State of Louisiana

Coastal Protection and Restoration Authority of Louisiana (CPRA)

2017 Operations, Maintenance, and Monitoring Report

for

West Belle Pass Barrier Headland Restoration (TE-52)

State Project Number TE-52
Priority Project List 16

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Operations, Maintenance, and Monitoring Report
for
West Belle Pass Barrier Headland Restoration
(TE-52)

Table of Contents

Preface

This report includes monitoring data collected through February 2017, and annual Maintenance Inspections through July 2017. The West Belle Pass Barrier Headland Restoration (TE-52) project is federally sponsored by the National Marine Fisheries Service (NMFS) and locally sponsored by the Coastal Protection and Restoration Authority of Louisiana (CPRA) under the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA, Public Law 101-646, Title III). TE-52 is listed on the 16th CWPPRA Priority Project List (PPL-16).

The 2017 report is the 2nd in a series of OM&M reports since the end of construction of this project in March 2013. This Operations, Maintenance, and Monitoring Report as well as an earlier report (Curole et al. 2015) in this series are posted on the Coastal Protection and Restoration Authority of Louisiana (CPRA) website at *http://cims.coastal.louisiana.gov/DocLibrary/DocumentSearch.aspx* and on the official CWPPRA website at http://www.lacoast.gov/new/Projects/Info.aspx?num=TE-52 .

I. Introduction

The West Belle Pass Barrier Headland Restoration (TE-52) project is a beach, dune, and marsh creation restoration project. TE-52 is located at the western terminus of the 27 km (17 mi) long Caminada-Moreau Headland and is positioned approximately 3 km (2 mi) southwest of Port Fourchon and 0.8 km (0.5 mi) west of Belle Pass in Lafourche Parish, Louisiana (Figures 1 and 2). The project area consists of supratidal, intertidal, and subtidal habitat found on the headland (Figure 3). The dune creation phase extends for 2,835 m (9,300 ft) along the Gulf of Mexico shoreline raising the supratidal, intertidal, and subtidal environments to dune and supratidal elevations. The marsh creation phase of the TE-52 restoration project elevated subtidal and intertidal areas directly behind the dune to intertidal and supratidal elevations. The western portion of the headland is separated from the vastly larger eastern part via the Belle Pass Rock Jetties and forms its southern border with the Gulf of Mexico and its northern border with Timbalier Bay (Figures 2 and 3).

The formation of the Lafourche delta complex began approximately 3,500 years before present (Peyronnin 1962; Frazier 1967; Otvos 1969; Conaster 1971; Harper 1977). During this time, nutrient rich sediments were deposited along the banks of the Lafourche delta distributaries primarily through overbank flooding. This created a vast network of swamps, marshes, and ridges along its numerous subdeltas (Frazier 1967; Reed 1995). Bayou Lafourche was one of the final subdeltas to form during the Lafourche delta period before the river switched its flow to the Plaquemines and Modern delta complexes. This subdelta was an active distributary of the Mississippi River from approximately 1800 to 100 years before present (Morgan and Larimore 1957; Peyronnin 1962; Frazier 1967). At the mouth of the Bayou Lafourche subdelta, a regressing network of accretionary sand ridges developed to form the Caminada-Moreau Headland (Figure 2). These ridges were geomorphodynamically formed by shaping delta front sheet sands through wind, wave, tidal, and longshore transport processes (Otvos 1969; Conaster 1971; Ritchie 1972; Bird 2000). Although not as numerous

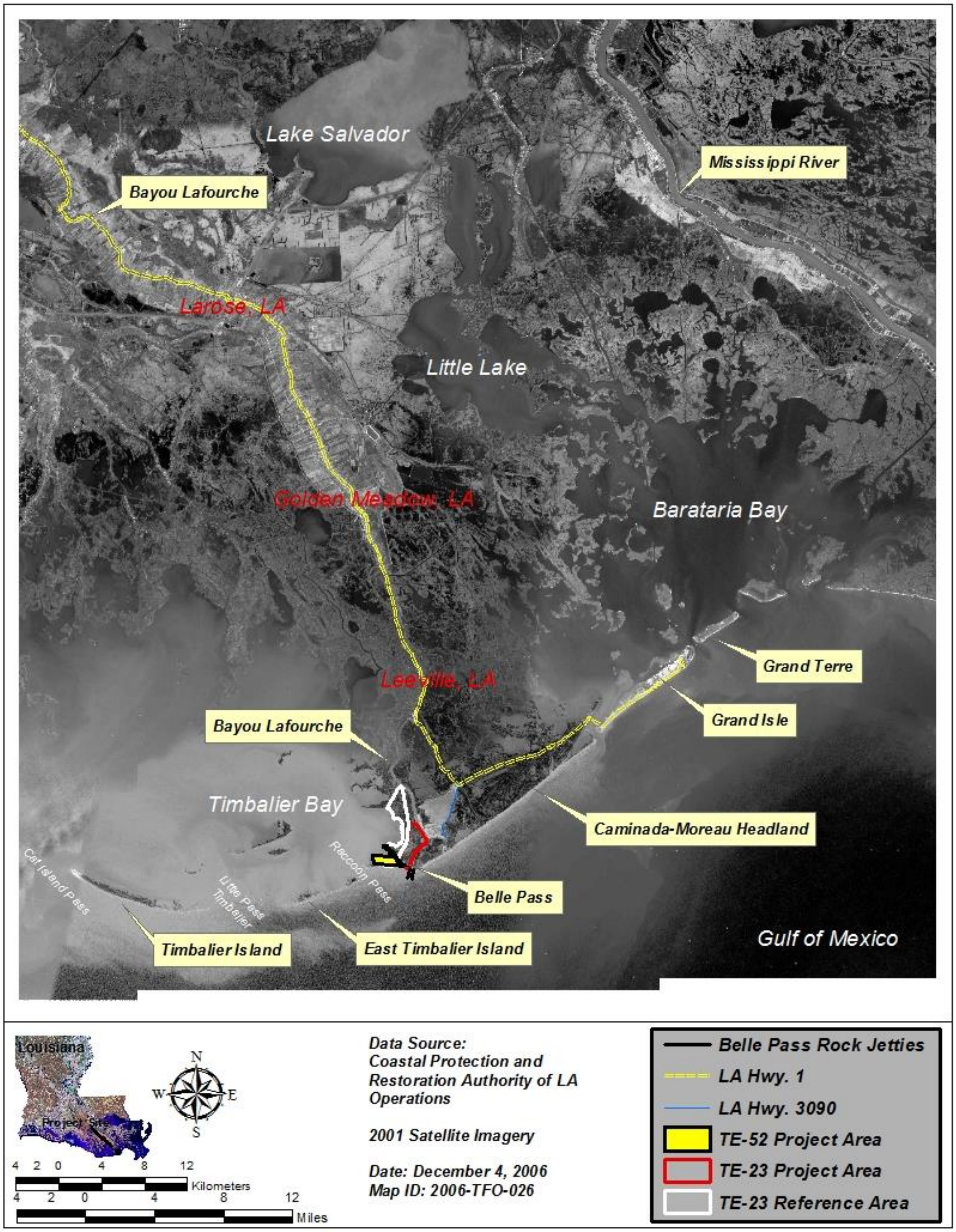


Figure 1. **Location and vicinity of the West Belle Pass Barrier Headland Restoration (TE-52) project.**

Figure 2. **Geomorphic and anthropogenic features of the Caminada-Moreau Headland.**

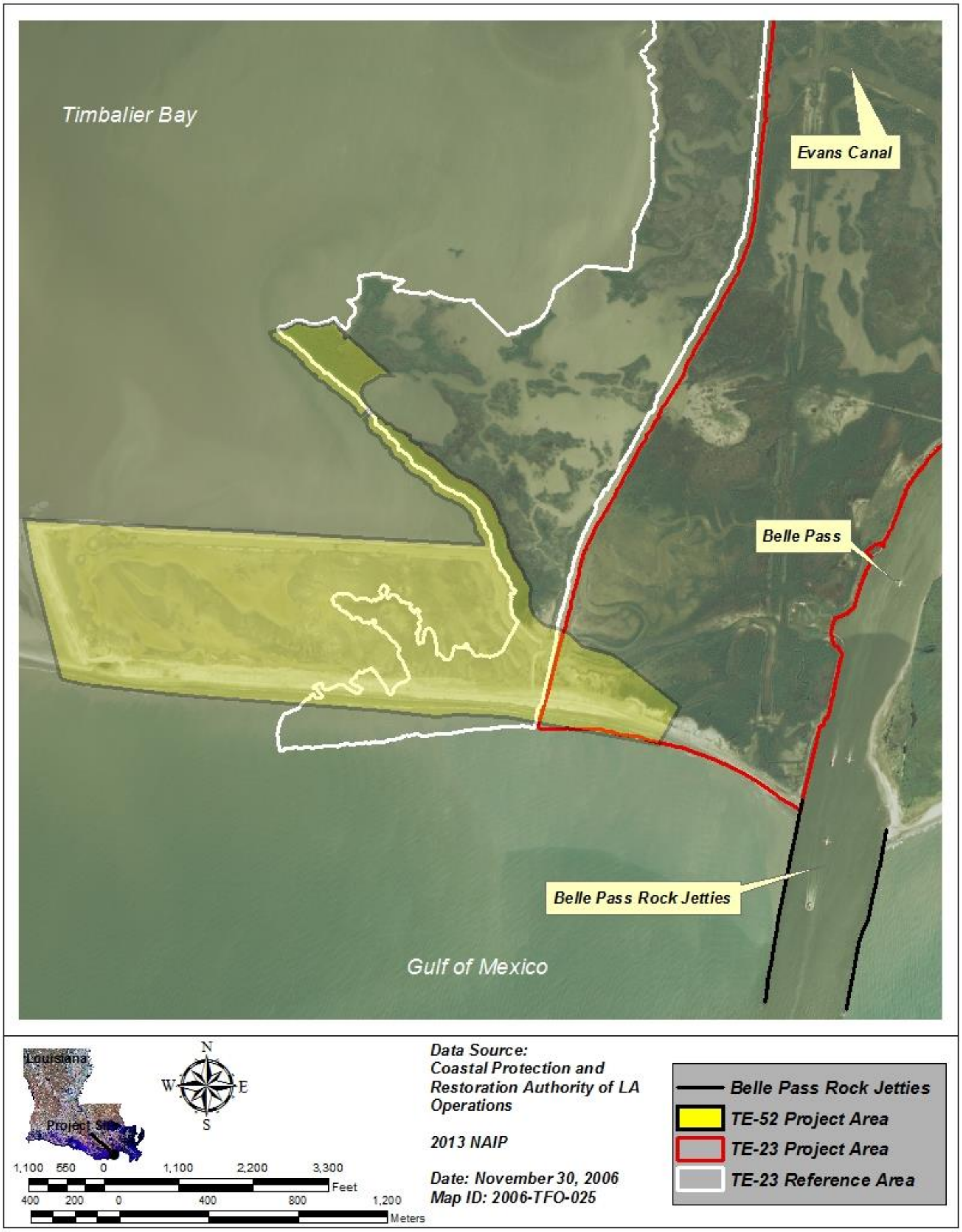


Figure 3. Location of the West Belle Pass Barrier Headland Restoration (TE-52) project area.

as the ridges on the eastern portion of the headland, sand ridges were also shaped on the West Belle Pass part of the headland and extended to the Timbalier Bay shoreline (Fisk 1955).

The soils in the project area are mostly composed of Felicity loamy fine sand soil. This soil is established along the Gulf of Mexico beaches and consists of a somewhat poorly drained sandy soil. Scatlake muck and Bellepass-Scatlake association soils are also found in or near the project area. The Scatlake muck soil is a very poorly drained mineral soil that is located along the Belle Pass and Bayou Lafourche shoreline while the Bellepass-Scatlake association is an organic and mineral soil that is found in very poorly drained saline marshes (USDA 1984).

Marsh vegetation in the project area is dominated by *Spartina alterniflora* Loisel. (smooth cordgrass) and *Avicennia germinans* (L.) L (black mangrove). *Spartina patens* (Ait.) Muhl. (marshhay cordgrass), *Salicornia virginica* L. (glasswort), *Solidago sempervirens* L. (seaside goldenrod), *Baccharis halimifolia* L. (eastern baccharis), *Iva frutescens* L. (bigleaf sumpweed), *Morella cerifera* (L.) Small (waxmyrtle), *Batis maritima* L. (saltwort), and *Distichlis spicata* (L.) Greene (seashore saltgrass) also inhabits the project area. Sasser et al. (2014) classified the project area as salt marsh habitat.

In the years since the creation of the Lafourche delta, the sediment and freshwater supply to the Caminada-Moreau Headland has decreased considerably while the shoreline has noticeably transgressed. The Mississippi River gradually changed its course to form the Plaquemine and Modern delta lobes significantly reducing the sediment supply to the Caminada-Moreau Headland (Frazier 1967; Reed 1995). By 1850, the Bayou Lafourche subdelta was discharging only 15.0 % of the Mississippi River's flow (Reed 1995). In 1904, a dam was placed at the junction of the Mississippi River and Bayou Lafourche essentially eliminating the source of river sediments to the headland (Morgan and Larimore 1957; Peyronnin 1962; Frazier 1967; Dantin et al. 1978; Reed 1995). Therefore, Bayou Lafourche has become a sediment starved, relict distributary of the Mississippi River (Peyronnin 1962; Ritchie 1972; Harper 1977; Dantin et al. 1978; Penland and Ritchie 1979; Boyd and Penland 1981; Ritchie and Penland 1988a; Ritchie and Penland 1988b; Penland and Ramsey 1990; Reed 1995; Pilkey and Fraser 2003). This sediment deficit and eustatic sea level rise (Scavia et al. 2002) has caused the subsidence rate along the Caminada-Moreau Headland to exceed 1.0 cm/yr (0.4 in/yr) (Coleman and Smith 1964; Swanson and Thurlow 1973; Penland and Ramsey 1990; Roberts et al. 1994). In addition, the placement of the Belle Pass jetties (Figures 2 and 3) and the net longshore transport have impeded the movement of sediments to the project area. Jetties and groins have been found to obstruct sand transport along beaches causing erosion on the downdrift side of these structures (Conaster 1971; Komar 1998) and are likely contributors to alterations in sediment transport in the project area. Net longshore transport west of the rock jetties is in the western direction (Peyronnin 1962; Dantin et al. 1978; Ritchie and Penland 1988b; Stone and Zhang 2001; Thomson et al. 2009) (Figure 2). Longshore transport processes have caused extensive shoreface erosion along the West Belle Pass area shifting sediments to downdrift barrier islands and tidal passes (Peyronnin 1962; Levin 1993; List et al. 1997; McBride and Byrnes 1997; Stone and Zhang 2001). The high frequency and intensity of tropical storm (Peyronnin 1962; Stone et al. 1997) and cold front

(Boyd and Penland 1981; Ritchie and Penland 1998b; Dingler and Reiss 1990; Georgiou et al. 2005) events have been shown to induce erosion along the Caminada-Moreau Headland. Moreover, this area has been classified as a storm dominated coast (Harper 1977; Boyd and Penland 1981) consisting of ephemeral dunes shaped by storm events (Ritchie 1972; Harper 1977; Penland and Ritchie 1979; Ritchie and Penland 1988a; Ritchie and Penland 1988b). The sediment deficit, subsidence, longshore transport, and the high frequency of storm events have resulted in high shoreline erosion rates along the low profile Caminada-Moreau Headland. The average rate of shoreline change on the West Belle Pass Headland has been estimated to be -132.7 ft/yr (-40.4 m/yr) from the 1880s to the 1930s, -44.8 ft/yr (-13.7 m/yr) from the 1930s to the 1950s, -68.6 ft/yr (-20.9 m/yr) from the 1950s to 1998, and 10.2 ft/yr (3.1 m/yr) from 2004 to the 2012 (Byrnes et al. 2017).

The geomorphology of the Caminada-Moreau Headland also has been strongly influenced through the frequent passage of tropical storms (Figure 4) and cold fronts. Numerous tropical storms (Peyronnin 1962; Stone et al. 1997) and cold fronts (Boyd and Penland 1981; Dingler and Reiss 1990; Ritchie and Penland 1998b; Georgiou et al. 2005) have elevated water levels high enough to cause partial or total overwash along the low profile Caminada-Moreau Headland. Hurricanes have caused severe overwash along or in the vicinity of the headland since 1856 (Peyronnin 1962; Stone et al. 1997). Specifically, Hurricane Betsy in 1965 (Conaster 1971), Hurricane Carmen in 1974 (Harper 1977), Hurricanes Juan, Danny, and Elena in 1985 (Ritchie and Penland 1988b), Hurricane Andrew in 1992 (Stone et al. 1993), Hurricanes Cindy, Katrina, and Rita in 2005 (Barras 2006), and Hurricane Isaac in 2012 (Devisse and Thomson 2013) have been documented as causing breaching, overwash, and shoreline retreat along the Caminada-Moreau Headland substantially altering the dune and washover environments (Figure 4). Hurricanes Isidore and Lili in 2002 (Curole et al. 2012), T. S. Matthew in 2004 (Roudrigue et al. 2011), Hurricanes Gustav and Ike in 2008 (Curole and Lee 2013), and T. S. Lee in 2011 (Brown 2011) have also been found to affect the geomorphology of barrier islands and wetlands in the vicinity of the headland and likely had an impact on the future TE-52 project area shorelines (Figure 4). As a result, hurricanes have been postulated as the major force driving morphodynamic change along the Caminada-Moreau Headland (Stone et al. 1997).

The construction of the Belle Pass Navigation Channel and Rock Jetties (Figures 2 and 3) has altered the TE-52 project area shorelines. Belle Pass dredging and jetty construction began in 1940 by increasing the depth and width of the channel to unspecified dimensions and constructing parallel rock jetties 152 m (500 ft) in length and 61 m (200 ft) in width. The jetties were extended by 90 m (300 ft) in 1945 due to shoreline erosion (Dantin et al. 1978). In 1958, the navigation channel was enlarged to a depth of -4 m (-12 ft) Mean Low Gulf (MLG) and a width of 30 m (100 ft). The channel was expanded to a 38 m (125 ft) bottom width and relocated to the west of the jetties in 1963 leaving only an eastern jetty. A western jetty was installed in 1974, and Belle Pass was dredged to a -6 m (-20 ft) MLG depth and a 91 m (300 ft) wide extent in 1975 (Dantin et al. 1978). In 1980, the jetties were extended to their current 793 m (2,600 ft) length and 366 m (1,200 ft) width (Figures 2 and 3). Finally, the navigation channel was dredged to a -8 m (-27 ft) MLG depth in 2001 (D. Breaux, GLPC,

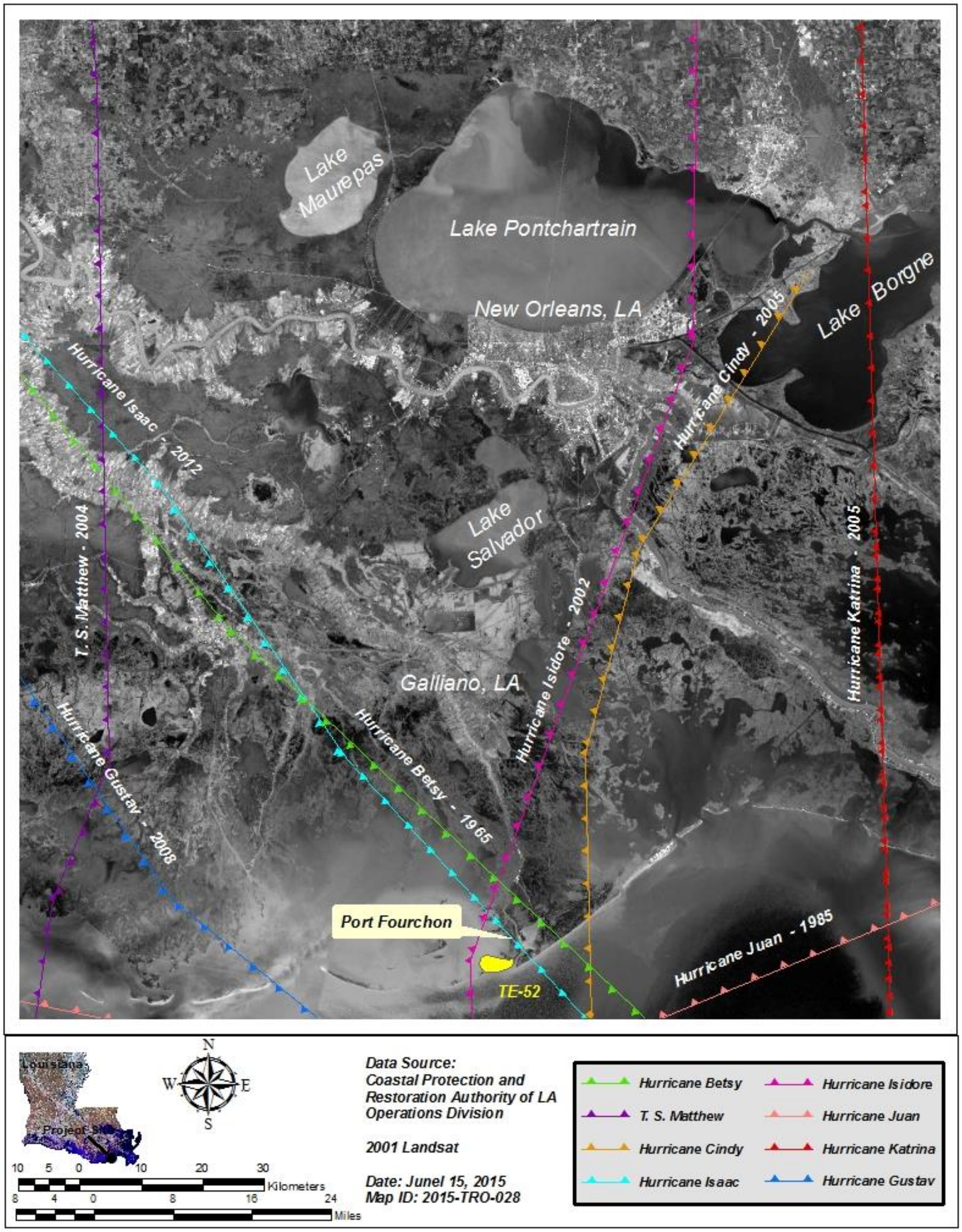


Figure 4. **Pre-construction (1965, 1985, 2002, 2004, 2005, and 2008) and construction (2012) tropical storms impacting the West Belle Pass Barrier Headland Restoration (TE-52) project area shoreline. Hurricanes Carmen (1974), Danny and Elena (1985), Andrew (1992), Lili (2002), Ivan (2004), Rita (2005), Ike (2008), and T. S. Lee (2011) are not shown because the eye wall of these storms traversed outside the extent of this map.**

pers. comm.). As previously discussed, the construction of these rock jetties disrupted the longshore transport processes along the Caminada-Moreau Headland considerably reducing the sand and sediment supply available to project area beaches (Harper 1977; Dantin et al. 1978; Boyd and Penland 1981; Ritchie and Penland 1988b; Stone and Zhang 2001).

In 1998, the Coastal Protection and Restoration Authority of Louisiana (CPRA) and the U. S. Army Corps of Engineers (USACE) initiated the West Belle Pass Headland Restoration (TE-23) project (Figures 1, 2, and 3). This project discharged 1.12 million m^3 (1.46 million yd^3) of sediment into three disposal areas creating 65 ha (160 acres) of supratidal, intertidal, and subtidal habitats and armored 5,182 m (17,000 ft) of Belle Pass and Bayou Lafourche. Approximately, 941,000 m^3 (1.23 million yd^3) of the sediments discharged were placed in the TE-23 marsh creation areas and 174,000 m^3 (228,000 yd^3) were deposited on the West Belle Pass beach. The TE-23 project was not successful in attaining its marsh creation goals, but the shoreline protection structures reduced erosion and maintained their structural stability (Curole and Huval 2005). A 2007 maintenance event was undertaken to enhance the TE-23 project and to remove shoaling from the federal channel (Bayou Lafourche and Belle Pass). During this event, 326,000 m^3 (426,000 yd^3) of dredged material were pumped into the marsh creation area, 85,000 m^3 (112,000 yd^3) were deposited on the West Belle Pass beach, and the Closure 1 structure was re-constructed with sheet pile. After this maintenance event, the TE-23 marsh creation goals were achieved (Curole and Hartman 2016). Figures 5 and 6 depict Gulf of Mexico shoreline change in the TE-23 project and reference areas from 1997 to 2008. Figure 5 shows the regressions in the project area shorelines (2001 and 2007 project shorelines) after the 1998 and 2007 sediment additions. However, these shorelines transgressed soon after the 2001 and 2007 shoreline positions were mapped possibly due to the high frequency of tropical storm events from 2002 to 2008 or the location of the TE-23 shorelines in the lee of the Belle Pass Rock Jetties. The TE-23 reference area shoreline illustrates constant shoreline transgression especially on the western reaches of this shoreline (Figure 6).

The West Belle Pass Barrier Headland Restoration (TE-52) project consists of beach, dune, and marsh creation features (Figures 7 and 8). The following synopsis was summarized from the TE-52 project completion report (Devisse and Thomson 2013). Construction began by building 2,605 m (8,545 ft) of primary containment dike on the Timbalier Bay side of the headland and placing beach fill along the Gulf of Mexico shoreline. The beach fill extended the TE-52 project area southward and westward. Beginning on the western template of the beach and dune fill area, the sand was shaped into a dune feature with a 2.0 m (6.5 ft) NAVD88 centerline elevation. The first 550 m (1,800 ft) of the western dune was oriented in a northwestern direction almost perpendicular to the Gulf of Mexico. This segment of the dune stretched from approximately Sta. 45+00 to Sta. 55+00 before abruptly reorienting its direction to parallel the Gulf of Mexico (Figure 7). The dune was shaped to the 2.0 m (6.5 ft) NAVD88 elevation for approximately two-thirds of its original project template. The remaining eastern sections of the dune were built to a 2.3 m (7.5 ft) NAVD88 centerline elevation. The approximate volume used to fill the beach and dune template was 2,041,361 m^3 (2,670,000 yd^3). Once the dune was constructed, a single row of sand fencing was added along the centerline of the dune. A total of 3,249 m (10,660 ft) of sand fencing was installed.

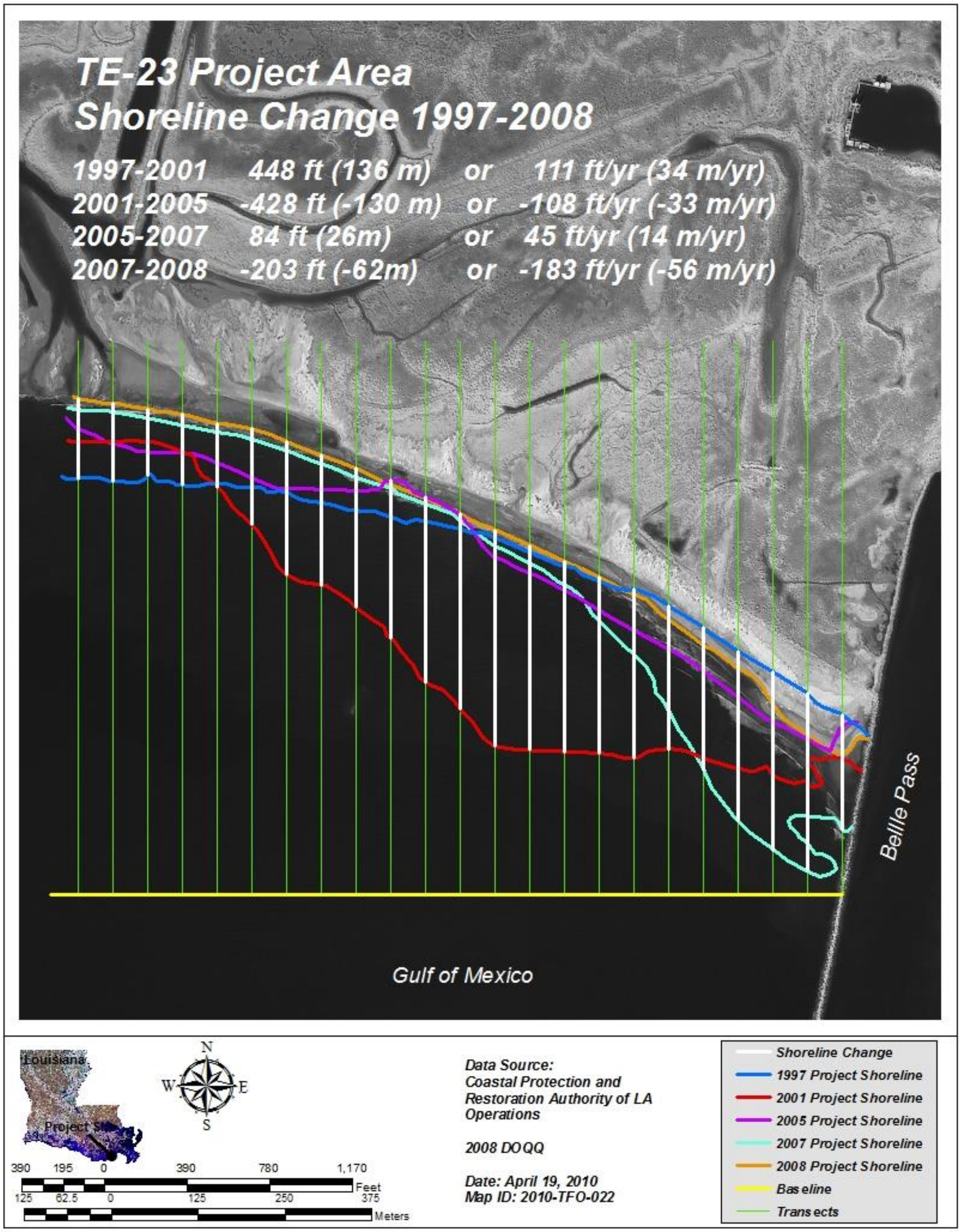


Figure 5. **Shoreline change along the West Belle Pass Headland Restoration (TE-23) project area reaches from 1997 to 2008.**

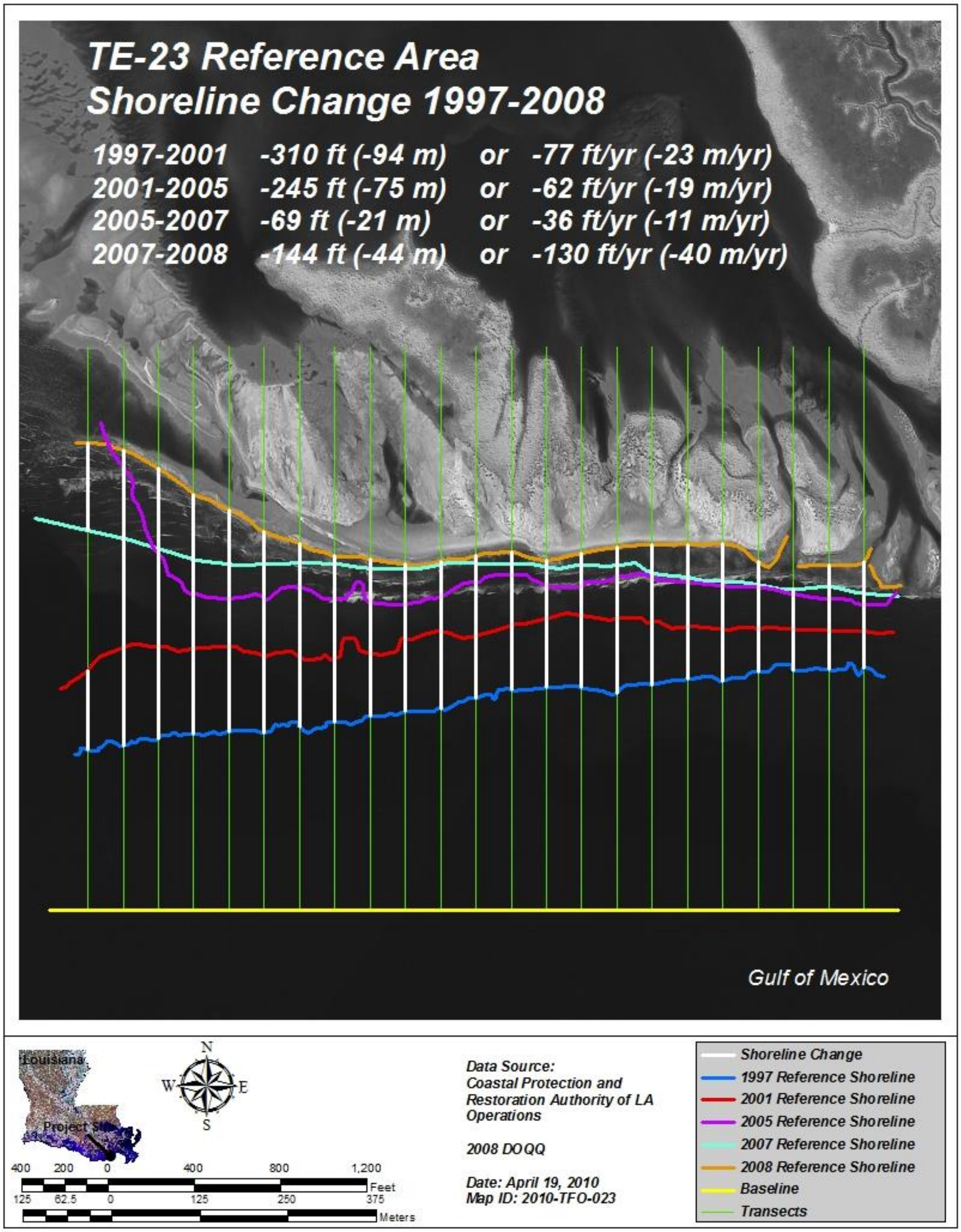


Figure 6. **Shoreline change along the West Belle Pass Headland Restoration (TE-23) reference area reaches from 1997 to 2008.**

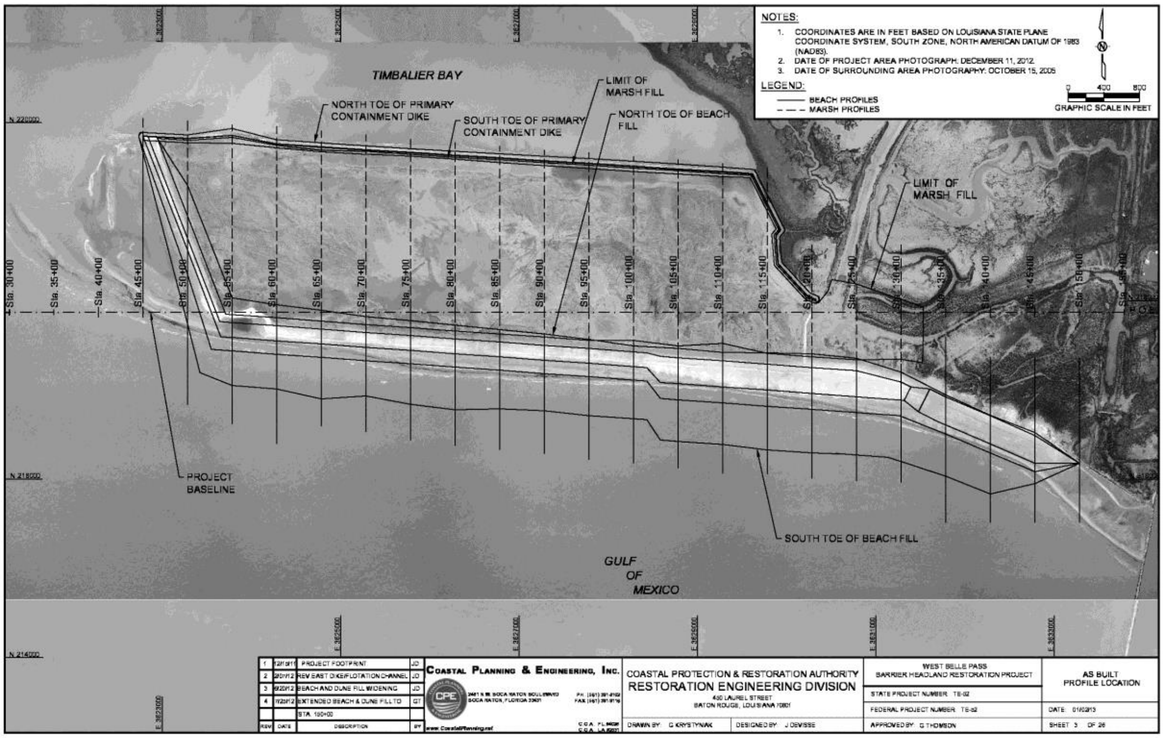


Figure 7. Location of the West Belle Pass Barrier Headland Restoration (TE-52) project features.

In addition to the original beach and dune template, the beach and dune features were extended eastward to tie-in with a USACE, Beneficial Use of Dredge Material (BUMP) project that was pumping dredged materials on to the West Belle Pass Beach (Figure 9). The BUMP project began by placing dredged materials on the edge of the Belle Pass Rock Jetties and moved westward. The expanded beach and dune template resulted in a constructed dune with a 1.4 m (4.5 ft) NAVD88 centerline elevation. A change order was issued to construct this additional beach and supratidal feature due to potential sand loss between the two projects and to create a continuous beach from the rock jetties to the western limits of the TE-52 project (Figure 9). The added features increased the project's sand volume by 57,147 m^3 (74,745 yd^3) and the length of sand fencing utilized by 516 m (1,692 ft). Therefore, the in place volume of sand rose to 2,098,508 m^3 (2,744,745 yd^3) and the linear length of sand fencing increased to 3,765 m (12,352 ft) with the expanded template. On August 29, 2012 ten days after completing the beach and dune segments of the project, Hurricane Isaac made landfall on the Caminada-Moreau Headland (Figure 4) and breached the dune and the primary containment dike (Figure 10). The breach in the primary dike was closed by constructing a 61 m (200 ft) metal sheet pile wall with 9 m (30ft) deep sheet piles. The dune breach was plugged using heavy equipment and sand that had been over washed into the marsh creation area. The re-constructed dune plug was offset from the original dune centerline and includes an area of low relief (old dune location) between the beach and the dune (Figure 10). In addition to the breach closures, approximately 610 m (2,000 ft) of sand fencing were replaced

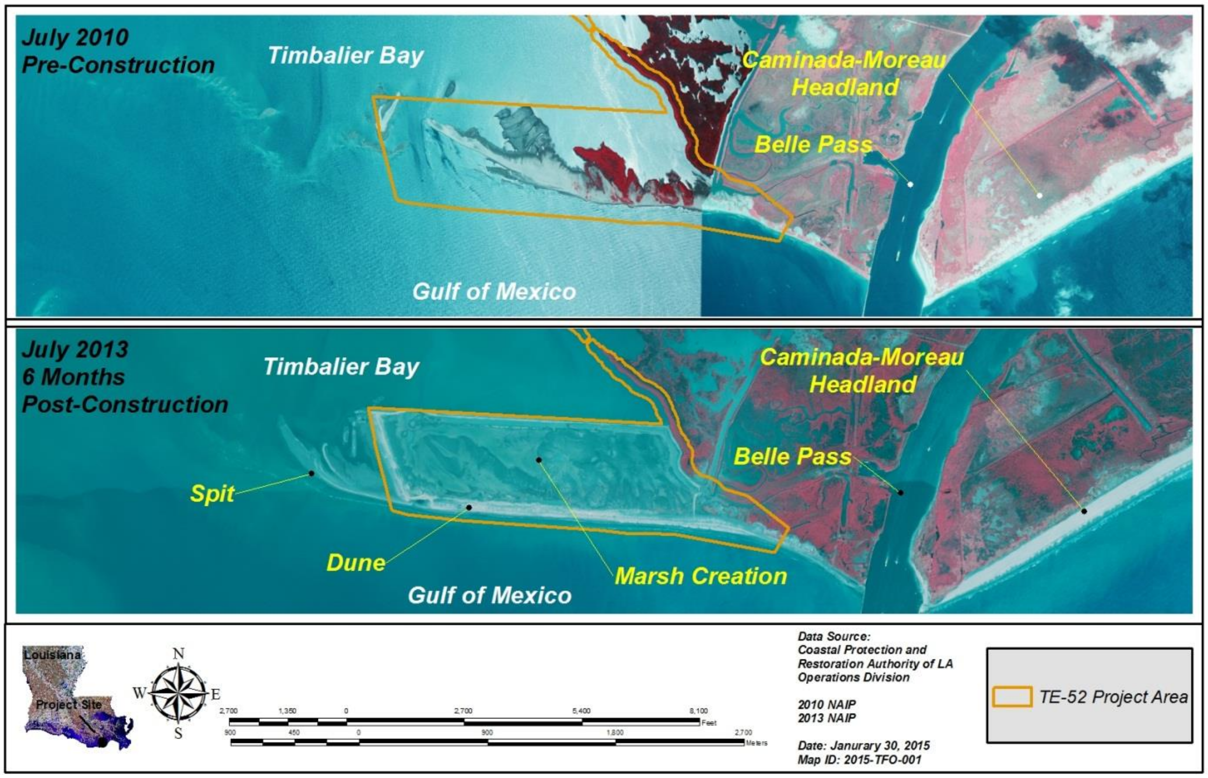


Figure 8. **Aerial photographs demarcating the pre- and post-construction West Belle Pass Barrier Headland Restoration (TE-52) project area and features. Note the extension and shaping of the spit immediately following construction.**

after the hurricane. Marsh creation activities commenced immediately following the passage of Hurricane Isaac. Silt and clay sediments were placed in the area between the beach and dune area's northern extents and the primary containment dike (Figures 7, 8, 9, and 10). Sediments in the marsh creation area were pumped to a final elevation range of 1.0-1.7 m (3.3-5.5 ft) NAVD88. A total of 1,575,142 m^3 (2,060,208 yd^3) of sediments were placed into the marsh creation area creating 135 ha (334 acres) of marsh. Six weir boxes were placed on the eastern edge of the marsh creation area between the dune and the primary containment dike to facilitate dewatering. After sediment consolidation, these weir boxes were removed and the dike was gapped to allow for tidal exchange between surrounding marshes and the marsh creation area. Vegetation was planted along the constructed beach and dune to stabilize these features and increase vegetation cover during the spring of 2013. *Panicum amarum* Elliot (bitter panicgrass), *Uniola paniculata* L. (seaoats), *Schizachyrium maritimum* (Chapm.) Nash (gulf bluestem), *Spartina patens* (Aiton) Muhl. (saltmeadow cordgrass), and *Distichlis spicata* (L.) Greene (saltgrass) were planted either in front of, behind, or on top of the dune feature. Construction of the TE-52 project began on October 25, 2011 and ended on March 12, 2013.

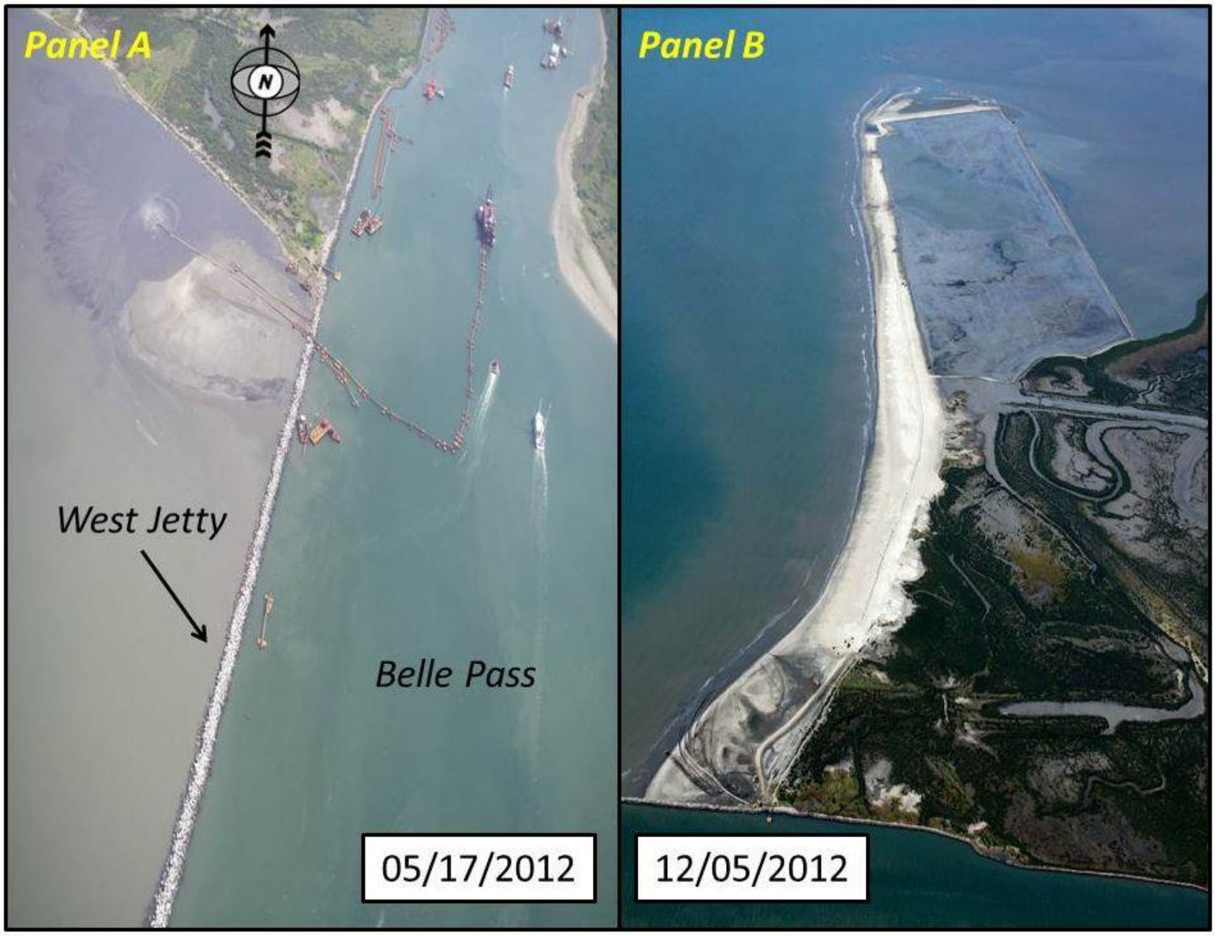


Figure 9. **Oblique aerial images showing the USACE's 2012 BUMP project under construction (Panel A) and the completed West Belle Pass Barrier Headland Restoration (TE-52) and BUMP projects (Panel B). Note the extent of the BUMP project can be delineated from Panel B by denoting the silt and clays in the sandy shoreline (black color).**

Figure 10. Oblique aerial images depicting the West Belle Pass Barrier Headland Restoration (TE-52) project before (Panel A) and after (Panel B) Hurricane Isaac and after dredging operations were complete (Panel C). Panels A and B were taken before marsh creation activities began. The earthen structure in the foreground of Panel A is the floatation channel spoil and can be seen in subsequent photographs. Note the breaching of the primary containment dike and the dune by the hurricane (Panel B) and the embryonic stages of the spit development in Panels B and C. Also note the offset position of the dune in the breached area and erosion along the Gulf of Mexico shoreline in panel C and the large volume of sand that was overwashed into the marsh creation area during beach and dune construction in panel A.

II. Maintenance Activity

a. Project Feature Inspection Procedures

The annual inspection of the TE-52 project took place on July 20th, 2017. In attendance were Benjamin Hartman and Glen Curole with CPRA, and Donna Rogers and Brandon Owens with the National Marine Fisheries Service. The attendees met at a launch near Port Fourchon and traveled to the project area by boat. The inspection began around 10:00 AM at the sheetpile structure within the northern containment dike and concluded around 12:00 at the same location. Photographs of the inspection are located in Appendix A (A-1–A-15).

The purpose of the annual inspection of the West Belle Pass Barrier Headland Restoration (TE-52) project is to evaluate the constructed project features in order to identify any deficiencies. The inspection results are used to prepare a report detailing the condition of the project features and recommendations of any corrective actions considered necessary. Should it be determined that corrective actions are needed, the CPRA shall provide, in the report, a detailed cost estimate for engineering, design, supervision, inspection, construction, and contingencies, as well as an assessment of the urgency of such repairs. An estimated projected budget for the upcoming three (3) years for operation, maintenance, and rehabilitation is included in Appendix B.

b. Inspection Results

Beach Fill

Overall, as the beach profile is continuing to adapt to the environmental conditions, the beach fill has completely eroded, with only a fragment left on the south western most tip. Longshore transport has eroded sand along the length of the beach face, depositing material immediately west and fueling the growth of a large spit. The dune scarping from Belle Pass to near Sta. 105 is continuing to increase and there are signs that water from storm activity regularly accesses the interior from the south east. Shoreline retreat has been measured at four locations along the beach dune, with the highest erosion occurring on the eastern side. Their location and measured retreat are as follows: Sta. 120+00, 271.00'; Sta. 100+00, 251.00'; Sta. 85+00, 119.00'; and Sta. 60+00, 97.00'. Settlement plates that were once in the center of the dune are now missing or in open water. There are no recommendations for maintenance at this time.

Marsh Fill

Minor erosion has occurred around the edges of the sheet pile wall; the western tip extends into open water with the shoreline 10 feet back towards the south and east. The marsh fill appears to be in good condition. There are no signs of extensive settlement and vegetation is continuing to emerge near tidal water sources. All containment dikes are fully intact, with the exception of the outfall area near the eastern adjacent marsh. This gap in the containment dike is providing a hydrologic connection to the channel that was formed as a result of the containment dike borrow area. The northern containment dike has a few low areas which may soon form gaps, providing additional connectivity to the interior marsh. To speed this up, the Thibodaux Regional Office of CPRA has put together a scope of work to create three 50.0' gaps in the northern containment dike plus remove the existing 200' steel sheet pile wall.

An additional 20,000 plugs of smooth cord grass were planted on May 8-10th on the marsh platform along the containment dike in non-vegetated areas. This was done to protect the platform from unabated erosion when Timbalier Bay finally establishes a connection with the internal ditch south of the containment dike. At a cost of $2.50 dollar/plug, Ecological Restoration Services was the low bidder. The annual inspection was held approximately 2 months after installation of the smooth cord grass plugs, observations show the planting area completely vegetated. Thick vegetation prevented the inspection from continuing into the marsh platform.

Sand Fencing

The sand fencing from Sta. 45+00 to Sta. 105+00 appears to be in good condition overall. Sand is accumulating along the fence as designed and the vegetation is growing around it. Approximately 100' of fencing near Sta. 55+00 headed north west has been damaged and is lying on the ground. Sand fencing from Sta. 105+00 to the eastern project extent is badly damaged or nonexistent. The scarp in the dune has reached the fencing and destroyed it. The fencing in this area will need to be replaced after the beach has stabilized to its natural position. There are no recommendations for maintenance at this time.

c. Maintenance Recommendations

The beach fill and marsh fill appear to be functioning as designed. Some scarping of the beach dune is still occurring on the eastern portion of the project as a result of erosional shadowing from the Belle Pass jetty. This scarping has caused extensive damage to the sand fencing that was placed along this stretch of dune. The sand fencing will need to be replaced in the future after the beach and dune has stabilized into its natural position. A large spit of sand has formed on the western end of the headland as a result of longshore sediment transport. The formation of this spit was expected and provides excellent habitat for shorebirds and other marine species. The marsh appears to be in good condition and is not experiencing any excessive settlement. The northern containment dike is beginning to breach, which will help to provide a hydrologic connection to the interior portions of the marsh. Regardless of further breaching, we are currently in the process of removing the steel sheet pile wall and constructing gaps in the northern containment dike. There are no other recommendations of maintenance to the beach fill, marsh fill, or sand fencing at this time.

III. Operations Activity

a. Operation Plan

There are no operations for the TE-52 project.

b. Actual Operations

There are no operations for the TE-52 project.

IV. Monitoring Activity

Pursuant to a CWPPRA Task Force decision on August 14, 2003 to adopt the Coastwide Reference Monitoring System-*Wetlands* (CRMS-*Wetlands*) for CWPPRA, updates were made to the TE-52 Monitoring Plan to merge it with CRMS-*Wetlands* and provide more useful information for modeling efforts and future project planning while maintaining the monitoring mandates of the Breaux Act. There are no CRMS sites located in the project area.

a. Monitoring Goals

The specific project strategies of the West Belle Pass Barrier Headland Restoration (TE-52) project are (1) to place sand on top of supratidal, intertidal, and subtidal habitats to increase the height and width of the headland, (2) to construct a marsh platform through the use of material dredged in the vicinity of the Caminada-Moreau Headland, and (3) to plant vegetation and construct sand fencing to stabilize and conserve newly placed sediments. Placement and settlement of dredged sediments created intertidal and supratidal back barrier marsh and appreciably increased the width and sustainability of the western part of the Caminada-Moreau Headland. Vegetative plantings in back barrier marsh area will hasten the development of marsh communities and support sediment retention. Dune formation, vegetative plantings, and sand fencing aided in sediment retention and prevented overwash on elevated dune segments during small cross-shore events.

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

1. Reestablish and increase headland longevity via dune and marsh creation.

2. Restore shoreline, dune, and back-barrier marsh to increase habitat utilization by essential fish and wildlife species both on the barrier headland and in the consequently developed quiescent bays through the creation of 150 acres of marsh habitat.

3. Prevent breaching along 9,300 feet of the headland over the 20-year project life.

4. Promote the re-establishment of historic longshore transport patterns along the Gulf shoreline.

b. Monitoring Elements

The following monitoring elements will provide the information necessary to evaluate the specific goals listed above:

Elevation

Topographic and bathymetric surveys were employed to document elevation and volume changes inside the West Belle Pass Barrier Headland Restoration (TE-52) project area. Design (August 2008), pre-construction (October 2011) and as-built (October 2012) elevation data were collected using traditional cross sectional and real time kinematic (RTK) survey methods. Subsequent post-construction surveys were conducted in January 2015 and February 2017. These surveys were conducted on 37 cross sectional transects that were separated by 152 m (500 ft) intervals (Figure 11). Several of the periodic surveys were missing transects – 2008 design (T1A-T1B and T26-T35), 2011 pre (T1B-T1 and T22-T35), 2012 as-built (T1B-T1 and T22-T35), and 2015 post-construction (T1A-T1B). In addition, the length of the survey transects and spacing between points was not always consistent. The survey data were collected using the Louisiana Coastal Zone (LCZ) GPS Network and the TE23-SM-01 monument. All data surveys were referenced to LA State Plane South Zone (1702) coordinates, and vertical elevations were referenced to NAVD88 in feet. Three different geoid models were employed to estimate vertical positions during the 6.4 year span in the surveys. GEOID03 was utilized in 2008, GEOID09 was utilized in 2011 and 2012, and GEOID12A was utilized in 2015 and 2017. All vertical positions were adjusted to tie in with the GEOID12A model using correction factors established on the TE23-SM-01 monument. Survey profiles were graphed for all transects utilizing the y-coordinates and the elevation points with the JMP (v13) statistical software.

The August 2008, October 2011, October 2012, January 2015, and February 2017 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-52 polygons to estimate elevation and volume changes within the beach and dune creation area, the marsh creation area, the nourishment area, and the spit area. The TE-52 polygons were adjusted to fit the smallest survey extent (transect number and length).

Elevation changes from August 2008-October 2011, October 2011-October 2012, October 2012-January 2015, October 2012-February 2017, January 2015-February 2017, August 2008-January 2015 (spit only), and August 2008-February 2017 (spit only) were calculated by subtracting the corresponding grid models using the Minus Tool utility of the Spatial Analyst extension of ArcGIS®. After the elevation change grid models were generated, the spatial distribution of elevation changes in the TE-52 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.

Figure 11. **Location of the West Belle Pass Barrier Headland Restoration (TE-52) project's topographic and bathymetric survey transects.**

Shoreline Change

Gulf of Mexico shoreline change data was analyzed for the beach and dune and spit areas using the Digital Shoreline Analysis System (DSAS version 2.1.1) extension of ArcView® GIS (Thieler et al. 2003). Shoreline positions were determined by extracting the 0 m (0 ft) NAVD88 contour lines from established elevation grid models using the Contour List operation of the 3D Analyst extension of ArcGIS®. The procedures utilized to create the grid models are described in the elevation methodology listed above. The shoreline positions were created from the zero meter contour of the August 2008, October 2011, October 2012, January 2015, and February 2017 elevation grid models. Once the shorelines were delineated a baseline was created and 1,500 m (4921 ft) simple transects were cast at 50 m (164 ft) intervals. Annual shoreline change rates (m/yr) were assessed and mapped for the ensuing periods August 2008-October 2011, October 2011-October 2012, October 2012-January 2015, and January 2015-February 2017. These data were graphed and analyzed for significance using a one-way ANOVA and the JMP (v13) statistical software.

Vegetation

Vegetation stations were established in the West Belle Pass Barrier Headland Restoration (TE-52) project area to document species composition and percent cover over time. Thirty (30) randomized plots were placed in both the beach and dune creation area and the marsh creation area (Figure 12). Vegetation data were collected in September 2013 (6 months post-construction), October 2014 (1.5 years post-construction), and September 2016 (3.5 years post-construction), via the semi-quantitative Braun-Blanquet method (Mueller-Dombois and Ellenberg 1974; Sawyer and Keeler-Wolf 1995; Barbour et al. 1999). Plant species at each station were identified, and cover values were ocularly estimated using Braun-Blanquet units (Mueller-Dombois and Ellenberg 1974) as described in Folse et al. (2014). The cover classes used were: solitary, <1%, 1-5%, 6-25%, 26-50%, 51-75%, and 76-100%. After sampling the plot, the residuals within a 5 m (16 ft) radius were inventoried. Sixty (60) stations were sampled in 2013 through 2014 and thirty-three (33) were sampled in 2016 using a $4m^2$ plot size. Beach and dune plots were not reestablished in 2016 due to the extensive erosion of these project features. Only three (3) beach and dune plots remain on the northwest oriented dune reach (Figure 12).

Mean cover and importance value (IV) were calculated and graphed to summarize vegetation data. Both these parameters were grouped by creation area and year. Relative cover represents the cover of each species as a percentage of total cover (Barbour et al. 1999). An IV is calculated using a minimum of two relative measures. The following IV formula was applied to this analysis: IV = (relative cover + relative frequency)/2. IV represents each species relative contribution to the vegetative community (Barbour et al. 1999). Since IV is a relative measure, each species earns a value ranging from 0 to 100. Cover estimates were analyzed with JMP (v13) statistical software.

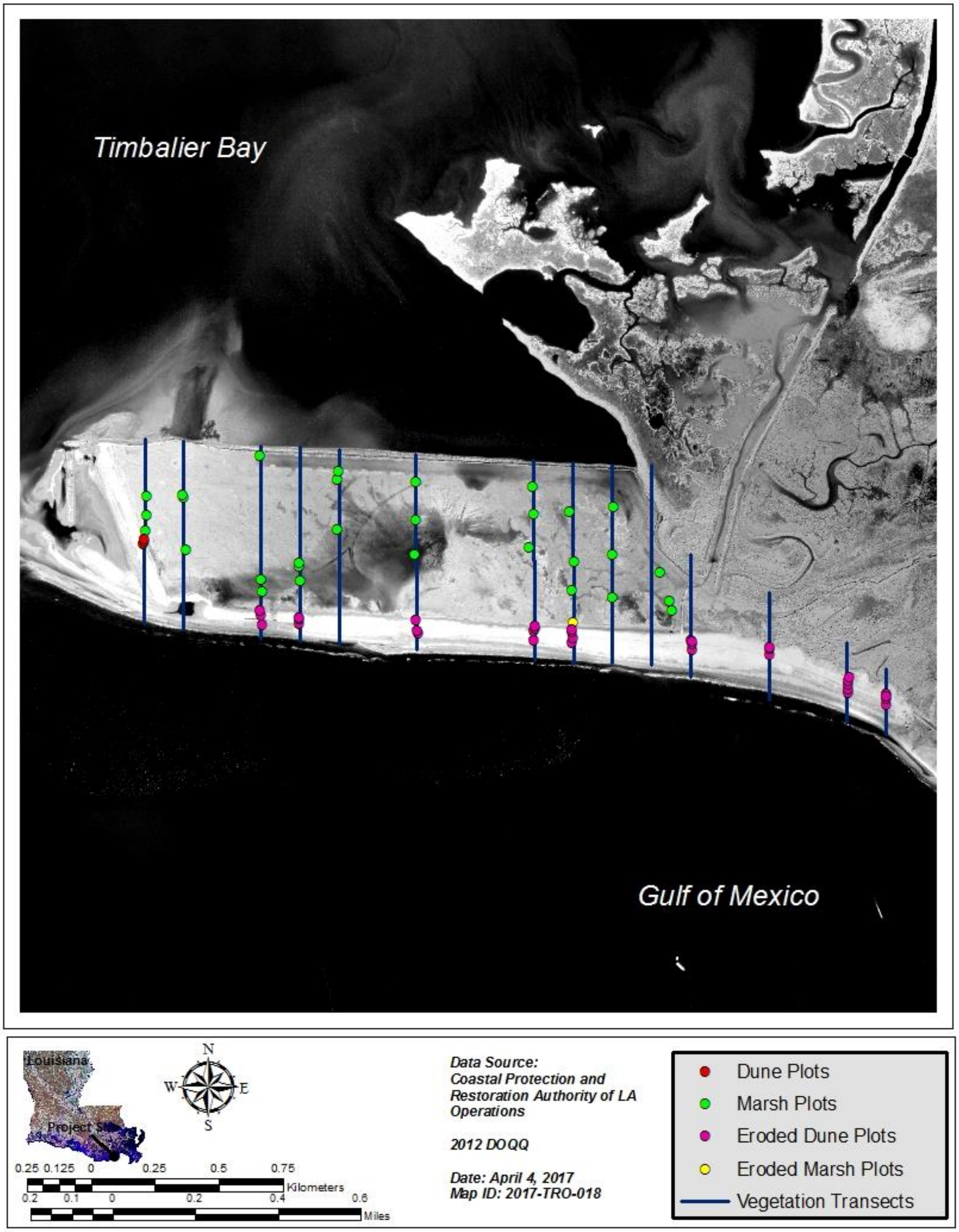


Figure 12. **Location of the West Belle Pass Barrier Headland Restoration (TE-52) project's vegetation plots and transects.**

Avian Habitat

As noted in the Curole et al. (2015), the USFWS designation of Critical Habitat for a large portion of the Louisiana coastline, due to the threatened Piping Plover *(Charadrius melodus)* and Rufa Red Knot *(Calidris canutus rufa)*, has required CPRA to survey winter shorebirds during construction of large scale beach and dune restorations. As such, the Barataria-Terrebonne National Estuary Program (BTNEP) conducted surveys along the Caminada Headland thru December 2016, and has covered the West Belle Pass Barrier Headland Restoration project (TE-52) area numerous times over the last three wintering seasons. Since this information was available and is being used to compare an older projects bird usage patterns to the newly placed sediment northeast of Belle Pass, CPRA decided to update the data and include limited discussion within this report. Pre-construction data is lacking for all these areas, and as such no comparisons can be made to pre-project bird abundance and distributions.

Winter shorebird surveys have focused on four species of concern. Piping Plovers, Rufa Red Knots, Wilsons Plover (*Charadrius wilsonia*), and Snowy Plover (*Charadrius nivosus*) are located and counted approximately every two weeks from late July through April of each winter season. All species seen are noted, but specific locations, numbers of individuals, and identification marks (color bands) are recorded for these four species.

c. Monitoring Results and Discussion

Elevation

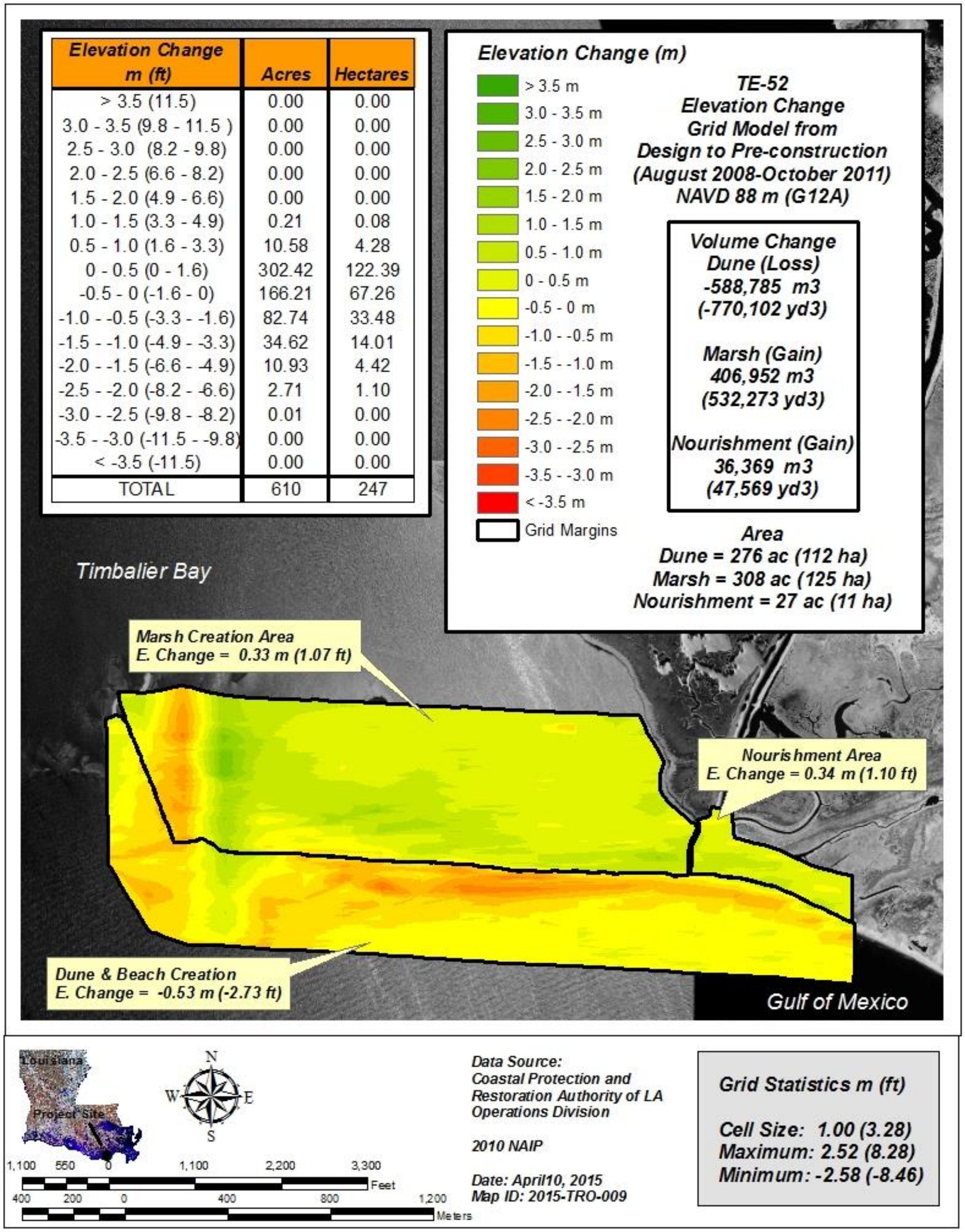
The West Belle Pass Barrier Headland Restoration (TE-52) project area has experienced pre- and post-construction volume changes and shoreline modifications. Volume changes over the period of the study are summarized in Tables 1 and 2, and survey profiles are illustrated in appendix C. Elevation change and volume distributions for the TE-52 project (beach and dune creation, marsh creation, and nourishment areas) are shown in Figure 13 (Aug 2008-Oct 2011), Figure 14 (Oct 2011-Oct 2012), Figure 15 (Oct 2012-Jan 2015), and Figure 16 (Oct 2012-Feb 2017). In addition, elevation change and volume distributions for the spit are presented in Figure 17 (Aug 2008-Jan 2015) and Figure 18 (Aug 2008-Feb 2017). Elevation grid models for all survey periods are also provided in appendix D. The TE-52 volume and mean elevation changes are also graphically shown in Figure 19 (beach and dune), Figure 20 (marsh creation and nourishment), and Figure 21 (spit only). In the discussion that follows, note that the as-built volumes computed for this narrative do not equal the volumes stated in the completion report (Devisse and Thomson 2013) because the beach and dune and marsh creation elevation grid models were clipped to different aerial extents.

Table 1. **Pre- and post-construction sediment volume changes in the TE-52 project area. Note that the volume changes in the beach and dune creation area include both the subaerial segments of the headland and the shoreface.**

Volume Change (m3)	*Aug 2008 Design - Oct 2011 Pre*	*Oct 2011 Pre-Oct 2012 As-blt*	*Oct 2012 As-blt-Jan 2015 2Yr Post*	*Oct 2012 As-blt-Feb 2017 4Yr Post*
Dune & Beach Creation Area	-588,785	1,339,240	-774,695	-1,474,810
Marsh Creation Area	406,952	1,695,860	-693,640	-813,868
Nourishment Area	36,369	29,039	-10,997	-24,065

Table 2. **Pre- and post-construction sediment volume changes in the TE-52 spit area. An expanded spit template was used to compare the post-construction surveys because the extent of the spit coverage increased to the west (additional survey transects). Note that the spit volume changes include both the subaerial segments of the headland and the shoreface.**

Volume Change (m3)	*Aug 2008 Design - Jan 2015 2Yr Post*	*Aug 2008 Design - Feb 2017 4Yr Post*	*Jan 2015 2Yr Post - Feb 2017 4Yr Post*
Spit Area	126,979	85,608	N/A
Extended Spit Area	N/A	N/A	548,704



Elevation Change m (ft)	Acres	Hectares
> 3.5 (11.5)	0.00	0.00
3.0 - 3.5 (9.8 - 11.5)	0.00	0.00
2.5 - 3.0 (8.2 - 9.8)	0.00	0.00
2.0 - 2.5 (6.6 - 8.2)	0.00	0.00
1.5 - 2.0 (4.9 - 6.6)	0.00	0.00
1.0 - 1.5 (3.3 - 4.9)	0.21	0.08
0.5 - 1.0 (1.6 - 3.3)	10.58	4.28
0 - 0.5 (0 - 1.6)	302.42	122.39
-0.5 - 0 (-1.6 - 0)	166.21	67.26
-1.0 - -0.5 (-3.3 - -1.6)	82.74	33.48
-1.5 - -1.0 (-4.9 - -3.3)	34.62	14.01
-2.0 - -1.5 (-6.6 - -4.9)	10.93	4.42
-2.5 - -2.0 (-8.2 - -6.6)	2.71	1.10
-3.0 - -2.5 (-9.8 - -8.2)	0.01	0.00
-3.5 - -3.0 (-11.5 - -9.8)	0.00	0.00
< -3.5 (-11.5)	0.00	0.00
TOTAL	610	247

Figure 13. **Elevation and volume change grid model for the beach and dune, marsh creation, and nourishment areas from design (Aug 2008) to pre-construction (Oct 2011) at the West Belle Pass Barrier Headland Restoration (TE-52) project.**

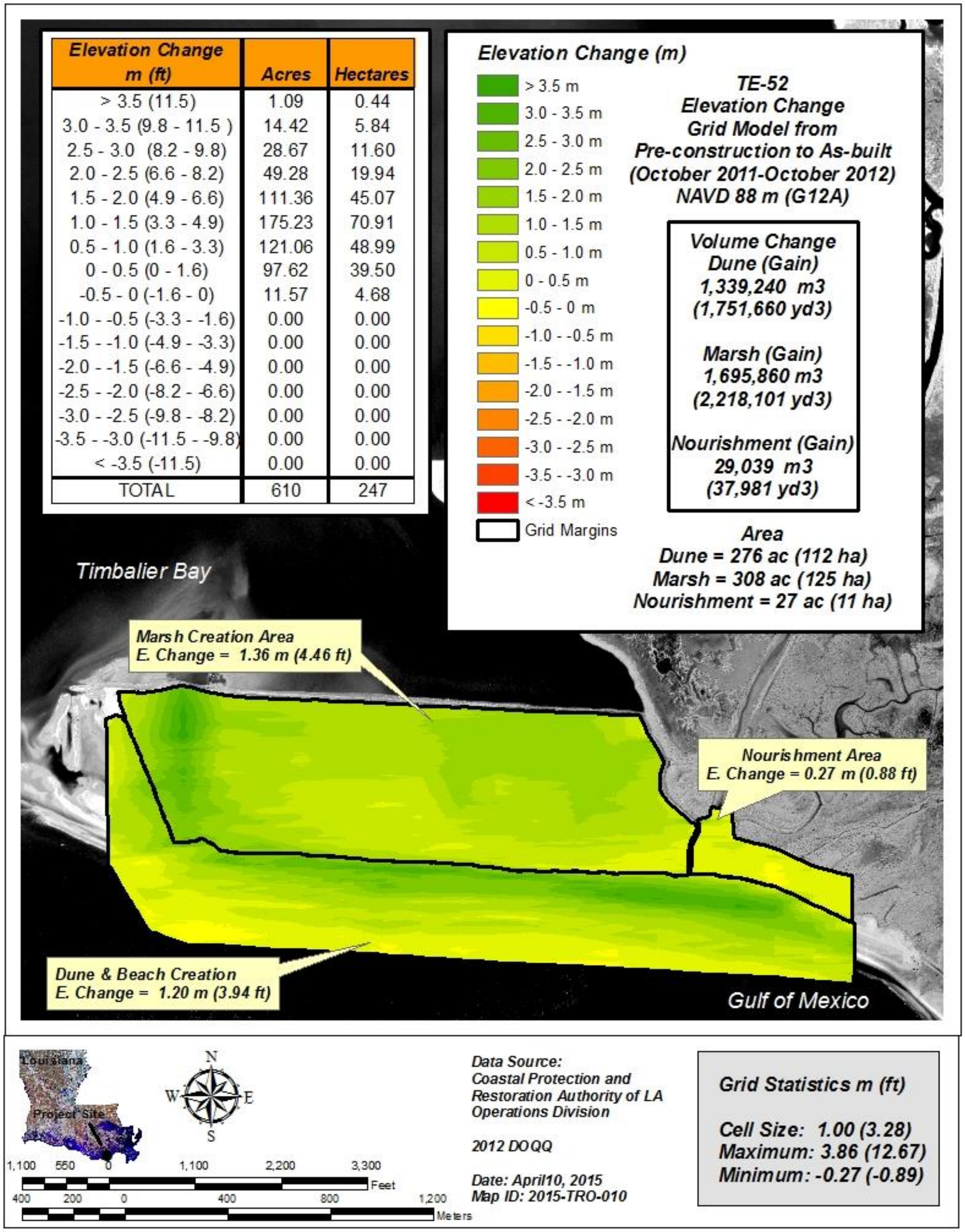


Figure 14. **Elevation and volume change grid model for the beach and dune, marsh creation, and nourishment areas from pre-construction (Oct 2011) to as-built (Oct 2012) at the West Belle Pass Barrier Headland Restoration (TE-52) project.**

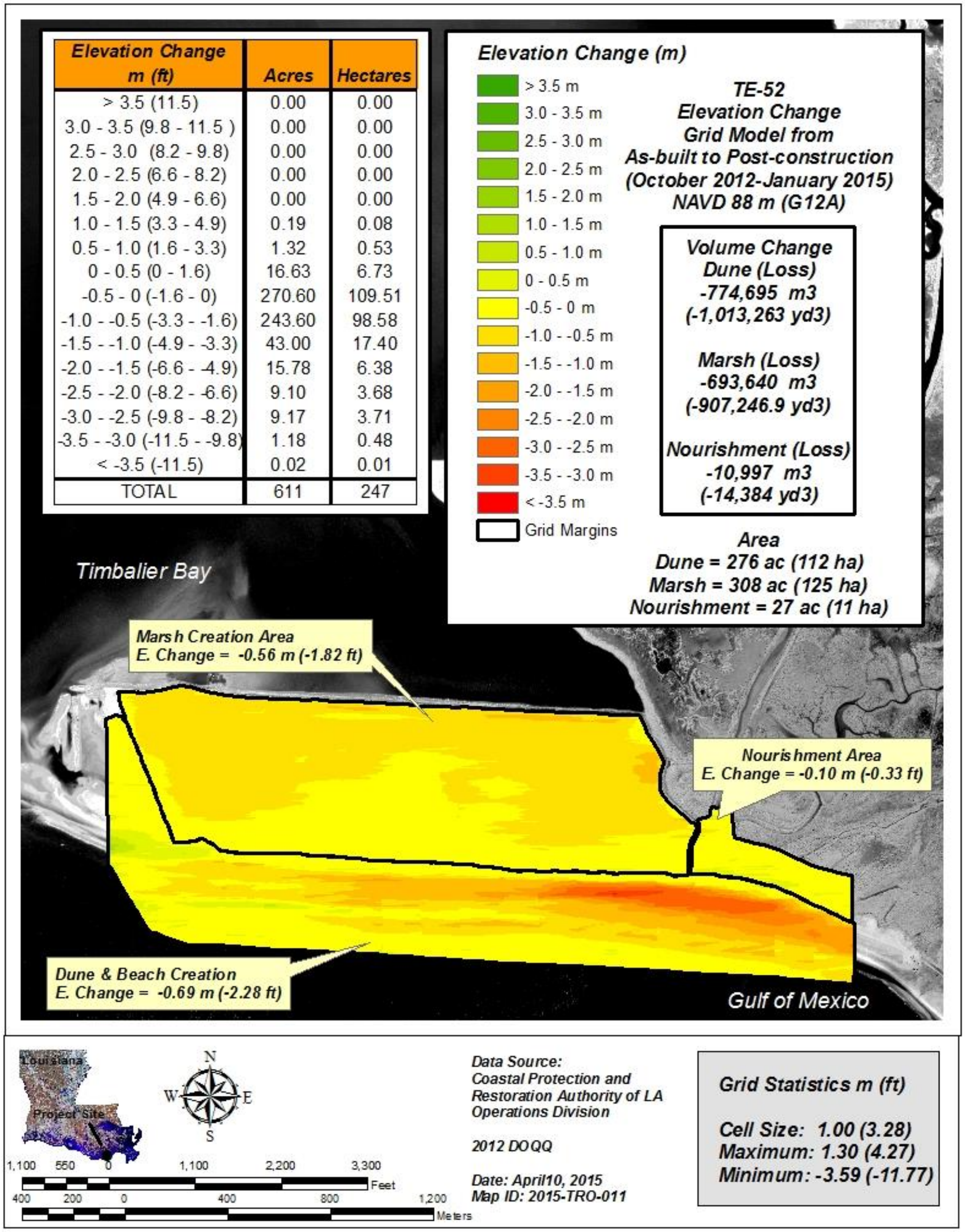


Figure 15. **Elevation and volume change grid model for the beach and dune, marsh creation, and nourishment areas from as-built (Oct 2012) to post-construction (Jan 2015) at the West Belle Pass Barrier Headland Restoration (TE-52) project.**

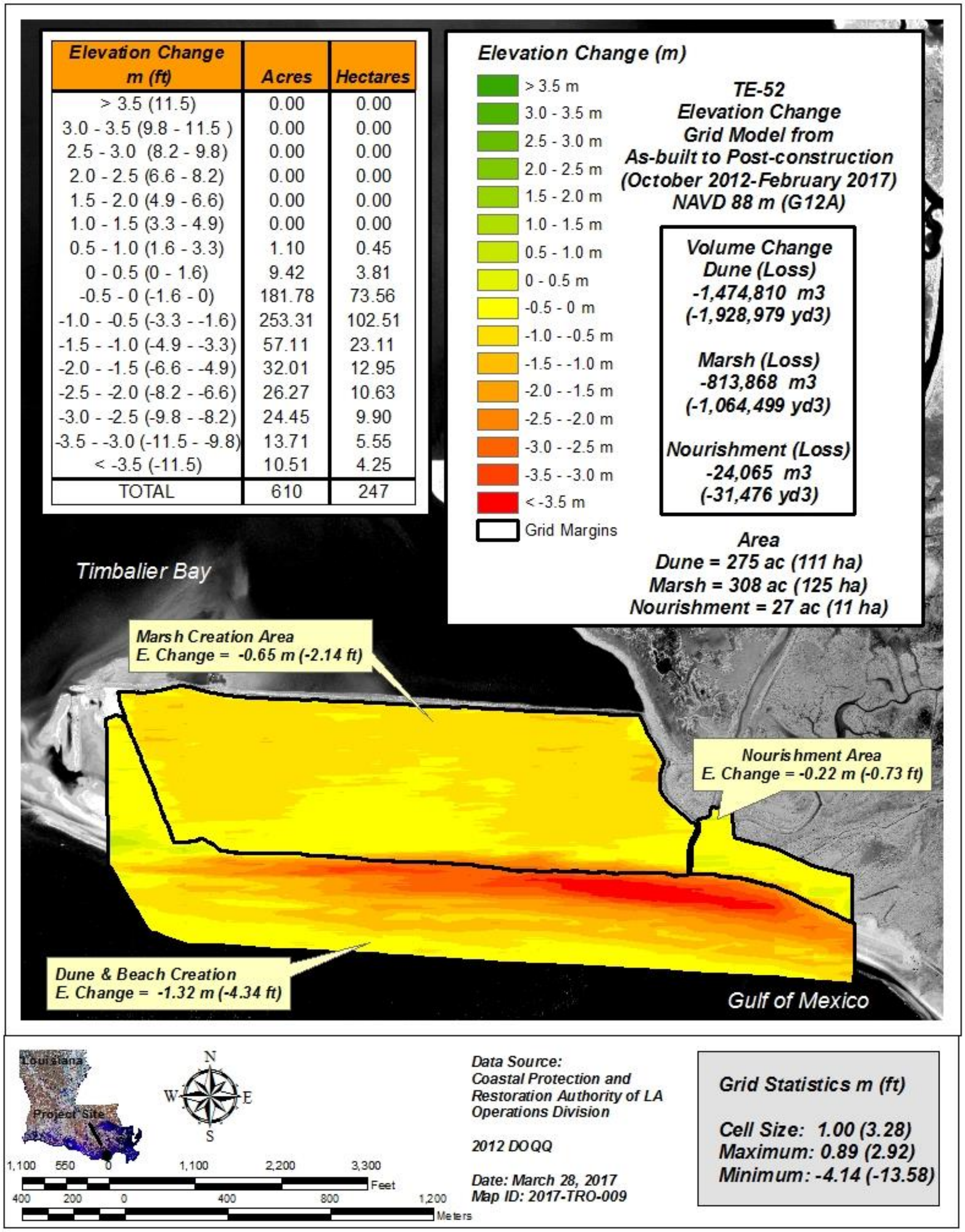
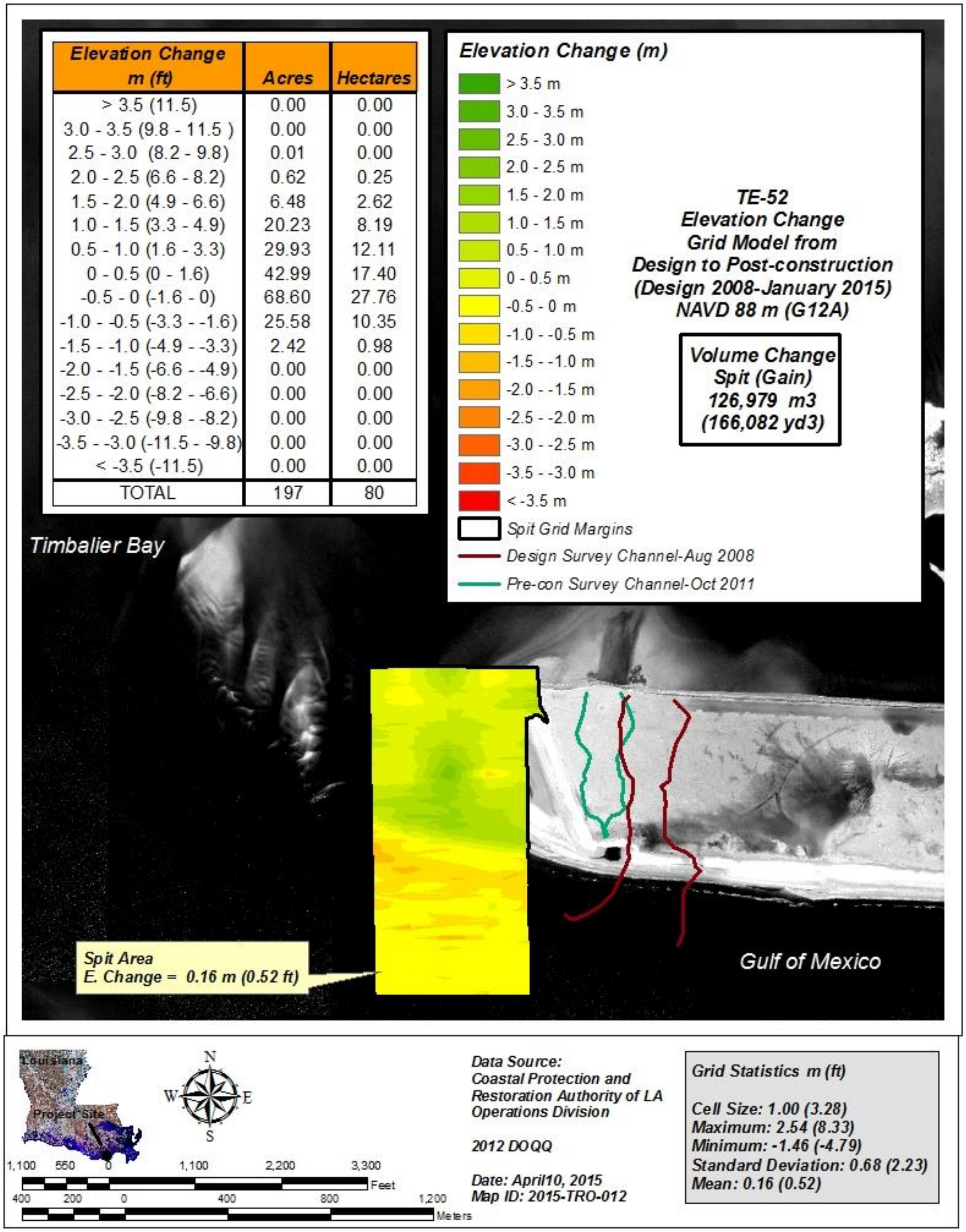


Figure 16. **Elevation and volume change grid model for the beach and dune, marsh creation, and nourishment areas from as-built (Oct 2012) to post-construction (Feb 2017) at the West Belle Pass Barrier Headland Restoration (TE-52) project.**



Elevation Change m (ft)	Acres	Hectares
> 3.5 (11.5)	0.00	0.00
3.0 - 3.5 (9.8 - 11.5)	0.00	0.00
2.5 - 3.0 (8.2 - 9.8)	0.01	0.00
2.0 - 2.5 (6.6 - 8.2)	0.62	0.25
1.5 - 2.0 (4.9 - 6.6)	6.48	2.62
1.0 - 1.5 (3.3 - 4.9)	20.23	8.19
0.5 - 1.0 (1.6 - 3.3)	29.93	12.11
0 - 0.5 (0 - 1.6)	42.99	17.40
-0.5 - 0 (-1.6 - 0)	68.60	27.76
-1.0 - -0.5 (-3.3 - -1.6)	25.58	10.35
-1.5 - -1.0 (-4.9 - -3.3)	2.42	0.98
-2.0 - -1.5 (-6.6 - -4.9)	0.00	0.00
-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	197	80

Figure 17. **Elevation and volume change grid model for the spit area from design (Aug 2008) to post-construction (Jan 2015) at the West Belle Pass Barrier Headland Restoration (TE-52) project.**

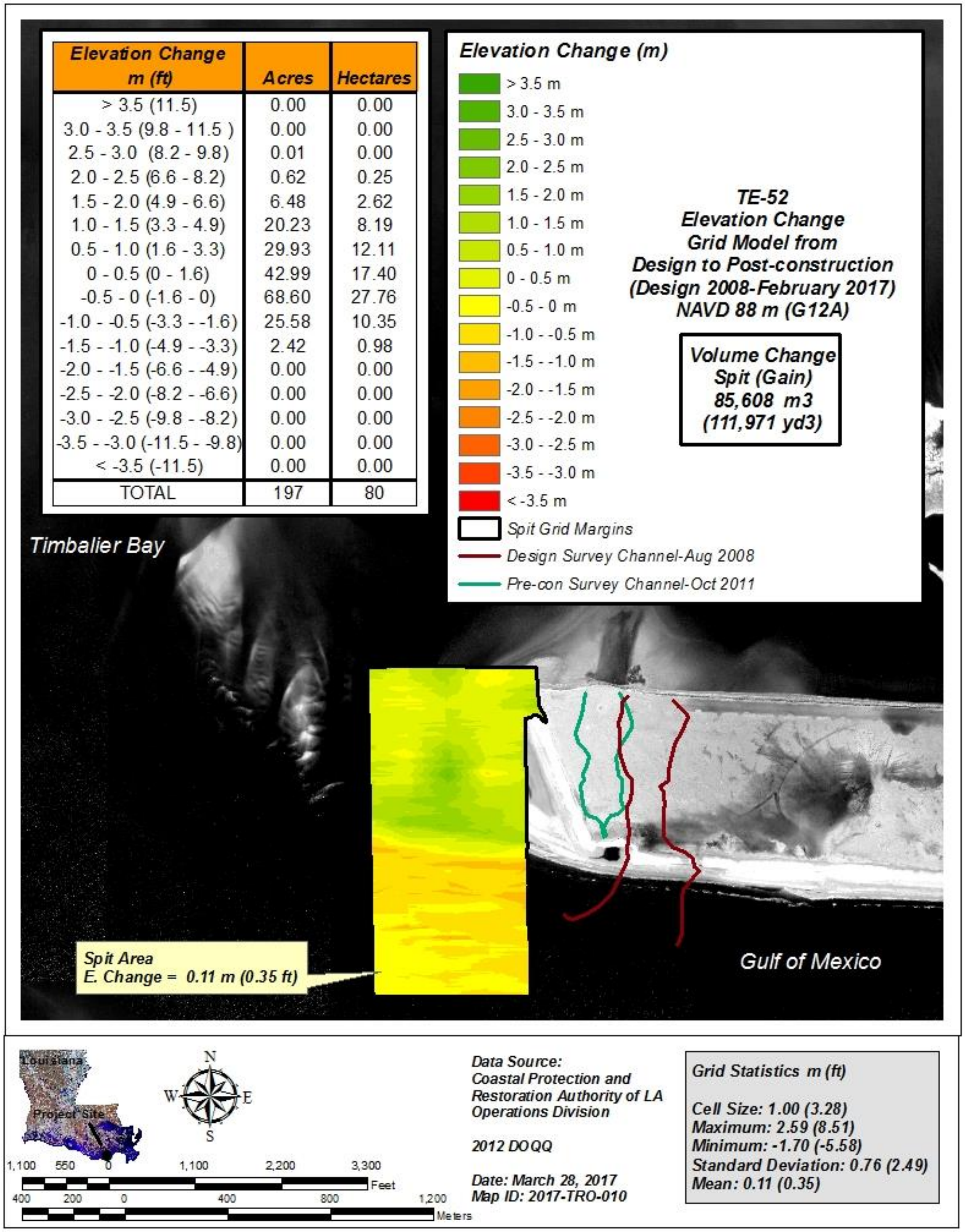


Figure 18. **Elevation and volume change grid model for the spit area from design (Aug 2008) to post-construction (Feb 2017) at the West Belle Pass Barrier Headland Restoration (TE-52) project.**

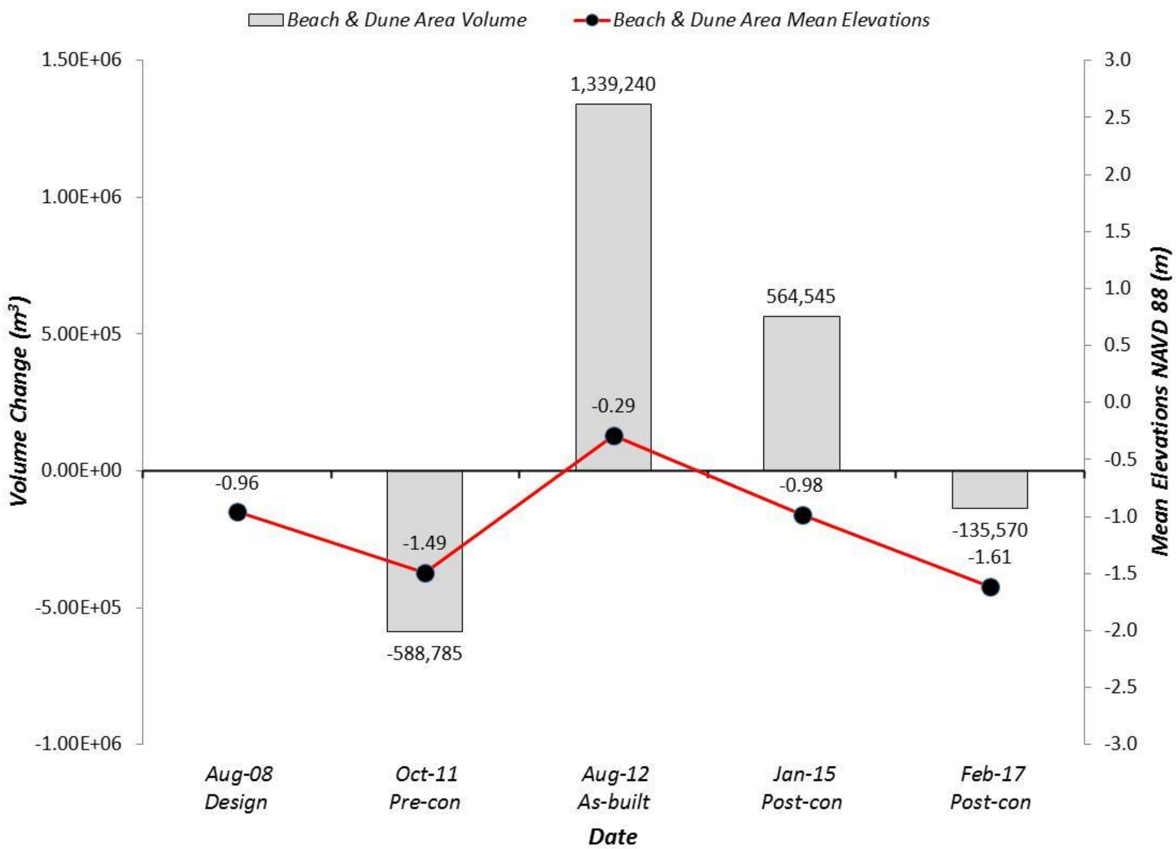


Figure 19. Sediment volume change and mean elevations over time along the West Belle Pass Barrier Headland Restoration (TE-52) project's beach and dune area.

The pre-construction elevation models (2008-2011) display large losses in the future beach and dune creation area and large volume gains in the future marsh creation and nourishment areas. The sediment volume in the beach and dune area was reduced by -588,785 m^3 (-770,102 yd^3) while the volume in the marsh creation [406,952 m^3 (532,273 yd^3)] and nourishment [36,369 m^3 (47,569 yd^3)] areas expanded (Table 1 and Figures 13, 19, and 20). The large sediment volume loss along the shoreline and shoreface exhibit the signature of a transgressing shoreline while the capture and retention of 75% sediment removed signifies cross-shore transport. Interestingly, a rather large channel that bisected the project area in-filled and relocated to the west from 2008 to 2011 (Figures 13, 17, D-1, and D-2). The 2008 hurricanes (Gustav and Ike) (Figure 22) and T. S. Lee in 2011 (Brown 2011) impacted the project area during the pre-construction interval and likely aided in the cross-shore sediment roll over in this area. The previously mentioned 2007 TE-23 maintenance event, which deposited 85,000 m^3 (112,000 yd^3) of sediment adjacent to the west jetty, also probably supported the sediment aggradation in the marsh creation and nourishment areas due to the partial removal of this material in 2008 (Figures 5 and 22) and almost complete removal of this material from its disposal area by 2010 (Figure 8).

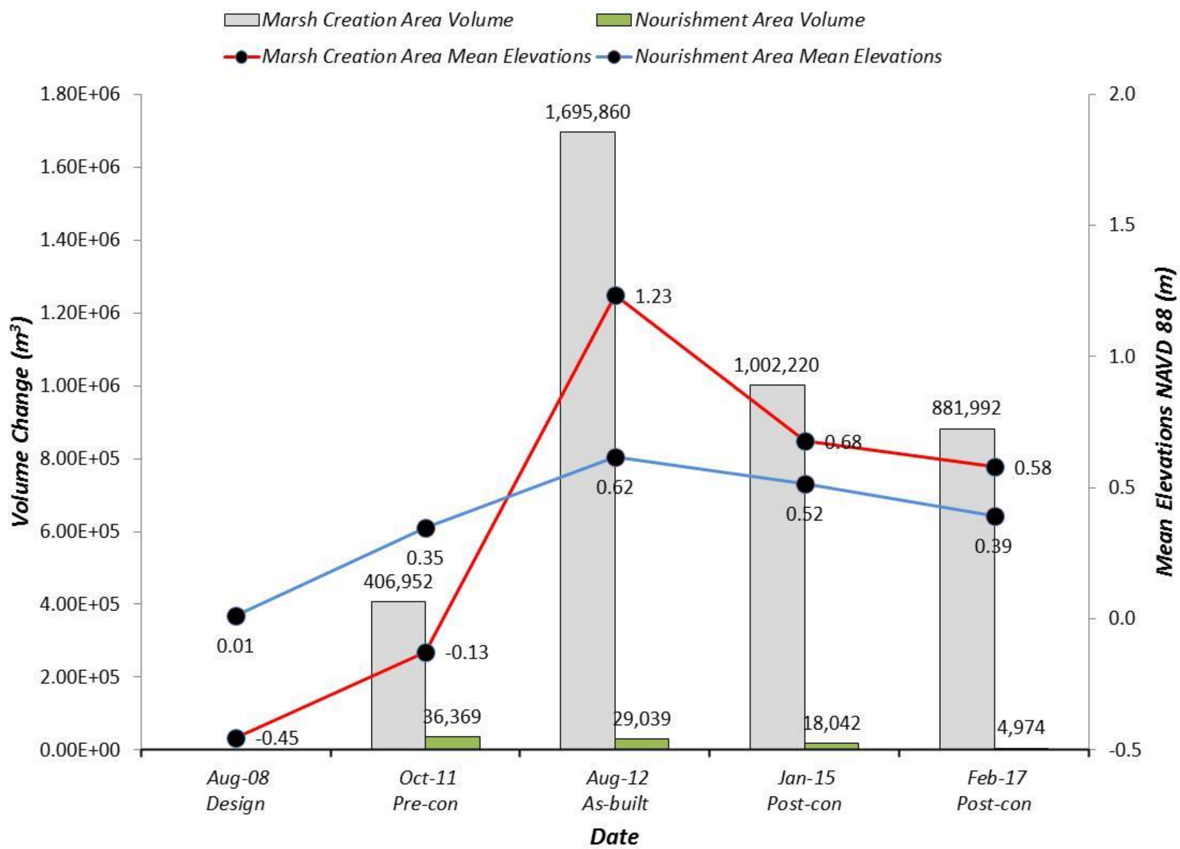


Figure 20. Sediment volume change and mean elevations over time along the West Belle Pass Barrier Headland Restoration (TE-52) project's marsh creation and nourishment areas.

The 2011 (pre) - 2012 (as-built) elevation change grid model (Figure 14) displays the substantial volume gains brought about by the construction of the TE-52 project. This figure depicts the dune and the location of the Oct 2011 channel (Figure 17) as incurring the greatest sediment volume increases (darkest green color). Figure D-3 also exhibits the high elevations of the dune, an almost ubiquitous elevation class in the marsh creation area [1.0-1.5 m (3.3-4.9 ft)] (yellow color), and the highest elevations in the nourishment area as occurring along the borders of the creation areas. The as-built (2012) volume and elevation increases are graphically illustrated in Figures 19 and 20 and are tabularized in Table 1. During the as-built time period, the sand volume in the beach and dune area increased by 1,339,240 m^3 (1,751,660 yd^3), the clay and silt volume in the marsh creation area increased by 1,659,860 m^3 (2,218,101 yd^3), and the sediment volume in the nourishment area increased by 29,039 m^3 (37,981 yd^3). The impacts of Hurricane Isaac and beach and dune project modifications induced by the storm are shown in Figure 10. This hurricane breached the dune, caused the dune to be offset at the breached location (change order), initiated the embryonic spit development (Panels B and C), and probably facilitated the high elevations in the nourishment area through cross-shore transport of construction sediments. In addition, the marsh creation area was allowed to be pumped to a higher elevation to prevent further breaching of the dune

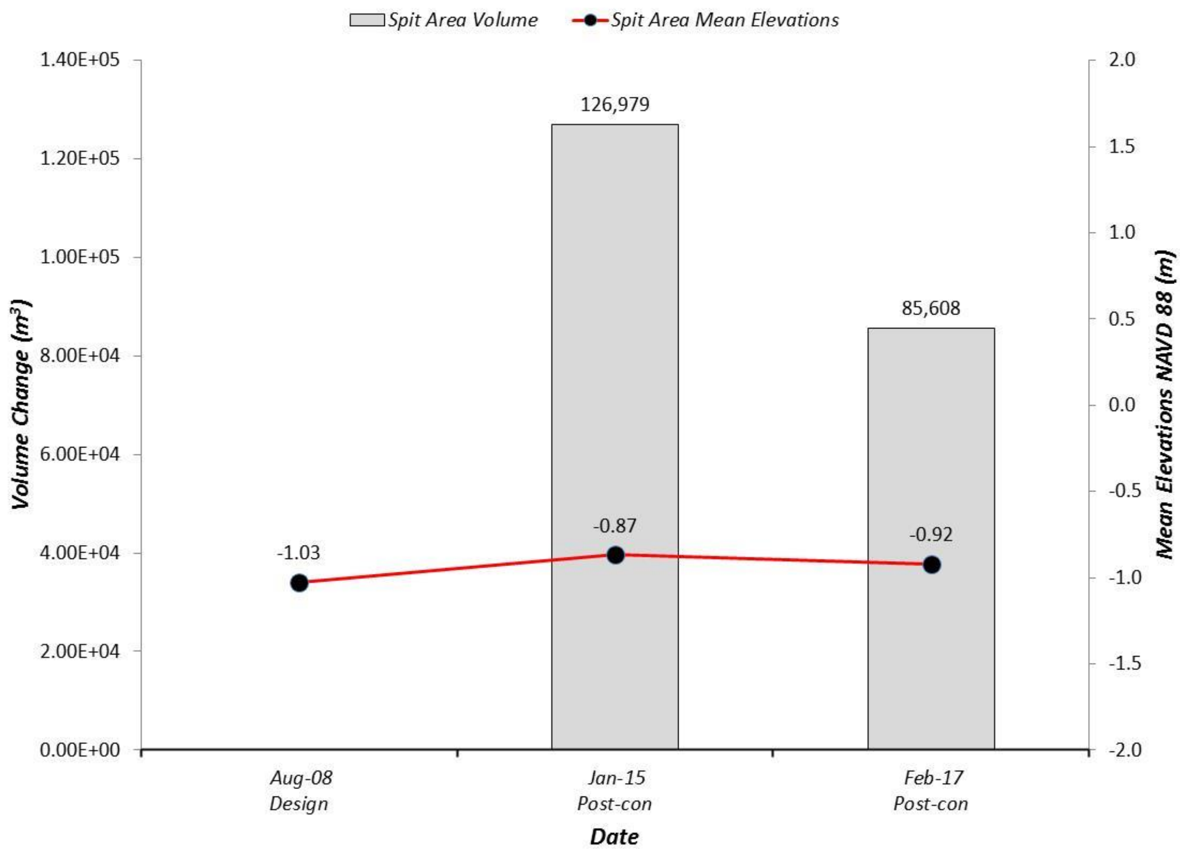


Figure 21. Sediment volume change and mean elevations over time along the West Belle Pass Barrier Headland Restoration (TE-52) project's spit area.

and primary dike (Devisse and Thomson 2013). Therefore, the passage of Hurricane Isaac during construction altered the features of this headland restoration project.

The first post-construction elevation models (2012-2015) display considerable sediment volume declines in the beach and dune and marsh creation areas and a more modest volume loss in the nourishment area. The sediment volume was reduced by 774,695 m^3 (1,013,263 yd^3) in the beach and dune creation area, by 693,640 m^3 (907,247 yd^3) in the marsh creation area, and by 10,997 m^3 (14,384 yd^3) in the nourishment area during the initial post-construction interval (Figure 15 and Table 1). The residual volumes were 564,545 m^3 (738,397 yd^3) (beach and dune), 1,002,220 m^3 (1,310,854 yd^3) (marsh creation), and 18,042 m^3 (23,598 yd^3) (nourishment) (Figures 19 and 20). This corresponds to 42% of the in place volume remaining in the beach and dune creation area, 59% of the in place volume remaining in the marsh creation area, and 62% of the as-built volume remaining in the nourishment area two years after construction. The considerable volume loss in the beach and dune area is a result of severe dune scarping and overwash (Figure 23). The extent and intensity of the beach and dune erosion is illustrated in Figure 15 (red and orange colors show areas with large volume deficits). All the segments of the dune that were installed parallel to the Gulf of

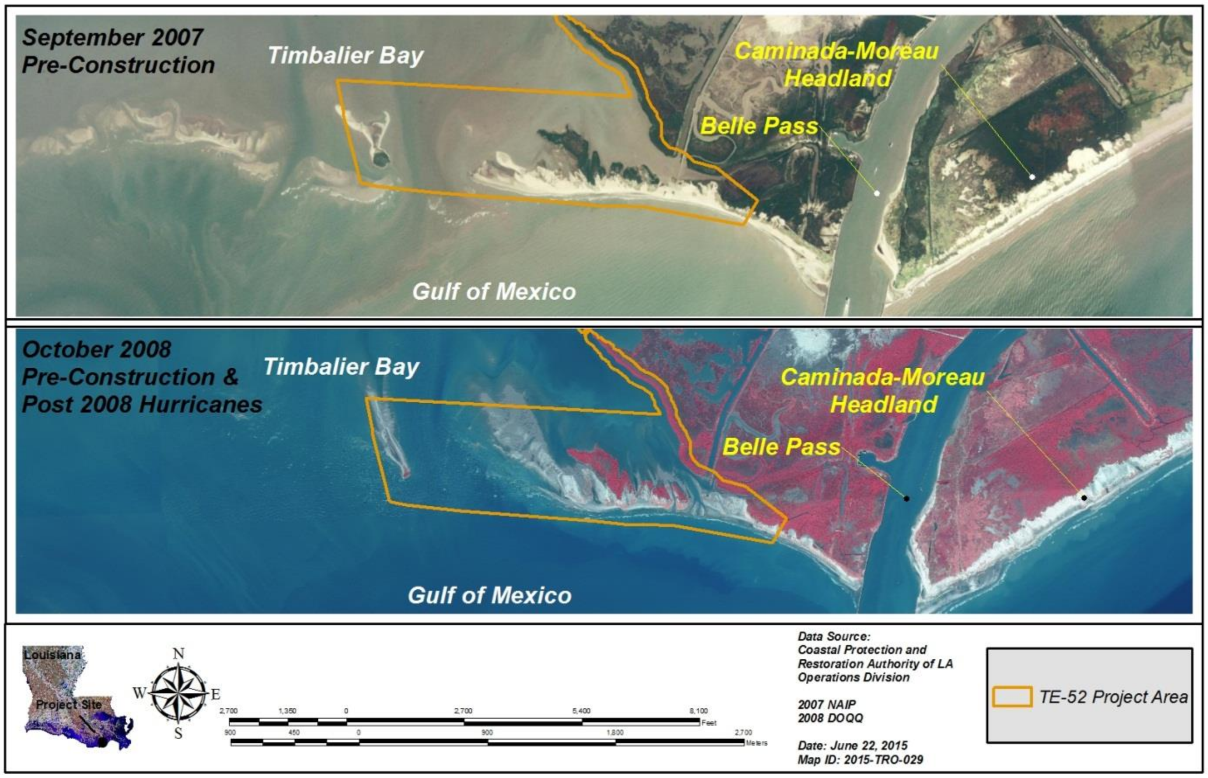


Figure 22. **Aerial photography (2007 and 2008) showing preconstruction geomorphic changes in the West Belle Pass Barrier Headland Restoration (TE-52) project area. Note the impact of the 2008 hurricanes on these shorelines and the 2007 addition of sediment along the west jetty by the channel maintenance event.**

Mexico shoreline was subjected to varying degrees of scarping. The scale of scarping generally increased to the east with the extreme eastern reaches being subjected to overwash and leveling. Approximately, 450 m (1,500 ft) of the eastern edge of the dune have been raised leaving only the beach and a small berm remaining. In addition, the sand fencing along the first 1,500 m (5,000 ft) of the eastern reaches was dismantled by the severe scarping of the dune feature (Figure 23). Moreover, Figure 23 demonstrates that the erosion of the dune is progressing northward over time by showing the position of the sand fencing in 2013 (Panels A and B) and 2014 (Panels C and D). It is rather alarming that the dune feature scoured at such a rapid rate in the absence of a major storm or more frequent tropical storm activity. In fact, only one tropical storm has entered the central Gulf of Mexico from 2012 to 2015, and this storm dissipated before landfall. Furthermore, the substantial erosion of the dune far exceeds the Delft3D predictions postulated during the engineering and design phase of this project (Thomson et al. 2009). Therefore, it seems plausible that Hurricane Isaac (Figures 4 and 10) may have induced greater shoreface erosion than previously thought and accelerated the beach and dune volume loss. While a sizeable volume of sediment was removed from the beach and dune, approximately 126,979 m^3 (166,082 yd^3) of these sediments were transported to the west aggrading and elongating the vertical profile of the spit (Figures 17, 21, and Tables 1 and 2). However, a larger volume of sediments could have been retained in the West Belle

Pass sediment budget if the proposed terminal groin was constructed on the western edge of the TE-52 project area (Dean 1997; Thomson et al. 2009). This structure was eliminated from the project design due to the fiscal constraints of the CWPPRA program. The loss of 41% of the marsh creation volume (Figures 15, 20 and Table 1) appears to be a by-product of sediment consolidation. Approximately, 0.6 m (1.8 ft) of sediment consolidation occurred from Oct 2012 to Jan 2015 (Figures 20, D3, and D4). As a result, it appears that the marsh creation area was still experiencing primary settlement at the time of the as-built survey. The nourishment area incurred a 38% volume reduction which correlates to a very small elevation change of 0.1 m (0.3 ft) NAVD 88. In contrast, earlier change models showed considerable volume gains (Figures 13, 14, 20, and Table 1). During the 2008-2011 interval, the nourishment area gained volume due to tropical storm induced cross-shore sediment transport. Hurricane Isaac (2012) also seems to have influenced the cross-shore transport of sediments into the nourishment area for the 2011-2012 interval. As a result, cross-shore transport does appear to be elevating the nourishment area during tropical storm events and is in agreement with earlier assessments (Penland and Ritchie 1979; Boyd and Penland 1981; Ritiche and Penland 1998a; Ritiche and Penland 1998b; Georgiou et al. 2005). In closing, this first post-construction interval (2012-2015) was shaped by longshore transport and lateral migration of sand facies to the northwest and primary settlement in the marsh creation area.

The second set of post-construction elevation change models (2012-2017) exhibit the continued trend of substantial sediment volume deficits in the beach and dune area and westward lateral migration of sediment to the spit while the marsh creation and nourishment areas experienced more limited declines in sediment elevation and volume. The sediment volume was reduced by 1,474,810 m^3 (1,928,979 yd^3) in the beach and dune creation area, by 813,868 m^3 (1,064,499 yd^3) in the marsh creation area, and by 24,065 m^3 (31,476 yd^3) in the nourishment area during this succeeding post-construction interval (Figure 16 and Table 1). The residual volumes were -135,570 m^3 (-177,319 yd^3) (beach and dune), 881,992 m^3 (1,153,602 yd^3) (marsh creation), and 4,974 m^3 (6,505 yd^3) (nourishment) (Figures 19 and 20). This corresponds to a -10% volume deficit in the beach and dune creation area while 52% of the in place volume remained in the marsh creation area and 17% of the as-built volume remained in the nourishment area four years after construction. The massive volume change in the beach and dune area is a result of large scale beach erosion and almost complete dune leveling (Figure 23). The only dune segments that retain the geomorphic dune form and functioning sand fencing are the offset dune and the northwestern oriented dune sections (Figures 10 and 24). The offset dune is further from the shore than the leveled segments, and the northwestern oriented dune sections are almost perpendicular to the Gulf and protected from wave action by the spit (Figure 8). The intensity and extent of sediment volume changes in the beach and dune area are shown by the red and orange colors detailed in Figure 16. These large volume changes span the entire length of the beach and dune area and extend past the borders of the marsh creation and nourishment areas (Figure 16). The leveled sections of dune have been transformed to washover and dune terrace landforms that consists of narrow beaches and small berms (Figure 23, Panels E and F). Although a vast quantity the sand

Figure 23. **The oblique images above depict scarping and leveling of the TE-52 project's dune feature in 2013, 2014, and 2016. Note the severe scarping that occurred several months after construction and the distance to the sand fencing in 2013 (Panels A and B). Panel B also shows channel formation during high water events along the eastern reaches of the dune feature. Several channels formed on the supratidal elevated expanded beach and dune template. Panels C and D display the steep edges of the remaining dune and sand fence deterioration. The sand fencing was placed in the center of the dune, so half of the dune form has been removed from panels C and D. By 2014 the dune feature along the eastern reaches of the project no longer exists. Panel C also illustrates a very narrow beach. These short beaches are typically the cause of sheer dune formations. Panels E and F exhibit washover and dune terrace landforms. By 2016 no dune feature exists parallel to the Gulf except the offset dune while the northwestern dune remains intact. Sand fencing only remains in these two areas.**

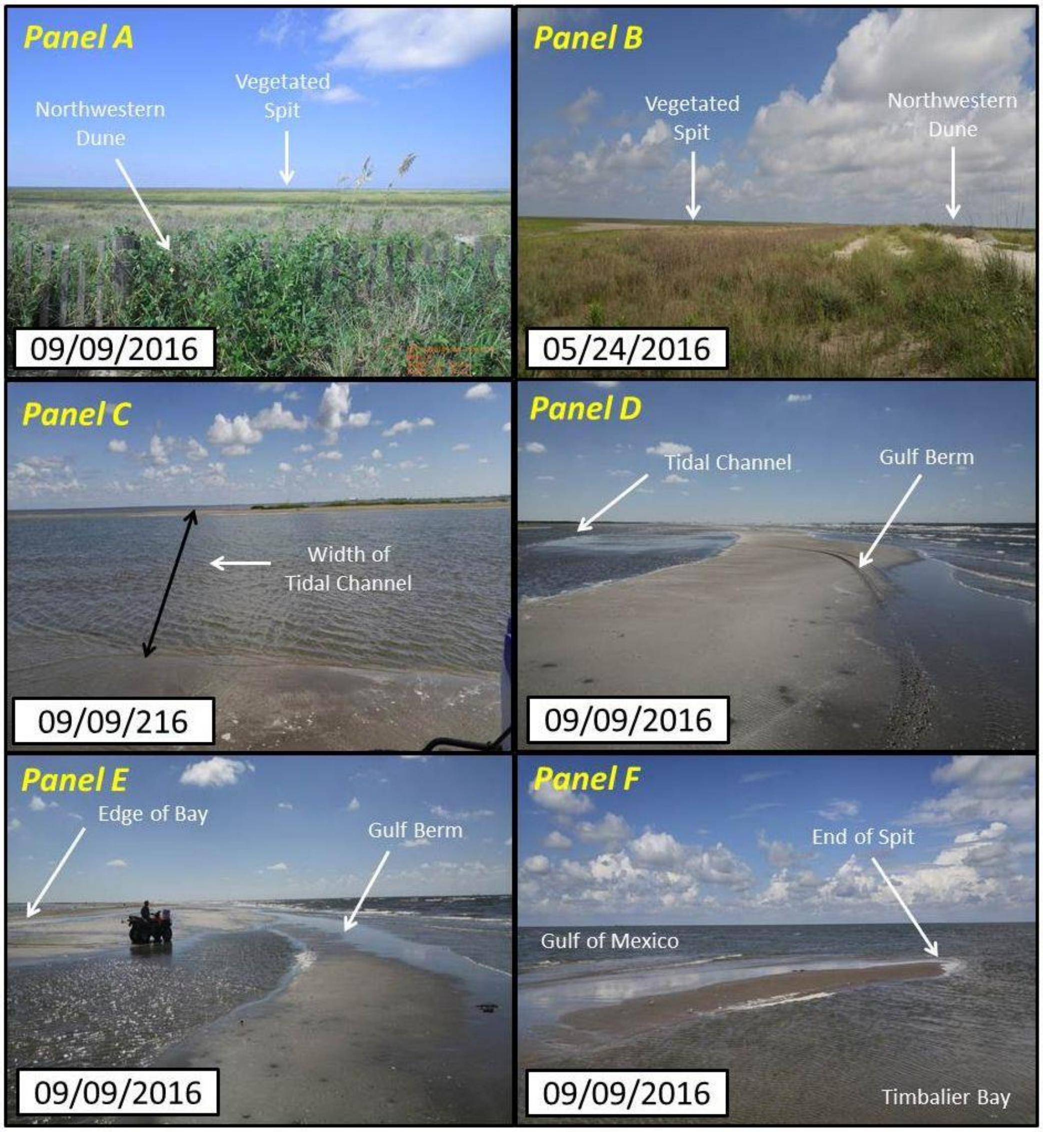
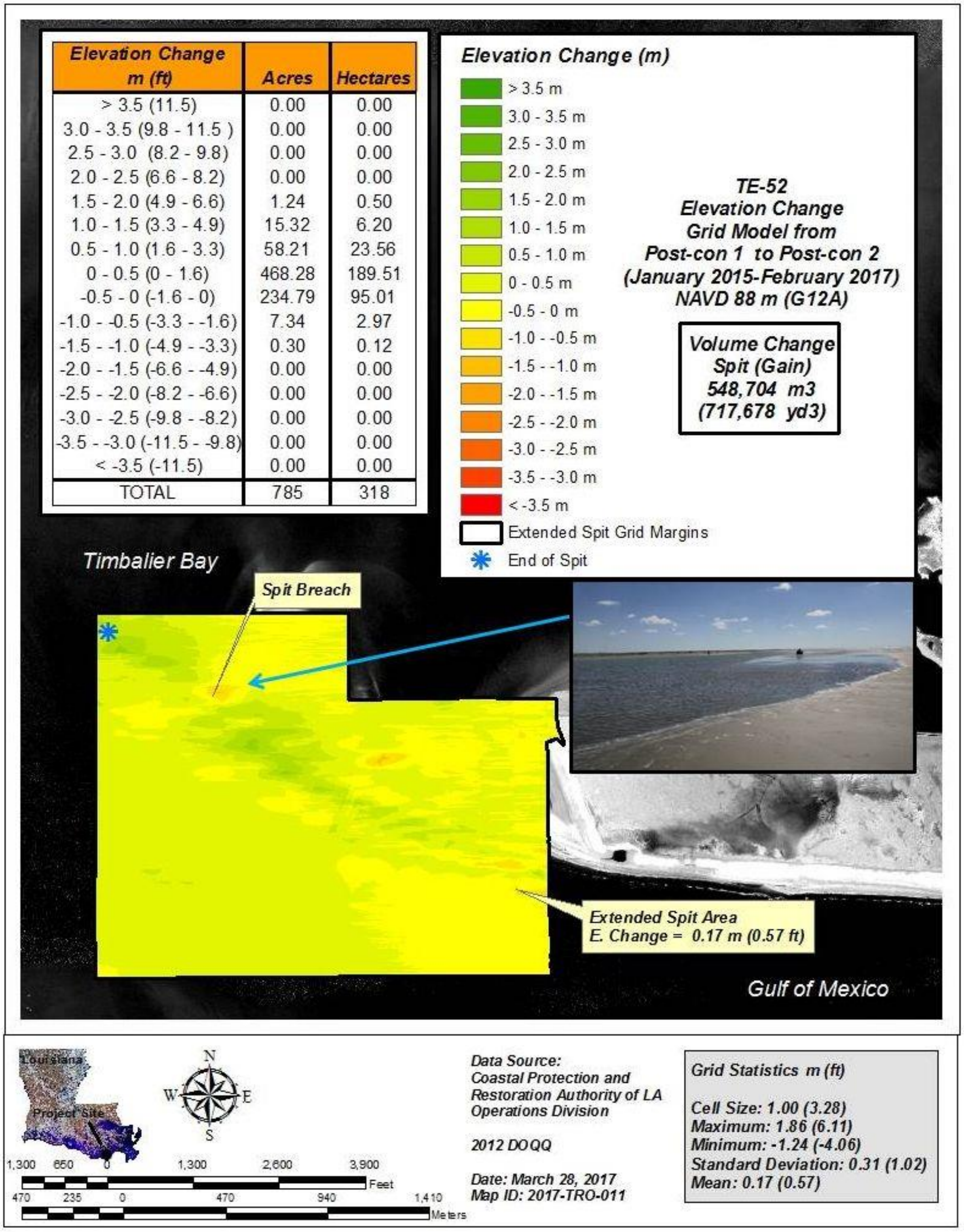


Figure 24. The images above illustrate the TE-52 project's spit habitats in 2016. Panels A and B show the northwestern oriented dune and the vegetated portion of the spit. Panels C and D exhibit a sinuous tidal channel that bisects the western end of the spit while panels E and F display the narrow width of the spit terminus.

resources have been removed from the beach and dune area, a considerable portion of these resources have been preserved within the headland system and stored within the laterally expanding spit. Volume changes for the part of the spit in the immediate lee of the beach and dune area are shown in Figures 17, 18, 21, and Table 2 for the intervals from 2008-2015 and 2008-2017. Though the volume decreased for the later interval due to shoreface and shoreline erosion, this small segment of the spit held 67% of its earlier volume. It also demonstrates that the eastern spit shoreline is transgressing as sediments aggregate westward. Sediment volumes for the entire spit (extended spit area) were captured during the 2015-2017 interval (Figure 25 and Table 2) and show extensive lateral migration and aggradation to the northwest



Elevation Change m (ft)	Acres	Hectares
> 3.5 (11.5)	0.00	0.00
3.0 - 3.5 (9.8 - 11.5)	0.00	0.00
2.5 - 3.0 (8.2 - 9.8)	0.00	0.00
2.0 - 2.5 (6.6 - 8.2)	0.00	0.00
1.5 - 2.0 (4.9 - 6.6)	1.24	0.50
1.0 - 1.5 (3.3 - 4.9)	15.32	6.20
0.5 - 1.0 (1.6 - 3.3)	58.21	23.56
0 - 0.5 (0 - 1.6)	468.28	189.51
-0.5 - 0 (-1.6 - 0)	234.79	95.01
-1.0 - -0.5 (-3.3 - -1.6)	7.34	2.97
-1.5 - -1.0 (-4.9 - -3.3)	0.30	0.12
-2.0 - -1.5 (-6.6 - -4.9)	0.00	0.00
-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	785	318

Figure 25. **Extended post-construction elevation and volume change grid model for the spit area from Jan 2015 to Feb 2017 at the West Belle Pass Barrier Headland Restoration (TE-52) project. Note the increased length and the breach across the spit.**

By September 2016 the subaerial part of the spit extended 2.47 km (1.54 mi) northwest of the beach and dune area. The blue asterisk in Figure 25 demarks the distal end of the spit for this date. In January of 2015 the subaerial part of the spit was 1.89 km (1.18 mi) in length. Figure 24 displays different habitats created on the spit – the vegetated eastern spit (Panels A & B), a wide sinuous channel bisecting the spit (Panel C & D), and the narrow and low-lying spit terminus (Panel C & D). For the 2015-2017 period, 700,115 m^3 (915,716 yd^3) of sediment were removed from the beach and dune area (1,474,810 – 774,695 m^3) (Figures 15, 16, and Table 1) and 548,704 m^3 (717,678 yd^3) of sediment were re-located to the spit (Figure 25 and Table 2). These results are graphically displayed in Figure 26 and translate to a sediment retention rate of 78%. Therefore, more than three-fourths of the eroded sediments were conserved within the headland system. This analysis would not have been possible without the extended transects and empirically reveals that in headland and barrier island systems elevation surveys need to extend past project borders to capture trends in sediment transport. Figure 27 shows these trends in sediment transport for the entire West Belle Pass Headland for the 2015-2017 interval. The massive erosion of sand faces from the TE-52 beach and dune area and the aggradation and lateral migration of the spit show that the primary post-construction trends are derived through longshore transport processes. Winter

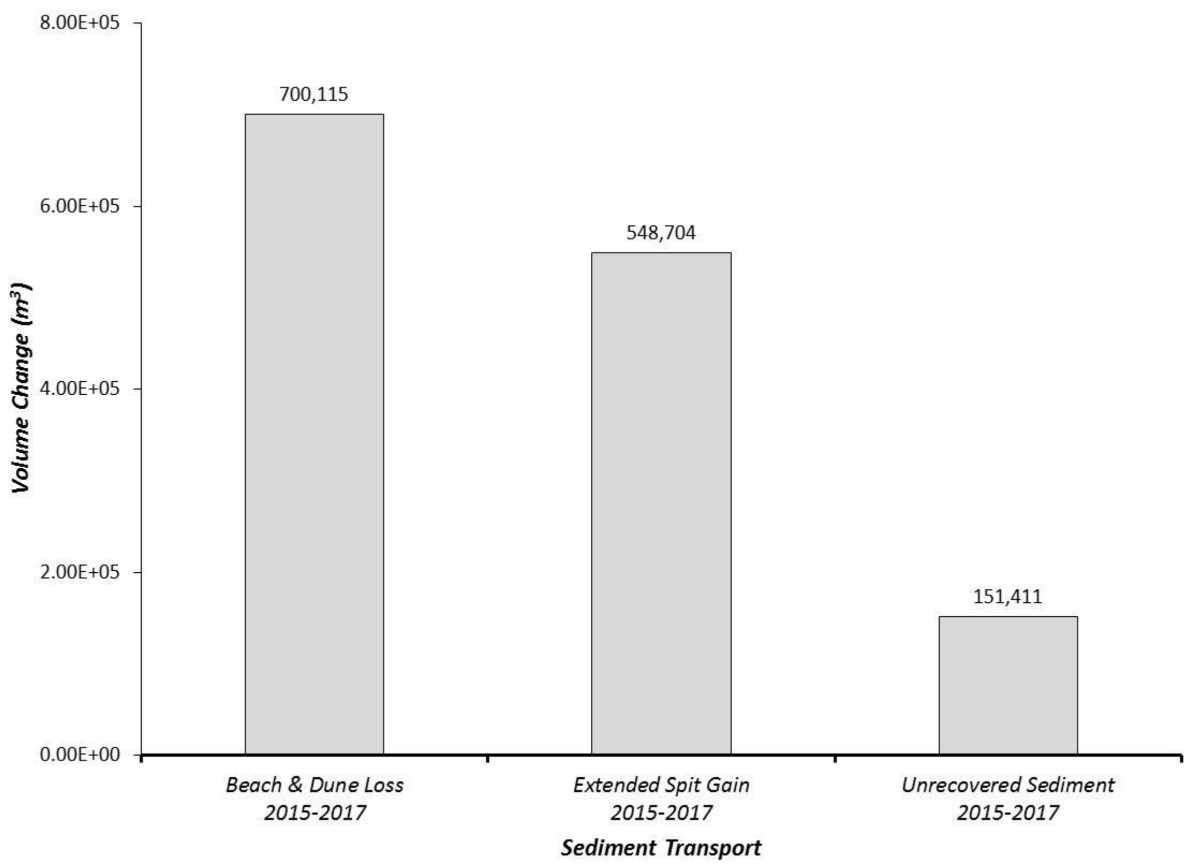


Figure 26. Sediment volume change distributions along the West Belle Pass Barrier Headland Restoration (TE-52) project's Gulf of Mexico shorelines for the 2015-2017 interval.

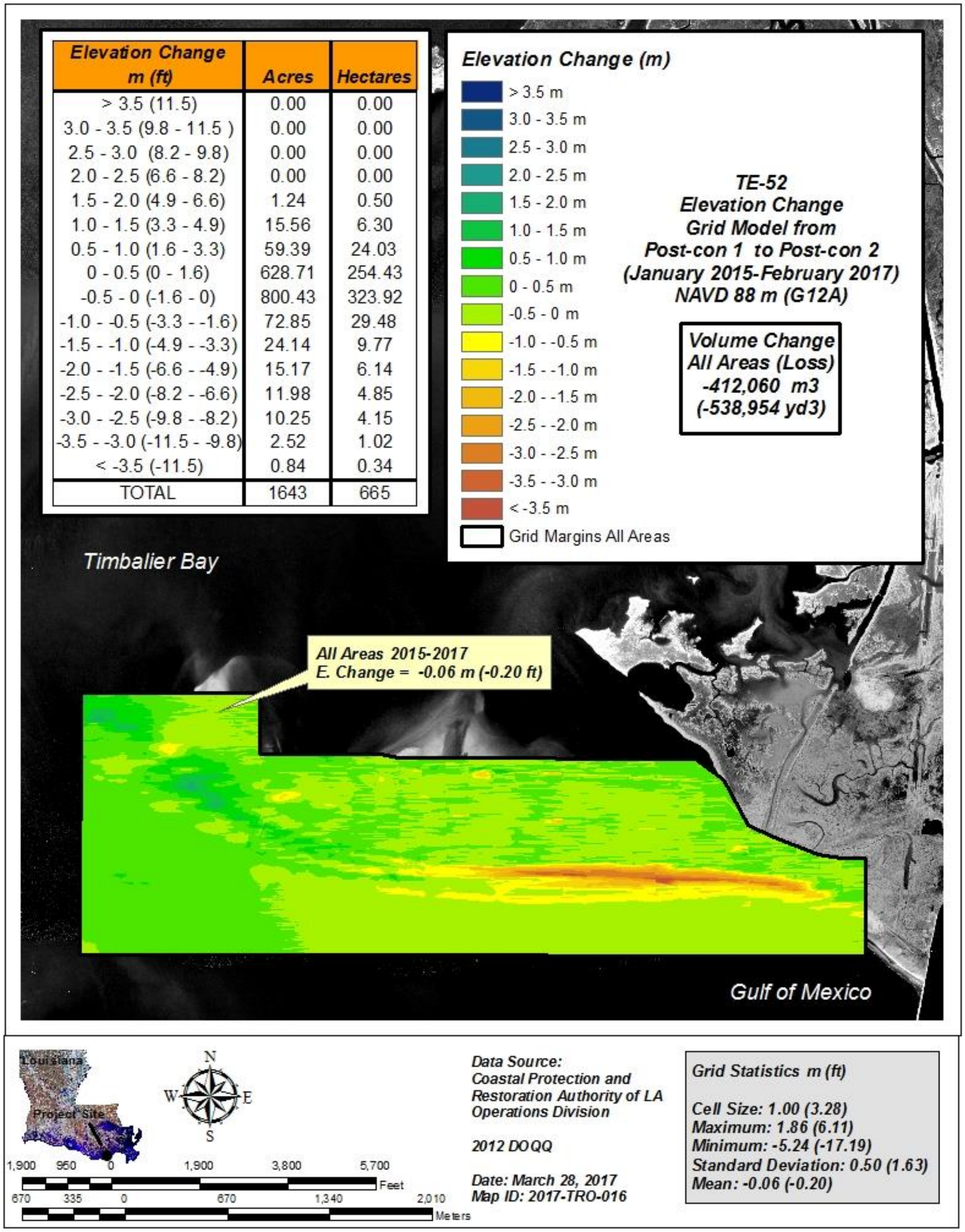


Figure 27. **Post-construction (2015-2017) elevation and volume change grid model showing height adjustments at all project and spit areas for this interval at the West Belle Pass Barrier Headland Restoration (TE-52) project.**

and non-tropical storms were probably instrumental in advancing the erosion of the beach and dune creation area and the lateral migration of the spit (Boyd and Penland 1981; Dingler and Reiss 1990; Ritchie and Penland 1998b; Georgiou et al. 2005). A second possible causative mechanism leading to the large beach and dune volume loss is the Belle Pass Rock Jetties. Erosion and sediment volume loss on the downdrift side of jetty systems is well documented and can be predicted to occur (Stauble and Morang 1992; Komar 1998; Kraus et al. 1999; Bird 2000; Larson et al. 2002). Penland and Suter (1988) surmised that the Belle Pass Rock Jetties have reduced the longshore transport to the Timbalier Islands (Figure 1), and Dantin et al. (1978) inferred from a physical model that sediments that by-pass the rock jetties are transported 1,530-2,440 m (5,000-8000 ft) to the west creating a shadowing effect in the immediate lee of the west jetty. Moreover, these rock jetties have been extended at least 457 m (1,500 ft) into the Gulf since the Dantin et al. (1978) model was created likely expanding the distance of the shadow effect. To illustrate further, the USACE has added sediment to the beach in the lee of the west jetty on four occasions (1998, 2007, 2012, and 2015) only to have the sediments reworked by coastal processes demonstrating that very little sediment is transported towards the western jetty (eastern littoral transport). The volume reductions in the marsh creation area considerably slowed for the second post-construction interval (Figures 15, 16, 20, and Table 1). The sediment volume in the marsh creation area declined by only 120,228 m^3 (157,252 yd^3) for the 2012-2017 interval. As a result, this area is experiencing secondary settlement and appears to be subsiding with its settlement curve (Fugro 2009). Moreover, not all of the volume losses in the marsh creation area were caused by settlement. Shoreline erosion along the southern marsh creation area also lowered the sediment volume. Likewise the nourishment area also incurred shoreline transgressions on its southern margin for the 2012-2017 interval (Figure 16). Additionally, volume reductions in the nourishment area were probably induced through wind erosion and subsidence. Interestingly, both the marsh creation and nourishment areas showed no signs of cross-shore transport in the absence of tropical storm activity. Therefore, the coastal edge elevation of the TE-52 project along Gulf of Mexico shoreline seems to be at high enough elevations to resist cross-shore transport during winter and non-tropical storms (Penland and Ritchie 1979; Boyd and Penland 1981; Ritiche and Penland 1998b). In closing, this second post-construction interval (2012-2017) was shaped by longshore transport and lateral migration and retention of sand facies to the northwest similar to the first post-construction interval.

In conclusion although there was considerable erosion and volume loss in the beach and dune creation area, the reestablish and increase headland longevity and prevent breaching goals are currently being attained because the headland has been reestablished and has not breached since construction. To promote the re-establishment of historic longshore transport patterns along the Gulf shoreline goal is really not an attainable goal because historically the longshore transport nourished East Timbalier and Timbalier Islands. However, the net longshore transport continues to flow to the west as described in the historical record (Peyronnin 1962; Dantin et al. 1978; Ritchie and Penland 1988b; Stone and Zhang 2001; Thomson et al. 2009) and is aggrading and laterally elongating the spit. The expanding spit is also conserving eroded beach and dune sand facies within the West Belle Pass Headland system.

Shoreline Change

The West Belle Pass Barrier Headland Restoration (TE-52) project area has incurred shoreline transgressions and expansions over the monitoring period (2008-2017). Figure 28 graphically displays the TE-52 shoreline changes during the pre-construction interval (2008-2011), the as-built interval (2011-2012), and the post-construction intervals (2012-2015 and 2015-2017). The shoreline positions (2008, 2011, 2012, 2015, and 2017) derived from the 0.0 m (0.0 ft) shoreline contours can be viewed in Figure E-1. For the pre-construction interval, the future TE-52 shorelines transgressed at rate of -19.62 m/yr (-64.37 ft/yr). A large part of the 2008-2011 shoreline erosion can be attributed to cross-shore transport generated from hurricanes and tropical storms. The 2008 hurricanes (Gustav and Ike) (Figure 4) caused overwash, breaching, truncation and shoreline transgressions along the West Belle Pass Headland (Figures 5, 6, and 22). T. S. Lee in 2011 caused tides to rise 1.2-1.8 m (4.0-6.0 ft) in the Terrebonne Basin (Brown 2011) and likely transgressed the project area shorelines during the pre-construction interval. Construction of the beach and dune feature for the TE-52 project

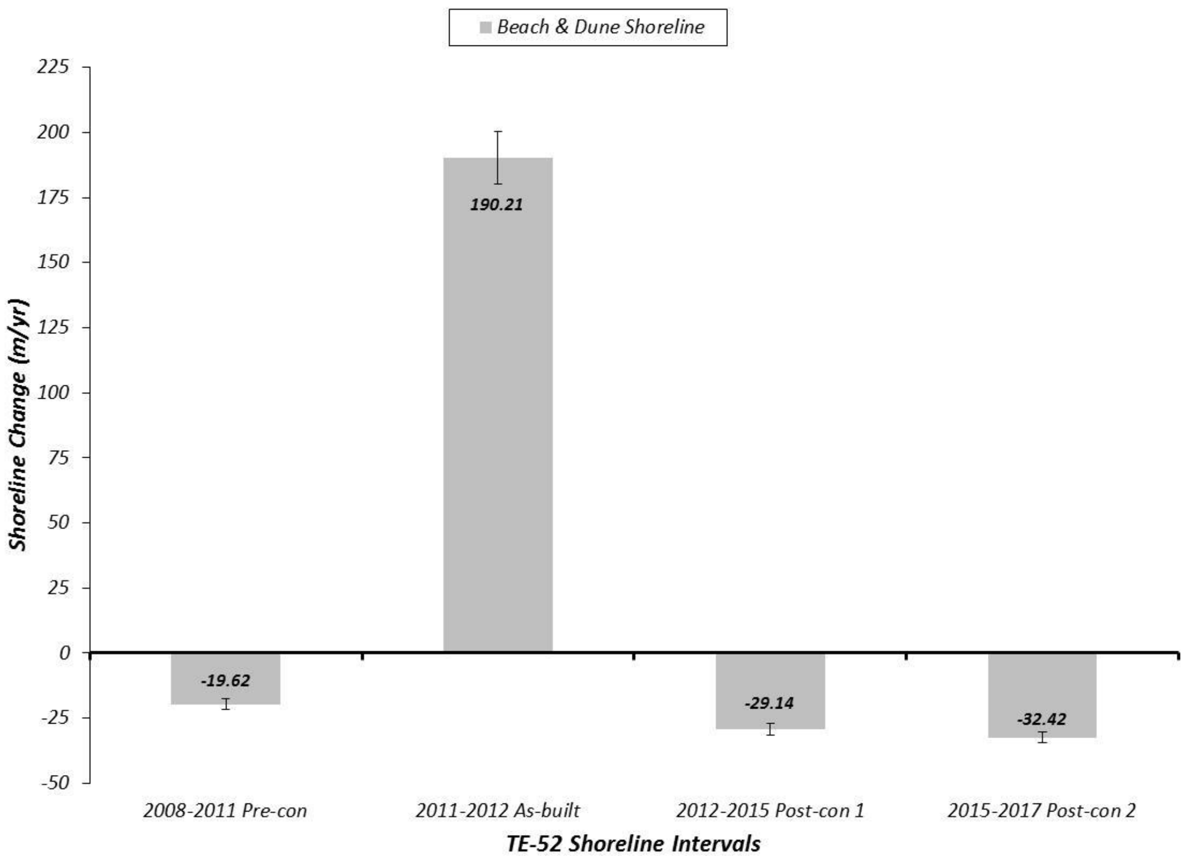


Figure 28. Shoreline transgressions along the West Belle Pass Barrier Headland Restoration (TE-52) project area from Aug 2008-Feb 2017.

extended the West Belle Pass shorelines further into the Gulf of Mexico. These shorelines prograded at a rate of 190.21 m/yr (624.05 ft/yr) for the as-built interval. However, not long after construction the beach and dune feature began to transgress. For the post-construction intervals, the TE-52 shorelines eroded at rates of -29.14 m/yr (-95.60 ft/yr) and -32.42 m/yr (-106.35 ft/yr). This erosion rates are three times higher than the projected rate of -9.75 m/yr (-32.00 ft/yr) suggested in the project design report (Thomson et al. 2009). Figure 23 shows the severe scarping and overwash that occurred in the project area for the post-construction time periods. As discussed in the elevation results, these shoreline transgressions were probably induced by the passage of Hurricane Isaac (Figures 4 and 10) (Devisse and Thomson 2013), winter and non-tropical storms (Boyd and Penland 1981; Dingler and Reiss 1990; Ritiche and Penland 1998b; Georgiou et al. 2005), and the influence of the Belle Pass Rock Jetties (Dantin et al. 1978; Penland and Suter 1988). The pre-construction, as-built, and post-construction temporal differences between intervals were significant ($P < 0.05$) while the post-construction differences were not ($P > 0.05$). Though substantial shoreline transgressions occurred, the prevent breaching goal is currently being achieved because no inlets have formed in the project area.

Vegetation

The West Belle Pass Barrier Headland Restoration (TE-52) vegetation data show that the dune community has essentially eroded into the Gulf of Mexico and marsh creation community is gradually beginning to vegetate. The results of the mean cover and importance value (IV) analyses are graphically illustrated in Figure 29 (dune mean cover), Figure 30 (dune IV), Figure 31 (marsh mean cover), and Figure 32 (marsh IV). One difference between the dune and marsh communities is that the dune was planted in the spring of 2013 and the marsh was not. The marsh creation area was only recently planted in the spring of 2017, and the plantings are not included in the analyses that follow. The beach and dune features constructed parallel to the Gulf have transgressed, have been leveled, and have been transported to the spit along with twenty-seven of the vegetation plots and the planted and natural vegetation communities (Figure 12). Only three beach and dune plots remain and are located on the northwest oriented dune reach (Figure 12). Therefore, the 2016 assessment has a mean of three whereas the earlier assessments have a mean of thirty. The dune had a percent cover of 12.6% in 2013, 21.3% in 2014, and 34.0% in 2016 (Figure 29). While extrapolation of data can lead to erroneous assumptions, the percent cover from the earlier samplings of the three remaining plots seem to be closely follow the mean of all the plots, 7.7% (2013) and 21.7% (2014). This gives some credence to the notion that if the dune had not eroded the vegetation community would have likely increased its mean cover values in 2016. The top five species found were all planted species in 2013 and 2014 while the other species covered approximately 1.0% of the dune for both sampling years (Figure 29). This changed in 2016 when only three of the planted species were found and the other species covered 10.7% of the dune. However, these findings are not surprising because the two planted species not present in 2016, *P. amarum* and *D. spicata*, were never found in the three remaining plots and the other species percentage would have probably been reduced with

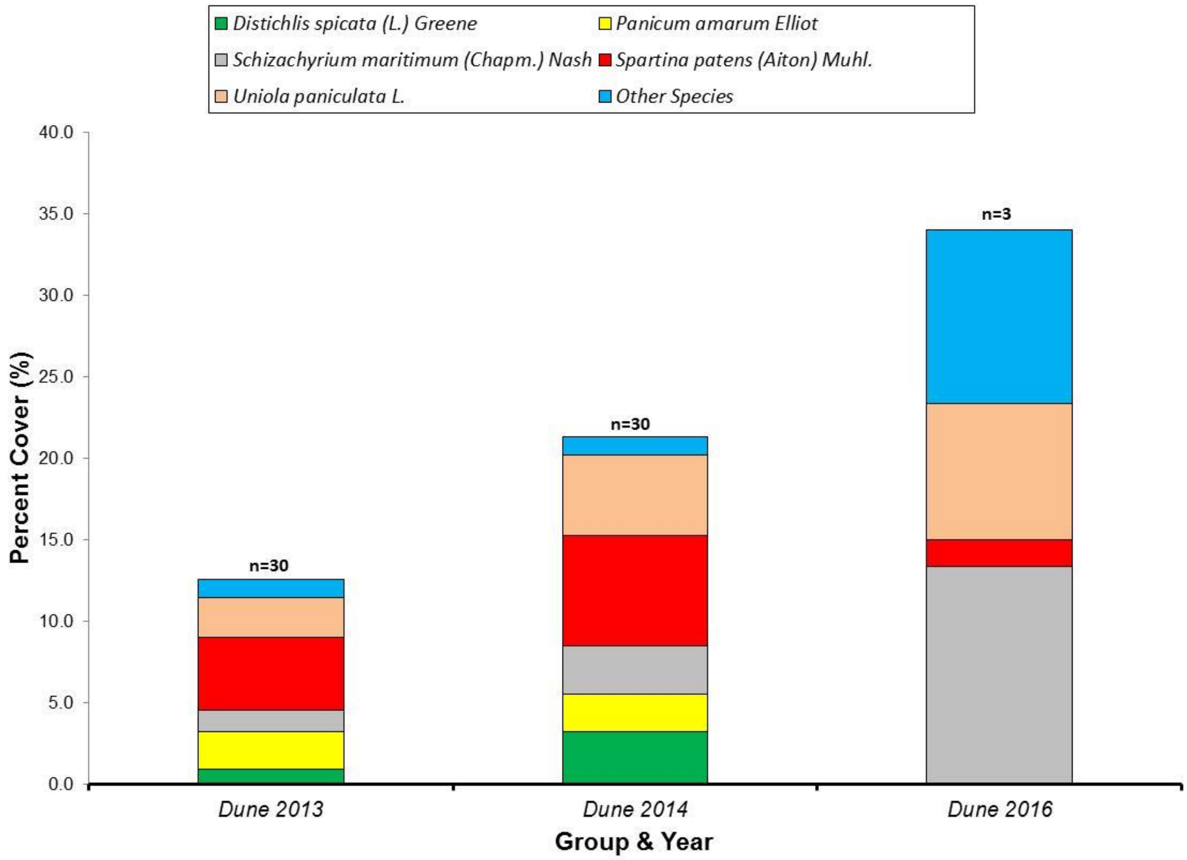


Figure 29. **Mean cover of the top five vegetation species populating the West Belle Pass Barrier Headland Restoration (TE-52) beach and dune creation area in 2013, 2014, and 2016. Ocular vegetation data were grouped by creation area and year.**

additional replication. Although the other species occupy a smaller proportion of the plot cover, up to eighteen species were part of the 2014 cover class and many are found on the outer perimeter of the plots. In addition, many of these species are common inhabitants of dune environments - *Heliotropium curassavicum* L. (salt heliotrope) and *Strophostyles helvola* (L.) Elliott (amberique-bean). The incremental growth in dune vegetation indicates that the remaining planted dune species are surviving and experiencing a modest amount of vegetative growth. The elimination of 90% of the plots also considerably altered the IV analysis. *S. patens* was the most important dune species in 2013 and 2014, but by 2016 its value declined. In 2016, *S. maritimum* and the other species increased in importance, and *U. paniculata* value increased slightly. *P. amarum* and *D. spicata* had no IV value in 2016 (Figure 30). Other dune creation projects in coastal Louisiana have experienced low vegetative cover of planted species in the first few growing seasons after installation only to have mean cover expand in subsequent samplings (West and Dearmond 2007; West et al. 2007). Therefore, the

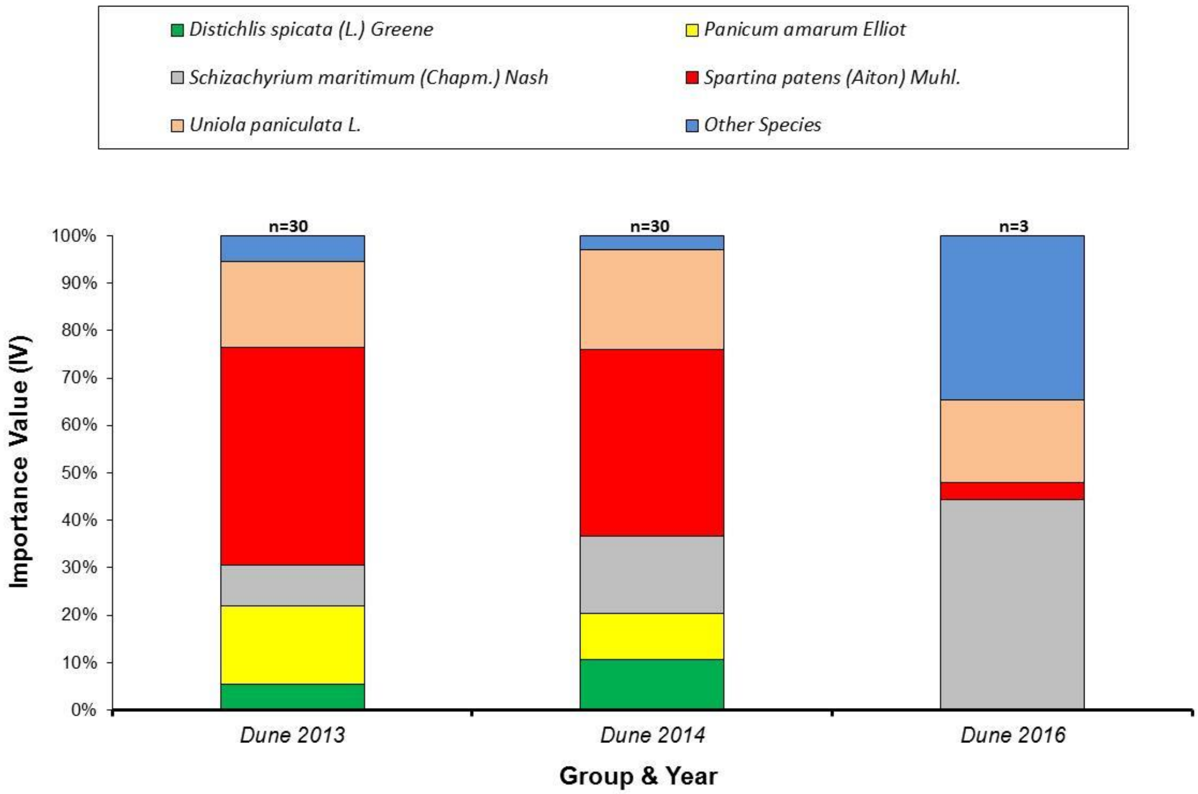


Figure 30. **Importance value (IV) of the top five vegetation species populating the West Belle Pass Barrier Headland Restoration (TE-52) beach and dune creation area in 2013, 2014, and 2016. Ocular vegetation data were grouped by creation area and year.**

vegetative cover of the remaining dune plots should increase over time. However, nitrogen deficiency in coastal dune habitats has been well documented (Woodhouse 1978; Kachi and Hirose 1983; Shumway 2000; Gilbert et al. 2008; Sigren et al. 2014) and may inhibit the growth and dispersal of the dune community. The marsh creation area had a percent cover of 0.3% in 2013, 3.6% in 2014, and 15.2% in 2016 (Figure 31). *Salicornia bigelovii* Torr. (dwarf saltwort) was the only species found in the marsh creation area plots in 2013. This species was joined by *Suaeda linearis* (Elliot) Moq. (annual seepweed), *Avicennia germinans* (L.) L. (black mangrove), and *S. patens* in 2014. In 2016, *Spartina alterniflora* Loisel. (smooth cordgrass), *Heliotropium curassavicum* L. (salt heliotrope), and *Leptochloa fusca* (L.) Kunth (Malabar sprangletop) also joined the list. No other species were encountered in the marsh creation area and *S. patens* only existed on the edge of the dune in 2014 (Figures 31 and 32). *S. bigelovii*, *S.linearis*, and *A. germinans* are all known for inhabiting salt flats (Tiner 1993), which perfectly describes the community constructed in the marsh creation area

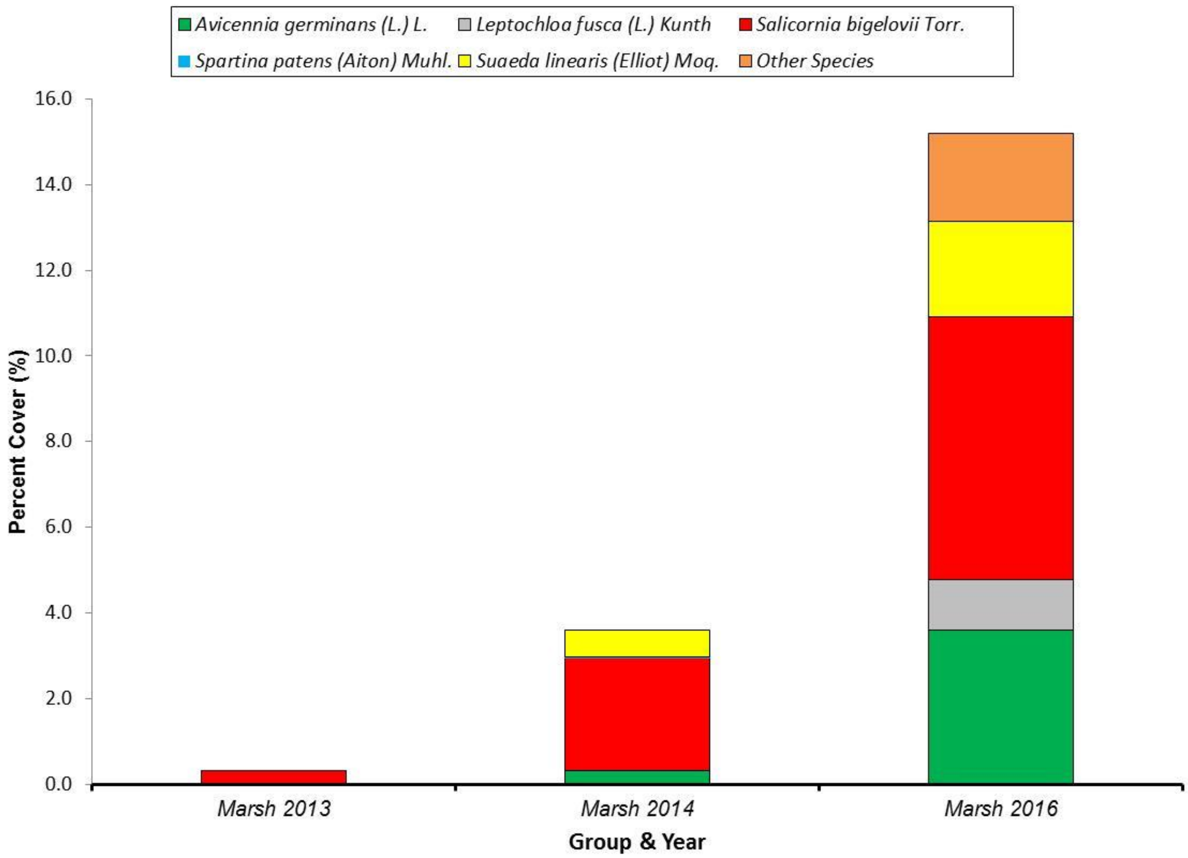


Figure 31. **Mean cover of the top five vegetation species populating the West Belle Pass Barrier Headland Restoration (TE-52) marsh creation area in 2013, 2014, and 2016. Ocular vegetation data were grouped by creation area and year.**

in 2013, 2014, and 2016. The only segment of the marsh creation area to be influenced by tidal activity in 2013 and 2014 was the marsh adjacent to the gapped section of the containment dike. At this location, a naturally formed tidal creek has initiated vegetation colonization along the banks of the low lying borrow area for the containment dike (Figure 33). The other segments of the marsh creation area were shielded from tidal activity due to the continued presence of remaining containment dike. Though parts of the containment dike were narrowed, the dike was not breached naturally. By 2016, both banks of the containment dike borrow area were colonized with *S. alterniflora* (Figures 33 and 34), surficial algal mats were forming in the northeast corner of the creation area, and embryonic tidal creeks were developing as very minor distributaries of the containment dike borrow area (Figure 34). The algal mats were naturally created due to periodic overtopping of the low northeast containment dike and likely also received overflow from the containment dike borrow area

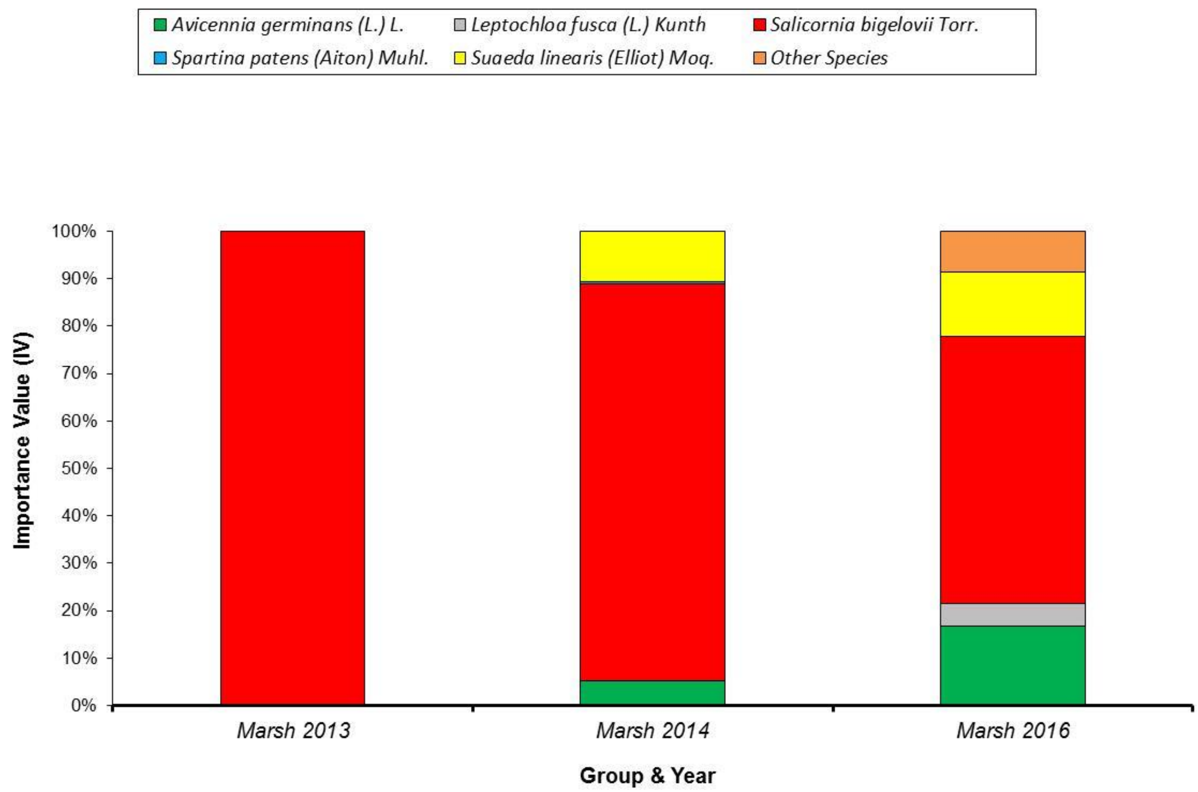


Figure 32. **Importance value (IV) of the top five vegetation species populating the West Belle Pass Barrier Headland Restoration (TE-52) marsh creation area in 2013, 2014, and 2016. Ocular vegetation data were grouped by creation area and year.**

during high water events. The peeling of the mats seen in Figure 34 signifies that they are desiccating when not flooded (Davis 1994). *A. germinans* has thinly populated these algal mats and seems to be productive in this habitat. The embryonic tidal creeks were formed along the southern banks of borrow area at breaks (low elevated areas) placed next to higher elevated areas created to construct the containment dike (Figures 10 and 34). These higher elevated areas are salt flat habitat, and the creeks are intermittently distributing water and *S. alterniflora* vegetation further inland (Figure 34). Although micro saline marsh habitats are being created, the marsh creation area is still largely salt flat habitat. Other back barrier marsh creation projects have not vegetated appreciably due to containment remaining in place (Curole and Lee 2013) or irregular tidal flooding (Texas GLO 1996). Moreover, increasing the area of tidal creeks has been shown to advance the establishment and maturation of saline back barrier marshes (Tyler and Zieman 1999). Two recent back barrier marsh creation

Figure 33. **Jan 2015 Google Earth image and Oct 2014 and Sep 2016 oblique images depicting tidal connectivity and vegetation colonization through the gapped containment dike at the West Belle Pass Barrier Headland Restoration (TE-52) project. Note the vegetation colonization along the edges of the low elevated containment dike borrow area.**

projects did not initially respond to vegetative plantings due to lack of tidal connectivity, one on Grand Terre Island (Lear 2007) and one on Whiskey Island (Hester et al. 2012). However, once regular tidal flushing began vegetation rapidly colonized these marshes (Lear 2007; Unpublished Data). Therefore, it is highly likely that TE-52 marsh creation area will vegetate when the barriers to tidal activity are broken. To enhance tidal connectivity and expand saline marsh colonization, a TE-52 containment dike gapping event is scheduled for the fall of 2017. During this event, the containment dike will be gapped in three locations. The gapping of the dike should enrich the marsh creation area's connection to the daily tidal cycle and increase the acreage of functioning saline marsh habitat. In closing, the restore shoreline, dune, and back barrier marsh to increase habitat utilization by essential fish and wildlife species goal is currently not being supported by the vegetation data because the marsh has not vegetated extensively with saline marsh species and the cover of the dune plantings is lower than desired. However, there is a great possibility that the created habitats will promote extensive utilization by fish and wildlife species if tidal connectivity is expanded and dune vegetative cover is enhanced.

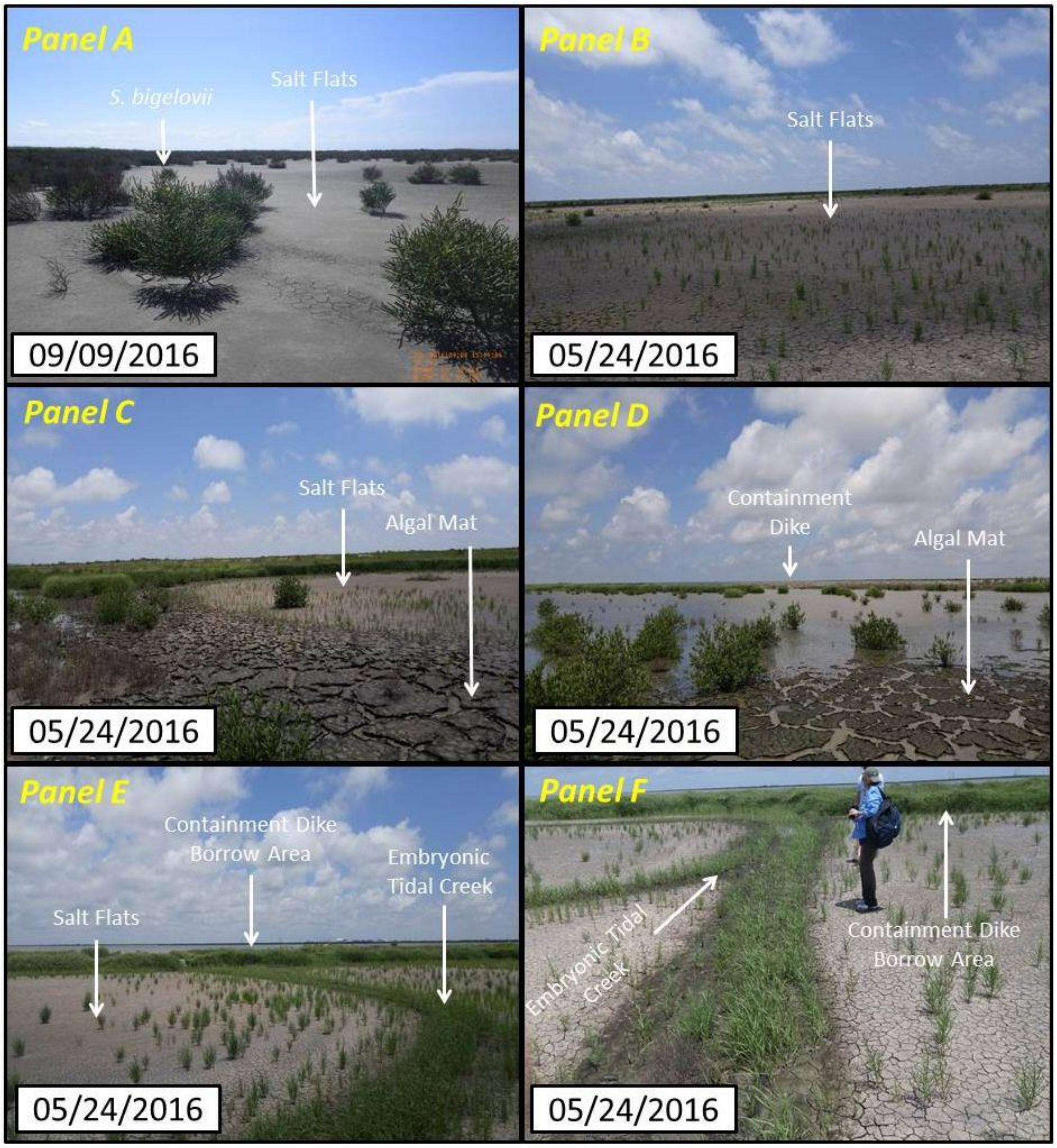


Figure 34. **The oblique images above depict habitats and tidal creek formations in the West Belle Pass Barrier Headland Restoration (TE-52) marsh creation area in 2016. Panels A and B display the dry and thinly vegetated salt flat habitats. Panel C exhibits the intersection of dry salt flat and moist algal mat habitats while Panel D shows algal mat habitat populated with *A. germinans*. Panels E and F illustrate embryonic tidal creeks formed in low lying areas adjacent to the containment dike borrow area. *S. alterniflora* is the species populating these tidal creeks. Note that this species has not colonized the dryer habitats without tidal connectivity.**

Avian Habitat

Winter shorebird usage of the West Belle Pass Barrier Headland Restoration (TE-52) project area has shown a pattern similar to the usage of the Caminada Headland (Figures 35, 36, 37, and 38). Fall distribution of birds indicates individuals spread out along the shoreline and then during the late winter (January – February) the birds tend to congregate into larger flocks in particular areas. Additionally, once spring arrives they spread out again along the shoreline. This pattern has been observed in each winter season and may be related to any number of habitat and environmental variables, including tide levels, weather, and prey availability.

Specifically at West Belle Pass Project, shorebird usage was limited along the approximately one year old beach and dune during the first winter season (2013-14). However by fall 2014 and continuing thru the 2016 surveys, the now two to three year old beach and dune feature shows bird usage along all portions of the project Gulf shoreline. Also, the spit habitat that formed thru longshore sediment transport, produce habitats heavily utilized by wintering

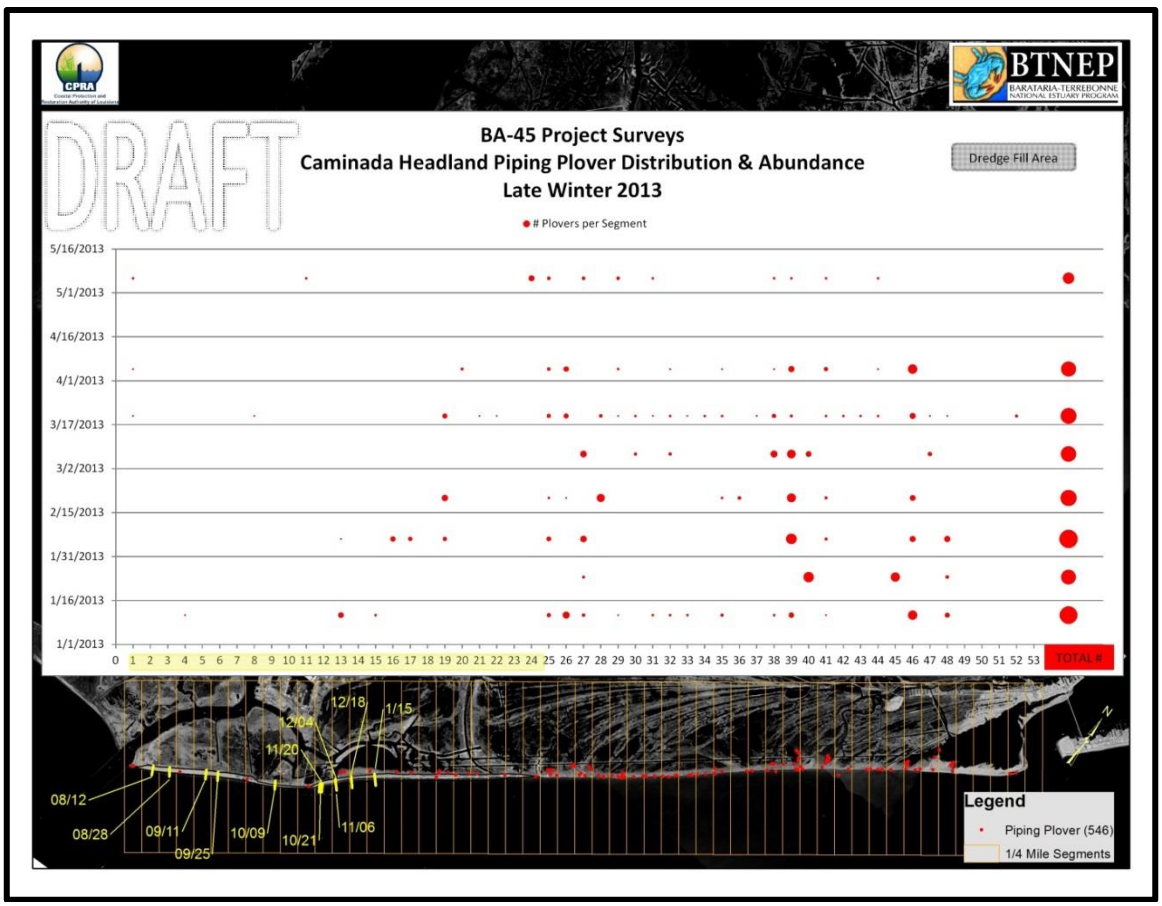


Figure 35. **Abundance and distribution of Piping Plovers along the Caminada Headland during the 2012/13 winter season. Dated yellow marks indicate the sediment fill location at the time of the survey.**

shorebirds. In fact, abundance of birds increased in beach zone three as spit formation created new areas that did not exist prior to construction (Figure 39). This expansion in intertidal and supralittoral habitats has increased the foraging area available to shorebirds (Dugan and Hubbard 2006; Schulte and Simons 2015).

Continuation of surveys since the last report (Curole et al. 2015) shows the use of the back barrier marsh platform has increased thru time, particularly in regards to Wilson's Plovers numbers. As noted for use along the beach, the increased abundance in the back marsh may be related to any number of habitat and environmental variables, including elevation, inundation, weather, and prey availability.

Studies indicate benthic prey items can take up to three years to recover from sediment deposition and may be a reason for limited usage early on in the project. However, usage by year two possibly indicates recovery of prey items. Additionally, shoreface slope adjustment

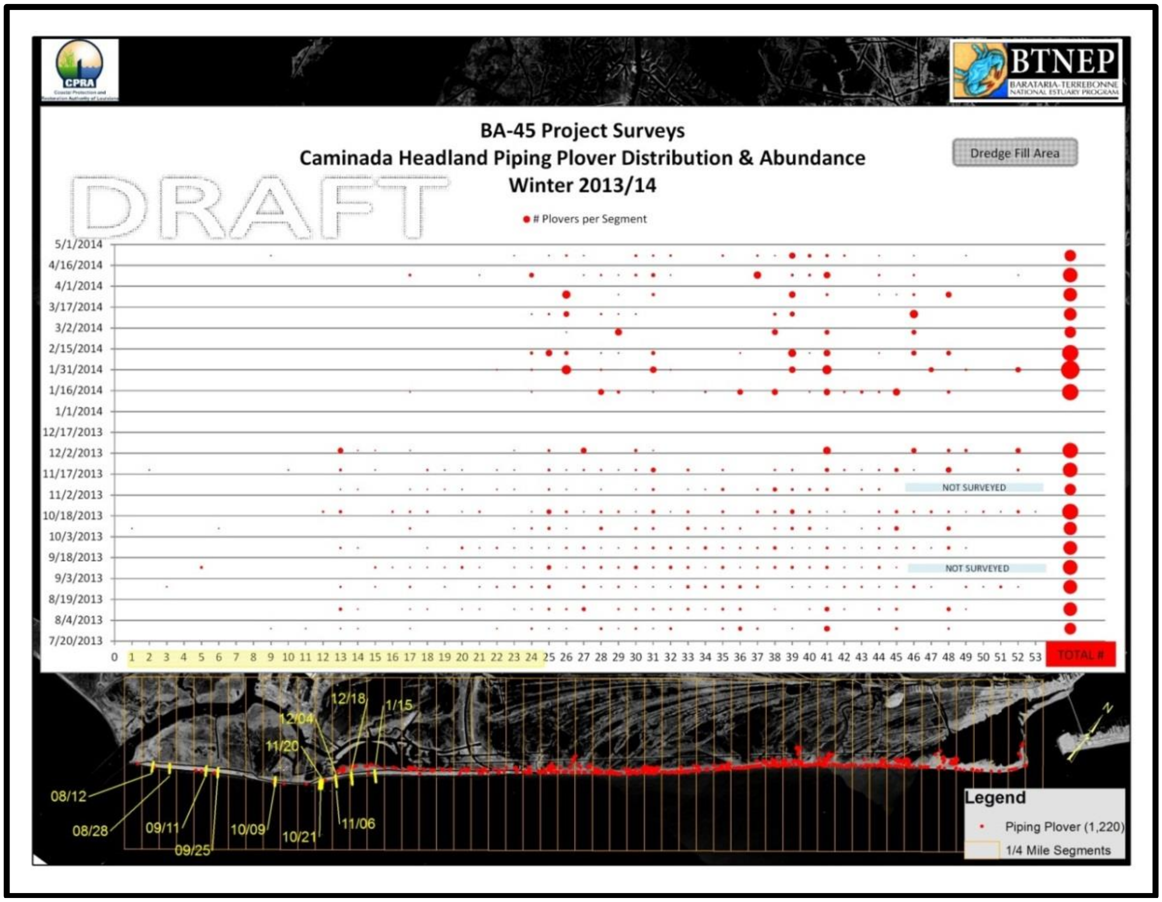


Figure 36. **Abundance and distribution of Piping Plovers along the Caminada Headland during the 2014/15 winter season. Dated yellow marks indicate the sediment fill location at the time of the survey.**

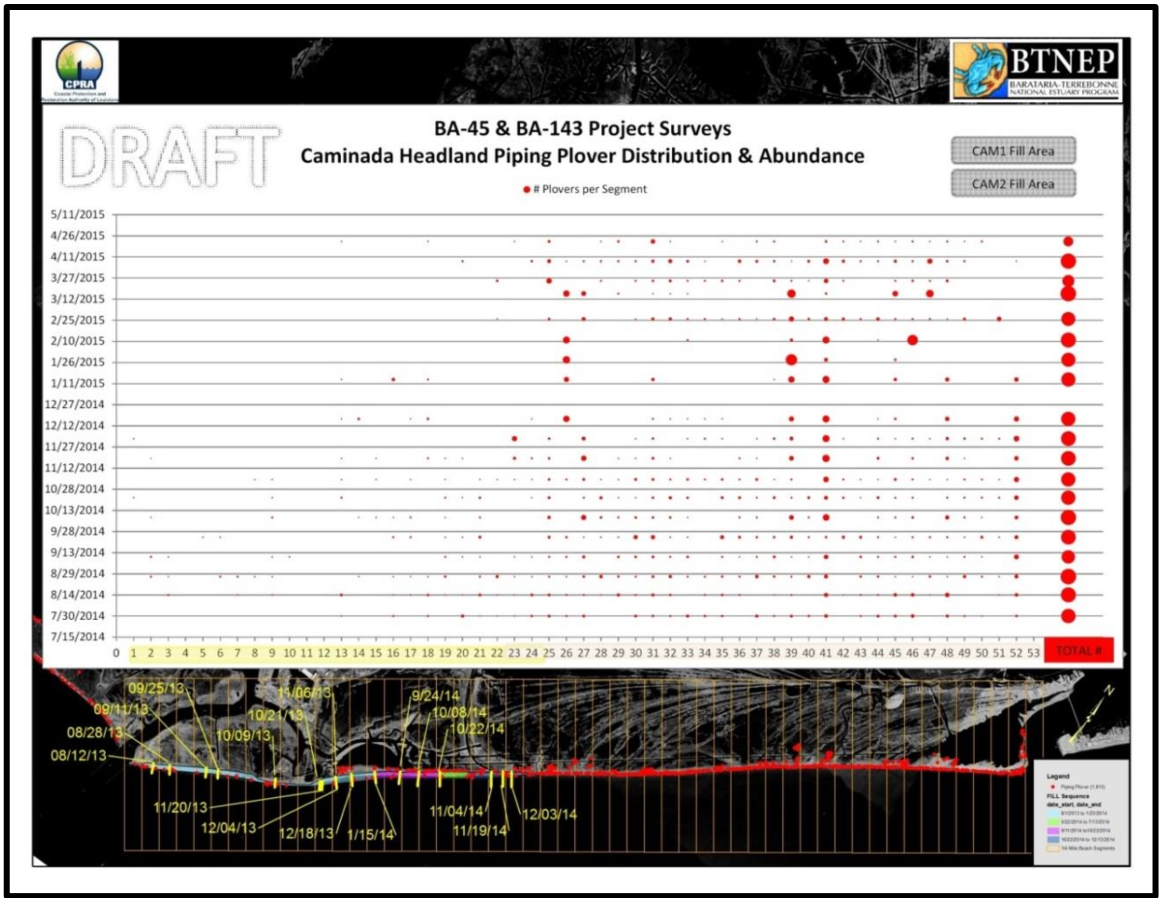


Figure 37. **Abundance and distribution of Piping Plovers along the Caminada Headland during the 2014/15 winter season. Dated yellow marks indicate the sediment fill location at the time of the survey.**

after initial deposition takes time and could also be a contributing factor in initial usage of the shoreline. Again, the Caminada Headland restoration data indicates a similar pattern along portions of the project between Belle Pass and Hwy 3090 (Figure 2). Sediment was placed along this reach of shoreline from August to November 2013, and initial surveys indicate little Piping Plover usage (Figure 35). However, by fall 2014 usage of this portion of the project had increased and is now seems heavily utilized (Figures 36, 37, and 38).

Benthic invertebrate sampling along the Caminada shoreline has been conducted to determine recovery of prey items. A benthic invertebrate survey in April 2013, before construction of the Caminada Headland project, was compared to an April 2014 survey in which two locations had received sediment four and eight months prior to the 2014 sampling. Comparisons at this early stage indicate both a decrease in diversity and a decrease in density of intertidal benthic prey items (McLelland 2014). However, there is some indication of recovery, as site one (8 months post-fill) showed much higher density than site two which had been filled only four months prior (Figure 40).

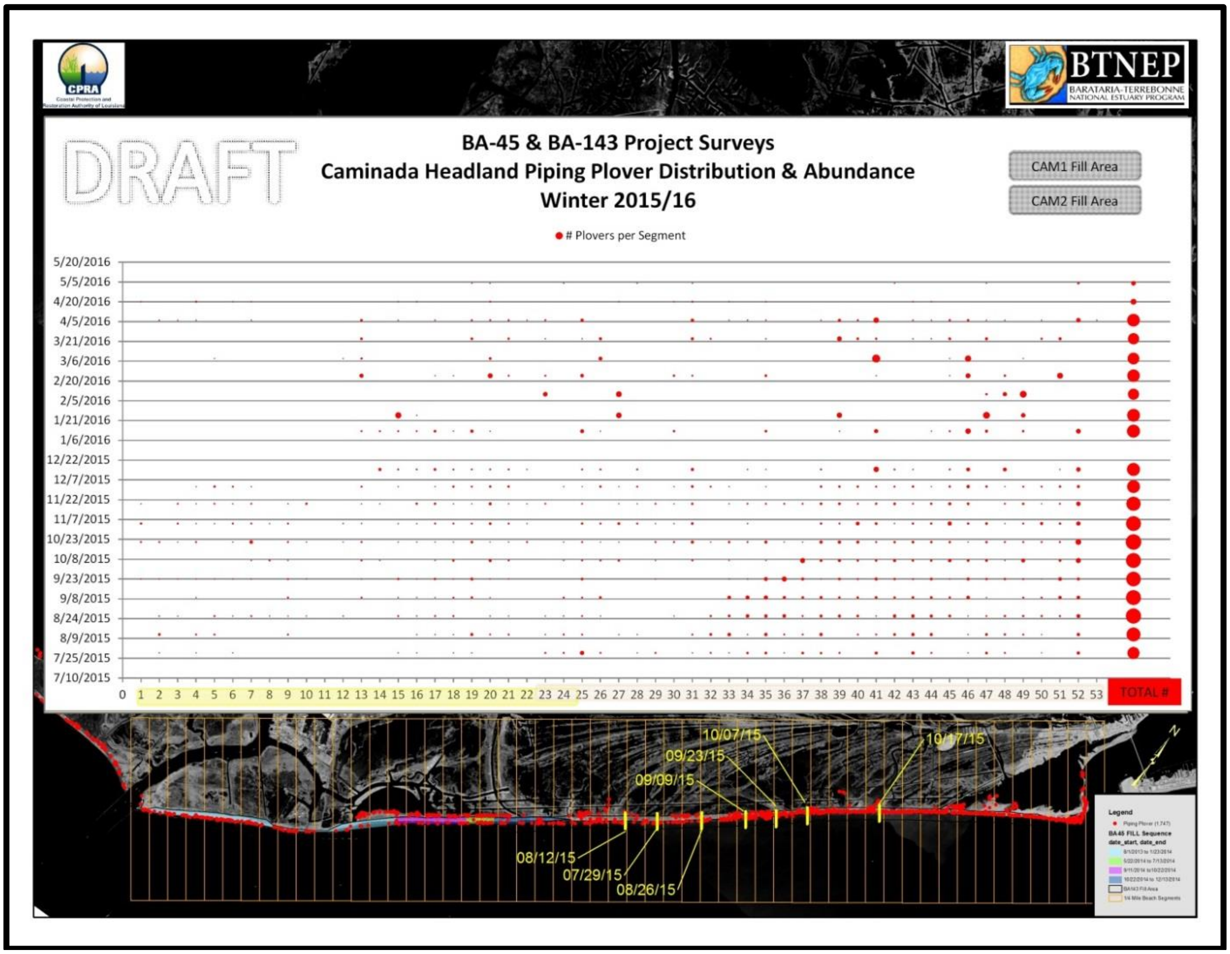


Figure 38. **Abundance and distribution of Piping Plovers along the Caminada Headland during the 2015/16 winter season. Dated yellow marks indicate the sediment fill location at the time of the survey.**

Additional benthic surveys have been conducted in 2015 and 2016. Pre-construction sampling was obtained at four sites for this project and the average prey biomass was 4.7 g/m^2, which makes a 70% threshold of 3.3 g/m^2 the required recovery threshold. However, due to the next increment of construction along the headland an additional six sites were established in 2014 and all ten sites have been sampled since then. So in regards to the four 2013 sites and threshold established above, the 2016 data was evaluated for the stations within the project fill area that had been filled for more than twelve month (n=4). The average is 17.4 g/m^2, or more than 5 times the required threshold within the fill footprint (Figure 41).

Again, due to the highly variable nature of benthic organisms and the availability of additional pre-fill data, CPRA looked at all samples regardless of year. This approach yielded nineteen samples from the ten sites along the headland before the location was filled. The average prey.

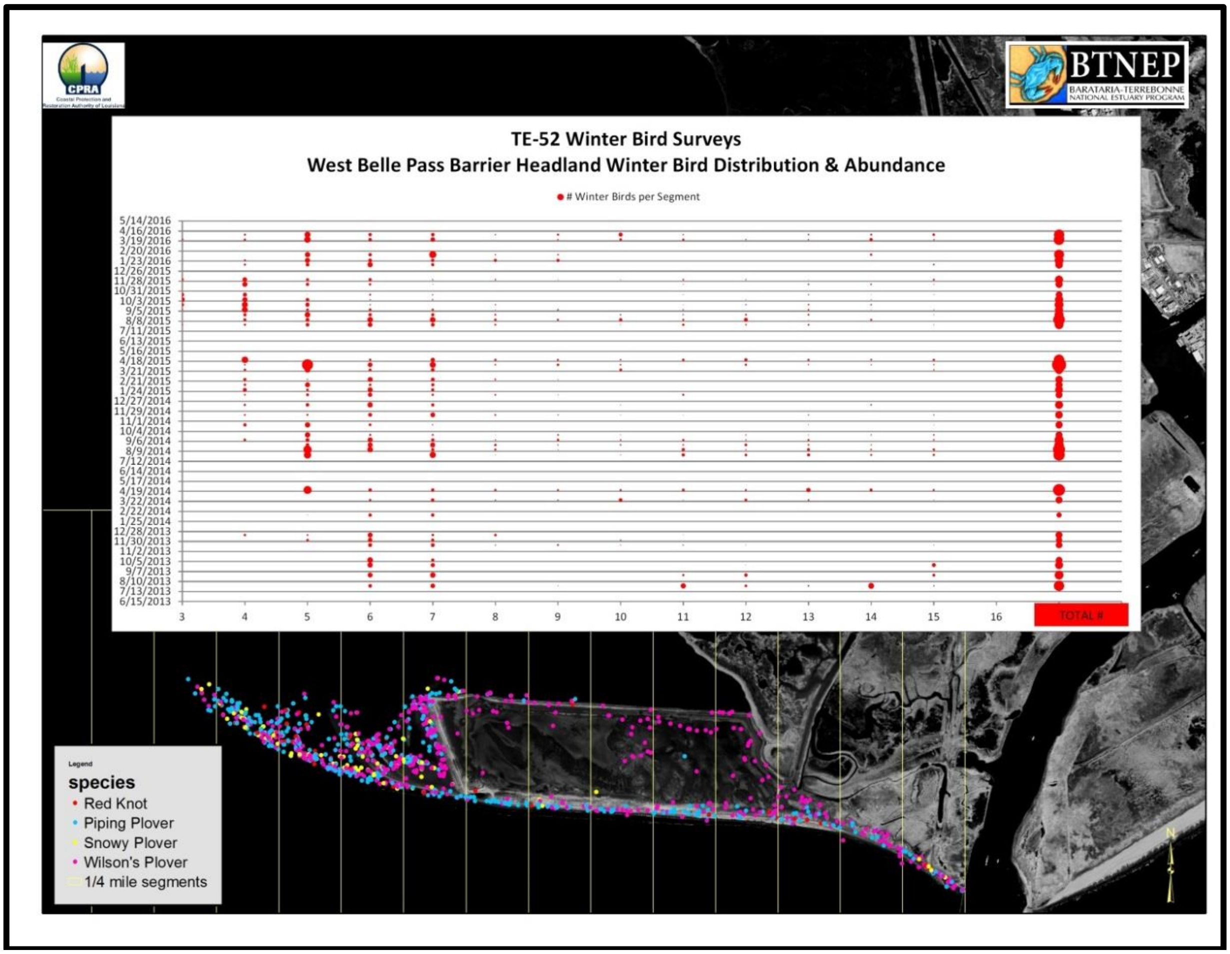


Figure 39. **Abundance and distribution of four wintering shorebirds in the West Belle Pass Headland Restoration (TE-52) project.**

biomass from all pre-fill samples is 24.5 g/m^2, which appears to confirm the highly variable nature of benthic organisms along shorelines. This means that post-construction the fill area must average at a minimum 17.1 g/m^2 of benthic prey biomass. CPRA regardless of year, averaged all samples taken from sites that had been filled at least twelve months (n = 6). This yields an average prey biomass of 26.8 g/m^2, again above the 17.1 g/m^2 threshold.

Benthic data definitely shows a decreased biomass in samples from recently filled sites. However, twelve months post-fill the majority of sites have recovered.

Overall, the winter bird usage of the project has shown patterns similar to other areas surveyed and provides a limited indication that habitats valuable to wintering shorebirds are

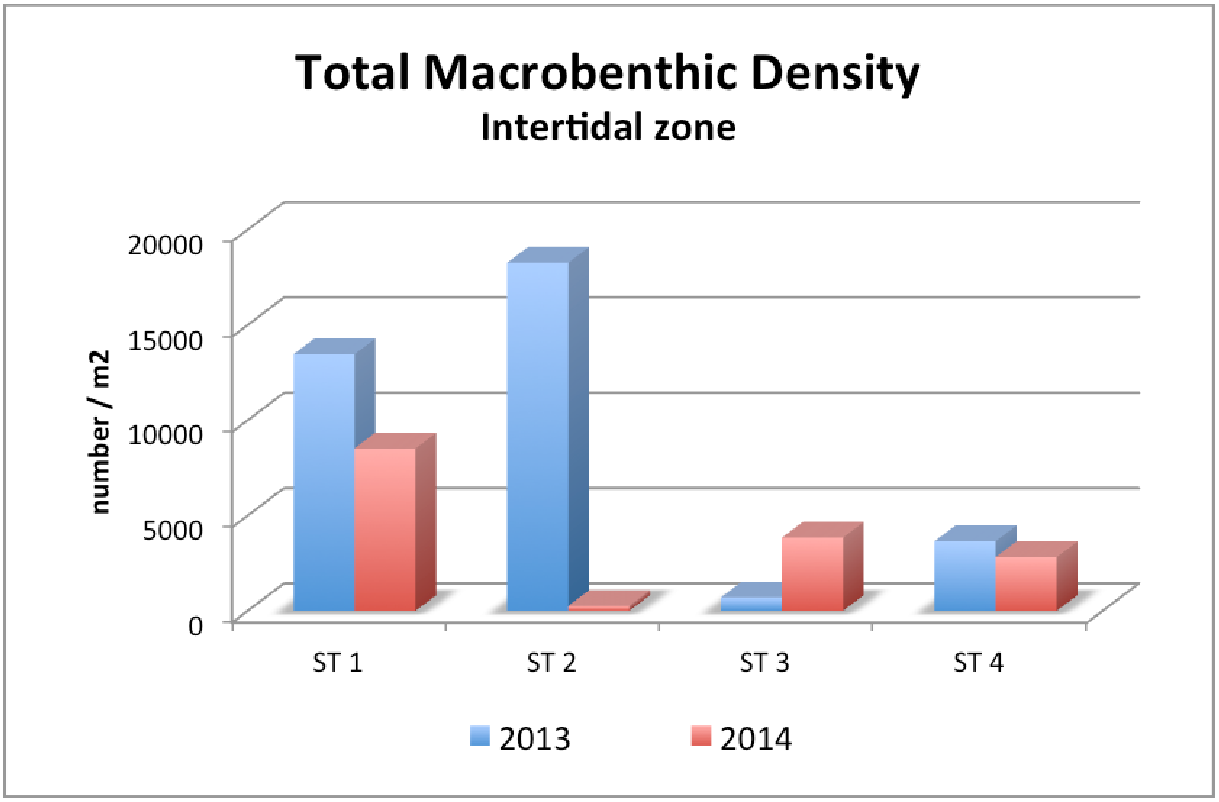


Figure 40. Pre- and during-construction intertidal benthic density at four locations along the Caminada Headland (McLelland 2014). Sites 1 and 2 had been filled four and eight months prior to the 2014 sampling, respectively. Sites 3 and 4 had not been filled prior to either sampling event.

developing rapidly due to project construction. Also, increased longevity of the area will potentially compensate for limited disturbances due to construction and prey item recovery. Therefore, the goal to restore shoreline, dune, and back-barrier marsh to increase habitat utilization by essential fish and wildlife species is being supported by the shorebird data at this time because the beach and spit habitats created by this project are being utilized by shorebirds and their foraging habitats are expanding.

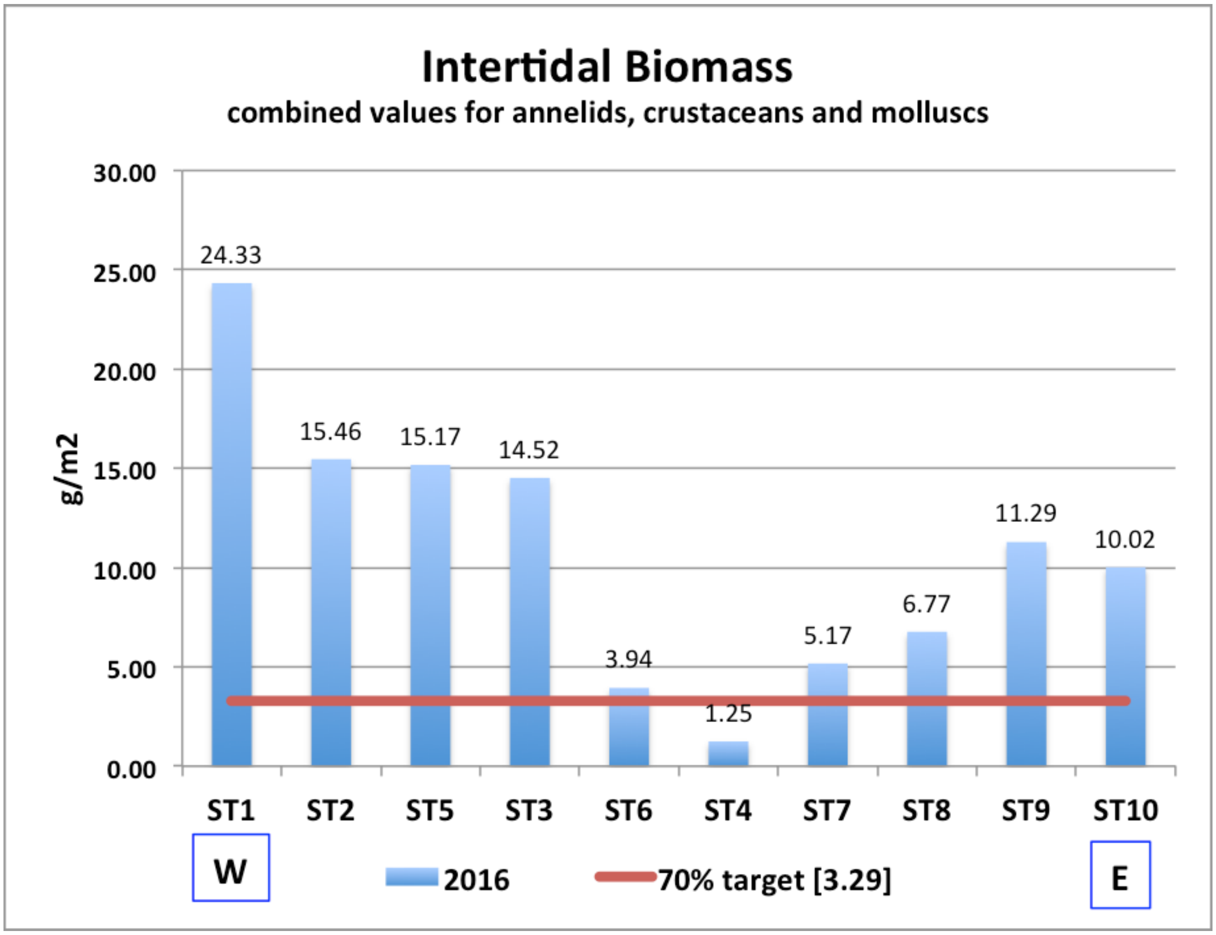


Figure 41. **2016 intertidal benthic density at ten locations along the Caminada Headland (McLelland 2016). Sites 1 through 7 had been filled from five to twenty-four months prior to the 2016 sampling. Sites 8 thru 10 had not been filled prior to the sampling event.**

V. Conclusions

a. Project Effectiveness

The results of the West Belle Pass Barrier Headland Restoration (TE-52) project reveal that two of the project goals were achieved, one was partially realized, and the fourth goal does not seem to be attainable as of this time. The first goal to reestablish and increase headland longevity via dune and marsh creation is presently being attained because the headland has been substantially enhanced by creating an over 3,048 m (10,000 ft) dune and a 121 ha (300 acre) back barrier marsh. The headland length is currently expanding due to longshore transport of beach and dune sediments to the downdrift spit, which is aggrading and elongating. However, a sizeable volume of sediment was removed from the beach and dune area during both post-construction intervals due to severe dune scarping, overwash, and leveling. Surprisingly, the extensive erosion of the dune feature occurred during a period of minimal tropical storm activity, and the pre-construction models vastly underestimated this volume loss (Thomson et al. 2009). The dune segments constructed parallel to the Gulf of Mexico shoreline were leveled along with their sand fencing while the northwestern facing dune segments (constructed parallel to the spit) did not incur scarping or large volume losses. Moreover, the lateral migration and aggradation of the spit seems to have protected the western flank of the project buffering this area from wave and storm impacts. The shoreline transgressions were probably induced by the passage of Hurricane Isaac (Figures 4 and 10), winter and non-tropical storms, and the influence of the Belle Pass Rock Jetties. While extensive shoreline transgressions occurred along the Gulf of Mexico shoreface, the marsh creation area only eroded along its southern border. Moreover, the longevity of the headland seems to have been prolonged by creating a wide back barrier marsh platform.

Secondly, the goal to prevent breaching along 9,300 feet of the headland over the 20-year project life is also currently being attained. No breaching occurred along the greater than 3,048 m (10,000 ft) of shoreline constructed for this project. Actually, the headland elongated during the study period through creation of the subaerial spit. However, the beach and dune creation area was substantially reshaped by the shoreline transgressions that occurred during both post-construction intervals. The large volume loss in the beach and dune area is a result of severe beach narrowing and dune leveling. Moreover, the dune was leveled over the entire length of its Gulf of Mexico shoreline forming washover and dune terrace landforms that consists of narrow beaches and small berms. However, the erosion in the TE-52 project area was mainly compartmentalized to beach and dune area because only the southern margins of marsh creation and nourishment areas incurred shoreline transgressions. Furthermore, the creation of a wide marsh creation area for the TE-52 project reduces the possibility of breaching and inlet formation.

The restore shoreline, dune, and back-barrier marsh to increase habitat utilization by essential fish and wildlife species goal is being partially realized at this time. The beach and spit habitats created by the TE-52 project are being utilized by shorebirds and their foraging habitats are expanding. Moreover, the intertidal and supralittoral habitats created through aggradation and elongation of the spit has increased the foraging area available to shorebirds.

As a result, the shorebird data supports this goal. While the beach and spit habitats enhance shorebird utilization, the constructed marsh is not enhancing marine fisheries habitat because there is very little tidal connectivity and vegetative cover on this platform due to the containment dike remaining in place. Although the tidal activity and vegetative cover have slightly increased in this project feature, the marsh creation area generally remains dry, salt flat habitat. However, saline marsh creation areas in Louisiana have been shown to rapidly vegetate when tidal connectivity is induced. Therefore, there is a great possibility that the created habitats will promote extensive utilization by marine fisheries if tidal connectivity is expanded.

The promote the re-establishment of historic longshore transport patterns along the Gulf shoreline goal is really not an attainable goal because historically the longshore transport nourished East Timbalier and Timbalier Islands. These barrier islands are currently southwest of the headland and are no longer downdrift of the headland's littoral current. However, the net longshore transport continues to flow to the west as described in the historical record.

b. Recommended Improvements

Several improvements would enhance the sustainability and increase habitat utilization of the West Belle Pass Barrier Headland Restoration (TE-52) project. The first recommendation to gap the primary containment dike is already slated to be constructed in the fall of 2017. The dike will be gapped in three locations during this event. Gapping of this dike will improve tidal exchange between Timbalier Bay and the marsh platform. This event should support the spring 2017 plantings in the marsh creation area, enhance the connection to the daily tidal cycle, and increase the acreage of functioning saline marsh habitat. Currently the marsh platform consists primarily of salt flat habitat. Two recent back barrier marsh creation projects have vegetated after tidal connectivity was established. Moreover, vegetation has colonized the creation area marshes adjacent to the gapped section of the containment dike and along the containment dike borrow area because of tidal creek formation. Therefore, it is highly likely that the TE-52 marsh creation area will vegetate when tidal connectivity is enhanced.

Secondly, in the future (later in the TE-52 project life) additional sand resources should be added to the West Belle Pass Headland system as per the State Master Plan (CPRA 2012) through a beach nourishment event to increase the width and elevation of the beach and enrich natural process development (Penland and Suter 1988; Feagin et al. 2010). Adding sand resources to the western headland littoral system via a beach nourishment event would prolong the longevity of the headland and reduce the possibility of breaching and inlet formation. Additionally, a terminal groin structure placed on the western edge of the spit should be considered to improve sediment retention on the western headland. Indeed, the preservation of limited sand resources is critical along the western headland because the Belle Pass Rock Jetties inhibit the transport of sediments from a potential major source.

c. Lessons Learned

Five lessons were learned from the first four years of the West Belle Pass Barrier Headland Restoration (TE-52) project. The first lesson is that a considerable volume of sediment was removed from the beach and dune area during the post-construction intervals due to severe beach narrowing and dune leveling. Approximately, 110% (-10% deficit) of the beach and dune volume was either relocated within or removed from the western headland's sediment budget four years after construction and with little tropical storm activity. Moreover, the project's design models did not foresee such substantial volume losses during the early post-construction period (Thomson et al. 2009). All the segments of the dune that were installed parallel to the Gulf of Mexico shoreline were leveled or scarped. While a substantial volume of sand was eroded from the beach and dune area, the 2015-2017 elevation data shows that 78% of these released sediments were retained within the system and conserved in the spit. The TE-52 shoreline transgressions were probably induced by the passage of Hurricane Isaac (Figures 4 and 10), winter storms, and the influence of the Belle Pass Rock Jetties. The erosion incurred during Hurricane Isaac seems to have been underestimated. Figure 10 indicates that the beach and dune were narrowed during Hurricane Isaac and this storm which made landfall approximately 1.6 km (1.0 mi) east of the TE-52 project on the Caminada-Moreau Headland produced an extensive storm surge (Figure 4). The Belle Pass Rock Jetties also wields a substantial influence on transport of sediments to and within the western headland. This is best illustrated by examining the results of the four USACE's sediment additions (1998, 2007, 2012, and 2015), which added sediment to the beach in the lee of the west jetty only to have the sediments reworked by coastal processes. Hence, these events demonstrate that very little sediment is transported towards the western jetty (eastern littoral transport). The post-construction elevation change grid models did not display evidence showing cross-shore transport. As a result, the coastal edge elevation constructed for the TE-52 project seems to be at high enough to resist cross-shore transport during winter and non-tropical storms. This reinforces the fact that the post-construction volume losses in the beach and dune area and the subsequent lateral migration of the spit were derived through longshore transport mechanisms.

The second lesson learned from the TE-52 project is that a western terminal groin should have been installed. This feature was considered as an alternative during the engineering and design of the TE-52 project. However, the project was approaching the upper limits of CWPPRA funding and the groin structure was removed from the project design. While a massive amount of the project’s sand resources were transported to the spit, a considerable portion of these resources could have been retained in the beach and dune area with the addition of a terminal groin. These terminal structures are necessary to hold limited sand resources in place when a headland or barrier island is truncated (Dean 1997) like the West Belle Pass Headland. Furthermore, the Belle Pass Rock Jetties serves as an impediment to the littoral transport of sand to the western headland forcing sediment retention to be essential to the sustainability of this sand deficient coastline.

The third lesson learned from the TE-52 project is that the primary containment dike is hindering tidal exchange between Timbalier Bay and the marsh platform. Currently the marsh platform consists primarily of salt flat habitat which does not support marine fisheries utilization. Back barrier creation projects on Grand Terre and Whiskey Islands demonstrate that the influence of tides can hasten saline marsh vegetation colonization and establishment. Moreover, vegetation colonization has been enhanced by the formation of small tidal creeks inside the TE-52 marsh creation area. Therefore, it is plausible to infer that the marsh platform will vegetate when tidal connectivity is established. Additionally, the question of when to gap containment dikes is a frequent problem inherent to back barrier marsh creation projects. When are the sediments sufficiently consolidated to allow gapping with minimal loss of dredged materials? Performance standards need to be derived to answer this question. For the TE-52 project it is clear that sediments have consolidated (Figures 20, D3, D4 and D5) and tidal connectivity needs to occur to create vegetated marsh habitat.

The fourth lesson learned from the TE-52 project is that the formation of the spit has enhanced shorebird utilization on the western headland. The beach and spit habitats created by the TE-52 project are being utilized by shorebirds and their foraging habitats are expanding (Figure 39). Moreover, the intertidal and supralittoral habitats created through aggradation and elongation of the spit has increased the foraging area available to shorebirds. As a result, the shorebird data provides evidence showing that spit formation can increase the acreage available to shorebirds. However, spit habitats are extremely vulnerable to storm induced cross-shore transport (Figure 22) (Curole and Lee 2013).

The last lesson is that the entire shoreface of the West Belle Pass Headland should have been topographically and bathymetrically surveyed during all sampling events. These surveys should have originated at the western jetty and extended to Raccoon Pass (Figure 1) to ascertain the influence of the sediment budget on the project. In addition, several of the periodic surveys were missing transects – 2008 design (T1A-T1B and T26-T35), 2011 pre (T1B-T1 and T22-T35), 2012 as-built (T1B-T1 and T22-T35), and 2015 post-construction (T1A-T1B). Moreover, the length of the survey transects and spacing between points was not always consistent. This led to narrowing the grid model extent to that of the most limited survey. Also, the extended dune feature and the BUMP projects influence were not able to be determined because these features were outside the extent of the surveys. Moreover, the placement of sediment affects the sediment budget for the whole headland including the spit, passes, and areas adjacent to coastal structures like jetties. Therefore, the elevation surveys should have verified changes on all of the geomorphic features of the headland to determine the effect of these volumetric differences on the residual sediment budget. The post-construction surveys (2015 and 2017) detail this and allow for estimation of sediment retention within the spit because they account for all geomorphic features within the headland system. By not surveying all geomorphic areas within a headland system or simply surveying only the constructed features of a beach and/or dune restoration project leads to an awkward analysis with unanswered questions. For instance, how much volume was conserved within the spit for the 2012-2015 interval? This question cannot be answered because of survey extent limitations.

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Appendix A
(Inspection Photographs)

Photo A-1. View of sheet pile condition in northern containment dike.

Photo A-2. View of sheet pile plug in northern containment dike, looking west.

Photo A-3. View of freshwater vegetation on small impounded area south of sheet pile wall.

Photo A-4. View of northern primary containment dike west of sheet pile wall.

Photo A-5. View of successful vegetative planting & sand fence, looking south.

Photo A-6. View of northern part of jetty as center of western marsh fill edge.

Photo A-7. View of jetty from sand fencing on western marsh fill edge.

Photo A-8. View of jetty beach face, looking west from southern tip of sand fence.

Photo A-9. View of beach dune and sand fencing looking west.

Photo A-10. View of beach erosion, looking east.

Photo A-11. View of settlement plate, marking the center of original dune.

Photo A-12. View of dune erosion and damaged sand fencing.

Photo A-13. View of area behind primary containment dike.

Photo A-14. View of remaining non vegetated section in center of marsh platform, on the western edge of project.


Photo A-15. View of flood and drainage canal near south-eastern corner of marsh fill.

Appendix B
(Three Year Budget Projection

WEST BELLE PASS BARRIER HEADLAND RESTORATION (TE-52)
Three-Year Operations & Maintenance Budgets 07/01/2017- 06/30/20

Project Manager	O & M Manager	Federal Sponsor	Prepared By
	Hartman	NMFS	Babin

	2017/2018	2018/2019	2019/2020
Maintenance Inspection	$ 15,536.00	$ 16,002.00	$ 16,482.00
Structure Operation	$ -	$ -	
CPRA Administration	$ 12,260.00		
NMFS Administration	$ 25,000.00	$ 5,000.00	$ 5,000.00

Maintenance/Rehabilitation

17/18 Description: Remove exisitng steel sheetpile, degrade back containment dike

	2017/2018
E&D	$ 4,669.00
Construction	$ 134,375.00
Construction Oversight	$ 33,667.00
Sub Total - Maint. And Rehab.	$ 172,711.00

18/19 Description: Maintenance Inspection

	2018/2019
E&D	
Construction	
	$ -
Sub Total - Maint. And Rehab.	$ -

19/20 Description: Maintenance Inspection

	2019/2020
E&D	$ -
Construction	$ -
Construction Oversight	$ -
Sub Total - Maint. And Rehab.	$ -

	2017/2018	2018/2019	2019/2020
Total O&M Budgets	$ 225,507.00	$ 21,002.00	$ 21,482.00

O&M Budget (3 Yr Total)	$ 267,991.00
Unexpended O&M Funds	$ 2,308,618.00
Remaining O&M Funds	$ 2,040,627.00

OPERATIONS & MAINTENANCE BUDGET WORKSHEET

Project: West Belle Pass Barrier Headland Restoration (TE-52)

FY 17/18 –

CPRA Administration		**$ 12,260**
Maintenance Inspection		**$ 15,536**
NMFS Administration:		**$ 25,000**
Operation:		$ 0
Maintenance:		**$ 172,711**
E&D, Const. Oversight:	$ 38,336	
Construction:	$ 134,375	

Maintenance Event No.1 – remove existing steel sheet pile from back dike and degrade back dike to marsh elevation.

Construction Cost Breakdown	
Mobilization (Lump Sum):	$ 50,000
Remove sheet Pile: (Approx. 150 lft.)	$ 20,000
Degrade Back Dike: (Approximately Approx. 5,000 Lft) $7.50/ Lft	$ 37,500
Total:	$ 107,500
Contingency (25%):	$ 26,875
TOTAL:	**$ 134,375**

Maintenance Event No.1 - Design, Construction Administration and Inspection	
E&D: (9% x Construction):	$ ~~23,344~~ 80% complete($4,669 Remaining)
Surveying:	~~$ 15,000~~ Completed
Permitting:	~~$ 5,000~~ Completed
Construction Administration: (100 hrs. @ $100/hr.)	$ 10,000
Inspection: (200 hrs @ $80/hr.)	$ 16,000
Total:	$ 30,669
Contingency: (25%):	$ 7,667
TOTAL:	**$ 38,336**

Total Estimate Project Budget: **$ 172,711**

CPRA Direct Costs

Maintenance Event No.1 – CPRA Administration

Engineer 3 (40 hrs @ $68/ hr.):	$ 2,720
Engineer 6 (20 hrs. @ $78/ hr.):	$ 1,560
Total Direct Cost:	**$ 4,280**

CPRA Indirect Costs

Maintenance Event No.1 – CPRA Administration

Engineer 3 (40 hrs @ $127/ hr.):	$ 5,080
Engineer 6 (20 hrs. @ $145/ hr.):	$ 2,900
Total In-Direct Cost:	**$ 7,980**

CPRA Direct Costs

Inspection:	
CPRA Engineer 3 – 12 hrs@ $68/hr.:	$ 816
CPRA Engineer 6 – 12 hrs @ $78/hr.	$ 936
CPRA Scientist 4 – 10 hrs @ $56/hr.	$ 560
	$ 2,312
Report:	
CPRA Engineer 6 – 40 hrs. @ $78/hr.	$ 3,120
Total Direct Costs:	**$ 5,432**

CPRA In-Direct Costs

Inspection:	
CPRA Engineer 3 – 12 hrs@ $127/hr.:	$ 1,524
CPRA Engineer 6 – 12 hrs @ $145/hr.	$ 1,740
CPRA Scientist 4 – 10 hrs @ $104/hr.	$ 1,040
	$ 4,304
Report:	
CPRA Engineer 6 – 40 hrs. @ $145/hr.	$ 5,800
Total In-Direct Costs:	**$10,104**
NMFS Administration:	**$25,000**

FY 18/19 –

CPRA Administration			**$ 16,002**
NMFS Administration:			**$ 5,000**
Operation:			$ 0
Maintenance:			**$ 0**
E&D and Const. Oversight:	$	0	
Construction:	$	0	

CPRA Direct Costs

Inspection:

CPRA Engineer 3 – 12 hrs@ $68/hr.:	$ 816
CPRA Engineer 6 – 12 hrs @ $78/hr.	$ 936
CPRA Scientist 4 – 10 hrs @ $56/hr.	$ 560
	$ 2,312

Report:

CPRA Engineer 6 – 40 hrs. @ $78/hr. $ 3,120

Total Direct Costs: $ 5,432 x 3% = $5,595

CPRA Indirect Costs

Inspection:

CPRA Engineer 3 – 12 hrs@ $127/hr.:	$ 1,524
CPRA Engineer 6 – 12 hrs @ $145/hr.	$ 1,740
CPRA Scientist 4 – 10 hrs @ $104/hr.	$ 1,040
	$ 4,304

Report:

CPRA Engineer 6 – 40 hrs. @ $145/hr. $ 5,800

Total In-Direct Costs: $10,104 x 3% = $10,407

FY 19/20 –

Administration			**$ 16,482**
NMFS Administration:			**$ 5,000**
O&M Inspection & Report			$ 0
Operation:			$ 0
Maintenance:			$ 0
E&D:	$	0	
Construction:	$	0	
Construction Oversight:	$	0	

CPRA Direct Costs

$5,595 x 3% = Total Direct CPRA Costs: $ 5,763

CPRA In-direct Costs

$10,407 x 3% = Total Indirect CPRA Costs: $ 10,719

O&M Accounting:

Total O&M Budget (Lana Report):	$ 2,478,866
CPRA Expenditures to Date (LaGov):	$ 170,248
Unexpended O&M Budget:	$ 2,308,618

Appendix C
(TE-52 Survey Profiles)

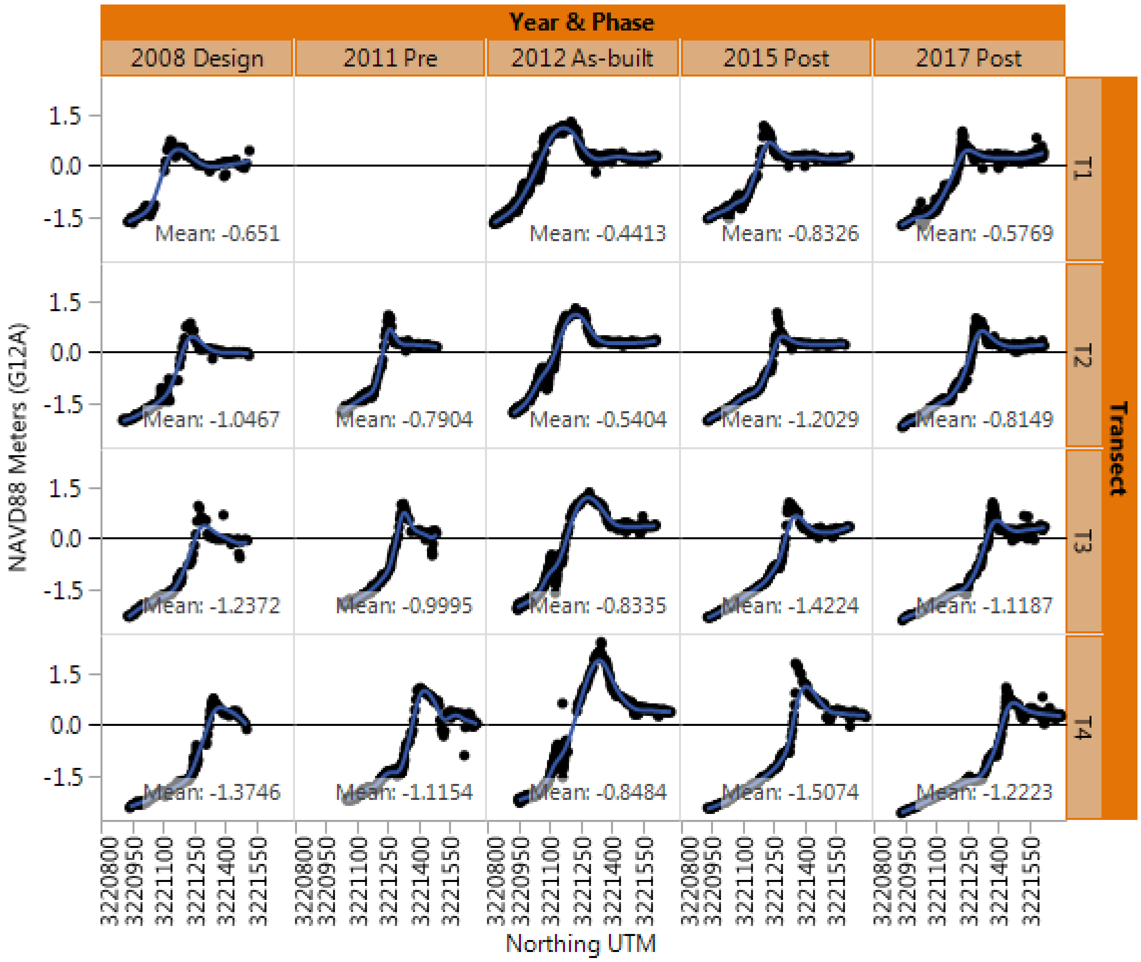


Figure C-1. **T1 to T4 survey profiles over time at the West Belle Pass Barrier Headland Restoration (TE-52) project. The graphs depict the elevation of the shoreface, beach, dune, and marsh habitats from 2008 to 2017.**

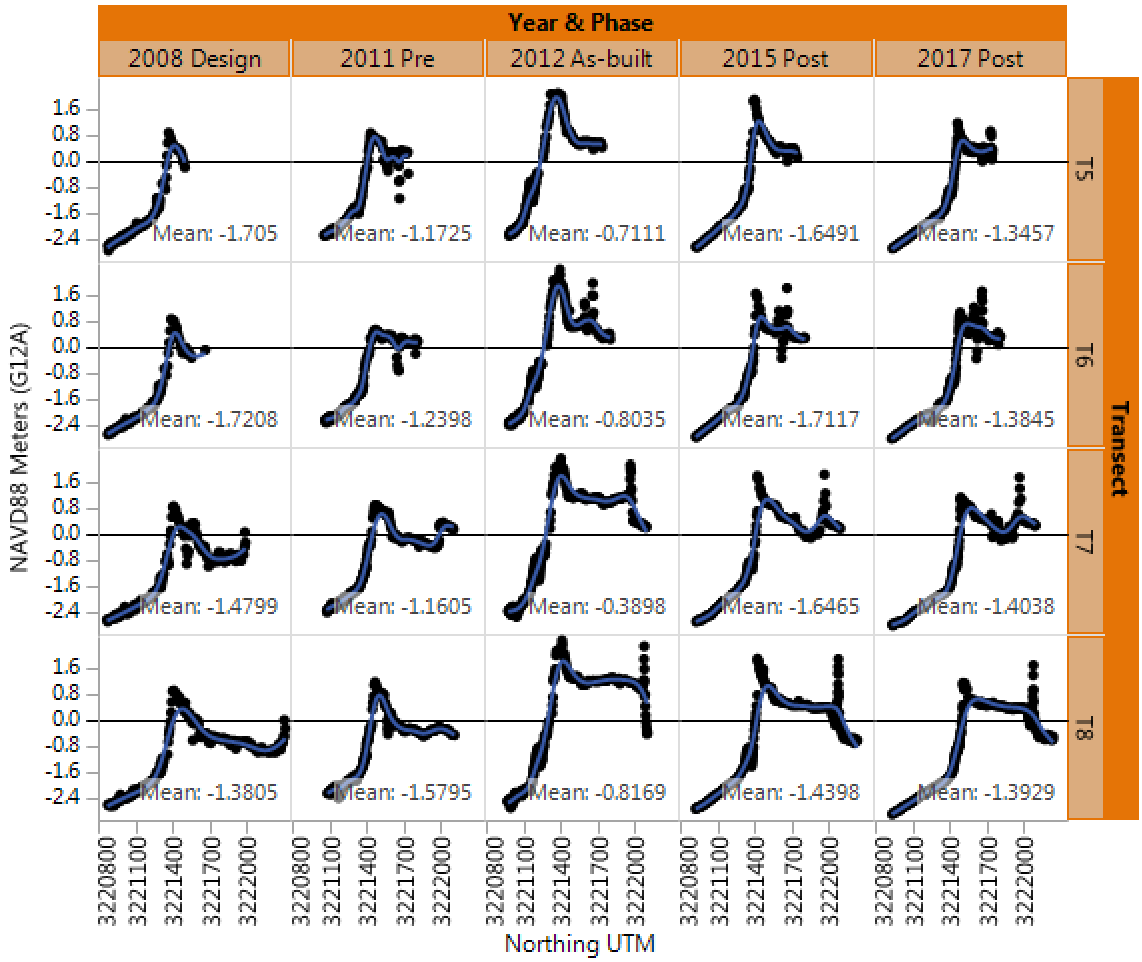


Figure C-2. **T5 to T8 survey profiles over time at the West Belle Pass Barrier Headland Restoration (TE-52) project. The graphs depict the elevation of the shoreface, beach, dune, and marsh habitats from 2008 to 2017.**

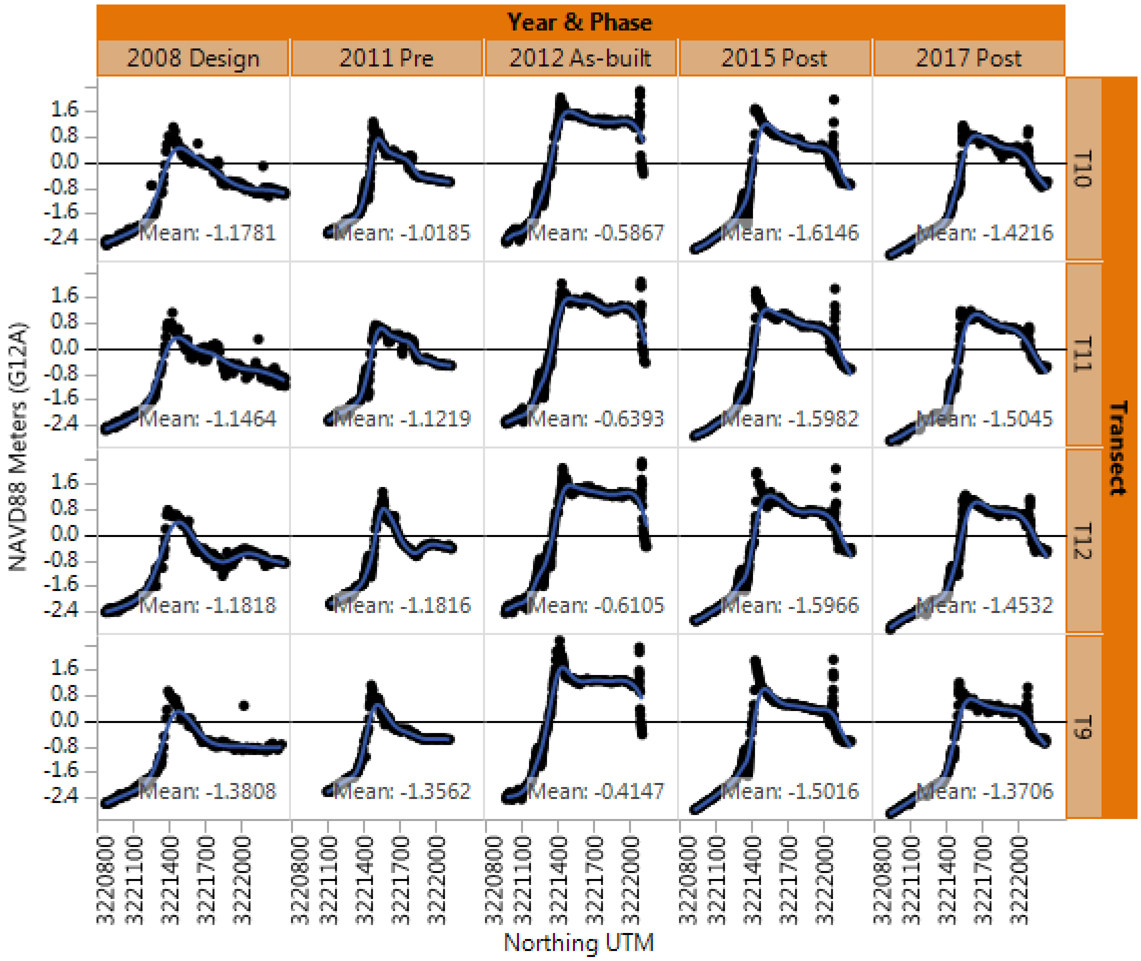


Figure C-3. **T9 to T12 survey profiles over time at the West Belle Pass Barrier Headland Restoration (TE-52) project. The graphs depict the elevation of the shoreface, beach, dune, and marsh habitats from 2008 to 2017.**

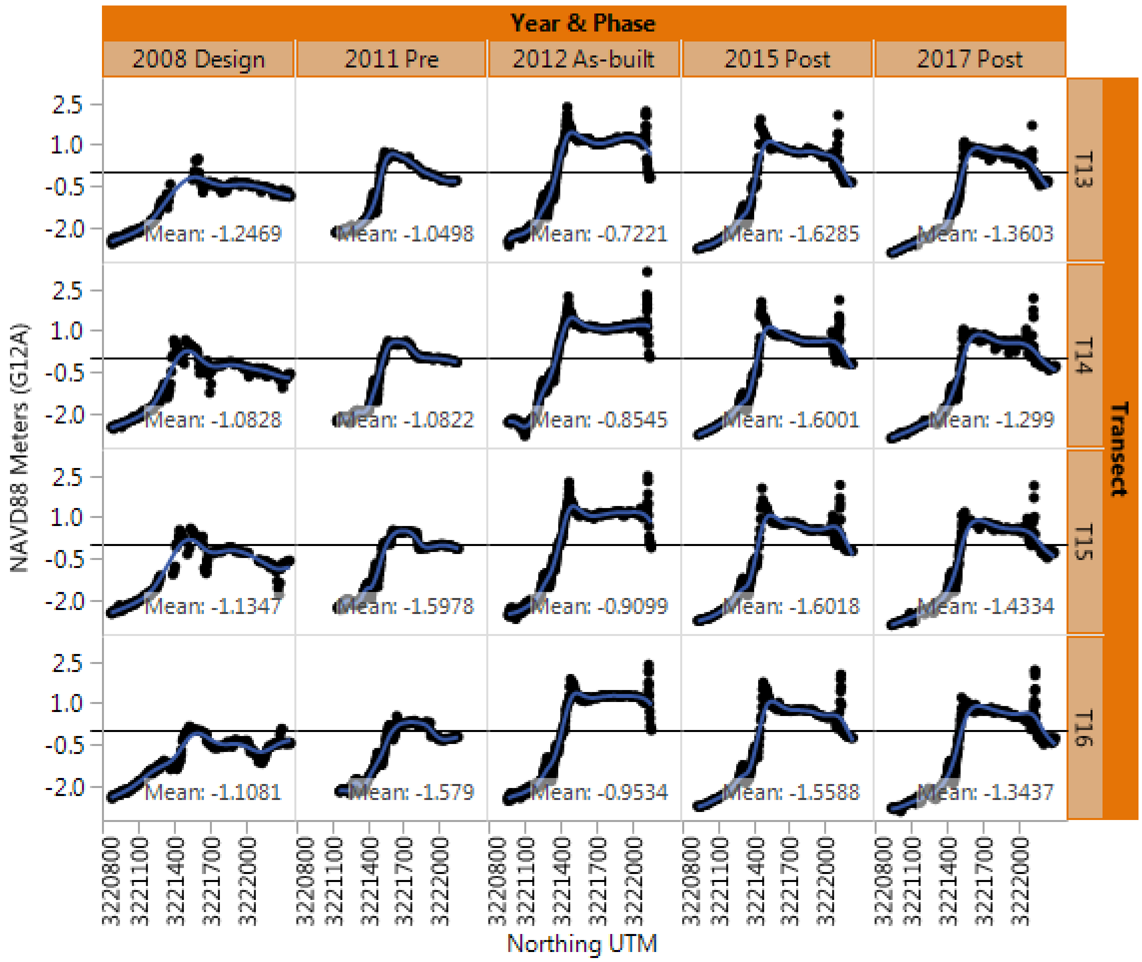


Figure C-4. **T13 to T16 survey profiles over time at the West Belle Pass Barrier Headland Restoration (TE-52) project. The graphs depict the elevation of the shoreface, beach, dune, and marsh habitats from 2008 to 2017.**

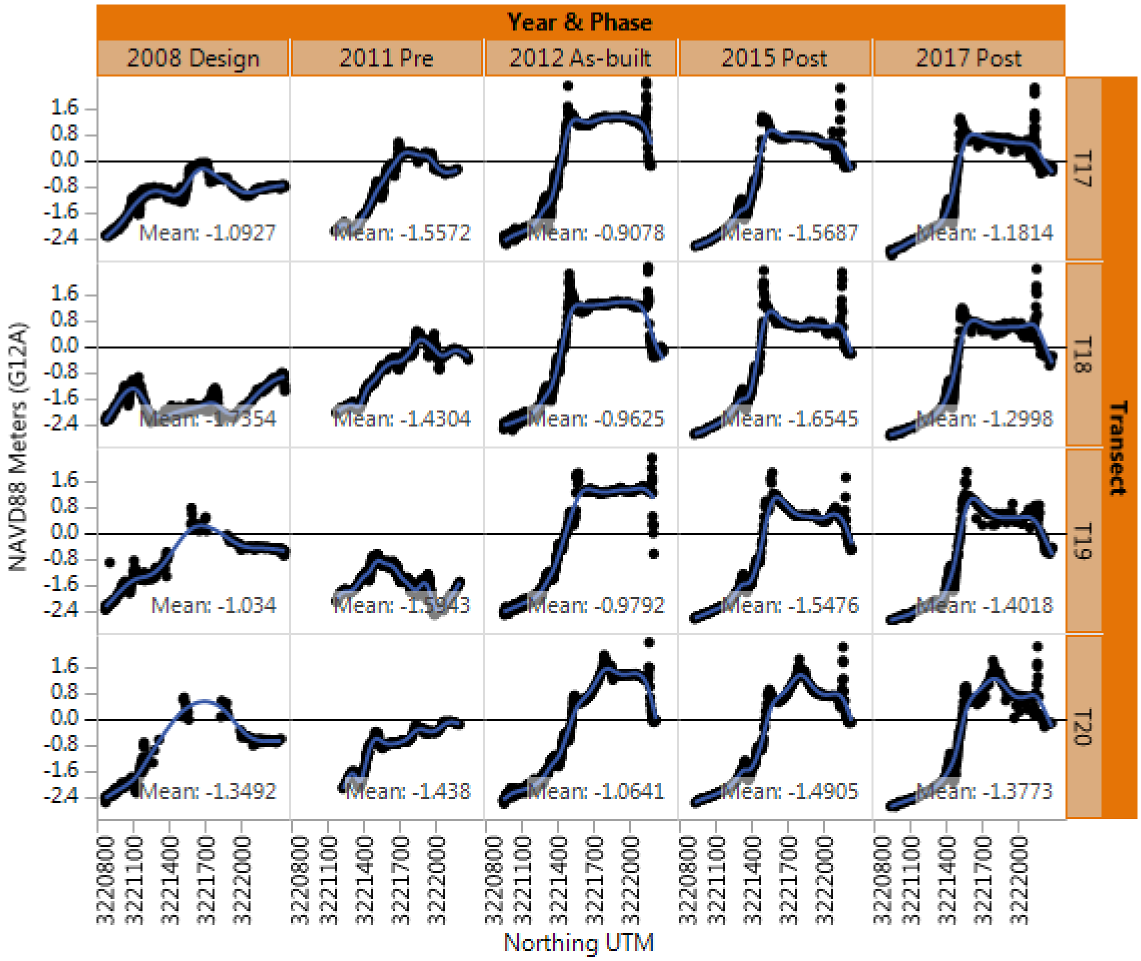


Figure C-5. **T17 to T20 survey profiles over time at the West Belle Pass Barrier Headland Restoration (TE-52) project. The graphs depict the elevation of the shoreface, beach, dune, and marsh habitats from 2008 to 2017.**

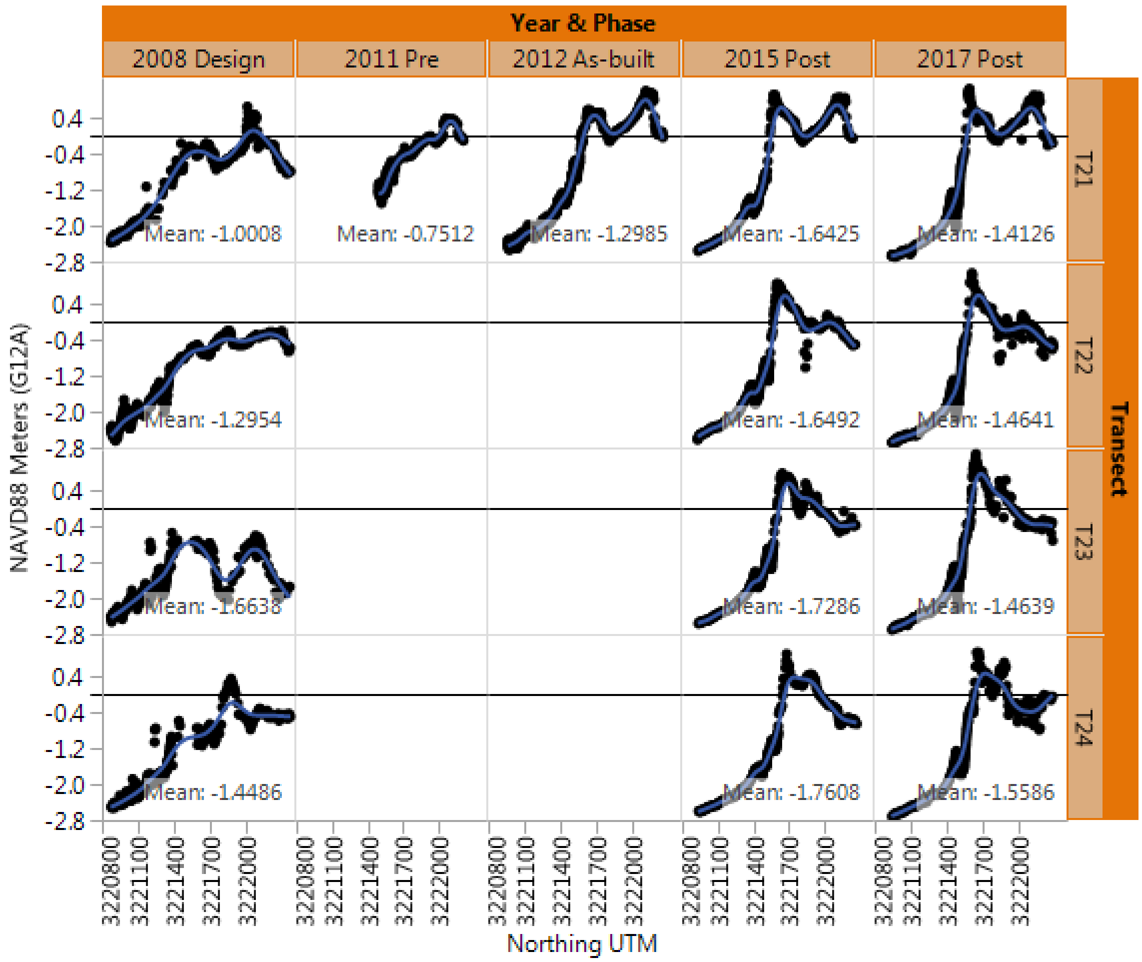


Figure C-6. **T21 to T24 survey profiles over time at the West Belle Pass Barrier Headland Restoration (TE-52) project. The graphs depict the elevation of the shoreface, beach, dune, and marsh habitats from 2008 to 2017.**

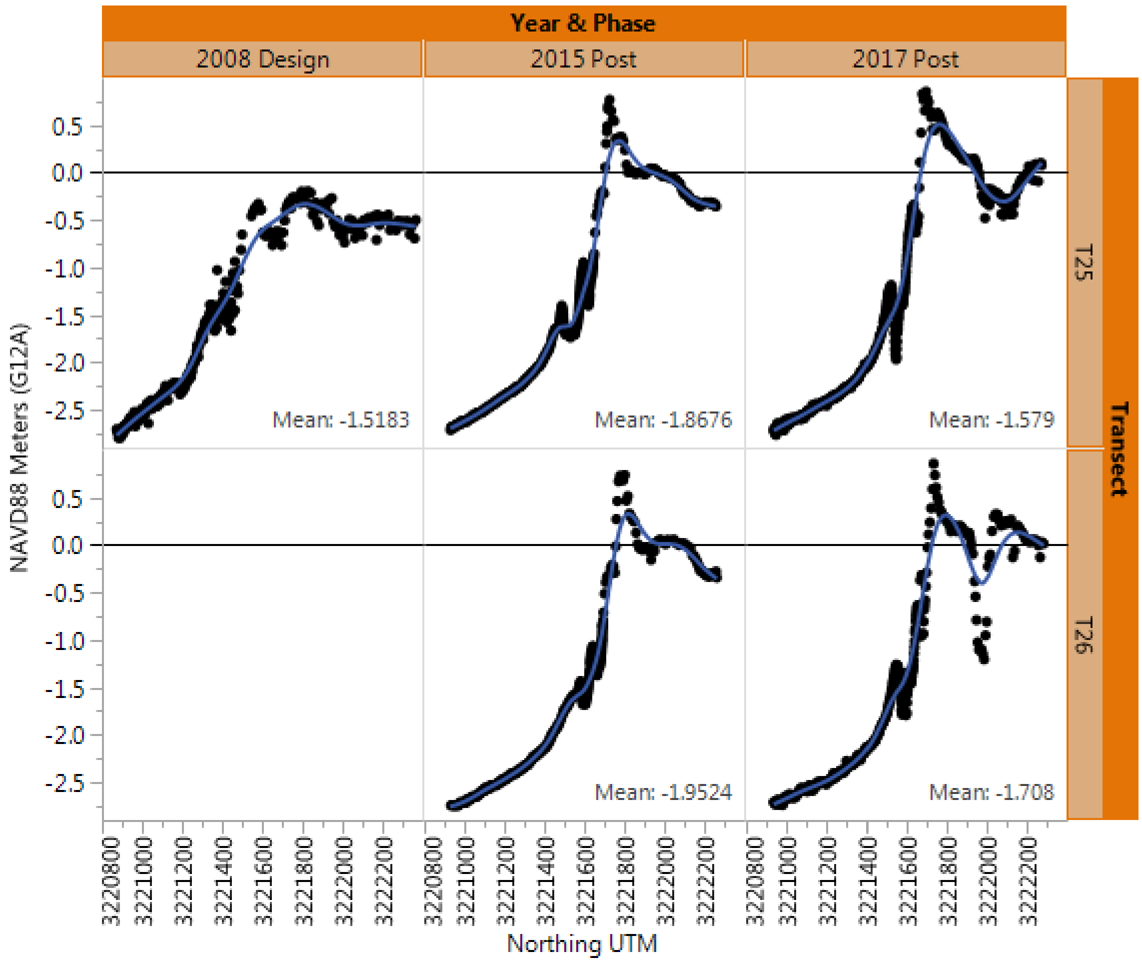


Figure C-7. **T25 to T26 survey profiles over time at the West Belle Pass Barrier Headland Restoration (TE-52) project. The graphs depict the elevation of the shoreface, beach, dune, and marsh habitats from 2008 to 2017.**

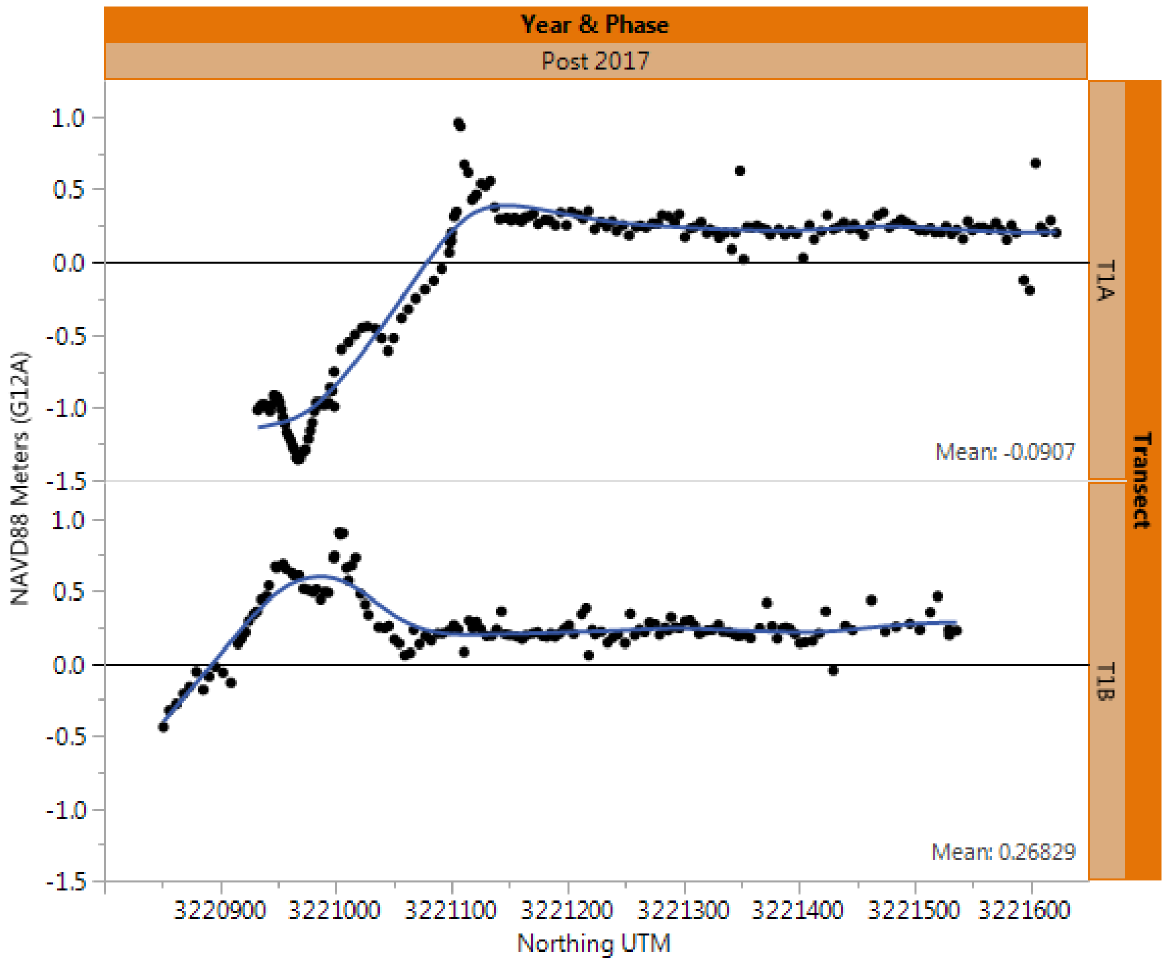


Figure C-8. **T1A to T1B survey profiles in February 2017 at the West Belle Pass Barrier Headland Restoration (TE-52) project. The graphs depict the elevation of the shoreface, beach, dune, and marsh habitats in 2017.**

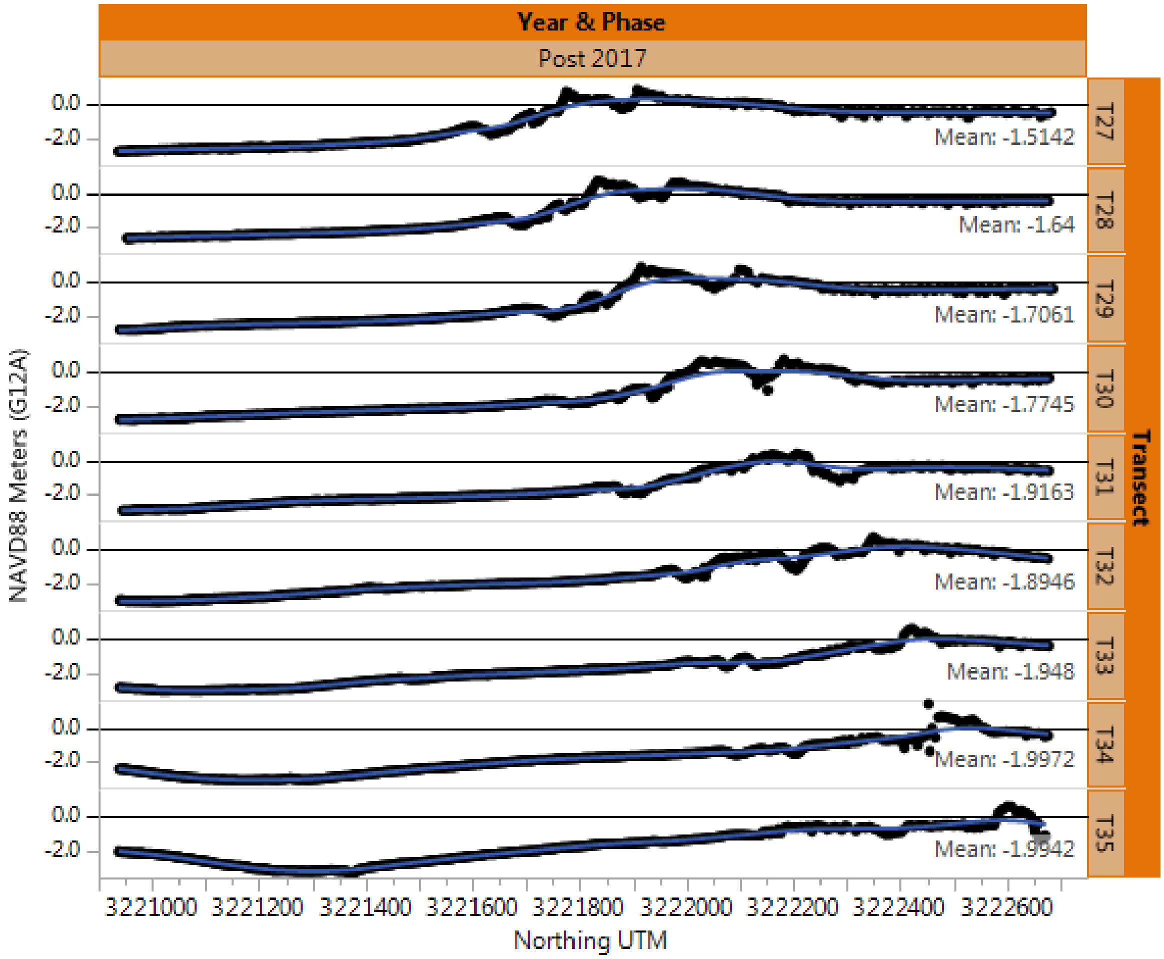
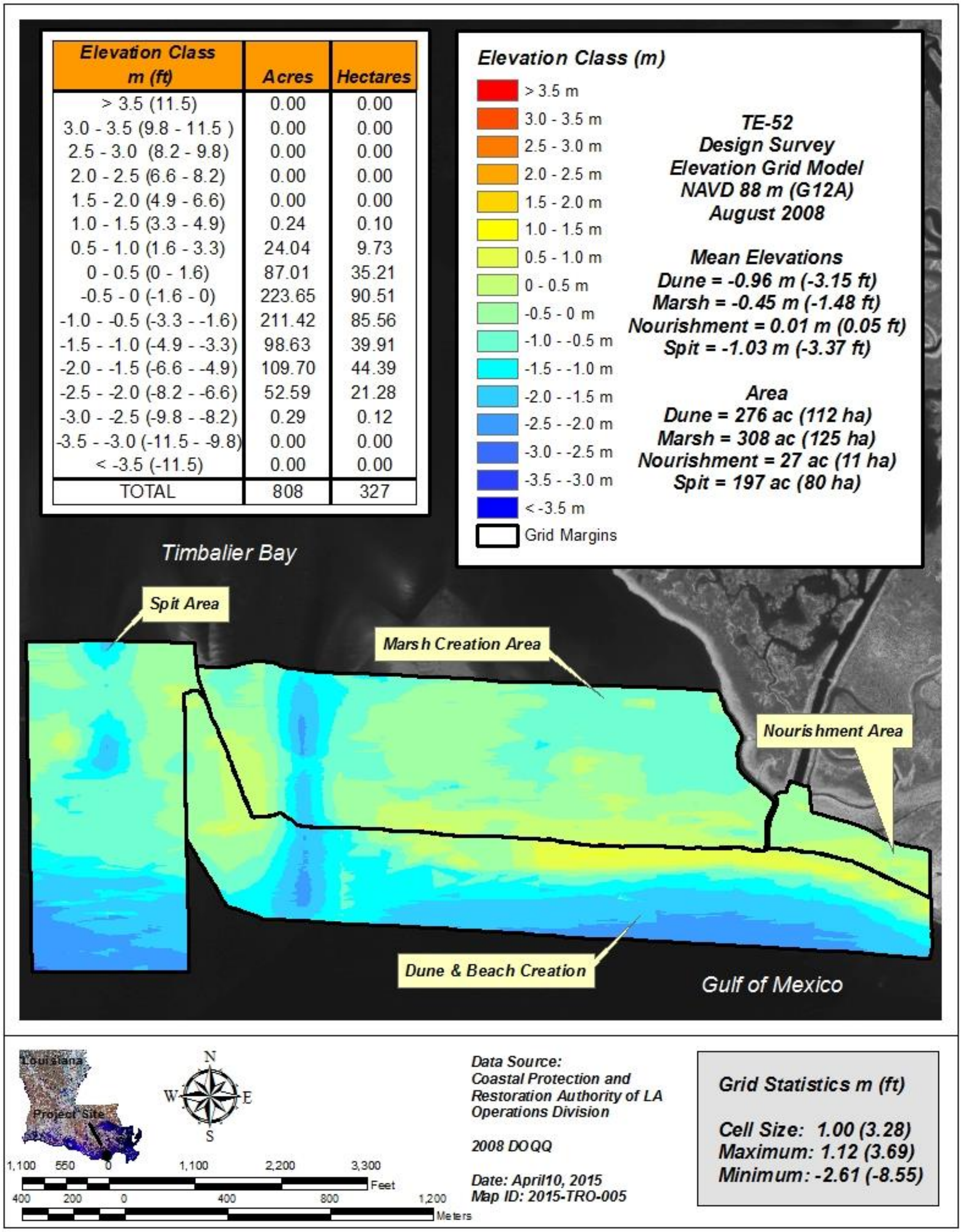


Figure C-9. **T27 to T35 survey profiles in February 2017 at the West Belle Pass Barrier Headland Restoration (TE-52) project. The graphs depict the elevation of the shoreface, beach, berm, and marsh habitats in 2017.**

Appendix D
(TE-52 Elevation Grid Models)



Elevation Class m (ft)	Acres	Hectares
> 3.5 (11.5)	0.00	0.00
3.0 - 3.5 (9.8 - 11.5)	0.00	0.00
2.5 - 3.0 (8.2 - 9.8)	0.00	0.00
2.0 - 2.5 (6.6 - 8.2)	0.00	0.00
1.5 - 2.0 (4.9 - 6.6)	0.00	0.00
1.0 - 1.5 (3.3 - 4.9)	0.24	0.10
0.5 - 1.0 (1.6 - 3.3)	24.04	9.73
0 - 0.5 (0 - 1.6)	87.01	35.21
-0.5 - 0 (-1.6 - 0)	223.65	90.51
-1.0 - -0.5 (-3.3 - -1.6)	211.42	85.56
-1.5 - -1.0 (-4.9 - -3.3)	98.63	39.91
-2.0 - -1.5 (-6.6 - -4.9)	109.70	44.39
-2.5 - -2.0 (-8.2 - -6.6)	52.59	21.28
-3.0 - -2.5 (-9.8 - -8.2)	0.29	0.12
-3.5 - -3.0 (-11.5 - -9.8)	0.00	0.00
< -3.5 (-11.5)	0.00	0.00
TOTAL	808	327

Figure D-1. **Design (Aug 2008) elevation grid model of the beach and dune, marsh creation, nourishment, and spit areas at the West Belle Pass Barrier Headland Restoration (TE-52) project.**

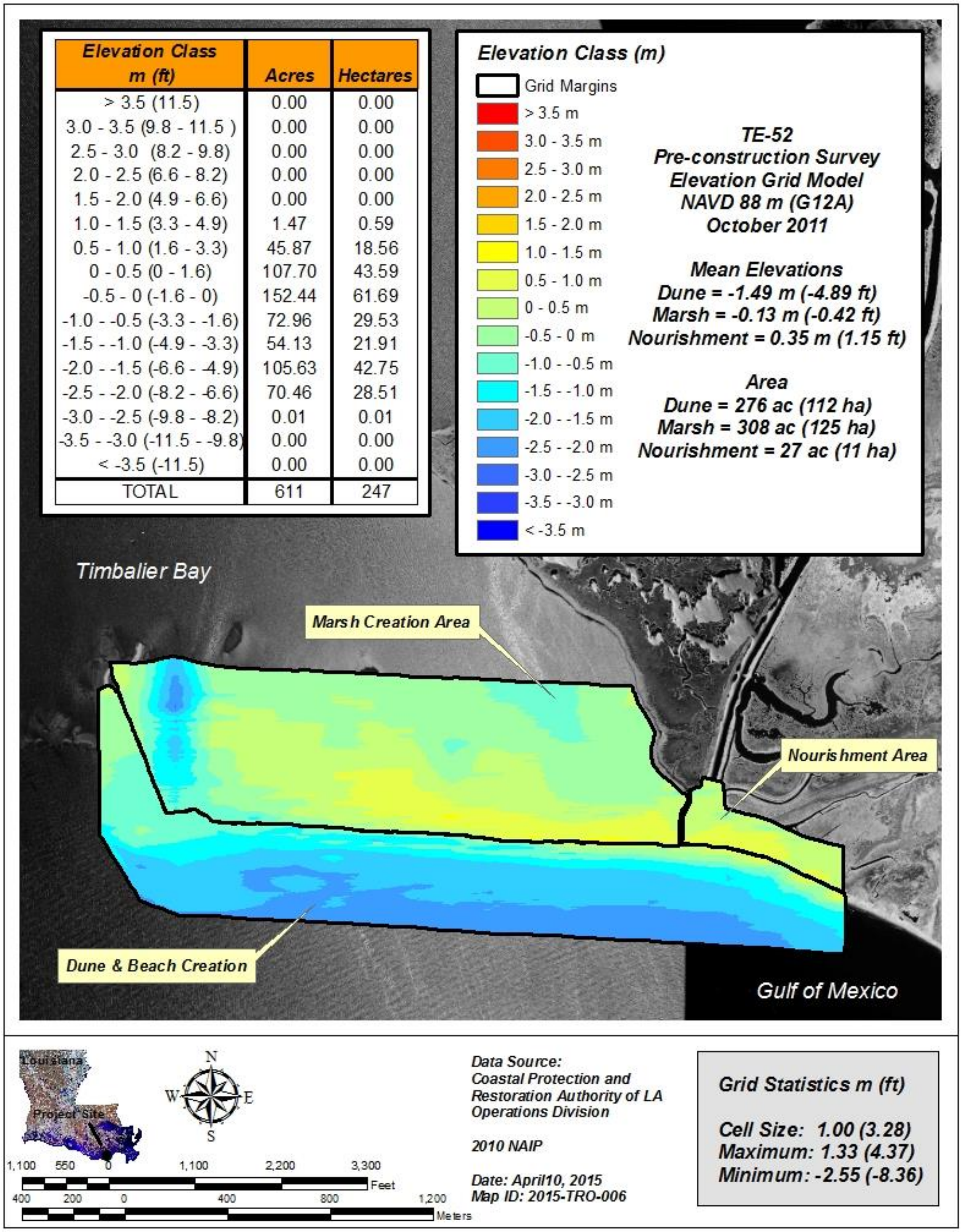
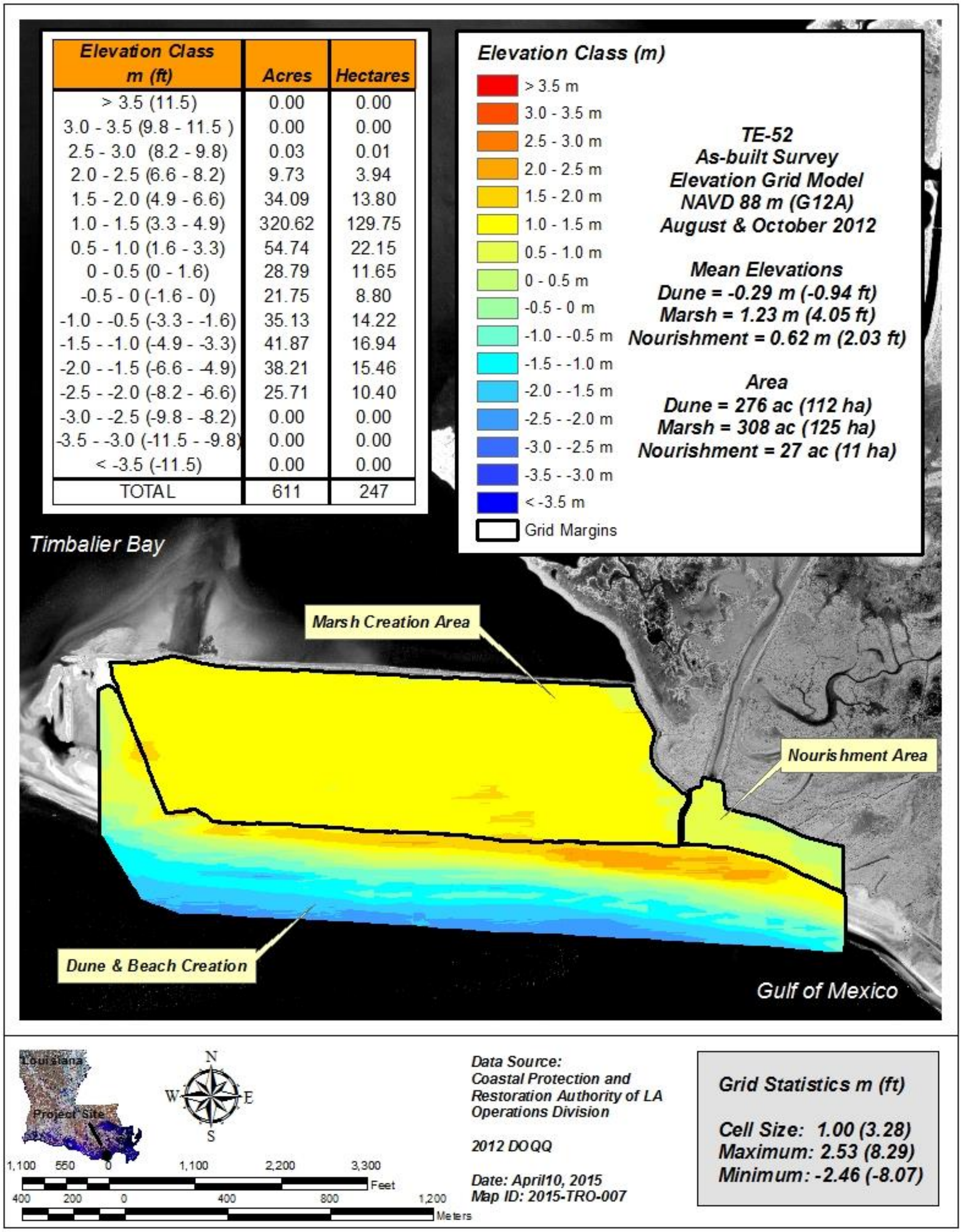


Figure D-2. Pre-construction (Oct 2011) elevation grid model of the beach and dune, marsh creation, and nourishment areas at the West Belle Pass Barrier Headland Restoration (TE-52) project.



Elevation Class m (ft)	Acres	Hectares
> 3.5 (11.5)	0.00	0.00
3.0 - 3.5 (9.8 - 11.5)	0.00	0.00
2.5 - 3.0 (8.2 - 9.8)	0.03	0.01
2.0 - 2.5 (6.6 - 8.2)	9.73	3.94
1.5 - 2.0 (4.9 - 6.6)	34.09	13.80
1.0 - 1.5 (3.3 - 4.9)	320.62	129.75
0.5 - 1.0 (1.6 - 3.3)	54.74	22.15
0 - 0.5 (0 - 1.6)	28.79	11.65
-0.5 - 0 (-1.6 - 0)	21.75	8.80
-1.0 - -0.5 (-3.3 - -1.6)	35.13	14.22
-1.5 - -1.0 (-4.9 - -3.3)	41.87	16.94
-2.0 - -1.5 (-6.6 - -4.9)	38.21	15.46
-2.5 - -2.0 (-8.2 - -6.6)	25.71	10.40
-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	611	247

Figure D-3. **As-built (Oct 2012) elevation grid model of the beach and dune, marsh creation, and nourishment areas at the West Belle Pass Barrier Headland Restoration (TE-52) project.**

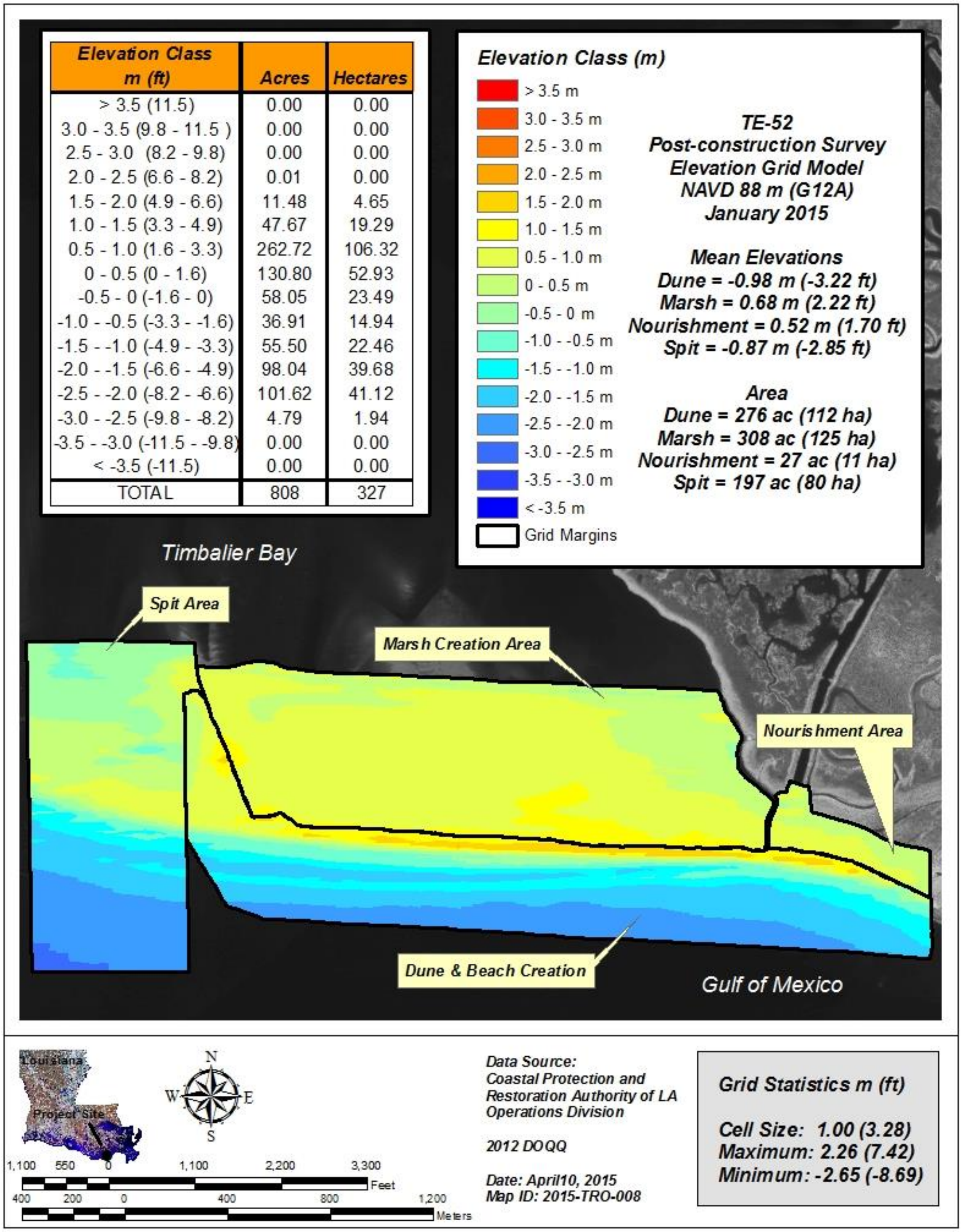
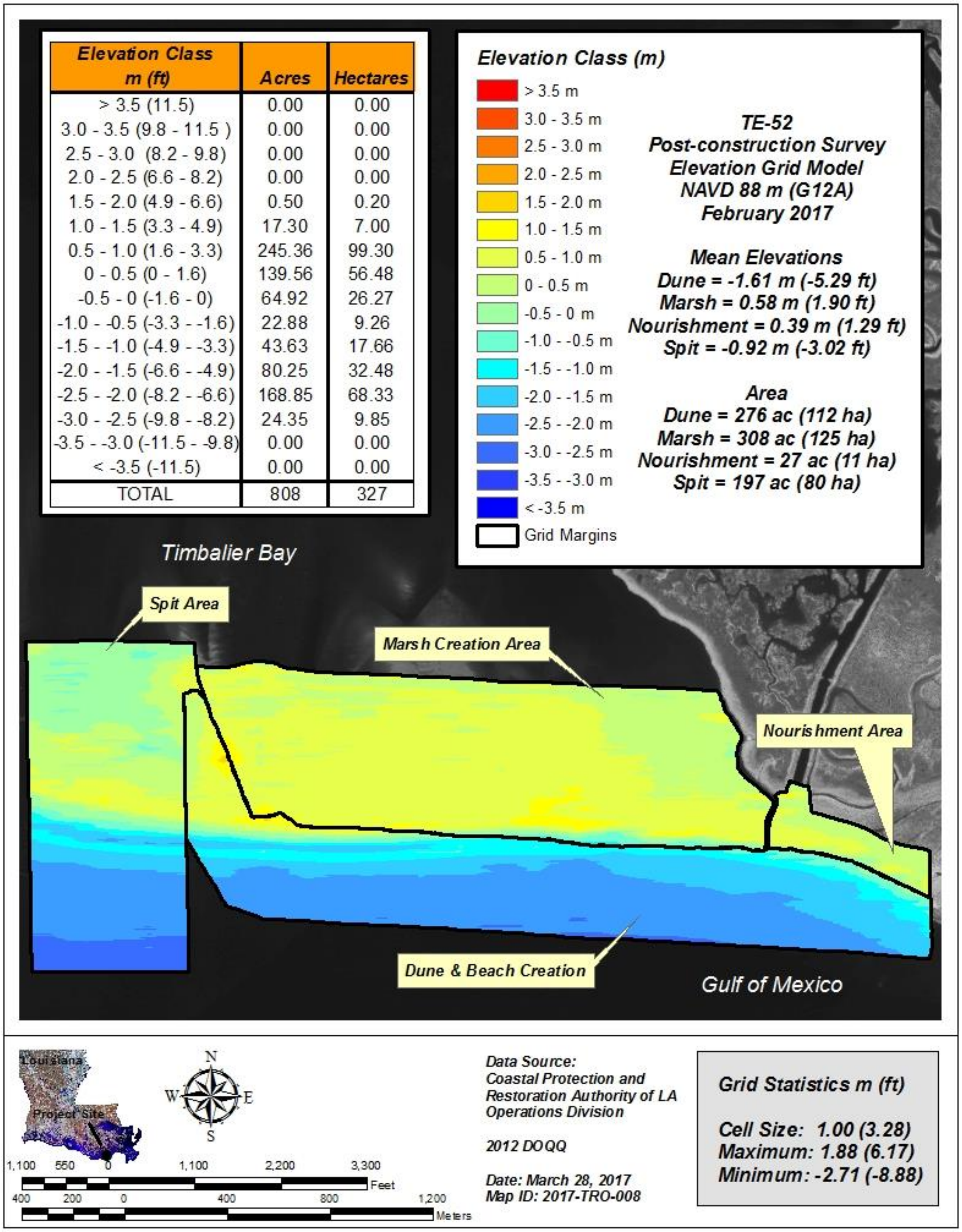
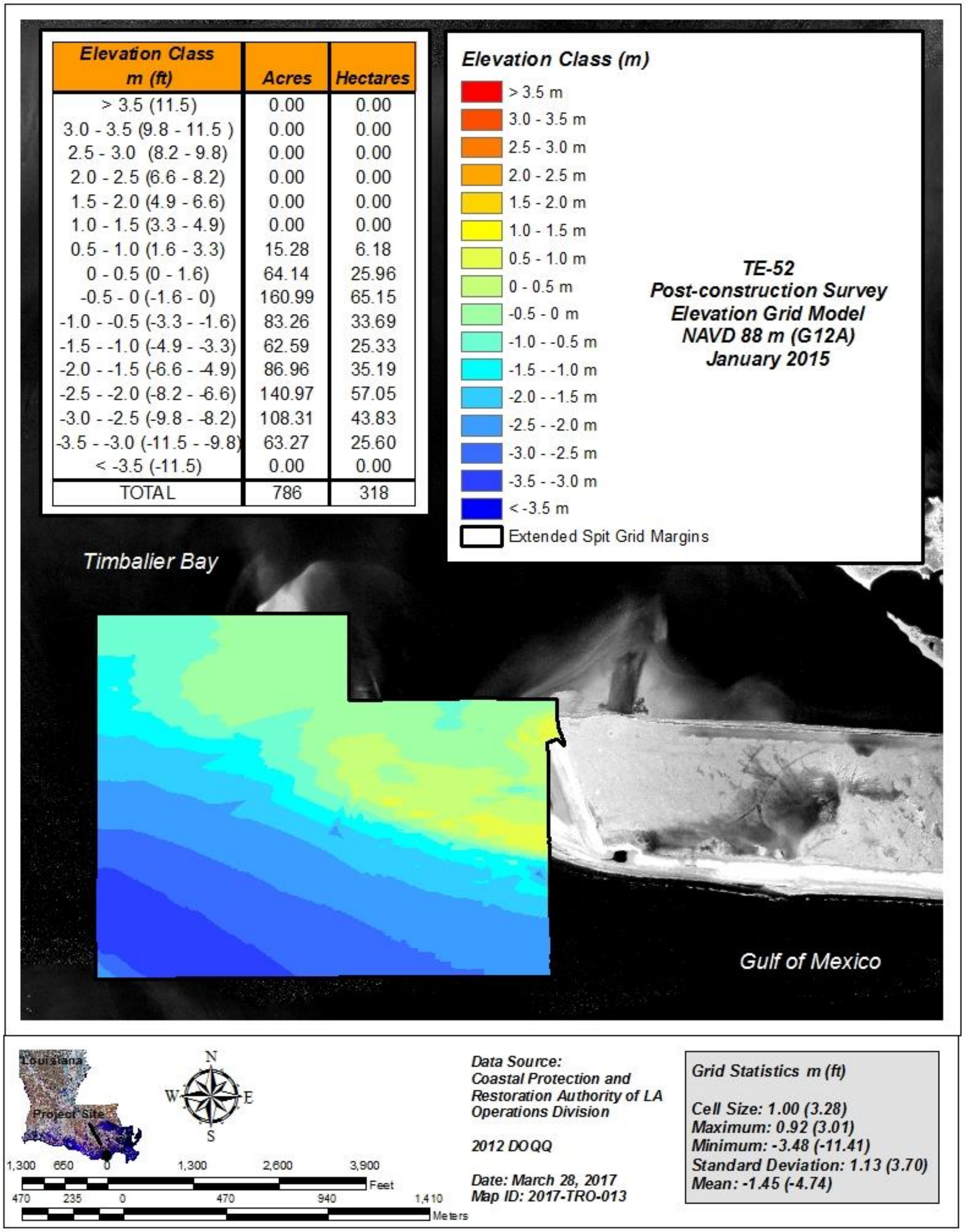


Figure D-4. Post-construction (Jan 2015) elevation grid model of the beach and dune, marsh creation, nourishment, and spit areas at the West Belle Pass Barrier Headland Restoration (TE-52) project.



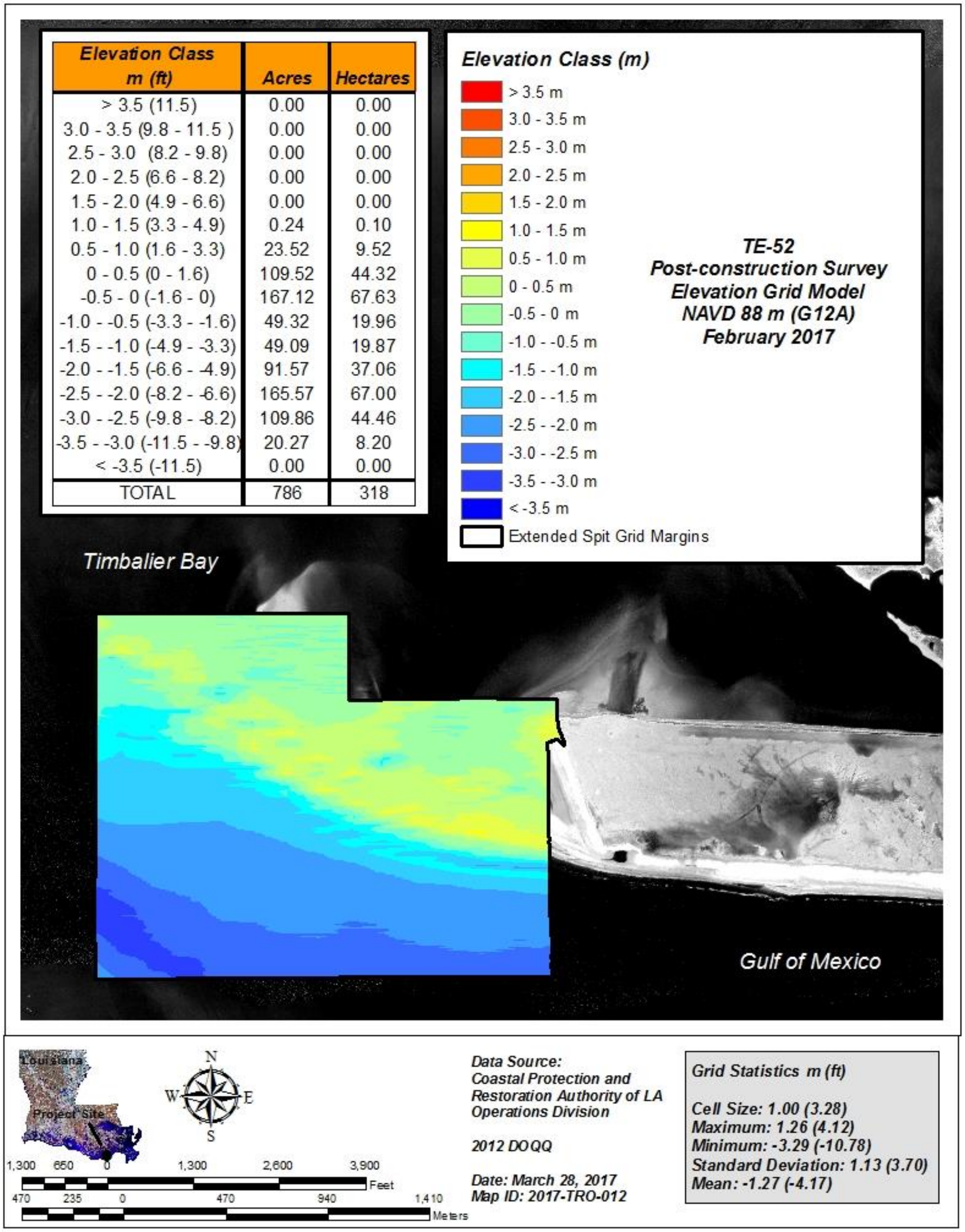
Elevation Class m (ft)	Acres	Hectares
> 3.5 (11.5)	0.00	0.00
3.0 - 3.5 (9.8 - 11.5)	0.00	0.00
2.5 - 3.0 (8.2 - 9.8)	0.00	0.00
2.0 - 2.5 (6.6 - 8.2)	0.00	0.00
1.5 - 2.0 (4.9 - 6.6)	0.50	0.20
1.0 - 1.5 (3.3 - 4.9)	17.30	7.00
0.5 - 1.0 (1.6 - 3.3)	245.36	99.30
0 - 0.5 (0 - 1.6)	139.56	56.48
-0.5 - 0 (-1.6 - 0)	64.92	26.27
-1.0 - -0.5 (-3.3 - -1.6)	22.88	9.26
-1.5 - -1.0 (-4.9 - -3.3)	43.63	17.66
-2.0 - -1.5 (-6.6 - -4.9)	80.25	32.48
-2.5 - -2.0 (-8.2 - -6.6)	168.85	68.33
-3.0 - -2.5 (-9.8 - -8.2)	24.35	9.85
-3.5 - -3.0 (-11.5 - -9.8)	0.00	0.00
< -3.5 (-11.5)	0.00	0.00
TOTAL	808	327

Figure D-5. **Post-construction (Feb 2017) elevation grid model of the beach and dune, marsh creation, nourishment, and spit areas at the West Belle Pass Barrier Headland Restoration (TE-52) project.**



Elevation Class m (ft)	Acres	Hectares
> 3.5 (11.5)	0.00	0.00
3.0 - 3.5 (9.8 - 11.5)	0.00	0.00
2.5 - 3.0 (8.2 - 9.8)	0.00	0.00
2.0 - 2.5 (6.6 - 8.2)	0.00	0.00
1.5 - 2.0 (4.9 - 6.6)	0.00	0.00
1.0 - 1.5 (3.3 - 4.9)	0.00	0.00
0.5 - 1.0 (1.6 - 3.3)	15.28	6.18
0 - 0.5 (0 - 1.6)	64.14	25.96
-0.5 - 0 (-1.6 - 0)	160.99	65.15
-1.0 - -0.5 (-3.3 - -1.6)	83.26	33.69
-1.5 - -1.0 (-4.9 - -3.3)	62.59	25.33
-2.0 - -1.5 (-6.6 - -4.9)	86.96	35.19
-2.5 - -2.0 (-8.2 - -6.6)	140.97	57.05
-3.0 - -2.5 (-9.8 - -8.2)	108.31	43.83
-3.5 - -3.0 (-11.5 - -9.8)	63.27	25.60
< -3.5 (-11.5)	0.00	0.00
TOTAL	786	318

Figure D-6. Post-construction (Jan 2015) elevation grid model of the extended spit area at the West Belle Pass Barrier Headland Restoration (TE-52) project.



Elevation Class m (ft)	Acres	Hectares
> 3.5 (11.5)	0.00	0.00
3.0 - 3.5 (9.8 - 11.5)	0.00	0.00
2.5 - 3.0 (8.2 - 9.8)	0.00	0.00
2.0 - 2.5 (6.6 - 8.2)	0.00	0.00
1.5 - 2.0 (4.9 - 6.6)	0.00	0.00
1.0 - 1.5 (3.3 - 4.9)	0.24	0.10
0.5 - 1.0 (1.6 - 3.3)	23.52	9.52
0 - 0.5 (0 - 1.6)	109.52	44.32
-0.5 - 0 (-1.6 - 0)	167.12	67.63
-1.0 - -0.5 (-3.3 - -1.6)	49.32	19.96
-1.5 - -1.0 (-4.9 - -3.3)	49.09	19.87
-2.0 - -1.5 (-6.6 - -4.9)	91.57	37.06
-2.5 - -2.0 (-8.2 - -6.6)	165.57	67.00
-3.0 - -2.5 (-9.8 - -8.2)	109.86	44.46
-3.5 - -3.0 (-11.5 - -9.8)	20.27	8.20
< -3.5 (-11.5)	0.00	0.00
TOTAL	786	318

Figure D-7. Post-construction (Feb 2017) elevation grid model of the extended spit area at the West Belle Pass Barrier Headland Restoration (TE-52) project.

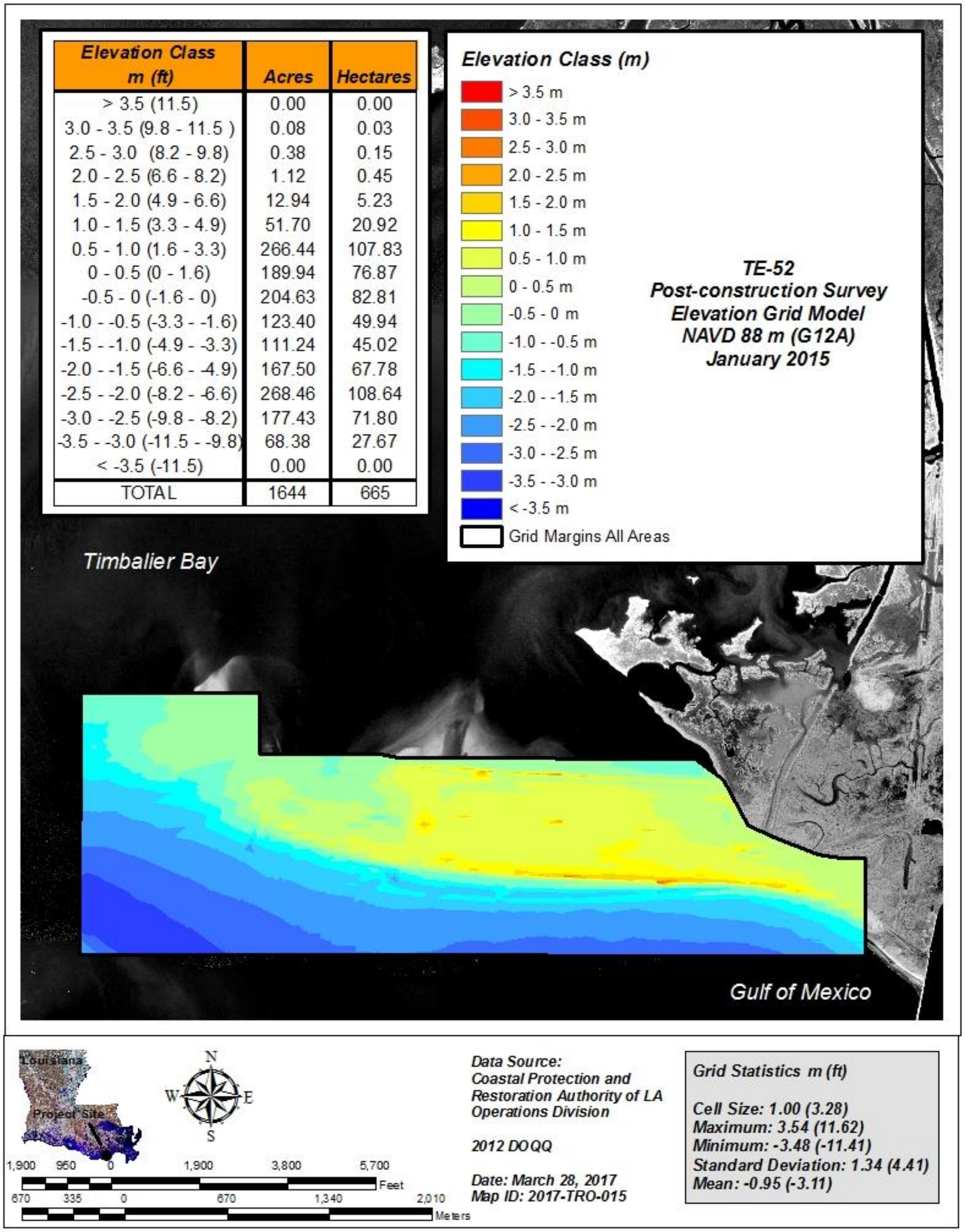
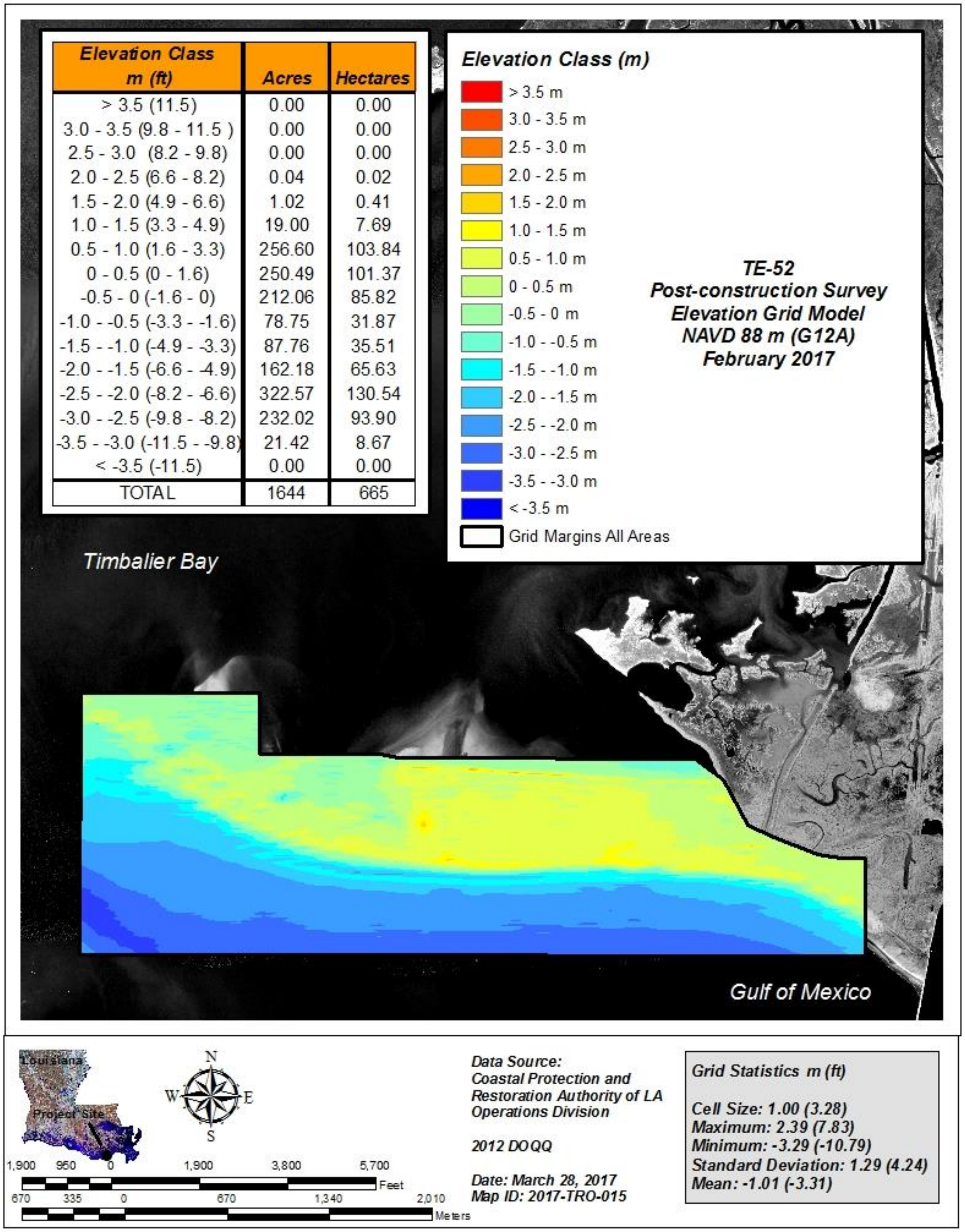


Figure D-8. **Post-construction (Jan 2015) elevation grid model of the beach and dune, marsh creation, nourishment, and extended spit areas at the West Belle Pass Barrier Headland Restoration (TE-52) project.**



Elevation Class m (ft)	Acres	Hectares
> 3.5 (11.5)	0.00	0.00
3.0 - 3.5 (9.8 - 11.5)	0.00	0.00
2.5 - 3.0 (8.2 - 9.8)	0.00	0.00
2.0 - 2.5 (6.6 - 8.2)	0.04	0.02
1.5 - 2.0 (4.9 - 6.6)	1.02	0.41
1.0 - 1.5 (3.3 - 4.9)	19.00	7.69
0.5 - 1.0 (1.6 - 3.3)	256.60	103.84
0 - 0.5 (0 - 1.6)	250.49	101.37
-0.5 - 0 (-1.6 - 0)	212.06	85.82
-1.0 - -0.5 (-3.3 - -1.6)	78.75	31.87
-1.5 - -1.0 (-4.9 - -3.3)	87.76	35.51
-2.0 - -1.5 (-6.6 - -4.9)	162.18	65.63
-2.5 - -2.0 (-8.2 - -6.6)	322.57	130.54
-3.0 - -2.5 (-9.8 - -8.2)	232.02	93.90
-3.5 - -3.0 (-11.5 - -9.8)	21.42	8.67
< -3.5 (-11.5)	0.00	0.00
TOTAL	1644	665

Figure D-9. Post-construction (Feb 2017) elevation grid model of the beach and dune, marsh creation, nourishment, and extended spit areas at the West Belle Pass Barrier Headland Restoration (TE-52) project.

Appendix E
(Shoreline Change Graphics)

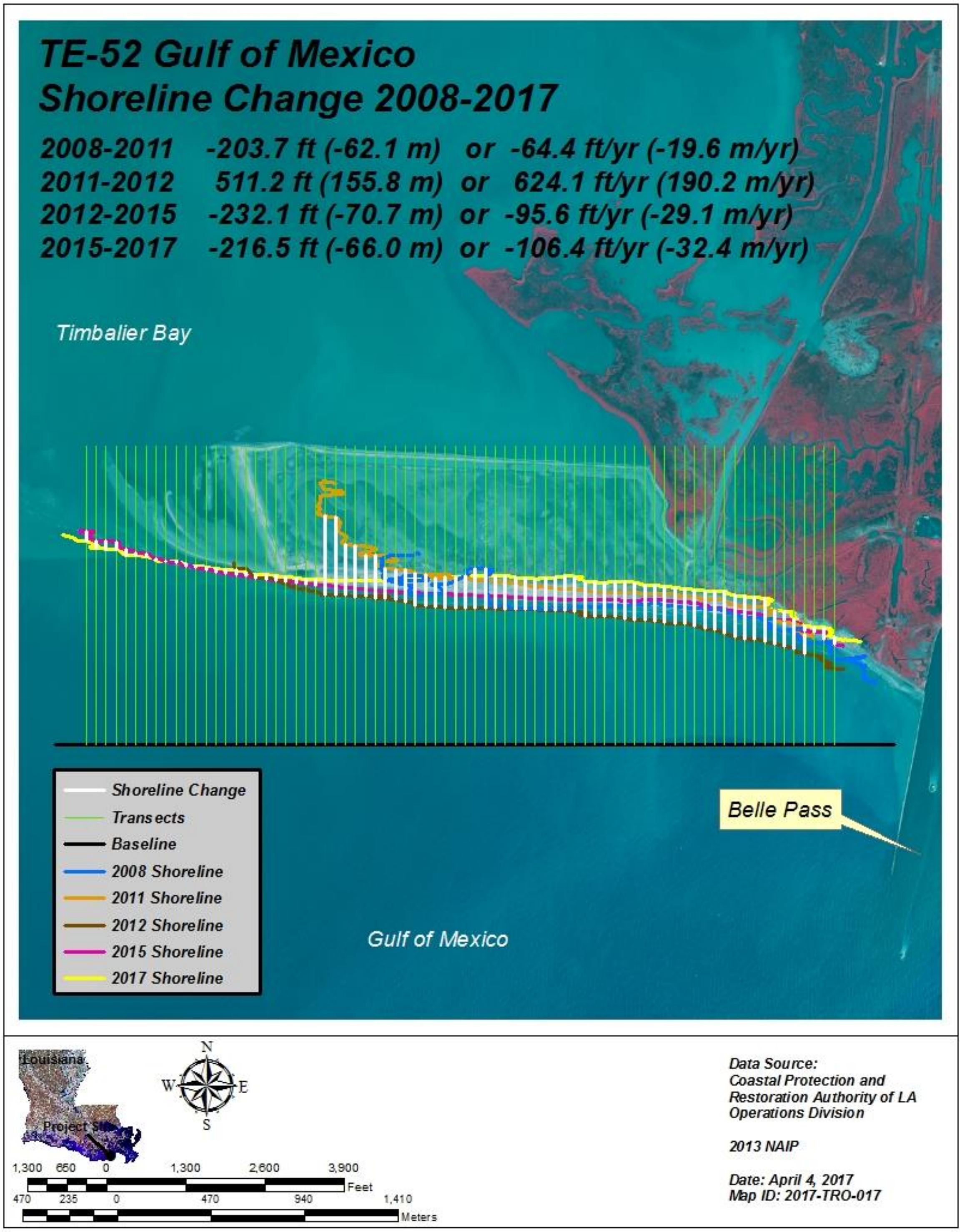


Figure E-1. **Shoreline change and zero meter contour lines used to delineate the shoreline position of the beach and dune area in Aug 2008, Oct 2011, Oct 2012, Jan 2015, and Feb 2017 at the West Belle Pass Barrier Headland Restoration (TE-52) project.**