile Geographical Information System (GIS) field applications with sub-meter accuracy.

At the project site, two personnel used the Trimble GeoXT GPS unit to navigate to the BICM bathymetric track lines where the potential vegetation station points were generated. Beginning at the vegetative line on the gulf side of the island and proceeding bayward along the transect, personnel identified the associated point in the GPS unit. This point was documented. Personnel proceeded along the transect until the geomorphic feature changed. At the transition zone, the associated point in the GPS unit was identified and documented. This process continued along the transect. At the end of the transect, the length of each zone was determined and the number of stations per zone was determined. Then stations were randomly selected using a random number generator. Personnel then walked back along the transect locating the point along the transect that was randomly selected. Five sampling locations were established along each of the transects and marked for the sampling teams with a PVC pole in the southeast corner. Plots were oriented in a North-South direction. Sampling teams then recorded species and visual estimates of percent cover for both the total plot and each individual species per the Braun-Blanquet method previously mentioned. There were twenty (20) stations monitored on Whiskey Island in 2007, and by 2016 there were 10 stations remaining. Only five (5) stations were common to the two time periods being used for this report due to erosion, but 5 additional stations were established in 2016 along the same BICM transects utilizing the same station selection methodology from 2007, leaving a total of twenty-five (25) stations for the 2007 - 2016 monitoring efforts (figure 8-1). Table 8-1 provides a list of stations per region by year for the four transects selected. The stations fell into 3 different geomorphic regions: upslope, swale, and marsh. The upslope region was the area closest to the Gulf of Mexico where the sand/water interface begins and rises upward in elevation until reaching the dune. The swale region is the area on the back side of the dune platform and slopes down to the marsh. The marsh region begins where the swale elevation has decreased as it nears the bay side of the island. Each region is characterized by a unique composition of emergent vegetation.

Table 8-1. Vegetation monitoring stations on Whiskey Island established in the 2007 redesign.

Vegetation Stations		
Sampling Years	**Station Count**	**Number of Stations per Region**
2007	20	7 Upslope, 12 Swale, 1 Marsh
2016	10	8 Swale, 2 Marsh

Following data collection, data sheets were reviewed by the field data recorder for accuracy and completeness. The data were entered into a Microsoft® Excel Workbook template and loaded into the CPRA/Coastal Information Management System (CIMS) temporary buffer for internal quality assurance review (CPRA 2018). Revisions were made to the data in the buffer based upon reviewer comments. The data were saved from the buffer to the CPRA/CIMS permanent database. Data were downloaded from the database and saved to a .csv file for analysis in SAS® version 9.4 (SAS®). Before analysis could proceed there was one adjustment made to the data set. For years that bare ground was not recorded as a species inside of the stations, this value was calculated based upon the total plot cover and added to the data set for analysis. The data file was analyzed for 1) relative mean percent cover for each individual species by year and region, and 2) species richness by year. Data results were brought into Microsoft Excel 2016 for chart development.

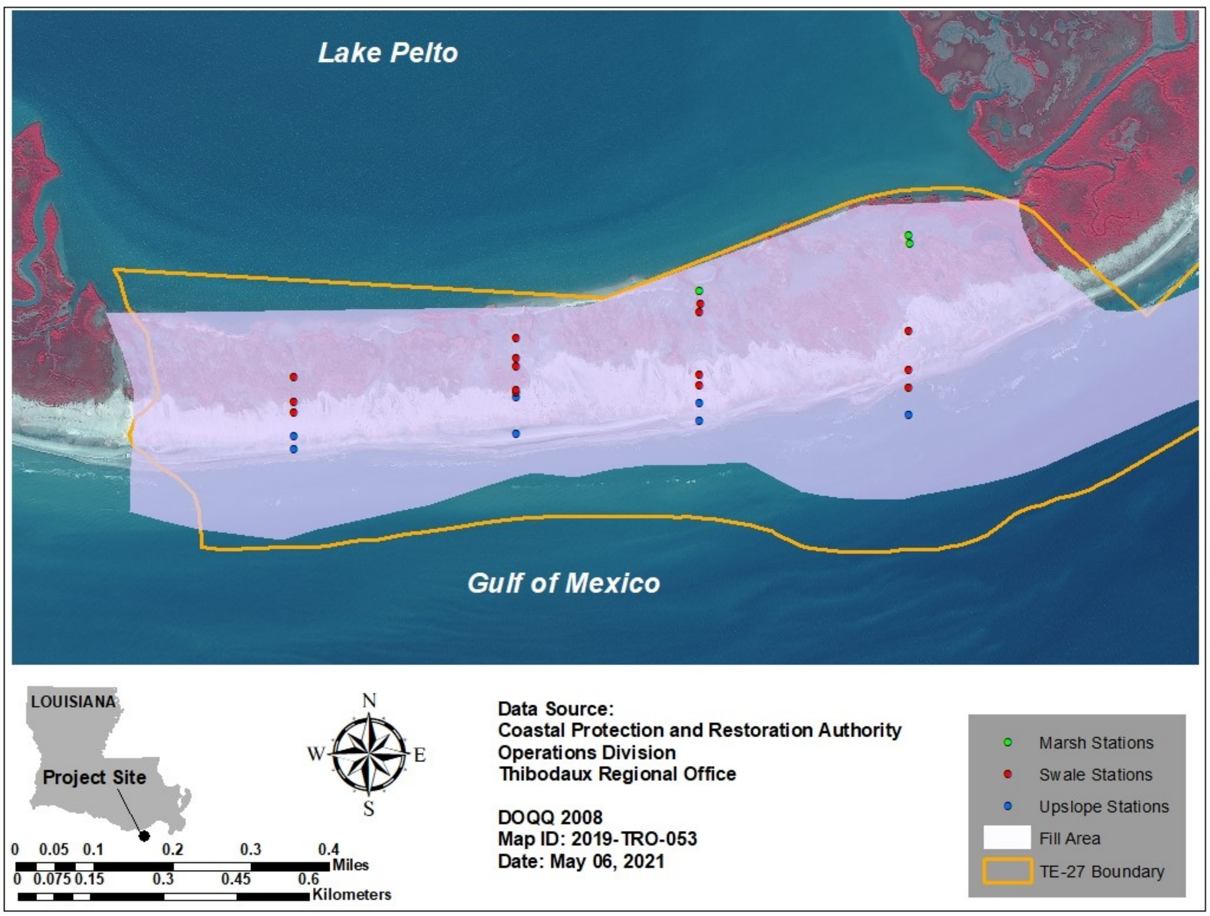

Figure 8-1. Location of the twenty-five (25) vegetation stations established to assess the vegetation community on Whiskey Island.

Results and Discussion

Upslope region stations on Whiskey Island had a relative mean vegetation cover of 63% in 2007 (figure 8-2) and there were sixteen species documented both inside and outside (within a 15 foot radius) of the stations, including bare ground as a species. The dominant species was *Spartina patens* (figure 8-3). The planted species, *Panicum amarum*, accounted for almost one-third of the upslope vegetation cover. In 2016 all of the upslope stations were in open water due to erosion through island migration.

Relative mean vegetation cover inside the swale region stations slightly increased from 2007 to 2016, while species richness slightly decreased (figure 8-2). Relative mean cover remained above 65%. *S. patens* was the dominant species with 23% and 25% relative mean cover in 2007 and 2016 respectively (figure 8-3). In 2007 *P. amarum* and *Sesuvium portulacastrum* both had over 10% relative mean cover, but by 2016 *P. amarum* had disappeared and *S. portulacastrum* was reduced to 4% cover. The disappearance and reduced cover of these two species signaled the loss of stations to erosion. Stations with *S.patens* as the dominant species were the majority in 2007, but by 2016 no S. patens remained. In 2016, diversity remained high, but the species composition shifted from predominately swale species to a larger number of salt pan and low back barrier marsh species.

Relative mean vegetation cover inside of the three marsh region stations remained above 65% between 2007 and 2016 (figure 8-2). Species richness increased from 8 to 13 species. The dominant species in 2007 was *Sporobolus virginicus* with 31% relative mean cover (figure 8-3). *S. patens* and *Salicornia bigelovii* had the next highest relative mean cover values, each with 18%. By 2016, the species composition shifted to a low back barrier marsh assemblage. The three species, *S. alterniflora, Avicennia germinans*, and *Batis maritima*, were codominant.

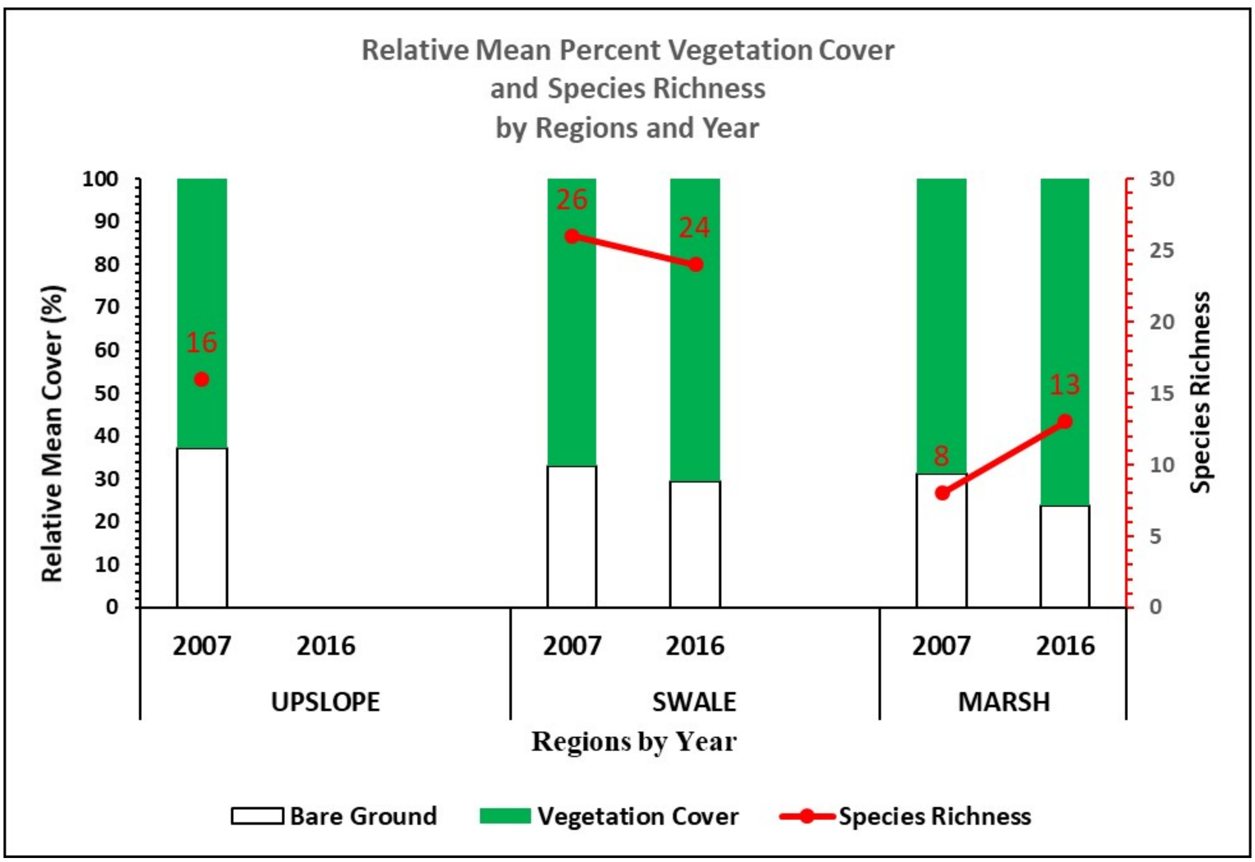

Figure 8-2. Relative mean cover of vegetation and species richness by region and year on Whiskey Island.

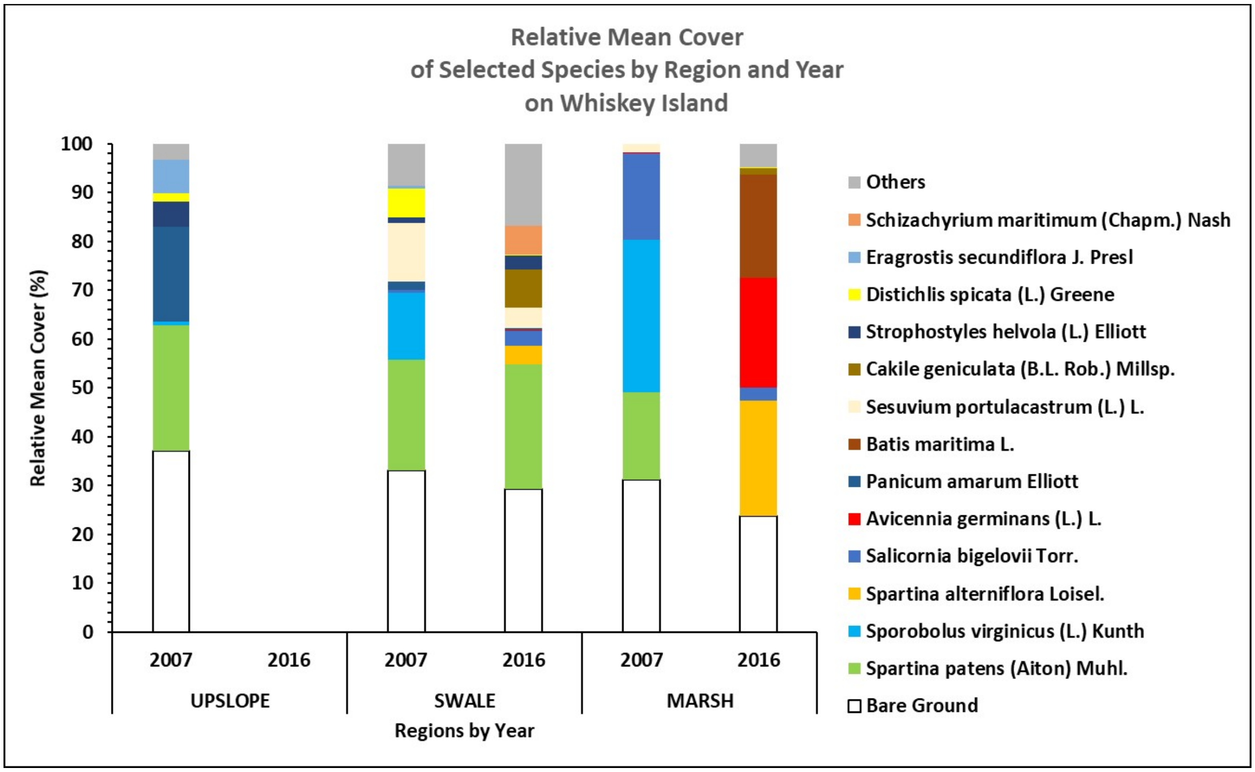

Figure 8-3. Relative mean percent vegetation cover of selected species inside the 4m² stations by region and year on Whiskey Island.

The goal to reduce loss of dredged sediments on the eastern half of Whiskey Island through the growth of vegetation was partially realized. Due to the migration of the island, 75% of the vegetation stations from the 2007 redesign were lost. Despite this loss, the remaining stations, including five (5) new stations established in 2016, maintained relative mean vegetation cover above 65%. Species richness also remained high. In the swale region, there was a shift in the species composition with the introduction of more salt-pan and low back-barrier marsh species. Species composition in the marsh region shifted from high marsh to a low back barrier assemblage.

Chapter 9 - Sediment Properties at Whiskey Island due to the Whiskey Island Restoration (TE-27) and the Whiskey Island Back Barrier Marsh Creation (TE-50) projects

Introduction

The Barrier Island Comprehensive Monitoring (BICM) program collected surficial sediment samples in the subaqueous and subaerial environments along coastal Louisiana, including Whiskey Island. These data were collected in 2008 and 2015 and were used to map sediment characteristics along the island. Neither of the two projects stated any goals or objectives related to the sediment size or characteristics; the authors of this report present this data due to its availability and support for other variables analyzed and discussed in this document.

Methods

Ponar grabber (subaqueous) and hand scoop (subaerial) sediment samples were obtained along seven (7) cross-shore transects along Whiskey Island for the Whiskey Island Restoration (TE-27) project in July 2008 and August 2015 to characterize the median grain size (D50) and percent sand (%) in the shoreface and other barrier island habitats. These sediment transects were separated on 3000 ft intervals and were funded through the BICM program (Troutman et al. 2003; Kulp et al. 2011; Kulp et al. 2015). One sample was collected from each distinguishable location: -15 ft (-5 m) contour, middle of shoreface, upper shoreface at mean low water, beach berm, dune, and back-barrier marsh. Horizontal coordinates (UTM NAD83 Zone 15 in meters) were also established with a DGPS for each sample to spatially display the position of each sediment sample.

Once collected the surficial sediments were visually characterized to determine the percentage of sand, silt, clay, organics, and shell content. No further analysis was undertaken on the samples that were less than 70% sand. The samples that had sand proportions that were equal to or exceeded the 70% threshold were analyzed with a Coulter LS 200 particle size analyzer and Gradistat® software. Percent sand and median grain size (D50) were calculated from this analysis along with the 10% and 90% granular intercepts (D10 and D90). In addition, the samples were sized using the Wentworth (1922) terms; and sorting, skewness, and kurtosis were also estimated for each sediment sample.

The July 2008 and August 2015 sediment core point data were imported into ArcGIS® software for surface interpolation. Surface grid models [10 m2 (33 ft2) cell size] were generated with the 2008 and 2015 percent sand (%) data using the Kriging function of the Spatial Analyst Tools extension of ArcGIS®. The percent sand grid model was then mapped in 5% increments to view the spatial distribution of sand in the Whiskey Island system. Multipoint median grain size (D50) shapefiles were also produced for both years using the Wentworth (1922) terms and overlain on top of the percent sand grid models to spatial view the median grain size distributions for Whiskey Island.

Results and Discussion

The results of the sediment properties analysis demonstrate that surficial sand deposits were present along the Whiskey Island shoreface, beach, dune, marsh, bay, and passes in 2008 and 2015 (figures 9-1 and 9-2). The percentage of sand (%) in 2008 ranged from < 70% to 95% for sediments extracted from the middle of shoreface to the marsh with the greatest concentrations of sand recovered from the western end of the spit (figure 9-1). The < 70% and 70-75% classes that encroach onto Whiskey Island were partially calculated from interpolation of distant points due to inadequate point spacing and may not be a representative depiction of the actual surficial sand percentages in this area. Moreover, the 75-80% and 80-85% classes in the bay behind the island and spit were also interpolated from distant points because no surficial samples were extracted from this area. The median grain sizes of these sediments fell within the very fine sand (62.5–125 µm) or fine sand (125–250 µm) size classes (figure 9-1). In 2015, the sand percentage (%) ranged from < 70 to 90% for sediments extracted from the middle of shoreface to the bay. The highest proportions of sand (85-90%) were observed along the eastern reaches of the island (figure 9-2). Unlike the 2008 sampling, the 2015 event did collect samples in the bay behind the island. These surficial samples showed Caillou Boca to contain considerable concentrations of silty sediments (figure 9-2). The point spacing in the shoreface reaches continues to be too distant for accurate model interpolations. The median grain sizes for the 2015 sediments fell within the very fine sand (62.5–125 µm) or fine sand (125–250 µm) size classes. The courser 2015 sediments followed the subaerial contour of the island and did not venture far into the shoreface (nearshore littoral zone) or the bay (figure 9-2). The longshore model (figure 9-1) demonstrates that a reasonable volume of westward transport occurred from 2006 to 2015 in the nearshore littoral zone, and the 2015 surficial sediment data suggest part of this transport was granular (figure 9-2). While elevation data illustrate that an enlarging (horizontal and vertical growth) shoal migrated to the west and marginally to the south since 2006 (figures 9-1 and 9-2), the 2015 data appears to suggest that these sediments have restricted granular constitutes (figure 9-2). Although moderate quantities of surficial sand deposits are available, the Isles Dernieres and Timbalier Barrier Islands have been characterized as having thin sand layers overlying silt and/or clay substratums (Peyronnin 1962; Penland et al. 1985; Kulp et al. 2005). Therefore, the depth of the granular deposits are projected to be predominantly surficial and the volume available for transport is probably limited. In the future, sediment cores should be extracted to establish a detailed sediment budget for Whiskey Island. These cores should extend 15-20 ft (5-6 m) below the ground surface and stretch from Whiskey Pass to the Coupe Colin Inlet and include shoreface, beach, dune, marsh, and bay habitats like the surficial samples.

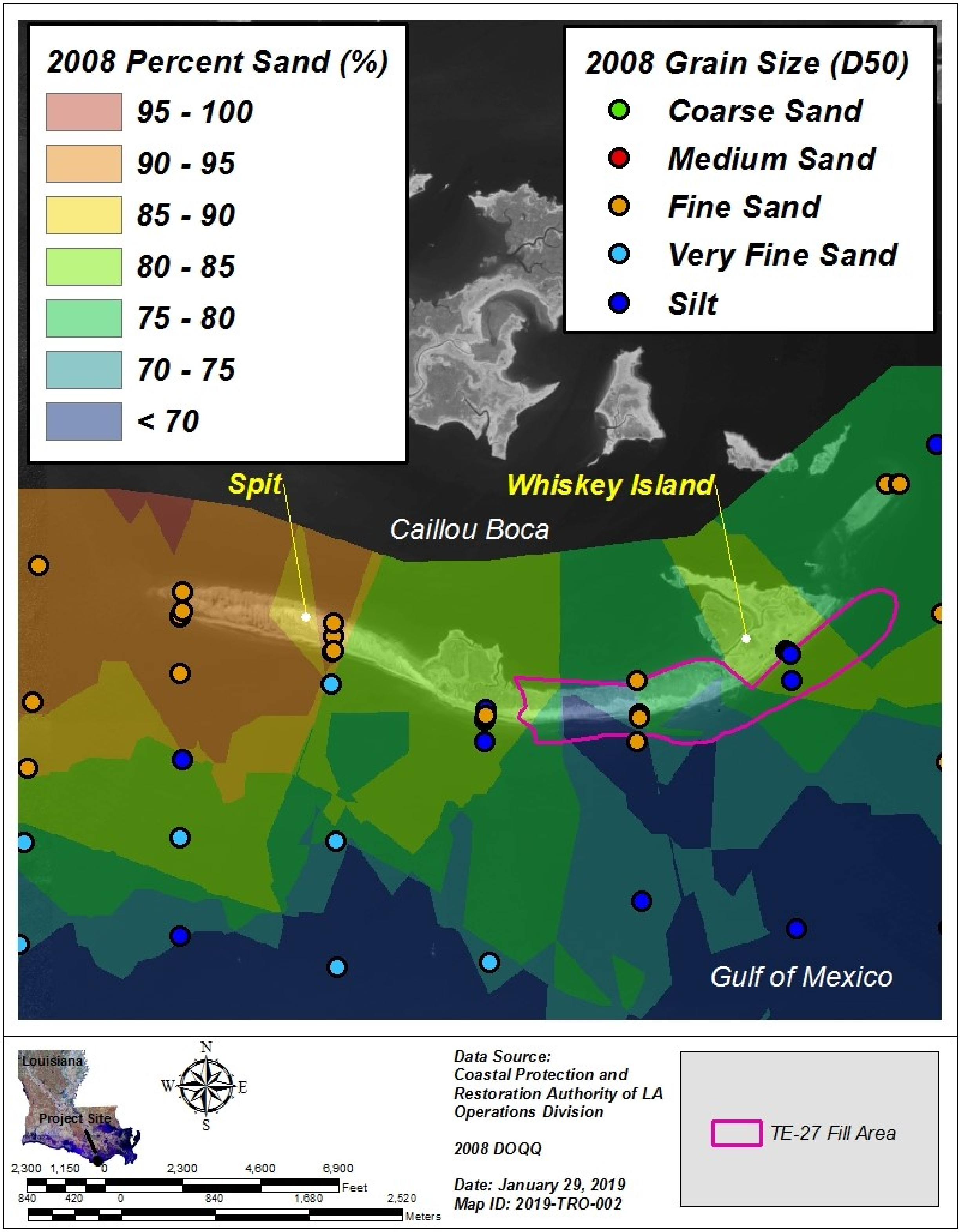

Figure 9-1. Median grain size (D50) and percent sand (%) distributions for Whiskey Island in July 2008.

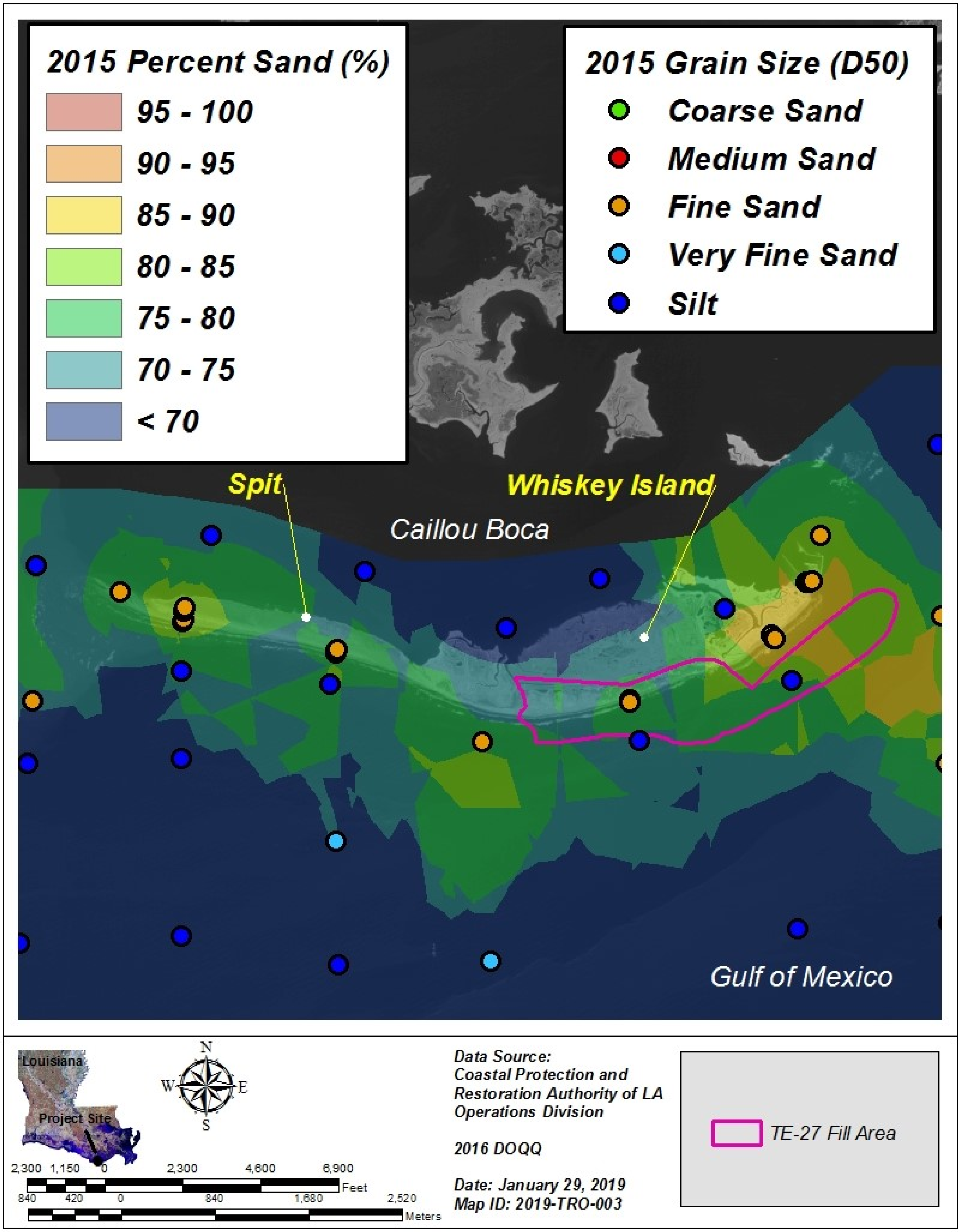

Figure 9-2. Median grain size (D50) and percent sand (%) distributions for Whiskey Island in August 2015.

Chapter 10 – Conclusion and Lessons Learned

The Whiskey Island Restoration (TE-27) and Whiskey Island Back Barrier Marsh Creation (TE-50) projects are accurately assessed as having met their various goals and objectives when assessed against the expected disappearance of Whiskey Island by 2014. The common goals and objectives of the projects related to island stabilization and increased longevity are satisfied based on positive trends in post-restoration shoreline erosion rates, as well as positive post-restoration trends in island length, width and area. Favorable trends were likewise observed in the desired habitat classes and vegetation species composition over time.

The projects had a positive impact on the aforementioned metrics for some time following their respective construction completion dates, and those effects are not only responsible for the mitigating role that Whiskey Island has played in protecting inland resources for the past 20 years, but also its very existence into 2021. The transport of sediment and subsequent migration to other areas points to the importance of these sediment additions in maintaining the island. This result highlights the need to assess barrier island projects within this migrating landscape and not just the specific project footprint.

The use of dredged sand and sediment, combined with sand fencing and vegetative plantings, has proven to be an effective means of increasing stabilization and prolonging the lives of barrier islands and the duration of their many benefits. Increased resilience of these features is vital to an array of environmental and anthropogenic interests. Tropical storm activity is a primary driver of the most dramatic changes observed in Louisiana's barrier islands, including breaches and overwashes that affect various aspects of topography, vegetation, habitat disturbance, and shoreline changes. Winter storms can likewise contribute to similar changes in these features by adding wind and wave energy to an already high energy environment in the open Gulf of Mexico. Despite the challenges which may exist in implementing restoration of an ephemeral geologic feature in this type of environment, the benefits to large sections of Louisiana's coastal zone are clear. Adding sediment from an outside source to the littoral system of Whiskey Island had immediate positive effects to interior marshes, shorelines, and the communities which they protect. Subaerial features protect the interior of the barrier islands immediately upon project completion and the augmentation of vital sediments to the system allows sediment transport processes to function more naturally to protect and enhance adjacent areas. Due to the implementation of these projects, Whiskey Island continues to offer storm protection to interior environments in 2020 and is expected to do so into the future.

Between the TE-27 and TE-50 projects, approximately 5.4 MCY of material was added to the coastal sediment budget (T. Baker Smith and Sons, Inc. 1998 and Department of Natural Resources, 2008), providing resilience to the outer deltaic coast which constitutes the first line of defense to the interior deltaic habitat from storm waves and water levels. The long-term benefit of this restoration approach is the addition of sediment to a littoral system that is otherwise sediment starved (Morang et al., 2013). Augmenting natural sediment delivery to the outer coast not only offers an immediate benefit by creating subaerial land that protects interior habitat, but replenishes adjacent environments through littoral sediment transport during the natural reworking process associated with barrier island restoration.

Lessons Learned

There have been several lessons learned over the decades since the TE-27 and TE-50 projects were constructed. Many of these lessons have been implemented into later projects to make adjustments to and further optimize construction and monitoring activities. Below is a summary of lessons learned and whether those lessons have been implemented:

Planning and Design

Goals and objectives must be better defined and measurable. The goals and objectives for these projects had neither clear definitions nor expected time frames. Goals such as “create acres of land” must indicate whether this is the initial expectation of construction or whether it is intended as the outcome of long-term results. Goals and objectives should also be related to a benchmark such as “projected future conditions without project”. There could be interim goals and objectives to make progress reports easier to compose and to define data collection methods. Planners and designers should frame goals and objects in measurable terms so that design alternatives can be evaluated against a measurable target and later monitoring activities can be planned to adequately assess them.

Monitoring

- Monitoring of elevations and volumes is hampered by survey coverages that are limited to the construction fill footprint, such as the pre-construction and as-built surveys. Barrier islands are a dynamic coastal feature, especially in Louisiana. Elevation data needs should be considered beyond design and construction needs because of the constant changes from environmental processes and extreme weather events. Some data collection events should be done on the entire island system, i.e., inlet to inlet, capturing offshore and bayward areas in order to assess sediment transport within the system through time. Limited spatial coverage only allows for the evaluation of the area common to all surveys over time, which may neglect some important movement of sediment and compounds. The reporting efforts have different numbers being generated for different spatial coverages. Future projects expand the immediate pre-construction or as-built surveys in order to cover additional areas beyond the construction template and provide baseline information for future analysis that incorporates the sediment transport processes.
- Data collection methodology and analysis should remain consistent to the extent possible and correspond as closely as possible to other regional or state initiated programs.
- Monitoring of vegetative plantings survival is different from monitoring of island vegetative succession. These projects initially established vegetative sample plots based on the location of plantings and the survival and spread of these plantings. However, long-term considerations of the goals and objectives were concerned more with establishment and coverage of particular habitats. This change in questions over the life of the project made earlier vegetative sampling schemes ineffective in addressing the questions presented. Vegetative sampling at subsequent projects focused more on assessing long-

term goals, and less on assessing the immediate results of plantings. Project teams need to assess needs and understand the differences in vegetative assessment approaches. Some projects may require both approaches, and this needs to be justified and budgeted.

- Data analysis for each variable should be considered. For example, habitat mapping of aerial imagery should assist ground vegetation data collection and analysis. Vegetation stations should be established to define and support the ground observations which can be used with computer-based algorithms.
- Aerial imagery should be captured immediately after construction to document the as-built condition and serves as the baseline after construction. Typical construction contracts now require both immediate pre-construction imagery as well as post-construction imagery for the as-built condition. The survey data coverages have limited, areas of analysis after construction. The same considerations should be applied to the aerial imagery as the survey coverages.
- When other projects are constructed with overlapping boundaries or within a proximity of influence, older projects that have data gathering components should be evaluated to see how to incorporate that information into new projects.

Literature Cited

Applied Coastal Research and Engineering (ACRE), 2020. Louisiana Operational Sediment Budget: Raccoon Point to Sandy Point, 1985-89 to 2013-16. Final Report prepared for Louisiana Coastal Protection and Restoration Authority, Contract 4400009020, Task 5, 118 p. plus Chapters.

Barras, John A. 2006. Land area change in coastal Louisiana after the 2005 hurricanes a series of three maps: U.S. Geological Survey Open-File Report 06-1274.

Boyd, R. and S. Penland. 1981. Washover of Deltaic Barriers on the Louisiana Coast. Transactions of the Gulf Coast Association of Geological Societies. 31: 243-248.

Byrnes, M.R., J.L. Berlinghoff, S.F. Griffee, and D.M. Lee. 2018. Louisiana Barrier Island Comprehensive Monitoring Program (BICM): Phase 2 – Updated Shoreline Compilation and Change Assessment, 1880s to 2015. Prepared for Louisiana Coastal Protection and Restoration Authority (CPRA) by Applied Coastal Research and Engineering, Mashpee, MA and Metairie, LA, 46 p. plus Chapters.

Choi, J. and J. W. Harvey. 2014. Relative Significance of Microtopography and Vegetation as Controls on Surface Water Flow on a Low-Gradient Floodplain. Wetlands. 34: 101–115.

Curole, G. 2007. Project No. TE-50 Whiskey Island Back Barrier Marsh Creation Monitoring Plan. Coastal Protection and Restoration Authority of Louisiana. 19pp.

Curole, G. P. and D. M. Lee. 2013. 2013 Operations, Maintenance, and Monitoring Report for Raccoon Island Shoreline Protection/Marsh Creation (TE-48), Coastal Protection and Restoration Authority of Louisiana, Thibodaux, Louisiana. 54 pp.

Curole, G. P., B. J. Hartman, and D. M. Lee. 2017. 2017 Operations, Maintenance, and Monitoring Report for West Belle Pass Barrier Headland Restoration (TE-52), Coastal Protection and Restoration Authority of Louisiana, Thibodaux, Louisiana. 67 pp.

Department of Natural Resources. 2008.TE-50 Whiskey Island Back Barrier Marsh Creation As-Built Drawings. https://cims.coastal.louisiana.gov/RecordDetail.aspx?Root=0&sid=22367#

Dingler, J. R. and T. E. Reiss. 1990. Cold-Front Driven Storm Erosion and Overwash in the Central Part of the Isles Dernieres, a Louisiana Barrier-Island Arc. Marine Geology. 91: 195-206.

Enwright, N.M., W.M. SooHoo, J.L. Dugas, C.P. Conzelmann, C. Laurenzano, D.M. Lee, K. Mouton, and S.J. Stelly. 2020. Louisiana Barrier Island Comprehensive Monitoring Program—Mapping habitats in beach, dune, and intertidal environments along the Louisiana Gulf of Mexico shoreline, 2008 and 2015–16: U.S. Geological Survey Open-File Report 2020–1030, 57 pages.

Eustis Engineering Company (Eustis), Inc. 2007. Geotechnical Investigation State of Louisiana Whiskey Island Back Barrier Marsh Creation, Terrebonne Parish, Louisiana. DNR Contract No. 2511-06-04. Eustis Project No. 19186. 43 pp. plus Chapters.

Fearnley, S., L. Brien, L. Martinez, M. Miner, M. Kulp, and S. Penland. 2009. Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Volume 5: Chenier Plain, South Central

Louisiana, and Chandeleur Islands - Habitat Mapping and Change Analysis 1996 to 2005. Prepared for the LA Dept. Natural Resources by the Pontchartrain Institute for Environmental Sciences, University of New Orleans. 11 pp.

Folse, T.M., Sharp, L.A., West, J.L., Hymel, M.K., Troutman, J.P., McGinnis, T.E., Weifenbach, D., Boshart, W.M., Rodrigue, L.B., Richardi, D.C., Wood, W.B., and Miller, C.M. 2008, revised 2014. A Standard Operating Procedures Manual for the Coast-wide Reference Monitoring System-Wetlands: Methods for Site Establishment, Data Collection, and Quality Assurance/Quality Control. Louisiana Coastal Protection and Restoration Authority. Baton Rouge, LA. 228 pp.

Frazier, D.E. 1967. Recent deposits of the Mississippi River, their development and chronology. Transactions, Gulf Coast Association of Geological Societies 17: 287-311.

Georgiou, I. Y., D. M. Fitzgerald, and G. W. Stone. 2005. The Impact of Physical Processes along the Louisiana Coast. Journal of Coastal Research SI 44: 72-89.

Himmelstoss, E.A., Henderson, R.E., Kratzmann, M.G., and Farris, A.S., 2018, Digital Shoreline Analysis System (DSAS) version 5.0 user guide: U.S. Geological Survey Open-File Report 2018–1179, 110 p., https://doi.org/10.3133/ofr20181179.

Hughes, Z. J., D. M. FitzGerald, C. A. Wilson, S. C. Pennings, K. Wieski, and A. Mahadevan. 2009. Rapid Headward Erosion of Marsh Creeks in Response to Relative Sea level Rise. Geophysical Research Letters. 36: 1-5. doi:10.1029/2008GL036000

Kindinger, J.L., Buster, N.A., Flocks, J.G., Bernier, J.C., and Kulp, M.A., 2013, Louisiana Barrier Island Comprehensive Monitoring (BICM) Program Summary Report: Data and Analyses 2006 through 2010: U.S. Geological Survey Open-File Report 2013–1083, 86 p.

Kulp, M., D. M. FitzGerald, and S. Penland. 2005. Sand-rich Lithosomes of the Holocene Mississippi River Delta Plain. in: J. Bhattacharya and L. Giosan (eds.), River Deltas: Concepts, Models, and Examples, Society for Sedimentary Geology (SEPM) Special Publication No. 83: 279-293.

Kulp, M. A., M. Miner, D. Weathers, J. P. Motti, P. McCarty, M. Brown, J. Labold, A Boudreaux, J. G. Flocks and C. Taylor. 2011. Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Volume 6, Part A: Characterization of Louisiana Coastal Zone Sediment Samples: Backbarrier through offshore samples of the Chenier Plain, South Central Barrier Island Systems and Chandeleur Islands. Pontchartrain Institute of Environmental Sciences, University of New Orleans, New Orleans, LA. 10 pp.

Kulp, M.A., I. Y Georgiou, M. Brown, A. Courtois, J. G. Flocks, and T. Tuten. 2015. Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Phase 2 - 2015 Characterization of Surficial Sediments in the Early Lafourche Delta, Late Lafourche Delta, Modern Delta, and Chandeleur Islands Regions: Part A - Data Collection, Sample Processing and Products. Prepared for Louisiana Coastal Protection and Restoration Authority (CPRA) by Pontchartrain Institute for Environmental Sciences, Baton Rouge, LA and New Orleans, LA, 16 pp.

Leatherman, S.P. 2003. Shoreline change mapping and management along the U.S. East Coast. In: Byrnes, M.R., M. Crowell, and C. Fowler (eds.), Shoreline Mapping and Change Analysis: Technical Considerations and Management Implications, Journal Coastal Research, Special Issue No. 38, pp. 5-13.

List, J.H., B.E. Jaffe, A.H. Sallenger, and M.E. Hansen. 1997. Bathymetric comparisons adjacent to the Louisiana barrier islands: processes of large scale change. Journal of Coastal Research 13:670-678.

Martinez, L., S. O'Brien, M. Bethel, S. Penland, and M. Kulp. 2009. Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Volume 2: Shoreline Changes and Barrier Island Land Loss 1800's-2005. Pontchartrain Institute of Environmental Sciences, University of New Orleans, New Orleans, LA. 32 pp.

McBride, R. A., S. Penland, B. E. Jaffe, S. J. Williams, A. H. Sallenger, and K. A. Westphal. 1989. Erosion and Deterioration of the Isles Dernieres barrier Island Arc-Louisiana, U.S.A.: 1853-1988. Transactions of the Gulf Coast Association of Geological Societies 39:431-444.

McBride, R.A., M.W. Hiland, S. Penland, S.J. Williams, M.R. Byrnes, K.A. Westphal, B.E. Jaffee, and A.H. Sallenger, Jr. 1991. Mapping barrier island changes in Louisiana: techniques, accuracy, and results. Seattle, WA: Coastal Sediments >91 Proceedings. pp 1011-1025.

McBride, R. A. and M. R. Byrnes. 1997. Regional Variations in Shore Response Along Barrier Island Systems of the Mississippi River Delta Plain: Historical Change and Future Prediction. Journal of Coastal Research. 13: 628-655.

Minello, T. J., R. J Zimmerman, and R. Medina. 1994. The Importance of Edge for Natant Macrofauna in a Created Salt Marsh. Wetlands 14: 184-198.

Morang, A., Rosati, J.D., and King, D.B., 2013. Regional sediment processes, sediment supply, and their impact on the Louisiana coast. In: Brock, J.C.; Barras, J.A., and Williams, S.J. (eds.), Understanding and Predicting Change in the Coastal Ecosystems of the Northern Gulf of Mexico, Journal of Coastal Research, Special Issue No. 63, pp. 141-165.

Morgan, J.P. and Larimore, P.B., 1957. Changes in the Louisiana shoreline. Gulf Coast Association of Geological Societies, Transactions, 7, 303-310.

Morton, R., T. Miller, and L. Moore. 2004. Vectorized Shoreline of Louisiana Derived from 1973-1978 Source Data: Open-File Report 2004-1089, U.S. Geological Survey, Coastal and Marine Geology Program, U.S. Geological Survey, Center for Coastal and Watershed Studies, St. Petersburg, FL.

Morton, R. A. and J. A. Barras. 2010. Hurricane Impacts on Coastal Wetlands: A Half-Century Record of Storm-Generated Features from Southern Louisiana. Journal of Coastal Research 27: 27-43.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, Inc. NY. 547 pp.

National Oceanographic and Atmospheric Administration (NOAA), 2002a. Tropical Cyclone Report, Hurricane Isidore, revised July 2003.
URL: https://www.nhc.noaa.gov/data/tcr/AL102002_Isidore.pdf
National Oceanographic and Atmospheric Administration (NOAA), 2002b. Tropical Cyclone Report, Hurricane Lili, revised April 2003 and August 2011. URL: https://www.nhc.noaa.gov/data/tcr/AL132002_Lili.pdf

National Oceanographic and Atmospheric Administration (NOAA), 2009. Tropical Cyclone Report, Hurricane Gustav, revised September 2009. URL: https://www.nhc.noaa.gov/data/tcr/AL072008_Gustav.pdf

National Oceanographic and Atmospheric Administration (NOAA), 2013. Tropical Cyclone Report, Hurricane Isaac. URL: https://www.nhc.noaa.gov/data/tcr/AL092012_Isaac.pdf

National Oceanographic and Atmospheric Administration (NOAA), 2019. Historical Hurricane Tracks. URL: https://coast.noaa.gov/hurricanes/; accessed on March 1, 2019.

Neumeier, U., P. Poulin, M. Rogé, A. Morisette, and A. Huard. 2013. Morphology and Evolution of Salt Marsh Pans in the Lower St. Lawrence Estuary. Coastal Dynamics. 1275-1286.

Novakowski, K. I., R. Torres, R. Gardner, and G. Voulgaris. 2004. Geomorphic Analysis of Tidal Creek Networks. Water Resources Research. 40: 1-13. doi:10.1029/2003WR002722

Penland, S., J. R. Suter, and R. Boyd. 1985. Barrier Island Arcs along Abandoned Mississippi River Deltas. Marine Geology 63: 197-233.

Penland, S., J.R. Suter, and R. Boyd. 1988. The transgressive depositional systems of the Mississippi River delta plain: A model for barrier shoreline and shelf sand development. Journal of Sedimentary Petrology 58:932-949.

Penland, S., P. Connor, F. Cretini, and K. Westphal. 2003. CWPPRA Adaptive Management: Assessment of five barrier island restoration projects in Louisiana. Pontchartrain Institute for Environmental Sciences, University of New Orleans, New Orleans, LA. 64pp, plus Chapters.

Penland, S. and K.E. Ramsey. 1990. Relative sea-level rise in Louisiana and the Gulf of Mexico: 1908-1988. Journal of Coastal Research 6:323-342.

Perillo, G. M. E. 2009. Tidal Courses: Classification, Origin and Functionality. Pp. 185-209 in G. M. E. Perillo, E. Wolanski, D. R. Cahoon, and M. M. Brinson, ed. Coastal Wetlands: An Integrated Ecosystem Approach. Elsevier. 940 pp.

Peterson, G. W. and R. E. Turner. 1994. The Value of Salt Marsh Edge vs Interior as a Habitat for Fish and Decapod Crustaceans in a Louisiana Tidal Marsh. Estuaries. 17. 235-262.

Peyronnin, C. A., Jr. 1962. Erosion of the Isles Dernieres and Timbalier Islands. Journal of the Waterways and Harbors Division, American Society of Civil Engineers 88: 57-69.

Ritchie, W. and S. Penland. 1988. Rapid Dune Changes Associated with Overwash Processes on the Deltaic Coast of South Louisiana. Marine Geology. 81: 97-122.

Rodrigue, L. B., G. P.Curole, D.M. Lee. and D. A. Dearmond. 2008. 2008 Operations, Maintenance, and Monitoring Report for Whiskey Island Restoration (TE-27) Project, Coastal Protection and Restoration Authority of Louisiana, Office of Coastal Protection and Restoration, Thibodaux, Louisiana. 26 pages plus appendices.

Rodrigue, L B., G. P. Curole, and D. M. Lee. 2011. 2011 Operations, Maintenance, and Monitoring Report for Timbalier Island Dune/Marsh Restoration Project (TE-40), Coastal Protection and Restoration Authority of Louisiana, Office of Coastal Protection and Restoration, Thibodaux, Louisiana. 27 pp.

Roy. 2002. Wetland Value Assessment Methodology – Barrier Island Community Model. Coastal Wetlands Planning, Protection and Restoration Act, Environmental Work Group. 21pp.

Shalowitz, A.L. 1964. Shoreline and Sea Boundaries, Volume 2. Washington, D.C.: U.S. Government Printing Office, U.S. Coast and Geodetic Survey, U.S. Department of Commerce Publication 10-1, 420p.

Stone, G. W. and X. Zhang. 2001. A Longshore Sediment Transport Model for the Timbalier Islands and Isle Dernieres, Louisiana. Coastal Studies Institute, Louisiana State University, Baton Rouge, LA. 28 pp.

Sylvest, J., G. Curole, E. Lear, T. Hubbell, D. Lee, and T. Folse. 2020. 2020 Monitoring Close-out Report for Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24) Projects, and New Cut Dune and Marsh Restoration (TE-37) Project. Thibodaux, Louisiana: Coastal Protection and Restoration Authority of Louisiana, 30p plus Chapters.

T. Baker Smith, Inc. 1998. Isle Dernieres Restoration Projects TE-27 – As-Built Report. https://cims.coastal.louisiana.gov/RecordDetail.aspx?Root=0&sid=952

T. Baker Smith, Inc. 2007. New Cut Dune/Marsh Restoration Project (TE-37), Project Completion Report. Prepared for LA Dept. Natural Resources by T. Baker Smith, Inc. Houma, LA. 11 pages plus Chapters.

T. Baker Smith, Inc. 2010. Whiskey Island Back Barrier Marsh Creation Project (TE-50), Project Completion Report. Prepared by T. Baker Smith, Inc. Houma, LA. 15 pages plus Appendices.

Townson, M. 1998. Monitoring Plan – Project No. TE-27 Whiskey Island Restoration. LA Dept. Natural Resources, Coastal Restoration Div, Thibodaux, LA 10 pgs.

Troutman, J. P., D. M. Lee, S. M. Khalil, B. S. Carter, K. S. Gray, and L. A. Reynolds. 2003. Draft Barrier Island Comprehensive Monitoring Program (BICM). Louisiana Department of Natural Resources Coastal Restoration Division Biological Monitoring Section.

Tyler, A. C. and J. C. Zieman. 1999. Patterns of Development in the Creekbank Region of a Barrier Island Spartina alterniflora Marsh. Marine Ecology Progress Series. 180: 161-177.

Vu, H. 2016. Biophysical Feedbacks Mediate Tidal Creek Formation in Salt Marshes. Ph.D. Dissertation, University of Houston 93 pp.

Wallace, K. J., J. C. Callaway, and J. B. Zedler. 2005. Evolution of Tidal Creek Networks in a High Sedimentation Environment: A 5-year Experiment at Tijuana Estuary, California. Estuaries. 28: 795-811.

Wentworth, C. K. 1922. A Scale of Grade and Class Terms for Clastic Sediments. Journal of Geology 30: 377-392.

West, J.L. and D. Dearmond. 2004. 2004 Operations, Maintenance, and Monitoring Report for Whiskey Island Restoration (TE-27), Louisiana Department of Natural Resources, Coastal Restoration Division, Thibodaux, Louisiana. 23pp.

West, J. L. and D. Dearmond. 2007. 2004 Operations, Maintenance, and Monitoring Report for Whiskey Island Restoration (TE-27), Louisiana Department of Natural Resources, Coastal Restoration Division, Thibodaux, Louisiana. 23 pp.

Williams, S.J., S. Penland, A. Sallenger, eds. 1992. Louisiana Barrier Island Erosion Study – Atlas of Shoreline Changes in Louisiana from 1853 to 1989. Prepared in cooperation with LA Geological Survey by US Geological Survey, Miscellaneous Investigations Series I-2150-A. Washington, DC.