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Coast 2050 Region 3

West Belle Pass Headland Restoration
TE-23 (PTE-27)

Second Priority List Marsh Creation and Shoreline Protection Project of the Coastal Wetlands Planning, Protection, and Restoration Act (Public Law 101-646)

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Acknowledgments

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Abstract

This comprehensive report examines the effectiveness of marsh creation and shoreline protection features along the Bayou Lafourche and Belle Pass navigation channel in Lafourche Parish, Louisiana. The shoreline protection phase of the West Belle Pass Headland Restoration (TE-23) project consists of a foreshore rock dike, two rock closures, a submerged rock weir, and a flotation channel while the marsh creation phase consists of marsh creation areas, an earthen retention dike, and three earthen closures. The goals established for the marsh creation phase of this project were to create 184.0 acres (74.5 ha) of marsh and increase marsh to open water ratio whereas the shoreline protection phase had a singular goal, to decrease the rate of shoreline retreat along the project area shoreline. To measure these goals, habitats were monitored in project and reference areas for the marsh creation phase while shoreline position was monitored in the project area for the shoreline protection phase. Little saline marsh habitat was created by this project. Only a 5.4 % increase in saline marsh area was attained. Moreover, substantially larger quantities of wetland scrub/shrub-salt and beach/bar/flat habitats were created. In addition, a fairly large upland barren habitat was also constructed, and a large open-water salt acreage still remains. Therefore, the environments created in the project area are not structurally similar to natural saline marshes and will not replicate salt marsh function. Furthermore, the project area is semi-impounded through pre-existing (spoil areas and pipeline canal spoil banks) and constructed (the flotation channel spoil bank and the Evans Canal retention dike) hydrologic barriers. While the project area failed to create structural and functional saline marsh habitat, the reference area showed signs of shoreline and marsh edge erosion during the post-construction period. In contrast to the marsh creation phase, the shoreline protection phase of this project was successful in lowering the Belle Pass and Bayou Lafourche shoreline erosion rate, and the foreshore rock dike is maintaining its structural stability. The inability of this project to create saline marsh environments is a direct result of construction failures, adverse impacts, and bad management practices employed before and during project construction. Moreover, this seems to be a common phenomenon inherent to many beneficial use projects, which are primarily concerned with navigation channel dredging and marsh creation is of secondary importance or simply a mechanism to dispose dredged materials. Therefore, the results of this restoration project seem to suggest that marsh creation, not dredged material disposal, should be emphasized when creating marsh with beneficial use sediments. With careful planning and site-specific designs, sediments dredged from navigation channels could be utilized to mediate coastal land-loss and create sustainable salt marsh communities along the rapidly transgressing deltaic plain coast of Louisiana.

Introduction

The West Belle Pass Headland Restoration (TE-23) project is a shoreline protection and saline marsh creation project located on the southwestern portion of the Caminada-Moreau Headland at the interface of the Belle Pass navigation channel and the Gulf of Mexico in Lafourche Parish, Louisiana (figures 1, 2, and 3). This project is located directly across the Bayou Lafourche navigation channel from Port Fourchon (figures 2 and 3). The project was federally sponsored by the United States Army Corps of Engineers, New Orleans District (USACE-NOD) and locally sponsored by the Louisiana Department of Natural Resources/Coastal Restoration Division (LDNR/CRD) under the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA, Public Law 101-646, Title III). The project area consists of 1341 acres (543 ha) of saline marsh, scrub-shrub, beach/bar/flat, and open water habitats (figure 3).

The formation of the Lafourche delta complex began approximately 3,500 years before present (Frazier 1967; Otvos 1969; Peyronnin 1962; Conaster 1971; Harper 1977). During this time, nutrient rich sediments were deposited along the banks of the Lafourche delta distributaries primarily through overbank flooding. This created a vast network of swamps, marshes, and ridges along its numerous subdeltas (Frazier 1967; Reed 1995). This delta lobe complex was the fifth deltaic sequence of the Mississippi River (Frazier 1967; Bird 2000) to form in the delta plain's geosyncline (Frazier 1967; Penland and Ramsey 1990; Roberts et al. 1994; Bird 2000). Bayou Lafourche was one of the final subdeltas to form during the Lafourche delta period before the river switched its flow to the Plaquemines and Modern delta complexes. This subdelta was an active distributary of the Mississippi River from approximately 1800 to 100 years before present (Frazier 1967; Morgan and Larimore 1957; Peyronnin 1962). At the mouth of the Bayou Lafourche subdelta, a regressing network of accretionary sand ridges developed to form the Caminada-Moreau Headland (figure 2). These ridges were geomorphodynamically formed by shaping delta front sheet sands through wind, wave, tidal, and longshore transport processes (Ritchie 1972; Otvos 1969; Conaster 1971; Bird 2000).

In the years since the creation of the Lafourche delta, the sediment and freshwater supply to the Caminada-Moreau Headland has decreased considerably. The Mississippi River gradually changed its course to form the Plaquemine and Modern delta lobes significantly reducing the sediment supply to the Caminada-Moreau Headland (Frazier 1967; Reed 1995). By 1850, the Bayou Lafourche subdelta was discharging only 15.0 % of the Mississippi River's flow (Reed 1995). In 1904, a dam was placed at the junction of the Mississippi River and Bayou Lafourche essentially eliminating the source of river sediments to the headland (Frazier 1967; Morgan and Larimore 1957; Peyronnin 1962; Dantin et al. 1978; Reed 1995). Therefore, Bayou Lafourche has become a sediment starved, relict distributary of the Mississippi River (Peyronnin 1962; Dantin et al. 1978; Reed 1995; Harper 1977; Ritchie 1972; Pilkey and Fraser 2003; Ritchie and Penland 1988a; Ritchie and Penland 1988b; Penland and Ritchie 1979; Boyd and Penland 1981; Penland and Ramsey 1990). This sediment deficit, the depth of the Holocene sediments in the delta plain's geosyncline (Penland and Ramsey 1990; Otvos 1969; Conaster 1971; Roberts et al. 1994; Bird 2000; Frazier 1967), and eustatic sea level rise (Scavia et al. 2002) have caused the subsidence rate along the

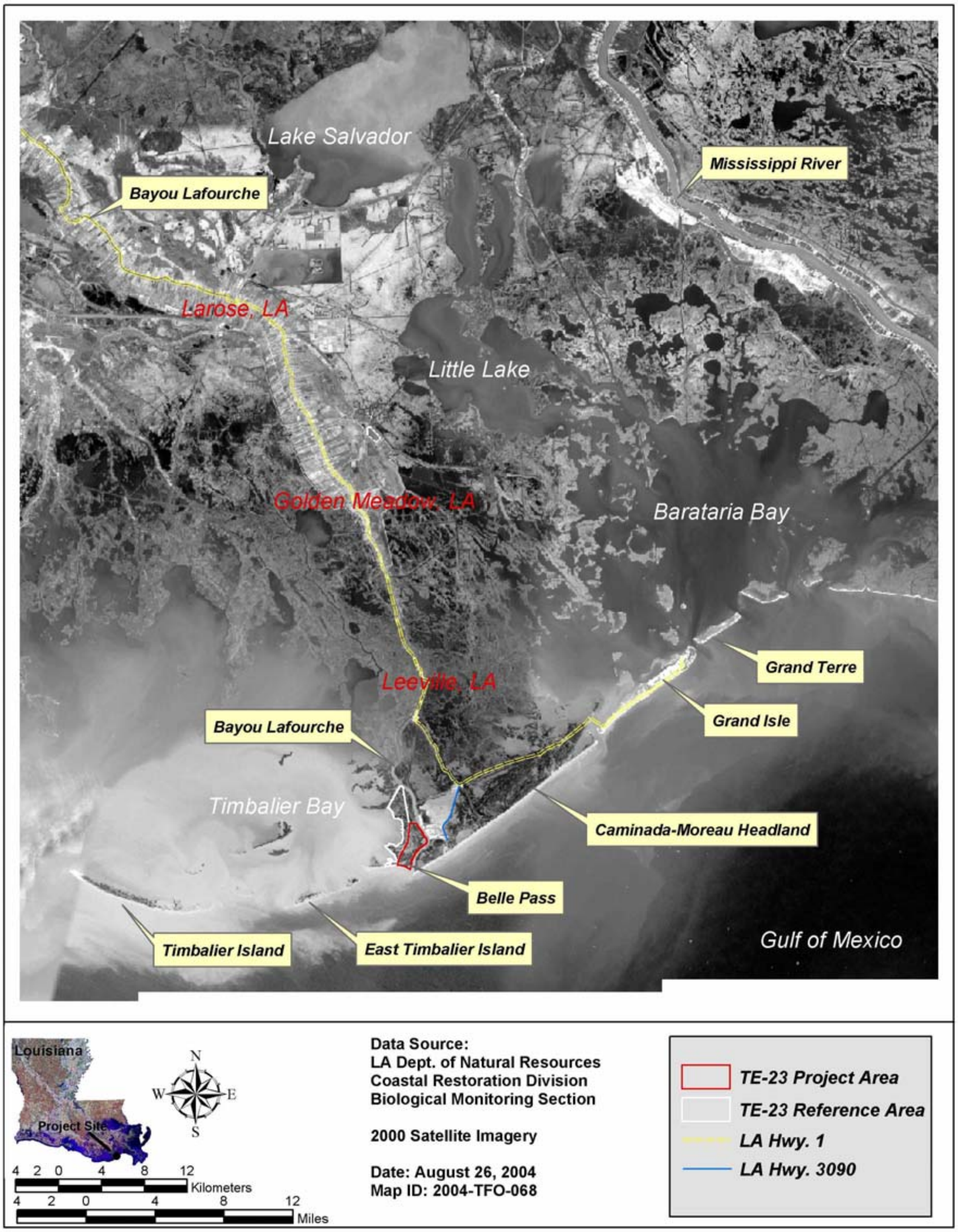


Figure 1. **Location and vicinity of the West Belle Pass Headland Restoration (TE-23) project along the relict Bayou Lafourche Delta.**

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

Figure 3. **Location of the West Belle Pass Headland Restoration (TE-23) project and reference areas. 2000 aerial photography provided courtesy of the University of New Orleans/Coastal Research Laboratory (UNO/CRL) and USACE-NOD.**

Caminada-Moreau Headland to exceed 0.4 in/yr (1.0 cm/yr) (Coleman and Smith 1964; Swanson and Thurlow 1973; Penland and Ramsey 1990; Roberts et al. 1994).

Natural and anthropogenic changes have modified the longshore transport and geomorphology of the Caminada-Moreau Headland. Jetties and groins have been found to obstruct sand transport along beaches causing erosion on the downdrift side of these structures (Komar 1998; Conaster 1971) and are likely contributors to alterations in sediment transport in the project area. The direction of the net longshore transport along the headland has been altered by the creation of a wave shadow and the installation of rock jetties at Belle Pass. The extension of the Modern delta lobe to the continental shelf has created a wave shadow, which has caused the net longshore transport to shift in a direction contrary to the geological record (Otvos 1969; Conaster 1971; Harper 1977). The net longshore transport now flows in a northeastern direction throughout half of the Caminada-Moreau Headland, causing accretion and recurved spit formation on the eastern portion of this headland while the central portion is transgressing (figure 2) (Stone and Zhang 2001; Otvos 1969; Conaster 1971; Harper 1977; Dantin et al. 1978). On the other half of the headland, net longshore transport is in the southwestern direction, causing accretion on the updrift side (eastern jetty) and erosion on the downdrift side (western jetty) of the of the Belle Pass rock jetties (figures 2 and 4) (Stone and Zhang 2001; Harper 1977; Ritchie and Penland 1988b; Dantin et al. 1978; Boyd and Penland 1981). West of the rock jetties net longshore transport is in the western direction (figures 2 and 4) (Stone and Zhang 2001; Ritchie and Penland 1988b; Peyronnin 1962; Dantin et al. 1978).

The geomorphology of the Caminada-Moreau Headland also has been strongly influenced through the frequent passage of tropical storms and cold fronts. Numerous tropical storms (Peyronnin 1962; Stone et al. 1997) and cold fronts (Boyd and Penland 1981; Ritiche and Penland 1998b; Dingler and Reiss 1990) have elevated water levels high enough to cause partial or total overwash along the low profile Caminada-Moreau Headland. Moreover, this area has been classified as a storm dominated coast (Harper 1977; Boyd and Penland 1981) consisting of ephemeral dunes shaped by storm events (Harper 1977; Ritchie 1972; Penland and Ritchie 1979; Ritchie and Penland 1988a; Ritchie and Penland 1988b). Approximately thirteen Hurricanes have caused severe overwash along or in the vicinity of the headland since 1856 (Peyronnin 1962; Stone et al. 1997). Specifically, Hurricane Betsy in 1965 (Conaster 1971), Hurricane Carmen in 1974 (Harper 1977), Hurricanes Juan, Danny, and Elena in 1985 (Ritchie and Penland 1988b), and Hurricane Andrew in 1992 (Stone et al. 1993) have been documented as causing breaching, overwash, and shoreline retreat along the Caminada-Moreau Headland substantially altering the dune and washover environments. Although little data are currently available, the recent passage of Hurricane Cindy (July 2005), Hurricane Katrina (August 2005), and Hurricane Rita (September 2005) will probably be recorded as important erosional events shaping the geomorphology of this headland. As a result, hurricanes have been postulated as the major force driving morphodynamic change along the Caminada-Moreau Headland (Stone et al. 1997).

The shoreline erosion rate along the Caminada-Moreau Headland is the highest in coastal Louisiana (Morgan and Larimore 1957). The sediment deficit, subsidence, longshore transport, and the high frequency of storm events have resulted in high shoreline erosion rates along the low profile

Figure 4. Anthropogenic modifications affecting hydrology and sediment distributions at the West Belle Pass Headland Restoration (TE-23) project. These alterations predate project construction.

Caminada-Moreau Headland. Morgan and Larimore (1957) reported shoreline erosion rates of 62.0 ft/yr (18.9 m/yr) from 1883-1954 along the headland while Williams et al. (1992) and McBride and Byrnes (1997) recorded erosion rates of 43.6 ft/yr (13.3 m/yr) during the hundred year interval from 1887-1988. While these erosion rates are extremely high, the shoreline erosion rate along the West Belle Pass Headland Restoration (TE-23) project area shoreline is considerably higher. Williams et al. (1992) found shoreline transgressions of 133.2 ft/yr (40.6 m/yr) and 89.6 ft/yr (27.3 m/yr) during time intervals from 1887-1934 and 1887-1988, respectively. Moreover, several areas of this shoreline transgressed 6566 ft (2000 m) during the period from 1887-1934 and 9842 ft (3000 m) during the period from 1887- 1988 (Williams et al 1992). Dantin et al. (1978) also calculated shoreline transgressions in the west Belle Pass area and found the project area shoreline to erode at 108.0 ft/yr (33.0 m/yr) from 1885-1932, 182.0 ft/yr (55.0 m/yr) from 1904-1932, and 53.0 ft/yr (16.0 m/yr) from 1945-1974. These shoreline transgressions illustrate the effect that the 1904 dam had on shoreline erosion at the mouth of the Bayou Lafourche subdelta. In addition, longshore transport processes have caused extensive shoreface erosion along the West Belle Pass area shifting sediments to downdrift barrier islands and tidal passes (McBride and Byrnes 1997; List et al. 1997; Stone and Zhang 2001; Peyronnin 1962; Levin 1993).

The construction of the Bayou Lafourche and Belle Pass navigation channel, the Belle Pass rock jetties, three pipeline canals, and two submerged pipelines (figure 4) have altered the West Belle Pass Headland Restoration (TE-23) project area marshes. Belle Pass dredging and jetty construction began in 1940 by increasing the depth and width of the channel to unspecified dimensions and constructing parallel rock jetties 500.0 ft (152.0 m) in length and 200.0 ft (61.0 m) in width. The jetties were extended by 300.0 ft (90.0m) in 1945 due to shoreline erosion. In 1958, the navigation channel was enlarged to a depth of -12 ft (-3.7 m) Mean Low Gulf (MLG) and a width of 100 ft (30.5 m). The channel was expanded to a 125.0 ft (38.0 m) bottom width and relocated to the west of the jetties in 1963 leaving only an eastern jetty (Dantin et al. 1978). A western jetty was installed in 1974, and Belle Pass was dredged to a -20 ft (-6.1 m) MLG depth and a 300.0 ft (91.4 m) wide extent in 1975. In 1980, the jetties were extended to their current 2,600.0 ft (792.5 m) length and 1,200.0 ft (365.8 m) width (figure 4). Finally, the navigation channel was dredged to a -27.0 ft (-8.2 m) MLG depth in 2001 (D. Breaux, GLPC, pers. comm.). As previously discussed, the construction of these rock jetties disrupted the longshore transport processes along the Caminada-Moreau Headland considerably reducing the sand and sediment supply available to project area beaches (Stone and Zhang 2001; Harper 1977; Ritchie and Penland 1988b; Dantin et al. 1978; Boyd and Penland 1981). In addition, a second consequence of navigation channel expansion was caused by the establishment of a highly elevated spoil area (figure 4) along the project area shoreline prior to 1972 (Harper 1977). Moreover, this spoil bank was formed by disposing dredged materials onto the existing marsh surface causing the project area to become semi-impounded. The project area was further modified by construction of three pipeline canals and two submerged pipelines between 1952 and 1972 (Harper 1977; Williams et al. 1992). The pipeline canals also impounded and probably induced tidal scouring in project area marshes (Gagliano and Wicker 1989). The elevated spoil bank, the pipeline canals, and the submerged pipelines aided in the destruction of the remaining remnants of the western Belle Pass sand ridges and disrupted the natural hydrology of project area marshes (Ritchie 1972). Moreover, semi-impounded and impounded marshes have been found to prolong the recovery period after hurricanes and experience more severe and long-term impacts (Conner et al.1989). As a result, these anthropogenic modifications to the Belle Pass area have substantially contributed to the 10.0 ft/yr (3.1 m/yr) shoreline and marsh edge erosion rate experienced from 1932-1983 (figure 5) (May and Britsch 1987).

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

Marsh vegetation in the project area is dominated by *Spartina alterniflora* Loisel. (smooth cordgrass). *Spartina patens* (Ait.) Muhl. (marshhay cordgrass), *Salicornia virginica* L. (glasswort), *Solidago sempervirens* L. (seaside goldenrod), *Baccharis halimifolia* L. (eastern baccharis), *Iva frutescens* L. (bigleaf sumpweed), *Morella cerifera* (L.) Small (waxmyrtle), *Batis maritima* L. (saltwort), *Distichlis spicata* (L.) Greene (seashore saltgrass) and *Avicennia germinans* (L.) L (black mangrove) also inhabit the project area. Chabreck and Linscombe (1997) classified the project area as salt marsh habitat.

The West Belle Pass Headland Restoration (TE-23) project will test the efficacy of utilizing navigation channel sediments, so called beneficial use of dredged materials (BUMP), to create saline marsh environments and the effectiveness of using a foreshore rock dike to slow the rate of shoreline transgressions along a navigation channel. The objectives of this project are to reduce the encroachment of Timbalier Bay into marsh on the west side of Bayou Lafourche and Belle Pass by creating 184.0 acres (74.5 ha) of wetlands and to prevent further shoreline retreat along the west bank of Belle Pass and Bayou Lafourche using armor stone. The specific measurable goals established to evaluate the effectiveness of the project are:

1) Create approximately 184.0 acres (74.5 ha) of marsh on the west side of Belle Pass through infilling of designated canals and shallow water bodies.

2) Increase the marsh to open water ratio.

3) Decrease the rate of shoreline retreat along the west bank of Belle Pass and Bayou Lafourche.

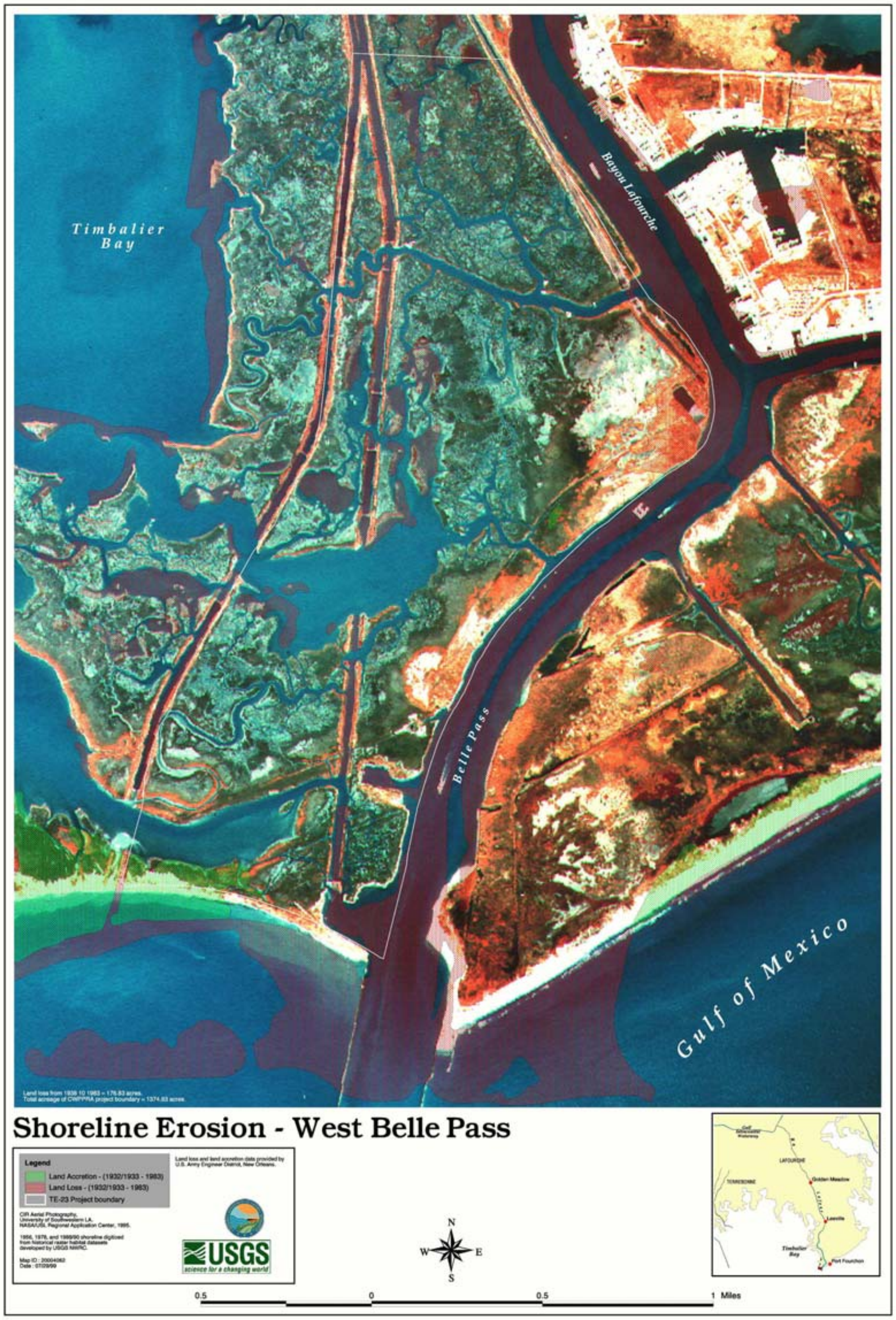


Figure 5. **Historic shoreline erosion data from the USACE at the West Belle Pass Headland Restoration (TE-23) project.**

Methods

Project Features

The West Belle Pass Headland Restoration (TE-23) project consists of two major features, shoreline protection structures and a marsh creation area. The shoreline protection phase of this restoration project extends for approximately 17,000 ft (5,182 m) along the western bank of Belle Pass and Bayou Lafourche (figure 6). This phase of this restoration project includes the construction of a flotation channel, a foreshore rock dike, two rock closures, and a submerged rock weir (figure 6). The marsh creation phase of the TE-23 project consists of an earthen retention dike, three earthen closures, and three disposal areas (figure 6). For discussion purposes the marsh creation area was subdivided into three distinct areas, the closure 1, closure 3, and closure 5 marsh creation areas. First, the closure 1 marsh creation area is irregular shaped and generally forms its western border with the eastern bank of a Tennessee Gas Pipeline Canal, its northern border with the southern bank of Evans Canal, its eastern border with a preexisting spoil area (figures 4 and 6), and its southern border lies directly south of closure 1. Next, the closure 3 marsh creation area generally forms its western border with the eastern bank of a Tennessee Gas Pipeline Canal, its eastern border with the Louisiana Intrastate Gas Pipeline Canal, and its southern border with the Gulf of Mexico (figure 6). Finally, the closure 5 marsh creation area forms its western border with the southern portion of the Louisiana Intrastate Gas Pipeline Canal, its eastern border with closure 5, and its southern border with the Gulf of Mexico (figure 6). Construction of the West Belle Pass Headland Restoration (TE-23) project began on February 10,1998 and was completed on July 17, 1998.

Foreshore Rock Dike: To access the shallow areas close to the shoreline while constructing the foreshore rock dike, a 75.0 ft (22.9 m) wide flotation channel was dredged to a maximum depth of -8.0 ft (-2.4 m) Mean Low Gulf (MLG) along the entire length of the rock structure using a 6.0 yd^3 (4.6 m^3) bucket dredge. The sediments dredged from the flotation channel were stacked behind the foreshore rock dike creating an elevated spoil bank directly behind the rock structure (figure 7). Approximately, 20,600 yd^3 (15,750 m^3) of benthic sediments were displaced to create the flotation channel. The construction of the flotation channel began on February 23, 1998 and was completed on April 12, 1998.

The 17,000 ft (5,182 m) foreshore rock dike and rock closures 4 and 5 were constructed along the -2.0 ft (-0.6 m) MLG shoreline contour by placing armor stone material on top of a 200 lb/in geotextile foundation using a 5.0 yd^3 (3.8 m^3) bucket dredge (figure 6). The dike and rock closures were built to a 6.0 ft (1.8 m) MLG elevation with side slopes of 1.5H:1V and were placed at least 20.0 ft (6.1 m) from the edge of the flotation channel. The geotextile foundation was allowed to extend 5.0 ft (1.5 m) beyond the toes of the rock dike and closures. Settlement plates were installed on 500 ft (152 m) intervals along the length of the rock dike and at the endpoints of the rock closures. An estimated 46,100 tons (37,738,890 kg) of armor stone and 50,500 yd^2 (42,224 m^2) of geotextile material were used to construct the rock structures. The construction of the rock dike and closures began on February 28, 1998 and were completed on April 16, 1998.

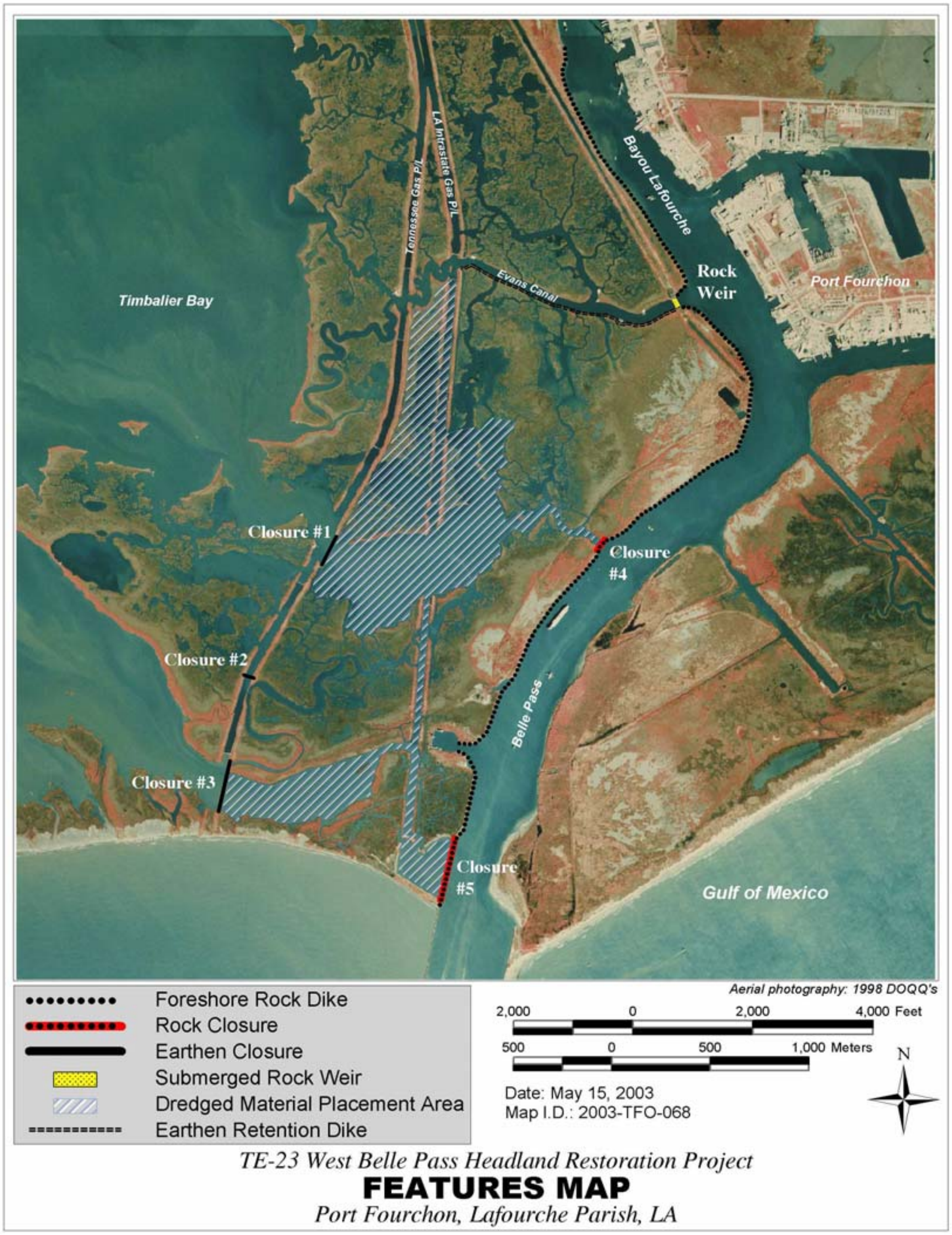


Figure 6. Location of the West Belle Pass Headland Restoration (TE-23) project features.

Figure 7. February 2001 view of a segment of the flotation spoil bank at the West Belle Pass Headland Restoration (TE-23) project.

A 40.0 ft (12.2 m) wide 2.0 ft (0.6 m) thick submerged rock weir was constructed across Evans Canal by placing armor stone material on top of a 200 lb/in geotextile foundation using a 5.0 yd^3 (3.8 m^3) bucket dredge. This rock weir was centered on the Tennessee Gas Pipeline crossing at Evans Canal near Bayou Lafourche and linked the pre-existing pipeline dams together (figure 4 and 6). The geotextile foundation was allowed to extend 5.0 ft (1.5 m) beyond the toes of the rock weir. The construction of the rock weir began on March 11, 1998 and was completed on March 12, 1998.

<u>*Marsh Creation*</u>: An earthen retention dike and three earthen closures were constructed to contain the dredged material effluent within the marsh creation areas. The earthen retention dike was constructed along the southern banks of Evans Canal extending from the submerged rock weir to the Louisiana Intrastate Gas Pipeline Canal while the earthen closures were constructed along the western Tennessee Gas Pipeline Canal (figure 6). These earthen structures were built to an elevation of 5.0 ft (1.5 m) MLG with a 5.0 ft (1.5 m) wide crown and side slopes of 3H:1V. The containment dike and closures were built on top of a 200 lb/in geotextile foundation with 5.0 ft (1.5 m) extensions and were constructed using sediments bucket dredged [6.0 yd^3 (4.6 m^3) bucket] from Evans Canal (earthen retention dike) and the marsh creation areas (closures 1, 2, and 3). The earthen retention dike and closure 1 were constructed with a barge mounted dredge while closures 2 and 3 were constructed with a marsh buggy mounted dredge. Moreover, a flotation channel of unknown dimensions was dredged across the closure 1 marsh creation area to construct earthen closure 1. The construction of the earthen retention dike and closures began on February 15, 1998 and were completed on April 3, 1998. Following construction and sediment consolidation, the earthen

retention dike was breached in two locations to reestablish tidal inlets for fisheries access.

Once construction of the retention dike and closures were complete, marsh creation activities were initiated from maintenance dredging of the Bayou Lafourche navigation channel. The 300.0 ft (91.4 m) wide navigation channel was dredged from a depth of -20.0 ft (6.1 m) MLG to a depth of -27.0 ft (8.2 m) MLG using a 30.0 in (76.2 cm) hydraulic dredge. Channel maintenance began by dredging the reach from centerline (C/L) station 235+00 to C/L station 280+00 (navigation channel between the Belle Pass Rock Jetties) (figure 4). Maintenance dredging activities were also conducted from C/L station 202+75 to C/L station 214+20 (navigation channel between Chevron Oil Pipelines) (figure 4), from C/L station 151+45 to C/L station 193+10 (navigation channel in the vicinity of closure 4) (figure 6), and from C/L station 76+85 to C/L station 92+65 (navigation channel in the vicinity of the northern limit of the foreshore rock dike) (figure 6). 1,231,409 yd^3 (941,480 m^3) of benthic sediments were removed from the navigation channel and placed in the marsh creation areas to an elevation of at least 2.75 ft (0.84 m) MLG. An additional 228,000 yd^3 (174,319 m^3) of dredged material were removed from the navigation channel and deposited outside the project area on the West Belle Pass beach (figure 8). Channel dredging and marsh creation began on May12, 1998 and were completed on June 13, 1998 while dredge pipe and spill box removal were not concluded until July 17,1998.

Construction Failures: Structural deterioration of earthen closures and a substantial reduction in the quantity of dredge material placed in the marsh creation areas affected the creation of subaerial marshes at the West Belle Pass Headland Restoration (TE-23) project. Closure 1 (E. Russo and R. Broussard, USACE-NOD, pers. comm.) and closure 3 (J. Harris, LDNR/CMD, pers. comm.) were breached during or slightly after construction of the marsh creation areas. E. Russo (USACE-NOD, pers. comm.) reported that severe storm activity induced closure 1 breaching and washout of dredged material from the closure 1 marsh creation area. While the closure 3 earthen structure was breached in two locations, the closure 1 earthen structure was severely weakened by breaching and washed-out by tidal currents and/or storm impacts. In addition, less than half of the required volume of dredged material was pumped into the marsh creation areas. Originally, designs called for 2,700,000 yd^3 (2,064,298 m^3) of dredged material to be pumped into the marsh creation areas. However, only 1,231,409 yd^3 (941,480 m^3) of dredged material were pumped into the marsh creation areas, which created a deficit of 1,486,591 yd^3 (1,122,818 m^3). Furthermore, J. Saxton (LDNR/CRD, pers. comm.) viewed the project shortly before completion of the marsh creation phase (June 9, 1998) and suggested that the volume of dredged material in some of the marsh creation areas was considerably lower than expected. As a result of the structural deterioration of the closures and the reduction in dredged material, small sections of the closure 3 marsh creation area and substantially larger sections of the closure 1 marsh creation area remained subaqueous (figure 9).

Adverse Impacts: Vegetated wetlands were needlessly damaged through improper construction procedures in violation of the West Belle Pass Headland Restoration (TE-23) project's consistency determination. Marsh buggies traversed across the project area repeatedly and often outside of the predetermined access corridors causing severe and moderate rutting throughout the project area (figures 8, 10, 11, and 12) (J. Harris, LDNR/CMD, pers. comm.). Moreover, the access corridors

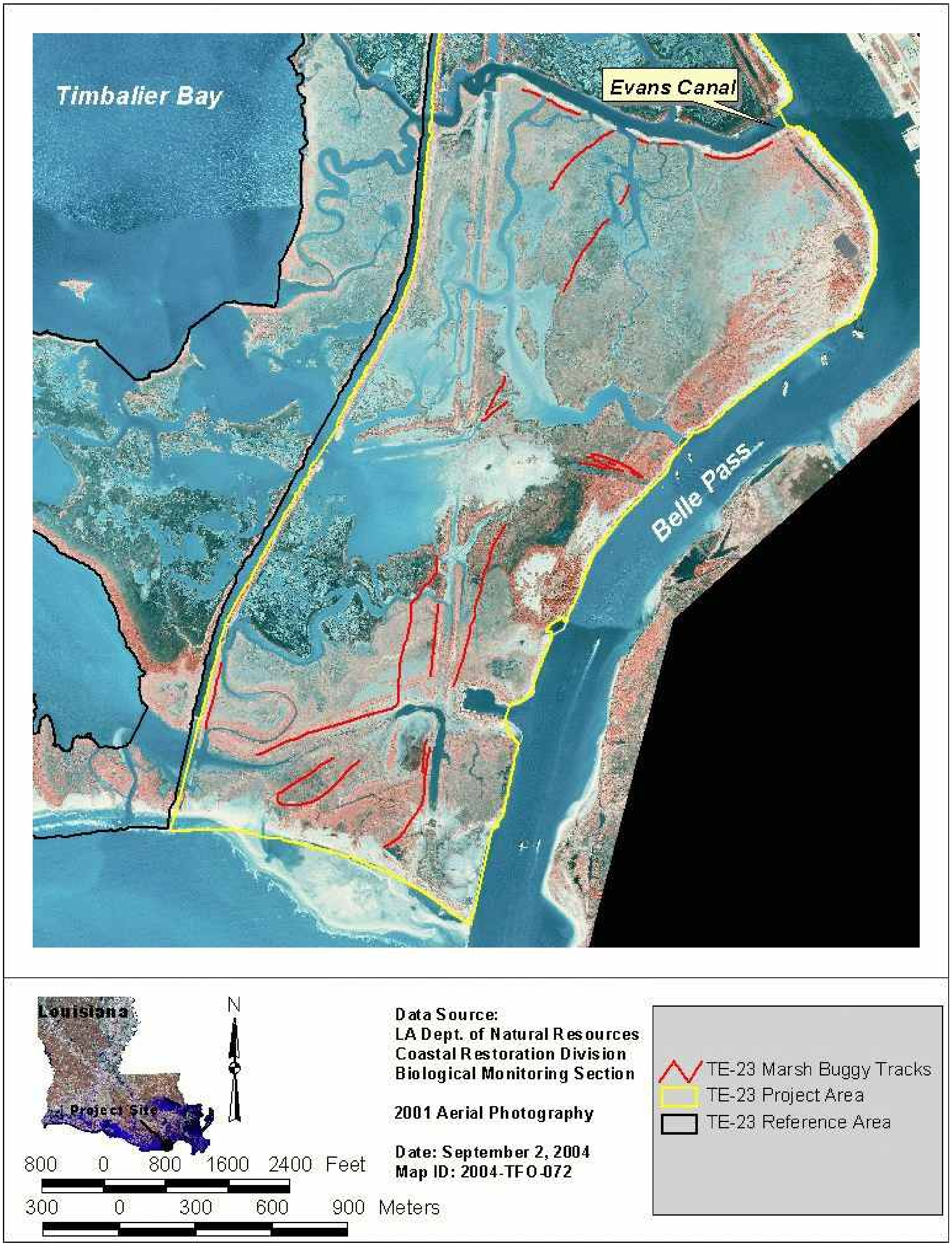


Figure 8. **Location of marsh buggy tracks within the West Belle Pass Headland Restoration (TE-23) project area.**

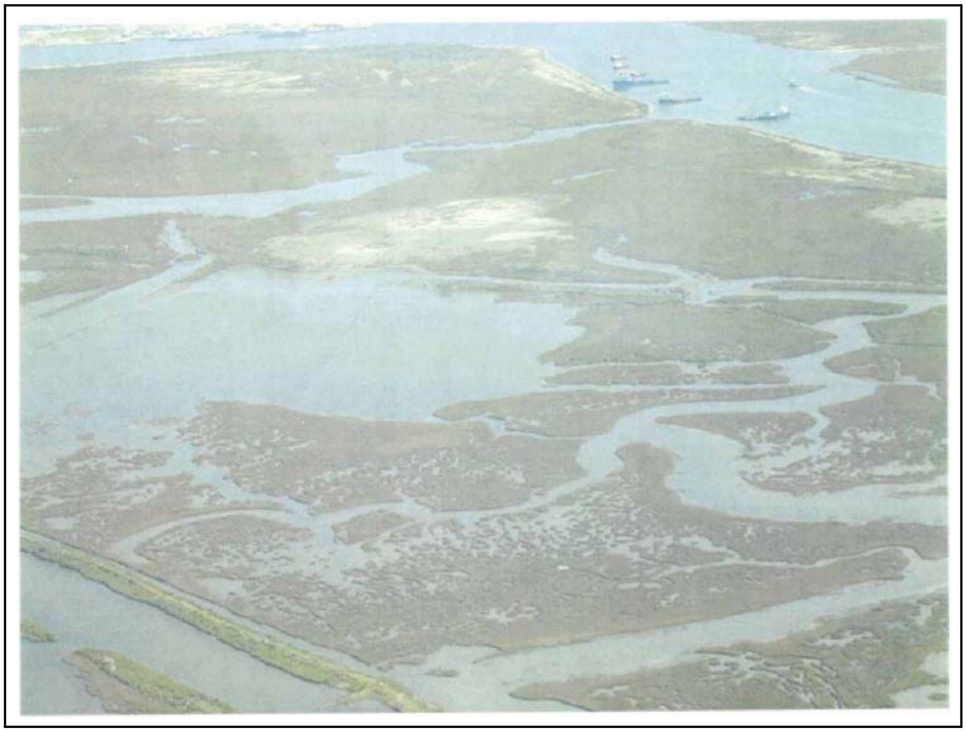


Figure 9. **February 2003 aerial view of the closure 1 marsh creation area at the West Belle Pass Headland Restoration (TE-23) project.**

Figure 10. **February 2003 aerial view of severe marsh tracks located along the southern bank of Evans Canal at the West Belle Pass Headland Restoration (TE-23) project. Also, depicted in the photograph is a gapped segment of the earthen retention dike.**

Figure 11. February 2003 aerial view of severe marsh tracks located along Belle Pass in the vicinity of closure 4 at the West Belle Pass Restoration (TE-23) project.

Figure 12. February 2003 aerial view of severe marsh tracks located just east of the Louisiana Intrastate Gas Pipeline Canal in the vicinity of the closure 1 marsh creation area at the West Belle Pass Headland Restoration (TE-23) project.

were to be utilized for pipeline handling, not for frequent crossings of the marsh, and were to be limited to open water and disposal areas. Approximately, 9.5 acres (3.8 ha) of vegetated wetlands were severely or moderately compacted by marsh buggies (J. Harris, LDNR/CMD, pers. comm.). A second violation of the consistency determination was caused by the disposal of 20,600 yd^3 (15,750 m^3) of flotation channel refuse onto the existing marsh surface. This dredged material was formed into a 10.0 to 20.0 ft (4.0 to 8.1 m) wide elevated spoil bank behind the foreshore rock dike partially or totally engulfing existing wetland vegetation (figure 7). An estimated 8.0 acres (3.2 ha) of marsh were buried under these dredged sediments resulting in vegetation stress and mortality (J. Harris, LDNR/CMD, pers. comm.). Therefore, 17.5 acres (8.1 ha) of vegetated wetlands were adversely impacted during construction of this restoration project.

Remedial Activities: Several restorative measures have been undertaken or proposed to alleviate the failures and impacts of the West Belle Pass Headland Restoration (TE-23) project. First, a second marsh creation phase is being planned for the closure 1 marsh creation area using funds remaining in the West Belle Pass Headland Restoration (TE-23) project construction budget (approx. $800,000). Sediments will again be supplied through maintenance dredging of the Bayou Lafourche Navigation Channel. To date, a bathymetric survey of closure 1 and the closure 1 marsh creation area was completed in February 2004 by Louisiana Department of Natural Resources/Coastal Engineering Division (LDNR/CED), and closure 1 is being redesigned by USACE-NOD (D. Dearmond, LDNR/CED, pers. comm.). Once closure 1 is reconstructed, the second marsh creation phase of this project will begin during the next navigation channel maintenance dredging cycle. Secondly, the marsh buggy tracks and burial issues were resolved with the primary contractor depositing $100,000 in the Louisiana Wetlands Conservation and Restoration Fund. However, no attempts have been made to restore the compacted or buried marshes.

Monitoring Design

A detailed description of the monitoring design over the entire project life can be found in Alonzo (1998). Variables chosen to evaluate the project effectiveness were habitat mapping and shoreline position change. In addition, bathymetry was used as a supplemental variable. The 2006 habitat mapping event was moved to 2001 to provide post-construction habitat analysis for this report. Water level variability was dropped from the monitoring plan in 1998 due to budgetary constraints, and all future shoreline position surveys (2006, 2012, and 2017) were canceled in 2004 due to reallocation of CWPPRA monitoring funds for the Coast-wide Reference Monitoring System-Wetlands (CRMS-*Wetlands).*

Habitat Mapping and Aerial Photography: The U.S. Geological Survey's National Wetlands Research Center (USGS/NWRC) obtained 1:12,000 scale color infrared (CIR) aerial photography. It was classified and photo-interpreted to perform habitat analysis of the West Belle Pass Headland Restoration (TE-23) project [1340.0 acres (542 ha)] and reference [1611.0 acres (652.0 ha)] areas (figures 1, 2, and 3). Pre-construction photography was acquired on November 8, 1997 and post-construction photography was acquired on November 19, 2001 (figure 13). Aerial photographs were scanned at 600 pixels per inch and georectified using ground control data collected with a global

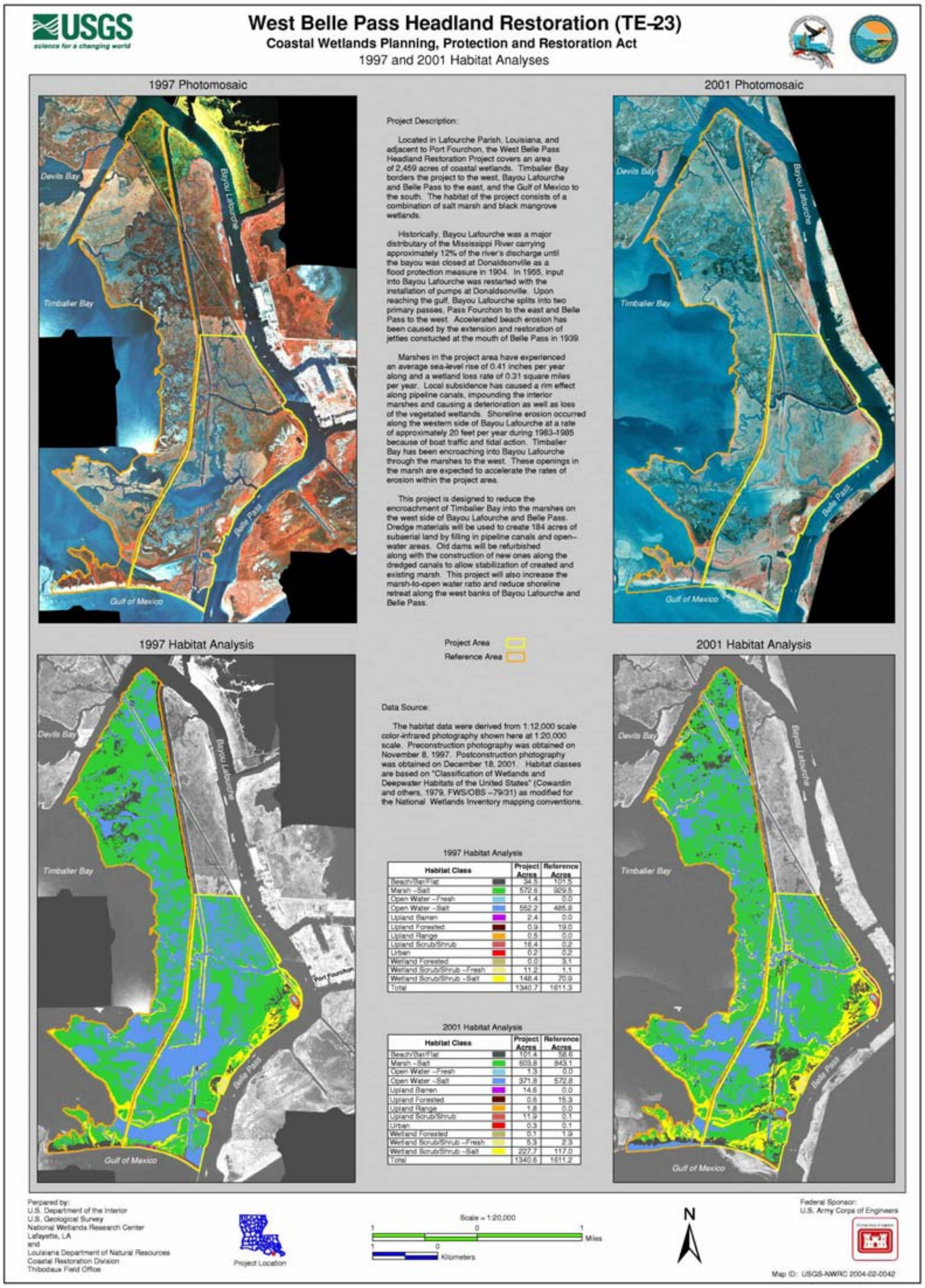


Figure 13. Pre-construction (1997) and post-construction (2001) photomosaics and habitat analysis for the West Belle Pass Headland Restoration (TE-23) project.

positioning system (GPS) and digital ortho quarter quads. These individually georectified frames were assembled to produce a mosaic of the project and reference areas.

Using the National Wetlands Inventory (NWI) classification system, the 1997 and 2001 photography were photointerpreted by USGS/NWRC personnel and classified to the subclass level (Cowardin et al. 1979). The habitat delineations were transferred to 1:6,000 scale mylar base maps and digitized. After being checked for quality and accuracy, the resulting digital data were analyzed using geographic information systems (GIS) to determine habitat change over time in the project and reference areas. The habitat types were aggregated into twelve habitat classes for the purpose of mapping change. Habitat classes were combined further to assess land to open water ratio changes. Land was considered to be a combination of marsh-salt, upland barren, upland forested, upland range, upland scrub/shrub, urban, wetland forested, wetland scrub/shrub-fresh, and wetland scrub/shrub-salt. The open water-salt and open water-fresh habitat classes were considered water.

Additional, 1:24,000 scale CIR georectified mosaics of Port Fourchon, LA were obtained from the University of New Orleans/Coastal Research Laboratory (UNO/CRL). This aerial photography was funded through USACE-NOD's Beneficial Use of Dredged Material Monitoring Program (BUMP). Post-construction aerial photography were acquired on January 14, 2000 and May 14, 2002 and were used to discern temporal variations in the project area. No habitat or land/water analysis was performed with this aerial photography.

Shoreline Change: Post-construction shoreline positions were determined in June 1998 (immediate post-construction) and in February 2001 (2.5 years post-construction) by LDNR/CRD personnel using a Trimble AGgps 122 differential GPS (DGPS) interfaced with Penmap® software. The June 1998 survey defined the shoreline position as the landward extent of the shoreline while the February 2001 survey utilized the Steyer et al. (1995) method, which defines shoreline position as the edge of the live emergent vegetation. Real-time differential correction was acquired from the United States Coast Guard's (USCG) Continuously Operated Reference Station (CORS) at English Turn, LA. The DGPS was adjusted to achieve sub-meter horizontal accuracy for each position (Trimble Navigation Ltd. 1996). The June 1998 survey was conducted using the North American Datum of 1983 (NAD 83) and the Louisiana State Plane, South Zone (LSZ) Coordinate System in meters while the February 2001 survey was conducted using the NAD 83 datum and the Universal Transverse Mercator (UTM) Zone 15R Coordinate System in meters. The June 1998 survey was subsequently converted to the UTM NAD 83 Coordinate System in meters by USGS/NWRC personnel. The June 1998 and February 2001 shoreline position measurements were conducted by stopping at approximately 5.0 ft (1.5 m) intervals along the shoreline and averaging 10 to 20 DGPS readings. A best fit line (polyline) was drawn to connect the points thereby establishing the shoreline position for the total area. LDNR/CRD personnel also recorded a point on a temporary benchmark to insure the DGPS accuracy at the time of data collection. After completing the shoreline position surveys, the Penmap® files (.pts) were exported as ESRI® shapefiles (.shp).

Bathymetry/Topography: Post-construction bathymetric surveys of the closure 1 marsh creation area were initiated by the LDNR/CED to design a future marsh creation event (D. Dearmond, LDNR/CED, pers. comm.). These bathymetric surveys were conducted with a real-time Kinematic (RTK) GPS Total Station in February 2004 (5.5 years post-construction) using the LSZ NAD83 coordinate system in feet, and vertical measurements were referenced to the North American Vertical Datum of 1988 (NAVD 88) in feet (Picciola & Associates, Inc. 2004). In addition, two existing staff gauges were surveyed to the NAVD 88 (ft) and were compared to previously published MLG (ft) surveys of these gauges. Therefore, these vertical surveys were used to detect the localized differences between the MLG (ft) and the NAVD 88 (ft) vertical datums in the Port Fourchon, LA area. Both gauges are located along Bayou Lafourche in the vicinity of Evans Canal (Picciola & Associates, Inc. 2004).

The closure 1 cross section survey data were re-projected horizontally and vertically to the UTM NAD83 coordinate system and the NAVD 88 vertical datum in meters using Corpscon® software. The re-projected data were imported into ArcView® GIS software for surface interpolation. A triangulated irregular network model (TIN) was produced from the point data set. Next, the TIN model was converted to a grid model (2.0 m^2 cell size), and the spatial distribution of elevations in the closure 1 marsh creation area were mapped in quarter meter elevation classes.

To estimate elevation and volume changes required to fill the closure 1 marsh creation area to a ubiquitous 2.0 ft (0.61 m) NAVD 88 elevation, a second elevation data set was developed from the 2004 survey. In this data set the NAVD 88 (m) elevations were all transformed to 2.0 ft (0.61 m) NAVD 88 elevations using the same UTM NAD 83 coordinates (m). Secondly, TIN and grid models (2.0 m^2 cell size) were interpolated from this modified data set using the procedures established in the preceding paragraph. Next, elevation changes were calculated by subtracting the empirical and modified grid models using the LIDAR Data Handler extension of ArcView® GIS. After the elevation change grid model was generated, the spatial distribution of elevation changes in the closure 1 marsh creation area were mapped in quarter meter elevation classes. Lastly, volume changes were calculated to quantify the amount of sediment required to elevate the closure 1 marsh creation area (survey extent) to a 2.0 ft (0.61 m) NAVD 88 elevation using the Cut/Fill Calculator routine of the LIDAR Data Handler extension of ArcView® GIS. Note, these elevation and volume calculations are valid only for the extent of the survey area.

In addition to the February 2004 survey, an undated (assumed to be the as-built survey) topographic and bathymetric elevation map (hard copy only) of the closure 1 and closure 3 marsh creation areas was acquired from USACE-NOD. This survey consists of twelve east/west transects in the closure 1 marsh creation area and six east/west transects in the closure 3 marsh creation area. However, the map is not referenced to a vertical datum (assumed to be MLG in feet). Despite these uncertainties, an effort was made to surmise and compare this survey data to subsequent elevation surveys (February 2004).

Reference Area: The 1611 acre (652 ha) habitat mapping reference area was selected to provide statistically valid comparisons as a means of assessing project effectiveness. The evaluation of sites was based on the criteria that both project and reference areas have similar vegetative, soils, hydrology, shoreline configuration, and salinity characteristics. The site chosen for the West Belle

Pass Headland Restoration (TE-23) project's habitat mapping reference area lies directly west of the project area, forms its western border with Timbalier Bay , and stretches from the Gulf of Mexico to the Havoline Canal (figures 1, 2, and 3). This area was selected because it has similar vegetation, soils, and hydrology as the project area. The reference area is dominated by *S. alterniflora* and possesses a similar mixture of other plant species found in the project area.

No appropriate reference area could be located for the shoreline protection aspect of this project. The eastern shoreline of Belle Pass has been historically used for depositing dredged material removed from the Bayou Lafourche navigation channel. The Bayou Lafourche shoreline north of the project area does not receive the same level of boat traffic and associated influences found in the project area. It is felt that since the foreshore rock dike is to be placed directly on the shoreline, measurements of shoreline retreat from the foreshore rock dike will provide a measurement of the effectiveness of this aspect of the project.

Results

Habitat Mapping: Pre- (1997) and post-construction (2001) habitat analysis of the project area reveal increases in wetland scrub/shrub-salt [79.3 acres (32.1 ha)], beach/bar/flat [66.9 acres (27.1 ha)], marsh-salt [31.2 acres (12.6 ha)], and upland barren [12.2 acres (4.9 ha)] habitats while the open water-salt habitat [-180.4 acres (-73.0 ha)] decreased substantially (table 1 and figures 13, 14, and 15). However, a large open-water salt acreage still remains. The reference area showed large-scale increases in open water-salt [87.0 acres (35.2 ha)] and wetland scrub/shrub-salt [46.1 acres (18.7 ha)] habitats and extensive declines in marsh-salt [-86.4 acres (-35.0 ha)] and beach/bar/flat [-42.9 acres (-17.4 ha)] habitats over the four year sampling interval (table 1 and figures 13, 14, and 15). Moreover, the reference area's marsh-salt [-21.4 acres/yr (-8.7 ha/yr)] and beach/bar/flat [-10.6 acres/yr (-4.3 ha/yr)] habitats eroded at a considerably higher rate than the long term rate of 3.8 acres/yr (1.5 ha/yr) established by May and Britsch (1987). Interestingly, erosion along the Gulf of Mexico shoreline induced the significant loss of beach/bar/flat habitat (-42.3 %) in the reference area (figures 13, 14, and 15).

The results of the habitat analysis denote that the goal to create 184.0 acres (74.5 ha) of marsh was not attained because merely 31.2 acres (12.6 ha) of marsh were created (table 1), which translates to a 5.4 % expansion in marsh acreage. Moreover, only 113.5 acres (45.9 ha) of land were created in the project area during construction of this project. The vast majority of habitats created by this restoration project were elevated wetland and barren habitats. Specifically, the wetland scrub/shrub-salt, beach/bar/flat, and upland barren habitats increased their areal extent in the project area by 53.4 %, 193.9 %, and 508.3 %, respectively. Surprisingly, the wetland scrub/shrub-salt habitat also enlarged its spatial coverage in the reference area by 65.0 %. Figures 16 (1997) and 17 (2001) depict the expansion of the major upland, scrub-shrub, and barren habitats in the project area since construction was completed in 1998. These figures along with figure 7 illustrate the considerable enlargement of the upland barren and beach/bar/flat habitats along the Bayou Lafourche and Belle Pass shorelines created by the disposal of flotation channel sediments. Figures 16 and 17 also delineate the spread of the wetland scrub/shrub-salt habitat in the project area, the large beach/bar/flat acreage in the closure 1 marsh creation area (figure 9), and the marked relief of the earthen retention dike along Evans Canal (figures 8, 10, and 18).

The results of the habitat analysis also indicate that the goal to increase the marsh to open water ratio was achieved. The project area marsh to open water ratio increased from a 1.0:1.0 ratio in 1997 to a 1.6:1.0 ratio in 2001. However, this growth in marsh to open water ratio was not reached through marsh creation (5.4 % increase) but was predominantly an effect of the reduction in open water-salt habitat (-32.6 %). The land to open water ratio also increased from 1.4:1.0 (1997) to 2.3:1.0 (2001) via reductions in open water-salt habitat (-32.6 %) and growth in wetland scrub/shrub-salt (53.4), marsh-salt (5.4 %), and upland barren (508.3 %) habitats. In contrast to the project area, the reference area's marsh to open water and land to open water ratios declined. The marsh to open water ratio in the reference area decreased from 1.9:1.0 in 1997 to 1.5:1.0 in 2001, and the land to open water ratio in the reference area decreased from 2.1:1.0 in 1997 to 1.7:1.0 in 2001. The primary

Table 1. National Wetlands Inventory habitat classes and acreages photo-interpreted from 1997 and 2001 aerial photography for the West Belle Pass Headland Restoration (TE-23) project.

TE-23 Habitat Classes	1997 Project	2001 Project	1997 Reference	2001 Reference	Change Project	Change Reference
Beach/Bar/Flat (acres)	34.50	101.40	101.50	58.60	66.90	-42.90
Marsh - Salt (acres)	572.60	603.80	929.50	843.10	31.20	-86.40
Open Water - Fresh (acres)	1.40	1.30	0.00	0.00	-0.10	0.00
Open Water - Salt (acres)	552.20	371.80	485.80	572.80	-180.40	87.00
Upland Barren (acres)	2.40	14.60	0.00	0.00	12.20	0.00
Upland Forested (acres)	0.90	0.60	19.00	15.30	-0.30	-3.70
Upland Range (acres)	0.50	1.80	0.00	0.00	1.30	0.00
Upland Scrub/Shrub (acres)	16.40	11.90	0.20	0.10	-4.50	-0.10
Urban (acres)	0.20	0.30	0.20	0.10	0.10	-0.10
Wetland Forested (acres)	0.00	0.10	3.10	1.90	0.10	-1.20
Wetland Scrub/Shrub -Fresh (acres)	11.20	5.30	1.10	2.30	-5.90	1.20
Wetland Scrub/Shrub -Salt (acres)	148.40	227.70	70.90	117.00	79.30	46.10
Total (acres)	**1340.70**	**1340.60**	**1611.30**	**1611.20**		

cause of the lowered marsh to open water and land to open water ratios in the reference area was an increase in the open water-salt (17.9 %) and a reduction in marsh-salt (-9.3 %) habitats.

Shoreline Change: No shoreline erosion rate was calculated along the west bank of Bayou Lafourche and Belle Pass due to dissimilar shoreline position methods. However, it was evident from field observations, 1998 and 2001 DGPS shoreline position measurements (figure 18), and maintenance inspections (Dearmond 2003) that no erosion occurred behind the foreshore rock dike, the pre-existing spoil area, and the flotation channel spoil bank. Therefore, the project was successful in decreasing the rate of shoreline erosion along the west bank of Belle Pass and Bayou Lafourche. While the shoreline behind the foreshore rock dike displayed no visible signs of erosion, large sections the pre-existing spoil area and the flotation channel spoil bank provide insignificant vegetative cover or remain unvegetated 3.5 years after construction (figure 18).

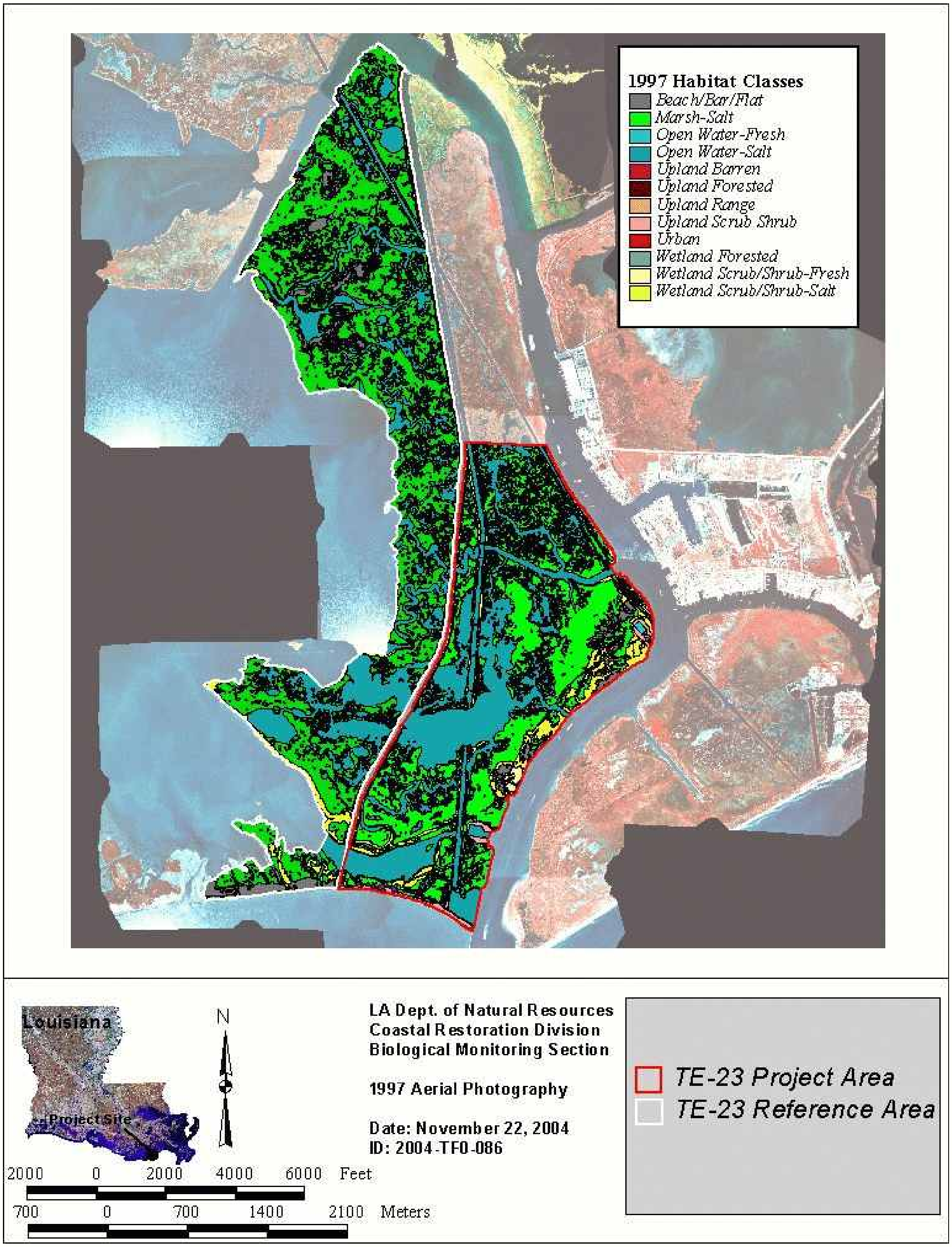


Figure 14. **Pre-construction (1997) habitat classifications of the West Belle Pass Headland Restoration (TE-23) project and reference areas.**

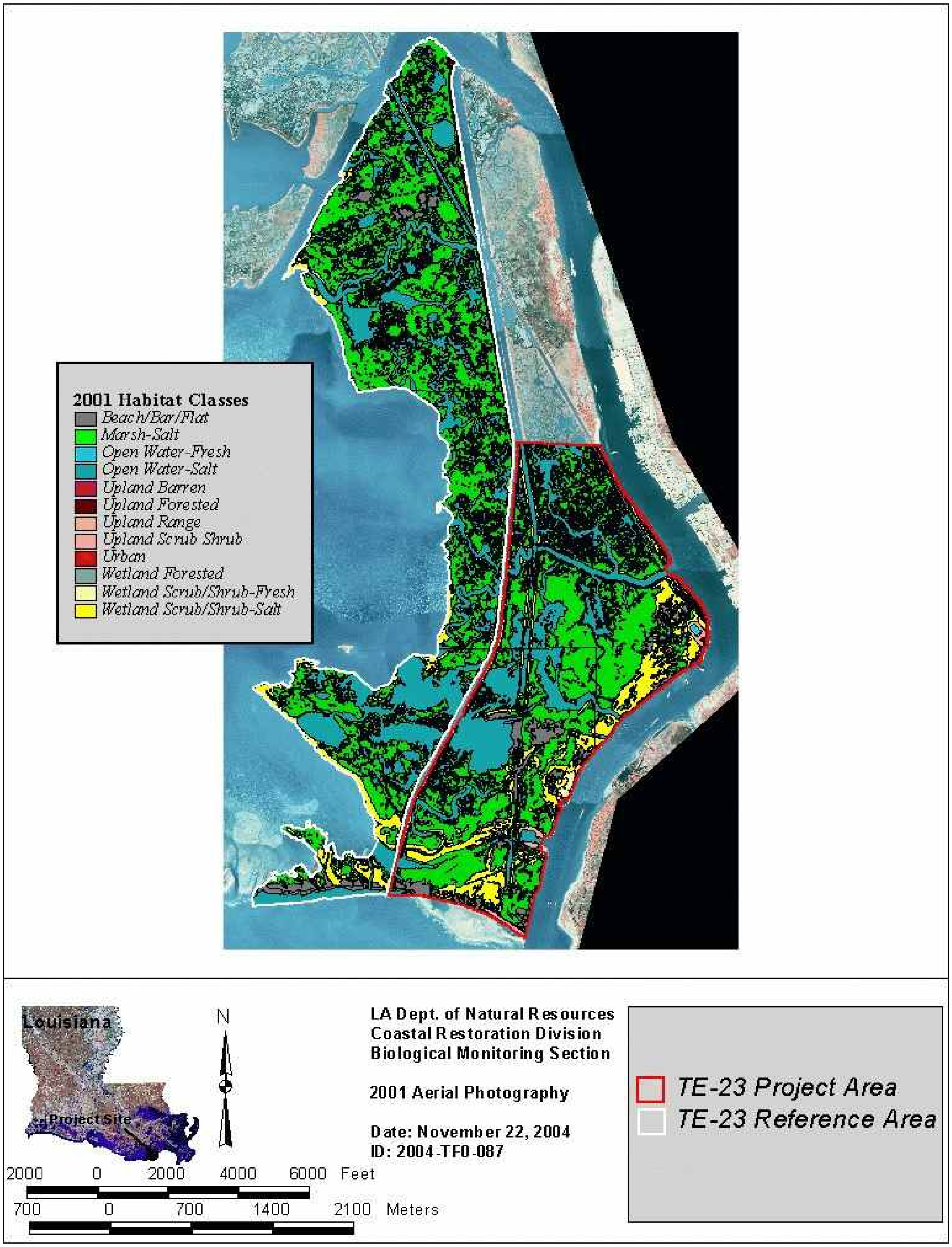


Figure 15. **Post-construction (2001) habitat classifications of the West Belle Pass Headland Restoration (TE-23) project and reference areas.**

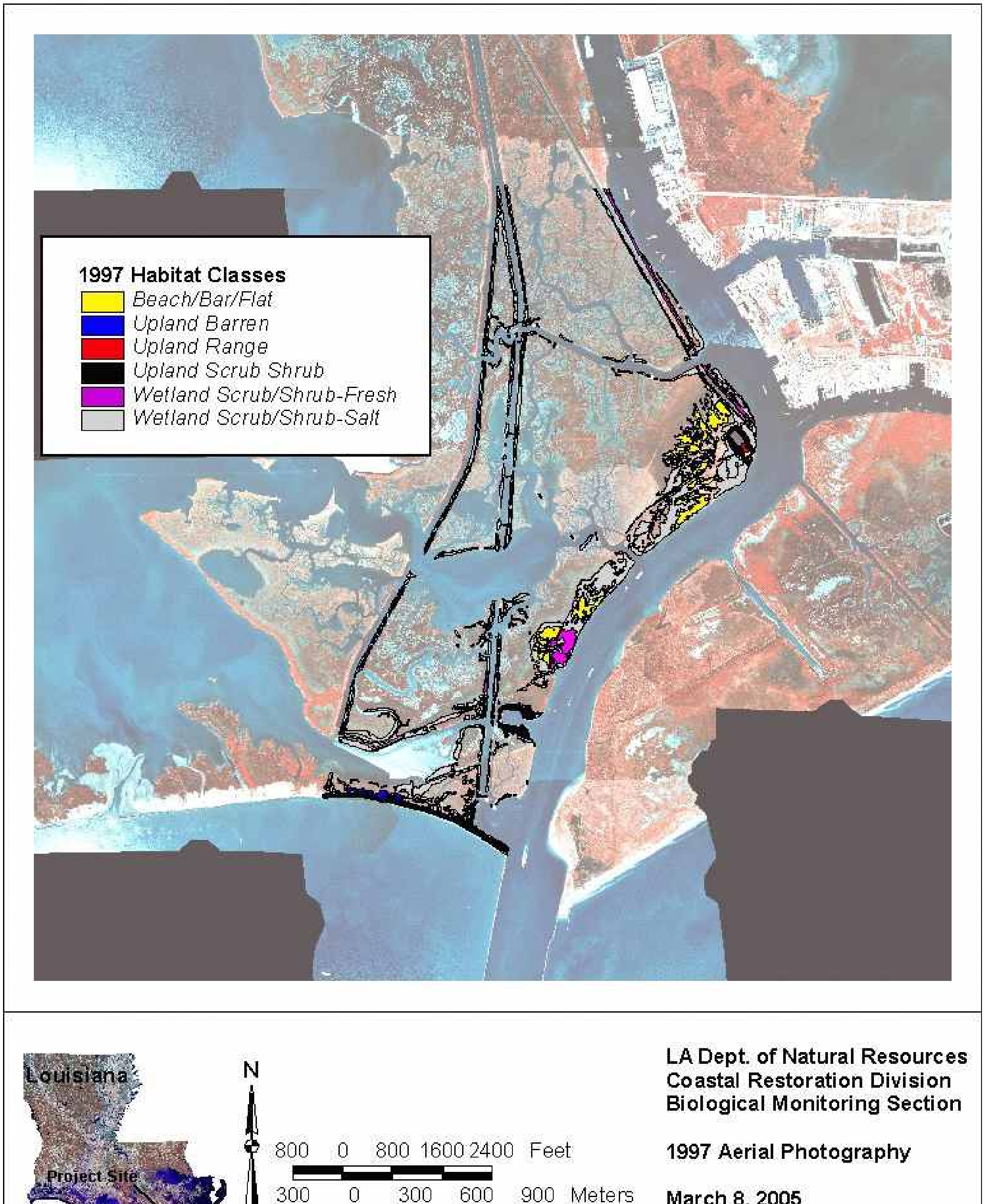


Figure 16. **Location of pre-construction (1997) upland, barren, and scrub-shrub habitats in the West Belle Pass Headland Restoration (TE-23) project area.**

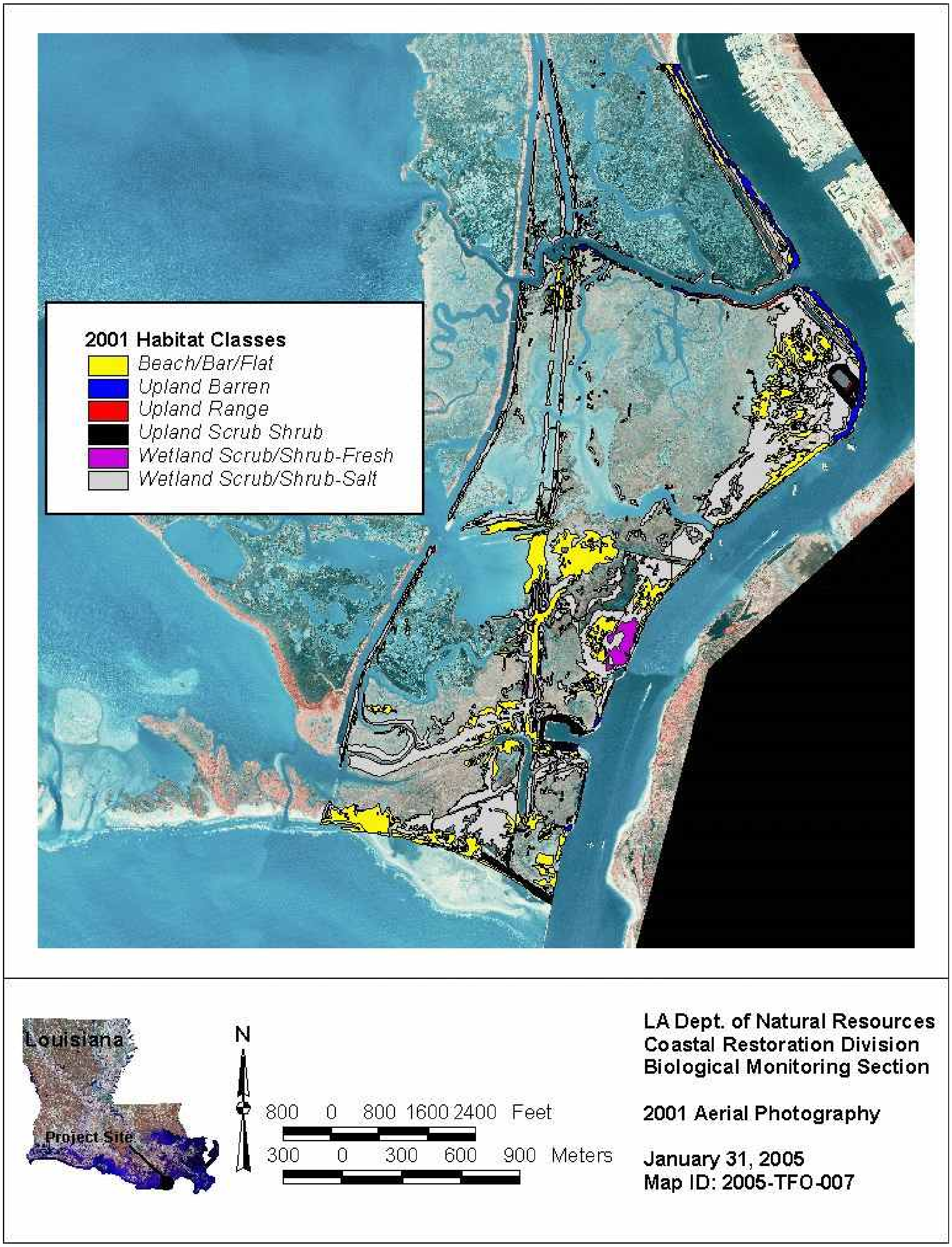


Figure 17. **Location of post-construction (2001) upland, barren, and scrub-shrub habitats in the West Belle Pass Headland Restoration (TE-23) project area.**

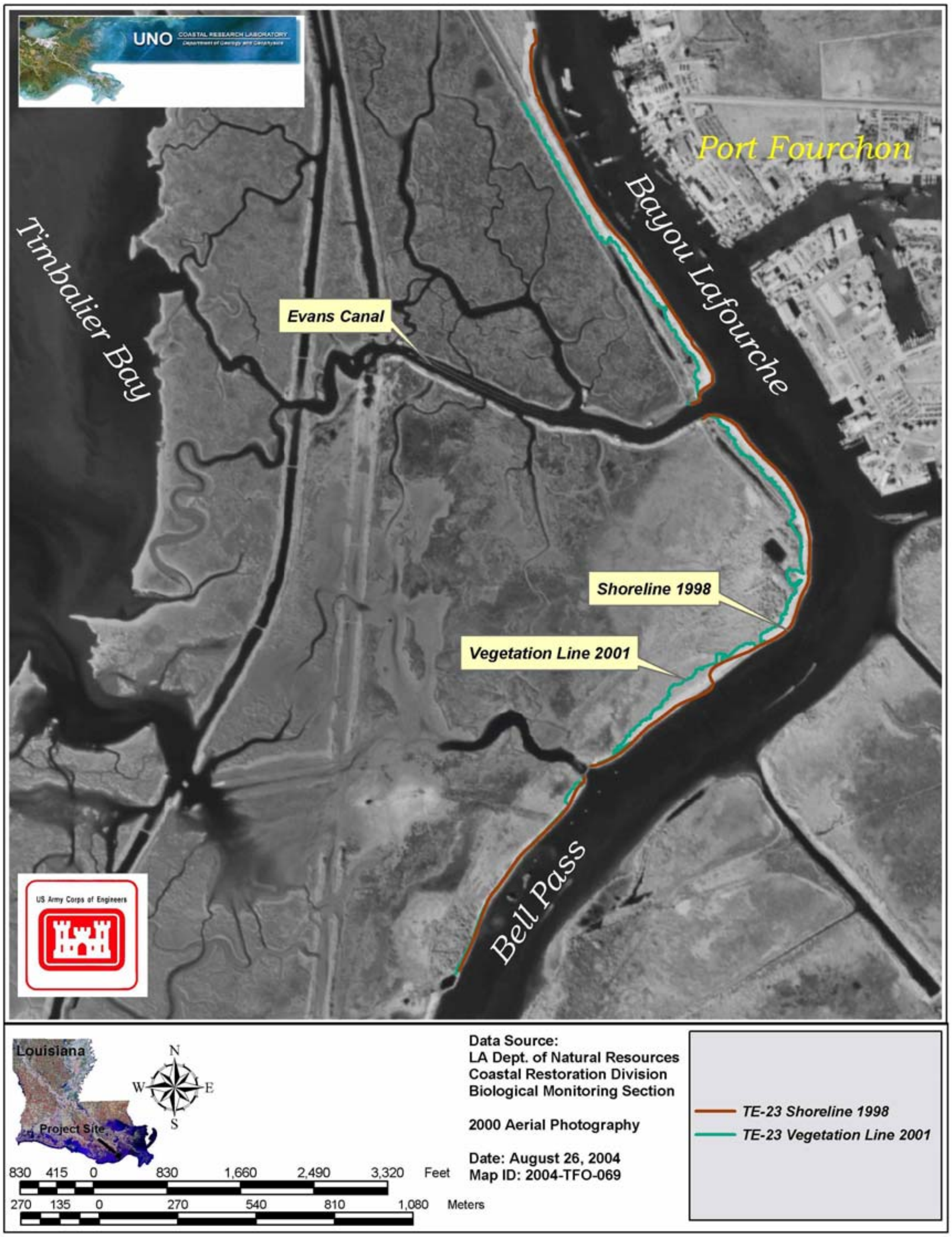


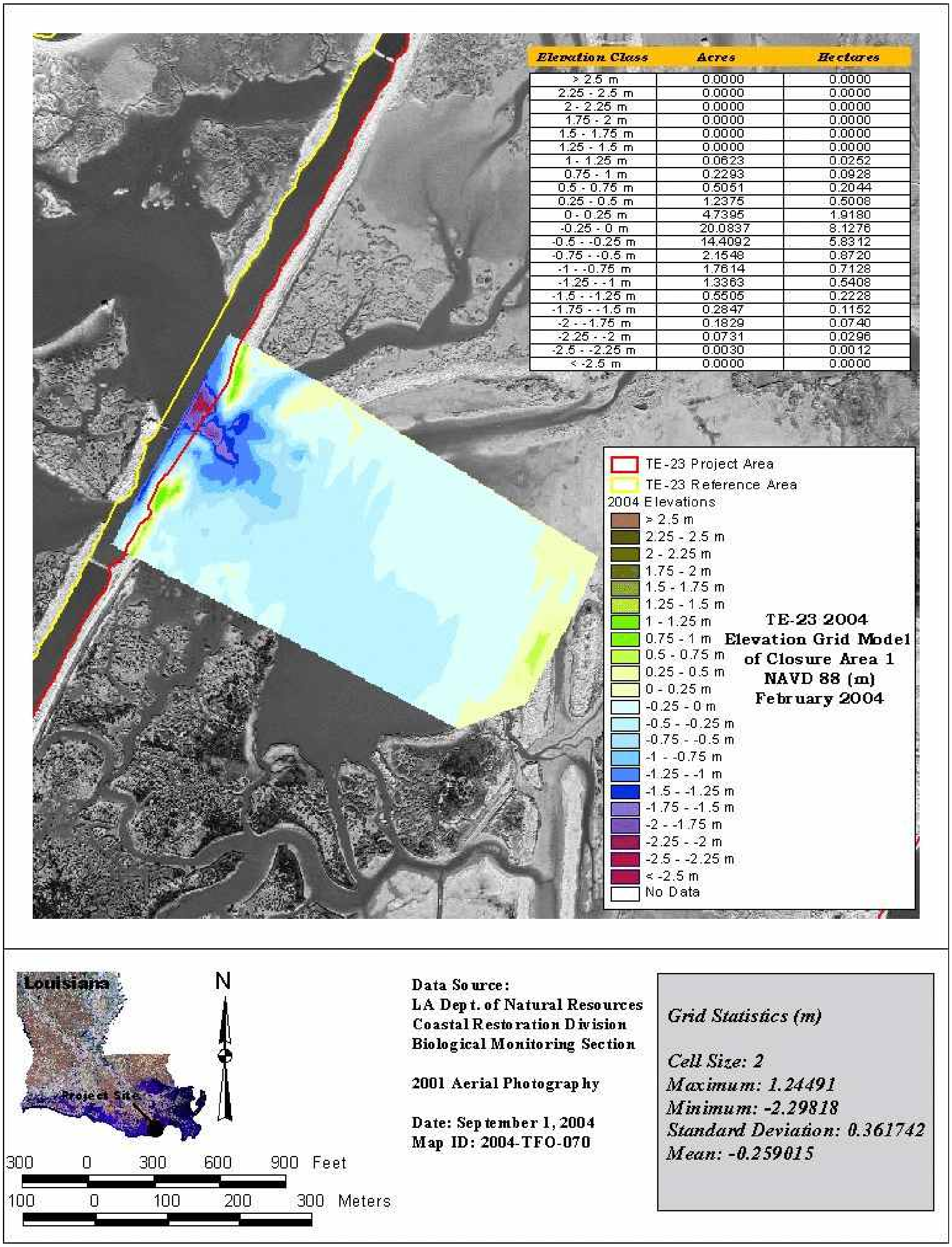
Figure 18. 1998 (immediate post-construction) and 2001 (2.5 years post-construction) shoreline surveys for the West Belle Pass Headland Restoration (TE-23) project area. 2000 aerial photography provided courtesy of UNO/CRL and USACE-NOD.

Bathymetry/Topography: Post-construction (2004) elevation distributions in a 47.6 acre (19.3 ha) portion of the closure 1 marsh creation area are shown in figure 19. The average elevation inside this predominantly subaqueous area was -0.85 ± 0.11 ft (-0.26 ± 0.36m) NAVD 88 (table 2). The elevation distributions and volume change required to fill this area to a 2.0 ft (0.61 m) NAVD 88 elevation are recorded in figure 20. This portion of the closure 1 marsh creation will have to be aggraded 2.85 ± 0.11 ft (0.87 ± 0.36m) NAVD 88 on average to reach the target elevation. Approximately, 153,981 yd^3 (117,537 m^3) of dredge material will be required to elevate this 47.6 acre (19.3 ha) area to the 2.0 ft (0.61 m) NAVD 88 elevation. This 2004 (5.5 years post-construction) survey also determined the localized difference between the MLG and NAVD 88 datums to be 1.07 ± 0.01 ft (0.33 ± 00 m) with the NAVD 88 being the lower datum (table 2).

The undated (assumed to be the as-built survey) and unreferenced (assumed to be MLG in feet) survey data showed the average elevation in the closure 3 marsh creation area to be 2.79 ± 0.44 ft (0.85 ± 0.13 m) MLG while the average elevation in the previously mentioned 47.6 acre (19.3 ha) portion of the closure 1 marsh creation area was 1.47 ± 1.09 ft (0.45 ± 0.33 m) MLG (table 2). When converted to NAVD 88 using the conversion factor in the preceding paragraph, the closure 3 marsh creation area exhibited an average elevation of 1.72 ± 0.44 ft (0.53 ± 0.13 m) NAVD 88 and the selected portion of the closure 1 marsh creation area displayed an average elevation of 0.40 ± 1.09 ft (0.12 ± 0.33 m) NAVD 88 (table 2). If these assumptions are correct, the closure 3 marsh creation was filled to the correct elevation while the closure 1 marsh creation was built to a much lower elevation [approximately 1.5 ft (0.46 m) lower than projected]. Moreover, the average elevation inside the 47.6 acre (19.3 ha) portion of the closure 1 marsh creation area would have subsided by 1.25 ft (0.38 m) NAVD 88 over the 5.5 year period between the surveys if these assumptions are correct (table 2).

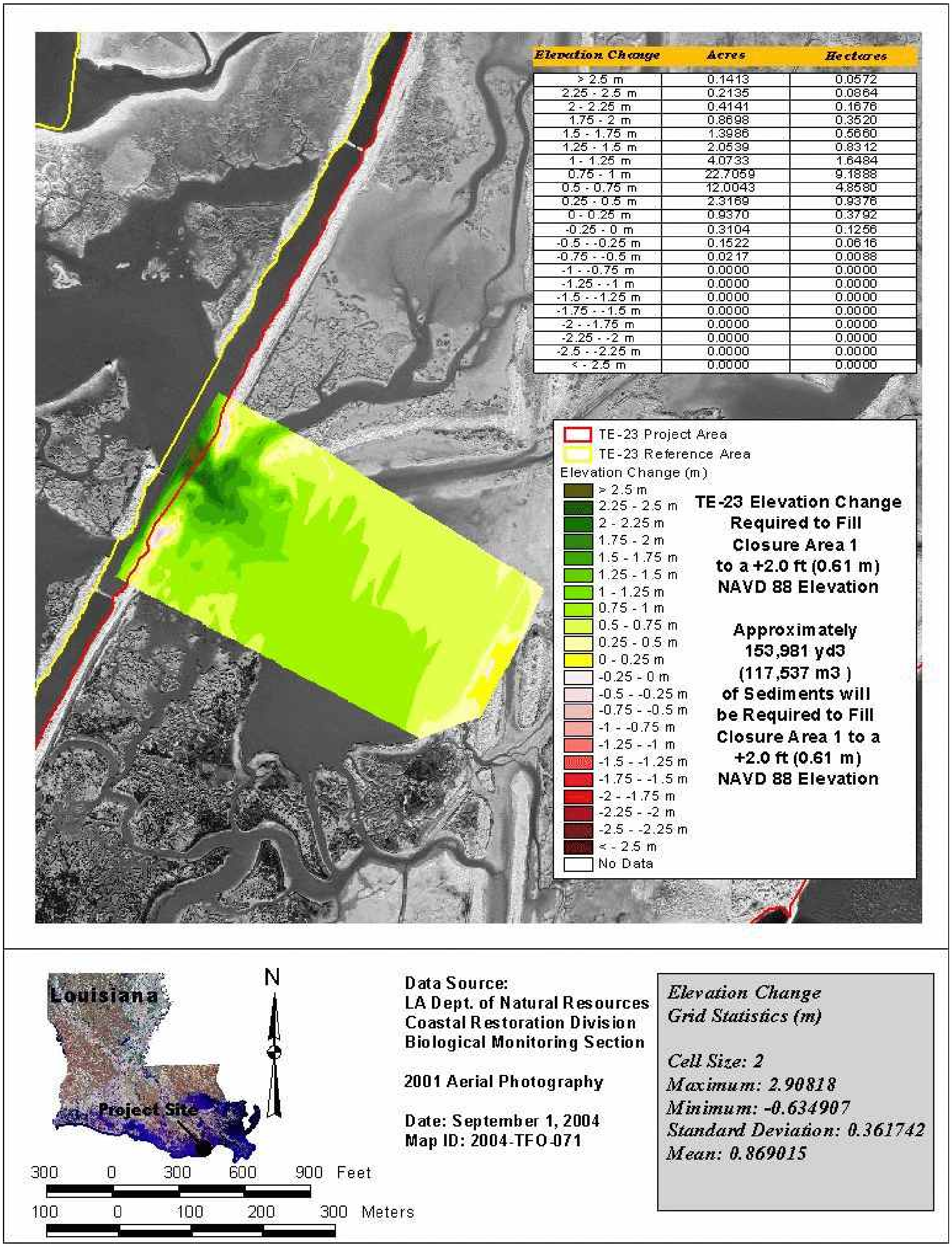
Table 2. Average elevations in the closure 1 and closure 3 marsh creation areas in MLG and NAVD 88 datums. Also shown are elevation change in the closure 1 marsh creation area, and the localized MLG to NAVD 88 conversion factor at the West Belle Pass Headland Restoration (TE-23) project.

Marsh Creation Area	Assumed As-built Survey	Assumed As-built Survey	2004 Survey	Elevation Change	Conversion Factor
	MLG ft (m)	NAVD 88 ft (m)	NAVD 88 ft (m)	NAVD 88 ft (m)	ft (m)
Closure 1	1.47 (0.45)	0.40 (0.12)	-0.85 (-0.26)	1.25 (0.38)	1.07 (0.33)
Closure 3	2.79 (0.85)	1.72 (0.53)	N/A	N/A	



Elevation Class	Acres	Hectares
> 2.5 m	0.0000	0.0000
2.25 - 2.5 m	0.0000	0.0000
2 - 2.25 m	0.0000	0.0000
1.75 - 2 m	0.0000	0.0000
1.5 - 1.75 m	0.0000	0.0000
1.25 - 1.5 m	0.0000	0.0000
1 - 1.25 m	0.0623	0.0252
0.75 - 1 m	0.2293	0.0928
0.5 - 0.75 m	0.5051	0.2044
0.25 - 0.5 m	1.2375	0.5008
0 - 0.25 m	4.7395	1.9180
-0.25 - 0 m	20.0837	8.1276
-0.5 - -0.25 m	14.4092	5.8312
-0.75 - -0.5 m	2.1548	0.8720
-1 - -0.75 m	1.7614	0.7128
-1.25 - -1 m	1.3363	0.5408
-1.5 - -1.25 m	0.5505	0.2228
-1.75 - -1.5 m	0.2847	0.1152
-2 - -1.75 m	0.1829	0.0740
-2.25 - -2 m	0.0731	0.0296
-2.5 - -2.25 m	0.0030	0.0012
< -2.5 m	0.0000	0.0000

Figure 19. **Post-construction 2004 elevation distributions in the 47.6 acre (19.3 ha) portion of the closure 1 marsh creation area at the West Belle Pass Headland Restoration (TE-23) project.**



Elevation Change	Acres	Hectares
> 2.5 m	0.1413	0.0572
2.25 - 2.5 m	0.2135	0.0864
2 - 2.25 m	0.4141	0.1676
1.75 - 2 m	0.8698	0.3520
1.5 - 1.75 m	1.3986	0.5660
1.25 - 1.5 m	2.0539	0.8312
1 - 1.25 m	4.0733	1.6484
0.75 - 1 m	22.7059	9.1888
0.5 - 0.75 m	12.0043	4.8580
0.25 - 0.5 m	2.3169	0.9376
0 - 0.25 m	0.9370	0.3792
-0.25 - 0 m	0.3104	0.1256
-0.5 - -0.25 m	0.1522	0.0616
-0.75 - -0.5 m	0.0217	0.0088
-1 - -0.75 m	0.0000	0.0000
-1.25 - -1 m	0.0000	0.0000
-1.5 - -1.25 m	0.0000	0.0000
-1.75 - -1.5 m	0.0000	0.0000
-2 - -1.75 m	0.0000	0.0000
-2.25 - -2 m	0.0000	0.0000
-2.5 - -2.25 m	0.0000	0.0000
< - 2.5 m	0.0000	0.0000

Figure 20. **Post-construction 2004 elevation and volume change required to fill the 47.6 acre (19.3 ha) portion of the closure 1 marsh creation area to a 2.0 ft (0.61 m) NAVD 88 elevation at the West Belle Pass Headland Restoration (TE-23) project.**

Discussion

The results of this marsh creation and shoreline protection wetlands restoration project indicate that the marsh creation goal was not attained, the marsh to open water ratio goal was reached through indirect methods, and the shoreline protection goal was realized. The creation of only 31.2 acres (12.6 ha) of saline marsh habitat fell far short of the predicted 184.0 acres (74.5 ha) and resulted in only a 5.4% increase in marsh area. The increase in marsh to open water ratio was primarily an effect of the reduction in open water-salt habitat (-32.6 %) through creation of wetland scrub/shrub-salt (53.4 % increase in area), beach/bar/flat (193.9 % increase in area), and upland barren (508.3 % increase in area) habitats (table 1). In contrast, the shoreline protection phase of this project has fortified the western banks of Belle Pass and Bayou Lafourche, substantially reducing the shoreline erosion rate.

<u>*Marsh Creation*</u>: The vast majority of habitats created by this project were not saline marsh. Approximately, 159.7 acres (64.6 ha) of non-marsh habitats were created while only 31.2 acres (12.6 ha) of salt marsh were constructed. The largest non-marsh environment created was the 79.3 acre (32.1 ha) wetland scrub/shrub-salt habitat followed by the thinly vegetated beach/bar/flat [66.9 acres (27.1 ha)] and upland barren [12.2 acres (4.9 ha)] habitats. Also, constructed was a 1.3 acre (0.5 ha) upland range habitat, which was created by building the Evans Canal earthen retention dike. Created scrub-shrub and upland barren habitats are formed by placing sediments at higher elevations than the natural marsh platform (Cowardin et al. 1979; Edwards and Proffitt 2003; Penland et al. 1996; Penland et al. 1997; Rapp et al. 2001; Boshart 2003; Curole 2003) while beach/bar/flat habitats are created at lower elevations than the natural marsh (Cowardin et al. 1979; Rapp et al. 2001; Curole 2003). As a result, these non-marsh habitats have different structures than natural or created salt marsh environments and cannot replicate marsh ecosystem functions (Edwards and Proffitt 2003). Moreover, even structurally similar constructed marshes require decades to approach functional equivalence with natural marshes (Craft et al. 1999; Moy and Levin 1991; Simenstad and Thom 1996; Edwards and Proffitt 2003; Stolt et al. 2000). However, little marsh was created and a large portion of the closure 1 marsh creation remains subaqueous, so there is not much structural similarity between the marsh creation areas and the natural marshes in the project and reference areas.

Tidal marshes in conjunction with estuaries function as nursery habitats for larval and juvenile stages of development for important gulf coast fisheries (Kutkhun 1966; Herke and Rogers 1989; Perret and Melancon 1991). Factors such as the amount of marsh edge (Minello et al. 1994) and the marsh acreage (Zimmerman et al. 2000; Kutkhun 1966; Herke and Rogers 1989; Perret and Melancon 1991) available to estuary-dependant fisheries influence the abundance of these species. Moreover, vegetated marsh habitats have been found to be more productive nursery environments than barren habitats (Zimmerman and Minello 1984; Zimmerman et al. 1984). Therefore, it seems plausible to infer that the creation of mostly scrub-shrub and barren habitats will not enhance fisheries development in the project area, and a secondary function of coastal marshes will not be restored.

Close examination of habitat maps and aerial photography reveal (figures 13, 15, and 17) that the marsh creation project areas are semi-impounded on three sides by pre-existing dredge spoil areas, pipeline canal spoil banks, the flotation channel spoil bank, and the Evans Canal retention dike. Therefore, the project has exacerbated the semi-impounded complexion of the project area by expanding the barriers to natural hydrologic flow. Impounded and semi-impounded marshes inhibit tidal flushing, prolong the duration of flooding events (Swenson and Turner 1987), lower sediment and nutrient inputs (Kuhn et al. 1999), and inhibit fisheries access (Kutkhun 1966; Herke and Rogers 1989; Perret and Melancon 1991). Generally, the distribution of *S. alterniflora* marshes is governed by tidal amplitude and elevation (Eleuterius and Eleuterius 1979; McKee and Patrick 1988). In addition, these marshes do require periodic draining to reduce plant stress (Eleuterius and Eleuterius 1979; Nyman et al. 1993), promote root elongation (DeLaune et al. 1993), and lower sulfide levels (Pezeshki et al. 1991; Nyman et al 1993; DeLaune et al. 1983) to sustain themselves. However, impounded and semi-impounded marshes do not promote these attributes and can lead to vegetation dieback (DeLaune et al. 1983; Mendelssohn and McKee 1988) and peat collapse (DeLaune et al. 1994). In contrast, the inhibition of tidal flushing along the created upland barren (figure 7) and closure 1 beach/bar/flat (figure 9) habitats may cause these environments to retain high salt concentrations and low vegetative cover (Edwards and Proffitt 2003; Mitsch and Gosselink 2000). Impounded and semi-impounded salt marshes have been found to have lower accretion rates and bulk densities than non-impounded marshes (Kuhn et al. 1999; DeLaune et al. 1992). Saline marshes require high bulk densities and accretion rates to keep pace with subsidence and sea level rise (Nyman et al. 1990; Nyman and DeLaune 1991; Kuhn et al. 1999; DeLaune et al. 1992). Moreover, these lowered mineral sediment and nutrient inputs have been determined to reduce the net annual primary productivity (NAPP) of impounded marshes (Kuhn et al 1999). Impounded and semi-impounded areas subdivide marshes and block migratory movements of fisheries, which lower fisheries yield in impounded areas (Kutkhun 1966; Herke and Rogers 1989; Perret and Melancon 1991). Therefore, impounded and semi-impounded wetlands like the marsh creation areas tend to induce plant stress, lower accretion rates, and reduce fisheries production.

While the marsh creation project areas created a primarily semi-impounded non-marsh habitat, the reference area showed evidence of shoreline and marsh edge erosion. This area sustained increases in open water-salt (17.9 %) and wetland scrub/shrub-salt (65.0 %) habitats and reductions in marsh-salt (-9.3 %) and beach/bar/flat (-42.3 %) habitats during the interval between the November 1997 and November 2001 habitat mapping events (table 1). The dominant mechanism of this land-loss in the reference area appears to be shoreface retreat along the Gulf of Mexico shoreline (figures 13, 14, and 15). The westerly drifting longshore transport of sediment in the Belle Pass area (figure 2) (Stone and Zhang 2001; Harper 1977; Peyronnin 1962; Dantin et al. 1978) and storm induced overwash events (Ritiche and Penland 1998a; Ritiche and Penland 1998b; Harper 1977; Peyronnin 1962; Stone et al. 1997; Stone et al. 1993; Penland and Ritiche 1979; Boyd and Penland 1981) are probably the principle morpyhodymanic agents causing the shoreline transgressions along the low profile reference area. During the sampling interval, Hurricane Georges (1998), Tropical Storm Allison (2001), and numerous cold fronts (Boyd and Penland 1981; Ritiche and Penland 1998b; Dingler and Reiss 1990) are likely to have caused overwash events along the storm dominated Caminada-Moreau Headland. Moreover, it is not surprising that the reference area shoreline is retreating since high rates of shoreline erosion along the Caminada-Moreau Headland have been reported for over a century (figure 5) (Morgan and Larimore 1957; Williams et al. 1992; Dantin et al. 1978; McBride and Byrnes 1997; May and Britsch 1987). However, the project area shoreline was relatively stable over the sampling period because it is probably buffered from overwash events by the 228,000 yd^3 (174,319 m^3) of dredged materials deposited on the beach (beach fill) just south of the project area (figures 13, 14, and 15). Although no quantitative data are available, it appears that the beach fill area has transgressed (since 2001) to its preconstruction position leaving the project area exposed to geomorphic processes (figure 21). In addition, the creation of a large wetland scrub/shrub-salt habitat on the marsh platform behind the eroded reference area shoreline was probably induced by overwash events (Courtemanche et al. 1999; Harper 1977; Ritiche and Penland 1998a; Ritiche and Penland 1998b; Penland and Ritiche 1979; Boyd and Penland 1981) and/or spillover effects of construction in marsh (closure 3 marsh creation area) and beach fill areas.

The West Belle Pass Headland Restoration (TE-23) project is not alone in its failure to fully create marsh environments. Several other projects have partially or totally failed to create emergent marsh. The Barataria Bay Waterway Wetland Restoration (BA-19) project (CWPPRA) did not create any new marsh and the entire project area remains subaqueous (Curole 2001). The Atchafalaya Sediment Delivery (AT-02) and Big Island Mining (AT-03) projects (CWPPRA) have created substantially more scrub-shrub and beach/bar/flat habitats than emergent marsh (Rapp et al 2001; Curole 2003). Maintenance dredging and disposal along the Lower Atchafalaya River Bay and Bar navigation channel has resulted in the creation of many dredge material islands in the Lower Atahafalaya River. The vegetative community on these artificially created islands differs greatly from naturally created habitats due to placement of dredged material at higher elevations than the naturally created deltaic lobe islands. The vegetative communities on these dredged material islands are mainly composed of wetland scrub-shrub, forested wetland, fresh marsh, and bare ground habitats while the natural islands are generally composed of fresh marsh with small acreages of forested wetland habitat (Penland et al. 1996; Penland et al. 1997). Maintenance dredging and disposal along the Calcasieu ship channel has resulted in the creation of some higher elevated habitats, which consist of scrub-shrub and high marsh vegetation (Edwards and Proffitt 2003). The Bayou LaBranche Wetland Creation (PO-17) project (CWPPRA) initially created higher elevated wetlands, which consisted of scrub-shrub habitat. However after four years of sediment consolidation, the project area experienced succession to a marsh habitat (Boshart 2003). Therefore, sediment consolidation is an important parameter that should be addressed during the engineering and design phase of a marsh creation project. In closing, all the above projects, including the West Belle Pass Headland Restoration (TE-23) project, could have created marsh habitats if they were built to the proper elevation and had sufficient containment (USACE 1987). Therefore, it is evident that better planning and site-specific designs are needed to create sustainable marsh communities. Specifically, these preconstruction data should consist of geotechnical investigations to include stratigraphy and accurate estimates of sediment consolidation and elevation surveys in the project and reference areas to determine fill volume and establish a site-specific target elevation (USACE 1987).

Figure 21. **September 2004 aerial image depicting shoreline transgressions in the beach fill and project areas at the West Belle Pass Headland Restoration (TE-23) project.**

Shoreline Protection: The shoreline protection phase of this project has stabilized the western banks of Belle Pass and Bayou Lafourche. The foreshore rock dike and the rock closures substantially reduced shoreline erosion along these navigation channels. Therefore, the goal to decrease the rate of shoreline retreat was attained. The rock structures also have proven to be structurally stable and resistant to erosion and show few signs of subsidence (Dearmond 2003). However, an elevation survey of the rock structures should be initiated to quantitatively determine the settlement rate of these structures. In summary, the foreshore rock dike and the rock closures appear well suited to protect the western banks of Belle Pass and Bayou Lafourche into the immediate future.

Construction Failures: Construction failures have severely impeded the West Belle Pass Headland Restoration (TE-23) project's ability to create sustainable saline marsh environments. The structural breakdown of the earthen closures (closures 1 and 3) resulted in breaching and washout of dredged material (figure 6). Therefore, a large portion of the closure 1 marsh creation area remains subaqueous (figure 9). The earthen structures should have been subject to geotechnical inspections before the marsh creation phase was initiated because these structures were constructed using Bellpass and Scatlake soils, which have low strength and high shrink-swell potentials (U.S. Soil Conservation Service 1984). Therefore, the containment dikes likely had very low shear strengths. These soils should not have been used to construct the containment dikes and alternative soils or materials like sheet pile and armor stone should have been utilized. Moreover, Dearmond (2003) reported that all three earthen closures (1, 2, and 3) were breached by early 2000. As a result, alternative soils or materials should be strongly considered before closure 1 is reconstructed for the second marsh creation phase. Once constructed, this structure should be carefully inspected for stability and strength. Secondly, less than half of the design volume of dredged material was pumped into the marsh creation areas. The construction completion report specifically states that all marsh creation areas were constructed to an elevation of at least 2.75 ft (0.84 m) MLG. However, the low volume of dredged materials removed from the borrow areas and the high volume of open water in the creation areas indicate that this estimate is greatly exaggerated. In addition, J. Saxton (LDNR/CRD, pers. comm.) also implies that the elevation in some of the marsh creation areas was lower than expected. The only plausible explanation for the dredged material shortage is the volume of sediments required to dredge the navigation channel to the desired depth was overestimated and dredging ceased as soon as the channel depth was reached. If marsh creation projects are to be successful, marsh creation not just navigation channel dredging and disposal, needs to be a priority (USACE 1987).

Consistency: Adverse environmental impacts destroyed or injured wetlands and violated the project's consistency determination. Approximately, 9.5 acres (3.8 ha) of vegetated wetlands were severely or moderately compacted by marsh buggies (figures 8, 10, 11, and 12) (J. Harris, LDNR/CMD, pers. comm.). Marsh-salt and wetland scrub/shrub-salt habitats in the project area were damaged through repeated passage of marsh buggies. Although many of the tracks caused moderate soil compaction, several of the tracks formed deep soil depressions (rutting) (figures 10, 11, and 12). Severely compacted soils have been found to modify vegetation patterns, cause vegetation mortality, alter hydrology and sediment distributions, and cause tidal scouring. Furthermore, in extreme cases persistent rutting has induced the formation of shallow ponds and lakes (Bass 1996; Bass 1997; Detro 1978; Whitehurst et al. 1977). The moderately and severely compacted soils in the project area have modified vegetation patterns and caused vegetation mortality while several of the severely compacted tracks have also altered hydrology and caused tidal scouring (figure 10). Although many of the moderately compacted tracks are not readily apparent during ground surveys, they are clearly visible on November 2001 and May 2002 CIR aerial photographs signifying that the majority of marsh buggy tracks are still affecting the structure and function of project area wetlands. As a result, future marsh creation projects should utilize marsh buggies only when no other construction alternatives are feasible. When marsh buggies are used to construct marsh creation projects, these tracked vehicles should be restricted to clearly defined access corridors and open water areas to minimize soil and vegetation compaction. If existing or created wetlands are impacted by marsh buggies during marsh creation projects, compacted soils and vegetation should be remediated before construction is completed. Secondly, 8.0 acres (3.2 ha) of vegetated wetlands were buried by creation of the flotation channel spoil bank (figure 8) (J. Harris, LDNR/CMD, pers. comm.). The establishment of this elevated berm converted marsh and wetland scrub/shrub-salt habitats to the predominantly barren beach/bar/flat and upland barren habitats. Moreover, high salt concentrations may be inhibiting further vegetation colonization on this spoil bank (Edwards and Proffitt 2003; Mitsch and Gosselink 2000). The contractor should have disposed of the flotation channel material without altering the wetland habitats. Alternative disposal techniques such as releasing the flotation channel refuse into the navigation channel or refilling the flotation channel once the foreshore rock dike was constructed should have been considered.

Although the violations were rectified using compensatory mitigation, no remedial steps have been taken to date, and the problems created by the violations persist. Future consistency determination or coastal use permit (CUP) violations on CWPPRA projects should be settled through site remediation and not through compensatory mitigation.

Management Practices: The West Belle Pass Headland Restoration (TE-23) project also has been marred by bad management practices. As can be attested to by the results of this project, very little regulatory oversight was exercised during project construction. Inspection services seem to be very limited or nonexistent since the construction difficulties and adverse impacts were allowed to take place. Furthermore, comprehensive inspections have been found to be essential to the success of marsh creation projects (USACE 1987). In addition, documentation of construction activities was exceedingly inadequate. The as-built drawings seem to be scarcely modified design drawings, and the construction completion report was lacking important details and accuracy. The as-built survey was submitted without a date or vertical datum identified. Although possible, it does not seem likely that the closure 1 marsh creation area experienced a 1.25 ft (0.38 m) elevation change during the interval from 1998 to 2004 (table 2). Therefore, there is little confidence in the provided survey. Moreover, it is hard to make assessments of project viability with assumed data. In addition, a very limited survey of the foreshore rock dike was undertaken, and no survey of the retention dike and closures seems to have taken place. Apparently, these structures were implicitly understood to be built to the proper elevation. Finally, the use of the MLG tidal datum also seems to be a bad management decision. While MLG may adequately estimate navigation channel depth, marsh creation requires more accurate estimates of orthometric heights since small changes in elevation can alter the habitat(s) created (USACE 1987). Localized tidal datums like MLG are inconsistent and are based on the arithmetic mean of tide gages over time while NAVD 88 creates a geoid model (equipotential surface) to consistently measure orthometric heights (NGS 1998). Moreover, the LDNR/CED has constructed a primary and secondary static monument network using NAVD 88, the Louisiana Coastal Zone (LCZ) GPS Network, to accurately measure orthometric heights in wetland areas (LDNR/CED 2003). Future marsh creation projects should use this network to measure orthometric heights. In conclusion, bad management practices contributed to the failure of the marsh creation phase of this project.

It seems that construction failures, adverse impacts, and bad management practices have limited the West Belle Pass Headland Restoration (TE-23) project's ability to create structural and functional saline marsh environments. Moreover, this seems to be a common phenomenon inherent to many beneficial use projects, which are primarily concerned with navigation channel dredging and marsh creation is of secondary importance or simply a mechanism to dispose of dredged materials. However with careful planning and site-specific designs, sediments dredged from navigation channels could be utilized to mediate coastal land-loss and create additional saline marshes along the rapidly transgressing deltaic plain coast of Louisiana.

Conclusions

It is always hoped that coastal restoration projects restore, enhance, and/or protect wetland environments. Moreover, marsh creation projects should aspire to replicate the structure and function of natural marshes while shoreline protection projects should strive to inhibit or slow the rate of shoreline erosion. Whereas the West Belle Pass Headland Restoration (TE-23) project was successful in achieving the shoreline protection goal, the marsh creation phase of this project failed to reach its goals. Although the marsh to open water ratio goal was technically accomplished, it was attained through reductions in open water habitat not through marsh creation because little saline marsh was created in the project area. Therefore, the goal to restore or enhance marsh ecosystem structure and function was not attained. This project primarily created semi-impounded non-marsh habitats due to construction failures, adverse impacts, and bad management practices. Furthermore, the quagmire that the marsh creation phase of this project has become is a direct result of planning, design, and construction decisions made before project completion. Therefore if structural and functional salt marshes are to be created using sediments dredged from navigation channels, marsh creation, not just dredged material disposal, should be the focus of the project. Moreover, restoration projects are especially critical along the Caminada-Moreau Headland, which is a rapidly transgressing and subsiding headland that has been removed from its sediment source for over a century.

Several improvements should be initiated to enhance the marsh creation phase of the West Belle Pass Headland Restoration (TE-23) project. First of all, the second marsh creation phase should begin during the next Belle Pass and Bayou Lafourche navigation channel maintenance cycle. Phase 2 should strive to create structural and functional salt marsh environments in the closure 1 marsh creation area. Secondly, site remediation should be performed to restore the wetlands impacted by marsh buggies and flotation channel refuse. Specifically, the severely rutted wetlands require site remediation to mitigate tidal scouring and hydrologic modifications, and the upland barren habitats should be lowered to allow vegetation colonization. Thirdly, the Evans Canal retention dike should be breached in several additional locations to increase tidal exchange within project area marshes. Next, soil samples should be collected and analyzed in the closure 1 marsh creation area's beach/bar/flat habitat and in the upland barren habitat to determine soil toxicity. If feasible, these sites should be remediated to allow vegetation colonization. Lastly, the remaining habitat mapping event, which is scheduled for 2017, should be advanced to evaluate the effectiveness of the phase 2 marsh creation event. This habitat mapping event should be scheduled three years after phase 2 is constructed.

Future CWPPRA marsh creation projects, including phase 2 of the West Belle Pass Headland Restoration (TE-23) project, should strive to replicate marsh ecosystem structure and function. Moreover if these projects are located along navigation channels, marsh creation, not dredged material disposal, should be emphasized. In addition, these projects should have a clear set of goals and objectives that are derived through careful planning and site-specific designs. Furthermore, the projects should employ geotechnical investigations and elevation surveys as the foundation of the design. Once construction begins, thorough inspections should be conducted and detailed documentation should follow. Next, all elevation data should be collected using the Louisiana Coastal Zone (LCZ) GPS Network. Finally, future marsh creation projects should restrict marsh buggies to confined corridors, and marsh buggies should be used only when other construction techniques are not viable. These mistakes should not be repeated when building marsh creation projects in the future.

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