COASTWIDE REFERENCE MONITORING SYSTEM (CRMS)

CRMS SITES THAT HIGHLIGHT COASTAL PROCESSES

APPENDIX C

REPORT: VERSION 01
DATE: MAY 2026
PREPARED BY: MARK MOULEDOUS, BERNARD WOOD, MARGARET DAIGLE, MELISSA HYMEL, TODD FOLSE, DANIELLE RICHARDI, ADAM CONSTANTIN, KIMBERLY HAMM, AND LEIGH ANNE SHARP

COASTAL PROTECTION AND RESTORATION AUTHORITY
635 CAJUNDOME BLVD
LAFAYETTE, LA 70506
WWW.COASTAL.LA.GOV

COASTWIDE REFERENCE MONITORING SYSTEM (CRMS)

This document features data collected through Louisiana's Coastwide Reference Monitoring System (CRMS), a network of 390 coastal monitoring sites that provide comprehensive information on coastal trends necessary to plan, implement and assess coastal restoration projects and in support of CPRA's Coastal Master Plan. The CRMS network was established in 2005 to provide a complete suite of monitoring data for Coastal Wetland Planning, Protection and Restoration Act (CWPPRA) projects. CRMS monitoring is conducted by the Coastal Protection and Restoration Authority (CPRA) and the U.S. Geological Survey (USGS) and is currently funded by the CWPPRA program, the Louisiana Trustee Implementation Group for the Deepwater Horizon Natural Resource Damage Assessment (NRDA) Trustees, and the State of Louisiana. CRMS data are publicly available from CPRA's Coastal Information Management System (CIMS; link) and derived data are available through USGS's CRMS website (link).

CITATION

Mouledous, M., Wood, W. B., Daigle, M. L., Hymel, M. K., Folse, T. M., Richardi, D.C., Constantin, A. J., Hamm, K. R, and Sharp, L. A. (2026), CRMS Data Synthesis – Appendix C – CRMS Sites that Highlight Coastal Processes. Lafayette, Louisiana: Coastal Protection and Restoration Authority.

ACKNOWLEDGEMENTS

This document was prepared by scientists from CPRA's Regional Offices in Lafayette, New Orleans and Thibodaux. Coastal insights were developed from twenty years of CRMS data collection and innumerable conversations with our partners at USGS and data collectors from CPRA's contractor, Coastal Estuary Services.

This work was funded, in part, by the Louisiana Trustee Implementation Group as part of the effort to restore natural resources injured by the 2010 *Deepwater Horizon* oil spill.

EXECUTIVE SUMMARY

This document is an appendix to the 2008-2023 CRMS Data Synthesis. It features CRMS sites that demonstrate coastal processes at work across Louisiana's nine coastal basins. This work is intended to highlight processes driving coastal change and is an outlet for CPRA scientists to document observations from twenty years of CRMS data collection.

This appendix includes examples of:

- Tidal salt and brackish marshes transitioning to fresh marsh due to crevasse influence in Breton Sound
- Elevation gain in deltas and along eroding shorelines
- Hurricane impacts ranging from high deposition to complete removal of the marsh platform
- Very high sediment deposition in the Mississippi River Delta
- Destabilization of impounded marshes on the Chenier Plain
- The effects herbivory and high salinity on vegetation
- Land loss in the Mississippi River Delta due to water hyacinth rafting
- Shallow expansion in response to persistent inundation across a range of coastal habitats

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AT ..... ATCHAFALAYA BASIN
BA ..... BARATARIA BASIN
BS..... BRETON SOUND BASIN
CCW..... CAMERON CREOLE WATERSHED
CIMS..... COASTAL INFORMATION MANAGEMENT SYSTEM
CPRA ..... COASTAL PROTECTION AND RESTORATION AUTHORITY
CS..... CALCASIEU/SABINE BASIN
CWPPRA ..... COASTAL WETLANDS PLANNING, PROTECTION, AND RESTORATION ACT
CRMS..... COASTWIDE REFERENCE MONITORING SYSTEM
GIWW ..... GULF INTRACOASTAL WATERWAY
LSU ..... LOUISIANA STATE UNIVERSITY
ME ..... MERMENTAU BASIN
MR..... MISSISSIPPI RIVER DELTA BASIN
MRGO ..... MISSISSIPPI RIVER GULF OUTLET
NRDA..... NATURAL RESOURCE DAMAGE ASSESSMENT
PO ..... PONTCHARTRAIN BASIN
RSET ..... ROD SURFACE ELEVATION TABLE
SSF ..... SHALLOW SOIL FACTOR
TE ..... TERREBONNE BASIN
TV ..... TECHE/VERMILION BASIN
USACE..... U.S. ARMY CORPS OF ENGINEERS
USFWS ..... U. S. FISH AND WILDLIFE SERVICE
USGS ..... U. S. GEOLOGICAL SURVEY SERVICE

1 – CREVASSE INFLUENCE AT MARDI GRAS PASS (CRMS0148 AND CRMS0119)

Mardi Gras Pass is a free-flowing channel located on the east bank of the Mississippi River at mile 43.5 above Head of Passes and is the northernmost distributary along a stretch of the river where levees on the east bank are not maintained. Formation of Mardi Gras Pass began during a 2011 Mississippi River flood event, which caused an area of scour along the natural levee. By February 2012, the channel had breached into a free-flowing distributary into Breton Sound. Since that time, several high river years (2018–2020) have caused further enlargement of the pass to a maximum discharge capacity of approximately 800 m^3/s (~28,000 cuffs) at river flood stage (Henkel et al. 2023). Two CRMS sites, CRMS0148 and CRMS0119, have captured effects of Mardi Gras Pass since its formation (Figure 1). CRMS0148 is located about three miles from the pass along the Back Levee Canal, which receives outflow directly from Mardi Gras Pass. CRMS0119 is located about 6.5 miles further south from the pass and is not on the direct flow path.

The effects of the 2018–2020 high river years are reflected in the monthly mean water elevation at CRMS0119 and CRMS0148 (Figure 9) with a greater increase in water level closer to the pass at CRMS0148. Increases in sediment deposition were observed at both sites following peak high river years in 2019 and 2020 (Figures 3 and 4). Surface elevation was slowly increasing prior to 2019 at both sites, but jumped significantly following the peak river years. A greater increase in sediment deposition was observed at CRMS0148 in the direct flow path of the pass.

Beginning in early 2013, a significant decrease in salinity was observed, particularly at CRMS0148, coinciding with the creation of Mardi Gras Pass (Figure 5). Lower salinities have persisted since that time leading to transitions in marsh type and vegetation species composition. Since the opening of Mardi Gras Pass in 2012, CRMS0119 has transitioned from saline to brackish marsh, and CRMS0148 has transitioned from brackish to fresh marsh (Figure 6), with fresh marsh persisting at CRMS0148 since 2019. Dominant species at CRMS0148 have shifted from marsh hay cordgrass (*Spartina patens*) and saltgrass (*Distichlis spicata*) through approximately 2015, to a more variable fresh mixture including smartweed (*Polygonum* spp.), hairypod cowpea (*Vigna luteola*), and giant cutgrass (*Zizaniopsis miliacea*) (Figure 7). Despite the changes observed in hydrology, surface elevation, and vegetation since the opening of Mardi Gras Pass, land acreage at both sites has remained stable over the CRMS data collection period (Figure 8).

Figure 1. Location of CRMS0148 and CRMS0119 in relation to Mardi Gras Pass

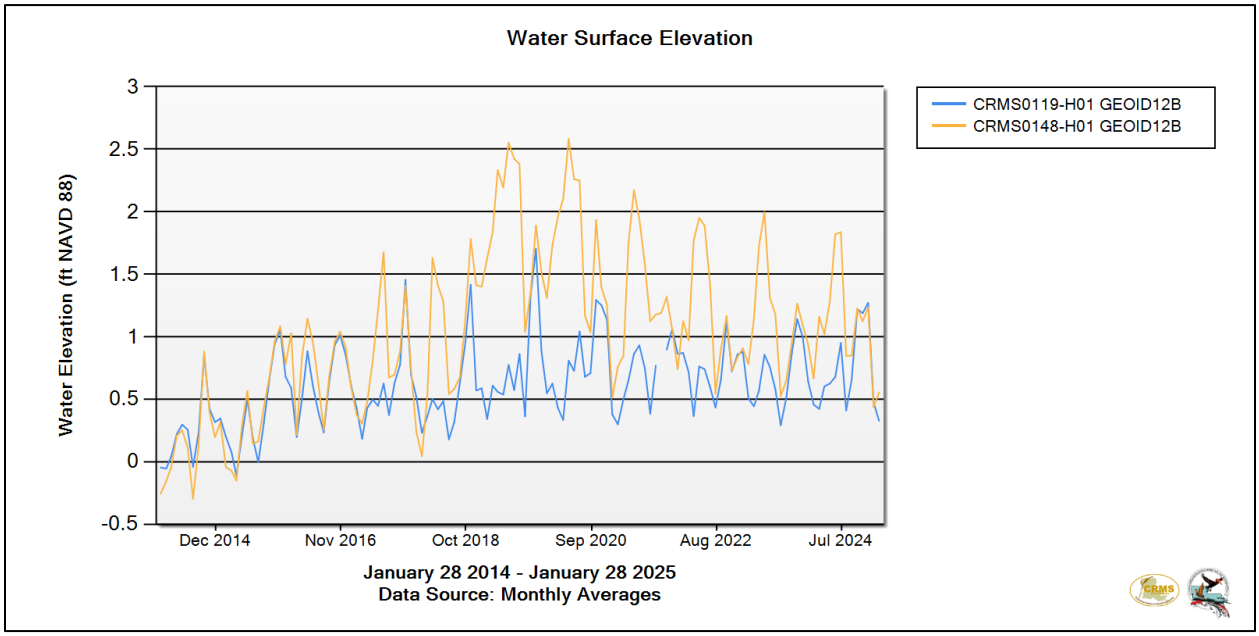


Figure 2. Water Elevation at CRMS0119 and CRMS0148 from 2014 to 2024

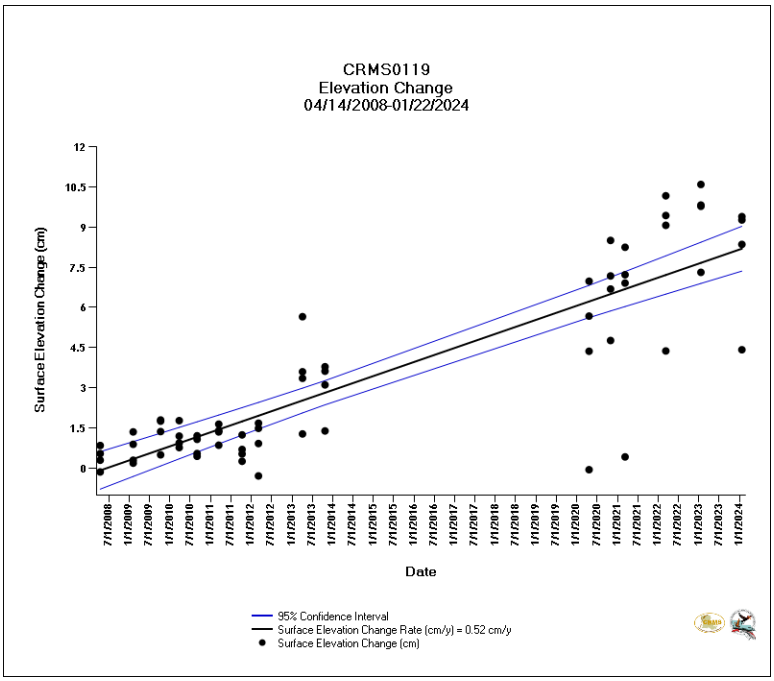


Figure 3. Surface Elevation Change at CRMS0119 2008-2024

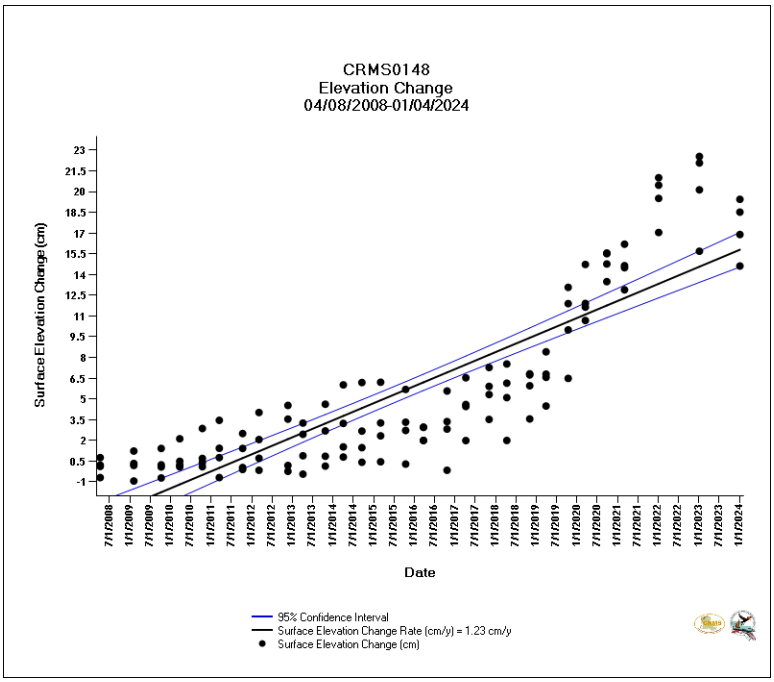


Figure 4. Surface Elevation Change at CRMS0148 2008-2024

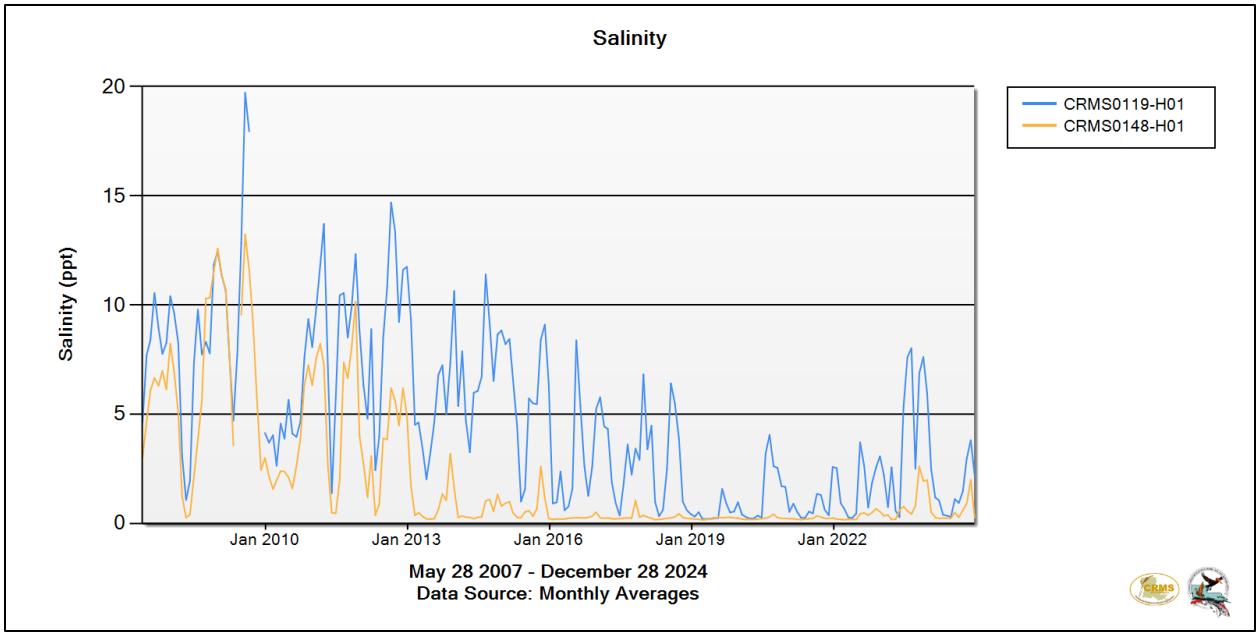


Figure 5. Salinity (ppt) at CRMS0119 and CRMS0148 from 2008 to 2024

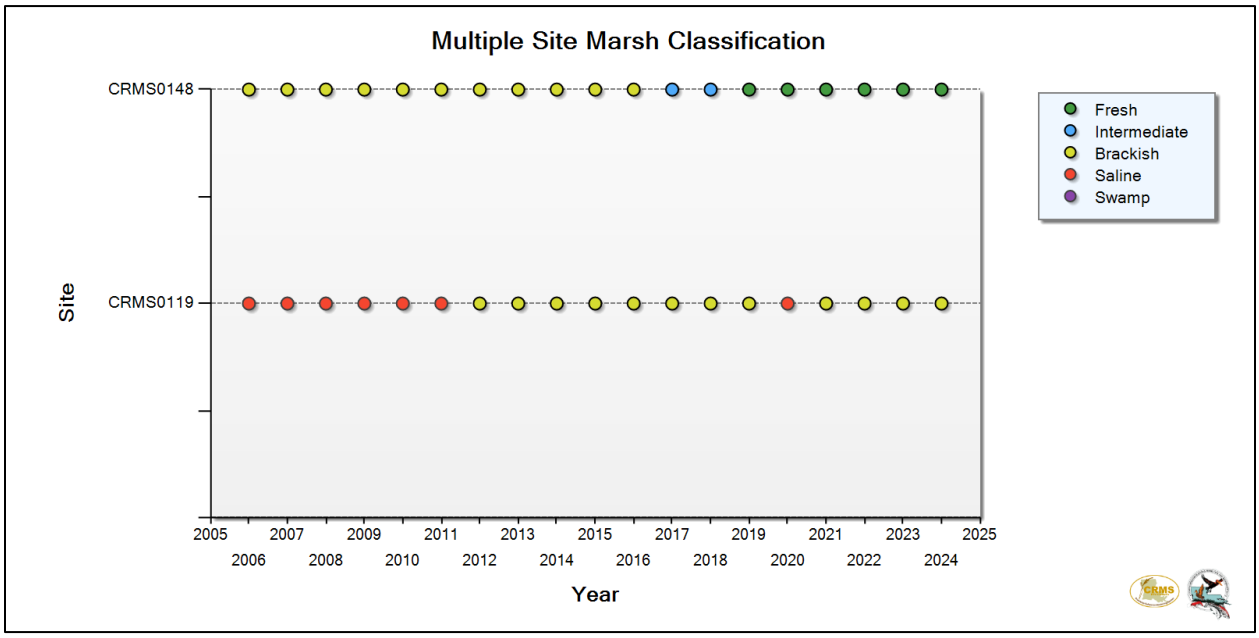


Figure 6. Change in marsh classification at CRMS0119 and 0148 from 2006 to 2024

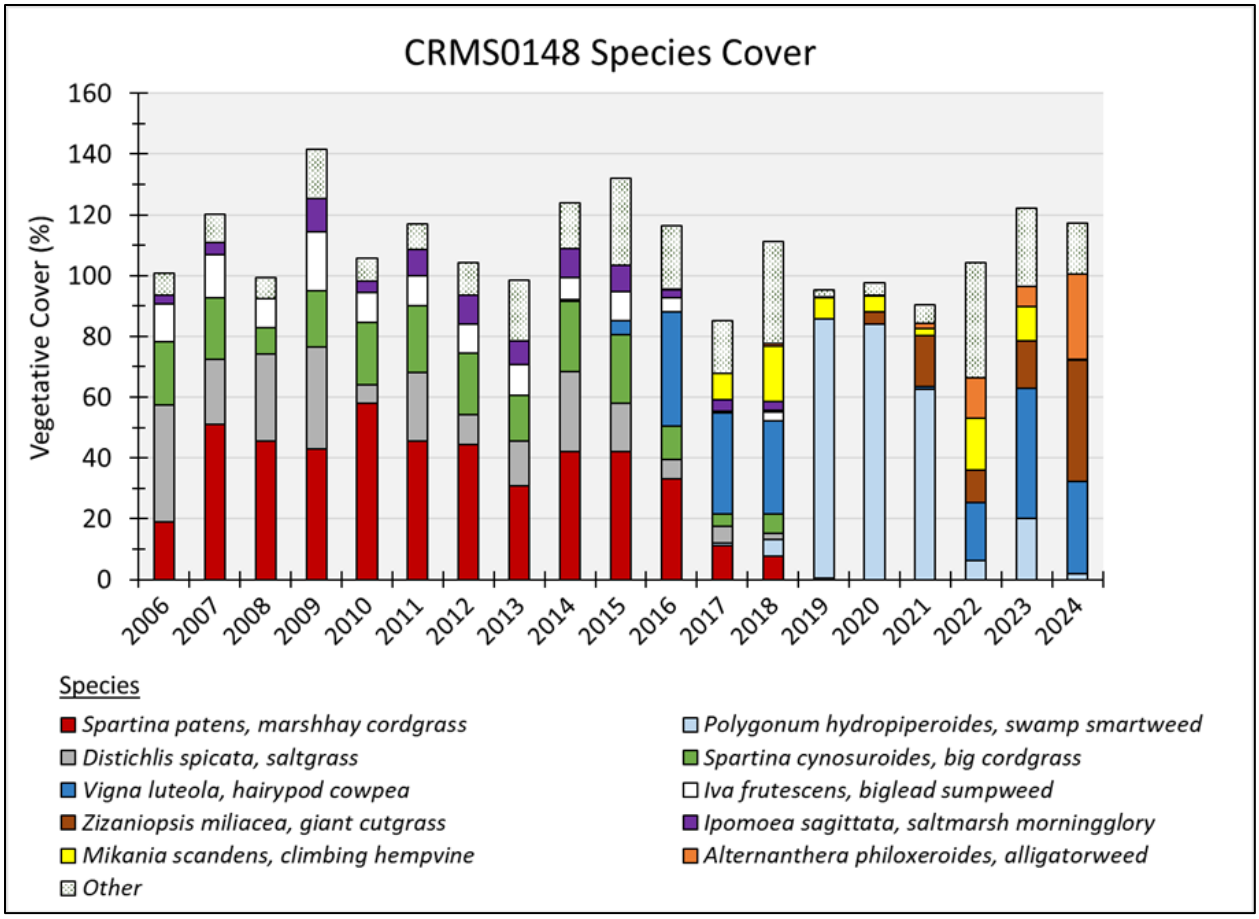


Figure 7. Vegetative cover (%) by species at CRMS0148 from 2006 to 2024

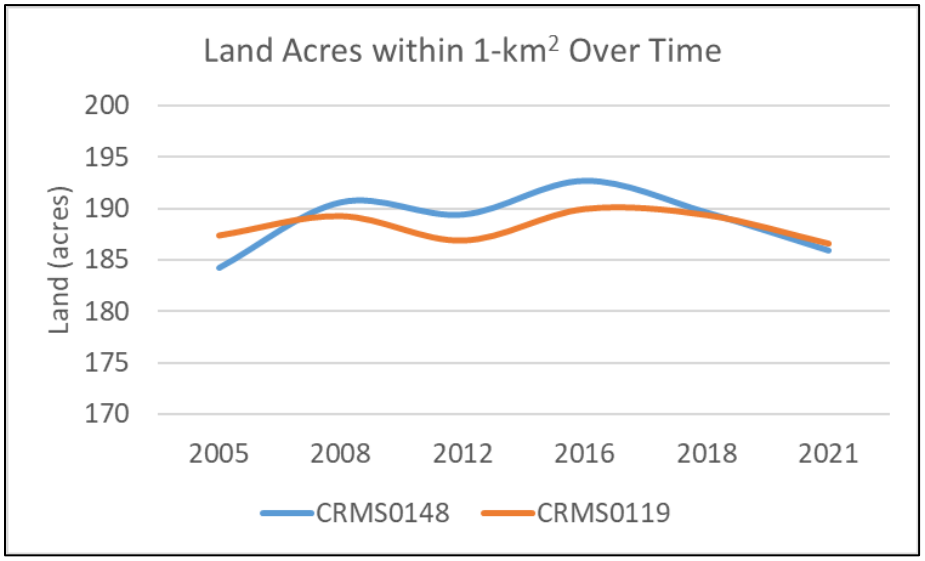


Figure 8. Land acreage at CRMS0119 and CRMS0148 quantified within the 1-km^2 from 2005 to 2021

2 - CREVASSE INFLUENCE AT NEPTUNE PASS (CRMS0118)

Neptune Pass is the largest new distributary to form along the Mississippi River in almost a century and is located on the east bank near Ostrica at approximately mile 24 above Head of Passes. An existing small crevasse first enlarged during the 2019 high river year and exhibited rapid expansion in 2020 and 2021. By 2024, flow through Neptune Pass exceeds 3,000 m^3/s (~106,000 cfs) at moderately high river flow, and diverts approximately 15-17% of the river's flow (Kolker et al. 2025). Since its formation, discharge through the pass has resulted in the development of a new delta in Quarantine Bay. CRMS0118 is located approximately two miles upriver from the main channel of the pass (Figure 9). While the site has historically received riverine influence through several small crevasses in the Ostrica region, this was significantly increased with the formation of Neptune Pass. An increase in water level in 2019 was observed at the site following the enlargement of the pass (Figure 10). Surface elevation change has been positive at the site since data collection began in 2008, but deposition due to the enlarged Neptune Pass diversion was reflected as a significant increase in the surface elevation since 2021 (Figure 11).

Although salinity has remained in the fresh/intermediate range for the entire period of sampling, there was a slight decrease in the long-term average salinity from 0.84 ppt (2008-2018) to 0.57 ppt in the post-Neptune Pass period (2019-2024) (Figure 12). A prolonged period of lower salinity was observed from 2018 to 2022 coinciding with pass formation, but higher salinities rebounded with the extreme drought of 2023. Marsh type at the site has fluctuated since 2006 between fresh and intermediate classifications. Changes in species composition have been observed in the post-Neptune Pass period including an increase in cattail (*Typha* spp.) and a decrease in hairypod cowpea (*Vigna luteola*) (Figure 13). Coverage of bulltongue arrowhead (*Sagittaria lancifolia*) has been generally decreasing at the site, although some fluctuations in coverage of this species were observed prior to the formation of Neptune Pass.

Figure 9. Location of CRMS0118 in relation to Neptune Pass

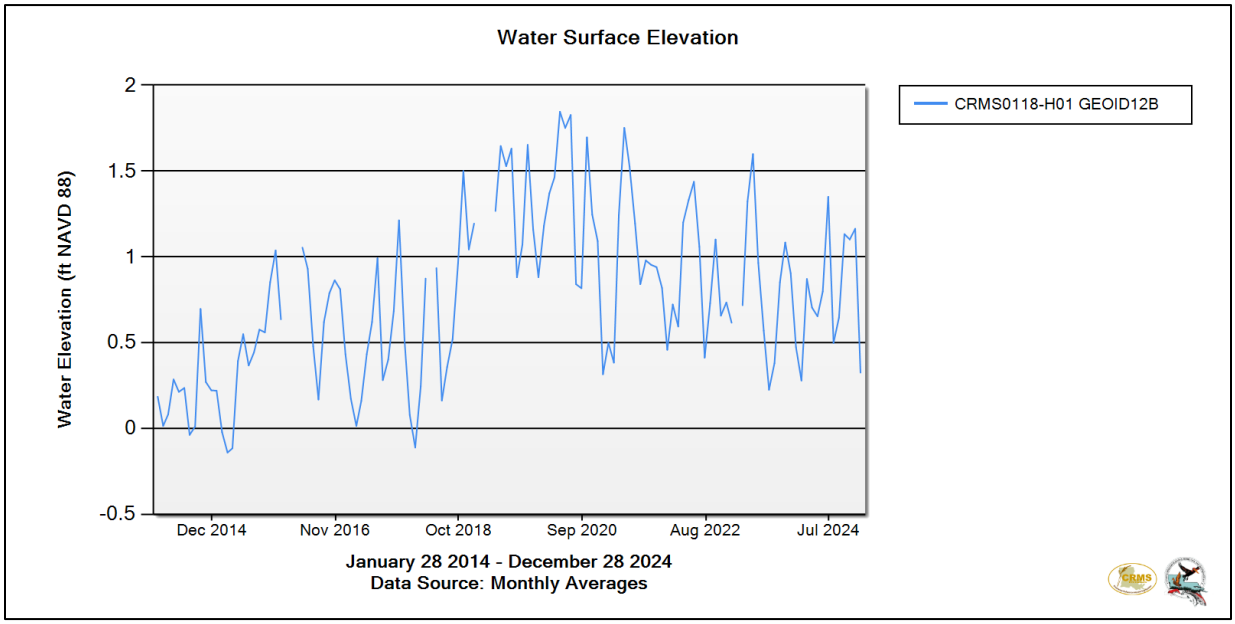


Figure 10. Water Elevation at CRMS0118 2014 - 2024

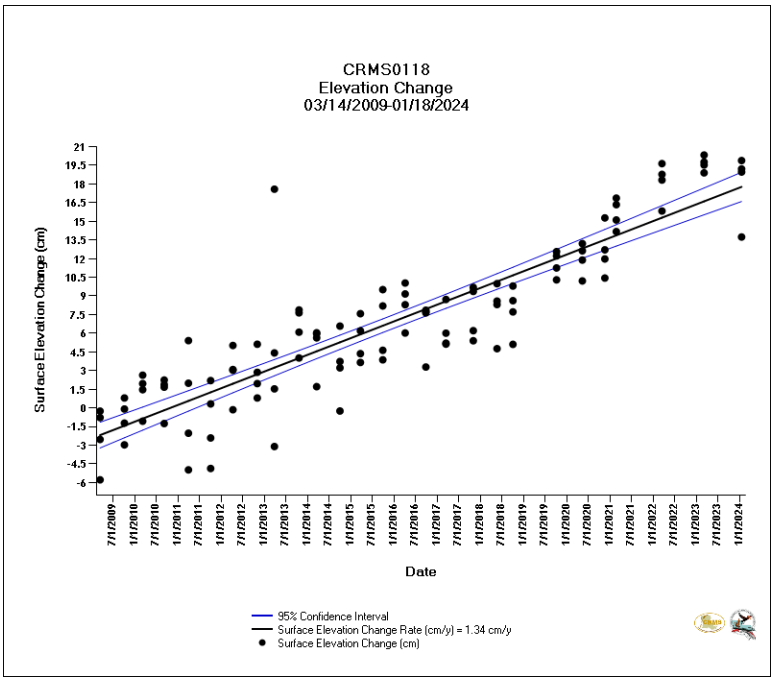


Figure 11. Surface Elevation Change at CRMS0118 2009-2024

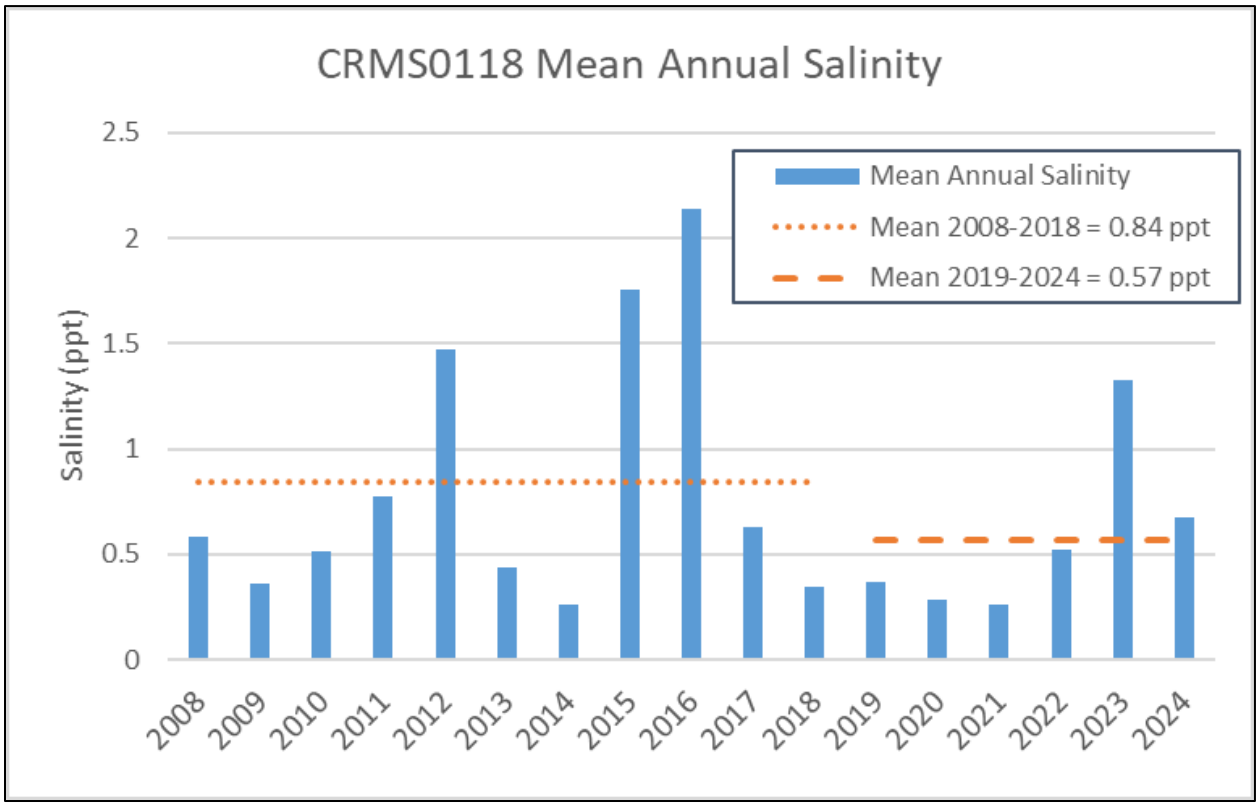


Figure 12. Salinity (ppt) at CRMS0118 from 2008 to 2024

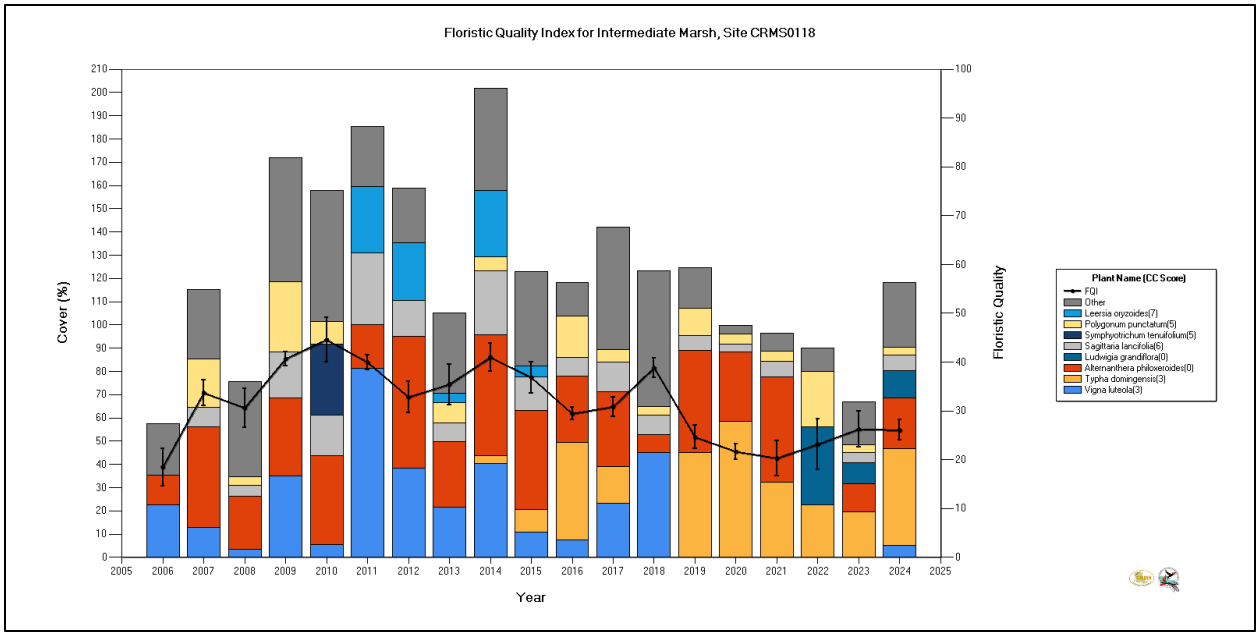


Figure 13. Mean percent coverage of vegetation at CRMS0118 from 2006 to 2024

3 – DELTA BUILDING AT FORT SAINT PHILIP (CRMS0139)

The Fort St. Philip Crevasse complex is a series of distributary channels located along the east bank of the Mississippi River between river miles 18 and 20 above Head of Passes. The crevasse complex initially formed during a significant Mississippi River flood event in 1973, and since that time, marshes in the region have converted from brackish to fresh/intermediate marsh. Collectively, the discharge through the complex of channels is estimated to be as high as 3,000 m^3/s (~100,000 cfs) at high river flow (Kolker et al. 2025, Suir et al. 2014). The Delta Management at Fort St. Philip project (BS-0011) was completed in 2006, which involved the construction of six artificial crevasses through existing spoil banks in the Fort St. Philip region, as well as construction of an earthen terrace field within the largest of the six receiving bays (Hymel and Blanche 2019; https://cims.coastal.la.gov/RecordDetail.aspx?Root=0&sid=23411). CRMS0139 was installed in 2007 within this large receiving bay along the edge of the constructed terrace field (Figure 14). Since that time, CRMS0139 has received riverine influence through the Fort St. Philip crevasse, and more recently from Neptune Pass, which formed upriver in 2019 and feeds directly into Bay Denesse.

An increase in water level at CRMS0139 was observed during the exceptionally high river years of 2019-2020, which also corresponded with the enlargement of Neptune Pass (Figures 15 and 16). Increased sediment deposition at the site was associated with higher river years. An increase in the surface elevation change rate began with the higher river year in 2016, and then increased further with the exceptionally high river year in 2019 (Figure 17). Overall, the surface elevation change rate from 2008 to 2024 was 1.5 cm/yr, but for the high river period only (2018 to 2021) it was 2.6 cm/yr. Salinity at CRMS0139 has remained in the fresh/intermediate range since monitoring began in 2007. Mean annual salinity (2008-2024) was 0.67 ppt and ranged from 0.2 to 2 ppt (Figure 18). An extended period of lower salinity from 2016 to 2021 along with higher flooding levels during the high river years potentially contributed to changes in species composition at the site beginning in 2016 (Figure 19). A variable mix of fresh/intermediate species has transitioned to a near monoculture of elephant ear (*Colocasia*

esculenta); however, mean percent cover of vegetation has remained high and above 90% in most years.

The 1-km^2 area used for land-water analysis at CRMS0139 includes the western half of the BS-0011 terrace field and analyses have captured land building which has occurred as a result of sediment capture within the terrace field (Figure 20). Land acreage within the 1-km^2 has doubled over the analysis period, increasing from 60.3 acres in 2005 (24% land) to 124 acres in 2021 (50% land). Satellite data shows positive land change over a longer time period indicating that there has been continuous land building since 1985, even before the BS-011 project (Figure 21).

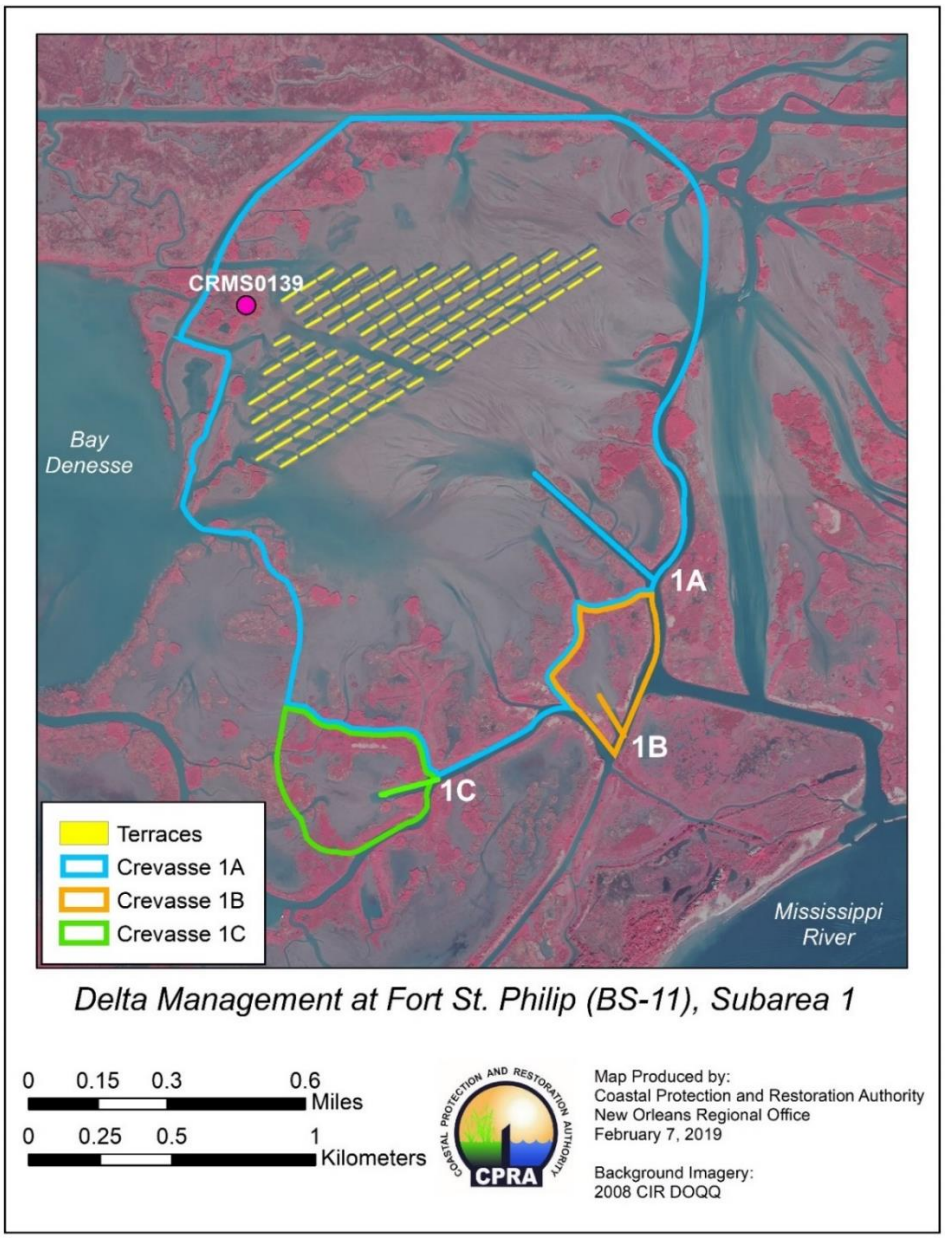


Figure 14. Location of CRMS0139 within the BS-0011 project area

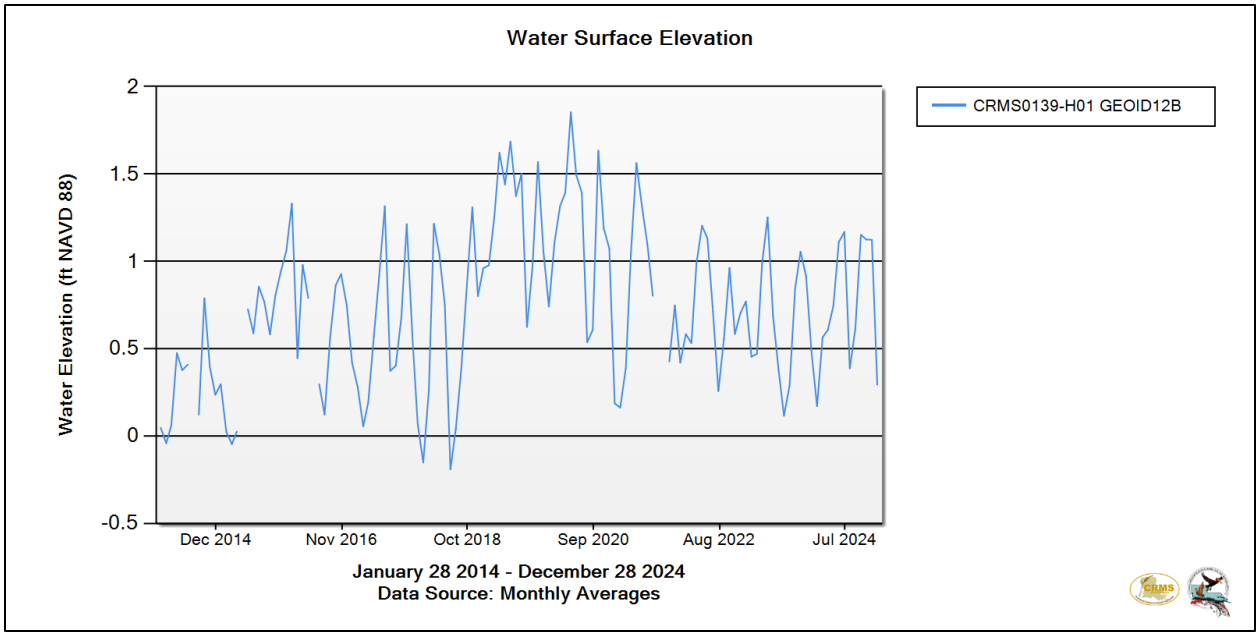


Figure 15. Water elevation (ft NAVD88) at CRMS0139 from 2014 to 2024

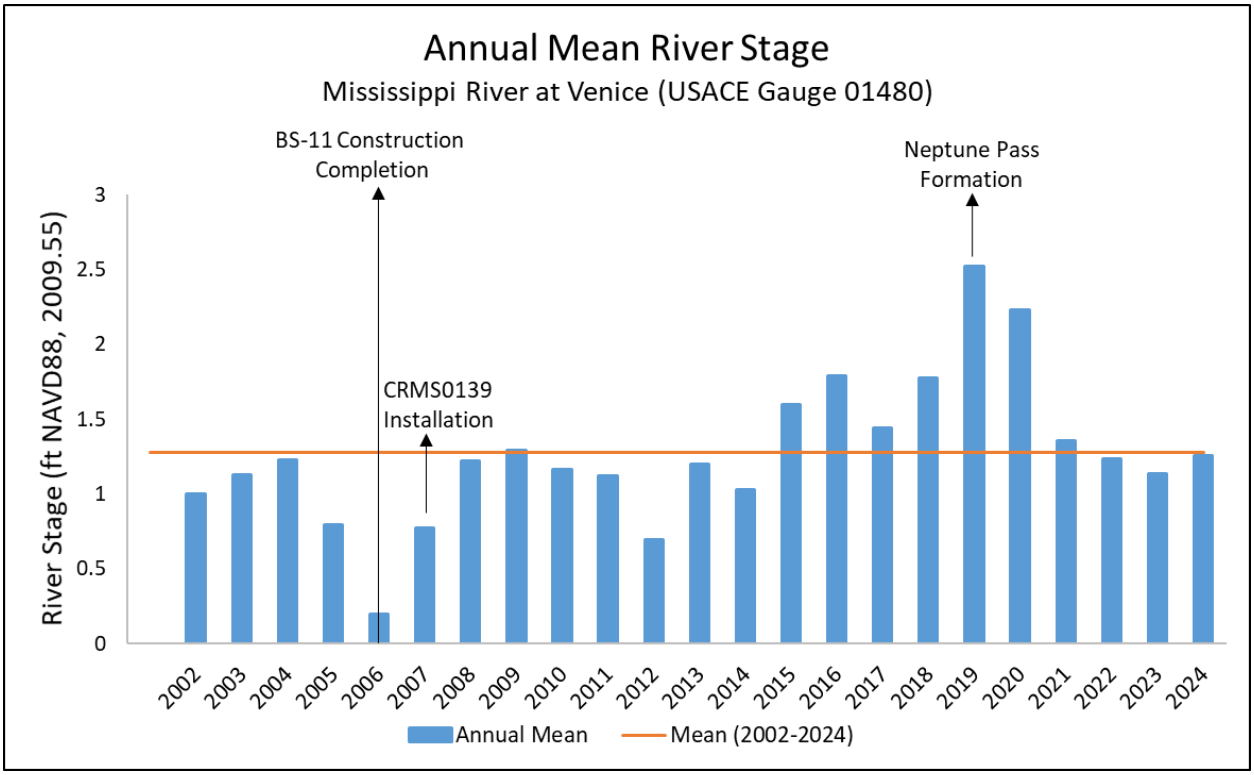


Figure 16. Annual mean Mississippi River stage (ft NAVD88, 2009.55) from 2002 to 2024 measured at USACE Gauge 01480 near Venice, LA

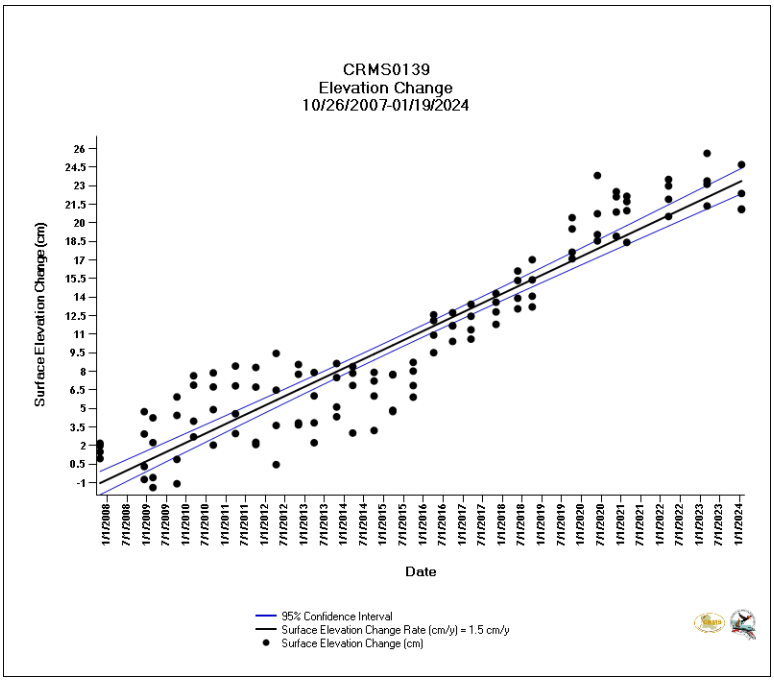


Figure 17. Surface Elevation change at CRMS0139 2008-2024

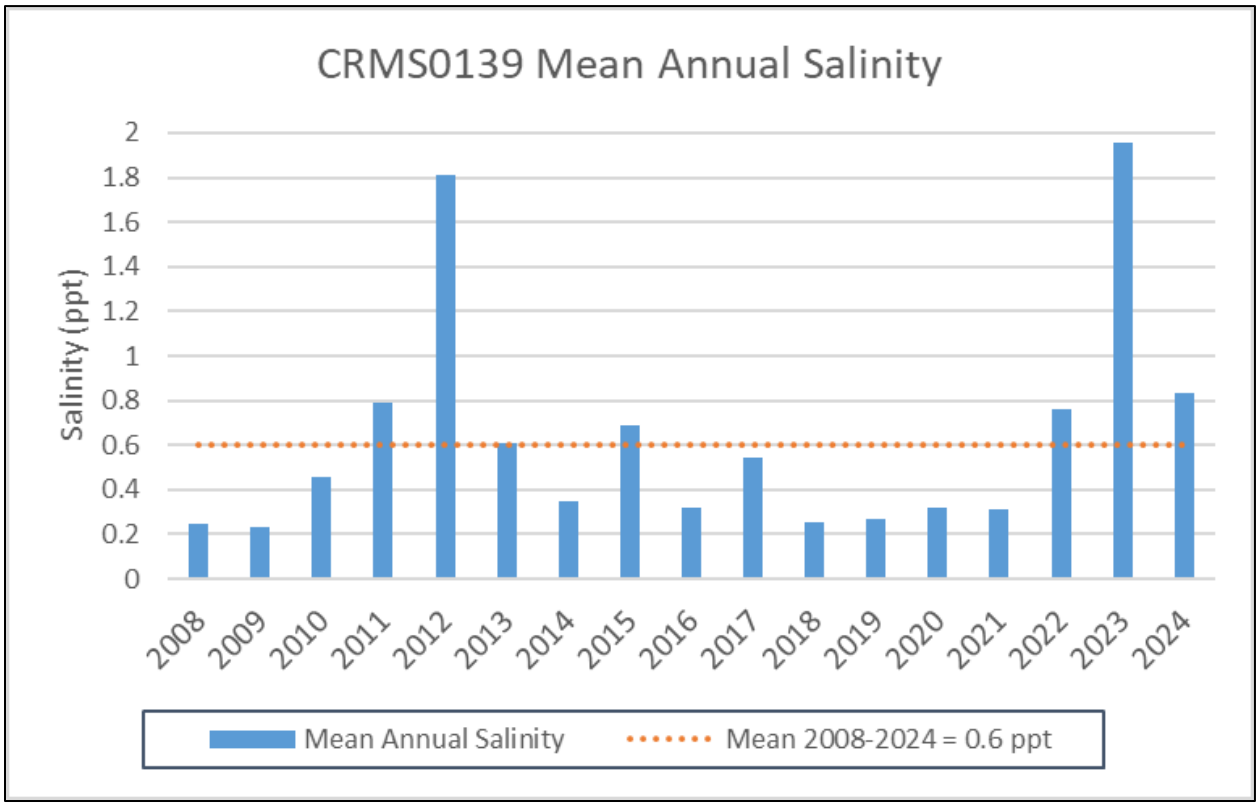


Figure 18. Mean annual salinity at CRMS0139 from 2008 to 2024

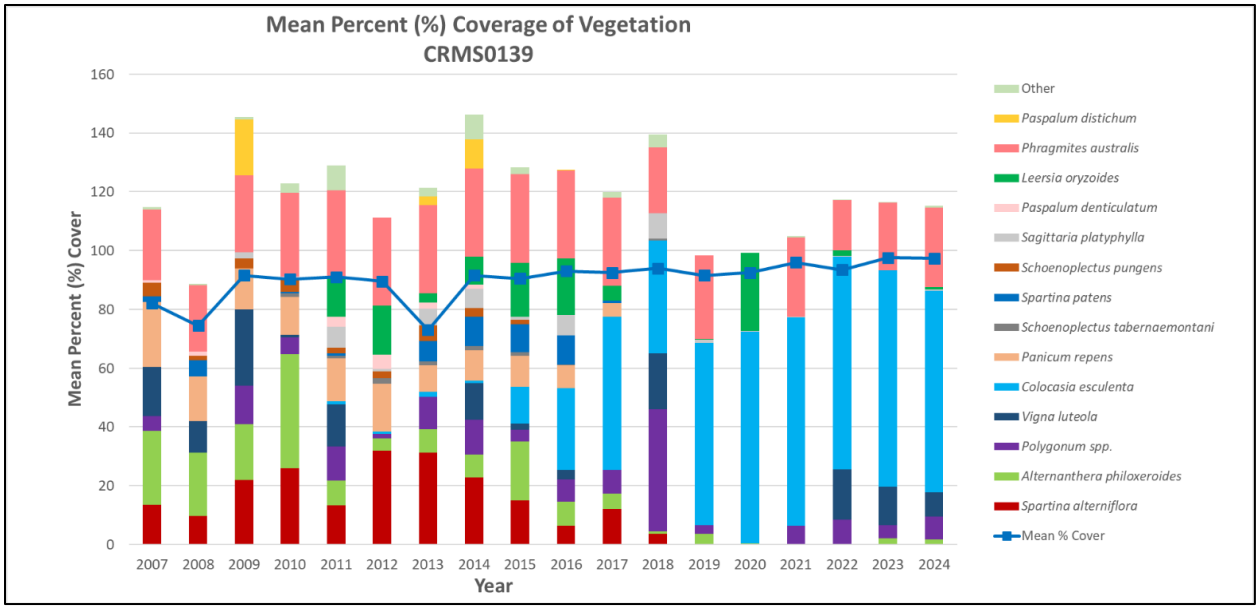


Figure 19. Mean percent coverage of vegetation at CRMS0139 from 2007 to 2024

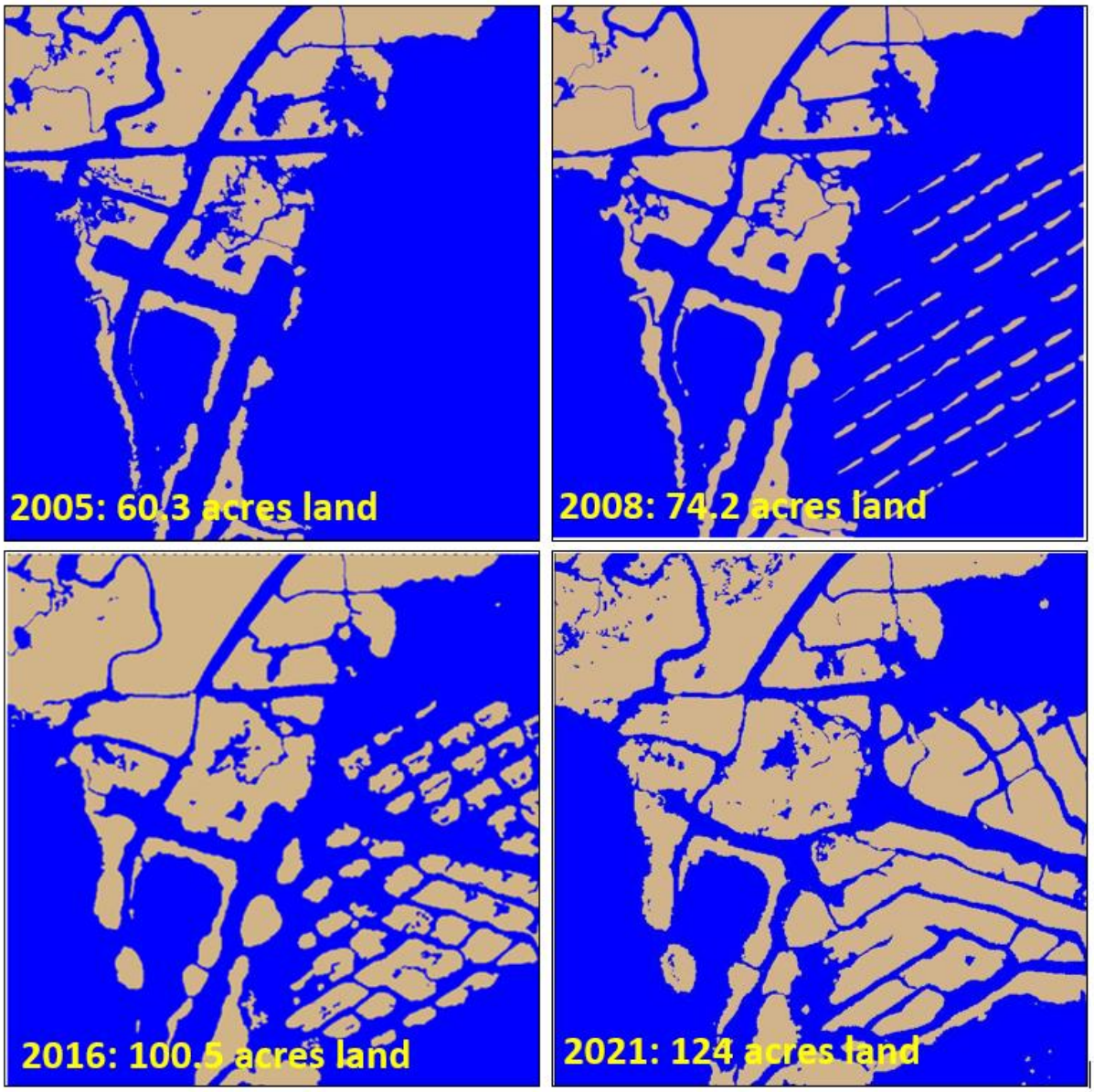


Figure 20. Land/water analyses within the CRMS0139 1-km^2 area from 2005 to 2021. Year 2008 shows the newly created BS-0011 terrace field and year 2021 shows significant land gain within the terrace field

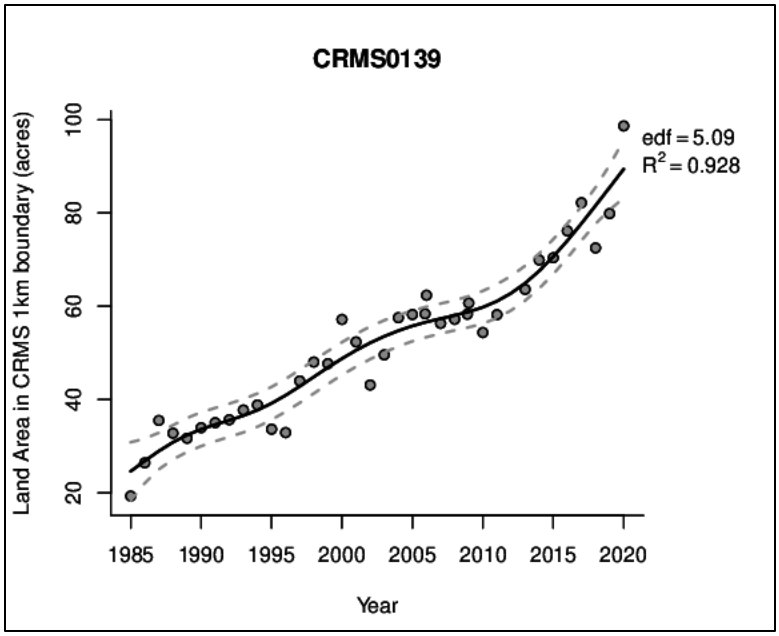


Figure 21. Land area at CRMS0139 1985-2020

4 – TRANSITION FROM MARSH TO SWAMP IN THE DAVIS POND FRESHWATER DIVERSION PONDING AREA/OUTFALL (CRMS3169)

CRMS3169 is located approximately 4.5 miles downstream from the Davis Pond Freshwater Diversion structure and is positioned within the diversion's primary flow path (Figure 22). The Davis Pond Diversion is located on the west bank of the Mississippi River at river mile 118 in St. Charles Parish, Louisiana, and is managed under a cooperative agreement between the United States Army Corps of Engineers (USACE) and CPRA. The structure is capable of diverting a maximum of 10,650 cubic feet per second (cfs) of Mississippi River water into an approximately 9,400-acre ponding area within the upper Barataria Basin; however, due to operational salinity targets and other constraints, the mean annual discharge between 2003 and 2024 has been considerably lower at 1,799 ± 996 cfs (standard deviation, SD). The ponding area slows the discharge of river water into Lake Cataouatche to allow for nutrient uptake and sediment deposition in the marsh.

CRMS3169 has benefited from this input of Mississippi River fresh water, sediment and nutrients. Changes in the wetland habitat at this site have been dramatic since the start of diversion operations in 2002. Since this site's establishment in 2008, it has transitioned from floating marsh, to attached marsh, to what is now primarily a forested habitat (Figure 23). A forested vegetation monitoring transect was added in 2021 to track the development of the swamp community through measurement of tree establishment and growth. Currently unique to the CRMS network, CRMS3169 contains both the original marsh vegetation monitoring transect and a swamp vegetation monitoring transect.

The marsh transect is composed of a mixture of fresh and fresh/intermediate marsh species, but an increase in black willow (*Salix nigra*) indicates a transition towards swamp habitat (Figure 24). Black willow, the dominant species in 2024, was first noted at CRMS3169 in 2012, following four years of consistently high diversion operations. This species has trended upwards in cover since that time, reaching its highest mean cover of 67% in 2023. In 2012, black willow was recorded at only 20% of the vegetation monitoring stations at the site, but since 2017 it has been recorded at 90%. In addition to black willow, the occurrence of other woody species has been increasing at CRMS3169 since 2013. Common buttonbush (*Cephalanthus occidentalis*) and red mulberry (*Morus rubra*) have all been documented within or just outside of stations for the last several years, and eastern baccharis (*Baccharis halimifolia*) has been surveyed at the site since 2015.

Mean percent canopy cover for the forested transect increased from 27 ± 35% SD in 2021 to 57 ± 47% SD in 2024, a gain of 111% (Figure 25). The standard deviation is large each year due to considerable differences in canopy cover between the three monitoring stations (F04, F05, and F07) that comprise the site. The number of tagged trees at the site increased from 77 in 2021 to 82 in 2024, and all were black willow, which is an aggressive early colonizer of forest habitats. The continued expansion of higher value woody species is anticipated over time as the forest matures and red mulberry may mature to a size that allows it to be tagged in the next tree survey that will occur in 2027.

The changes in vegetation at CRMS3169 are largely in response to the changes in soil properties and surface elevation at the site. These changes can be seen both through visual examination of soil samples, site visits, and quantifiable data. Soil coring conducted from the CRMS3169 boardwalk visually demonstrates the considerable accumulation of mineral sediment that has been deposited from Mississippi River water flowing over the marsh surface (Figure 26). Laboratory analyses of soil cores between 2008 and 2018 show an increase in bulk density due to mineral sediment deposition from the river water (Figure 27).

A rod surface elevation table (RSET) was first established at CRMS3169 in 2018, after a site assessment indicated the marsh was no longer floating. The period of surface elevation change monitoring is short (2018–2025) compared to other CRMS sites that had RSETs installed during site establishment, typically in 2007 or 2008 (Figure 28). Additionally, the data fail to capture the change in surface elevation since the start of operations in 2002, and due to the short time frame, are heavily influenced by the large increase in surface elevation change from Hurricane Ida (August 2021), when sediment was deposited on top of the marsh from the storm surge. Diversion operations have been relatively low during the RSET period of monitoring, and while the elevation change rate (1.09 cm/yr) is positive at the site for the period of record, a longer monitoring period that captures years with higher discharge will provide greater insight into diversion impacts on elevation change at the site.

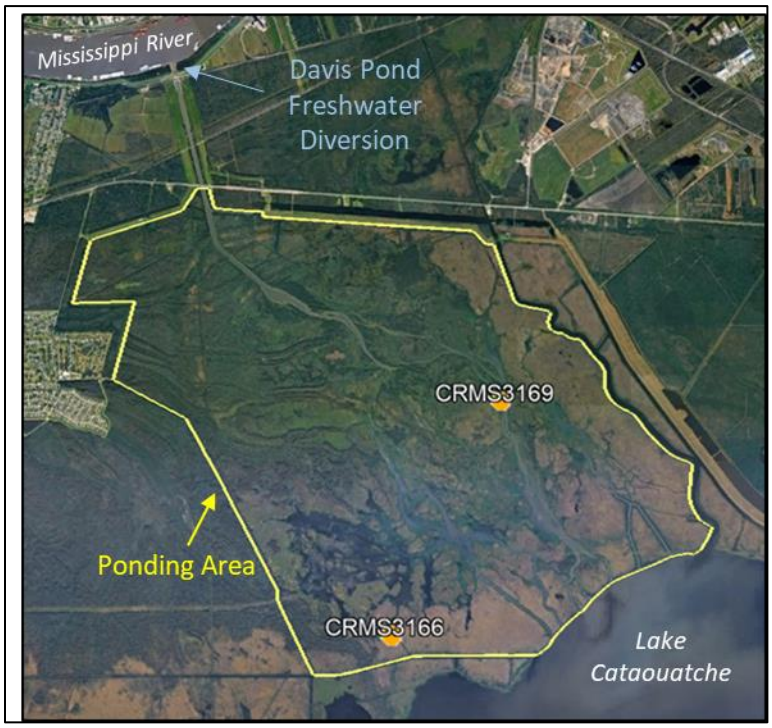


Figure 22. Location of the Davis Pond Freshwater Diversion, CRMS3169, and Davis Pond ponding area. CRMS3166 is also located within the ponding area, but it is further from the diversion outflow and is not in the direct flow path. Google Earth Imagery, 12/01/2024

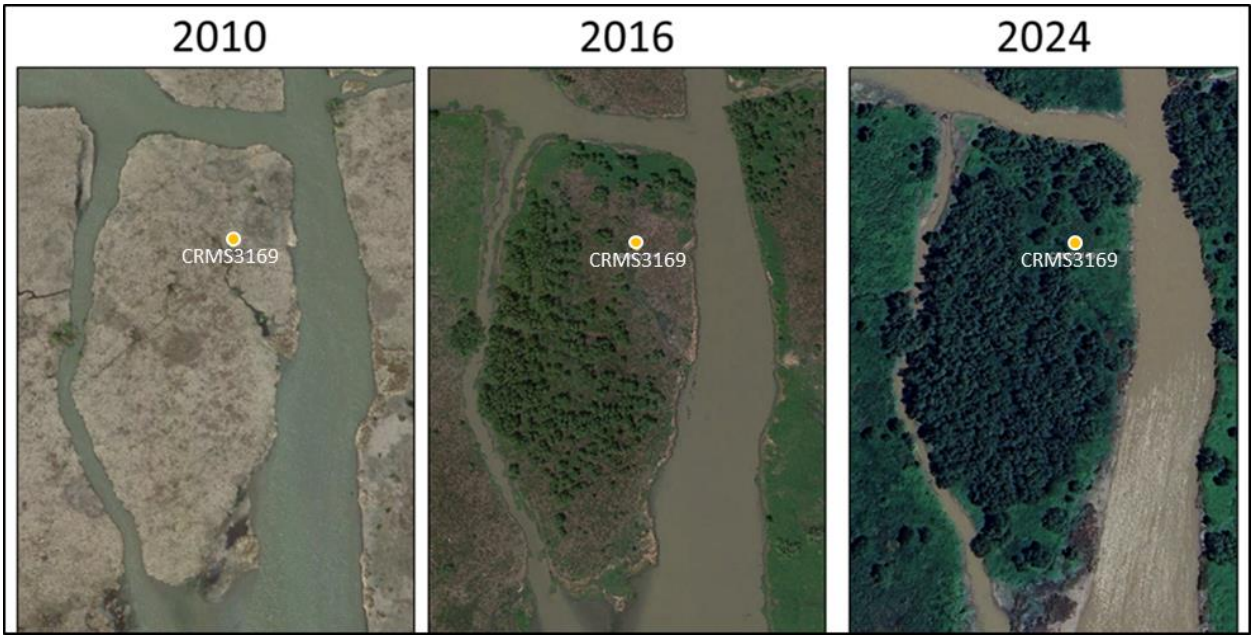


Figure 23. Google Earth imagery showing the transition from marsh (2010) to primarily forested habitat (2024) at CRMS3169

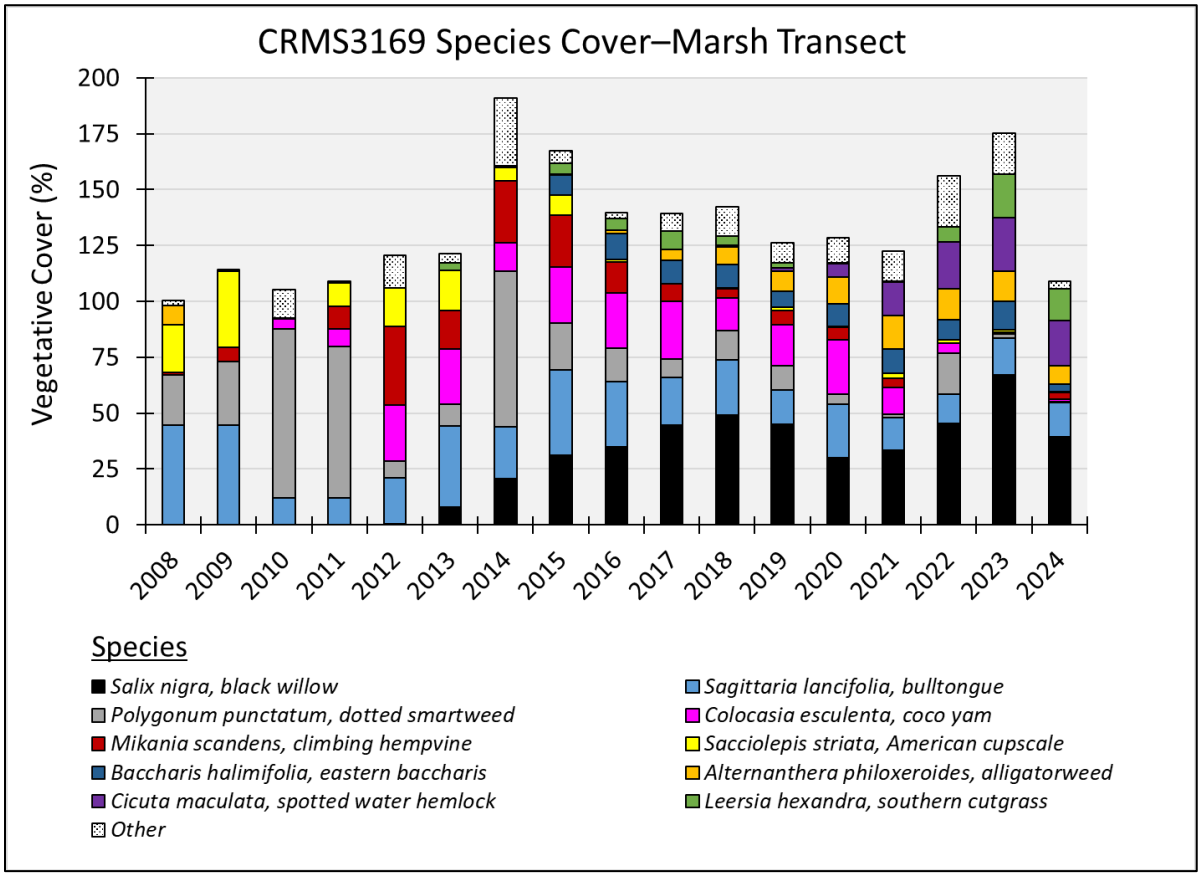


Figure 24. Mean percent vegetative cover by species for the CRMS3169 marsh transect 2008–2024

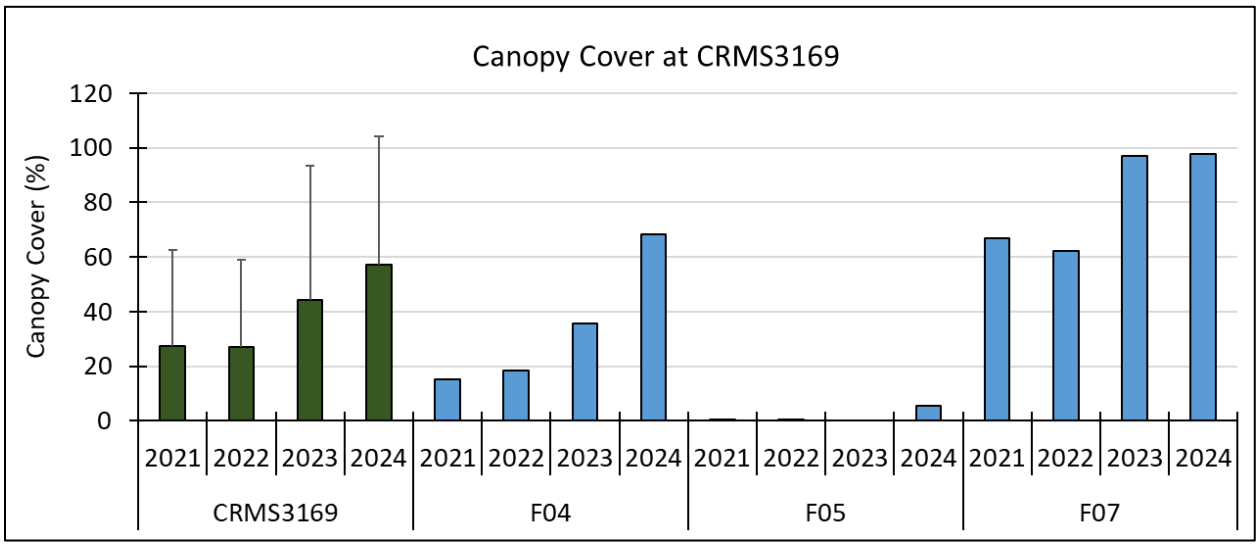


Figure 25. Percent canopy cover for the CRMS3169 forested transect 2021–2024 for the site (+SD) and the three individual stations that comprise the site


Figure 26. Soil core taken at CRMS3169 in 2024 shows the grey, fine mineral sediment that has accumulated on the marsh above the highly organic sediment below

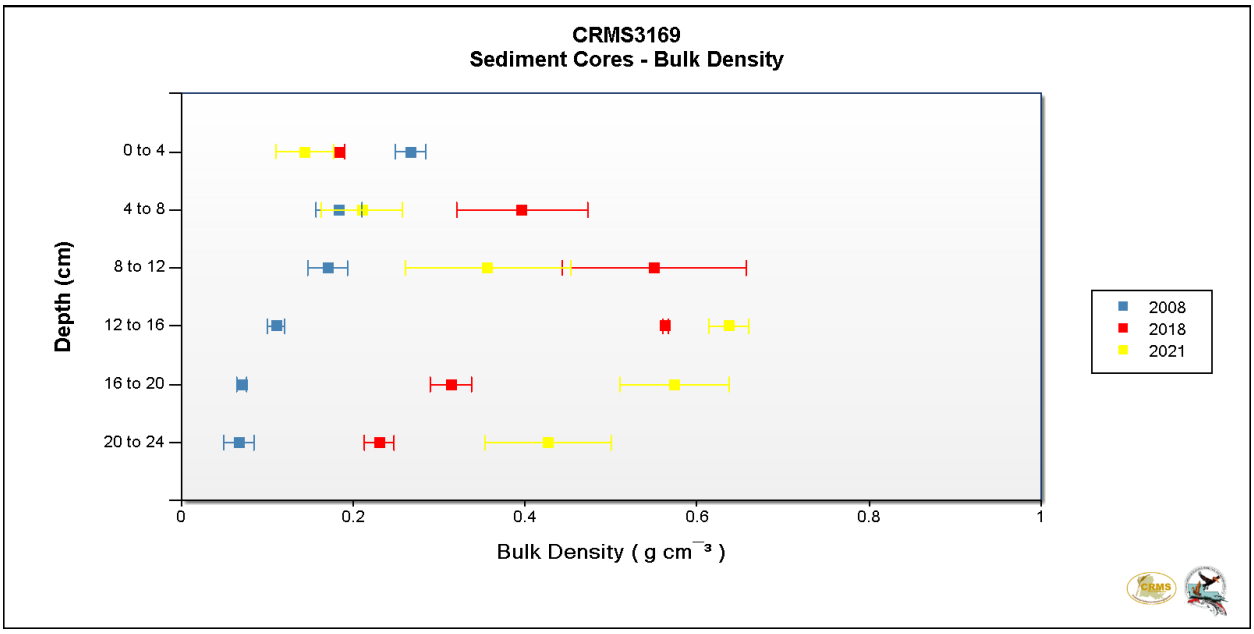


Figure 27. Changes in bulk density between 2008 and 2021 from sediment cores sampled at CRMS3169

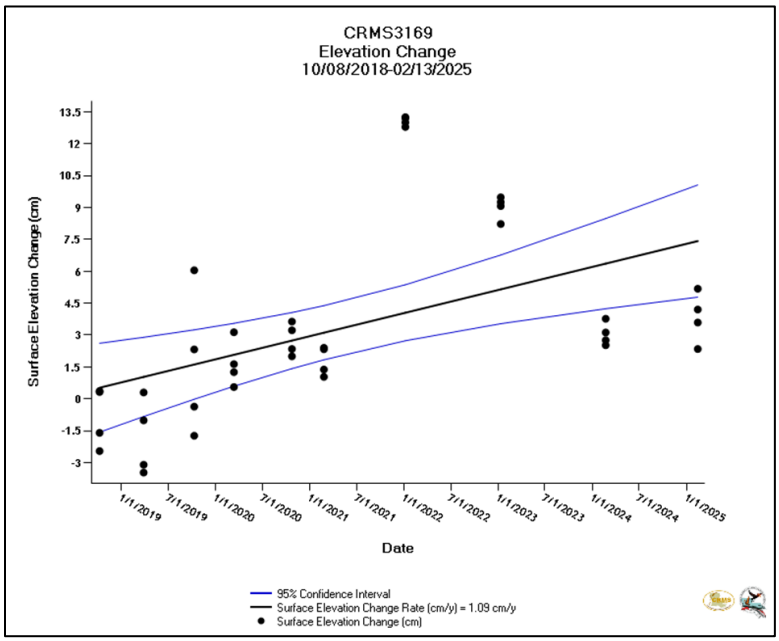


Figure 28. Surface elevation change at CRMS3169 between 2018 and 2025

5 – ELEVATION LOSS DUE TO WATER MANAGEMENT ON BAYOU SAUVAGE NWR (CRMS4107)

CRMS4107 is located within an impounded unit of the Bayou Sauvage National Wildlife Refuge (NWR), which is managed by the U. S. Fish and Wildlife Service (Figure 29). The unit has been hydrologically isolated from the surrounding estuary since construction of the hurricane protection levee in 1956, resulting in precipitation as the major water source. Over time, impounded rainfall and loss of daily tidal exchange resulted in extended periods of inundation during the growing season, which led to a decline in marsh habitat and a transition from brackish to fresh/intermediate marsh. Alternatively, during periods of drought, dewatered sediments were subjected to oxidation, subsidence, and extreme compaction resulting in significant lowering of the impounded marsh elevation relative to the surrounding tidal marsh. The mean marsh elevation measured at CRMS4107 has decreased over time (Figure 30) and was approximately -0.50 ft NAVD, G12b by 2021, which is the sixth lowest of all CRMS sites coast-wide. Comparatively, the tidally influenced CRMS sites just outside the hurricane protection levee show significantly higher mean marsh elevations of +0.82 ft (CRMS3626), +0.77 ft (CRMS3650), and +0.72 ft (CRMS0002; Figure 31).

The USFWS has the ability to passively drain the impoundments through a series of flap-gated weirs, which require sufficient head differential for drainage. As a means for actively removing excess water, the Bayou Sauvage NWR Hydrologic Restoration CWPPRA project (Phase 1, PO-16) was constructed in May 1996, which involved the installation of two pump stations: one within the CRMS4107 unit and one within an adjacent weir-connected unit (Hymel and Richard 2016; https://cims.coastal.la.gov/RecordDetail.aspx?Root=0&sid=19576) (Figure 29). Evaluation of PO-16 project effectiveness was hindered by incomplete operations records, and by extended periods when the pumps were offline due to damage following Hurricane Katrina and during HSDRRS levee enlargement (28% of the 20-yr project life). Per USFWS, management of water levels using the weirs and pumps is currently based on visual observations of water levels in the impoundment and not on any specific gauge or water level trigger, and the pumps are typically only operated during extreme high water events. An additional weir was recently installed in January 2024 to increase capacity for passive drainage.

There has been a general decreasing trend in water level over time within the impoundment (Figure 30) indicating some success in water level management; however, a concurrent decreasing trend in soil surface elevation change rate (Figure 32) means that high flooding potential remains. Comparatively, water levels at tidal CRMS sites outside the impoundment are increasing, and soil surface elevation change rates are also increasing (Figure 33). Vegetative cover at CRMS4107 has fluctuated over the years and is currently on a decreasing trend (Figure 34). While marsh hay cordgrass (*Spartina patens*) remains the dominant species, lower water levels and lower salinity in recent years have encouraged growth of other species, including black willow (*Salix nigra*). Land change data has shown an increase in land area since 2008 (Figure 35), also likely attributable to lower water levels. The adjacent impoundment to the south, which has consisted of mostly open water for many years, has seen a significant increase in vegetated land since 2020 due to a combination of lower water levels and successful planting of flood-tolerant California bulrush (*Schoenoplectus californicus*) through the LA-0039 CWPPRA Coastwide Vegetative Planting Project (McGinnis et al. 2021; https://cims.coastal.la.gov/.aspx?Root=0&sid=24638).

Due to its exceptionably low marsh elevation, this impounded site continues to be uniquely vulnerable to extremes in precipitation levels, and would be particularly at risk in the event of levee overtopping or pump failure. It would be beneficial to develop an updated water management plan that would identify a water level trigger for pump operations that is conducive to current marsh elevations. It may be beneficial to consider direct restoration efforts, such as dedicated dredging of sediments to increase surface elevations within the impoundment, for future sustainability of the marshes within.

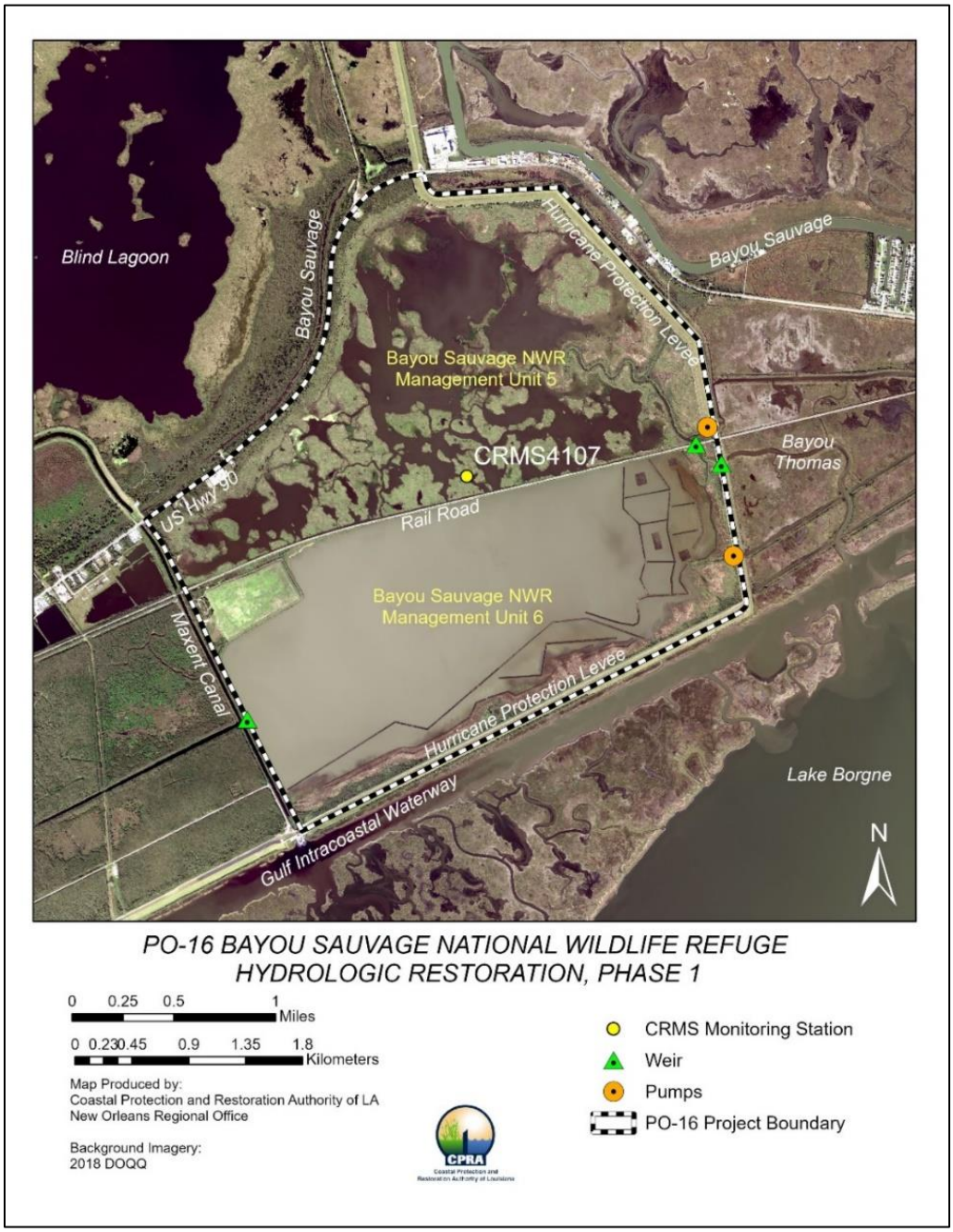


Figure 29. Location of CRMS4107 within the PO-0016 Bayou Sauvage National Wildlife Refuge Hydrologic Restoration, Phase 1 project boundary

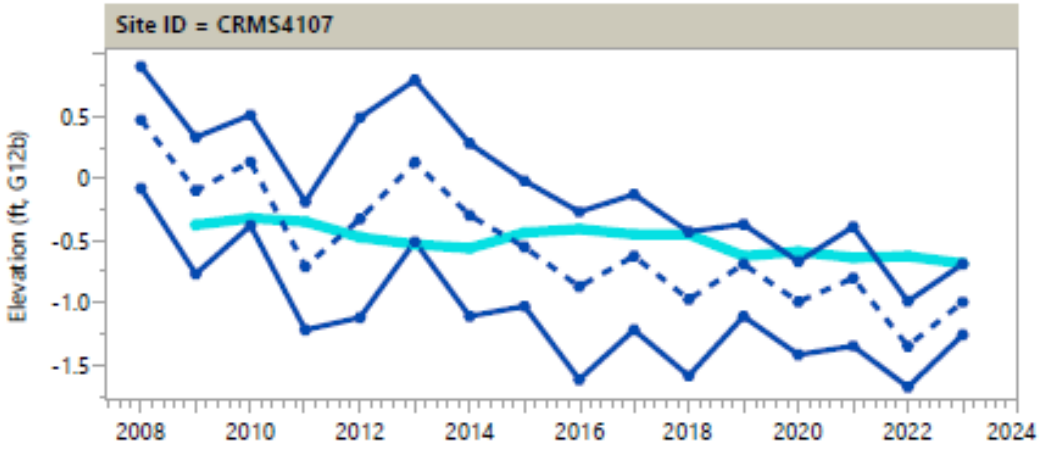


Figure 30. Marsh Elevation (NAVD88 Geoid12b) of CRMS4107 derived from RSET measurements plotted against water elevation displaying the site's position within the hydrologic range

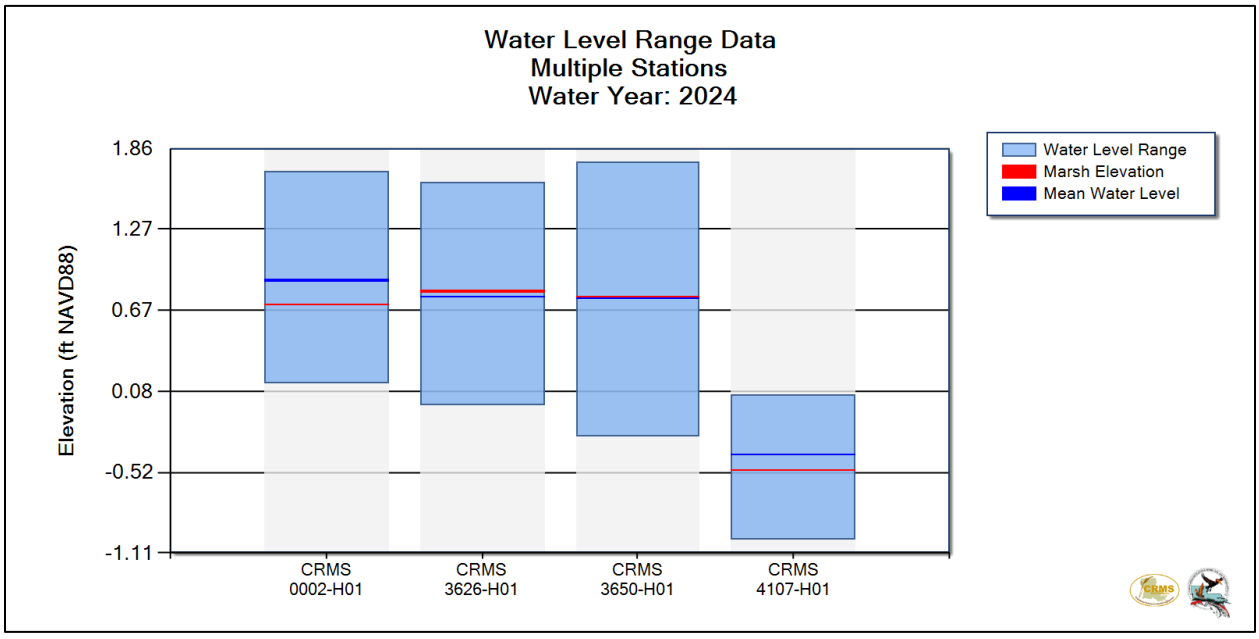


Figure 31. The 2024 water level range in relation to mean marsh elevation (ft NAVD88, Geoid12b) at impounded CRMS4107 vs three tidal CRMS sites (CRMS0002, CRMS3626, CRMS3650)

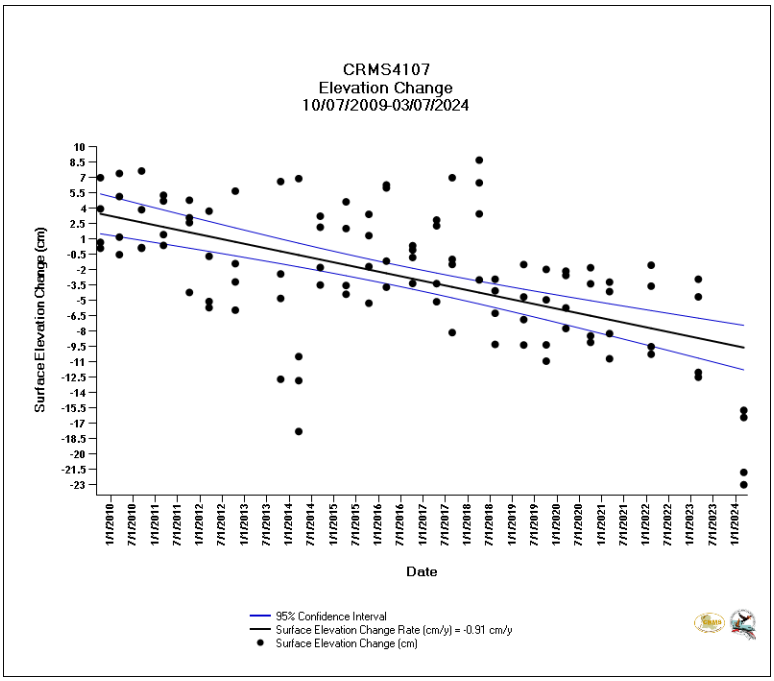


Figure 32. Surface elevation change at CRMS4107 within the BSNWR impoundment

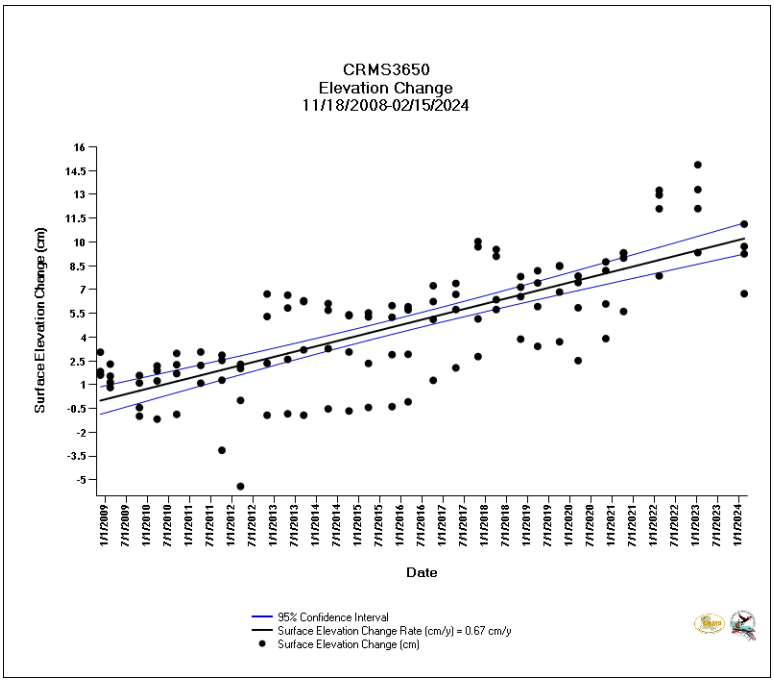


Figure 33. Surface elevation change at CRMS3650 located within tidally influenced marsh outside of the BSNWR impoundment

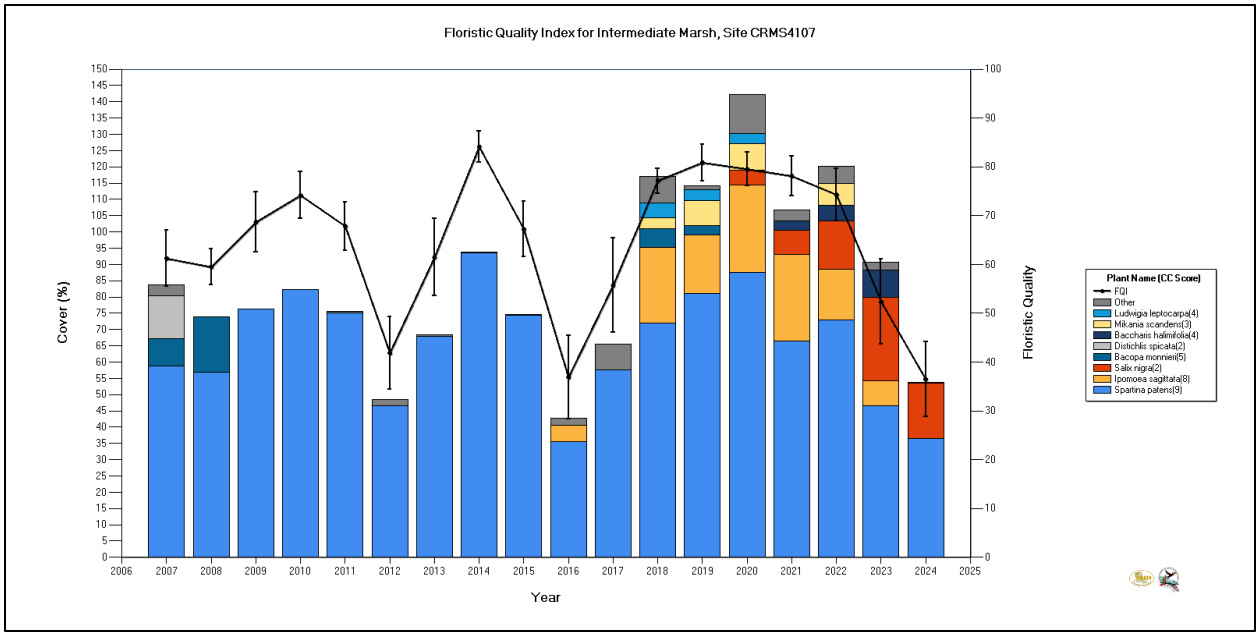


Figure 34. Floristic Quality Index for CRMS4107

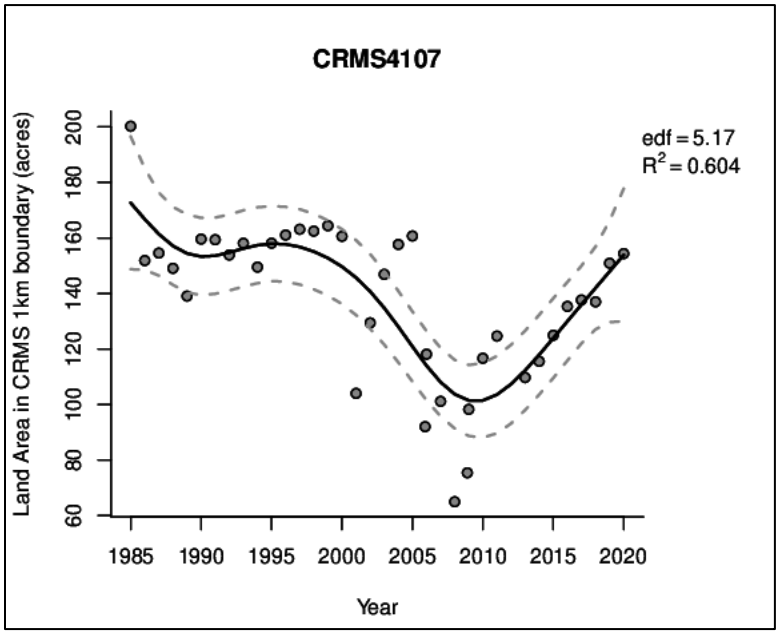


Figure 35. Land area at CRMS4107 1985-2020

6 – RESPONSE TO DROUGHT AND VERY HIGH SALINITY (100 PPT AT CRMS0589)

CRMS0589 is located within a borrow canal on Rockefeller Refuge that sees occasional overwash of the beach rim. Drought conditions in the summer of 2023 caused extremely low water levels and hypersaline conditions at this location due to evaporation. Salinity readings in the small ponds that remained reached the highest salinities ever measured at CRMS sites, over 100 ppt (Figure 36). Handheld salinity meters only measure up to 70 ppt so water samples were sent to an LSU laboratory to confirm the >100 ppt values. Salinities remained elevated through the end of the year. The drought event caused a shift in species assemblage without land loss. In the first year post drought, only *Distichlis spicata* emerged (Figures 37a and 37b).

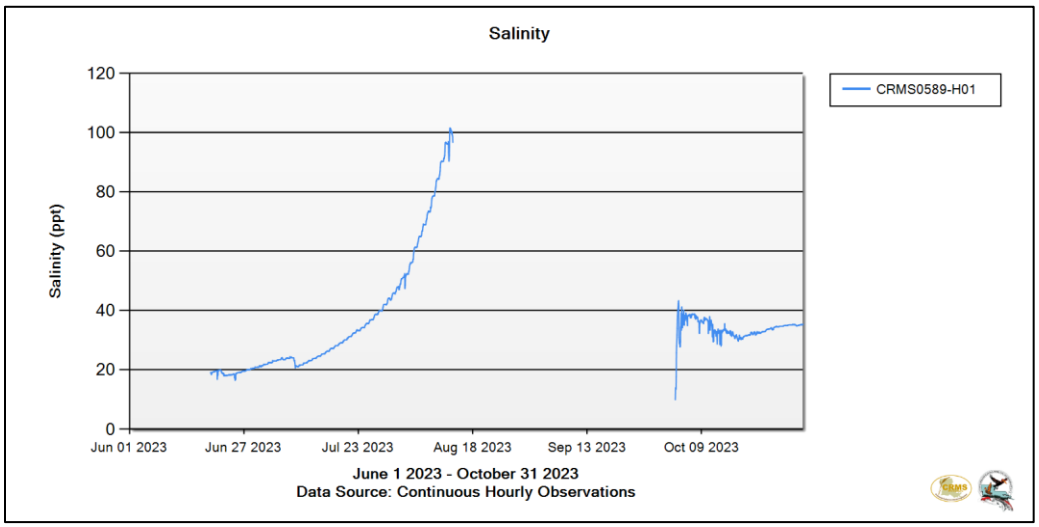


Figure 36. Record salinity readings during the summer of 2023 at CRMS0589

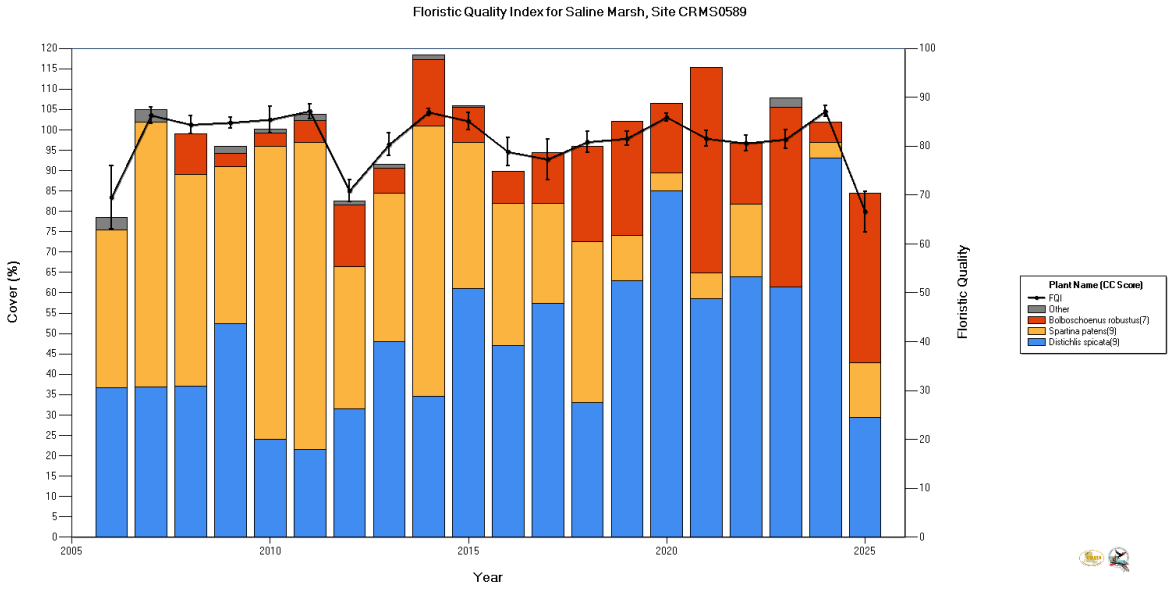


Figure 37a. Floristic Quality Index for CRMS0589

Figure 37b. Photograph of CRMS0589 vegetation station in 2024 after very high salinity in the 2023 drought. Note monoculture of *Distichlis spicata*.

7 - DESTABILIZATION OF SALINE IMPOUNDMENT - EAST MUD LAKE (CS-20) PROJECT AREA (CRMS0672)

The East Mud Lake Hydrologic Restoration Project was a successful CWPPRA project that reached the end of its 20 year project life in 2016. The landowner continued to implement the water management plan after 2016 that worked up until that time. During the sea level acceleration that began in 2015, salt water came over the levees of the project from the south and west and could not be evacuated with existing project infrastructure. Suddenly, water levels were unmanageable with the existing water management plan. Continuous saltwater inundation led to mat detachment and accompanied land loss that was captured at CRMS0672 (a brackish marsh site) within the project area (Figures 38 and 39a). The marsh destabilized and most of the remaining vegetation within the management units was lost (Figures 39b and 40). Note, some of the lost vegetation returned during the drought which indicates that this kind of land loss can be recovered with water level management.

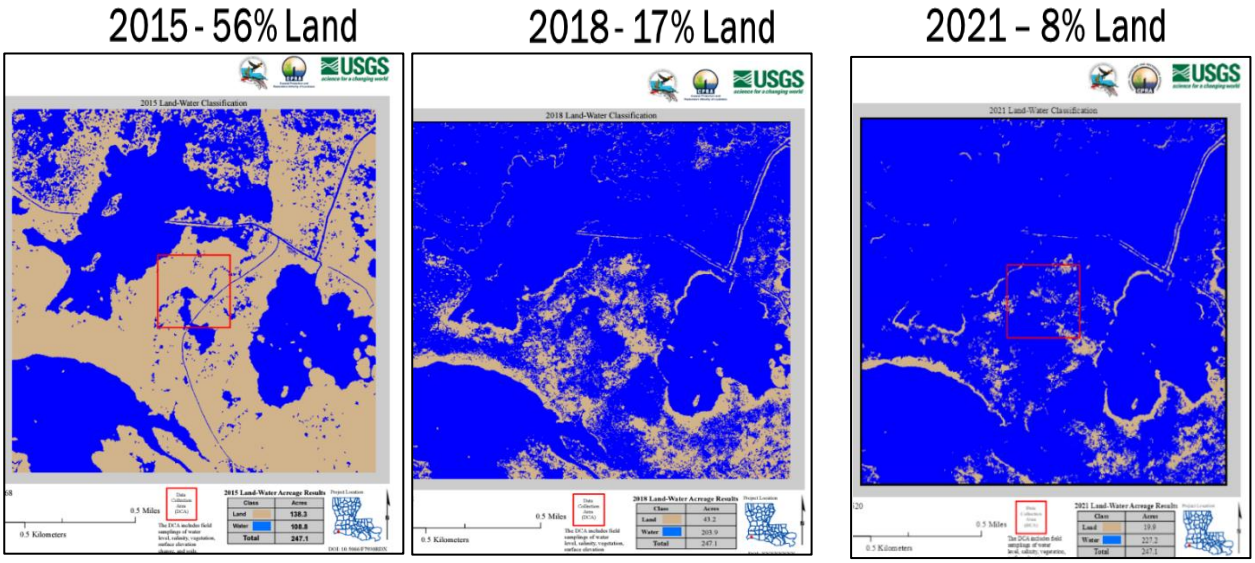


Figure 38. Land/Water Analysis through time at CRMS0672 showing land loss following

saltwater inundation

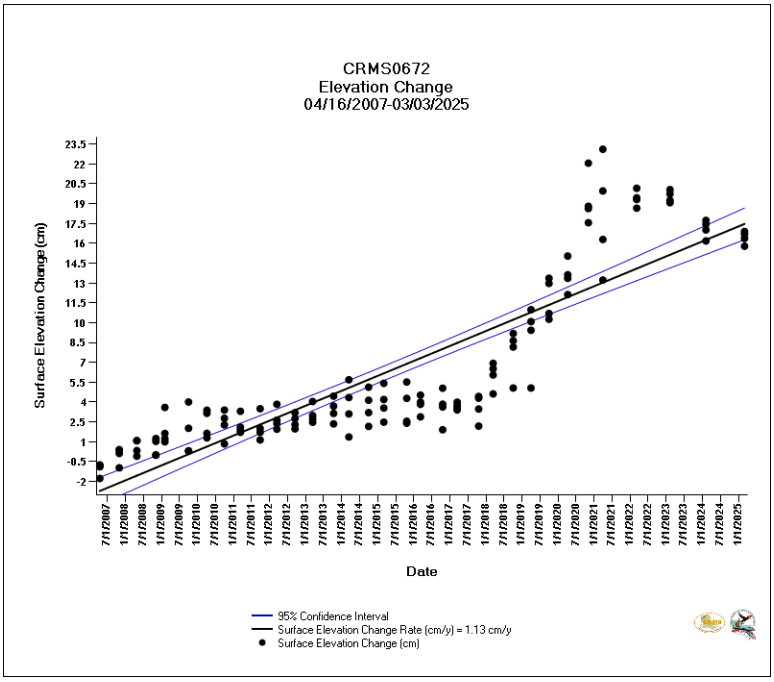


Figure 39a. Surface elevation change at CRMS0672. Note, elevation gain from 2018 to 2021 is due to floating marsh behavior and not sediment deposition. Surprisingly, most elevation gained while floating was retained.

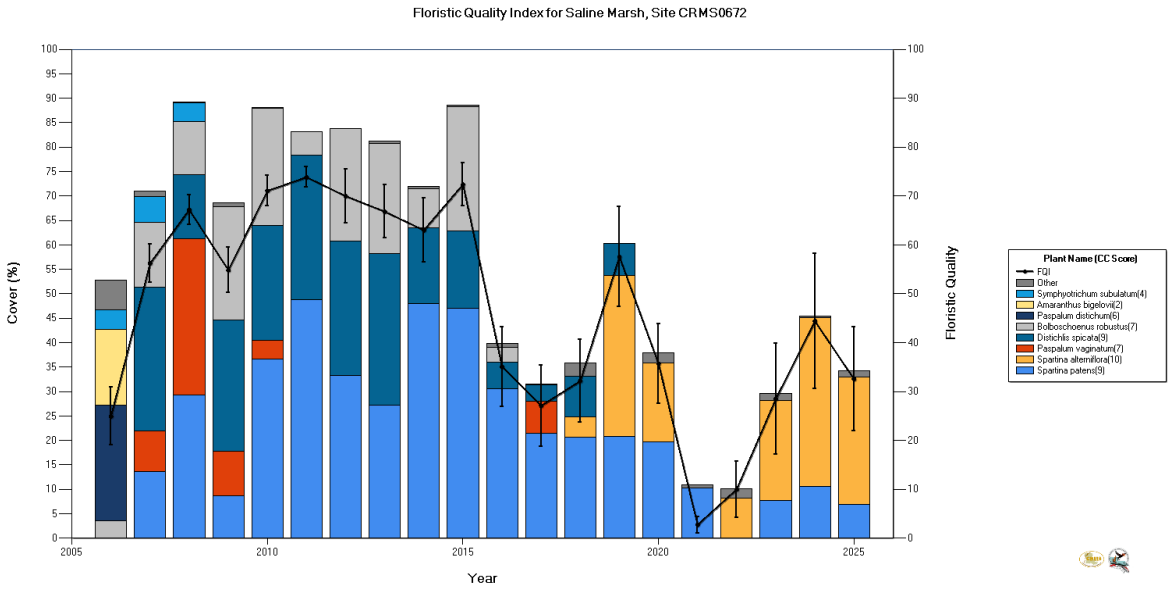


Figure 39b. Floristic Quality Index for CRMS0672

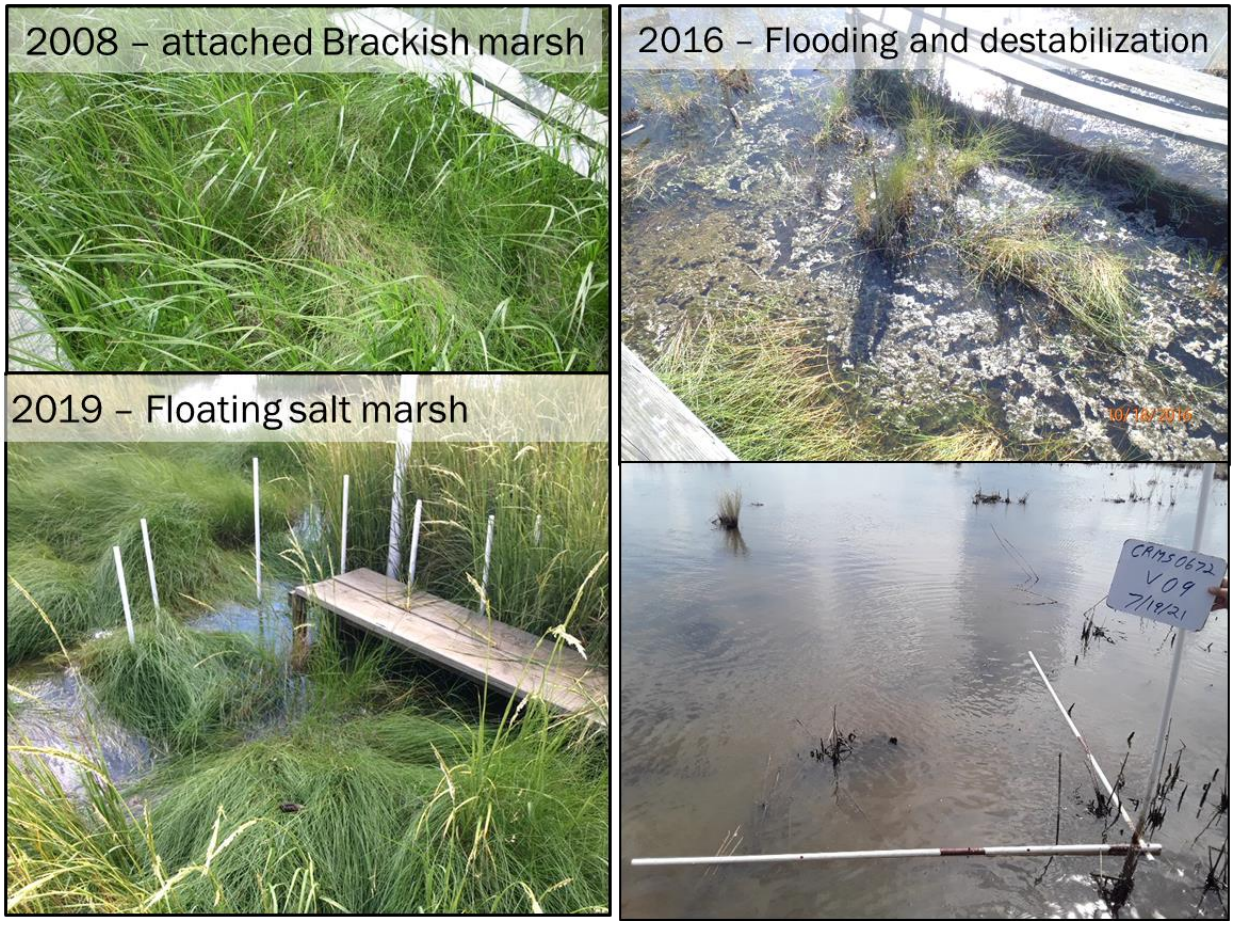


Figure 40. Images of CRMS0672 from 2008 through 2021 showing destabilization and eventual marsh collapse

8 - CAMERON CREOLE WATERSHED MANAGEMENT (CS-04 & CS-87)

The Cameron Creole Watershed (CCW) encompasses 63,959 acres of fresh-to-saline marsh and open water on the east side of Calcasieu Lake. The Cameron-Creole Watershed project (CS-04a) was constructed to reduce saltwater intrusion and preserve the deteriorating marshes through the use of a protection levee and five water control structures. The operations of these structures have been performed by CPRA since 2023 and are guided by hydrologic management targets that promote healthy vegetation commonly used for marsh management in SW LA (Figure 41). Historically, operational closures were due to salinity but have shifted due to increased water level and resulting marsh inundation since 2015.

Operations implementation did stabilize and reverse the historic land loss trend (Figure 42). Between 1985 and 2004, the area gained about 7000 acres, primarily east of the 5 ppt line. Hurricane Rita removed about 15,000 acres of marsh in 2005 but by 2019, approximately 8,500 acres had recovered, mostly in the eastern portion of the watershed (Figure 43).

Hurricanes Laura and Delta removed approximately 12,700 acres throughout the CCW in 2020 (Figure 44). Approximately 7,000 acres had been recovered by October 2023, primarily in eastern CCW and in northern managed areas. Initial recovery was stimulated by drought, but open water remains in southern CCW and along the lake rim.

Sea level rise has made management challenging in recent years. Limited drainage opportunities have trapped water on the landscape and led to chronic flooding making it difficult to impossible at times to achieve water level goals. The resulting persistent inundation has weakened marsh vegetation and contributed to land loss. The Calcasieu-Sabine Large-Scale Marsh and Hydrologic Restoration Project (CS-87) seeks to reduce marsh stress from inundation within the CCW by improving marsh drainage and increasing elevation capital with dredged sediment (Figure 45). The project will construct seven new drainage structures and improve existing conveyance channels with the aim to increasing drainage when lower tides and low lake levels seen with frontal passages result in a favorable head differential. One benefit of this increased drainage is it will allow for more frequent and longer openings of the five existing manual water control structures.

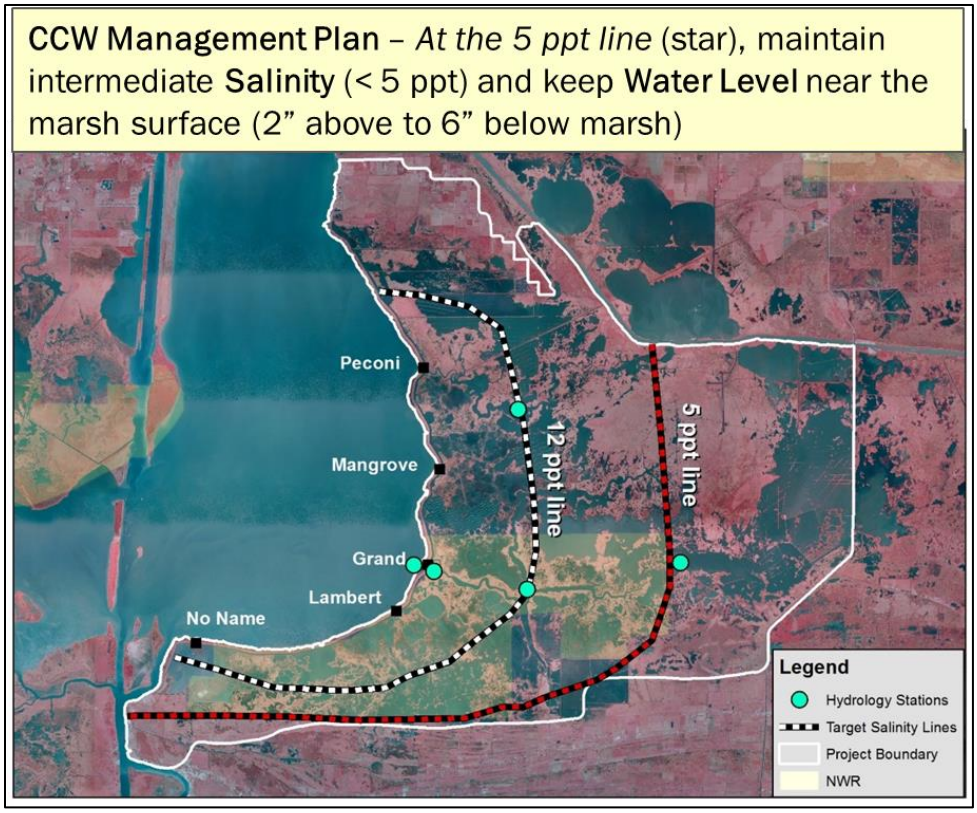


Figure 41. The CCW Management Plan that guides operations

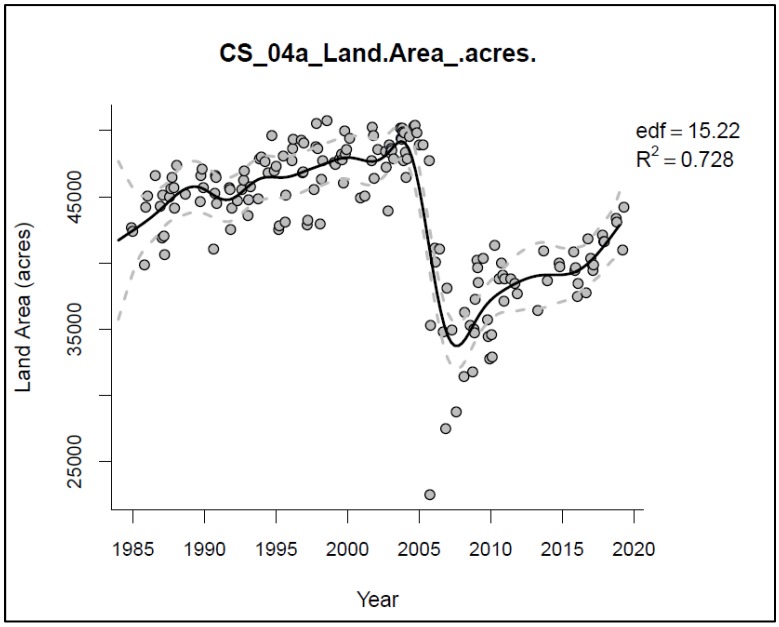


Figure 42. Land area within the CCW 1985-2020

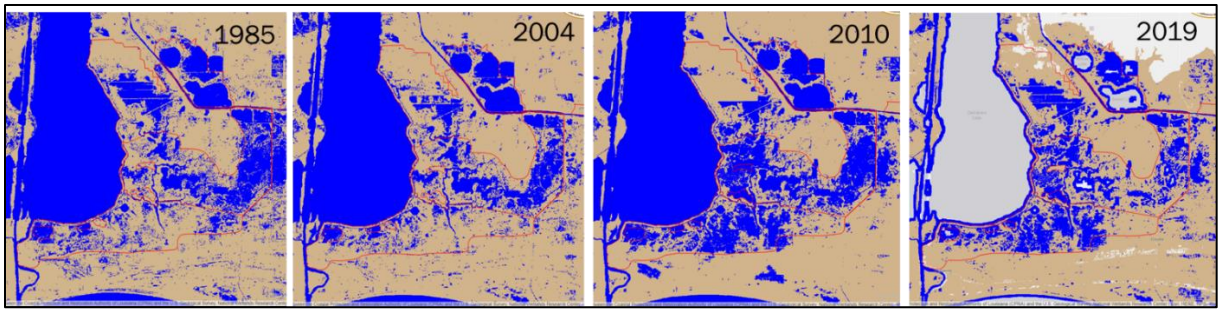


Figure 43. Land/Water Analyses of the CCW 1985, 2004, 2010 and 2019

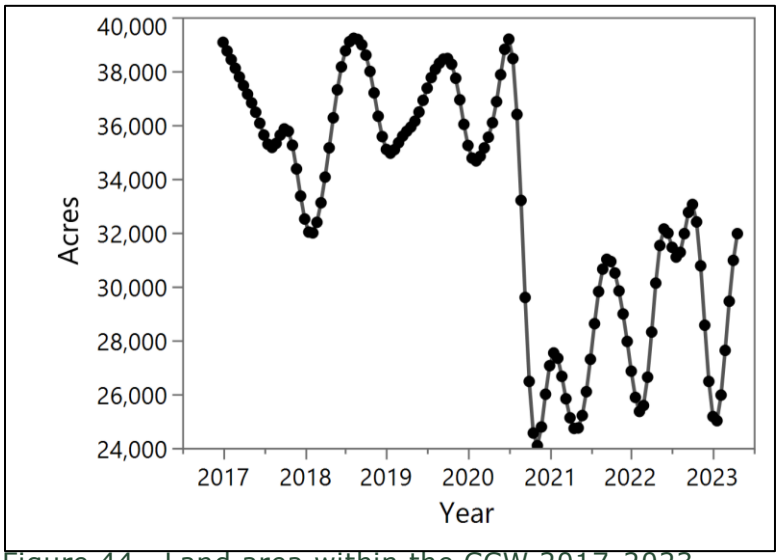


Figure 44. Land area within the CCW 2017-2023

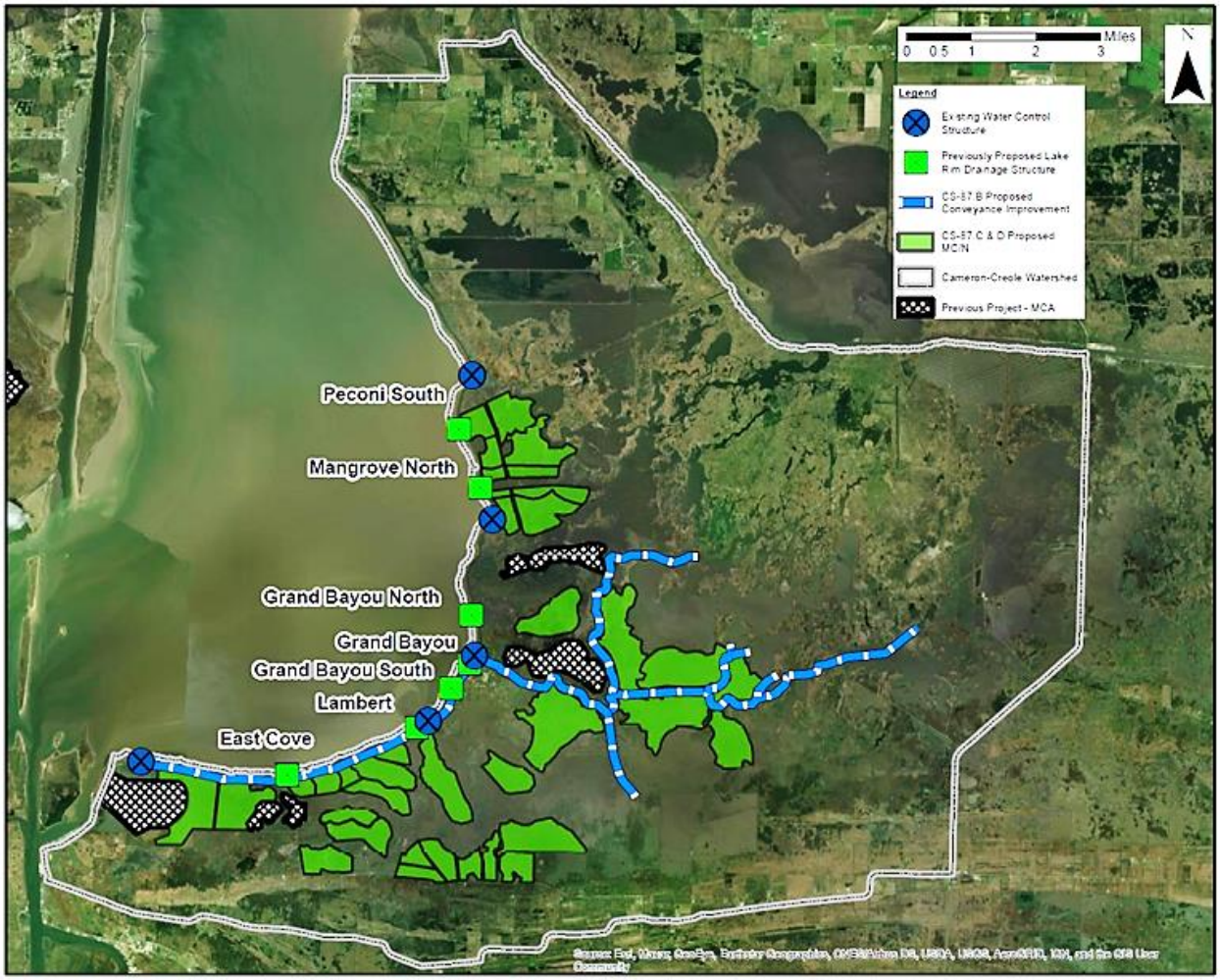


Figure 45. Calcasieu-Sabine Large-Scale Marsh and Hydrologic Restoration (CS-87) Project features

9 - TROPICAL CYCLONE IMPACTS TO COASTAL MARSHES

Tropical cyclones have varying degrees of impact to coastal marshes depending on the many factors, which may include, but not limited to, wind strength, tidal surge, duration, proximity of marshes to the storm, type of marsh, path of cyclone, and/or natural verses created marsh. On August 29, 2012, Hurricane Isaac made landfall along the Caminada Headland just a few miles east of Port Fourchon. Hurricane Isaac at landfall was a category 1 storm with winds of 80 mph. It traveled in a northwest direction at the southwest corner the Barataria basin before entering the Terrebonne basin. Minimal damage to the marshes were observed. It was not until August 29, 2021 before another hurricane made landfall in the same proximity to Hurricane Isaac. Hurricane Ida made landfall near Port Fourchon on August 29, 2021 which is the border of the Barataria and Terrebonne hydrologic basins in south Louisiana. At landfall the hurricane was a category 4 storm having sustained winds of 150 miles per hour. The hurricane traveled northward along the western edge of the Barataria basin causing severe damage to the marshes in the eastern Terrebonne and western Barataria basins. As a result of this hurricane, several thousand acres of marsh were lost between the barrier islands and the Gulf Intracoastal Waterway (GIWW). The loss of these marshes reduced the buffering capacity for keeping the higher saline water's along the coast from the less saline interior marshes. The table below shows the number of acres of land within the 1 kilometer square (247.1 acres) for several CRMS sites along the western and eastern edges of the basins over several time periods (Table 1, Figure 46).

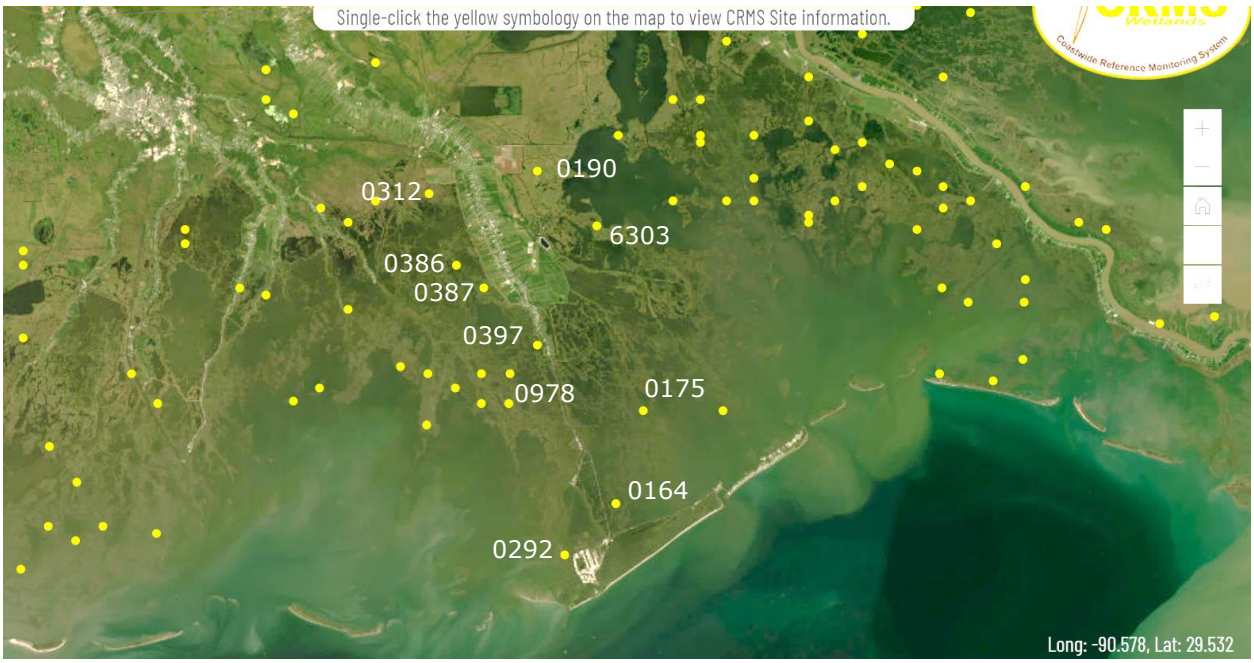


Figure 46. CRMS site locations east and west of Bayou Lafourche

Table 1: Number of acres of land within the 1 square kilometer that represents the site. Note: 1 square kilometer equates to 247.1 acres

Site	Basin	2005	2008	2012	2016	2018	2021
CRMS0164	BA	105.0	101.8	93.0	88.7	80.2	75.9
CRMS0175	BA	55.7	51.3	44.2	40.8	35.4	29.9
CRMS6303	BA	130.5	187.2	195.1	198.3	193.1	79.9
CRMS0190	**BA**	**220.7**	**211.2**	**213.5**	**225.6**	**221.5**	**7.6**
CRMS0292	TE	180.6	150.3	151.3	151.2	150.3	151.2
CRMS0978	TE	124.1	121.6	115.1	115.2	100.2	81.2
CRMS0397	TE	98.3	88.4	85.9	88.4	76.0	24.5
CRMS0387	TE	113.5	107.5	118.9	112.0	98.0	42.3
CRMS0386	TE	93.9	92.1	98.6	86.5	71.8	10.5
CRMS0312	**TE**	**224.9**	**219.2**	**219.1**	**217.0**	**211.0**	**180.4**

Summing up the total land area for all stations in the above table for 2012, 2016, 2018, and 2021 and then taking the difference between 2016 and 2012 as well as 2021 and 2018 shows that Hurricane Isaac had less marsh loss. There was only 11 acres of marsh lost between 2012 and 2016 while there was 554.1 acres lost between 2018 and 2021.

CRMS0312 is located in the eastern Terrebonne basin at approximately 29 30 18 N and CRMS0190 is located in the western Barataria basin at approximately 29 32 25 N. The stations are separated by levees, uplands, and Bayou Lafourche. However, salinity data from each station show the same basic signature from before and after Hurricane Ida made landfall. After Hurricane Ida, the salinity drastically rose from below 5 ppt to above 10 ppt (Figure 47). These salinities may cause the sites to go from intermediate type marshes to brackish marshes.

A third data set that shows the impacts of hurricanes to coastal marshes is outputs generated from the vegetation data. The Floristic Quality Index (FQI) is used to determine the quality of a wetland based on the vegetation species at ten stations at a site. Each species is assigned a Coefficient of Conservatism (CC) score ranging from 0 -10 depending on if they are invasive, CC= 0, to native dominant species, CC = 10. Also used to determine the index is the percent cover of the specie at the station. The figures below represent the FQI for CRMS0190 and CRMS0312 from 2006 to 2025 (Figures 47 and 48). Notice that the FQI for CRMS0190 stops in 2021 as there are no longer any vegetation stations on a marsh to collect data since Hurricane Ida. CRMS0312 still has some marsh and active vegetation stations; however, the species composition has changed from fresher species to more saline species and the FQI has declined.

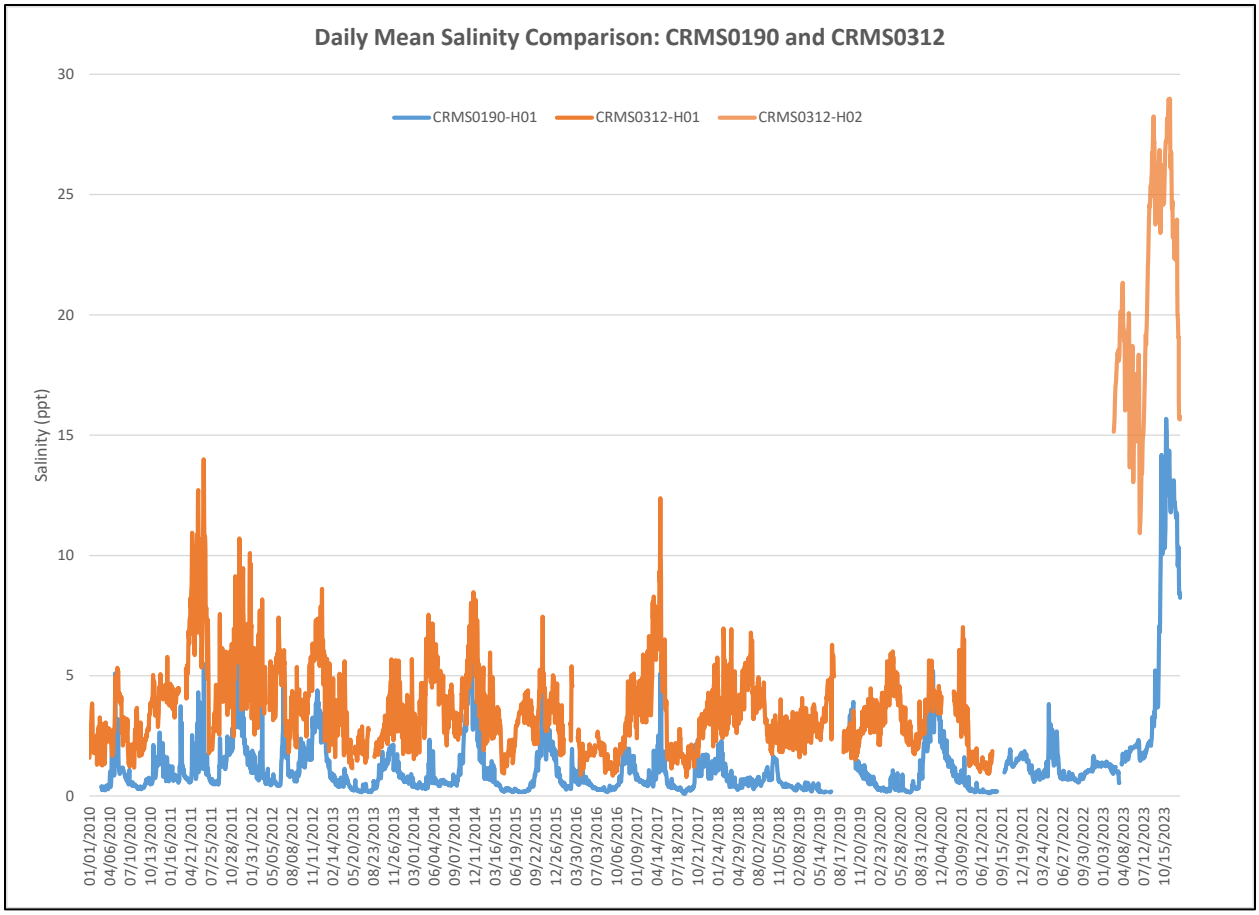


Figure 47. Using hourly readings from CRMS0190 and 0312, mean daily salinity values were calculated and plotted. The continuous recorder for CRMS0312 had to be relocated as a result of Hurricane Ida and was assigned H02, but the data is representative of the H01 area

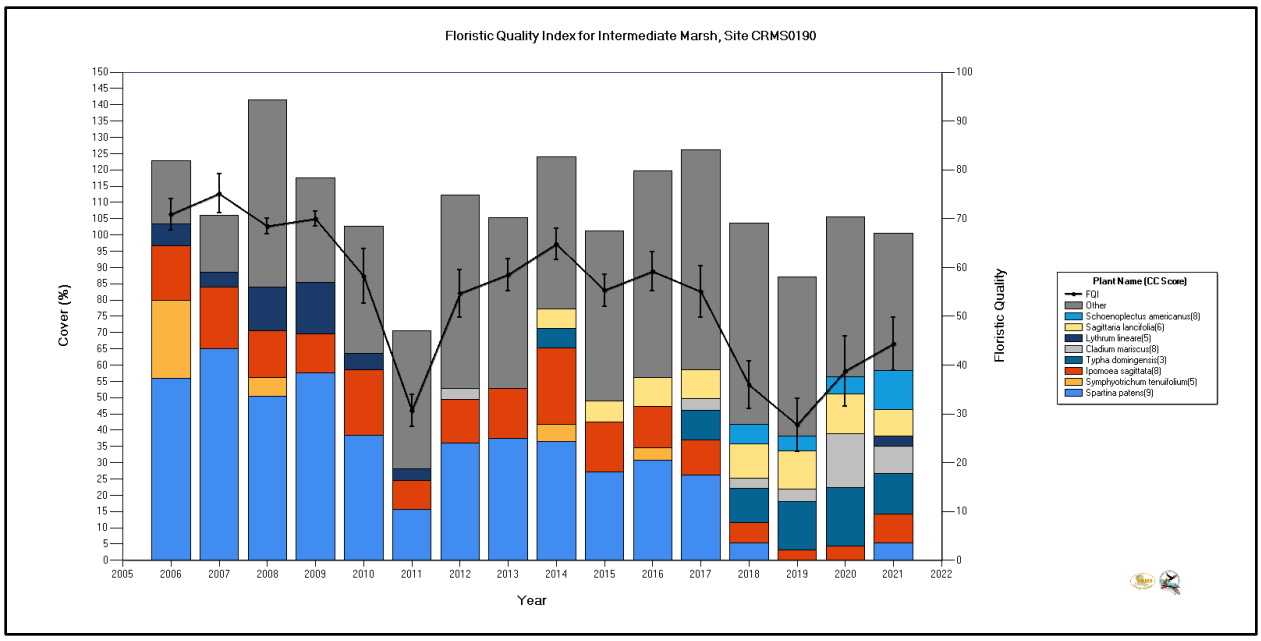


Figure 48a. Vegetative species by percent cover and the Floristic Quality Index for CRMS0190 from 2006 to 2021 when Hurricane Ida destroyed the marsh at the site

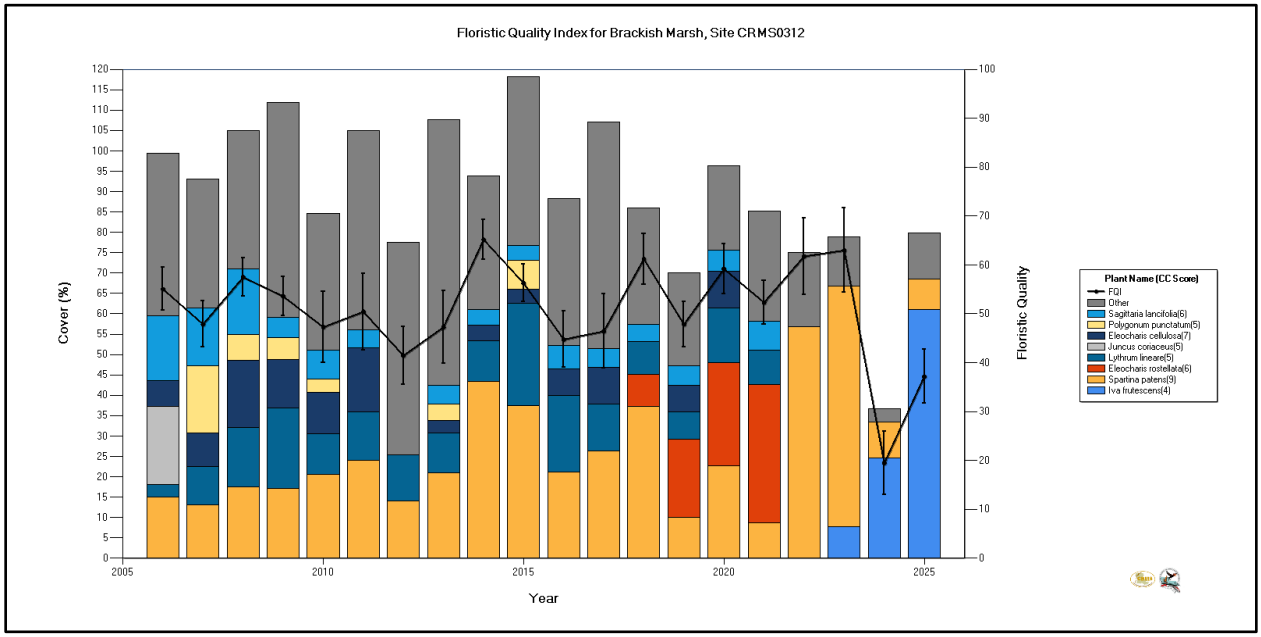


Figure 48b. Vegetative species by percent cover and the Floristic Quality Index for CRMS0312 from 2006 to 2025. Notice the change in species composition after 2021

10 – EDGE EROSION IN THE TERREBONNE BASIN (CRMS0315)

CRMS Rod Sediment Elevation Table (RSET) stations were established within vegetation when the program was established in 2004 through 2007. CRMS0315 was gaining elevation until the eroding edge reached the station and has since been slowly losing elevation (Figure 49). Because this is a relatively low energy environment, the RSET rod has remained stable and data collection has continued though the measurements capture pond bottom conditions.

Although the land has been lost at the RSET station, land loss data indicate the marshes in this region are relatively stable (Figure 50). In 2005, there was 85.4 acres of land and in 2021 71.0 acres remained. The loss of 14.4 acres over this time period represents a land loss rate of 0.9 acres per year. Despite land loss, these eroding environments could likely be retained with erosion control and sediment trapping.

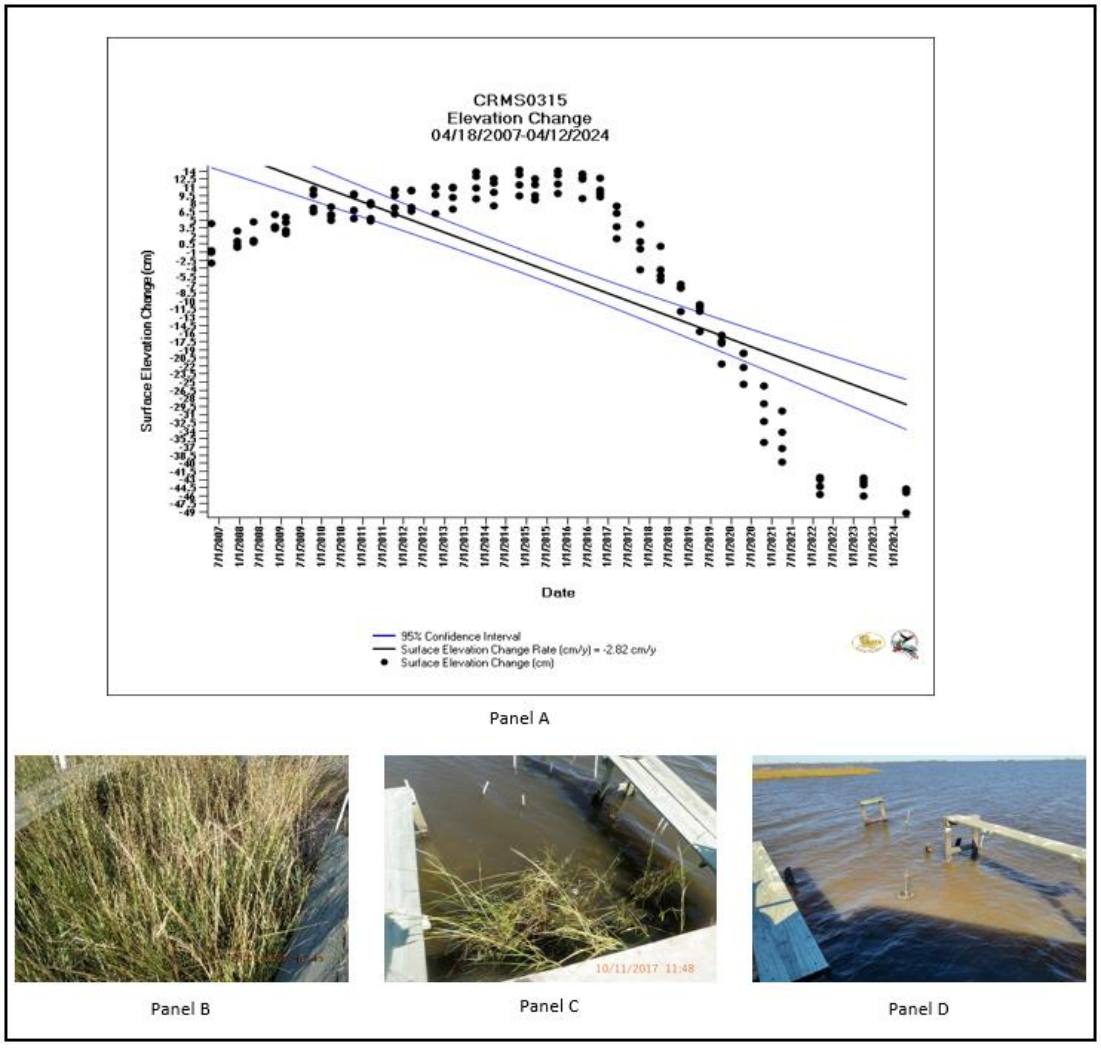


Figure 49. Elevation change data and photos from CRMS0315. Panel A illustrates elevation increasing from the time of establishment until 2016 before a dramatic decrease. Panel B is a photograph taken where the data is collected in 2007. Panel C is from 2017 and Panel D is from 2025.

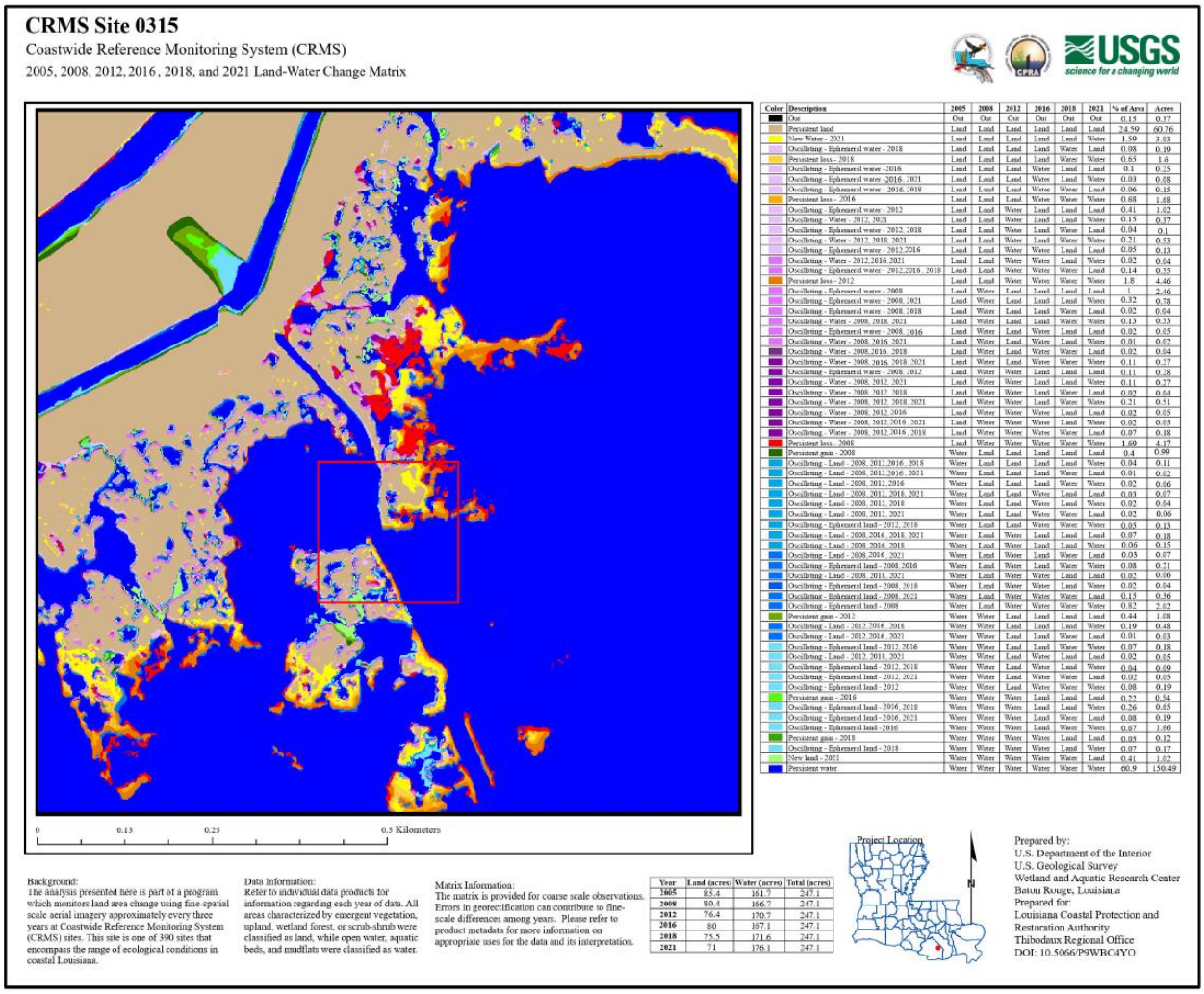


Figure 50. Land-Water Change Matrix for CRMS0315 2005-2021. Land is being removed from the edge. Otherwise, vegetation is stable.

11 – RAPID ELEVATION GAIN IN DELTAS (CRMS2627)

Very high elevation gain is common in active deltas due to high sediment deposition. CRMS2627 is located within the birdsfoot delta of the Mississippi River (Figure 51). At 55 mm/yr, the elevation gain rate at this site is highest among all the CRMS sites. Though the site has continuously gained elevation since site establishment, increased elevation gain occurred during high river years in 2011 and 2016 due to higher sediment load in the river.

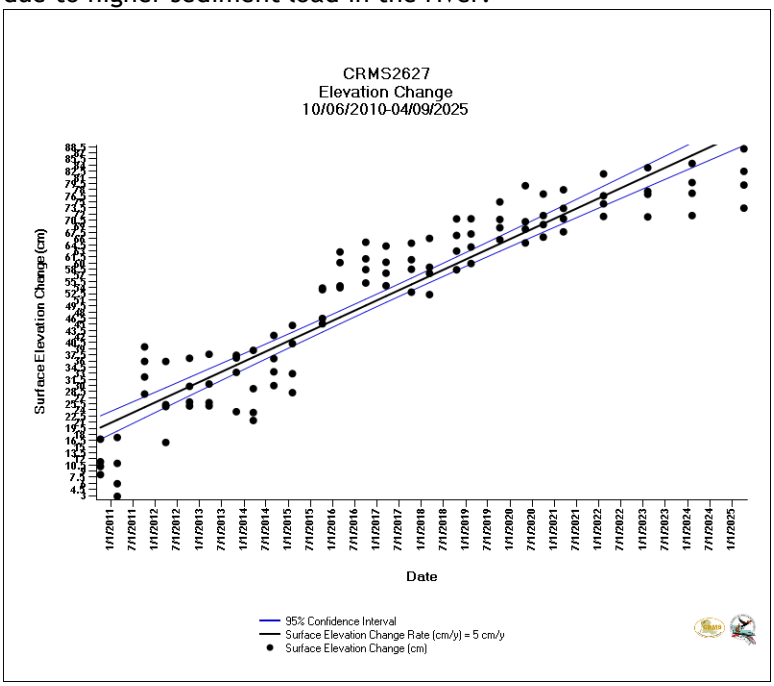


Figure 51a. Surface Elevation change data from CRMS2627 (the highest elevation gain rate among CRMS sites) for 2010-2025. The site has continuously gained elevation since establishment. Note increased elevation gain during high river years of 2011 and 2016

Figure 51b. Photograph of the boardwalk at CRMS2627 buried in sediment in September, 2016. Boardwalk was constructed 1.5’ above the marsh surface in 2008.

12 – STORM SURGE DEPOSITION HELPS MAINTAIN SURFACE ELEVATION (CRMS0225 AND CRMS0600)

Very high elevation gain can also occur due to storm surge deposition. CRMS0225 near Myrtle Grove saw depositional events following Hurricanes Gustav in 2008 (~12 cm) and Ida in 2021 (~5 cm) (Figure 52). Elevation in this region is maintained by storm surge deposition. CRMS data capture large contributions from each storm followed by stability between storms. Elevation deposited during storms is the equivalent of decades of tidal deposition and the elevation gained from storms is retained.

CRMS0600 at the mouth of Rollover Bayou on Rockefeller Refuge is adjacent to the Gulf. Hurricane Laura deposited about 17 cm of sediment which was still visible in the 2021 vegetation survey (Figure 54). Storm surge deposition is a process that produces elevation gain and helps retain marshes coastwide, that is, unless the marsh platform itself is removed by the storm in which case that sediment nourishes wetlands further inland.

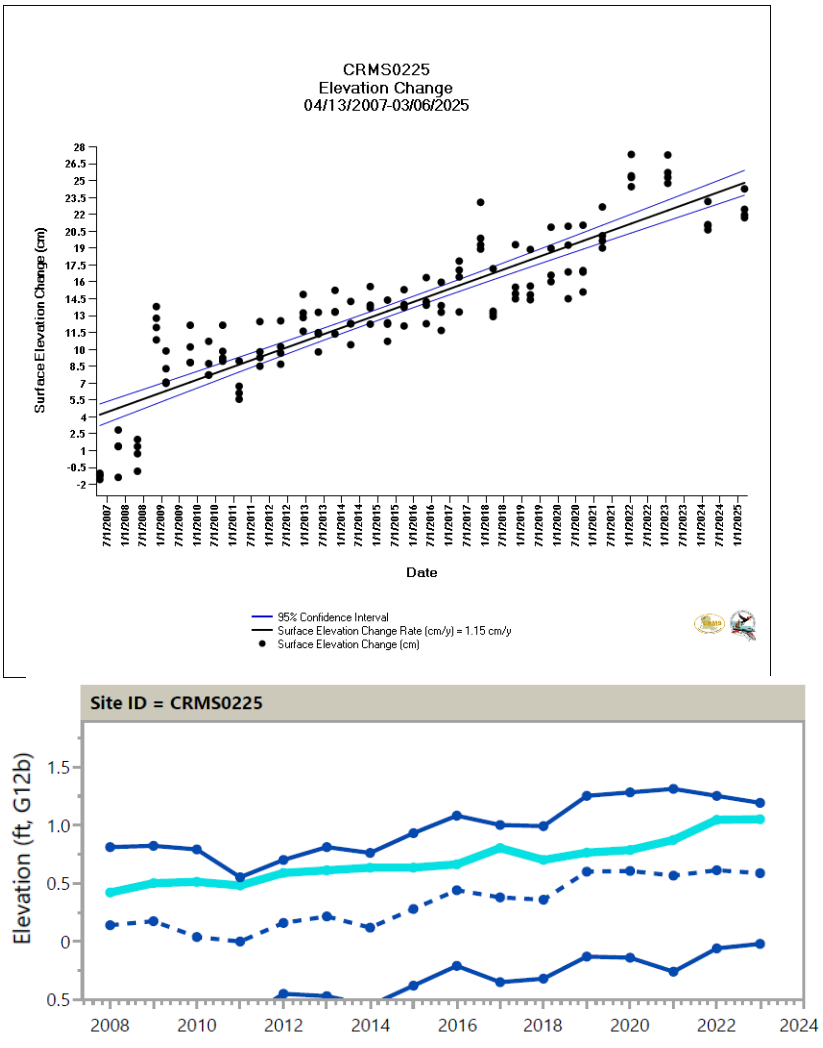


Figure 52. Surface elevation change data from CRMS0225 (Top) and the same data converted to datum (NAVD88, Geoid 12b) and plotted with water elevation (Bottom). Note depositional events following Hurricane Gustav in 2008 and Hurricane Ike in 2021

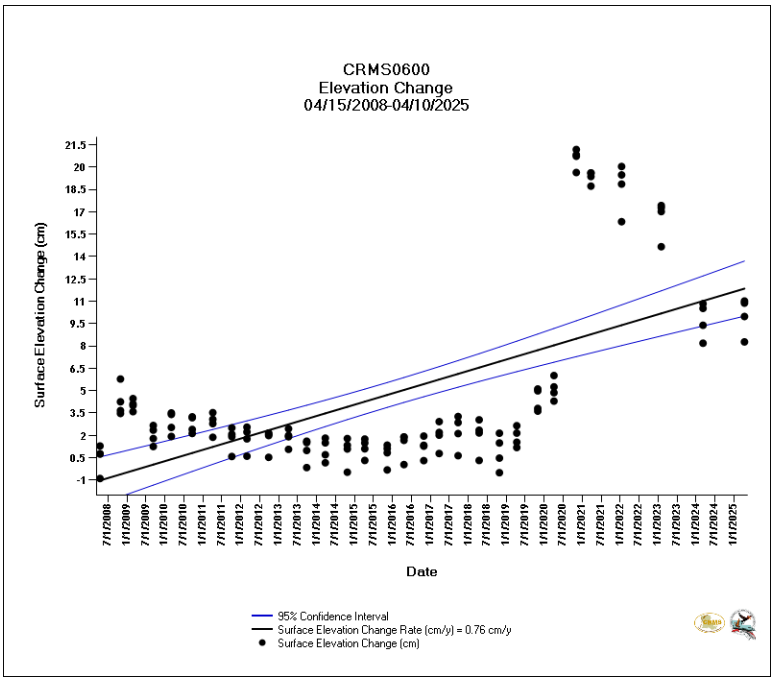


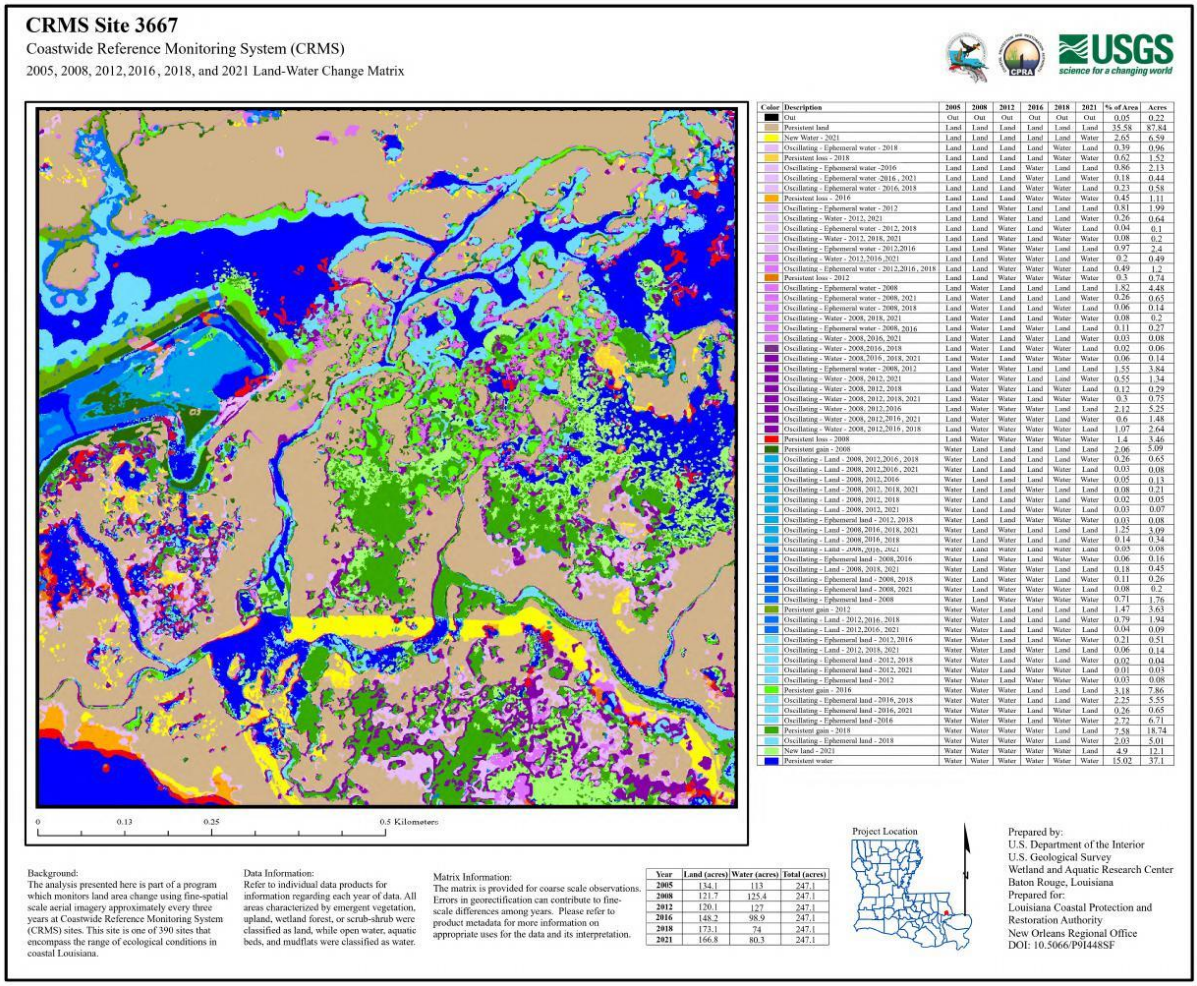
Figure 53. Surface Elevation change data from CRMS0600. Note large depositional event following Hurricane Laura in 2020

Figure 54. Sediment deposition from Hurricane Laura at CRMS0600. Photo taken during June 2021 Vegetation survey

13 – MARSH CREATION AND NOURISHMENT IN THE PONTCHARTRAIN BASIN (CRMS3667)

The spatial analysis area for Land/Water at CRMS3667 includes the footprint of two marsh creation projects (Figure 55). PO-0033 (west) and PO-0104 (south) are marsh creation projects constructed in 2009 and 2018, respectively. Of the 247.1 acres within the CRMS3667 1 km^2 footprint, approximately 39 acres fall within marsh creation projects (6.5 acres in PO-0033 and 33 acres in PO-0104).

A significant amount of marsh nourishment occurred during construction of PO-0104 in 2017. Mud was released all at once and flowed through the marsh like a wave. The area that was nourished is illustrated with green in center of Figure 55. Vegetation was lifted by the mud wave and a section of the vegetation transect was transported about 100 yards away from where it had been. At the boardwalk, there was about 60 cm of elevation gain with 30 cm of deposition in accretion plots indicating the vegetation was lifted by the mud wave (Figures 56a and 56b). The deposit is now settling at a rate of about 3.5 cm/yr and the surface is still about 30 cm above the pre-deposition level.



Year	Land (acres)	Water (acres)	Total (acres)
2005	134.1	113	247.1
2008	121.7	125.4	247.1
2012	120.1	127	247.1
2016	148.2	98.9	247.1
2018	173.1	74	247.1
2021	166.8	80.3	247.1

Color	Description	2005	2008	2012	2016	2018	2021	% of Area	Acres
	Out	Out	Out	Out	Out	Out	Out	0.05	0.22
	Persistent land	Land	Land	Land	Land	Land	Land	35.58	87.84
	New Water - 2021	Land	Land	Land	Land	Land	Water	2.65	6.59
	Oscillating - Ephemeral water - 2018	Land	Land	Land	Land	Water	Land	0.39	0.96
	Persistent loss - 2018	Land	Land	Land	Land	Water	Water	0.62	1.52
	Oscillating - Ephemeral water -2016	Land	Land	Land	Water	Land	Land	0.86	2.13
	Oscillating - Ephemeral water -2016 , 2021	Land	Land	Land	Water	Land	Water	0.18	0.44
	Oscillating - Ephemeral water - 2016, 2018	Land	Land	Land	Water	Water	Land	0.23	0.58
	Persistent loss - 2016	Land	Land	Land	Water	Water	Water	0.45	1.11
	Oscillating - Ephemeral water - 2012	Land	Land	Water	Land	Land	Land	0.81	1.99
	Oscillating - Water - 2012, 2021	Land	Land	Water	Land	Land	Water	0.26	0.64
	Oscillating - Ephemeral water - 2012, 2018	Land	Land	Water	Land	Water	Land	0.04	0.1
	Oscillating - Water - 2012, 2018, 2021	Land	Land	Water	Land	Water	Water	0.08	0.2
	Oscillating - Ephemeral water - 2012,2016	Land	Land	Water	Water	Land	Land	0.97	2.4
	Oscillating - Water - 2012,2016 ,2021	Land	Land	Water	Water	Land	Water	0.2	0.49
	Oscillating - Ephemeral water - 2012,2016 , 2018	Land	Land	Water	Water	Land	Water	0.49	1.2
	Persistent loss - 2012	Land	Land	Water	Water	Water	Water	0.3	0.74
	Oscillating - Ephemeral water - 2008	Land	Water	Land	Land	Land	Land	1.82	4.48
	Oscillating - Ephemeral water - 2008, 2021	Land	Water	Land	Land	Land	Water	0.26	0.65
	Oscillating - Ephemeral water - 2008, 2018	Land	Water	Land	Land	Water	Land	0.06	0.14
	Oscillating - Water - 2008, 2018, 2021	Land	Water	Land	Land	Water	Water	0.08	0.2
	Oscillating - Ephemeral water - 2008, 2016	Land	Water	Land	Water	Land	Land	0.11	0.27
	Oscillating - Water - 2008, 2016, 2021	Land	Water	Land	Water	Land	Water	0.03	0.08
	Oscillating - Water - 2008,2016, 2018	Land	Water	Land	Water	Land	Water	0.02	0.06
	Oscillating - Water - 2008, 2016, 2018, 2021	Land	Water	Land	Water	Water	Water	0.06	0.14
	Oscillating - Ephemeral water - 2008, 2012	Land	Water	Water	Land	Land	Land	1.55	3.84
	Oscillating - Water - 2008, 2012, 2021	Land	Water	Water	Land	Land	Water	0.55	1.34
	Oscillating - Water - 2008, 2012, 2018	Land	Water	Water	Land	Water	Land	0.12	0.29
	Oscillating - Water - 2008, 2012, 2018, 2021	Land	Water	Water	Land	Water	Water	0.3	0.75
	Oscillating - Water - 2008, 2012, 2016	Land	Water	Water	Water	Land	Land	2.12	5.25
	Oscillating - Water - 2008, 2012,2016 , 2021	Land	Water	Water	Water	Land	Water	0.6	1.48
	Oscillating - Water - 2008, 2012,2016 , 2018	Land	Water	Water	Water	Land	Water	1.07	2.64
	Persistent loss - 2008	Land	Water	Water	Water	Water	Water	1.4	3.46
	Persistent gain - 2008	Water	Land	Land	Land	Land	Land	2.06	5.09
	Oscillating - Land - 2008, 2012,2016, 2018	Water	Land	Land	Land	Land	Water	0.26	0.65
	Oscillating - Land - 2008, 2012,2016 , 2021	Water	Land	Land	Land	Water	Land	0.03	0.08
	Oscillating - Land - 2008, 2012, 2016	Water	Land	Land	Land	Water	Water	0.05	0.13
	Oscillating - Land - 2008, 2012, 2018, 2021	Water	Land	Land	Water	Land	Land	0.08	0.21
	Oscillating - Land - 2008, 2012, 2018	Water	Land	Land	Water	Land	Water	0.02	0.05
	Oscillating - Land - 2008, 2012, 2021	Water	Land	Land	Water	Water	Land	0.03	0.07
	Oscillating - Ephemeral land - 2012, 2018	Water	Land	Land	Water	Land	Water	0.03	0.08
	Oscillating - Land - 2008,2016, 2018, 2021	Water	Land	Water	Land	Land	Land	1.25	3.09
	Oscillating - Land - 2008, 2016, 2018	Water	Land	Water	Land	Land	Water	0.14	0.34
	Oscillating - Land - 2008, 2016, 2021	Water	Land	Water	Land	Water	Land	0.03	0.08
	Oscillating - Ephemeral land - 2008, 2016	Water	Land	Water	Land	Water	Water	0.06	0.16
	Oscillating - Land - 2008, 2018, 2021	Water	Land	Water	Water	Land	Land	0.18	0.45
	Oscillating - Ephemeral land - 2008, 2018	Water	Land	Water	Water	Land	Water	0.11	0.26
	Oscillating - Ephemeral land - 2008, 2021	Water	Land	Water	Water	Water	Land	0.08	0.2
	Oscillating - Ephemeral land - 2008	Water	Land	Water	Water	Water	Water	0.71	1.76
	Persistent gain - 2012	Water	Water	Land	Land	Land	Land	1.47	3.63
	Oscillating - Land - 2012,2016, 2018	Water	Water	Land	Land	Land	Water	0.79	1.94
	Oscillating - Land - 2012,2016, 2021	Water	Water	Land	Land	Water	Land	0.04	0.09
	Oscillating - Ephemeral land - 2012,2016	Water	Water	Land	Land	Water	Water	0.21	0.51
	Oscillating - Land - 2012, 2018, 2021	Water	Water	Land	Water	Land	Land	0.06	0.14
	Oscillating - Ephemeral land - 2012, 2018	Water	Water	Land	Water	Land	Water	0.02	0.04
	Oscillating - Ephemeral land - 2012, 2021	Water	Water	Land	Water	Water	Land	0.01	0.03
	Oscillating - Ephemeral land - 2012	Water	Water	Land	Water	Water	Water	0.03	0.08
	Persistent gain - 2016	Water	Water	Water	Land	Land	Land	3.18	7.86
	Oscillating - Ephemeral land - 2016, 2018	Water	Water	Water	Land	Land	Water	2.25	5.55
	Oscillating - Ephemeral land - 2016, 2021	Water	Water	Water	Land	Water	Land	0.26	0.65
	Oscillating - Ephemeral land - 2016	Water	Water	Water	Land	Water	Water	2.72	6.71
	Persistent gain - 2018	Water	Water	Water	Water	Land	Land	7.58	18.74
	Oscillating - Ephemeral land - 2018	Water	Water	Water	Water	Land	Water	2.03	5.01
	New land - 2021	Water	Water	Water	Water	Water	Land	4.9	12.1
	Persistent water	Water	Water	Water	Water	Water	Water	15.02	37.1

Figure 55. USGS Land/Water Matrix showing land gain from two marsh creation projects within the CRMS3667 1-km^2 footprint. PO-0033 can be seen on the central western edge of the above figure and PO-0104 can be seen on the south/southeastern extent

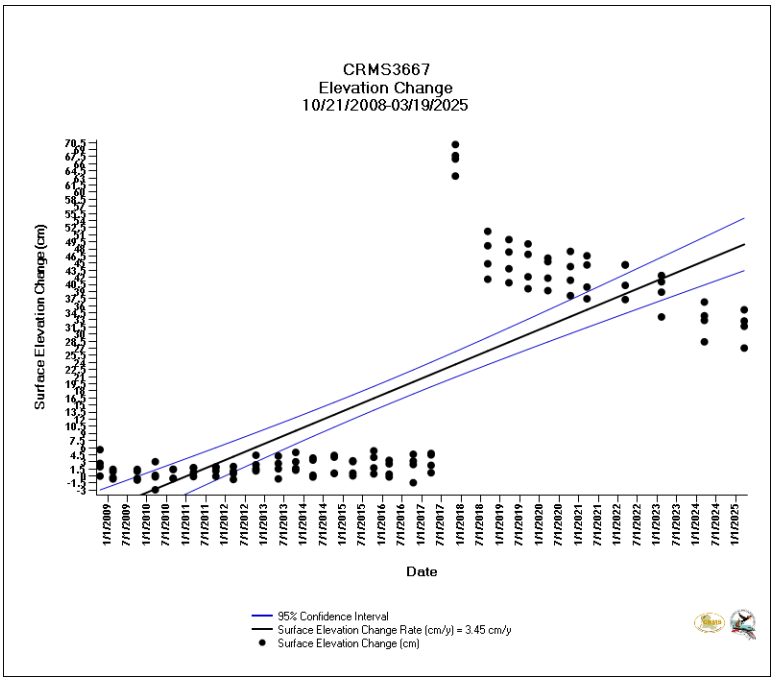


Figure 56a. Surface Elevation Change at CRMS3667 2009-2024

Figure 56a. Photograph of the boardwalk at CRMS3667 after marsh nourishment in 2017. Note new boardwalk constructed on top of old boardwalk due to very high sedimentation.

14 – LAND LOSS FROM WATER HYACINTH RAFTING IN THE DELTA (CRMS0161)

At CRMS0161, a steep increase in surface elevation was recorded (Figure 57) which coincided with the presence of a large floating raft of water hyacinth (*Pontederia crassipes*) observed at the site. The raft sat on top of the existing marsh platform, smothering vegetation, and trapping deposited sediment (Figure 58). When the water hyacinth raft was later removed by natural processes, previous elevation gains were lost and elevation dropped lower than what they were prior to hyacinth raft presence. Persistent elevation and vegetation loss has been observed at this site since that event.

There are five Mississippi River Delta CRMS sites where water hyacinth raft associated land loss has been documented (CRMS0161, CRMS2627, CRMS4448, CRMS0157, and CRMS0162). Edge erosion and hyacinth rafting are the only two processes that removed marshes in the Mississippi River delta within the CRMS monitoring timeframe.

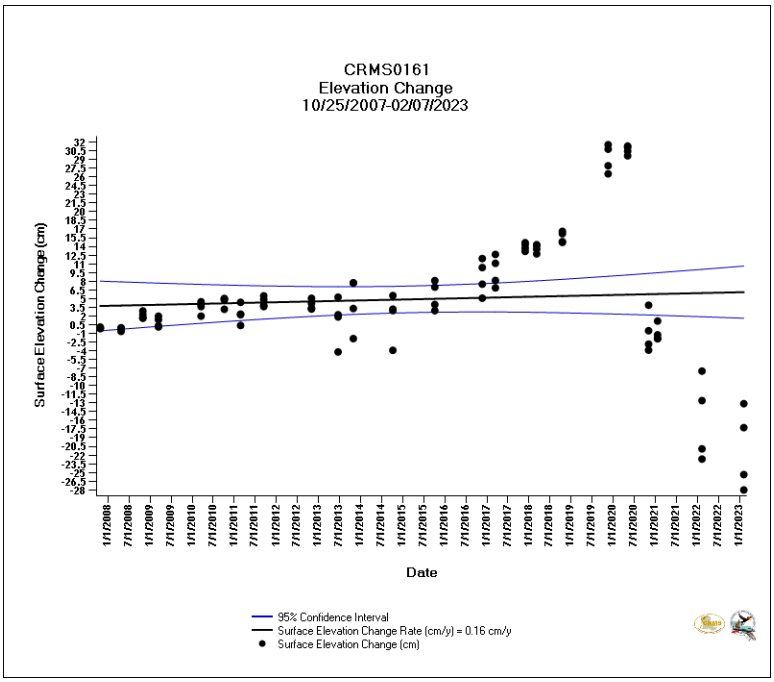


Figure 57. Surface Elevation Change at CRMS0161 2008-2023.

Figure 58. Photos taken at CRMS0161 showing water hyacinth raft at the boardwalk in 2019 (above) and after it washed away in 2020 (right)

15 – SHALLOW EXPANSION OR FLOATING MARSH TYPE BEHAVIOR IN THE MERMENTAU BASIN (CRMS1100)

CRMS1100 is situated within an impounded interior marsh located between highway 82 and White Lake in the hydrologically managed Mermentau Lakes sub basin. A pattern of surface elevation gain and loss has been documented over the years as long-term flooded conditions create an environment for shallow expansion in between less frequent dry conditions (Figure 59). Shallow Expansion in a marsh occurs when flooded conditions cause marsh substrate to expand as the low-density, buoyant root/soil matrix is filled with water and expands. This phenomenon is often challenging to characterize on a single field trip, as perceptible physical indicators are generally limited to a "bouncy" or "quaking" substrate under foot and/or vegetative community shift to plant species associated with floating marsh conditions.

Further, although vegetative composition change can be a good indicator for a floating marsh (i.e., shallow expansion), these responses are delayed and often take many years to fully materialize, as existing plant communities exhibit stress responses and resilience to persist in their historic habitation. At CRMS1100, plant community composition held on to the pre-existing *Spartina patens* species assemblage for years before fully switching to plant species communities indicative of floating marsh (Figures 60 and 61). The limited available signals for shallow expansion present a challenge for identifying its presence in marsh systems.

However, by subtracting accretion from surface elevation change, a shallow soil factor (SSF) can be derived, which indicates the process of shallow expansion in flooded marshes by isolating below and aboveground processing of elevation change (Figure 62). A positive SSF value indicates shallow expansion, because there is positive elevation change not accounted for by accretion. When this value goes down, it indicates that the site is no longer floating and it would be expected for elevation change to follow a similar trend.

Shallow expansion followed by a change in vegetation community was observed throughout the interior Mermentau Basin during the high water timeframe. Wetland vegetation doesn't drown when inundation increases. Instead, surfaces expand and may begin to float.

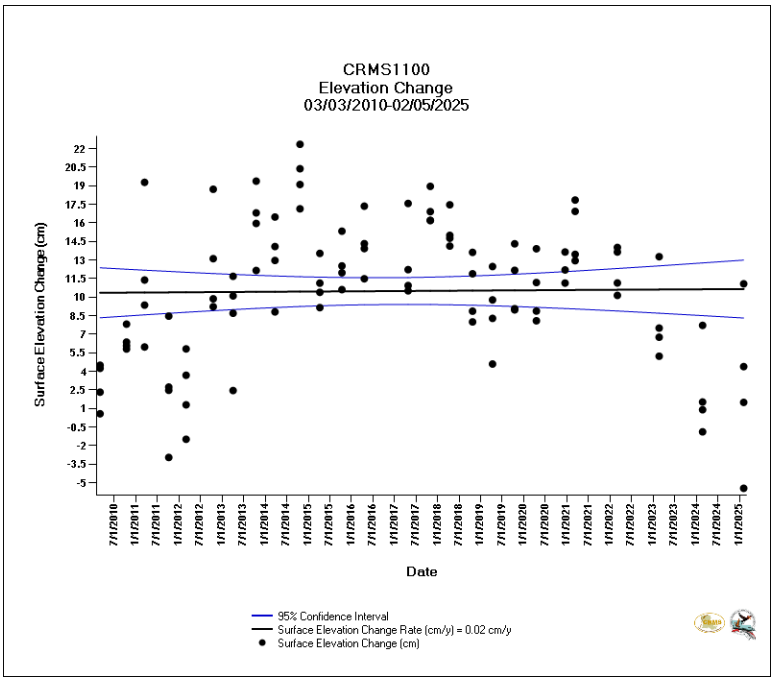


Figure 59. Surface Elevation Change at CRMS1100 2010-2025

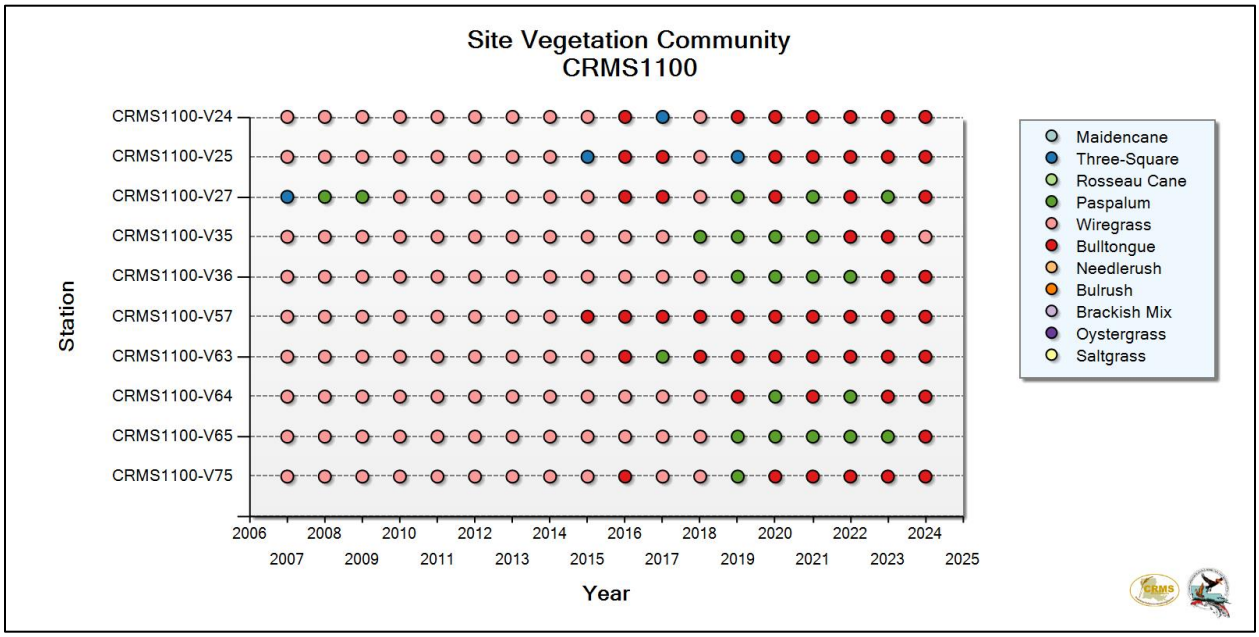


Figure 60. Site level vegetation community change at CRMS 1100 from 2006–2025

Figure 61. Photos taken at vegetation plot V36 at CRMS1100 in 2013, 2017 and 2021 showing species composition shift over time

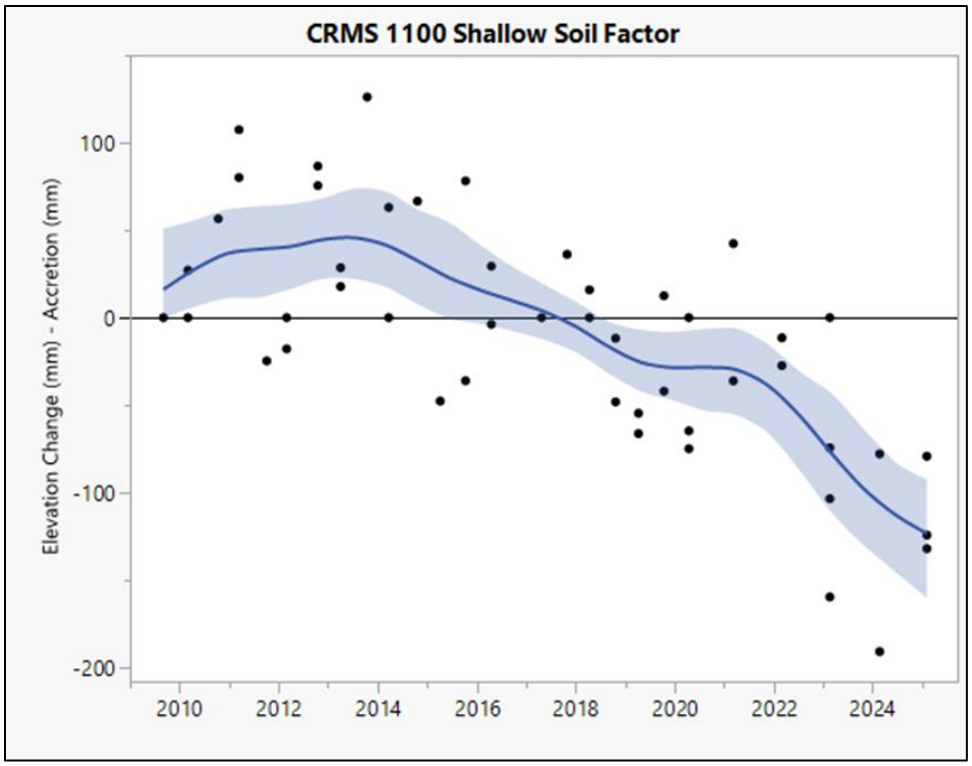


Figure 62. Shallow soil factor (elevation change minus accretion) at CRMS1100 from 2010-2025. A positive value indicates shallow soil expansion and a negative value indicates shallow soil contraction

16 – ELEVATION LOSS DUE TO HURRICANE ISAAC IN MID BARATARIA (CRMS0258 & CRMS0260)

Storm related elevation loss is common place in coastal Louisiana as storm surges apply shear force to the marsh platform, either removing it entirely or denuding it of vegetation thereby exposing weak soils to wave and tidal forces. CRMS0258 lost approximately 30 cm of elevation in response to Hurricane Isaac in 2012 which caused wide spread wetland damage with a surge of up to 17 feet in Plaquemines Parish (Figure 63). Prior to the hurricane, CRMS0258 was a fragmented saltmarsh with small islands of intact vegetation (Figure 64). Hurricane Isaac removed the vegetation, root mass, and some quantity of mineral soil at the RSET site leaving behind shallow open water interspersed with random clumps of vegetation and roots (Figures 65 and 66). This site has remained in that state for 13 years post storm even in the face of rising sea-level and other named storms, notably Hurricane Ida in 2021. The site has regained 20 cm of elevation through tidal reworking and storm deposition as of 2025 with a modest vegetative response around the RSET. These sites in close proximity to one another capture the dynamic nature of storm surge deposition. Storms re-distribute sediment across the landscape, often at the expense of other marshes that are removed by the storm.

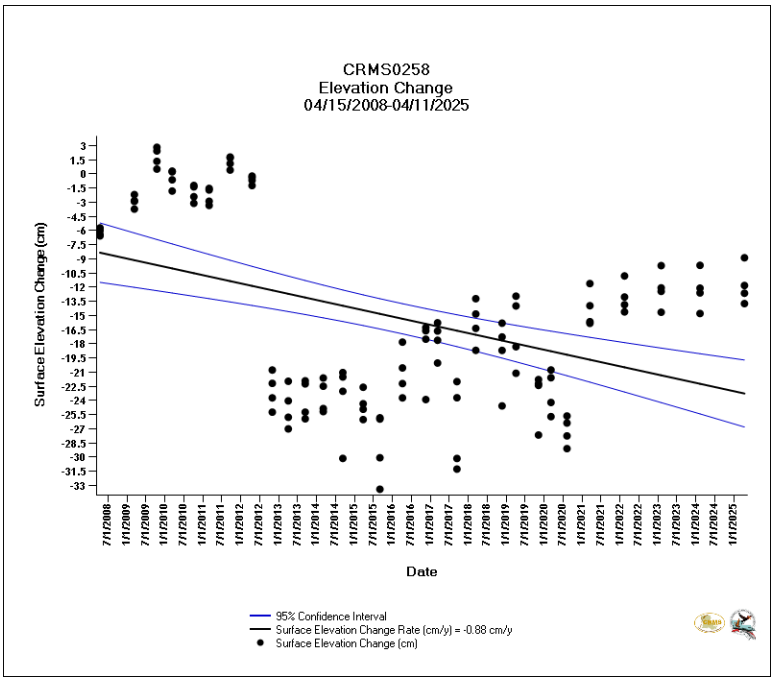


Figure 63. The surface elevation change at CRMS0258 has been dynamic, with extensive loss and minimal recovery in the decade plus post storm. The site has stabilized over the last 5 years but has not regained significant elevation to fully revegetate

Figure 64. CRMS0258 RSET station in the fall of 2011 pre Hurricane Isaac with robust above ground vegetation present

Figure 65. CRMS0258 RSET station in the fall of 2012 post Hurricane Isaac with minimal above ground vegetation present, mostly containing shallow open water

Figure 66. CRMS0258 RSET station in the fall of 2025, 13 years after the top 30 cm of soil was removed containing mostly shallow open water, mudflats, and minimal vegetation

CRMS0260, which is approximately two miles away from CRMS258, has had a very different storm related timeline, but the overall results of surface elevation loss from storm surge remain the same. CRMS0260 is located on the bank of Bayou Grande Cheniere south of Lake Judge Perez. This site also lost nearly 30 cm of surface elevation (Figure 67) from storm surge but the effects of the individual storms were opposite, with Hurricane Isaac adding 10 cm of material to the marsh platform (Figure 68) while Hurricane Ida removed 30 cm (Figure 69). The site is now on the edge of a CWPPRA marsh creation project (BA-173) and recovering, albeit unevenly at the RSET station (Figure 70). The directions of the RSET measurements in the vegetated marsh are almost back to the original baseline conditions, while the pins in open water still show significant elevation loss.

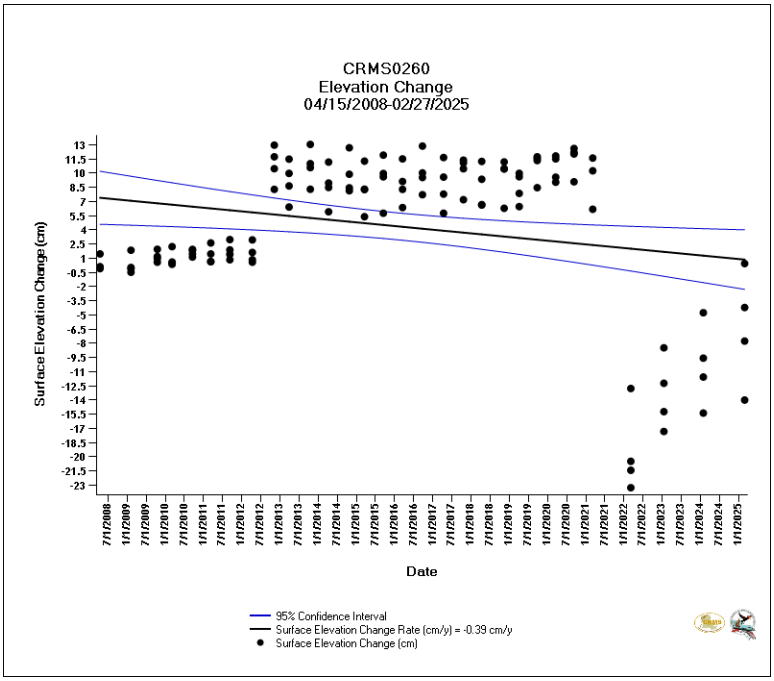


Figure 67. The surface elevation change at CRMS0260 has been energetic, with storm deposition, removal, and some recovery during the CRMS monitoring epoch. The site is located in a now protected intersection of a bayou and a marsh and ridge restoration project. This is affording the RSET station the opportunity to recover and gain elevation post scour event

Figure 68. CRMS0260 RSET station in the spring of 2013, post Hurricane Isaac with healthy above ground biomass present

Figure 69. CRMS0260 RSET station in the spring of 2023, post Hurricane Ida after the wrack deposited from the storm washed away leaving half of the station in shallow open water

Figure 70. CRMS0260 RSET station in the spring of 2025 with broken marsh interspersed with lower elevation open water. The station is recovering elevation with the vegetated side gaining more rapidly due to sedimentation in the vegetative growth

17 – SETTLING OF HURRICANE KATRINA AND GUSTAV DEPOSITS IN BRETON SOUND (CRMS0131)

Storm surge depositions can impact marsh elevation for a long time. Breton Sound marshes received piles of organic debris and sediment from Hurricanes Katrina (2005) and Gustav (2008) and have been settling since CRMS measurements began in 2008. CRMS0131 on the banks of River Aux Chenes received a mix of organic and mineral deposition from Katrina and Gustav (Figure 71). This material compacted and decomposed through much of the early CRMS monitoring period, leading to elevation loss of approximately 10 cm from 2008-2012 which then stabilized through the summer of 2020.

When plotted against CRMS water elevation data, it is clear that the surface was above the tidal frame when measurements began (Figure 72). It settled down to the top of the tidal frame between 2008 and 2020. Storm surge deposition from Hurricanes Laura (2020) and Ida (2021) pushed the marsh surface back to the top of the tidal frame. There appears to be sufficient deposition from storms to prevent drowning in Breton Sound.

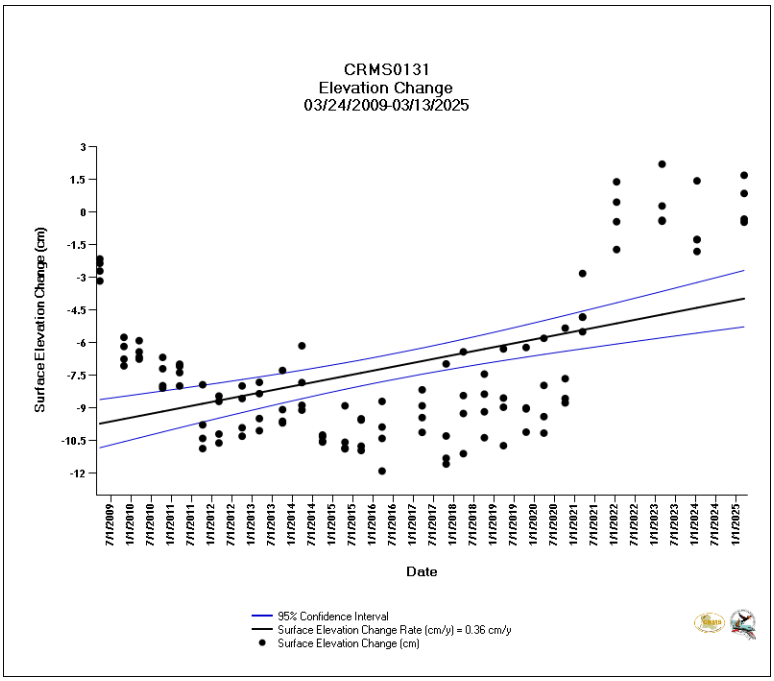


Figure 71. The surface elevation change at CRMS0131 has a parabolic response to hurricane deposition, with the elevation record beginning post Katrina showing elevation loss until the 2022 spring sampling campaign captured the Hurricane Ida deposition

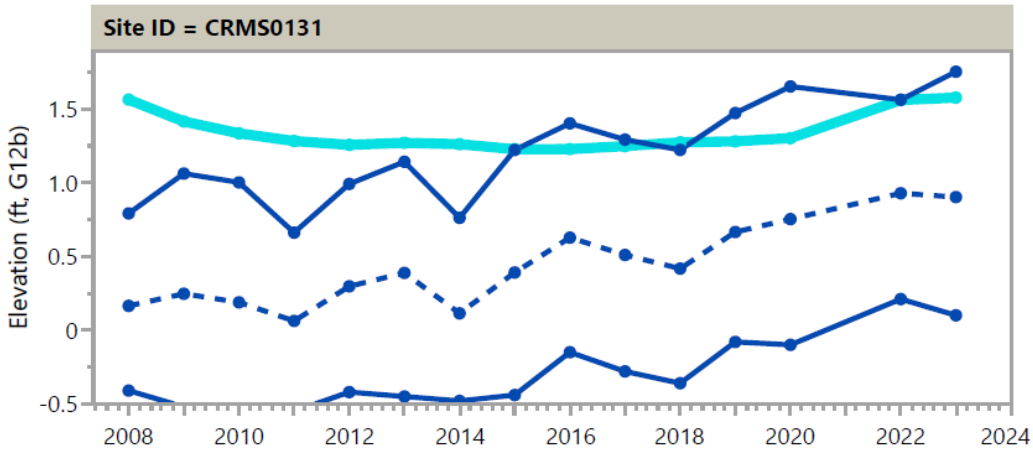


Figure 72. Marsh Elevation (NAVD88 Geoid12b) of CRMS0131 derived from RSET measurements plotted against water elevation displaying the site's position within the hydrologic range.

18 – ELEVATION LOSS DUE TO HERBIVORY AND FLOOD STRESS (CRMS0635 & CRMS0553)

During the CRMS monitoring timeframe, there have been periods of intense drought, flooding, and storms. These are powerful effects independently but when transitioning between extremes rapidly it intensifies the stress to the vegetated marsh surface causing species switching and destabilization. One of these events was captured at CRMS0635 in Sabine National Wildlife Refuge during a period of sea level acceleration and localized flooding. From spring 2016 to fall 2016 the RSET elevation loss was nearly 18 cm caused by herbivory during a freshwater flood resulting in vegetation removal (Figure 73). As the vegetation was completely destroyed in a previously health marsh platform, this caused the soil surface to destabilize and liquefy. Through herbivore management and continued flooded fresh conditions, the vegetation returned and the soil surface stabilized regaining pre disruption elevations (Figures 74-76).

CRMS0553 north of Little Cheniere in the Mermentau basin also experienced a vegetation switching from intermediate to fresh along with an herbivory event (Figures 77-80). But this site recovered almost 30 cm of elevation facilitated by the marsh platform floating and further stabilized by organic deposition from hurricanes in 2020 and herbaceous growth. That elevation was maintained even as drought and low water dominated the hydrologic conditions from 2023-2025. This dramatic elevation gain if maintained moving forward is a relatively understudied mechanism for impounded marshes to maintain elevation with a lack of mineral deposition.

Together, these sites illuminate the fact that vegetation in impoundments can be lost to herbivory but marshes have the opportunity to recover because they are not exposed to tidal exchange.

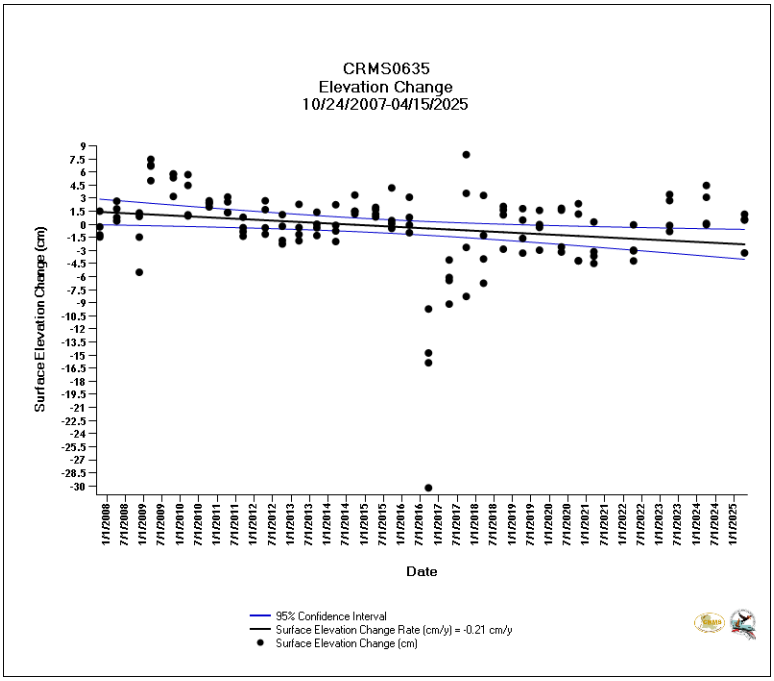


Figure 73. The surface elevation change at CRMS0635 showing a temporary elevation collapse in 2016 and subsequent recovery by 2019.

Figure 74. CRMS0635 RSET station in the spring of 2015; this shows a response to freshwater flooding, which is causing the vegetation to transition from *Spartina patens* dominated vegetation to *Typha* dominated. This is a more preferable food source for nutria and muskrats

Figure 75. CRMS0635 RSET station in the spring of 2017 after a winter herbivory event at the site denuded the vegetation and destabilized the soil

Figure 76. CRMS0635 RSET station in the spring of 2025, post winter fire showing full recovery of both the marsh vegetation and the elevation of the marsh platform

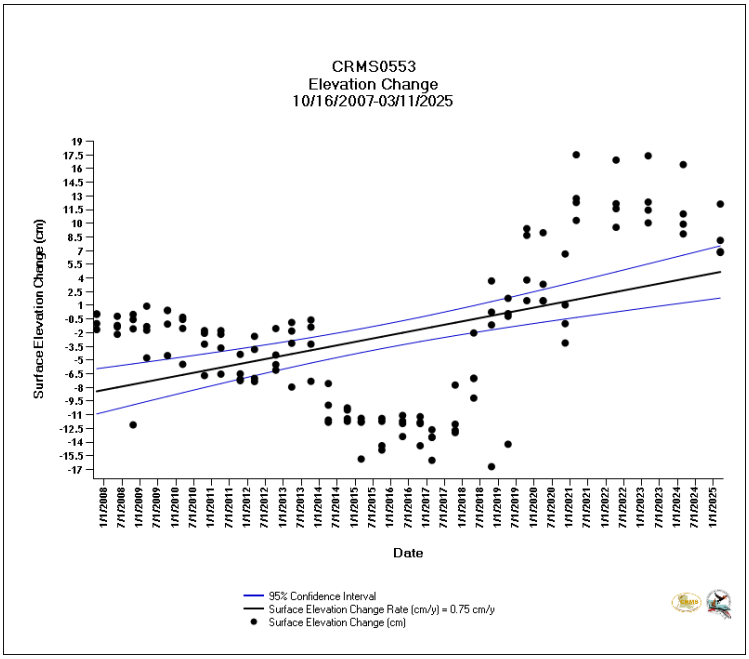


Figure 77. The surface elevation change at CRMS0553 shows elevation collapse through 2017 that quickly rebounded from the marsh platform floating in 2019 at peak regional flooding. This floating mat was stabilized by vegetation recovery and organic deposition from Hurricanes Laura and Delta in 2020 and has maintained the majority of this elevation through a drought and low water cycle from 2023-2025

Figure 78. CRMS0553 RSET station in the spring of 2013 dominated by *Spartina patens*

Figure 79. CRMS0553 RSET station in the spring of 2021 showing a floating marsh platform of dead above ground vegetation and live root mass

Figure 80. CRMS0553 RSET station in the spring of 2025 displaying a thriving marsh, while maintaining the elevation gained through floating and hurricane deposition

REFERENCES

Henkel, T. K., A. M. Freeman, D. C. Lindquist, J. W. Pahl, and J. P. Troutman 2023. Lessons learned from 30-years of operation of the Caernarvon Freshwater Diversion, Louisiana USA, Ocean & Coastal Management, Vol 244:106782, https://doi.org/10.1016/j.ocecoaman.2023.106782.

Hymel, M. K. and B. J. Richard. 2016. *2016 Operations, Maintenance, and Monitoring Report for Bayou Sauvage National Wildlife Refuge, Phase 1 (PO-16)*. Coastal Protection and Restoration Authority of Louisiana, New Orleans, Louisiana. 53 pp.

Hymel M. K. and E. Blanche 2019. *2019 Operations, Maintenance, and Monitoring Report for Delta Management at Fort St. Philip,* Coastal Protection and Restoration Authority of Louisiana, New Orleans, Louisiana. 81 pp. (https://cims.coastal.la.gov/RecordDetail.aspx?Root=0&sid=23411)

Kolker, A. S., H. D. Weathers, C. Swann, A. A. Renfro 2025. Distributary development in a 21st century river: The evolution of Neptune Pass and its delta, the largest new offshoot of the Mississippi River. PLoS ONE 20(4): e0320502.

McGinnis, T.E.; Daigle, M.; Lear, E.J.; Mouledous, M.; Richardi, D.C.; Wood, B. 2021. *2021 Operations, Maintenance, and Monitoring Report for Coastwide Vegetative Planting Project (LA-0039)*: Coastal Protection and Restoration Authority of Louisiana. 284 pp and Appendix.

Suir, G. M., W. R. Jones, A. L. Garber, and J. A. Barras 2014. Pictorial Account and Landscape Evolution of the Crevasses near Fort St. Philip, Louisiana. Mississippi River Geomorphology & Potamology Program (U.S.) Technical Report No. 2. 37 pp.