Coastal monitoring and data management for restoration in Louisiana

By

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ABSTRACT

The Coastal Protection and Restoration Authority (CPRA) of Louisiana was created after the devastating hurricanes of 2005 (Katrina and Rita) and is responsible for planning and implementing projects that will either reduce storm-induced losses (protection) or restore coastal ecosystems that have been lost or are in danger of being lost (restoration). The first task of the CPRA board was to develop Louisiana's first Coastal Master Plan (CPRA 2007), which formally integrates and guides the protection and restoration of Louisiana's coast. The System-Wide Assessment and Monitoring Program (SWAMP) was subsequently developed as a long-term monitoring program to ensure that a comprehensive network of coastal data collection activities is in place to support the planning, development, implementation, and adaptive management of the protection and restoration program and projects within coastal Louisiana. SWAMP includes both natural-system and human-system components and also incorporates the previously-developed Coastwide Reference Monitoring System (CRMS), the Barrier Island Comprehensive Monitoring (BICM) program, and fisheries data collected by the Louisiana Department of Wildlife and Fisheries (LDWF) in addition to other aspects of system dynamics, including offshore and inland water-body boundary conditions, water quality, risk status, and protection performance, which have historically not been the subject of CPRA-coordinated monitoring. This program further facilitates the integration of project-specific data needs into a larger, system-level design framework. Monitoring and operation of restoration and protection projects will be nested within a larger hydrologic basin-wide and coast-wide SWAMP framework and will allow informed decisions to be made with an understanding of system conditions and dynamics at multiple scales.

This paper also provides an update on the implementation of various components of SWAMP in Coastal Louisiana, which began as a Barataria Basin pilot implementation program in 2015. During 2017, the second phase of SWAMP was initiated in the areas east of the Mississippi River. In 2019, development of SWAMP design was completed for the remaining basins in coastal Louisiana west of Bayou Lafourche (Figure 1).

Data collection is important to inform decisions, however if the data are not properly managed or are not discoverable, they are of limited use. CPRA is committed to ensuring that information is organized and publicly available to help all coastal stakeholders make informed, science-based decisions. As a part of this effort, CPRA has re-engineered its data management system to include spatial viewers, tabular download web pages, and a library/document retrieval system along with a suite of public-facing web services providing programmatic access. This system is collectively called the Coastal Information Management System (CIMS). CPRA and U.S. Geological Survey (USGS) are also developing a proposal to create an interface for CIMS data to be exported to a neutral template that could then be ingested into NOAA's Data Integration Visualization, Exploration and Reporting (DIVER) repository, and vice versa. DIVER is the repository that the Natural Resource Damage Assessment (NRDA) program is using to manage NRDA-funded project data throughout the Gulf of Mexico. Linking CIMS and DIVER will make it easier to aggregate data across Gulf states and look at larger, ecosystem-level changes.

KEYWORDS: Deepwater Horizon; System Wide Assessment and Monitoring Program; Coastal Information Management System; Gulf of Mexico.

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The State of Louisiana and its partners have allocated considerable resources and have made long-term commitments to the restoration and management of wetland and aquatic resources in its coastal zone. Beginning two decades before the Deepwater Horizon (DWH) oil spill, early project-specific monitoring efforts through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) program quickly became challenging as adequate reference areas were difficult to identify and monitoring parameters were not consistent among various projects. This resulted in challenges when attempting to look at aggregate effects and ecosystem-level changes. Within its first 10 years, CWPPRA developed the Coastwide Reference Monitoring System (CRMS) to address these challenges. Then in the early 2000s, prior to Hurricanes Katrina and Rita (2005), the Louisiana Coastal Area (LCA) Ecosystem Restoration Study (a joint federal/state program) proposed expanding CRMS to include coastal waters and barrier islands. Although a formal coastal waters program was not implemented, the monitoring of barrier islands as a collective system was initiated by the Louisiana Department of Natural Resources (LDNR) Coastal Restoration Division (later incorporated into CPRA), known as the Barrier Island Comprehensive Monitoring (BICM) Program.

These programs (CRMS and BICM) were tailored to monitor ecosystem elements that are relevant to wetland and barrier island restoration. However, after the hurricanes of 2005, the function of protecting Louisiana's coast and its residents from storm-induced damage (previously managed by the Department of Transportation and Development [DOTD]) was integrated within the state government with coastal wetland restoration efforts (previously managed by the Department of Natural Resources

[DNR]). The Coastal Protection and Restoration Authority (CPRA) combined these functions and was legislatively created as the single state entity with authority to articulate a clear statement of priorities and to focus development and implementation efforts to achieve comprehensive coastal protection and restoration for Louisiana. For the first time in Louisiana's history, this single state authority began integrating coastal restoration and hurricane protection by marshaling the expertise and resources of the DNR, the DOTD and other state agencies to collaboratively plan, prepare and adapt to the anticipated changes in Louisiana's coast. Concurrent with this shift in governance was an expansion of monitoring needs to also include protection and human dimension attributes.

In the midst of re-engineering Louisiana's protection and restoration efforts, another pair of hurricanes (Gustav and Ike) impacted coastal Louisiana in 2008, followed by the DWH disaster (20 April 2010), furthering the need for Louisiana to adapt to both human disasters as well as natural ones. Over the next several years, Louisiana along with the other Gulf states and a number of federal agencies directed tremendous resources to assess damages from DWH and also plan for the recovery of the Gulf. Through several of the DWH settlement revenue streams (Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act [RESTORE Act]; National Fish and Wildlife Foundation [NFWF] Gulf Environmental Benefits Fund; and Natural Resources Damage Assessment [NRDA]), the various architects of the DWH settlement components (civil and criminal penalties, and environmental fines) recognized the importance of data and information to track the recovery of injured resources and the substantial blow that the oil spill caused to Louisiana's coastal environment. As a result, significant funds have been made available for monitoring and adaptively managing Louisiana's restoration and protection efforts (as well as to the other Gulf States), allowing Louisiana to adapt, expand and build implementation momentum for its monitoring efforts to be commensurate with the growing need.

After Louisiana's second Coastal Master Plan (CPRA 2012) and before major DWH settlements were reached, Louisiana took another look at expanding its monitoring program in light of all of the changes. In 2013, CPRA commissioned The Water Institute of the Gulf (WI) to assist in developing a System Wide Assessment and Monitoring Program (SWAMP) Inventory (Reed 2013) and Framework (Hijuelos *et al.* 2013); a coastwide design and Barataria Basin pilot (Hijuelos and Hemmerling 2015) for SWAMP; a Pontchartrain region design (east of the Mississippi River; Hijuelos and Hemmerling 2016) for SWAMP; and a SWAMP design for the western region of the state (from Bayou Lafourche to the Sabine River; The Water Institute of the Gulf 2019). Beginning in 2015, CPRA began using DWH funding, which became available through NFWF, to begin the Barataria Basin pilot of SWAMP. Louisiana has been leveraging DWH funding to incrementally implement SWAMP in Barataria and other basins.

SYSTEM WIDE ASSESSMENT AND MONITORING PROGRAM

SWAMP development began with an effort to identify system drivers within coastal Louisiana that would be important for tracking trajectories of change with respect to a number of overlapping priorities: restoration of coastal landforms, recovery of human and natural systems from DWH injuries, and adaptively managing the portfolios of projects identified in Louisiana's Coastal Master Plan. An extensive inventory of existing data within coastal Louisiana was concurrently developed to identify existing resources that would offer insight to the statistical design of SWAMP (variability, sample size, etc.) as well as offering potential future leveraging opportunities for SWAMP implementation. The process provided the framework for implementing a comprehensive monitoring plan for both natural and human systems. CPRA engaged a number of data collectors and data users within coastal Louisiana in these discussions. The interactions were motivated by capitalizing on available expertise within the region and also by potential opportunities to leverage CPRA's needs with the needs and resources of others. In addition, the human component of a coupled human-natural system is a coherent system of biophysical and social factors capable of adaptation and sustainability over time, exhibiting boundaries, resource flows, social structures, and dynamic continuity (Machlis *et al.* 1997). A number of critical resources are essential to sustain the human system, including natural resources, socioeconomic resources, and cultural resources. Changes to any of these critical resources have the potential to impact the overall well-being and sustainability of the human communities that rely on them. This is especially true of coastal Louisiana, where natural and anthropogenic alterations to the landscape may impact any of these critical resources in numerous ways, thereby placing many of the region's traditional renewable resource extraction cultures and communities at risk (Laska *et al.* 2005). SWAMP's natural system variables filled identified gaps where existing monitoring programs did not provide adequate data parameters and/or frequency (Table 1). SWAMP's human system monitoring plan identifies and quantifies changes to the coupled human-environmental ecosystem and the critical resources that sustain it. The human system approach utilizes existing data, such as the American Community Survey (ACS), to meet many of the monitoring variables and objectives. Primary data collection needs and methods were also identified for those variables and objectives that could not be met by the secondary data. The result was the development of key human-system parameters that were included within the SWAMP design (Table 2).

Funding the implementation of SWAMP

Data collection and analysis through SWAMP have been funded by a variety of revenue streams, including those from DWH settlements. In Louisiana, the DWH plea agreements required that NFWF funds be allocated solely to barrier island restoration projects and river diversion projects along the Mississippi and Atchafalaya Rivers, consequently NFWF-funded data collected through SWAMP was geographically restricted. Although RESTORE funding is also limited by law, it has the broadest application of the DWH settlement revenue streams. RESTORE dollars must be utilized to restore and protect the natural resources, ecosystems, fisheries, marine and wildlife habitats, beaches, coastal wetlands, and economy of the Gulf Coast region. NRDA funding is intended to restore injured resources to pre-oil spill conditions, and any funding awarded through NRDA must be approved by the Louisi-

Table 1.
System Wide Assessment and Monitoring Program (SWAMP) Natural System variables and funding sources. (Funding sources are separated by parameter, space, and/or time so there is no overlap in funding at any point.)

Data category	Variable	Funding source NFWF	RESTORE	NRDA	CWPPRA
Weather & climate					
	Wind & precipitation	x	x		
Biotic integrity					
	Nekton community composition	x		x	
	Oyster biomass	x		x	
	Soil condition (marsh)	x	x		x
	Soil characteristics (water bottoms)	x			
	Wetland vegetation community composition	x	x		x
	Wetland vegetation biomass	x	x		
Water quality					
	Hourly CRMS-wetland salinity/water level	x	x		x
	Leveraged USGS sites (add'l parameters)	x	x		
	New water quality sites	x	x		
Hydrology					
	Existing CRMS-wetlands water level	x			x
	New continuous water level sites	x	x		
	New wave/current stations	x			
Physical terrain					
	Surface elevation (CRMS-wetland measurements)				x
	Benchmark network maintenance				x
	Bathymetry (nearshore)	x			
	Bathymetry (inshore)	x	x		
	Subsidence	x	x		
	Surface elevation (LiDAR)	x	x		
	Land area (leveraged with USGS)				x
	Shoreline position	x			
	Shoreline assessment	x			

ana Trustee Implementation Group (LA TIG). All of these DWH revenue sources have been used for either SWAMP development and/or SWAMP implementation.

Below are some examples of SWAMP activities that have been funded by DWH. These data are important for understanding how Louisiana's coastal systems are changing and provides information for selecting the most successful portfolios of projects for restoration.

NFWF (Barataria Basin and east of the Mississippi River)

• Above- and below-ground biomass (leveraged with existing CRMS sites) east of Bayou Lafourche

• Discrete and continuous water quality (leveraged with Louisiana Department of Environmental Quality (DEQ) and USGS; east of Bayou Lafourche)

• Design and construction of three new real-time data collection platforms in lower Barataria Basin (leveraged with USGS funding)

• Adding new wave instrumentation to 2 existing data collection platforms in Barataria Bay (leverage funding from U.S. Army Corps of Engineers (USACE) and USGS)

• Adding one new wave buoy southeast of Grand Isle (in partnership with the USACE/Engineer Research and Development Center (ERDC) Field Research Facility, Louisiana State University, and Scripps)

• Collecting geophysical data (bathymetry, side-scan sonar, magnetometer, and sub-bottom profiles) in Barataria Basin and east of the Mississippi River. These data were also used to delineate and confirm various bottom types, including oyster reefs.

• Developing a sediment budget for the Barataria shoreline

• Developing new and refined estimates of subsidence within Barataria Basin and east of the Mississippi River.

• LiDAR acquisition of the upper delta region

RESTORE

• Design of SWAMP for the western part of Louisiana's coast (from Bayou Lafourche to Sabine River)

• Soil cores, bulk density and nutrients (leveraged with existing CRMS sites)

• Above- and below-ground biomass (leveraged with existing CRMS sites) west of Bayou Lafourche

• Discrete and continuous water quality (leveraged with DEQ and USGS; west of Bayou Lafourche)

• Collecting geophysical data (bathymetry, side-scan sonar, magnetometer, and sub-bottom profiles) in areas west of Bayou Lafourche. These data were also used to delineate and confirm various bottom types, including oyster reefs.

• LiDAR acquisition of the Chenier Plain

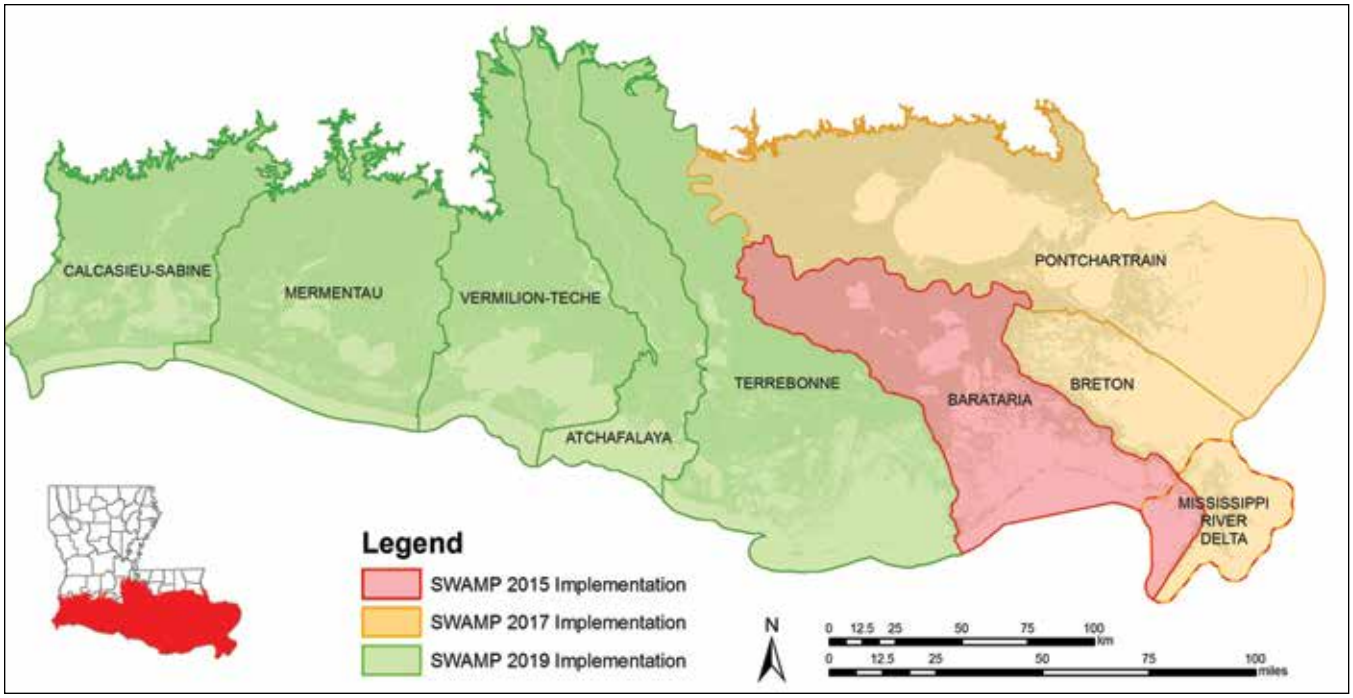

Figure 1. Louisiana coastal area showing hydrologic basins and timing of SWAMP implementation.

- Data management support

NRDA

The NRDA LA TIG is currently developing a decision-support strategy to help make decisions about how to prioritize and fund future activities related to Monitoring and Adaptive Management under NRDA. Here are some activities that have been funded to date:

- Development of an Adaptive Management Strategy
- Collection of fishery independent monitoring program (FIMP) data for the entire coast of Louisiana
- Fishery gear comparison study
- Dolphin photo identification survey
- Colonial waterbird monitoring and analysis
- Secretive marsh birds study

Concurrent with these activities within Louisiana, NRDA and RESTORE have also developed working groups that cross state lines in an effort to develop consistency and uniformity in the way various data are collected. The NRDA Cross-TIG Monitoring and Adaptive Management working group (Cross-TIG MAM) and the RESTORE Council Monitoring and Assessment Working Group (CMAWG) engage all five Gulf of Mexico states and federal partners to develop guidance for the states implementing projects and collecting monitor-

Table 2.

System Wide Assessment and Monitoring Program (SWAMP) Human System variables.

Data category	Variable
Population & demographics	
	Number of households
	Total population
	Race and ethnicity
Housing & community characteristics	
	Residential stability
	Home ownership
	Residential occupancy rates
	Property values
Economy and employment	
	Economic activity
	Income levels
	Poverty rates
	Unemployment levels
Ecosystem dependency	
	Natural resource extraction
	Cultural and traditional use of natural resources
	Natural resource-based employment
	Tourism and recreational use of natural resources
Residential properties protection	
	Residual risk reduction
	Households receiving structural protection
	Residential properties receiving non-structural protection
Critical infrastructure and essential services protection	
	Risk reduction for essential facilities and critical infrastructure
	Miles of levees created and maintained
	Number of essential facilities and critical infrastructure receiving structural protection
	Public and commercial properties receiving non-structural protection

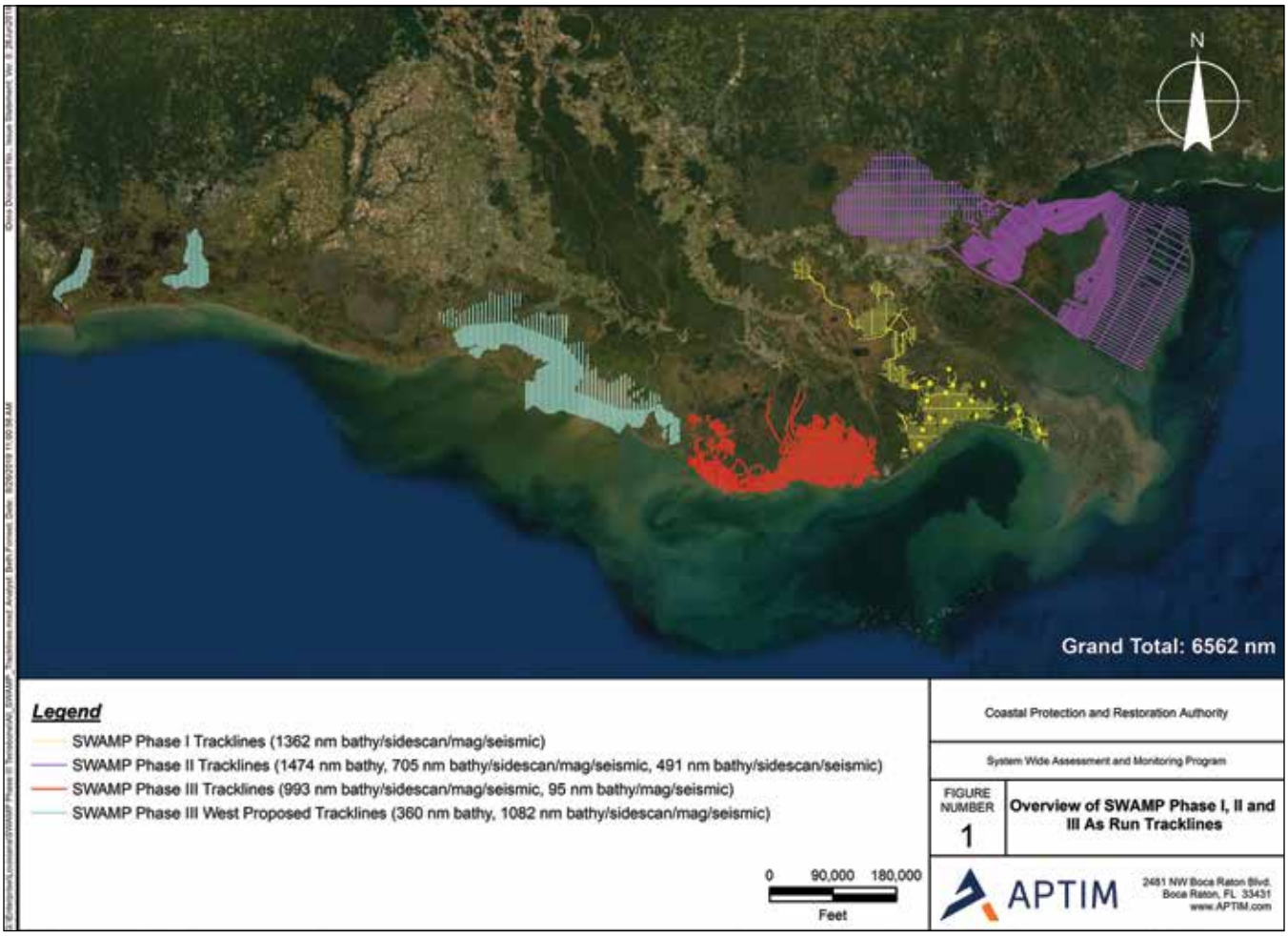

Figure 2. Inshore track lines for collecting geophysical data in coastal Louisiana. Surveys in Phase 1 and 2 (yellow and purple) were funded by NFWF, whereas Phase 3 and 4 (red and blue) were funded by RESTORE.

ing data to encourage consistency which may allow for aggregation of information across states. This is important for assessing cumulative and small-scale recovery of resources across political boundaries. These groups are benefitting from the monitoring experience of Louisiana and have incorporated many of Louisiana's processes into their recommendations for both RESTORE and NRDA.

EXAMPLES OF SWAMP PRODUCTS

Geophysical surveys:[1]

Geophysical properties are critical to understand the dynamics of Louisiana's coastal environment. The entire coast of Louisiana resulted from the growth and abandonment of various river delta lobes and the longshore transport of sediment to create cheniers to the west. Storms and other impacts also affected development of the landscape. Bathymetry of the coastal bays can dictate wave characteristics during storms, buried pipelines could render sediment resources inaccessible, sub-bottom profiles could identify buried paleo-channels, and side-scan sonar can identify areas that have an appropriate substrate for oyster growth. Although these data are important to restoration and protection efforts, comprehensive data sets are 80-100 years old, limited in scale or scope, or are non-existent. Therefore, CPRA commissioned the collection of hydrographic and geophysical data within Barataria Basin as part of the Barataria Pilot Study of SWAMP. After successful surveys within Barataria Basin, this effort was expanded to the rest of the coastal area as shown in Figure 2.

Subaerial topography using Light Detection and Ranging (LiDAR):

Documenting subaerial topographical changes over time relative to a vertical datum will improve digital elevation models and contribute to spatial maps of relative sea-level rise rates. Surface elevation refers to the height of the land surface relative to a vertical datum, such as mean sea level or NAVD88. Large, short-term changes in land elevation can occur because of changes in astronomical tides and meteorological conditions (e.g. pressure or wind-driven events) that influence subsurface processes, above ground production, and sediment deposition, among other factors (Cahoon *et al.* 2011). Long-term trends in elevation are a function of underlying tectonics, Holocene sediment compaction, sediment loading, glacial isostatic adjustment, surface water drainage and management, and sea level rise (Yuill *et al.* 2009). CPRA utilized a long-standing partnership with USGS to incrementally acquire LiDAR data for the entire coastal zone of Louisiana (Figure 3). These data have informed the coastal master plan models and improve predictive capabilities under future possible environmental scenarios.

Subsidence measurements in Barataria Basin:

The primary goal of this project was to assess recent subsidence rates within the

1) For details on geophysical surveys, please see the paper entitled "Overview of statewide geophysical surveys for ecosystem restoration in Louisiana" in this dedicated issue by Syed Khalil and others.

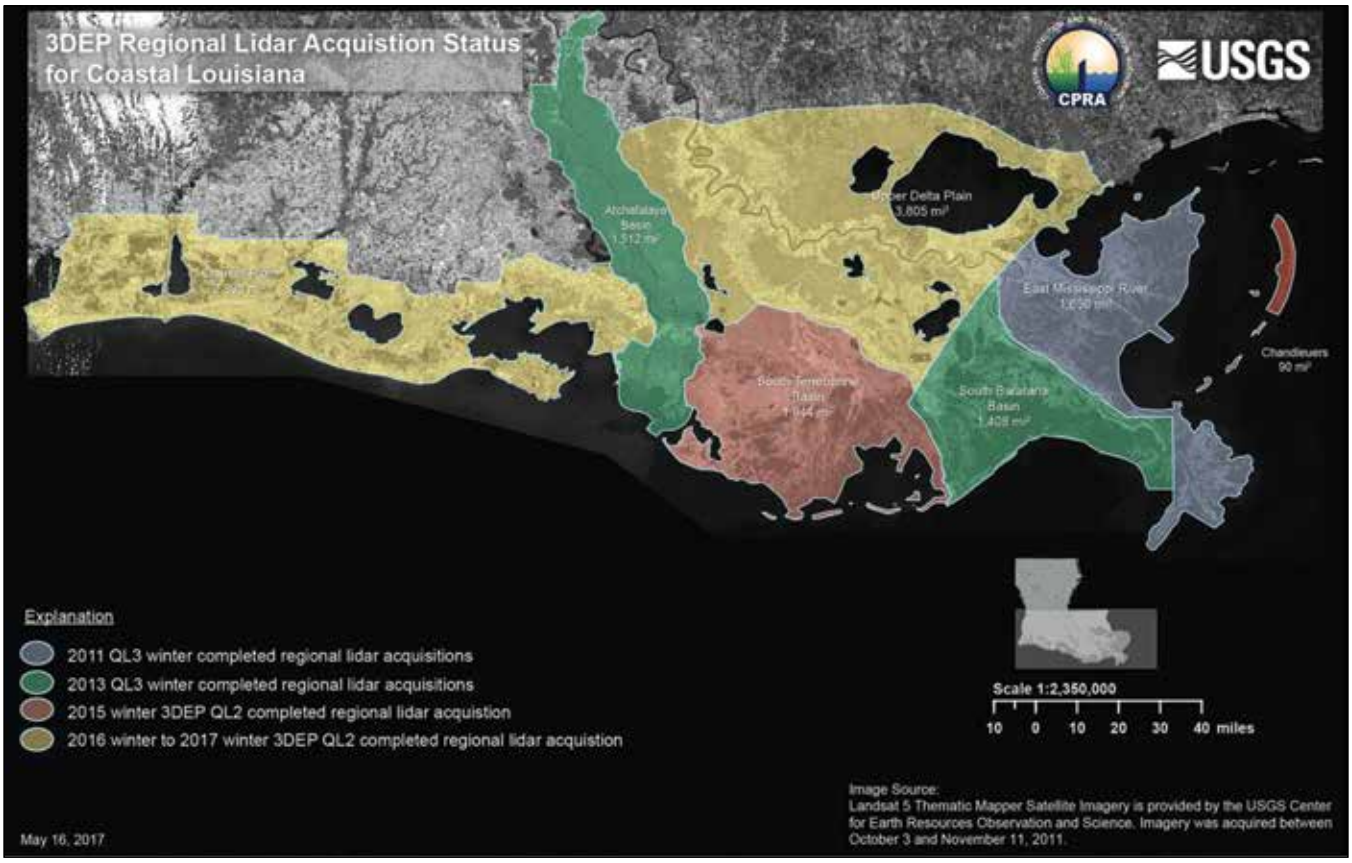

Figure 3. Location and year of acquisition for LiDAR surveys conducted by CPRA and USGS. The survey titled "Chenier Plain" was funded by RESTORE, and the survey titled "Upper Delta Plain" was funded by NFWF.

Barataria Basin. In particular, geodetic GPS elevation measurements for CORS primary benchmarks and CPRA/NGS secondary benchmarks were used to determine subsidence velocities (ACRE 2018). These data record short-term subsidence trends (4-15 year time series) from direct survey measurements that were expected to reflect conditions at proposed restoration sites over the next 20-50 years. Further, water-level gauge measurements were evaluated for documenting subsidence relative to eustatic sea-level rise estimates for the northern Gulf of Mexico.

Three geological cross-sections depicting stratigraphy for northern, central, and southern Barataria Basin were developed based on several deep borehole logs. High-resolution geodetic GPS elevation measurements at 19 benchmarks (five CORS and 14 CPRA/NGS locations) were used to determine recent subsidence velocities for Barataria Basin. Water elevation change from two gauges in the southern part of the basin supplemented survey data, resulting in a range of subsidence velocities at 21 locations from -2 to -7 mm/yr. Spatial variability in subsidence velocities indicates a compelling relationship between subsidence and age, composition, and thickness of Holocene deltaic deposits. In northern Barataria Basin, regional subsidence variations are relatively low, ranging from -2 to -4 mm/yr (Figure 4). Greatest subsidence rates were recorded in the southern portion of the basin where Holocene sediment thickness is greatest, deltaic sediment is youngest, and subsurface sediment composition is primarily fine-grained; velocities ranged from -5 to -7 mm/yr. Mid-basin subsidence rates ranged from -4 to -5 mm/yr, reflecting a transition in subsurface geologic characteristics between northern and southern areas. These data indicate that subsidence rate ranges used in the 2017 Master Plan for Barataria Basin can be refined from -2 to -20 mm/yr (used in the 2012 Master Plan) to -2 to -7 mm/yr (refined by SWAMP).

Soil characteristics and vegetation biomass:

Documenting changes in soil condition (organic matter content and bulk density) and changes in wetland above- and below-ground biomass will improve the understanding of the effect of climate, hydrology, geomorphology, and management activities on plant productivity and wetland sustainability. Soil and vegetation parameters collectively are critical to understanding changes in vegetation health, shifts in vegetation communities, or reasons for loss of vegetation.

Bulk density is used to estimate and evaluate many physical soil properties, such as porosity, water retention, buoyancy and compressibility (Ruehlmann and Körschens 2009). Organic matter and mineral content of wetland soils are key determinants of soil development and are often used to describe the roles of organic accumulation — derived from above- and below-ground plant material — and mineral sediment deposition (Neubauer 2008; Nyman et al. 2006). Both processes will vary with plant communities and other aspects of wetland dynamics, including soil inundation, drainage, redox potential, and other biogeochemical processes (Reddy *et al.* 2000).

Wetland vegetation biomass refers to both the above- and below-ground components of the plant. Biomass is a function of inundation, nutrient concentrations, soil properties, and for plants with C3 metabolisms, atmospheric CO^2 (Bazzaz 1990; Day *et al.* 2013; Kirwan and Guntenspergen 2012). Measurements of

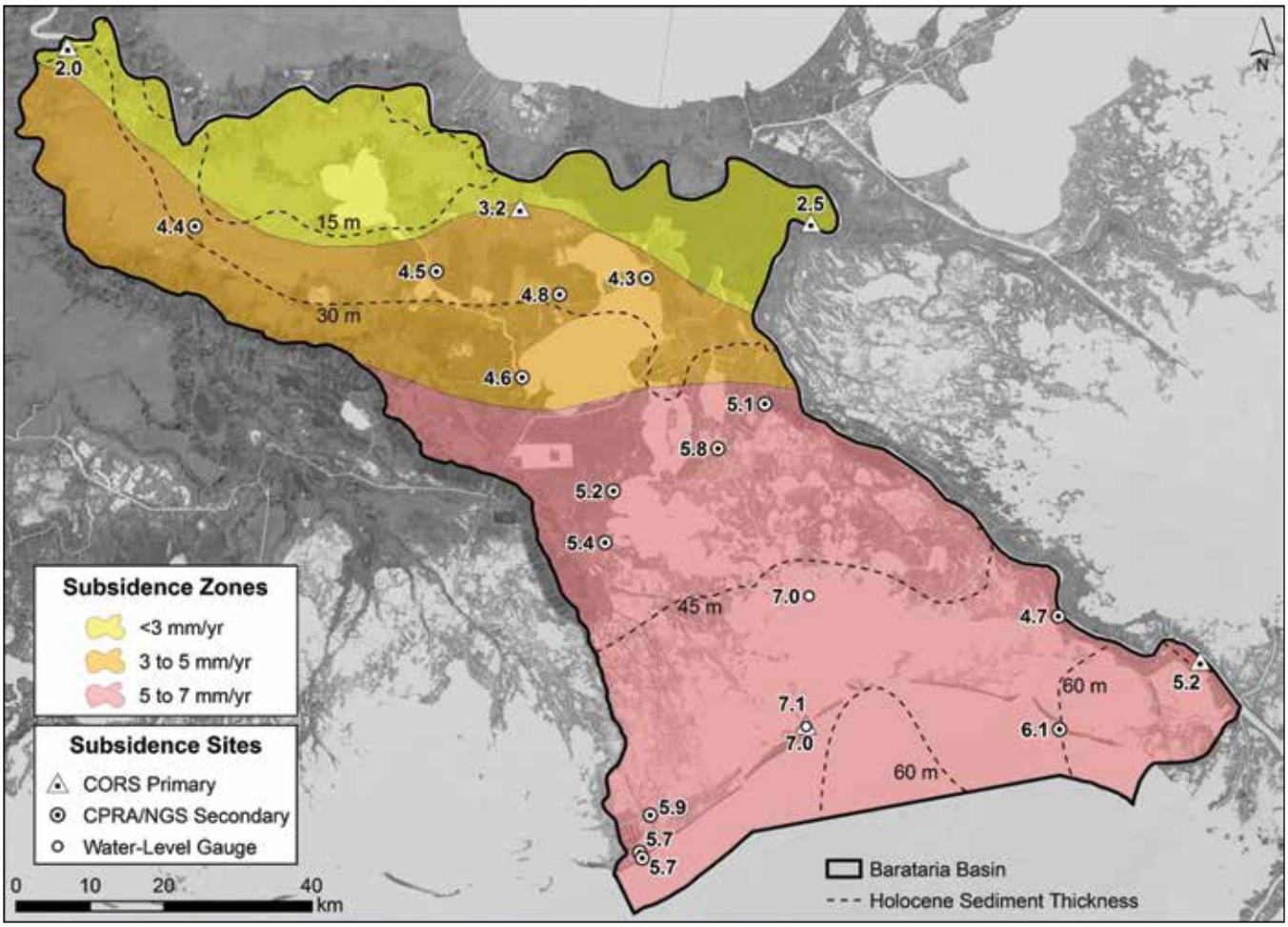

Figure 4. Map showing the subsidence velocities in Barataria Basin (ACRE 2018).

biomass over time can be used to evaluate wetland primary productivity.

CPRA leveraged CWPPRA's existing Coastwide Reference Monitoring System (CRMS) to add necessary parameters at a stratified random subsample of sites (Figure 5).

DATA MANAGEMENT

CPRA and collaborators collect a variety of data, both programmatic and project-specific, in support of coastal protection and restoration projects and activities. These data support various aspects of the coastal protection and restoration program including strategic planning, engineering and design, construction, operations, maintenance, monitoring, and adaptive management. Moreover, CPRA data collection and analysis efforts are dynamic and change as the program expands in order to meet modeling, monitoring, and assessment needs. Collecting and storing data will not improve knowledge and understanding unless the data and associated information are readily available to those responsible for making decisions.

Ever growing responsibilities, an increase in data generation, and the need to deliver information in a timely and efficient manner have inspired an effort by the CPRA to significantly improve its data management and delivery capabilities. In 2013, CPRA commissioned The Water Institute of the Gulf to develop a Data Management Plan (The Water Institute of the Gulf 2013). CPRA then partnered with the USGS' Wetland and Aquatic Research Center to produce the CPRA Coastal Information Management System (CIMS) (http://cims.coastal.louisiana.gov) to support its data management and delivery capabilities. CIMS combines several applications (e.g., a network of webpages hosted by CPRA (www.coastal.la.gov), GIS databases, and a relational tabular database) into one public-facing, GIS-integrated system capable of robust visualizations and data delivery. Any data or information generated through the coastal protection and restoration program is available to all interested parties through the various CIMS application portals including spatial viewers, tabular download web pages, and a library/document retrieval system along with a suite of public-facing web services providing programmatic access. CPRA is committed to sharing information to help all coastal stakeholders make informed, science-based decisions.

Specific activities performed by the CPRA Data Management Team (DMT) in cooperation with the USGS include management, dissemination and visualization of all tabular and spatial ecological, geophysical and engineering data generated by the CPRA (including SWAMP, CRMS, BICM, Louisiana Sand Resource Database [LASARD], Coastal Master Plan, etc.) to assist coastal protection and restoration planning, design, operations, maintenance, monitoring, and adaptive management efforts. Although these activities provide immediate assistance to CPRA, they also lay the foundation of a scalable system, which facilitates addressing future data challenges ranging from new monitoring efforts to supporting any future CPRA sponsored modeling endeavors. Required services also include data management support of Coastal Master Plan modeling efforts

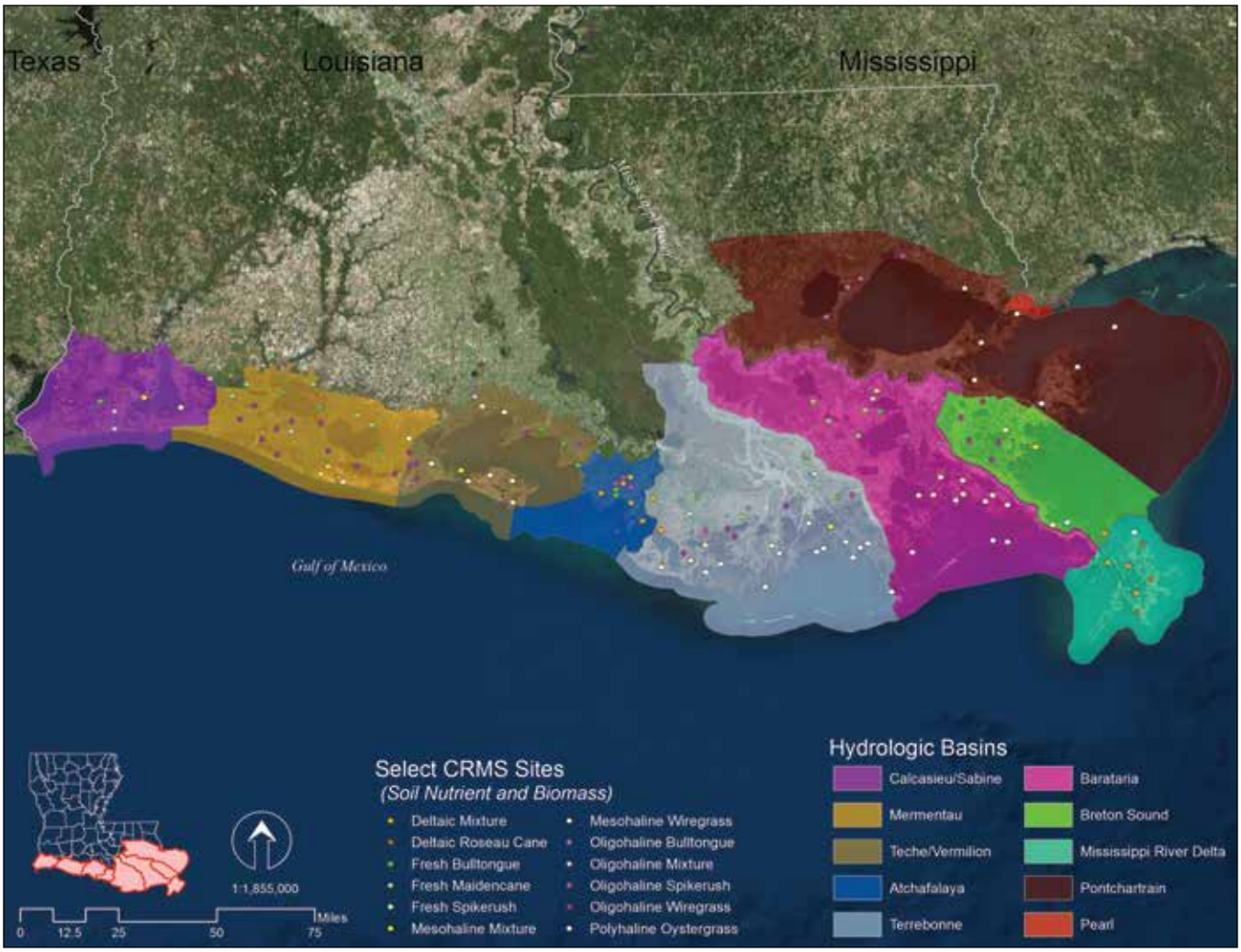

Figure 5. Location of CRMS sites that were stratified randomly selected for additional soil and vegetation biomass sampling under the System Wide Assessment and Monitoring Program (SWAMP). These soil and vegetation biomass data collection efforts are funded by NFWF (east of Bayou Lafourche) and by RESTORE (west of Bayou Lafourche). Bayou Lafourche separates Barataria and Terrebonne basins.

including support for storage and sharing of modeling input data files, output data files, and model code. Also critical to the success of any data collection and management effort are the development and documentation of policies, standard operating procedures, data conventions, and quality assurance/quality control (QA/QC) procedures (Khalil *et al.* 2016; Folse *et al.* 2018; CPRA 2016). These are living documents that are regularly updated as part of data management activities.

In a parallel effort to CPRA's development of CIMS, NOAA developed a repository named DIVER as the public NOAA repository for data related to the DWH Trustees' NRDA efforts. CPRA and USGS are working on a proposal to create an interface for CIMS data to be exported to a neutral template that could then be ingested into DIVER, and vice versa. This process will make it easier to aggregate data across states and look at larger, ecosystem-level changes. To provide additional context to the NRDA data, the DIVER site also includes historical (pre-2010) contaminant chemistry data for the onshore area of the Gulf of Mexico, as well as contaminant chemistry data collected during the response efforts. These data are available to the general public and are accessed through a query and mapping interface called DIVER Explorer.

Categories of Trustee NRDA data include:

- Photographs of the emergency response, the oiled animals, plants, fish, and beaches.
- Telemetry information collected from remote sensing devices such as transmitter data from animal monitoring.
- Field observations such as notes about the condition of animals found in the spill and extent of oiling in marshes.
- Instrument data such as water temperatures and salinity collected during the spill.
- Sample results of laboratory analysis on tissue, sediment, oil, and water.

DWH restoration projects and monitoring data will also be incorporated into DIVER as information becomes available. To ease information availability, efforts are ongoing to make recommendations for standardization of data collection methods and data formats across the Gulf.

DISCUSSION

It is expected that coastal areas will increasingly need to adapt to disasters (whether natural, human, or both). In the Gulf of Mexico, and in Louisiana in-particular, both natural and human impacts have resulted in irreversible consequences to the coastal landscape. Louisiana's coast has historically been

rich in natural resources and as humans have exploited them for sustenance or for profit, populations have become situated in precarious positions relative to recent events and potential future risk. Louisiana's CPRA has been given the legislative authority to integrate coastal restoration and hurricane protection for the state, to marshal the expertise and resources of other state agencies, which must operate in means that are consistent with (not in conflict with or opposing) the state's Coastal Master Plan, and to lead the state's efforts to preserve Louisiana's coast and its resources. Louisiana had established the commitment and dedication to restoring the coast prior to the DWH disaster. The state had organized its governance around working with stakeholders and partnering state and federal agencies, and had already developed a Coastal Master Plan with a portfolio of projects aimed at restoring and protecting its coast. As a result, when the DWH disaster occurred, Louisiana was more prepared to respond. This preparation facilitated the documentation of injuries and losses, which informed decisions on what was necessary to restore the coastal system.

The DWH disaster in Louisiana had far-reaching impacts, including ecological, socioeconomic, and other impacts. Several of the settlement funding streams included not only funds to restore impacted habitat, but also included funding to address other impacts as well. One important aspect of the various DWH settlements is that funding was included for dedicated monitoring and adaptive management to improve the scientific understanding of coastal systems. With the help of NFWF, RESTORE and NRDA, Louisiana accelerated the development and implementation of much needed monitoring to be able to evaluate trajectories of resource recovery. CPRA has commissioned the collection of much-needed data at an unprecedented scale to fuel predictive ecosystem-scale models and also to investigate the recovery and sustainability of resources injured by the DWH disaster. However, data collection by itself is not adequate to evaluate success. Data management activities will also ensure that a variety of tools continue to provide management and access to data that are collected by SWAMP, as well as other programs within CPRA. Data management and data availability are cornerstones of adaptive management by ensuring that information is available and accessible when necessary to make informed decisions. Data must be turned into information, which includes managing it in a way that is discoverable and is available to those that need it to make decisions. Louisiana has redesigned its system to significantly improve its data management and delivery capabilities.

Efforts are currently under way to expand synthesis reporting to additional hydrologic basins, expanding on the Mermentau Basin and Calcasieu-Sabine Basin Reports written by CPRA's Lafayette Regional Office, and considering scales beyond individual hydrologic basins to improve the understanding of coastal change at the ecosystem-scale. SWAMP data are being combined with historic CRMS and BICM data and data from other programs to improve our understanding of the complexity of larger ecosystems and their restoration trajectory.

In addition to the incremental developments related to monitoring and data management, Louisiana is also represented in the NRDA Cross-TIG Monitoring and Adaptive Management work group as well as the RESTORE Council Monitoring and Assessment Work Group. These groups have been focused across states within the Gulf of Mexico (Texas, Louisiana, Mississippi, Alabama, and Florida) to develop guidelines for applying monitoring and adaptive management to DWH projects in a manner that is consistent across jurisdictions and also to facilitate aggregating information to a larger, Gulf-wide context. These groups are benefitting from the monitoring experience of Louisiana and have incorporated many of Louisiana's processes into their recommendations for both RESTORE and NRDA.

Collaboration and partnerships across Gulf States provide opportunity to leverage knowledge, experience and promote consistency in how DWH projects are monitored and evaluated. Consistency across states will promote aggregation of data across larger regions and will provide insight into resource recovery from the DWH disaster across political boundaries.

CONCLUSIONS

The motivation for developing SWAMP was to establish a long-term regional monitoring program to ensure that a comprehensive network of coastal data collection activities to support the planning, development, implementation, and adaptive management of the protection and restoration programs and projects within coastal Louisiana. SWAMP was designed, under its overarching umbrella, to encompass CRMS (regional wetland monitoring) and BICM (regional barrier island monitoring) and a well as fisheries data collected by the Louisiana Department of Wildlife and Fisheries (LDWF). SWAMP was also designed to identify important human-system parameters that collectively inform the trajectory of communities living in the coastal area. In addition, monitoring and operation of restoration and protection projects will be nested within a larger basin-wide and coast-wide SWAMP framework and will allow informed decisions to be made with an understanding of system conditions and dynamics at multiple scales. The concept of SWAMP preceded the DWH disaster, but its design and subsequent implementation of various components was only facilitated by DWH funding. SWAMP was initially designed for Barataria Basin as a Pilot Project in 2015. Since then it has been expanded to the east of the Mississippi River in Breton Sound/Chandeleur Sound and Pontchartrain Basin, followed by expansion to the west to cover the entire Louisiana coast.

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