Ecosystem restoration in Louisiana — a decade after the Deep Water Horizon oil spill

By

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ABSTRACT

Louisiana has a long history of coastal management and restoration actions with multiple projects implementing common approaches. Traditionally, most of the restoration efforts have been ongoing in Louisiana by state and federal agencies through the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA). These activities are now being expanded significantly through additional funding and implementing entities such as the Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States (RESTORE) Act of 2012 Council, National Resource and Damage Assessment (NRDA) through the Louisiana Trustee Implementation Group (LA TIG), and the National Fish and Wildlife Foundation (NFWF). Considering a broader ecosystem or landscape context for implemented restoration projects can provide a framework for emphasizing commonality of restoration goals. Such a framework allows for multiple benefits of restoration efforts to be quantified, including prioritized natural resources, ultimately assessing the effectiveness of large-scale restoration efforts in coastal Louisiana. Three disasters have completely changed the trajectory of Louisiana's coastal restoration and protection program. Hurricanes Katrina and Rita (2005) compelled the state to take serious note of the vagaries of nature, especially high-energy events like hurricanes, and to develop a comprehensive/robust coastal protection and restoration plan. Five years later, the Deepwater Horizon (DWH) oil spill exposed the fragility of the Louisiana coast but at the same time penalty monies provided much needed funding to implement the state's coastal protection and restoration plans. This paper provides a high-level assessment of project implementation and makes the case that Louisiana could move quickly in the implementation of various restoration plans because robust and comprehensive restoration plans were previously developed and are available. Here, it must be appreciated that for the first time, dedicated funding is available not only for regional programmatic monitoring to implement adaptive management, but also for development of the art and science of restoration. It is also suggested that for efficient and cost effective implementation of Louisiana's Coastal Master Plan federal agencies must work in tandem with the state/CPRA who not only bring the most comprehensive plan but expertise along with institutional knowledge to the table.

KEYWORDS: Coastal restoration, Deepwater Horizon, adaptive management, coastal management.

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INTRODUCTION

Historical perspective of land loss in Louisiana — ecocatastrophe

To refer to the ecosystem degradation in Louisiana caused by unprecedented land loss as an "ecocatastrophe" would not be an overstatement. Since the coast of Louisiana is not a uniform single geomorphic entity, the magnitude of degradation is not the same. It is a geologically diverse system and could be broadly divided into three major physiographic provinces viz. Mississippi River Delta Plain (MRDP), Marginal Delta Plain, and Chenier Plain (Figure 1). Like most of the deltaic plains of the world the MRDP, a partially submerged landform that makes up Louisiana's southeastern coastal region, is an example of a rapidly deteriorating major delta plain made increasingly unstable through sediment deficits, historical engineering infrastructure, and climate change. With subsidence and erosion rates unparalleled anywhere else in North America, the MRDP is facing large-scale environmental perturbations and physical changes resulting from the combined effect of natural and anthropogenic factors. Louisiana's coastal problems are not restricted to the MRDP, but also extend across the Marginal Delta Plain to the Chenier Plain in the southwestern part of the state. Despite efforts to reverse land losses in the late 20th century, Louisiana continues to lose wetlands at a rate of approximately 28 square kilometers per year (Couvillion *et al.* 2017). This high rate of land loss threatens coastal communities, industries and associated infrastructure, and a range of key local and national physical, economic, ecological and cultural assets (Khalil *et al.* 2011). Coastal Louisiana is vital not only to the state but the nation's economic health and annually sends more than $120 billion in goods to the rest of the United States and exports $36.2 billion internationally (CPRA 2017). Before human intervention, Louisiana's expansive and ecologically/biologically rich coastal landscape was sculpted over the preceding 6,000-7,000 years by avulsions of the Mississippi River as it shifted its course east and west, forming active and abandoned deltas through cyclic repetitions of active sedimentation followed by subsidence and coastal retreat (Roberts 1997). Sea level rise and subsidence were historically offset by the Mississippi River's land building processes in the MRDP, and mud stream accretion in the Chenier Plain (Stone *et al.* 2005; Penland *et al.* 2000). Geological studies have shown that since the early 20th century the rate of land loss has accelerated due to the combined effects of natural causes and multiple human interventions along the Louisiana coastal plain and throughout the Mississippi River watershed (Boesch *et al.* 1994; Gagliano *et al.* 1981). Coastal scientists and experts consider the Mississippi River Flood Control and Navigation System and the extensive matrix of oil and

gas pipeline and navigation canals to be among the major anthropogenic interventions causing land loss in Louisiana (Boesch *et al.* 1994; Turner 1997; Penland *et al.* 2000). During a short span of 70-80 years, the state's coast has lost almost one quarter (25%) of the land built over 6,000-7,000 years of geological history. One of the main reasons is that currently the sediment load of Mississippi River has been reduced by large-scale human activities to approximately 145 MMT from historically 400 MMT per year (Blum and Roberts 2009; Meade and Moody 2010).

The fragility of this system was palpable first during Hurricanes Katrina and Rita in 2005, and then during the DWH oil spill five years later in 2010. These three extraordinary disasters — two natural and the third anthropogenic — were wake-up calls. In 2007, in response to the hurricane events, Louisiana's Coastal Protection and Restoration Authority (CPRA) produced the first Ecosystem Restoration and Hurricane Protection Plan (Louisiana's Comprehensive Master Plan for a Sustainable Coast) pursuant to Act 8, analyzing and synthesizing decades of thinking about coastal projects and technical designs from previous plans, and emphasizing coordinated storm risk reduction and coastal restoration planning (Killebrew and Khalil 2018). Its focus was to achieve a sustainable coastal landscape using structural and nonstructural approaches as a prerequisite for both storm protection and ecological restoration (CPRA 2007). Lessons from the 2005 hurricanes provided the impetus to consolidate the various plans contemplated for decades and the subsequent 2010 oil spill provided the financial resources to fulfill these plans.

Concept of sustainable ecosystem restoration

Building, maintenance, and dissolution of the coastal landscape is primarily a mass-balance between sediment input and accommodation space created due to various natural and anthropogenic causes (Khalil *et al.* 2018). Plans and projects to restore coastal Louisiana have existed in some form or fashion at least since 1927, and both state and federal governments have expended considerable time and funds in plan development (Killebrew and Khalil 2018). These efforts, while laying the foundation for future actions, also suggested the need for a single, overarching strategic approach to guide the state in addressing a highly complex scientific and social problem that requires a shared vision. Of late, in order to mitigate rapid degradation of coastal Louisiana in general, and the MRDP in particular, there have been sustained efforts to plan and implement coastal restoration projects (CPRA 2007, 2012, 2017; Louisiana Coastal Wetlands Conservation and Restoration Task Force 1998). Land building is one of the two main objectives of 2017 Coastal Master Plan (CMP) (CPRA 2017). Land building helps recreate and/or replace the degraded or lost geomorphic forms from the coastal Louisiana landscape. Sedimentological restoration helps replicate/create the geomorphic forms that serve as a foundation for ecological restoration which in turn helps restore the ecological functions (Killebrew and Khalil 2018). It is important to emphasize that a balanced approach to sedimentological and ecological restoration completes the loop for sustainable ecosystem restoration of coastal Louisiana.

History of restoration strategies in Louisiana

Louisiana coastal restoration plans and programs, in their various manifestations, have been in existence for several decades. The state has worked with local and federal entities to implement a large number of ecosystem restoration projects to sustain and restore coastal Louisiana. These projects were conceived and implemented to address a wide variety of perceived issues such as saltwater intrusion, shoreline erosion, tidal scour, and sediment starvation. In addition, enactments of state and federal legislations over the years have resulted in the development of numerous programs and plans as consequences of several studies (Killebrew and Khalil 2018). Though never articulated, there appears to be unanimous consensus about some of the most effective mitigative strategies viz. river diversions, barrier island restoration, marsh platform creation, and shoreline protection.

Since 2007, state-legislated CMPs evaluate projects through a set of linked predictive models and risk assessment (CPRA 2012, 2017). Among the constraints considered are other funding sources, sediment, and river uses. The 2017 update to the CMP acknowledges that efficient use of funding and sediment resources is required. The state's 2012 CMP envisaged nine different strategies to be adopted to restore coastal Louisiana via a portfolio of 109 projects (CPRA 2012). Three restoration strategies that dominated the 2012 and 2017 CMP (river diversions, barrier island restoration, and marsh platform creation) are directly related to land building and are indicative of the importance of sedimentological restoration creating geomorphic forms (Khalil *et al.* 2018). The intent is to strategically restore critical landforms that have been lost and to re-establish land-sustaining processes to achieve a no net loss scenario in the future. As stated earlier, the 2017 CMP carries forward on the same trajectory by laying equal emphasis on land building via river diversions as well as marsh platform creation and maintaining robust barrier islands as the first line of defense. Its success critically depends upon an aggressive schedule of implementation. Several new funding sources for coastal restoration (mentioned above) in Louisiana have reduced the budgetary constraints faced by large, ecosystem scale projects and have provided an impetus to expedite project development and construction.

DWH OIL SPILL EVENT/DISASTER[1]

On 20 April 2010, approximately 3.19 million barrels (134 million gallons) of oil were released into the ocean (U.S. v. BP *et al.* 2015) from BP's Macondo well due to the explosion of the Deepwater Horizon drilling unit. This is by far the largest offshore oil spill in U.S. history with the total volume of oil released about 12 times more than the 1989 *Exxon Valdez* spill. For 87 days after the explosion, oil and natural gas continuously and uncontrollably flowed into the northern Gulf of Mexico. Oil moved with deep-sea currents, creating a plume of oil within the deep sea. Oil and associated "marine oil snow" also settled on the sea floor. More buoyant oil traveled up through about 1.6 kilometers of water column and formed large surface slicks. At the slick's maximum extent on 19 June 2010, oil covered more than 40,000 square kilometers of the ocean. Cumulatively, over the course of the spill, oil was detected on over 112,100 square kilometers of the ocean. Currents, winds, and tides carried these surface oil slicks to the Northern Gulf states, polluting more than 2,100 kilometers of shoreline, including beaches, bays, estuaries, and marshes from eastern Texas

1) For details on DWH Funding, please see the paper entitled "A short history of funding and accomplishments post-Deepwater Horizon" by Alyssa Dausman and Jessica Henkel in this dedicated issue.

Table 1.
Table showing dollar amount of various funding sources.

Total restoration funds to the State of Louisiana = $7.1 billion	
Louisiana NRD allocations	**Dollar amount**
Louisiana total	$5 billion
Early Restoration Phases I-IV	$368 million
Approximate balance remaining	$4.6 billion
Clean Water Act Allocation	
Louisiana Total (RESTORE 1, 3, and Centers of Excellence) = $787 million	
Centers of Excellence	$22 million
Bucket 1 — Direct component	$308 million
30% coastal parishes	$92 million
70% state	$216 million
Bucket 3 — Spill impact component	$457 million

to the Florida Panhandle. In addition, some lighter oil compounds evaporated from the slicks, exposing air-breathing organisms like marine mammals and sea turtles to noxious fumes at the sea surface.

As a result of the spill, consequences were measured from the deepwater drilling site through the nearshore oceanic environment, along the Gulf shoreline and into the sensitive estuaries of the Gulf states. Offshore impacts resulted from the release of oil and natural gas itself, dispersants, drilling mud, and in situ burning. As the oil reached the shoreline, consequences resulted not only from exposure to oil, but also from response activities viz. skimming, freshwater releases, shoreline protection activities, boom placement, construction of berms and wildlife rehabilitation and relocation.

Through the Emergency Sand Berm Project, 6.2 million cubic yards of sand were placed on 15.7 miles of Chandeleur, Scofield, Pelican, and East Shell Islands (CPE 2013) to prevent oil from reaching sensitive marshes and the only significant community of submerged aquatic vegetation in coastal Louisiana (LaRoe *et al.* 1995). This sand was mined from "outside the system," from either Mississippi River maintenance dredging spoil deposits or from Hewes Point. On the positive side, these berms added a significant amount of sand to the barrier island system.

DETAILS OF VARIOUS FUNDING SOURCES

History of funding in Louisiana

Traditionally, restoration and protection efforts are funded from multiple revenue streams that have significant compliance requirements. Funding sources include constitutionally dedicated state mineral revenues derived from oil and gas royalties, bonuses, and severance taxes that are used primarily as a state match for CWPPRA funded projects. This is the only recurring state revenue in the coastal program. The amount varies each year and fiscal year 2020-2021 projections are at about $25 million. The CWPPRA Program provides $75 million to $80 million per year through the current authorization. USFWS's Coastal Impact Assistance Program (CIAP) in Louisiana contained 99 projects funded with state and/or parish CIAP funding totaling approximately $496 million. The Gulf of Mexico Energy Security Act (GOMESA) established a revenue sharing arrangement for OCS oil and gas revenues for the Gulf Coast producing states. Estimates for Louisiana (Fiscal Year 2021) are approximately $88 million with 80% (~$70 million) of the Louisiana share allocated to CPRA.

New funding streams have largely been associated with the DWH oil spill of 2010 stemming from violations of the Oil Pollution Act, Clean Water Act, and injuries to natural resources and have included projects funded through the Berm-to-Barrier, Natural Resource Damage Assessment (NRDA), Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act (RESTORE Act), and the Gulf Environmental Benefit Fund administered by the National Fish and Wildlife Federation (NFWF). The NFWF grants (approximately $1.272 billion) resulting from criminal settlements are restricted to barrier island and river diversion projects in Louisiana. The RESTORE Act directs 80% of the Clean Water Act penalties into five different funding streams directed at restoring coastal and Gulf ecosystems and is an additional source of revenue for ecosystem restoration in all five Gulf states. Together these funding streams total approximately $7.1 billion projected out for the next 15 years (Killebrew and Khalil 2018).

To date, about $510 million paid by BP and its partners has already been used to complete restoration work on seven major projects. Another $6.8 billion will be used on several other projects through 2032, the deadline for BP to pay money owed under various court settlement agreements. Louisiana's share of NRDA payments required under the Oil Pollution Act of 1990, totaling at least $5 billion, was agreed to by BP as part of a global settlement with federal, state and parish governments. More than $787 million in Clean Water Act civil fines have also been directed to Louisiana under the federal RESTORE Act. Much of that money is being paid to the state in increments over 15 years ending in 2032. The state was also provided $360 million directly by BP in the weeks after the spill in 2010 to build sand berms along existing barrier islands along the coast to intercept oil before it moved beyond the islands into the more fragile wetlands. When the well was capped, BP agreed to allow the state to use more than $120 million of the remaining berm money for barrier island restoration (Table 1 and Table 2).

Restoration plans and programs

It has been mentioned that, although Louisiana has had a coastal wetland ecosystem restoration program for several decades, the first integrated hurricane protection and ecosystem restoration "Coastal Master Plan" (CPRA 2007), was produced in 2007 following Hurricanes Katrina and Rita (Khalil and Raynie 2015a). This was followed by the 2012 Coastal Master Plan that included a detailed prediction of the future of the Louisiana coast without action, and an objective evaluation of the performance of hundreds of previously proposed projects over the next 50 years (CPRA 2012). Subsequently the 2017 Coastal Master Plan proposes to build and maintain over 2,000 square kilometers of coastal land in the next 50 years (CPRA 2017). It is also mentioned that barrier island restoration, marsh platform creation, and sediment diversions, are most-emphasized restoration strategies by both 2012 and 2017 Coastal Master Plans and are directly related to land building (Killebrew and Khalil 2018). The intent is to restore/create critical landforms/geomorphic forms (viz.

Table 2.

Table showing status of various active Deep Water Horizon projects.

Barrier island restoration projects		**Funding**	**Status 2020**
BA-0040	Riverine Sand Mining/Scofield Island Restoration	BERM	Completed
BA-0076	Cheniere Ronquille Barrier Island Restoration	NRDA	Completed
BA-0110	Shell Island East — Berm	BERM	Completed
BA-0111	Shell Island West — NRDA	NRDA	Completed
BA-0143	Caminada Headland Beach and Dune Restoration Incr2	NFWF	Completed
BA-0197	West Grand Terre Beach Nourishment and Stabilization	RESTORE	Construction
BA-0202	Queen Bess Island Restoration	NRDA	Construction
BS-0029	North Breton Island	NRDA	E&D
CS-0080	Rabbit Island Restoration	NRDA	Completed
TE-0100	NRDA Caillou Lake Headlands	NFWF	Construction
TE-0143	Terrebonne Basin Barrier Island and Beach Nourishment		
Marsh platform creation, marsh nourishment and ridge restoration projects		**Funding**	**Status 2020**
BA-0042	Lake Hermitage Marsh Creation	NRDA	Completed
BA-0141	NRDA Lake Hermitage Marsh Creation Increment	NRDA	Completed
BA-0203	Barataria Basin Ridge and Marsh Creation — Spanish Pass Increment	NRDA	E&D
BA-0207	Large-Scale Barataria Marsh Creation	NRDA	E&D
BA-0240	Grand Cheniere Ridge Marsh Creation	NRDA	E&D
BS-0034	Lake Lery Marsh Creation	RESTORE	Construction
PO-0163	Golden Triangle Marsh Creation	RESTORE	E&D
PO-0180	Lake Borgne Marsh Creation — Increment 1	NRDA	E&D
TE-0139	Terrebonne Basin Ridge/Marsh Creation — Bayou Terrebonne Increment	NRDA	E&D
Sediment diversion projects		**Funding**	**Status 2020**
BA-0153	Mid-Barataria Sediment Diversion	NFWF	E&D
BS-0030	Mid-Breton Sediment Diversion	NFWF	E&D
PO-0029	River Reintroduction Into Maurepas Swamp	RESTORE	E&D
TE-0110	Increase Atchafalaya Flow to Terrebonne	NFWF	E&D
Recreational use projects		**Funding**	**Status 2020**
AT-0019	Atchafalaya Delta WMA Boat Access	NRDA	E&D
AT-0020	Atchafalaya Delta WMA Campground Improvements	NRDA	E&D
BA-0208	Science Center and Educational Complex	NRDA	E&D
BA-0213	Bayou Segnette State Park Improvements	NRDA	E&D
BA-0214	Grand Isle State Park Improvements	NRDA	Construction
BS-0036	St. Bernard State Park	NRDA	E&D
CS-0083	Elmer's Island Access Enhancement	NRDA	E&D
CS-0084	Sam Houston Jones State Park	NRDA	E&D
ME-0036	Rockefeller Piers and Signage	NRDA	Construction
MR-0168	Lowermost Mississippi River Management Program	RESTORE	Program
MR-0169	Pass a Loutre Crevasses NRDA	NRDA	Construction
MR-0170	Pass a Loutre Campgrounds NRDA	NRDA	Construction
NA-1	Belle Chasse Boat Launch	NRDA	E&D
NA-2	Chitimacha Boat Launch	NRDA	E&D
NA-3	Des Allemands Boat Launch	NRDA	E&D
NA-4	Grand Avoille Boat Launch	NRDA	E&D
NA-5	The Wetlands Center	NRDA	E&D
NA-6	WHARF Phase 1	NRDA	E&D
NA-7	LDWF Artificial Reefs (Not on Map)	NRDA	Construction
PR-0001	Middle Pearl River WMA Boat Launch	NRDA	E&D
TE-0144	Island Road Fishing Piers	NRDA	Construction
TE-0145	Grand Bayou Freshwater Reintroduction	RESTORE	E&D
TE-0146	Pointe-Aux-Chene WMA Enhancement	NRDA	E&D
TV-0081	Cypremort Point State Park Improvements	NRDA	E&D
Other project types		**Funding**	**Status 2020**
CS-0065	Calcasieu Ship Channel Salinity Control Measures	RESTORE	E&D
ME-0035	Rockefeller Shoreline Stabilization	RESTORE	E&D
PO-0174	Biloxi Marsh Living Shoreline	RESTORE	E&D
PO-0183	Manchac Landbridge Shoreline Protection	RESTORE	E&D
TE-0113	Houma Navigation Canal Lock Complex	RESTORE	E&D
TE-0145	Grand Bayou Freshwater Reintroduction	RESTORE	E&D
TV-0079	Freshwater Bayou Bank Stabilization	RESTORE	E&D
BA-0209	Paradis Canal Gate	RESTORE	Construction

Figure 1. Map showing three major geomorphic environments, Bird's Foot Delta and barrier island restoration projects under various stages of completion (Active Deep Water Horizon Projects).

delta, barrier islands, marsh platform) that have been lost, and to re-establish land-sustaining processes to achieve a point of no net loss in the future. Various restoration projects funded by DWH related funding sources under various stages of completion are listed in Table 2.

Barrier island restoration projects

The restoration of Louisiana's barrier islands has been a priority for a number of programs over the past several decades. In the 1990s, barrier island restoration was a primary focus for the CWPPRA program, which funded construction of several of barrier island restoration projects. Since then, the state of Louisiana and federal partners have used funds from other programs and sources to construct more than 40 barrier island restoration projects over the past two and a half decades (Khalil and Raynie 2019). DWH funds helped complete the loop by providing funding for construction of six of these large-scale barrier island restoration projects (Table 2; Figure 1). The following barrier islands, which were all directly impacted by oil during the spill, were restored in an expedited manner as they were under various stages of readiness from a design standpoint with funding from other restoration initiatives:

1) Restoration of Shell Island West, in southern Plaquemines was completed in 2017.

2) Reconstruction of Shell Island East in Plaquemines was completed in 2016.

3) Reconstruction of the Caillou Lake Headlands on Whiskey Island in Terrebonne Parish, was completed in 2018.

4) The second increment of the Caminada Headlands in Lafourche and Jefferson parishes was completed in 2017.

5) Rebuilding Cheniere Ronquille Barrier Island in Plaquemines was completed in 2017.

6) Rebuilding Scofield Island in Plaquemines was completed in 2013.

In addition to the projects above, the Terrebonne Basin Barrier Island (TE-0143) project is currently under construction whereas West Grand Terre Beach Nourishment and Stabilization (BA-0197) project is anticipated to be advertised for construction in 2020. Breton Island Restoration by NRDA Early Restoration Phase 3 funds is currently advertised for construction. Queen Bess Island is under construction and anticipated to be complete in early 2020. The Rabbit Island Restoration is currently in the Engineering and Design (E&D) phase and anticipated to be advertised for construction in 2020. These last two islands are not barrier island restoration projects, but they are being restored to provide bird habitat for the purpose of mitigating the impacts to bird populations from the oil spill.

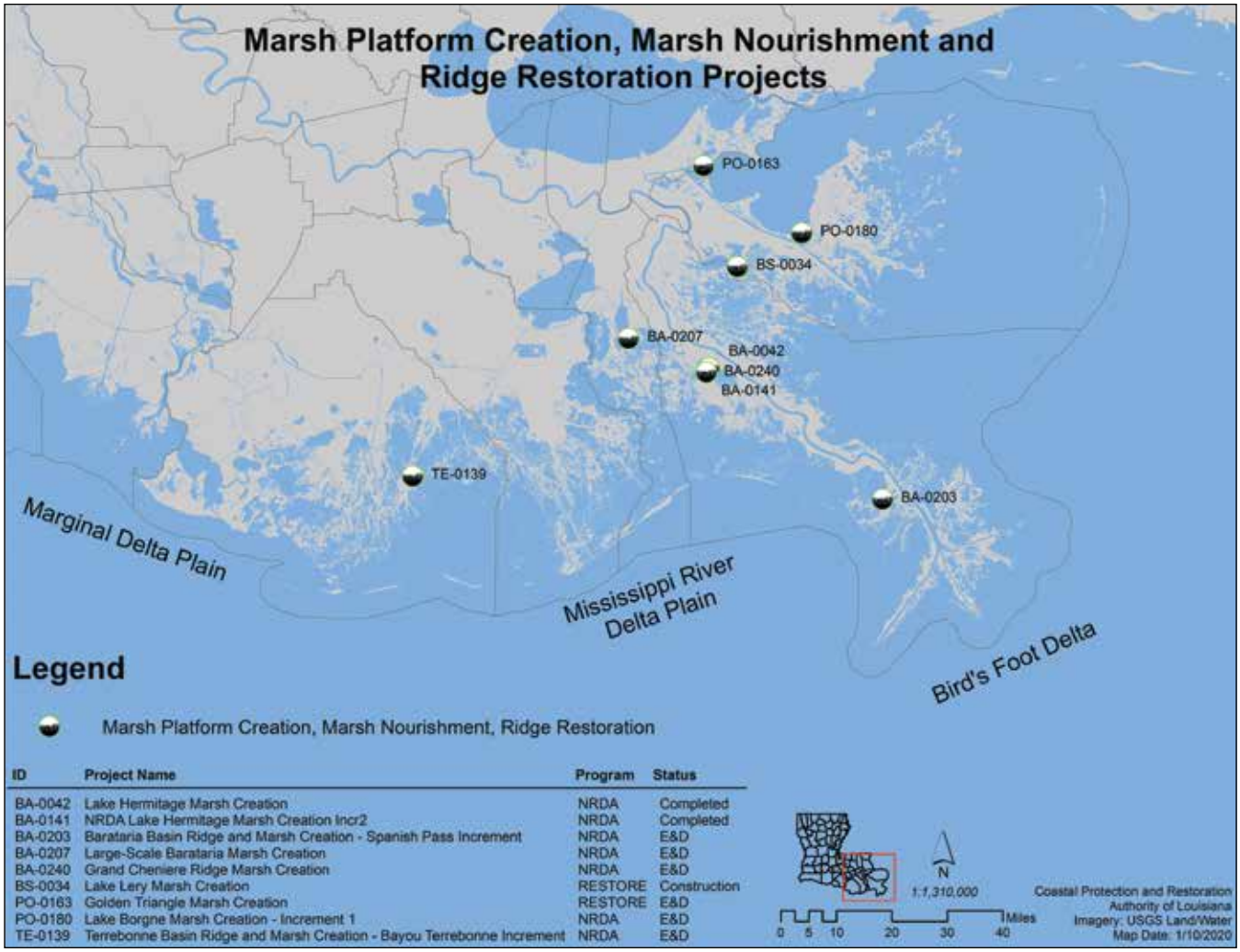

Figure 2. Map showing marsh platform creation, marsh nourishment, and ridge restoration projects under various stages of completion (Active Deep Water Horizon Projects).

These constructed restoration projects have been studied and their performance assessed to adaptively improve resilience of these barriers. Khalil and Raynie (2015b) suggested a system-wide approach over restoration and maintenance of individual barrier islands. Such a holistic approach is essential as individual barrier islands are interrelated as a system. The 2017 Coastal Master Plan recommended development of a barrier island management program to meet the need for ongoing maintenance of the state's barrier island systems. The basic premise is that maintaining and managing barrier islands as a system is not only scientifically appropriate but technically efficient and fiscally cost-effective. The state proposes a comprehensive programmatic system approach (Barrier Island System Management or BISM) to monitor and assess barrier islands as a system of islands to drive project investment and provide a framework to promptly react when maintenance and management of any single barrier island may compromise the system as a whole, especially after catastrophic events such as future hurricanes. This program will provide a tool for CPRA to prioritize and implement future projects based on sound science, while maintaining the ability to respond to unexpected coastal changes. Process formalization will include development of the Structured Decision Making (SDM) model to evaluate morphologic changes in the barrier island systems and identify opportunities to improve the geomorphic forms and ecological functions of the barrier systems (Khalil *et al.* 2019). BISM is funded by NFWF.

Marsh platform creation, marsh nourishment, and ridge restoration

The coastal marshes of Louisiana are vital not only to recreational and agricultural interests but also provide nursery habitat to support the state's multimillion-dollar seafood industry (Khalil and Raynie 2015a). These marshes also provide a second line of defense (behind barrier islands) against flooding from frontal passages, sea-level rise and hurricane induced storms by acting as "horizontal levees." In addition to the projects listed in Khalil *et al.* (2011), Louisiana has continued to create thousands of acres of new marshes through marsh nourishment/enhancement projects (Khalil and Raynie 2015a). The Mississippi River Sediment Delivery System is an example of utilizing renewable sediment resources of the Mississippi River for marsh restoration (Khalil *et al.* 2011). This concept of using renewable river sediment to build marsh platforms has subsequently led to the construction of thousands of additional acres via the same process (Khalil and Raynie 2015a). The 2012 Coastal Master Plan stressed the creation of marsh platforms via dedicated dredging. Similarly, the 2017 Coastal Master Plan also emphasizes the need for marsh platform creation using dedicated dredging and long distance

Figure 3. Map showing sediment diversion projects under various stages of completion (Active Deep Water Horizon Projects).

pipeline transport, in combination with sediment diversions, and ridge features.

In 2016, Increment 2 of the Lake Hermitage wetlands restoration project in Plaquemines Parish was completed (Figure 2). The initial increment of the Lake Hermitage project was funded through the CWPPRA Program. Through the second increment, approximately 104 acres of new wetlands were built with $14.4 million in BP NRDA Early Restoration money, using about 1 MCY of sand from the Lower Mississippi River leveraging the work from the initial phase of construction.

Currently, the State of Louisiana/ CPRA is advancing the engineering and design of several large scale marsh creation projects viz. Barataria Basin Ridge & Marsh Creation, Terrebonne Ridge & Marsh Restoration, Barataria Basin Restoration Plan, Orleans East Land Bridge Marsh Creation, Golden Triangle Marsh Creation, and Lake Borgne Marsh Creation, which are anticipated to begin the construction phase in 2020 (Figure 2).

Sediment diversion projects

Sediment/river diversions are structures designed to mimic the natural pattern of deltaic land formation by reconnecting the river to the coastal system. The primary purpose of river diversions is to supply freshwater, nutrients, and sediments to aid in the restoration and maintenance of coastal wetlands (Khalil *et al.* 2010) and intercept sediment before it is transported to the Gulf and lost from the system. All previous restoration plans generated over the past 30 years have identified the need to reconnect the Mississippi River to its deltaic plain through freshwater and/or sediment diversions (Khalil and Raynie 2015a). Extensive modeling supports CPRA's selection of the "Mid-Barataria Sediment Diversion" (Barataria Basin) and "Mid-Breton Sediment Diversion" (Breton Sound) projects, originally included in the 2012 Coastal Master Plan among several large-scale river diversions designed to reconnect the river to its coastal plain (Killebrew and Khalil 2018) (Figure 3). The state/ CPRA is moving forward with two diversion projects; Mid-Barataria Sediment Diversion and Mid-Breton Sediment Diversion (Table 2). This is a step in the right direction, as it is understood and appreciated that to maximize efficiency diversions should be sited high up in the estuary, which will not only mimic natural delta building processes but will also provide a receiving basin with higher sediment retention capacity, which is crucial for the land building process (Khalil and Freeman 2014). River diversions are not exclusive to the Mississippi River in Louisiana. The "Increase Atchafalaya Flow to Terrebonne" project (Figure 3) is targeted to utilize freshwater and sediment from the Atchafalaya River in order to build, sustain, and maintain wetlands within the Terrebonne Basin. Terrebonne Basin has experienced very high rates of wetland loss in recent decades due to

Figure 4. Map showing recreational use projects under various stages of completion (Active Deep Water Horizon Projects).

the combined effects of isolation from riverine influence, canal construction, fluid withdrawal, global sea level rise, and subsidence (Khalil and Raynie 2015b). In addition, the Maurepas Diversion, a freshwater river diversion, is currently in the Engineering and Design Phase.

Recreation use projects

In addition to the injuries to natural resources caused by the DWH oil spill, recreational use of Louisiana's coast suffered a substantial setback. Louisiana is nicknamed "Sportsman's Paradise" largely in part due to the abundance of and easy access to natural resources for recreation. An amount of $60 million was allocated to Louisiana through NRDA to enhance outdoor recreation opportunities through 23 recreational improvement projects in coastal parishes (Figure 4). Fishing piers in Cameron, Jefferson, St. Mary and Terrebonne parishes; boating access improvements in Jefferson, Plaquemines, St. Charles, St. Mary, St. Tammany and Terrebonne Parishes; educational upgrades to the Lake Charles Science Center in Calcasieu Parish and The Wetlands Center in Jefferson Parish to promote conservation; and enhancements to 11 existing artificial reef sites across the coastline are some items on the list, which has been in development for more than two years. Work on some projects began mid-2018 as the settlement money became available for design and construction.

The final project list was drafted by the Louisiana Trustee Implementation Group (LA TIG) after a thorough process that included months of public hearings and input. The projects selected include a mix of state and local, as well as one that falls under the U.S. Department of the Interior and another under the Chitimacha Tribe. Projects are meant to encourage tourists and Louisiana residents to fish, camp, boat, and take part in other outdoor activities and recreation along the coast.

Jefferson Parish will receive $18.5 million for six recreational use projects, including nearly $1 million toward a boardwalk for fishing and wildlife viewing, fishing piers, restrooms and lighting as part of the first phase of the Wetlands Harbor Activities Recreational Facility project in Westwego. Grand Isle State Park will receive $6.1 million in upgrades, and $6 million will go toward enhanced access to and recreational features on Elmer's Island. The Lake Charles Science Center will get $7 million, the largest individual project award, to construct a visitor's center, youth fishing pond and other educational exhibits.

Other project types

Other project types include bank-line stabilization (one project), hurricane protection (one project), hydrologic restoration (three projects), oyster reef restoration (one project), and shoreline protection (two projects; Figure 5).

ADAPTIVE MANAGEMENT

Adaptive management is notably critical in coastal Louisiana as most of the

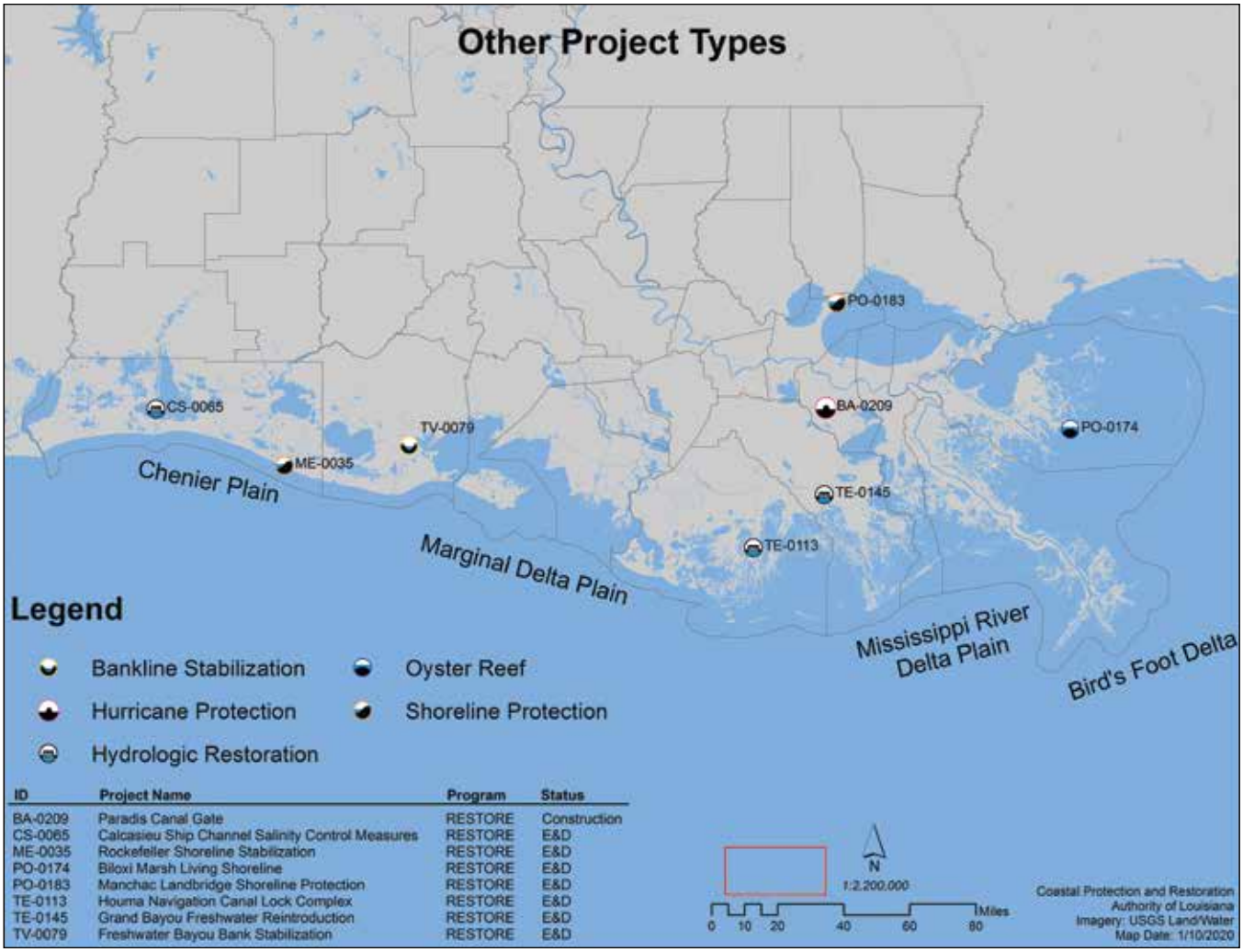

Figure 5. Map showing other projects (including bank-line stabilization, hurricane protection, hydrologic restoration, oyster reef restoration, and shoreline protection) under various stages of completion (Active Deep Water Horizon Projects).

strategies adopted for restoration of this highly degraded ecosystem are a first-of-their-kind, either in scale or scope, and do not have well-established textbook templates to follow (Killebrew and Khalil 2018). At the same time, Louisiana has a long history of coastal management and restoration actions with multiple projects implementing common approaches. CPRA has practiced informal adaptive management as key personnel pass on accumulated wisdom and lessons learned. There is currently an increased need for large-scale restoration due to ongoing land loss as well as major new restoration funding entities resulting from the DWH spill. Thus, there is increased incentive to develop processes that formalize common learning to improve decision making. We know that environmental systems are inherently complex and non-linear, and consequently, predicting the success of restoration projects is challenging (National Research Council 1992).

Approximately $285 million have been set aside from NRDA and RESTORE specifically for adaptive management and its implementation (via various monitoring programs) as the importance of the role of adaptive management is appreciated in the ongoing restoration effort in Louisiana. Louisiana has developed an Adaptive Management Implementation Plan (AMIP) along with a handbook.[2] In order to implement adaptive management in Louisiana monitoring of various parameters are important. This is being done under the overarching umbrella of the System Wide Assessment and Monitoring Program (SWAMP).[3] The state was also able to continue implementation of its other regional monitoring programs like the Barrier Island Comprehensive Monitoring (BICM) program and partially support the Coastwide Reference Monitoring System (CRMS).

DISCUSSION

Land loss is an ongoing process and coastal Louisiana is losing land at an astounding pace as we write this. Understanding the gravity of the situation, numerous studies have been conducted over decades and several comprehensive plans were developed to mitigate the situation. Most of the time, the focus of these studies and plans was on land loss and hence coastal restoration took the front seat. However, the events of 2005 prompted the state of Louisiana to re-evaluate and change its approach to dealing with coastal restoration. For the first time in the state's history, coastal protection and restoration were combined

2) For details on adaptive management, please see the paper entitled "Current status of adaptive management related to coastal restoration in Louisiana with recommendations for improved implementation" in this dedicated issue by Tim Carruthers and others.

3) For details on SWAMP, please see the paper entitled " Statewide monitoring for restoration of coastal Louisiana and data management" in this dedicated issue by Richard Raynie and others.

under Act 8 of the First Extraordinary Session of 2005.[4] In order to implement Act 8, the CPRA was established and flood risk was added to the portfolio of land loss and land building projects. The DWH oil spill in 2010 further highlighted the vulnerability and fragility of coastal Louisiana. Coastal Louisiana's natural resources were impacted more than any other northern Gulf of Mexico state due to its fragility and proximity to the spewing oil well. Both geomorphological damages and ecological injuries were significant, not only directly due to the oil spill but also due to recovery and mitigative actions.

The funds that resulted from the civil and criminal penalties of the DWH disaster helped Louisiana to make great strides towards fulfilling its plans for the completion of many restoration projects. The magnitude of funding suddenly changed from millions to billions of dollars. The confluence of additional funding and existence of comprehensive coastal restoration plans has aptly positioned CPRA to address coastal land loss in particular and ecosystem sustainability in general. For example, for decades it was common knowledge that the long-term solution to Louisiana's perpetual land loss problem was reconnecting the river with surrounding marshes, restoration of barrier islands, and creation of marsh platforms via dedicated dredging. These concepts were put into plans and the availability of DWH funds helped to make these plans a reality. Without this funding, the state could not implement its plans to build large sediment diversions, which is the only long-term solution to the land loss problem.

Coastal Louisiana, especially its southeastern deltaic environment, is uniquely challenged due to the interdependence and delicate balance of land, water, and ecosystems, along with the future uncertainties regarding the magnitude and rate of climate change impacts (Killebrew and Khalil 2018). Killebrew and Khalil (2018) state that "…management of such a complex ecosystem in which the natural and socioeconomic systems are highly integrated is inherently difficult...." This complexity is further compounded by widespread degradation, which can be attributed to multiple stressors resulting from natural variabilities and human interventions. Therefore, a broad knowledge of coastal environments, including the human component, is necessary to enable their management in a manner consistent with ecological, social and economic benefits.

Further it is realized and appreciated that the natural resources of coastal Louisiana support communities and the economy of Louisiana as well as the entire United States. However, future conditions of coastal Louisiana are highly uncertain due to the dynamic processes of the MRDP, unpredictable storm events, subsidence, sea level rise, and increasing temperatures. Extensive human interventions intended to protect communities and infrastructure have additionally altered or ceased natural processes. Adaptive management is a great help, and has been rightly funded, to allow us the opportunity to modify and adjust these plans, but we can't afford to have "do-overs". Adaptive management in deltaic environments encourages an integrated and flexible approach to land and water management that considers risk and uncertainty. It promotes solutions that are sustainable under dynamic or unknown conditions by providing a science-based and -structured process for making decisions and programmatic or project adjustments. Connecting short-term investments with long-term changes and the selection of actions that allow for maximum flexibility of future decisions are two of the key concepts of "Adaptive Delta Management" (Delta Alliance 2014). As mentioned earlier, the development of an AMIP is not only very much needed but would be very effective in developing the most appropriate strategy for coastal protection and restoration.

In the past, due to limited funding, monitoring of various parameters on a regional scale could not be undertaken at the magnitude desired. However, recent funding has helped alleviate the situation. While the state/CPRA has proceeded aggressively with project implementation and monitoring, funding provided through the DWH settlement provides an opportunity to assess the effects of ecosystem protection and restoration on the entire coastal system—a vital component of adaptive management at programmatic and project levels.

While DWH funding on the one hand has opened up unprecedented opportunities, it has at the same time introduced several significant governance and bureaucratic challenges due to various settlements and several decision-making entities and governing bodies. The individual trustees that make up the various governing bodies have different perspectives and different approaches depending upon the mission of their respective agencies. This has, at times, complicated our ability to move forward despite the fact that our overarching goal is the same. Such diversity in approach and perception is healthy as long as it does not impede productivity due to bureaucratic delays. The challenge is how to make this diverse group efficiently and cost effectively coordinate, cooperate, and collaborate to achieve the common goal as envisaged in Coastal Master Plan. This will come with the realization that CPRA is ultimately responsible for implementation of protection and restoration strategies to mitigate the rapidly degrading coastal area of Louisiana. CPRA plays this important role as it is well positioned with the institutional knowledge and experience to fulfil its commitment to implement its legislated duty. The importance of this responsibility cannot be overstated and we must never let our guard down as "…posterity will judge (us) critically how wisely and effectively these funds were expended in implementation of the plans as they will have or not have the coastal landscape we propose to build…" (Killebrew and Khalil 2018).

CONCLUSIONS

The State of Louisiana has been able to efficiently and effectively implement restoration projects funded through recent programs because of the hard work done through previous programs and planning efforts. Decades of progress by a critical mass of experts made up of local, state and federal natural resource agency staff, academia, political leaders, volunteers, nongovernmental agencies, and concerned citizens funded through the State Coastal Protection and Restoration Trust Fund, CWPPRA Program and planning initiatives like the COAST 2050 Plan paved the way for the expedited implementation of recent work. It is expected that the results of science and engineering research on the state's coastal landscape will provide a showcase for coastal protection, restoration, and

4) Louisiana state legislature passed Act 8 of the First Extraordinary Session of 2005, which required an integrated coastal protection and restoration policy and program for the first time in the state's history.

management of coastal ecosystems and river delta plains worldwide. However, the next decade or two will be crucial as to how effectively we coordinate with our partners and maintain the trajectory of progress by steering the implementation adeptly away from bureaucratic hurdles and impediments. To ensure this, we should never forget why we are getting these funds and why we need them. The loss of life that occurred as a result of the DWH disaster and the oil that flowed into the Gulf for months was devastating to our land, our people, our environment, our economy, our fisheries, and our wildlife. There is much to remedy, and the State of Louisiana should continue to work diligently with the other four Gulf states and federal partners to do just that.

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