The National Academies of SCIENCES ENGINEERING MEDICINE
GULF RESEARCH PROGRAM

Healthy Ecosystems Grants 2 Final Report

Project Title: Understanding the Trajectory of Coastal Salt Marsh Structure, Function, and Processes in the Face of Sea-Level Rise: A Synthesis from Historical Imagery, Biophysical Processes, and Hierarchical Modeling
Award Amount: $506,619
Awardee: Dauphin Island Sea Lab – University of South Alabama
Award Start Date: 12/04/15
Award End Date: 06/03/18
NAS Grant ID: 2000006421

Project Director: Patrick Biber
Affiliation: Gulf Coast Research Laboratory, University of Southern Mississippi

Project Key Personnel:

- Wei Wu, Coastal Science, University of Southern Mississippi
- Greg Carter, Geography and Geology, University of Southern Mississippi
- Deepak Mishra, Geography, University of Georgia

I. PROJECT SUMMARY (from proposal)

The proposed research will integrate and synthesize existing historical aerial photography and satellite imagery with fragmentation analysis, as well as existing biophysical and CO2 flux data with biophysical process models to better understand the trajectory and implications of sea-level rise (SLR) on coastal marshes in the northern Gulf of Mexico. The goal of the proposed research are to analyze and synthesize the long-term health and productivity trends of coastal wetlands by developing a better mechanistic understanding of the current and historical extent, condition, productivity, and function of these saltmarshes. The specific objectives are to combine existing data from archives of aerial photography and satellite imagery with geospatial mapping and fragmentation analysis, to use existing in-situ vegetation monitoring data to refine and develop biophysical process models and hierarchical Bayesian modeling at multiple spatial scales that will help to improve future predictions for this vulnerable habitat. The proposed research addresses key components of the Gulf Research Program by developing innovative ideas on the use and analysis of existing data collected in the Gulf of Mexico and associated coastal wetland communities to advance the understanding of environmental conditions, ecosystem services, and community health important for developing improved restoration outcomes in the face of future climate change and sea level rise. The anticipated products will be a time-series of historical maps showing change in marsh extent, composition, and fragmentation, overlayed with biophysical process rates (productivity, canopy traits, plant biomass) for selected dominant plant species. The result of this historical mapping data analysis and modeling synthesis will be an efficient and non-destructive protocol for wetland structural and biophysical characteristics, which can be used for assessing the success of future restoration projects, identifying areas of degradation from oil and energy related activities in the coastal zone, and in evaluating the productivity of marshes that are impacted by anthropogenic development activity and sea level rise. The various biophysical modeling

products will be integrated and spatially scaled using an hierarchical Bayesian model to develop better future forecasts for sea level rise and marsh vulnerability. The resultant products will be broadly applicable to inform plans for marsh preservation, restoration, and the future viability of the numerous ecosystem services provided by coastal marshes to human communities. This project will address goals 2 and 3 of the Gulf Research Program by improving understanding of key connections in long-term salt marsh resilience that will help to support healthy future Gulf communities, and by advancing understanding of the multiple linkages between climate, sea level rise and marsh habitat dynamics over decadal time scales to better inform the protection and restoration of this key ecosystem.

II. PROJECT SUMMARY (from final report)

The key issues in this research are coastal marsh erosion and retreat, an increasingly common problem being reported from many places around the Gulf. Marsh sustainability is influenced by the combination of the ability of the marsh platform to build up and maintain elevation relative to the mean tidal height, and the ability of marsh plants to retreat landward with rising sea level.

This project is the first of its kind to assimilate historical aerial photography and satellite remote sensing data and combine these data with advanced mapping and habitat classification, vegetation biophysical indices, and landscape fragmentation analyses to better synthesize the rates and potential impacts of future coastal marsh change through simulation and modeling. The unique multi-disciplinary team we have developed that spans botany, ecology, geography and mathematical modeling with long-time series data analysis and scenario projections is unparalleled.

The products developed by this team included historical maps showing change in salt marsh extent, composition, and fragmentation, biophysical processes for marsh habitat, and future scenarios of salt marsh extent and function. The result is a comprehensive synthesis of salt marsh structural and biophysical characteristics that can be used for assessing the success of future restoration projects, identifying areas of degradation from oil and energy related activities in the coastal zone, and for evaluating productivity of marshes. The resultant products can be broadly applicable to inform plans for preservation, restoration, and the future viability of the numerous ecosystem services provided by coastal marshes to human communities.

III. PROJECT RESULTS

Accomplishments

The primary problem addressed in this project was providing a better understanding of the processes causing the ongoing and accelerating loss of coastal marshes in the northern Gulf of Mexico due to sea level rise. Coastal marsh loss is essentially a result of either edge erosion and/or interior marsh platform subsidence. Both processes reduce the area of remaining marsh, but can occur for different reasons.
To address the primary problem and to study these processes further, we selected two representative study sites in Mississippi, the Grand Bay National Estuarine Reserve (GB) and the Pascagoula River delta (PR). These two sites are very close (<30km apart) and represent two very different marsh sustainability conditions, allowing for a detailed cross-system comparison. The GB marshes are characterized by high rates of marsh loss, lack of upland sediment supply, and high salinity, with marshes dominated by black needlerush (Juncus roemerianus). In contrast, the PR marshes have remained more stable over time, with

sediment supplied from riverine sources, but salinity is low, with marshes transitioning from smooth cordgrass (Spartina alterniflora) to sawgrass (Cladium jamaicense) and arrowhead (Sagittaria lancifolia) as salinity decreases up river.

In each of these two study sites we collected existing datasets related to marsh change over time. To map change, we accessed archived historical aerial photography from USGS and other data sources. Both gray scale and color imagery was used over the time-period from 1955 to 2014 (59 years). Images were georeferenced, georectified, and classified into water, marsh, woodland, other (saltpan, urban) categories, and change detection run on the marsh class. Marsh loss in GB was 11% over this time- period, with the majority reverting to open water, the dominant process was edge erosion with up to 8.3 m per year average marsh edge retreat in select locations. Interior subsidence and conversion of marsh to water was also observed in GB, counter to our prior expectations.

Further detailed investigation of the landscape arrangement of marsh patches was accomplished using FRAGSTATS to calculate various metrics related to landscape fragmentation. A conceptual model for fragmentation processes was developed and tested in GB to highlight the expected changes in total area, number of patches, and total edge conditions as fragmentation increases. A threshold condition occurs when between 25-50% of a given area of the landscape remains as marsh, with rapid and irreversible change to open water as fragmentation proceeds.

To go beyond just mapping marsh change over time and to better understand the potential implications of future climate on marsh processes, we used archived MODIS 250m and 500m data to develop biophysical process models of vegetation dynamics. We created 8-day composites and developed robust algorithms to derive parameters such as leaf area index (LAI), canopy chlorophyll content (Chl), vegetation fraction (VF), and above- and belowground biomass (BM). From these metrics, and ground-truthed data obtained from our eddy covariance tower, we then calculated Gross Primary Production (GPP) using a new model developed especially for Gulf salt marshes, and used the resulting GPP composites to create comprehensive site-specific phenological analysis over the time-period 2000 to 2016. The GPP time–series composites and the seasonality parameters were able to capture both intra– seasonal as well as inter–seasonal variability of GPP of the GB and PR salt marshes. This is the first study attempting to develop models for mapping GPP for salt marsh habitats in the Gulf Coast, using MODIS images. The study has the potential to improve our understanding of long–term carbon dynamics of salt marsh habitats along the Gulf Coast, and similar salt marsh settings elsewhere.

From these different datasets, we then developed a mechanistic simulation model to predict the impact of future sea level rise on salt marshes by integrating the vegetation dynamics, as well as hydrological and sediment processes. In this model, the elevation of the marsh surface changes due to sea-level rise, subsidence, sedimentation from organic and mineral matter, and erosion. Consequently, we simulated various scenarios of future changes of coastal marshes at GB by 2100, including inundation and conversion of vegetation, under multiple environmental stressors that interact with each other. We applied the model to simulate wetland dynamics by 2050 and 2100 under the scenarios of SLR rates ranging from 4 mm/yr (current sea level rise rate) to 20 mm/yr (high end of SLR rate predictions) using an increment of 0.5 mm/yr. This provided the predicted total wetland areas under 33 different scenarios of SLR rates, and from this we derived the thresholds of SLR rate beyond which coastal wetlands will

fragment into a less desirable state with much smaller emergent wetland areas and the resulting loss of marsh to open water. While it seems in this case study that coastal wetlands are resilient to SLR by 2050 under both low and high emission scenarios, it is very likely that highly vulnerable coastal wetlands like Grand Bay could collapse by the end of the century, especially under the high warming scenario. Salt marshes in the Pascagoula delta were found to be more resilient to SLR than at the Grand Bay as the SLR threshold is larger for Pascagoula marshes, likely due to more abundant land-borne sediment available from river discharge. Our model provides a transferrable and useful method for evaluating coastal wetlands' nonlinear response to SLR, especially in marine-dominated systems, and facilitating design of mitigation and adaption policy under future climate change.

In summary, we synthesized existing data from a variety of sources including historical aerial photography, satellite remote sensing, and ground-truth data and developed novel algorithms and models to better capture landscape change, fragmentation, and biophysical process dynamics coupled to mechanistic modeling of future scenarios over a range of sea level rise and climate change. The outcome of this research has provided a more detailed synthesis of recent landscape changes occurring in coastal marshes in Mississippi that highlight the potential for vulnerability of these valuable natural systems and the consequences of future loss of associated ecosystem services to coastal communities.

Implications

This project is the first of its kind to assimilate historical aerial photography in grey scale (1940's-1960's), modern-era color IR photography (1970's-present day), and satellite remote sensing data (MODIS: 2000 - present) and combine these data with advanced mapping and habitat classification algorithms, vegetation biophysical index algorithms, and landscape fragmentation analyses to begin to better synthesize the rates and potential impacts of future coastal marsh change through simulation and modeling. This project has allowed the research team to continue existing projects (biophysical vegetation modeling and CO2 flux monitoring at GB), expand development of previous techniques and algorithm refinement (textural classifications for greyscale imagery), and develop new models for forecasting future coastal landscape conditions (fragmentation and simulation). The resulting synthesis and conceptual models set the foundation for future research endeavors to expand and test these ideas in other systems and beyond the Gulf of Mexico. Team members are actively pursuing additional funding options from various sources including USGS, NASA, NOAA, EPA and other federal and state funding sources.

The findings of our research include a recognition that in the northern Gulf of Mexico coastal marsh sustainability over longer time scales (decades to centuries) is influenced by the combination of: (1) the ability of the marsh platform to build up and maintain elevation relative to the mean tidal height, and (2) the ability of the marsh plants to retreat landward as mean water levels increase with rising sea level. Coastal vegetation retreat is a natural process that has occurred in the historical past when marsh platforms were inundated, however, in today's built-up coastline there is often no longer green space available for upland marsh migration. As a consequence, coastal marshes are starting to become increasingly fragmented habitats with the end result that they can no longer provide many important and valuable ecosystem services, such as coastal protection, sediment and nutrient removal, estuarine nursery habitat, and carbon burial.

The implications of this research suggest a future where coastal marshes in the northern Gulf of Mexico are less extensive and provide fewer ecosystem services than they have in the past. An important ecosystem service provided by marshes that many coastal residents rely on is protection from high water and storm surge. Coastal marshes help to reduce wave energy and coastal erosion, providing protection for built infrastructure like houses and roads. However, as our research has demonstrated, marshes are already eroding and subsiding, and this process will continue to speed up as sea level rise accelerates into the future. Ongoing, but gradual, coastal erosion brings the water closer to built structures increasing the risk of catastrophic damage during storm events. Therefore, loss of coastal marshes with sea level rise increases the cost of insuring, rebuilding, or relocating property along the coastline.

Another important set of ecosystem services provide by coastal marshes are related to their role as habitat and as filters. Coastal marshes remove sediments, nutrients, and pollutants from the water, improving coastal water quality. These nutrients and sediments help the plants to grow, providing both structure and food for many commercially and recreationally valuable fisheries species during the juvenile phase. This is why marshes are often called the "nursery" for the coastal estuary. The loss of these economically valuable resources is an often under-appreciated consequence of coastal marsh loss, as it may be less visible than loss from flooding and storm damage. Loss of marshes, therefore, also affects viability of coastal societies and economies through loss of fisheries production, loss of clean water, and loss of tourism and recreational opportunities.

Unexpected Results

Loss of marsh area resulting from processes most likely related to interior subsidence was an unexpected finding for Mississippi. While this process is now well established for Louisiana marshes of the Mississippi River delta, it was previously not reported in smaller coastal marsh areas found in Mississippi and Alabama. We discovered evidence of likely subsidence of the marsh platform at GB and in selected areas of the PR, which allowed interior areas with existing marsh habitat to convert to open water between 1955 to 2014. Once this happens, additional marsh edge loss can occur along this new marsh-water margin, resulting in more rapid fragmentation of marsh, and a faster rate of conversion of former marsh to open water.

Another unexpected result was the increase in the woodland class which expanded in area in both the GB and PR study sites between 1955 to 2014. At GB alone woodland increased by more than 230 ha over the 59 years. This was largely the result of a change in land management practices from an actively logged forest in the 1950s to a conservation status in the late 1990s when the NERR was formed. We did not find expected evidence of forest retreat as a function of salt water intrusion, suggesting an important role of groundwater in mitigating against the salinification effects of sea level rise. We are currently evaluating groundwater data collected between 2015-2018 at GB to better understand the role of below-ground hydrology and its interactions with the plant rhizosphere.

Project Relevance

The following audiences would be most interested in the results of this project:

- Researchers
- Educators

- Community Leaders

Researchers are interested in the development and application of the algorithms and techniques developed during this project. We have received interested and valuable feedback at conferences and workshops on various aspects of the research conducted to date, which has helped inform a strong vision for future research opportunities. Publications, produced in part with this funding, are beginning to be increasingly cited, indicating interest by other researchers in our products.

Educators are interested in the broader implications of the research. The Marine Education Center at GCRL has fielded an increase in the number of inquiries related to climate change and sea level rise research being conducted in Mississippi and the northern Gulf of Mexico. The results obtained in part through this project are informing interested educators and their students of the importance of coastal marsh habitats and the potential future consequences of climate change in the region. An education-outreach Wetland Loss Estimator web tool was developed to make this information more accessible to middle-school students.

Community Leaders are particularly interested in understanding the potential impacts and possible solutions to the problems that affect societal and economic well-being and resilience. Recognizing that coastal marshes provide more than just storm protection is an important message for coastal communities. The economic, cultural, and spiritual values of the many other ecosystem services provided by coastal marsh habitats is an important outcome of this research that is resonating with local community leaders.

Education and Training

Number of students, postdoctoral scholars, or educational components involved in the project:

- Undergraduate students: 4
- Graduate students: 5
- Postdoctoral scholars: 3
- Other educational components: 3

At USM, we trained two graduate students, one postdoctoral associates, and two undergraduate students. Additionally, three technicians were trained on data collection and analysis and geospatial techniques. All three were either recent USM graduates or pursuing a graduate degree in a non-related discipline, and as such were not supported as students for the purposes of this grant. The data produced was used for Task 1 – historical image interpretation and Task 4 – future scenario modeling.
At UGA, we trained two graduate students, two postdoctoral associates, and two undergraduate students. The students and postdocs were involved in Task 3- establishing the Eddy Flux Towers, data processing, biophysical model development, and time-series and phenometric analysis.

IV. DATA AND INFORMATION PRODUCTS

This project produced data and information products of the following types:

- Data
- Scholarly publications, reports or monographs, workshop summaries or conference proceedings
- Websites or data portals

- Models or simulations
- Software packages or digital tools, or other interactive media

DATA

See attached Data Report.

Relationships between data sets:

This project was composed of multiple linked tasks headed by the individual PIs. The four tasks of this project were to:

- Task 1 - Collate and synthesize existing historical imagery from 1940s to present and develop georeferenced habitat classes focusing on coastal marshes.
- Task 2 - Undertake a change analysis of selected marsh habitats over time and a fragmentation analysis of coastal marsh using FRAGSTATS.
- Task 3 - Develop composite salt marsh biophysical products from MODIS and Landsat data including distributions of chlorophyll content (Chl), vegetation fraction (VF), leaf area index (LAI), and green biomass (GB) using field monitoring data collected from 2000 to 2015. Develop a biophysical parameter- centered gross primary productivity (GPP) model and prototype 8-day composites of salt marsh GPP using MODIS data.
- Task 4 - Assimilate mapping and biophysical data to develop and calibrate a mechanistic model which integrates vegetation, hydrology, and sediment dynamics to project future change in selected coastal marshes.

Each research group produced one or more data products as part of their efforts under these four tasks. We have listed eight data products that represent the final output resulting from the different research tasks. Two data products are listed for each task and are summarized below:

- Task 1 – A time series of classified habitat maps for the Grand Bay (1955, 1992, 2014) and Pascagoula River (1980, 1996, 2014) study sites derived from analysis of historical aerial photography using consistent classification algorithms. These data informed the analyses performed in Task 2.
- Task 2 - A fragmentation analysis of selected 250 m grid cells in coastal marsh in Grand Bay using FRAGSTATS to derive total area, number of patches, and total edge over a range of marsh percent cover (100%, 90%, 75%, 50%, 25%, 10%, 0%). Transition matrix probabilities for marsh-to-marsh, marsh-to- water, water-to-marsh, and water-to-water conversions for the different combinations of time steps. These data complement the analyses performed in Task 1, and provided needed information to evaluate Task 4 outputs.
- Task 3 – Time series of salt marsh biophysical products including spatial and temporal distributions of chlorophyll content (Chl), vegetation fraction (VF), leaf area index (LAI), and green biomass (GB) from 2000 to 2015 at each of the two study sites. Time series of a biophysical parameter-centered gross primary productivity (GPP) model for salt marsh from 2000 to 2016 at each of the two study sites. These data helped to inform the modeling in Task 4.
- Task 4 – Output of a mechanistic model based on data created in Tasks 1, 2, and 3 was used to evaluate and project scenarios of future landscape change (2050, 2100) in Grand Bay coastal marshes. Both geospatial (maps) and tabular (model parameters) results were produced.

The data products produced as part of these different tasks were inter-related and helped to synthesize existing information from a wide range of different data sources, with the common goal of better understanding the trajectory and implications of sea-level rise on coastal marshes in the northern Gulf of Mexico.

Additional documentation produced to describe data:
Additional documentation was produced as part of the data products outlined above in our response to 4.1 and details are listed below:

- Task 1 – Classification algorithms were developed using gray-scale brightness and texture analyses using Maximum-Likelihood and evaluated using spatial statistics. These steps are reported in the Master's Thesis of Ms. Heather Nicholson (https://aquila.usm.edu/masters_theses/317).
- Task 2 – Workflow procedures were developed in ESRI ArcGIS for 250 m grid cells to process image information into shapefiles (vector polygons), which were then used in the fragmentation analysis and transition matrix data generation steps. These steps are reported in a manuscript that is in preparation by Dr. Saranee Dutta.
- Task 3 – Algorithms were applied to calculate wetland biophysical characteristics based on statistical relationships between MODIS 250m and 500m surface reflectance products and in-situ estimates of vegetation indices including Above–ground Green Biomass (BM), Vegetation Fraction (VF), Leaf Area Index (LAI), and Canopy Chlorophyll (CHL). These algorithms are published in Ghosh et al. 2016 (https://doi.org/10.1016/j.rse.2015.11.015). New algorithms were developed in this project to calculate a biophysical parameter centered Gross Primary Production (GPP) model for Gulf salt marshes. The GPP model has a direct relationship with photosynthetic capacity and other biophysical parameters calculate above. These newly developed algorithms are reported in a manuscript that is in preparation by Dr. Deepak Mishra.
- Task 4 – Mechanistic model code and output was applied to evaluate and project scenarios of future landscape change (2050, 2100) in Grand Bay coastal marshes. The model construct and steps in developing the 33 scenarios is reported in Wu et al. 2017 (https://doi.org/10.1002/ece3.3550) and supplementary information.

Other activities to make data discoverable:
Additional activities were undertaken to ensure others can easily discover project data. These include the development of a general-public oriented website (https://sites.google.com/view/ms-coastal-marsh-synthesis/home) detailing the different project tasks and outcomes, as well as links to our databases and further information related to the project.

To better ensure that others can access and re-use these data in the future, we are providing information describing the data and outputs, which is in addition to the metadata required. This is in the form of information products (publications, reports, annotated code) as well as the project website, which is the main information portal linking to these various data. All data will be housed in multiple locations including Aquila USM and KNB repositories, and the use of Google Sites for the webpage all enhances search engine discovery for future access. In addition, all data is backed up and archived in individual PI research labs and institutions allowing for further redundancy in data preservation.

Individual PIs and their students also have presented results at a number of conferences and workshops over the past 2 years. A listing is provided here:

- Bell, M., G. Carter and P. Biber. 2018. Detecting coastal salt marsh change from aerial imagery: Pascagoula River Marsh, 1996-2014. Ecological Society of America, New Orleans, LA, 7 Aug 2018
- W. Wu, P. Biber, M. Bethel. 2017. Thresholds of sea-level rise rate and sea-level rise acceleration rate for a vulnerable coastal wetland. American Geophysical Union Fall Meeting, New Orleans, LA, December 11, 2017.
- Nicholson, H, and G. Carter. 2017. Detecting Coastal Salt Marsh Change in Grand Bay National Estuarine Research and Reserve from 1940 – 2014 Using Texture Methods on Panchromatic Imagery. ASPRS IGTF 2017, Baltimore, MD, 16 March 2017.
- Wu, W, P. Biber, M. Bethel. 2017. Thresholds of sea-level rise rate and sea-level acceleration rate in a vulnerable coastal wetland. Grand Bay NERR Research Symposium, Grand Bay, MS, 8 Sept 2017.
- Nicholson, H. 2016. Detecting Change in Coastal Marshlands from 1950 – 2014 using Textural Analysis of Panchromatic Imagery. Bays and Bayous Symposium, Biloxi, MS, 29 Nov 2016.
- Wu, W, M. Bethel, P. Biber. 2016. Developing A Hybrid Model To Predict The Impact Of Sea-Level Rise On Coastal Wetlands. Bays and Bayous Symposium, Biloxi, MS, 30 Nov 2016.
- Ghosh, S, J. Tao, D. Mishra. 2016. Analyzing MODIS Derived Site–specific Tidal Wetland Phenology using TIMESAT. American Association of Geographers Conference, San Francisco, CA, April 2016.

INFORMATION PRODUCTS

Citations for Project Publications, Reports and Monographs, and Workshop and Conference Proceedings:

Publications:

Shuvankar Ghosh, Deepak R. Mishra, Anatoly A. Gitelson. 2016. "Long-term monitoring of biophysical characteristics of tidal wetlands in the northern Gulf of Mexico — A methodological approach using MODIS." Remote Sensing of Environment 173: 39-58.

Wu W, Biber P, Bethel M. 2017. "Thresholds of sea-level rise rate and sea-level rise acceleration rate in a vulnerable coastal wetland." Ecology and Evolution 7: 10890–10903.

Reports:

Nicholson, Heather Michelle, "Textural Analysis of Historical Aerial Photography to Determine Change In Coastal Marsh Extent: Site of the Present-Day Grand Bay National Estuarine Research Reserve (GBNERR), Mississippi, 1955-2014" (2017). Master's Theses. 317.

Websites and Data Portals:

- Project Website: Understanding The Trajectory Of Mississippi Coastal Salt Marsh Structure, Function, And Processes In The Face Of Sea Level Rise: A Synthesis - https://sites.google.com/view/ms-coastal-marsh- synthesis/home
- Project Data Portal: Understanding The Trajectory Of Mississippi Coastal Salt Marsh Structure, Function, And Processes In The Face Of Sea Level Rise: Data and Information Portal - https://aquila.usm.edu/saltmarsh/

- An education-outreach Wetland Loss Estimator web tool was developed to make information more accessible to middle-school students - https://ecospatial.usm.edu/2017/05/01/education-outreach-sea- level-rise-wetland-loss/

The Project Website and Data Portal will be actively updated and maintained for a period of 24 months as outlined in the proposal Data Management Plan: "The data and metadata management plans will be followed for an additional 24 months after the end of the project, during which time investigators will collaborate to write manuscripts and make presentations to the scientific community at various conferences. The research data from this project will be made available to collaborators and to the broader research community after this period of time. Two years after the project ends, the entire dataset (digital data and derived products) will be archived on a publicly accessible website for distribution to the public, policy makers, and scientific community. Data use by other investigators in subsequent work requires citation and a statement acknowledging the PI's lab for collecting the data and NAS for funding the project."

After this 2 year update and maintenance period ends (June 2020), all long term management will be through the Knowledge Network for Biocomplexity (KNB), which is an international repository intended to facilitate ecological and environmental research, as recommended by the NAS GRP program. Data will be transitioned from USM Aquila to archival storage after conversion into non-proprietary .csv and .txt formats for long-term access at KNB during the 24 month period following the conclusion of the research activities and as final verification of the data is completed. This also provides time for any publications to be included in the final archive. Long-term management of archival data will be handed over to KNB. Any "internal" archival procedures by the PIs and partner universities will be followed for those data they may have generated including but not limited to established data preservation periods and data integrity checking protocols. Where possible citations of publications will make use of stable DOI or URL links. Long term archived data access will be provided by KNB through their web portal and direct contact links.

Documentation to Describe Information Products
Documentation for models or simulations was produced as part of the modeling efforts resulting publication of Wu et al 2017 (https://doi.org/10.1002/ece3.3550). Annotated code is included as part of this documentation.

Information Product Inventory:
See attached Information Products Report.

Other Activities to Ensure Access to Information Products:
Additional activities were undertaken to ensure others can easily discover project information. These include the development of a general-public oriented website (https://sites.google.com/view/ms-coastal- marsh-synthesis/home) detailing the different project tasks and outcomes, as well as links to our databases (https://aquila.usm.edu/saltmarsh/) and further information related to the project.

Individual PIs and their students have presented results at a number of conferences and workshops over the past 2 years. A listing is provided here:

- Bell, M., G. Carter and P. Biber. 2018. Detecting coastal salt marsh change from aerial imagery: Pascagoula River Marsh, 1996-2014. Ecological Society of America, New Orleans, LA, 7 Aug 2018
- W. Wu, P. Biber, M. Bethel. 2017. Thresholds of sea-level rise rate and sea-level rise acceleration rate for a vulnerable coastal wetland. American Geophysical Union Fall Meeting, New Orleans, LA, December 11, 2017.
- Nicholson, H, and G. Carter. 2017. Detecting Coastal Salt Marsh Change in Grand Bay National Estuarine Research and Reserve from 1940 – 2014 Using Texture Methods on Panchromatic Imagery. ASPRS IGTF 2017, Baltimore, MD, 16 March 2017.
- Wu, W, P. Biber, M. Bethel. 2017. Thresholds of sea-level rise rate and sea-level acceleration rate in a vulnerable coastal wetland. Grand Bay NERR Research Symposium, Grand Bay, MS, 8 Sept 2017.
- Nicholson, H. 2016. Detecting Change in Coastal Marshlands from 1950 – 2014 using Textural Analysis of Panchromatic Imagery. Bays and Bayous Symposium, Biloxi, MS, 29 Nov 2016.
- Wu, W, M. Bethel, P. Biber 2016. Developing A Hybrid Model To Predict The Impact Of Sea-Level Rise On Coastal Wetlands. Bays and Bayous Symposium, Biloxi, MS, 30 Nov 2016.
- Ghosh, S, J. Tao, D. Mishra. 2016. Analyzing MODIS Derived Site–specific Tidal Wetland Phenology using TIMESAT. American Association of Geographers Conference, San Francisco, CA, April 2016.

Institutional press releases on the project funding were made available to the public:

- January 2016: University of Southern Mississippi researchers receive $507,000 for research program (http://gcrl.usm.edu/news/gcrl.in.the.news.php)

Social media including Facebook (https://www.facebook.com/Coastal-Plant-Restoration-309682115813305/ and https://www.facebook.com/GCRL1/) and Twitter (https://twitter.com/GCRL1 and https://twitter.com/geographyuga) were used to highlight research activities and results and to help recruit students, interns, and volunteers.

V. PUBLIC INTEREST AND COMMUNICATIONS

Most Unique or Innovative Aspect of the Project

This project developed innovative solutions to synthesize important ecological datasets that combine habitat mapping with vegetation process attributes. This approach provides a more comprehensive assessment of ecosystem services than either methodology by itself, significantly enhancing our understanding of ecosystem processes and dynamics. Furthermore, by developing scenarios of future change the researchers can combine changes to habitat extent with changes to vegetation phenology to better estimate future coastal marsh function under various sea level rise projections to facilitate sustainable use of natural coastal marshes. This innovative aspect of the project will help managers and decision makers to better anticipate and mitigate environmental change associated with coastal marsh resources that coastal communities and industries depend on in the northern Gulf of Mexico.

Most Exciting or Surprising Thing Learned During the Project

The most exciting thing for me as project lead was being able to work with talented researchers that bring a range of different but interlinked perspectives to come up with a more holistic solution to a pressing environmental problem. Developing this innovative approach to combining many different

sources of data and information in the pursuit of a comprehensive assessment of coastal marsh change was to me a very satisfying outcome of the research conducted during this project. I am excited to leverage these results to future funding sources so that this approach can be applied to a broader range of coastal marsh ecosystems within the Gulf and around the nation.

Most Important Outcome or Benefit of Project

The most important outcome of this project will be enhanced information to better communicate the future changes to coastal marshes that will occur in the life-time of many people. Our research indicates that significant changes will happen between 2050 and 2100 to coastal marshes in Mississippi, as exemplified in the Wetland Loss Estimator web-tool, which will have profound impacts to coastal communities and economies. Sustainability of many current industries (fishing, tourism, oil and gas) is tightly linked to healthy and thriving coastal marshes that provide valuable ecosystem services such as coastal protection, fisheries resources, aesthetic and cultural identity, and carbon mitigation. To better protect and restore these valuable coastal habitats for future generations, the full range of impacts from sea level rise and climate change needs to be communicated to managers, decision-makers, and the public to catalyze the necessity for change.

Communications, Outreach, and Dissemination Activities of Project

Institutional press releases on the project funding were made available to the public:

- January 2016: University of Southern Mississippi researchers receive $507,000 for research program (http://gcrl.usm.edu/news/gcrl.in.the.news.php)

Social media including Facebook (https://www.facebook.com/Coastal-Plant-Restoration-309682115813305/ and https://www.facebook.com/GCRL1/) and Twitter (https://twitter.com/GCRL1 and https://twitter.com/geographyuga) were used to highlight research activities and results and to help recruit students, interns, and volunteers.

Development of a general-public oriented website (https://sites.google.com/view/ms-coastal-marsh-synthesis/home) detailing the different project tasks and outcomes, as well as links to our databases (https://aquila.usm.edu/saltmarsh/) and further information related to the project.
An education-outreach Wetland Loss Estimator web tool (https://ecospatial.usm.edu/2017/05/01/education-outreach-sea-level-rise-wetland-loss/) was developed based on the results published in Wu et al. 2017 to make this information more accessible to middle-school students.