Coastal Protection and Restoration Authority of Louisiana

2023
Monitoring Close-out Report

for

Timbalier Island Dune and Marsh Restoration (TE-40)

State Project Number TE-0040
Priority Project List 9

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Terrebonne Parish

Prepared by: Joshua Sylvest, Todd Hubbell and Glen Curole

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

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Chapter 1 – Historical and Project Background

Historical Background

Timbalier Island is considered part of the Bayou Lafourche barrier system and is located about 63 miles (101 km) west of the mouth of the Mississippi River's Southwest Pass and approximately 62 miles (100 km) south of downtown New Orleans (Figure 1-1). The island originated from the westward progradation of the Caminada-Moreau headland. Erosion from the Caminada-Moreau headland remains the primary source of sand to Timbalier Island.

An important function of barrier islands is to protect wetland areas from waves, storm surges, and salt water intrusion (McBride et al. 1992). Timbalier Island acts as a buffer for the bays, estuaries, and wetlands of the Terrebonne Basin, reducing the wave energy the marshes experience by shielding Timbalier Bay from the Gulf of Mexico. These bays, estuaries, and wetlands are important for commercial and recreational fisheries and wildlife, and as protection against storm damage to nearby oil and gas facilities and other infrastructure farther inland. In addition, barrier islands provide important stop over habitat for neotropical trans-gulf migrants and permanent homes for many native bird species.

The first mapping of the Timbalier Island occurred in the 1880's showing 3,646 acres of land (Figure 1-2); since that time, additional mapping efforts have allowed erosion rates to be estimated for multiple intervals. The average gulfside erosion rate between 1887 and 1988 was 7.9 ft/yr; the average gulfside erosion rate in the final ten years of that analysis period, however, was 22.9 ft/yr indicating that erosion was accelerating.

A longshore sediment transport model for Timbalier Island demonstrates net sediment transport is westward (Stone and Zhang 2001). This suggests that sand being eroded from the east flank is being transported to the west where it is deposited along the west flank of the island and in Cat Island Pass (Miner et al. 2009). The majority of passes are serving as sinks to longshore transport (Levin 1993). The eastern flanks of the Timbalier Islands and the Isles Dernieres are serving as sediment sources for transport of sediment to spit ends and to the passes (Stone and Zhang 2001).

The barrier islands on the Timbalier and Isles Dernieres chain have entered a final phase of disintegration that involves a complex structured longshore sediment transport system. Timbalier Island decreased in size by 58% over the course of the twentieth century (Townson et al 1999), this reduction primarily attributable to sea level rise, winter storms, and tropical events. There have been 88 tropical systems pass within 60 nautical miles of the project area between 1856 and 2012. While no additional tropical systems passed as closely between 2012 and 2019, seven more storms passed within 60 nautical miles of the island between 2019 and 2021 (Appendix A). Storm characteristics such as forward speed, size and/ or intensity allow additional storms to impact the project area despite passing outside of a 60 nautical mile radius; Hurricanes Lili (2002) and Rita (2005) were two such hurricanes. Each passed south and west of the project area as large, category 4 and 5 cyclones, respectively, causing the most intense quadrant of the storm to influence the project area.

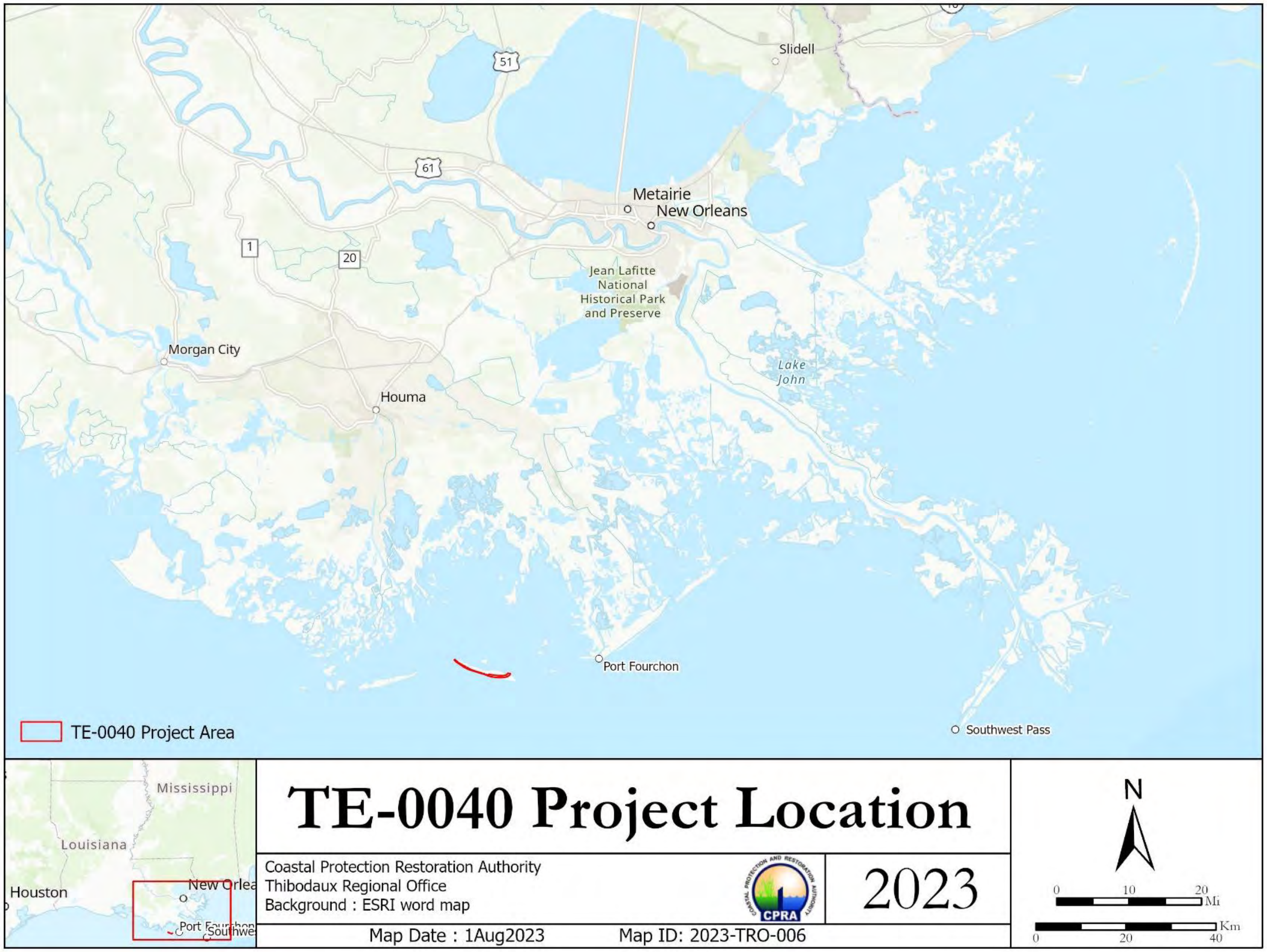


Figure 1-1. Map showing Timbalier Island and Timbalier Island Dune and Marsh Restoration (TE-0040) project area relative to New Orleans, Port Fourchon and the Mississippi River's Southwest Pass.

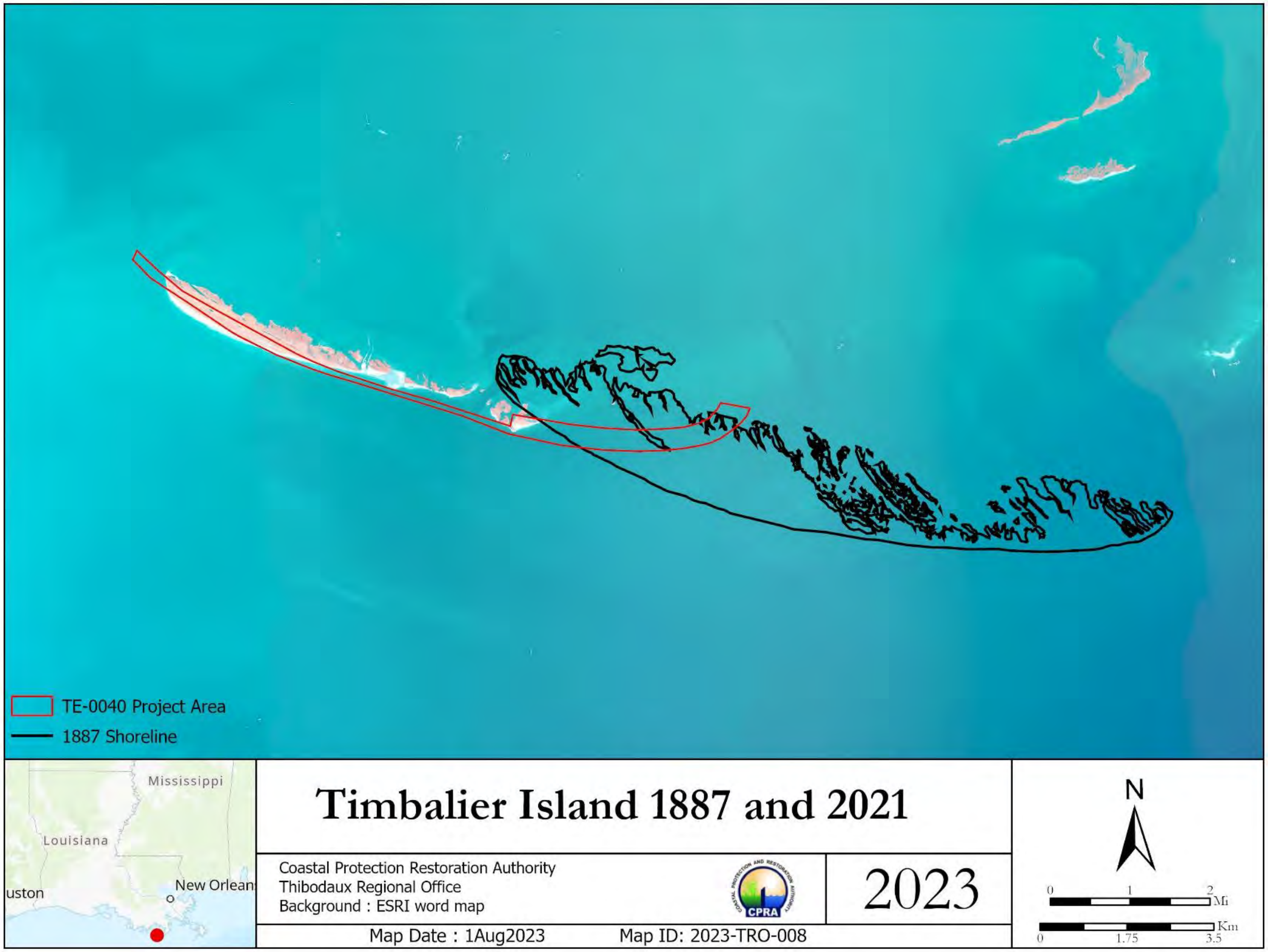


Figure 1-2. Satellite image taken in 2021 showing Timbalier Island and Timbalier Island Dune and Marsh Restoration (TE-0040) project area, and the Timbalier 1887 Shoreline (black outline).

At the time of project conception, Timbalier Island was projected to disappear by year 2050 without restoration (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority 1998), while analyses in chapter 2 of this report suggested that the island could disappear as early as 2041 (Figure 1-3).

Project Background

The Timbalier Island Dune and Marsh Restoration (TE-40) project was proposed at the January 1999 regional nomination workshop conducted by the Planning and Evaluation (P&E) as part of the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) which was signed into law on November 29, 1990 (CWPPRA, Public Law 101-646, Title III). The proposed project consisted of two areas, A and B. Area A is on the east end of the island and consisted of 197 acres of open water and 200 acres of beach, vegetated dune, and marsh. Area A included the area to be directly restored by the creation of dune and marsh. Area B included an area to be enhanced by the addition of sediment into the nearshore system and consisted of 112 acres of land and 154 areas of open water. The reason the project was proposed was due to the islands rapid migration to the west/northwest. The western end of the island was undergoing lateral migration by spit-building process, at the expense of erosion along the eastern end, while the island overall was shortening and narrowing. This loss can be attributed to an inadequate sediment supply, relative sea level rise, and the passage of storms. The island was projected to disappear by the year 2050.

On March 31, 1999, the Timbalier Island Dune and Marsh Creation project was selected by the Technical Committee for designing and cost estimating and became a project on the Project Priority List (PPL) number 9. On January 11, 2000, the project was selected for engineering and design (Phase I) funding by the CWPPRA Task Force. At the end of the design phase, the design selected for construction consisted of:

- A dune feature that was designed to a +8.0 ft elevation and a width of ~400 ft
- A berm feature between the dune and marsh platform; +4.0 ft and ~100 ft wide
- A marsh platform that was sloped from a +1.6 ft at the berm to a +0.6 ft at the bay; ~ 800 ft wide
- 22,750 linear feet of sand fencing

The design was for a 20-year project life.

In January 2003, the project was awarded the funds for construction through CWPPRA. Construction began in June 2004, dredging was completed 6 months later in December 2004, and the project was accepted for completion a month later in January 2005. The sand fencing was installed from October 2004 through December 2004. A second sand fencing construction event was accepted in April 2006, adding an additional 11,648.5 linear foot of sand fencing. This event utilized remaining funds from construction.

Plantings were installed in March 2005 and was completed in June 2005. A second plantings event occurred in May/June 2006 where, twenty-eight nutrias were eradicated from the island prior to planting an additional 40,000 plugs and 2,000 containers were planted.

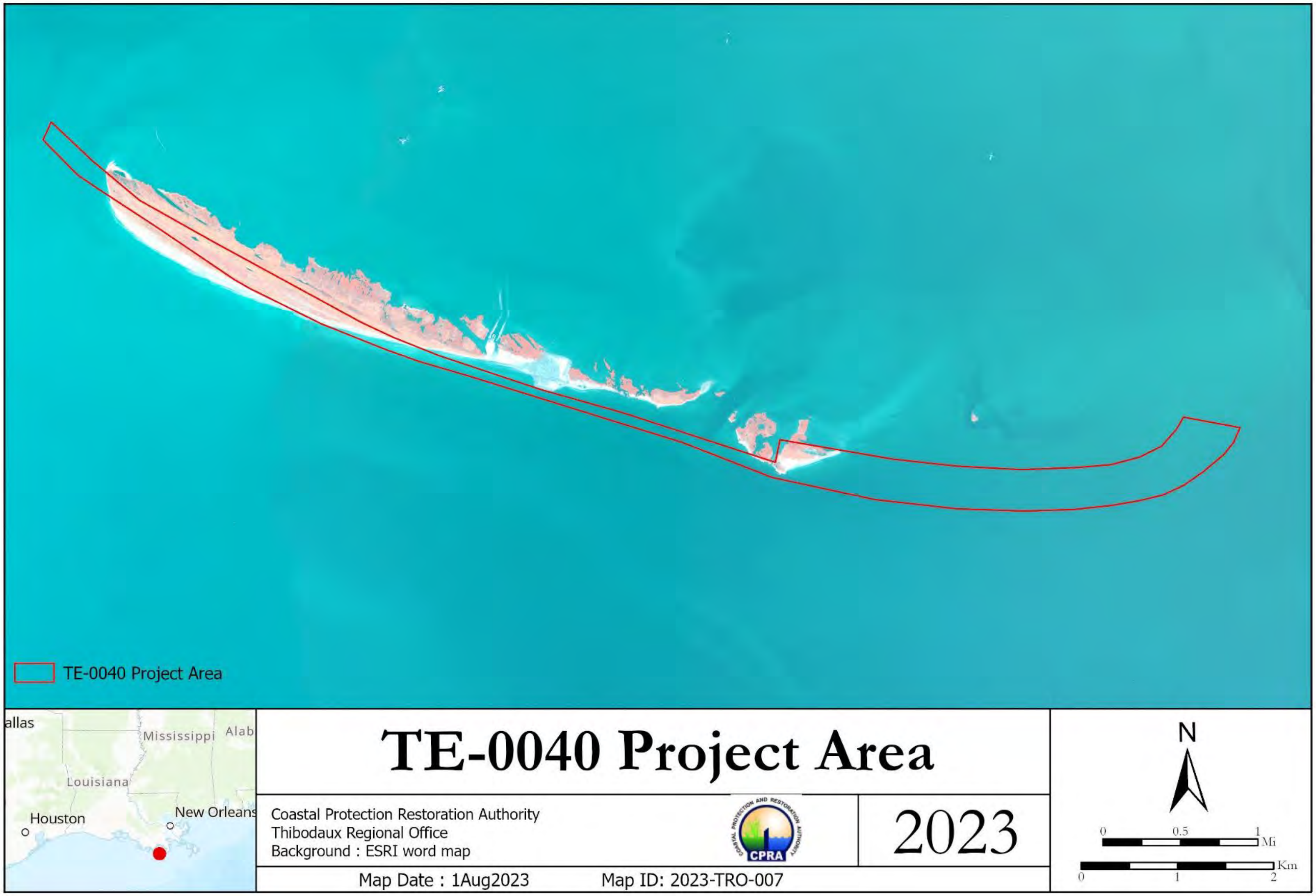


Figure 1-3. Satellite image taken in 2021 showing Timbalier Island and Timbalier Island Marsh and Dune Restoration (TE-40) project area.

The project is sponsored by the United States Environmental Protection Agency (EPA) and the Louisiana Office of Coastal Protection and Restoration (OCPR) under the Coastal Wetlands Planning, Protection, and Restoration Act.

Project Goals and Objectives

The project goals were to construct dune and salt marsh such that the overall area (length and width) and sediment volume of Timbalier Island would increase. Construction of the dune will immediately increase the area of the dune and the maximum and average elevation of the island; while construction of the salt marsh will eventually increase the area of salt marsh on the island. Planting vegetation and installing sand fencing should reduce the rate of loss of sand from the disposal area. The project goals were (1) to restore the eastern end of Timbalier Island and (2) to maintain the lateral migration of Timbalier Island. The project strategy was that the dune and marsh platform would be constructed and stabilized through the deposition of dredge material, vegetative plantings, and sand fencing. These project goals and strategies are stated in the monitoring plan (2007).

The specific measurable monitoring goals established to evaluate the effectiveness of the project are:

1. Determine the area, average width, length, and position of Timbalier Island and the project area over time.
2. Determine the effectiveness of project features in reducing the rate of erosion as compared to historical rates of erosion and maintaining the littoral transport of the shoreline.
3. Determine sediment characteristics and their change over time.
4. Determine the evolution of tidal channel development.
5. Determine elevation and habitat classes in the project area.

This report evaluates the project based on changes of the shoreline, area, length, width, volume of sediment, and habitat. Prior to restoration efforts, the prediction was that the island would become subaqueous by 2041 (Chapter 2) or 2050 (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority 1998). If the analysis of post-construction data (2004-2016) indicates that Timablier Island will be subaerial beyond 2041, and/or the acreage at the end of the data analysis is greater than the pre-construction prediction, then the project should be deemed a success.

Chapter 2 - Land Area and Dimensional Change at Timbalier Island due to the Timbalier Island Dune and Marsh Creation (TE-40) Project

Introduction

In order to assess the restoration efforts of the Timbalier Island Dune and Marsh Creation (TE-40) project on Timbalier Island, georectified aerial photographs were analyzed to determine land area change rates both prior to and following project completion in 2005. This assessment of land area and dimensional change will help to evaluate aspects of the first stated goal to determine the area, length and width of Timbalier Island.

Methods

Length, width, and area were calculated along the entire subaerial length of Timbalier Island for the Timbalier Island Dune and Marsh Restoration (TE-40) project using UTM NAD83 georectified aerial photography. Island lengths were estimated with the linear measuring tool of ArcGIS® at a 1:5000 scale. To quantify island length in meters (m), an east to west line was drawn with the measuring tool in the center of the island. This line was sketched only where visible subaerial land existed. Pre-construction (February 4, 1998, May14, 2002, and January 19, 2004), as-built (October 28, 2005), and post-construction (October 30, 2008, November 7, 2012, and November 1, 2016) aerial photographs were utilized to outline the length of Timbalier Island over time. Once all lengths were measured, changes in island length (m) over time were calculated through subtraction and percent differences (%) for the following intervals: February 1998-May 2002, February 1998-January 2004, January 2004-October 2005, October 2005-October 2008, October 2005-November 2012, and October 2005-November 2016.

To determine the north to south width of Timbalier Island over time, the Digital Shoreline Analysis System (DSAS version 2.1.1) extension of ArcView® GIS was utilized (Thieler et al 2003). The first step in this process was to outline the Gulf of Mexico and Caillou Pass shoreline positions for each aerial photograph. Shoreline positions were determined by digitizing UTM NAD83 georectified aerial photographs at a 1:5000 scale as per the Folse et al. (2008) method. Pre-construction (February 4, 1998, May14, 2002, and January 19, 2004), as-built (October 28, 2005), and post-construction (October 30, 2008, November 7, 2012, and November 1, 2016) aerial photographs were applied to define the width of Timbalier Island over time. These were the same aerial photographs used to establish island length. Once the shorelines were delineated a baseline was created and 4,000 m (13,123 ft) simple transects were cast at 152 m (500 ft) intervals to assess the distance (m) between the gulf and pass shoreline positions (island width) for each aerial image. The transect widths were averaged and the population sizes (n) were tabulated to summarize the island width as a single value for each time period. Once all widths were measured, changes in island width (m) over time were calculated through subtraction and percent differences (%) for the following intervals (same intervals as length measurements) February 1998-May 2002, February 1998-January 2004, January 2004-October 2005, October 2005-October 2008, October 2005-November 2012, and October 2005-November 2016. All results were reported in a tabular format.

The areal extent of Timbalier Island was estimated over time by drawing polygons around the visible subaerial land habitats on the island using UTM NAD83 georectified aerial photography. The Barrier Island Comprehensive Monitoring (BICM) program delineated these areas and created polygons from aerial photographs in February 4, 1998, January 19, 2004, October 28, 2005, October 30, 2008, November 7, 2012, and August 26, 2015 (Byrnes et al. 2018). In addition, area was estimated for May14, 2002 and November 1, 2016 aerial images by adapting BICM polygons to fit the overlain images at a 1:5000 scale (May14, 2002 adapted from January 19, 2004 polygon and November 1, 2016 adapted from August 26, 2015 polygon). After outlining the areal extent of subaerial land, areas (U.S. Acres) inside the polygons were calculated using the Calculate Area function of ArcGIS®. Once all areas were calculated, changes in island area (m) over time were calculated through subtraction and percent differences (%) for the following intervals February 1998-May 2002, February 1998-January 2004, January 2004-October 2005, October 2005-October 2008, October 2005-November 2012, October 2005-August 2015, and October 2005-November 2016. All results were reported in a tabular format.

Results and Discussion

The width, length, and area of Timbalier Island have declined since construction of the TE-40 project. Table 2-1 lists these measurements chronologically from 1998 to 2016 while Table 2-2 (width and length) and Table 2-3 (area) display deviations in these variables (changes and percent differences) for pre- and post-construction intervals over the project timeline. Sub-areal measurements between 1978 and 2016 are also graphically displayed in Figure 2-1 to compare trends in this metric before and after the restoration, and to estimate how quickly the island would disappear without restoration. This analysis estimated that Timbalier Island would disappear in 2041 without the construction of Timbalier Island Dune and Marsh Restoration (TE-40) Project.

For the pre-construction period, the width of the island increased and the length decreased (Tables 2-1 and 2-2). The reduction in length for this period was a result of constriction of both the eastern [229 m (750 ft)] and western [305 m (1,000 ft)] fringes of the island. Due to the expansion in width and the diminished island length, the pre-construction changes in area were nominal for the 1998-2004 interval (Table 2-3). Also in 2004, four small inlets formed across the eastern end of the island and were likely initiated by hurricanes Isidore and Lili in 2002. The pre-construction grid model (June 2004) displays the formation of three of these breaches. Moreover, pre-construction aerial images have shown that in the recent past, the eastern margins of Timbalier Island have been prone to overwash and inlet formation due to the narrow width and fragmented landscape of the eastern reaches. In addition, aerial images depict erosion in the lee of the revetment for the 1998-2004 interval.

Table 2-1. Mean width, length, and area of Timbalier Island during the TE-40 project timeline (1998-2016).

Timbalier Island (Year)	Project Timeline	Mean Width m (ft)	Width Sample Size (n)	Mean Length m (ft)	Area (Acres)
1998	Pre1	299 (980)	82	13,142 (43,118)	1,095
2002	Pre2	331 (1,087)	83	13,236 (43,424)	1,269
2004	Pre3	371 (1,216)	81	12,584 (41,284)	1,077
2005	As-built	396 (1,300)	76	10,898 (35,755)	1,029
2008	Post1	361 (1,186)	67	9,656 (31,678)	938
2012	Post2	385 (1,262)	66	10,086 (33,090)	962
2015	Post3	-	-	-	974
2016	Post4	325 (1,067)	69	10,828 (35,525)	958

Table 2-2. Timbalier Island width and length deviations (changes and percent differences) during the TE-40 project timeline (1998-2016).

Timbalier Intervals	Project Timeline	Change Width m (ft)	Width Percent Difference (%)	Change Length m (ft)	Length Percent Difference (%)
1998-2002	Pre1-Pre2	32 (105)	11	93 (306)	1
1998-2004	Pre1-Pre3	72 (236)	24	-559 (-1,834)	-4
2004-2005	Pre3-As-built	26 (85)	7	-1,685 (-5,529)	-13
2005-2008	As-built-Post1	-35 (-115)	-9	-1,243 (-4,077)	-11
2005-2012	As-built-Post2	-12 (-39)	-3	-703 (-2,305)	-7
2005-2016	As-built-Post4	-71 (-233)	-18	-70 (-230)	-1

Table 2-3. Timbalier Island area deviations (changes and percent differences) during the TE-40 project timeline (1998-2016).

Timbalier Area Intervals	Project Timeline	Change Area Acres	Area Percent Difference (%)
1998-2002	Pre1-Pre2	174	16
1998-2004	Pre1-Pre3	-18	-2
2004-2005	Pre3-As-built	-49	-5
2005-2008	As-built-Post1	-91	-9
2005-2012	As-built-Post2	-67	-7
2005-2015	As-built-Post3	-54	-5
2005-2016	As-built-Post4	-71	-7

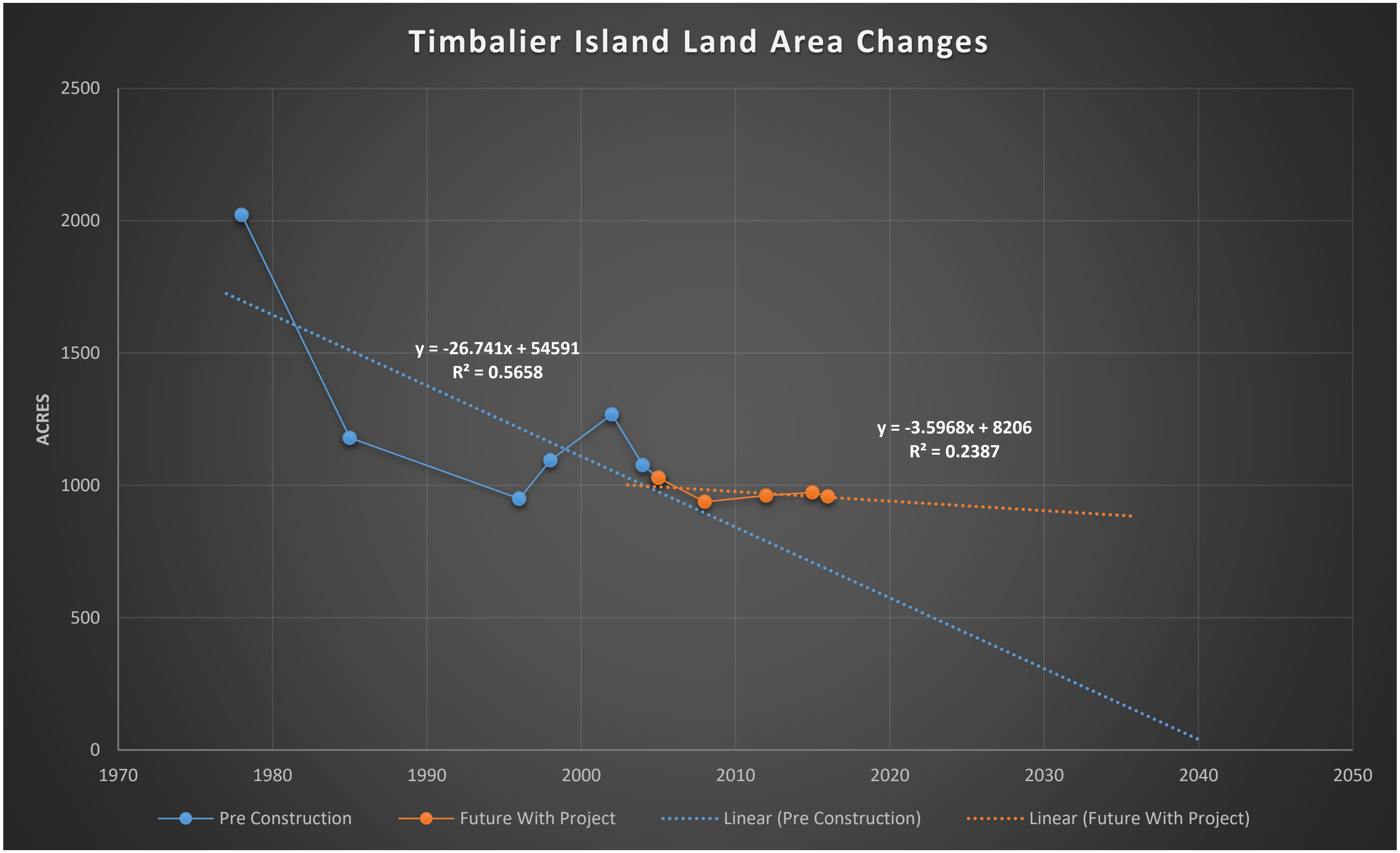


Figure 2-1. Land area changes from 1978 through 2016 at Timbalier Island, Terrebonne Parish, LA. Pre-construction trends suggest that without restoration, the island would have become subaqueous by 2041.

During the as-built timeline (2005) and interval (2004-2005), Timbalier Island's width expanded while its length and area were condensed (Tables 2-1, 2-2, and 2-3). It must be noted that the as-built image was captured in October 2005 after the passage of the historical hurricanes of 2005 (Cindy, Katrina, and Rita) (Barras 2006; Fearnley et al. 2009; Martinez et al. 2009) although the TE-40 project was completed in January 2005. Therefore, the reduction in inland length and area were primarily caused through hurricane forcing on the eastern edge of the island, and the gain in island width was a consequence of the addition of granular sediments by the TE-40 project.

Ensuing post-construction dimensional measurements show that post-construction losses in length and area peaked in 2008 and reductions in width were also considerable in 2008 (Tables 2-1, 2-2, and 2-3). Hurricanes Gustav (September 2008) and Ike (September 2008) forced the TE-40 fill area to transgress in the western direction and moderately reduced the western extents of the island. Hurricane Gustav passed within 8 km (5 mi) of Timbalier Island and induced substantial erosion and land loss in the TE-40 fill area (Morton and Barras 2010; Rodrigue et al. 2011). In 2012 width, length, and area exhibited minor recoveries (Tables 2-1, 2-2, and 2-3) and the eastern part of the island began to rotate around the revetment to the northwest (counter clockwise) while the western reaches of the island maintained their horizontal positions. The 2016 dimensional measurements indicate that Timbalier Island's width was sizably reduced, the island elongated to the east, and the area of the island slightly declined (Tables 2-1, 2-2, and 2-3). The reduction in island width was a result of the elongation of a very narrow spit to the east, erosion on both sides of the revetment including the remaining vestiges or the TE-40 fill area, and erosion on the bay side of the island likely induced by winter storms (Boyd and Penland 1981; Dingler and Reiss 1990; Ritchie and Penland 1998; Georgiou et al. 2005). The shoreline reach behind the revetment is being formed into a classical V-shaped cuspate. Over time, the east and west appendages of the cuspate are becoming steeper and better defined while the revetment is pinning the center point in place. Therefore, this cuspate is probably being shaped through the diffraction of waves around the revetment. This effect is particularly prominent in the lee of the structure to the west.

Chapter 3 - Restoration Impacts on Shoreline Position at Timbalier Island due to the Timbalier Island Dune and Marsh Restoration (TE-40) Project

Introduction

Following the Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) Program's implementation of the TE-40 project at Timbalier Island, digitized shoreline datasets were compiled from various sources to determine shoreline erosions rates. This assessment helps to examine aspects of the second stated monitoring goal related to reducing erosion compared to historical rates. By comparing changes in shoreline erosion rates prior to and following the construction of the project, cumulative effects were also examined relative to the projected disappearance of the island by 2041 as predicted in Chapter 2.

Methods

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. Rates of change were determined by subtracting the shoreline position changes from the previously established baseline for distinct time periods and then dividing by the exact acquisition period for each shoreline location. These analyses used the shorelines, analysis transects and baseline established by the BICM program to help assess project impacts on the shoreline change rates at Timbalier Island before and after restoration. The time periods chosen for analysis were: 1) 1998 to 2004, 2) 2004 to 2015, 3) 2004 to 2012, and 4) 2012 to 2015. These periods were chosen in order to compare shoreline change rates immediately prior to (1998-2004) and immediately following (2004-2015) restoration. Other periods were analyzed in an attempt to parse out any changes in erosion rates as various natural processes impacted the island over time.

Results and Discussion

Shoreline change at Timbalier Island in the time period between the 1950s and 1998 was reported by Byrnes et al (2018) as -12.4 ft/yr, whereas the 1930s to 1950s and 1880s to 1930s periods exhibited more modest change rates of -10.4 and -7.7 ft/yr, respectively. This general trend of increasing shoreline recession rates continued into the 2004 to 2012 period when it was calculated to be -14.4 ft/yr, which coincides with peak losses in width and area highlighted in Chapter 2; but, in examining the 1998 to 2015 period, Byrnes et al (2018) reported shoreline change rates of only -11.6 ft/yr, closer to the historical rates from the previous century. To tease out and more closely examine potential project effects during this time period which fully encapsulates TE-40 construction completed in 2004, additional time periods just prior to and immediately following project completion were also analyzed and are presented in Table 3-1.

The period between 1998 and 2004 was identified as the pre-construction period and was found to exhibit shoreline change at a rate averaging -22.7 ft/yr (Table 3-1). The first post-construction period considered in this report was 2004 to 2012, for which Byrnes et al (2018) had previously reported shoreline change rates of -14.4 ft/yr. We extended this period for 3 additional years for the second post-construction period and found that shoreline change rates between 2004 and 2015 were -8.8 ft/yr, representing a ~39% decrease in shoreline recession in the second post-construction period compared to the first.

Table 3-1. Shoreline position changes during various time periods at Timbalier Island, Terrebonne Parish, LA. Values in red were previously derived by Byrnes et al (2018) while values in black represent project specific analysis periods.

TIME PERIOD	CHANGE RATE (FT/YR)	STANDARD DEVIATION (FT)
1950S TO 1998	-12.4	25.7
1998 TO 2015	-11.6	40.8
1998 TO 2004	-22.7	50.1
2004 TO 2012	-14.4	41.0
2004 TO 2015	-8.8	39.7
2012 TO 2015	4.1	60

The hurricanes of 2004, 2005, 2008 and 2012 are well-documented to have variously impacted Louisiana's barrier island shorelines as discussed in Chapter 2. The improvement in erosion rates between the second post-construction period and the first seem to suggest that completion of TE-40 helped mitigate the myriad of deleterious storm impacts the island experienced over the first 8 years following project completion. The partial recovery observed by comparing the post-construction rates is highlighted in our analysis of the abbreviated 2012-2015 period in which we found positive shoreline change of 4.1 ft/yr.

In comparing the second post-construction period (2004-2015) with the pre-construction period (1998-2004), shoreline erosion was decreased by 61% as erosion rates dropped from -22.7 ft/yr to -8.8 ft/yr. The 1950s to 1998 rate of -12.4 ft/yr is also a useful pre-construction historical rate to compare and that calculation revealed a ~34% decrease in shoreline erosion.

Assessment of shoreline change rates at Timbalier Island before and after the restoration was completed in 2004 reveals that project features have had a positive impact in reducing rates of erosion. Shoreline change rates trended favorably, although the processes which act on barrier islands in general were not altered and the initial benefits of the project are immediately susceptible to natural coastal processes upon project completion. Still, positive trends in erosion rates were evident from these analyses, and project contributions to stabilizing Timbalier Island and increasing its longevity are considered to have been achieved (Figure 3-1).

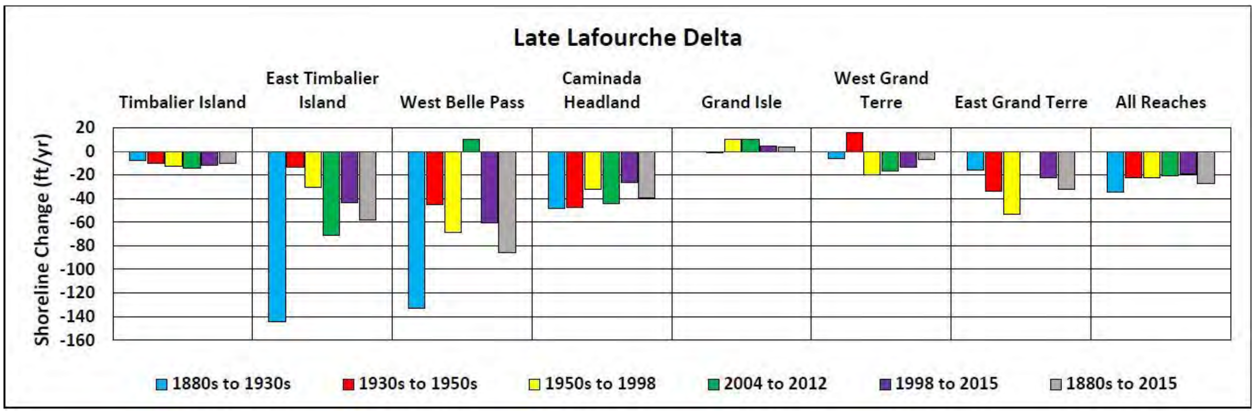


Figure 3-1. BICM shoreline change for the Late Lafourche Delta (from Byrnes et al. 2018).

Chapter 4 - Restoration Impacts on Elevation and Sediment Volume Changes at Timbalier Island due to the Timbalier Island Dune and Marsh Restoration (TE-40) project

Introduction

To assess project changes to Timbalier Island Dune and Marsh Restoration (TE-40) project, elevation data sets were analyzed and temporal modifications to island heights and volumetric changes in sedimentation were assessed within the surveyed vicinity of the TE-40 project area. Monitoring goal five relates to determining the elevation classes of Timbalier Island while monitoring goal two relates to littoral transport, both of which this chapter will assess.

Methods

Topographic and bathymetric surveys were employed to document elevation and volume changes inside and surrounding the TE-40 project fill area. Pre-construction (June 2004) and as-built (January 2005) elevation data were collected using traditional cross sectional and real time kinematic (RTK) survey methods. Subsequent post-construction topographic surveys were conducted using Light Detection and Ranging (LiDAR) procedures (Brock et al. 2003; Hansen and Howd 2009). These post-construction surveys were performed in July 2006 and February 2015 and established elevations for all subaerial habitats of this barrier island. The post-construction LiDAR surveys and separate bathymetric surveys were funded through the Barrier Island Comprehensive Monitoring (BICM) program in July 2006 and April 2016 (Troutman et al. 2003). These bathymetric surveys recorded subaqueous elevations in the shoreface, passes, and bay regions surrounding Timbalier Island exceeding the footprint of the fill area. The 2006 LiDAR and bathymetric surveys were joined to form a single continuous elevation model of this barrier island and its immediate vicinity while the 2015 LiDAR and 2016 bathymetric data were joined by merging grid models to form the 2016 single continuous model. The procedure to merge grid models is described in the second paragraph below. The survey data were established using or adjusted to tie in with the Louisiana Coastal Zone (LCZ) GPS Network and the TE40-SM-01 monument. The elevation surveys were referenced to LA State Plane South Zone (1702) coordinates, and vertical elevations were referenced to NAVD88 in feet. All vertical positions were collected using or adjusted to tie in with the GEOID12B model using correction factors established on the TE40-SM-01 monument.

The July 2004, January 2005, July 2006, and April 2016 survey data were re-projected horizontally and vertically to the UTM NAD83 coordinate system and the NAVD88 vertical datum in meters using Corpscon® software. The re-projected data were imported into ArcGIS® software for surface interpolation. Triangulated irregular network models (TIN) were produced from the point data sets. Next, the TIN models were converted to grid models [1.0 m^2 (3.3 ft^2) cell size], and the spatial distribution of elevations were mapped in half meter elevation classes. The grid models were clipped to the TE-40 fill area polygon to estimate elevation and volume changes within the fill area. Two other polygons were produced to assess the greater spatial distributions of the combined BICM LiDAR and bathymetric surveys in 2006 and 2016 – a Timbalier Island polygon and a longshore transport polygon. The Timbalier Island polygon was utilized to evaluate elevation and volume changes to the whole island system (from pass to pass) not just the fill area while the longshore transport polygon provided an estimate of longshore transport.

The February 2015 LiDAR and the April 2016 bathymetric data were merged to form a 2016 single continuous elevation grid model of Timbalier Island using the procedure listed below. The new merged grid will be referred to as the April 2016 grid. The first step in this process was to create two separate grid models with both data sets (2015 LiDAR and 2016 bathymetric) 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 ArcGIS®. Next, the grids were merged using the Mosaic to New Raster function of the Data Management Tools extension of ArcGIS®. This method created a new merged grid with both the LiDAR and bathymetric data sets that was further processed along with the other elevation grids to show elevation and volume changes with the procedure in the next paragraph.

Elevation changes from July 2004-January 2005, January 2005-July 2006, and January 2005-April 2016 were calculated by subtracting the corresponding grid models using the Minus Tool utility of the Spatial Analyst extension of ArcGIS®. The elevation change interval compared for the entire Timbalier Island system and the longshore transport assessments was the July 2006-April 2016 interval. After the elevation change grid models were generated, the spatial distribution of elevation changes in the TE-40 and Timbalier Island areas were mapped in half meter elevation classes. Lastly, volume changes in the breakwater field and spit areas were calculated in cubic meters (m^3) using the Cut/Fill Calculator function of the 3D Analyst extension of ArcGIS®. Note, these elevation and volume calculations are valid only for the extent of corresponding survey areas.

Results and Discussion

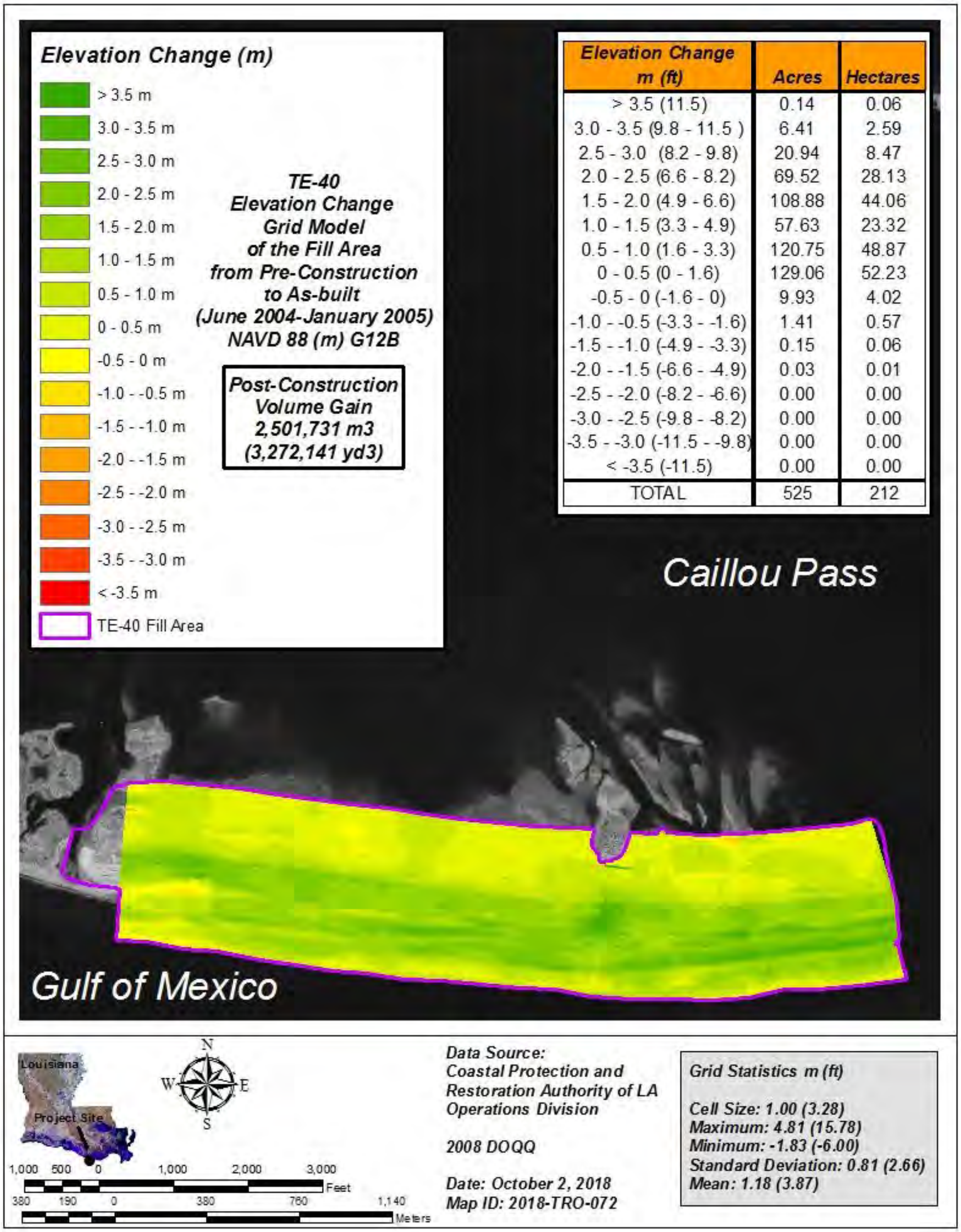
The TE-40 fill area experienced volume reductions and shoreline transgressions since construction was completed in 2005. Table 4-1 list the volume changes (m^3 and %) in the fill area over the project timeline and details longshore transport on Timbalier Island during the 2006-2016 interval. Elevation change and volume distributions for the TE-40 fill area are shown in Figure 4-1 (June 2004-January 2005), Figure 4-2 (January 2005-July 2006), and Figure 4-3 (January 2005-April 2016). Additional post-construction elevation change models are shown for the 2006-2016 interval. These models depict volume changes for the entire Timbalier Island system (Figure 4-4) and enumerate longshore transport (Figure 4-5) using the expanded BICM elevation surveys. Approximately, 2,501,731 m^3 (3,272,141 yd^3) of sediment were deposited during construction in the fill area (Figure 4-1 and Table 4-1). Moreover, while the project was under construction, erosion transpired along the beaches because of Hurricane Ivan (September 2004) and Tropical Storm Matthew (October 2004) requiring granular sediments to be resupplied to the TE-40 fill area (Shaw Coastal Inc. 2005).

Table 4-1. Pre-, as-built, and post-construction sediment volume changes in the TE-40 fill area over time. Longshore transport is also estimated for the 2006-2016 interval. Volume changes are recorded in m^3 (cubic meters), percent removed (%), and percent remaining (%).

TE-40 Elevation Intervals	Project Timeline	Volume Loss/Gain (m3)	Percent Volume Removed (%) From Fill Area	Percent Volume Remaining (%) in Fill Area	Percent Volume Gained (%) on Island	Percent Volume Conserved (%) in Island System
2004-2005	Pre-As-built	2,501,731	-	-	-	-
2005-2006	As-built-Post1	-1,724,798	-69	31	-	-
2005-2016	As-built-Post2	-4,127,942	-165	-65	-	-
2006-2016	Longshore Transport	7,276,472	-	-	126	226

In the post-construction period, sediment volume decreased by 69% from January 2005 to July 2006 leaving only 31% of the as-built volume remaining within the TE-40 fill area (Figure 4-2 and Table 4-1). The total sediment volume loss in the fill area from January 2005 to July 2006 was approximately 1,724,798 m^3 (2,255,951 yd^3). The dominant cause of this substantial volume loss in the fill area was shoreline erosion induced during the passage of Hurricane Cindy (July), Hurricane Katrina (August), and Hurricane Rita (September) in 2005. The TE-40 fill area shoreline truncated to the west and transgressed northward after the 2005 hurricane season. The eastern edge of the island relocated approximately 731 m (2,400 ft) to the west causing 488 m (1,600 ft) of the TE-40 dune to be leveled (Rodrigue et al. 2011 and Figure 4-2). Barras (2006), Fearnley et al. (2009), and Martinez et al. (2009) have also documented the erosion of the eastern reaches of Timbalier Island following the 2005 hurricane season.

For the second post-construction interval (2005-2016), massive quantities of sediments were eroded from the TE-40 fill area. Sediment volume declined by 4,127,942 m^3 (5,399,144 yd^3) for this interval resulting in considerably more sediment losses than added during construction (in place as-built volume). This translates into a 165% sediment volume deficit in the fill area (Figure 4-3 and Table 4-1). A sizable part of this large sediment volume loss was sustained due to Hurricanes Gustav (September) and Ike (September) in 2008. Hurricane Gustav passed within 8 km (5 mi) of Timbalier Island and probably induced the greatest erosion and land loss on the TE-40 fill area. Other sandy shorelines in the Terrebonne Basin have also reported extensive land loss as a result of these 2008 storms (Morton and Barras 2010; Curole and Lee 2013; Curole et al. 2017; Sylvest et al. 2020; Sylvest et al. 2022). The eastern shoreline of Timbalier Island transgressed to the west, and 1,402 m (4,600 ft) of the TE-40 dune was leveled in the aftermath of the 2008 hurricanes. By 2016, only 1,143 m (3,750 ft) of the TE-40 dune remained as the Timbalier Island shoreline receded to the west and north. Figure 4-3 shows the substantial volume losses in the



Elevation Change m (ft)	Acres	Hectares
> 3.5 (11.5)	0.14	0.06
3.0 - 3.5 (9.8 - 11.5)	6.41	2.59
2.5 - 3.0 (8.2 - 9.8)	20.94	8.47
2.0 - 2.5 (6.6 - 8.2)	69.52	28.13
1.5 - 2.0 (4.9 - 6.6)	108.88	44.06
1.0 - 1.5 (3.3 - 4.9)	57.63	23.32
0.5 - 1.0 (1.6 - 3.3)	120.75	48.87
0 - 0.5 (0 - 1.6)	129.06	52.23
-0.5 - 0 (-1.6 - 0)	9.93	4.02
-1.0 - -0.5 (-3.3 - -1.6)	1.41	0.57
-1.5 - -1.0 (-4.9 - -3.3)	0.15	0.06
-2.0 - -1.5 (-6.6 - -4.9)	0.03	0.01
-2.5 - -2.0 (-8.2 - -6.6)	0.00	0.00
-3.0 - -2.5 (-9.8 - -8.2)	0.00	0.00
-3.5 - -3.0 (-11.5 - -9.8)	0.00	0.00
< -3.5 (-11.5)	0.00	0.00
TOTAL	525	212

Figure 4-1. Elevation and volume change grid model for the TE-40 fill area from pre-construction (Jun 2004) to as-built (Jan 2005) at the Timbalier Island Dune and Marsh Restoration (TE-40) project.

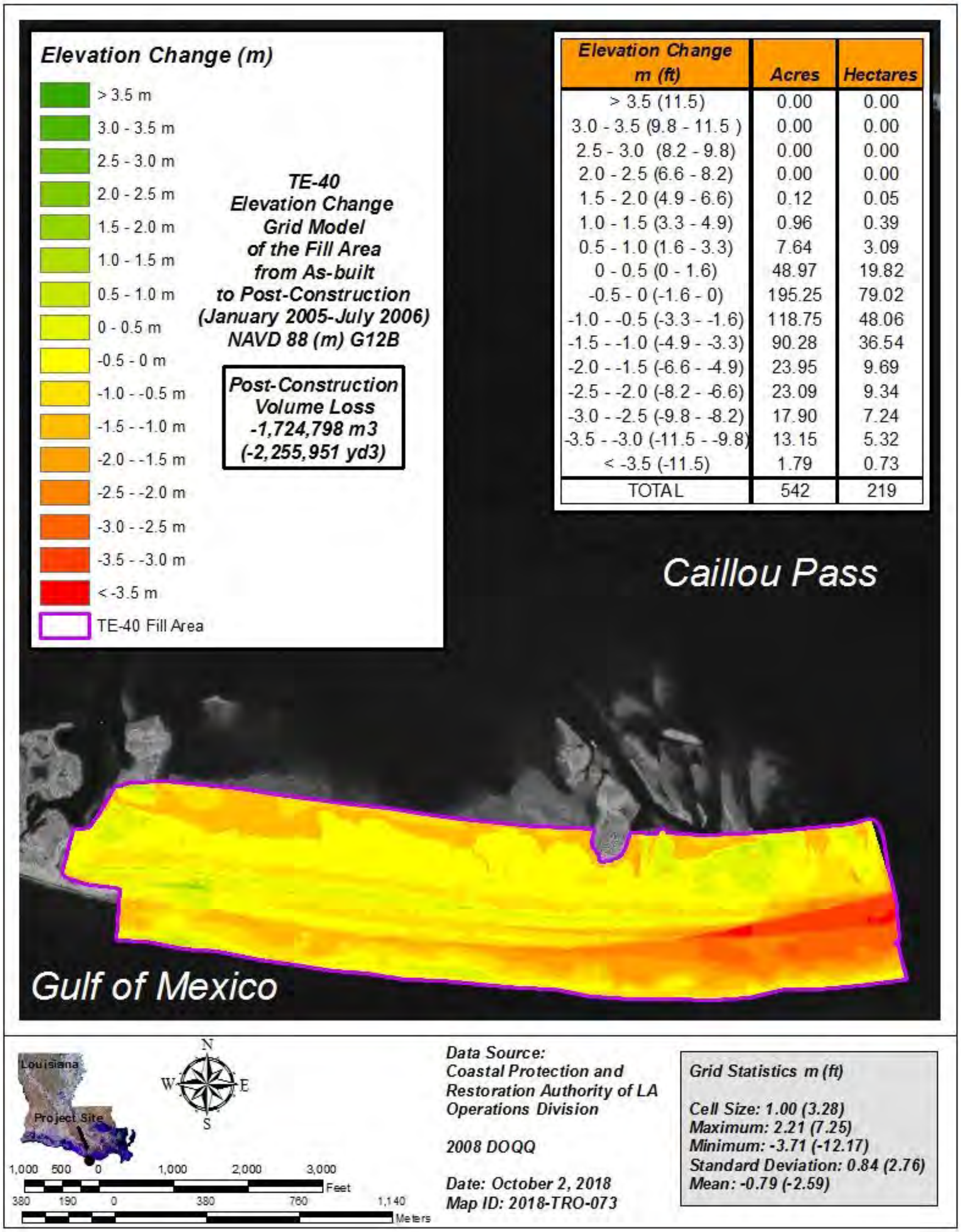


Figure 4-2. Elevation and volume change grid model for the TE-40 fill area from as-built (Jan 2005) to post-construction 1 (Jul 2006) at the Timbalier Island Dune and Marsh Restoration (TE-40) project.

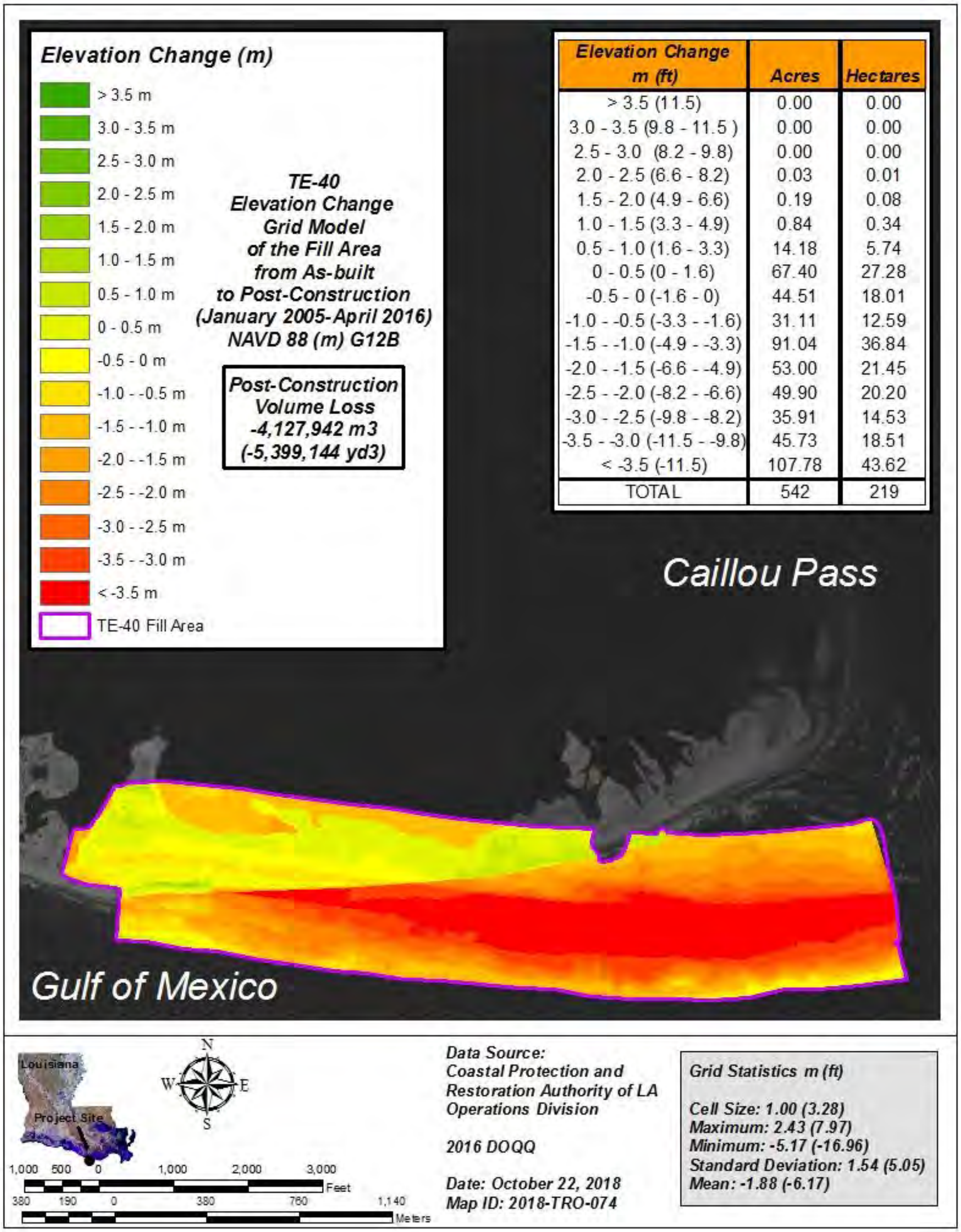
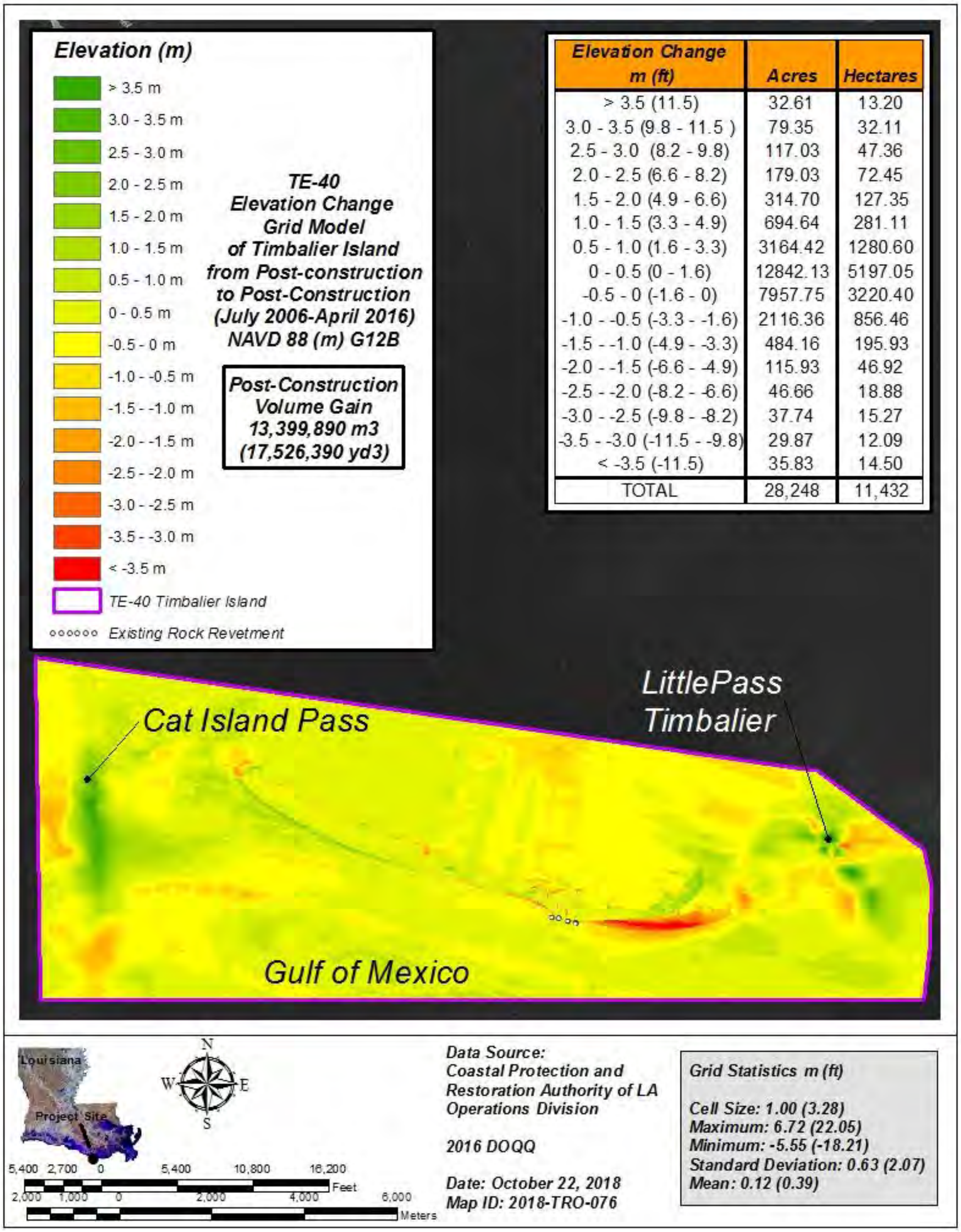
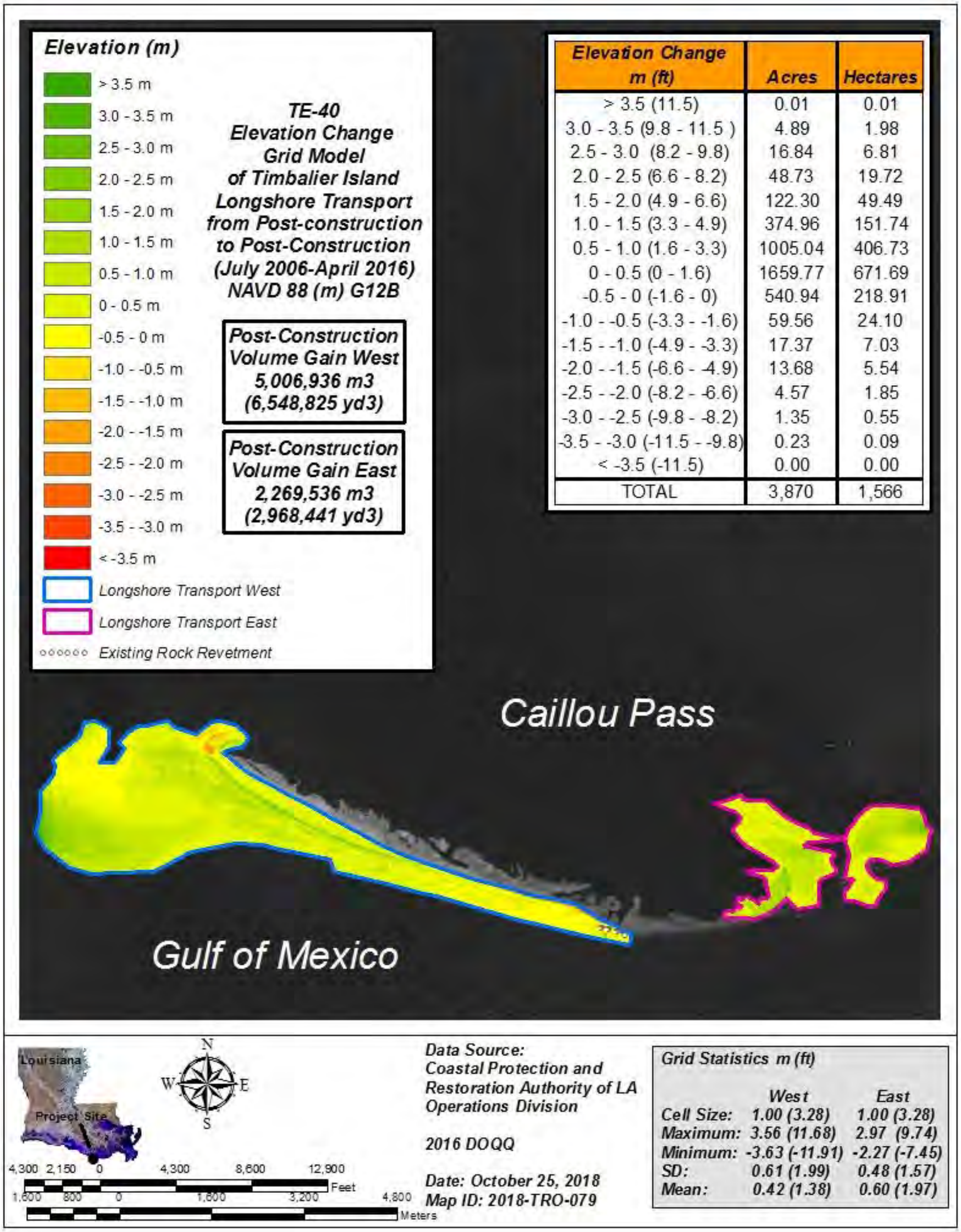


Figure 4-3. Elevation and volume change grid model for the TE-40 fill area from as-built (Jan 2005) to post-construction 2 (Apr 2016) at the Timbalier Island Dune and Marsh Restoration (TE-40) project.



Elevation Change m (ft)	Acres	Hectares
> 3.5 (11.5)	32.61	13.20
3.0 - 3.5 (9.8 - 11.5)	79.35	32.11
2.5 - 3.0 (8.2 - 9.8)	117.03	47.36
2.0 - 2.5 (6.6 - 8.2)	179.03	72.45
1.5 - 2.0 (4.9 - 6.6)	314.70	127.35
1.0 - 1.5 (3.3 - 4.9)	694.64	281.11
0.5 - 1.0 (1.6 - 3.3)	3164.42	1280.60
0 - 0.5 (0 - 1.6)	12842.13	5197.05
-0.5 - 0 (-1.6 - 0)	7957.75	3220.40
-1.0 - -0.5 (-3.3 - -1.6)	2116.36	856.46
-1.5 - -1.0 (-4.9 - -3.3)	484.16	195.93
-2.0 - -1.5 (-6.6 - -4.9)	115.93	46.92
-2.5 - -2.0 (-8.2 - -6.6)	46.66	18.88
-3.0 - -2.5 (-9.8 - -8.2)	37.74	15.27
-3.5 - -3.0 (-11.5 - -9.8)	29.87	12.09
< -3.5 (-11.5)	35.83	14.50
TOTAL	28,248	11,432

Figure 4-4. Elevation and volume change grid model for the Timbalier Island system from Jul 2006 to Apr 2016. This timeline represents the post-construction 1 to the post-construction 2 interval for the Timbalier Island Dune and Marsh Restoration (TE-40) project.



Elevation Change m (ft)	Acres	Hectares
> 3.5 (11.5)	0.01	0.01
3.0 - 3.5 (9.8 - 11.5)	4.89	1.98
2.5 - 3.0 (8.2 - 9.8)	16.84	6.81
2.0 - 2.5 (6.6 - 8.2)	48.73	19.72
1.5 - 2.0 (4.9 - 6.6)	122.30	49.49
1.0 - 1.5 (3.3 - 4.9)	374.96	151.74
0.5 - 1.0 (1.6 - 3.3)	1005.04	406.73
0 - 0.5 (0 - 1.6)	1659.77	671.69
-0.5 - 0 (-1.6 - 0)	540.94	218.91
-1.0 - -0.5 (-3.3 - -1.6)	59.56	24.10
-1.5 - -1.0 (-4.9 - -3.3)	17.37	7.03
-2.0 - -1.5 (-6.6 - -4.9)	13.68	5.54
-2.5 - -2.0 (-8.2 - -6.6)	4.57	1.85
-3.0 - -2.5 (-9.8 - -8.2)	1.35	0.55
-3.5 - -3.0 (-11.5 - -9.8)	0.23	0.09
< -3.5 (-11.5)	0.00	0.00
TOTAL	3,870	1,566

Grid Statistics m (ft)	West	East
Cell Size:	1.00 (3.28)	1.00 (3.28)
Maximum:	3.56 (11.68)	2.97 (9.74)
Minimum:	-3.63 (-11.91)	-2.27 (-7.45)
SD:	0.61 (1.99)	0.48 (1.57)
Mean:	0.42 (1.38)	0.60 (1.97)

Figure 4-5. Elevation and volume change grid model depicting longshore transport along Trinity Island from Jul 2006 to Apr 2016. This timeline represents the post-construction 1 to the post-construction 2 interval for the Timbalier Island Dune and Marsh Restoration (TE-40) project..

TE-40 fill area, cross-shore transport in the remnant subaerial landscape of the fill area, and the counter clockwise rotation and elongation of the of the eastern margins of Timbalier Island leading to the formation of a narrow spit. The TE-40 elevation and habitat goal is not currently being attained due to the sizeable transgressions along the gulf shoreline and the considerable subaerial volume losses within the fill area. The substantial forcing of the 2005 and 2008 hurricane seasons not long after project construction set the stage for the large shoreline and volume losses that occurred within the fill area. In addition, the evolution of tidal channel development goal was discontinued since the channel study areas have migrated out of the TE-40 fill area. No channel development was found in 2010 (Rodrigue et al. 2011).

The expanded 2006-2016 change model shows aggradation in the Timbalier Island sediment budget for this defined interval. Figure 4-4 delineates the trends in sediment transport surrounding Timbalier Island for the period from 2006-2016 and displays a sediment accruing trend. Although the general trend reveals sediment aggradation, Figure 4-4 also exhibits reaches with marked erosional activity. The most prominent of these erosional hot spots is the TE-40 fill area. This reach is described in the preceding paragraphs and is illustrated with the dark red tone. Other erosional hot spots include the reach immediately to the west of the rock revetment, several areas near the island passes, the recurved spit on the western edge of the island, and the bay shoreline of the island. 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 1998b; Georgiou et al. 2005). In contrast, several reaches show intense aggradation and are outlined with dark green colors (Figure 4-4). These accretionary reaches include the shoaling of Cat Island Pass and Little Pass Timbalier and the eastern edge of Timbalier Island, which is rotating away from the TE-40 fill area in a counter clockwise direction. This rotation of the island has led to the shaping of a narrow but aggrading eastern spit and a sandy (100% fine sand) flood shoal between the island and Little Pass Timbalier (Figures 4-4). Other accretionary reaches are found along the western gulf shoreline of Timbalier Island and a large ebb shoal is forming south of this shoreline on the terminal end of the island. This large shoal formed and is probably aggrading through longshore transport processes and the forcing of Cat Island Pass because net longshore transport flows westward on Timbalier Island (Peyronnin 1962; Ritchie and Penland 1988; Stone and Zhang 2001; Georgiou et al. 2005). Additionally, the ebb shoal has enlarged and migrated southward since 2006 (Figures 4-4). Moreover, the surficial sediments of the shoal are composed primarily of fine sand grains (85-95%). The Timbalier Island westward longshore transport gain for the period from 2006 to 2016 has been estimated to be 5,006,936 m^3 (6,548,825 yd^3) while the eastern longshore gain was estimated to be 2,269,536 m^3 (2,968,441 yd^3). The total eastern and western longshore gain for this period was 7,276,472 m^3 (9,517,266 yd^3) (Table 4-1 and Figure 4-5). The data shows that more granular sediments remain in the Timbalier Island shoreface, the western ebb shoal, and the eastern flood shoal than were eroded from the TE-40 fill area. As a result, it is logical to assume that a reasonable percentage of these sediments were eroded from the fill area because the net longshore transport flows westward and the rotation of the eastern island edge is focusing sediments to the northeast and forming the flood shoal. Therefore, TE-40 fill area granular sediments have been conserved within the Timbalier Island system and are currently nourishing the western reaches of the island, the ebb shoal, and the eastern flood shoal (Table 4-1 and Figure 4-5). For the above reasons, the rate of erosion and littoral transport goal has been realized.

Chapter 5 - Habitat Changes at Timbalier Island due to the Timbalier Island Dune and Marsh Restoration (TE-40) project

Introduction

Following the Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) Program's implementation of the Timbalier Island Dune and Marsh Restoration (TE-40) project, habitat classification datasets were compiled to determine habitat classes in the project area and to determine acreages and changes in those classes over time. For this assessment, we will evaluate project effectiveness by comparing before project habitat datasets with subsequent habitat datasets collected over the life of the project to assess the aspect of monitoring goal five dealing with project effects on habitat classes.

Methods

Habitat datasets provide a snapshot of the various habitats which make up a given land area 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 5-1).

Table 5-1. 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) de- veloped 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) de- veloped 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 typi- cal 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 veg- etation, 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 infra- structure 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

Results and Discussion

Habitat classification datasets for Timbalier Island were available for six time periods between 1996 and 2016. This 20-year period includes 2 datasets acquired prior to restoration and four datasets compiled over the subsequent 12 years following project completion in 2004. The habitat changes observed over the years at Timbalier Island have primarily been driven by tropical cyclone activity and the reworking of the island as it transgresses toward the west and the vegetative colonization and other successional processes which follow those disturbances.

Marsh habitat categories remained fairly stable throughout the 1996, 2002 and 2004 (pre-construction) periods (Table 5-2 and Figure 5-1). The imagery used for habitat classifications in 2005 was taken after Hurricanes Cindy, Katrina and Rita, and the ~29% reduction of marsh observed between 2004 and 2005 is attributed to tropical cyclone activity in early fall of that year. Bare land decreased by 41% during the same time period, while the beach classification saw the most dramatic change among the land categories as it increased from 67 to 253 acres, a 277% increase. Intertidal flat saw the largest change among non-land classes, increasing by 62% as previously vegetated areas were stripped of vegetation and substrate, exposing them to gulf tides.

Table 5-2. Habitat acreages by BICM general habitat class between 1996 and 2016 for Timbalier Island, Terrebonne Parish, LA.

Habitat Classes	1996	2002	2004	2005	2008	2016
Water	8,821	8,047	8,116	19,156	19,473	7,985
Intertidal Flat	358	520	393	638	279	30
Marsh	806	837	800	569	308	349
Barrier Vegetation	0	3	21	0	408	486
Bare Land	14	22	127	74	78	3
Beach	127	95	67	253	142	46
Rip Rap	2	1	1	1	1	1
Structure	1	1	1	1	3	2
Analysis Extent	10,129	9,526	9,526	20,693	20,693	8,903
Only LAND total	950	959	1017	898	940	888

Intertidal flat coverage peaked in 2005 at 638 acres and declined in the 2008 and 2016 periods when it was calculated at 279 and 30 acres, respectively. This is attributed to intertidal areas eroding from the eastern reaches of the island and some other intertidal areas on the bay side either eroding or transitioning to marsh or barrier vegetation.

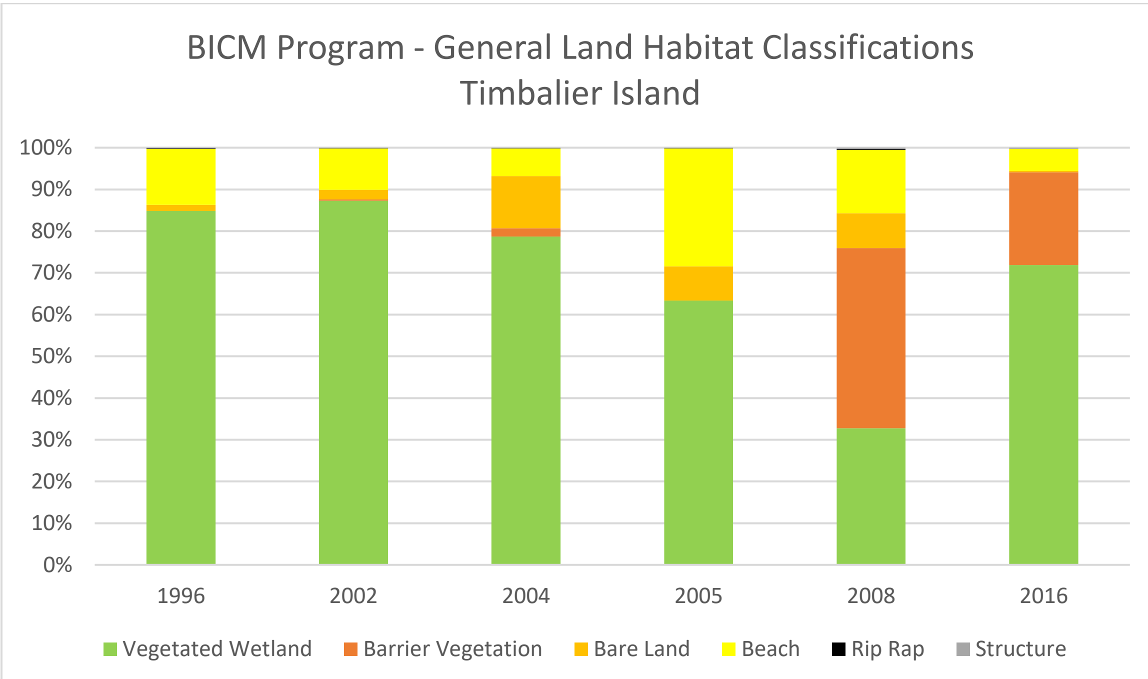


Figure 5-1. BICM land habitat classifications showing percent cover of 6 land cover types at Timbalier Island, Terrebonne Parish, LA. Changes in habitat classes indicate impacts of restoration events and storms over time. (Areas classified as water were removed for the purposes of displaying the data graphically and parsing out land classification changes.)

The barrier vegetation and bare land habitat classes are the categories that map dunes within the BICM general classifications (Table 5-1), and we examine these categories to help evaluate how well the project performed regarding the goals and objectives related to determining habit classes. In 1996 and 2002, prior to restoration, there were only 0 and 3 acres of barrier vegetation, respectively (Table 5-2), accounting for only 0.003% of the total land area when it was present in 2002. By 2008, barrier vegetation accounted for 43% of the total land area of Timbalier, and by 2016 made up over half of the subaerial land at ~54%. Between 2008 and 2016, the marsh category increased from 308 to 349 acres; these 41 additional marsh acres were gained during a period of overall land loss on Timbalier and much of it is likely attributed to beach and bare land categories transitioning in the center of the island as elevations there began to decrease as detailed in Chapter 4.

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 disturbance events. The ephemeral nature of barrier island habitats, their sensitivity to various disturbances or lack thereof, and the propensity for habitat categories to quickly transition caused substantial fluctuations between analysis years. Compared to the more frequent storm impacts to the island during the initial 8 years following construction, the relatively low number of tropical cyclones and resulting overwash events between 2012 and 2016 likely provided for vegetation to increase as natural succession progressed (Figure 5-2). The material added to Timbalier Island likely sustained its existence beyond the predicted island life.

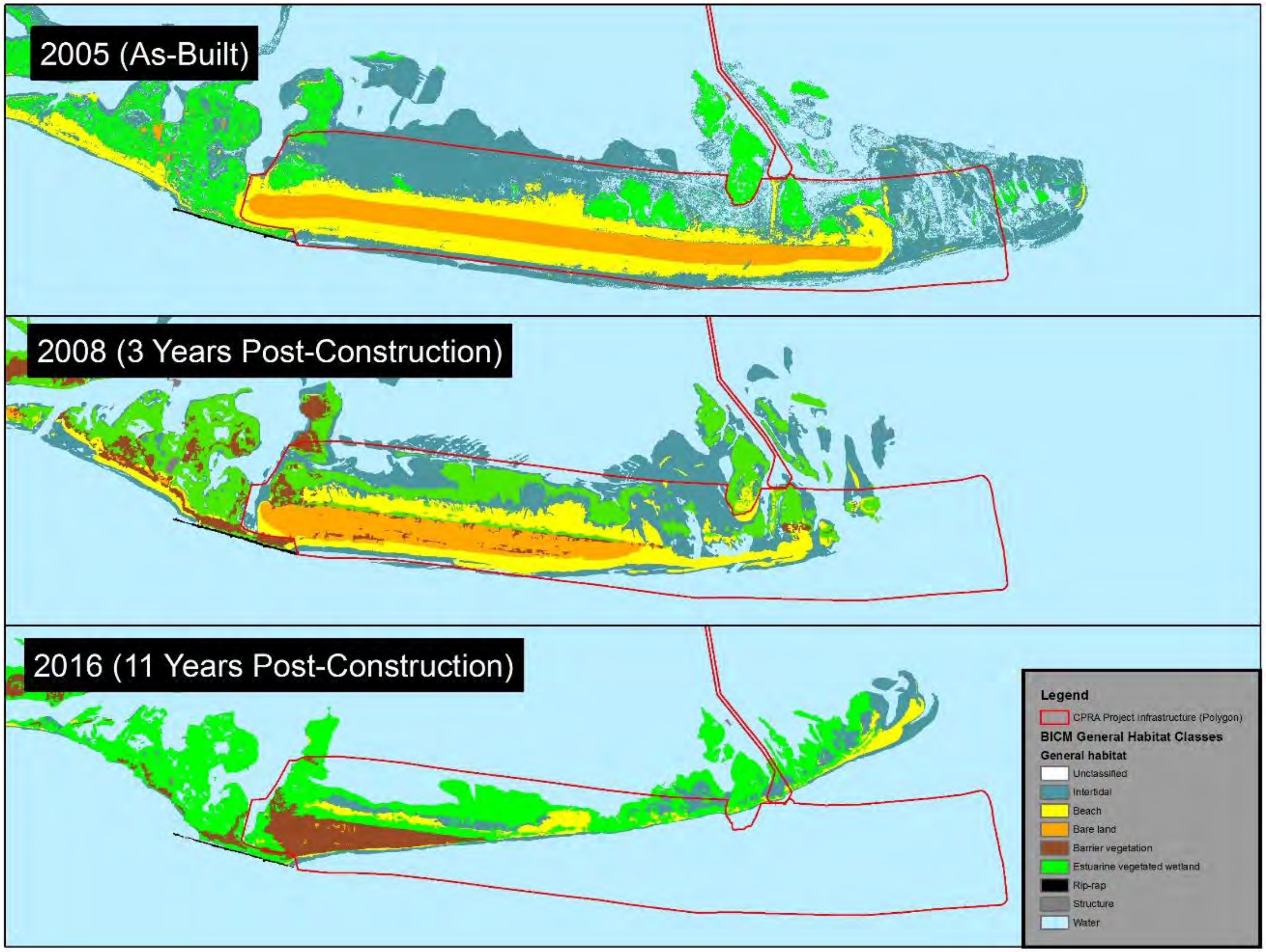


Figure 5-2. BICM general habitat classification maps for 2005, 2008 and 2016 at Timbalier Island, Terrebonne Parish, LA.

Chapter 6 - Vegetation Community at Timbalier Island due to the Timbalier Island Dune and Marsh Restoration (TE-40) project

Introduction

The Timbalier Island Dune and Marsh Restoration (TE-40) project did not have project goals specific to the vegetation community. However, vegetation data was collected on the island in the fall of 2016 and has been summarized and presented here for ancillary consideration.

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. 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.

Sampling of TE-40 in 2016 was conducted utilizing shore perpendicular cross sections for the establishment of 31 stations to ascertain barrier island plant community composition and cover (Figure 6-1). Shore perpendicular Barrier Island Comprehensive Monitoring (BICM) transects are spaced approximately 1,500 feet apart along most of the Louisiana gulf shoreface. Where these lines intersect the TE-40 project area, 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. Two personnel used the Trimble GeoXT GPS unit to navigate to the BICM transects where the potential vegetation station points were generated and stations were established using a random number generator. 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.

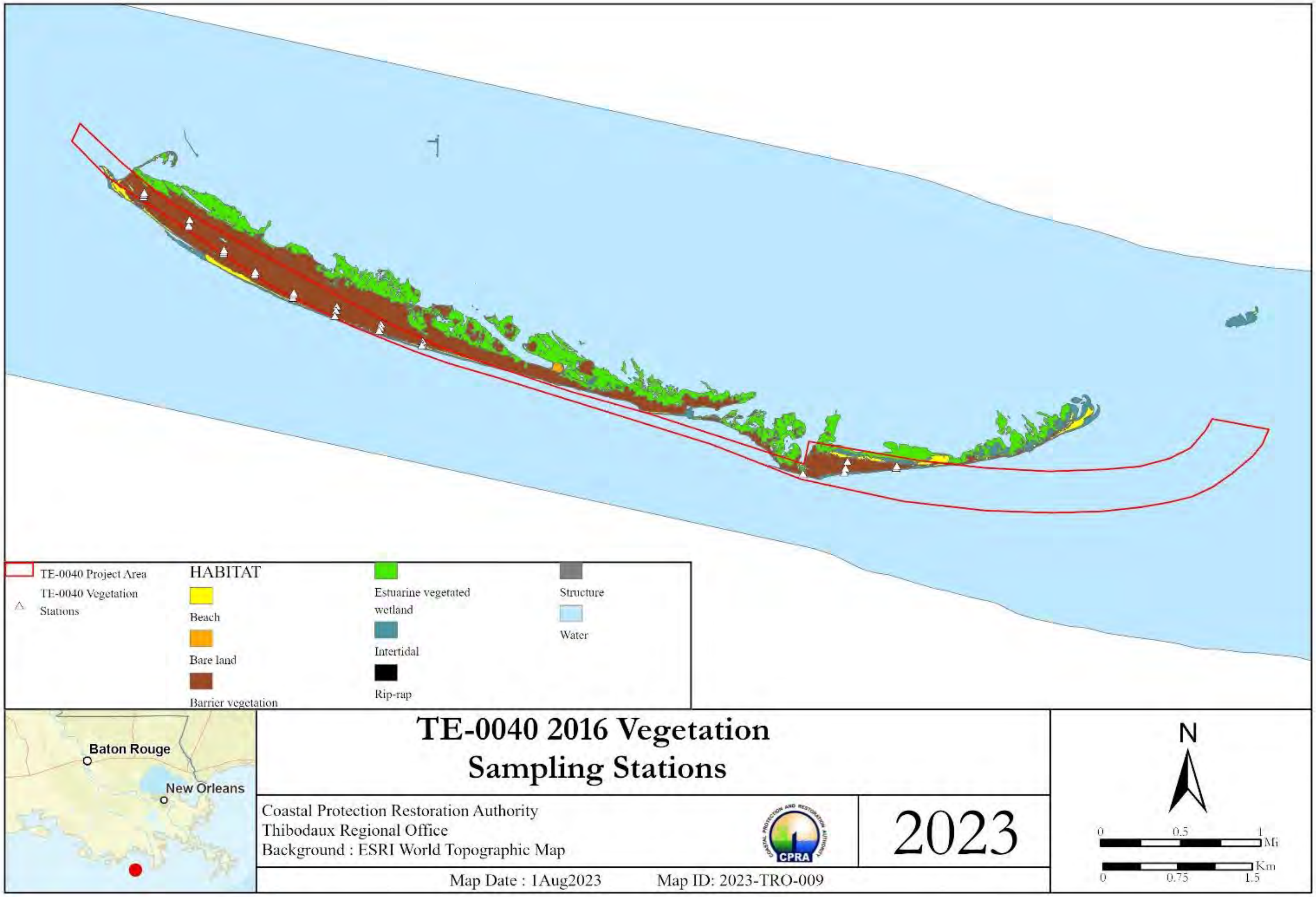


Figure 6-1. *2016 TE-40 Vegetation sampling locations on Timbalier Island and BICM 2016 Habitat data.*

Results and Discussion

Forty-three species were represented in the overall TE-40 vegetation monitoring event at Timbalier Island in 2016, a fairly high measure of species richness in a barrier island system (Figure 6-2). Torpedo grass (*Panicum repens*) had the highest relative cover of any vegetation species identified at 17%, followed by rattlebush (*Sesbania drummondii*) at 12%. Bare ground accounted for 5% of the total area. Several other species that are important to barrier island ecology and supportive of their overall health were well represented with cover values ranging between 3 to 5%; these included saltmeadow cordgrass (*Spartina patens)*, saltgrass (*Distichlis spicata)*, gulf bluestem (*Schizachyrium maritimum)*, and bayhops (*Ipomoea pes-caprae)*.

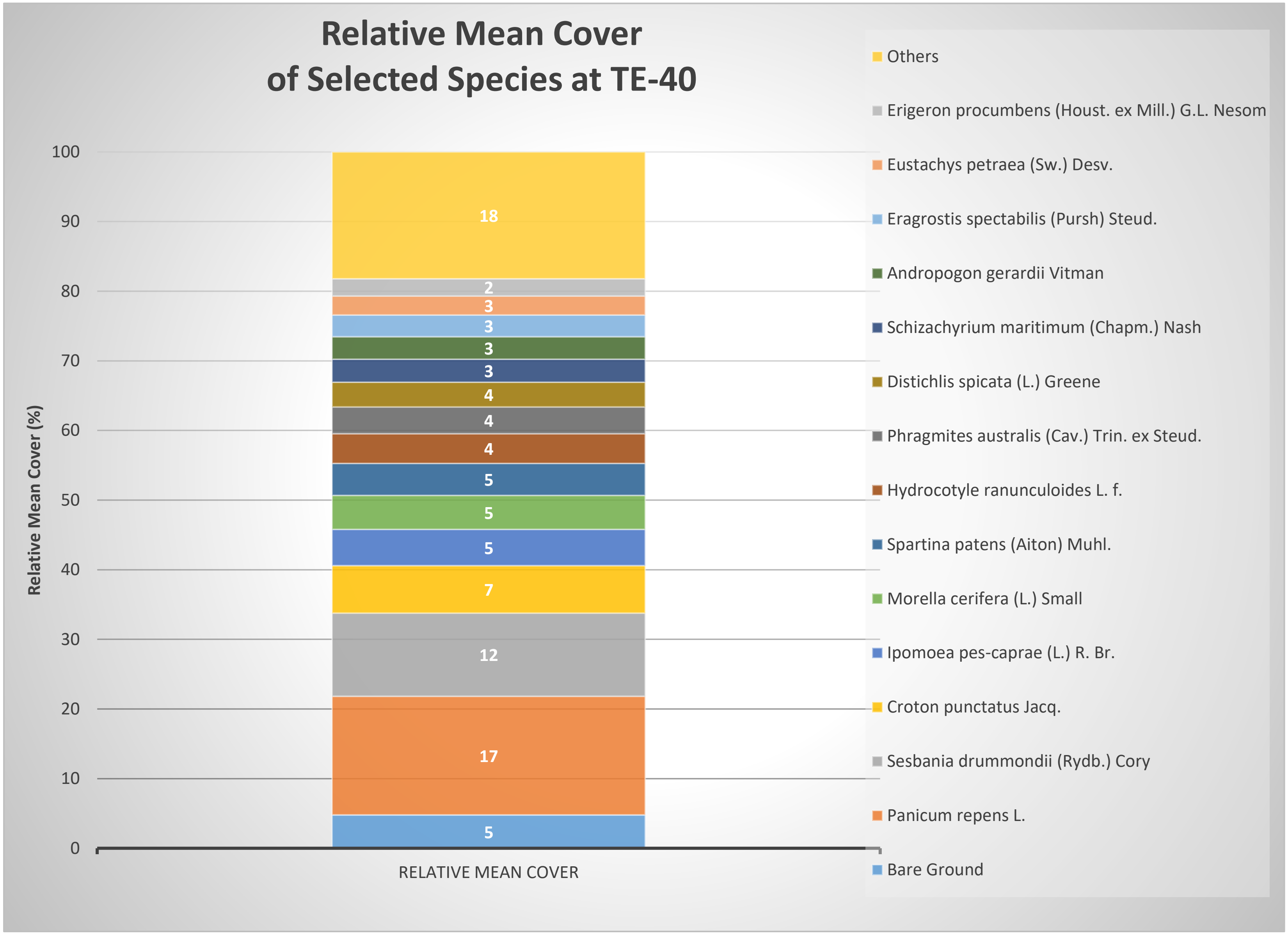


Figure 6-2. Relative mean percent vegetation cover of selected species inside the 4m² stations sampled during 2016 within the TE-40 project area on Timbalier Island.

Chapter 7 - Sediment Properties at Timbalier Island due to the Timbalier Island Dune and Marsh Restoration (TE-40) project

Introduction

The Barrier Island Comprehensive Monitoring (BICM) program collected surficial sediment samples in the subaqueous and subaerial environments along coastal Louisiana, including Timbalier Island. These data were collected in 2008 and 2015 and were used to map sediment characteristics along the island. Monitoring goal three relates to project effects on sediment characterization over time which is assessed in this chapter.

Methods

Ponar grabber (subaqueous) and hand scoop (subaerial) sediment samples were obtained along thirteen (13) cross-shore transects along Timbalier Island which included the Timbalier Island Dune and Marsh Restoration (TE-40) project in June 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 3,000 ft. (914 m) intervals and were funded through the Barrier Island Comprehensive Monitoring (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 June 2008 and August 2015 sediment core point data were imported into ArcGIS® software for surface interpolation. Surface grid models [10 m^2 (33 ft^2) 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 Timbalier 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 Timbalier Island.

Results and Discussion

The results of the sediment properties analysis demonstrate that surficial sand deposits were present along the Timbalier Island shoreface, beach, dune, marsh, bay, and passes in 2008 and 2015 (Figures 7-1 and 7-2). The percentage of sand (%) in 2008 ranged from 80 to 100% for sediments extracted from the middle of shoreface to the marsh with the greatest concentrations of sand found in the passes and on the eastern side of the island. 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 7-1). In 2015, the sand percentage (%) ranged from 75 to 100% for sediments extracted from the middle of shoreface to the bay. The proportion of sand was highest surrounding the island and diminished with distance from the shoreline. Similar to the 2008 grain sizes, 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 (Figure 7-2). Granular sediments were also found in the bay in 2015 confirming that the percent sand (%) interpolation of the bay in the 2008 model has some merit because no samples were taken in the bay behind the island in 2008. Comparisons of the 2008 and 2015 models display a concentrated (≥ 90%) fine sand shoal forming on the western terminus of the island (Figures 7-1 and 7-2). This ebb shoal has enlarged, grown vertically, and migrated to the south since 2006 and likely formed via longshore transport processes. East/Trinity Island also experienced ebb shoal relocation to the south between 2008 and 2015 (Sylvest et al. 2020). In addition, the high percentage of surficial sand deposits found encircling the island in 2015 may have been enhanced by cross-shore transport processes because the 2008 sediment samples were collected immediately prior to the massive 2008 hurricanes (Gustav and Ike). Although the distribution of sand resources appears favorable, Timbalier and the Isles Dernieres 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 Timbalier Island. These cores should extend 5-6 m (15-20 ft.) below the ground surface (bgs) and stretch from Little Pass Timbalier Pass to Cat Island Pass and include shoreface, beach, dune, marsh, and bay habitats like the surficial samples.

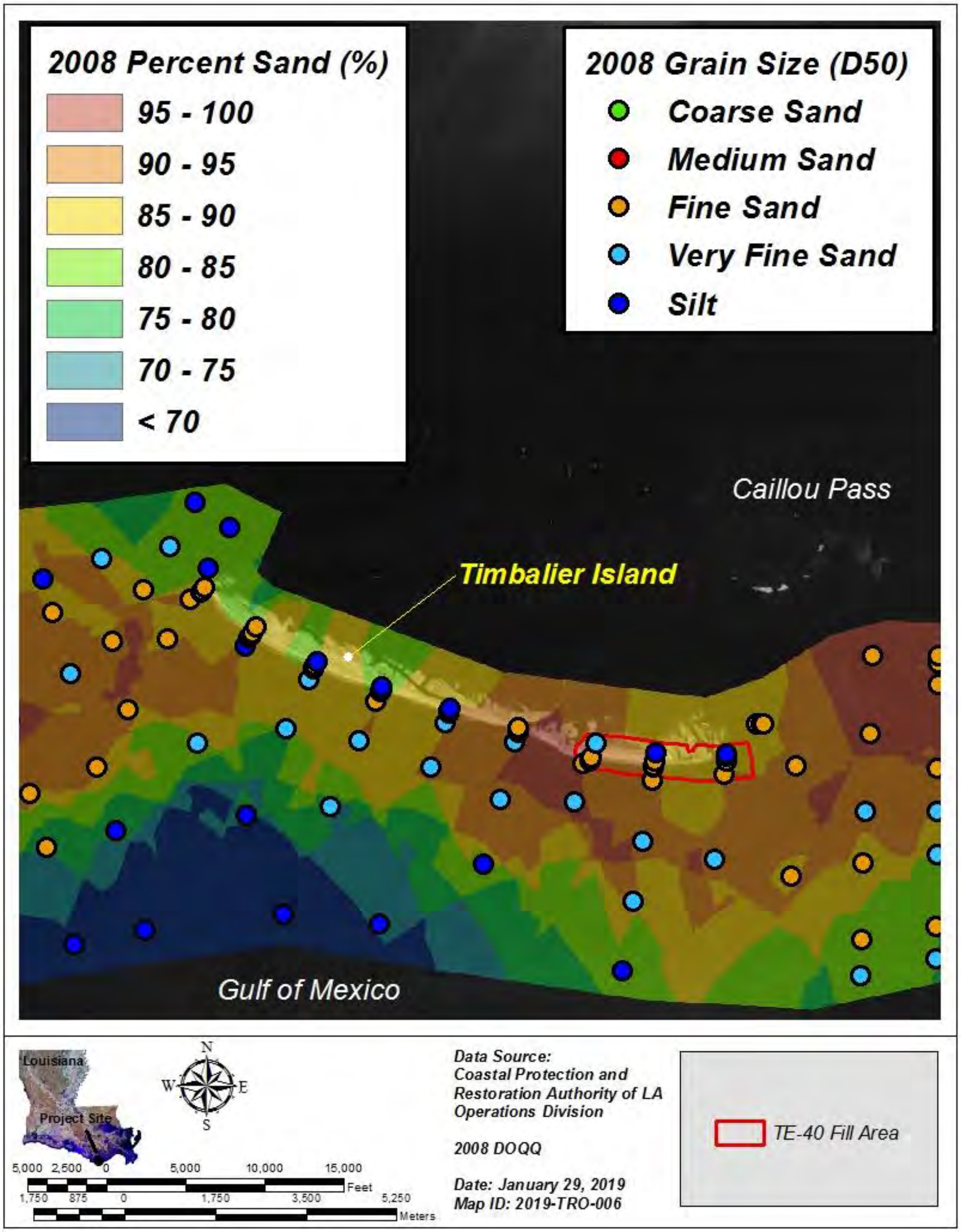


Figure 7-1. Median grain size (D50) and percent sand (%) distributions for Timbalier Island in June 2008.

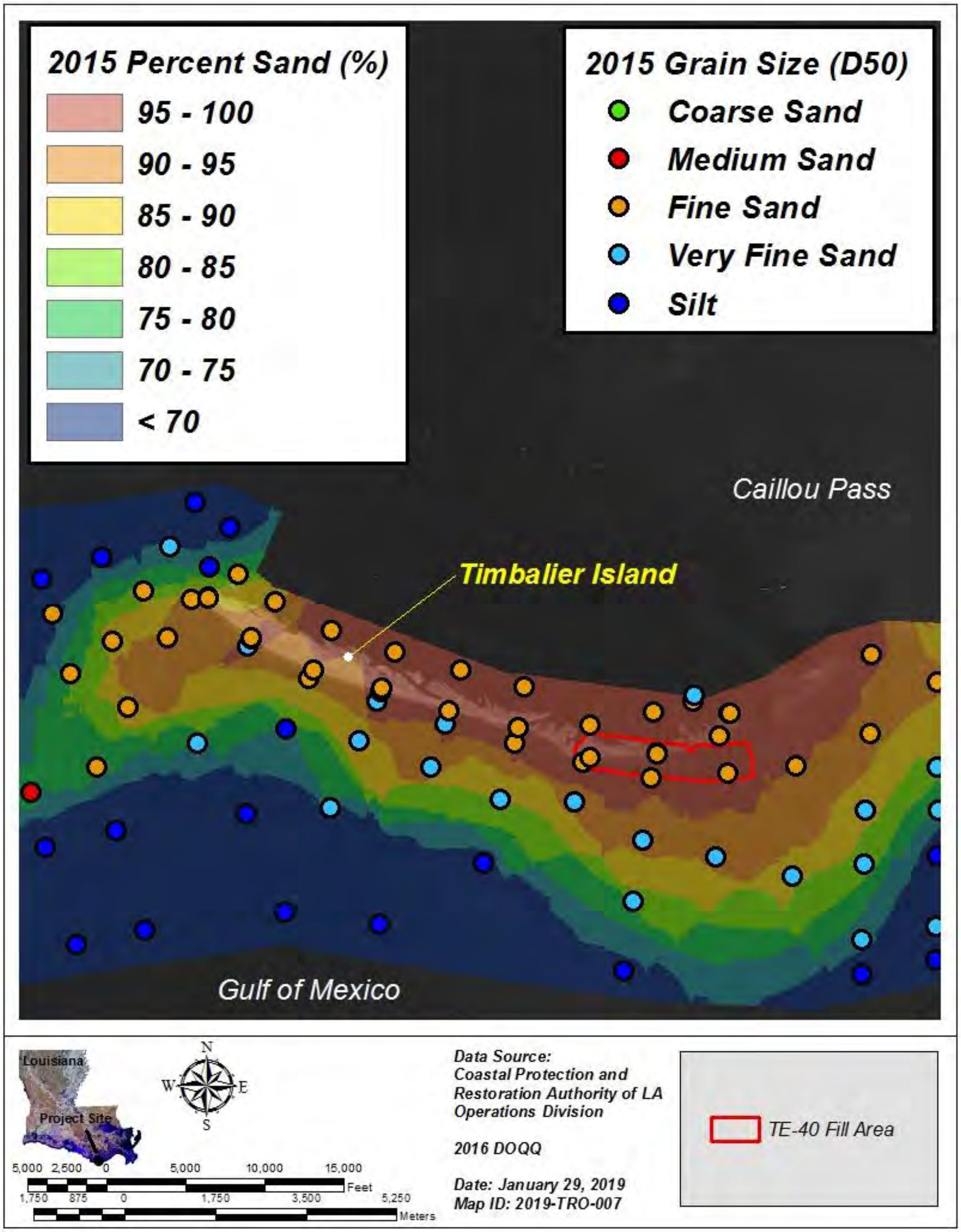


Figure 7-2. Median grain size (D50) and percent sand (%) distributions for Timbalier Island in August 2015.

Chapter 8 – Project Conclusion, Timbalier Island Dune and Marsh Restoration (TE-40)

This report examined the effects of the Timbalier Island Dune and Marsh Restoration (TE-40) project based on changes measured in its shoreline, area, length, width, sediment volume and habitats over time. The success of the project over the course of the 20 year life was evaluated against predictions that it would become subaqueous in 2041 (Chapter 2) or 2050 (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority 1998) without restoration efforts. Post-construction trends in each of the aforementioned metrics were improved in comparison to pre-construction data trends; additional sediments added to the Timbalier Island system directly contributed to reductions in subaerial land losses and shoreline erosion rates, contributing to overall stabilization and increased longevity of the island and its littoral transport system.

The positive impact of the project on these metrics extended for some time following construction completion and those effects are not only responsible for the mitigating role that Timbalier Island has played in protecting inland resources for the past 20 years, but also its ability to do so into the future. 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 Timbalier Island had immediate positive effects to interior marshes, shorelines, and the communities which they protect.

Lessons Learned

Lessons learned over the course of the Timbalier Island Dune and Marsh Restoration (TE-40) project mirror many of those learned during the earliest of the several other barrier island projects constructed only a few years prior. The general challenges and lessons learned in each phase of these projects are summarized below, with an emphasis on the implications for future project planning and monitoring optimization.

The barrier island projects which predated the Timbalier Island Dune and Marsh Restoration (TE-40) project included project goals and objectives that were loosely defined and on vague timelines. Goals like island stabilization need to be defined in order to be assessed, and time horizons for the longevity of newly created acreages or other project features are necessary to include as success criteria when monitoring an ephemeral feature such as a barrier island for 20 years. Monitoring strategies were clearly defined, allowing for straightforward data trend comparison of the same suite of metrics for the evaluation of the TE-40 project goals. The results of the evaluation, however, are left to interpretation since stated goals and objectives were not referenced to any particular phase or timeframe of the project; for this reason, pre- and post-construction data trends were used in assessing project efficacy.

Monitoring of dynamic features like barrier islands requires flexibility to collect elevation and volume survey data beyond the confines of the original project footprint. Barrier islands are constantly changing shape and dimensions due to natural coastal processes and extreme weather events; project success is best evaluated by considering the entire island system by expanding some data collection events to include offshore and bayward areas to help evaluate project effects on the sediment transport processes that shape and sustain barrier islands. These considerations for expanding survey coverage are likewise applicable to aerial imagery acquisition.

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Appendix A

Tropical Activity in the area of Timbalier Island 1856 to 2021

Table A. Listing of Tropical Activity near Timbalier Island 1856 to 2021

Tropical Storm/Hurricane	Strength at Landfall	Maximum Strenght in Gulf	Year	Distance from Project
Unnamed 1856	H4	H4	1856	Within 40 miles
Unnamed 1893	H4	H4	1893	Within 40 miles
Unnamed 1909	H3	H3	1909	Within 60 miles
Unnamed 1915	**H3**	**H4**	**1915**	**Within 20 miles**
Unnamed 1920	**H2**	**H2**	**1920**	**Within 20 miles**
Unnamed 1923	H1	H1	1923	Within 40 miles
Unnamed 1926	H3	H3	1926	Within 40 miles
Unnamed 1931	TS	TS	1931	Within 60 miles
Unnamed 1941	TS	TS	1941	Within 60 miles
Unnamed 1944	TS	TS	1944	Within 60 miles
Unnamed 1947	TS	H1	1947	Within 60 miles
Unnamed 1947	H2	H2	1947	Within 60 miles
Unnamed 1948	**H1**	**H1**	**1948**	**Within 20 miles**
Unnamed 1956	**TS**	**TS**	**1956**	**Within 40 miles**
Flossy	H1	H1	1956	Within 40 miles
Esther	TS	TS	1957	Within 40 miles
Debbie	TD	TS	1965	Within 20 miles
Betsy	H4	H4	1965	Within 40 miles
Unnamed 1966	D	D	1966	Within 20 miles
Carmen	H4	H4	1974	Within 40 miles
Babe	H1	H1	1977	Within 60 miles
Bob	H1	H1	1979	Within 20 miles
Danielle	TS	TS	1980	Within 60 miles
Juan	H1	TS	1985	Within 20 miles
Andrew	H4	H4	1992	Within 40 miles
Danny	H1	H1	1997	Within 20 miles
Hermine	TS	TS	1998	Within 40 miles
Allison	TD	TS	2001	Within 60 miles
Isidore	TS	TS	2002	Within 20 miles
Bertha	TD	TD	2002	Within 60 miles
Bill	TS	TS	2003	Within 40 miles
Matthew	TS	TS	2004	Within 40 miles

Tropical Storm/Hurricane	Strength at Landfall	Maximum Strenght in Gulf	Year	Distance from Project
Cindy	H1	H1	2005	Within 20 miles
Katrina	H3	H5	2005	Within 60 miles
Gustav	H2	H3	2008	Within 20 miles
Edouard	TS	TS	2008	Within 60 miles
Bonnie	TD	TD	2010	Within 60 miles
Isaac	H1	H1	2012	Within 20 miles
Olga	ET	TS	2019	Within 40 miles
Barry	H1	H1	2019	Within 60 miles
Zeta	H3	H3	2020	Within 20 miles
Cristobal	TS	TS	2020	Within 40 miles
Marco	TS	H1	2020	Within 40 miles
Ida	H4	H4	2021	Within 20 miles
Claudette	TS	TS	2021	Within 40 miles
Other Notable Hurricanes				
Lili	H1	H4	2002	
Rita	H3	H5	2005	