Coastal Protection and Restoration Authority of Louisiana

2020
Monitoring Close-out Report

for

Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24) and New Cut Dune and Marsh Restoration (TE-37) Projects

State Project Number TE-20, TE-24, and TE-37
Priority Project List 1, 2, and 9

September 1, 2020

Terrebonne Parish

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Suggested Citation:

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

Executive Summary

Prior to the hurricane of August 10, 1856, Isle Derniere was a single barrier island arc formed during the abandonment of the Caillou headland which was part of the Early Lafourche Delta complex. Since the hurricane of August 10, 1856, the Isle Derniere has become the Isles Dernieres and is composed of what is today known as Raccoon Island, Whiskey Island, Trinity/East Island with some publications including Wine Island. Prior to 2005, Trinity/East Island was considered two separate islands.

As part of the Coastal Wetland Planning Protection and Restoration Act, three barrier island projects were constructed on the Isles Dernieres. These projects included the Isles Dernieres Restoration East Island (TE-20) project, the Isles Dernieres Restoration Trinity Island (TE-24) project, and the New Cut Dune and Marsh Restoration (TE-37) project. The TE-20 and TE-24 projects were constructed in 1998 while the TE-37 project was constructed in 2007 using sediment dredged from nearby borrow sources and carried to the project locations via pipelines. The impetus for the TE-20 and TE-24 projects is attributed to projections that between 2007 and 2019 they were projected to become subaqueous shoals which would no longer provide subaerial habitat nor provide the same crucial benefits of protecting inland marshes.

Through data collected by these projects and other State programs, data were evaluated to document the status of the three projects' as of 2016. Data was evaluated to determine land area, width, and length changes; elevation changes; sediment volume changes; habitat changes; vegetation changes; and sediment property changes.

Since the addition of sediment to the TE-20 and TE-24 project areas in 1998, aerial images in subsequent years show the migration of the two islands towards each other. By 2005, habitat mapping shows the area between the islands as supratidal and by the time of the TE-37 project construction in 2007, the elevation was raised such that the areas were then classified as dune. Hence, the reference to Trinity and East Islands has become Trinity/East Island.

Data from 2016 used in this report indicates there was still 636.1 acres of land, of which 163.3 acres (26%) was classified as dune through habitat mapping. More importantly, new calculations extend the time of this island becoming subaqueous until approximately 2061. With another restoration project currently in construction, the life expectancy of Trinity/East Island may be extended even further into the future.

These three projects have had dramatic effects on these two islands of the Isles Dernieres such that the two islands are now considered one. It is still subaerial, and its life expectancy is some forty plus years in the future. These projects have provided benefits to the citizens of Louisiana by extending various ecosystem services including but not limited to storm impact reductions and providing habitat for fish and wildlife.

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Chapter 1 – Historical and Project Background

Historical Background

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

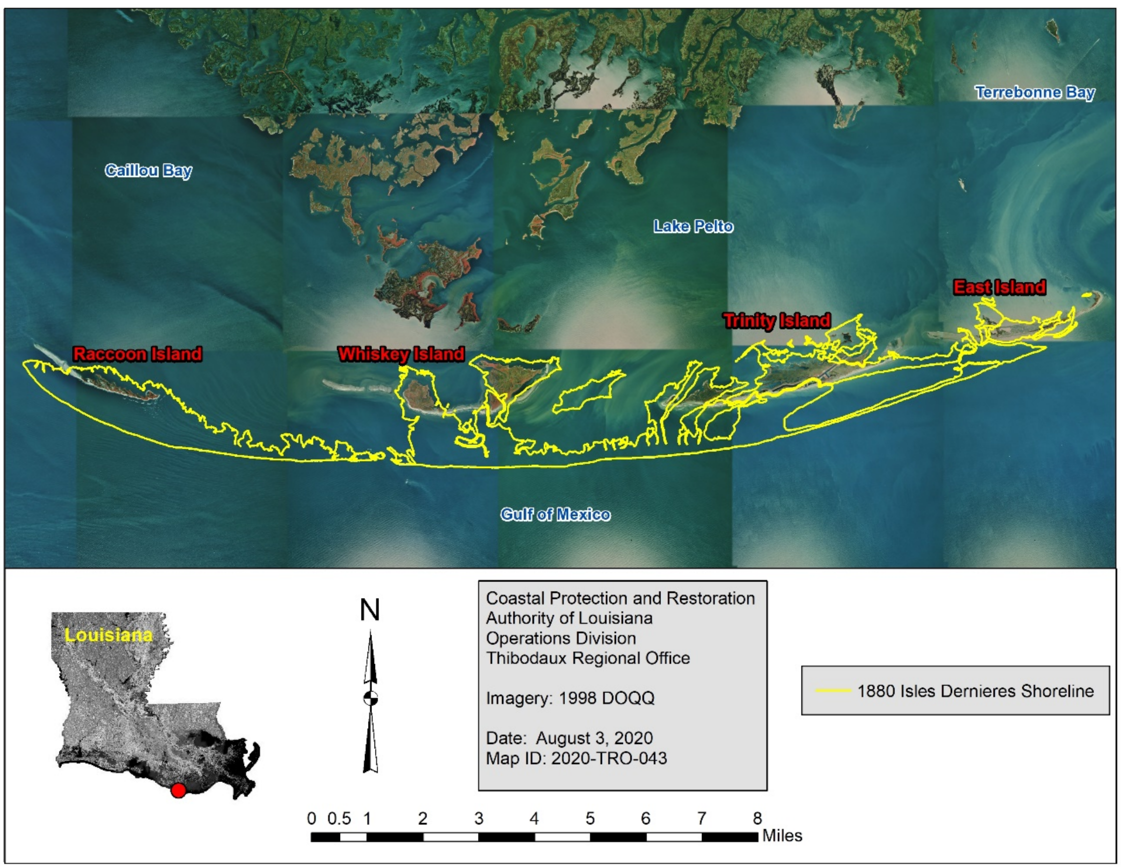

Figure 1. Isle Derniere 1880s shoreline position (Byrnes et al 2018).

On August 10, 1856, a hurricane impacted the Isle Derniere with such force that the island was split in half. Since this hurricane, the area continued to be affected by tropical cyclones and other natural and anthropogenic disturbances such that the Isle Derniere was eventually segmented into four islands: Raccoon Island, Whiskey Island, Trinity Island, and East Island (McBride et al. 1989) (figure 1). Like all of Louisiana's barrier islands, these islands are experiencing narrowing and land loss as a consequence of a complex interaction among global sea level rise, subsidence, wave and storm processes, inadequate sediment supply, and significant anthropogenic disturbances (Penland et al. 1988, McBride et al. 1989, Penland and Ramsey 1990, List et al. 1997). This report focuses on the restoration efforts associated with the portion of the Isles Dernieres known as Trinity and East Islands and the region between them referred to as Trinity/East Island.

Numerous studies have documented land loss and shoreline erosion trends in this area. McBride et al. (1989) reported land loss rates in the Isles Dernieres as a whole that approached 69.6 ac/yr between 1887 and 1988, and Byrnes et al. (2018) documented shoreline erosion rates from 1880s through 2015 at both the Trinity and East island reaches at 35.4 and 26.8 ft/yr, respectively. Between 1978 and 1988, shoreline erosion was reported as high as 116.6 ft/yr by McBride et al. (1989). These conditions have led to the rapid landward migration, termed barrier island rollover, and disintegration of the Isles Dernieres as well as a decrease in the ability of the island chain to protect the adjacent mainland marshes and wetlands from the effects of storm surge, saltwater intrusion, increased tidal prism, and energetic storm waves (McBride and Byrnes 1997). Erosional models have estimated that the Isles Dernieres would gradually narrow, fragment, and transgress through time eventually becoming subaqueous sand shoals. Estimates, including data developed by the State's Barrier Island Comprehensive Monitoring (BICM) program, estimate Isles Dernieres disappearance between 2007 (McBride et al. 1991) and 2019 (Penland et al. 1988) unless restoration efforts were made.

In an effort to combat the natural and anthropogenic processes causing the islands to potentially become shoals, the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA, Public Law 101-646, Title III) has constructed three (3) projects: the Isles Dernieres Restoration East Island (TE-20) project which is a Project Priority List (PPL) 1 project, the Isles Dernieres Restoration Trinity Island (TE-24) which is a PPL 2 project, and the New Cut Dune and Marsh Restoration (TE-37) which is a PPL 9 project. All three CWPPRA projects are sponsored by the U.S. Environmental Protection Agency (EPA) in conjunction with the former Louisiana Department of Natural Resources, Coastal Restoration Division, currently the Coastal Protection and Restoration Authority (CPRA) of Louisiana.

Project Background

The Isles Dernieres Restoration East Island (TE-20) project was approved for engineering and design and construction by the CWPPRA Task Force on October 31, 1991. The project is located geographically at 29º 03' 41" N, 90º 39' 35" W (figure 2). The goals of the project were to restore coastal dunes, reduce the loss of sediment, and enhance the stability of the islands, through an increase in the elevation and width of the island and subsequent vegetative planting. Upon completion of the sediment deposition portion in October 1998, approximately 3.935 million cubic yards (MCY) of sediment was dredged from a borrow area just north of the east side of the island (T. Baker Smith & Sons, Inc. 1998). The sediment created approximately 242 ac of dunes and wetlands including supratidal (beach, dune, barrier flat), and intertidal (beach and marsh) habitat.

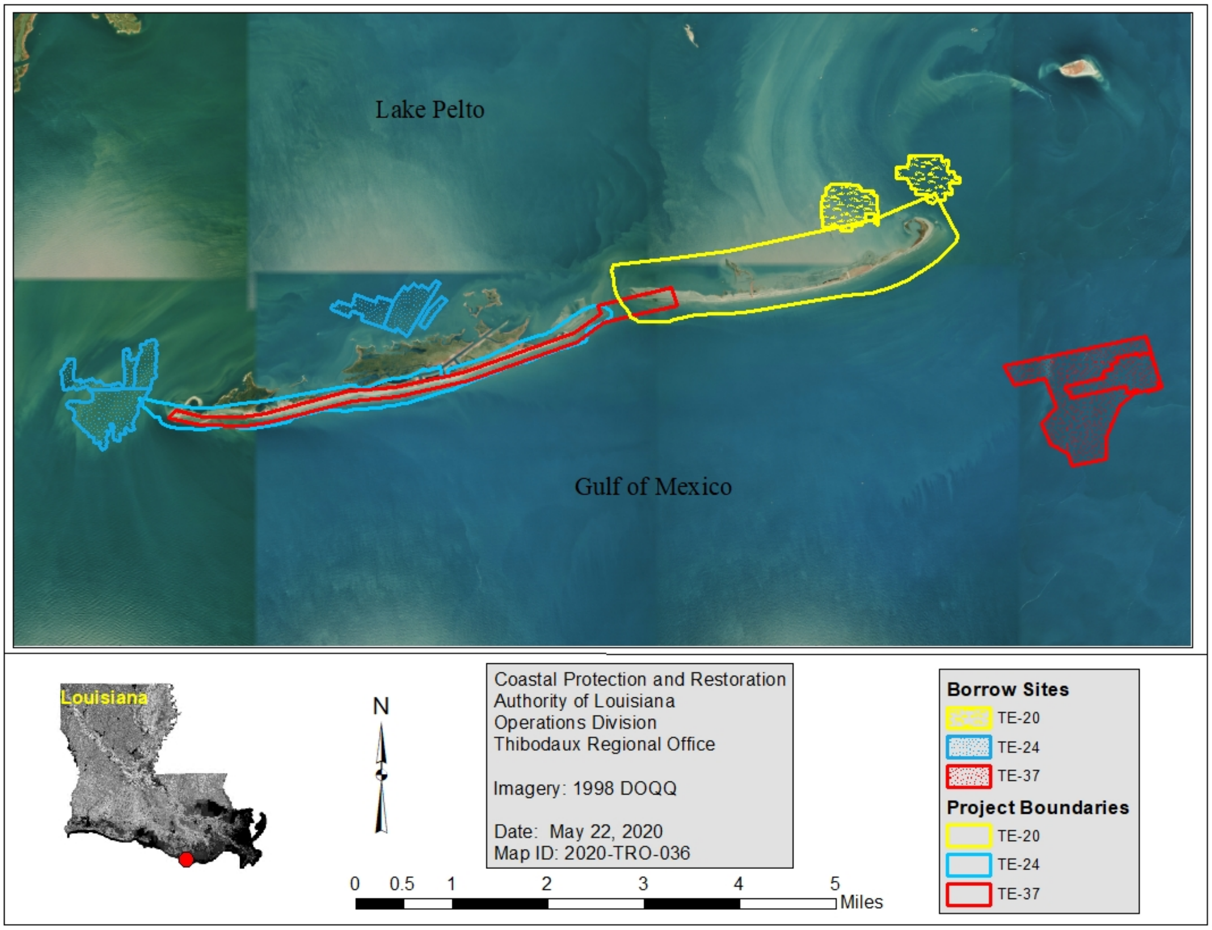

Figure 2. Location and project boundaries for the Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24), and the New Cut Dune and Marsh Restoration (TE-37).

The target elevations ranged from +3 ft to +8 ft National Geodetic Vertical Datum of 1929 (NGVD29) (T. Baker Smith & Sons, Inc. and Coastal Engineering and Environmental Consultants, Inc. 1994). As part of initial construction, approximately 17,500 ft of sand fencing was installed across the width of the island in a southwest to northeast direction. Immediately post-dredging, *Cynodon dactylon* (Bermuda grass) was planted via aerial seeding. In May and June 1999, a planting effort was conducted to stabilize the newly placed sediment. A total of 12,075 *Spartina alterniflora* (smooth cordgrass), 5,431 *Spartina patens* (marshhay cordgrass), and 5,431 *Panicum amarum* (bitter panicum) plants were installed. These plants were installed in the dune area, in the back-bay area, and on spurs from the dune area across the island near the sand fencing.

The Isles Dernieres Restoration Trinity Island (TE-24) project was approved for engineering and design and construction by the CWPPRA Task Force on October 19, 1992. The project is located geographically at 29° 02' 46" N, 90° 43' 48" W (figure 2). The goals of the project were to restore coastal dunes, reduce the loss of sediment, and enhance the stability of the islands, through an increase in the elevation and width of the island and subsequent vegetative planting. Upon completion of the project in May 1999, approximately 4.85 MCY of sediment was dredged from a borrow area in Whiskey Pass (T. Baker Smith & Sons, Inc. 1998). The sediment created approximately 353 ac of dunes and wetlands including supratidal (beach, dune, barrier flat), and intertidal (beach and marsh) habitat. The dune/berm, dune, and marsh platform extended the entire length of the island which was approximately 23,000 ft. The target elevations ranged from +3 ft to +8 ft NGVD29 (T. Baker Smith & Sons, Inc. and Coastal Engineering and Environmental Consultants, Inc. 1994). As part of initial construction, approximately 22,500 ft of sand fencing was installed on the gulf side of the dune. Immediately post-dredging, *Cynodon dactylon* (Bermuda grass) was planted via aerial seeding. In May 1999, a planting effort was conducted to stabilize the newly placed sediment. A total of 8,348 *Spartina alterniflora* (smooth cordgrass), 10,579 *Spartina patens* (marshhay cordgrass), and 10,579 *Panicum amarum* (bitter panicum) plants were installed. These plants were installed in the dune area, in the back-bay area, and on spurs from the dune area across the island near the sand fencing.

The New Cut Dune and Marsh Restoration (TE-37) project was approved for engineering and design by the CWPPRA Task Force on January 11, 2000 and for construction by the CWPPRA Task Force on January 10, 2001. The project overlaps the western edge of TE-20 and the southern and eastern edges of the TE-24 project (figure 2). New Cut was formed in 1974 when the eastern end of Trinity Island was breached during Hurricane Carmen, forming Trinity and East Islands. The breach was further widened by Hurricane Juan in 1985 and Hurricane Andrew in 1993 (Design Report 2005). The goals of the project were to close the breach between Trinity and East Islands through the direct creation of beach, dune, and marsh habitat. The project would also lengthen the structural integrity of the western Isles Dernieres by restoring the littoral drift (i.e., material transported by the longshore current) and adding sediment into the nearshore system (Design Report 2005). Upon completion of the project in July 2007, 1.00 MCY of sediment was placed on the island from a borrow area located about three (3) miles south of Wine Island in South Timbalier Blocks 9 and 10 (T. Baker Smith, Inc. 2007). The sediment created approximately 8,300 linear ft of dune and nourished approximately 248 ac of beach / island area (T. Baker Smith, Inc. 2007). The target elevations ranged from +2 ft to +8 ft, NAVD88. As part of construction, approximately 17,050 ft of sand fencing was installed on the gulf side of the dune. Immediately post-dredging, *Cynodon dactylon* (Bermuda grass) was planted via seeding.

As part of the CWPPRA program, an Operation and Maintenance (O&M) Plan and a Monitoring Plan are developed for each project if funds are allocated. The O&M Plan for barrier island projects provides guidance for activities such as sand fencing repairs and initial or supplemental vegetative plantings. Monitoring plans are developed prior to project construction. The monitoring plan outlines the goals and objectives for the project and how data will be collected to assess project performance. Both plans are written to provide guidance on the timing of these activities throughout the project's twenty (20) year life. There were no O&M Plans developed for the TE-20 and TE-24 projects; however, there was an O&M Plan developed for the TE-37 project (CPRA 2017). This 2020 report does not focus on the O&M activities of the project because there have not been any repairs or O&M events. A monitoring plan was developed for each of the three projects that established goals and objectives for the performance of the project throughout its 20-year life. All monitoring and O&M plans can be found in the document library on CPRA's Coastal Information Management System (CIMS) database:
https://cims.coastal.louisiana.gov/Default.aspx.

This 2020 monitoring report serves as the close-out report for all three projects (TE-20, TE-24, TE-37). Although the TE-37 project has not reached its end of life (20 years), the monitoring plan included the final report for the project when the TE-20 and TE-24 reached their end of life (20 years).

Chapter 2 – Project Goals and Objectives

Since the TE-20 and TE-24 projects were approved one year apart and were constructed at the same time, both projects share the same objectives which were (1) to restore the coastal dunes of the Eastern Isles Dernieres and (2) to reduce loss of sediment and to enhance the physical stability of East and Trinity Island using hand-planted vegetation (Townson 1998a and 1998b). The TE-37 project was approved eight years later and had a project goal to close New Cut (the pass between Trinity Island and East Island) using dredged material and to restore intertidal and supra-tidal habitats similar to those restored on Trinity and East Islands (Hubbell 2001).

The project objectives outlined to accomplish the goals for TE-20 and TE-24 were stated to (1) increase the height and width of East and Trinity Islands and close breaches using dredged sediments and (2) reduce loss of sediment through vegetative plantings increasing the stability of the island. The stated TE-37 goals were to (1) create approximately 261 acres of island, with intertidal and supratidal habitats using sediments dredged from Wine Island Pass, (2) establish and stabilize a primary dune system several hundred feet seaward of the dune platform using sand fencing, (3) stabilize dune platform using sand fencing and vegetation plantings, (4) establish vegetation cover of planted species along the newly constructed marsh platform as well as the dune platform and primary dune system; and (5) contribute to the restoration of the littoral drift system along the eastern Isle Dernieres.

The goals and objectives outlined in the monitoring plans are not well defined and difficult to measure. Statements such as "island stability", "reduced loss of sediment", and even "create 261 ac" have no defined amount or time frame referenced. For example, are the 261 ac to be created at TE-37 expected immediately or at the end of the 20 yr project life. Some objectives such as increased heights and widths could be implicitly evaluated, but other statements need more specificity. This lack of specificity in the project goals means that goal accomplishments are evaluated based on changes in trends (shoreline erosion and land loss rates post-restoration), and the success of the projects based on the land area change data predicting East and Trinity Islands would be completely subaqueous in 2011.

Chapter 3 – Project Performance

Data analysis for this report used project specific collected data and products from the Barrier Island Comprehensive Monitoring (BICM) program (Kindinger et al. 2013) administered by the Coastal Protection and Restoration Authority (CPRA) of Louisiana. The BICM program encompasses a wide variety of datasets and analysis that include: 1) shoreline assessment photography and period comparisons, 2) coast-wide shoreline delineation and change analysis, 3) topography data and elevation change, 4) bathymetry data and elevation change, 5) habitat delineation with habitat and land/water changes, and 6) surficial sediment composition and change. In order to develop data sets prior to CWPPRA, BICM has assembled and formatted older data sets. One goal of the BICM program is to aggregate and standardize data sets for comparability over time. The results of each BICM variable used to assess the success of the project(s) appears in subsequent sections. More detail concerning data analysis methodologies and specific time interval changes can be found in Appendices A through F.

Land Area Change

The land loss rate experienced prior to restoration (1978 – 1998) continued after restoration (1998 – 2016); however, the loss rate dropped from 54 ac/yr to 14 ac/yr. This reduction in the land areas change rate occurred at a time when tropical storms and hurricanes within 150 nautical miles of the center of Isles Dernieres averaged 9.4 per decade. This is higher than the 6.7 storms per decade during the pre-restoration epoch of 1978 – 1998 (NOAA 2019). Considering the importance of storms on barrier island land loss, a reduced rate during a period of higher-than-average tropical weather activity indicates that the projects have contributed significantly to stabilizing/maintaining the islands.

Land area trends shown in figure 3 indicate the significant contribution of the TE-20 and TE-24 projects to land gains. The immediate pre-restoration land area in 1998 totaled 729 ac and by May 2002 there was a 50% increase in land area to 1091 ac. Both of these projects contributed differently to this increase in land area. The TE-20 project increased the land area of East Island from 193 ac in 1998 to 380 ac in May 2002. This is a 97% increase in the land area of East Island, with some land loss likely occurring between construction in late 1998 and May 2002. During this same time frame, the TE-24 project increased the land area of Trinity Island by 93 ac, or 15%. Penland et al. (2003) attributed the differences to pre-restoration island configurations. The approach of placing fill material behind the existing beach was similar at both sites, but the TE-20 fill area was mostly in shallow open water, while a large portion of the fill material for the TE-24 project was placed on existing Trinity Island land area (figure 4).

Land area trends shown in figure 3 do not show a direct impact of the 1 MCY of fill material added to the island by the TE-37 project constructed in 2007. A project goal of TE-37 was to create 261 ac of island. When the project was approved for design in 2000 the fill area was predominately water, but the 2005 BICM habitat data, which was 2 years prior to construction in 2007, classified the area as land (figure 5). Although the project did not contribute to the creation of land, it did increase the existing land elevation from an intertidal habitat to beach habitat (figure 5).

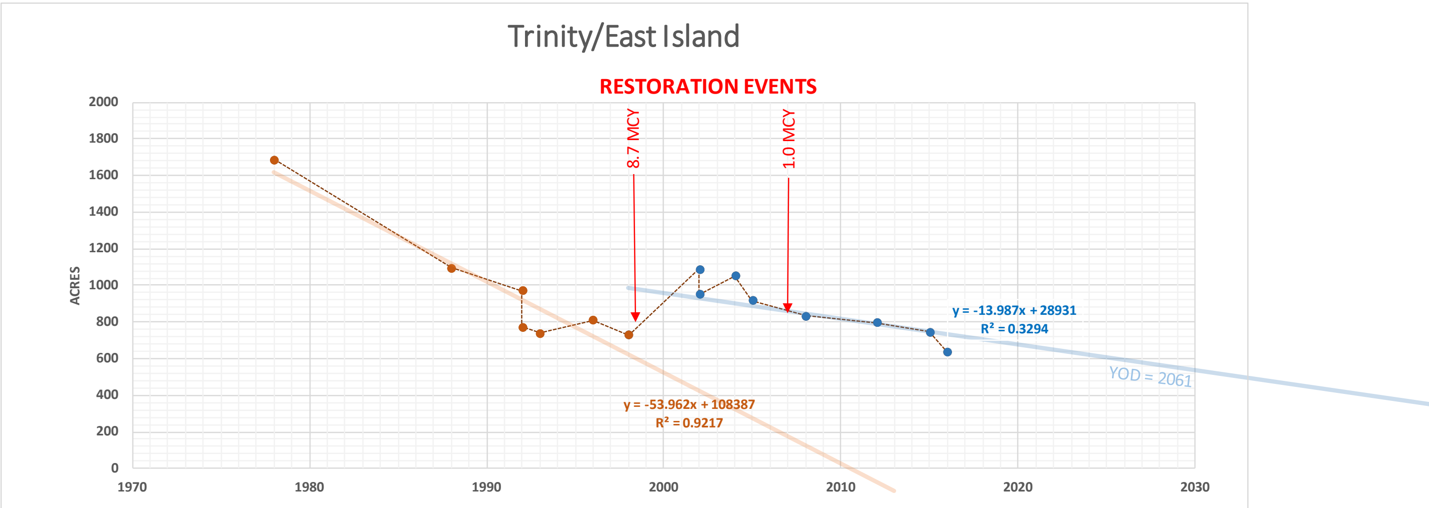

Figure 3. Land area changes from 1978 through 2016 at Trinity/East Island, Isles Dernieres, Terrebonne Parish, LA.

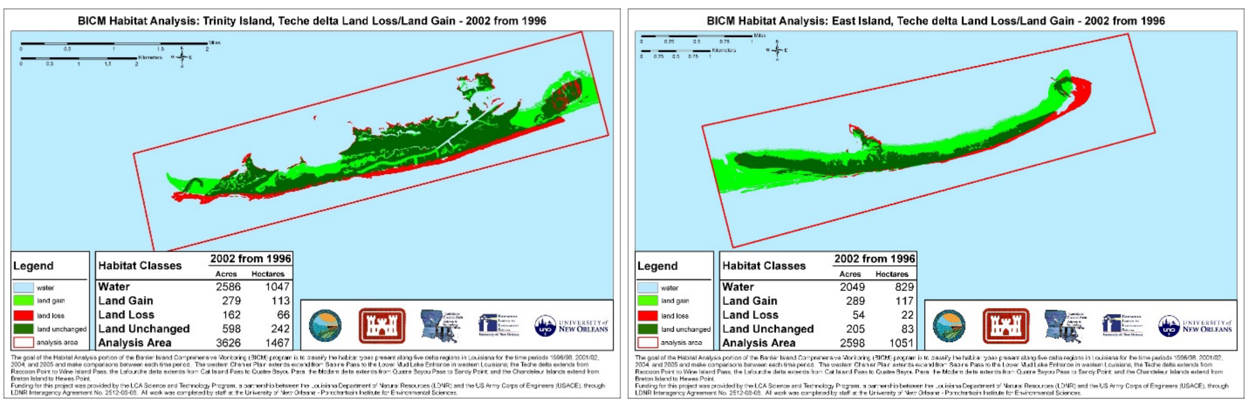

Figure 4. Land area change at Trinity and East Islands from December 1996 to November 2002 (from Martinez et al. 2009). Note the large areas of gain on the north side of East Island as opposed to Trinity Island where more land already existed and was covered with sediments as noted in Penland et al. (2003).

While it is impossible to state the specific contribution of the TE-37 project to the overall reduction in land loss rates and the maintenance of 636 ac on East/Trinity Island in 2016, the project must be acknowledged as a contributor to maintaining the land area noted previously. From 2005 to 2016 the island lost 283 ac (approximately 26 ac per year). Even this slightly higher land loss rate during the later portion of the post-restoration epoch is a reduction of 48% from the pre-restoration epoch. This period included major storm events such as Hurricanes Gustav (2008), Ike (2008), and Isaac (2012).

The land area change data shows that the three projects can be considered successful because there was 636 ac of land in 2016 when data sources indicated that this area would be subaqueous in 2011 without restoration. It is now predicted that the Trinity/East Island will not become subaqueous until 2061 because of the addition of sediment from the three CWPPRA projects.

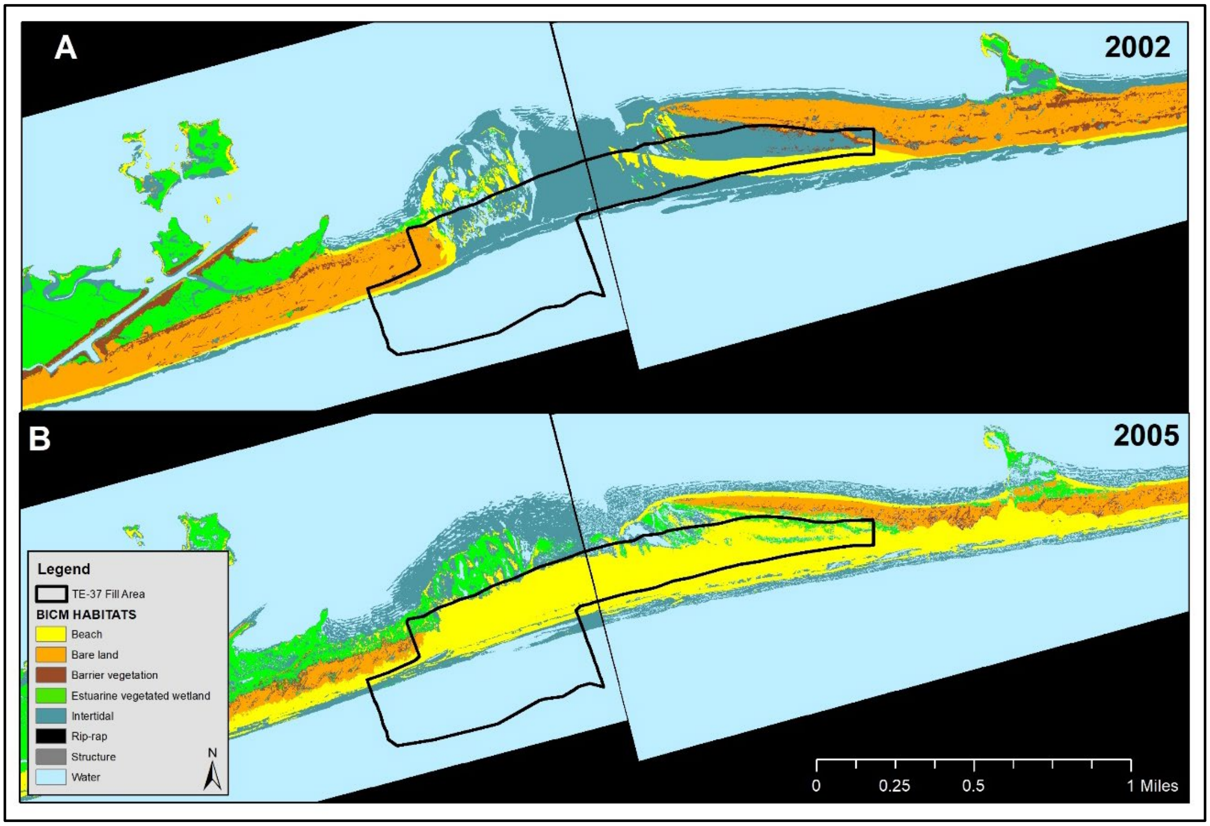

Figure 5. BICM habitat data in 2002 (A) and 2005 (B) indicating the conversion of water to land prior to the TE-37 project in 2007. The TE-37 fill area (outlined in black) in overlain to show the area the project will impact.

Island Change: Shoreline, Length, and Width

After restoration efforts at Trinity/East Island, the 1998 to 2015 period exhibited a 35.6 ft/yr shoreline erosion rate compared to an average of 34.3 ft/yr for the 1950s-1998 period (Table 1). The lack of change in the Trinity/East Island shoreline erosion rate post-restoration may indicate that the processes associated with shoreline erosion have not been dramatically altered by these projects. However, it should also be noted that a higher than average number of storms occurred during the 1998 to 2015 period (Appendix A), and this may negate potential restoration effects on shorelines positions. These projects were early designs which placed the sediment behind the existing shoreline (figure 6). This design does not move the shoreline gulfward as later designs have done, thereby leaving shoreline positions unaffected initially and therefore does not directly affect change rates.

Examining the data by island, Trinity Island's erosion rate declined post-restoration to 34.0 ft/yr from 43.0 ft/yr while East Island's erosion rate almost doubled from 24.2 ft/yr pre-restoration to 42.8 ft/yr post-restoration. The reduction of the erosion rate in the Trinity Island reach, with a corresponding increase in the East Island reaches erosion rate, supports the sediment budget research indicating sediments transported along shore from the East Island reach is helping to maintain the Trinity reach shoreline (Applied Coastal Research and Engineering, 2020) (figure 7).

Table 1. Shoreline position changes during various periods at Trinity/East Island, Isles Dernieres, Terrebonne Parish, LA.

Epoch	Change Rate (ft/yr)	Standard Deviation (ft)
1950s to 1998 (PREConstruction)	-34.3	15.5
1998 to 2015 (POSTconstruction)	-35.6	47.9
1998 to 2004	-30.4	18.7
2004 to 2008	-35.5	33.1
2008 to 2015	-26.1	60.8
2012 to 2015	-10.6	21.5

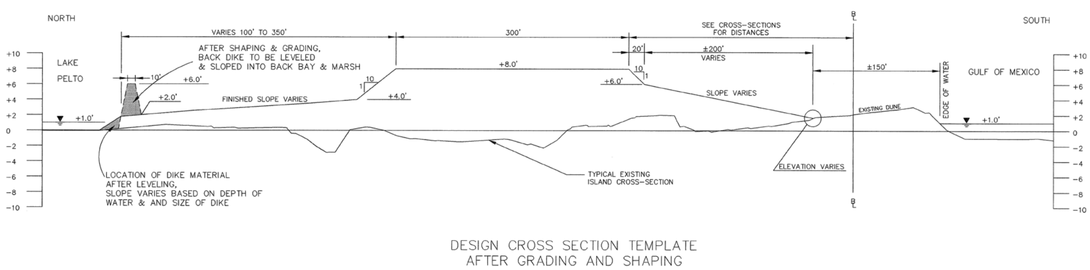

Figure 6. Typical construction template cross section at TE-24 showing the fill placement behind the existing shoreline.

Trinity/East Island exhibited a reduction in length during the pre- and post-restoration periods (figure 8). In 1978, the length of Trinity/East totaled approximately 45,275 ft, but by 1998 was reduced to 39,206 ft; a loss of approximately 303 ft/yr. After restoration, the island continued to exhibit a reduction in length and by 2016 was reduced to approximately 35,925 feet in length; a loss of approximately a 182 ft/yr. The eastern end of the island is the area showing the greatest reduction in length as approximately 9,678 ft of the former East Island land area has completely eroded.

This increased rate of reduction in island length during the 18-years after restoration may indicate that these projects are not counteracting the impacts of system drivers, such as an increasing tidal prism, that affect island length and fragmentation. The continuing wetland loss within the back barrier bays is not being addressed sufficiently, and as such resulting in more and or larger tidal cross sections. This process is documented to impact island length and other shoreline processes (FitzGerald 1984, FitzGerald et al. 1984, FitzGerald et al. 2003).

The period from 1998 to 2004 exhibited increases in island length due to longshore transport processes as the New Cut area was filled with transported sediment. The total lengths increased from approximately 39,206 ft to 43,471 ft during this period, completely closing the New Cut breach by 2005 as the shoreline continued to build in this area. After 2005, the island was reduced in length again until the second period of island lengthening occurred from 2012 to 2015. During this time the island increased 3,117 feet in length due to an accretion of the terminal spits on each

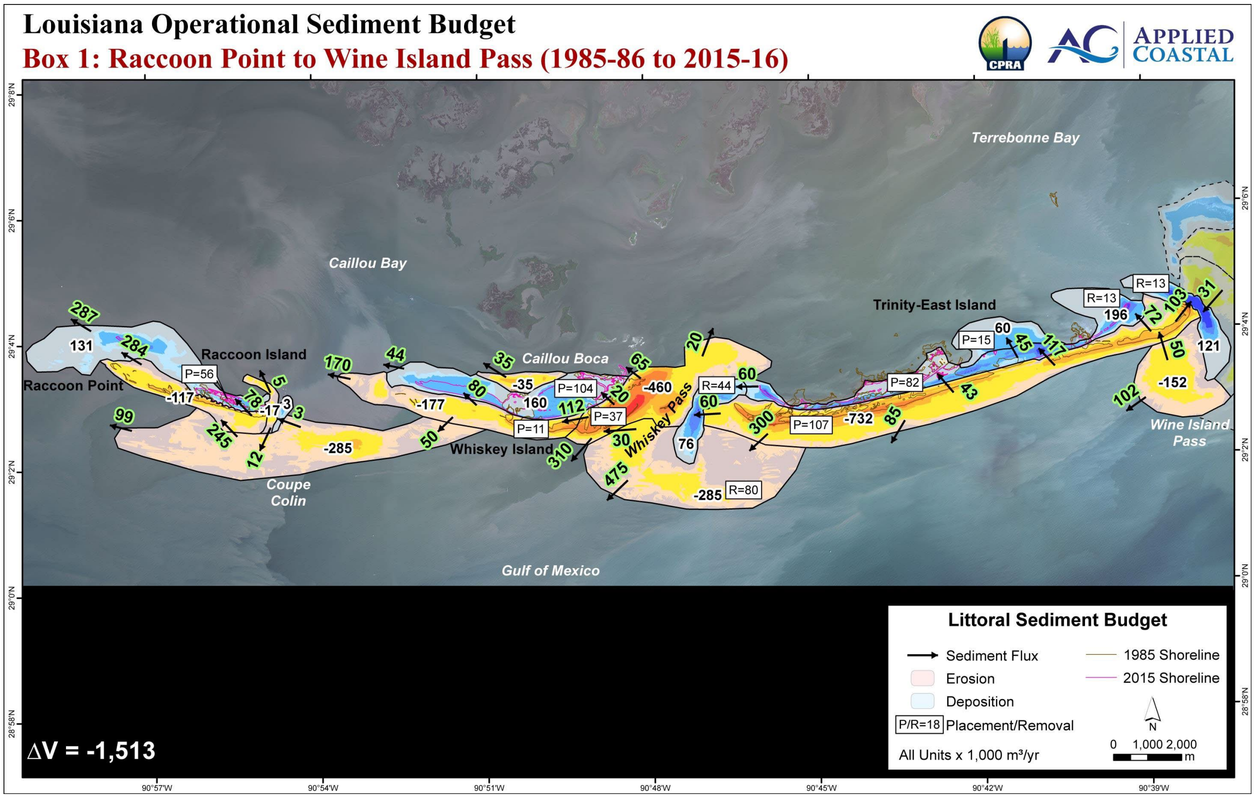

Figure 7. Detailed sediment transport pathways and quantities for Box 1 of the macro-scale sediment budget, 1985-86 to 2015-16. Arrows represent the direction of sediment movement, and black numbers with green border reflect the magnitudes of net sediment transport in thousands of m3/yr. Black numbers with white border represent net volume change for a particular zone. (from ACRE 2020).

end. This lengthening corresponds to a very low shoreline recession rate of 10.6 ft/yr during this period (Table 1). Both these periods point to the potential benefits of transported sediment filling shallow breaches and building large terminal spits during low storm periods.

Measurements of island widths were not readily available prior to restoration. Only 1978 and 1998 data sets are available. During this pre-restoration period the average width decreased by approximately 17.4 ft/yr. After restoration the island narrowed at a rate of approximately 13 ft/yr (figure 9). Like the island length analysis that showed lengthening immediately after restoration (1998 to 2004), this was also a period of island widening. The average width increased during this period by approximately 77.7 feet, predominantly due to the restoration template of TE-20 which filled shallow open water on the bayside of the existing land area (figure 4 and Appendix A). Once the initial widening occurred, the island exhibited a decrease in width from 2004 to 2005, which is attributed to Hurricanes Katrina and Rita. A period of stability occurred from 2005 to 2012 where the average width of the island only changed approximately 2%. A steep reduction in average width is noted after Hurricane Isaac in 2012, which increases the overall rate of narrowing to approximately 21.1 ft/yr. The period of stable island width corresponds to the construction of the TE-37 project in 2007 that added sediment to the New Cut area. However, the project was built on existing land and contributed little to widening the island (Appendix A).

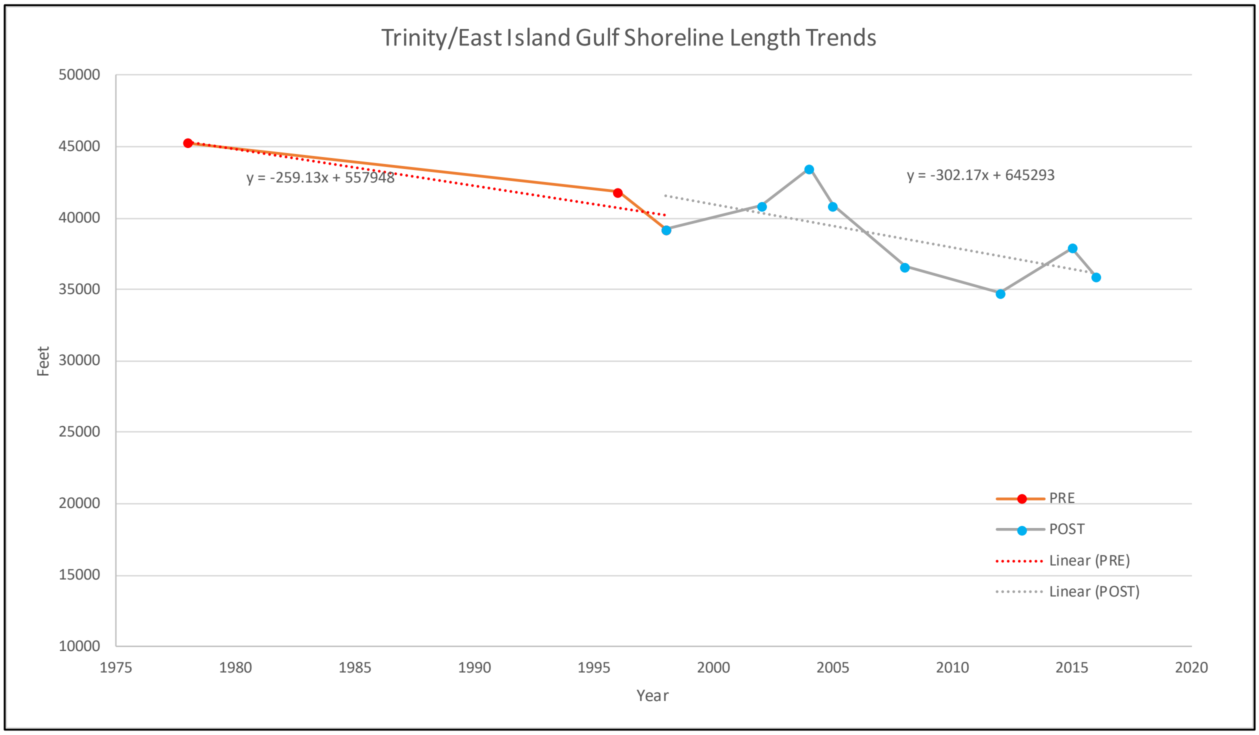

Figure 8. Island lengths at Trinity and East Islands from 1978 to 2016. Note the increase in length from 1998 to 2005 as New Cut filled with sediment and created a contiguous island. The overall trend indicates island shortening over time regardless of the initial increase in length. The post restoration shortening rate is 17% greater than the pre-restoration rate.

The shoreline position changes, island lengths, and average island widths all exhibit little overall trend changes from the pre-restoration condition to the post-restoration condition. The projects did not meet the stated goal of reducing rates of erosion, but did slightly reduce island narrowing through initial widening. This indicates that the goals concerning acreage creation and island stability were not met as well. The fact that the islands still have subaerial land indicates that initially increasing the island land area (Appendix A) and the brief periods of positive change during the various time periods point to positive outcomes. Each of the three variables; 1) shoreline position, 2) island length, and 3) island width, exhibited some positive impacts during the various time periods analyzed. Each shows that the projects contributed to reducing erosion rates, increasing lengths, and increasing widths for some period of time during the project life that contributed to accomplishing the overarching goals.

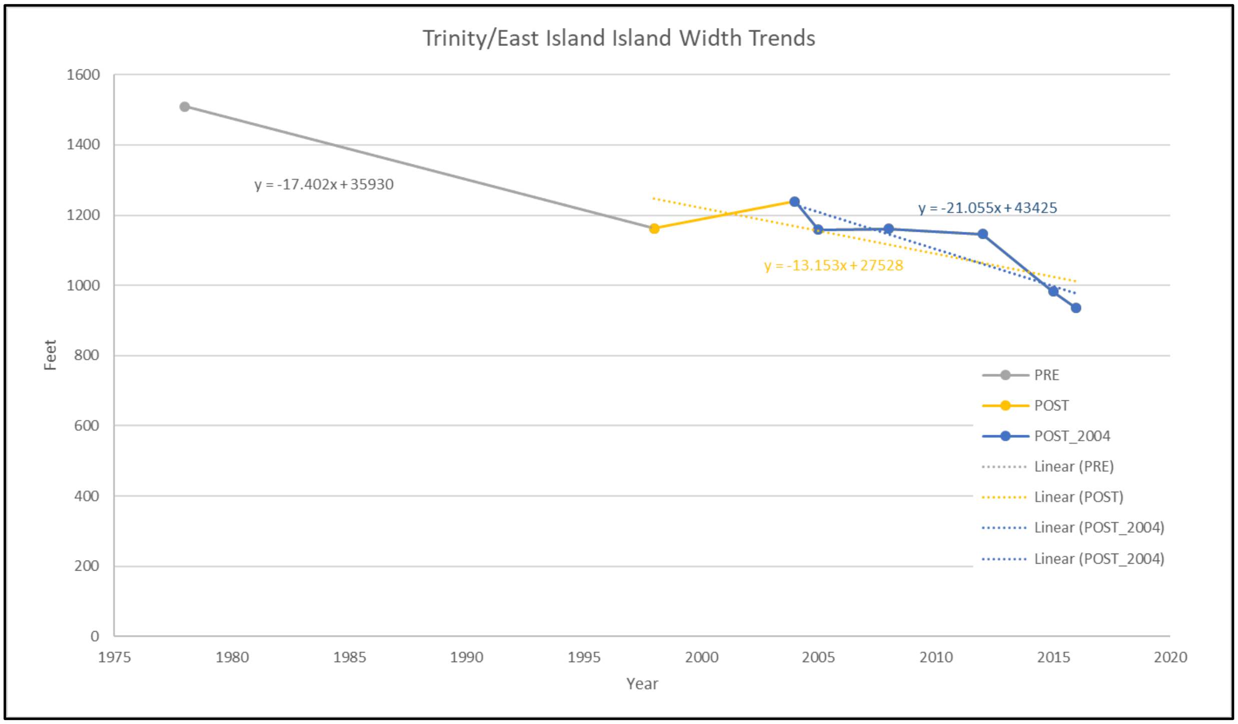

Figure 9. Average island widths at Trinity and East Islands from 1978 to 2016. A slight decrease in island narrowing after restoration is attributed to the increase in width from 1998 through 2004 when the initial restoration efforts are constructed and New Cut is filled with sediment creating a contiguous island. The overall trend indicates island narrowing over time regardless of the initial increase in width., After restoration there is a 20% narrowing of the island and a higher rate of narrowing after 2004.

Elevation and Sediment Volume

Analysis and assessment of elevation and volume changes are hampered due to the limited survey coverage during some time periods. Upon completion of the construction activities associated with the TE-20 and TE-24 projects, the objective to restore coastal dunes could be considered achieved because fill material was placed to elevations classified as dunes (>+5.0 ft). There was total of 325.8 acres of dune in the elevation analysis areas after construction in 1998 (Table 2).

From December 1998 to March 2000, approximately 16.8% of the placed sediment volume was lost from the analysis area. These losses were due to minor changes in elevation classes (Table 2) and sediment volume losses due to transport or compaction of underlying sediments (Table 3). This was a period with very little tropical storm activity. The TE-20 and TE-24 sediment volumes declined by virtually parallel magnitudes for this interval (Table 3).

From 2000 to 2015, changes in the overall elevation and sediment volume within the analysis area occurred. The overall elevation for the TE-20 analysis area was reduced by 8.56 ft while the TE-24 analysis area was reduced by 5.58 ft. As a result of the loss of elevation, there was a corresponding loss of sediment volume of 3,565,864 yd^3 for TE-20 and 3,130,807 yd^3 for TE-24. Since TE-37 was constructed in 2007, the overall elevation was reduced by 1.33 ft and sediment volume was reduced by 528,391 yd^3 by 2015. The driving force for the reduction in elevation and

Table 2. WVA elevation classifications for the TE-20, TE-24, TE-37 elevation analysis areas showing number of acres for each time period.

		Dune	***Supratidal***	***Intertidal***	***Subtidal***	***Non-WVA***	***Overall Analysis Area Elevation***
Project/Area	**Year**	**> 5.0 ft**	**2.0 - 5.0 ft**	**0 - 2 ft**	**-1.5 - 0 ft**	**< -1.5 ft**	**ft**
TE-20	1998	125.4 ac	109.6 ac	6.2 ac	0.6 ac	0.0 ac	5.31
TE-20	2000	86.2 ac	132.2 ac	23.1 ac	0.3 ac	0.0 ac	4.13
TE-20	2006	40.5 ac	96.3 ac	34.4 ac	13.9 ac	56.6 ac	0.73
TE-20	2015	14.8 ac	35.2 ac	4.3 ac	0.3 ac	187.1 ac	-4.43
TE-24	1998	200.4 ac	138.4 ac	9.5 ac	0.1 ac	0.0 ac	5.47
TE-24	2000	146.3 ac	180.3 ac	20.7 ac	0.5 ac	0.0 ac	4.56
TE-24	2006	69.5 ac	150.6 ac	63.8 ac	17.9 ac	48.3 ac	2.3
TE-24	2015	76.8 ac	79.7 ac	5.3 ac	0.3 ac	188.0 ac	-1.02
TE-37	2007	63.1 ac	100.2 ac	16.4 ac	6.8 ac	61.5 ac	1.27
TE-37	2015	43.6 ac	116.0 ac	3.4 ac	0.0 ac	85.0 ac	-0.06
Trinity/East Island	2006	116.4 ac	311.9 ac	426.0 ac	357.2 ac	24,400.1 ac	NA
Trinity/East Island	2015	143.4 ac	331.5ac	242.2 ac	61.6 ac	24,829.6 ac	NA

Table 3. Sediment volume change between time intervals by project.

Project	**Time Interval**	**Volume Change (yd^3)**
TE-20	1998 – 2000	-542,361
TE-20	1998 – 2006	-1,878,572
TE-20	1998 – 2015	-4,108,225
TE-24	1998 – 2000	-526,121
TE-24	1998 – 2006	-1,780,929
TE-24	1998 – 2015	-3,656,928
TE-37	2007 - 2015	-528,391

loss of sediment volume is attributed to the numerous tropical storms/hurricanes that affected the project areas during this period.

Even though there was an overall loss in elevation and sediment volume in the analysis areas, TE-20's analysis area still had 14.8 ac of dune and 35.2 ac of supratidal habitats after 17 years, and TE-24's analysis area had 76.8 ac of dune and 79.7 ac of supratidal habitats remaining. TE-37 had 43.6 ac of dune and 116.0 ac of supratidal habitats eight years after restoration within the analysis area. For more in-depth review of 2000 – 2006 and 2006 – 2015 periods, refer to Appendix C.

The individual analysis areas for TE-20, TE-24, and TE-37 have incurred sizeable volume and elevation losses; however, these projects have stabilized the Trinity/East Island area for eighteen years by adding needed granular sediments to the island system. Restoration efforts are projected to extended the subaerial life of the island to beyond 2060.

Habitat

The habitat change trends exhibited overall loss of habitats considered land, as was noted in the land area change section above and the more extensive analysis in Appendix A. Even with an overall trend of land loss, some of the individual habitats showed increases or stability after restoration. The project goals revolved around the restoration, establishment, or maintenance of dunes. The general BICM habitat classification scheme does not map dune habitat directly. Using the habitat mapping data from BICM, dune habitat can be mapped within either the barrier vegetation or bare land classifications (Table 4). In 1996, the data indicate 22.8 ac of barrier vegetation and 15.0 ac of bare land prior to restoration (Table 5), which equates to 4.7% of the total land area. Land area is defined (Appendix A) as any general habitat class other than water or intertidal flat. By 2002, the barrier vegetation and bare land classes totaled 595.2 ac. Bare land was the predominate cover type. The increase in both habitat classes and the extensive coverage of bare land is attributed to the initial restoration projects in 1998 and the time necessary for vegetation to establish. Both projects contained seeding and vegetative plantings.

The combination of bare land and barrier vegetation classes shows variability within the total acreages as well as the individual classes through time (figure 10). Continued vegetative colonization and succession and impacts of storms that reduce vegetative cover and change habitat classes are potential causes of the variability. From 2004 to 2005 the total land area only lost 3 ac, but showed a dramatic decrease of both bare land and barrier vegetation with a corresponding increase in beach habitat. By 2016 the bare land and barrier vegetation classes totaled 163.3 ac, 25% of the current land area total. Beach habitat was greatly reduced and bare land class only contributed 1.3 ac (Table 5) by 2016.

As of 2016 there was 125.5 ac of additional bare land and barrier vegetation compared to 1996 before restoration occurred, indicating that the three restoration projects have accomplished the goals related to the creation, maintenance, and stabilization of dunes. The reductions and increases within each particular habitat class through time supports the idea that construction impacts to specific habitats are mitigated by both habitat succession and habitat changes into the future and the overall maintenance of subaerial habitats beyond the predicted island life.

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

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

Table 5. Habitat acreages by BICM general habitat class between 1996 and 2016 for Trinity/East Island, Isles Dernieres, Terrebonne Parish, LA.

Habitat Classes	1996	2002	2004	2005	2008 [1]	2016 [1]
Water	5,204.5	4,851.4	5,061.1	4,962.6	13,301.8	13,596.6
Intertidal Flat	208.8	419.6	287.7	388.7	173.6	48.0
Vegetated Wetlands	447.8	245.1	287.0	246.8	319.9	428.0
Barrier Vegetation	22.8	73.0	218.7	20.4	56.9	162.0
Bare Land	15.0	522.2	264.9	154.1	69.9	1.3
Beach	324.7	111.6	103.9	450.7	357.7	44.2
Rip Rap	0.0	0.0	0.0	0.0	0.0	0.6
Structure	0.4	0.4	0.2	0.0	0.9	0.0
Land Area [2]	810.7	952.3	874.7	871.9	805.3	636.1

[1] Analysis areas do not match previous years data so acreage totals that include water are not appropriate.

[2] Land Area defined as sum of all habitat classes other than Water or Intertidal Flat

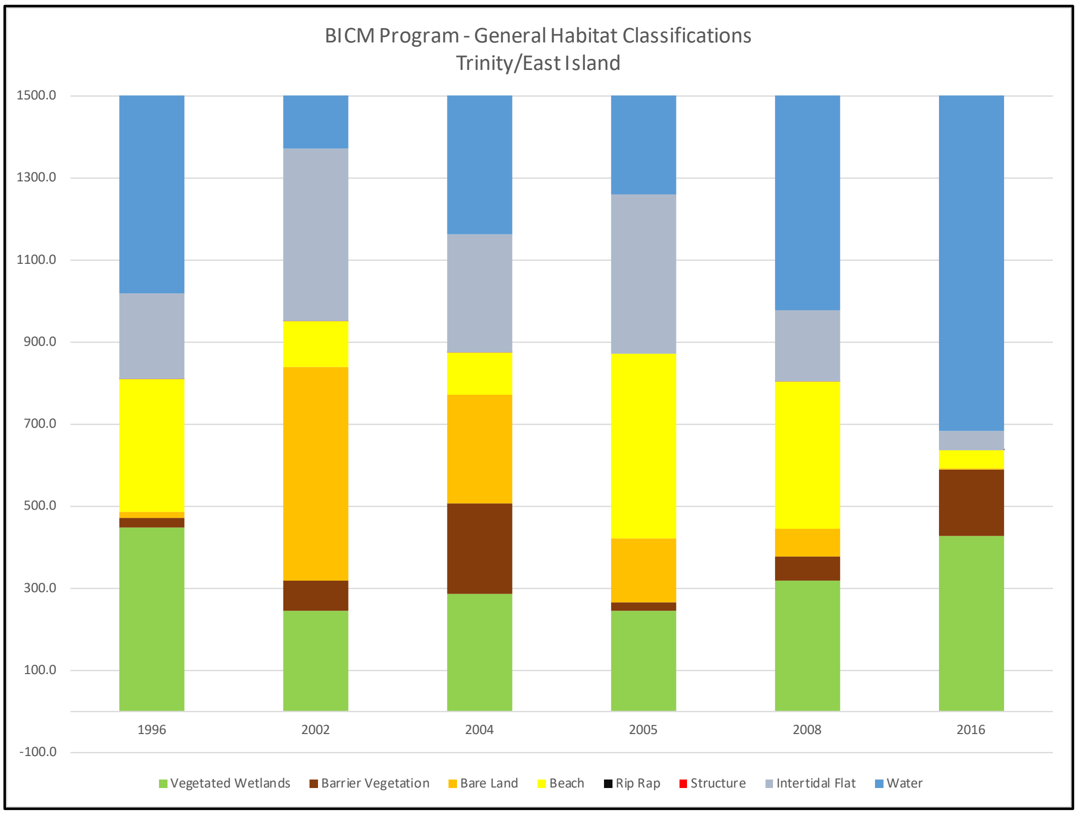

Figure 10. BICM habitat classifications showing cumulative acres of all the habitats at Trinity/East Island, Isles Dernieres, Terrebonne Parish, LA. Changes in habitat classes indicate the effects of restoration events and storms over time. Note that the total habitat analysis areas were larger than the graphed totals, but these additional acres were not shown as they consisted of acres classified only as water. This allowed better discernment between the other classes.

Vegetation

Relative mean percent cover of vegetation during 2006/07 on Trinity/East Island was 65% and increased to 67% during 2013/16. Four species, *Paspalum vaginatum, Phyla nodiflora, Solidago semprevirens, and Spartina alterniflora* that existed in 2006/07 were replaced with *Andropogon glomeratus, Distichlis spicata, Erigeron procumbens, and Phragmities australis* in 2013/16. *D. spicata* increased in cover by 5.6%, *E. procumbens* by 6.5%, and *P. australis* by 6.5% between the two time periods.

For both time periods, the dominant species was *Spartina patens* with a relative mean percent cover of 10.9% in 2006/07 and 11.4% in 2013/16. *Spartina patens* was initially planted in all three projects at the end of construction. *Cynodon dactylon*, planted via seeding immediately after construction, was not found in or around any of the vegetation stations in 2006/07 or 2013/16. There was a drastic shift between the two sampling periods for *Spartina alterniflora*, 8.3% relative mean percent cover in 2006/07 to 0% in 2013/16. *S. alterniflora* was not identified in any station and only identified outside of one station. For *Panicum amarum*, the relative mean percent cover remained similar at 3.1% in 2006/07 and 2.4% in 2013/16.

In 2006/07, thirty-eight plant species plus the bare ground cover type were identified at one or more of the vegetation stations. When species fifteen feet from the stations were included, the number of species increased to forty-four. In 2013/16, forty-one species were documented inside the stations, while an additional eight species were recorded in the fifteen-foot zone outside the stations. Of the species identified inside of the stations, 24 species were common to both sampling periods. Ten species identified inside of the stations in 2006/07 were not found inside the stations in 2013/16. This accounted for approximately 15.1% relative mean percent cover which indicates that there was a species shift. *Erigeron procumbens* accounted for 6.5% of the shift as this species was not identified in 2006/07 and another eleven species were identified in 2013/16 that made up another 6.8% and were not identified during the previous period.

Sediment Properties

None of the three projects had goals specifically related to sediment properties. The data discussed here were available through the BICM program and reported here as ancillary information. Georgiou et al. (2019) compared BICM sediment samples between 2008 and 2016 and plotted changes to percentages of sand and average grain size along the whole Isles Dernieres shoreline (figure 11, figure 12, and Table 6). The dune, berm, and beach face environments indicate decreases in grain size along the eastern end of Trinity/East and subsequent increases in both grain size and sand content as one moves westward to the central portion of the island. Sand content and grain size begin to decline toward the western end of the island, particularly in the dune and beach berm environments. These results illustrate the regional sediment transport processes moving sandy sediments from east to west along the shoreline and, like the land area change data, support the assertion that all volumes removed from the elevation analysis areas are not "washed away", but transported to other locations of the island and continue to provide benefits. This also directly indicates that the TE-37 goal of contributing to the littoral drift system was addressed.

The results of the Trinity/East Island sediment properties model presented in Appendix F corroborate the results above. Surficial sand deposits were present along most of the Trinity/East Island onshore and nearshore environments in both 2008 and 2015 as expected (figures 13 and 14). However, the models show the reductions in percentage of sand on the eastern end of the island near Cat Island Pass and increases in sand content in the central and western portions of the island along the shoreface. The models also show the reduction of the sandy sediments in Whiskey Pass off the western end of Trinity/East island (figures 13 and 14), indicating that the Pass maybe scouring and moving sandy sediments either offshore or into the bay.

Although the distribution of sand resources appears favorable, the Isles Dernieres Islands have been characterized as having thin sand layers overlying silt and/or clay substratums (Peyronnin 1962; Penland et al. 1985; Kulp et al. 2005). Therefore, the depth of the granular deposits is projected to be predominantly surficial and the volume available for transport is probably limited.

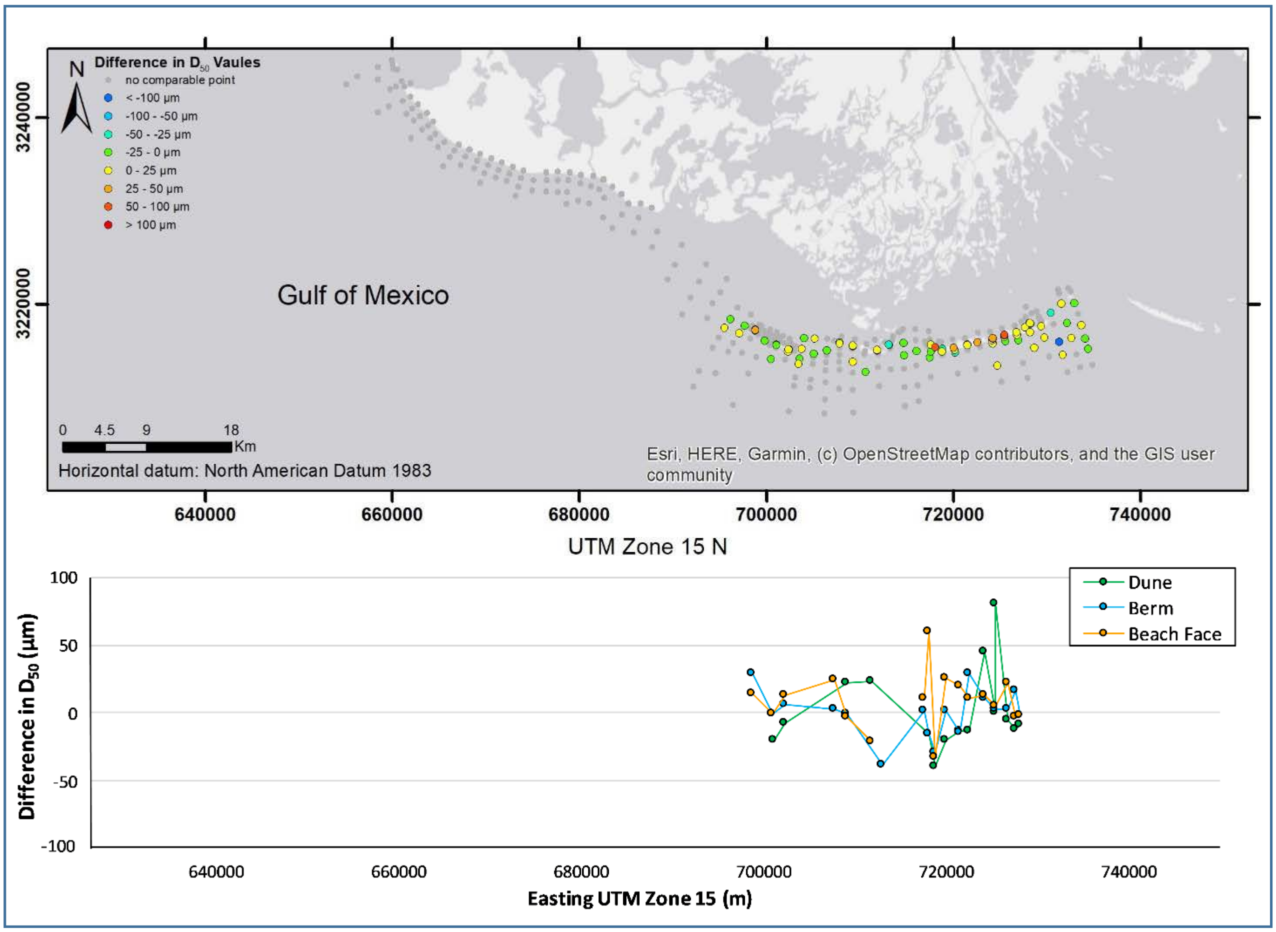

Figure 11. Grain size differences along the Early Lafourche Delta Regions from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face). Note numbers above zero indicate increases in grain sizes with decreases less than zero (from Georgiou et al. 2019).

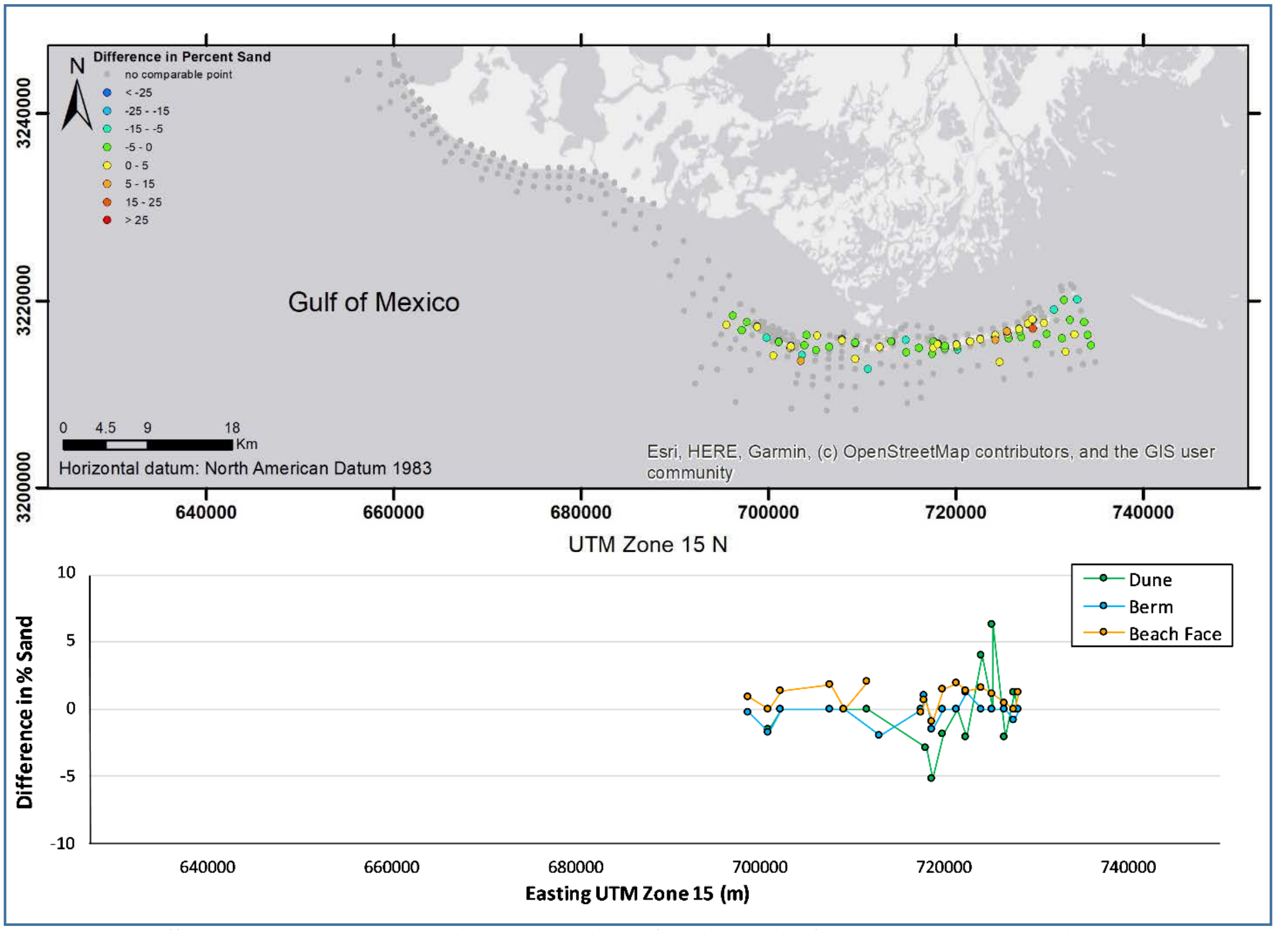

Figure 12. Differences in sand content along the Early Lafourche Delta from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face). Note numbers above zero indicate increases in sand content with decreases less than zero (from Georgiou et al. 2019).

Table 6. Summary of Isle Dernieres grain size statistics for all comparable points in 2008 and 2015 (n = number of samples used in average).

Environment	Year	n	D_{50}	% Sand	Sorting	Skewness	Kurtosis
Backbarrier	2008	4	Fine Sand (217µm)	99%	Moderate Well (1.47)	Coarse (0.15)	Leptokurtic (1.29)
	2015		Fine Sand (207µm)	99%	Well (1.39)	Symmetrical (0.05)	Leptokurtic (1.15)
Dune	2008	15	Fine Sand (202µm)	99%	Well (1.38)	Symmetrical (0.01)	Mesokurtic (1.06)
	2015		Fine Sand (203µm)	99%	Well (1.35)	Symmetrical (-0.02)	Leptokurtic (1.10)
Berm	2008	17	Fine Sand (203µm)	100%	Well (1.31)	Symmetrical (0.00)	Mesokurtic (0.97)
	2015		Fine Sand (203µm)	100%	Well (1.32)	Symmetrical (0.00)	Mesokurtic (1.01)
Beach Face	2008	17	Fine Sand (202µm)	99%	Moderate Well (1.54)	Coarse (0.18)	Leptokurtic (1.32)
	2015		Fine Sand (211µm)	100%	Moderate Well (1.42)	Coarse (0.14)	Leptokurtic (1.23)
Inlet	2008	26	Fine Sand (182µm)	95%	Moderate Well (1.57)	Fine (-0.11)	Leptokurtic (1.42)
	2015		Fine Sand (163µm)	93%	Moderate (1.67)	Fine (-0.18)	Very Leptokurtic (1.71)
Upper Shoreface	2008	8	Fine Sand (147µm)	94%	Moderate (1.69)	Fine (-0.12)	Leptokurtic (1.32)
	2015		Fine Sand (153µm)	95%	Moderate Well (1.52)	Fine (-0.14)	Leptokurtic (1.33)
Middle Shoreface	2008	6	Very Fine Sand (118µm)	85%	Moderate (1.91)	Very Fine (-0.34)	Very Leptokurtic (1.79)
	2015		Very Fine Sand (113µm)	86%	Moderate (1.89)	Very Fine (-0.35)	Very Leptokurtic (2.10)
Lower Shoreface	2008	5	Very Fine Sand (119µm)	91%	Moderate Well (1.56)	Fine (-0.23)	Very Leptokurtic (1.69)
	2015		Very Fine Sand (117µm)	91%	Moderate (1.62)	Fine (-0.27)	Very Leptokurtic (1.84)
Total Average	2008	98	Fine Sand (184µm)	96%	Moderate Well (1.52)	Symmetrical (-0.03)	Leptokurtic (1.29)
	2015		Fine Sand (180µm)	96%	Moderate Well (1.50)	Symmetrical (-0.07)	Leptokurtic (1.39)
Onshore Average	2008	53	Fine Sand (203µm)	99%	Moderate Well (1.41)	Symmetrical (0.07)	Leptokurtic (1.13)
	2015		Fine Sand (206µm)	99%	Well (1.37)	Symmetrical (0.04)	Leptokurtic (1.11)
Offshore Average	2008	45	Fine Sand (160µm)	93%	Moderate (1.64)	Fine (-0.15)	Leptokurtic (1.48)
	2015		Fine Sand (150µm)	92%	Moderate (1.66)	Fine (-0.20)	Very Leptokurtic (1.71)

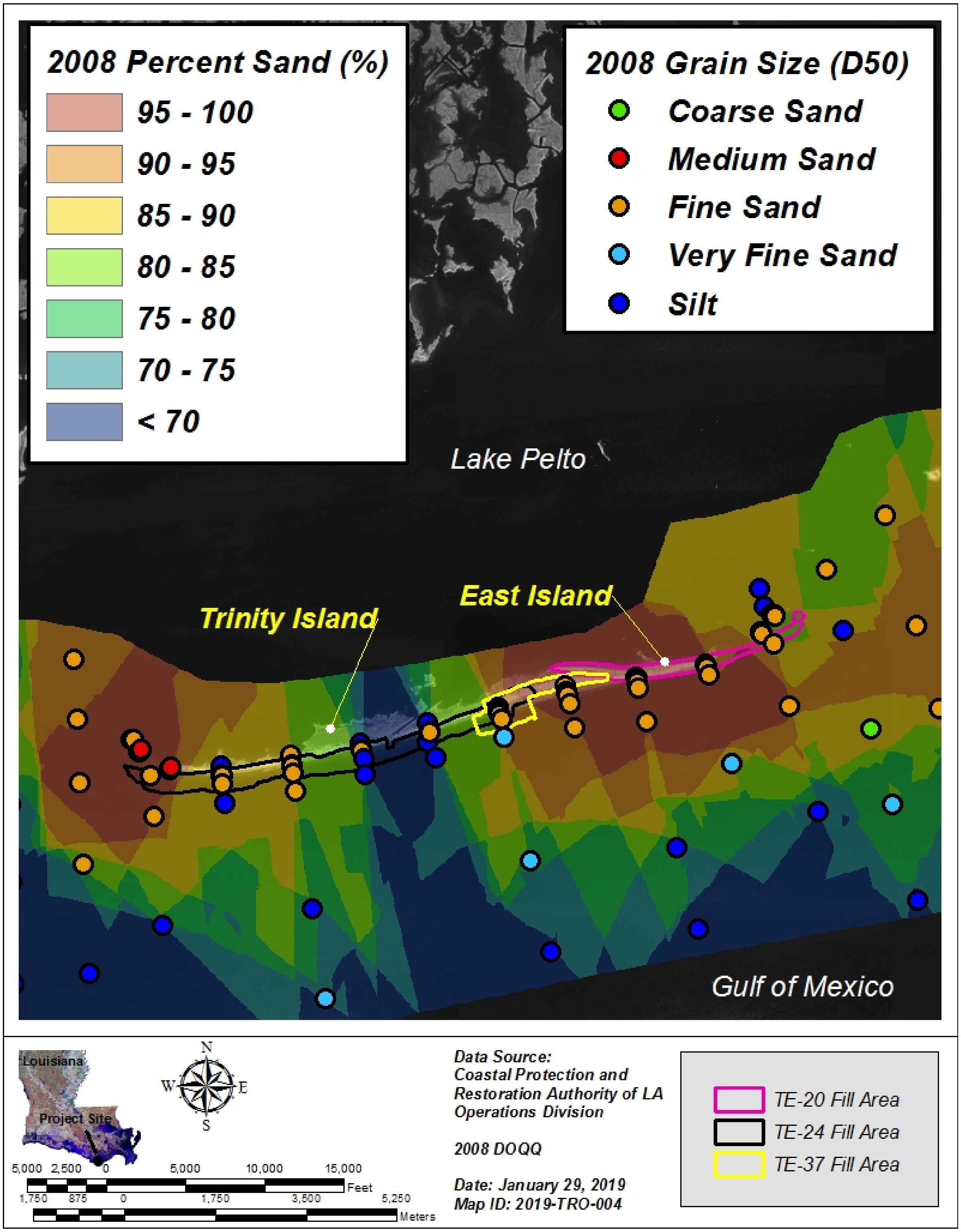

Figure 13. Median grain size (D50) and percent sand (%) distribution for Trinity/East Island in July 2008.

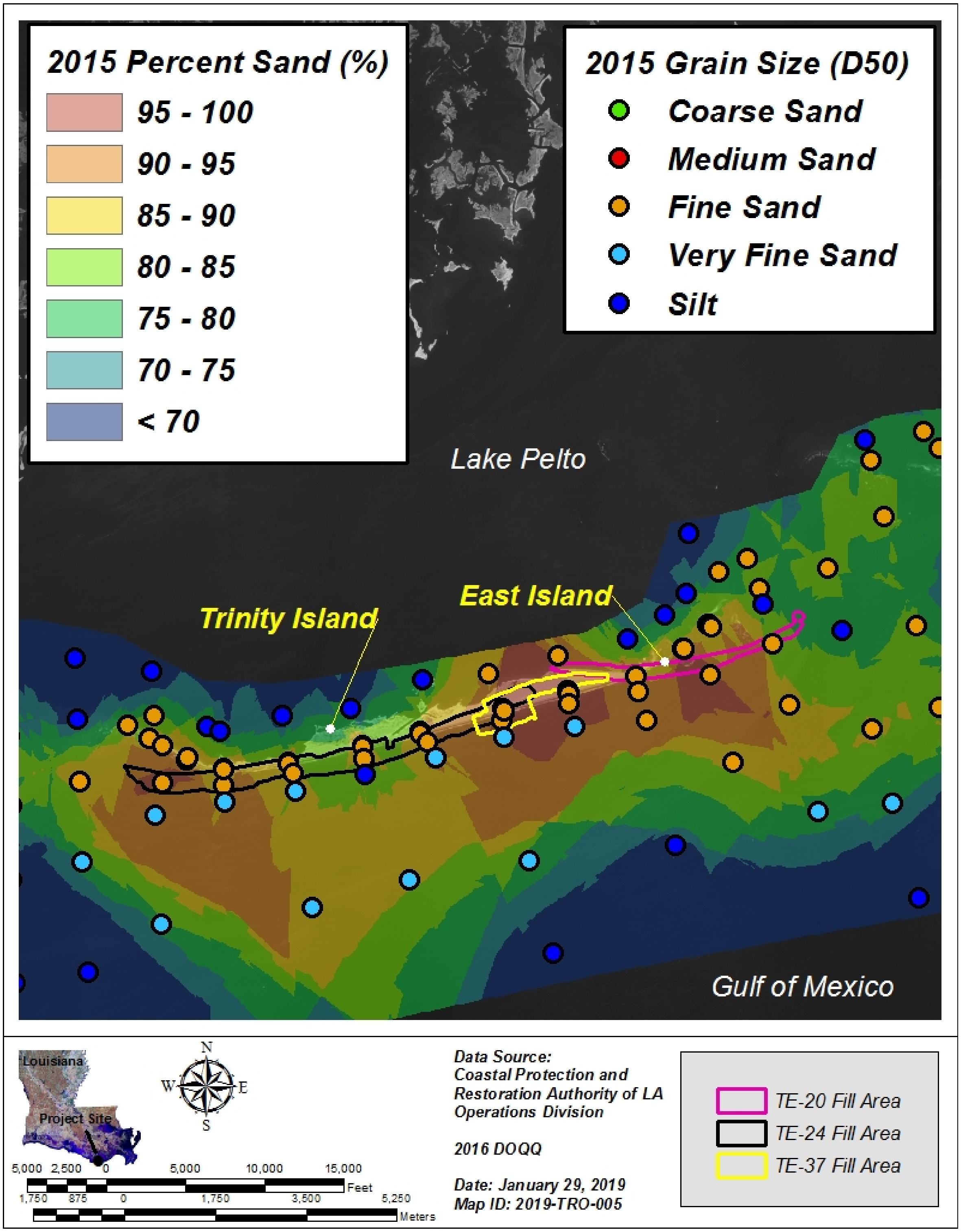

Figure 14. Median grain size (D50) and percent sand (%) distribution for Trinity/East Island in August 2015.

Chapter 4 – Conclusion and Lessons Learned

These projects, when assessed against the expected disappearance of the Trinity/East Island complex in 2011, the existence of various elevations, and the existence of specific habitat types as described in the goals, have met the various goals and objectives. While particular variables such as shoreline erosion, island shortening, and island narrowing may not exhibit reductions after restoration, the projects affected these measures for some time period. These temporary changes were enough to positively impact the life expectancy of the Trinity/East Island, thus meeting the goals. While the volume lost exceeded the volume placed, the transport of sediment and subsequent migration to other areas points to the importance of these sediment additions in maintaining the island. This result highlights the need to assess barrier island projects within this migrating landscape and not just the specific project footprint.

The use of dredged sand and sediment, combined with sand fencing and vegetative plantings, has proven to be an effective means of increasing the stabilization of barrier islands and prolonging the lives of the islands and, by extension their many benefits. Increased resilience of these features is vital to an array of environmental and anthropogenic interests. Tropical storm activity is a primary driver of the most dramatic changes observed in Louisiana's barrier islands, including breaches and overwashes that affect various aspects of topography, vegetation, habitat disturbance, and shoreline changes. Winter storms can likewise contribute to similar changes in these features by adding wind and wave energy to an already high energy environment in the open Gulf of Mexico. Despite the challenges which may exist in implementing restoration of an ephemeral geologic feature in this type of environment, the benefits to large sections of Louisiana's coastal zone are clear. Adding sediment from an outside source to the littoral system of the Isles Dernieres had immediate positive effects as well as long term benefits to the Isles Dernieres system itself, including the interior marshes, shorelines, and communities that it protects. Subaerial features protect the interior of the barrier islands immediately upon project completion and the augmentation of vital sediments to the system allows sediment transport processes to function more naturally to protect and enhance adjacent areas. Due to the implementation of these three projects on the Isles Dernieres, this barrier island system continues to offer storm protection to interior environments in 2020 and is expected to do so until 2061 or longer.

Between the TE-20, TE-24, and TE-37 projects, approximately 9.7 MCY of material was added to the coastal sediment budget (T. Baker Smith and Sons, Inc. 1998 and T. Baker Smith, Inc. 2007), providing resilience to the outer deltaic coast that constitutes the first line of defense to the interior deltaic habitat from storm waves and water levels. The long-term benefit of this restoration approach is the addition of sediment to a littoral system that is otherwise sediment starved (Morang et al., 2013). Augmenting natural sediment delivery to the outer coast not only offers an immediate benefit by creating subaerial land that protects interior habitat, but replenishes adjacent environments through littoral sediment transport during the natural reworking process associated with barrier island restoration.

Lessons Learned

There have been many lessons learned over the eighteen years since the TE-20 and TE-24 projects were constructed. Many of these lessons have been implemented as new projects were constructed and monitoring activities changed. Below is a summary of lessons learned and whether those lessons have been implemented:

- Planning and Design
  - Goals and objectives must be better defined and measurable. The goals and objectives for these projects had neither clear definitions nor expected time frames. Goals such as "create acres of land" must indicate whether this is the initial expectation of construction or whether they are the outcome of long-term results. They must also be related to a benchmark such as the "projected future conditions without project" used for TE-20 and TE-24. There could be interim goals and objectives to make progress reports easier to compose and to define data collection methods. Planners and designers should frame goals and objectives in measurable terms so that design alternatives can be evaluated against a measurable target and later monitoring activities can adequately assess targets.
- Engineering and Design
  - Sediments mined for the creation, restoration, or enhancement of barrier islands need to be located outside of the depth of closure whether the borrow area is in the bay or gulf. The depth of closure is where there is no significant change in bottom elevation and no significant net sediment exchange between the nearshore and the offshore.
- Construction
  - Design templates did not include marsh platforms in areas without back barrier marshes and they did not form as part of natural project succession. While project plans labeled elevations as marsh, the initial TE-20 and TE-24 projects did not include intertidal elevations as part of construction. Personal communications with the design engineers suggested that the designers felt back barrier marshes would form along the fill areas due to fill slope adjustments and sediment transport. While marshes have formed due to transport, they did not form directly behind fill templates due to slope adjustment. Because back barrier marsh platforms are important in capturing sediment during overwash events, designers need to ensure that there is an existing component or one should be included in the design. The majority of restoration projects now include back barrier marsh platforms as construction components.
  - Early sand fencing layouts did not accumulate sand in the proper geomorphic dune configuration and added linear footage of fencing that was unnecessary and added cost. Sand fencing components of the TE-20 and TE-24 projects used various configurations. These configurations accumulated sand but the locations of these sand "dunes" did not necessarily create the appropriate desired shore parallel geomorphic dune feature. The non-continuous sand accumulations created in some sand fence configurations created low areas where overwash was focused into channelized flow that increased sediment scour across the islands. Some fence layouts used a zig-zag configuration that increased the linear feet of fencing and

cost with no increase in benefits. Currently, all sand fencing is placed parallel to the shore in single rows to cover the maximum distance with the minimal amount of fencing and to create higher sand dunes in a natural geomorphic feature.
    - Sand fencing was initially installed using metal t-posts which are readily available at low cost. Over time these posts rusted and were l exposed creating a public safety hazard. All sand fencing is now supported with wood posts only for new projects.
    - Sand fencing was designed based on beach fill examples and did not account for the differences in sediment transport related to rebuilding a complete island. Due to these restoration efforts being a complete barrier island template, rather than a beach nourishment type project, the sand transport was predominantly from the bay toward the gulf during the initial post-construction period. The sand fences initially accumulated sand on the gulf side of the fences then the sand transported back north because of the large areas of bare sand. This process was different from the literature as those sites did not have the large bare sands on the bay side of the fences. Placement of fences and supplemental plantings now take into account sand transport during the winter cold fronts and the changes in these processes as vegetative cover begins to spread and stop transport away from the sand fencing due to north winds.
    - Initial plantings on the dune platform consisted of *P. amarum* and *S. patens*. *S. patens* did not perform well on the upper dune areas and has been discontinued. *S. patens* planted on the back slope did well in some locations and is still used with mixed results. *S. alterniflora* planted on the back slope and bay interface did not survive. The initial slope adjustment and wave energies were too severe for establishment and most plantings were washed away rapidly. Plantings along the back bay interface should only be attempted after initial adjustment, but it will still be difficult unless there is a large marsh platform.
    - Seeding had varying results. Some seeds did not sprout while others did with varying degrees of coverage. The amount of rain received after seeding seemed to drastically impact germination. Where the seeding did provide coverage, the amount of sand transported to fences could be reduced which would make the fences less effective at creating additional elevation. Future projects should evaluate the needs and interactions of seeding and sand fencing in order to determine if one or both are needed to meet project objectives.
    - *C. dactylon* was used in some of the seeding locations. It is a non-native species and should only be used when no other suitable alternative can be found.
- O&M
    - Early projects had no O&M budgets and visual inspections of the project were unfunded. The ability to replace sand fencing and perform additional plantings was not available through the project budget. Future projects, including the TE-37 project, have included an O&M budget that funds inspections, some sand fence replacement and additional plantings.
- Monitoring
    - Monitoring elevations and volumes is hampered by survey coverages that are limited to the construction fill footprint, such as the pre-construction and as-built surveys. Barrier islands are a dynamic coastal feature, especially in Louisiana. Elevation data needs should be considered beyond design and construction needs

because of the constant changes from environmental processes and extreme weather events. Some data collection events should be done on the entire island system, i.e., inlet to inlet, capturing offshore and bayward areas in order to assess sediment transport within the system through time. Limited spatial coverage only allows for the evaluation of the area common to all surveys over time, which may neglect some important movement of sediment and compounds. The reporting efforts have different numbers being generated for different spatial coverages. Future projects expand the immediate pre-construction or as-built surveys in order to cover additional areas beyond the construction template and provide baseline information for future analysis that incorporates the sediment transport processes.

- Data collection methodology and analysis should remain consistent to the extent possible and correspond as closely as possible to other regional or state initiated programs.
- Monitoring of vegetative plantings survival is different from monitoring of island vegetative succession. These projects initially established vegetative sample plots based on the location of plantings and the survival and spread of these plantings. However, long-term considerations of the goals and objectives were concerned more with establishment and coverage of particular habitats. This change in questions over the life of the project made earlier vegetative sampling schemes ineffective in addressing the questions presented. Vegetative sampling at subsequent projects focused more on assessing long-term goals, and less on assessing the immediate results of plantings. Project teams need to assess needs and understand the differences in vegetative assessment approaches. Some projects may require both approaches, and this needs to be justified and budgeted.
- Data analysis for each variable should be considered. For example, habitat mapping of aerial imagery should assist ground vegetation data collection and analysis. Vegetation stations should be established to define and support the ground observations which can be used with computer-based algorithms.
- Aerial imagery should be captured immediately after construction to document the as-built condition and serves as the baseline after construction. Typical construction contracts now require both immediate pre-construction imagery as well as post-construction imagery for the as-built condition. The survey data coverages have limited, areas of analysis after construction. The same considerations should be applied to the aerial imagery as the survey coverages.
- When other projects are constructed with overlapping boundaries or within a proximity of influence, older projects that have data gathering components should be evaluated to see how to incorporate that information into new projects.

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Appendix A

Land Area Changes at Trinity/East Island due to the Isles Dernieres Restoration, East Island (TE-20), Isles Dernieres Restoration, Trinity Island (TE-24), and New Cut Dune and Marsh Restoration (TE-37) projects, Terrebonne Parish, LA

May 1, 2020

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Introduction

In order to assess aspects of the restoration efforts on Trinity/East Island, a combination of digitized shorelines and habitat mapping datasets were compiled from various sources to determine land area change rates prior to and after three large-scale Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) Program restoration efforts (figure A1). These efforts included the Isles Dernieres Restoration, East Island (TE-20) and Isles Dernieres Restoration, Trinity Island (TE-24) in 1998 and the New Cut Dune and Marsh Restoration (TE-37) in 2007 (Rodrigue et al. 2008a, Rodrigue et al. 2008b, and T. Baker Smith, Inc. 2007). Both TE-20 and TE-24 projects have goals related to island "stability", and the TE-37 project has goals related to creating island acreage and "stabilizing dunes". For this assessment the author will measure terms like "stability" and "create island" in relation to changes in barrier island land loss rates through time.

Methods

Land area changes have been utilized extensively to assess barrier island erosion and deterioration (Morgan and Larimore, 1957, Williams et al. 1992). A variety of data types including maps, charts, aerial photographs, satellite imagery, and elevation surveys have been used to determine the land area and changes through time. However, comparisons of various datasets and types is complex due to differing methods and scales utilized to produce the various data types (McBride et al. 1989). In order to assess these projects implemented at various times, we will utilize both digitized shorelines as well as the more recently available habitat classification data developed from imagery. This approach allows for as many data points as possible prior to and after construction, and potentially allows these various epochs to help determine individual project impacts.

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

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

BICM also develops habitat classification datasets for the barrier shoreline during recent years. Habitat datasets have been developed for the BICM program by researchers at the University of New Orleans – Pontchartrain Institute for Environmental Sciences (UNO – PIES) for 1996/1998, 2001/02, 2004, and 2005 (Fearnley et al. 2009). In 2016, the BICM program partnered with the U.S. Geological Survey - Wetland and Aquatic Research Center (USGS-WARC) to develop habitat datasets for 2008 and 2015/2016 (Enwright et al. 2020). Habitat datasets for 1996/1998,

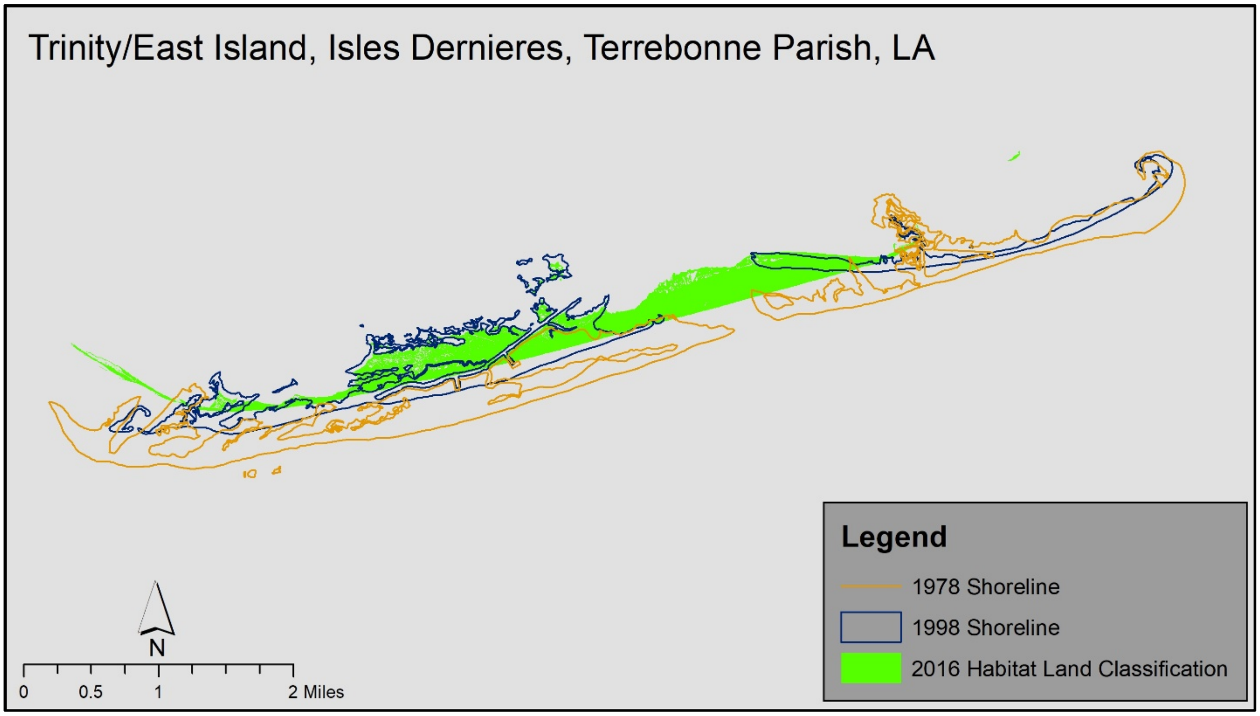


Figure A1. Three example land areas of Trinity/East Island developed from digitized shorelines and habitat classification datasets available from various sources.

2001/02, 2004, and 2005 were developed by the UNO - PIES using supervised and unsupervised classification of ortho-photography. The classification methods currently used by USGS-WARC for the 2008 and 2015/16 periods generate habitat datasets from high-resolution ortho-photography using object-based analyses in the Trimble eCognition software. This software allows for a variety of data, such as aerial imagery and elevation data, to be integrated into the habitat classification process. However, new habitat classifications and comparability with the older UNO-PIES datasets was maintained to ensure comparisons. For detailed information on the sources and methods used for these datasets see Fearnley et al. (2009) and Enwright et al. (2020).

In addition to the nine shorelines and six habitat classification datasets complied by BICM, various publications provided five supplemental land area datasets (table A1). These datasets were compiled from both shoreline digitization and habitat classification procedures similar to the ones described above. The land area calculation reported in publications provided additional time periods both prior to and after project construction which allows the development of better trends in land area changes. Five of the datasets were digitized shorelines and one was habitat classification using the BICM methodology. For detailed information on the sources and methods used for these datasets, see Penland et al. 2003.

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

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

For this analysis the habitat datasets utilized the BICM general eight-class habitat scheme which was further aggregated into either land or water, based on the BICM classification definitions (table A2). The water category contains two habitat classes, water and intertidal, with the remaining six classes aggregated into the land category. Intertidal is defined as bare or sparsely vegetated areas located between the extreme low water and extreme high water spring tide levels, with vegetation cover generally less than 30 percent. Due to the lack of vegetation cover and the intertidal nature of this classification it was not considered land in this analysis. This is opposed to the beach class that while also low in vegetated cover is typically mapped above extreme high water springs tide levels. Also, the marsh classification is considered land due to the dense cover of emergent vegetation.

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

For south Louisiana, the wet/dry boundary on the beach at high tide was the primary shoreline marker. Where marsh shoreline type was dominant, shoreline position was mapped as the vegetation/water boundary, consistent with USC&GS historical shoreline mapping (Shalowitz, 1964).

To examine the comparability of land areas determined by shorelines and habitat datasets, three time periods had both data types produced by the BICM program (table A3). Differences in land area ranged from a maximum of 20% in 2004 to as little as 4% in 2008, with an average of 10% providing confidence in trend development over the long-term. Most of the difference appears related to the detailed classification of intertidal areas within the back-barrier marshes (figure A2). This leads to shoreline datasets exhibiting a slightly higher land area when compared to aggregated habitat classifications presented here. Due to the majority of older datasets being produced with shoreline digitization, where 2 data types existed for the same time period, the shoreline was utilized in order to maximize consistency.

Final compilation of land area acreages for the Trinity/East Island assessment included fifteen data points from 1978 through 2016. Land areas were determined from 11 digitized shorelines and 4 habitat classification datasets. The BICM program developed 9 of the datasets with 6 provided through other sources (Penland et al. 2003, Byrnes et al. 2018, Enwright et al. 2020). A time series plot of land areas was created and a linear regression line was fit to the data points during both prior to (1998), as well as post restoration periods (figure A3).

Table A2. Louisiana Barrier Island Comprehensive Monitoring (BICM) Program detailed and general habitat classification schemes used in habitat mapping efforts for the Louisiana Gulf of Mexico shoreline (from Enwright at al. 2020).

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

Table A3. Comparison of land areas developed from BICM digitized shorelines and habitat classifications dataset available for the same time periods. Area in acres.

Year	Shoreline	Habitat	% Difference
2004	1051.6	874.7	20%
2005	919.1	871.9	5%
2008	834.6	805.3	4%
		Average Difference	**10%**

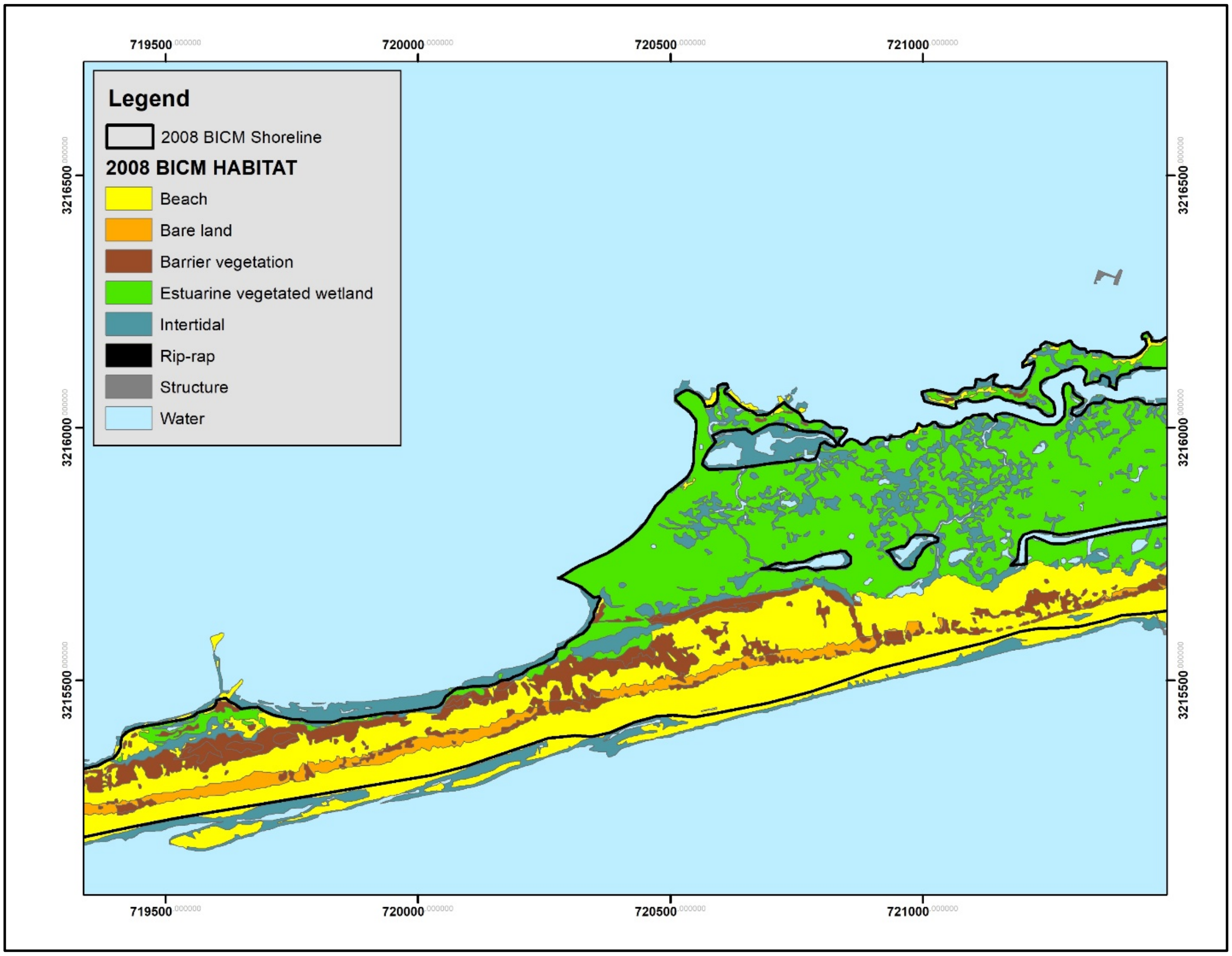


Figure A2. BICM shoreline and habitat data at a location on Trinity/East Island in 2008. Note shoreline data does not delineate the same detail within the emergent marsh dominated areas and therefore captures more intertidal area within the "land" category than does the habitat classification methods.

Results

Land area data for Trinity/East Island was available for fifteen time periods ranging from 1978 through 2016. This period of thirty-eight years allows for an epoch of 20 years (1978 – 1998) prior to restoration and an epoch of 18 years which the three restoration events impacted the system (1998 – 2016). The land area trends during both epochs exhibited land loss. However, the trends of loss were drastically different.

From 1978 to 1998 the land area of Trinity/East went from 1685 ac to 729 ac. This is an average loss of approximately 54 ac per year, and if that rate where to have continued the entire land area of Trinity/East would have become a subaqueous shoal in 2011. This expected date of disappearance supports previously published dates of disappearance for the individual islands mapped at the time. McBride et al. (1989) using shorelines from 1880s to 1988 projected that the individual East and Trinity Islands would become completely subaqueous by 2007, with East Island proceeding Trinity's disappearance by nine years. McBride et al. (1989) predicted disappearance was five years earlier than predicted here, however a smaller restoration event was conducted on East Island in 1994 using Federal Emergency Management Agency (FEMA) funds (Penland et al. 2003) and this may contribute to the additional 5 years for predicted disappearance.

In sharp contrast to the pre-restoration period, the restoration epoch (1998 to 2016) shows a 74% reduction in the overall land loss rate, only losing an average of 14 ac per year. This trend if projected forward from the 636 acres of land in 2016, would indicate approximately 45 years before the Trinity/East Island becomes a subaqueous shoal.

Interestingly, the post-restoration reduction in land loss trends occurs during a period where tropical storms or hurricanes within 150 nautical miles of the center of the Isles Dernieres averaged 9.4 per decade (1999-2016). This occurrence of tropical weather activity is higher than the long-term average (1842-2016) of 8.2 storms per decade, and in direct contrast to the pre-restoration epoch (1978-1998) which exhibited lower than average tropical weather activity at only 6.7 storm per decade (NOAA 2019). Considering the importance of storms on barrier island land loss, a reduced land loss rate during a period of higher than average tropical weather activity, indicates that island "stability" as measured by reduced land area change has been successful.

Land area trends shown in figure A3 indicate the significant contribution of the TE-20 and TE-24 projects to land gains, as the immediate pre-restoration land area in 1998 totaled 729 acres, while by May 2002 there was a 50% increase in land area to 1091 acres. However, both projects contributed differently to this increase. The TE-20 project dramatically increased the land area of East Island from 193 acres in 1998 to 380 acres in May 2002. This is a 97% increase in the land area of East Island, with some land loss likely between construction in late 1998 and the May 2002 data point. In contrast, during this same time frame the TE-24 project only increased the size of Trinity Island by 93 acres, or 15%. We agree with Penland et al. (2003) who attributed the differences to pre-restoration island configurations, such that while the approach of placing fill material behind the existing beach was similar at both sites, the TE-20 fill area was mostly in shallow open water while the TE-24 project placed a large portion of its material on existing Trinity Island land area (figure A4).

Between May 2002 and 2005 several tropical weather events impacted the islands. Among others, these included Hurricanes Lili and Isadore in 2002 and Katrina and Rita in 2005. These storms contributed to 172 acres of land loss during this time frame, with 139 acres being lost between May and November 2002 alone. The loss in 2002 would be 81% of the total loss during this period, pointing toward the tremendous impacts of tropical weather intensity and track, as well as the possible differences in storm impacts on a newly restored area versus an older and more vegetated site. In 2002 the habitat data indicated 48% of the land area was classified as Bare Land, whereas by 2005, post Hurricanes Katrina and Rita, the Bare Land class comprised only 18% of the land area with change between 2004 and 2005 of only 3 acres (figure A5).

While the two early projects did not state a specific acreage goal be achieved, the TE-37 project did have a goal of "creating 261 acres of island" with both supra- and inter-tidal habitats specified. This goal, as many CWPPRA goals, does not define the timeframe for goal achievement so we

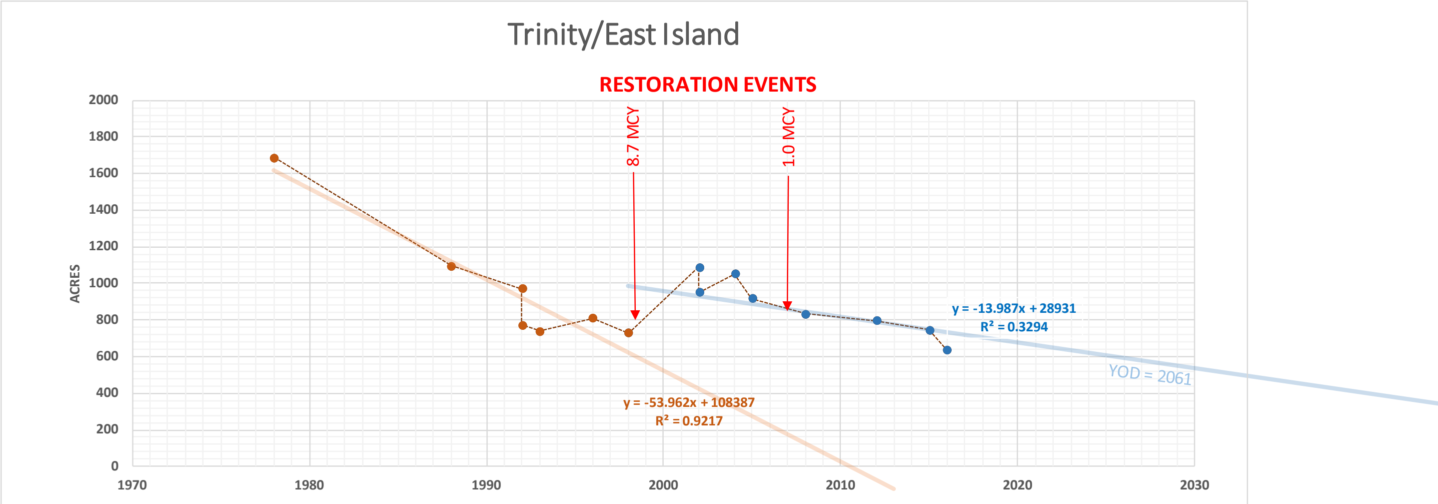
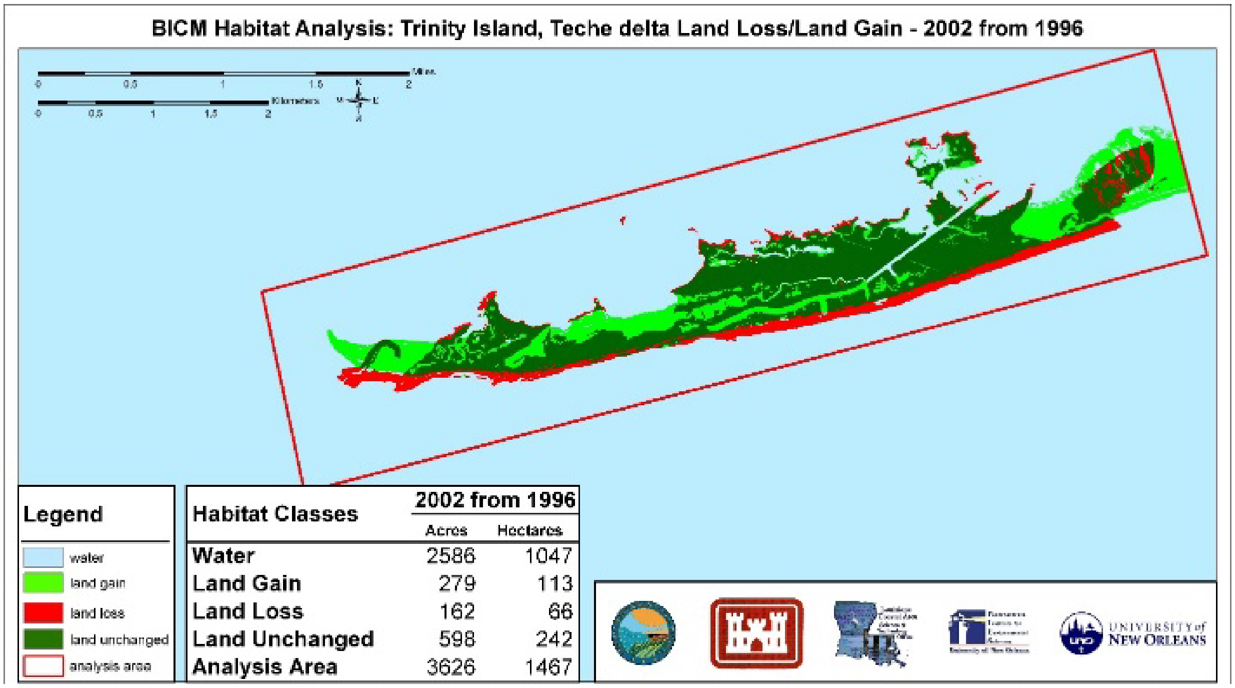


Figure A3. Land area changes from 1978 through 2016 at Trinity/East Island, Isles Dernieres, Terrebonne Parrish, LA.

must assess the creation of acres broadly. The land area data in figures A3 and A5 show no direct impacts of the TE-37 project to immediately creating an additional 261 acres of land. When the TE-37 project was initially approved for design by CWPPRA in 2000, the New Cut area was predominantly water (figure A6). By the time the project was constructed the majority of TE-37 fill area was already classified as land in the 2005 BICM habitat dataset (figure A6) and as such, almost no land was created by the initial construction.

While it is impossible to state the specific contribution of the TE-37 project to the overall reduction in land loss rates and the maintenance of the current 636 acres at East/Trinity Island, it must be acknowledged as a contributor to maintaining the land area noted previously. From 2005 to 2016 the island has lost 283 acres or approximately 26 acres per year. Even this slightly higher land loss rate during the later portion of the post-restoration epoch is a reduction of 48% from the pre-restoration epoch. Again, this is during a period that includes among others, Hurricanes Gustav and Ike in 2008 and Hurricane Isaac in 2012.

Based on the overall project goals of increased island “stability” and creation of “island”, the reported trends and corresponding increased subaerial longevity of the Trinity/East Island indicates these goals have been met.



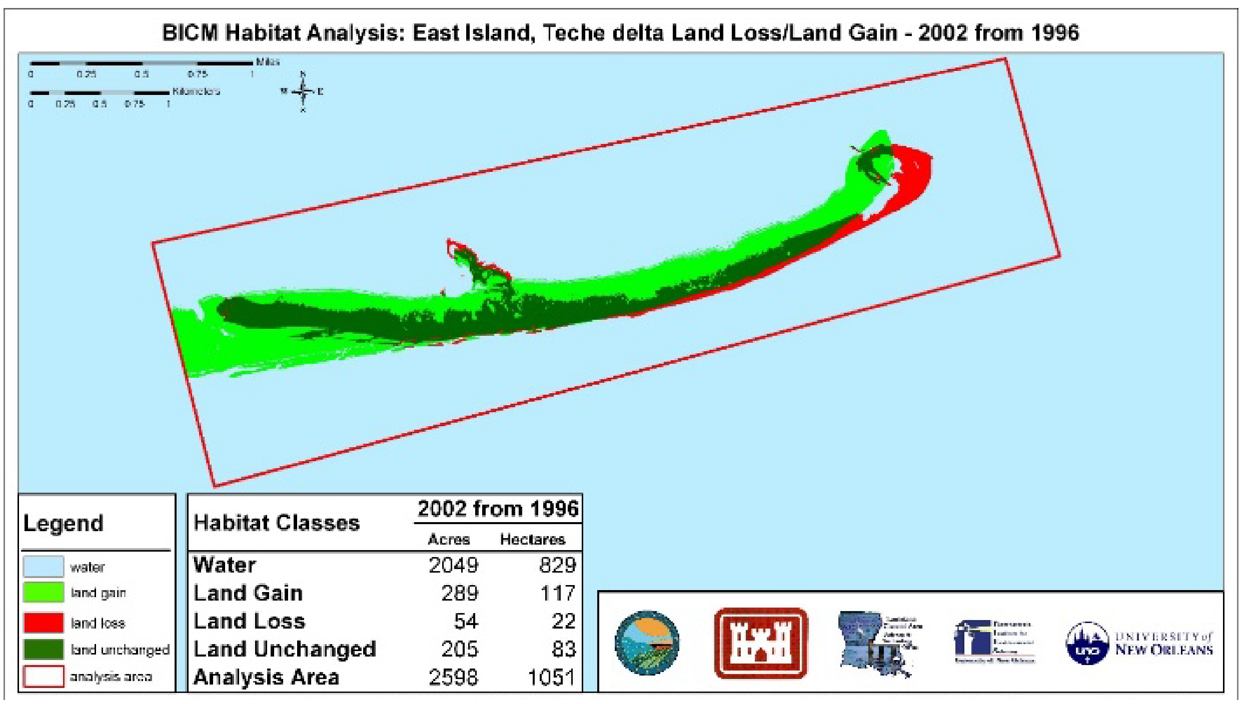


Figure A4. Land area change at Trinity and East Islands from December 1996 to November 2002 (from Martinez et al. 2009). Note the large areas of gain on the north side of East Island as opposed to Trinity Island where more land already existed and was covered with sediments as noted in Penland et al. (2003).

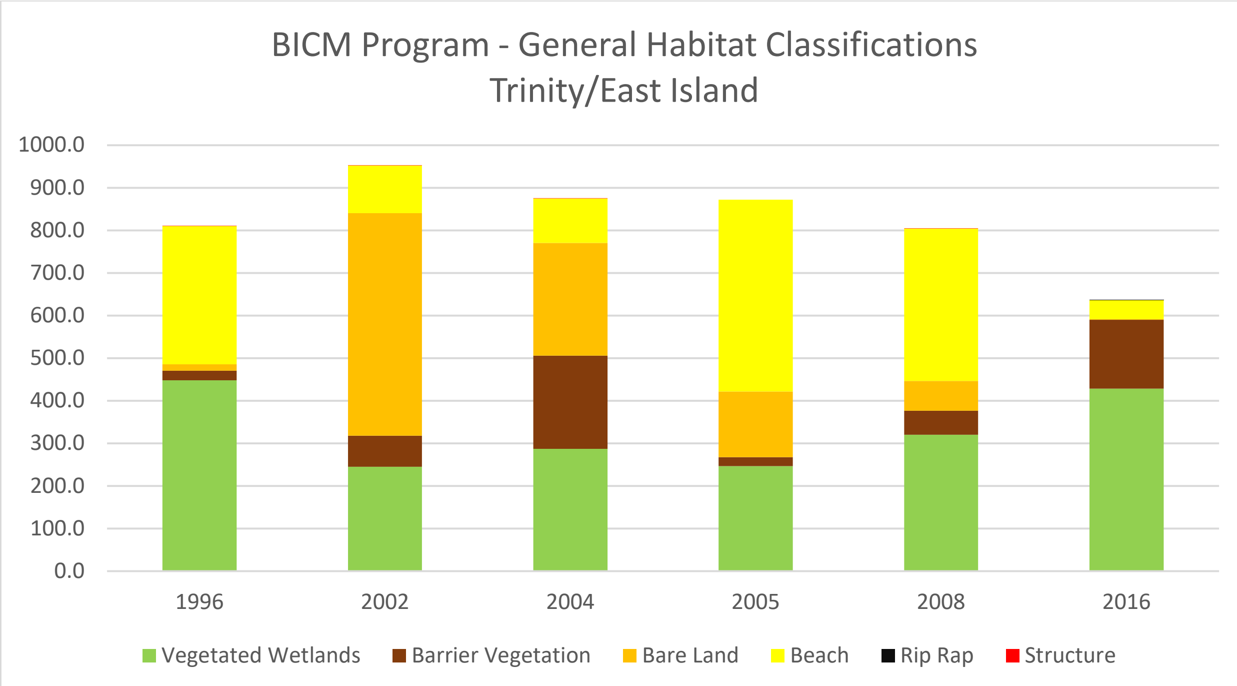


Figure A5. BICM habitat classifications for Trinity/East Island showing cumulative acres of all the land categories. Note similar trends in total land area changes as reported in Figure A2, with gain after restoration efforts in 1998 and land loss thereafter. Changes in habitat classes indicates impacts of restoration events and storms over time.

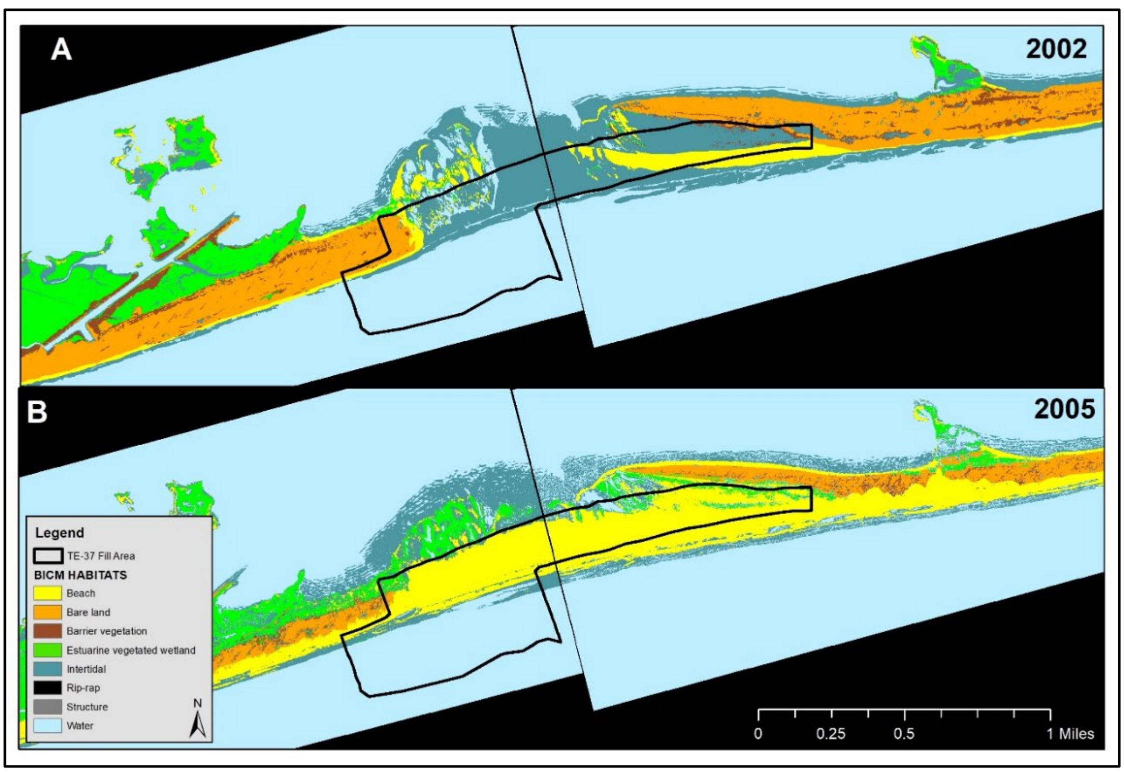


Figure A6. BICM habitat data in 2002 (A) and 2005 (B) indicating the conversion of water to land within the TE-37 fill area (outlined in black).

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Appendix B

Restoration Impacts on Shoreline Positions, Island Lengths, and Island Widths at Trinity/East Island due to the Isles Dernieres Restoration, East Island (TE-20), Isles Dernieres Restoration, Trinity Island (TE-24), and New Cut Dune and Marsh Restoration (TE-37) projects, Terrebonne Parish, LA

May 1, 2020

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Introduction

In order to assess aspects of the restoration efforts on Trinity/East Island, a combination of digitized shorelines and habitat mapping datasets were compiled from various sources to determine shoreline erosions rates, along with island lengths and widths. Data was available prior to and after three large-scale Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) Program restoration efforts (figure B1). These efforts included the Isles Dernieres Restoration, East Island (TE-20) and Isles Dernieres Restoration, Trinity Island (TE-24) in 1998, as well as the New Cut Dune and Marsh Restoration (TE-37) in 2007 (Rodrigue et al. 2008a, Rodrigue et al. 2008b, and T. Baker Smith, Inc. 2007). Both TE-20 and TE-24 projects have goals related to increasing the height and width of the islands, and the TE-37 project has goals related to creating island acreage and "stabilizing dunes". Additionally, all project monitoring plans contained anticipated testing of widths and heights compared to pre-restoration conditions, as well as statements of expected reductions in shoreline erosion rates post-restoration (Townson 1998a, 1998b, and Hubbell 2001). For this assessment the authors will assess terms like "stability" and "create island" by relating post restoration shoreline erosions rates, island lengths, and island widths to pre-restored conditions and rates. Additionally, island lengths and widths will be assessed against the projected disappearance of all subaerial portions of this island by 2011 as predicted in the land area change analysis reported in Appendix A.

Methods

Shoreline Erosion

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

Once the shorelines were compiled and attributed, the USGS Digital Shoreline Analysis System (DSAS version 4.3) was used to quantify changes in shoreline position. Shoreline change analysis was completed by establishing region-specific baselines and shore-perpendicular transects at 50-m (164-ft) longshore intervals. Rates of change were determined by subtracting shoreline positions from each region-specific baseline for distinct time periods and dividing by the exact acquisition period for each shoreline location (figure B2). For detailed information on the sources and methods used for these analyses, see Byrnes et al. 2018.

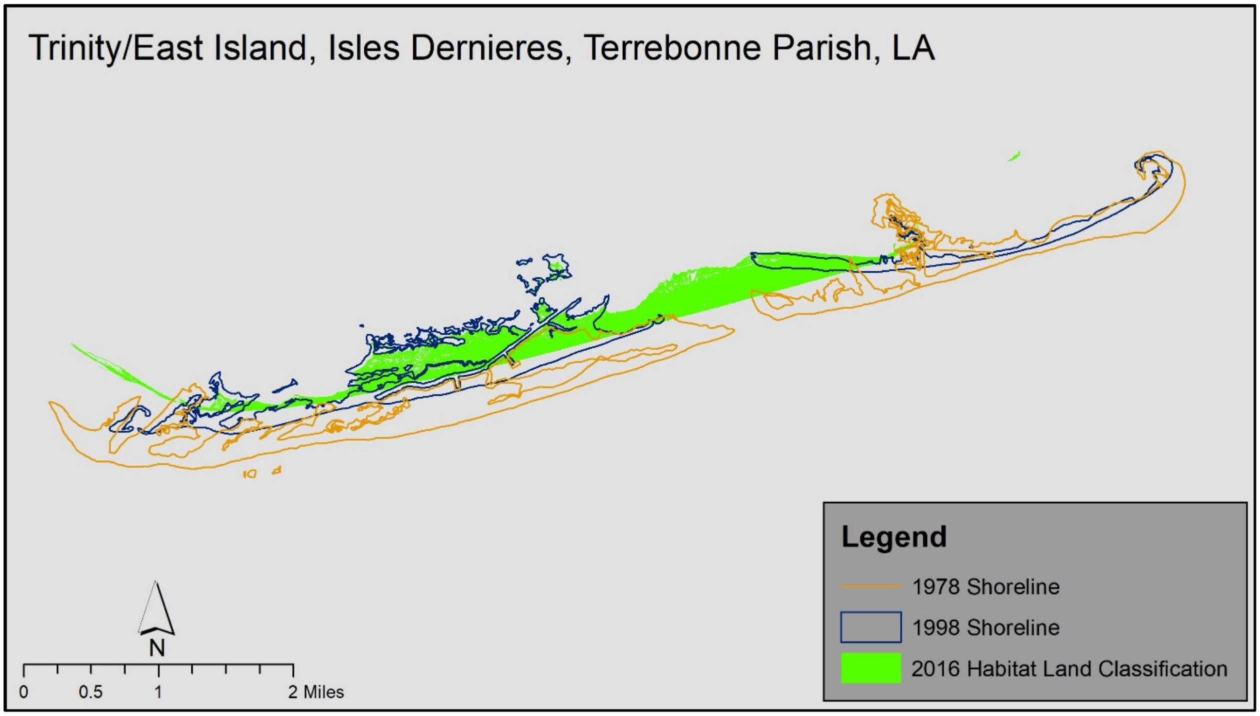

Figure B1. Three example shorelines of Trinity/East Island developed from digitization or habitat classification datasets available from various sources.

In order to assess the impacts of these restoration projects, the shorelines and analysis transects developed by the BICM program were utilized, but data was analyzed as a single shoreline reach, with epochs defined to better assess shoreline change rates prior to and after restoration. Epochs chosen for analysis were: 1) 1950s to 1998, 2) 1998 to 2015, 3) 1998 to 2004, 4) 2004 to 2008, and 5) 2008 to 2015. These time periods represent both a significant period prior to restoration (1950s to 1998), as well as the seventeen years after restoration efforts began (1998 to 2015). The three other periods attempt to parse the impacts of initial restoration events from later restoration at New Cut which was completed in 2007. These epochs were also delineated to look at possible changes in erosion rates as various processes impact the introduced sediments through the project's life.

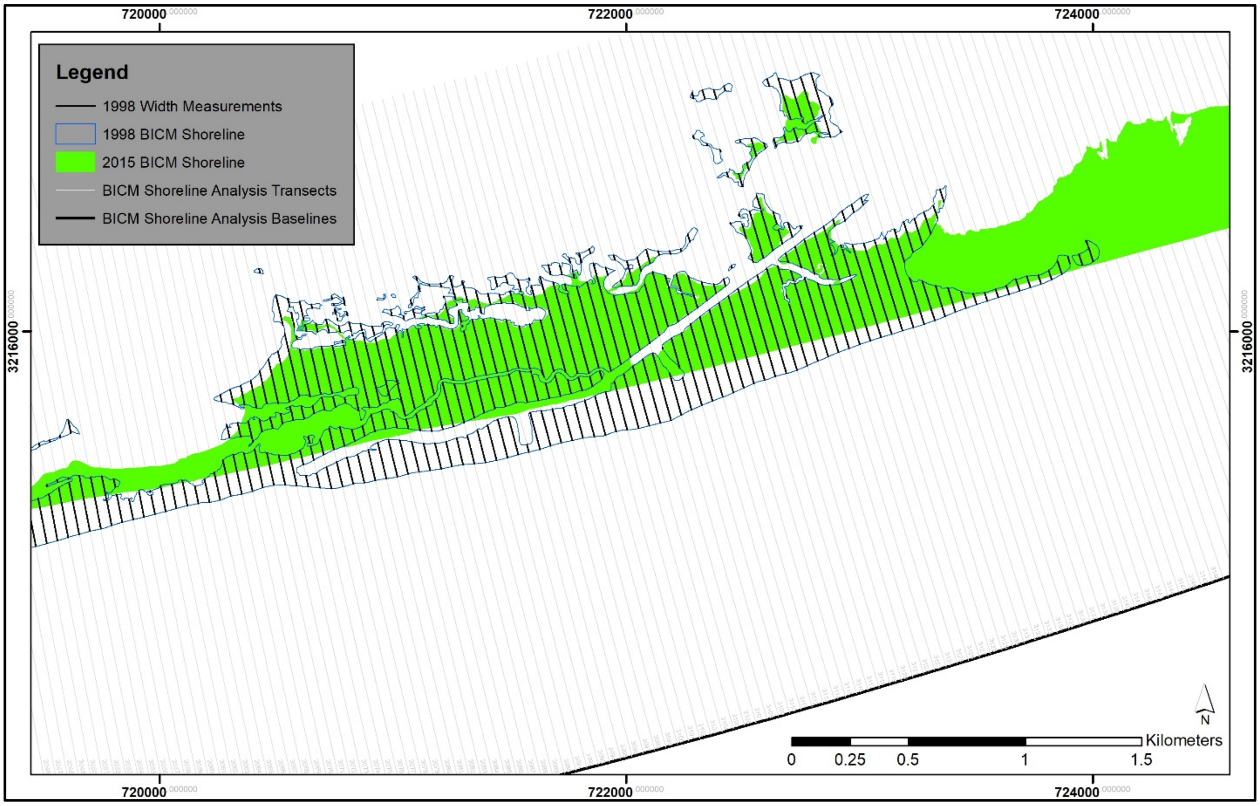

Figure B2. Example of the BICM shoreline measurement baseline and transects along a portion of Trinity/East Island overlain on the 1998 and 2015 datasets. Standardized measurement transects were used for all analysis including shoreline positions, island lengths, and average island widths. Note the measurement transects clipped to the island outline and used to calculate the island width along each transect in 1998.

Island Length

In addition to the BICM shorelines discussed above, a 1978 shoreline is available from USGS (Morton et al. 2004). This shoreline was utilized in determinations of island length due to it being 20 years prior to the large-scale restoration events and providing a pre-restoration epoch similar to the 18-year post-restoration time period.

Lastly, BICM produces habitat classification datasets as described in Fearnley et al. (2009) and Enwright et al. (2020). Per the land area change analysis reported in Appendix A, portions of this analysis utilized the habitat datasets for 1996, 2002, and 2016 by aggregating classes to land and water as was done in the land area change analysis. The aggregation was done in order to determine the land area and define island length.

Island lengths were determined using the same method for both habitat classification datasets as well as digitized shoreline data. Island length was determined from a compilation of all island fragments during each time period. Each fragments length was defined from the first BICM shore-perpendicular measurement transects noted above until the last transect that intersected the digitized line, and the total number of transects was multiplied by the 50m distance between transects (figure B3). The use of the BICM shoreline change baselines and shore-perpendicular transects provided an unbiased determination of the beginning and end of each island fragment

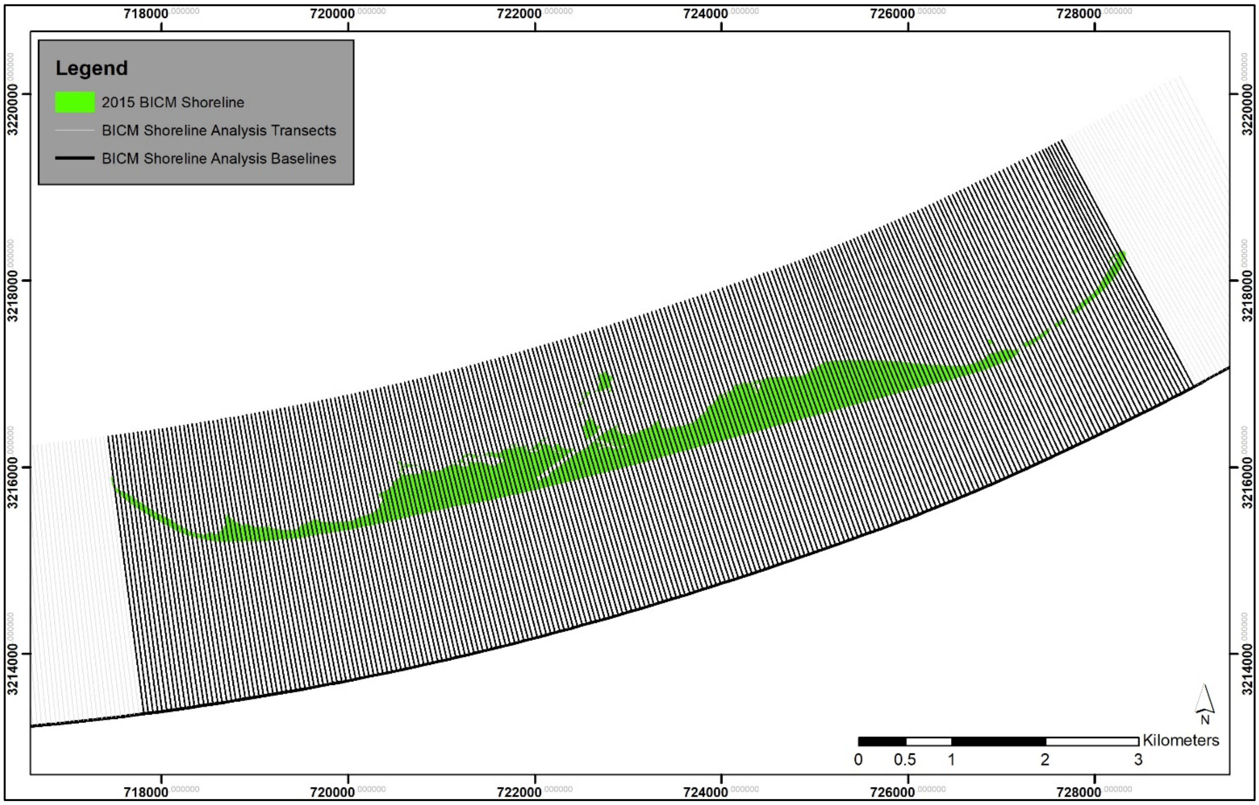

Figure B3. Example of BICM shoreline measurement transects used to define the island length in 2015 at Trinity/East Island, Isles Derniers, Terrebonne Parrish, LA.

and was felt to be more representative of the island length as opposed to a direct computation of the shoreline length, which could be affected by an area of deeply convoluted shoreline.

Final compilation of island lengths for the Trinity/East Island assessment included 10 data points from 1978 through 2016. Island lengths were determined from 7 digitized shorelines and 3 habitat classification datasets. The BICM program developed 9 of the datasets with 1 provided through other sources (Morton et al. 2004, Byrnes et al. 2018, Enwright et al. 2020). A time series plot of island length was created and linear regression lines were fit to the data points before (1998), during, and after restoration periods (figure B4).

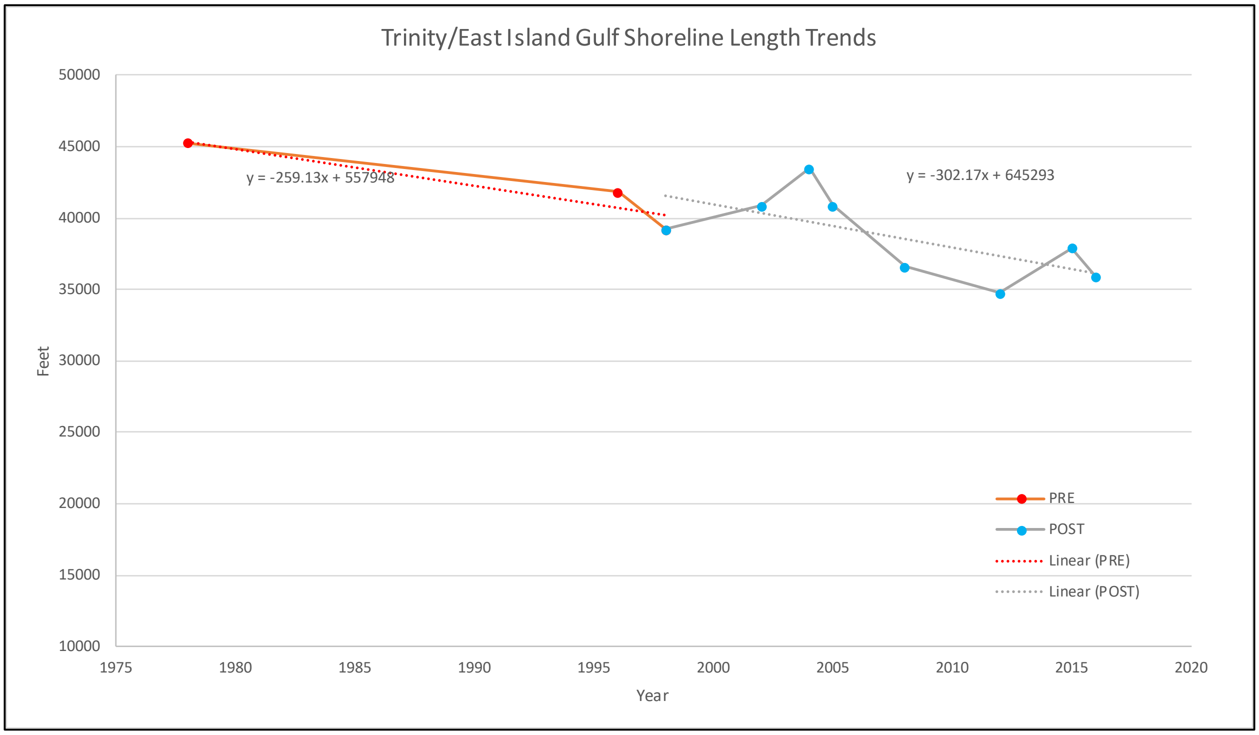

Figure B4. Island lengths at Trinity and East Islands from 1978 to 2016. Note the increase in length from 1998 through 2005 as New Cut filled with sediment and created a contiguous island. However, the overall trend indicates island shortening over time regardless of the initial increase in length, with a post-restoration shortening rate 17% greater than pre-restoration.

Island Width

The BICM program created island polygons for periods after 1978 using the digitized shoreline datasets which allowed for the calculation of island widths to be determined using the previously described BICM shore-perpendicular measurement transects. Island areas available were 1978, 1998, 2004, 2005, 2008, 2012, and 2015. The transects, at 50-m (164-ft) longshore intervals, were clipped to the shoreline polygons (figure B2). Because the BICM datasets are grid based projections, the starting and ending coordinates of the clipped lines were used to determine the line distance geometrically. This allowed the maximum distance to be calculated and it includes ponds, canals, and small bays to be considered part of the island's width. Once maximum distance was calculated for each transect, they were averaged to determine the island width for each period.

Additionally, the 2016 BICM habitat dataset was also used to determine island width. Using the dissolve tool in ESRI® ArcMap™, the individual habitat classification polygons of this datasets were merged into single polygons by habitat class. The polygons classified as water and intertidal were then removed and the remaining habitat polygons were dissolved to produce a single polygon classified as land. This land polygon represents a shoreline as described in the land area change analysis (Appendix A). This polygon was used to determine island width in the same manner as the 7 other BICM shoreline polygons described above. A time series plot of average island width was created and linear regression lines were fit to the data points for various time periods (figure B5).

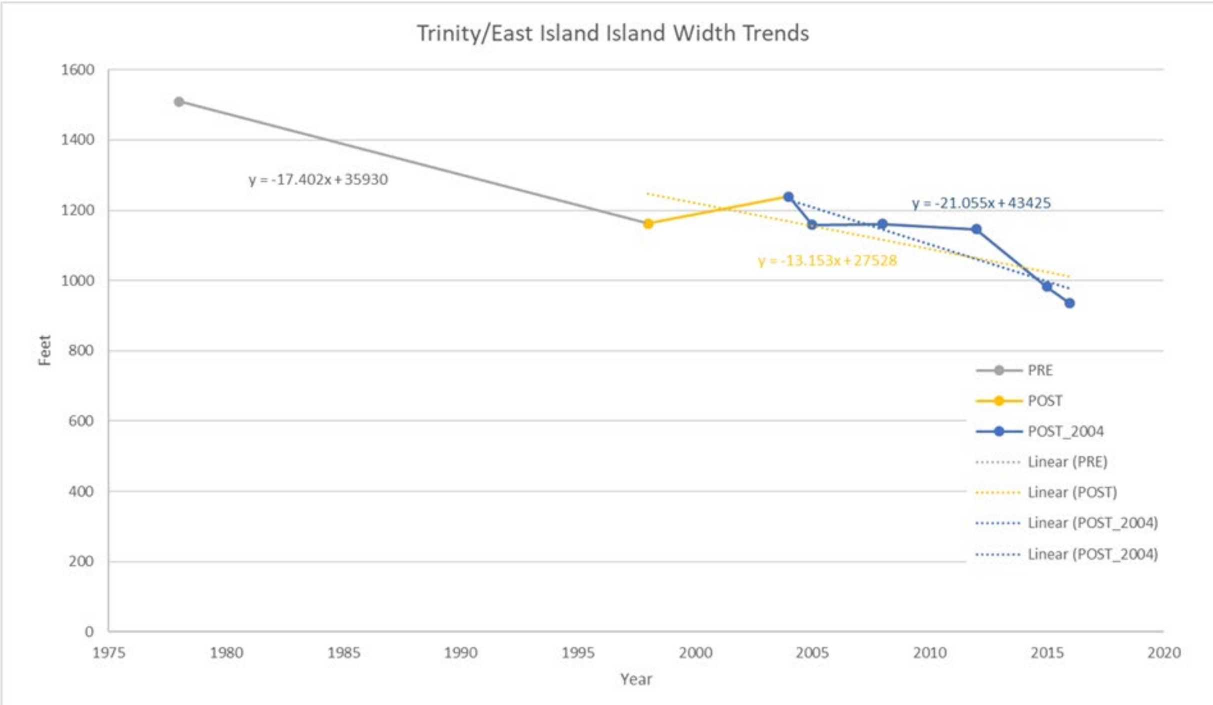

Figure B5. Average island widths at Trinity and East Islands from 1978 to 2016. Note a slight decrease in island narrowing post restoration. This is attributed to the increase in width from 1998 through 2004 as the initial restoration efforts are constructed and New Cut filled with sediment creating a contiguous island. However, the overall trend indicates island narrowing over time regardless of the initial increase in width, with a 20% narrowing of the island post-restoration and a higher rate of narrowing after 2004.

Results

Calculations of shoreline recession at Trinity/East Island in the epoch prior to large scale restoration (1950s-1998) averaged 34.3 ft/yr (table B1), with individual reaches reported by Byrnes et al. (2018) eroding at 43.0 ft/yr and 24.2 ft/yr within the Trinity and East reaches, respectively. After restoration efforts, the 1998 to 2015 epoch exhibits a 35.6 ft/yr shoreline recession rate at Trinity/East (table B1). This is slightly higher than the pre-restoration rate. However, each reach exhibits different results. Trinity's recession rate declined to 34.0 ft/yr during this period, while the East Island reach's recession rate almost doubles to 42.8 ft/yr (figure B6).

When examining various epochs after restoration, the initial post restoration period (1998 – 2004) at Trinity/East exhibits a slightly reduced shoreline recession rate of 30.4 ft/yr. This minor reduction is during a period in which Hurricanes Lili and Isadore, among others occurred (NOAA 2019). The land area change data presented in Appendix A shows 2002 has some of the worst land loss in any single year as Hurricanes Lili and Isadore made landfall in close proximity to the island. From 2004 to 2008 the island again exhibits a high erosion rate at -35.5 ft/yr. During this period, Hurricanes Ivan, Katrina, Rita, Gustav, and Ike impacted south Louisiana, with Gustav passing directly east of the island in 2008. Lastly, the period from 2008 to 2015 provides the lowest erosion rate of any post-restoration epochs. Trinity/East during this period eroded 26.1 ft/yr, even with Hurricane Isaac making landfall just east of the islands in 2012. This reduced rate may be due to the low number of storms during this period or the TE-37 project adding sediment to the system.

Table B1. Shoreline position changes during various Epochs at Trinity/East Island, Isles Dernieres, Terrebonne Parish, LA.

EPOCH	CHANGE RATE (FT/YR)	STANDARD DEVIATION (FT)
1950S TO 1998 (PRE)	-34.3	15.5
1998 TO 2015 (POST)	-35.6	47.9
1998 TO 2004	-30.4	18.7
2004 TO 2008	-35.5	33.1
2008 TO 2015	-26.1	60.8
2012 TO 2015	-10.6	21.5

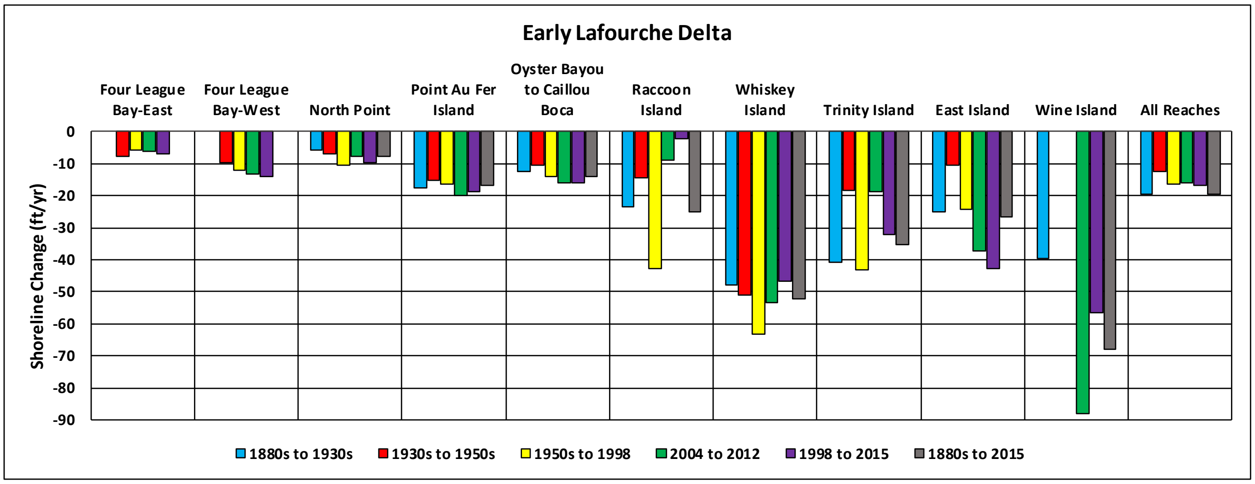

Figure B6. BICM shoreline change for the Early Lafourche Delta (from Byrnes et al. 2018). Note the Trinity Island reduction in erosion post restoration (1998-2015), while East Island exhibits a large increase during this period.

The lack of change in shoreline erosion rates post-restoration may indicate that the processes associated with shoreline erosion have not been dramatically altered by these projects. However, it should also be noted that a higher than average number of storms occurred during the 1998 to 2015 epoch, as documented in the land area change analysis (Appendix A), and this may negate potential restoration effects on shoreline positions. Additionally, the reduction in the recession rate in the Trinity reach, while the East reach exhibited a significantly increased erosion rate, supports the idea that sediment transported along shore from the East Island reach is helping to maintain the Trinity shoreline. However, no sediment is replenishing the East Island area and the erosion rates are significantly increasing. Lastly, these projects were early designs which placed the sediment behind the existing shoreline. This design does not move the shoreline gulfward as later designs have done, thereby leaving shoreline positions unaffected initially. These early designs do not change the position of the shoreline through initial construction and therefore do not directly affect change rates.

Trinity/East Island also exhibited a reduction in length during both the pre- and post-restoration periods (figure B4). In 1978, 20 years prior to restoration, the length of Trinity/East totaled approximately 45,275 feet and by 1998 had reduced to approximately 39,206 feet, which is an approximate rate of –303 ft/yr. After restoration the island continued to exhibit a reduction in length and by 2016 had been reduced to approximately 35,925 feet in length, which is an approximate rate of -182 ft/yr. Noticeably, the eastern end of the island is the area of greatest shortening as approximately 9,678 ft of the former East Island portion has completely eroded.

This increased rate of shortening during the 18 years post-restoration may indicate that these restoration projects are not overriding the impacts of system drivers that affect island shortening and fragmentation, such as an increasing tidal prism. The continuing wetland loss within the back barrier bays is not being addressed sufficiently, driving the need for more and or larger tidal cross sections. This process is documented to impact island length and other shoreline processes (FitzGerald 1984, FitzGerald et al. 1984 and 2003).

During two post-restoration epochs there were periods of increased island length. The period from 1998 until 2004 exhibited tremendous increases in island length, driven predominantly as the New Cut area was filled with sediment due to longshore transport processes. The total lengths went from approximately 39,206 feet to 43,471 feet during this period, as the shoreline built in this area, completely closing the New Cut breach by 2005. After 2005 the island was reduced in length again until the second period of island lengthening occurred between 2012 and 2015. During this time the island increased 3,117 feet in length, due to an accretion of the terminal spits on each end. This lengthening corresponds to a very low shoreline recession rate of only 10.6 ft/yr during this period (table B1). Both these periods point to the potential impacts of added sediments filling shallow breaches, as well as transported sediments building large terminal spits during low storm periods.

Island widths were not readily available prior to restoration with only 1978 and 1998 datasets available. During this period the average width decreased by approximately 17.4 ft/yr. However, post-restoration the island only narrowed at a rate of approximately 13 ft/yr (figure B6). Like the island length analysis, which showed lengthening during the immediate post-restoration period of 1998 to 2004, this was a period of widening. The average width was increased during this period by approximately 77.7 feet, predominantly due to the restoration template of TE-20 which filled shallow open water on the bayside of the existing land area as described in the land area change analysis (Appendix A). However, once the initial widening was achieved, the island exhibited a decrease in width between 2004 and 2005, attributed to Hurricanes Katrina and Rita, and a period of stability from 2005 to 2012 during which the average width of the island only changes approximately 2%.

This stability changes dramatically after Hurricane Isaac in 2012, as a steep reduction in average width is noted which increases the overall rate of narrowing during this period to approximately 21.1 ft/yr. The period of stabile island widths does correspond to the construction of the TE-37 project in 2007 which adds sediment to the New Cut area. As noted in the land area change analysis in Appendix A, the project was built on existing land and as such contributed little to initial widening of the island, however the sediment placed in the Trinity/East Island system may have contributed to maintaining the width indirectly.

The shoreline position changes, island lengths, and average island widths all exhibit little overall trend changes post-restoration. This leads to the conclusion that the projects did not meet the directly stated goal of reducing rates of erosion but did slightly reduce island narrowing although via initial widening. These results also indicate that the less well-defined goal statements concerning acreage creation, and island stability were not met as well. However, the fact that the islands still have subaerial land indicates that initially increasing island land area as discussed in Appendix A and the brief periods of positive change during the various epochs analyzed lead toward positive outcomes. We must integrate the results here with the land area change analysis which predicted no sub-aerial land existing in 2011. Each of the three variables; 1) shoreline position, 2) island length, and 3) average width, exhibited some positive impacts during the various epochs analyzed. Each shows contributions of the projects to reduced erosions rates or increased lengths and widths for some periods that surely contributed to accomplishing the projects overarching goals as well as the individual goals for short period(s) post-construction.

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Appendix C

Elevation and Sediment Volume Changes at Trinity/East Island due to the Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24), and New Cut Dune and Marsh Restoration (TE-37) projects, Terrebonne Parish, LA

June 1, 2020

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Introduction

In order to assess project changes to the Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24), and New Cut Dune and Marsh Restoration (TE-37) projects as well as the Trinity/East Island area, five (5) elevation data sets were analyzed to ascertain the impacts to island heights and volumetric changes related to the sediment within a portion of the three (3) project areas, which will be referred to as the analysis area. Additionally, sediment and volume changes will be assessed for Trinity/East Island as a whole in order to address the processes of sediment transport that are expected to move placed sediments. Trinity/East Island were two separate islands known as East Island and Trinity Island, with a breach between them referred to as New Cut. Once the New Cut breach was closed as a result of longshore sand transport in 2005, the island has been referred to as Trinity/East Island and encompasses the TE-20, TE-24, and TE-37 project areas. Both the TE-20 and TE-24 projects have goals related to increasing the height of each island by using dredged sediment, while the TE-37 project has goals of creating dune and supratidal habitats. For this assessment, acreages for five (5) elevation classes were determined along with the overall average elevations, and the sediment volume changes for the available surveys.

Methods

In order to assess individual project impacts as well as the overall impact to Trinity/East Island, elevation data was analyzed to ascertain heights, classify those heights into predefined Wetland Value Assessment (WVA) elevation classes, and calculate the area of each class. The analysis also determined the average/overall height, and volumetric changes within project analysis areas. The analysis area is a limited portion of the project area where elevation data was collected in commonality over all time periods. Upon completion of individual projects, each project had sediment deposited within a more limited construction footprint (T. Baker Smith 2007). These footprints were surveyed at various spatial coverages and common analysis areas were developed that covered as much of the construction footprint as possible. The analysis area represents as much of the initial sediment deposition as possible but only indicates trends in sediment and elevation changes within the initial construction footprint. For the TE-20 project, the analysis area represents 16% of the project area; the TE-24 analysis area represents 48% of the project area; and the TE-37 analysis area represents 66% of the project area.

Topographic and bathymetric surveys were employed to document elevation. Surveys utilized for this report were collected pre-construction for engineering and design, upon completion of a project (as-built), and at various times post-construction through various funding sources. Depending on the funding source and purpose, each survey had a slightly different spatial coverage. Due to the limited coverage of the engineering and design survey, no pre-construction data is presented in this report; hence, only data collected as part of as-builts and thereafter are analyzed. Through the CWPPRA program, surveys for a project often times just covered the construction footprint or slightly outside of it. Whereas surveys conducted through the Barrier Island Comprehensive Monitoring (BICM) program were not project specific, these surveys were coast-wide. Hence, the bathymetric portion of BICM surveys were more general in nature (1,500 ft transect spacing) verses more detailed project funded surveys (250 – 500 ft transect spacing).

However, BICM topography was LiDAR based and provided very detailed topographic data coverage as opposed to the project funded surveys transect spacing.

When comparing older data sets to newer data sets, transformations between various datums used at the time of each survey were needed in order to ensure datasets were comparable. All data were adjusted to the Universal Transverse Mercator (UTM) North American Datum of 1983 (NAD83) coordinate system and the North American Vertical Datum of 1988 (NAVD88) in meters using Corpscon® software. Detailed information on the various surveys can be found in individual survey reports or project completion reports. Table C1 summarizes when surveys were conducted, the project(s) associated, the project phase, and the associated source for the data.

Table C1. Topography and bathymetry survey data acquisition dates, associated projects and time periods, method of data collection, and the funding source.

Survey Acquisition Date	Project(s)	Project Period	Data Type	Funding Source
December 1998	TE-20 & TE-24	As-Built	RTK cross-sectional	Project
March 2000	TE-20 & TE-24	Post-construction	LiDAR	Project
July 2006	TE-20, TE-24, & TE-37	Pre- & Post-construction	LiDAR & Bathymetry	BICM
January 2007	TE-37	Pre-Construction	RTK cross-sectional	Project
July 2007	TE-37	As-Built	RTK cross-sectional	Project
February & December 2015	TE-20, TE-24, & TE-37	Post-construction	LiDAR & Bathymetry	BICM

The adjusted data were imported into ESRI®ArcMap™ software for surface interpolation. Triangulated irregular network (TIN) models were produced from the point data sets. Next, the TIN models were converted to raster grid models (3.3 ft^2 cell size), and the spatial distribution of elevations were mapped into five (5) elevation classes: 1) dune, which is any elevation >5.0 ft; 2) supratidal, consisting of elevations between 2.0 – 5.0 ft; 3) intertidal, consisting of elevations between 0 – 2 ft; 4) subtidal, consisting of elevations between -1.5 – 0 ft; and 5) non-WVA, consisting of elevations <-1.5 ft (Roy 2002). The grid models were clipped to the TE-20, TE-24, and TE-37 analysis area polygons to estimate elevation and volume changes within each analysis area. One other polygon was produced to assess the greater spatial distributions of the combined BICM Light Detection and Ranging (LiDAR) and bathymetric surveys in 2006 and 2015 – a Trinity/East Island polygon. The Trinity/East Island polygon was utilized to evaluate elevation and volume changes to the whole island system (from pass to pass) due to the BICM surveys more extensive spatial coverage.

The 2006 BICM LiDAR and bathymetric surveys were joined to form a single continuous elevation model of this barrier island as described above, however the 2015 BICM LiDAR and 2015 bathymetric data needed no transformations and were simply joined by merging existing BICM program grid models to form a single continuous surface. The February 2015 LiDAR and the December 2015 bathymetric data were merged to form a single continuous elevation grid model, referred to as the December 2015 dataset, of Trinity/East Island. The first step in this process was to create two separate grid models for topography and bathymetry using the methodology from the previous paragraph. Next, a hole was created in the bathymetric grid at the island position (location of the LiDAR grid) by creating a polygon that is slightly smaller than the LiDAR grid to allow the two grids to be blended seamlessly. This procedure was completed with the Mask Function of the Image Analysis Tool of ESRI®ArcMap™. Next, the grids were merged using the Mosaic to New Raster function of the Data Management Tools extension of ESRI®ArcMap™. This created a single grid with both the LiDAR and bathymetric data incorporated.

Elevation changes were calculated for TE-20, TE-24, and TE-37 by subtracting the various combinations of grid models using the Minus Tool utility of the Spatial Analyst extension of ESRI® ArcMap™. Volume changes were calculated in cubic meters (m^3) using the Cut/Fill Calculator function of the 3D Analyst extension of ArcMap™. Once calculated, volume changes were summarized in a tabular format (ft^3 and %) to display project and area trends. In addition, the volume changes (ft^3) and grid model mean elevations (ft) were graphically illustrated for each analysis area. Note, these elevation and volume calculations are valid only for the extent of analysis areas based on the availability of corresponding survey areas.

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

The 2008 Operations, Maintenance, and Monitoring reports for the TE-20 and TE-24 projects analyzed and reported on the survey data collected in September 1997, December 1998, and March 2000 (Rodrigue et al. 2008a and 2008b). This report focuses on the later data sets and the larger Trinity/East Island system, particularly the period after addition of sediment from the TE-37 project in 2007. As noted above, the elevations presented in this report are representative of the NAVD88 Geoid12B model, whereas the previous reports used the NAVD88 Geoid99 model. Hence, there may be slight differences amongst heights and volumes presented here for the same time periods presented by Rodrigue et al. (2008a and 2008b).

Results

As defined by the WVA elevation classes used in this assessment, upon the immediate conclusion of construction at TE-20 and TE-24 in 1998, the objective to restore coastal dunes appeared to have been met. As indicated in figures C1 and C2 and table C2, there was a total of 325.8 acres of dune elevation class (>+5.0 ft) represented within the analysis areas. As stated above the, pre-construction survey spatial coverage was severely limited and so acreages of dune elevations were not available prior to construction. However, the 1996 BICM habitat data presented in Appendix

D classifies 37.8 ac of the island in habitat classes potentially containing dune elevations. While different methodologies, this may be an indicator of a substantial increase in the amount of dune elevation class at Trinity/East island due to the construction activities.

Between December 1998 to March 2000, minor changes in elevation classes along with small sediment volume losses (Figure C1 and C2; Table C2 and C3) within the TE-20 and TE-24 analysis areas. This was a quiescent period with very little tropical storm activity along Louisiana's Gulf of Mexico shoreline. Interestingly, the TE-20 and TE-24 sediment volumes declined by virtually parallel magnitudes for this interval (Table C3), yet still amounted to 12.2 % of the original fill volumes placed during project construction.

Between March 2000 and July 2006, both the TE-20 and TE-24 analysis areas showed larger changes in elevation class acreages and sediment volumes. The TE-20 analysis area experienced an overall elevation reduction of 3.4 ft with a corresponding loss of 45.7 ac of dune and 35.9 ac of supratidal elevations. These acreage reductions corresponded to a sediment volume loss calculation of 1,336,210 cubic yards (yd^3). The TE-24 analysis area experienced a slightly lower elevation reduction of 2.26 ft, and experienced a loss of 76.8 ac of dune and 29.7 ac of supratidal elevations. The elevation losses at TE-24 corresponded to a sediment loss of 1,254,809 yd^3. The volume reductions with the TE-20 and TE-24 analysis areas correspond to 19.8% of the total 6,345,000 yd^3 construction volume placed by these two projects.

During this period, as the acreages of dune and supratidal classes decreased in the analysis areas, the intertidal, subtidal, and non-WVA class acreages increased. The dominant causes of these changes is attributed to the impacts of several storms during the 2002 and 2005 hurricane seasons, with Hurricanes Isidore and Lili in 2002 and Cindy, Katrina, and Rita in 2005 being noteworthy.

These storms reduced sediment volumes, altered shorelines, and induced overwash on Trinity/East Island (Georgiou et al. 2005; West and Dearmond 2007a; West and Dearmond 2007b; Morton and Barras 2010). Particularly there was a 2,500 ft reduction of island length within the analysis area along the eastern end of TE-20, and shoreline recession in the central reach of TE-24 (Figure C1 and C2). Moreover, a large proportion of the TE-20 project does not have supporting back barrier marshes leaving these narrow beach and dune barriers predisposed to overwash, truncation, elevation declines, and large sediment volume losses.

It must be emphasized here that these island length and volume changes are specifically associated with the analysis area extents only and island length and volume losses presented may be offset as sediment transport moves sediment to other areas of the Trinity/East system not surveyed. For example, the New Cut inlet is not captured in this elevation analysis due to a 4,000 ft gap between the TE-20 and TE-24 analysis areas. Since restoration in 1998 the New Cut breach has exhibited considerable infilling, with the majority of this inlet being classified as habitats considered subaerial by 2005 (Appendix D). Additional documentation is provided by the 2006 BICM program elevation datasets capturing the joining of the two islands as noted by the intertidal elevations in the center portion (Figure C3). Nine years later the BICM 2015 survey again captures the union of these two islands, as well as the even higher elevations which are attributed to the 2007 construction of the New Cut Dune and Marsh Restoration (TE-37) project (Figure C3).

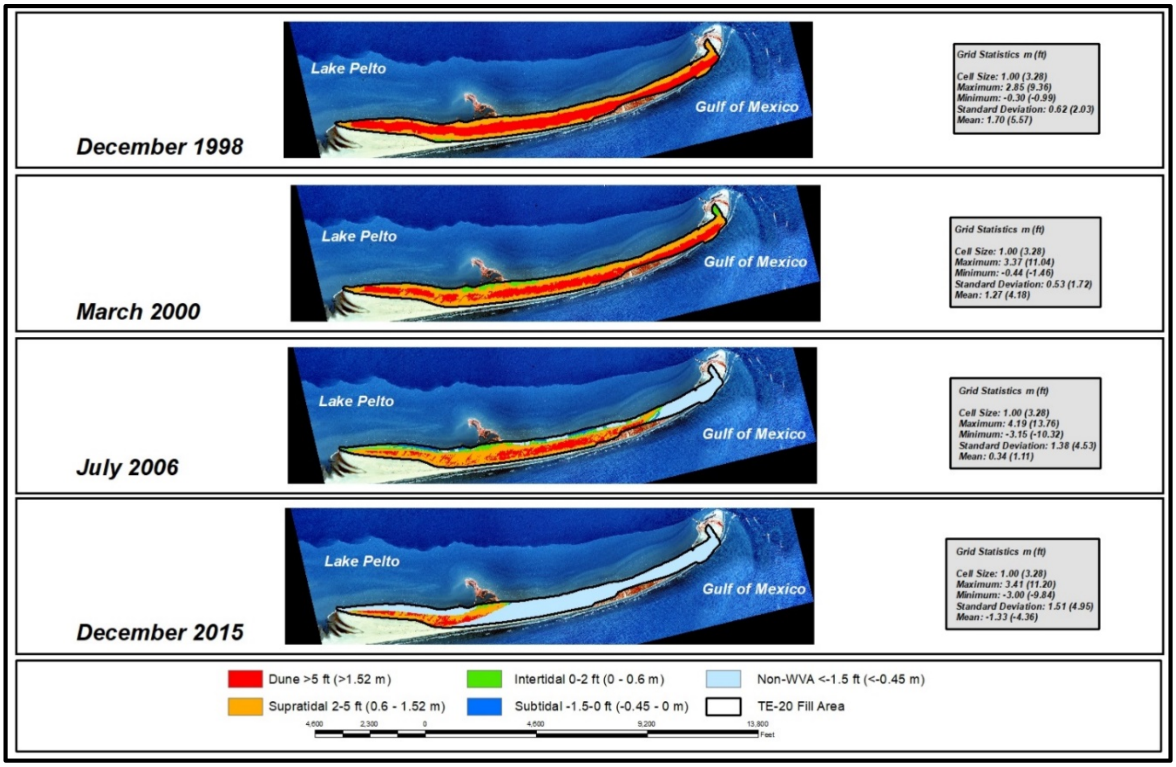


Figure C 1. Elevation classification of the analysis area for the Isles Dernieres Restoration East Island (TE-20) project for four time periods from as-built (1998) to seventeen years post-construction (2015).

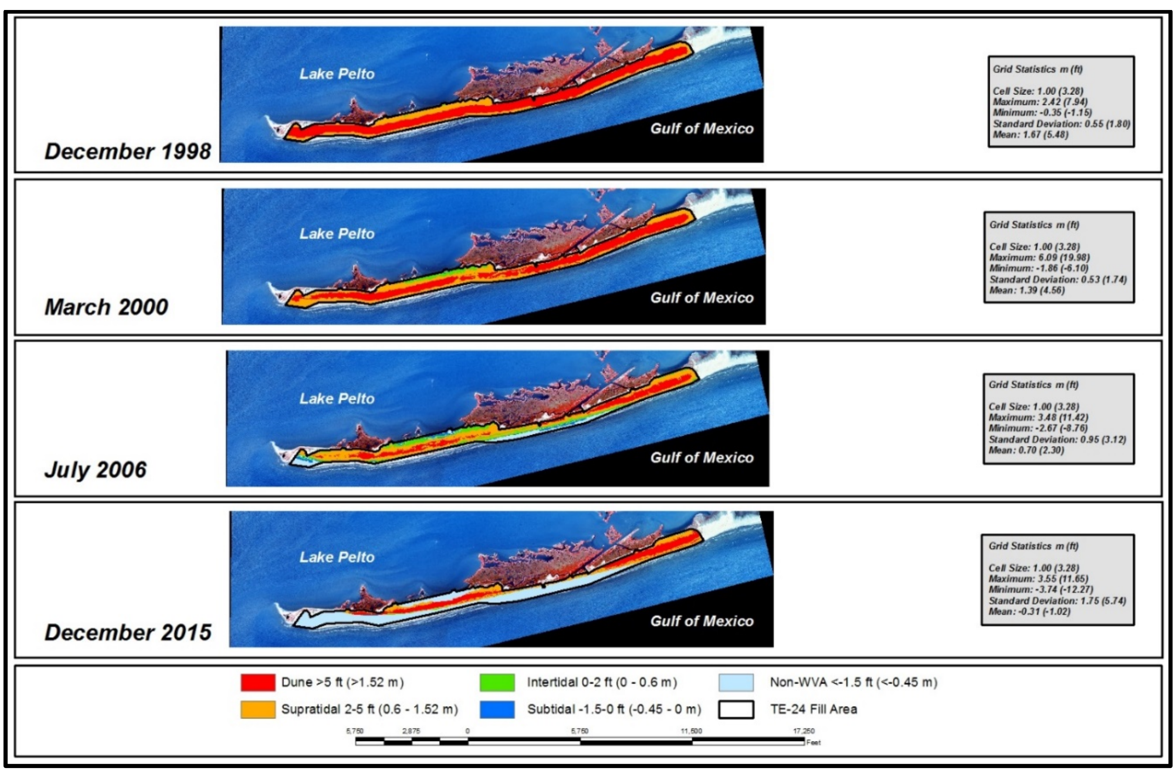


Figure C 2. Elevation classification of the analysis area for the Isles Dernieres Restoration Trinity Island (TE-24) project for four time periods from as-built (1998) to seventeen years post-construction (2015).

Table C2. Area within each WVA Elevation Classification for the TE-20, TE-24, TE-37 projects between 1998 and 2015 along with the Trinity/East Island complex areas in 2006 and 2015.

		Dune	*Supratidal*	*Intertidal*	*Subtidal*	*Non-WVA*	*Overall Analysis Area Elevation*
Project/Area	**Year**	**> 5.0 ft**	**2.0 - 5.0 ft**	**0 - 2 ft**	**-1.5 - 0 ft**	**< -1.5 ft**	**ft**
TE-20	1998	125.4 ac	109.6 ac	6.2 ac	0.6 ac	0.0 ac	5.31
TE-20	2000	86.2 ac	132.2 ac	23.1 ac	0.3 ac	0.0 ac	4.13
TE-20	2006	40.5 ac	96.3 ac	34.4 ac	13.9 ac	56.6 ac	0.73
TE-20	2015	14.8 ac	35.2 ac	4.3 ac	0.3 ac	187.1 ac	-4.43
TE-24	1998	200.4 ac	138.4 ac	9.5 ac	0.1 ac	0.0 ac	5.47
TE-24	2000	146.3 ac	180.3 ac	20.7 ac	0.5 ac	0.0 ac	4.56
TE-24	2006	69.5 ac	150.6 ac	63.8 ac	17.9 ac	48.3 ac	2.3
TE-24	2015	76.8 ac	79.7 ac	5.3 ac	0.3 ac	188.0 ac	-1.02
TE-37	2007	63.1 ac	100.2 ac	16.4 ac	6.8 ac	61.5 ac	1.27
TE-37	2015	43.6 ac	116.0 ac	3.4 ac	0.0 ac	85.0 ac	-0.06
Trinity/East Island	2006	116.4 ac	311.9 ac	426.0 ac	357.2 ac	24,400.1 ac	NA
Trinity/East Island	2015	143.4 ac	331.5ac	242.2 ac	61.6 ac	24,829.6 ac	NA

Table C3. Sediment volume change between time intervals by project.

Project	**Time Interval**	**Volume Change (yd^3)**
TE-20	1998 – 2000	-542,361
TE-20	1998 – 2006	-1,878,572
TE-20	1998 – 2015	-4,108,225
TE-24	1998 – 2000	-526,121
TE-24	1998 – 2006	-1,780,929
TE-24	1998 – 2015	-3,656,928
TE-37	2007 - 2015	-528,391

Analysis areas continued to show changes in the dune and supratidal elevation classes between July 2006 and July 2015. The TE-20 analysis area experienced a sediment volume loss of 2,229,653 yd^3, with corresponding losses of 25.7 ac of dune, 61.1 ac of supratidal, 30.1 ac of intertidal and 13.6 ac of subtidal classes. Overall the TE-20 analysis area had an average elevation reduction of 5.16 ft. Concurrently, the TE-24 analysis area experienced a sediment volume loss of 1,875,999 yd^3, but had a slight increase in dune elevation class of 3.0 ac during this period. The elevation classes of supratidal, intertidal, and subtidal each had reductions of 70.9 ac, 58.5 ac, and 17.6 ac, respectively. This led to an overall elevation reduction of 3.32 ft in the analysis area. The combined volume reductions in the analysis areas during this period accounted for an additional 64.7% of the original construction volumes placed.

During 2006 to 2015 period, as the acreages of dune, supratidal, intertidal, and subtidal changed, the non-WVA class acreages increased. A considerable part of these large sediment volume losses and elevation class changes are attributed to Hurricanes Gustav and Ike in September 2008.

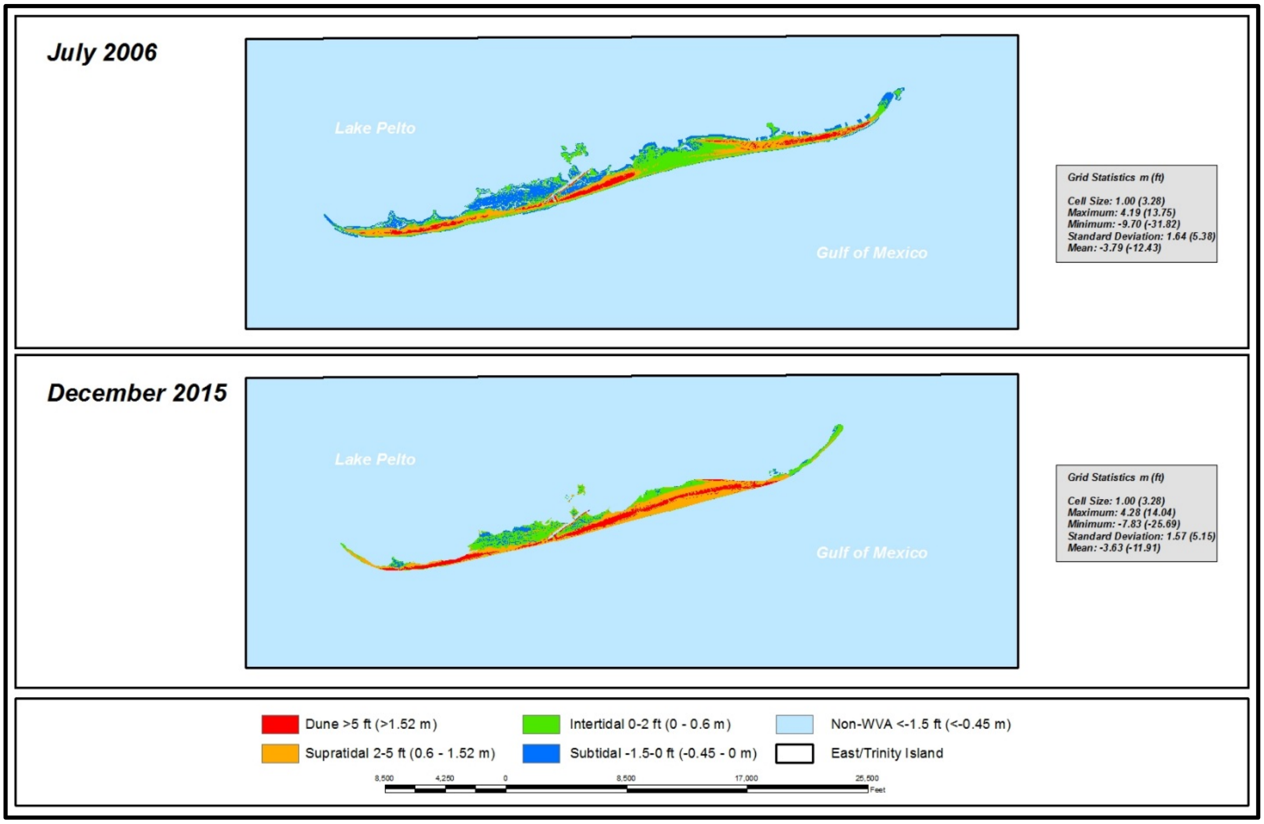


Figure C3. Elevation classification of the Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24), and New Cut Dune and Marsh Restoration (TE-37) projects after joining in 2004/05. Data for larger spatial coverage obtained from the BICM program.

Hurricane Gustav passed within 0.5 mi of the eastern tip of Trinity/East Island and induced considerable modifications to the island's geomorphology. During these storms, the eastern reaches of TE-20 were relocated approximately 3,500 ft to the west, such that the 2008 eastern edge was 7,000 ft from its 2004 position. Other sandy shorelines in the Terrebonne Basin have also reported extensive land loss as a result of these 2008 storms (Morton and Barras 2010; Rodrigue et al. 2011; Curole and Lee 2013; Curole et al. 2017).

However, the 2008 storms are not the only cause of the substantial volume losses that occurred in the analysis areas as of 2016. The island shoreface within the TE-20 and TE-24 analysis areas continued to steepen as noted by the large increase in non-WVA elevation class acreages over time. Also, by 2015, the eastern terminal end of TE-20 had truncated approximately 10,000 ft to the west causing the subaerial acreage of this analysis area to decline (Table C2). As sediment was transported either along shore or cross shore, the analysis area continued to deepen below -1.5 ft. However, we must again note that the limited survey coverage and the subsequent analysis area boundaries do not capture sediment that may be transported outside the analysis area, yet still contribute to maintaining acreages of the higher elevation classes or maintaining island lengths. In fact, the island length analysis presented in Appendix B shows that the overall length of Trinity/East island was longer in 2015 than in 2008, indicating that while transgression of the shoreline and sediment transport were impacting the analysis areas negatively, the island was not impacted by these processes to the same extent.

While the TE-20 and TE-24 analysis areas were eroding on their edges, they likely buffered the TE-37 analysis from shoreline transgressions. The volume of the TE-37 project declined by 528,391 yd^3 for the interval from July 2007 to December 2015 (Table C3). During this period while 19.5 ac of dune elevations were lost, a corresponding 15.8 ac of supratidal elevations were gained, and the overall analysis area elevation declined 1.34 ft. Moreover, the largest volume losses in the TE-37 analysis area occurred along the shoreface area of the analysis area (Figure C4). This volume loss within the analysis area would account for 52.8% of the total construction fill volume placed.

Volume changes within the various project analysis areas, as expected, indicated loss of sediment through time. TE-20 for example shows more volume removed than placed within the total construction fill footprint. However, the BICM program surveys in 2006 and 2015 allow a comprehensive look at sediment volumes within the complete island system, and indications are that sediment placed is contributing to maintaining volumes within the island system during this period (Figure C5). The elevation changes during this period indicate shoreface erosion with corresponding landward migration/deposition of the island, particularly at each end. Additionally, sediments are being deposited off each end of the island into the corresponding passes forming depositional shoals. This pattern mimics the longer term Operational Sediment Budget (OSB) geomorphic changes from 1985/86 through 2015/16 (Figure C6) (ACRE 2020).

Overall volume changes for the island system analysis indicate an increase in sediment volume since 2006, with an approximate increase of 3.1 million cubic yards (MCY). During, this period the TE-37 project directly added 1.0 MCY. However, this increase in volume does not match the long-term trend in the OSB, which indicates that Trinity/East Island losses approximately 564,000 cubic yards of sediment per year. This 2006 to 2015/16 analysis is not a detailed OSB and as such should not be directly compared. However, this analysis showing geomorphic trends that match the longer-term, yet have increased volumes, may indicate that the projects during this short-term period are definitely helping offset some of the average transport processes, and contributing to the increased projected longevity. Additionally, the OSB analysis period includes the 3 project sediment additions within overall transport calculations, and the rate produced implies that the projects total sediment addition of 9.8 MCY would be removed in 17 years. Again indicating that the projects have supplied significant sediments to the overall system.

As expected the individual analysis areas have incurred sizeable volume and elevation losses over time, with the TE-20 and TE-24 polygons indicating more than the construction volumes placed have been transported out of the areas. However, when accessing the overall systemic impacts of the projects, the existence of 143.4 ac of dune and 331.5 ac of supratidal elevations in 2015 is a strong indication that the project goals of increasing heights, creating dune and supratidal habitats have been met. Particularly in comparison to the 1996 BICM habitat data presented in Appendix D, which indicated only 37.8 ac of potential dunes prior to restoration. Also, as reported in previous studies, and confirmed in land areas changes presented in Appendix A, Trinity/East Island was projected to become an inner shelf shoal early in the 21 century (McBride et al. 1989; McBride and Byrnes 1997; Penland et al. 2003). However, as of 2016, there was 636 ac of land remaining with another restoration project adding sediment to this island in 2020. Moreover, these projects withstood the substantial impacts of three (2002, 2005, and 2008) catastrophic hurricane seasons over their life histories while contributing to the maintenance of this island.

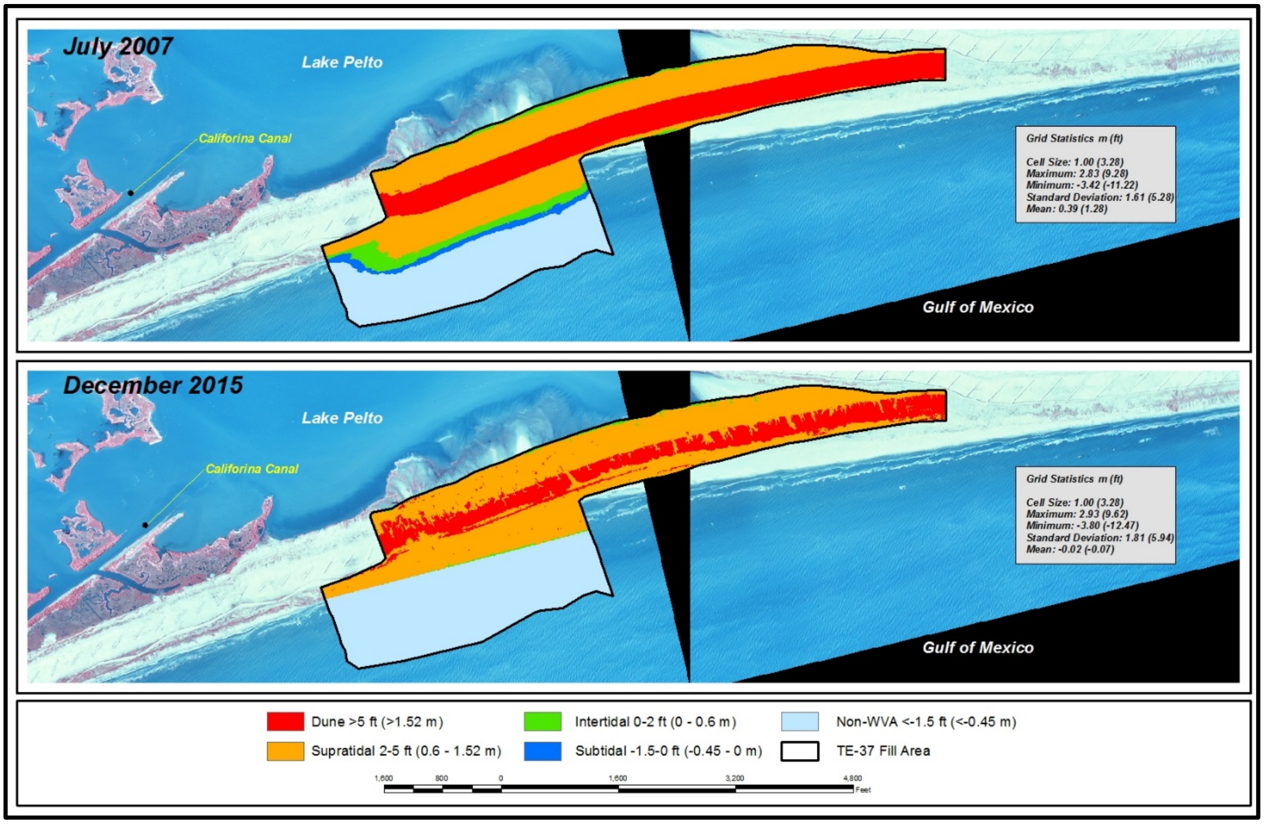
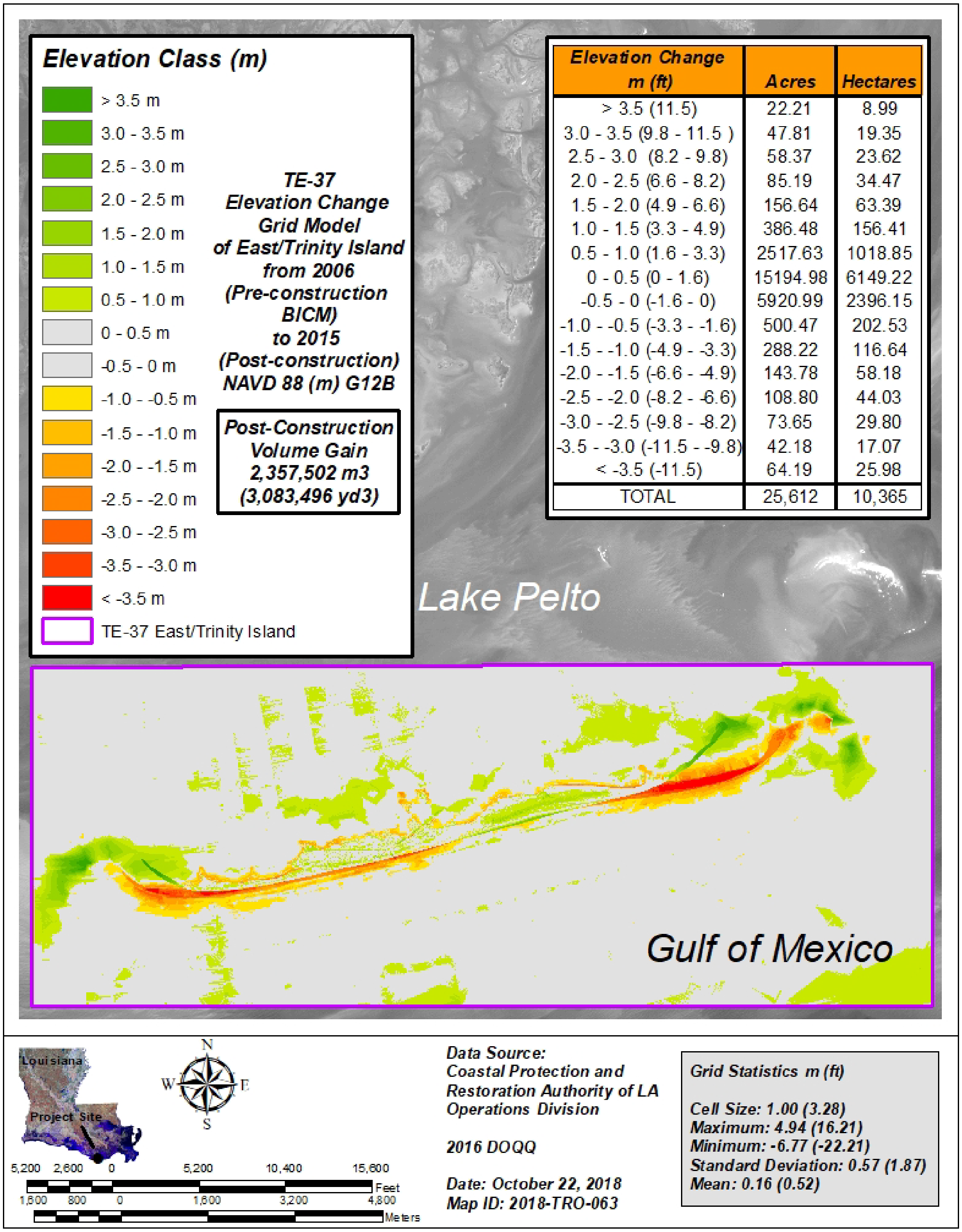


Figure C4. Elevation classification of the analysis area for the New Cut Dune and Marsh Restoration (TE-37) project for two time periods from as-built (2007) to eight years post-construction (2015).



Elevation Change m (ft)	Acres	Hectares
> 3.5 (11.5)	22.21	8.99
3.0 - 3.5 (9.8 - 11.5)	47.81	19.35
2.5 - 3.0 (8.2 - 9.8)	58.37	23.62
2.0 - 2.5 (6.6 - 8.2)	85.19	34.47
1.5 - 2.0 (4.9 - 6.6)	156.64	63.39
1.0 - 1.5 (3.3 - 4.9)	386.48	156.41
0.5 - 1.0 (1.6 - 3.3)	2517.63	1018.85
0 - 0.5 (0 - 1.6)	15194.98	6149.22
-0.5 - 0 (-1.6 - 0)	5920.99	2396.15
-1.0 - -0.5 (-3.3 - -1.6)	500.47	202.53
-1.5 - -1.0 (-4.9 - -3.3)	288.22	116.64
-2.0 - -1.5 (-6.6 - -4.9)	143.78	58.18
-2.5 - -2.0 (-8.2 - -6.6)	108.80	44.03
-3.0 - -2.5 (-9.8 - -8.2)	73.65	29.80
-3.5 - -3.0 (-11.5 - -9.8)	42.18	17.07
< -3.5 (-11.5)	64.19	25.98
TOTAL	25,612	10,365

Figure C5. Elevation change surface, 2006 to 2015/16 at Trinity/East Island. Yellows and reds illustrate erosion areas; greens illustrate deposition areas. Grey areas represent areas within model uncertainties and are excluded from the volume calculations.

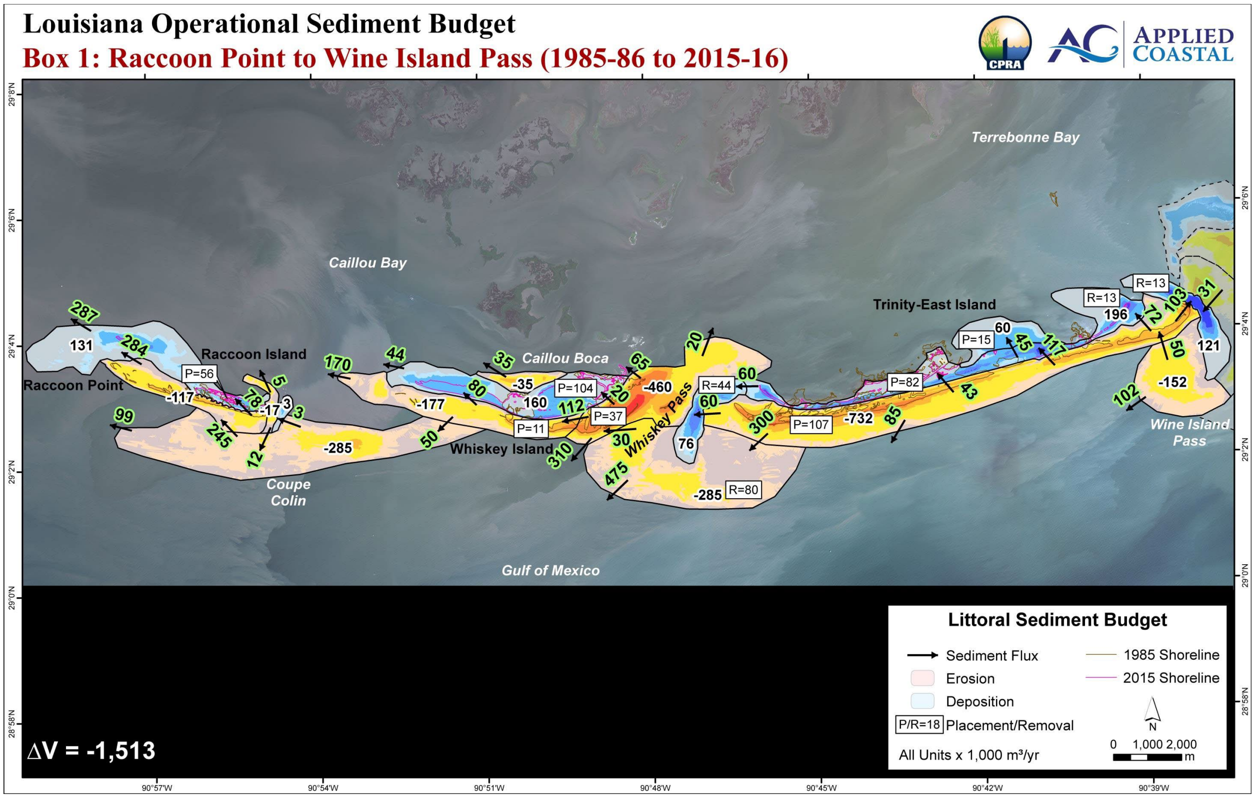


Figure C6. Detailed sediment transport pathways and quantities for the Isle Dernieres for the macro-scale sediment budget, 1985-86 to 2015-16. Arrows represent the direction of sediment movement, and black numbers with green border reflect the magnitudes of net sediment transport in thousands of m3/yr. Black numbers with white border represent net volume change for a particular zone. (from ACRE 2020).

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Appendix D

Habitat Changes at Trinity/East Island due to the Isles Dernieres Restoration, East Island (TE-20), Isles Dernieres Restoration, Trinity Island (TE-24), and New Cut Dune and Marsh Restoration (TE-37) projects, Terrebonne Parish, LA

May 1, 2020

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Introduction

In order to assess aspects of the restoration efforts on Trinity/East Island, habitat classification datasets were compiled to determine habitats and changes after three large-scale Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) Program restoration efforts. These efforts included the Isles Dernieres Restoration, East Island (TE-20) and Isles Dernieres Restoration, Trinity Island (TE-24) in 1998, and the New Cut Dune and Marsh Restoration (TE-37) in 2007 (Rodrigue et al. 2008a, Rodrigue et al. 2008b, and T. Baker Smith, Inc. 2007). Both TE-20 and TE-24 projects have goals related to island "stability" and the restoration of "coastal dunes", while the TE-37 project has goals related to creating island acreage, and "stabilizing dunes". For this assessment the authors will evaluate terms like "stabilize" and "create" dunes in relation to both pre project habitat acreages as well as projected total island disappearance in 2011. For an assessment of the total land area changes see the analysis presented in Appendix A.

Methods

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

Habitat datasets for 1996/1998, 2001/02, 2004, and 2005 were developed by the UNO - PIES using supervised and unsupervised classification of ortho-photography. The classification methods currently used by USGS-WARC for the 2008 and 2015/16 periods generate habitat datasets from high-resolution ortho-photography using object-based analyses in the Trimble eCognition software. This software allows for a variety of data, such as aerial imagery and elevation data, to be integrated into the habitat classification process. However, new habitat classifications and comparability with the older UNO-PIES datasets was maintained to ensure comparisons (table D1).

For detailed information on the sources and methods used for these datasets see Fearnley et al. (2009) and Enwright et al. (2020). This comparison of the 6 available datasets will utilize the BICM general classification scheme for all assessments (figures D1 and D2).

Table D1. Louisiana Barrier Island Comprehensive Monitoring (BICM) Program detailed and general habitat classification schemes used in habitat mapping efforts for the Louisiana Gulf of Mexico shoreline (from Enwright at al. 2020).

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

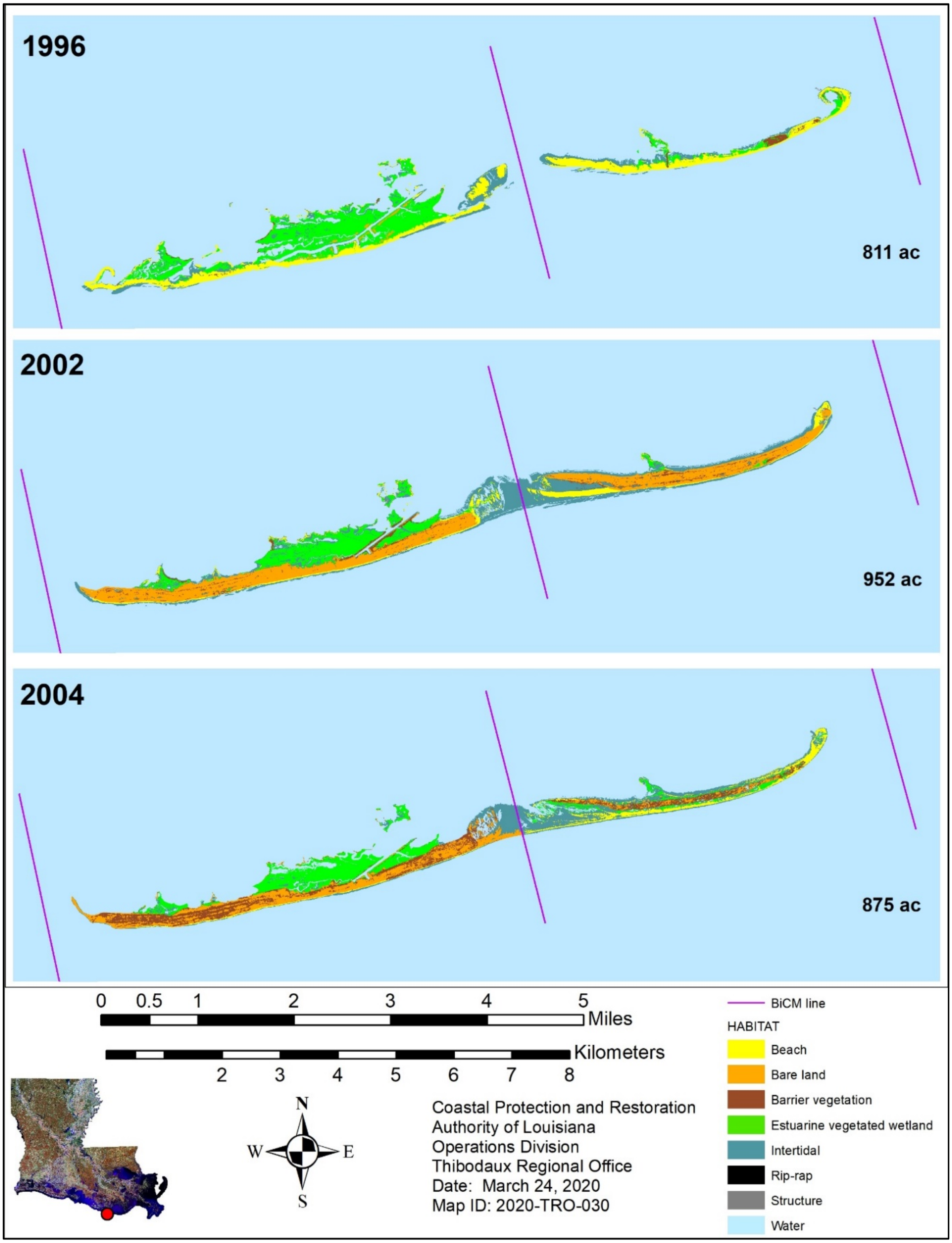

Figure D1. BICM general habitat classification maps between 1996 and 2004 at Trinity/East Island, Isles Dernieres, Terrebonne Parish, LA.

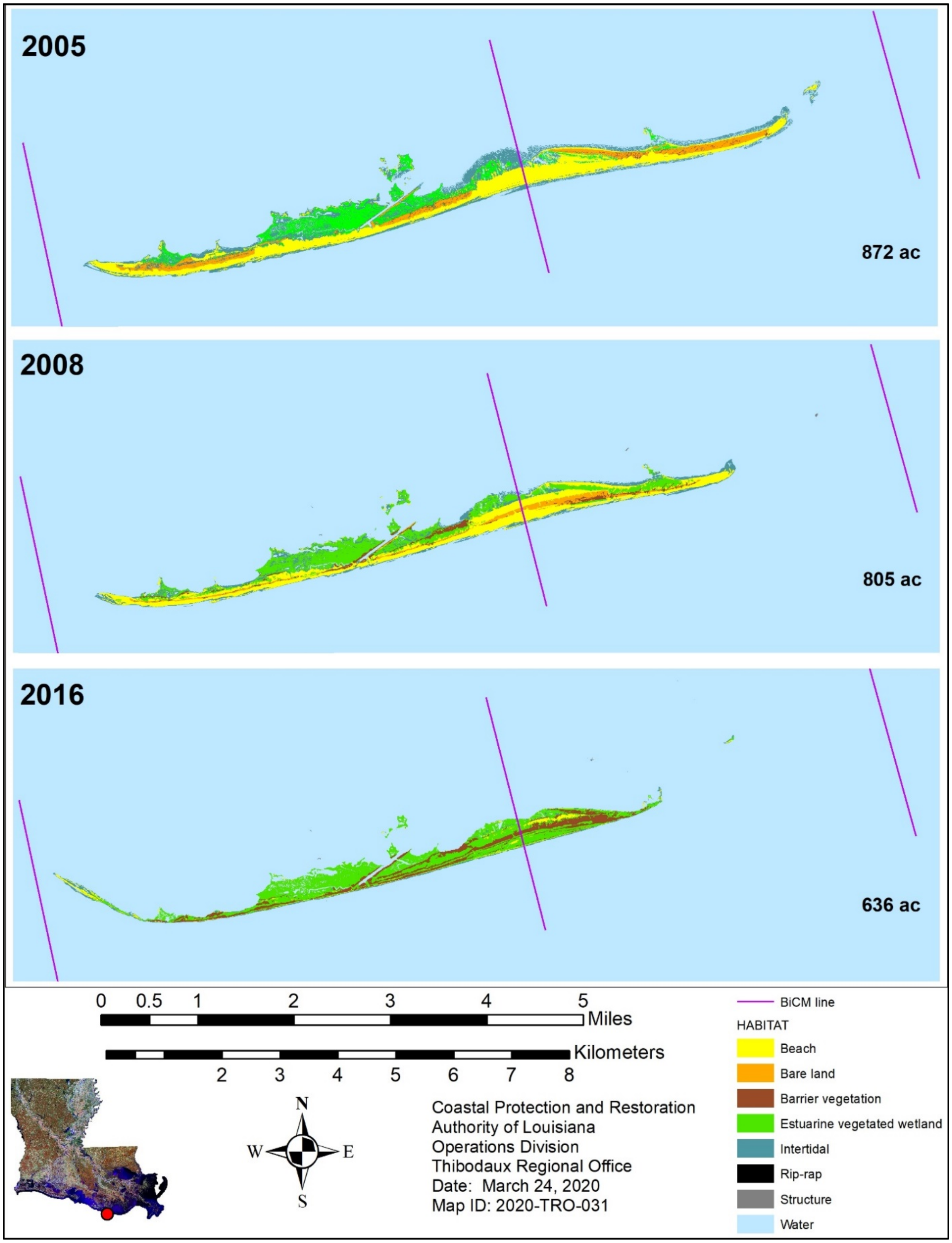

Figure D2. BICM general habitat classification maps between 2005 and 2016 at Trinity/East Island, Isles Dernieres, Terrebonne Parish, LA.

Results

Habitat classification data for Trinity/East Island was available for six time periods ranging from 1996 through 2016 (figure D3). This period of 20 years allows for only one dataset prior to restoration (1996), but an epoch of 18 years during which the three restoration events impacted the system (1998 – 2016). The habitat change trends exhibited overall land loss, as was noted in the more extensive land area change analysis in Appendix A. However, even with an overall trend of land loss, some of the individual habitats showed increases or stability post-restoration as desired in the project goals.

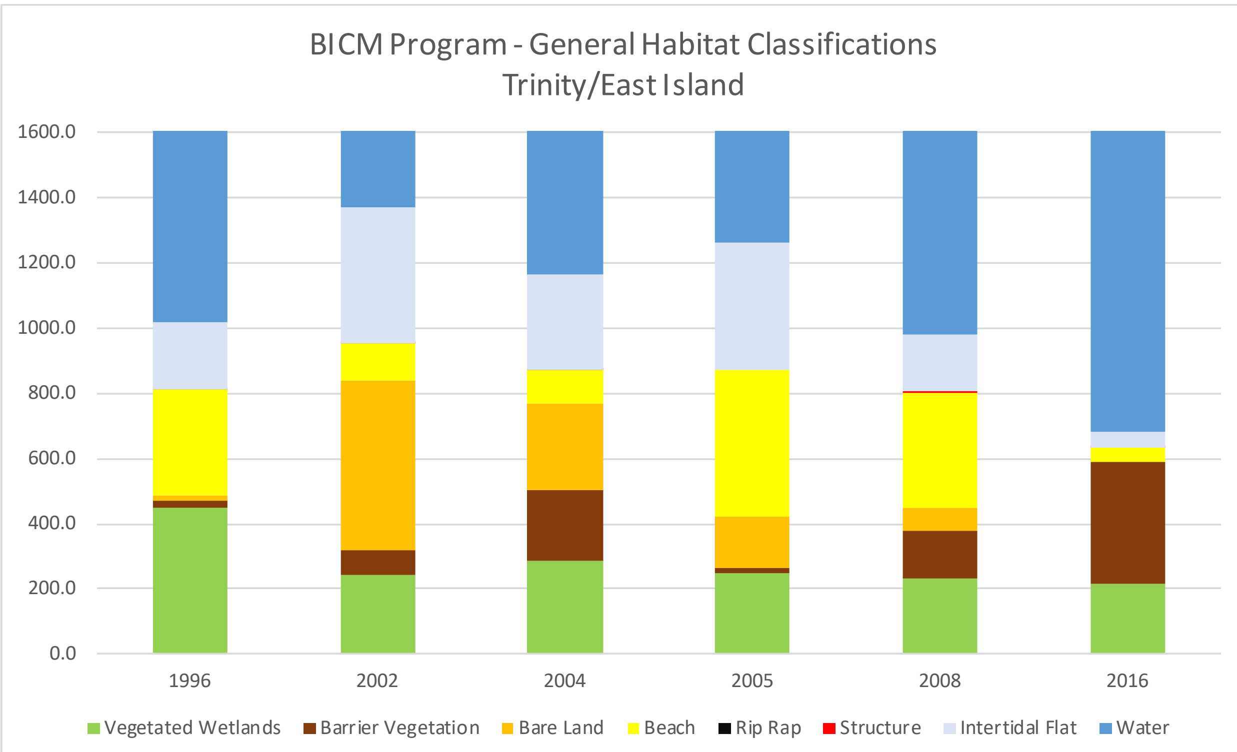

Figure D3. BICM habitat classifications showing cumulative acres of all the habitats at Trinity/East Island, Isles Dernieres, Terrebonne Parish, LA. Changes in habitat classes indicates impacts of restoration events and storms over time. Note that the total habitat analysis areas where larger than the graphed totals, but these additional acres were not show as they consisted of acres classified only as water. This allowed better details to be discerned between the other classes.

As stated, the goals of these projects all included the restoration, establishment, or maintenance of "dunes". The habitat classes of barrier vegetation and bare land are the categories that map dunes within the BICM general classification definitions presented in table D1. In 1996 the data indicates 22.8 ac of barrier vegetation along with 15.0 ac of bare land prior to restoration (table D2), which equates to 4.7% of the total land area. Land area is defined in Appendix A as any general habitat class other than water or intertidal flat. However, by 2002 the barrier vegetation and bare land habitats totaled 595.2 ac, with bare land predominating. This increase in both habitats and the extensive coverage of bare land is attributed to the initial restoration projects in 1998, and the time necessary for vegetation to establish, even with these projects containing both seeding and vegetative planting components (T. Baker Smith et al. 1994, T. Baker Smith 1998, and T. Baker Smith 2007).

Table D2. Habitat acreages by BICM general habitat class between 1996 and 2016 for Trinity/East Island, Isles Dernieres, Terrebonne Parish, LA.

Habitat Classes	1996	2002	2004	2005	2008 [1]	2016 [1]
Water	5204.5	4851.4	5061.1	4962.6	13301.8	13596.6
Intertidal Flat	208.8	419.6	287.7	388.7	173.6	48.0
Vegetated Wetlands	447.8	245.1	287.0	246.8	319.9	428.0
Barrier Vegetation	22.8	73.0	218.7	20.4	56.9	162.0
Bare Land	15.0	522.2	264.9	154.1	69.9	1.3
Beach	324.7	111.6	103.9	450.7	357.7	44.2
Rip Rap	0.0	0.0	0.0	0.0	0.0	0.6
Structure	0.4	0.4	0.2	0.0	0.9	0.0
Land Area [2]	810.7	952.3	874.7	871.9	805.3	636.1

[1] Analysis areas do not match previous years data so acreage totals that include water are not appropriate.

[2] Land Area defined as sum of all habitat classes other than Water or Intertidal Flat

The combination of bare land and barrier vegetation shows variability within the total acreages as well as the individual classes thru time (figure D3). This is contributed to the continued vegetative colonization and succession as well as impacts of storms which set back vegetative cover and change habitat classes. For example, between 2004 and 2005 the total land area only loses 3 ac, but shows a dramatic decrease of these two classes, with a corresponding increase in the beach habitat. However, by 2016 the bare land and barrier vegetation classes total 163.3 ac, which is 25% of the current land area total and beach habitat is greatly reduced. Additionally, by this time the bare land class only contributes 1.3 ac (table D2).

The vegetated wetlands class, which includes the intertidal areas dominated by marsh vegetation or mangroves, also showed variability over the analysis period. In 1996 the islands had 447.8 ac and by 2002 that acreage had been reduced by 45% to only 245.1 ac. Again, as discussed in Appendix A, this is mainly attributed to the TE-24 projects construction template which placed a large portion of its dredged sediments on existing land areas classified as vegetated wetlands. However, by 2016 the vegetated wetlands habitat class contained 216.1 ac, accounting for 34% of the total land area remaining. This also means that as of 2016 the islands still contained the equivalent of 48.3% of the initial vegetated wetlands quantity mapped in 1996.

The amount of beach habitat, although highly variable through time, is the land category class that shows dramatic decrease. In 1996 there was 324.7 ac classified as beach, but by 2016 there was only 44.2 ac of beach habitat mapped. Beach habitat showed variability, as did the other classes, but the beach habitat is the one land class that ultimately reduced during the post-restoration epoch. A major factor postulated to explain the reduced beach habitat post-restoration is that the beach class, within the BICM general classification system, lumps together some of the un-vegetated bayside flats and meadows which have vegetated as the island is not overwashed as much and the storm frequency has been lower in the last several years allowing vegetation to spread.

Additionally, the loss of terminal sand spits, as noted in the island length analysis presented in Appendix B, could be a contributor to beach habitat reductions.

Clearly the land areas remaining subaerial and these areas providing more "dune" than in 1996 indicates the projects have accomplished the goals related to creating, maintaining, and stabilizing "dunes". Also, the reductions and increases within each particular habitat through time supports the idea that project construction impacts to particular habitats are mitigated by both the succession and changes in habitats in the future as well as the overall maintenance of subaerial habitats beyond the predicted island life.

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Appendix E

Vegetation Community at Trinity/East Island due to the Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24), and New Cut Dune and Marsh Restoration (TE-37) projects, Terrebonne Parish, LA

June 1, 2020

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Introduction

In order to assess the vegetation community across the Trinity/East Island that are associated with three Coastal Wetlands Planning Protection and Restoration Act (CWPPPRA) projects, the Barrier Island Comprehensive Monitoring (BICM) program's shore perpendicular bathymetric track lines were extended to establish cross island transects upon which a total of sixty–one (61) vegetation stations were randomly placed for sampling. The CWPRRA program implemented the Isles Dernieres Restoration East Island (TE-20) and Isles Dernieres Restoration Trinity Island (TE-24) projects in 1998, followed by the New Cut Dune and Marsh Restoration (TE-37) project in 2007. Both the TE-20 and TE-24 projects have goals of reducing sediment loss through the use of vegetative plantings thereby increasing the stability of the island. These goals were assessed in the earlier project reports (West and Dearmond 2004a and 2004b) prior to portions of the construction fill areas and subsequently some plantings being eroded away, and will not be repeated here. Only the data collected from 2006 through 2016 are presented in this report. Additionally, the TE-37 project has goals of stabilizing the dune platform with vegetative plantings and establishing vegetative cover of planted species in the created marsh and dune platforms. For this assessment the authors determined the overall relative percent cover, the relative percent cover by species, and the species count for the post 2006 datasets in order to assess if the goals of stabilizing dunes and establishing vegetative cover of planted species were accomplished.

Methods

The Coastal Protection and Restoration Authority (CPRA) of Louisiana has used the Braun-Blanquet method (Mueller-Dombois and Ellenberg 1974) for collecting vegetation data for all three projects, TE-20, TE-24 and TE-37. This method records visual estimates of percent cover for each species observed within a four (4) square meter sample plot by vegetative layers which include; 1) tree, 2) shrub, 3) herbaceous, and/or 4) carpet. Estimates of percent cover use the following classifications: solitary, <1%, 1-5%, 6-25%, 26-50%, 51-75%, and 76-100%, although observations are recorded to the nearest 5% when cover is above 5% and to the nearest whole number when below 5%. Vegetation outside of each sample plot, but within 15 feet are also identified and recorded. Over the course of the project life, the method for establishing the vegetation stations changed as a result of changes to the original project footprints and vegetation. After completion of the TE-20 and TE-24 construction and the installation of plants in 1999, three vegetation sampling efforts took place in fall of 1999, 2001, and 2003 whereby the vegetation stations were established randomly along rows of planting to monitor the differences between planted and unplanted areas and plantings survival. Sampling during the later years of the project, 2006 and afterwards, was conducted utilizing shore perpendicular cross sections for station establishment as described below to better ascertain barrier island community composition and cover as vegetative succession occurred, and the fill areas were impacted by natural process. Two vegetation sampling efforts occurred for the TE-37 project, one in 2006 and the other in 2013, and they both followed the post 2006 sampling design utilized for TE-20 and TE-24.

Vegetation sampling was conducted in 2006 for the TE-37 project, 2007 for the TE-20 and TE-24 projects, 2013 for the TE-37 project, and 2016 for the TE-20 and TE-24 projects. As mentioned above, the method of station establishment changed in 2006. The shore perpendicular BICM bathymetric track lines are spaced approximately 1,500 feet apart along most of the Louisiana gulf shoreface. Where these lines intersect the respective subaerial project areas of TE-20, TE-24 and TE-37, they were digitally extended via ESRI® ArcMap™ such that they would completely cross the island. Points were generated every 2 meters along these lines and assigned a numerical value to facilitate random locations of vegetation stations. Files generated in ArcMap™ were then transferred to a handheld Trimble GeoXT Global Positioning System (GPS) unit for mobile Geographical Information System (GIS) field applications with sub-meter accuracy.

Upon arrival onsite, transects were located by a team of two field personnel using the Trimble GeoXT unit. Stations were randomly selected beginning at the vegetative line along the gulf side of the island proceeding bayward. Five sample locations from the points generated in ArcMap™ were randomly chosen per transect, navigated to with the GPS unit and marked for the sampling teams with a PVC pole in the southeast corner. Plots were oriented in a North-South direction. Sampling teams then recorded species and visual estimates of percent cover for both the total plot and each individual species per the Braun-Blanquet method previously mentioned. There were sixty-one (61) stations monitored on Isle Dernieres throughout 2006-2016 (figure E1). These 61 stations were common to the two time periods being used for this report.

Following data collection, data sheets were reviewed by the field data recorder for accuracy and completeness. The data were entered into a Microsoft® Excel Workbook template and loaded into the CPRA/Coastal Information Management System (CIMS) temporary buffer for internal quality assurance review (CPRA 2018). Revisions were made to the data in the buffer based upon reviewer comments. The data were saved from the buffer to the CPRA/CIMS permanent database. Data were downloaded from the database and saved to a .csv file for analysis in SAS® version 9.4 (SAS®). Before analysis could proceed there was one adjustment made to the data set. For years that bare ground was not recorded as a species inside of the stations, this value was calculated based upon the total plot cover and added to the data set for analysis. For purposes of this report, data collected from the TE-37 project in 2006 where combined with data collected from the TE-20 and TE-24 projects in 2007 as well as the TE-37 data collected in 2013 and the TE-20 and TE-24 data collected in 2016. Since no severe topical activity occurred between these time periods, data was combined into a 2006/07 and 2013/16 analysis to provide a Trinity/East Island system analysis. Once this adjustment was made, the data file was analyzed for 1) relative mean percent cover for each individual species by year, and 2) species richness by year. Data results were brought into Microsoft Excel 2016 for chart development.

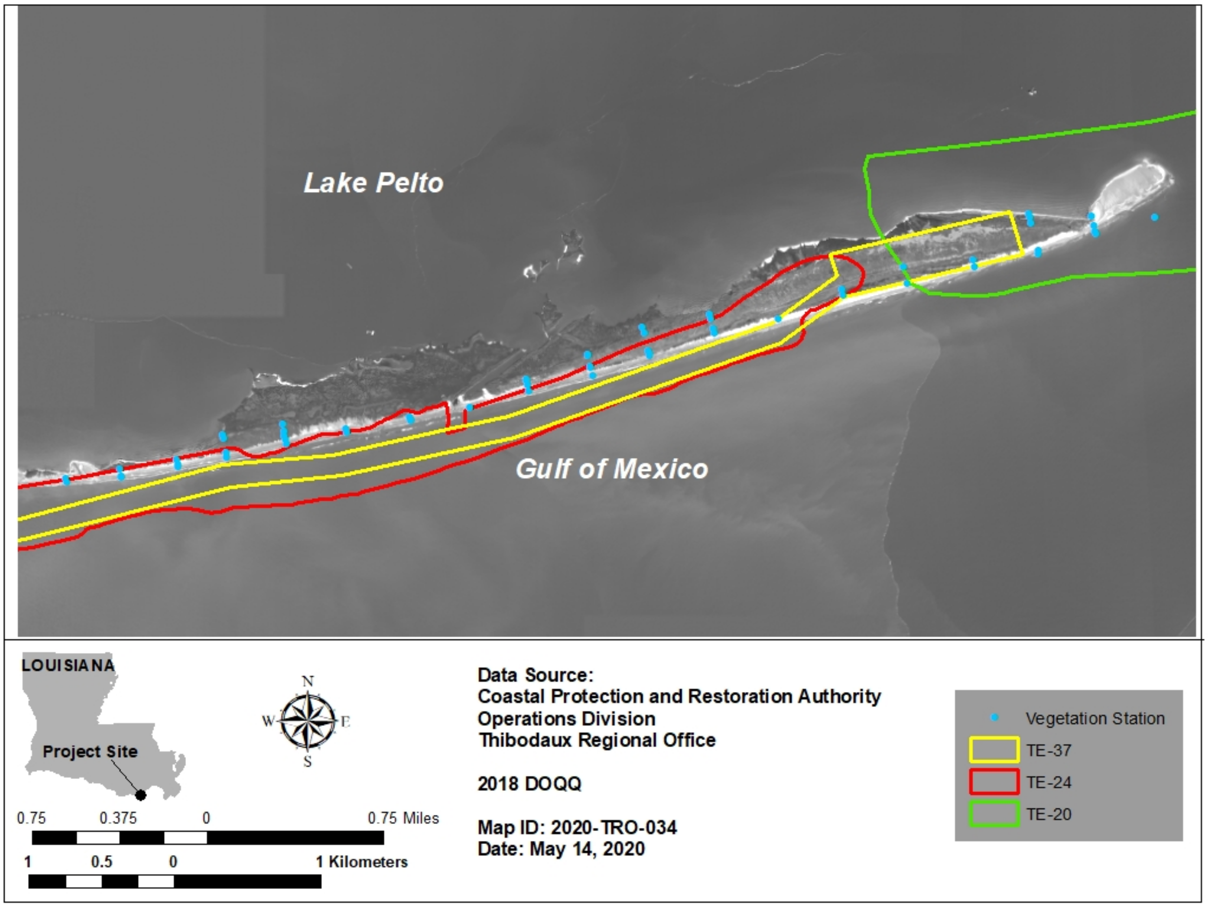

Figure E1. Location of the sixty-one (61) vegetation stations established to assess the vegetation community on Trinity/East Island.

Results

Relative mean percent cover of vegetation on Trinity/East Island was 65% and 67% during the 2006/07 and 2013/16 sample periods, respectively (figure E2). Examining figure E2, four (4) species, *Paspalum vaginatum, Phyla nodiflora, Solidago semprevirens, and Spartina alterniflora*, in 2006/07 were replaced with *Andropogon glomeratus, Distichlis spicata, Erigeron procumbens, and Phragmities australis* in 2013/16. *D. spicata* increased in cover by 5.6%, *E. procumbens* by 6.5%, and *P. australis* by 6.5% between the two sampling efforts. There were other species that had increases or decreases; however, these were the most drastic.

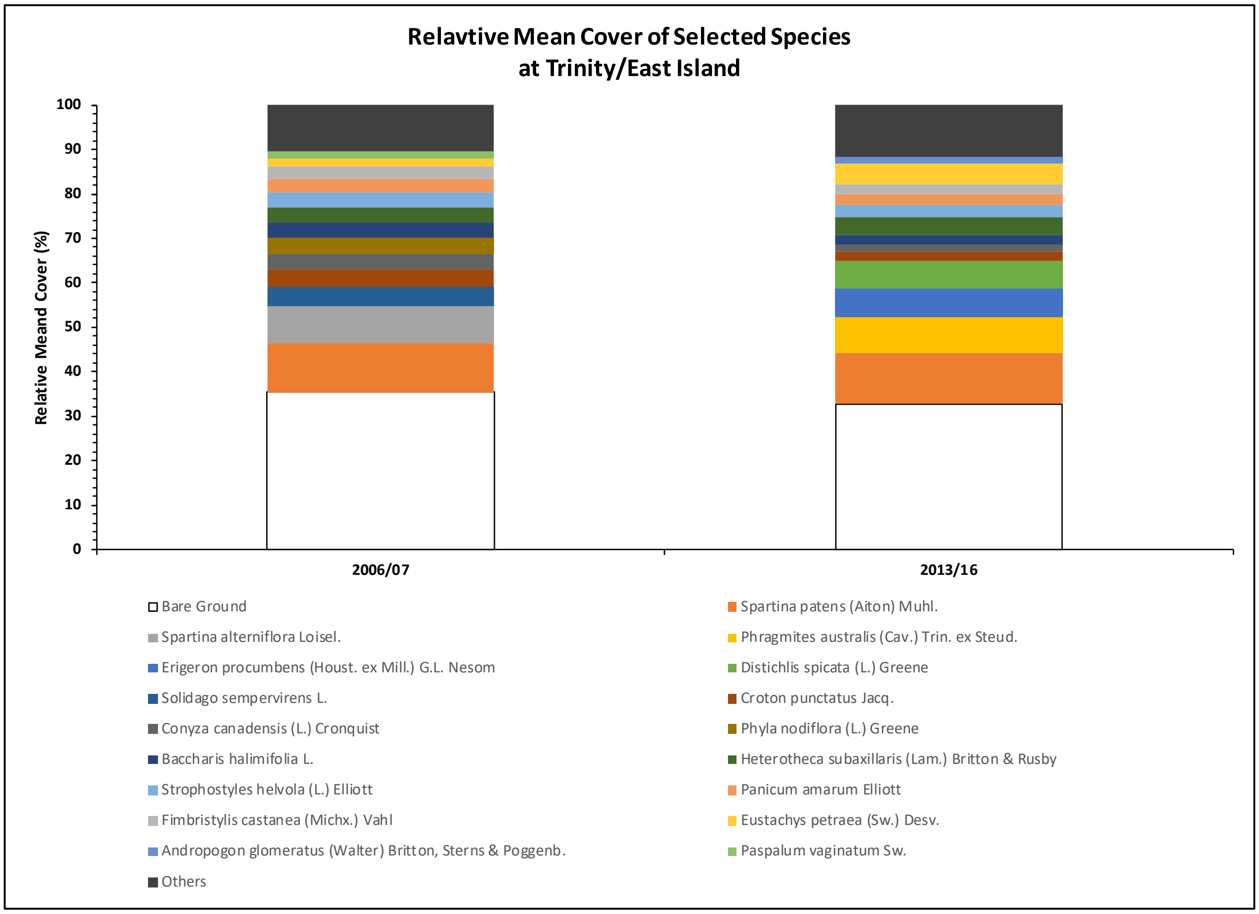

Figure E2. Relative mean cover of species found in 61 stations on Trinity/East Island in association with the Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24), and New Cut Dune and Marsh Restoration (TE-37) projects in 2006/07 and 2013/16.

For both time periods the dominant species was *Spartina patens* with a relative mean percent cover of 10.9% in 2006/07 and 11.4% in 2013/16 which was a species that was initially planted in all three projects at the end of construction. However, *Cynodon dactylon* which was planted via seeding immediately after fill completion was not found in or around any of the 61 vegetation stations in 2006/07 or 2013/16. For *Spartina alterniflora*, there was a drastic shift between the two sampling periods, 8.3% relative mean cover in 2006/07 to 0% in 2013/16. In 2013/16, *S. alterniflora* was not identified in any station and only identified outside of one station. For *Panicum amarum*, the relative mean cover remained similar at 3.1% in 2006/07 and 2.4% in 2013/16.

In 2006/07 species counts inside of the sixty-one $4m^2$ stations identified thirty-nine species, with bare ground included. When species from fifteen feet outside of the stations were included, richness increased to forty-four (Table E1). In 2013/16 forty-one species were documented inside the stations, while an additional eight species were recorded in the 15 ft zone outside the stations. Of the species identified inside of the stations, 24 species were common to both sampling periods. Ten species identified inside of the stations in 2006/07 were not found inside the stations in 2013/16 and accounted for approximately 15.1% cover which indicates there was a slight species shift. *Erigeron procumbens* accounted for 6.5% of the shift as this species was not identified in

2006/07 and another 11 species were identified in 2013/16 that were not in the previous period that made up another 6.8%.

Table E1. Species Count by sample period. Counts were conducted for species documented inside of the 4m² stations only, as well as both inside and outside of the stations.

Species Count			
2006 - 2007		**2013 - 2016**	
IN Only	**IN/OUT**	**IN Only**	**IN/OUT**
39	44	41	49

These results indicate that the Trinity/East Island areas sampled during both periods had well established vegetative cover and a developed vegetative composition that was somewhat stable. Hester and Willis 2015 sampled vegetative composition at both TE-24 and TE-37 in the fall of 2014 and reported species richness for these two areas were not significantly different on any of the dune, swale, and marsh habitats sampled. However, they did find significant differences in vegetative cover on plots specifically placed in the "dune", although not in the other habitats.

Hester and Willis (2015) found significant differences between the TE-24 and TE-37 sites, based on the age. Non-metric multi-dimensional scaling (NMMS) ordinations revealed that species influencing the differences in these sites included many of the species showing shifts in our samples. These included reductions in *S. alterniflora* and increases in *S. patens*, among others. Our analysis did not separate plots by habitat type, but this analysis along with ours indicates the stable vegetative cover and consistent species counts are meeting the goals.

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Appendix F

Sediment Properties at Trinity/East Island due to the Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24), and New Cut Dune and Marsh Restoration (TE-37) projects, Terrebonne Parish, LA

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Introduction

The Barrier Island Comprehensive Monitoring (BICM) program collected surficial sediment samples in the subaqueous and subaerial environments along coastal Louisiana, including Trinity/East Island. Data collected in 2008 and 2015 were used to map sediment characteristics along the Trinity/East Island. The Isles Dernieres Restoration East Island (TE-20), Isles Dernieres Restoration Trinity Island (TE-24), New Cut Dune and Marsh Restoration (TE-37) projects funded through the Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) did not postulate any goals related to the sediment size or characteristics. The authors of this report present this data due to its availability and support for other variables analyzed and discussed in this document.

Methods

Ponar grabber (subaqueous) and hand scoop (subaerial) sediment samples were obtained along fourteen (14) cross-shore transects along Trinity/East Island for the Isles Dernieres Restoration East Island (TE-20), the Isles Dernieres Restoration Trinity Island (TE-24), and the New Cut Dune/Marsh Restoration (TE-37) projects in July 2008 and August 2015. These samples were utilized to characterize the median grain size (D50) and sand percentage (%) of surficial sediments in the shoreface and other barrier island habitats. These sediment transects were separated on 3,000 ft (914 m) intervals and were funded through the BICM program. One sample was collected from each distinguishable location: -15 ft contour, middle of shoreface, upper shoreface at mean low water, beach berm, dune, and back-barrier marsh. Horizontal coordinates (UTM NAD83 Zone 15 in meters) were also established with a differential global positioning system for each sample to spatially display the position of each sediment sample. For more details on sample collections and analysis see Kulp et al. (2011 and 2015).

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

The July 2008 and August 2015 sediment core point data were imported into ESRI ArcMap™ software for surface interpolation. Surface grid models (33 ft^2 cell size) were generated with the 2008 and 2015 percent sand (%) data using the Kriging function of the Spatial Analyst Tools extension of ArcMap™. The percent sand grid model was then mapped in 5% increments to view the spatial distribution of sand in the Trinity/East Island system. Multipoint median grain size (D50) shapefiles were also produced for both years using the Wentworth (1922) terms and overlain on top of the percent sand grid models to spatial view the median grain size distributions for Trinity/East Island.

Results

Between the TE-20, TE-24, and TE-37 projects, approximately 9.785 million cubic yards (T. Baker Smith and Sons, Inc. 1998 and T. Baker Smith, Inc. 2007) of material was added to Trinity/East Island, thereby providing resilience to the outer deltaic coast that constitutes the first line of defense to interior deltaic habitat from storm waves and water levels. The long-term benefit of this restoration approach is the addition of sediment to a littoral system that is otherwise sediment starved (Morang et al., 2013). Augmenting natural sediment delivery to the outer coast not only offers an immediate benefit in that created subaerial land protects interior habitat, but sediment added to the system replenishes adjacent environments through littoral sediment transport during the natural reworking process associated with barrier restoration.

The results of the sediment properties analysis demonstrate that as expected, surficial sand deposits were present along the Trinity/East Island shoreface, beach, dune, marsh, bay, and passes in 2008 and 2015 (figures F1 and F2). The percentage of sand (%) in 2008 ranged from < 70% to 100% for sediments extracted from the middle of shoreface to the marsh with the greatest concentrations of sand recovered from the TE-20 and TE-37 fill areas and extended to their shorefaces on the eastern side of the island. A second large cache of granular sediments was uncovered from the western tip of the island and formed a moderately sized flood/ebb shoal. Of note is the large area of < 70% sand that bisects the center of the island that is likely a model anomaly derived through inadequate point spacing. Although, some silty cores were found in close proximity to the island in this area.

The median grain sizes of these sediments fell within the silt (< 62.5 μm) or fine sand (125–250 μm) size classes (figure F1). Interestingly, two medium sand (250–500 μm) and one course sand (500–1000 μm) surficial samples were unearthed in the island system. The medium grained sand samples were found on the edge of the western spit in the shoreface abutting the island while the coarse grained sample was collected southeast of the island on the edge of the lower shoreface (figure F1). In 2015, the sand percentage (%) ranged from 70 to 100% for sediments extracted from the middle of shoreface to the bay. Similar to the 2008 percentages, the largest proportions of sand (90-100%) were observed along the TE-20 and TE-37 shorelines and the western tip of the island (figure F2).

In contrast with the 2008 sand percentages, the 2015 model displayed a continuous sand layer of 80-90% sand joining the eastern and western granular sediment sinks. The 2015 model also depicts the transport of sand sized sediments into the New Cut Inlet prior to the merging of East and Trinity Islands (figure F2). This was possible due to collection of sediment samples in the bay directly behind Trinity/East Island. No samples were taken in the bay in 2008. Furthermore, the 2015 model captures the relocation of the western granular 2008 flood/ebb shoal to the south (figures F1 and F2) causing what was a formerly a fine sand flood/ebb shoal (2008) to become only a very fine sand ebb shoal in 2015. Timbalier Island experienced this same phenomenon between 2008 and 2015.

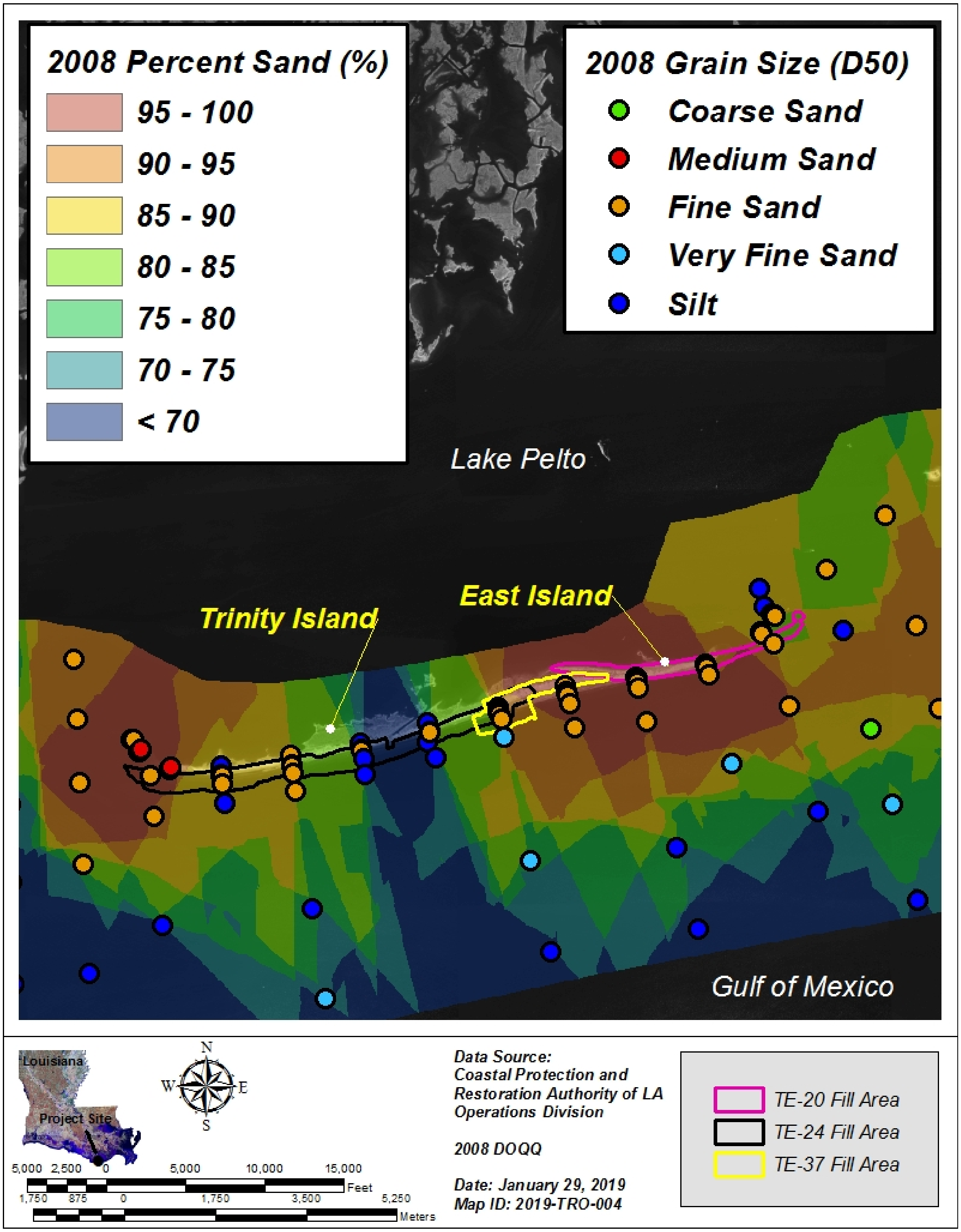

Figure F1. Median grain size (D50) and percent sand (%) distribution for Trinity/East Island in July 2008.

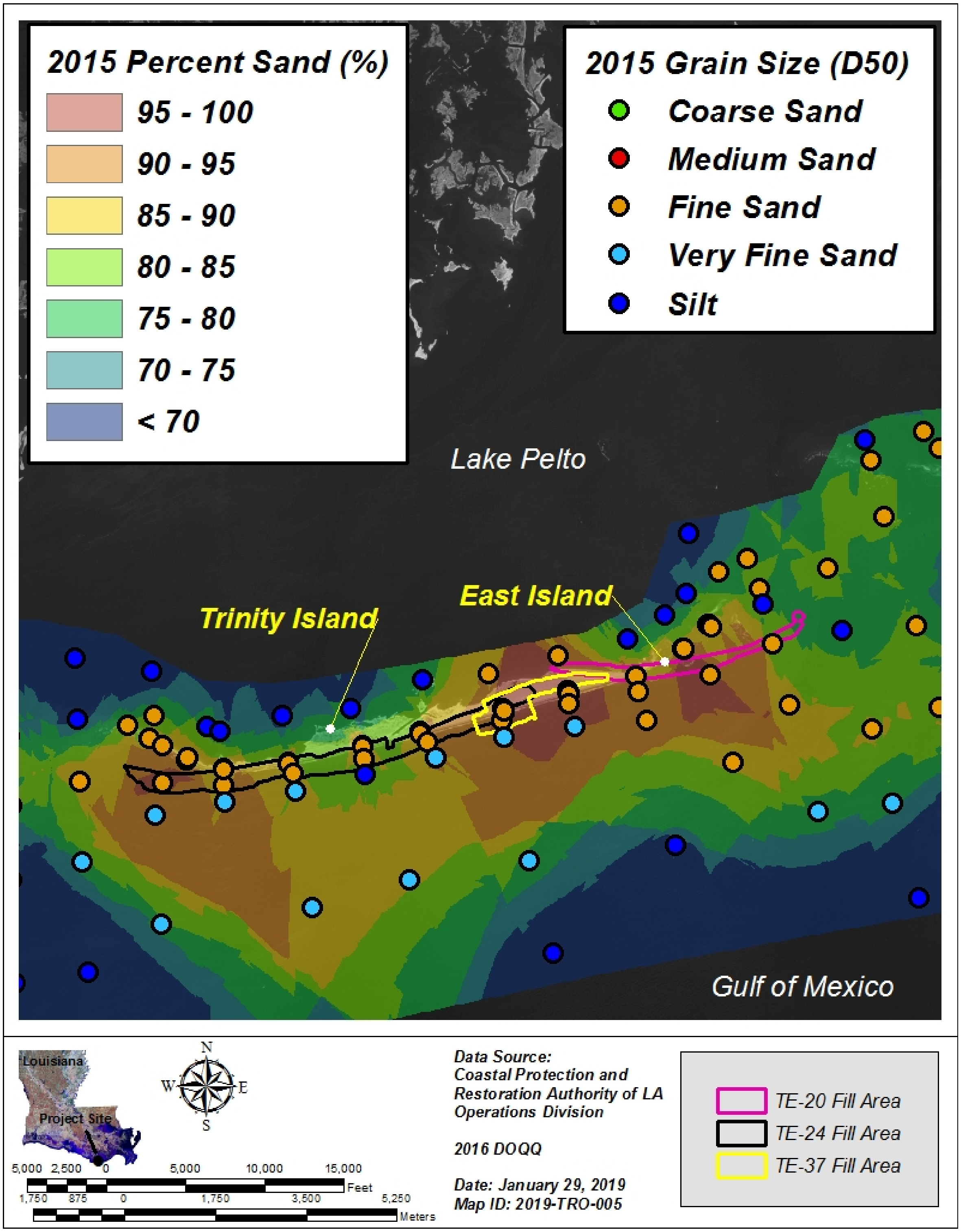

Figure F2. Median grain size (D50) and percent sand (%) distribution for Trinity/East Island in August 2015.

The median grain sizes for the 2015 sediments fell within the very fine sand (62.5–125 µm) or fine sand (125–250 µm) size classes (figure F2). However, unlike the 2008 sampling no courser grained sediment samples were found in 2015. Although the distribution of sand resources appears favorable, the Isles Dernieres and Timbalier Barrier Islands have been characterized as having thin sand layers overlying silt and/or clay substratums (Peyronnin 1962; Penland et al. 1985; Kulp et al. 2005). Therefore, the depth of the granular deposits is projected to be predominantly surficial and the volume available for transport is probably limited.

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