Coastal Protection and Restoration Authority of Louisiana

2022 Operations, Maintenance, and Monitoring Report

for

Bayou Dupont Marsh and Ridge Creation (BA-0048)

State Project Number BA-0048
Priority Project List 17

December 2022

Prepared by:
Danielle Richardi, Theryn Henkel, and Barry Richard

Operations Division
New Orleans Regional Office
2045 Lakeshore Drive, Suite 309
New Orleans, LA 70122

Suggested Citation:

Richardi, D.C., T.K. Henkel, and B.J. Richard. 2022. *2022 Operations, Maintenance, and Monitoring Report for Bayou Dupont Marsh and Ridge Creation (BA-0048),* Coastal Protection and Restoration Authority of Louisiana, New Orleans, Louisiana. 50 pp. and Appendices.

Operations, Maintenance, and Monitoring Report
for
Bayou Dupont Marsh and Ridge Creation (BA-0048)

Table of Contents

Preface

The Bayou Dupont Marsh and Ridge Creation (BA-0048) project was funded through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) on the 17th Priority Project List. The National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) is the federal sponsor and the Coastal Protection and Restoration Authority (CPRA) is the state sponsor. The 2022 Operations, Maintenance, & Monitoring (OM&M) report for the BA-0048 project is the first in a series of reports to summarize OM&M activities conducted during the project's life. This report includes an analysis of BA-0048 monitoring data available through 2021 and a summary of the 2021 maintenance inspection. Additional documents pertaining to the BA-0048 project may be accessed on CPRA's website at: https://cims.coastal.la.gov/outreach/projects/ProjectView?projID=BA-0048 or on CWPPRA's website at https://lacoast.gov/new/Projects/Info.aspx?num=BA-48.

I. Introduction

The Bayou Dupont Marsh and Ridge Creation (BA-0048) project is located in the Barataria Basin, approximately 5.2 miles southeast of Lafitte, Louisiana, along the south bank of Bayou Dupont in Jefferson and Plaquemines Parishes (Figure 1). Bayou Dupont is a shallow waterway that flows southeast from Bayou Barataria, a historic distributary of the Mississippi River. This distributary system carried seasonal floodwaters into the basin, where overbank flooding deposited coarser sediments and gradually formed natural levees (or ridges) parallel to the channels. An 1880 report by the United States Army Corps of Engineers describes the natural levees south of Lafitte as averaging two feet in height, with a heavy growth of live oaks (Douglas 1881). However, the distributaries have since been disconnected from seasonal floodwaters and without regular sediment inputs, the natural levees and adjacent wetlands have subsided. Saltwater intrusion, dredging, and wave-driven erosion, have all contributed to land loss in the area, which was estimated to occur at a rate of -0.52% per year between 1985 and 2009 (NMFS 2010).

The goals of the BA-0048 project are to restore the natural ridge along the southwestern shoreline of Bayou Dupont and re-establish adjacent marsh using renewable sediment from the Mississippi River (NMFS 2011). To attain these goals and restore ridge and marsh function in the area of Bayou Dupont, an approximately 10,798-linear-foot maritime ridge and 389-acre marsh platform were constructed. The marsh platform was constructed using sediment hydraulically dredged and pumped from the Mississippi River using the Long-Distance Sediment Pipeline (LDSP, BA-0043-EB). The ridge was constructed with a combination of riverine and *in situ* sediment (sediment dredged from within the project area). Both the Alliance Anchorage (primary) and Wills Point borrow sites were used as riverine sediment sources for project construction (Figure 1). After construction, approximately 980 linear feet of the ridge and approximately half an acre of marsh were planted with a mixture of seven native tree and shrub species.

Natural ridges in southeast Louisiana are higher elevation landscape features created by repeated overbank flooding along bayous or former river distributaries (Fisk 1944) and are considered one of the multiple lines of defense in reducing storm impacts (Lopez 2009). In addition to deflecting storm surge and providing structural protection for adjacent marshes, ridges support woody vegetation that provides valuable habitat for a diversity of wildlife such as neotropical migrant birds (Providence 2009).

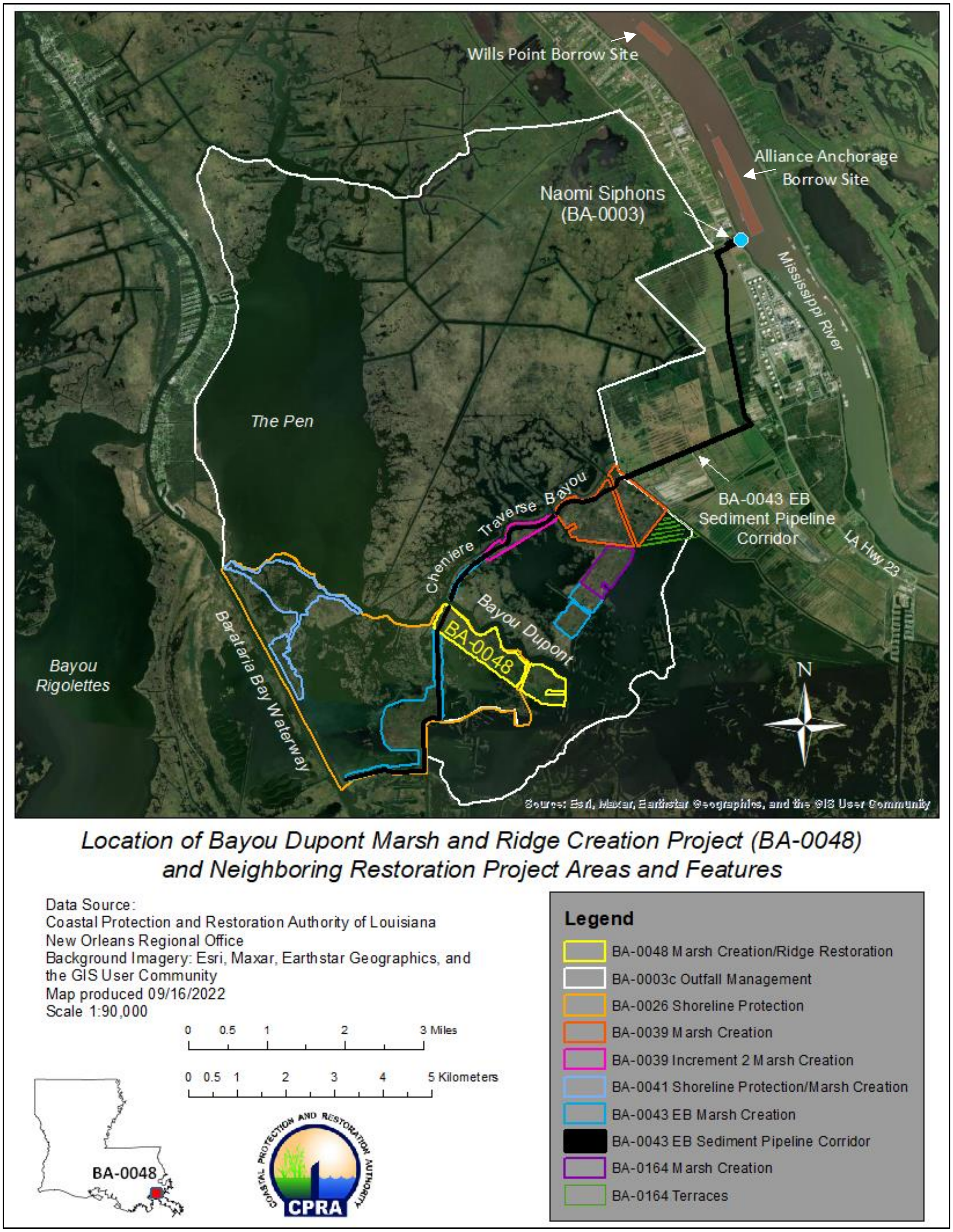


Figure 1: Bayou Dupont Marsh and Ridge Creation (BA-0048) project location, Mississippi River sediment borrow site locations, and neighboring, constructed restoration projects.

Bayou Dupont Marsh and Ridge Creation (BA-0048) is one of the first ridge restoration projects to be constructed in coastal Louisiana. The Grand Liard Marsh and Ridge Restoration project (BA-0068), another CWPPRA project sponsored by the NMFS, has similar project features and was constructed at approximately the same time as BA-0048. The construction of these projects followed the earlier construction of the Fourchon Maritime Forest Ridge and Marsh Restoration Project, which was funded through the Coastal Impact Assistance Program (CIAP) and led by the Barataria-Terrebonne National Estuary Program (BTNEP) and the Greater Lafourche Port Commission, with additional partners. The Fourchon ridge is located approximately 11 miles ENE of Grand Isle, Louisiana, and was constructed in two phases between 2005 and 2008, with multiple experimental native planting efforts that extended through 2014 (Benoit 2016). Additional woody plantings were conducted on the ridge in 2016 and 2017.

The BA-0048 project complements multiple completed coastal restoration projects in the Barataria Basin, with hydrologic restoration and management, shoreline protection, marsh creation, and terrace creation projects all occurring within a few-mile radius (Figure 1). These projects are primarily supported through CWPPRA, but some projects were supported through alternate funding sources, including CIAP and the American Recovery and Reinvestment Act. The Long-Distance Sediment Pipeline (LDSP) was utilized for construction of all of the neighboring marsh creation projects, and will be utilized again in 2022 to construct the Large-Scale Marsh Creation Project-Upper Barataria Component (BA-0207), which will extend between the BA-0048 project area and the Barataria Bay Waterway and create approximately 882 areas of marsh.

Construction and Project Features

Construction of the BA-0048 project began in May 2014, and was completed in March 2015 (Moffatt and Nichol 2018). The project was designed using the North American Vertical Datum of 1988 (NAVD88) and Geoid99, but it was constructed using Geoid09, which resulted in it being built approximately 0.7 ft higher than specified. The difference between geoids resulted from the BA-0048 and BA-0043-EB Marsh Creation projects being combined on one construction contract. The BA-0043-EB project used Geoid09 for project design and construction, and this geoid was inadvertently also used for construction of BA-0048. The impacts of this divergence from the construction specifications is addressed in the Monitoring Activity section under Elevation (p. 14).

Construction of the BA-0048 project area began with the construction of earthen containment dikes around the perimeter of the two marsh creation cells using *in situ* sediment. The dikes were designed to an elevation of +4.0 ± 0.5 ft NAVD88 (Geoid99), but due to the shift in geoids, were constructed to a higher elevation of +4.7 ± 0.5 ft. The dikes were built with a crown width of 6.0 ft and side slopes of 1(V):4(H) (Coco 2010). Once construction of the containment dikes was completed, Mississippi River sediment was pumped into the marsh creation cells to construct the marsh platform. The design fill elevation for the marsh was +3.0 ± 0.5 ft NAVD88 (Geoid99), but the shift in geoids resulted in the marsh being constructed to a higher fill elevation of +3.7 ± 0.5 ft. Based on the design fill elevation, the marsh was projected to settle to +1.3 ft approximately five years after construction. After initial settlement, the marsh was expected to remain in the intertidal zone through the remainder of the project's 20-year life (Coco 2010).

The earthen ridge was constructed by amending the containment dike along Bayou Dupont using Mississippi River sediment to widen and shape the ridge on the marsh side to its specified dimensions. The ridge was designed for a constructed height of +4.5 + 0.5 ft NAVD88 (Geoid99), with a crown width of 30 ft and side slopes of 1(V):4(H). A wedge with a slope of 1(V):5(H) was constructed on the marsh side of the ridge to more gradually transition down to marsh elevation. At this stage of construction, the bayou side of the ridge was primarily *in situ* sediment, but the expanded marsh side was nearly 100% river sediment. Therefore, the final stage of ridge construction involved the deposition of approximately six inches of *in situ* sediment on the ridge crown to increase the organic content and bring the ridge up to its final elevation. This action was intended to improve the growing conditions on the ridge for the planting of native shrub and tree species. The *in situ* sediment was pulled from the bayou side of the ridge, where additional material had been deposited earlier for this purpose. The ridge was constructed to approximately +5.2 + 0.5 ft, 0.7 ft higher than designed, due to the previously-mentioned difference between geoids. Based on the initial design elevation, the ridge was projected to settle to approximately +2.5 ft at year five and +1.8 ft at the end of the 20-year project life (URS Corporation 2009).

The CPRA contracted with BTNEP in 2015 to provide seven native shrub and tree species to plant on the ridge. They collected the seeds locally and germinated and grew the woody species until they were approximately two years old. The species cultivated included *Callicarpa americana* (American beautyberry), *Celtis laevigata* (sugarberry), *Diospyros virginiana* (common persimmon), *Ilex vomitoria* (yaupon), *Morella cerifera* (wax myrtle), *Morus rubra* (red mulberry), and *Quercus virginiana* (live oak). By the time the ridge was planted February 25–27, 2019, it had naturally populated with woody species that included *Baccharis halimifolia* (eastern baccharis), *Iva frutescens* (Jesuit's bark) and *Salix nigra* (black willow), greatly restricting the space available for planting. Due to this limitation, 360 trees were planted in the far northeastern corner of the western marsh creation area, where the 2017 topographic survey indicated elevation was relatively high in comparison to most of the marsh in the project area. Only 37 trees were planted on the western ridge; however, 337 trees were planted on the eastern ridge in areas that were slower to naturally vegetate. The planting contractor noted a total of 750 trees planted in the project area; however, CPRA staff located only 734 trees during surveys. All planted saplings were staked and protected with nutria exclusion devices, which guard against herbivory. Additionally, species identification tags were attached to each stake. The number of each species planted by planting location and a discussion on survival is included in the section on Vegetation. *Plantings* (p. 35).

II. Maintenance Activity

a. Project Feature Inspection Procedures

The purpose of annual inspections is to evaluate the constructed project features to identify any deficiencies and to prepare a report detailing the condition of project features and recommended corrective actions needed. The inspection procedure consists of a site visit, with a visual inspection of the project features. If corrective actions are required, CPRA shall provide a detailed cost estimate for engineering, design, supervision, inspection, and construction contingencies, and an assessment of the urgency of such repairs. The annual inspection report also contains a summary of maintenance events and an estimated projected budget for the upcoming three years for operation, maintenance and rehabilitation. The three-year projected operation and maintenance budget is shown in Appendix A.

An inspection of the BA-0048 project was conducted on November 2, 2021, by Barry Richard, Danielle Richardi, and Theryn Henkel of CPRA. There was a light wind and clear skies during the inspection. Photographs of the inspection are included in Appendix B.

b. Inspection Results

Marsh Restoration Areas

No erosion or land loss was noted of the marsh fill areas from Hurricane Ida (08/29/2021). The marsh is highly vegetated, with vegetation varying between herbaceous and woody species throughout the project area.

Ridge Restoration Area

The ridge restoration area visually appears to be settling faster in some areas than others. Wind damage from Hurricane Ida was evident on the ridge, with some naturally-recruited and planted shrubs and trees leaning over. However, most of the observed planted trees were still alive, and many were still standing upright. Some erosion is occurring along the base of the ridge along Bayou Dupont.

c. Maintenance Recommendations

Immediate/Emergency Repairs

No immediate repairs are necessary at this time.

Programmatic/Routine Repairs

There are no scheduled repairs at this time.

d. Maintenance History

During the project life, the ridge is being assessed for the presence of the invasive tree *Triadica sebifera* (Chinese tallow). If the species is detected at a concentration where its presence could have a negative effect on the establishment and/or growth of native species, it will be eradicated through the use of chemical spray and manual removal. As of the 2019 vegetation survey, less than five Chinese tallow trees were identified. A treatment event was not recommended at that time; however, the need for treatment will continue to be assessed.

III. Operation Activity

Operations are not required for this project.

IV. Monitoring Activity

a. Monitoring Goals

The goals of the BA-0048 project are to restore the natural southern ridge of Bayou Dupont and re-establish adjacent marsh using renewable sediment from the Mississippi River. The specific objectives of the project are as follows:

- Restore approximately 10,798 linear feet (10.5 acres) of maritime ridge habitat along the southwestern shoreline of Bayou Dupont.
- Create and nourish approximately 389 acres of marsh through sediment pipeline delivery from the Mississippi River. With marsh nourishment, sediment is typically filled around existing marsh and allowed to flow over the surface to the as-built elevation, thereby supplementing the marsh with new sediment and nutrients.

b. Monitoring Elements

The following monitoring elements (Richardi 2017) are being utilized to assess the success of the BA-0048 project during its 20-year monitoring life. For the purpose of this report, the two cells that were created for the BA-0048 project will be referred to as the west cell and the east cell (Figure 3). When referring to the separate marsh and ridge features within each cell, these features will be referred to as the west or east marsh, or the west or east ridge (Figure 3).

Land-Water and Habitat Analyses

Analysis of aerial photography is being used to evaluate land to water ratios within the marsh and ridge creation areas over the project's 20-year monitoring life. The acres of land and water within the project area were determined by the United States Geologic Survey (USGS) Wetland and Aquatic Research Center (WARC) using 1-m resolution color infrared orthoimagery (Z/I Imaging digital mapping camera) acquired October 11, 2016, through the Coastwide Reference Monitoring System (CRMS) program. The analysis was conducted using standard operating procedures documented in Steyer et al. 1995 (revised 2000), in which all areas characterized by emergent vegetation, wetland forest, scrub-shrub, or upland habitat are classified as land, while open water, aquatic beds, and non-vegetated mudflats are classified as water. Future land-water analyses are scheduled for 2024 (year 9) and 2033 (year 18), dependent on the scheduling of CRMS flights.

The USGS WARC conducted a habitat analysis on the same 2016 imagery to further delineate the acres of land and water into specific habitats. Habitat classes are based on Cowardin et al. 1979, as modified for the National Wetlands Inventory mapping conventions. The "upland range" and "barren" classifications were based on Anderson et al. 1976. The habitat analysis divided the project area into nine different habitat classifications and provided the acres for each of these classifications. Future habitat analyses are scheduled to coincide with land-water analyses in 2024 and 2033.

Elevation

Surface elevation data from real-time kinematic (RTK) topographic surveys are being used to determine if the created marsh and ridge are settling at the predicted rate and if the marsh and ridge are maintaining elevations that promote healthy marsh and ridge habitat. A pre-construction topographic/bathymetric survey was conducted April–June 2014, and post-construction surveys were conducted October 2015 (year 1), October 2017 (Year 2) and October 2019 (year 4), following CPRA's surveying guidelines (CPRA 2017). For consistency, the post-construction surveys maintained the established survey transects used for the pre-construction and construction surveys. The marsh transects follow a grid-pattern with 400-foot spacing, with survey points collected every 50 ft along each transect (Figure 2). For the ridge, additional transects were established between the marsh transects, and points were collected a minimum of every 10 feet. A centerline transect was also completed along the ridge in 2015 and 2017 (Figure 2). Future topographic surveys are scheduled for 2024 (year 9) and 2028 (year 13).

Elevation data were processed and analyzed in ArcMap 10.5.1. All data sets were provided in feet, NAVD88, and Geoid12A or 12B, which are identical in this region. To convert from Geoid12A/12B to the approximate Geoid99 design elevations, add 0.5 feet. Polygons that outlined the marsh and ridge were produced in order to constrain the analyses. For each survey year, elevation point shapefiles were clipped to the marsh and ridge polygons. The “natural neighbor” tool was used to interpolate an elevation surface using an output cell size of 1.0. The interpolated surface was then clipped to the marsh and ridge polygons for each survey year, for a total of eight difference surfaces. These surfaces were used to calculate elevation over time. Elevation difference was calculated using the “minus” tool in ArcMap, which compares two elevation surfaces, resulting in a new surface that indicates where and how much elevation was gained or lost between survey years. The elevation surfaces were also used to calculate the area of land that was within specific elevation contours (e.g. how much area was between 0.0 ft and +1.0 ft, etc.). All analyses were repeated for the marsh and ridge, separating the western and eastern cells in order to determine if settlement rates were different between the two areas. The mean marsh elevation was compared to the predicted settlement curve for the marsh. For the ridge, this comparison was conducted using elevation data collected from the ridge crown.

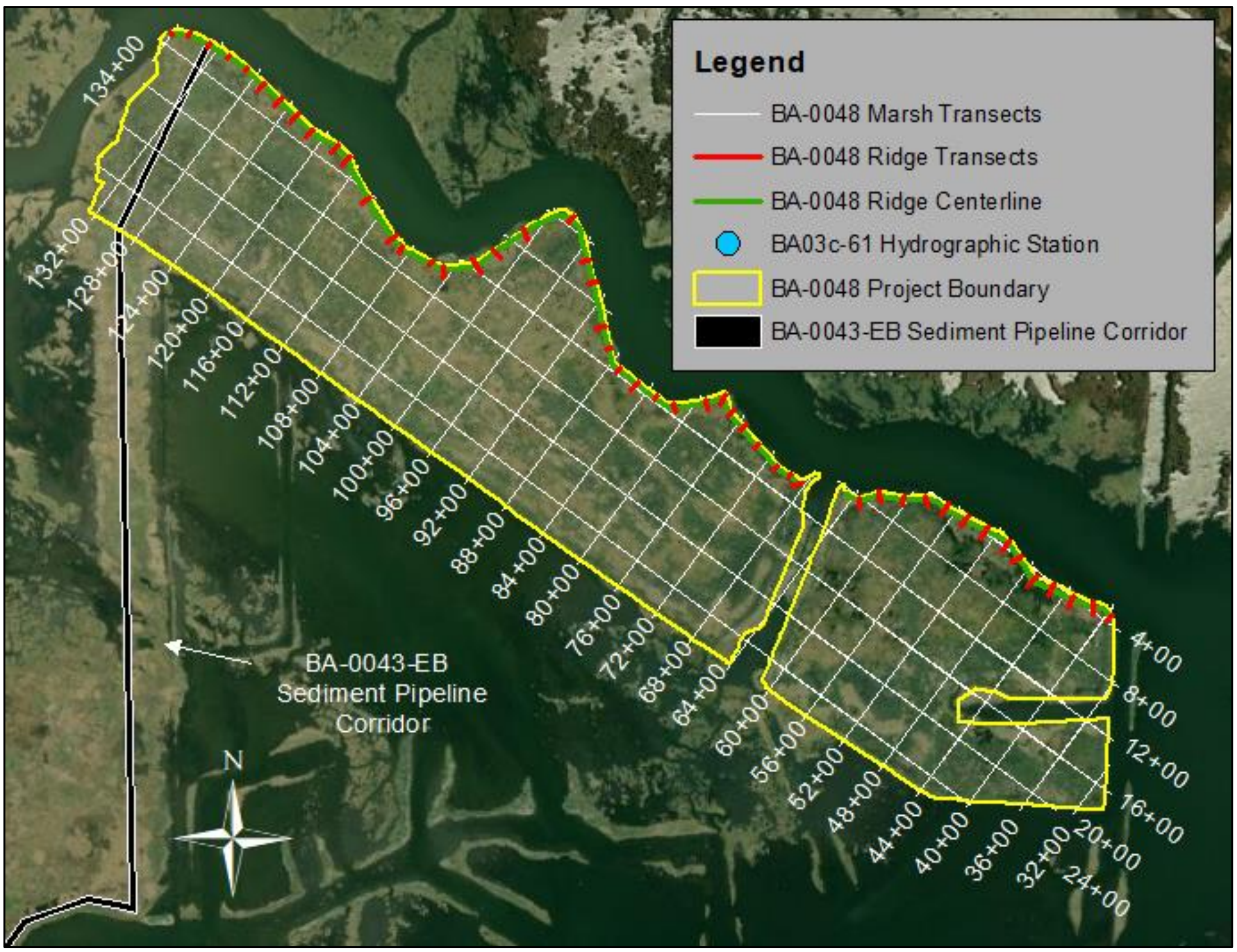


Figure 2. BA-0048 marsh and ridge established elevation survey transects.

Vegetation

Marsh vegetation data are being collected to assess the colonization and transition of vegetation on the marsh platform and to gauge the quality and stability of the vegetative community. Marsh vegetation was sampled in September 2016 and August 2019 at 13 stations (2 m x 2 m) using a modified Braun-Blanquet sampling method (Mueller-Dombois and Ellenberg 1974) as described in Folse et al. 2020. Station locations were distributed throughout the project area to maximize representation of all areas (Figure 3). Data collected at each station included an identification of all vegetative species and an assessment of total, layer, and species percent covers. Future marsh vegetation surveys are scheduled for 2025 (year 10), 2030 (year 15), and 2034 (year 19). Analyses were conducted using ANOVA in RStudio (RStudioTeam 2016) or ANOVA, Proc GLM ($\alpha = 0.05$), using SAS software (SAS Institute Inc. 2002–2012).

Ridge vegetation surveys were conducted in 2019 at 26 monitoring stations (Figure 3), following the protocols described for marsh. The stations were divided into three locations, including ridge crown (n = 14), ridge slope on the bayou side (n = 6) and ridge slope on the marsh side (n = 6). The ridge slope stations were always paired with each other on the two sides and with a ridge crown station (essentially a transect across the ridge). There were eight crown stations on the western ridge and six crown stations on the eastern ridge. There were three pairs of slope stations on both the western and eastern ridge. Analyses were conducted using ANOVA in RStudio (RStudioTeam 2016) or ANOVA, Proc GLM ($\alpha = 0.05$), using SAS software (SAS Institute Inc. 2002–2012). Ridge survivorship surveys of the planted shrubs and trees were conducted in 2019 and 2020. Future ridge vegetation and survivorship surveys are planned for 2022 (year 7), 2025 (year 10), 2030 (year 15) and 2034 (year 19).

Soil Properties

Soil samples are being analyzed to monitor changes in soil properties of the created marsh and ridge over time and to compare soils of the created marsh to that of local, natural marsh habitat. Ridge soil data were collected prior to planting to ensure that the soil characteristics were within ranges to support the survival of the planted shrubs and trees. Soil properties analyzed included bulk density, percent organic matter, pH, salinity (EC), and percent moisture, with sampling and analyses following CRMS methodology (Folse et al. 2020). Soil cores are sampled from the surface down to 24 cm deep and are sectioned into six individual samples, each 4 cm deep. Individual soil cores were collected from six stations along the ridge crown in 2016 and 2017, with three additional ridge stations added in 2018 to investigate soil conditions in potential planting locations. Individual soil cores were collected from five stations in the marsh in 2016, with one additional core collected in 2019 from the location that was planted with shrubs and trees (Figure 3). Future sampling events are scheduled for 2025 (year 10) and 2034 (year 19). Soil parameters were analyzed using the statistical software RStudio (RStudioTeam 2016). Analysis was conducted using analysis of variance (ANOVA), comparing all the parameters listed above between habitats (marsh vs. ridge), cell (west vs. east), and years. Pairwise comparisons were made using Tukey's Honest Significant Difference test in RStudio.

The bulk density and percent organic matter of the marsh soils from the BA-0048 project and from CRMS4103 were compared in order to assess soil differences between a created marsh and a natural, nearby marsh. An ANOVA was conducted comparing bulk density and percent organic matter by location (BA-0048 or CRMS4103), year (2016 and 2019 for BA-0048; 2008 and 2018 for CRMS4103), depth, and their interaction.

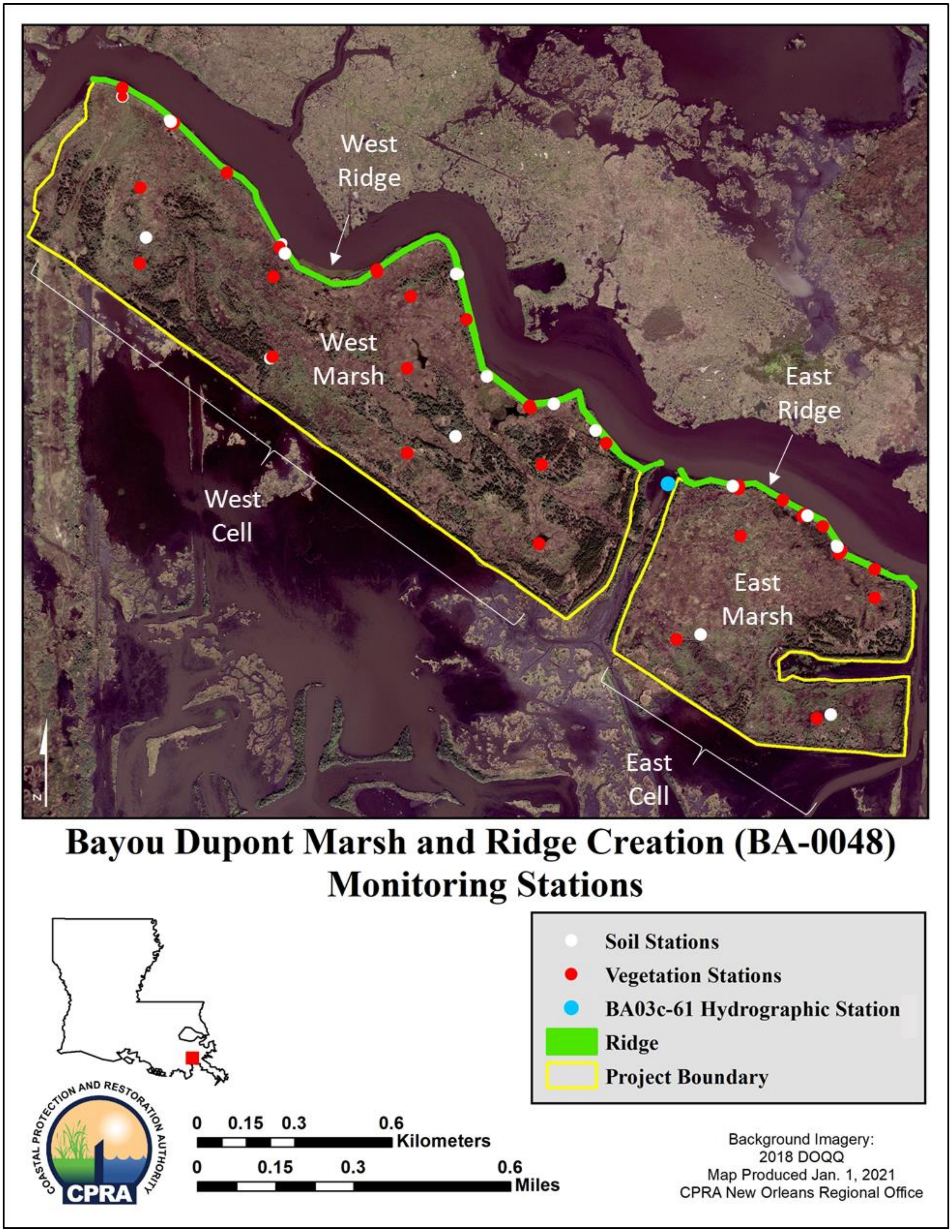


Figure 3. BA-0048 monitoring station locations and project area naming conventions.

c. Monitoring Results and Discussion

The monitoring results and discussion for each monitoring element are described below, using BA-0048 data available through 2021. These results will be updated with new data in subsequent OM&M reports that are scheduled to be written in 2026 and 2035, allowing for a continued assessment of project performance over the 20-year monitoring life. All means are reported with standard deviation (SD).

i. Land-Water and Habitat Analysis

As of 2009, the western ridge of Bayou Dupont within the BA-0048 project boundary had largely eroded, with only two acres of land remaining in the 24-acre assessed ridge footprint. Likewise, the marsh within the project boundary had eroded significantly, with a reduction to 94 acres of land within the assessed 285-acre footprint (NMFS 2010). GoogleEarth satellite imagery from October 2012 shows the vast extent of open water that existed within the project footprint prior to project construction (Figure 4). Subsequent GoogleEarth imagery from January 2021, over five years after construction was completed, shows those acres of previously open water largely replaced by vegetated land.

Figure 4. GoogleEarth imagery of the BA-0048 project area in 2012 (before construction) and in 2021 (after construction).

In order to quantify the acres of created and nourished land, a land-water analysis of the BA-0048 project area (marsh and ridge) was conducted using CRMS aerial photography acquired on October 11, 2016, approximately 1.5 years after construction was completed. The analysis revealed that there were 392 acres of land (95% of the project area) and 20 acres of water (5% of the project area) (Figure 5). A habitat analysis was also conducted to distinguish and quantify the diverse habitats observed in the project area during site visits and from aerial imagery. Habitat analysis allows for a quantification of detailed habitat categories, greatly expanding the description of the project area beyond simply land and water (Cowardin et al. 1979, Anderson et al. 1976).

Marsh

The marsh creation area was categorized primarily as estuarine intertidal emergent habitat (330.8 acres, 80%), which is generally defined as herbaceous marsh that experiences inundation as a result of tidal influence (Figure 6). The habitat classification with the second largest number of acres was estuarine intertidal scrub shrub (35.9 acres, 9%). This habitat is composed of shrubs and young trees, and based on the 2016 vegetation survey that occurred just a month prior to the habitat analysis, was largely represented by young *Salix nigra* (black willow). Estuarine intertidal unconsolidated shore habitat (5.6 acres, 1.4%) was present along the LDSP corridor and in small patches throughout the marsh. This habitat is characterized by unconsolidated sediments with typically low vegetative cover that may see temporary increases in cover by pioneer plants when growing conditions are favorable. There were also 20.3 acres (4.9%) of permanently-flooded habitat that are a result of ponding in lower-elevation areas of the marsh. All of these habitats are explained in greater detail in Cowardin et al. 1979.

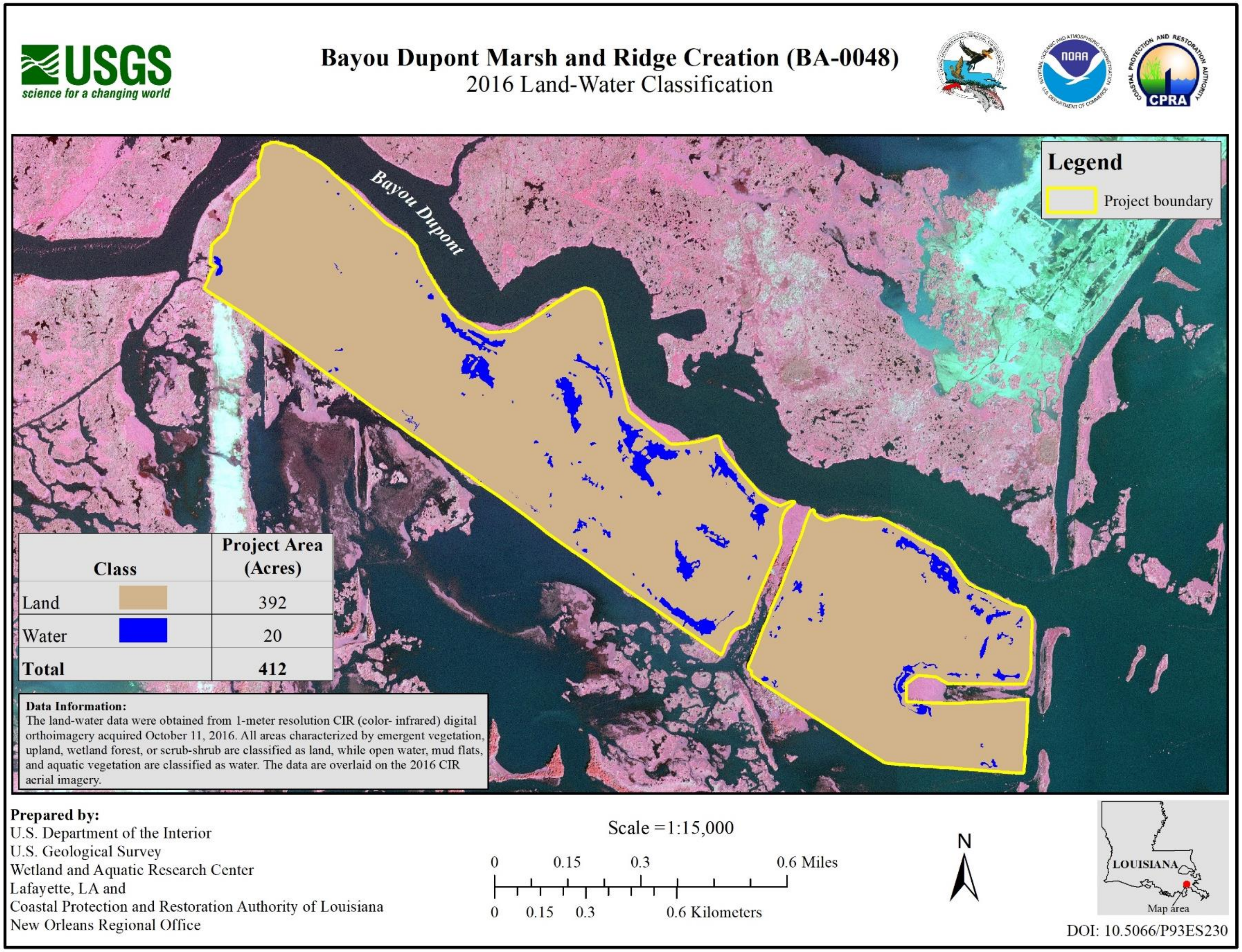
Ridge

Because the Cowardin classification system used for habitat analysis is focused on wetland habitat, Anderson et al. 1976 was utilized to describe some of the more upland habitats (range and barren land) found on the ridge. The ridge was not separated from the containment dikes for analysis; therefore, the reported acres for each habitat in Figure 6 applies to the entire project area. The CPRA conducted an additional analysis by deleting the containment dike data to estimate the actual ridge acres by habitat, and these values are reported below.

The majority of the ridge was classified as upland range (6.7 acres) and was populated by herbaceous, grassy vegetation. The second most prevalent ridge habitat was classified as upland scrub shrub (2.5 acres), which represents habitat where natural recruitment of shrubs and young trees had already occurred prior to the planting event. Also of note, primarily on the eastern ridge, was the presence of upland barren land transitional habitat (0.5 acres). This area is described (in reference to this project) as an area where less than 1/3 of the land is vegetated, the land is in transition, and the land has been altered by filling.

Prior to project construction, both upland forest deciduous spoil and upland scrub-shrub habitats were present along the pre-existing spoil banks that border the canal that divides the project area into the western and eastern cells (Figure 6). Gapped containment dikes were built for each cell just interior of these existing spoil banks to protect these habitats during project construction. The interior containment dike is discernable in the western cell by the presence of upland habitats, especially scrub-shrub, along a narrow internal "ridge" that parallels the cell's eastern edge.

The majority of the BA-0048 project area was already classified as emergent marsh habitat for the 2016 analysis. However, as will be discussed in the upcoming vegetation section, by the 2019 vegetation survey, woody vegetation had increased in the marsh. Despite this expansion, the percentage of marsh in the project area is expected to increase with time as the higher elevation areas currently fostering scrub-shrub habitat continue to settle and transition to marsh as a result of increased tidal inundation. Multiple site visits since 2016 and data collected during the 2019 vegetation survey all indicate that the ridge has largely self-vegetated with shrub and tree species. It is expected that the next habitat analysis in 2024 will indicate a dominance of scrub-shrub habitat on the ridge and a decline or disappearance in upland range and upland barren land habitats.



Class	Project Area (Acres)
Land	392
Water	20
Total	**412**

Figure 5. Land-water analysis of the BA-0048 project area conducted on CRMS aerial imagery acquired October 11, 2016.

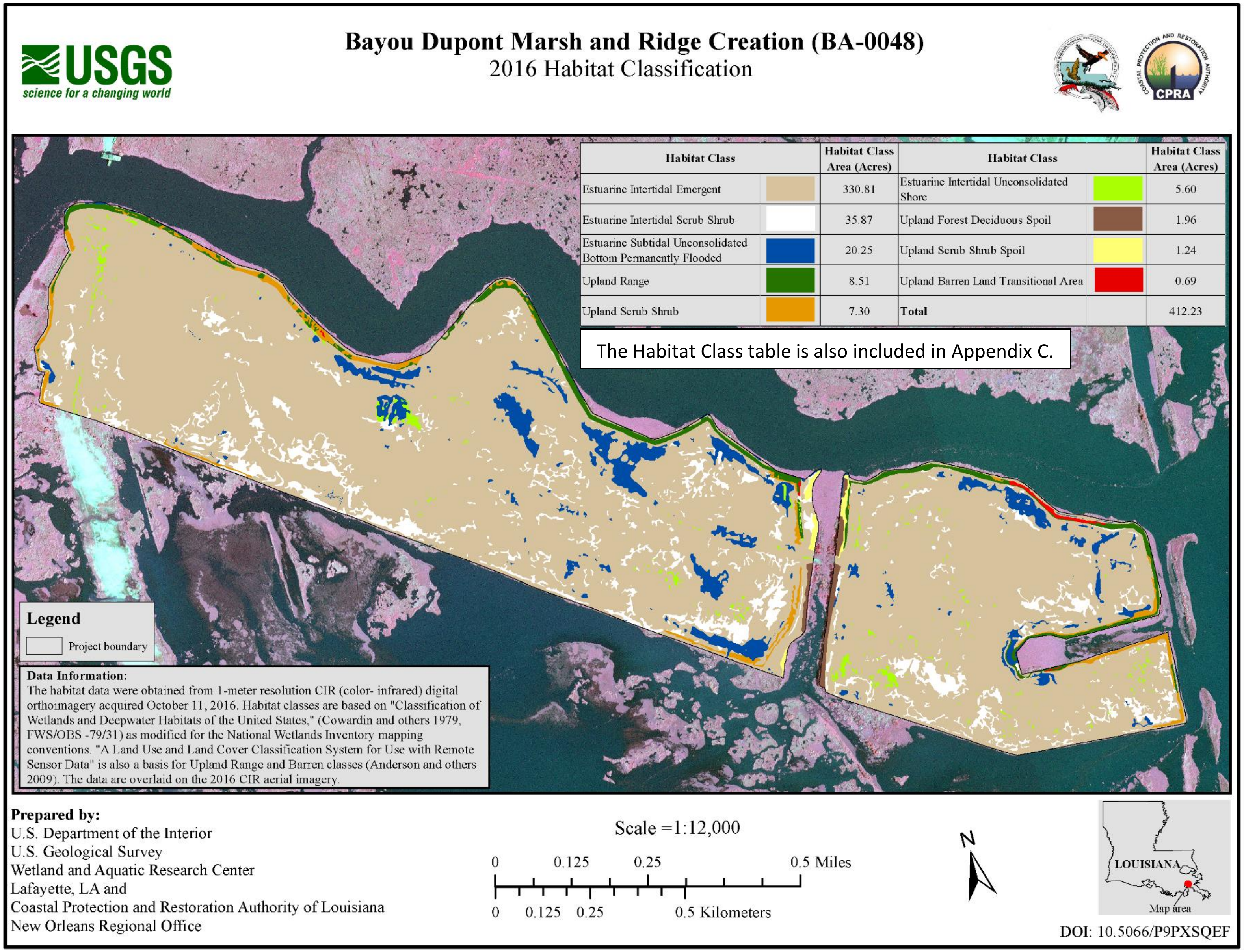


Figure 6. Habitat analysis of the BA-0048 project area conducted on CRMS imagery acquired October 11, 2016.

ii. <u>Elevation</u>

Elevation surveys are being conducted throughout the life of the BA-0048 project to assess whether the project area is at an elevation that supports healthy marsh and ridge habitat and to compare measured settlement to the projected settlement curve. Elevation surveys of the project area were conducted April–June 2014 (pre-construction), October 2015 (~ 6 months post-construction), October 2017 (~ 2.5 years post-construction) and October–November 2019 (~ 4.5 years post-construction). As previously noted, the project was designed in Geoid99 but constructed in Geoid09, resulting in the project features being built approximately 0.7 ft higher than intended. Additionally, elevation analysis was conducted using the updated Geoid12A or 12B, which are identical in this region. For clarity, the original design elevation in Geoid99, the actual constructed elevation in Geoid99, and the converted Geoid12B elevations are included in Table 1. All survey data in this section are presented in feet, NAVD88, and Geoid12A/B. Elevation was assessed separately for the marsh and ridge. In addition to calculating mean elevations for the marsh and ridge, acres were divided into one-foot elevation increments to create elevation contour maps and more precisely observe elevation change over time and area.

Table 1. Design and constructed elevations for the marsh and ridge in Geoid99 (used for design) and Geoid12B (used for analysis).

	Marsh		Ridge	
	Geoid99	Geoid12B	Geoid99	Geoid12B
Design Elevation (ft)	+3.0 ± 0.5	+2.5 ± 0.5	+4.5 + 0.5	+4.0 + 0.5
Constructed Elevation (ft)	+3.7 ± 0.5	+3.2 ± 0.5	+5.2 + 0.5	+4.7 + 0.5

Marsh

The marsh boundary that was used for elevation analysis excluded the ridge, containment dikes and pre-existing spoil banks to avoid a false inflation of marsh elevation. Mean elevation in the marsh boundary for the 2014 pre-construction survey was -1.2 ± 0.9 ft, with the largest percentage of acres (42.5%) between -2.0 ft and -1.0 ft (Figure 7). Elevations > 0.0 ft corresponded to areas of remaining marsh. Six months after construction was completed, the marsh had a mean elevation of +2.2 ± 0.4 ft, with 71% of the marsh between +2.0 ft and +3.0 ft (Figure 8). By the 2017 survey, mean marsh elevation had settled 0.4 ft to +1.8 ± 0.4 ft, with 72% of the marsh now at a lower elevation between +1.0 ft and +2.0 ft (Figure 9). The marsh elevation largely stabilized between the 2017 and 2019 surveys, declining only 0.2 ft to a mean elevation of +1.6 ± 0.5 ft, with 71% of the marsh still at an elevation between +1.0 ft and +2.0 ft (Figure 10). Between the 2015 and 2019 post-construction surveys, the mean marsh elevation decreased a total of 0.6 ft and 88.1% of the marsh area settled between 0.0 ft and 1.0 ft (Figure 11). The marsh elevation by acres (%) and survey year is summarized by one-foot increments in Figure 12.

Six months after construction completion, the western marsh had a mean elevation of +2.3 ± 0.4 ft and the eastern marsh had a slightly lower elevation of +2.1 ± 0.3 ft. The western marsh remained at a higher elevation than the eastern marsh through the 2019 survey, with settlement to +1.7 ± 0.5 ft and +1.4 ± 0.4 ft, respectively. The highest elevations have been concentrated in the northwestern area of the western marsh. River sediment was pumped into the northwestern project area first to build up the sediment pipeline corridor and to construct the BA-0048 construction staging area. As this heavy mineral sediment discharged into BA-0048, it rapidly compacted and dislodged some of the underlying organic sediment southeastward in "mud waves". Organic soils take longer to dewater and compact than mineral soils. As a result, areas with a greater depth of fill from river sediment, such as the pipeline corridor, likely stabilized more rapidly during construction, while stabilization in areas where soils had a higher organic content occurred over a longer time.

For the 2019 survey, a higher elevation area between +3.0 ft and +4.0 ft appears to have expanded in the western marsh (Figure 10). The area was heavily forested with *Salix nigra* (black willow) in 2019 and the survey crew deviated from and truncated some of the transects to avoid the densely-vegetated terrain. While this is an area of relatively high elevation, the increasing 2019 elevations are likely an artifact of interpolation between surrounding higher elevation points and are not a true reflection of increasing elevation in the area.

The 2019 elevation analysis also indicates an area of lower elevation within the dead-end canal or "keyhole" in the eastern marsh (Figure 10). During construction, deeper than expected elevations were discovered along the far interior bank of the canal. As a result, the containment dike was moved slightly inwards at this location. A short length of the containment dike was never built to grade, and was instead left as a gap to foster hydrologic exchange. Three additional gaps were strategically placed along the western containment dike of the western cell to allow hydrologic exchange in areas of slightly lower elevation.

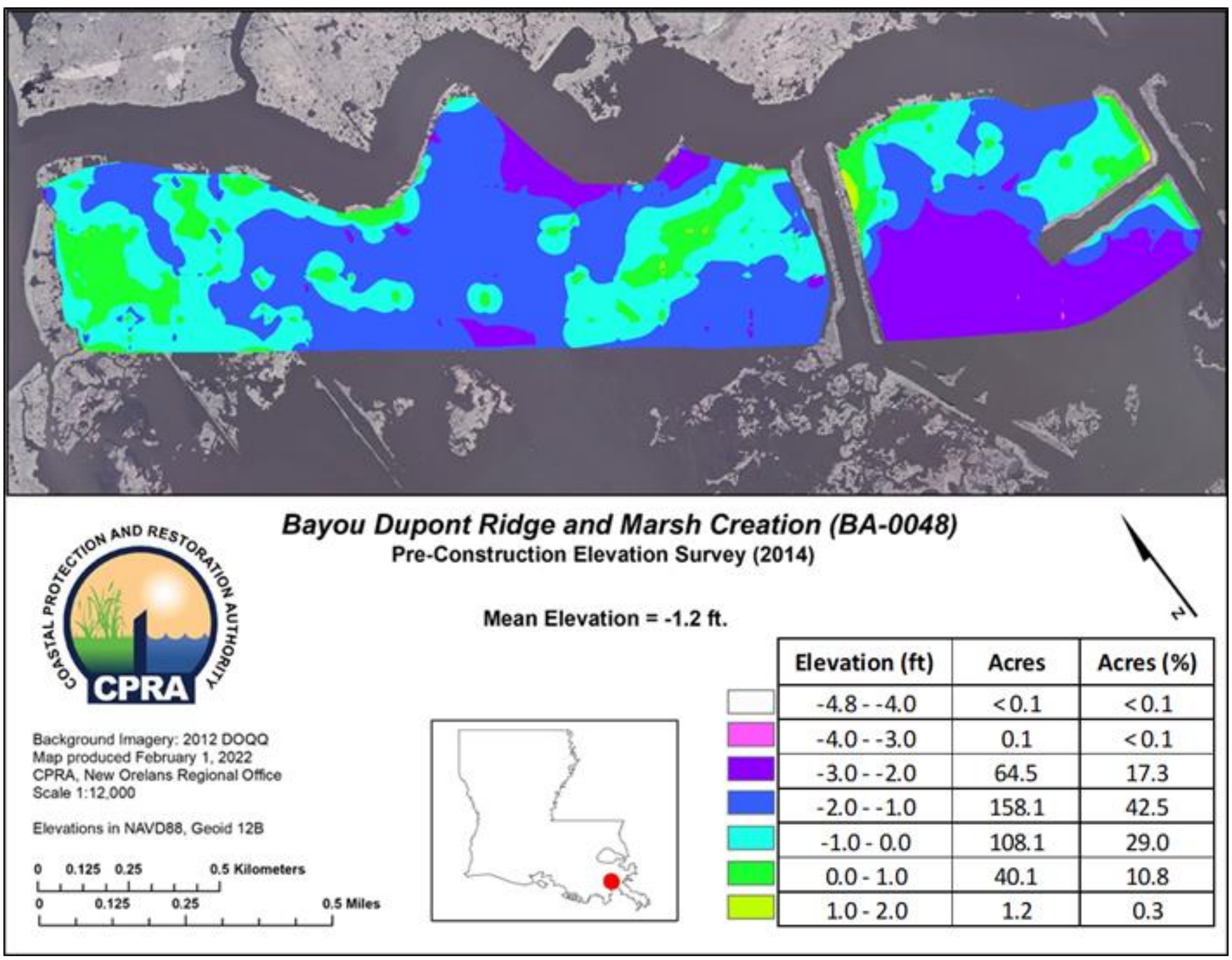
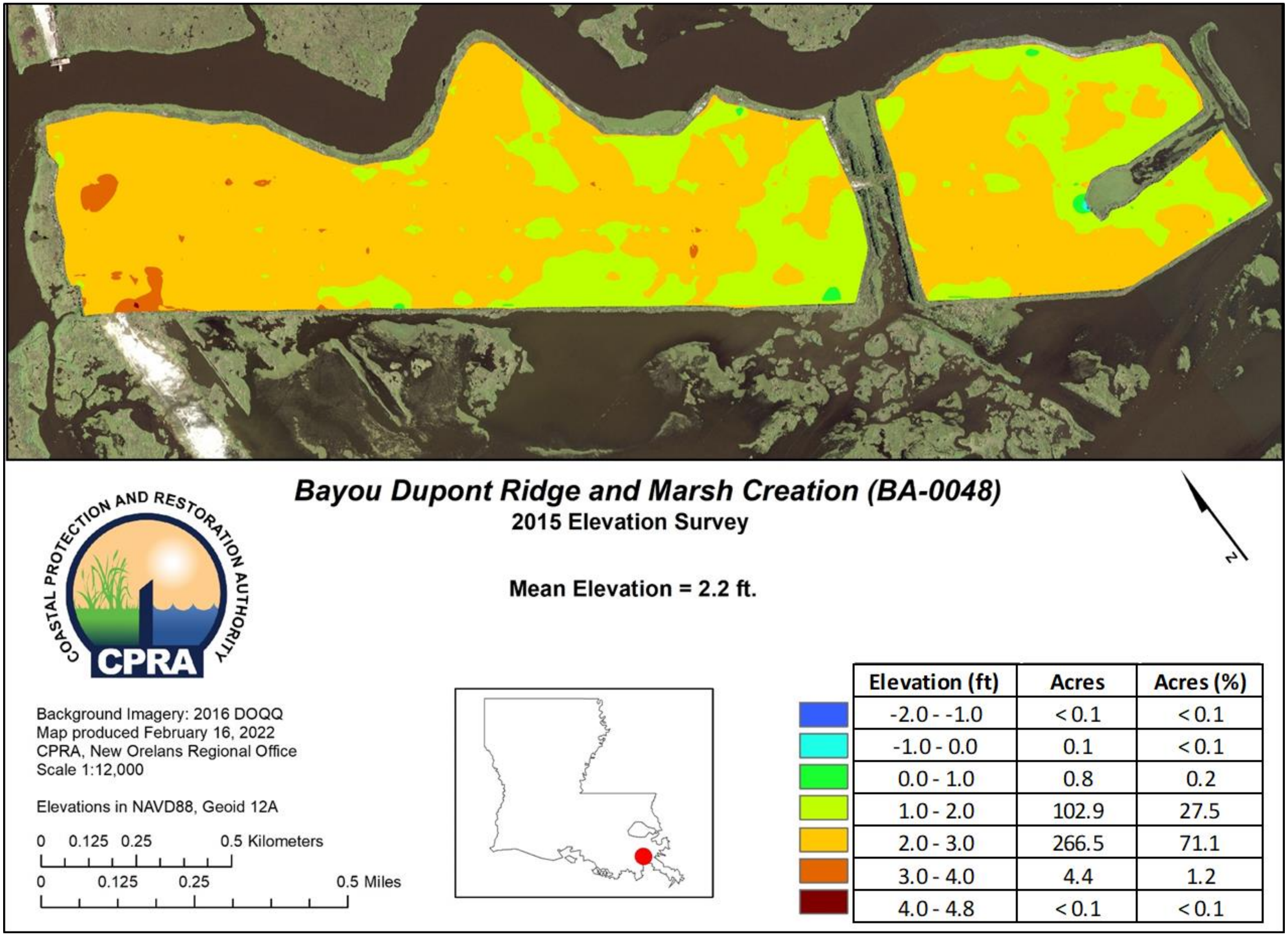
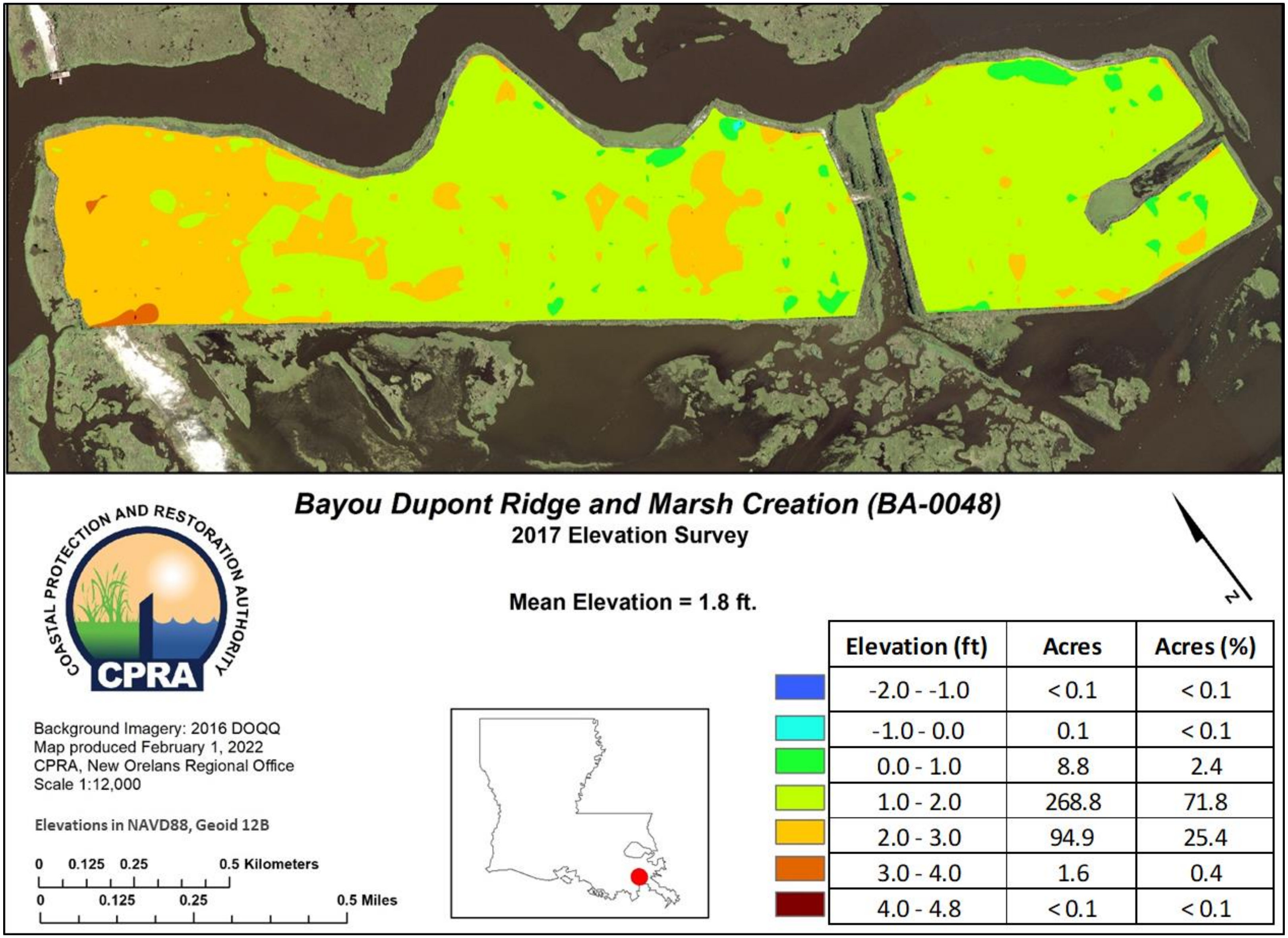


Figure 7. Elevation in the BA-0048 marsh boundary prior to construction (2014).



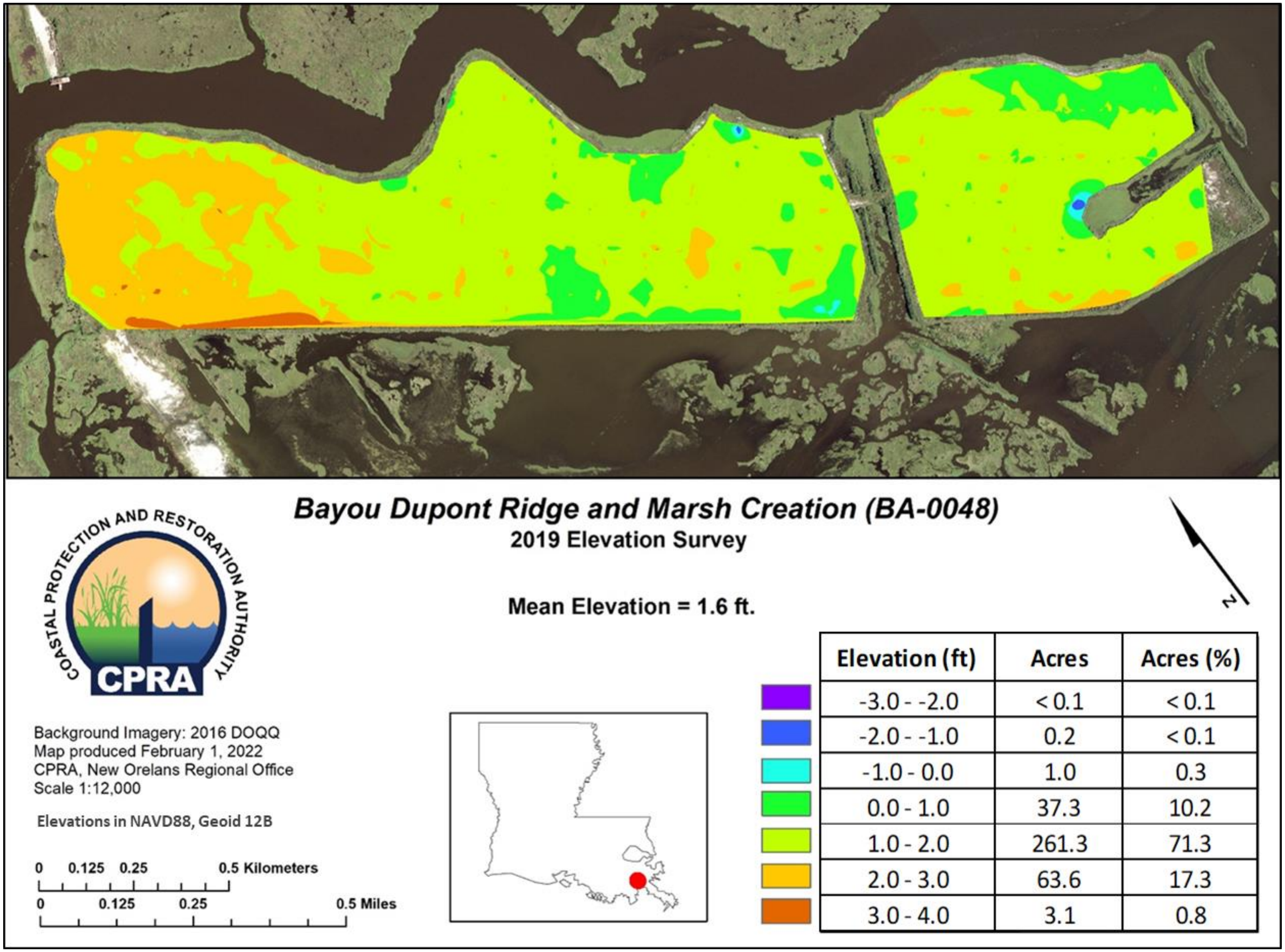
Elevation (ft)	Acres	Acres (%)
-2.0 - -1.0	< 0.1	< 0.1
-1.0 - 0.0	0.1	< 0.1
0.0 - 1.0	0.8	0.2
1.0 - 2.0	102.9	27.5
2.0 - 3.0	266.5	71.1
3.0 - 4.0	4.4	1.2
4.0 - 4.8	< 0.1	< 0.1

Figure 8. Elevation of the BA-0048 marsh approximately six months after construction (2015).



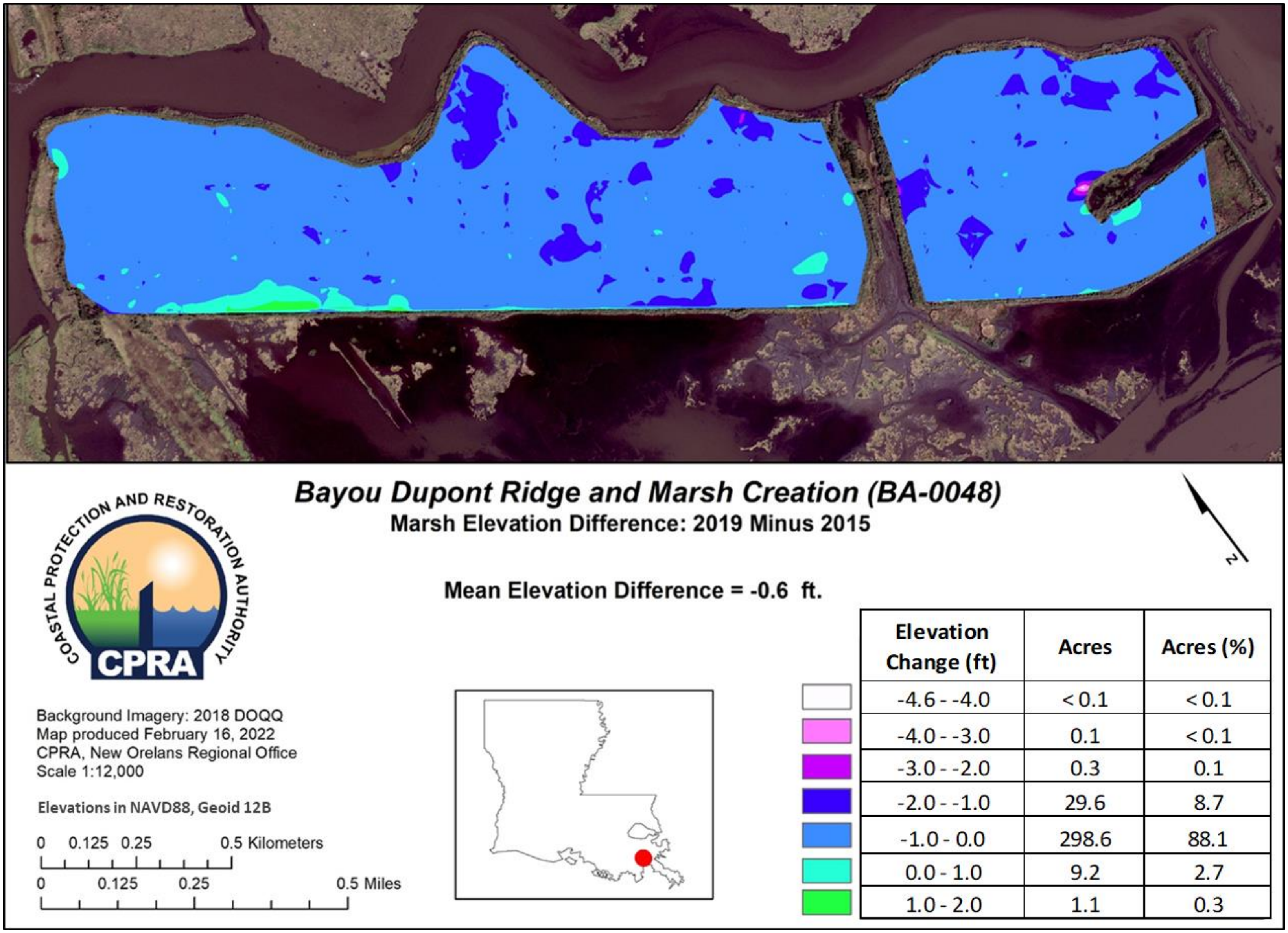
Elevation (ft)	Acres	Acres (%)
-2.0 - -1.0	< 0.1	< 0.1
-1.0 - 0.0	0.1	< 0.1
0.0 - 1.0	8.8	2.4
1.0 - 2.0	268.8	71.8
2.0 - 3.0	94.9	25.4
3.0 - 4.0	1.6	0.4
4.0 - 4.8	< 0.1	< 0.1

Figure 9. Elevation of the BA-0048 marsh approximately two years after construction (2017).



Elevation (ft)	Acres	Acres (%)
-3.0 - -2.0	< 0.1	< 0.1
-2.0 - -1.0	0.2	< 0.1
-1.0 - 0.0	1.0	0.3
0.0 - 1.0	37.3	10.2
1.0 - 2.0	261.3	71.3
2.0 - 3.0	63.6	17.3
3.0 - 4.0	3.1	0.8

Figure 10. Elevation of the BA-0048 marsh approximately four years after construction (2019).



Elevation Change (ft)	Acres	Acres (%)
-4.6 - -4.0	< 0.1	< 0.1
-4.0 - -3.0	0.1	< 0.1
-3.0 - -2.0	0.3	0.1
-2.0 - -1.0	29.6	8.7
-1.0 - 0.0	298.6	88.1
0.0 - 1.0	9.2	2.7
1.0 - 2.0	1.1	0.3

Figure 11. Elevation change for the BA-0048 marsh between the 2015 and 2019 post-construction surveys.

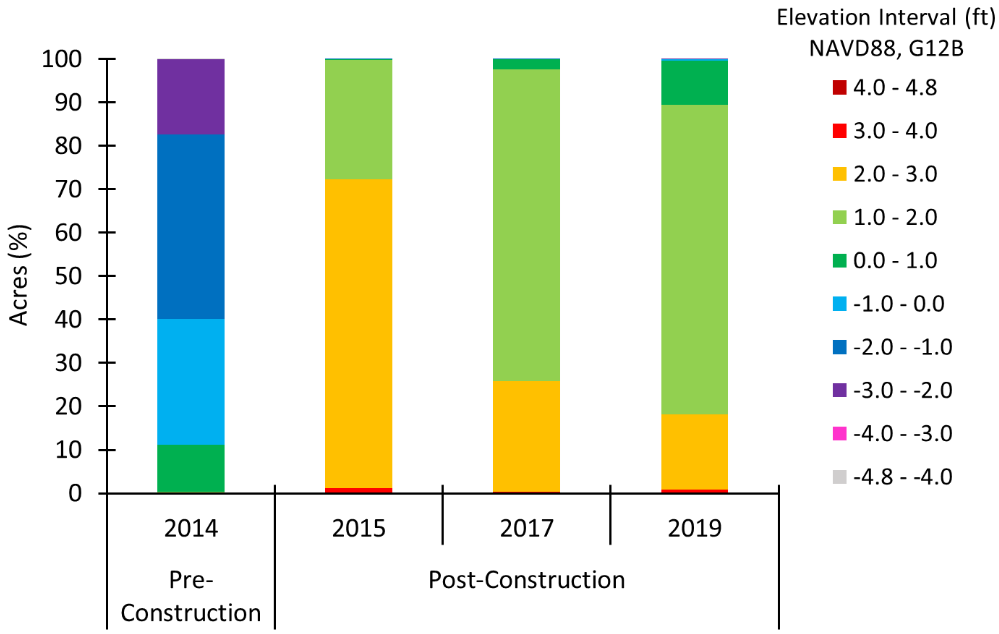
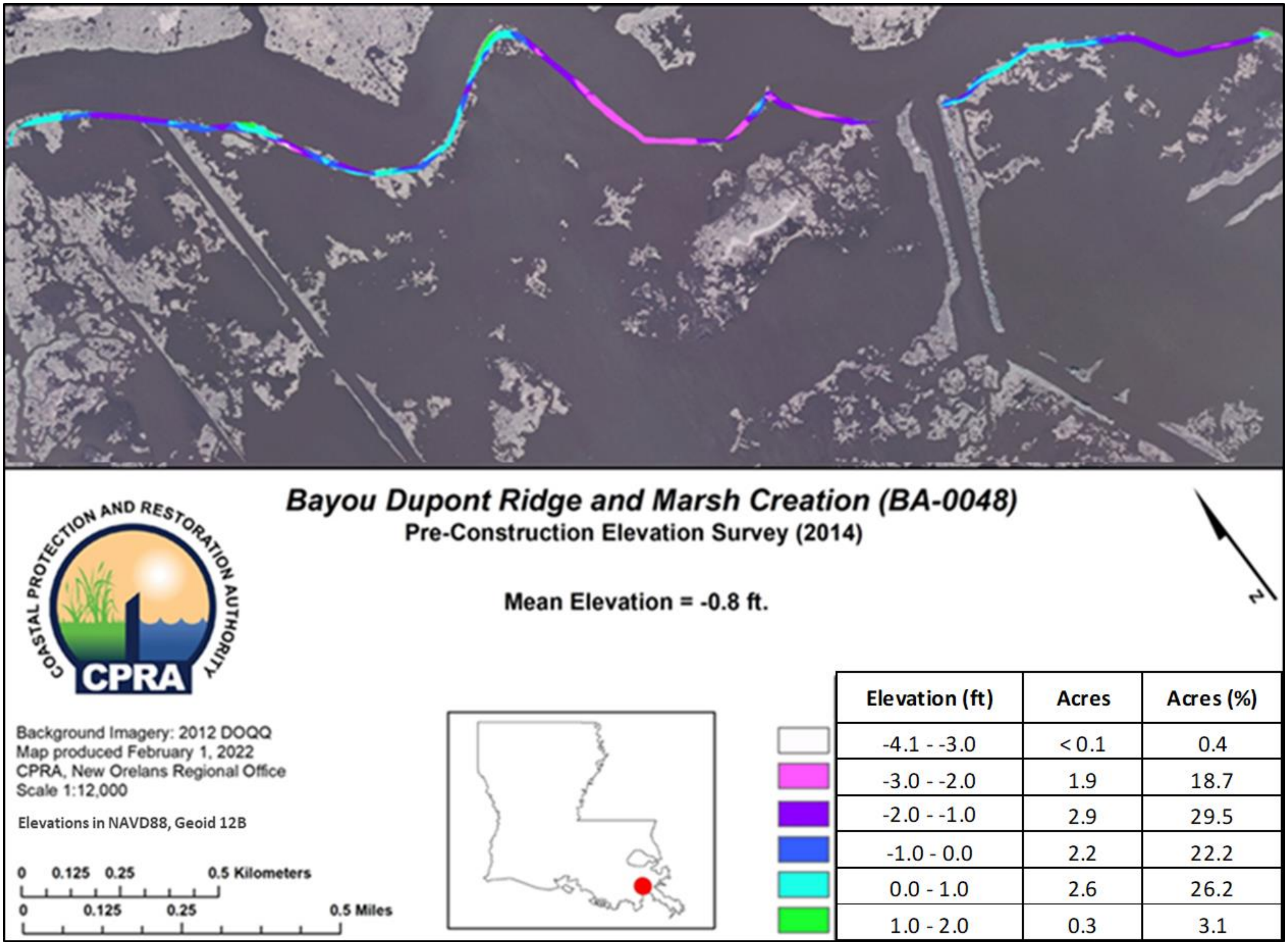


Figure 12. Percent of marsh acres within each one-foot elevation interval in the BA-0048 project area for the pre- and post-construction surveys.

Ridge

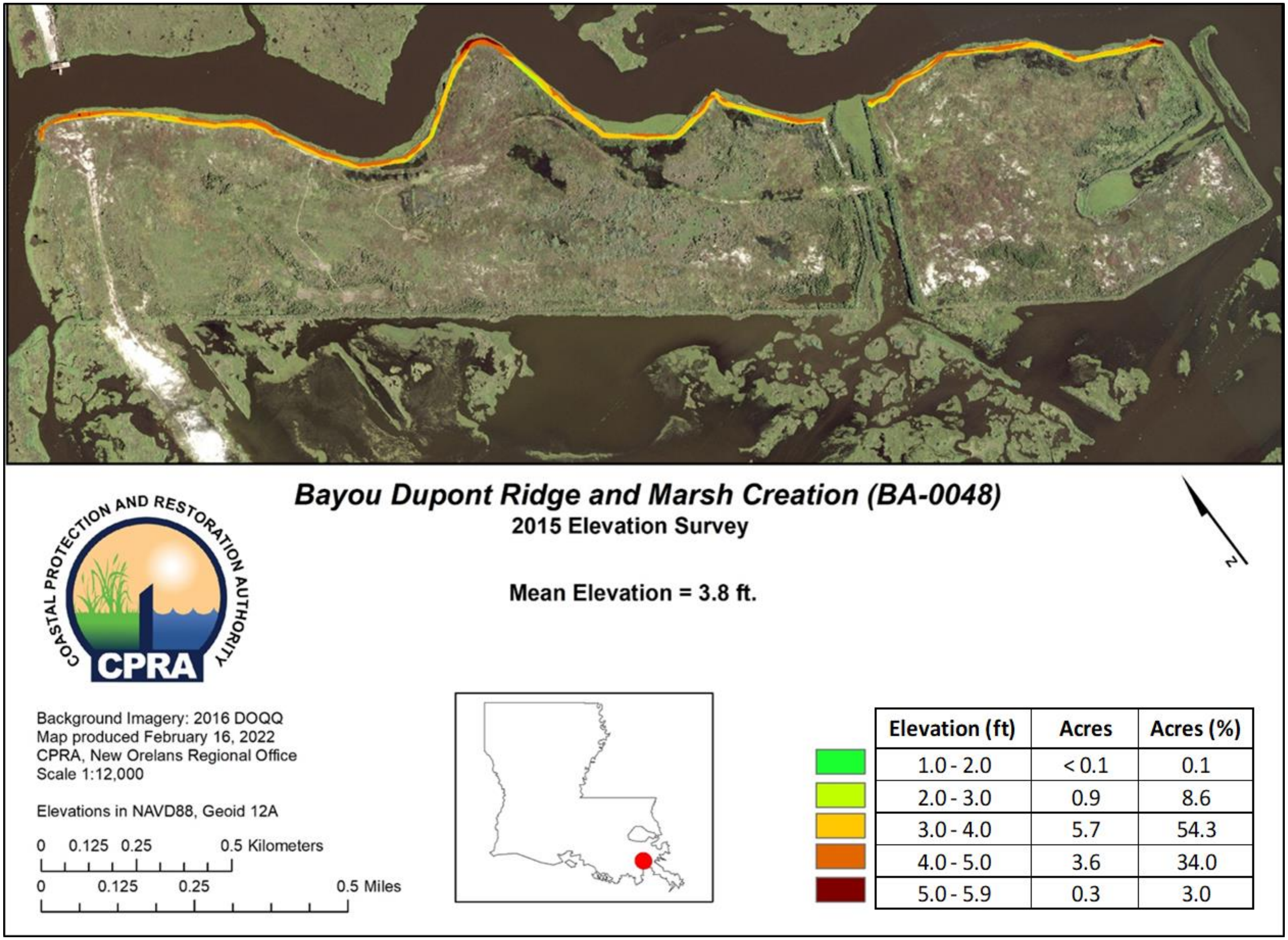
The ridge was constructed to a height of +4.7 + 0.5 ft, Geoid 12B, which is 0.7 feet taller than the design elevation of +4.0 ft due to the project being constructed using Geoid09 rather than Geoid99, as previously discussed. The approximately 10-acre boundary that was used for elevation analysis contains both the crown and slope of the ridge in order to assess the entire ridge habitat. A separate analysis of the ridge crown elevation will also be discussed in relation to the settlement curve. Elevation survey transects were established across the ridge (from marsh to bayou), and along the length of the ridge crown (centerline) (Figure 2). The centerline survey was completed in 2015 and 2017, but by 2019, most of the ridge had densely vegetated with shrubs that prevented the survey team from completing the transect. Ridge crown data were still collected as part of the transects that ran perpendicularly across the ridge (Figure 2).

Mean elevation in the ridge boundary for the 2014 pre-construction elevation survey was -0.8 ± 1.1 ft (Figure 13). The greatest percentage of acres (29.5%) was between -2.0 ft and -1.0 ft. Areas in the lower part of the elevation range, generally below -1.0 ft, corresponded to shallow open water, while areas in the higher elevation range corresponded to remnant marsh along the bayou, as can be seen in Figure 13. Approximately six months after project completion (2015), the newly-constructed ridge had a mean elevation of +3.8 ± 0.6 ft, with the majority of the ridge (54.3%) between +3.0 ft and +4.0 ft (Figure 14). Over a third of the ridge was at a higher elevation, with 34% of the ridge between +4.0 ft and +5.0 ft. By 2017, the mean ridge elevation had decreased by 1.0 ft to +2.8 ± 0.6 ft, with most of the ridge (57.3%) at an elevation between +2.0 ft and +3.0 ft (Figure 15). Between the 2017 and 2019 surveys, the mean ridge elevation further decreased by 0.5 ft to +2.3 ± 0.5 ft, with a majority of the ridge (66.4%) still at an elevation between +2.0 ft and +3.0 ft (Figure 16). Between the 2015 and 2019 surveys, the ridge decreased by a total of 1.5 ft, with 57% of the ridge declining between 1.0 ft and 2.0 ft (Figure 17). The ridge elevation by acres (%) and survey year is summarized in Figure 18. There was no meaningful difference in the overall settlement between the western and eastern ridge, with both areas having a mean elevation of +3.8 ft in 2015 and +2.3 ft in 2019.



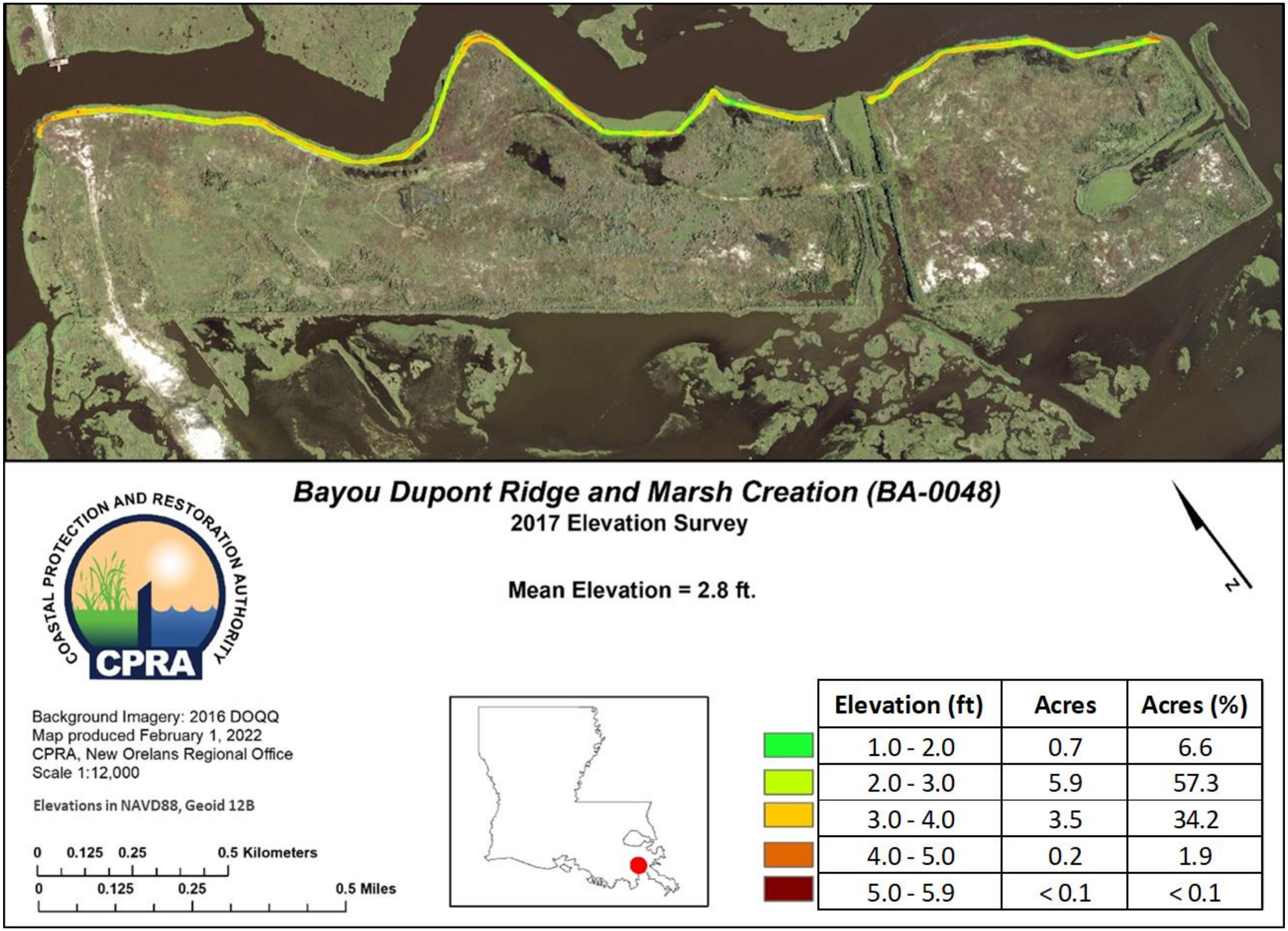
Elevation (ft)	Acres	Acres (%)
-4.1 - -3.0	< 0.1	0.4
-3.0 - -2.0	1.9	18.7
-2.0 - -1.0	2.9	29.5
-1.0 - 0.0	2.2	22.2
0.0 - 1.0	2.6	26.2
1.0 - 2.0	0.3	3.1

Figure 13. Elevation within the BA-0048 ridge footprint as surveyed in 2014, prior to project construction.



Elevation (ft)	Acres	Acres (%)
1.0 - 2.0	< 0.1	0.1
2.0 - 3.0	0.9	8.6
3.0 - 4.0	5.7	54.3
4.0 - 5.0	3.6	34.0
5.0 - 5.9	0.3	3.0

Figure 14. Elevation of the BA-0048 ridge approximately six months after construction (2015).



Elevation (ft)	Acres	Acres (%)
1.0 - 2.0	0.7	6.6
2.0 - 3.0	5.9	57.3
3.0 - 4.0	3.5	34.2
4.0 - 5.0	0.2	1.9
5.0 - 5.9	< 0.1	< 0.1

Figure 15. Elevation of the BA-0048 ridge approximately two years after construction (2017).

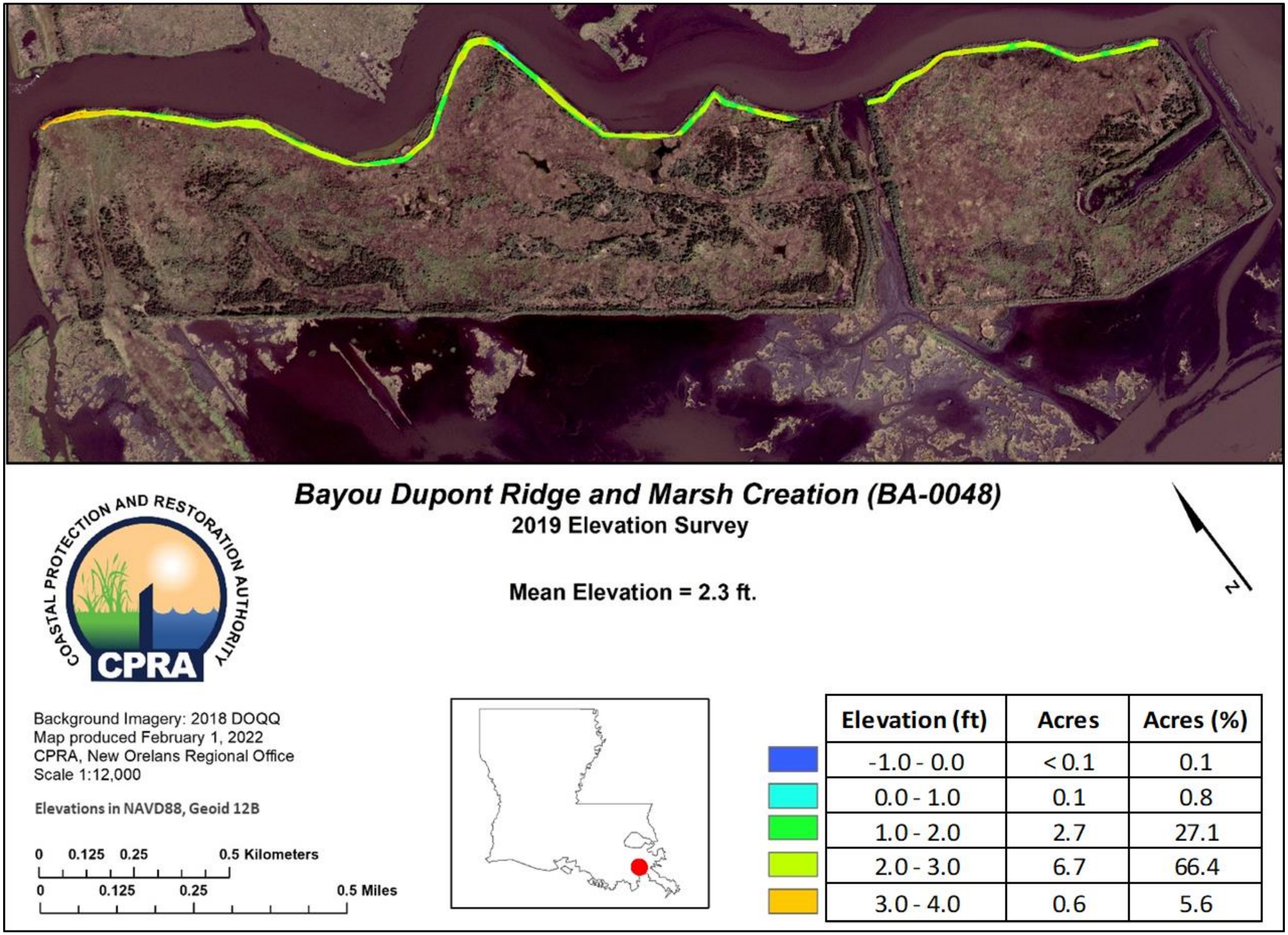


Figure 16. Elevation of the BA-0048 ridge approximately four years after construction (2019).

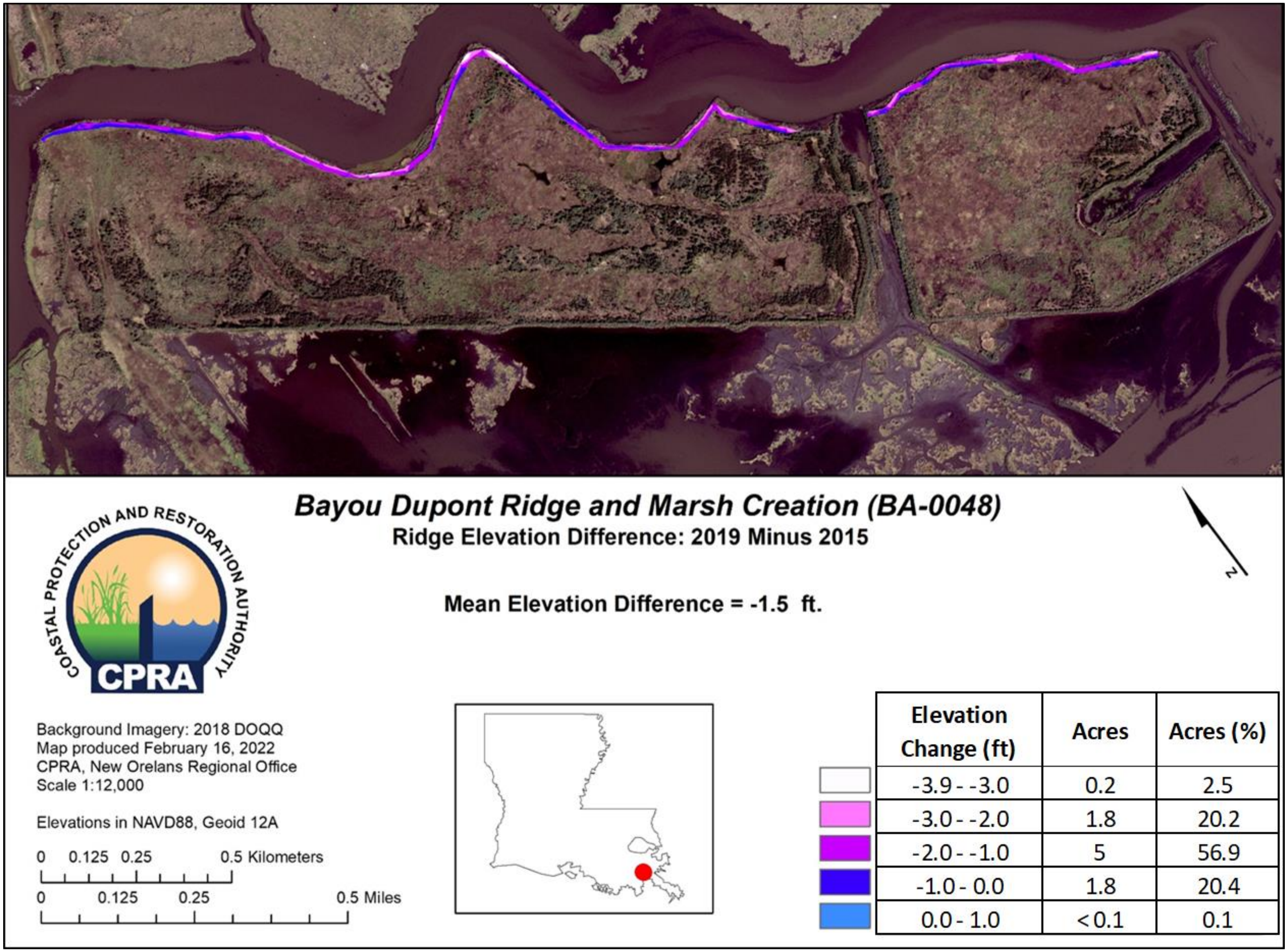


Figure 17. Total elevation change for the BA-0048 ridge between the 2015 and 2019 post-construction surveys.

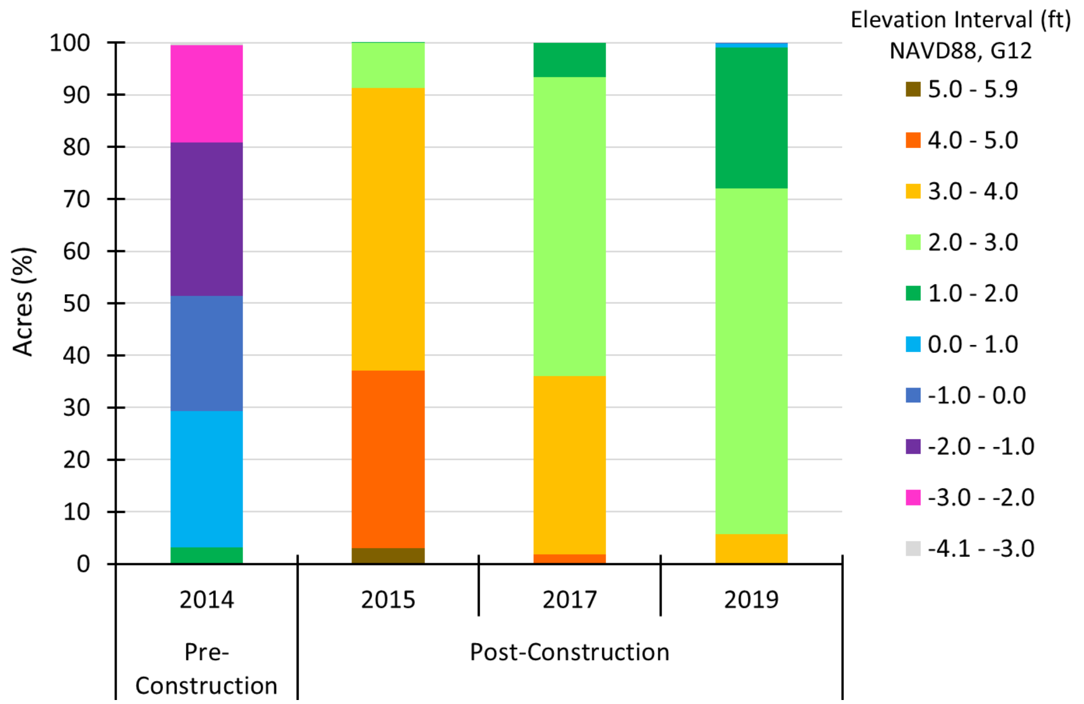


Figure 18. Percent of ridge acres within each one-foot elevation interval in the BA-0048 project area for the pre- and post-construction surveys.

<u>Settlement Curves</u>

Marsh

During the design phase, settlement curves for multiple fill elevations were developed for the BA-0048 marsh to determine the best construction elevation to provide long-term sustainability of the marsh habitat. The curves factored in settlement and dewatering of the newly deposited soils, as well as subsidence of the underlying soils. As previously noted, the marsh was constructed approximately 0.7 ft higher than intended, which resulted in a targeted constructed marsh elevation of +3.2 ± 0.5 ft NAVD88 G12B. The closest settlement curve to this marsh elevation is +3.1 ft NAVD88 G12B, and this curve will be utilized to compare to the surveyed mean marsh elevations.

The 2015 elevation survey was conducted approximately six months after construction was completed. Due to the rapid settlement that occurs in the first few months after construction, this survey did not capture the as-built marsh elevation. The mean marsh elevation for the 2015 survey was +2.2 ± 0.4 ft and was approximately 0.3 ft below the predicted elevation at that time (Figure 19). Assuming a constructed elevation of +3.2 ± 0.5 ft, the settlement rate within the first six months was higher than anticipated. However, by the 2017 survey, the surveyed and predicted mean marsh elevations were similar, at +1.7 ± 0.4 ft and approximately +1.8 ft, respectively. Between the 2017 and 2019 surveys, the settlement rate declined in relation to the predicted curve, with the 2019 mean elevation approximately 0.3 ft above the predicted curve (actual: +1.6 ± 0.5 ft, predicted: +1.3 ft). If a slower settlement rate is maintained, the marsh elevation may be significantly higher than the +0.3 ft elevation predicted at year 20 (Figure 19).

A separate assessment of the western and eastern marsh elevations indicates that the western marsh remained at a higher mean elevation than the eastern marsh through the 2019 survey and appeared to settle at a slower rate between the 2015 and 2017 surveys. (Figure 19). The difference in elevations and settlement is primarily due to the higher elevation area in the vicinity of the sediment pipeline corridor in the western marsh, as previously discussed (p. 14–15).

The marsh was expected to settle into the intertidal zone by approximately year five (2020), with a target elevation of +0.8 ft NAVD88 (Coco 2010), but based on the 2019 elevation survey, the mean marsh elevation was likely > 0.5 ft higher at that time (Figure 19). When plotted with the daily mean water elevation from station BA03c-61 (see Figure 2 for location), the 2019 mean marsh elevation is at the higher range of the hydrograph, while the target elevation is near the middle (Figure 20). However, habitat analysis of BA-0048 aerial imagery (Figure 6) indicates that 80% of the project area was already classified as emergent marsh habitat by 2016. Therefore, despite the higher-than-expected marsh elevation in 2019, the marsh creation platform had already vegetated with primarily marsh habitat only 1.5 years after construction completion. However, the occurrence of woody vegetation species increased between the 2016 and 2019 vegetation surveys, as is discussed in detail in the Vegetation section (p. 29).

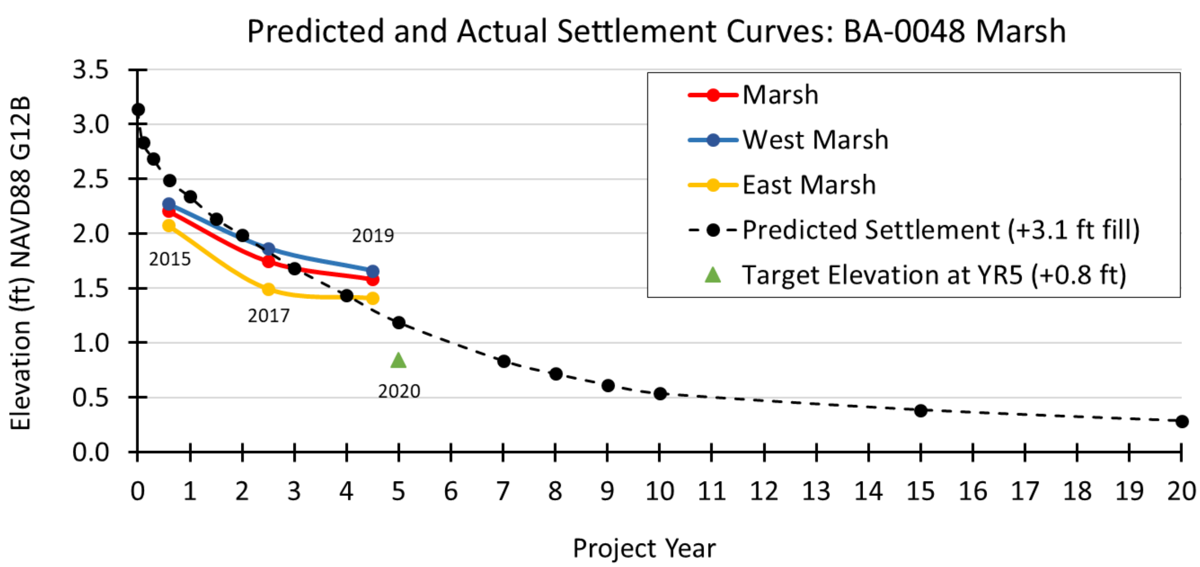


Figure 19. Predicted and actual marsh settlement for BA-0048. The target marsh elevation at year five is included for reference.

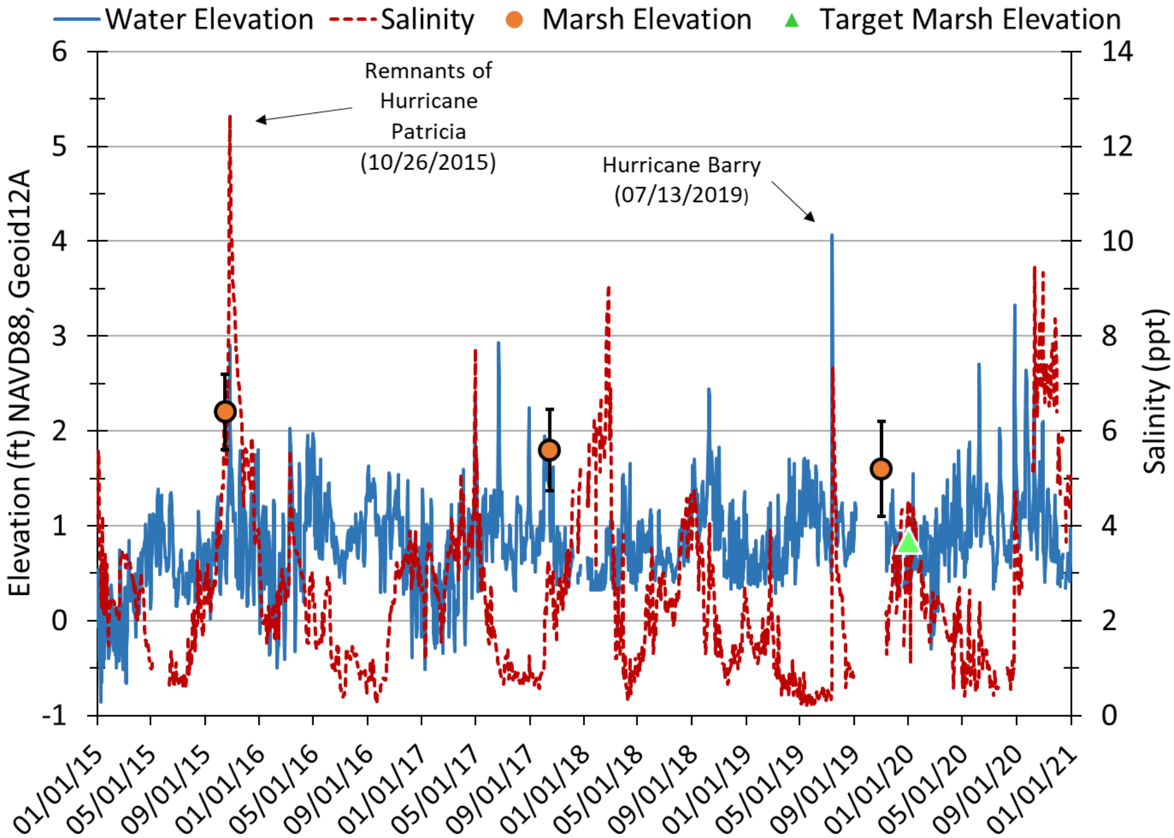


Figure 20. Mean daily water elevation and salinity at hydrographic station BA03c-61, with the mean marsh elevation (± SD) for each survey, and the target marsh elevation at year five.

Ridge

As with the marsh, settlement curves were developed for the ridge to identify the optimal constructed elevation. The predicted settlement curves for a constructed ridge elevation of +4.1 ft NAVD88 G12B (closest to the design height of +4.0 + 0.5 ft) and a constructed ridge elevation of +5.1 ft NAVD88 G12B (closest to the actual constructed height of +4.7 + 0.5 ft) will both be presented. Unlike the previous ridge elevation analyses that incorporated the entire project feature, including the ridge slope, this analysis is focused solely on the crown height. Also, since the mean crown elevations for the western and eastern ridges were nearly identical, only the combined crown elevations are presented on the settlement curve.

The 2015 ridge elevation survey was conducted approximately six months after the end of construction, and did not capture the actual as-built elevation. The 2015 mean crown elevation of +4.0 ± 0.6 ft closely aligns with the predicted 2015 elevation for the higher +5.1 ft curve (Figure 21). However, there is a significant divergence from this curve for the 2017 and 2019 surveys, with settlement slowing at a greater rate than predicted. The mean crown elevation decreased to +3.2 ± 0.5 ft by 2019, meaning between the 2015 and 2019 surveys, the crown elevation decreased by only 0.8 ft. Based on the current ridge settlement rate, the elevation at year 5 (2020) was likely > 1.0 ft higher than the targeted ridge elevation at this time of +2.0 ft (Figure 21).

The slower settlement of the ridge crown may be explained by the number of lifts and partial lifts that occurred during ridge construction (May 2014–March 2015), with the contractor continuing to fill in lower elevation areas of the ridge to meet construction specifications. During the extended period of ridge construction, the ridge and underlying sediments continued to compact, likely resulting in a slower settlement rate than would typically be expected at the end of construction. If the ridge crown maintains a slower-than-predicted settlement rate through the project life, the life-expectancy of the scrub-shrub habitat could be greatly extended.

For comparison, the mean ridge elevation that included the entire ridge feature (including the slope), was also plotted on the settlement curve (Figure 21). The mean survey elevations for the entire ridge feature follow the projected curve for a +5.1 ft fill elevation. This curve has a higher rate of settlement than the crown, which may be an indication of erosion along the ridge slopes.

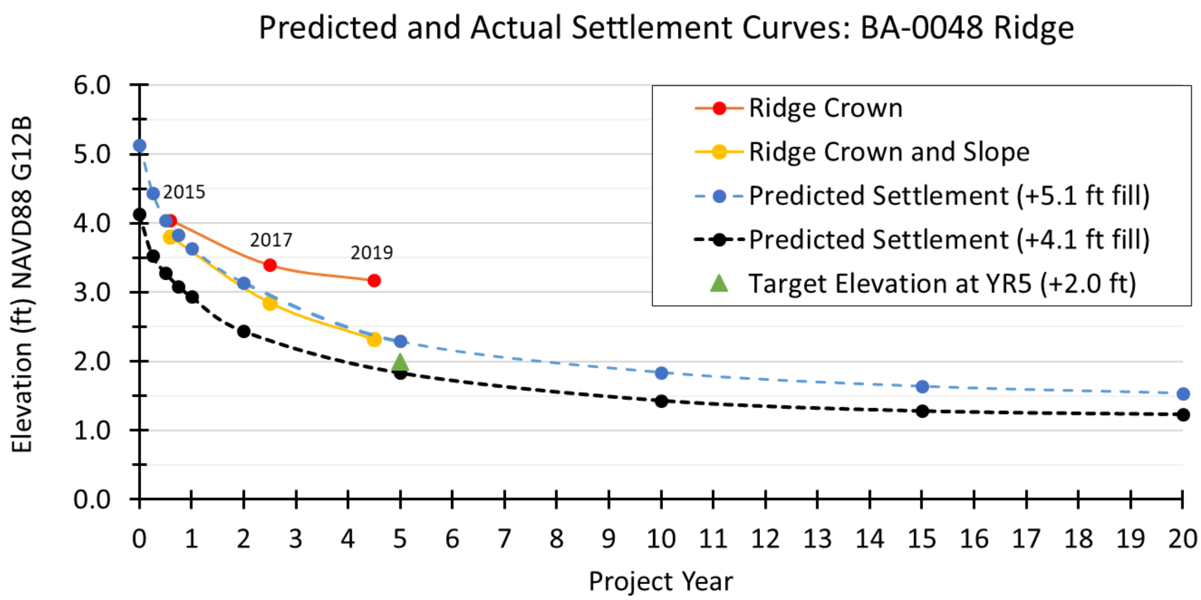


Figure 21. Predicted and actual settlement of the BA-0048 ridge.

iii. Vegetation

Two habitats, marsh and ridge, were created as part of the BA-0048 project. Because distinct vegetation communities will develop in response to the different elevations and hydrologic regimes associated with each habitat, the vegetation assessments for the marsh and ridge are conducted separately.

Marsh

Total Percent Cover

Total percent cover is an assessment that is made at each vegetation monitoring station of the total live vegetative cover, with the maximum cover being 100%. A total percent cover of 100% means that if a station was viewed from above, no ground would be viewable beneath the vegetation. The BA-0048 marsh platform vegetated rapidly, with a mean total percent cover of 82 ± 11% measured in September 2016, after just two growing seasons (Figure 22). Mean total percent cover was similar between the western marsh and eastern marsh cells. By the August 2019 survey, mean total percent cover had declined significantly in the marsh to 63 ± 25% (p = 0.0218, F = 6.02). A separate analysis of each marsh creation cell found this decline significant only in the western marsh (p = 0.0246, F = 6.16) (Figure 22). One explanation for the decrease in cover could be the timing of Hurricane Barry, a Category 1 storm that made landfall on July 13, 2019, in Vermilion Parish, LA, just west of Vermilion Bay. The vegetation survey was conducted less than two months after the hurricane, which caused a spike in water level and salinity in the project area (Figure 21). While hurricane-related stressors could have resulted in a reduction of live vegetative cover for the 2019 survey, especially herbaceous cover, the early successional vegetative community was also undergoing a change in species composition and structure (layer) that may have contributed to the overall decline. These changes will be discussed in the following sections on Layer Percent Cover and Species Cover and Distribution.

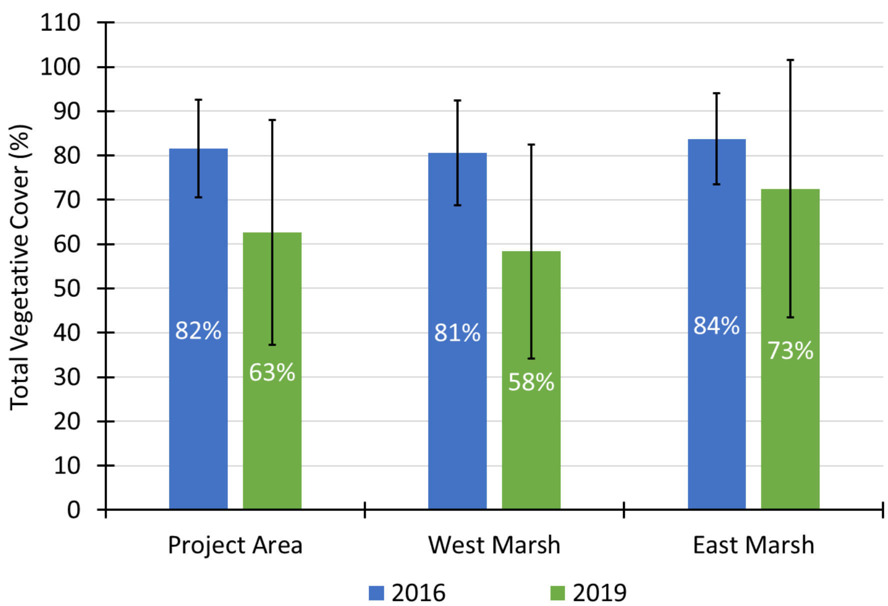


Figure 22. Comparison of total percent vegetative cover (± SD) in the BA-0048 marsh for the 2016 and 2019 vegetation surveys.

Layer Percent Cover

Four vegetative layers—tree, shrub, herbaceous, and carpet—are included in the assessment of vegetation at each monitoring station (Folse et al. 2020). These layers are largely differentiated by height and whether the species are herbaceous or woody (i.e., shrubs and trees). Each layer is assessed individually, allowing for an observation of changes to vertical structure and habitat within the community. Between the 2016 and 2019 surveys, layer percent cover changed significantly for the herbaceous and tree layers (p = 0.0038, F = 10.30 and p = 0.0387, F = 4.79, respectively). The herbaceous layer cover declined between 2016 and 2019 from 78 ± 15% to 52 ± 24% and was largely responsible for the previously reported decline in total percent cover. Hurricane Barry may have negatively impacted herbaceous cover; however, increased shading from an expansion of woody vegetation at some stations may have also influenced its decline. Tree layer cover increased significantly from 0% in 2016 to 12 ± 19% in 2019, as a result of the growth and expansion of *Salix nigra* (black willow). Although shrub cover was not significantly different between surveys, shrub cover trended upwards from 6 ± 9% in 2016 to 15 ± 24% in 2019, due to an expansion of *Baccharis halimifolia* (eastern baccharis). The carpet layer is categorized by herbaceous vegetation that is no taller than 10 cm. In 2016, a carpet layer of *Eleocharis vivipara* (viviparous spikerush) and *Bacopa monnieri* (herb of grace) was noted at two stations; however, no carpet layer was recorded for the 2019 survey and the overall impact to total cover between years was insignificant.

Species Cover and Distribution
The three species with the highest mean percent cover for the 2016 marsh vegetation survey were all herbaceous marsh species and included the vine *Vigna luteola* (hairypod cowpea,18%), *Typha latifolia* (broadleaf cattail, 16%) and *B. monnieri* (16%) (Figure 23). While *B. monnieri* remained in the top three highest covers for the 2019 survey at 15%, the covers dropped considerably for *V. luteola* and *T. latifolia* to 2% and 5% cover, respectively. The dominant species in 2019 were the tree *Salix nigra* (18%), the shrub *B. halimifolia* (10%), and *Schoenoplectus americanus* (chairmaker's bulrush, 10%). As the marsh elevation declines and intertidal connectivity increases throughout the project area, habitat can be expected to become more uniformly marsh, with woody species being replaced by species more indicative of an emergent marsh habitat.

The three species with the highest mean covers in 2016 (*V. luteola, T. latifolia and B. monnieri*) were also the most widely-distributed species at stations that year, occurring at 62%, 77%, and 69% of stations, respectively. By the 2019 survey, *S. nigra* had become the most widely-occurring species at stations (69%) as it continued to expand into higher elevation areas of the marsh. After *S. nigra*, the species with the highest distribution at stations included *B. monnieri, T. latifolia, Solidago sempervirens* (seaside goldenrod) and *S. americanus*, all identified at 54% of stations and all common species in marsh habitat.

As expected in newly-created marsh, the cover and distribution of vegetative species is still greatly in transition; however, the number of species has not changed significantly between years. In 2016 there were 30 species documented at stations, while in 2019 there were 27. The complete list of all species both years, along with their mean covers, distributions, and associated marsh habitats, is included in Appendix E. Photographs from the marsh vegetation monitoring stations are included in Appendix D (photos 7–9).

Floristic Quality Index
The Floristic Quality Index (FQI) goes beyond providing information on species cover and distribution by characterizing the quality and stability of the marsh. The calculation of the FQI was developed by Swink and Wilhelm (1979), but has been modified by Cretini et al. (2011) to more effectively describe the coastal community in Louisiana. The FQI is calculated using the percent cover for each species and a value that is assigned to each species based on how indicative it is of a stable community. This value is called the coefficient of conservatism (CC) and ranges from 0 to 10, with 0 being a species of lowest value (e.g., invasive species) and 10 being a species that is characteristic of a vigorous coastal wetland (e.g., *Spartina alterniflora*). A station with a high FQI score represents a community that has a low percentage of invasive and disturbance species and is dominated by species that are found in a stable marsh community. An FQI score greater than 71 is considered good, less than 39 is considered poor, and between these ranges is considered fair (based on a maximum score of 100) (CPRA 2021).

The FQI score in the BA-0048 project area was 42 ± 15 in 2016 and 38 ± 17 in 2019, with the slight decline from the "good" range in 2016 to the "poor" range in 2019 attributed primarily to a lower vegetative cover (Figure 23). There was no significant difference in the FQI score between years or between the marsh creation cells. For both years, the marsh was dominated by species with a low to medium CC score. However, there was an increase in cover for a few high value species in 2019, including *S. americanaus* (CC: 8) in the western marsh and *Juncus roemerianus* (needlegrass rush, CC: 9) and *Eleocharis cellulosa* (Gulf Coast spikerush, CC: 7) in the eastern marsh. The large standard deviation (SD) in FQI values between stations is explained by the variability in species and covers throughout the marsh.

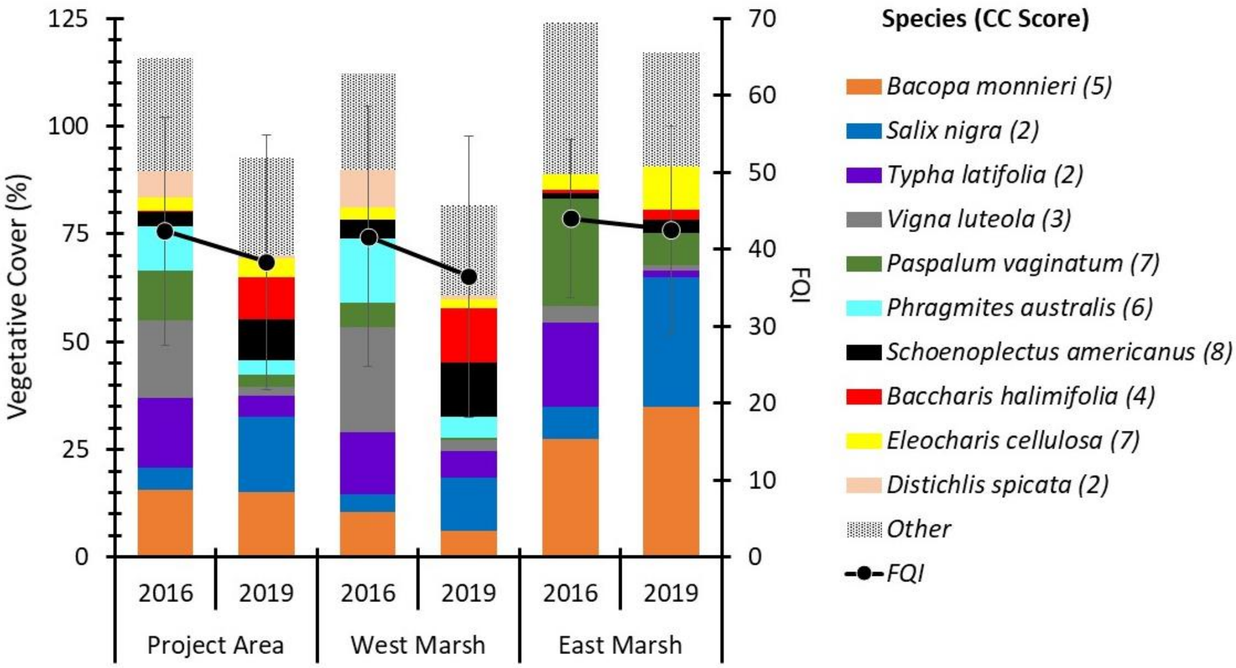


Figure 23. Mean species percent covers and mean FQI score (± SD) by year and area for the BA-0048 marsh. The graph shows the sum of the mean covers for each species. Due to the physical overlap of individual species at stations, this sum can be greater than 100%.

Ridge

Vegetation monitoring stations were established and surveyed in 2019 on the ridge crown, and for a subset of stations, also at associated stations on both sides of the ridge slope. Data collection and analyses followed the same protocols as marsh vegetation monitoring (Folse et al. 2020). Initial vegetation analyses that compared the crown and slope communities indicated no significant difference between habitats; therefore, the data were combined for all subsequent analyses.

Total Percent Cover

Total percent cover for the 2019 survey was high, at 81 ± 15%, with no significant difference in cover between the western and eastern ridge (Figure 24). The variability in cover between stations on the eastern ridge was greater than on the western ridge due to the location of monitoring stations both in locations that quickly vegetated, and locations where natural establishment was slow to occur. Total percent cover was higher on the ridge than in the marsh (marsh: 63 ± 25%) for the 2019 survey.

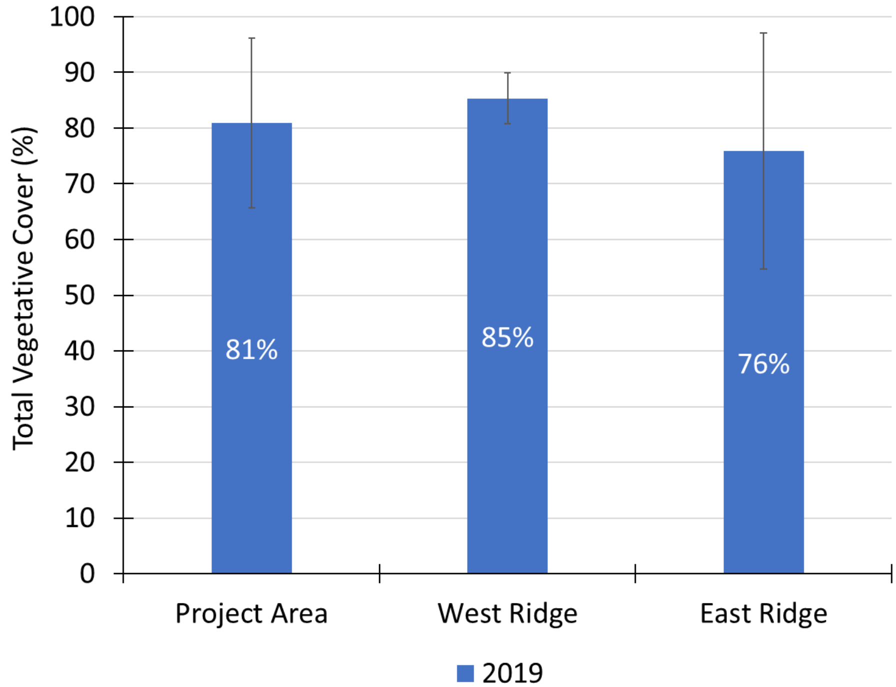


Figure 24. Total percent vegetative cover (± SD) on the BA-0048 ridge for the 2019 vegetation survey.

Layer Cover

Most of the vegetation on the ridge was classified in the shrub or herbaceous layers at 55 ± 33% and 48 ± 25%, respectively. The tree and carpet layers each contributed less than 3% cover on the ridge and were insignificant factors in the 2019 community. Mean percent shrub cover was significantly higher (p = 0.0091, F = 8.04) on the western ridge (70 ± 23%) than on the eastern ridge (37 ± 35%). Referring back to the 2016 habitat analysis (p. 11), the areas on the eastern ridge with lower shrub cover and higher herbaceous cover were classified as upland range habitat, while the areas that were still devoid or sparsely vegetated with herbaceous vegetation were classified as upland barren land transitional area. Both of these habitats were targeted for the tree planting that occurred in February 2019. The eastern ridge had a higher mean percent herbaceous cover than the western ridge at 57 ± 26% and 41 ± 21% respectively, but the difference was not significant.

Species Cover and Distribution

The three species with the highest mean percent cover on the ridge for the 2019 vegetation survey were the shrub *B. halimifolia* (47%), *Solidago sempervirens* (19%) and *Spartina patens* (saltmeadow cordgrass, 13%) (Figure 25). *Baccharis halimifolia* had the highest cover on both ridges, but the cover of this shrub species was noticeably higher on the western ridge than on the eastern ridge (58% and 35%, respectively). *Iva frutescens* (Jesuit's bark), another shrub species, had the third highest cover on the western ridge at 12% cover; however, this species had only 3% cover on the eastern ridge. Also of interest is the higher percent cover of the grass *S. patens* on the eastern ridge, as compared to the western ridge. *Spartina patens* had the second highest cover (22%) on the eastern ridge, but had only 6% cover on the western ridge.

Solidago sempervirens, *B. halimifolia*, and *Panicum repens* (torpedo grass) were the most widely distributed species at ridge vegetation stations, occurring at 96%, 85%, and 65% of sites, respectively. These three species had the widest distribution on both the western and eastern ridges. Of the three species, *B. halimifolia* had the largest difference in distribution between ridges with an occurrence at 93% of stations on the western ridge, but only 75% of stations on the eastern ridge. There was a total of 30 species recorded on the ridge. The complete list of these species, along with their mean covers, distributions, and associated marsh habitats, is included in Appendix E. Photographs from the ridge vegetation monitoring stations are included in Appendix D (photos 10–12).

Floristic Quality Index

The FQI value for the BA-0048 ridge for the 2019 vegetation survey was 42 ± 12% and it was similar between the western and eastern ridges (Figure 25). The variability (standard deviation) was larger between stations on the eastern ridge due to greater differences in species composition and cover. It should be noted that the FQI is targeted for marsh habitat, and species with high CC scores are assigned those scores due to their significance of being species that represent stable marsh environments. For example, 100% cover of *S. patens* (C = 9) would be favorable in the marsh, but the prevalence of this species is not indicative of a thriving ridge environment. Therefore, the application of this index to the BA-0048 ridge is helpful in assessing the presence of native versus invasive species, but it is not entirely effective at gauging the quality of the ridge vegetative community. The forested floristic quality index (FFQI) uses tree basal area and CC score values of trees and may be useful for future ridge assessments (Wood et al. 2017).

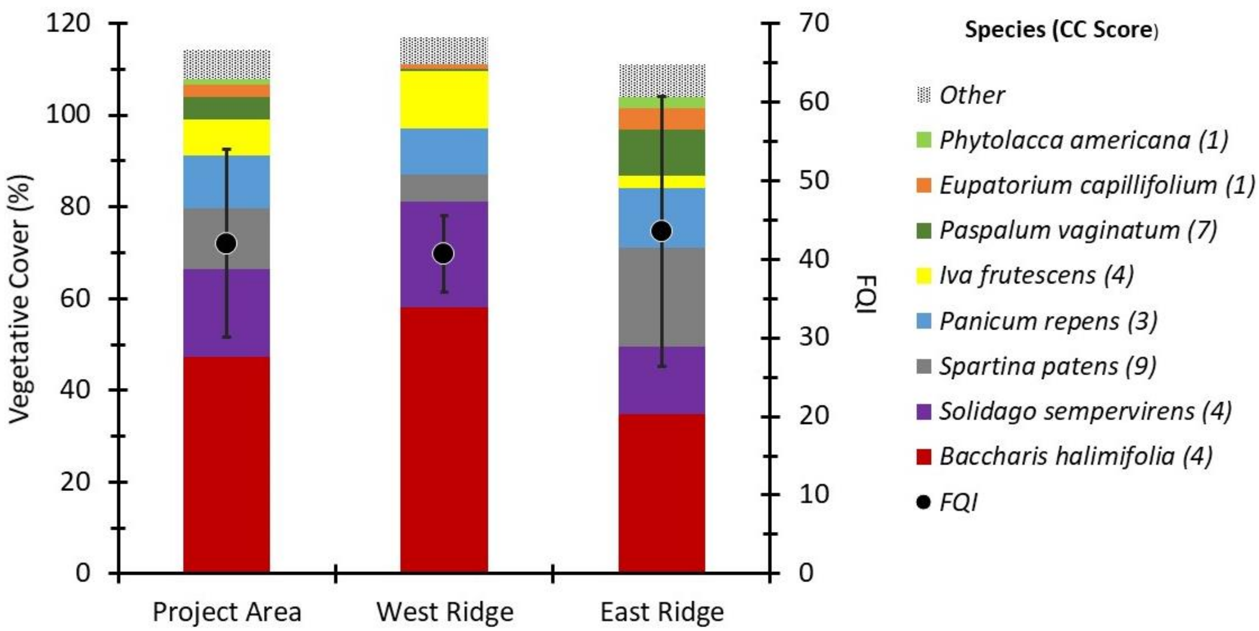


Figure 25. Mean species percent covers and mean FQI scores (± SD) by area for the 2019 BA-0048 ridge survey. The graph shows the sum of the mean covers for each species. Due to the physical overlap of individual species at stations, this sum can be greater than 100%.

Plantings

A total of 750 saplings, composed of seven native species of trees and shrubs, was documented as planted in designated areas of the BA-0048 project area in February 2019 (Table 2). The species chosen for the ridge planting were selected due to their suitability for coastal ridges in Louisiana and their benefit for wildlife, especially foraging migratory birds. Post-planting survivorship surveys located only 734 of these trees, and this number will be used for survivorship assessment. Due to the rapid natural recruitment of vegetation on the ridge and the resulting lack of available space for planting, 360 trees composed of four species (*Callicarpa americana, Celtis laevigata, Ilex vomitoria* and *Morella cerifera*) were planted in the west marsh, in the far northeastern corner, where elevation was relatively high (Table 2, Figure 26). Two of these species (*I. vomitoria* and *C. laevigata*), totaling 37 trees, were planted on the west ridge in an area adjacent to this marsh planting area, where the sediment pipeline had crossed the ridge and a small area continued to have reduced vegetative growth. All seven species, totaling 337 trees and shrubs, were planted along the sparsely-vegetated stretch of the eastern ridge.

Table 2. Number and planting location of each species planted in the BA-0048 project area.

		Number of Trees Planted			
Scientific Name	**Common Name**	**West Marsh**	**West Ridge**	**East Ridge**	**Total**
Callicarpa americana	Beautyberry	74		25	**99**
Celtis laevigata	Hackberry	96	8	46	**150**
Ilex vomitoria	Yaupon	162	29	58	**249**
Morella cerifera	Wax Myrtle	28		63	**91**
Morus rubra	Red Mulberry			48	**48**
Quercus virginiana	Live Oak			48	**48**
Diospyros virginiana	Persimmon			49	**49**
	Total	**360**	**37**	**337**	**734**

Figure 26. Location of the BA-0048 planting areas. Imagery from GoogleEarth, 01/17/2021.

Survivorship of the trees planted on the ridge was high on both the western (97%) and eastern (94%) ridge for the first survey in August 2019, conducted six months after the planting (Figure 27). By species, survival ranged from a high of 99% for *I. vomitoria*, to a low of 89% for *C. laevigata* (Figure 28). Survivorship remained high on the ridge for the 2020 survey, with survival on the western ridge at 97% and survival on the eastern ridge declining slightly to 91%. All species except *C. laevigata* (77%) and *Morella cerifera* (86%) remained at > 95% survival. An increase in survival of *Quercus virginiana* from 94% in 2019 to 96% in 2020 is explained by an additional five trees that were either located or reclassified as *Q. virginiana* during the 2020 survey.

Survivorship of the trees planted in the marsh was lower than on the ridge for the 2019 survey, with an overall survival of 40% and a species survival range from a high of 79% for *C. laevigata* to a low of 15% for *C. americana* (Figures 27, 28). Overall survivorship further declined between the 2019 and 2020 surveys, dropping to 32% in 2020. *Celtis laevigata* maintained the highest survival in the marsh at 60%, while *C. americana* had the lowest survival at 12%. Despite the relatively higher survival of *C. laevigata* in the marsh, 93% of the living trees were noted as stressed during the 2020 survey. This observation, coupled with the highest continuing mortality of any species between the 2019 and 2020 surveys in the marsh and on the ridge, may indicate that survivorship of this species for the 2022 survey will be low. In comparison, none of the 11 surviving *M. cerifera* were noted as stressed and this species experienced no additional mortality in the marsh between the 2019 and 2020 surveys, potentially indicating a greater chance of longer-term survivability.

The minimal natural recruitment of shrubs in the marsh planting area, even in 2021, indicates that soil and/or hydrologic conditions have not been favorable for the development of woody ridge species. Only one soil core was extracted and analyzed from this planting area during the 2019 marsh survey, so results need to be considered in reference to the low sample size. The soil core collected in the planting area differed from the other cores collected in the marsh and on the ridge between 2016 and 2019 in the following ways: 1) the mean percent organic content (1.7%) was the lowest of any cores since 2016, 2) the mean bulk density (1.5 g/cm^3) was the highest of any cores, 3) the mean percent moisture (19.6%) was the lowest of any cores, and 4) the mean soil pH (8.0) was the highest of any cores. Multiple soil factors have likely influenced the poor survival of the planted trees, including the lack of organic material in the soils. The soils in the planting area are nearly pure river sediment and did not receive the amendment of *in situ* organic material that was placed on the ridge. Additionally, the high bulk density could be restricting the drainage of water through the soils and hindering root development.

Despite targeting a marsh planting area that neighbored the ridge and was in an area of overall higher elevation, the October 2019 elevation survey indicates that the ~ 0.5-acre planting area may be at an elevation that is slightly lower than the immediate surrounding marsh. As such, the area could be ponding water after heavy rain events, with the high bulk density of the soils perhaps restricting drainage. Photographs of the marsh and ridge planting areas are included in Appendix C (photos 1–6).

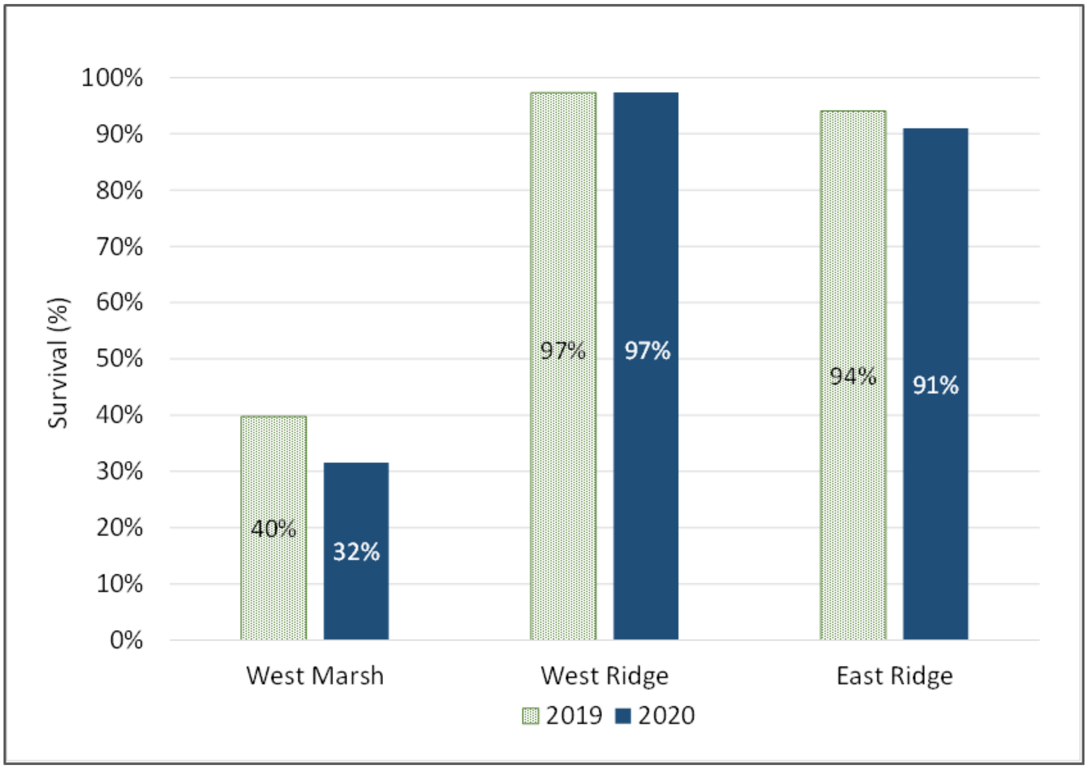


Figure 27. BA-0048 tree planting survival in the marsh and on the ridge.

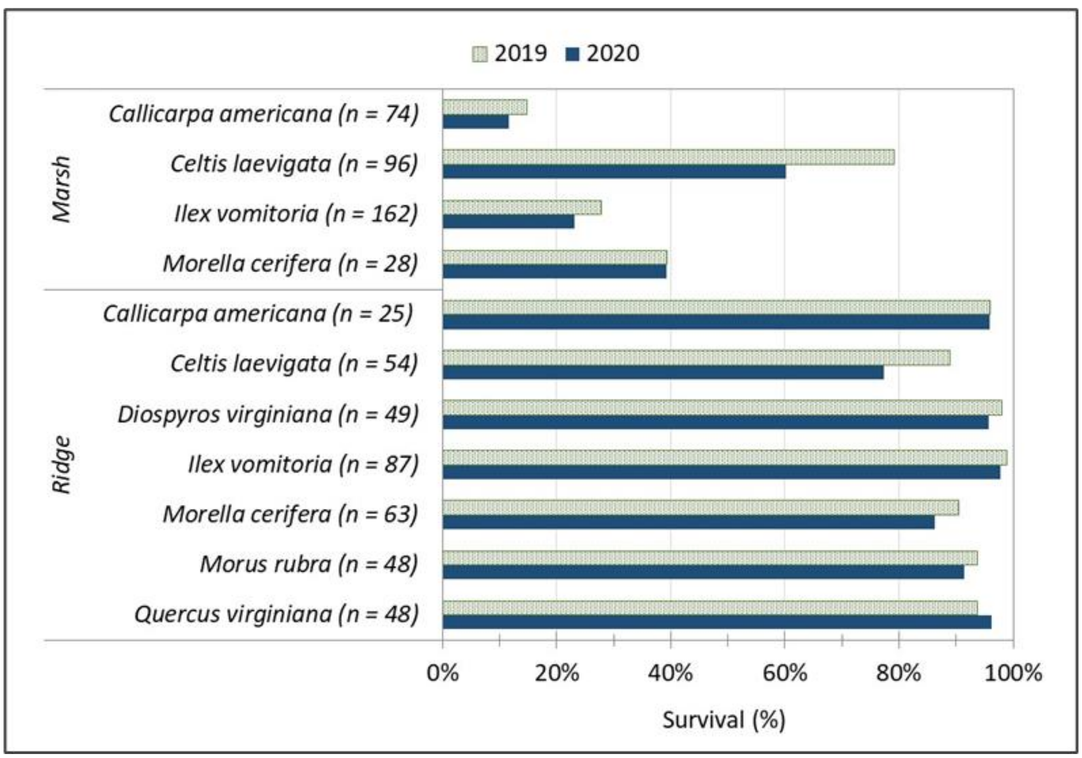


Figure 28. BA-0048 tree planting survival by species in the marsh and on the ridge. n = the number planted, as determined by counts during surveys.

iv. <u>Soil Properties</u>

An analysis of sediment can provide insight into vegetation recruitment and planting survival, as well as a multitude of other factors related to project assessment. Sediments were analyzed by habitat type (ridge/marsh), marsh creation cell (west/east), time (if appropriate), and the interaction of these parameters. There was a total of 15 monitoring stations, which included 5 or 6 marsh stations, and 6 to 9 ridge stations, depending on the year of analysis. It is important to note that sample sizes were small, and they varied depending on the analysis. Additionally, because soil properties were analyzed by core depth (six 4-cm increments, from the surface down to 24 cm depth), when the depth results were pooled it resulted in higher sample sizes. This should not be considered true replication since the different depths were all acquired at the same location. Ridge sampling occurred in 2016, 2017 and 2018 to assess soil conditions prior to planting. Marsh sampling occurred in 2016 and 2019.

Bulk Density

When all data were combined across years, bulk density (BD) was significantly different between the marsh and ridge (p < 0.001, F = 19.07) and by the interaction of habitat type and cell (p < 0.001, F = 18.36) (Figure 29) The mean BD of the marsh soils (0.95 ± 0.57 g/cm^3) was higher than the ridge soils (0.68 ± 0.25 g/cm^3). Higher BD in the marsh is expected, since the marsh was constructed solely with mineral river sediment (typically high BD), while the ridge was topped with organic *in situ* sediment (typically low BD). The main driver of the interaction of habitat type and cell was the mean BD in the marsh soils, which was significantly higher in the eastern marsh (1.2 ± 0.47 g/cm^3) than in the western marsh (0.81 ± 0.58 g/cm^3) (p = 0.0066, F = 7.92). This result was unexpected, but an examination of the individual core characteristics provides an explanation as described below. The BD of the western and eastern ridge soils was similar, and there was no significant difference in BD for the marsh or ridge over years.

The BD of individual marsh sediment cores ranged from values common in a highly-organic marsh environment, including Louisiana marshes, to values indicative of highly mineral soils (Mitsch and Gosselink 2015, Wang et al. 2016). When analyzed by coring station, it is clear that the wide range in BD is due to non-uniform soils throughout the project area (Figure 30). Specifically, stations 8 and 9 in the western marsh have a low BD and are highly organic (BD: station 8 = 0.49 ± 0.36 g/cm^3, station 9 = 0.29 ± 0.09 g/cm^3) and the remaining stations have high BD and are highly mineral (mean BD of remaining stations = 1.28 ± 0.42 g/cm^3). The difference in BD between soils is explained by the development of localized “mud waves” during construction. The two stations with organic soils are in an area where the underlying organic soils were displaced and brought to the surface in a “wave” during construction by the deposition of heavy river sediment. Because the cores sampled from stations 8 and 9 are from a different sediment source than the rest of the marsh cores (*in situ* organic sediment vs. riverine mineral sediment), sediment properties were different at these stations for all analyzed parameters.

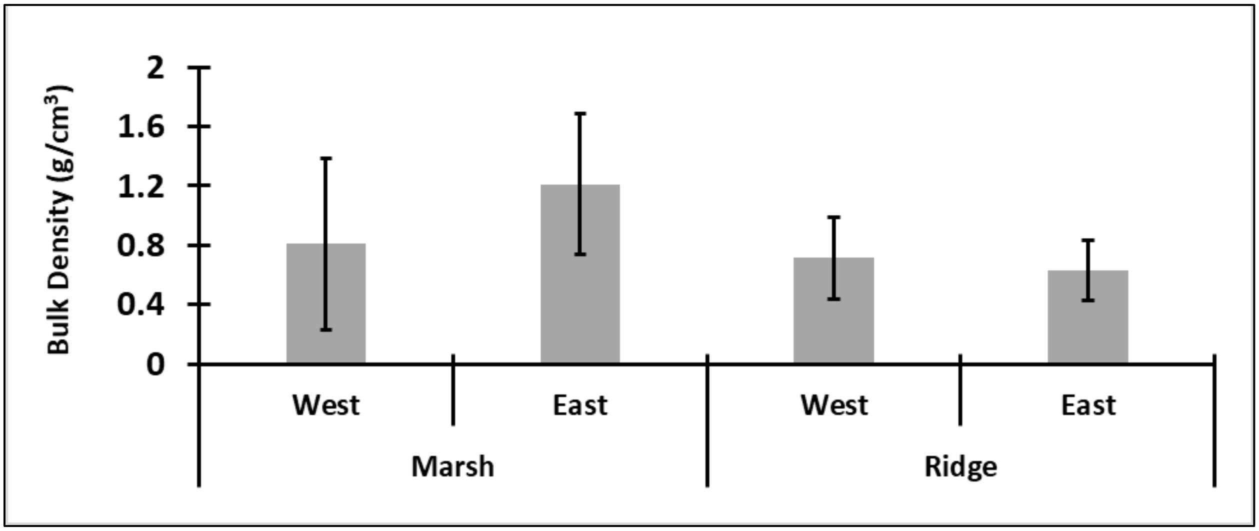


Figure 29. Mean bulk density (± SD) of the marsh and ridge soils for the western and eastern cells.

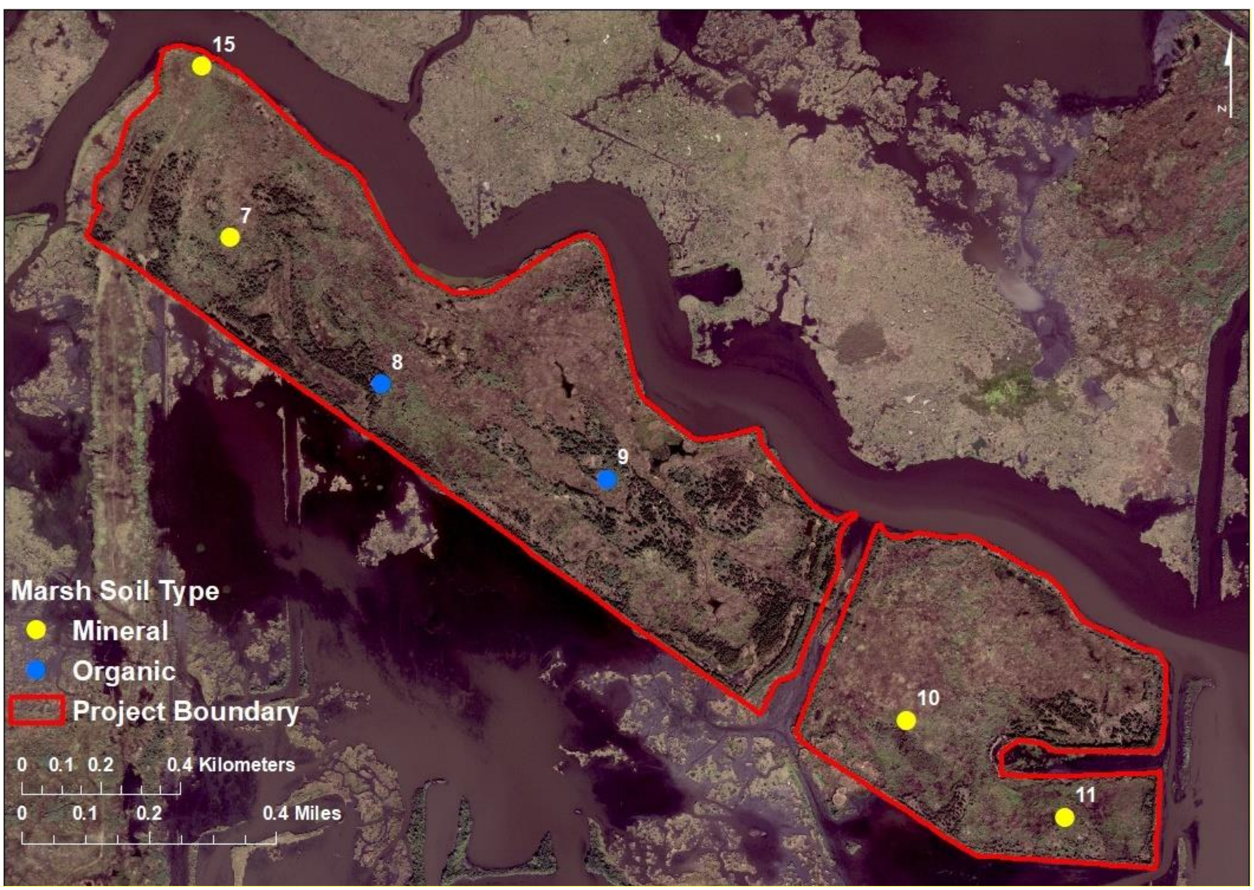


Figure 30. Marsh soil sampling locations, separated into organic and mineral soils.

Organic Matter (%)

When all data were combined across years, percent organic matter (OM) was significantly different only by the interaction of habitat type and cell ($p < 0.001$, F = 12.36). The difference was driven by a significant difference in the OM of the marsh soils by cell, with the western marsh soils having a mean OM of 20.4 ± 21.1% and the eastern marsh soils having a mean OM of 7.2 ± 12.5% (p = 0.0090, F = 7.28) (Figure 31). The higher OM of the western marsh was due to the organic soils at stations 8 and 9 (Figure 30), as previously discussed for bulk density. These stations had a mean OM of 37.8 ± 0.3%, while the remaining stations had a lower mean OM of 5.8 ± 11.8%.

The mean percent OM of the ridge soils was similar between the western and eastern cells; however, there were significant differences over years (p = 0.0186, F = 4.12). The mean OM of the ridge increased from 15.9 ± 9.5% in 2016 to 17.9 ± 10.6% in 2017, and then decreased to 12.4 ± 7.7% in 2019. There are multiple possible explanations for the variance in OM between years, with differences in sampling location and the depth of the *in situ* surface sediment being two of the more likely causes. The continuing expansion of the scrub-shrub habitat on the ridge indicates that the organic content has been sufficient to support woody vegetation.

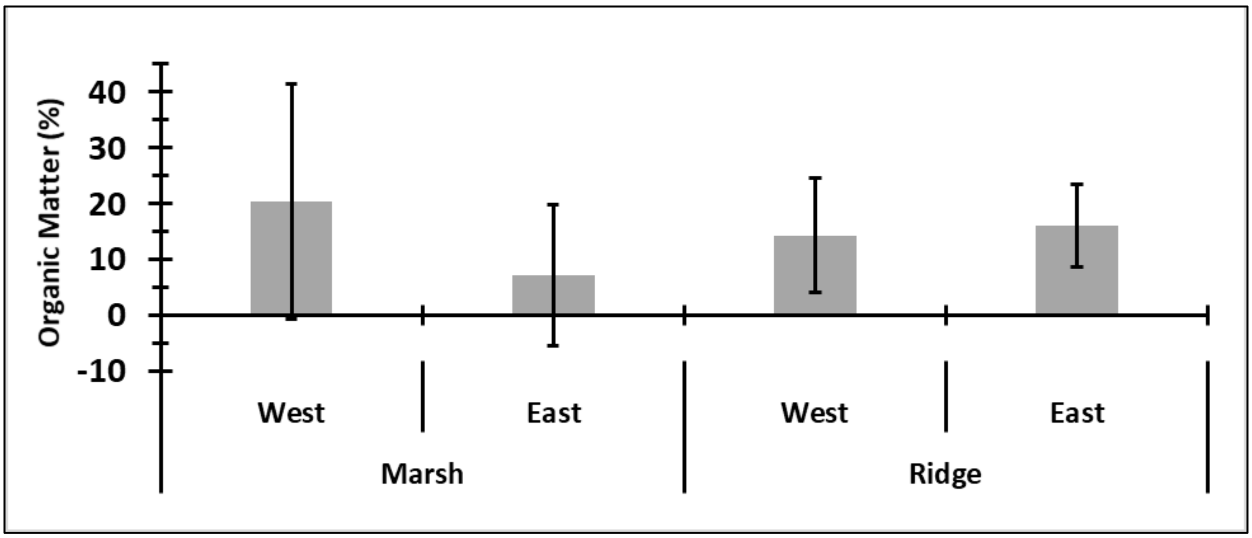


Figure 31. Mean percent organic matter (± SD) of the marsh and ridge soils for the western and eastern fill cells.

pH

When all data were combined across years, pH was significantly different between the marsh and ridge habitats, the western and eastern cell, and their interaction ($p < 0.001$, for all, F = 65.13, 61.82, and 72.44, respectively). The marsh had a higher mean pH (6.8 ± 0.9) than the ridge (5.5 ± 1.5) and the western cell (6.4 ± 1.2) had a higher mean pH than the eastern cell (5.2 ± 1.6) (Figure 32). These differences were driven by differences in the ridge pH, with the eastern ridge having a significantly lower mean pH than the western ridge (4.1 ± 0.6 and 6.2 ± 1.1, respectively), ($p <$ 0.001, F = 115.7). Thus, eastern ridge soils were acidic (pH < 5.5 is acidic) and the marsh soils and western ridge soils were in the neutral range (Tinner 1999, Mitsch and Gosselink 2015).

In addition to the pH being significantly different between the western and eastern ridge, it was also different over years (*p* = 0.021, F = 3.99). There was a trend of ridge soils becoming less acidic over time, but the eastern ridge soils remained acidic in 2018 (Figure 33). Despite the acidic soils on the eastern ridge, as of the 2020 vegetation survey, all planted tree and shrub species, except for *Celtis laevigata* (hackberry), exhibited over 85% survival. However, the eastern ridge did have significantly less natural colonization of shrubs than the western ridge during the period of assessment.

The pH of the marsh soils was significantly different only by cell (*p* = 0.0103, F = 7.01) with a mean pH of 6.6 ± 1.1 in the western marsh and 7.2 ± 0.1 in the eastern marsh. The pH of the western marsh was lower than the eastern marsh due to the lower pH of the organic soils at stations 8 and 9 (Figure 30). However, mean pH in both cells was in the neutral range and did not appear to hinder the natural colonization of plants.

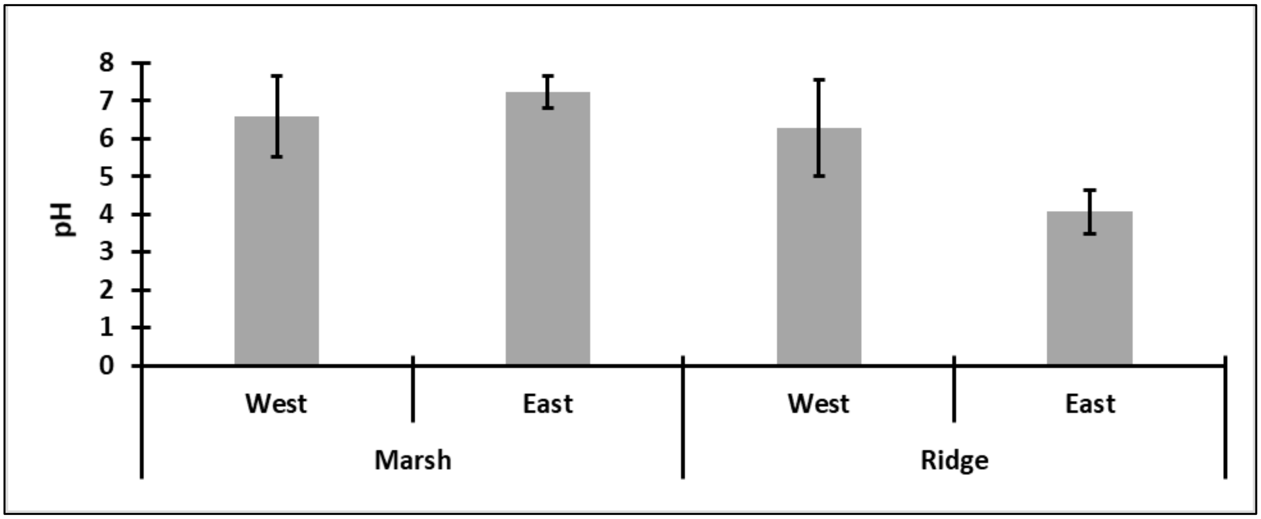


Figure 32. Mean pH (± SD) of the marsh and ridge soils for the western and eastern cells.

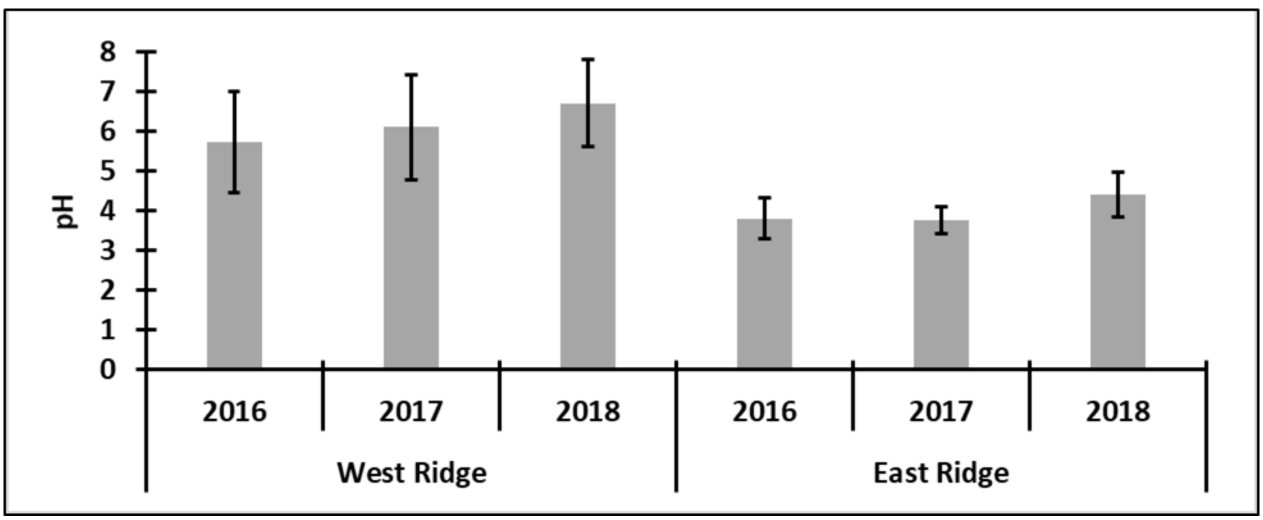


Figure 33. Mean soil pH (± SD) by year for the western and eastern ridge.

Salinity

Mean soil salinity was significantly different between the marsh and ridge habitats in 2016 (p = 0.0069, F = 7.79) and across all years ($p < 0.001$, F = 13.32). Soil salinity was significantly higher in ridge soils than in marsh soils (Figure 34). For example, in 2016, mean salinity for the ridge soils was 1.2 ± 0.9 ppt and for the marsh soils it was 0.6 ± 0.7 ppt. The higher salinity of the ridge soils, especially in 2016, is likely due to the topping of the ridge with sediment dredged from within the project area, which contained more salt than the sediment dredged from the Mississippi River.

When considering only the ridge soil samples, mean soil salinity for the ridge was significantly different by year (p = 0.0245, F = 3.82) and the interaction of cell and year (p = 0.0024, F = 6.36). For the western ridge, mean salinity was 1.2 ± 1.1 ppt in 2016, decreased substantially in 2017 to 0.5 ± 0.2 ppt, and then increased back to 1.2 ± 0.9 ppt in 2018 (Figure 35). On the eastern ridge, salinity showed a steady decline, from a high of 1.3 ± 0.3 ppt in 2016, to a low of 0.7 ± 0.4 ppt in 2018. A decrease in soil salinity over time and prior to planting was anticipated due to rain rinsing salts from the *in situ* soils.

The increase in salinity on the western ridge in 2018 may be the result of some cores being collected from sampling locations with more *in situ* sediment. In fact, the high standard deviation for mean salinity on the western ridge in 2018 (and 2016) indicates high salinity variation between locations and may point to samples with different ratios of *in situ* and riverine sediment. However, the increase in salinity may also be partially due to sampling methodology. In 2018, several ridge sediment cores were difficult to extract from the sampling corer and water from Bayou Dupont was used to loosen the cores from the extractor. The mean salinity from neighboring hydrographic station BA03c-61 on the days of soil coring was 4.5 ± 0.2 ppt, and the addition of this water may have increased the salinity of the samples. Percent moisture was also lowest on the ridge in 2018, which could have concentrated salts.

For the marsh soils, salinity was significantly different between the western and eastern marsh (p = 0.0097, F = 7.13). However, the differences were not ecologically significant. For example, the mean soil salinity in the western marsh was 0.7 ± 0.7 ppt and in the eastern marsh was 0.3 ± 0.2 ppt. Both of these salinity levels would be considered fresh and most likely did not convey any effect on plant colonization.

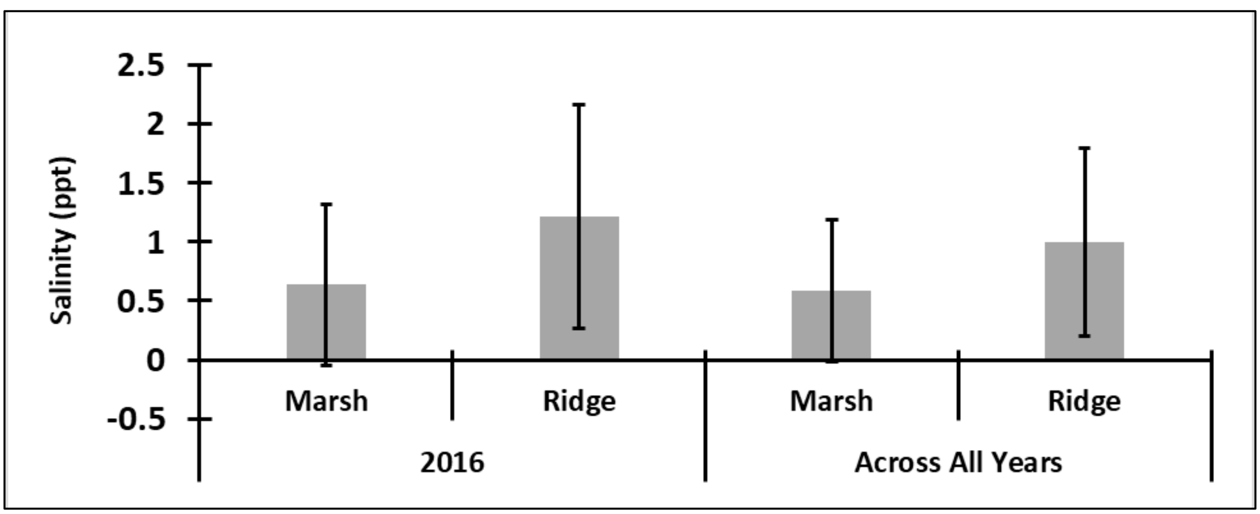


Figure 34. Mean soil salinity (± SD) for the marsh and the ridge in 2016 and across all years.

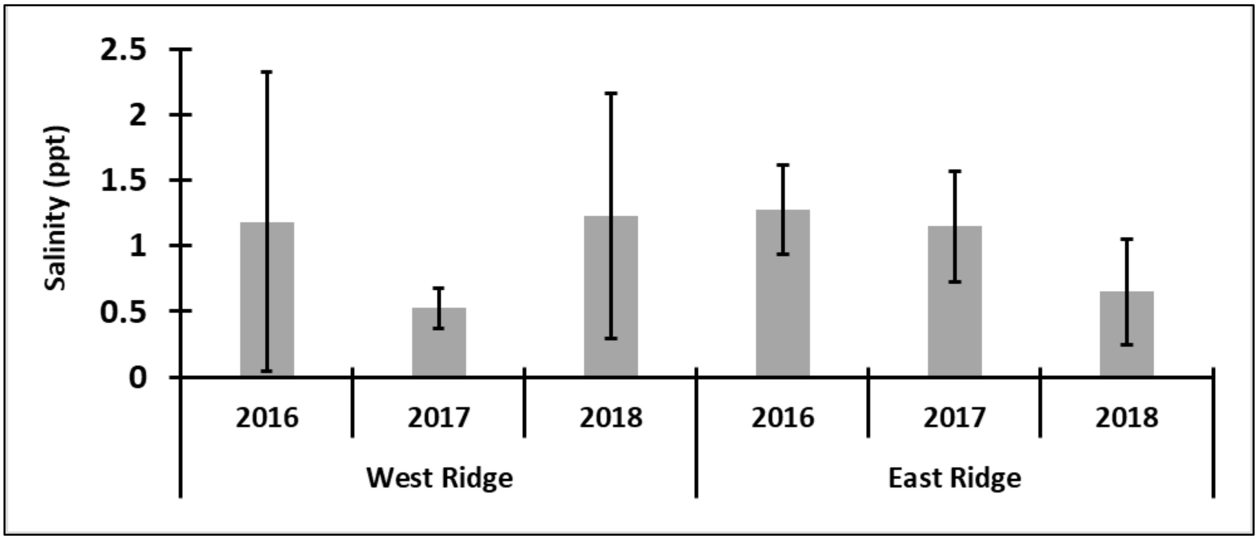


Figure 35. Mean soil salinity (± SD) over time for the western and eastern ridge.

Percent Moisture

When all data were combined across years, soil percent moisture was significantly different only by the interaction of habitat type and cell ($p < 0.001$, F = 12.14). This difference was driven by a significant difference in mean percent moisture between the western and eastern marsh (p = 0.0084, F = 7.42; Figure 36). The western marsh had a significantly higher percent moisture (49 ± 25%) than the eastern marsh (32 ± 17%), which was due to the higher moisture content of the organic soils at stations 8 and 9 (Figure 30). The percent moisture was significantly different only by year in the ridge soils (p = 0.0383, F = 3.35), where it declined from 43.5 ± 12.6% in 2016 to 38.0 ± 11.2% in 2018.

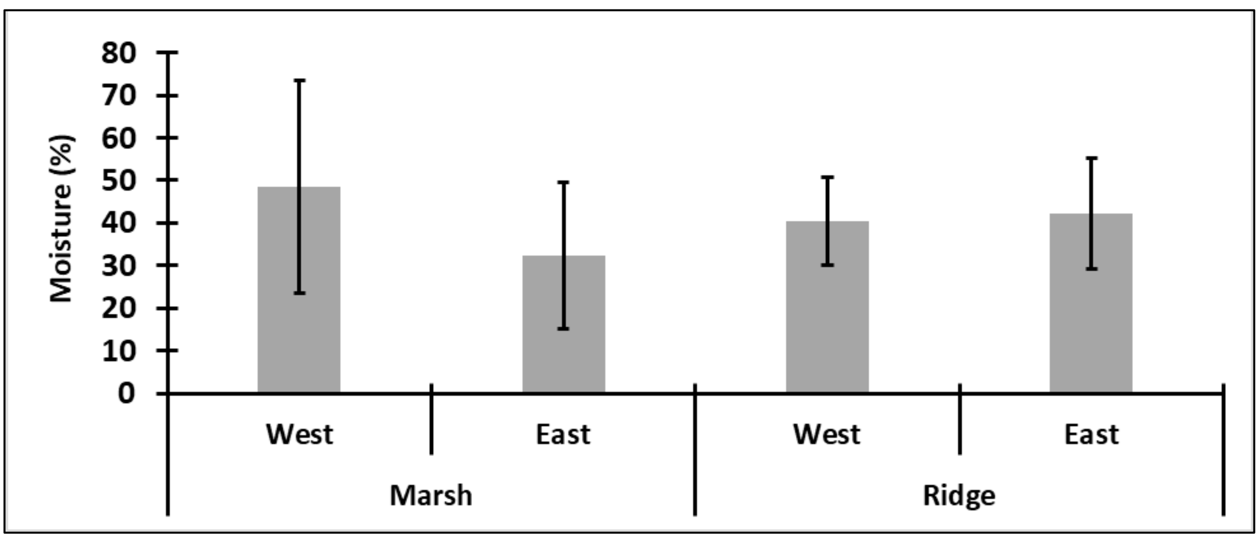


Figure 36. Mean percent moisture of the marsh and ridge by cell.

Comparison of BA-0048 and CRMS4103 marsh soils

Soil bulk density and percent organic matter were compared between the constructed BA-0048 marsh and the natural marsh at nearby CRMS4103. Sample collection occurred in 2016 and 2019 for BA-0048 and in 2008 and 2018 at CRMS4103. All samples were collected and analyzed using the same methodology (Folse et al. 2020). The soil BD and OM were significantly different by site ($p < 0.001$ for both, F = 75.42 and 142.11, respectively) but not by year, depth, or any interaction. The BA-0048 soils had a significantly higher BD (0.95 ± 0.57 g/cm^3) than the soils at CRMS4103 (0.12 ± 0.03 g/cm^3) (Figure 37). Conversely, the BA-0048 soils had a significantly lower OM content (15.9 ± 19.5%) than the CRMS4103 soils (57.9 ± 11.9%) (Figure 38). These results are expected as the riverine sediment used to construct BA-0048 had a high mineral content and was low in organic matter. Marsh creation projects can take decades to reach similar soil conditions to natural marsh, with organic matter typically increasing slowly over time. However, the vegetation community can become similar on a much shorter scale (Craft 2000, Edwards and Proffitt 2003, Hossler and Bouchard 2010). Also, the standard deviations for the soil measurements at BA-0048 were much larger than for CRMS4103, indicating a higher variability in the soil composition as compared to more uniform soils at the CRMS site.

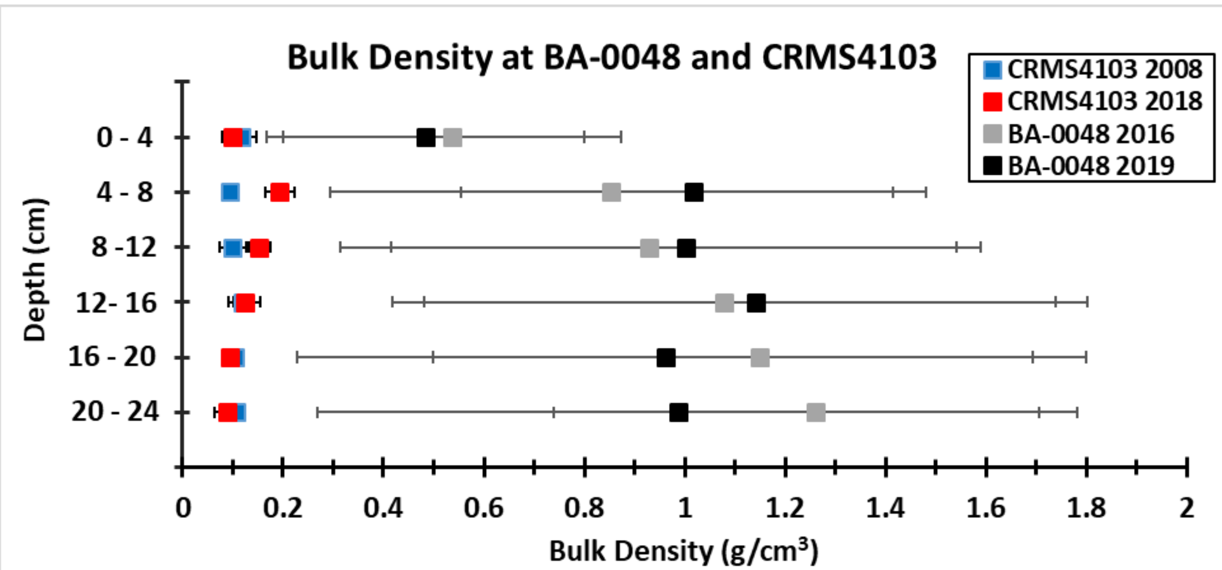


Figure 37. Mean soil bulk density (± SD) at BA-0048 (constructed marsh) and CRMS4103 (natural marsh) by depth.

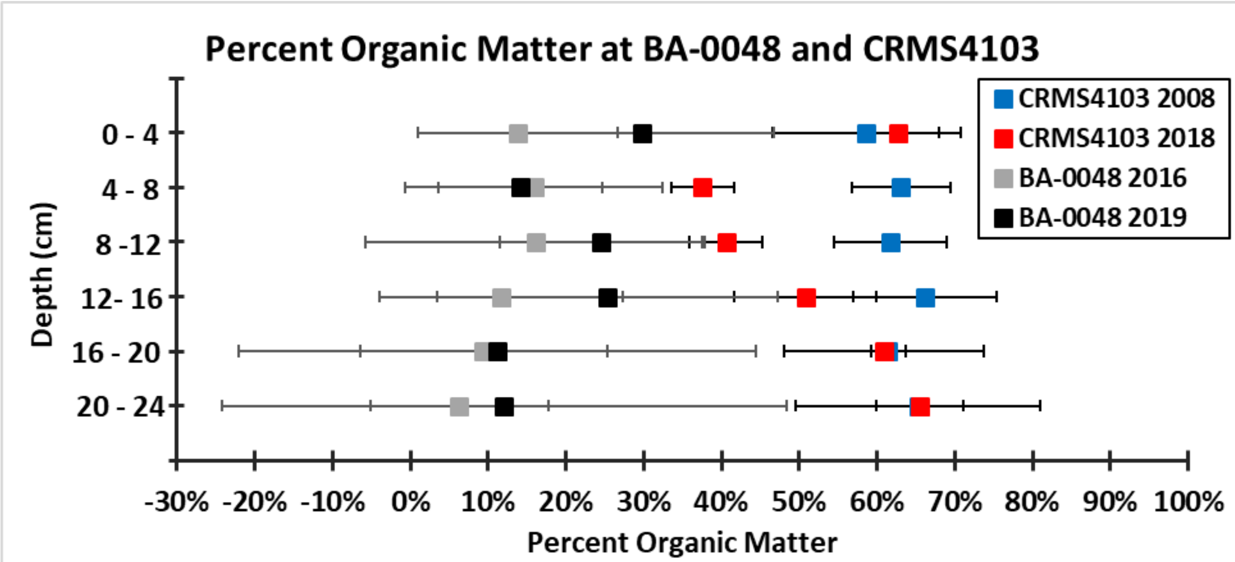


Figure 38. Mean soil organic matter content (± SD) at BA-0048 (constructed marsh) and CRMS4103 (natural marsh) by depth.

V. Conclusions

The goals of the Bayou Dupont Marsh and Ridge Restoration project (BA-0048) are as follows:

- Create and nourish approximately 389 acres of marsh through sediment pipeline delivery from the Mississippi River;
- Restore approximately 10,798 linear ft. (10.5 acres) of maritime ridge habitat along the southwestern shoreline of Bayou Dupont.

a. Project Effectiveness

Based on the 2016 BA-0048 marsh and ridge land-water analysis, 392 total acres of land were created, while 20 acres of water remained in the project area due to ponding at lower elevations. A further categorization of the land into distinct habitats allowed for a separation of estuarine intertidal habitats from the more upland habitats that were found on the ridge, as well as a further differentiation of herbaceous vs. woody communities within these broader categories. The habitat analysis showed that 331 acres of estuarine emergent intertidal marsh had been created by 2016, less than two years after construction, with 36 acres supporting estuarine intertidal scrub-shrub habitat.

Vegetation surveys have shown that between the 2016 and 2019 surveys, woody species have increased in coverage in the marsh. This has likely resulted in a temporary expansion of scrub-shrub and forested habitat, but as the elevation of the marsh creation areas continues to settle into the intertidal zone, these habitats will transition to marsh. Additionally, some of the shallow, open-water habitat may transition to marsh in the near future, with the likely expansion of species such as cattails that can tolerate persistent flooding. Marsh habitat may not reach the goal of exactly 389 acres, as some of these acres include spoil banks that will likely not transition to marsh during the 20-year OM&M time frame. However, increases in marsh acreage could occur over the next several years, and may already become evident by the next habitat analysis in 2024.

The majority of the constructed ridge is functioning structurally as a ridge habitat, with a vigorous community of naturally-established woody species; however, the ridge woody species diversity is low, due to the rapid expansion of *Baccharis halimifolia* and *Iva frutescens*. The shrub and tree species chosen for ridge planting were grown from locally-collected seeds and appear to have been well-selected for survival on the Bayou Dupont ridge. Additionally, contracting with the knowledgeable staff at BTNEP, who had experience with seed selection, seed germination, tree grow-out, and ridge planting (Benoit 2016), likely added to the vigor and survivability of the trees. The effectiveness of the planting was greatly reduced due to the lack of open space available on the ridge, forcing an expansion of the planting into the high marsh, where conditions were not amenable for survival. As of the 2020 survey, planting survival in the marsh was low at 32%, but the ridge plantings showed a high survivability at 97% on the western ridge and 91% on the eastern ridge.

The use of river sediment to expand the containment dike into the larger ridge appeared to offer great benefit during construction. The sandy river sediment provided greater stability for ridge construction and allowed for the construction of a larger ridge template than would have been possible with *in situ* sediment. The bayou-side slope of the ridge is primary *in situ* sediment, and some erosion has been observed along the ridge shoreline. Topping the ridge with organic *in situ* sediment likely improved growing conditions, with most of the ridge rapidly vegetating with herbaceous and shrubby vegetation within two growing seasons.

The BA-0048 project was constructed approximately 0.7 feet higher than intended due to the use of a different geoid than was used for design. As a result, the marsh and ridge features may both benefit from an extended life. In addition to the higher constructed elevation, the ridge and marsh both appear to be settling at a slower rate than anticipated, which may further add to the project's longevity. The only downside to the higher marsh elevation is the delay of settlement into the intertidal zone and the prevalence of woody, rather than herbaceous species in higher elevation areas of the marsh. Currently there is a great diversity of habitats, which may be benefiting a wider range of flora and fauna than would be found in solely a marsh environment.

b. Recommended Improvements

1. An herbaceous, flood-tolerant species, such as *Spartina alterniflora* (smooth cordgrass), should be planted on the slope of the ridge at the water interface to help solidify soils and reduce erosion. *Spartina alterniflora* was planted by CPRA and the Coalition to Restore Coastal Louisiana along the terrace edges of the Bayou Dupont Sediment Delivery Marsh Creation #3 and Terracing (BA-0164) project and this species has rapidly grown and expanded, creating a buffer from wave erosion.

2. The monitoring plan for BA-0048 is robust, but the addition of a ridge shoreline analysis for this project and all created ridges is recommended. More intensive surveying of the ridge could be added to the already scheduled elevation surveys to more precisely monitor edge erosion or accretion, and to identify the need for adaptive management.

3. The use of plastic NEDs to protect planted seedlings and saplings is often encouraged to prevent early herbivory; however, a plan needs to be implemented for their eventual removal, and if possible, recycling. The cost for this event needs to be included in the O&M budget.

c. Lessons Learned

1. Geoids must be clearly articulated to all construction contractors and must be included on all documents that reference vertical elevations, in particular on all design documents and construction plans and specifications.

2. The ridge should have been planted sooner with woody species. The ridge was planted nearly three years after project construction to allow for a reduction of salinity and an increase of pH in the ridge soils. During this waiting period, the ridge quickly self-vegetated with dense *Baccharis halimifolia* and *Iva frutescens* and limited space was available for planting. Based on the exceptionally high early survivorship of the planting on the ridge and the low survivorship in the marsh, an earlier planting of more trees on the ridge would likely have resulted in an overall higher planting survival.

3. Planting the ridge crown and upper slope shortly after construction with an herbaceous species such as *Paspalum vaginatum* could help to increase the organic content of the soils, improve drainage within the soils, and minimize top layer erosion.

4. Control of undesirable vegetation by herbicidal spraying or removal should be considered for woody species plantings to reduce early competition from aggressive species.

VI. References

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. USGS Professional Paper 964. 34pp.

Benoit, M. 2016. Fourchon maritime forest ridge and marsh restoration: Vegetative efforts. Barataria-Terrebonne National Estuary Program. Thibodaux, Louisiana. 100 pp.

Chatelain, K. 2018. Soil characteristics of recently restored coastal ridge habitats. Master's Thesis, Department of Marine and Environmental Biology, Nicholls State University. 69 pp.

Coastal Protection and Restoration Authority of Louisiana. 2021. Coastwide Reference Monitoring System (CRMS) Basin Level Report Card: Barataria Basin, 2021. 13 pp. https://warcservices.usgs.gov/CRMS/ChartingAPI/dataCharting/Report_Cards/BA_2021_ReportCard.pdf

Coastal Protection and Restoration Authority of Louisiana. March 2017. *A Contractor's Guide to the Standards of Practice: For CPRA Contractors Performing Topographical, Construction, Monitoring Surveys, and Determining GPS Derived Orthometric Heights within the Louisiana Coastal Zone*. 53 pp.

Coastal Protection and Restoration Authority of Louisiana. 2012. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Coastal Protection and Restoration Authroity, Baton Rouge, Louisiana. 188 p.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/wetlands/classwet/index.htm (Version 04DEC1998).

Craft, C. 2000. Co-development of wetland soils and benthic invertebrate communities following salt marsh creation. *Wetlands Ecology and Management* 8:197–207.

Cretini, K.F., J.M. Visser, K.W. Krauss, and G.D. Steyer. 2012. Development and use of a floristic quality index for coastal Louisiana marshes. *Environmental Monitoring and Assessment* 184:2389–2403.

Douglas, H.S. 1881. Appendix M: Survey of Barataria Bay, from New Orleans to Grand Pass, and of Little Lake and Bayou André, p. 1307-1315. In: Annual Report of the Chief of Engineers, United States Army, to the Secretary of War for the Year 1881. Government Printing Office, Washington D.C.

Edwards, K.R., and C.E. Proffitt. 2003. Comparison of wetland structural characteristics between created and natural salt marshes in southwest Louisiana, USA. *Wetlands* 23:344–356.

Fisk, H.N. 1944. Geological investigation of the alluvial valley of the lower Mississippi River. Mississippi River Committee. Vicksburg, Mississippi.

Folse, T.M., T.E. McGinnis, L.A. Sharp, J.L. West, M.K. Hymel, J.P. Troutman, D. Weifenbach, W.M. Boshart, L.B. Rodrigue, D.C. Richardi, W.B. Wood, C.M. Miller, E.M. Robinson, A.M. Freeman, C.L. Stagg, B.R. Couvillion, and H.J. Beck. 2020. A standard operating procedures manual for the Coastwide Reference Monitoring System- Wetlands and the system-wide assessment and monitoring program: Methods for site establishment, data collection, and quality assurance/quality control. Louisiana Coastal Protection and Restoration Authority. Baton Rouge, LA, 252 pp.

Hossler, K., and V. Bouchard. 2010. Soil development and establishment of carbon-based properties in created freshwater marshes. *Ecological Applications* 20:539–553.

Lopez, J. A. 2009. The Multiple Lines of Defense Strategy to Sustain Coastal Louisiana. *Journal of Coastal Research* SI 54:186–197.

Mitsch, W.J., and J.G. Gosselink. 2015. Wetlands, 5th ed. John Wiley & Sons, Inc, Hoboken, NJ.

Moffatt and Nichol. 2018. Bayou Dupont Marsh and Ridge Creation (BA-48) project completion report. Prepared for: State of Louisiana, Coastal Protection and Restoration Authority. M&N project no. 8386-01. 56 pp.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, Inc. New York.

NMFS. 2011. Bayou Dupont Marsh and Ridge Creation CWPPRA Project Fed No. BA-0048. Environmental Assessment. National Marine Fisheries Service. 16 pp.

NMFS. 2010. Bayou Dupont Marsh and Ridge Creation-Candidate Project of the Coastal Wetlands Planning, Protection and Restoration Act. Final Project Information Sheet for Wetland Value Assessment (WVA) Request for Phase II Funding. National Marine Fisheries Service. Baton Rouge, Louisiana. 22 pp.

Providence. 2009. Cheniers and natural ridges study. Providence Engineering and Environmental Group LLC. State of Louisiana Department of Natural Resources Contract Number 2533-08-02. 272 pp.

Richardi, D.C. 2017. Monitoring plan for Bayou Dupont Marsh and Ridge Creation (BA-0048). Coastal Protection and Restoration Authority, New Orleans Regional Office. 12 pp. https://cims.coastal.louisiana.gov/RecordDetail.aspx?Root=0&sid=20952.

RStudioTeam. 2016. RStudio: Integrated Development for R. RStudio, Inc., Boston, MA http://www.rstudio.com/.

SAS Institute. 2002-2012. SAS for Windows, Release 9.4. The SAS Institute Inc., Cary, NC, USA.

Steyer, G.F., R.C. Raynie, D.L. Steller, D. Fuller, and E. Swenson. 1995, revised 2000. Quality management plan for Coastal Wetlands Planning, Protection, and Restoration Act monitoring program. Open-file report no. 95-01. Louisiana Department of Natural Resources, Coastal Restoration Division, Baton Rouge, LA. 97 pp. plus appendices.

Tinner, R.W. 1999. Wetland indicators: A guide to wetland identification, delineation, classification, and mapping. CRC Press, LLC., Boca Raton, FL.

URS Corporation. 2009. Geotechnical investigation report for the Bayou Dupont Marsh Creation and Ridge Restoration project. Baton Rouge, Louisiana. 16 pp. plus appendices.

Wang, H., S. Piazza, L. Sharp, C. Stagg, B. Couvillion, G. Steyer, and T. McGinnis. 2016. Determining the Spatial Variability of Wetland Soil Bulk Density, Organic Matter, and the Conversion Factor between Organic Matter and Organic Carbon across Coastal Louisiana, U.S.A. *Journal of Coastal Research*. 33(3):507–517.

Wood, W.B., G.P. Shaffer, J.M. Visser, S.C. Piazza, and K.F. Cretini. 2017. Forested Floristic Quality Index—An assessment tool for forested wetland habitats using the quality and quantity of woody vegetation at Coastwide Reference Monitoring System (CRMS) vegetation monitoring stations: U.S. Geological Survey Open-File Report 2017-1002. 15 pp. https://doi.org/10.3133/ofr20171002.

Appendix A: Three Year O&M Budget Projection

Bayou Dupont Marsh and Ridge Creation (BA-48)

Federal Sponsor: NMFS

Construction Completed : 2015

PPL 17

Current Approved O&M Budget	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Project Life	Currently
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	Budget	Funded
State O&M	$46,312	$6,425	$288,848	$6,659	$142,187	$13,356	$0	$13,841	$0	$95,624	$14,602	$0	$0	$179,260	$0	$0	$16,252	$0	$0	$32,145	$855,510	$517,627
Corps Admin	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$1,225	$2,245	$25,520	$9,800
Federal S&A	$1,331	$0	$5,021	$0	$2,565	$1,336	$0	$1,384	$0	$1,331	$1,460	$0	$0	$2,565	$0	$0	$1,625	$0	$0	$1,714	$20,332	$11,637
Total																					$901,362	$539,064

Projected O&M Expenditures	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Remaining Project Life	Current Budget
Maintenance Inspection	$6,312	$6,425	$6,541	$6,659		$13,356		$13,841			$14,602			$15,405			$16,252			$32,145	$92,244	$13,841
Construction:																						
egetative Plantings/Tallow Control			$123,436		$64,544									$75,785							$75,785	$0
Dike Gapping			$31,250																		$0	$0
Subtotal with 25% Contingency			$193,358		$80,680									$94,732							$94,732	$0
Construction Inspection			$8,100		$8,175									$8,175							$8,175	$0
Surveys	$40,000		$40,000		$43,732					$95,624				$51,349							$146,973	$0
State S&A			$9,600		$9,600									$9,600							$9,600	$0
Federal S&A	$1,331		$5,021		$2,565	$1,336		$1,384		$1,331	$1,460			$2,565			$1,625			$1,714	$10,080	$1,384
Total	$47,643	$6,425	$288,848	$6,659	$142,187	$14,691	$0	$15,225	$0	$95,624	$16,062	$0	$0	$179,260	$0	$0	$17,877	$0	$0	$33,859	$361,803	$15,225

O&M Expenditures from COE Report	$212,903
State O&M Expenditures not submitted for in-kind credit	$0
Federal Sponsor MIPRs (if applicable)	$0
Total Estimated O&M Expenditures (as of March 2020)	$212,903

Current O&M Budget less COE Admin	$541,906
Estimated O&M Expenditures to-date	$212,903
Remaining Available O&M Budget	**$329,003**
Projected 3-Year Budget Expenditures	$15,225
3-Year Budget Surplus (Shortfall Request)	$313,778

Current Project Life Budget less COE Admin	$875,842
Total Projected Project Life Budget	$574,706
Project Life Budget Surplus (Shortfall)	**$301,136**

Appendix B: Inspection Photographs

Photo 1. Planted *Ilex vomitoria* (yaupon) with berries on the eastern ridge.

Photo 2. Trees and shrubs planted on the eastern ridge.

Photo 3. Western marsh creation area with *Salix nigra* (black willow) trees.

Photo 4. Ridge habitat with noticeable erosion at the edge of Bayou Dupont.

Photo 5. Planted *Quercus virginiana* (live oak) with acorn on the eastern ridge.

Photo 6. Ponding water in an area of lower elevation in the eastern marsh. Note the growth of flood-tolerant cattails along the far edge of the pond.

Appendix C: Habitat Analysis Habitat Class Table

Table 1. Habitat analysis table that corresponds to Figure 6, p. 13, in the main body of the BA-0048 OM&M report.

Habitat Class	Map Color	Habitat Class Area (Acres)
Estuarine Intertidal Emergent		330.81
Estuarine Intertidal Scrub Shrub		35.87
Estuarine Subtidal Unconsolidated Bottom Permanently Flooded		20.25
Upland Range		8.51
Upland Scrub Shrub		7.30
Estuarine Intertidal Unconsolidated Shore		5.60
Upland Forest Deciduous Spoil		1.96
Upland Scrub Shrub Spoil		1.24
Upland Barren Land Transitional Area		0.69
Total		**412.23**

Appendix D: Vegetation Survey and Planting Photographs

Photo 1. Thriving *Morella cerifera* (wax myrtle) in the marsh planting area (09/25/2020).

Photo 2. Marsh planting area (09/25/2020). The blue plastic sleeves are nutria exclusion devices (NEDs) meant to protect seedlings and saplings from predators.

Photo 3. *Quercus virginiana* (live oak) planted along the eastern ridge (09/25/2020).

Photo 4. *Ilex vomitoria* (yaupon), right foreground, and *Diospyros virginiana* (persimmon), tall tree in center background, planted along the eastern ridge (09/25/2020).

Photo 5. Eastern ridge planting along an expanse of the ridge crown where vegetation remains sparse, yet tree survival was still strong at the time of this survey (09/25/2020).

Photo 6. Fruiting planted *Callicarpa americana* (beautyberry) along the eastern ridge (09/25/2020).

Photo 7. *Schoenoplectus americanus* (chairmaker's bulrush) at a marsh vegetation monitoring station (08/28/19).

Photo 8. Marsh vegetation monitoring station with dense *Bacopa monnieri* (herb of grace) growing in the foreground and *Salix nigra* (black willow*)* in the background (08/28/19).

Photo 9. Forested community with *Salix nigra* (black willow) and *Thelypteris palustris* (eastern marsh fern) at a marsh vegetation monitoring station (08/28/19).

Photo 10. Dense *Baccharis halimifolia* (eastern baccharis) and *Iva frutescens* (Jesuit's bark) scrub-shrub community at a ridge vegetation monitoring station on the western ridge (08/27/2019).

Photo 11. Ridge vegetation monitoring station on the western ridge with a mixture of scrub-shrub and herbaceous species (08/28/2019).

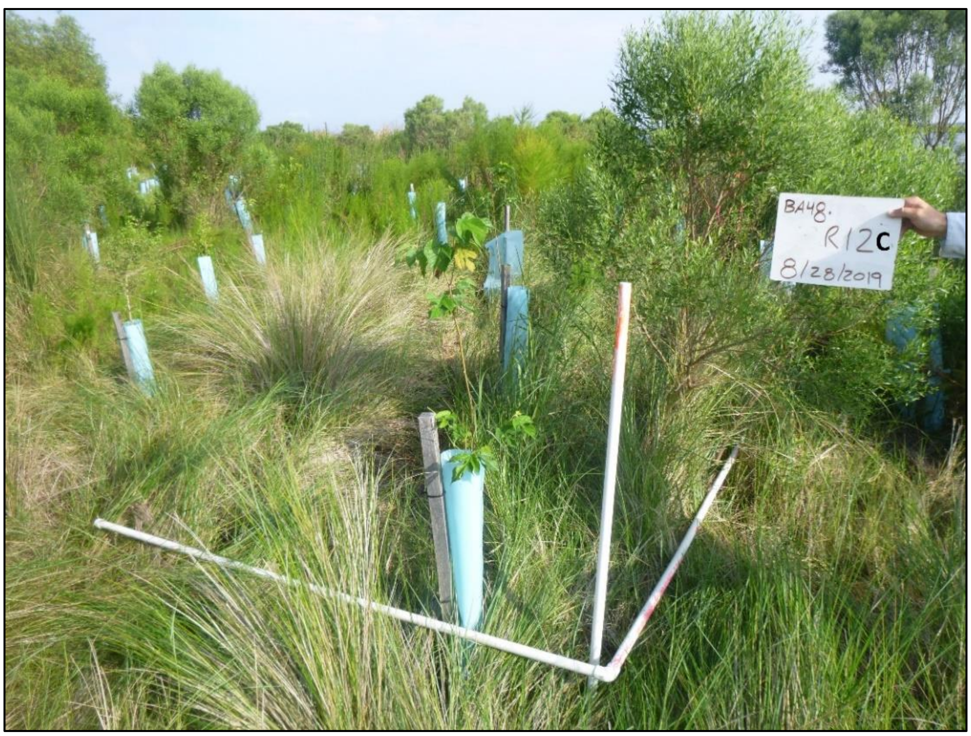


Photo 12. Ridge vegetation monitoring station on the eastern ridge, with dense *Spartina patens* (saltmeadow cordgrass). The tree planted in the plot is *Morus rubra* (red mulberry) (08/28/2019).

Appendix E: Vegetation Tables

Table 1. Percent cover and percent occurrence of each species at marsh vegetation stations in the BA-0048 project area. N = number of stations surveyed. *Habitat* is the marsh habitat where the species is most commonly found. F = freshwater, I = intermediate, B = brackish, S = saltwater.

Scientific Name	Common Name	BA-0048 2016 (N = 30)		BA-0048 2019 (N = 27)		Habitat
		% Cover	% of Stations	% Cover	% of Stations	
Ammannia latifolia	pink redstem	0.2	8	0.1	8	F/I
Baccharis halimifolia	eastern baccharis	0.2	8	9.6	46	F/I
Bacopa monnieri	herb of grace	15.7	69	15.0	54	F/I
Bolboschoenus robustus	sturdy bulrush			0.5	15	B
Cyperus sp.	flatsedge	0.1	8			F/I
Cyperus filicinus	fern flatsedge	0.5	23	0.4	8	F/I
Cyperus odoratus	fragrant flatsedge	0.2	8			I
Cyperus oxylepis	sharpscale flatsedge	0.4	8			F
Cyperus virens	green flatsedge			0.2	8	F
Desmanthus illinoensis	Illinois bundleflower	0.4	8			F
Distichlis spicata	saltgrass	6.2	23	0.8	15	B/S
Echinochloa walteri	coast cockspur grass	0.4	15			I
Eclipta prostrata	false daisy			0.1	8	F
Eleocharis cellulosa	Gulf Coast spikerush	3.1	31	4.4	38	F/I
Eleocharis flavescens	yellow spikerush	1.2	8			I/B
Eleocharis vivipara	viviparous spikerush	2.7	8			F
Hibiscus moscheutos	crimsoneyed rosemallow			1.3	15	F/I
Hydrocotyle sp.	hydrocotyle			0.2	8	F
Ipomoea sagittata	saltmarsh morning-glory			0.2	8	F/I
Juncus roemerianus	needlegrass rush			5.4	15	B/S
Kosteletzkya virginica	Virginia saltmarsh mallow	1.5	8			F/I
Leptochloa fusca	Malabar sprangletop	0.1	8			I
Lythrum lineare	wand lythrum	2.5	31	0.6	23	I/B
Panicum dichotomiflorum	fall panicgrass	0.4	8			F/I
Panicum rigidulum	redtop panicgrass			0.2	8	F
Paspalum vaginatum	seashore paspalum	11.5	31	2.7	23	I
Phragmites australis	common reed	10.4	15	3.5	23	I
Pluchea odorata	sweetscent	6.3	54	0.2	8	I/B
Polygonum punctatum	dotted smartweed	1.3	15	3.8	8	F/I
Salix nigra	black willow	5.2	38	17.7	69	F
Schoenoplectus americanus	chairmaker's bulrush	3.3	46	9.5	54	I/B
Sesbania drummondii	poisonbean	1.5	8			F
Sesbania herbacea	bigpod sesbania	2.1	23			I
Solidago sempervirens	seaside goldenrod	0.6	23	5.7	54	F/I
Spartina patens	saltmeadow cordgrass	3.3	23	0.8	15	I/B
Symphyotrichum divaricatum	southern annual saltmarsh aster	0.7	23	0.4	8	F
Thelypteris palustris	eastern marsh fern			2.7	8	F
Typha latifolia	broadleaf cattail	16.1	77	4.8	54	F
Vigna luteola	hairypod cowpea	18.1	62	2.1	31	I

Table 2. Percent cover and percent occurrence of each species at ridge vegetation stations in the BA-0048 project area. N = number of stations surveyed. *Habitat* is the marsh habitat where the species is most commonly found. F = freshwater, I = intermediate, B = brackish, S = saltwater.

Scientific Name	Common Name	BA-0048 2019 (N = 30)		Habitat
		% Cover	% of Stations	
Andropogon glomeratus	bushy bluestem	0.3	12	F
Baccharis halimifolia	eastern baccharis	47.4	85	F/I
Bacopa monnieri	herb of grace	0.2	4	F/I
Carex sp.	sedge	0.1	4	F
Celtis laevigata (planted)	sugarberry	0.1	4	F
Cyperus elegans	royal flatsedge	0.0	4	F/I
Cyperus filicinus	fern flatsedge	0.0	4	F/I
Eupatorium capillifolium	dogfennel	2.7	35	F
Ilex vomitoria (planted)	yaupon	0.3	8	F
Ipomoea sagittata	saltmarsh morning-glory	0.8	23	F/I
Iva frutescens	Jesuit's bark	7.9	38	I
Kosteletzkya virginica	Virginia saltmarsh mallow	0.2	8	F/I
Ludwigia octovalvis	Mexican primrose-willow	0.6	4	F
Mimosa strigillosa	powderpuff	0.2	4	F
Morella cerifera (planted)	wax myrtle	0.1	4	F
Morus rubra (planted)	red mulberry	0.2	8	F
Panicum repens	torpedo grass	11.5	65	I
Panicum rigidulum	redtop panicgrass	0.1	4	F
Paspalum vaginatum	seashore paspalum	4.9	35	I
Phytolacca americana	American pokeweed	1.1	15	I
Polygonum punctatum	dotted smartweed	0.8	15	F/I
Rorippa palustris	bog yellowcress	0.4	4	F
Salix nigra	black willow	0.4	4	F
Solanum sp.	nightshade	0.1	4	F
Solidago sempervirens	seaside goldenrod	19.1	96	F/I
Spartina patens	saltmeadow cordgrass	13.2	50	I/B
Thelypteris palustris	eastern marsh fern	0.0	4	F
Triadica sebifera	Chinese tallow	0.6	4	F
Typha domingensis	southern cattail	0.1	4	I
Vigna luteola	hairypod cowpea	0.8	31	I